RADIO FREQUENCY AMPLIFICATION

THEORY AND PRACTICE

KENNETH HARKNESS

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BY

KENNETH HARKNESS

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INTRODUCTION

While conducting the Radio Department of the **Literary Digest**, and in writing my book **Practical Radio** and the volume on Radio in my **Story of Modern Science**, I have had occasion to confer with Mr. Kenneth Harkness many times and to quote from his admirably lucid and informative writings, particularly with reference to the practicalities of receiving sets using the principle of Radio Frequency Amplification.

Moreover, I have had his practical co-operation in the construction of such sets for my own use, and have had opportunity to witness at first hand the experiments through which Mr. Harkness has developed his quite unusual mastery of both principles and practise in a field until recently very little explored. It was, indeed, personal observation of, and tests with, instruments made by Mr. Harkness that confirmed my belief in the all-importance of the Radio Frequency method of reception—notably for the short-wave messages of the Broadcasting stations—at a time when most experts in this country looked askance at the method, or even openly decried it.

It is indeed fortunate for the radio public that Mr. Harkness is a practised writer no less than a practical radio engineer. He cannot only do things, but can tell others how to do them. His book on Radio Frequency Amplification, standing practically alone in its field, should mark the beginning of a new era in radio reception for a host of eager listeners who have not hitherto been able to reach out to distant stations, but who now, under expert guidance, may reconstruct their sets with the ambition to "tune in" at will, under favorable conditions, on the program of any high-power broadcasting station from Boston to Los Angeles and from Montreal to Havana.

When you have that kind of a set on your desk, radio will take on new meanings. For the average amateur, who must work with relatively simple means, Radio Frequency alone offers such possibilities. And Kenneth Harkness is Radio Frequency's most ardent protagonist.

HENRY SMITH WILLIAMS.

PREFACE TO THE FIRST EDITION

I have often been interested to witness the reactions of a total stranger to "radio" when he first hears some event of current interest **properly** reproduced.

A little incident which occurred recently may possibly interest the readers of this book. I made the acquaintance of a gentleman who was violently opposed to radio. We shall call him Mr. Conover. Mr. Conover's opposition was mainly based on his impression that all radio receivers give forth the "horrible noises" which issue from the horns outside some radio stores and fill the neighborhood with a deafening uproar. We have all heard them. Unfortunately we cannot avoid hearing them. The stentorian voice of the announcer shakes the windows across the street. The modest strains of a violin are thrown out of the horn with an ear-splitting blast of triumph. A harmless little crackle of static rends the air like a bolt of thunder. Should a soprano sing, the air is filled with the piercing shriek of a steam whistle. This strange form of so-called advertising has successfully prevented thousands of people from possessing the slightest desire to own a radio receiver.

These blatant distortions of radio reproduction had dinned in the ears of my friend Mr. Conover and followed him for blocks as he passed through the streets of the city. Each time he passed a radio store he made a mental reservation that he would never permit his young son, who threatened to take up radio, to transform his home into a madhouse by the installation of any apparatus which was capable of creating such an uproarious racket.

When this gentleman learned that I was engaged in the manufacture of radio receivers there was a distinct feeling of coldness between us. I could see that he regarded me as a decided pest. I immediately decided that he would make an excellent subject and that I would see whether I could alter his decidedly prejudiced opinion of radio reception.

Being possessed of a normal pair of ear-drums the resemblance between the voice of a soprano singer and the blare of a steam whistle appeals to me as being rather remote and I told him so. I asked him if he would like to hear the same soprano voice toned down to a more natural volume. No, he wouldn't. Then how about listening in on the big boxing match that afternoon?

He wavered and fell, although protesting loudly that he expected it would be terrible and that he didn't know why he should waste his time. Still, the ringside seats were $15.00 and he at least wanted to know the result of the fight.

He accompanied me to my studio where I actually have a radio receiver installed for no other reason than to enjoy the broadcasting.

For a few minutes we listened to some pianoforte selections. A strange expression of puzzled wonderment had come over my companion's countenance.

"Is that radio?" he asked.

I assured him that it was.

"Why, it's marvelous," he declared. "I never heard anything like it. I could swear there was somebody playing a piano in the next room."

His swift reversal of opinion concerning radio was the most convincing proof I have ever witnessed that over-amplification is more of a curse than a blessing.

Making ourselves comfortable, we tuned in to the station which was broadcasting the prize-fight. The preliminaries were over and the big fight was about to begin. The clanging of the bell was heard calling for silence as Joe Humphreys, in his shrill, inimitable voice, announced the combatants. Then the fight was on.

"Clang" went the bell opening the first round.

"The men are sparring in the center of the ring," announced Major White and continued to report the progress of the fight in his easy, convincing manner.

By radio we were transplanted to expensive ringside seats and enjoyed all the thrills of watching a fistic battle. None of the excitement was lacking. Each blow was reported as it hit and we could almost hear the thuds of the blows themselves. The roaring of the crowd and the flying epithets of encouragement or anathema seemed to be a natural accompaniment of the scene. We were not reading about it in cold print. We were actually there. We couldn't glance at the headlines and know beforehand the name of the winner. We had to wait in suspense with the rest of the crowd who were watching the fight.

When the bell rang at the end of the fifth round Mr. Conover removed his coat. He seemed to be laboring under the stress of considerable excitement and had apparently forgotten my existence. So far as he was concerned he was at the ringside.

Near the end of the next round the crowd roared with excitement as one of the combatants fell to the canvas.

"One—two—three—four"—shouted the referee.

Would he be counted out? Conover bent forward to catch every sound with the perspiration standing out on his forehead. "Five—six—seven—clang!"

"The bell saved him," Major White announced.

"Whew! That was a close shave," said Conover, leaning back to wipe his forehead. "Afraid he won't last the next round, though."

The next round ended the fight.

For a few moments Conover sat with a dazed expression on his face. Then, of course, he wanted to know all about it.

It seems unnecessary to tell the remainder of the story. Of course, he became an enthusiastic supporter of radio. The last time I heard of him he was engaged in the construction of his eleventh receiver!

Is it any wonder that radio is so popular? There is nothing which can take its place. There is a reality about it, a natural faithfulness of reproduction which cannot be equalled. To read about a news event after it has happened seems flat and stale if one can, by radio, follow its progress while it is happening. Music can be reproduced by radio with a perfection which is almost super-natural.

I say that all these things can be. That does not necessarily mean that they are in every case. The horrible shrieks which emanate from some loudspeaking horns might be called super-natural but they are unpleasantly so.

With the proper receiving set and the right kind of a reproducer—whether it be headphones or horn—music and speech can be reproduced by radio with an unparalleled impeccability. The remark that "radio is about as good as a phonograph" is the least descriptive characterization of radio reproduction that it is possible to make.

As good as a phonograph? To my mind there is as much difference between a phonograph and a radio receiver as there is between a broom and a vacuum cleaner. Both serve a useful purpose. You can do things with a broom that you can't do with a vacuum cleaner but that doesn't mean that the vacuum cleaner is outclassed by the broom. A phonograph and a radio receiver simply don't compete with each other.

But, as I have said, one must have the proper receiving set and the right reproducer. That is only natural. The tinny noises that were supposed to represent music as produced by the old-fashioned phonographs sounded just as bad as a poor radio receiver and reproducer sound today.

One object of this book, then, is to show the construction of receivers which, with the right reproducer, faithfully duplicate the music and voice broadcasted by radio. We are giving complete details of the design, the apparatus employed and the wiring diagrams of commercial receivers which accomplish this. These receivers, by a natural process of evolution, have been developed gradually. Over a period of months different designs and apparatus have been tried and in some cases incorporated in the sets. If a change was made, it improved the sensitiveness, the selectivity, the durability, the appearance or the ease of operation. Each and every receiver was tested twice before it was permitted to leave the factory. As hundreds of these receivers have passed through our hands it will be appreciated that we have had ample opportunity to locate any faulty design or apparatus. If the same fault made its appearance too often in testing, the source of trouble was removed and a new type of apparatus took its place in all subsequent sets.

Usual or unusual faults were rectified until the apparatus and design of the receivers were brought to such a state of perfection that the testing of each one is now only a matter of a few moments. Rarely is any trouble encountered.

It is these finished products that we are now revealing for the benefit of the amateur who wants to make his own set. The instructions are explicit so that even without a knowledge of the principles of radio reception any one can make one of these receivers. If you are not interested in the theory of radio reception, by all means turn to Part 2 and learn how hyper-sensitive receivers are made.

For those who desire to know more about the principles involved, Part 1 outlines the theories of radio reception, with particular reference to radio frequency amplification. Of course, the receivers described in this book will employ radio frequency amplification. I recently received a letter from a gentleman in Cuba informing me that he had heard a California broadcasting station using only a small loop as antenna. He has the set which is described in Lesson 10 of Part 2. If a man in Cuba can receive a broadcasting station in California with a small loop as antenna—even though it be a freak occurrence which might not happen again in years—there seems to be little question that radio frequency amplification made it possible. It also seems to demonstrate that, if it is inconvenient for the city dweller to erect an outdoor aerial, a loop antenna, with radio frequency amplification, will admirably serve the purpose.

There are many other advantages which radio frequency amplification offers. This book tells about them.

KENNETH HARKNESS.

New York, N. Y., June, 1923.

PREFACE TO THE SECOND EDITION

When the first edition of this book was published a few months ago the use of Radio Frequency Amplification was still limited. It was considered by many to be impractical as a means of aiding short wave reception. This pernicious and all too persistent fallacy has at last been successfully confounded and today Radio Frequency Amplification is the vogue. In one form or other it has been adopted by both radio manufacturers and amateur radio constructors. True, some of the systems in use are comparatively inefficient, but the trend of progress is in the right direction.

During the winter of 1923 the so-called "Neutrodyne" system has had a reign of great popularity and this has fortunately paved the way to further improvements in the tuned Radio Frequency Amplifying system of reception. Our own "Harkness Receiver," employing tuned Radio Frequency Amplication, has entered the ranks of renown and daily becomes more prominent. The ascension of this circuit to its present position of eminence has not been brought about by means of advertising. The merits of the system are alone responsible for its popularity. The circuit was initially made public in the first edition of this volume. Then "Radio Broadcast," a popular radio magazine with a national circulation, recognized the numerous advantages of the receiver and published an article by the present Author in the November, 1923, issue. The article aroused so much interest that each succeeding issue of the magazine contained more information on the subject, and to satisfy the great number of readers who were unable to procure the November issue the Editor actually found it desirable to reprint the original article in the April, 1924, issue. Other radio magazines and newspapers also featured the Harkness Receiver in their publications. Amateur constructors, ever on the *qui vive* for something new, built receivers using the circuit and were pleasantly surprised to find that the system did more than was claimed for it. They found that, by using this circuit with only one vacuum tube, they were able to produce signals of sufficient strength to operate a loudspeaker with ease and receive distant stations within a radius of 1,000 to 2,500 miles. Since the system has only two controls they found the receiver unusually easy to operate; yet the tuned circuits insured high selectivity. Most pleasing of all was the discovery that the receiver actually does not oscillate, and that they could tune in stations without generating a single whistle or squeal.

The good tidings of this latest and most useful type of receiver was spread abroad by those who had constructed it and who were enthusiastic and unstinting in their praise of its merits. As a result, thousands of "Harkness Receivers" have been built and the entire output of a large factory was required to supply the demand for parts before a single line of advertising was inserted to promote their sale.

It is important to realize that the extended use of the "Harkness Receiver" will greatly improve the quality of radio reception in general by reducing the interference caused by oscillating regenerative receivers. The latter are directly responsible for the whistles and squeals which now interfere with radio reception, whereas the "Harkness Receiver" does not re-radiate and cannot interfere with the reception of others. If regenerative receivers for broadcast reception become extinct—as we hope they eventually will—owners of radio receivers will be able to listen in to the radio broadcast without hearing a single whistle or squeal. Distant stations will be received with far greater ease than at present and without the chirping, twittering chorus which now accompanies DX reception.

If you, a reader of this book, possess a regenerative receiver you must face the fact that you are causing interference. When you tune in your receiver tonight realize that, with each turn of your dial, you are causing shrill whistles and discordant wails to emanate from a thousand loudspeakers in the homes of your neighbors near and far.

The Harkness Receiver does not oscillate and cannot cause interference to others. Yet you can receive farther and produce infinitely louder signals with a non-interfering "Harkness Receiver" than you can with an interference-producing regenerative receiver. Moreover, the operation is simpler, the selectivity higher, the reproduction clearer and the cost is lower. Therefore if you discard your regenerative receiver and build a "Harkness Receiver" to take its place your neighbors will not only be relieved from a great deal of unnecessary interference, but you yourself will receive far better than before and with less expense.

For the second edition of this volume we have entirely rewritten and greatly enlarged the chapter which describes the "Harkness Receiver," and have given complete instructions for building both the single-tube and two-tube models. The very latest and most improved type of these receivers are illustrated and explained.

The Author wishes to thank the many readers of the first edition who wrote him expressing their appreciation of his work and those who have written him reporting the highly satisfactory operation of their home-built "Harkness Receivers." He has endeavored to answer these letters individually, but if, at times, other duties have intervened to prevent this, he feels confident that those who failed to receive a personal response will accept this expression of thanks.

KENNETH HARKNESS.

New York, February, 1924.

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CONSTRUCTION OF RECEIVERS

PART I

THEORY OF RADIO RECEPTION

LESSON 1.

ELEMENTARY LAWS OF ELECTRICITY.

1. To understand the principles of radio reception one must be fairly well grounded in the laws of elementary electricity. These are outlined in this chapter. Of necessity our definitions must be brief. To those who desire further explanation we recommend the perusal of an elementary text-book on electricity.

2. **Matter and Electricity.** Under certain conditions matter is known to us as solids, liquids and gases. It will be remembered, however, that matter is classified under the headings of elements and compounds. An element is a substance which cannot be decomposed or chemically changed. A compound is a combination of elements. The molecule is the smallest particle of a compound while the atom is the smallest portion of an element which can combine with the atoms of other elements to form a molecule. Thus one molecule of water is composed of two atoms of the element hydrogen and one atom of the element oxygen. Later discoveries of science disproved the theory that the atom was indivisible. Although the atom is so small that it cannot be seen with the most powerful microscopes, its actions have been studied. Just as we know of the presence of air by the force and energy it displays, so the movements of atoms have been studied and investigation has made it clear that each atom contains still smaller things which are known as electrons. Some scientists have even succeeded in establishing the weight and size of electrons and the speed at which they travel.

3. **The Electron** is the unit of electrical energy. It represents a charge of negative electricity. Each atom of matter normally possesses a certain number of electrons. Electrons may be removed from atoms by the application of heat or electrical pressure.

4. **Electric Strains:** When the atoms of a body lack their full complement of electrons, the body is said to be **positively** charged with electricity. When the atoms of a body have more than their normal supply of electrons, the body is said to be **negatively** charged with electricity.

5. When a body is thus robbed or over-supplied with electrons, it is not in a normal state and it has been found that it exerts a force or strain in the space surrounding it. This

strain may be represented in an illustration by lines although, of course, the force is invisible. Thus Fig. 1 shows lines of electric strain emanating from a body which is positively charged, or which lacks electrons. In a similar way the negatively charged body exerts a strain but in this case the direction of the lines of electric strain is inwards, towards the body itself.

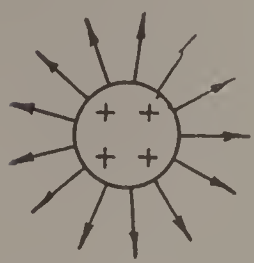


Fig. 1

6. The presence of these strains exerted by positively or negatively charged bodies can clearly be demonstrated by simple experiments. These experiments establish some fundamental electrical laws. If two positively charged bodies are brought close together, the strains are exerted by the two bodies oppose each other. If the bodies are composed of very light material the effect of this opposition is plainly evident. The two bodies are forced apart. On the other hand, if one body is positively charged and the other is negatively charged, the electric strains surrounding each body causes them to be attracted to one another. Like charges of electricity repel and unlike charges attract.

7. **Electrical Pressure:** If two bodies are charged with unequal **shares** of electricity and are then connected together by a copper wire, as in Fig. 2, electrons flow from one to the other to equalize the share of electrons. This does not necessarily mean that one body has a greater **quantity** of electricity than the other. For instance, a small body may have a greater **share** of electricity than a large body, although the former may have a **smaller** quantity than the latter. This will be explained further in a moment.

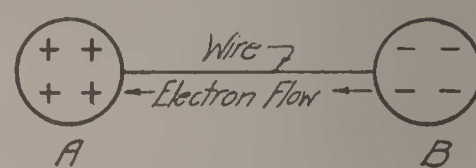


Fig. 2

8. The excess electrons in the body B of Fig. 2 flow through the wire into A as soon as the path is provided. Before that time the space between the two bodies is strained. There is a certain effort on the part of the electrons in B to reach A. This effort is known as **electrical pressure.**

9. **Potential Difference:** A difference of potential is said to exist between two bodies which do not possess an equal share of electrons. If they are provided with a conducting path electrons will flow from one to the other to equalize the share. When we speak of potential or difference of potential, we must therefore have two points in mind.

10. The earth is such a large body that its electrical condition is constant. Any excess or loss of electrons is immediately equalized. The earth, therefore, has zero potential.

11. Electrical pressure is measured in units called Volts. If any object by itself is said to have a positive potential of 20 volts it means that the difference in potential **between the object and the earth** is 20 volts. The object, being positively charged, lacks electrons. The force exerted by the electrons of the earth

to reach the positively charged body and reduce its potential to zero is measured as 20 volts. But if it is said that there is a difference of potential of 20 volts between two objects, this does not necessarily mean that one object is at zero potential and the other at 20 volts positive or negative. If one object has a positive potential, with respect to the earth, of 60 volts and the other a positive potential, with respect to the earth, of 80 volts, the difference of potential between the two objects is 20 volts and it is this difference which forces a flow of electrons from one to the other if a conducting path is provided.

12. **Capacity**: As we intimated in Paragraph 7, the potential to which an object is raised by a charge of electricity does not solely depend upon the quantity of electricity with which the object is charged. It also depends upon the size of the object and upon other considerations which we shall investigate later. These govern what is called the "Capacity" of any conductor. Capacity describes the ability of a body to hold a charge of electricity. A given charge will raise the potential of an object with a small capacity to a higher value than one with a large capacity.

13. **Electromotive Force**: The flow of electrons between the bodies B and A of Fig. 2 is practically instantaneous and as soon as the potential difference between the two is reduced to zero, no further flow of electrons takes place.

Now if, while these two bodies are joined together by a wire, the potential difference between them can be maintained, there will be a continual flow of electrons from B to A and a continuous current of electricity will pass through the copper wire. To maintain this potential difference it will evidently be necessary to constantly supply the body B with electrons to keep it negatively charged and constantly remove electrons from A to keep it positively charged.

14. There are different methods which can be used to maintain potential difference between the two ends of a conductor through which a current continually flows. The simplest way is by chemical action.

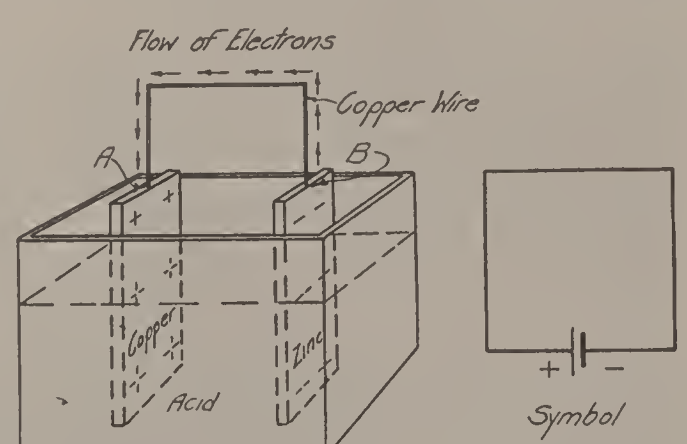


Fig. 3

15. In Fig. 3, the plate A is of copper and the plate B of zinc. When these are immersed in acid, chemical action takes place which causes electrons to leave the copper plate and enter the zinc plate. The zinc gains more than its normal supply of electrons and is consequently charged negatively while the copper loses some of its electrons and is positively charged. The two plates are therefore in the same electrical condition as the bodies A and B of Fig. 2.

If the two plates are joined together by a copper wire, electrons flow from B to A, but the chemical action continues to remove electrons from the copper plate and add electrons to the zinc plate so that the potential difference between the two plates is maintained and a continuous current of electricity flows through the copper wire.

16. Any apparatus which, by chemical action or otherwise, is able to maintain one of its terminals at a higher potential than the other, even while current is flowing through it, is said to develop **electromotive force.** This expression is usually contracted to e.m.f.

17. The arrangement illustrated in Fig. 3 is called a primary cell. Cells are connected together in series to form a **"battery."** The object is to increase the available potential difference. Thus, the difference in potential between the terminals of a battery of three cells is three times as great as the potential difference of each cell, if they are all equal. There are many different kinds of batteries but they serve the same purpose. They are all sources of e. m. f.

Fig. 4

Fig. 4 shows two of the batteries used in radio reception, with the symbol employed to represent a battery in a wiring diagram.

18. **Measurement of Current:** Electrons in motion constitute an electric current. Electrons pass through the copper wire of Fig. 2. Electrons flow from the zinc to the copper plate of Fig. 3, through an outside wire. In each case an electric current is said to flow. The magnitude of a current is measured by the quantity or number of electrons which pass a given point in one second. The **Ampere** is the unit of current. If a certain number of electrons pass a given point each second, the current is said to be one ampere.

19. **Direction of Current:** In Figs. 3 and 4, we have shown the current as flowing from a point of negative potential to a point of positive potential. This is in accordance with the now accepted electron theory. However, years ago, before much was known about electricity, it was arbitrarily decided that electric current flows from positive to negative. This early conception has not been corrected. Current is still said to flow from a point of positive potential to one of negative potential. It should be realized, however, that the movement of electrons, which actually constitutes an electric current, is invariably from negative to positive.

20. **Resistance:** All substances offer resistance to the passage of an electric current. Resistance in electricity corresponds with friction in mechanics. In both cases energy is consumed in the production of heat. Some substances offer such a high resistance to the passage of electricity that they are called **nonconductors** or **insulators.** Other substances, particularly metals, offer low resistance and are known as **conductors.**

The resistance of a conductor depends upon the material of which it is composed, its size and its length. Different metals have different values of resistance. A long wire offers more resistance than a short one. Similarly a wire of small diameter offers more resistance than one of larger diameter.

21. **The Ohm** is the electrical unit of resistance. A conductor with a resistance of 1 ohm requires an e.m.f. of 1 volt to force a current of 1 ampere through it.

22. **Ohm's Law:** It is evident from the foregoing that there is a relationship between e.m.f., current and resistance. We can increase the current passing through a given conductor by increasing the voltage of the e.m.f. acting on the ends of the conductor. We can also increase the current passing through a conductor across which a given e.m.f. is applied by decreasing the resistance of the conductor.

23. The relationship between e.m.f., current and resistance is stated by Ohm's Law, as follows:

The current flowing through a circuit is directly proportional to the e.m.f. across it and inversely proportional to the resistance of the circuit.

$$\text{Or Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

24. **Circuit:** The term "circuit" is used to describe the path of an electric current. Continuous current flows from one side of a source of e.m.f. through a conductor or conductors and back again through the source of e.m.f. This circular movement of the current continues as long as the source of e.m.f. is maintained and as long as the continuous path or circuit remains unbroken. In this circuit may be connected apparatus through which the current passes to provide light, heat or to serve some other useful purpose. The apparatus in the circuit must, of course, provide a conducting path for the current or the circuit will be broken and no current can flow.

25. **Direct Current:** The current which flows through a circuit connected across a battery is called a Continuous or Direct Current (D. C.) because it continually flows in one direction.

26. **Alternating Current:** The current which flows in a circuit connected across an alternator, which generates an alternating e.m.f., continually reverses in direction and is called an Alternating Current (A. C.).

27. The e.m.f. generated by an alternator can best be understood by studying the curve of Fig. 5. The comparison of values which are made possible by a curve of this type should be fully appreciated.

28. In this curve diagram the elapse of time is measured in fractions of seconds along the horizontal axis from the point of zero. The values of the factor or factors which are to be compared as time elapses are measured along the vertical line from the point of zero.

At this time we wish to compare the different values and direction of an alternating e.m.f. while time elapses. An alternating e.m.f. does not always act in the same direction. It is continually reversing in direction. At one moment one of the terminals of the alternator is positive with respect to the other and the next moment it is negative.

29. We can show the direction as well as the value of the e.m.f. at any moment of time by measuring the values of the e. m. f. in a positive direction along the vertical line **above** the point of zero and by measuring the values of the e. m. f. in the opposite or negative direction along the vertical line **below** the point of **zero.** In this way the curve of Fig. 5 shows clearly the values and direction of the e. m. f. as time elapses.

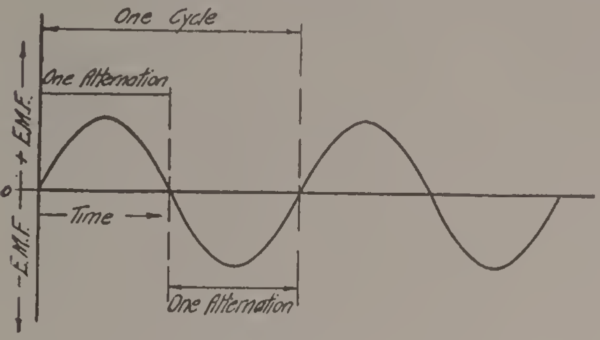


Fig. 5

30. It will be noted from this curve that the voltage generated by an alternator passes through a definite cycle of values and direction. Commencing at zero the voltage increases rapidly and then less rapidly until it reaches a maximum in a positive direction. Then it decreases, slowly at first but more rapidly later until it falls to zero. At this moment it reverses direction, increases to a maximum in a negative direction and again falls to zero. This complete cycle is continually repeated.

31. The **Frequency** of an alternating e.m.f. is represented by the number of complete cycles of voltage generated per second of time. The frequency of the alternators commonly used for lighting circuits is about 60 cycles per second.

32. **Current in A. C. circuit with Resistance Only:** The current which flows in a circuit across which an alternating e.m.f. is applied must, of course, be an alternating current. We will see later that there are certain factors in a circuit which affect the value of an alternating current. If we consider, however, that a circuit only possesses resistance, the strength of an alternating current **at any instant of time** can be determined by Ohm's Law.

33. In Fig. 6, the current curve is shown with the voltage curve. The conditions represented by these curves obtain **when the circuit has resistance only.** The value of the current at any moment can be found by dividing the voltage at that instant by the resistance of the circuit, in accordance with Ohm's Law. Consequently, the current is in phase with the voltage and has a similar form.

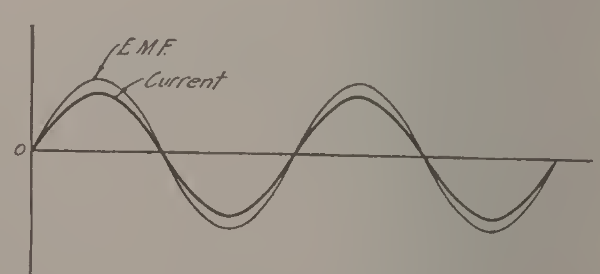


Fig. 6

LESSON 2.

GENERAL OUTLINE OF RADIO COMMUNICATION.

34. Radio magazines and newspapers are frequently asked to answer the question, "What is the difference between radio and audio frequency amplification?" The questioner probably has a radio receiver with three vacuum tubes. The first tube is the "detector" and the other two the "amplifiers." There seems to be no logical place in the receiver for the addition of further amplification. The signals are loud. If a third stage of amplification were added, the nearby stations might be unpleasantly loud.

35. But if this typical radio receiver is analyzed for a moment it will be realized that the amplifying tubes and transformers are merely magnifying a signal which is made audible by the detector tube itself. The function of the detector tube and its circuits is to convert the energy induced in the receiving antenna by passing radio waves into currents which will produce audible sounds when they pass through a telephone receiver. The manner in which the tube and its circuits accomplish this is naturally somewhat complicated but it is probably known to all that the amplifying tubes take no part in this operation.

36. The variations of current in the output circuit of a detector tube will cause a telephone receiver diaphragm to vibrate if the telephone is included in this circuit. If the telephone is held to the ear, the vibrations of the diaphragm will be "heard."

37. These variations in the output circuit of a detector tube may be impressed upon the input circuit of an amplifying tube through a transformer. The variations will be greatly magnified. If the telephone is included in the output circuit of the amplifying tube, the vibrations of the diaphragm will be much more pronounced and a louder sound produced. The amplified variations can be still further magnified by impressing them upon the input circuit of a third tube. Usually two or three stages of such amplification are sufficient for all practical purposes.

38. This type of amplification in a radio receiver is therefore called "audio frequency amplification," and refers to the magnification of the audio frequency current variations in the output circuit of the detector tube.

39. It will be evident, however, that audio frequency amplification does not actually increase the sensitiveness of a radio

receiver. It only magnifies signals which are made audible by the action of the detector tube and its circuits. If the waves radiated by a distant transmitting station do not induce sufficient energy in the **input** circuit of the detector tube to operate this device, the signals will not be audible in the output circuit. Nor will they be audible in the output circuits of the first, second or third audio frequency amplifying tubes. These tubes and their circuits merely amplify the audio frequency variations in the output circuit of the detector tube.

40. The amplifying properties of the vacuum tube, however, can be utilized in another manner to increase the **sensitiveness** of a radio receiver. The current which is induced in the receiving antenna by radio waves may be amplified **before** it is impressed on the input circuit of the detector tube and converted into sound. This method is known as "radio frequency amplification."

Without this amplification the currents induced in the receiving antenna by waves radiated from distant transmitting stations may frequently be too feeble to operate the detector and no signal can be heard. Radio frequency amplification magnifies these currents before they are impressed upon the detector circuit and the signal becomes audible.

41. It may be said, then, that radio frequency amplification increases the **range** of any radio receiver. For instance, if, under freak conditions, an amateur is able to receive signals transmitted by a station a thousand miles distant, the addition of two stages of radio frequency amplification will ensure the **nightly** reception of this station and probably many stations much more distant which he could not possibly hear without radio frequency amplification.

42. **Principles of Radio Communication:** To understand the nature of the currents which are induced in a receiving antenna by radio waves and which may be magnified by radio frequency amplification, it is necessary to have a general conception of the principles of raido communication.

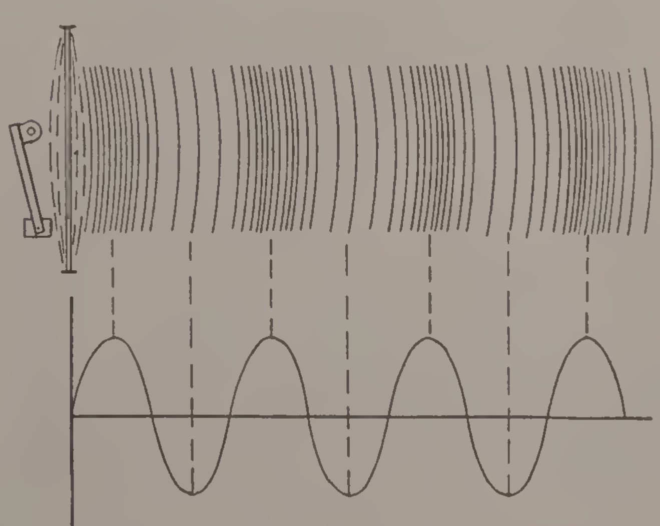


Fig. 7

43. The transmission and reception of radio ways may be compared with the production and reception of sound waves. As an illustration of the manner in which sound or pressure waves are produced and radiated, Fig. 7 depicts the radiation of waves set up by the vibrations of a wire which has been struck by a hammer, as in a piano. This sound wave depends for its existence upon the variations of air pressure above and below normal pressure produced by the vibrations of the wire.

44. The vibrations of the wire may be represented by the curve of Fig. 8. Distances along the vertical line in either direction from the point of zero represent, in this case, the movement of the wire from its normal position. All points along the vertical line above zero represent distances in one direction, while all points on the vertical line below the horizontal represent distances in the opposite direction. It will be noticed from this curve that the vibrations gradually subside. The initial elastic energy furnished by striking the wire is lost in overcoming the friction of air.

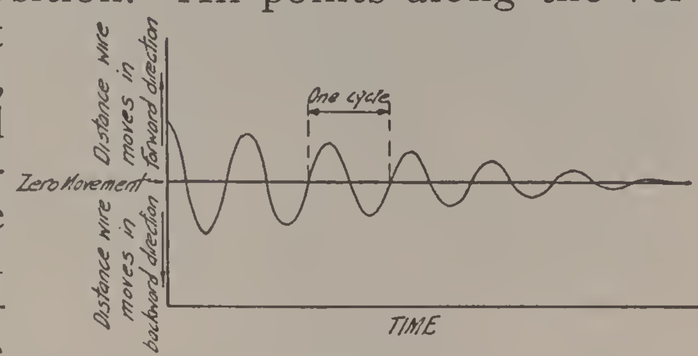


Fig. 8

45. The effect of a single to and fro vibration on the air surrounding the wire is to increase its pressure above normal, reduce it to normal, lower it below normal and again raise it to normal. This complete cycle is repeated again and again as long as the wire vibrates.

46. In accordance with the principles of wave motion, a group of waves is radiated in the form of expanding spherical areas of compressed and rarefied air as illustrated in Fig. 7. Each complete cycle of vibration produces a single wave.

47. When these waves strike the ear-drum of a listener within their radius they cause it to vibrate **at the same frequency** and with the same form as the vibrations of the wire which produced the waves. These vibrations of the ear-drum create the sensation of sound in the brain of the listener.

48. The vibrations of the wire in this illustration may be taken to represent the alternating current which is caused to flow in the aerial of a radio transmitting station. These alternations of current cause strains in the surrounding space and radio waves are set in motion which radiate in all directions with the speed of light.

49. At the receiving station, the energy of the successive waves is impressed upon the receiving aerial and a feeble alternating e.m.f. is induced having the same frequency as the alternating current in the transmitting aerial and of similar form. The value of the alternating current which flows in the receiving aerial as a result of this induced e.m.f. depends upon other factors which we will consider later.

MEASUREMENTS OF WAVES.

50. In Fig. 9, representing a group of waves, we have indicated some of the terms which are used to describe the measurements of waves. We will consider the meaning of these and other terms.

51. The **amplitude** of any wave is the measurement of the maximum energy contained in the wave. This is represented in the curve by the distance from the normal level to the highest point. In the case of the familiar water wave it is evident that

a high wave contains more energy than a low one. The high wave is said to have a greater amplitude than the low wave. The amplitude or measurement of maximum energy contained in a sound wave is represented by the degree of compression to which the air is raised above normal pressure by the wave. Similarly the amplitude or power of a radio wave is measured by the intensity of the electric field produced by the wave.

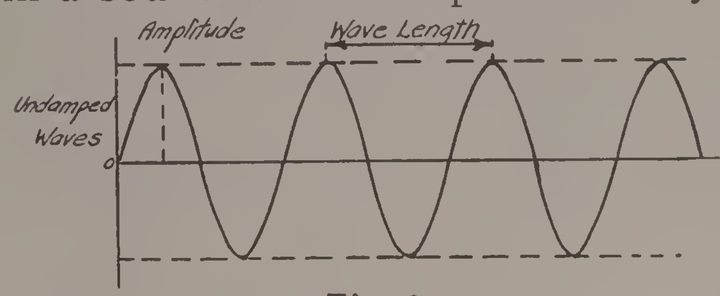


Fig. 9

52. The amplitude of a wave decreases as the wave travels. This can easily be observed in water waves. The ripple of waves which spreads out over the surface of a pond into which a pebble is dropped commences from the starting point with maximum amplitude. The waves gradually flatten out as they travel outwards in circles over the surface of the water until the energy is entirely expended.

53. The distance which radio waves travel, then, depends upon the initial amplitude of the waves at the transmitting station and the amount of energy in the waves at any given distance from the transmitter also depends upon this initial amplitude. The initial amplitude, of course, is governed by the value of the alternating current in the transmitting aerial which is producing the waves, just as the initial amplitude of sound waves and the distance they travel depends upon the strength of the vibrations which are producing them.

54. The expression amplitude is also used to describe the maximum value reached by an alternating current during one alternation. Referring to the curve of Fig. 6 it will be noted that each alternation of current commences with a zero value, gradually increases until it reaches a maximum and again decreases to zero.

The amplitude of any particular alternation is the measurement of the maximum value the current attains during that alternation. This is represented by the vertical distance from the horizontal line to the highest point of the curve.

55. The amplitude of an alternating current, therefore, is evidently a measurement of the energy in the circuit in which the current flows. If the amplitude is increased, the available energy is increased and vice versa.

56. It may be said, then, that the initial amplitude of a radio wave depends upon the amplitude of the cycle of alternating current producing the wave.

57. **Wave Groups:** A single wave is produced by each complete cycle of alternating current in the transmitting aerial. If the alternating current continues to flow, a group of waves is radiated. The number of waves in the group, of course, is the same as the number of cycles of alternating current. Moreover, the amplitude of each successive wave in the group depends upon the amplitude of each successive cycle of alternating current.

58. **Undamped Waves:** If the amplitude of each consecutive cycle of alternating current is the same as its predecessor, a group of waves of constant amplitude is radiated, as illustrated in Fig. 9. Waves of this character are known as "Undamped" waves.

59. **Damped Waves:** But if the amplitude of each consecutive alternation of alternating current is less than its predecessor, a group of waves of decreasing amplitude is radiated as represented by Fig. 10. The waves in a group of this nature are called "Damped" waves.

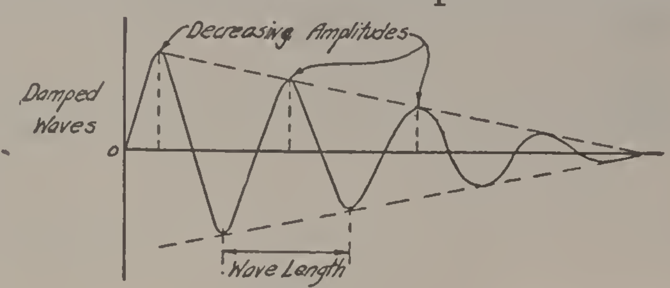


Fig. 10

60. **Modulated Waves:** The amplitude of the waves which are produced by alternations of current in a transmitting aerial, then, follow exactly the amplitudes of the successive cycles of alternating current. If the amplitudes of the alternating current increase and decrease as illustrated in Fig. 11, the amplitudes of the waves follow these variations, no matter how complicated they may be. The waves in a group of this character are continuous but their amplitudes are **"modulated."**

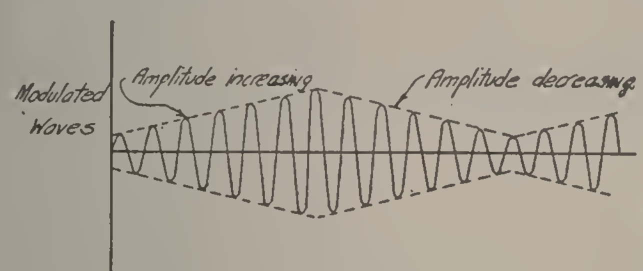


Fig. 11

61. **Velocity:** A radio wave travels at a definite speed. The velocity of a wave or group of radio waves is 300,000,000 meters per second which is equal to about 186,000 miles per second. This almost inconceivable velocity, which is the same as that of light, ensures practically instantaneous communication between radio stations, no matter how far distant they may be from each other. This velocity is a constant value, irrespective of the amplitude or length of the wave.

62. **Wave-length:** The length of a wave is the horizontal distance from the crest of one wave to the crest of the next. This measurement of radio waves is made in meters. A meter is 39.37 inches. The length of a wave remains constant, no matter how far the wave travels.

63. **Frequency:** The frequency of waves is the number of waves which are produced or pass a given point in one second. Since a single wave is produced by one cycle of alternating current, the number of waves which are produced in one second depends upon the number of cycles of alternating current in one second. In other words, the frequency of the waves depends upon the frequency of the alternating current which is producing the waves. If the frequency is increased, more waves are produced per second and vice persa.

64. Since the velocity of radio waves is constant, we may establish a relationship between frequency, wave-length and velocity.

If a radio transmitter sends out a stream of continuous waves for a period of one second, the first wave will, if it is powerful enough, have travelled 300,000,000 meters by the time the last wave is just leaving the transmitting aerial, since radio waves travel at the speed of 300,000,000 meters per second. Therefore, the total length of this group of waves is 300,000,000 meters. It follows that the length of each wave in this group must be equal to 300,000,000 meters divided by the total number of waves in the group. For instance, if 15,000 waves are transmitted during one second, or, in other words, if the frequency is 15,000 cycles, the length of each wave must be 300,000,000 divided by 15,000=20,000 meters.

65. We may state this relationship in an equation as follows:

$$\text{Wave-length} = \frac{\text{Velocity}}{\text{Frequency}}$$

$$\text{or Velocity} = \text{Wave-length} \times \text{Frequency}.$$

It is evident that, since the velocity is a constant value, the length of a radio wave depends entirely on the frequency with which the waves are produced or, in other words, on the frequency of the alternating current in the transmitting antenna. Further, the **higher** the frequency the **shorter** the wave-length and vice versa.

66. Now, to contain a useful amount of energy and for many other reasons, a radio wave cannot be much longer than 20,000 meters. The waves now in common use for radio communication measure from 150 meters to 25,000 meters. The frequency corresponding to the wave-length of 150 meters is 2,000,000 cycles per second and that corresponding to 25,000 meters is 12,000 cycles per second. The frequencies embraced by these limits are the frequencies of the waves now used for radio communication.

67. To produce waves of these frequencies, then, the currents in the transmitting antenna must be capable of alternating at some frequency from 12,000 cycles per second to 2,000,000 cycles per second, depending upon the wave-length upon which it is desired to transmit. The frequency of the alternating currents used in lighting systems is only 60 cycles per second. Special apparatus is therefore used in radio transmission to produce the extremely high frequency alternating currents which are necessary to transmit radio waves.

68. To distinguish high frequency alternating currents from those of lower frequency, the former are called "Oscillations" and the currents are said to alternate at "radio frequency." Hereafter, we will use these terms to describe high frequency alternating currents.

FORM AND FREQUENCY OF E.M.F. INDUCED BY RADIO WAVES.

69. The amplitude of a wave represents the maximum amount of energy contained in the wave. Therefore, a group

of undamped waves (of constant amplitude) as represented by Fig. 9 induce **an undamped alternating e.m.f.** in a receiving antenna within the radius of the waves. Although, when they reach the receiving station, the amplitude of each wave in the group is considerably less than the initial amplitude, the waves all decrease in the same proportion. Consequently the same amount of energy is induced in the receiving antenna by each successive wave.

70. A group of damped waves similarly induce a **damped** alternating e.m.f. in the receiving antenna. The energy, or amplitude, of each consecutive wave is less than its predecessor and consequently the e.m.f. induced in the receiving antenna by each successive wave is less than its predecessor.

71. In the same way, a group of modulated continuous waves induce in a receiving antenna a modulated alternating e.m.f. The variations in amplitude bear the same relation to each other as the modulations in amplitude of the current in the transmitting aerial.

72. It will also be evident that the frequency of the alternating e.m.f. induced in the receiving antenna is the same as the frequency of the transmitting current. The frequency with which the waves are produced depends upon the frequency of the transmitting current. Each successive wave induces a complete cycle of alternating e.m.f. in the receiving antenna. Therefore, the number of complete cycles of alternating e.m.f. which are induced in one second (frequency) depends upon the rapidity with which the waves follow each other. This, in turn, depends upon the frequency of the transmitting current.

It is plain, then, that the alternating e.m.f. induced in the receiving antenna has exactly the same frequency as the transmitting current. We have already noted that to produce radio waves the transmitting current must have a very high frequency, ranging from 12,000 cycles per second to 2,000,000 cycles per second.

73. Therefore, the e.m.f. induced in a receiving antenna by radio waves is an oscillating e.m.f. and the frequency is the same as the frequency of the oscillations in the transmitting aerial radiating the waves. Moreover, the induced oscillations follow exactly the variations in amplitude, if any, of the transmitting current.

74. **Different Types of Radio Telegraph Transmission:** In Fig. 12, we have illustrated the different types of waves which are radiated by transmitting stations to communicate by radio telegraphy.

75. Fig. 12A represents a single train of damped waves radiated by a "spark" transmitter. Each of these trains is produced by a damped oscillating current in the transmitting antenna. The trains of waves follow each other in rapid succession, usually about 500 complete trains per second.

76. Trains of damped waves are only used in communicating by telegraphic code, or "dot-dash" system. The telegraph key opens and closes the transmitting circuit. While the key is open

no waves are radiated. When the key is closed wave trains are radiated, following each other at a frequency in the neighborhood of 500 per second. The exact number of wave trains per second depends upon the "spark frequency" of the transmitter. If the spark frequency is 500 and the telegraph key is held down for one second to form the "dash" of some letter of the Morse code, 500 complete trains are radiated during this second. The operator at the transmitting station manipulates the key in accordance with the spacings of the code. The Continental code is internationally used in radio telegraph transmission. At the receiving station each succesive train of damped waves induces a damped oscillating e. m. f. in the antenna. We will see later how these oscillations are "detected."

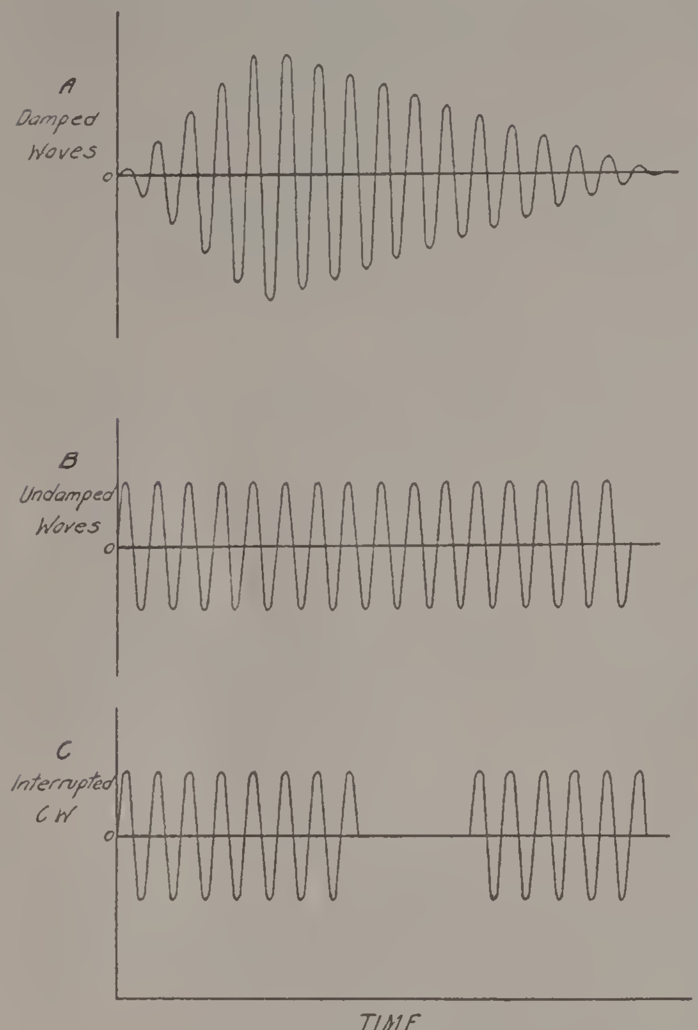


Fig. 12

77. Fig. 12B illustrates the undamped continuous waves which are radiated by another type of transmitter. Undamped waves are produced by continuous oscillations of constant amplitude in the transmitting antenna. As long as the telegraph key at the transmitting station is held down a continuous stream of undamped waves is radiated. The key is again manipulated in accordance with the spacings of the telegraphic code.

At the receiving station each group of undamped waves, constituting by its length a "dot" or a "dash," induces an undamped oscillating e.m.f. in the antenna. Between each dot and dash no waves are radiated (for during these space periods the key at the transmitter is open) and consequently no oscillations are induced in the receiving antenna during these periods.

This type of radio telegraph transmission is commonly called "C.W." (continuous wave) transmission and is by far the most efficient method of radio communication. We will show later that special apparatus is necessary to receive C.W. telegraph signals.

78. Another system of radio telegraph transmission is illustrated in Fig. 12C. This is known as I.C.W., or interrupted continuous wave transmission. The object of this method is to avoid the necessity of special apparatus at the receiving station. Undamped waves are radiated but they are broken up into comparatively short groups, somewhat after the style of the "spark" method except that each wave train is undamped. Similar

groups of undamped oscillations are induced in the receiving antenna.

79. **Radio Telephony:** Continuous waves are also utilized for the transmission of radio telephony. Radio telephony may be defined as the reproduction at a distant point of sounds which are produced at the transmitting station, with radio waves acting as the medium or "carrier" of the sounds.

80. Now "sounds" are really pressure waves produced by vibratory motion. When sound waves strike the ear-drum of a listener they cause it to vibrate. The organism of the ear detects the difference between sound waves possessing different frequencies and "wave-form" and thus translates the waves into musical sounds, speech or other forms of sound. For instance, if pressure waves are transmitted through the air at, say, a frequency of 500 cycles per second, the waves cause the ear-drum of a listener to vibrate at this frequency and create the sensation of a certain musical note. Similarly, waves of higher frequency create the sensation of higher notes and vice versa. But the human ear is only susceptible to waves below a certain frequency. If pressure waves are transmitted at frequencies much above 10,000 cycles per second, the ear-drums of the average person will not respond. Frequencies below about 10,000 cycles per second are therefore called audio frequencies (or audible frequencies). The average frequency of the sound waves produced by the human voice is only about 800 cycles per second.

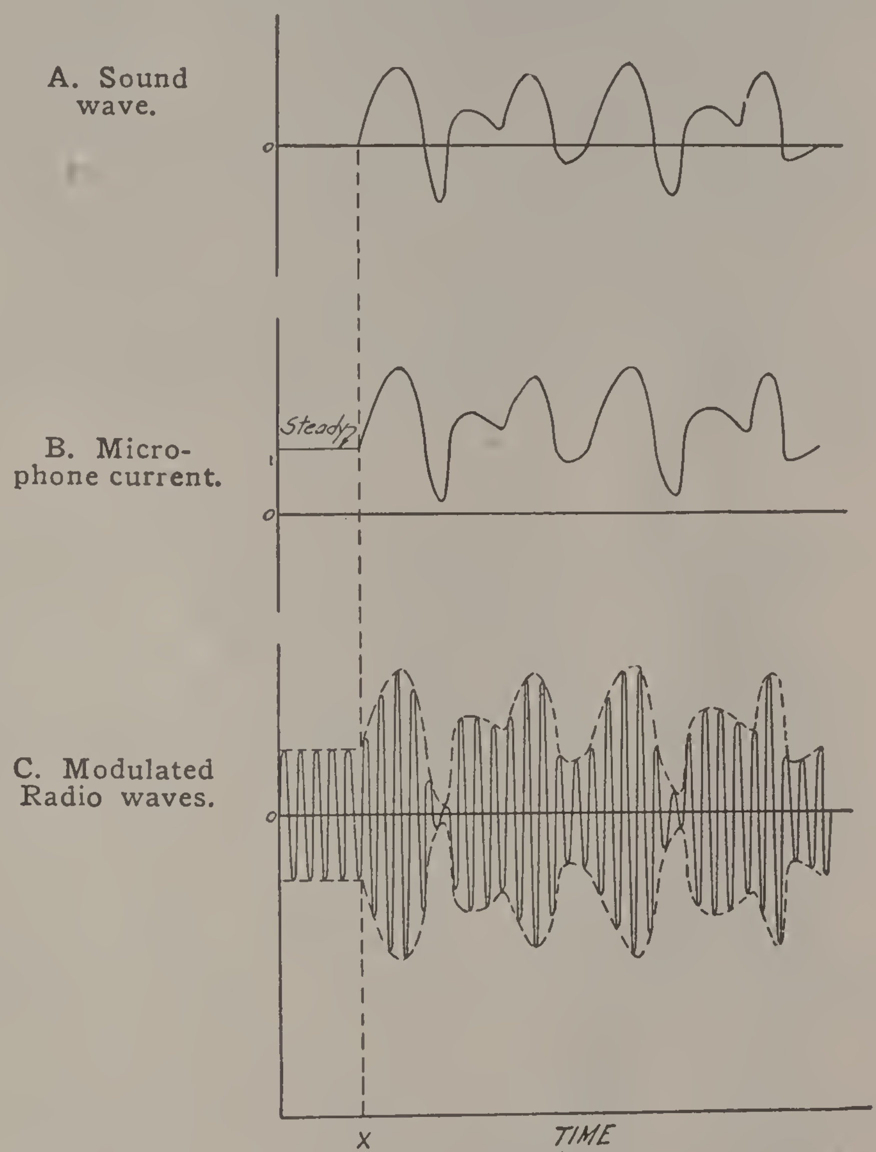


Fig. 13

81. The sound waves produced by the vibrations of the human voice and some musical instruments do not follow a pure harmonic curve. Sound vibrations are made up of numerous harmonics and overtones resulting in the transmission of a wave of varying amplitude. Thus, the "wave form" of a single vowel sound as pronounced by the vibrations of the voice might produce a curve similar to that shown in Fig. 13A. In many cases,

the wave form is even more complicated but it invariably repeats itself at regular intervals.

82. In the communication of speech or music by radio these complicated waves must be exactly transmitted and again reproduced at the receiver. This would be practically impossible were it not for the great difference in frequency between radio waves and sound waves. In the early days of radio telephony, many experiments were made using "arc" continuous wave transmitters but only by the perfection of the three electrode vacuum tube and its use in the production of completely steady or undamped waves of very high frequency and also in amplifying audible frequency currents has it been possible to bring the radio telephone to its present efficiency.

83. The continuous high frequency waves act as the "carrier" of the low frequency sound waves. This is accomplished by varying the amplitude of the continuous high frequency waves so that the variations in amplitude conform to the frequency and wave-form of the sound waves.

84. The curves of Fig. 13 show how the sound wave form and frequency are carried by the radio waves.

At the transmitting station, the speaker addresses a microphone and curve A is supposed to represent a portion of the sound waves which are produced by his voice. A current of electricity is constantly flowing through the microphone and the action of the sound waves produces variations in this current; the current rises and falls in conformity with the frequency and form of the sound waves. This fluctuation of the microphone current is shown in Fig. 13B. The sound waves strike the microphone at the moment X when the speaker commences to talk. Before that time, the microphone current is steady.

The radio transmitting apparatus generates and radiates a constant stream of radio waves of high frequency. The fluctuations of the microphone current, produced by the voice, are amplified and applied to the generator of radio waves in such a way that the amplitude of the radio waves rises and falls at this applied frequency, as indicated by Fig. 13C, thus preserving the wave form and frequency of the sound wave. Before the moment X the microphone current is steady; the amplitude of the waves is only varied while sound waves are striking the microphone.

85. At the receiving station an oscillating e.m.f. is induced in the antenna and the amplitude of this e.m.f. is modulated in the same manner as the modulations of the oscillations in the transmitting aerial. We shall see later how the sound waves are reproduced at the receiving station.

MAGNITUDE OF E.M.F. IN RECEIVING ANTENNA.

86. The magnitude or strength of an oscillating e.m.f. induced in a receiving antenna depends upon various factors. Since the amplitude of the waves decreases as they travel, the value of the induced e.m.f. decreases as the distance between the transmitting station and the receiving station increases. Again,

since the initial amplitude of the waves depends upon the amplitude of the oscillating current in the transmitting aerial, the value of the oscillating e.m.f. induced in the receiving antenna decreases as the power of the transmitter decreases. It is conceivable that a higher value of e.m.f. may be induced at a receiving station by the waves radiated from a high-power radio transmitting station 500 miles distant than the e.m.f. induced by the waves from a low-power station only 100 miles distant.

87. The magnitude of the oscillating e.m.f. induced at a receiving station by the waves radiated by any given transmitting station, however, is not a constant value, even if the power used at the transmitter is unchanged. For instance, at night radio waves travel great distances without decreasing in amplitude to the same extent as during the day. The amplitude of the waves is also affected by atmospheric conditions, the nature of the country lying between the transmitting and receiving stations, etc.

88 All the above factors, however, which govern the value of the oscillating e.m.f. induced in the receiving antenna, are beyond the control of the owner of the receiving station. He cannot decrease the distance between the transmitting stations and his own receiver nor can he control the power used by the transmitters. No matter what type of receiving apparatus he employs he is able to receive much better at night than during the day.

89. The only controllable factor which ensures the highest possible value of induced e.m.f. by any given radio wave is the design of the receiving antenna itself. A greater value of e.m.f. is induced in a high outdoor aerial than a low aerial by the same radio waves. In either case the induced e.m.f. is a higher value than that induced in a low indoor antenna or a loop antenna. Even this factor may be beyond the control of the owner of a receiving station. It is sometimes inconvenient to erect an outdoor aerial. The city dweller is often forced to use an indoor antenna.

90. The amplitude of the current which flows in any receiving antenna as a result of a given value of induced e.m.f. depends upon other factors which we will consider in the next Lesson. However, even if the antenna circuit is suitably adjusted so that a maximum oscillating current flows as a result of a given value of induced e.m.f. it is conceivable that the latter value may be so low that insufficient energy is produced to operate the "detecting" device which translates the received oscillations into audible sounds. As outlined above, this may be due to the design of the receiving antenna itself, the distance between the transmitter and receiver, the power of the transmitter, etc.

91. A Radio Frequency amplifier may be used to magnify these feeble oscillations induced in the receiving antenna so that sufficient energy is applied to the detector to operate this device and thereby make signals audible which would otherwise be too weak to operate the detector. It will now be evident that

this type of amplification is called "radio frequency amplification" because the oscillations induced in a receiving antenna by radio waves alternate at "radio frequency" and it is these high frequency oscillations which are magnified by the radio frequency amplifier.

PRINCIPLES OF DETECTION.

92. The necessity of some device to make the message carried by the radio waves perceptible to one of the human senses is apparent. Visual detection is sometimes utilized for radio telegraphy but audible detection is much more common and is, of course, necessary to reproduce sounds by radio telephony. A telephone receiver of some kind is used to convert the energy into air vibrations or sound.

Fig. 14

93. But if the telephone receivers are merely placed in series with the receiving antenna, the diaphragms will not be vibrated by the oscillations induced in the antenna by radio waves, and no sound will be heard. The inertia of the diaphragms prevents them from following the extremely rapid reversals of radio frequency current. In any case, even if the diaphragms could vibrate at this high frequency, no sound would be heard because the frequency would be above the limit of audibility.

94. It is evident, then, that the high frequency currents must be changed in some manner so that they can pass through the telephones and vibrate the diaphragm at some audible frequency. This can be accomplished by means of a **rectifier** which assists in detecting the radio signals.

95. A rectifier is a device which offers infinite resistance to the passage of current in one direction but freely allows it to pass in the opposite direction. This condition is never realized in practice but the more closely it is approached, the better is the rectification. Some minerals are natural rectifiers and the vacuum tube can also be used to rectify alternating currents.

96. If a crystal rectifier is inserted in series with the receiving antenna and telephones, as indicated in Fig. 14, an oscillating current can flow in the antenna in one direction only.

97. Let us suppose that the waves from a spark transmitting station induce an oscillating voltage in the antenna.

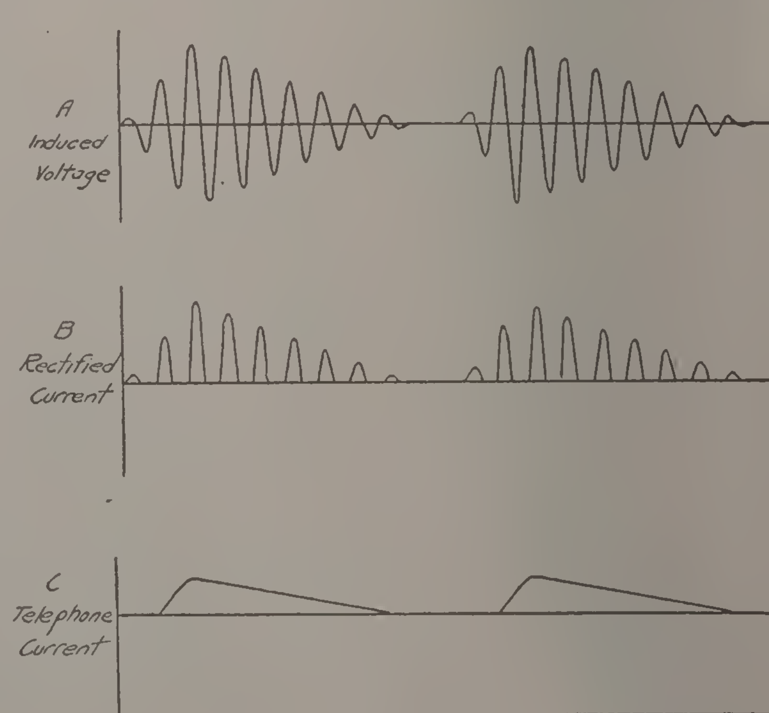


Fig. 15

The voltage induced by two of the wave trains is graphically illustrated in Fig. 15A.

The current which flows in the antenna is indicated at B from which it may be seen that each negative half cycle of voltage is unable to cause a current to flow because the rectifier offers high resistance to current in that direction. During each wave-train, therefore, the radio frequency pulsations of current are all acting in the same direction.

Owing to the inertia and resistance of the telephones, this results in a single surge of current through the telephones as shown at C. Each surge of current pulls the diaphragms. Since the wave trains follow each other at a frequency in the neighborhood of 500 per second, the diaphragms vibrate at this frequency and produce an audible note. As long as the operator at the transmitting station holds down the telegraph key wave trains are radiated and an audible vibration is sustained in the receiving telephone. Therefore, if the transmitting operator closes the telegraph key and sends a message by Morse code, the signals are audible in the receiving telephone and can be read by one skilled in the code.

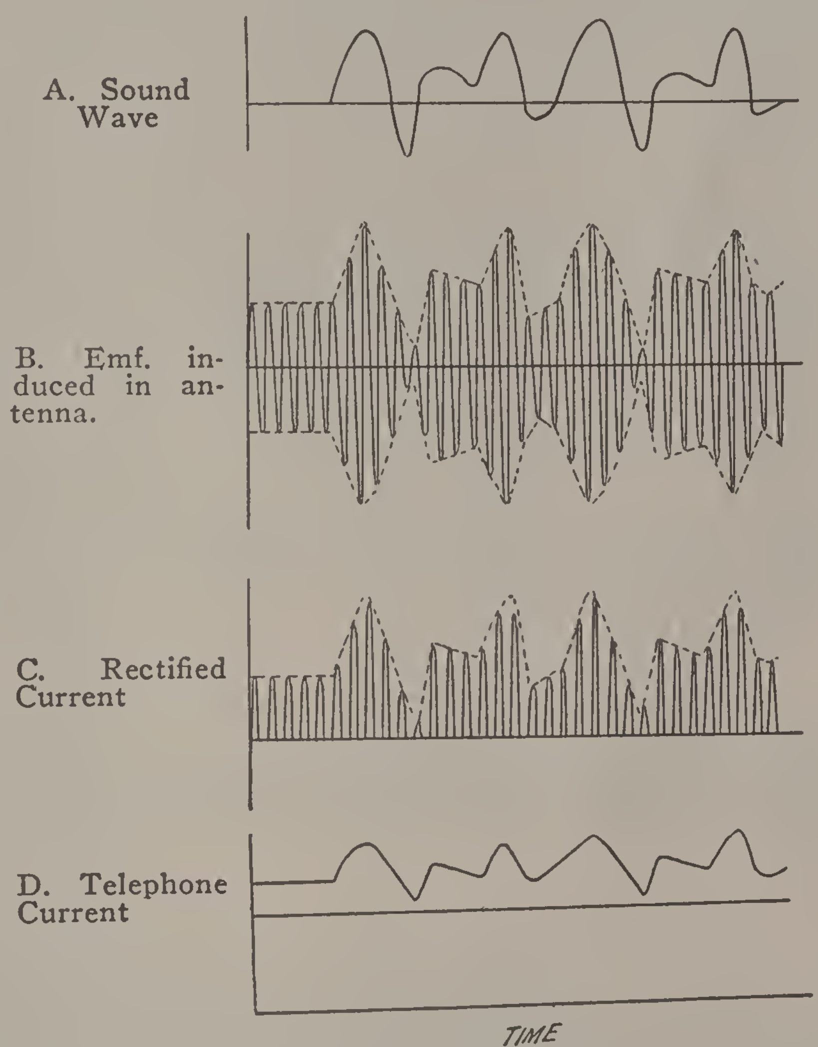


Fig. 16

98. A rectifier can be used in the same way to detect signals sent out by an I.C.W. transmitter, the only difference between the two methods of transmission being the amplitude and length of the wave trains. Since the trains of waves radiated by I.C.W. are undamped a higher value of current flows in the antenna during each train and consequently the telephones are traversed by a stronger surge of current. The audibility of the signals is greater.

99. Radio telephone signals can also be detected with the assistance of a rectifier. To explain the manner in which speech and music are reproduced by the radio receiver we show in Fig. 16A, a portion of the sound wave which is supposed to be produced at the transmitting station by a speaker's voice or a musical instrument.

Fig. 16B indicates how the sound wave form and frequency are preserved by the modulations in amplitude of the oscillating e.m.f. induced in the receiving antenna as previously explained. Unmodulated waves induce in the receiving antenna an undamped oscillating e.m.f. but modulated waves induce an oscillating e.m.f. of varying amplitude. The variations in amplitude have the same form and frequency as the sound wave. The high frequency current is rectified by the crystal. Fig. 16C illustrates the resulting uni-directional pulses of current.

The rectified **undamped** oscillations cause current to flow through the telephones but the value of this current does not change and therefore the diaphragm does not vibrate and no sound is heard. But the rectified oscillations of varying amplitude increase and decrease the value of the current passing through the 'phones in step with the changes in amplitude. The resulting telephone current is shown in Fig. 16D. The changes in this current have the same form and frequency as the sound wave produced at the transmitting station. The vibrations of the telephone diaphragm follow this changing current and consequently a sound is produced at the receiving station which duplicates the original sound at the transmitter.

100. **Detection of Undamped Waves.** It will be noted from the foregoing paragraphs that a telephone receiver with simple rectifier can be used to detect every type of radio signal except undamped wave signals. Undamped oscillations are rectified but this does not assist in their detection because the continuous oscillations are not interrupted or modulated in any way and consequently the telephone current does not change in value except at the beginning and end of each dot and dash. The telephone diaphragm does not vibrate and no sound is heard.

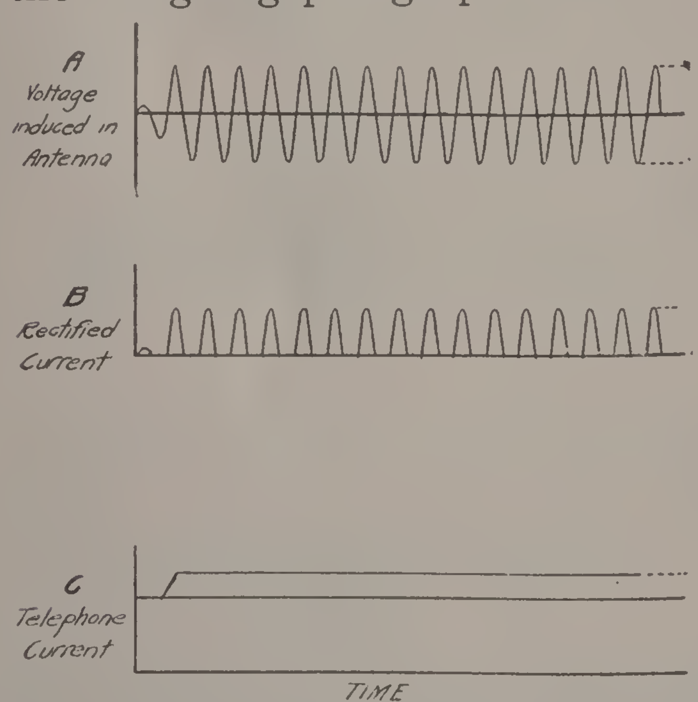


Fig. 17

101. This will be made clear by the curves of Fig. 17 which show at A the oscillating e.m.f. induced in the receiving antenna by undamped waves radiated from a transmitting station. B shows the rectified current which flows in the circuit while C indicates the resulting telephone current. The latter commences to flow at the beginning of the wave group, maintains a steady value as long as the oscillations are induced and falls to zero when the wave group terminates. As there are no changes in the telephone current during this time, the diaphragm does not vibrate at an audible frequency.

102. Special apparatus is therefore required at the receiving station to detect undamped waves. To produce an audible note

in the 'phones, it is necessary to modulate or interrupt in some way the continuous oscillations induced in the antenna. This can best be accomplished by locally inducing in the receiving antenna an undamped oscillating e.m.f. which has a frequency slightly different from that of the incoming signal. The local oscillations can be generated by a small vacuum tube with suitable circuits. This high frequency oscillator, as it is called, acts as a miniature transmitting station and induces an undamped oscillating e.m.f. in the receiving antenna in the same manner as the distant transmitting station. The circuits of the oscillator are arranged in such a way that it is possible to vary the frequency of the local oscillations.

103. If the local oscillation is continuously maintained and no signal e.m.f. is being induced, the current flowing through the telephones will be as illustrated in Fig 17. A steady current will flow through the telephone receiver as long as the local oscillations are maintained.

104. But if, in the same receiving circuit, an oscillating e. m. f. of slightly different frequency is induced by the undamped waves of a distant transmitter, the current produced by the combined oscillations **alternately increases and decreases in amplitude** as the two oscillations come in and out of phase with each other.

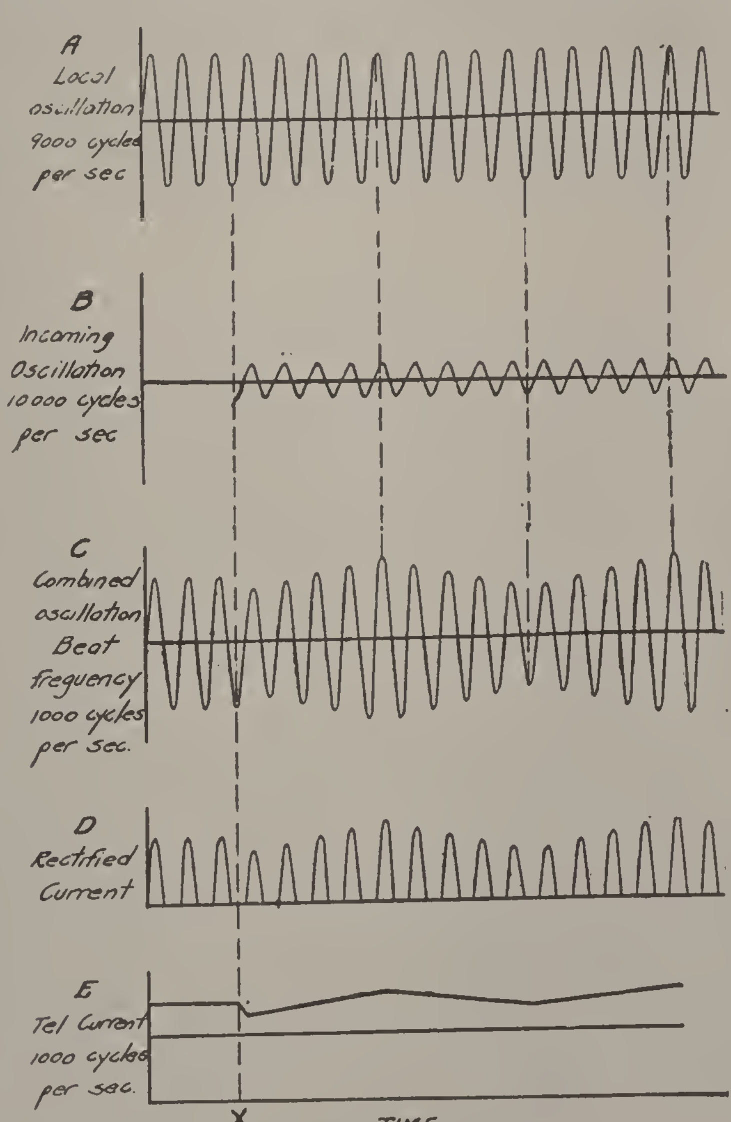


Fig. 18

105. A detailed explanation of this phenomenom of "beats" in the amplitude of the current produced by two super-imposed oscillations of different frequency is not necessary at this time. A study of the curves of Fig. 18 will make it clear.

106. The frequency at which the amplitude of the oscillation rises and falls is equal to the difference between the frequencies of the two separate oscillations. For instance, if the signal oscillation has a frequency of 10,000 cycles per second and the local oscillation is adjusted to a frequency of 9,000 cycles per second, the amplitude of the resultant oscillation rises and falls at a frequency of 1000 cycles per second.

107. The desired object of producing an audible note in the telephones while an undamped wave signal voltage is being induced in the antenna can therefore be realized by the method above described. The manner in which this audible note is obtained is shown by the curves of Fig. 18 which represent, at A, the oscillation induced by the local high frequency oscillator. At the moment X, the signal oscillation shown at B is also induced in the antenna.

108. The curve at C indicates the resulting oscillation. Before the moment X the local oscillation induces a continuous undamped oscillation. At the moment X the signal oscillation is super-imposed upon the local oscillation and the amplitude of the resulting oscillation alternately rises and falls at a definite frequency as the two oscillations come in and out of phase.

Let us suppose, as illustrated, that the signal oscillation has a frequency of 10,000 cycles per second. If the frequency of the local oscillations is adjusted to either 9,000 cycles per second or 11,000 cycles per second a beat frequency of 1,000 cycles per second is produced.

109. The effect of rectification on the current is indicated at D, and the resulting telephone current at E. From these curves it will be plain that variations in the current flowing through the telephones are only produced when the signal oscillation is induced in the antenna and that the frequency of the resulting vibrations of the telephone diaphragm depends upon the beat frequency. The latter can be varied by varying the frequency of the local oscillator. As this frequency is varied, within certain limits, the pitch of the note in the telephone is changed.

110. For example, to receive an undamped wave transmitting station which is sending on 200 meters, corresponding to a frequency of 1,500,000 cycles per second, the local oscillator may be adjusted to a frequency of 1,501,000 to obtain a beat frequency and audible note in the telephones of 1000 cycles per second. If the frequency of the local oscillator is changed to 1,500,500 the beat frequency and the audible note in the telephones is changed to 500 cycles per second.

LESSON 3.

INDUCTANCE—CAPACITY—RESONANCE.

111. The simple receiving system of Fig. 14 can never be used in practice. The rectifier and telephones in series with the antenna offer such a high effective resistance that it is extremely difficult for any high frequency current to flow in the circuit.

112. To efficiently receive signals the circuit or circuits of a radio receiver must be arranged in such a way that a maximum current can flow for a given induced voltage. In order that the greatest amount of energy may be produced the effective resistance of the circuits must be reduced to a minimum.

113. To undersand how this is accomplished, the effects of **Inductance** and **Capacity** in an electrical circuit must be fully appreciated. We will explain these separately.

INDUCTANCE.

114. **Electro-magnetism:** Some of the effects of electric currents are familiar to all. We know that they may be utilized for the production of heat and light. But there are other effects of electric currents which may be harnessed to do useful work; of these one of the most important is the magnetic effect.

115. When a current of electricity passes through a conductor a magnetic field is built up round the conductor. The magnetic strain is represented by lines which are called "magnetic lines of force." The intensity of the magnetic force at different points in the field is measured by the proximity of the lines of force to each other. The magnetic field in and around a wire carrying current is illustrated in the cross-sectional view of Fig. 19.

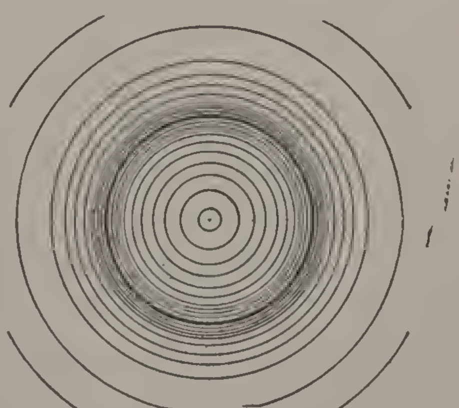


Fig. 19

116. The magnetic field acts in a definite direction and this direction depends upon the direction of the current

through the conductor. Fig. 20 shows the direction of the concentric circles of magnetic force round a wire carrying current for the direction of current indicated. If the direction of the current reverses the direction of the magnetic field also reverses.

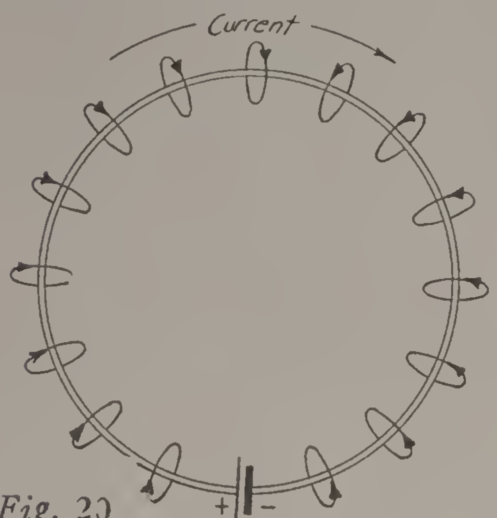


Fig. 20

117. The intensity of the field produced by a given current can be greatly increased by winding the wire carrying the current in the form of a coil. Fig. 21 shows how the lines of force would appear round a coil carrying current if the lines were visible.

118. The strength of the magnetic field produced by curent flowing through a coil depends upon three factors:

1. The value of the current.
2. The number of turns in the coil.
3. The "reluctance" of the magnetic path.

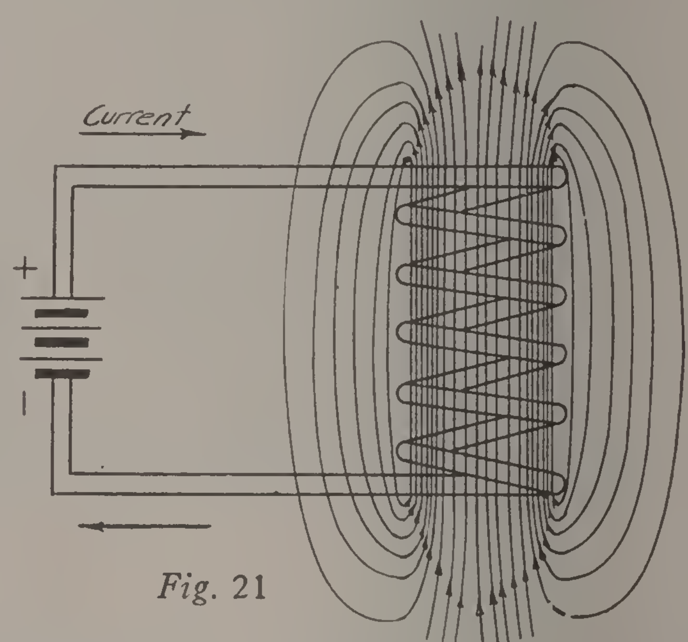


Fig. 21

119. "Reluctance" in a magnetic circuit corresponds to resistance in an electrical circuit. If the core of a coil is filled with iron, any given value of current passing through the coil sets up a very much stronger magnetic field than that which would be produced if the iron core were not present. This is due to the fact that iron has very much greater magnetic "Permeability" than air. In other words, it is much easier to set up magnetic lines of force in iron than in air.

120. **Law of Induced E.M.F.:** If a conductor is surrounded by a magnetic field and the strength of the magnetic field changes, an e.m.f. is induced in the conductor. A change in the strength of a magnetic field produces, in effect, an increase or decrease in the number of lines of force threading the conductor and it is this change which induces an e.m.f. in the conductor. This law of induced e.m.f. underlies the operation of most electrical apparatus.

121. If a number of wires are surrounded by a magnetic field and the strength of the field changes, an e.m.f. is induced in each wire. If the wires are joined together in series the total e.m.f. is equal to the sum of the individual e.m.f.'s. It is obvious the same result will be obtained if a coil of wire is surrounded by a changing magnetic field. Each turn of the coil may be regarded as a separate wire in which an e.m.f. is induced. Since all the turns of a coil are in series with each other the e.m.f. in-

duced across the entire coil is equal to the sum of the e.m.f.'s induced in each turn. It is also evident that the value of the e.m.f. induced is **proportional to the number of turns in the coil.**

122. The value of the e.m.f. induced in a coil is also governed by two other factors, viz:

1. The extent of the increase or decrease in the number of lines of force threading the coil.
2. The rapidity with which this change takes place.

For example, if a certain e. m. f. is induced in a coil by an increase or decrease of 100 lines of force **during one second** an increase or decrease of 200 lines of force during one second will induce an e. m. f. twice as great but a change of 200 lines of force **during two seconds** will induce the same value of e. m. f. as a change of 100 lines during **one** second.

123. In other words, the value of the e.m.f. induced in a coil is proportional to the **rate of change** in the number of lines of force threading the coil.

Therefore, value of
Induced E.M.F. = Rate of Change × Number of turns.

124. **Self-Induction:** A wire or coil through which a current is passing is surrounded by a magnetic field produced by the current. If the magnetic field increases in strength new lines of force are formed and there is an increase in the number of lines of force threading the conductor. Conversely, if the magnetic field decreases in strength there is a decrease in the number of lines of force threading the conductor.

Now, according to the rule of induced e.m.f., if there is any change in the number of magnetic lines of force threading a conductor, an e.m.f. is induced in that conductor.

125. Therefore, if the magnetic field in and around a wire or coil carrying current increases or decreases in strength an e.m.f. is induced in the wire or coil.

But the magnetic field in and around a conductor carrying current only increases or decreases in strength when the value of the current increases or decreases.

126. Therefore, if the **current** passing through a conductor increases or decreases in value, an e.m.f. is induced in the conductor. If the current does not change there is no change in the magnetic field and consequently no e.m.f. is induced.

127. The e.m.f. which is induced in a circuit by a change in its own current is called **the e.m.f. of self-induction.**

128. **Direction of self-induced e.m.f.:** An e.m.f. is induced in a coil or wire by a relative movement between the conductor and a magnetic field, providing that this movement changes the number of lines of force threading the conductor. The effect can be produced by moving a conductor from a weak to a stronger portion of a magnetic field or by holding the conductor stationary and moving the magnetic field.

129. The direction of the induced e.m.f. is governed by the direction of the magnetic field and the direction of motion of the conductor through the magnetic field. In the case of a self-induced e.m.f., of course, the conductor remains stationary but

if the current increases the lines of force cut the conductor with an outward direction of motion as they expand. If the current decreases the lines of force cut the conductor with the opposite direction of motion as they contract. Therefore the direction of a self-induced e.m.f. depends upon whether the current is increasing or decreasing in value.

130. Moreover, since the direction of the lines of force themselves depend upon the direction of current flow, the direction of the self-induced e.m.f. will similarly depend upon the direction of the current.

131. In effect it is found that a self-induced e.m.f. is **always in such a direction that it opposes the change of current which produces it.** That is to say, if the current increases, the self-induced e.m.f. is in the opposite direction to the applied e.m.f. of the circuit. This tends to decrease the effective e.m.f. and opposes the increase of current. On the other hand, if the current decreases, the self-induced e.m.f. is in the same direction as the applied e.m.f. and tends to increase the effective e.m.f. of the circuit and oppose the decrease of current.

132. The effect of self-induction in a circuit can best be understood by comparison with the mechanical properties of inertia and momentum.

133. It is well known that a heavy vehicle resists any effort to start it in motion. When it is started its speed only gradually increases. However, after its **inertia** is overcome and it has attained a uniform speed the only opposition to the driving power is the resistance of friction. So long as it continues to travel at a uniform speed there is no inertia.

134. In an electrical circuit when a direct current commences to flow, the building up of the magnetic field in and around the conductor produces a self-induced e.m.f. which opposes the applied e.m.f. and thereby acts to decrease the effective e.m.f. When the magnetic field is entirely built up the number of lines of force threading the conductor is constant and no further counter e.m.f. is induced. The current in the circuit, which is analogous to the speed of a vehicle, only increases gradually as the counter self-induced e.m.f. decreases. After a brief period it reaches its maximum value for a given applied e.m.f. Thereafter, the only opposition to the flow of the current is the resistance of the circuit itself. The ultimate value of the current is determined by Ohm's Law. This ultimate value is not affected by the self-induction of the circuit, which only affects the initial value of the current when the e.m.f. is applied across the circuit.

135. If a vehicle is travelling at a uniform speed there is no inertia. Its mass does not affect its speed. However, if the speed is accelerated its inertia again resists this **change** of speed.

136. In an electrical circuit, if a steady direct current is flowing and the current is increased, either by increasing the applied e.m.f. or decreasing the resistance of the circuit, the increase of current sets up new lines of force round the conductor. A counter e.m.f. is self-induced which resists this **change** of current. In a brief period of time the magnetic field and the cur-

rent both reach a new higher value and the effect of self-induction is not present, provided there is no further change in the current.

137. Again, while a vehicle is travelling at a uniform speed its mass opposes any attempt to stop its motion. Its momentum causes it to continue in the direction in which it is travelling.

138. In an electrical circuit, if a steady direct current is flowing and the source of e.m.f. is removed, the magnetic field round the conductor contracts and induces an e.m.f. in the circuit in the same direction as the applied e.m.f. As a result, the current does not immediately stop flowing when the source of e.m.f. is removed but slowly decreases to zero; provided, of course, the circuit is not opened by a switch.

139. In the same way, if a steady direct current is flowing in a circuit and the current is reduced, either by an increase or a reduction of applied e.m.f., the magnetic field contracts, induces an e.m.f. in the conductor in the same direction as the applied e.m.f. and thereby acts to increase the effective voltage of the circuit. The self-induced e.m.f. falls to zero when the contraction of the magnetic field ceases. Consequently the current in the circuit gradually decreases and only reaches the value determined by Ohm's Law when the self-induced e.m.f. falls to zero.

140. The distinction between the effects of resistance and self-induction should be observed. Resistance obstructs the flow of electricity in a circuit at all times but self-induction merely opposes any **change** in the value of the current. Resistance absorbs energy in the production of heat—it wastes energy. Self-induction **stores** energy in the production of a magnetic field when the current is increasing and gives this energy back to the circuit when the current decreases and the magnetic field contracts.

141. **Value of a self-induced e.m.f.:** It will be evident that the self-induction of a circuit is entirely due to the magnetic field which is produced by the current in the circuit. The self-induction effects are only present when there is a change in the current because this change of current alters the strength of the magnetic field.

Therefore, the value of the e.m.f. self-induced in a coil by a change of current can be determined from the formula of Paragraph 123, viz.:

Induced e.m.f. = Number of turns × Rate of change of magnetic lines of force.

142. Thus the value of the self-induced e.m.f. in a circuit is increased by winding some of the conductor in the form of a coil. The greater the number of turns in this coil the greater is the self-induced e.m.f. The self-induced e.m.f. can also be greatly increased by providing the coil with an iron core because this increases the extent of the change in the number of lines of force threading the coil for any given change of current.

143. Now, the rate of change of magnetic lines of force which governs the value of a self-induced e.m.f. in any given circuit is manifestly dependent upon the rate of change of the current in

the circuit. The rise or fall in strength of the magnetic field and the speed at which the change takes place are determined by the rise or fall in the strength of the current and the rapidity of the change of current strength.

144. If the current is changing at the rate of one ampere per second a certain e.m.f. is self-induced in the coil or circuit. If the current changes in strength with greater speed the value of the self-induced e.m.f. is greater. For instance, if during one-hundredth of a second the current increases or decreases by one ampere this corresponds to a change of 100 amperes in one second. The self-induced e.m.f. is correspondingly higher in value. Again, if the current changes 2 amperes during one-hundredth of a second this corresponds to a change of 200 amperes per second. The self-induced e.m.f. is still greater in value.

145. **Unit of Inductance:** If any coil or circuit has induced in it an e.m.f. of **one volt** by a change of current of **one ampere per second,** it is said to have an **"Inductance"** of **One Henry.** The Henry is the unit of Self-Induction and from this unit we can measure the effects of self-induction in other coils or circuits.

146. Thus, suppose a coil has an inductance of 5 henrys. This means that a change of current of one ampere per second induces in the coil a back e.m.f. of 5 volts. If a change of current of one ampere per second induces in a coil a back e.m.f. of 10 volts the coil has an inductance of 10 henrys. The coil with an inductance of 10 henrys must have a greater number of turns or more iron in its magnetic path than the first coil since the same rate of current change induces in it a higher voltage.

Naturally, if the current changes at a higher rate than one ampere per second, the back e.m.f. induced in either coil is correspondingly increased.

147. Therefore, the value of the voltage self-induced in a coil by a change of current is equal to the product of its inductance and the rate of change of current, or

Self-Induced e.m.f. (in volts) = Inductance (henrys) × Current change per second (in amperes)

148. **Effects of inductance in a D.C. circuit:** Self-induction effects in a direct current circuit are only present when the current is started or stopped or when the current is increased or decreased. No e.m.f. is self-induced if the current does not change in value. Therefore, self-induction does not affect the value of the current which can be determined by Ohm's Law.

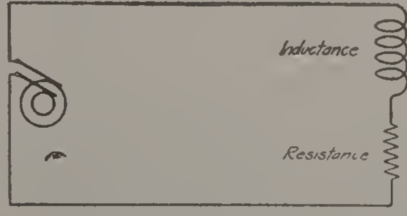


Fig. 22

149. **Current in an A. C. circuit with Inductance and Resistance:** A back e. m. f. is induced in an inductive circuit by a changing current. An alternating current is constantly changing in value and in direction. Therefore, the effects of self-induction are constantly present if an alternating e. m. f. is applied across an inductive circuit as in Fig. 22. The back e. m. f. of inductance in an A. C. circuit has a maximum value when the alternating current is changing at the greatest rate, i.e., when it is passing through its zero values. Conversely, the back e.m.f.

of inductance is zero when the rate of current change is zero, i.e., when the current reaches its maximum amplitude. In other words, the back e.m.f. of self-induction is maximum when the current is zero and is zero when the current is maximum. Fig. 23 shows the alternating current curve and the back e.m.f. curve. The latter is invariably 90 degrees (one-quarter cycle) behind the current. This will always be the relationship between the current in an A.C. circuit and the back e. m. f. of inductance. The phase relationship is not affected by the relationship between the applied e. m. f. and the current.

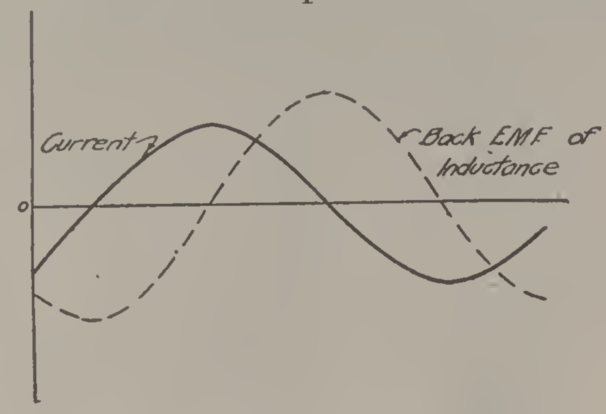


Fig. 23

150. **Reactance**: The effective resistance which the back e. m. f. of self-induction offers to the flow of current in an A. C. circuit is called reactance or, more particularly, inductance reactance. The total resistance of the circuit including the reactance and ohmic resistance, is called the impedance of the circuit.

151. The alternating e.m.f. applied across the circuit of Fig. 22, which is supposed to possess inductance and resistance only, must be equal to the sum of the voltage drops across the inductance and the resistance. Therefore, the current which flows in an A.C. circuit possessing inductance and resistance is always lower than that which flows if the inductance is not present. **The applied e.m.f. must overcome the reacting force of self-induction as well as the resistance of the circuit.**

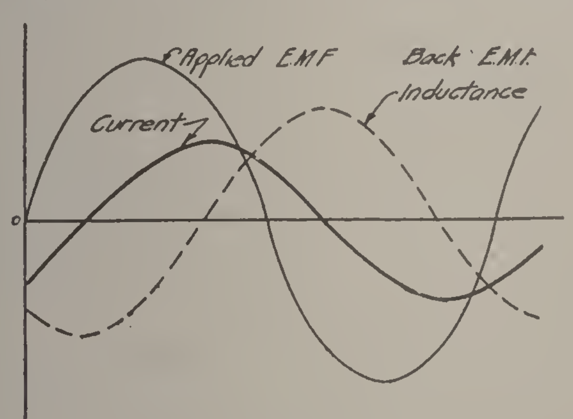


Fig. 24

152. The relation between the applied e. m. f., the current and the back e. m. f. of self-induction in the circuit of Fig. 22 is shown in Fig. 24. From this diagram it will be noted that the effect of inductance in the circuit is to make the current lag behind the voltage nearly 90 degrees. The current curve in this diagram should be compared with that of Fig. 6 showing the relation between current and impressed voltage in an A. C. circuit with resistance only.

153. **Value of Inductance Reactance**: The back e.m.f. self-induced in a circuit depends upon the inductance of the circuit and the rate of current change (Par. 147).

154. All parts of an electrical circuit possess some value of inductance. The inductance can be increased by including a coil in the circuit and the inductance of this coil depends upon the number of turns, its diameter, etc. If the coil has an iron core it has a greater inductance than if the iron is not present. The greater the inductance of the A.C. circuit the higher is the value of the inductance reactance.

155. The higher the frequency of the alternations in an A.C. circuit the more rapid is the rate of current change and therefore the greater is the back e.m.f. of inductance, or inductance reactance.

156. We may say, then, that inductance reactance in an A.C. circuit is directly proportional to the inductance of the circuit and to the frequency of the current; the latter, of course, being the same as the frequency of the applied e.m.f.

157. The value of inductance reactance in an A.C. circuit may be written

$$6.28 \times f \times L$$

where f = the frequency of the applied e.m.f. in cycles per second.

and L = inductance of the circuit in henrys.

The product gives, **in ohms**, the effective resistance of inductance reactance to the flow of current in an A.C. circuit.

158. With a given value of impressed e.m.f. the effect of increasing either the frequency or the inductance is to increase the inductance reactance and decrease the value of the current. At zero frequency (Direct Current) the reactance is zero. At high frequencies the reactance is very high; the voltage is mostly used up in overcoming the high reactance and the current is very small.

159. We have already noted that the current oscillations in a receiving antenna have a very high frequency. Therefore, the coils used in radio receivers have a low value of inductance, measured in smaller units called millihenrys, microhenrys and centimeters.

1 henry = 1,000 millihenrys
1,000,000 microhenrys
1,000,000,000 centimeters.

160. The coils used in radio receivers are called "inductance coils" or "inductances." They are sometimes tapped and by means of a switch the number of active turns of the coil in the circuit is varied to vary the inductance of the circuit.

161. It should be understood that although the coils of a radio receiver have a comparatively low value of inductance and are often composed of just a few turns of wire wound on a three or four-inch tube, their reactance to radio frequency currents may be very high. If the same coils were included in, say a 60 cycle lighting circuit their effect would be negligible. The frequency of the current in the lighting circuit is so low that hardly any back e.m.f. would be induced in the coils. But the currents in radio circuits may have as high a frequency as 2,000,000 cycles per second and consequently the reactance voltage set up across these small inductances may be very high.

CAPACITY.

162. **Factors governing Capacity**: In the first chapter we explained that the potential to which a body is raised by a given charge of electricity depends upon the capacity of the body; its ability to hold the charge. We also stated that one factor

governing the capacity of a body is its size. A given charge of electricity raises the potential of a small body to a higher potential than a large body.

163. There are other factors which govern the capacity of a body. Let us suppose that an insulated plate A is charged to a positive potential of 20 volts and that this potential is measured when the plate is not in proximity to any other body. Now if an insulated plate B is brought near to A as in Fig. 25, and the potential of A is again measured it will be found that its potential has dropped. In other words its **capacity** has increased. Moreover, it will be found that the closer the plate B is brought to the plate A the more the potential of A drops; the greater becomes its capacity. Then, if we insert a sheet of glass between the two plates we will find that the capacity is still greater.

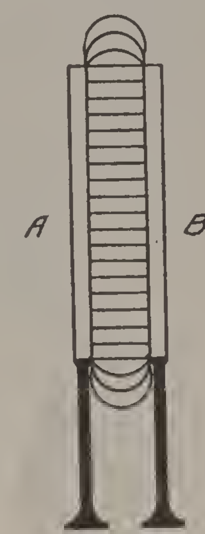


Fig. 25

164. The increase in capacity is caused by an increase of the electrical straining of the space between the two plates. As we previously stated, a charged body exerts a strain on the surrounding ether. When the plate B, which we will assume is at zero potential, is brought near the positively charged plate A the lines of electric strain issuing from A disturb the electrons in B. Free electrons in B, each representing a negative charge of electricity, are attracted in the direction of the positive plate A. As a result of bringing the plate B within the field of A a charge of negative electricity is accumulated on the side of B near to A. This effect is described as **static induction.** The closer B is brought to A the greater is the charge induced on the former. Fig. 25 shows the lines of electric strain which issue from A and terminate in the negative electrons of B. The electric field of A is therefore mostly concentrated in the space between the two plates.

165. The strength of the charge induced on B also depends upon the material occupying the space between the two plates. This may be air, glass, mica or other non-conductor and is known as the **dielectric**. For any given spacing, if the dielectric is glass, mica or other substance with high **inductive capacity** the charge induced on B is greater than if the dielectric is air.

166. As the charge on B is increased, the potential of A drops and consequently the capacity is increased.

167. **The Condenser**: The electrical condenser is based on the principles of static-induction. A simple form of condenser consists of two metal plates placed parallel to each other and separated by air, glass or other dielectric, as in Fig. 25.

168. From the foregoing paragraphs it will be seen that the capacity of a condenser depends upon:

1. The size and shape of the plates of which the condenser is composed.
2. The thinness of the dielectric.
3. The inductive capacity of the dielectric.

If any of these factors is increased, a larger quantity of electricity must flow into the condenser to raise its potential to a given value or, in other words, the greater is the capacity of the condenser.

169. **Mechanical Analogy of Capacity**: A good understanding of the effects of capacity in electrical circuits can be obtained by comparing the capacity of a condenser with the flexibility of a spring.

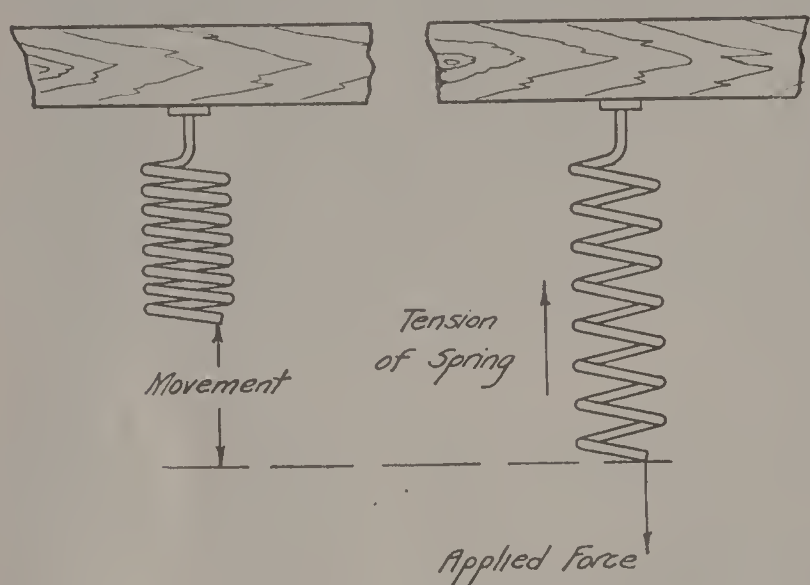


Fig. 26

170. If a downward force of a definite value is applied to the spring of Fig. 26 the spring will be extended a certain distance until it exerts a force exactly equal and opposite to the applied force. The distance which the spring moves before it exerts a force equal and opposite to the applied force depends upon the inflexibility of the spring.

171. Similarly if a continuous e.m.f. is applied across a condenser a quantity of electricity will flow into the condenser until it exerts a pressure equal and opposite to the applied e.m.f. The quantity of electricity which must flow into the condenser before it exerts a pressure equal and opposite to the applied e.m.f. depends upon the capacity of the condenser.

172. Thus, in Fig. 27, there is no difference of potential between the plates A and B of the condenser before the switch S is closed. When the switch is closed the plate A becomes 6 volts positive with respect to B. To produce this difference of potential between the plates of the condenser electrons must flow from one plate to the other. The condenser then exerts an e. m. f. equal and opposite to the e. m. f. of the battery and the condenser is said to be charged. Now the **quantity** of electricity which must flow to charge the condenser to a difference of potential of six volts depends upon the capacity of the condenser.

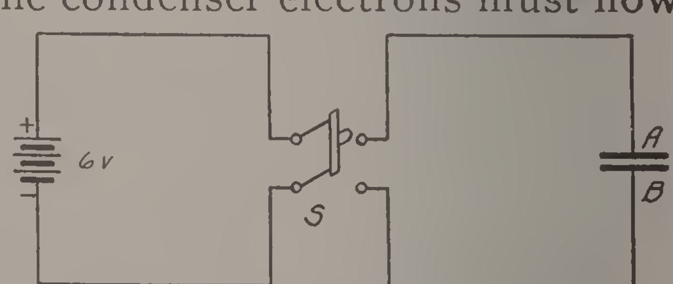


Fig. 27

173. **Measurement of Capacity**: A condenser of unit capacity would be one which requires a unit charge of electricity to bring its plates to a potential difference of one volt. The coulomb is the unit of quantity (One coulomb per second equals one ampere). Therefore a condenser which requires a charge of one coulomb to bring its plates to a potential difference of one volt is said to have a capacity of one **Farad**. But this unit is too large for ordinary purposes. The microfarad (one millionth of

a farad) is the practical unit of capacity. Very small values of capacity are used in radio circuits, however, and are expressed in milli-microfarads (one thousandth of a microfarad) and in micro-microfarads (one millionth of a microfarad). It is more common, however, to designate the capacities of condensers used in radio circuits in decimal fractions of a microfarad. Thus 1 millimicrofarad is commonly expressed as .001 mfd (microfarad).

A condenser of .001 mfd. requires a charge of one billionth of a coulomb to charge it to a potential of one volt. In other words, since a current of one ampere represents one coulomb per second, a current of one ampere would have to flow for only one billionth of a second to charge a .001 mfd. condenser to a potential of one volt; or, similarly, if a current of one milli-microampere flows for one second, it will charge the condenser to a potential of one volt.

174. **Discharge of a Condenser:** Referring again to Fig. 26, we have seen that if a downward force is applied to the spring it will extend until the opposing force of the spring equals the applied force. So long as the applied force remains at a steady value the spring will not move.

But if the applied force is **removed** or **decreased** in value the tension of the spring will cause it to **contract**.

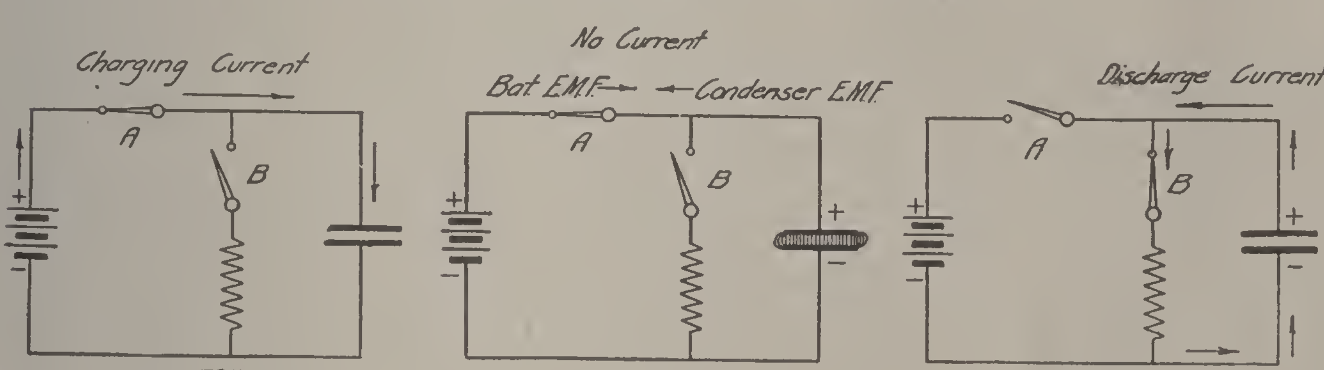


Fig. 28A 28*B* 28*C*

175. Similarly, in the electrical circuit of Fig. 28 (a), when the switch A is closed (B being open) a current flows which charges the condenser. When the condenser is charged it exerts a pressure equal and opposite to the applied e.m.f. and no further flow of current takes place—(see Fig. 28 [b]).

176. But now, if the switch A is opened and simultaneously switch B is closed, as in Fig. 28(c) the condenser will discharge through the resistance. That is to say, if the e.m.f. applied across a condenser is **removed** the potential difference of the condenser will force a current through the circuit (providing, of course, a conducting path exists.) Moreover, this current will be in the **opposite direction** to the charging current.

177. In the same way, if the e.m.f. applied across a condenser **decreases** in value the higher potential difference of the condenser will force a current through the circuit in the **opposite direction** to the charging current until the potential difference of the condenser is the same as the applied e.m.f.

178. **Current Flow in A.C. Circuit with Capacity only:** If an alternating e.m.f. is applied across a condenser, as in Fig. 29

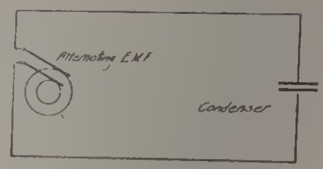


Fig. 29

and if the current possesses neither inductance nor resistance, the alternating current which flows in the circuit can be represented by the current curve of Fig. 30.

179. The value of this current and its phase relation to the applied e.m.f. can best be understood by comparing the conditions represented by the circuit of Fig. 29 with similar conditions in the mechanical analogy of the movements of a spring.

180. The e.m.f. applied across the condenser of Fig. 29 is an alternating e.m.f.; it is constantly changing in value and direction. During each alternation it rises from zero to a maximum and again falls to zero. If a force of a similar changing nature is applied to the spring of Fig. 26, the spring will extend or contract as the applied force increases or decreases. **The direction of movement of the spring depends upon whether the applied force is increasing or decreasing.** If it increases in value, the spring moves in the same direction as the applied force. If the applied force decreases in value the opposing tension of the spring causes it to contract and the spring moves in the opposite direction to the applied force.

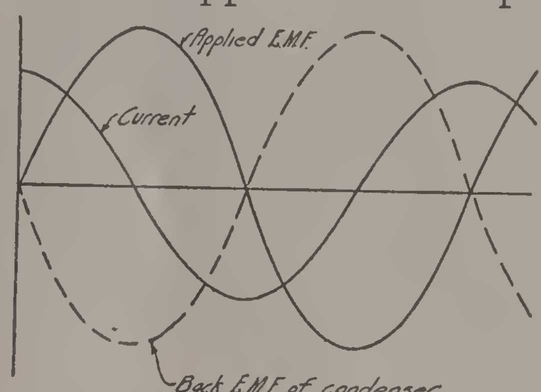


Fig. 30

181. As can be seen from the curves, the **direction** of the current in the circuit of Fig. 29 similarly depends upon whether the applied e.m.f. is increasing or decreasing. While the e.m.f. is **increasing** from zero to maximum, the current is in the **same** direction as the e.m.f. but while the e.m.f. is **decreasing** from maximum to zero, the current is in the **opposite** direction to the e.m.f. When the applied e.m.f. is decreasing the opposing e.m.f. of the condenser, being greater than the applied e.m.f. forces a current through the circuit in the **opposite** direction to the applied e.m.f.

182. The magnitude of the current at any moment can be compared with the **speed** of a spring when a changing force is applied to it. A current of electricity is measured as quantity per second (amperes) and speed is measured as distance of movement per second.

The speed at which a spring extends or contracts depends upon the **rate** of **change** in the applied force and the **flexibility** of the spring. For instance, with a spring of given flexibility, if the applied force **increases at a constant rate**, the spring will extend at **constant** speed. If at any time the applied force ceases to increase and remains at some steady value, the spring will not move. The applied force and the tension of the spring, being equal and opposite forces, produce no movement of the spring unless the applied force either increases or decreases in value. If the applied force **decreases at a constant rate**, the spring will contract at a constant speed. But if the applied force increases or decreases at **non-uniform rate,** the speed of the spring depends upon the rate of change in the applied force.

183. Similarly, in an A.C. circuit with capacity only the magnitude of the current at any moment depends upon the **rate of change** in the applied e.m.f. and the **capacity** of the condenser. With a condenser of given capacity, the current reaches its maximum value when the e.m.f. is changing at its greatest rate. That is to say, the current is maximum when the e.m.f. is passing through its zero values. The current is zero when the e.m.f. is at maximum because, at this point, there is **no** change in the applied e.m.f. The applied e.m.f. and the back e.m.f. of the condenser are equal and opposite to each other. A current flows only when the applied e.m.f. changes in value.

184. We can say, then, that the current which flows in an A.C. circuit **with capacity only** has a similar form to the applied e.m.f. but **leads the e.m.f. by 90 degrees.** The current is reversed in direction by the back e.m.f. of the condenser one-quarter cycle before the applied e.m.f. reverses its direction.

185. The diagram of Fig. 30 shows this relationship between current and applied e.m.f. and also shows the curve of the condenser back e.m.f. The back e.m.f. of the condenser invariably reaches its maximum when the current has flowed into the condenser in one direction for the greatest length of time. That is to say, at the end of each alternation of current, when the current is zero, the back e.m.f. of the condenser is maximum. **The back e.m.f. of capacity is invariably 90 degrees ahead of the current.** This will be true irrespective of the phase relation between the applied e.m.f. and the current. The back e.m.f. of a condenser in an A.C. circuit is always 90 degrees ahead of the current in the circuit.

186. **Capacity Reactance:** The effective resistance which the back e.m.f. of a condenser offers to the flow of the current in an A.C. circuit is called the reactance of the condenser or capacity reactance.

187. The **current** in an A.C. circuit with capacity only is **proportional to the capacity of the condenser and to the frequency of the applied e.m.f.** The condenser will always take a sufficient charge to raise its potential to that of the applied e.m.f. If the capacity is large a greater quantity of electricity is required to raise its potential than if the capacity is small. Since a current is quantity per second an increase in capacity means an increase in current for any given frequency of applied e.m.f. If the frequency of the applied e.m.f. is increased the rate of change of the applied e.m.f. is increased and therefore the current in the circuit is increased.

188. Since the **current** is **proportional** to the capacity of the condenser and to the frequency of the applied e.m.f., it follows that the effective resistance or **reactance of capacity in an A. C. circuit is inversely proportional to the capacity of the circuit and the frequency of the applied e.m.f.**

189. Mathematically, the capacity reactance of an A.C. circuit can be written:

$$\frac{1}{6.28 \times f \times C}$$

Where f = frequency of the applied e.m.f. in cycles per second

and C = Capacity of the circuit in farads.

The quotient gives the effective resistance, **in ohms,** of capacity to the flow of current in an A.C. circuit.

190. In radio circuits, the currents have very high frequencies. Therefore, if we wish the circuits to exert any appreciable capacity reactance, we must make the values of the capacity very low. The lower the capacity, the higher is the capacity reactance for any given frequency. This should be remembered as we shall refer to it later. The condensers used for "tuning" radio circuits seldom have a higher capacity than .001 mfd. Even this capacity may, under certain conditions, be altogether too high.

RESONANCE.

191. The foregoing explanations of the separate effects of inductance and capacity in an A.C. circuit will explain how an oscillating current, which is merely a high frequency alternating current, can flow in the aerial of a radio receiving station. Direct current cannot flow in the aerial because there is no continuously conducting path but alternating current can flow because the overhead wires of the aerial and the earth below may be considered as the two sides of a condenser with the space between acting as the dielectric, as illustrated in Fig. 31. This capacity of an aerial is "distributed." It is not concentrated in two or more plates as in the ordinary electrical condenser but is distributed along the wires. An aerial also possesses a certain value of distributed inductance. A magnetic field is set up round a conductor carrying current even although it is not wound in the form of a coil. To wind the conductor in the form of a coil increases its inductance but even when the wires are stretched out straight they possess a certain value of inductance.

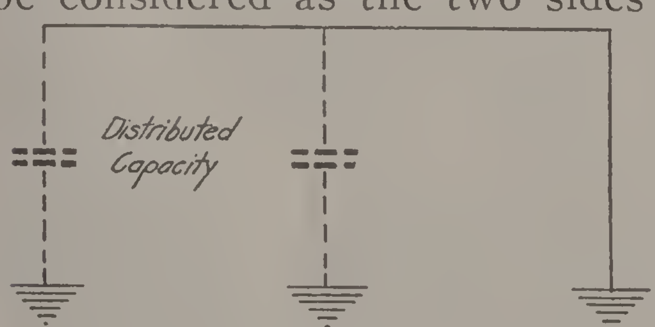


Fig. 31

192. **Oscillatory Circuits:** An oscillatory circuit is fundamentally the same as any other circuit with inductance and capacity (and all circuits possess some value of each)—but we have learned that the frequency of alternating current in a circuit has a marked effect on the reacting voltages set up by both inductance and capacity. In an oscillatory circuit, the values of the inductance and capacity are arranged so that a high frequency current can flow to the best advantage.

193. An aerial, in which the inductance and capacity are both distributed, is called an open oscillatory circuit, whereas a circuit in which the inductance is mostly concentrated in a coil and the capacity in a condenser is called a closed oscillatory

circuit. The latter is illustrated in Fig. 32. The main difference between an open and a closed oscillatory circuit is that the open circuit is a better radiator of waves than the closed circuit. When an oscillating current flows in an open circuit, it radiates waves of comparatively high amplitude, whereas the closed circuit radiates waves of very low amplitude; it is a very poor radiator.

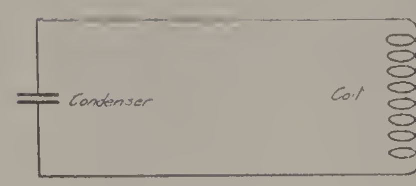


Fig. 32

194. **Tuning an oscillatory circuit**: As we intimated at the beginning of this chapter, it is necessary to arrange the circuits of a radio receiver in such a way that a maximum current can flow for a given induced voltage so that the greatest amount of energy may be produced to operate the detecting system. We will now explain how this may be accomplished.

195. We have considered separately the opposing reactions of inductance and capacity in an alternating current circuit. Let us contrast the effect of these reactances:

CAPACITY	INDUCTANCE
The reactance of a condenser **of given capacity** in an A. C. circuit is **decreased** by an increase in the frequency of the applied e.m.f. and vice versa, the reactance is increased by a decrease of frequency.	The reactance of a **given inductance** in an A. C. circuit is **increased** by an increase in the frequency of the applied e.m.f. and, vice versa, the reactance is decreased by a decrease of frequency.
At zero frequency (Direct Current) the reactance of the condenser in the circuit is **infinite.** The current is **zero.** As the frequency increases, the reactance **decreases** until, at very high frequencies, the capacity reactance is very **small** and the current proportionately **large.**	At zero frequency (Direct Current) the reactance of the inductance is **zero.** The current is a **maximum.** As the frequency increases, the **reactance increases** until at very high frequencies the inductance reactance is very **high** and the current proportionately **small.**
The reactance of a condenser is **decreased** by an increase of its capacity. The smaller the capacity, the **higher** is its reactance for any given frequency.	The reactance of a coil is **increased** by an increase of its inductance. The smaller the inductance the **lower** is its reactance for any given frequency.
The effect of capacity is to make the current **lead** the applied e.m.f.	The effect of inductance is to make the current **lag** behind the applied e.m.f.
The reacting force of capacity in volts is set up 90 degrees **ahead** of the current. This voltage is in direct opposition to the voltage set up by inductance. See Figs. 30 and 23.	The reacting force of inductance in volts is set up 90 degrees **behind** the current. This voltage is in direct opposition to the voltage set up by capacity. See Figs. 23 and 30.

196. How can we obtain a maximum current in an oscillatory circuit in which **both** these effects are present—in a circuit which has both inductance and capacity?

The answer is evident. We can obtain a maximum current by balancing the two reactances against each other. They act in direct opposition. If we can arrange the circuit so that the voltages set up by the inductance and capacity are exactly equal they completely neutralize each other. **It does not matter how high or how low the reactance voltages may be. So long as they are equal they neutralize each other** and the only remaining opposition to the current in the circuit is the resistance of the circuit. In other words, if we can make the two reactances **equal,** the total reactance is zero, the current is in phase with the applied volts and the current in the circuit at any moment of time may be determined by Ohm's Law, viz:

$$\text{Current} = \frac{\text{Applied Volts}}{\text{Resistance}}$$

197. How, then, can we arrange an oscillatory circuit so that these conditions are realized? If we change the inductance or capacity of the circuit we change the reactance but there is still the factor of the frequency of the applied e.m.f., which governs both the capacity reactance and the inductance reactance.

198. Let us presume, then, that the frequency of the applied e.m.f. is a fixed value. Applying the conditions to the antenna circuit of a radio receiver, we will presume that we wish to receive a message transmitted by a certain station on a wavelength of 400 meters, corresponding to a frequency of 750,000 cycles per second. The e.m.f. induced in the antenna oscillates at this frequency. How can the circuit be arranged so that the capacity reactance neutralizes the inductance reactance?

Always remembering that inductance reactance is increased by an increase of inductance whereas capacity reactance is increased by a **decrease** of capacity, the inductance and capacity of the circuit can evidently be varied until two values are found at which (for the given frequency) the reactances are equal and neutralize each other. If the inductance is fixed and cannot be varied, then, of course, it will be necessary to adjust the capacity until the capacity reactance is equal to the fixed reactance of the inductance for the given frequency.

199. When the inductance and capacity of an oscillatory circuit are so adjusted that the total reactance to a given frequency of applied e.m.f. is zero the circuit is said to be **in resonance** with this frequency.

200. It should be understood that one is not limited to a single combination of inductance and capacity to bring a circuit into resonance with any frequency. It is the product of the inductance and capacity of a circuit which determines its resonant frequency. For instance, a circuit with an inductance of 200 microhenrys and a capacity of .001 mfd will still be resonant at the same frequency if its inductance is increased to 400 microhenrys and its capacity decreased to .0005 mfd. The product is the same in each case.

201. It should be noted, however, that if resonance is ob-

tained with a high inductance and a low capacity the reactance voltages across both the inductance and the capacity, while neutralizing each other, both possess much higher values than when resonance is obtained with a low inductance and a high capacity. This is sometimes an important consideration in designing radio receiving apparatus. It is often desirable to tune a circuit to resonance with a certain frequency and yet choose such values of inductance and capacity which will make the neutralizing reactances at this frequency as high as possible. The circuit should then be tuned to resonance with as large a value of inductance and as small a value of capacity as possible.

202. This is particularly important when receiving the very high frequencies of short waves. A very small capacity which, at low frequencies, has a fairly high reactance, may have a very low reactance at extremely high frequencies. If the capacity is fixed, resonance can then only be secured by reducing the reactance of the inductance until it neutralizes the low reactance of the capacity. Both reactances are correspondingly low, even though the circuit is in resonance with the applied frequency.

203. **The Resonance Curve**: Let us suppose that to receive a certain station the inductance and capacity of the antenna circuit of a receiving system have been chosen so that the circuit is resonant at a frequency of 750,000 cycles. In radio parlance, the antenna is tuned to a wave-length of 400 meters. How sharply is it tuned to this wave-length? If another station is transmitting on 350 meters, will it be heard and cause interference?

204. If the circuit is resonant at 400 meters the reactance is zero at this frequency only. At the higher frequency of 350 meters the inductance reactance is higher than the capacity reactance and the e.m.f. induced in the aerial by the 350-meter station will encounter a positive reactance. The current will be smaller than at the resonant frequency.

205. But if there is enough current to operate the detecting system the 350-meter station will be heard and cause interference. Can this be avoided? If a number of stations are transmitting, can we not pick out the one we wish to hear and avoid the interference caused by the signals of other stations?

206. This can, to a great extent, be accomplished, as we shall see later. This factor is one of the most important to be considered in the design of a radio receiver. In New York City alone, three or four broadcasting stations are frequently transmitting at the same time. One is transmitting on 405 meters; another on 455 meters; still another on 492 meters. A receiving set must be able to select one station without interference from the others.

207. We can very easily determine the factors governing the **selectivity** of an oscillatory circuit by a simple experiment. The same method can be used to determine the selectivity of any oscillatory circuit in a radio receiver.

208. The circuit of Fig. 33 consists of a fixed inductance L, a variable condenser C, a variable resistance R, and a meter A, the latter being capable of recording the value of any oscillating current in the circuit.

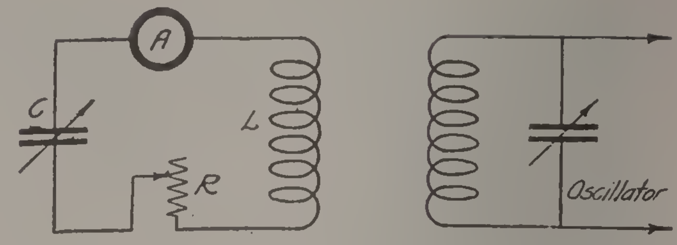


Fig. 33

209. An oscillator is used to induce in this circuit an oscillating e.m.f. of any desired frequency. We shall see later how an oscillator is made and how it operates. In the meantime we may regard it as a miniature transmitter which sends out a continuous stream of undamped waves. The oscillator is provided with a variable condenser so that the frequency of the waves (or wave-length) may be constantly varied over its scale.

210. The variable condenser C is turned to a midway position and the variable resistance R is almost cut out of the circuit. With the condenser of the oscillator at zero (which, by previous measurement, is known to adjust the oscillator to a wave-length of 200 meters) undamped waves are radiated. The value of the oscillating current in the circuit LC is read on the meter and recorded. The variable condenser of the oscillator is then varied from zero to maximum and readings of the current in LC taken from time to time to record the current in the circuit. At the maximum adjustment the oscillator is radiating undamped waves on a wave-length of 600 meters. By plotting a curve to represent the readings of the current in LC for all waves from 200 to 600 meters, we can very easily determine how selective the circuit is.

211. A curve of this type is called a resonance curve and is reproduced in Fig. 34. From this curve it is quite evident that the resonant frequency of the circuit LC is 750,000 cycles per second, corresponding to a wave-length of 400 meters.

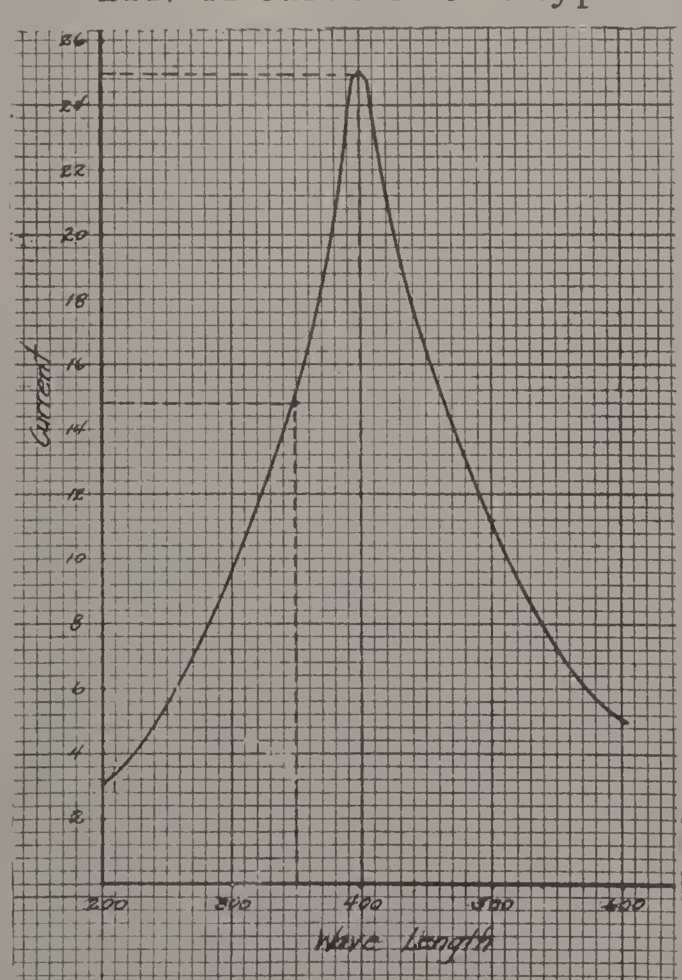


Fig. 34

212. At this frequency the total reactance of the circuit is zero, the current is in phase with the induced e.m.f., and is only limited in value by the resistance of the circuit. If it were possible to entirely eliminate the resistance of the circuit, the current at the resonant frequency would be infinitely great.

213. From the shape of this curve we can see that the selectivity of the circuit LC is fairly good. It is resonant at 400 meters and if an e.m.f. is induced at a frequency corres-

ponding to 350 meters, the current is much lower.

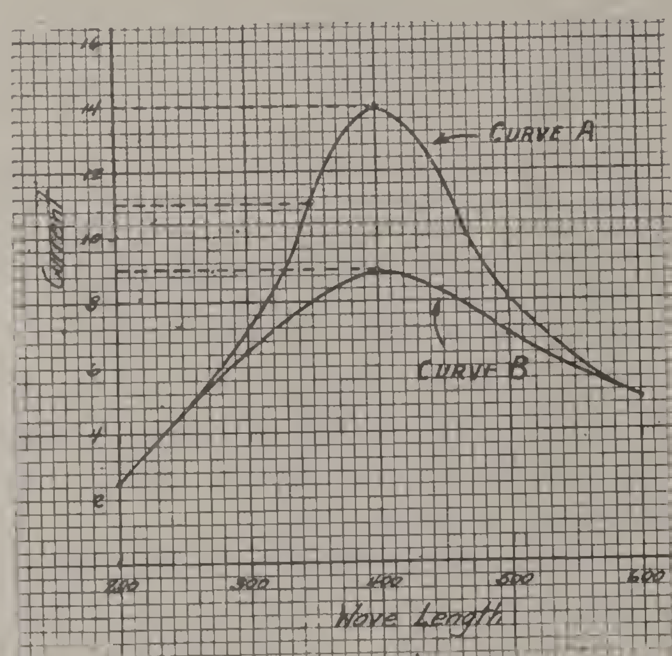
Effect of Resistance on Resonance Curve: Now let us include some of the resistance R in the circuit and repeat the experiment. The result is represented by the curve A of Fig. 35.

The effects of this additional resistance in the circuit are evidently detrimental. Not only is the current at resonance less than before, but the curve is "broader." The circuit is less selective.

215. The curve B was obtained with all the resistance R in the circuit. This curve is even "broader" than A. The selectivity is very poor. If an e.m.f. is induced in the circuit by waves radiated on a wave-length of 350 meters, the current in the circuit is almost as great as the current at the resonant frequency of 400 meters. Even at the resonant frequency the current is quite low.

216. It is evident that the curves of Figs. 34 and 35 could have been obtained by adjusting the oscillator to radiate on a wave-length of 400 meters and then varying the condenser C of the oscillatory circuit from zero to maximum.

The curves, then, represent the ability of this circuit, with different values of resistance, to "select" any desired signal. The curves measure accurately its degree of selectivity.



Fi. 35

217. It is quite evident from these curves that, if selectivity and a high value of current at resonance are desired, **the resistance of an oscillatory circuit must be kept as low as possible.**

218. **Damping:** The current in an oscillatory circuit is measured by its final amplitude. If an undamped oscillating e.m.f. is impressed upon an oscillatory circuit, **tuned to resonance,** the current builds up until it reaches a certain maximum amplitude. The final amplitude is limited only by the resistance of the circuit. As the oscillations increase in amplitude the time is eventually reached when the energy dissipated by the resistance of the circuit is equal to the energy supplied the circuit by the impressed e.m.f. If the reaction of resistance is high, the current reaches its maximum amplitude in a short period of time and this final amplitude is comparatively low. If the resistance of the circuit is small, the current takes a longer time to reach its maximum amplitude and this final amplitude has a higher value.

219. Let us suppose, however, that an undamped oscillating e.m.f. is impressed on a resonant oscillatory circuit which has **no** resistance. As the circuit has zero resistance the current continues to increase in amplitude as long as the impressed e.m.f. is maintained. If the impressed e.m.f. is removed, the oscillations continue forever at the amplitude they had at-

tained when the impressed e.m.f. is removed; there is no resistance in the circuit to damp out the oscillations.

220. But if the circuit has resistance and if, after the oscillations have built up to a certain amplitude, the impressed e.m.f. is removed, the oscillations in the circuit continue but gradually decrease in amplitude as energy is dissipated by the resistance until they are completely damped out.

221. The rate at which oscillations in such a circuit decrease in amplitude is called the "damping" of the circuit.

The damping naturally depends upon the resistance of the circuit. If the resistance is high the damping is rapid, whereas if the resistance is small the damping is slower.

222. Now, if the impressed e.m.f. is itself damped, it is evident that this will have the same effect on the oscillations as resistance in the circuit itself. If a damped oscillation is induced, it will have the same effect on the form of the resonance curve as resistance in the oscillatory circuit itself.

It is for this reason that the reception of undamped waves can be effected with a very much higher degree of selectivity than any other method of radio communication.

223. The extent to which damped waves affect the sharpness of tuning of an oscillatory circuit depends upon the damping of the waves themselves. The waves radiated by some spark transmitters have such a high damping decrement that it is quite impossible to tune them sharply. Modulated continuous waves have the same effect on the tuning but only to a very limited extent.

224. **Resistance of an Oscillatory Circuit:** Any factor which causes a loss of energy in a circuit contributes to the resistance of the circuit. The resistance of an oscillatory circuit mainly comprises the loss of energy due to

1. The resistance of the conductor itself;
2. Radiation of electro-magnetic waves.

225. **Conductor Resistance:** The resistance of the conductor depends upon the composition, thickness and length of the wire. For all practical purposes, No. 22 copper wire, covered with one layer of cotton and a second layer of silk insulation, offers as little resistance, wound in the form of a coil or otherwise, as most conductors. Litzendraht wire has some advantage over solid wire. But, unless the radio receiver is otherwise so insensitive that this slight advantage is imperative, the use of Litzendraht wire is not necessary. Too much distributed capacity in an inductance coil will increase the resistance of a circuit, especially if the coil is not shunted by a variable condenser to tune the circuit to resonance. Every coil has some value of distributed capacity but it should be kept as low as possible. It is usually unnecessary to use shellac on a single layer solenoid. This increases the distributed capacity and the resistance.

Scraping contacts, instead of pig-tail connections, are a more frequent cause of conductor resistance than any other part of the oscillatory circuit of some radio receivers; and an unsoldered joint in the wiring of a receiver may have greater resistance than a coil smothered in shellac.

226. **Resistance of an Iron-core Coil:** At high frequencies an inductance coil with an iron core has a greater effective resistance than an air-core coil. This resistance is due to eddy-current losses in the iron core. These eddy-currents also have the effect of reducing the permeability of the iron at high frequencies so that the inductance of the coil is less than it should be. Eddy-currents can be partially eliminated by making the laminations of the iron core very thin and insulating them well from each other.

227. **Radiation Resistance:** The radiation of electro-magnetic waves is just as much a loss of energy and therefore a factor of resistance as conductor losses in an oscillatory circuit. As we have already noted, an aerial is a very much better radiator of waves than a closed oscillatory circuit. The aerial, therefore, has a greater resistance than the closed circuit. The resistance of an antenna is also high because of its distributed capacity. Its resistance is increased by a poor ground connection.

228. **A Simple Receiving Circuit:** Fig. 36 shows a simple receiving circuit designed according to the principles of resonance we have learned in this chapter. The aerial of the receiving station is tuned to resonance with any desired frequency by inserting a variable inductance, in the form of a tapped coil, and a variable condenser between the aerial and the ground. A suitable maximum value for the variable condenser is .001 mfd.

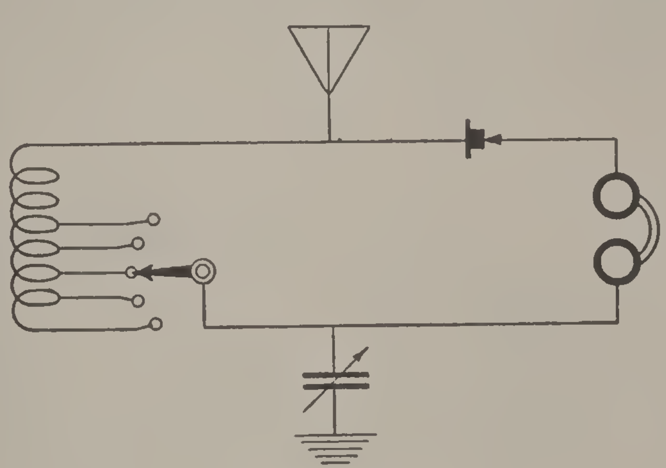


Fig. 36

229. The value of the inductance coil depends upon the wave-length range it is desired to cover. To tune the aerial to wave-lengths from 200 meters to 600 meters the coil may be wound with 100 turns of wire on a 3 or 4-inch tube and tapped every 20th turn. The inductance taps are used for coarse tuning and the variable condenser for fine tuning.

230. For reasons already given, the rectifier and telephones cannot be included directly in the antenna circuit. The detecting circuit can, however, be connected across the inductance coil as shown in Fig. 36. The reacting voltage which is set up across the terminals of this coil by the oscillations in the aerial act upon the detecting circuit and signals are detected.

This arrangement constitutes one of the simplest receiving systems with any degree of efficiency.

LESSON 4.

CURRENTS IN COUPLED CIRCUITS.

231. The simple receiving circuit of Fig. 36 has several disadvantages. In the first place, the detecting system is only connected across a portion of the inductance of the antenna circuit. Full advantage is not being taken of all the energy in the antenna circuit. The most undesirable feature of this arrangement, however, is its lack of selectivity. The resistance of an open oscillatory circuit is quite high and consequently sharp tuning cannot be obtained. The resonance curve of such a circuit is quite broad.

232. These disadvantages may be partially overcome by connecting the detecting circuit across a closed oscillatory circuit and "coupling" the closed circuit to the open antenna circuit. One such arrangement is shown in Fig. 37. If the energy in the antenna circuit can be transferred to the closed circuit and the latter tuned to resonance, greater audibility and selectivity are made possible. The detecting system is connected across all the inductance and capacity of the closed circuit and therefore takes advantage of all the energy in the circuit. Moreover, the resistance of the closed circuit is considerably less than that of the antenna circuit.

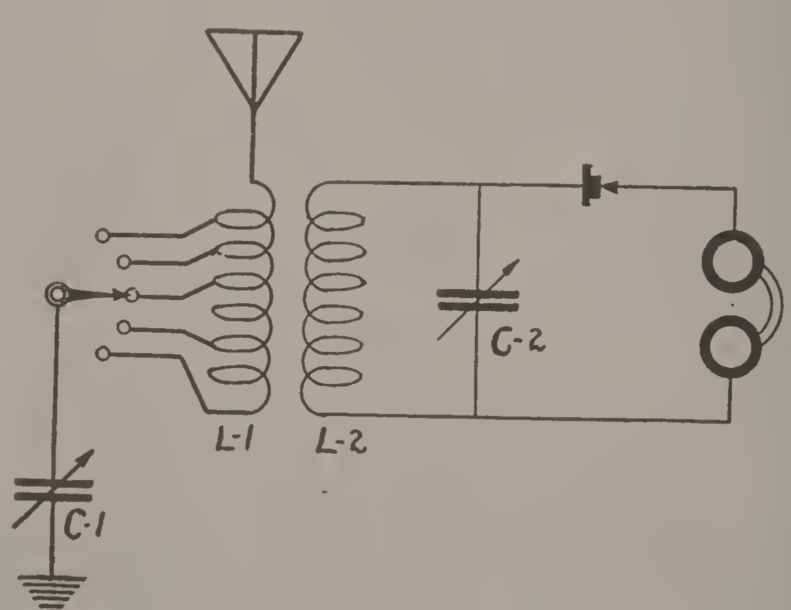


Fig. 37

233. In this chapter we will discuss the methods of transferring energy from one circuit to a second circuit and the effect of this transfer upon the currents in the circuits.

234. **Different Kinds of Coupling:** When energy is transferred from one circuit to another the circuits are said to be coupled. There are different types of coupling, the most im-

portant being inductance and condenser coupling. In the former, part of the magnetic field set up by currents in the system is common to both circuits. In the latter, part of the electro-static field is common to both circuits. The first is called magnetic or inductive coupling and the second is called static or capacitive coupling.

235. If, as in Fig. 38, energy in the tuned circuit L1, C1, M is transferred through the common inductance M, to the tuned circuit L2, C2, M, the common inductance M is used to transfer the energy and the magnetic coupling is said to be **direct.**

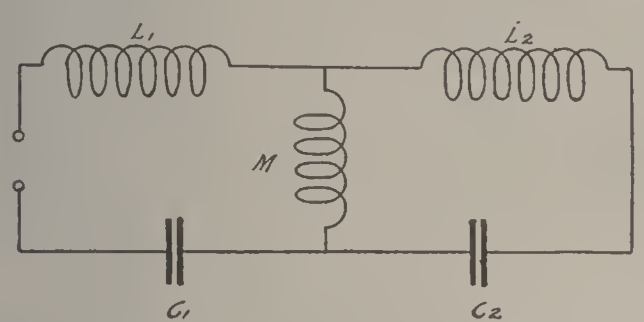


Fig. 38

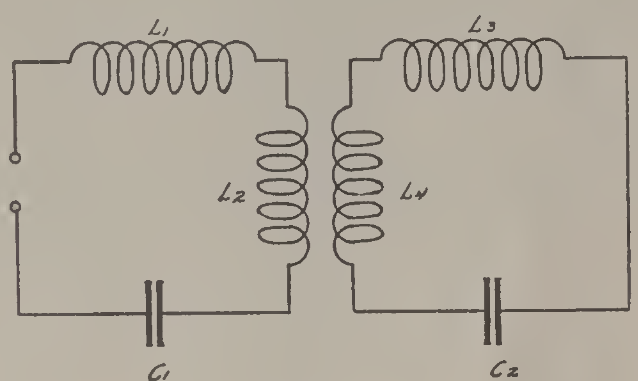


Fig. 39

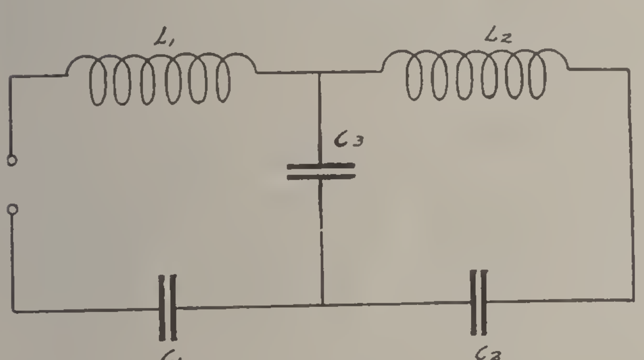


Fig. 40

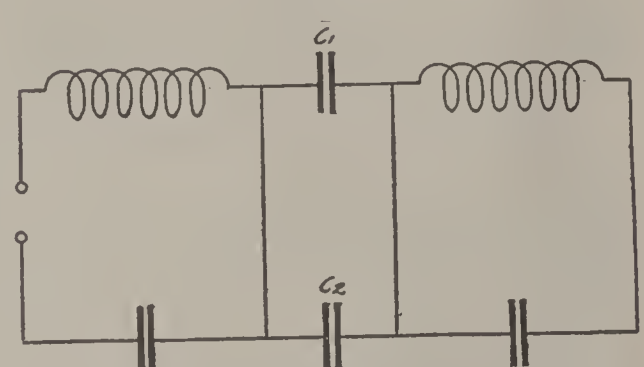


Fig. 41

236. If, as in Fig. 39, energy in the tuned circuit L1, L2, C1 is transferred to the tuned circuit L3, L4, C2 through that part of the magnetic field, set up around L2 and L4 which is common to both circuits, the coupling is **inductive,** but is not direct.

237. In Fig. 40 energy in the tuned circuit L2, C1, C3 may be transferred to the tuned circuit L2, C2, C3, through the common capacity C3. The two circuits are coupled capacitively.

238. Fig. 41 shows another example of capacitive coupling in which the condensers C1 and C2 are the coupling capacities.

239. Inductive coupling is most commonly used to couple the circuits of a radio receiver. We will explain this type of coupling in some detail.

240. **Mutual Induction:** According to the law of induced e.m.f. (Par. 120) an e.m.f. is induced in a conductor if it is surrounded by a magnetic field and the strength of the magnetic field changes. We have already noted that this has the effect of self-inducing an opposing e.m.f. in a coil carrying a changing current.

241. But an e.m.f. is induced in a conductor which is surrounded by a changing magnetic field, even if the field is not being produced by current passing through the conductor itself but through another conductor in proximity to the first.

242. For instance, if current is flowing through the coil L1 of Fig. 42, some of the magnetic field produced by this current interlinks with the coil L2 in proximity to L1. If the current in L1 increases, the magnetic field expands as the new lines of force developed by the increase of current intensify the magnetic field. The coil L2, without any movement on its own part, enters a stronger portion of the magnetic field and is threaded by an increased number of lines of force. Consequently an e.m.f. is induced in L2. If its terminals are connected across a circuit, a current will flow in the circuit.

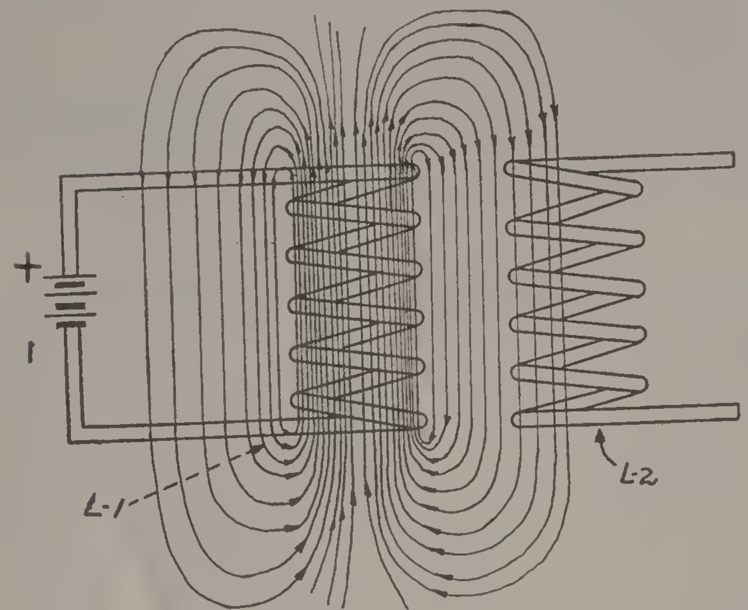


Fig. 42

243. When a change in the strength of the magnetic field set up by current in one coil induces an e.m.f. in a second coil in proximity to the first, the induced e.m.f. is described as the e.m.f. of mutual induction.

244. **Value of e.m.f. Induced by Mutual Induction:** This value depends upon factors similar to the e.m.f. of self-induction. The voltage **self-induced** in a coil by a change of current is equal to the product of its inductance and the rate of current change (see Par. 147).

In the same way, the voltage induced in a coil by a change of current in another coil is proportional to the **rate of current change** in the latter and to the **mutual induction** of the two coils.

245. Mutual induction is measured in the same units as self-induction, viz: henrys, millihenrys, etc. If the mutual induction of two coils is 2 henries, this means that a current change of one ampere per second in the first coil induces an e.m.f. of two volts in the second coil.

246. Mutual induction evidently depends upon the number of turns in each of the two coils and upon their position with respect to each other. If the two coils are widely separated, the mutual induction is low. Similarly, if one coil is turned at right angles to the other, the mutual induction is very low.

247. By rotating one coil inside or alongside another it is possible to vary the mutual induction of two coils from a low minimum to a certain maximum, the latter depending upon the number of turns on each of the coils and their distance apart.

248. **Coefficient of Coupling:** The Coefficient of coupling defines the relationship between the mutual induction of two circuits and the total self-induction of the circuits themselves; in other words, it defines the extent to which the circuits are coupled. Suppose two circuits are coupled by mutual induction and the self-induction of each of the two circuits, separately, is ten millihenrys. Then if the mutual induction is also ten milli-

henrys the coupling between the circuits is one hundred percent. One hundred percent coupling can only be obtained if the total magnetic field of the two circuits is common to both circuits. If, in the instance given above, the mutual induction is only five millihenrys, the coupling is 50 percent; or if the mutual induction is two millihenrys, the coupling is 20 percent, etc.

249. The relationship between the mutual induction and the total self-induction of two circuits which determines the co-efficient of coupling between the circuits can be written

$$k = \frac{M}{\sqrt{L1 \times L2}}$$

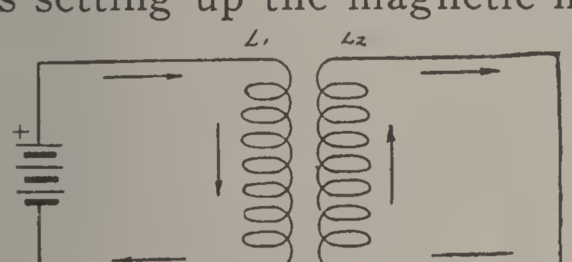
where k = coefficient of coupling
M = mutual induction between two circuits
L1 = Total self-induction of first circuit
L2 = Total self-induction of second circuit.

Thus, in the case given above of 100 percent coupling, if M, L1 and L2 are each 10 millihenrys, then

$$k = \frac{10}{\sqrt{10 \times 10}} = \text{unity (100 percent)}$$

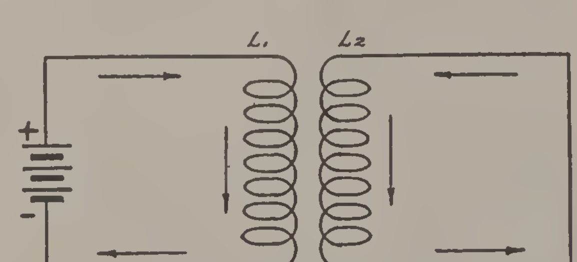
but if M = 5 millihenrys then k = .5 or 50 percent coupling.

250. **Direction of Induced e.m.f.:** The direction of an e.m.f. induced in a coil depends upon the direction of motion of the magnetic field across the coil and the direction of the magnetic field itself (Par. 129). The direction of the field, of course, depends upon the direction of the current through the coil which is setting up the magnetic field.



CURRENT IN L1 INCREASING

Fig. 43



Current in L1 decreasing

Fig. 44

251. For instance, if the current in L1, Fig. 43, **increases**, the magnetic field expands and cuts the coil L2 with an outward motion. An e.m.f. is induced in L2 and if L2 is connected across a circuit, a current flows through the circuit **in the opposite direction** to that of the current through L1.

252. If the current in L1 **decreases**, the field contracts and cuts the coil L2 with an inward motion. But the direction of the current in L1 has not changed. Therefore the current through L2 is **in the same direction** as the current through L1 (See Fig. 44).

If the current in L1 does not change, no e.m.f. is induced in L2.

253. All other factors being equal, the value of the e.m.f. induced in L2 depends upon the rate of change of the current in L1.

254. It is evident, then, that if the current through L1 alternately increases and decreases, an **alternating** e.m.f. will be induced in L2.

For instance, if, by a variation of the resistance of the "primary" circuit in which L1 is connected, the current in L1 increases and decreases in the manner indicated in Fig. 45A, the primary current never changes its direction but the variations have a form similar to that of an alternating current. Fig. 45B shows the form and direction of the e.m.f. which is induced in L2 by these variations of the primary current.

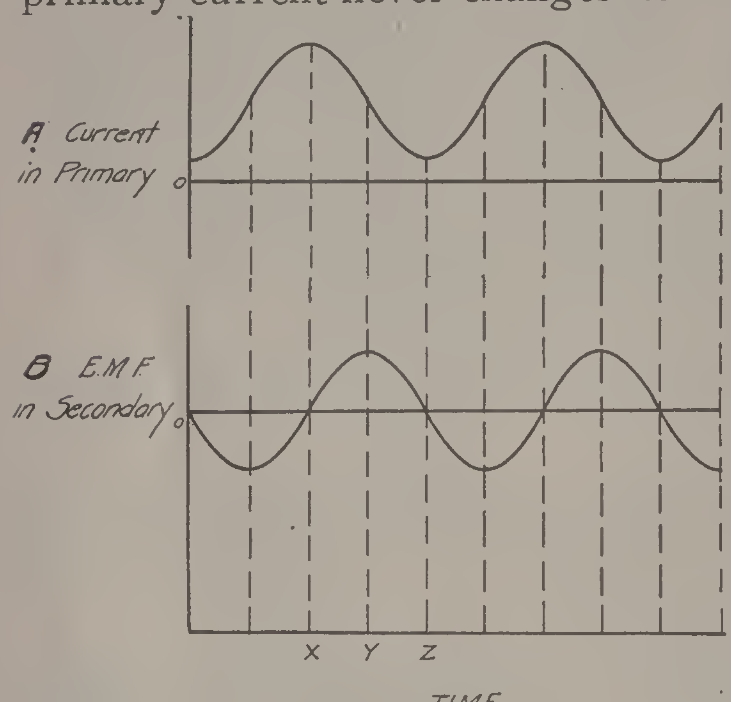


Fig. 45

255. It will be noticed that the e.m.f. induced in L2 is an alternating e.m.f. and its form is exactly similar to the form of the current variations in the primary; the e.m.f. alternations in L2, however, lag 90 degrees behind the primary current variations. This can be explained as follows:

256. During the time X to Z, Fig. 45, the current in L1 is decreasing. Therefore the e.m.f. in L2 is in the **same** direction as the primary current. The value of this e.m.f. depends upon the rate of current change in the primary. The primary current changes at the greatest rate at the moment Y and the e.m.f. in L2 is therefore at its highest value at that moment. At the moments X and Z the current in the primary is neither increasing nor decreasing; at these moments the e.m.f. in L2 is **zero.** Up to the moment X the current in the primary is **increasing.** Therefore during this time the e.m.f. in the secondary is in the **opposite** direction to the primary current.

257. We can say, then, that if two circuits are coupled inductively and a varying direct current flows in the primary circuit, an alternating e.m.f. is induced in the secondary; the e.m.f. alternations have the same form as the current variations in the primary but lag 90 degrees behind these variations.

258. It can also be shown that if two circuits are coupled inductively, an alternating e.m.f. is induced in the secondary circuit if an **alternating** current flows in the

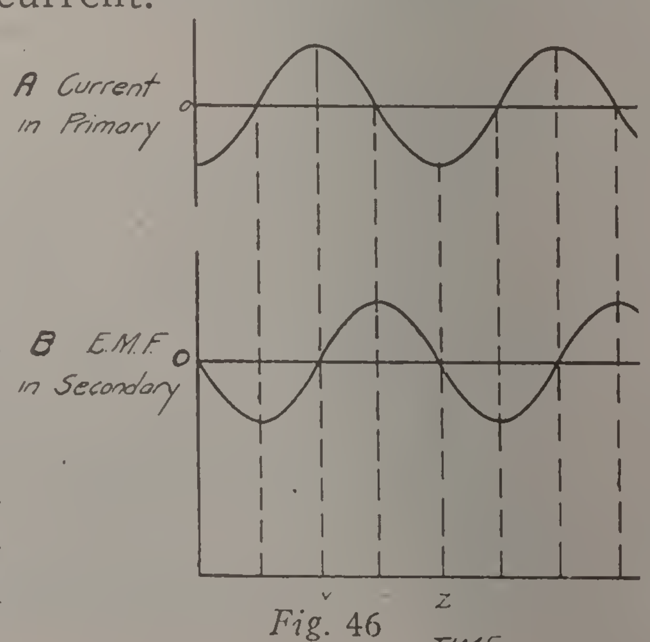


Fig. 46

primary.

259. Fig. 46, A shows the curve of the alternating current in the primary and the resulting e.m.f. induced in the secondary is shown at B. In explanation of this diagram, consider the e.m.f. alternation in the secondary circuit from the moment X to the moment Z. From X to Y the current in the primary is decreasing and is in a positive direction. The e.m.f. in the secondary is therefore also in a positive direction during this period. From the moment Y to the moment Z the current in the primary is increasing but it is now in a negative direction. Therefore the e.m.f. in the secondary is still in a positive direction. The rate of current change in the primary is greatest when it is passing through its zero values; therefore the e.m.f. induced in the secondary is maximum at these moments. On the other hand, the rate of current change in the primary is zero when it is maximum; therefore the e.m.f. induced in the secondary is zero at these moments.

260. We can say, then, that if two circuits are coupled inductively and an alternating current flows in the primary circuit, an alternating e.m.f. is induced in the secondary; the e.m.f. alternations have the same form as the current in the primary but lag 90 degrees behind the primary current alternations.

261. In either of the two instances cited above in Paragraphs 257 and 260, an alternating current will flow in the secondary circuit, provided that the impedance of the secondary circuit is low enough to allow a current to flow. The impedance offered by the secondary circuit, of course, depends upon its inductance, capacity and resistance as well as the frequency of the induced e.m.f. If, for a given frequency of induced e.m.f. the impedance is high enough, no current will flow in the secondary circuit; only e.m.f. alternations will be set up across it.

262. **Effect of Coupling Upon Resonance Curve:** When considering the effect of coupling upon the resonance curve of coupled circuits, a great many factors have to be taken into consideration. For instance, if two circuits are inductively coupled and an alternating current flows in the secondary circuit as a result of the e.m.f. induced by a changing current in the primary, the current in the secondary circuit induces an e.m.f. back in the primary circuit. The e.m.f. induced in the secondary by the primary current lags 90 degrees behind the primary current. Similarly the e.m.f. induced in the primary by current in the secondary lags 90 degrees behind the secondary current. If the secondary is a tuned circuit the secondary current may lead the voltage induced in it; it may be in phase with the voltage or it may lag behind the voltage, according to the frequency of the induced voltage.

263. There are other effects which must be considered but it is evident that the interactions between two coupled circuits are very complicated and require a very lengthy explanation which is beyond the scope of this work. In any case, it may be better understood if we merely explain the actual effects in practice.

264. We will demonstrate the effect of coupling upon the resonance curve of two inductively coupled circuits **when each of the circuits is tuned to the same resonant frequency.** This is the most common type of coupling in the high frequency circuits of a radio receiver. For example, in Fig. 37, the antenna circuit is inductively coupled to the closed circuit L2 C2, and to receive signals each circuit is tuned to the frequency of the signal oscillation.

265. Fig. 47 represents the same arrangement of circuits. The primary tuned circuit L1, L2 C1 is coupled to the secondary tuned circuit L3 C2 by the mutual inductance between the coils L2 and L3. By means of the condensers C1 and C2 the circuits are separately tuned to the same resonant frequency and the resonance curve of either circuit is represented by the diagram of Fig. 48.

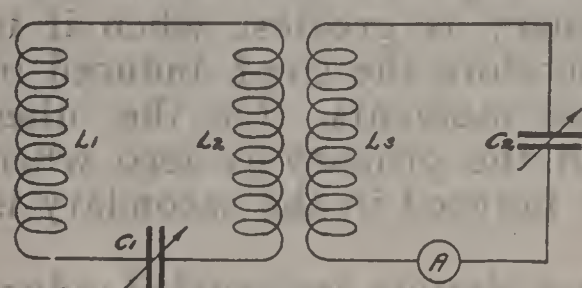


Fig. 47

The mutual inductance between L2 and L3 is such that the coeficient of coupling of the circuits is, say .35, or a coupling of 35 percent. In the secondary circuit is connected a high frequency current measuring meter A.

266. Now if, by means of an oscillator, we induce in the primary circuit an undamped oscillating e.m.f. and vary the frequency of this e.m.f. from below the resonant frequency of either circuit to above the resonant frequency and note the readings of the meter A from time to time we can plot a curve which will show the effect the coupling of the circuits has upon the resonance curve of the secondary circuit.

267. Fig. 49 shows the resulting curve together with the resonance curve of Fig. 48 as a dotted line for comparison. It can be seen from the curve that there are two frequencies of applied e.m.f. at which the total reactance is zero; in other words, there are two resonant frequencies, one lower and the other higher than the fundamental frequency of the circuit by itself. These two frequencies are shown by the peaks in the resonance curve. A similar curve can be obtained if readings are taken of the primary current against frequency.

268. It should be clearly understood that this curve does **not** show that the current in either primary or secondary circuit oscillates at two different frequencies when an oscillating e.m.f. is induced in the primary circuit. It shows that a forced oscillation **at the frequency of the applied e.m.f.** flows in the circuits and that there are **two frequencies of applied e.m.f.** at which the current in either circuit is a maximum.

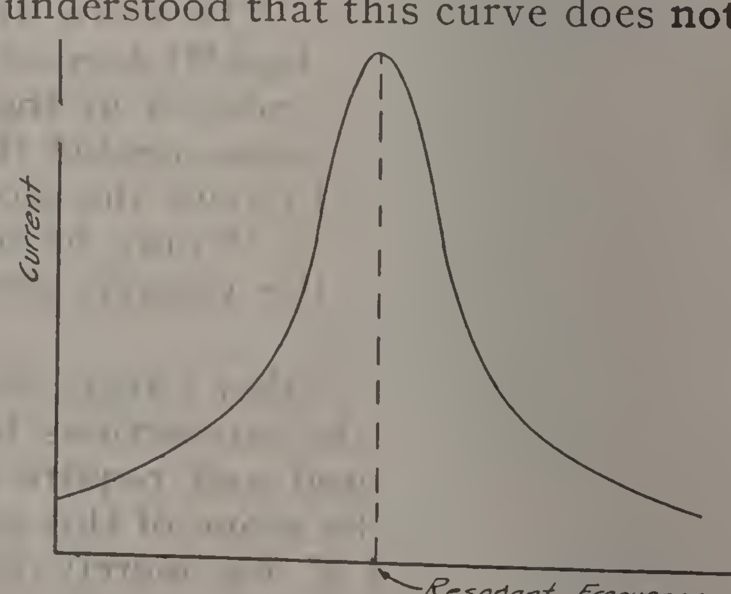


Fig. 48

269. It is evident, then, that if two tuned circuits are coupled closely, the system has a broad resonance curve with two peaks. If the resistance of either circuit is fairly high the peaks will be flattened out considerably, resulting in a very broad, flat resonance curve.

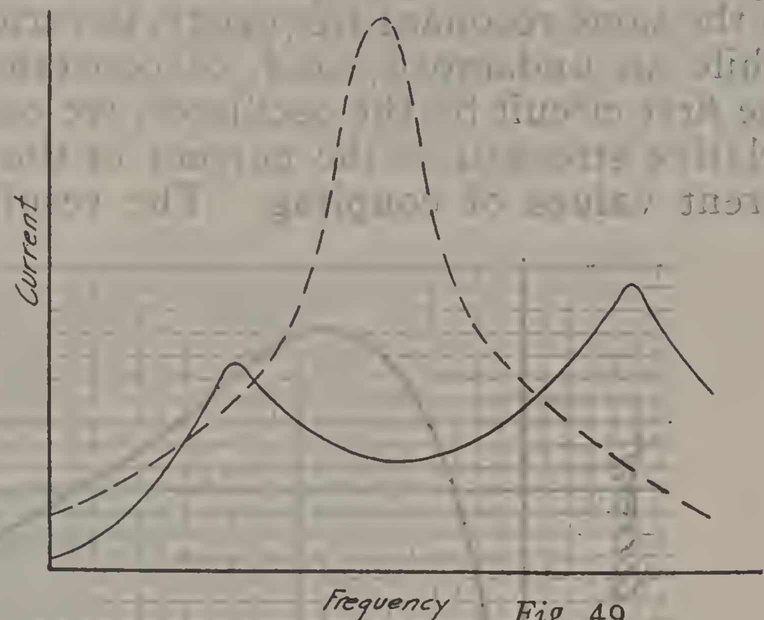


Fig. 49

270. Obviously these conditions are unsuitable for the circuits of a radio receptor if selectivity is desired. Sharp tuning cannot possibly be obtained with such a broad resonance curve. Moreover, the amplitude of the current is quite low.

271. Now if the coupling between the two tuned circuits of Fig. 47 is reduced, by decreasing the mutual inductance, and a new resonance curve is then plotted, its form will be similar to the curve A of Fig. 50. It will be seen from this curve that as the coupling is decreased the two resonant frequencies are less widely separated.

If the coupling is again reduced the two frequencies approach the natural frequency of each circuit, until, at some low value of coupling, the two frequencies merge into one—the natural frequency of either circuit (See Curve B).

272. The curves of Figs. 49 and 50 plainly demonstrate the effect which coupling has upon the selectivity of a radio receiver with inductively coupled circuits. For instance, if the secondary closed circuit of the receiving system of Fig. 37 is closely coupled to the open antenna circuit, the tuning will be very broad and the greater the resistance of either circuit, the broader will the tuning become. With tight coupling selective reception is impossible.

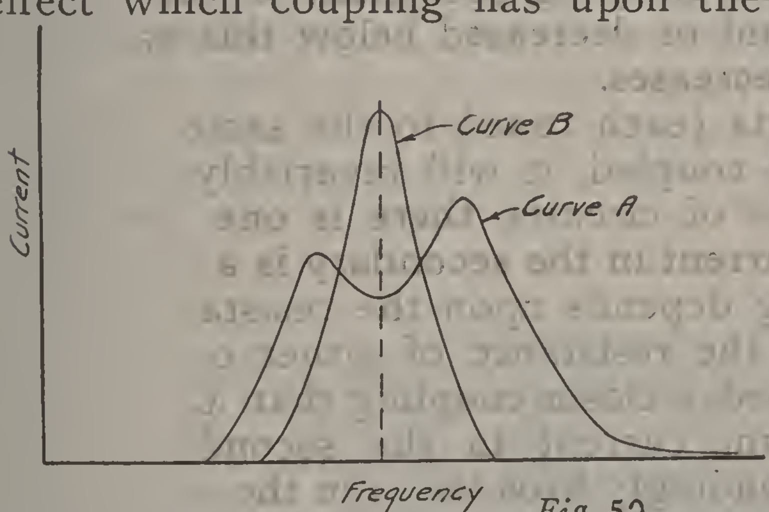


Fig. 50

273. If the mutual induction between the two circuits of Fig. 37 is reduced, the coupling is reduced and **the more the coupling is reduced the more selective will the receiving system become.**

274. But what effect will this reduction of coupling have upon the strength of signals in a receiver with inductively coupled circuits? The signal strength—or audibility—is proportional to the amplitude of the currents in the circuits.

Let us see, then, how **the amplitude of the current** in the secondary of two coupled oscillatory circuits is affected by a variation of **coupling.**

275. If the coupling of the two circuits of Fig. 47, each tuned to the same resonant frequency, is varied from zero to 40 percent, while an undamped e.m.f. of constant frequency is induced in the first circuit by the oscillator, we can plot a curve to show the relative strength of the current in the secondary circuit for different values of coupling. The result is given in Fig. 51. It

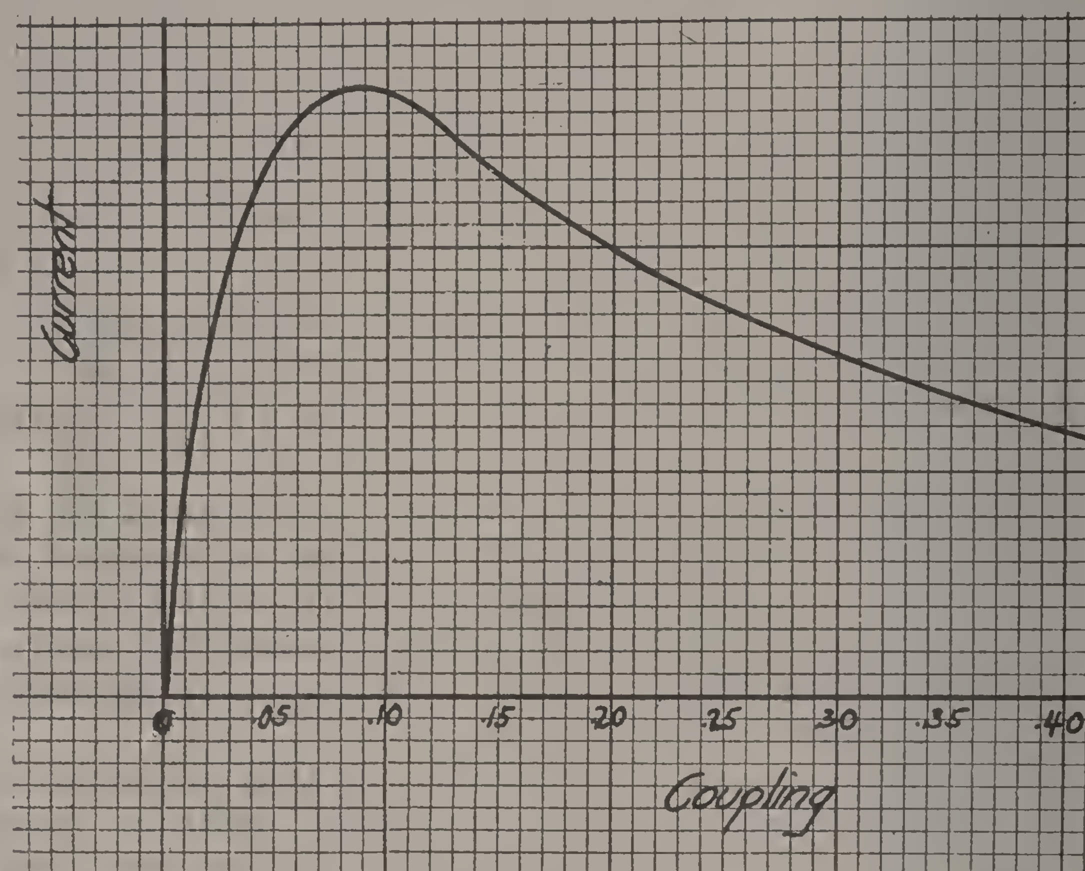


Fig. 51

will be seen from this curve that in this case the secondary current is a maximum with a coupling coefficient of .09. As the **coupling is increased beyond or decreased below this value the current in the secondary decreases.**

276. When two circuits (each tuned to the same resonant frequency) are inductively coupled, it will invariably be found that, for a given resistance of circuits, **there is one low value of coupling at which the current in the secondary is a maximum.** This low value of coupling depends upon the resistance of the circuits. For instance, if the resistance of either or both the circuits of Fig. 47 is increased, a closer coupling than .09 is necessary to obtain a maximum current in the secondary. The resonance curve is correspondingly broader. On the other hand, if the resistance of the circuits is decreased, a looser coupling than .06 is necessary to obtain a maximum current in the secondary; the resonance curve is correspondingly sharper.

277. **Transformer:** A transformer consists of two coils placed in such a relation to each other that a change of current in one coil induces an e.m.f. in the other. The coil in which the original change of current takes place is called the primary and the second coil is called the secondary. A transformer is used, of course, to couple two circuits inductively. The design of a transformer depends upon the purpose for which it is intended and the frequency of the currents to be carried by the trans-

former. In Lesson 7 more details are given of the transformers used to couple the circuits of a radio receiver.

278. The coils L1 and L2 of Fig. 37 constitute a transformer to inductively couple the antenna and secondary circuits of this receiving system. From the foregoing paragraphs of this chap-

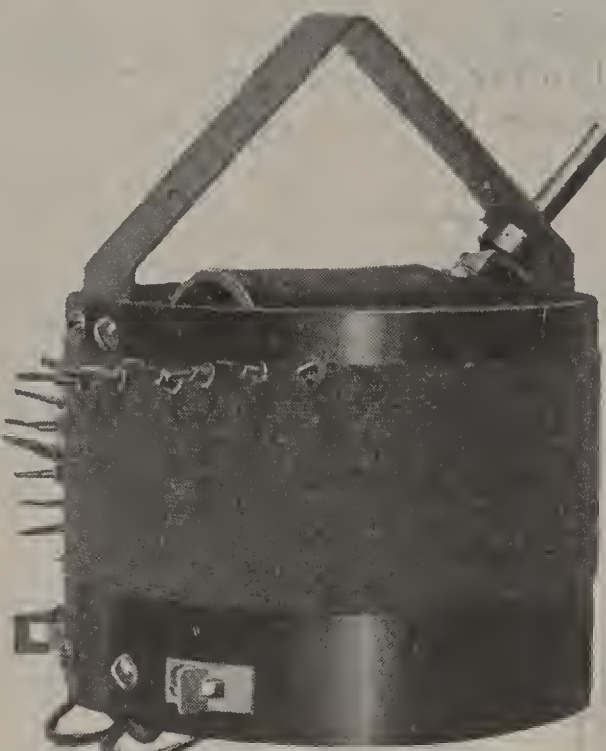


Fig. 52

ter it is evident that, to adjust this circuit for maximum sensitiveness, it should be possible to vary the coupling between the antenna and secondary circuits. The exact low degree of coupling which gives maximum audibility depends upon the resistance of the two circuits and some variation of coupling is necessary to control the selectivity of the system.

279. Fig. 52 shows a transformer with variable coupling, known as a vario-coupler, which is used in the inductively

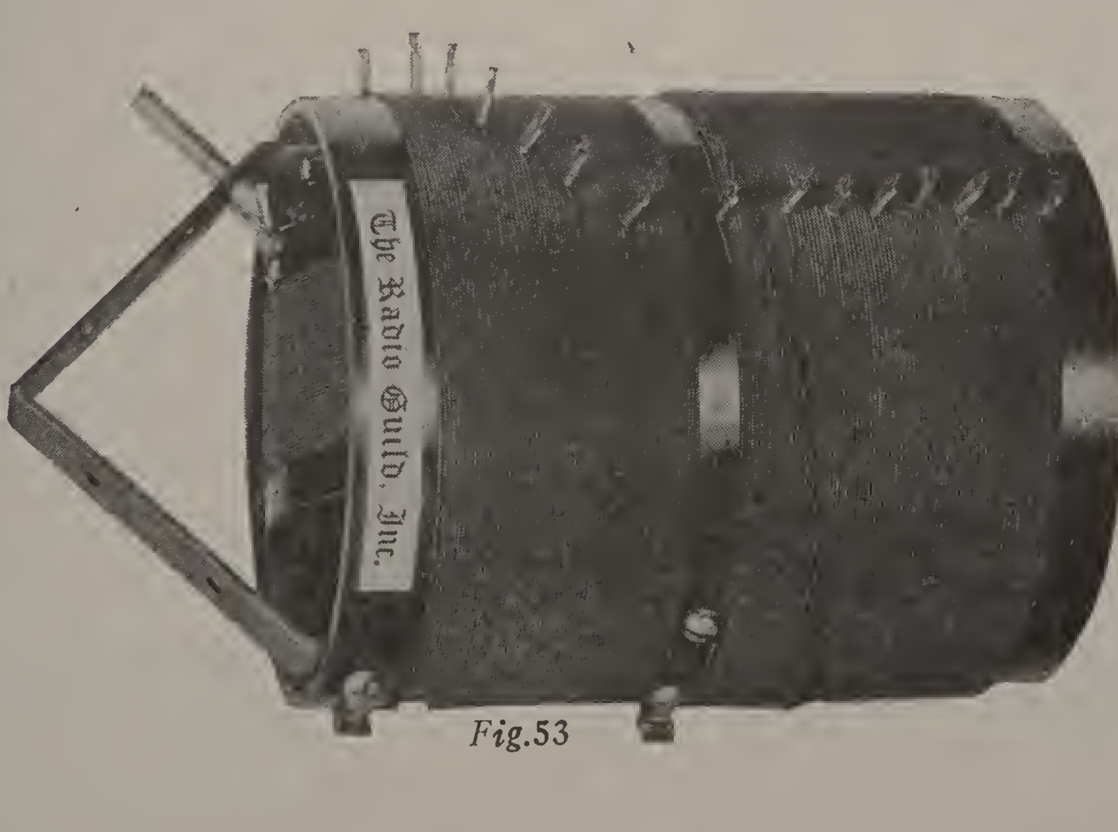


*Fig.*53

coupled receiving system of Fig. 37. The outside coil of this coupler is connected in series with the antenna to form the coil L1 of Fig. 37. Taps are made so that the antenna circuit may be tuned to resonance by varying the inductance. The inner coil of the coupler forms the inductance of the secondary closed circuit. A variable condenser is connected across its terminals. This inner coil is called the rotor as it can be revolved by means of the shaft to which it is attached. The turning of this rotor varies the mutual induction between the coils and thereby varies the coupling between the two circuits.

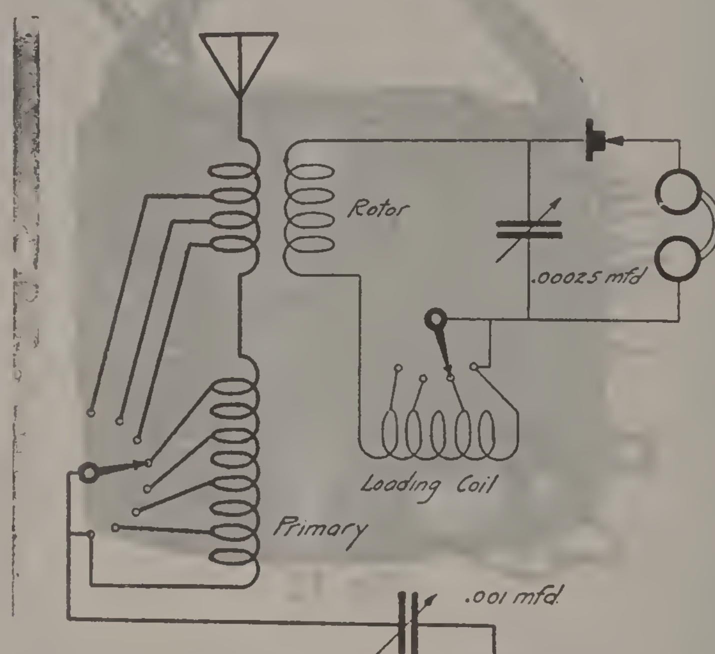


Fig. 54

280. Fig. 53 shows another type of coupler which is called a "Multi-Range" coupler as the primary is wound with sufficient turns of wire to tune the antenna to receive signals from 200 to 3,000 meters. If this coupler is used with a crystal detector an additional loading coil is required in the secondary circuit to tune the secondary to the long waves. The complete circuit is given in Fig. 54.

LESSON 5.

THE VACUUM TUBE DETECTOR.

281. Modern methods of radio transmission and reception are all based on the functioning of the three electrode vacuum tube. Improvements are constantly made. New circuits are developed. There are innumerable ways in which one or more vacuum tubes can be used in both transmitting and receiving circuits. But in every case the operation of the circuit is based on the functioning of the vacuum tube itself. The tube has well been called the "heart" of modern radio.

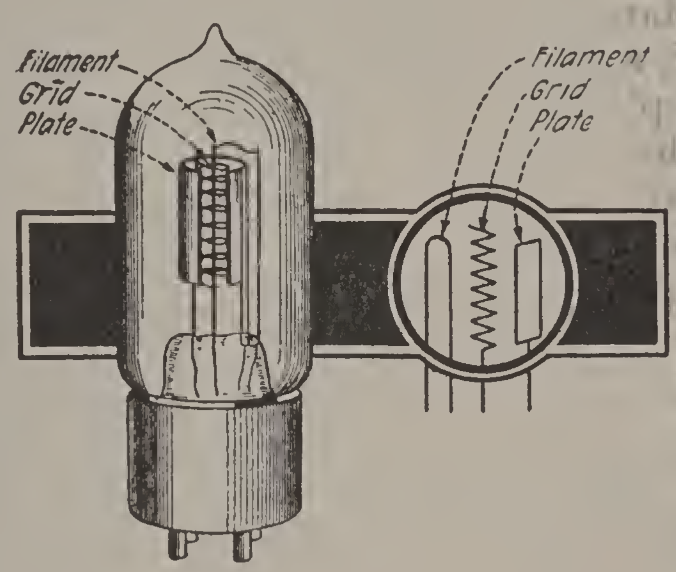


Fig. 55

282. Fig. 55 illustrates a typical vacuum tube together with the signs which are used to represent the three electrode tube, or triode, in wiring diagrams. The filament of the tube is similar to the filament of an electric light bulb. Two other elements, known as the plate and the grid, are included in the tube. The size and shape of these three elements vary in different types of tubes. In one type, as represented, the plate is a cylindrical piece of metal which encloses both the grid and filament. The grid resembles a small spring in the center of which is suspended the filament. The three electrodes are enclosed in a glass envelope. Air is excluded from the space inside producing a very high vacuum.

THEORY OF OPERATION.

283. **Filament Circuit:** When a current passes through the filament of a tube it is heated and incidentally produces light.

In Fig. 56 the Filament or "A" battery is the source of the current which heats the filament. The variable resistance, called the filament rheostat, controls the value of the current passing through the filament and thus regulates its temperature. The object of passing current through the filament is not to produce light but it has been found that electrons are emitted from some metals in vacua when their temperature is raised above a certain degree. Increase of temperature usually promotes this emission of electrons.

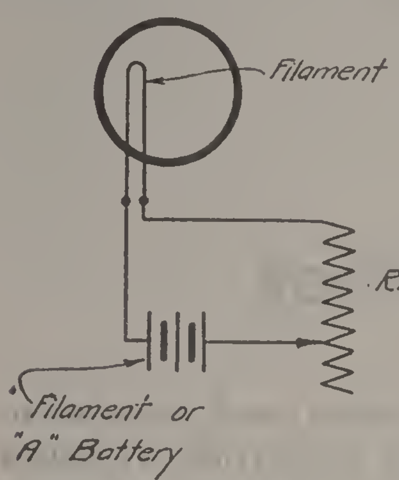


Fig. 56

284. **Current in Plate Circuit**: It is possible to attract the negative electrons emitted by the filament to the **plate** of the tube if the plate is raised to a positive potential with respect to the filament. As we have learned, one of the elementary laws of electricity is that unlike charges attract each other. Thus, if we connect the plate of a tube to the positive terminal of a battery, as in Fig. 57, and connect the negative end of the battery to the filament, the plate is at a positive potential with respect to the filament. The electrons emitted by the filament are attracted to the plate and **a current flows in the circuit of Bl,** or plate circuit as it is called.

285. **Value of Plate Current**: The value of this current depends upon the potential to which the plate is charged and the temperature of the filament. There is, however, an upper limit to the value of the current for a given temperature of filament. If the voltage of the battery Bl, Fig. 57, is steadily increased, the rate at which electrons are attracted to the plate increases until the potential difference between the plate and filament reaches a certain value. Beyond this value of Bl the plate current does not increase. To increase the plate current the temperature of the filament must be raised. Again, however, a limit is reached.

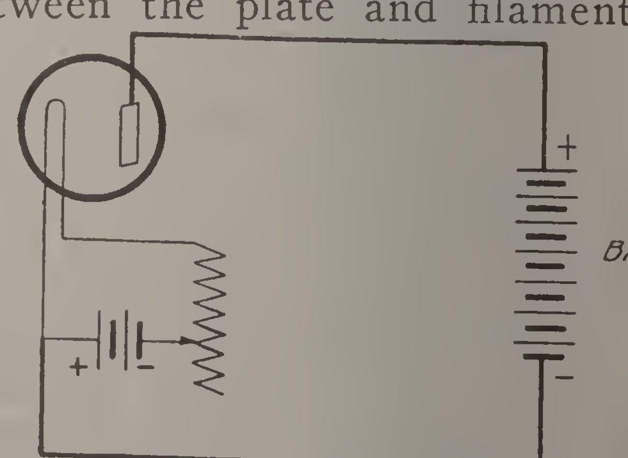


Fig. 57

286. The reason for this saturation value of the plate current is explained by the fact that the electrons occupying the space between the filament and the plate themselves constitute a negative charge of electricity. This charge is called the "space charge" of the tube. The space charge, being negative, assists the negative electrons near the plate in their movement towards the plate but tends to repel the electrons leaving the filament and retards their movement towards the plate.

287. **Unilateral conductivity of tube**: If the filament circuit is opened the filament is cold and no electrons are emitted. The

space between the filament and the plate does not conduct current. Therefore, no current can flow in the plate circuit. It is important to note, however, that even when the filament is heated and electrons are emitted, the space between the filament and the plate will only conduct current **in one direction.** That is to say, the electrons emitted by the filament will only be attracted to the plate if it is positively charged with respect to the filament. If it is negatively charged the negative electrons emitted by the filament will be repelled by the like charge on the plate.

288. Therefore, if a source of alternating e.m.f. is connected in place of the battery B1 of Fig. 57 current only flows in the plate circuit when the direction of the alternating e.m.f. raises the plate to a positive potential with respect to the filament. During the negative alternations no current flows. In other words, **the A.C. current is rectified.**

289. A two electrode tube (with filament and plate only) can be used to rectify alternating currents and was formerly used as the rectifier of a radio detecting system. For the latter purpose, however, it has been superceded by the three electrode tube.

290. **The grid:** The principles underlying the use of the third electrode, or grid, can best be understood by investigating the effect on the current through a tube when the potential of the grid with respect to the filament is varied above and below zero. This test can be made with the arrangement of apparatus shown in Fig. 58.

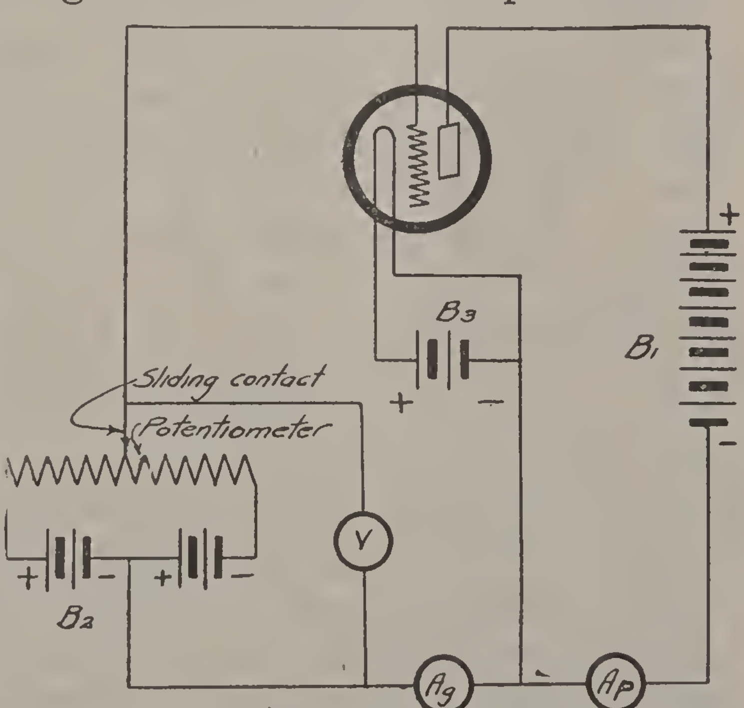


Fig. 58

291. In this circuit, the plate is held at a fixed potential with respect to the filament by the battery B1. The filament temperature is also fixed by the battery B3. However, the potential of the grid with respect to the filament may be varied from a certain negative potential to a certain positive potential by moving the sliding contact along the potentiometer resistance which is connected with the grid battery B2. When the contact is at the exact center of the potentiometer the grid is at zero potential in relation to the negative end of the filament. If the contact moves towards the positive end of B2 the grid is at a positive potential to the filament and if the contact moves from center towards the negative end of B3 the grid is at a negative potential.

292. If this diagram is carefully considered, it will be seen that there are now two circuits through the tube—the plate circuit and the grid circuit. The former consists of the plate, the battery B1 and the filament. So long as electrons pass from the filament to the plate a current flows in this circuit, the battery B1 being the source of e.m.f. The value of the plate current at any time can be read on the current measuring meter Ap. The grid circuit consists of the grid, the potentiometer and the filament. If the grid is at a negative potential in relation to the filament little or no current can flow in this circuit but if the grid is positive electrons are attracted to the grid and a current flows, the grid battery B3 being the source of e.m.f. The value of the grid current at any time may be ascertained from the meter Ag. The voltage of the grid with respect to the filament, for any position of the potentiometer contact, can be measured by the voltmeter V.

293. **Effect of grid potential on plate current:** It should be fairly evident that the voltage of the grid has a considerable effect upon the value of the plate current. We have already seen that an increase of plate potential increases the plate current up to a certain limit. When the plate potential is raised it tends to neutralize the space charge and thereby increases the current. The raising of the potential of the grid has the same effect. However, since the grid is between the filament and plate a given change of grid potential has a much greater effect upon the space charge than the same change of plate potential. It follows that a given change of grid potential has a much greater effect upon the plate current than the same change of plate potential. For example, an increase of 2 volts grid potential may increase the plate current to the same extent as an increase of 10 volts plate potential.

294. To increase the plate current the grid need not actually be raised to a positive potential with respect to the filament. For instance, if the grid is at a negative potential of 2 volts and its potential is raised to 1 volt, the plate current is increased although the grid is still negative to the filament. For a given temperature of filament and plate potential the raising of the grid potential, however, does not increase the plate current beyond a definite saturation point.

295. The lowering of the grid potential has the same effect as lowering the plate potential but, for the reasons above, a very small decrease in the grid potential may greatly decrease the plate current. If the grid is lowered to a negative potential with respect to the filament some value of grid potential will be reached which completely repels the electrons emitted by the filament so that none can reach the plate. The plate current will then be reduced to zero.

296. The actual effect upon the plate current of a tube by any given variation of grid potential depends upon the temperature of the filament, the plate potential and the construction of the tube.

297. **Characteristic Curve:** If we move the sliding contact

of the potentiometer of Fig. 58 so that the grid voltage varies from some negative value at which the plate current is zero to some higher value at which the plate current is maximum and plot a curve showing the values of the plate current as the grid potential is varied we obtain what is known as the "characteristic" curve of a tube.

298. One curve of this type is shown in Fig. 59. It will be noticed in this case that when the grid potential is 2 volts negative the plate current is zero. As the grid voltage is increased the plate current increased slowly at first, then more rapidly and at a constant rate of increase. At a grid potential of from 2 to 3 volts positive the rate of increase is non-uniform and the plate current reaches a maximum value when the grid potential is 3 volts positive.

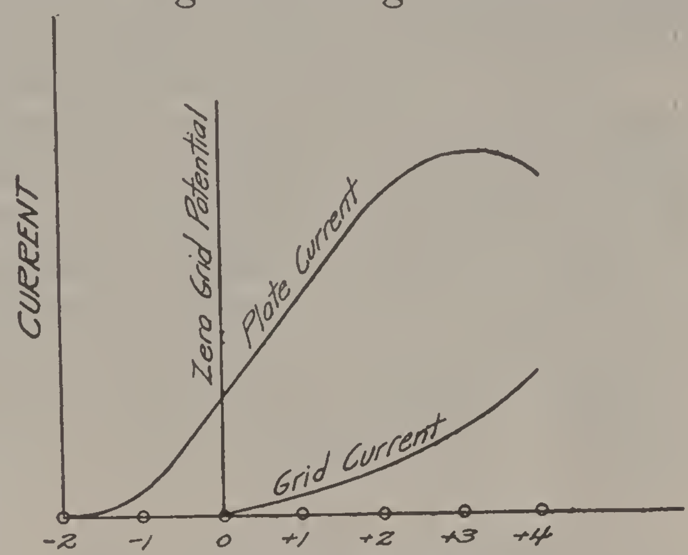


Fig. 59

299. The grid current, as shown, is negligible while the grid potential is negative. An appreciable current only flows in the grid circuit when the grid becomes positive to the filament.

300. It will be noted that the plate current curve, chiefly due to the effect of the space charge, is not a straight line. There is a lower and upper bend joined together by a fairly symmetrical linear portion.

301. The characteristic curve of a triode invariably takes a form similar to this. The actual values of grid potential and plate current, as measured on the horizontal and vertical axes of the diagram, depend upon the three factors we have mentioned—the filament temperature, the plate potential and the construction of the tube itself—but in every case the general shape of the plate current curve is similar to the curve of Fig. 59.

THE VACUUM TUBE AS A DETECTOR.

302. One method of using the triode as the rectifier of a radio receiver can be explained by means of the circuit of Fig. 60. The plate of the tube in this circuit is held at a positive potential by the battery B1. When the filament is heated by current from B3 electrons are emitted and a certain steady value of continuous current flows in the plate circuit. If all other factors are unchanged this steady value depends upon the potential of the grid. In Fig. 61 is reproduced the characteristic curve of Fig. 59. We will presume that this curve represents the relation between the grid potential and the plate current of the tube in the circuit of Fig. 60.

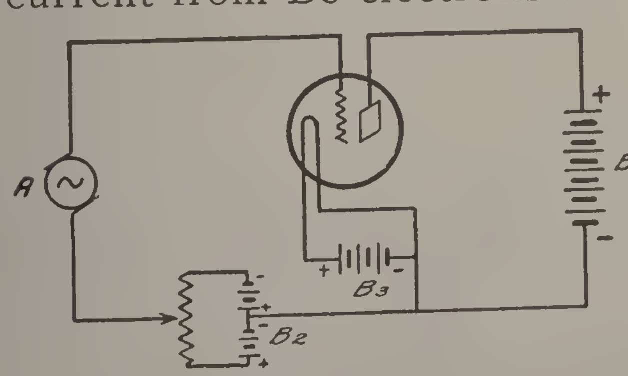


Fig. 60

303. Now, by means of the potentiometer, the normal potential of the grid may be adjusted so that the plate current possesses any value represented by some point along the characteristic curve.

To operate the tube as a rectifier the grid potential is adjusted so that the plate current has a value represented by a point on the lower bend of the characteristic curve. This point of intersection between the normal grid potential and the normal plate current is called the "operating point." The position of the operating point is manifestly adjustable.

304. Now if a source of alternating e.m.f., Fig. 60, is connected across the grid and filament of the tube, the voltage of the grid is alternately raised and lowered above and below normal. This evidently results in an alternating increase and decrease of the plate current. In the diagram of Fig. 61 are indicated the variations of grid voltage caused by the alternations of A and the resulting variations of the plate current. The frequency of the grid potential and plate current variations, of course, is the same as the frequency of A.

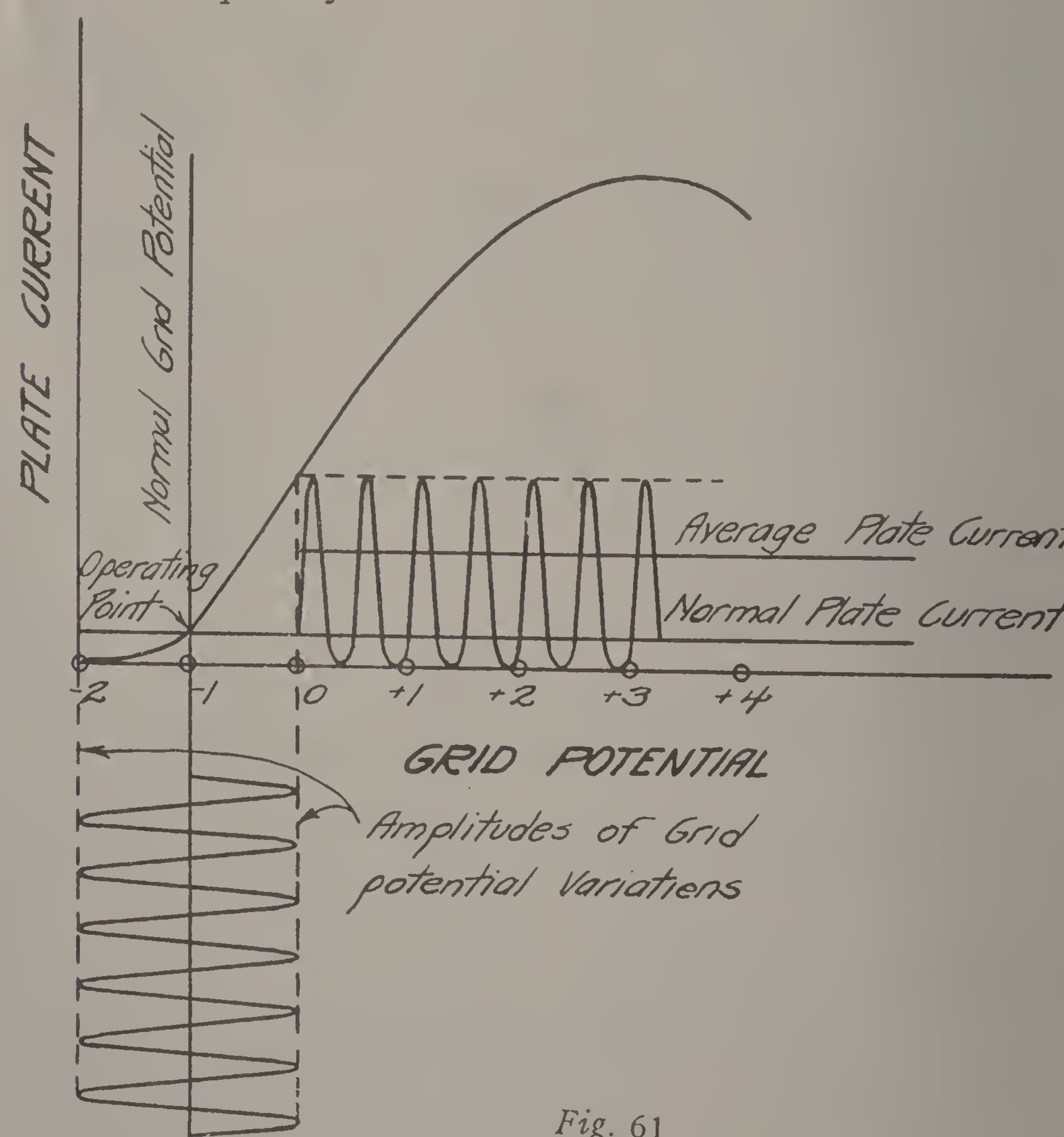


Fig. 61

305. It is shown on the diagram that the alternations of A raise and lower the potential of the grid by 1 volt above and below normal. But on account of the non-linear form of the characteristic curve the variations of the plate current above and below normal are unequal. The increases are larger than the decreases. In other words, equal variations of grid potential cause unequal variations of the plate current.

306. If the variations of plate current were equal the **average** value of the current would continue to be the same as the normal value; but since the increases are greater than the decreases there is an apparent rectification of the plate current variations and **the average value of the plate current is greater than the normal value.**

307. As long as the alternator A impresses an alternating e.m.f. across the grid and filament of the tube the plate current varies at the frequency of the alternator and the average plate current is higher than the normal plate current.

308. Presuming that the variable factors of the tube circuit are adjusted so that the apparent rectification of the plate current variations is as efficient as possible for the particular tube used, the extent to which the plate current is raised above its normal value depends upon the amplitude of the alternating e.m.f. across the grid circuit. For instance, if the alternator A varies the grid potential above and below normal by 2 volts instead of 1 volt, the average plate current will be still higher than before.

309. An oscillating e.m.f. impressed upon the grid circuit of a vacuum tube has a similar effect upon the plate current as the alternating e.m.f. of Fig. 60. The plate current varies at the high frequency of the impressed oscillations and if the variable factors of the circuit are properly adjusted the plate current variations appear to be rectified. The extent to which this increases the average plate current then depends upon the amplitude of the impressed e.m.f.

310. **Receiving circuit with V.T. detector**: A possible radio receiving circuit employing a vacuum tube as rectifier can therefore be represented by the diagram of Fig. 62. The antenna circuit can be tuned to resonance with the incoming signal oscillation by the condenser C1 and the secondary oscillatory circuit by the condenser C2. The two circuits are coupled by mutual induction. Signal oscillations in the secondary circuit create an oscillatory e.m.f. across the inductance L2, and capacity C2. These e.m.f. oscillations are impressed between the grid and filament of the tube. Any changes in the average value of the direct plate current passing through the telephones will produce corresponding movements of the telephone diaphragms. High frequency variations of the plate current are carried by the condenser C3 which is called a by-pass condenser.

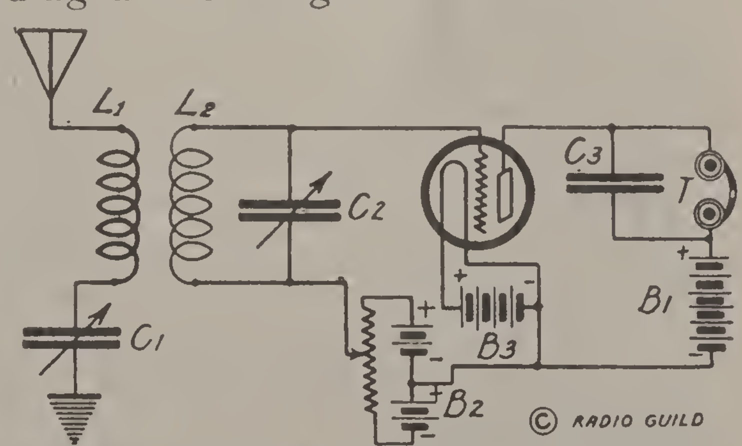


Fig. 62

311. If an undamped signal oscillation is impressed on the grid circuit the radio frequency variations of the plate current are rectified and the average plate current is raised above normal. As

the signal oscillation is of constant amplitude, the average plate current remains steadily at this higher value as long as the signal oscillation is impressed on the grid circuit.

312. The telephone diaphragms, responding to the changes in the average value of the plate current, are pulled closer to the magnets by the increase of plate current, but then remain stationary as long as the undamped oscillation is impressed. Therefore, this circuit, in common with the crystal rectifier, cannot be used to detect undamped waves.

313. But if the **amplitude** of the oscillating e.m.f. impressed on the grid circuit varies at some audible frequency, as in the reception of radio telephony or modulated telegraph signals, the average plate current follows the variations in amplitude of the incoming oscillations. These audio frequency variations of the average plate current vibrate the telephone diaphragms and corresponding sound waves are produced.

314. Spark and I.C.W. telegraph signals can also be detected by the system of Fig. 62. Each wave train increases the average plate current. At the end of each wave train the plate current returns to normal. As the wave trains follow each other at an audible frequency the plate current passing through the telephones increases and returns to normal at this frequency. Consequently a musical note is produced by the vibrations of the telephone diaphragms.

315. **The Operating Point**: To detect signals by the method of Fig. 62, we have noted the necessity of adjusting the operating point to the lower bend of the characteristic curve of the tube. That is to say, for equal variations of the grid voltage to cause unequal variations of the plate current, the normal grid potential and the normal plate current must intersect at the lower bend of the curve.

316. Owing to differences of construction all tubes have different characteristic curves, even if the variable factors of the circuit in which they operate are constant. For this reason some tubes are much better detectors than others; some tubes are good detectors but cannot be used as amplifiers and so forth.

317. However, the construction of the tube is not a controllable factor so far as the user is concerned. The manufacturer of the tube determines its characteristics; although as nearly as possible tubes of each type have approximately the same characteristics.

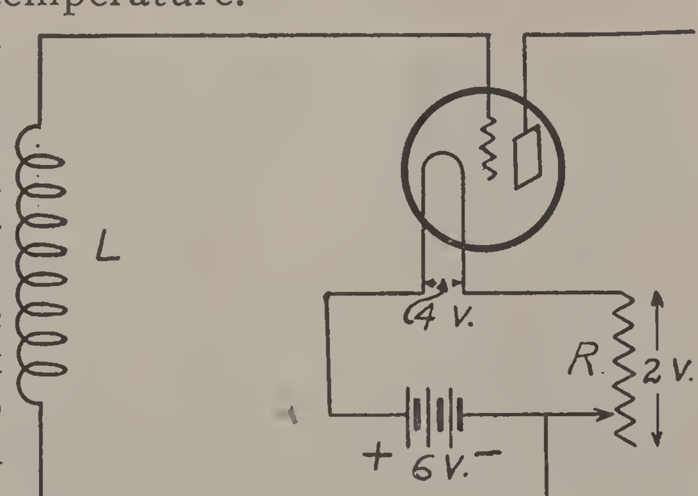
318. **Methods of Adjusting Operating Point**: We have seen that the operating point of a tube can be adjusted to ensure the best possible rectification by varying the grid potential, as in Fig. 62. In this circuit a separate grid battery is used across which is connected a potentiometer resistance. By changing the position of the sliding contact of the potentiometer the potential of the grid with respect to the negative end of the filament can be altered.

319. However, the operating point can be adjusted without necessarily varying the grid potential. It will be recalled that, apart from the construction of the tube itself, there are three

factors which determine the characteristic curve of a tube, viz: grid potential, filament temperature and plate potential. In practice, when a close adjustment of the operating point is required the plate potential is usually chosen at some approximate value which, with a slight variation of either the grid potential or the filament temperature, brings the operating point to the position of maximum sensitiveness. But a potentiometer is required to adjust the grid potential itself and to reduce the controls this is often eliminated. The grid potential is then fixed and the operating point is found by varying the filament temperature, a suitable value of plate potential being chosen for the purpose.

320. When tubes are used in an audio frequency amplifying circuit a close adjustment of the operating point is usually unnecessary. The operation of a radio receiver using audio frequency amplification can be greatly simplified by omitting unessential controls to closely adjust grid potential or filament temperature. The grid potential can be fixed, the filament temperature governed by an automatic control and the plate potential chosen at some value which will give suitable amplification.

321. The methods of adjusting the operating point of a tube are illustrated in Figs. 63 and 64. In these diagrams the plate circuit is not shown. It is understood that the plate potential may be varied, if desired, by changing the value of the plate battery. However, even when close adjustments are necessary, the plate potential is not changed after its proper value is chosen. Minute variations, if necessary, are made by altering the grid potential or filament temperature.



322. In Fig. 63 the inductance L is connected across the grid and filament of a tube. The connection to the filament is made directly to the negative side of the filament battery.

The normal potential of the grid must be the same as that part of the filament circuit to which it is connected. In speaking of grid potential and in drawing characteristic curves it is customary to compare the potential of the grid with the **negative** side of the **tube filament.** That is to say, if the grid is connected to the negative end of the tube filament it is at "zero potential;" and since there is a drop of potenial across the filament, the grid is then at a negative potential with respect to all other parts of the filament. In the same way, if the grid is connected to the positive side of the filament it is at a positive potenial in relation to the negative and to all other parts of the filament except the end to which it is connected.

323. In the circuit of Fig. 63 the drop across the filament is supposed to be 4 volts. A 6 volt battery is used to supply the filament current and a rheostat is connected between the filament

and the negative end of the battery. The drop across the resistance is 2 volts. The grid, being connected to the negative side of the filament battery, is therefore at a negative potential of 2 volts with respect to the negative end of the tube filament.

324. With this arrangement the best operating point can be found by varying the temperature of the filament with the rheostat R. Incidentally, when the value of R is altered the normal potential of the grid in relation to the negative end of the filament is also changed.

325. In Fig. 64, a greater range of adjustment of the operating point is made possible by the use of the potentiometer. Instead of connecting the grid directly to the negative side of the filament battery as in Fig. 63, the grid is connected to the sliding contact of the potentiometer. If the drop across R is 2 volts the potential of the grid may be varied from 4 volts positive to 2 volts negative with respect to the negative end of the tube filament. The filament temperature may also be changed by the rheostat R. However, as in Fig. 63, if the value of R is altered the normal grid potential is also affected.

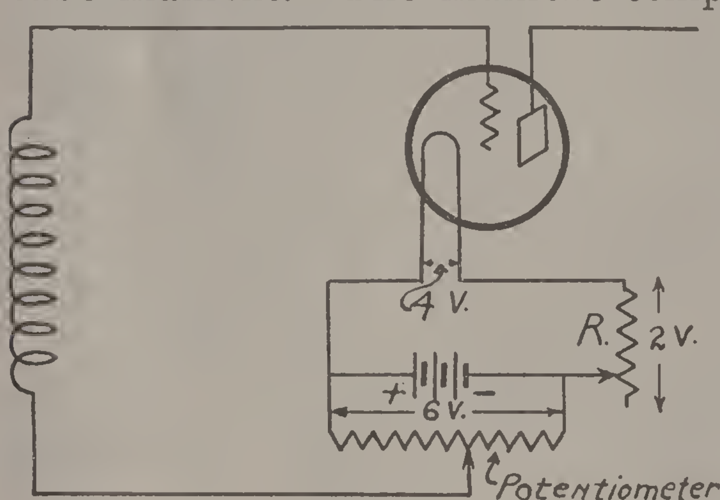


Fig. 64

326. If, by moving the sliding contact of the potentiometer, the grid becomes positive to the negative end of the filament, the grid circuit is conductive. In terms of the electron theory, electrons can pass from the filament to the grid or, according to the older theory, current can pass from the grid to the filament. As a matter of fact the grid circuit may be slightly conductive even when the grid is at a negative potential provided the negative potential value of the grid is not too great.

327. **The Triode as Detector with Grid Condenser:** A more efficient use of the three-electrode tube as a detector is by the "grid condenser" method represented by the circuit of Fig 65. In this case the grid is not connected directly to the filament except through a high resistance "leak" of about 1 megohm (1 million ohms). A small blocking condenser is connected in series with the grid. This system of detection may be briefly explained as follows:

328. The grid assumes a normal potential which is governed by the value of the grid leak, the form of the grid current curve and the potential of the point on the filament circuit to which the leak is connected. It is best to connect the grid leak to the positive side of the filament.

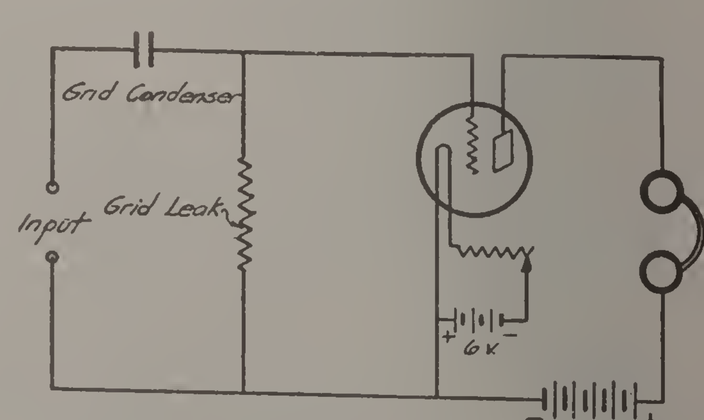


Fig. 65

329. At this normal grid potential there is usually a very low value of grid current. Owing to the form of the grid current curve, if a positive e.m.f. is impressed on the grid which raises its potential the grid current is greatly increased. But if an equal negative e.m.f. is impressed which lowers the normal potential of the grid the grid current is only slightly decreased.

330. If oscillations are impressed across the input terminals of the circuit of Fig. 65, the grid current varies at the frequency of the impressed oscillation but the grid current variations are rectified. The increases of grid current are greater than the decreases and **the average grid current is increased.**

331. The direction of the electrons constituting the grid current is from filament to grid. But as there is no easy path for the electrons to pass back to the filament **the grid accumulates electrons** as a result of this increase of average grid current. This means that **the average potential of the grid is lowered** below its normal value.

332. Now as the grid potential varies at the frequency of the impressed e.m.f. the plate current also varies at this frequency and as the **average** grid potential decreases the average plate current also decreases.

333. The extent to which the average grid potential is lowered depends upon the amplitude of the impressed oscillation. If the amplitude is constant the average grid potential is lowered to a constant value. If the amplitude increases the average grid potential is again lowered. If the amplitude decreases the excess electrons on the grid leak off to the filament through the high resistance leak and the grid potential is raised. If the impressed e.m.f. is removed the grid potential comes back to normal.

334. Therefore, if the impressed oscillating e.m.f. varies in amplitude at some audible frequency, as in the reception of radio telephony, the average grid potential and average plate current vary at this frequency and audible sounds are produced by the vibrations of the telephone diaphragms.

335. Spark and I.C.W. signals can also be detected by this system. It is evident, however, that undamped wave signals will not be detected. The undamped oscillations impressed on the grid and filament reduce the average grid potential and average plate current but, as the amplitude does not vary, the average plate current remains constant and no vibrations of the telephone diaphragms are produced.

336. It will be noted that in the system of detection represented by Fig. 62, the average plate current is **increased** by the effect of an incoming oscillation whereas by the grid condenser system the average plate current is **decreased.**

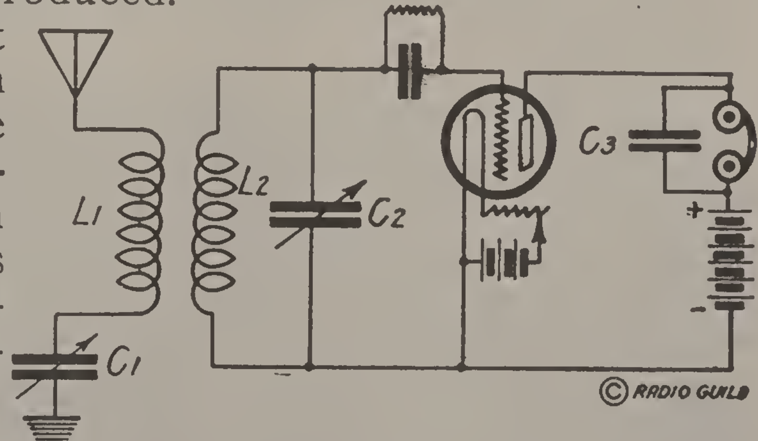


Fig. 66

337. Fig. 66 shows a complete receiving circuit employing the grid condenser method of detection.

LESSON 6.

APPLICATIONS OF THE FEED-BACK PRINCIPLE.

338. The expression "radio frequency amplification" has been popularly applied to the multi-stage system of high frequency amplification in which the output of one tube is coupled to the input of the succeeding tube through a transformer or other repeating device. Before discussing these systems, however, we must understand the principles of regeneration and the use of the vacuum tube as a generator of oscillations.

339. By a proper arrangement of its circuits a single vacuum tube which is used to rectify high frequency oscillations can be made to amplify the incoming oscillations themselves. In other words, while acting as a rectifier it can act as a radio frequency amplifier at the same time, thereby greatly increasing the sensitiveness of the receiving system.

340. The principle which governs the arrangement of the circuits to produce this useful effect is called the "feed-back" principle and was first defined by Armstrong.

341. **Feed-back System with inductive coupling:** Fig. 67 shows one of the applications of this principle in a radio receiving system. It will be seen that the only difference between this circuit and the circuit of Fig. 66 is the inclusion of the coil L3 in the plate circuit.

342. If this coil is brought close to the coil L2 of the grid circuit any current changes in L3 will induce an e.m.f. in L2; in other words there will be mutual inductance between the two coils and the grid and plate circuits will be inductively coupled. Provision is usually made to allow the coil L3 to revolve about its own axis so that the coupling between the two circuits can be varied.

343. To study the operation of this circuit let us first presume that the coupling between the grid and plate circuits is zero. In effect the operation of this circuit is then exactly as described in connection with Fig. 66. If an oscillating e.m.f. is induced by a signal in the circuit L2 C2 the amount of energy released in the plate circuit and consequently the loudness of the signal in the telephones depends upon the amplitude of the e.m.f. oscillations impressed on the grid. The final amplitude of the oscillations which build up in the L2 C2 circuit when

tuned to resonance, is limited only by the resistance of this circuit. No matter how carefully we may arrange the grid circuit to avoid unnecessary causes of resistance and consequent losses of energy, the circuit will possess some value of resistance which will limit the final amplitude of the oscillations.

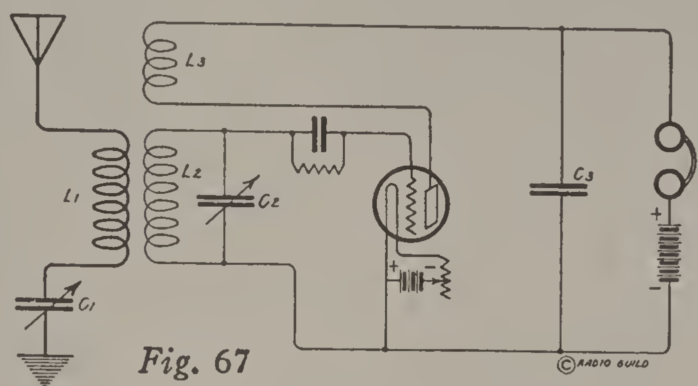


Fig. 67

344. Now if, in some way, it is possible to overcome the resistance reaction of the grid circuit, the oscillations will build up to a greater amplitude than before so that more energy will be released in the plate circuit and a louder signal heard.

345. The resistance reaction of the grid circuit can be partially or completely neutralized by the feed-back system and it is in this way that amplification is obtained.

346. If the coil L3 of Fig. 67 is revolved so that there is a slight coupling between the plate and grid circuits the radio frequency current variations in the plate circuit induce an oscillating e.m.f. in the L2 C2 circuit. The magnitude of this e.m.f. depends upon the coupling between the two circuits.

347. The plate current variations, of course, have the same frequency as the signal oscillations in the grid circuit which produce them. Then if the current through L3 is in the proper direction, the oscillating e.m.f. induced in the grid circuit by the current variations of the plate circuit will aid the signal e.m.f. and offset the effect of resistance in the grid circuit.

348. Energy is dissipated by the resistance of the grid circuit but this loss of energy can be partially or completely counterbalanced by feeding back energy from the plate circuit. The amount of energy supplied by the plate circuit and therefore the extent to which the resistance reaction is overcome depends upon the coupling between the plate and grid circuits.

349. It is evident that by revolving L3 some value of coupling can be found at which the energy transferred to the grid circuit from the plate circuit exactly equals the amount of energy consumed by the resistance of the grid circuit. The effective resistance of the grid circuit is then zero and the circuit acts as though it had no damping effect upon the oscillations.

350. The value of this simple method of amplification is apparent and it might seem that there is no limit to the magnification made possible by its use. There is, however, a decided limit.

351. **Self-generation:** If the coupling between the plate and grid circuits of the tube is increased beyond a certain value the tube **becomes a generator of continuous oscillations.** It is not necessary for a signal e.m.f. to be impressed on the grid circuit to produce these self-generated oscillations. They are invariably built up if the coupling is sufficiently close. The slightest impulse is sufficient to set up a weak oscillation which gradually builds up until it reaches a certain amplitude and then continues at this amplitude indefinitely. The impulse may be an atmospheric disturbance, the closing of one of the circuits or an irregularity in electron emission of the tube. No matter how slight, it is sufficient to start an oscillation. This oscillation is amplified in the plate circuit and fed back to the grid circuit by the coupling between the two circuits. The original oscillation is then reinforced. This releases more energy in the plate circuit which is again fed back to the grid circuit.

352. The amplitude of the oscillation builds up in this manner until sufficient energy is released in the plate circuit to induce an e.m.f. in the grid circuit which maintains the oscillation against the resistance of the grid circuit. When it reaches this amplitude the oscillation continues steadily.

353. If, while a signal e.m.f. is impressed on the grid circuit, the feed-back coupling is increased to the point when **the effective resistance is zero,** the conditions for self-oscillation are fulfilled.

354. **Regeneration:** Now let us see how this feed-back system of amplification can be utilized in reception. If the coupling between plate and grid circuits is zero there is no feed-back amplification. But, if the coil L3 of Fig. 67 is revolved so that there is a slight coupling between the circuits the effective resistance of the grid circuit is reduced. If a signal e.m.f. is induced the oscillations build up to a higher amplitude and a louder signal is heard than would otherwise be the case. The amplification is said to be obtained by "regeneration." An oscillating e.m.f. is regenerated in the grid current by the current variations in the plate circuit.

355. If, while a signal e.m.f. is being impressed on the grid circuit, the coil L3 is again revolved the amplification increases as the coupling between the two circuits is tightened. As the resistance of the grid circuit more closely approaches zero, the signal becomes louder and louder.

356. But, if the coupling is increased to the point when the energy fed back to the grid circuit from the plate circuit **completely** counterbalances the loss of energy due to the resistance of the grid circuit the effective resistance is then zero and a more complicated state exists.

357. A free oscillation is self-generated which continues steadily at a constant amplitude irrespective of the signal oscillation. The frequency of this self-generated oscillation is

governed by the resonant frequency of the grid circuit; the self-generated oscillation has the frequency to which the grid circuit is tuned.

358. If the grid circuit is accurately tuned to resonance with the incoming signal oscillation the self-generated oscillation and the signal oscillation both have the same frequency. If this condition exists the self-generated oscillation very greatly amplifies the signal; in practice, however, it is very difficult to so accurately tune the grid circuit that the self-generated oscillation and the incoming signal oscillation have both absolutely the same frequency.

359. If the resonant frequency of the grid circuit is only slightly different from that of the signal oscillation the grid circuit is then excited by oscillations of two different frequencies. This results in the production of an oscillation of varying amplitude with a beat frequency equal to the difference in frequency between the two separate oscillations. (See Par.104). The consequent distortion of signals may not be a very serious drawback so far as telegraphic signals are concerned but if the modulations of a radio telephone signal are distorted the speech or music is unrecognizable when reproduced.

360. In practice, therefore, it is usually necessary to prevent the generation of continuous oscillations in the regenerative system and this can only be done by maintaining the resistance of the grid circuit at some **positive** value. The coupling between the grid and plate circuits can not be increased beyond the point at which the resistance of the grid circuit is almost zero and the amplification obtainable by regeneration is thereby limited.

361. Users of regenerative receivers will realize this fact in the operation of the system. Amplification increases as the feed-back is increased and the greatest amplification is obtained **just below the point of self-oscillation.** If the feed-back coupling is still further increased the "tube oscillates" and only distorted signals are heard.

362. **Autodyne Reception of Undamped Waves**: The fact that the vacuum tube can become a generator of continuous oscillations is utilized both in radio transmission and reception. Vacuum tubes are used as sources of power for the transmission of undamped waves, modulated continuous waves (including radio telephony) and interrupted continuous waves. A small vacuum tube is also used as the generator of the local oscillations in the reception of undamped waves by the heterodyne or "beat" method, as explained in Paragraph 100. The "oscillator" referred to in that explanation consists of a vacuum tube with the plate and grid circuits closely coupled and a variable condenser to change the frequency of the oscillations produced. An undamped oscillating e.m.f. of any desired frequency is induced in the receiving circuit by this oscillator.

363. It is possible, however, to use the feed-back system for the reception of undamped waves without using a separate vacuum tube to generate the local oscillations. For instance, to detect undamped wave signals by the system of Fig. 67 the

coupling between the grid and plate circuits is increased by revolving the "Tickler" coil L3 until a click is heard in the phones and the system commences to generate continuous oscillations. The frequency of these oscillations can be varied by revolving the condenser C2. At any time the frequency of the self-generated oscillations is the same as the resonant frequency of the grid circuit.

364. Now, if an undamped signal e.m.f. is impressed on the grid circuit the circuit is excited by oscillations of two different frequencies. By revolving the condenser C2 the frequency of the self-generated oscillations can be varied until the difference between the two frequencies produces an audible beat note.

365. This is called the "autodyne" method of detecting undamped waves. It is the same as the "heterodyne" system previously described with the exception of the fact that only one tube is required, the local oscillations being generated by the same tube that detects the signals.

366. There is one important difference between the autodyne and heterodyne systems. To detect undamped waves by the autodyne method the natural frequency of the grid circuit must, of necessity, be different from that of the signal oscillation. Therefore, the grid circuit cannot be accurately tuned to the incoming signal and the signal oscillations are limited in amplitude by the reactance of the circuit.

367. This disadvantage is sometimes compensated by the fact that only one tube is required; but the heterodyne system is invariably more efficient as the grid circuit of the detecting tube can be accurately tuned to resonance with the signal frequency, while the frequency of the local oscillations is independently varied.

368. **Preferred system for detecting undamped waves:** In Fig. 68 the heterodyne system of detecting undamped waves is

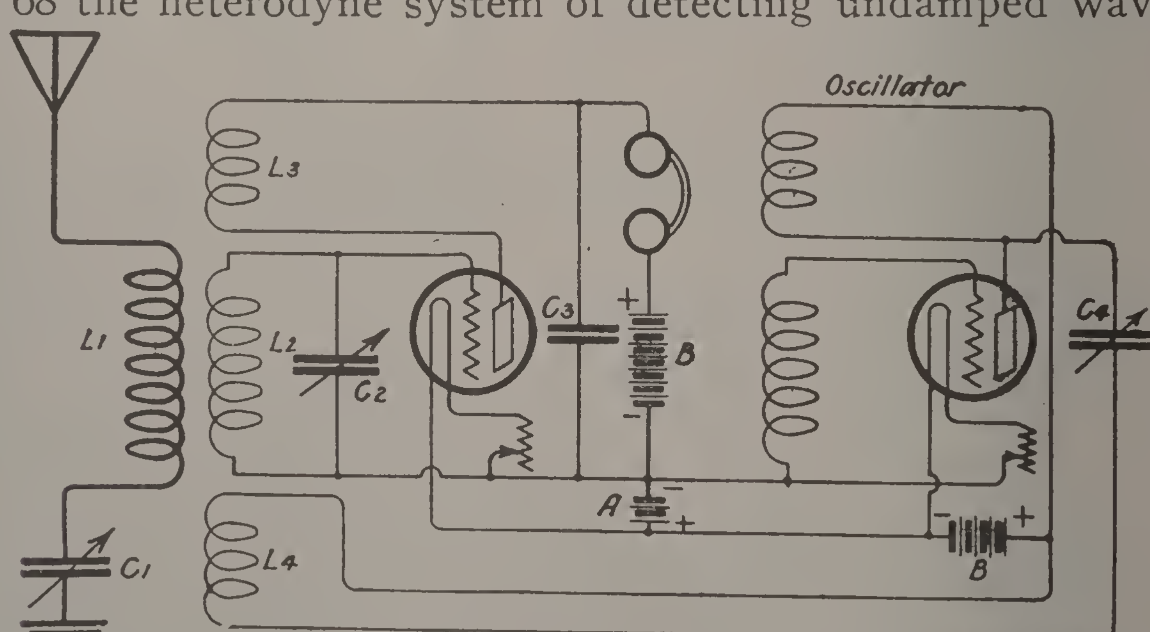


Fig. 68

used but the detecting circuit is regenerative. Amplification and selectivity to a degree which cannot be achieved by the autodyne system are easily obtained. The actual arrangement of parts suggested by the diagram does not necessarily have to be followed but the principle of using a regenerative circuit in connection with an external generator of continuous oscillations is undoubtedly the most efficient for the reception of undamped waves. The advantages of this circuit are particularly apparent when long waves are to be detected.

369. The local oscillations are generated by the "oscillator" and their frequency can be varied by means of the condenser C4. The antenna circuit and L2 C2 circuit are each tuned to the frequency of the incoming signal oscillation. The coupling between L3 and L2 is adjusted to bring the resistance of the grid circuit to nearly zero. This permits the oscillations in the L2 C2 circuit produced by the signal to build up to a very high amplitude. Being exactly tuned to resonance the total reactance is zero while the resistance is very nearly zero, due to the feeding back of energy from the plate circuit.

370. The oscillations generated by the oscillator are introduced into the L2 C2 circuit by the coupling coil L4. The value of the oscillating e.m.f. induced in the L2 C2 circuit by the oscillations in L4 can be controlled by varying the mutual inductance between L4 and L2. This adjustment has a considerable effect upon the strength of a given signal. With a separate oscillator it is a simple matter to adjust the amplitude of the local oscillation induced in the detecting circuit but it is much more difficult to make this adjustment when the autodyne system is used.

The construction and use of an oscillator will be given in greater detail in Part 2.

371. **Feed-back system with capacitive coupling:** In the regenerative circuit of Fig. 67 inductive coupling is used to feed back energy from the plate to the grid circuit. In the circuit of Fig. 69, however, **capacitive** coupling is used instead of inductive coupling.

372. This circuit depends for its operation upon the oscillations which are set up across the coil L3 by the radio frequency variations of the plate current. The coil L3 is a variable inductance so that, with its distributed capacity, it can possess any desired resonant frequency.

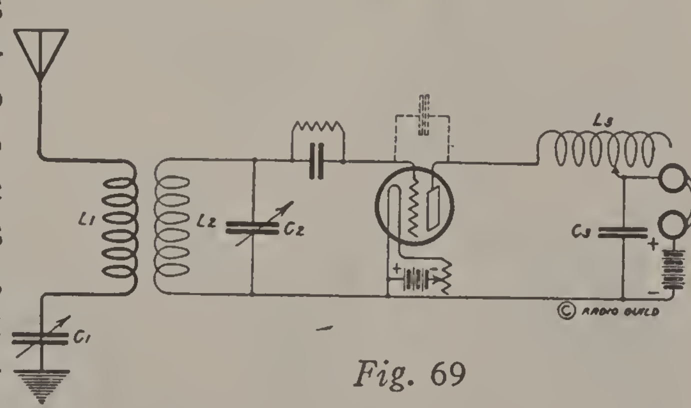


Fig. 69

373. If an oscillating e.m.f. is induced by a signal in the L2 C2 circuit and the latter tuned to resonance the amplitude of the oscillations is limited by the resistance of the grid circuit. The plate current r.f. variations have the same frequency as the signal oscillation. When the plate current increases a self-induced voltage is set up across L3 and the direction of this voltage reduces the effective e.m.f. of the circuit so that the plate potential is lowered below normal. When the plate current decreases a self-induced voltage is set up across L3 in the opposite direction, increasing the effective e.m.f. of the circuit so that the plate potential is raised above normal.

374. Therefore, as long as the oscillating signal e.m.f. is impressed on the grid, oscillations of the same frequency are

produced across the coil L3 in the plate circuit and the plate potential rises and falls above and below normal at this frequency.

375. If the plate and grid circuits are **capacitively** coupled energy will be fed back from the plate to the grid circuit **in the proper phase** to produce amplification of the oscillations in the grid circuit.

376. The two circuits can be coupled capacitively by means of a variable or fixed condenser but the capacity existing between the plate and grid **inside the tube** is sufficient coupling to produce regeneration if the signal has a high frequency.

377. Presuming the circuits are coupled through a fixed condenser or the capacity of the tube itself the amplification obtained depends upon the extent to which the plate potential rises and falls. This, in turn, depends upon the amplitude of the oscillations across L3. The latter can be increased by varying the inductance of L3 so that, with its distributed capacity, its resonant frequency approaches the frequency of the oscillations produced across it by the r.f. plate current variations.

378. If L3 is tuned to exact resonance and the frequency is high, the energy fed back from the plate circuit to the grid circuit will be sufficient to sustain continuous oscillations in the system so that the tube becomes a generator of oscillations. If the frequency is low or if the internal capacity of the tube is very small, continuous oscillations can be generated by increasing the capacitive coupling between plate and grid circuits with an external condenser.

379. The system of Fig. 69 is greatly used today for the reception of short wave signals—undamped waves by the autodyne system and others with regenerative amplification. Sometimes a variometer is used to continuously vary the inductance of L3 and at others a variable condenser is connected across L3 to tune the plate oscillatory circuit. The principle of operation is the same in every case.

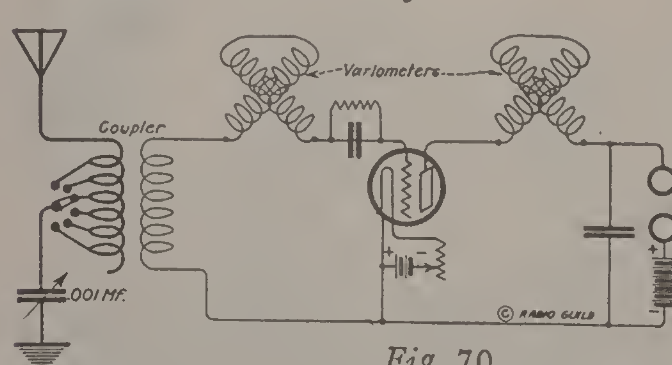


Fig. 70

380. Fig. 70 shows the most popular application of this principle with internal capacitive feed-back coupling. A variometer is used in place of a variable condenser to tune the grid circuit to resonance. The object of this is to tune the grid circuit to resonance with a preponderance of inductance so that the e.m.f. oscillations will have as great an amplitude as possible. The advantage of this is sometimes lost in the distributed capacity of the variometer.

381. **Single-circuit vs. Loose-coupled Regenerative Receiver:** One of the principal advantages of the regenerative receiver is the selectivity it affords. The regenerative action reduces the effective resistance of the grid circuit to some value closely approaching zero. This not only increases the amplitude of the oscillations in the grid circuit but makes the circuit very selective.

382. There is frequently some debate amongst amateurs as to whether a "single circuit" or an inductively coupled regenerative receiver is the more desirable. Both are selective and sensitive but there is no question whatsoever that the loose-coupled receiver permits a very much higher degree of selectivity and also allows a finer control of regeneration than the other. These advantages, in our opinion, outweigh the merit of simplicity possessed by the single circuit receiver. Figure 71 shows the latter circuit. L1 is the primary of a vario-coupler (with a fairly close coupling) and L2 the secondary which is used as the tickler coil; the antenna circuit can be tuned to resonance with the variable condenser C1. This circuit is only selective because the regenerative action reduces the effective resistance of the antenna circuit. The audibility is good and a fair degree of selectivity is obtained but regeneration is somewhat difficult to control.

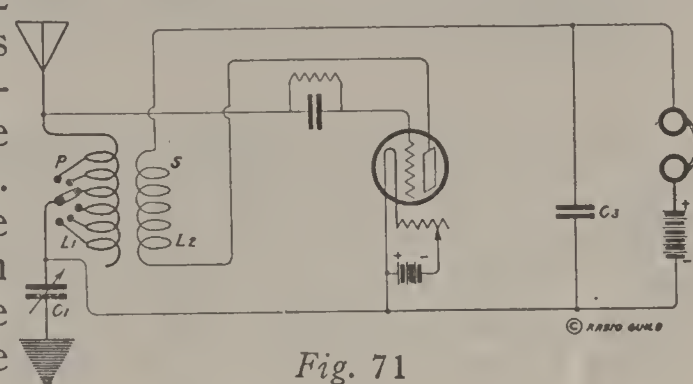


Fig. 71

383. With the inductively-coupled regenerative circuits shown in Figs. 69 and 70 both the antenna circuit and the secondary circuit are tuned to resonance. The antenna, because of its size and resistance cannot be tuned to any particular frequency without being subject to forced oscillations of other frequencies. Static and atmospheric strays of varying frequencies all produce forced oscillations in the antenna circuit, irrespective of the wave-length to which it is tuned, although oscillations of the latter frequency persist longer and reach a greater amplitude than the others. The secondary circuit, however, can be accurately tuned to any desired frequency and is subject to forced oscillations of other frequencies only to a very slight extent. If, by regenerative action, the resistance of the secondary circuit approaches zero, it is extremely selective.

384. In discussing coupled oscillatory circuits in Lesson 4, we observed the necessity of maintaining a loose-coupling if selectivity is to be gained. An inductively coupled regenerative receiver, however, necessitates a looser coupling than the non-regenerative circuit because the energy in the secondary circuit is amplified by regeneration. As the energy is increased the reaction between the secondary circuit and the antenna circuit is also increased and, to maintain resonance, it is necessary to loosen the coupling. This, of course, automatically results in an increase of selectivity, as the looser coupling prevents to a greater extent the transfer to the secondary circuit of forced oscillations of undesired frequencies in the antenna circuit.

385. Another desirable feature of the loose-coupled receiver is the fact that less energy is lost by re-radiation from the antenna. The single circuit regenerative receiver radiates strongly. This is undesirable, from the standpoint of conserving energy and also because of the interference which this re-radiation causes to other receiving stations in the neighborhood.

LESSON 7.

RADIO AND AUDIO FREQUENCY AMPLIFIERS.

386. **The Triode as an Amplifier:** It will be realized that the three-electrode vacuum tube is, in effect, an electrical relay. It is impossible to magnify energy but, by a relay system, we can make a small amount of energy control a large amount of energy. This is what takes place in the vacuum tube. A small variation of the potential of the grid produces a large variation of the plate current. But the grid circuit and the plate circuit are separate and distinct. The energy in the plate circuit is not **supplied** by the incoming signal voltage. The latter, acting upon the grid, merely **releases** energy in the plate circuit supplied by the plate battery.

387. By this relaying system, a small amount of energy expended on the grid circuit releases a large amount of energy in the plate circuit. The amplified energy which is released in the plate circuit is utilized instead of the feebler energy impressed on the grid circuit.

388. The amplification which can be obtained with a single tube is, of course, limited; but just as one relay may be used to operate a second relay or any number of relays in succession—each relay multiplying the energy of its predecessor until finally a great amount of energy is controlled by a small initial force—so vacuum tubes may be used to amplify the permutations of electric current.

389. An "amplifier," then, usually consists of two or more vacuum tubes arranged so that a varying voltage impressed on the grid of the first tube will produce a similar and undistored variation of the plate current; this variation of the plate current must then produce a varying voltage between the grid and filament of the second tube. A transformer or other device is used to repeat the amplified variations from one tube to the next. In a similar way the variations are relayed from tube to tube.

390. The diagram of Fig. 72 shows how the amplifying tube, without causing distortion, relays the variations impressed on the grid. This diagram shows the characteristic curve of an amplifying tube. The variations of grid potential and corresponding variations of plate current are indicated. As the operating point is chosen on the straight portion of the characteristic curve, equal variations of grid potential produce equal varia-

tions of plate current. Even if the variations of grid potential have the complicated form of a speech wave they will be exactly

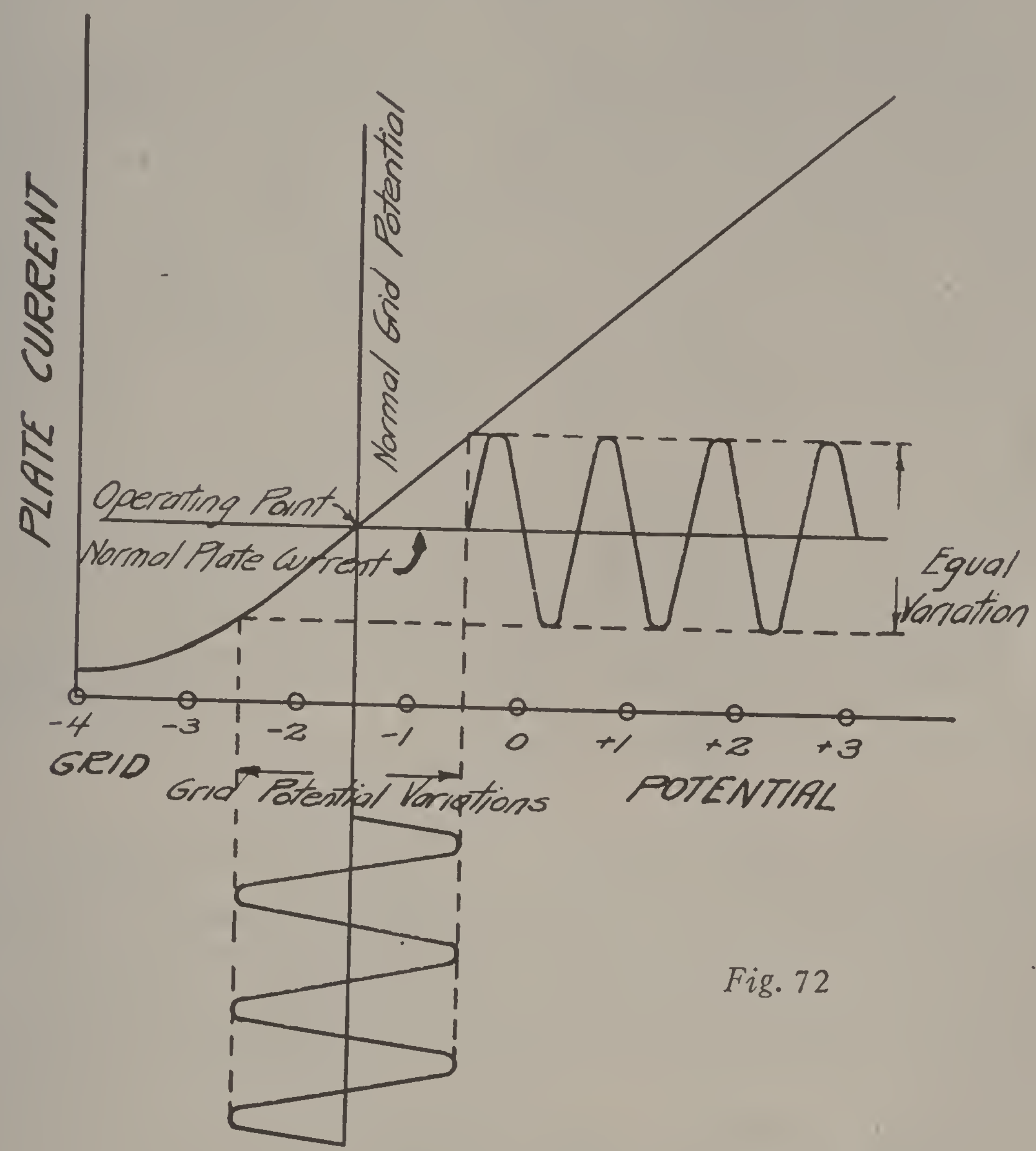


Fig. 72

reproduced in the plate circuit. There will be no distortion, provided the operating point is correctly chosen.

391. **Functions of Radio and Audio Frequency Amplifiers:** Amplifiers, as used to aid radio reception, are divided into two main divisions:

1. Radio Frequency Amplifiers.
2. Audio Frequency Amplifiers.

Basically the two types of amplifiers operate under the same principles. In each case the amplifying characteristics of vacuum tubes are utilized to magnify varying voltages and currents without distorting their original form. The audio frequency amplifier magnifies variations of a low audible frequency whereas the radio frequency amplifier magnifies the very high frequencies used in radio transmission. For this reason the amplifiers of the two systems are not interchangeable. Of necessity the apparatus in the circuits is designed according to the frequency of the currents to be amplified.

392. The exact function of each division of a radio receiver employing both radio and audio frequency amplification is briefly recapitulated below and illustrated by the drawing of Fig. 73,

the latter showing the logical sequence of the various divisions.

393. **Tuner or Receptor:** Radio waves induce in the receiving antenna an oscillating e.m.f. The frequency of the oscillations depends upon the frequency of the waves or, in radio parlance, upon the wave-length. The frequency is always high-above audibility. The strength or amplitude of the signal e.m.f. depends upon the distance between the transmitter and the receiver, the design of the receiving antenna, the power of the transmitter and other variable conditions outlined in Paragraph 86. The signal oscillations may be of constant amplitude or varying amplitude, continuous or in trains, according to the type of transmission producing the waves.

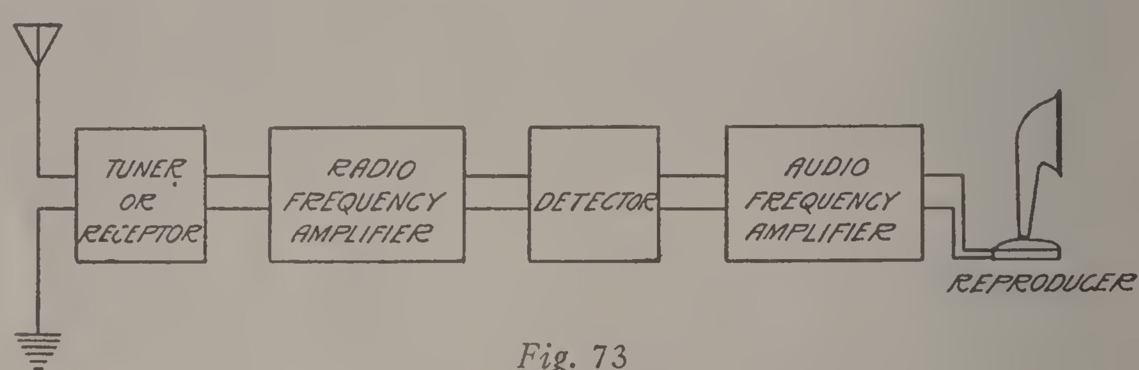


Fig. 73

The function of the tuner is to adjust the receiving circuit or circuits to resonance with the particular signal oscillation to be detected, thereby permitting current and voltage oscillations of the greatest possible amplitude to build up in these circuits and offering impedance to oscillations of different frequencies produced by other waves. The lower the resistance of the tuning circuits the higher the amplitude of the resonant oscillations and the greater the selectivity of the receiver.

394. **Radio Frequency Amplifier:** This amplifier is used to magnify the high frequency oscillations of incoming signals **before** rectification. The oscillations in the tuner circuits may be too weak to operate the rectifier. By radio frequency amplification they are magnified without distortion and the oscillations which are finally rectified have a very much greater amplitude than the oscillations in the tuner circuits.

395. **Detector:** The high frequency oscillations are rectified by the detecting system. The strength of the rectified current varies in step with the variations in amplitude of the impressed high frequency oscillations. As these variations of amplitude occur at an audible frequency the varying current produced by the rectifying action will cause audible vibrations of a telephone receiver diaphragm if the current flows through the coils of the telephone. The rectifier with the telephone detects the signal —makes it audible.

396. **Audio Frequency Amplifier:** This amplifier increases the audibility or loudness of the detected signal. The variations magnified by audio frequency amplification are the variations in strength of the rectified current produced by the detecting system.

397. **Reproducer**: The signals are finally reproduced by the sound waves created by the vibrations of a telephone diaphragm. The sound waves themselves may be amplified and the quality of reproduction improved by means of a horn or other acoustical amplifier.

398. It should be quite clear, that whereas the audio frequency amplifier increases the audibility of a detected signal, the radio frequency amplifier makes possible the detection of signals which could not otherwise be heard; it increases the sensitiveness of the receiver.

399. Just what is meant by this may be understood better if we say that radio frequency amplification, in effect, brings the transmitting station closer to the receiving station. For instance, if a certain amateur receiving station A is 1000 miles away from a transmitting station B and A is tuned accurately to the wave-length on which B is transmitting, the oscillations in the receiving circuits of A may be too feeble to operate the rectifier. The signals of B are inaudible. Now A can increase the amplitude of the oscillations and make the signals from B audible by moving closer to transmitter B but he can achieve the same result by using a radio frequency amplifier to magnify the oscillations.

400. To give another example of the use of a radio frequency amplifier: Suppose that it is inconvenient for the owner of a receiver to erect an aerial and instead he uses a small indoor antenna. His receiving range is naturally limited. However, if he uses a radio frequency amplifier the sensitiveness of his apparatus will be greatly increased and his receiving range extended.

401. **Classification of Amplifiers**: Amplifiers, whether for radio or audio frequency amplification, are divided into three main classes:

1. Resistance—Coupled Amplifiers.
2. Inductance—Coupled Amplifiers.
3. Transformer—Coupled Amplifiers.

These classifications are made according to the arrangement used for repeating the variations from one tube to the next.

RESISTANCE—COUPLED AMPLIFIERS.

402. Fig. 74 illustrates the principles of a resistance-coupled amplifier. The varying voltage to be amplified, at radio or audio frequency as the case may be, is applied across the input terminals which connect to the grid and filament of the first tube. The object of tube A is then to produce a varying voltage across the points X and Y of its external plate circuit. This voltage must be similar in form to that impressed on the grid and as much larger as possible. The amplified voltage variations are then applied between the grid and filament of tube B, as shown. The capacity C1 is inserted to prevent the steady voltage of B2 from affecting the grid of the second tube. Only the **variations** in voltage are impressed on the grid through the capacity C1.

403. Let us see how variations of voltage are produced across the points X and Y of tube B. We know that a change of grid potential changes the plate current of a tube. But if any resistance is connected in the plate circuit, outside the tube, a variation of grid potential changes the potential drop across this resistance.

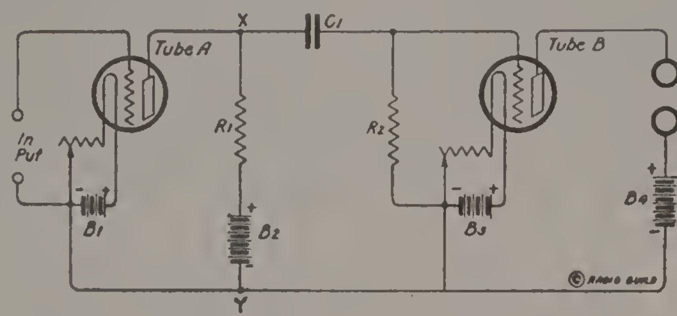


Fig. 74

404. In Fig 74, the complete plate circuit of tube A is formed by the filament and the plate (within the tube) the resistance R1 and the plate battery B1 (external). The plate circuit, of course, offers impedance to the current variations which flow in it as a result of the grid potential variations. The plate-filament (internal) impedance of the tube is usually determined mainly by the resistance of this path which, for the tubes used in radio receivers, may be in the neighborhood of 5,000 to 30,000 ohms. Similarly the impedance of R1 is usually determined by its resistance alone. It is constructed to possess no inductance and as small a capacity as possible.

405. It should be noted, however, that both the plate-filament path and the external resistance R1 have capacity as well as resistance. The values of these capacities are very small and have little or no effect upon the impedance of the plate circuit when the current variations are of low frequency. But, the reactance of a given capacity decreases with an increase of frequency and if the current variations in the plate circuit have a high frequency the capacity reactances of the tube and the resistance R1 may be low enough to determine the impedance of the plate circuit; if the frequency is high enough the impedance may be less than the resistance.

406. When the grid potential of tube A is changed, the plate current is changed. But the current in a circuit can only be changed by a change in the e.m.f. or the resistance. Since the plate current is changed by a variation of grid voltage without altering the e.m.f. of the plate battery, it is evident that the change of grid voltage alters the plate-filament resistance of the tube.

407. The complete plate circuit of tube A, therefore, can be represented by the simple electrical circuit of Fig. 75. B1 represents the plate battery, R1 the external plate circuit resistance and R2 the variable resistance of the tube. The resistance of R2 depends upon the voltage of the grid. If a varying e.m.f. is impressed on the grid the resistance R2 varies at the frequency of the impressed e.m.f. The resistance of R1 is constant. The total resistance of the plate circuit is equal to R1 plus R2. The current in the circuit, by Ohm's Law, is equal to the e.m.f. of B1 divided by the total resistance of the circuit. The drop in potential across R1 at any moment is equal to the

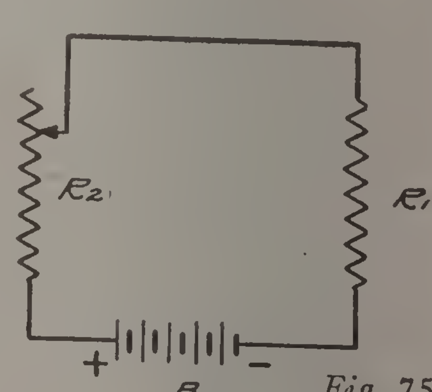


Fig. 75

current in the circuit at that moment, multiplied by the resistance of R1. It is evident, therefore, that if the current through the **constant** resistance R1 is varied by a variation of R2, the **potential drop across R1 also varies.**

408. Referring again to Fig. 74, then, the variations of the grid potential of tube A produce a varying difference of potential across the high resistance R1 and since the resistance of battery B1 is low, it follows that a varying difference of potential of almost the same value is produced across the points X and Y.

409. **Voltage Amplification of Resistance Amplifier:** The voltage amplification obtained by tube A is determined by the extent to which a given variation of grid voltage changes the potential across the external plate circuit. For instance, if a change of grid potential of 1 volt produces a change in the potential across the external plate circuit of 10 volts, the voltage amplification is 10.

410. The voltage amplification can be increased by increasing the resistance of R1, at the same time increasing the voltage of B1, but it is impractical to increase the voltage of B1 indefinitely and the gain in amplification after R1 passes a certain value of resistance is very small, even for large increases of R1. The useful value of R1 depends upon the type of tubes employed and is usually from 20,000 to 100,000 ohms. Fig 76 shows a photograph of a lavite resistance which is suitable for use in a resistance-repeating amplifier. This resistance is non-inductive and has very small capacity so that its impedance is practically constant for all frequencies.

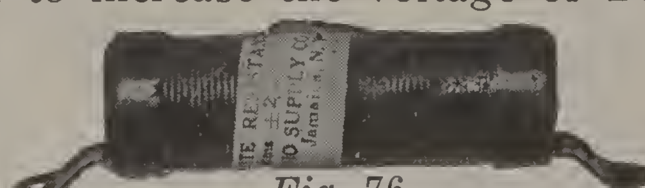


Fig. 76

411. **Repeating Action:** The amplified variations of voltage produced across the points X Y of Fig. 74 are applied between the grid and filament of tube B. The amplified signal is then reproduced by the telephones in the plate circuit of this tube. The external plate circuit (XY) across which the voltage variations are produced is shunted by the grid-filament circuit of tube B. This circuit is formed by the leak R2 and the capacity and resistance of grid to filament within tube B. Provided that the impedance of this circuit is much greater than the resistance of R1 it will not affect the voltage across X Y. But if the impedance of the grid-filament circuit of tube B is less than the impedance of R1, it will very seriously reduce the voltage across X Y. The amplification will then be diminished.

412. **Grid Condenser and Leak:** The value of the grid condenser C1 depends upon the frequency of the current variations to be amplified by the system although this condenser does not require a close adjustment. The reactance of the condenser, of course, depends upon its capacity and the frequency of the variations which it carries. If its reactance is too high, as compared with the reactance of the grid to filament circuit, the drop in potential across the condenser will reduce the voltage impressed on the grid.

413. On the other hand, if the capacity of the grid condenser

is increased to reduce its reactance, the capacity may be so large that the amplifier will be "paralyzed." The condenser will take too long to discharge. If a sudden pulse of e.m.f. is impressed on the condenser the grid may become so negative that the plate current is reduced to zero. If the condenser cannot quickly discharge, the amplifier will be "dead." Of course, this could be remedied by reducing the value of the grid leak R2, but if R2 becomes too low it reduces the impedance of the grid to filament circuit; this will tend to reduce the voltage across X Y and diminish the amplification.

414. The values of the grid condenser and grid leak, therefore, are chosen to obtain the maximum possible efficiency according to the frequency of the variations to be amplified. Roughly, the grid condenser should be about .0005 mfd. for frequencies above 100,000 cycles per second (wave-length 3,000 meters), and about .003 mfd. for audio frequencies. The grid leak should be from one to five million ohms. The best value is found by experiment.

415. **Resistance Amplifier for Audio Frequencies:** This type of amplifier for audio frequency amplification is practically obsolete. One of its disadvantages is that the resistances absorb a large part of the voltage of the plate battery. The plate battery voltage must be made from two to four times the normal value. In any case the amplification per stage is much less than with the transformer-coupled amplifier.

416. **Resistance Amplifier for Radio Frequencies:** Fig. 77 shows the connections of a one-stage resistance amplifier and detector. This amplifier is intended, of course, to magnify radio frequency signal oscillations.

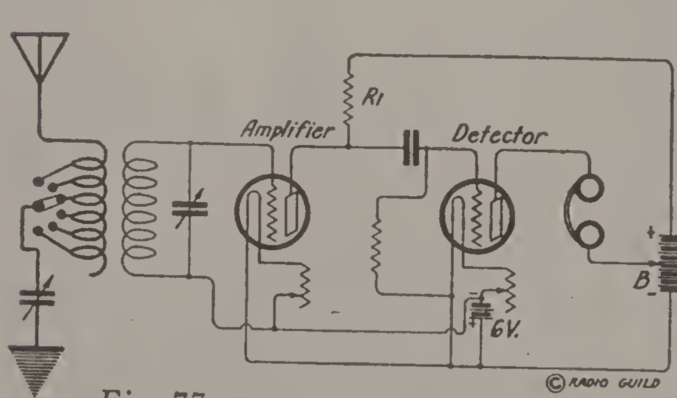


Fig. 77

The sole advantage of the resistance-coupled r.f. amplifier is that it magnifies signals over a very wide range of frequencies. It will amplify signals from 1,000 meters up to, say 15,000 meters. This feature makes it rather useful for commercial work and on shipboard for the reception of long-wave signals over a wide range of frequencies.

417. However, the resistance amplifier is useless for the amplification of short-wave signals and the reasons for this should be understood, as the same difficulties are invariably encountered in designing a radio frequency amplifier for short waves.

418. The voltage amplification obtainable with a short-wave radio frequency amplifier of any type is never as great as that which can be obtained with a long-wave amplifier or an audio frequency amplifier. This does not mean that the amplification of short waves is impractical. It merely means that the apparatus employed must be very carefully designed and the amplifier constructed to ensure the maximum possible amplification.

419. The great obstacle to the amplification of short waves is the low reactance of even small capacities in the circuits to these high frequency currents. For instance, when a resistance amplifier is used for **audio** frequency amplification, the reactance of the grid to filament capacity of a tube is from one to two million ohms so that the impedance of the grid filament circuit is entirely determined by the actual resistance of grid to filament (together with the resistance of the grid leak). This resistance may be about 200,000 ohms. But if the amplifier is used for high frequencies the reactance of the grid to filament capacity may be as low as five or six thousand ohms. The impedance of the grid-filament circuit is then almost entirely determined by this reactance which is considerably less than the actual resistance of the tube. The same conditions apply in the plate-filament circuit. The reactance is high for low frequency currents but is quite low for high frequency currents. Additionally any long wires connecting the apparatus together, the tube bases and sockets and other apparatus in the circuits, may possess capacity which will reduce the impedance of the plate-filament and grid-filament circuits.

420. Referring back to Fig. 74 it will be evident that if the resistance R1, which may have a value of 50,000 to 100,000 ohms, is shunted by a grid-filament impedance of 6,000 ohms, the impedance of the external plate circuit is so greatly reduced that there is very little voltage amplification. If a resistance amplifier with four or five tubes is used to magnify the high frequency oscillations of a 200-meter wave it is conceivable that the voltage finally impressed on the last tube **may be even less than the voltage impressed on the first tube.** The amplifier is then useless.

421. The resistance amplifier can be used for wave-lengths down to about 600 meters if special tubes are employed with a very low internal capacity—particularly between grid and filament. The Meyers tube has the least capacity of any tube at present obtainable and would be especially suitable for use in a resistance amplifier. In constructing an amplifier of this type it is very necessary to use the shortest possible leads between the apparatus in the circuit, particularly the grid and plate leads, to eliminate capacity effects.

INDUCTANCE-COUPLED AMPLIFIERS.

422. An inductance-coupled amplifier is similar to the resistance-coupled amplifier except that an inductance is used in the plate circuit of each amplifying tube instead of a resistance. Instead of relying on the resistance of the external plate circuit to produce potential variations across it when the grid voltage is varied, the same effect is obtained by the reactance of an inductance with a comparatively low D.C. resistance.

423. Fig. 78 illustrates the principles of an inductance-coupled amplifier. It will be seen that this corresponds exactly with the diagram of Fig. 74 except that an inductance is used instead of a resistance in the external plate circuit. Again the

object of tube A is to produce a varying voltage across the points X and Y, this voltage to be similar in form to that impressed on the grid and as much larger as possible.

424. The manner in which this is accomplished should be fairly evident. When the grid potential of tube A is varied, the plate current varies. But the self-induction of L causes a reacting voltage to be set up across the coil, acting in opposition to the changes of current passing through it. Therefore variations of the grid potential of the tube A produce a varying voltage across the points X and Y of the external plate circuit. The manner in which these variations are repeated from tube to tube correspond exactly with the repeating action of the resistance amplifier. An advantage of the inductance amplifier, however, is that the coil offers very little resistance to the flow of direct current in the plate circuit so that the plate battery can be of normal value.

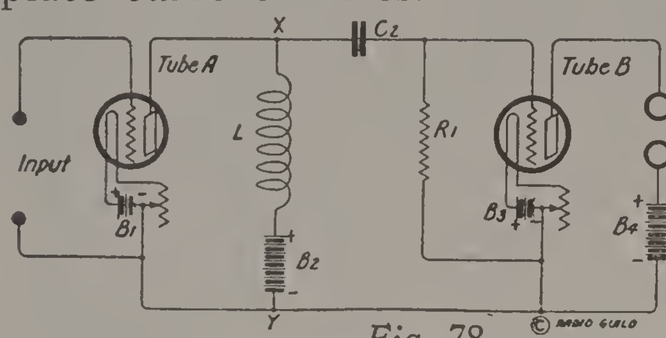


Fig. 78

425. The voltage amplification of an inductance-coupled amplifier depends upon the reactance of the inductance. The greatest amplification is obtained when the reactance is infinitely high. But the gain in amplification after the reactance exceeds a certain value is very small. Therefore the repeating inductance is designed to have a certain high reactance depending upon the tubes employed. The actual inductance of the coil (that is to say, the number of turns, etc.) which gives this reactance, depends upon the frequency for which the amplifier is designed. For instance, suppose it is found that a reactance of 30,000 ohms gives good amplification with the tubes to be used in the amplifier, and the coils are wound to possess an inductance which will offer this reactance to an audio frequency of say 1,000 cycles per second. The coils would have such a comparatively high distributed capacity that the capacity reactance to a high frequency current would be very low. High frequency currents would be carried by the capacity of the coil and hardly any reacting voltage would be set up.

The coils of the inductance-coupled amplifier, therefore, must be designed according to the frequency to be amplified.

426. **Inductance-Coupled Amplifier for Audio Frequencies:** The inductances for this type of amplifier are wound on an iron core and constructed to possess a low value of distributed capacity. The amplifier operates over a comparatively wide range of low frequencies and gives fairly even amplification over this band. Unless the frequency is above the upper limit of the range for which the amplifier is designed, the impedance of the inductances is not affected to any extent by their distributed capacity. The inductance-coupled amplifier for audio frequencies, however, is obsolete as much greater amplification can be obtained with the transformer-coupled system.

427. **Inductance-Coupled Amplifier for Radio Frequencies:** The effects of distributed capacity prohibit the construction of a

high frequency amplifier which will operate over a broad band of frequencies. Suppose that a reactance of 30,000 ohms is the most suitable value for the coils in the amplifier. If, without considering the effect of distributed capacity, an ordinary solenoidal coil is wound to give an inductance reactance of 30,000 ohms to a frequency of, say 1,000,000 cycles (300 meters), the actual reactance for this frequency, due to the capacity of the coil, is much less than 30,000 ohms. Small capacities, which hardly affect the impedance of the coils in the audio frequency amplifier, have a serious effect upon the impedance of the coils in the radio frequency amplifier.

428. The effect of the distributed capacity of a coil in the radio frequency amplifier is to make the coil, with its capacity, a tuned circuit with a resonant frequency within the range of frequencies covered by the amplifier. A signal at this resonant frequency is amplified well—since the oscillations set up across the tuned circuit formed by the coil and its distributed capacity are a maximum at this frequency. But the amplification of other signals of different frequency is poor.

429. This undesirable feature of the inductance-coupled high frequency amplifier can be overcome by actually tuning the external plate circuit of each tube in the amplifier. If the amplifier is intended for the amplification of very short waves—say 200 to 500 meters—the plate circuits can be tuned to resonance with the signal frequency by means of variometers; or the circuits can be tuned by connecting a variable condenser across each plate inductance. In this way the maximum possible amplification can be obtained for any wave-length within the range covered by the tuning of the circuits.

430. This "tuned impedance" system of r.f. amplification is quite efficient but not so efficient as the transformer-repeating systems we shall presently describe. However, before passing on the third class of amplifier, we wish to call attention to the circuit of Fig. 79, representing a tuned impedance high frequency amplifier which will be found of practical service to many. While we do not believe it to be as efficient as the transformer-coupled system, we show this circuit because many amateurs will be able to adopt it with only a slight rearrangement of their present apparatus and a few inexpensive additions.

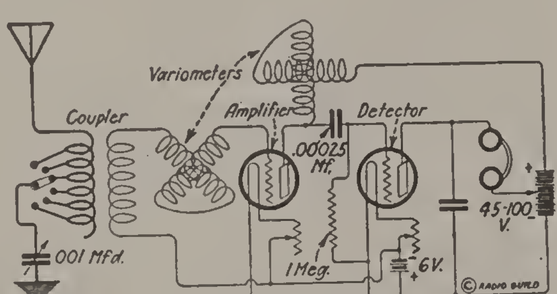


Fig. 79

431. The circuit shows a simple method of adding one stage of radio frequency amplification to a standard regenerative receiver with tuned plate circuit. The addition requires only one tube, a few accessories and simple changes in the wiring of the receiver. This can easily be verified by comparing the circuit of Fig. 79 with the simple regenerative circuit of Fig. 70. The number of controls is not altered but the sensitiveness of the system is greatly increased. The addition does not change the operation of the receiver in any way. The grid circuit is tuned with the grid variometer and the plate circuit with the plate

variometer. When the plate circuit is tuned to resonance, continuous oscillations are generated and C.W. signals detected. With the plate circuit tuned just below the point of self-oscillation, high amplification is obtained of spark and radiophone signals. Chapter 8 gives particulars of the type of vario-coupler which should be used with this circuit.

TRANSFORMER-COUPLED AMPLIFIERS.

432. Transformer-coupled amplifiers have almost entirely superseded the resistance-coupled and inductance-coupled types, They have many advantages over the other systems.

433. **Audio Frequency Amplifiers**: The great advantage of this type of amplifier is the step-up of voltage which can be effected by means of the transformers. The varying voltage impressed on the grid of each tube of the amplifier may be four or five times as great as the voltage across the external plate circuit of the preceding tube.

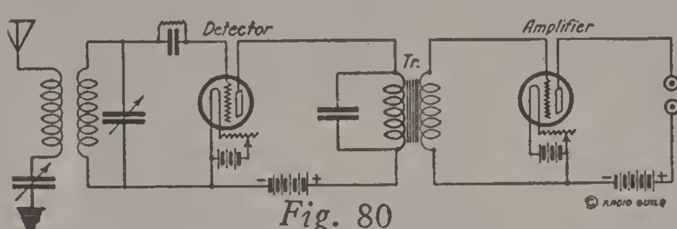


Fig. 80

434. Fig. 80 shows the principles of a receiver with one stage of transformer-coupled audio frequency amplification. The primary of the transformer Tr. is connected in the plate circuit of the detecting tube. The secondary of the transformer is connected across the grid and filament of the amplifying tube. The transformer is wound with a step-up ratio of turns, and is designed so that any audio frequency changes of current in the primary induce a high voltage in the secondary. Thus, when a signal oscillation is impressed on the grid circuit of the detector tube, the radio frequency variations of the plate current are carried by the by-pass condenser while the audio frequency changes in the average plate current produce variations in the intensity and direction of the magnetic field round the primary of the transformer. An alternating e.m.f. of similar form is induced in the transformer secondary and applied between the grid and filament of the amplifying tube. As the telephones are included in the plate circuit of the second tube, the received signals are reproduced with much greater volume of sound.

435. For the sake of clarity Fig. 80 shows independent filament and plate batteries for each tube. However, this is unnecessary in practice. The same batteries can be used for the two tubes and Fig. 81 shows the connections. In operation, the circuit of Fig. 81 is exactly the same as that of Fig. 80.

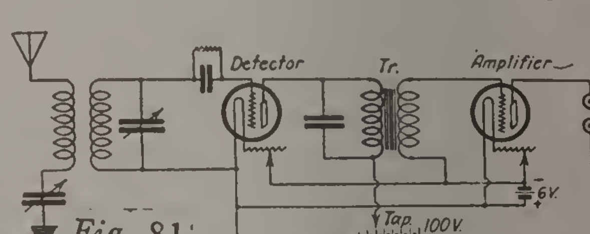


Fig. 81

436. If still louder reproduction of signals is desired, a two or three-stage audio frequency amplifier can be used to magnify the output of the detector tube. With more than three stages unpleasantly loud signals are produced and unless there is some special need for terrific volume of sound, three stages are sufficient. Fig. 82 shows the wiring diagram of a two-stage

amplifier. The "input" terminals are connected in the plate circuit of the detector tube.

437. In these diagrams it should be noted that the grid of each amplifying tube is connected through the secondary of the transformer to a point of negative potential on the filament. The reason for this is that the impedance of the grid-filament circuit must be held at a high value. It is necesary to maintain the grid at such a negative potential with respect to the filament that even a strong signal will not raise the grid potential above zero. If the grid becomes positive with respect to the filament, the grid-filament circuit is conductive—a grid current can flow. This reduces the voltage across the secondary of the transformer. Power is consumed in the production of a grid current. In fact, if the normal potential of the grid is positive in relation to the filament there may be practically no amplification. The voltage across the secondary of the transformer may be less than the voltage impressed across the primary.

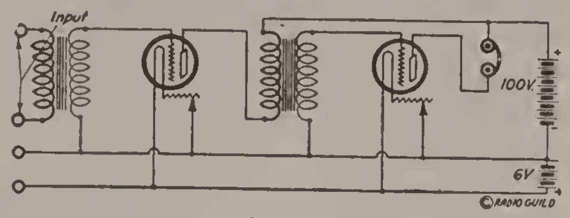


Fig. 82

438. To avoid grid current losses the grid must be connected through the secondary of the transformer to a point on the filament circuit which is about 1 or 1½ volts negative with respect to the negative end of the filament. The method of accomplishing this is shown in the diagrams. This was also illustrated in Fig. 63 and described in Paragraph 322.

439. **The Audio Frequency Transformer:** The efficiency of an a.f. amplifier chiefly depends upon the transformers employed. If the plate and filament batteries have the correct values for the tubes used and the apparatus is connected together properly, good amplification should easily be obtained unless the transformers are poorly designed or constructed. The object of the transformer, of course, is to make the audio frequency current variations in the plate circuit of one tube induce the highest possible e.m.f. in the secondary which is connected across the grid and filament of the succeeding tube.

440. We can only touch briefly upon the many factors which enter into the design of the audio frequency transformer. The coupling between the primary and secondary should be as close as possible so that the e.m.f. induced in the secondary by a given current change in the primary may be as high as possible.

441. It is, in practice, impossible to obtain 100 per cent coupling between two circuits, no matter how the transformer is designed. The mutual induction can never be as great as the square root of the product of the self-induction of each circuit. Some of the magnetic field of one circuit does not interlink with the other circuit through the transformer. There is some magnetic leakage.

442. To obtain as close coupling as possible and also because of the necessary high inductance of both primary and secondary windings the transformer is wound on a closed iron core, the secondary being wound over the primary, as illustrated in Fig. 83.

443. The close coupling this affords can be explained as follows: Owing to the greater permeability of iron, any magnetic field set up by an **increase** of current in the primary coil builds up from the primary windings and takes the position indicated **in the iron core.** Very little of the magnetic flux remains round the primary coil itself. However, before taking up its position in the iron core, the magnetic field must expand through the air space between the primary coil and the iron and in so doing it cuts through the secondary windings which are laid over the primary. Similarly if the current in the primary **decreases**, the magnetic flux contracts and leaving the iron core, it cuts through the secondary windings as it collapses upon the primary. Thus very nearly all the magnetic flux set up by the primary interlinks with the secondary and the coupling is very close. The iron must be of finest quality and carefully laminated to reduce iron losses to a minimum.

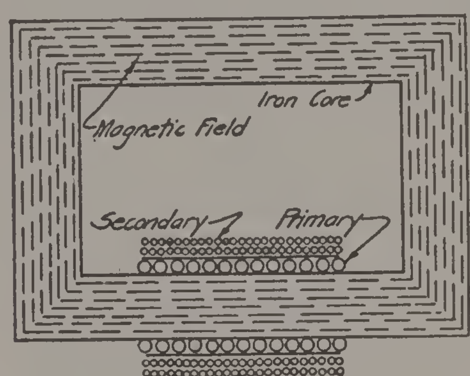


Fig. 83

444. To further increase the value of the e.m.f. induced in the secondary, the secondary is wound with more turns than the primary. The voltage is stepped up in the ratio of the number of turns in the primary to the number of turns in the secondary.

445. The impedance of the primary has to be chosen in accordance with the frequency of the currents to be amplified and the type of tubes employed. To increase the ratio of transformation, the impedance of the secondary should be high; but, on the other hand, if the secondary is wound with too many turns the resulting increase of distributed capacity may reduce the impedance and the voltage amplification. It has been found that the transformer with a ratio of 4 or 5 generally gives a **greater** step-up of voltage than one with a higher ratio.

446. The efficiency of a transformer, however, is not alone judged by the voltage amplification it affords. It must be designed to amplify uniformly over a fairly wide range of frequencies. This is especially important if the transformer is to be used in the audio frequency amplifier of a radiophone receiver. Speech and music cover all the frequencies from about 100 to 4,000 cycles. If the transformer does not amplify uniformly over this range some frequencies will be magnified more than others. This is evidently undesirable and prohibits true reproduction of voice or music. This fault is present in some transformers.

447. One hears a great deal about "shielding the stages of an audio frequency amplifier to prevent interaction between the circuits and consequent howling." For this reason, some transformers are carefully enclosed in an impenetrable housing of steel. The author has seen some German transformers which one would imagine were designed to withstand gunfire. In practice we have never appreciated the necessity for all these precautions unless more than three stages are used or unless there is

something radically wrong with the design of the transformer. If the transformer is properly designed, shielding is not needed in a two or three-stage amplifier. If the amplifier howls, it is usually caused by improper connection of the transformer terminals or by the capacity effect of unnecessarily long connecting wires.

448. Fig. 84 is a photograph of a simple, well designed and constructed transformer with a 1 to 4 ratio, which we are now using with great success. Tests show that the amplification with this unshielded low-ratio transformer is greater than with most

Fig. 84

of the shell-proof high-ratio types. The amplification is even over the required range of frequencies, thus eliminating distortion of tones.

449. This transformer is constructed in such a way that the leads to the terminals of the tube sockets can be made extremely short, which is a distinct advantage; long leads, with consequent capacity effects, are a frequent source of howling. Fig. 85 is a bottom view of the transformer suspended underneath a tube


Fig. 85

socket and clearly shows the very short connecting leads. In one of the receivers we shall describe later three of these transformers are used in a three-stage audio frequency amplifier and the spacing from center to center of each transformer is only about three inches. No shielding whatsoever is used and yet howling or distortion are never experienced.

450. **Transformer-coupled Radio Frequency Amplifier:** The radio frequency amplifier using transformers to repeat the signals from tube to tube is similar to the audio frequency amplifier of the same type except that the transformers are designed ac-

cording to the frequency of the currents to be amplified. However, while the audio frequency amplifier operates over a wide range of frequencies without being affected to any great extent by the distributed capacity of the transformer coils the high frequency amplifier may be restricted to a very limited range of frequencies by the effect of distributed capacity.

451. A step-up ratio transformer is out of the question for the capacity of the secondary coil would reduce the voltage across the grid circuit and diminish the amplification to almost zero. But even if the transformer is wound with a 1 to 1 ratio, the effect of the distributed capacity, as we already learned in connection with the inductance-coupled amplifier, would be to give each coil a resonant frequency within the range of frequencies to be covered by the amplifier. This would render the amplifier useless for practical purposes. To be of any use at all, it must magnify signals over a definite even though limited range of frequencies.

452. **Tuned Radio Frequency Amplifier**: One way of overcoming this difficulty is illustrated in Fig. 86 which shows a

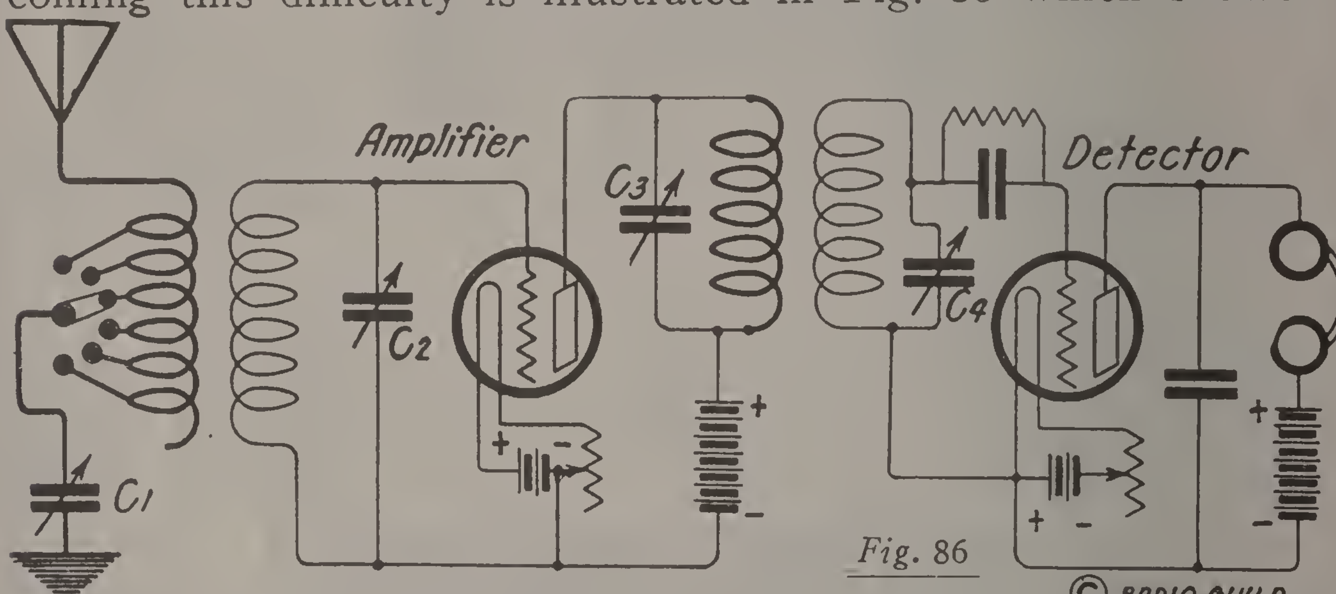


Fig. 86

one-stage "tuned" radio frequency amplifier and detector. Each circuit is provided with a variable tuning element so that the amplifier can be adjusted to magnify any frequency within a limited range by tuning each circuit to resonance with the incoming signal. The variable condenser C3 is used to tune the external plate circuit of the amplifying tube and the condenser C4 to tune the input circuit of the detector tube.

453. It is at once evident that while this arrangement is very efficient and might be used with only one stage of radio frequency amplification, the tuning adjustments would be too numerous with more than one stage. For instance, if a three-stage radio frequency amplifier of this type were constructed, there would be no less than seven or eight controls to be varied, each one tuning sharply and requiring careful adjustment. This would render the picking up of signals so difficult that the radio frequency amplifier would be impractical to operate.

454. **Modified Tuned R.F. Amplifier**: The tuned amplifier, however, can be used in a modified form. With seven or eight controls tuning is impossible but if the controls can be reduced to not more than three variable elements without losing too much of the amplification, the system becomes practical.

455. Fig. 87 shows the wiring diagram of a complete receiver with two stages of tuned radio frequency amplification and detector in which only three variable condensers are required for tuning. The antenna circuit and the external plate circuits of both amplifying tubes are untuned. The secondary circuits are tuned to resonance with the incoming signal by the three variable condensers, C1, C2 and C3.

456. In this system, since the primary circuits are not tuned, they are made aperiodic. That is to say, the coils L1, L3 and L5 are wound so that the resonant frequency of each of the primary circuits is greater than the highest frequency to be amplified. For instance, if the tuning of the secondary circuits covers

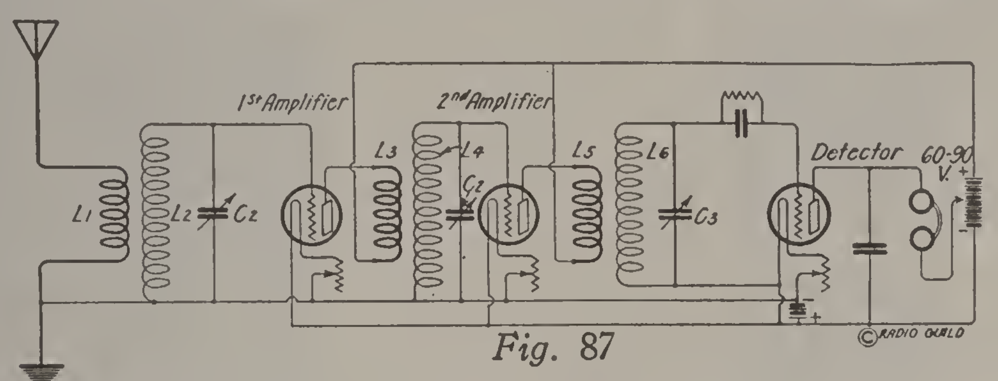


Fig. 87

the wave-length range of 200 to 600 meters, the natural wave-length (resonant frequency) of each of the primary circuits is made less than 200 meters.

457. The object of this is to permit tight coupling between primary and secondary circuits and at the same time preserve selectivity, eliminating the necessity of a variable coupling control. The coupling is made close to induce the highest possible e.m.f. in the secondary. But if the primary circuit has a resonant frequency within the range covered by the secondary tuning element, the selectivity is destroyed and the amplification diminished (see Chapter IV). The primary circuits are therefore made aperiodic. Additional amplification is obtained by the tight coupling because the reaction of the secondary upon the primary, when the secondary is tuned to resonance with an incoming signal, increases the resistance of the primary to this frequency and thereby magnifies the potential variations across the external plate circuit. In other words, the tuning of the secondary partially tunes the primary.

458. The amplification obtainable by this system, of course, is not so great as when the primary circuits are also tuned to resonance but the design of a tuned radio frequency amplifying receiver is invariably somewhat of a compromise. The amplification can only be increased by complicating the operation of the system to such an extent that it becomes useless for practical work. The designer must take all the factors into consideration and find some combination which produces the greatest amount of amplification without unduly complicating the operation. For instance, in Fig. 87 an antenna tuning condenser and a variable coupling between the antenna and L2 C2 circuit are sacrificed because selective reception is assured by the tuning of the input circuits of the two succeeding tubes. In this way two controls are eliminated without any serious loss of efficiency.

459. In short, the system of Fig. 87 is quite efficient. The amplification is good; the selectivity excellent; the operation simple. Provided the apparatus used in the circuit is well designed and constructed, a receiver based on this system of amplification will give very satisfactory results.

In Part 2 practical information will be given concerning the construction of receivers employing this system of radio frequency amplification.

460. **The Lowell R.F. Transformer-coupled Amplifier:** Late improvements in the design of radio frequency transformers have now greatly simplified the design and operation of radio frequency amplifiers. A two or three-stage high frequency amplifier operating with the stability of an audio frequency amplifier is now made possible by the use of a transformer designed and patented by P. D. Lowell, of the United States Bureau of Standards, Radio Division. Under the trade name of "DX" his transformer is already well known to the radio amateur.

461. The Lowell transformer obviates the necessity of tuning the intermediate stages of a radio frequency amplifier. The capacity of the transformer is reduced to such a very low minimum by the patented design that the effect of this capacity upon the impedance of the primary and secondary coils is almost negligible. The wave-length range covered by the transformer is determined by the inductance of the primary and secondary coils, the mutual inductance between them, and the capacity of the tubes in the amplifier.

462. The Lowell or DX transformer undoubtedly provides the solution to the problem of amplifying the high frequencies of short waves in a simple, efficient manner. The simplicity and stability of the audio frequency amplifier are duplicated in the high frequency amplifier with DX transformers. Many imitations of the transformer have appeared on the market but none has equalled the original as devised by Mr. Lowell.

463. The reason for the high efficiency of the DX transformer, of course, lies in the almost total absence of capacity in the device. In his patent application, on which patent No. 1,439,563 was issued Dec. 19, 1922, Mr. Lowell outlines the defects in earlier types of radio frequency transformers which were designed to eliminate the necessity of tuning the intermediate circuits of a high frequency amplifier. These earlier transformers were of two principal types; one of the shell type in which the primary and secondary windings were wound one beneath the other on the central core of a shell frame; and the other in which thin, flat coils were employed and the primary and secondary arranged with their flat sides parallel. Both these types were inefficient, Mr. Lowell explained, because of the high distributed capacity between turns, the capacity between primary and secondary and, in the first type, the capacity to the core of the transformer. All these capacity effects restrict the wave length range of the transformer and diminish the amplification.

464. The construction of the DX transformer, designed by Mr. Lowell, and the manner in which this form of construction reduces to an absolute minimum all the capacity effects out-

lined above, can best be comprehended by referring to the series of photographs of Figs. 88 and 95, which show the transformer in its different stages of construction. The particular type of DX transformer in these photographs covers the wave-length range of 250 to 585 meters.

465. **Coil Form** (Fig. 88): Formica tubing is used for the form on which the transformer is wound in order to ensure the best insulation and uniformity in construction. Slots are cut round the tubes to hold the coils. The slots are accurately made by carefully adjusted machines, so that there is no variation in thickness of spacing greater than one thousandth of an inch.

Fig. 88

Fig. 8

466. **Completely Wound Form** (Fig. 89): The primary and secondary coils are wound with very fine copper wire in the slots cut in the coil form. The primary is wound in the six slots at one end of the form and the secondary in the six slots at the opposite end. The winding in each slot is completed before beginning the winding in the next adjacent slot. Each slot is wound with the same number of turns. Thus the primary and secondary coils each consist of a number of distinct and spaced windings connected in series with each other, each groove containing only a few turns of wire. In this way the inherent capacity of the coils is made extremely low. Not only is the capacity between turns in each groove very small, but the total capacity across the entire coil is even smaller as **the capacities of all six separate windings are joined together in series.**

The primary and secondary coils are separated from each other by a spacing of about ¾". The spacing depends upon the wave-length range for which the transformer is designed as the spacing governs the mutual inductance between primary and secondary. In the short-wave transformer shown, the wide separation between primary and secondary renders the capacity between them practically zero.

Connecting wires are carefully soldered to the coil terminals and in soldering no paste or corrosive flux is used. This eliminates the possibility of corrosion at the soldered terminals.

467. **Steel Core** (Fig. 90): The spacing between the primary and secondary coils of the transformer would be altogether too great and the coupling too loose if the transformer were of the air core type. But the core of the transformer is filled with strips of best sheet silicon steel. To keep the electrical losses negligible this steel is extremely thin and is carefully prepared before inserting in the transformer, thus eliminating all possibility of adjacent sheets becoming short circuited and reducing the efficiency. Exactly the same quantity of steel is used in the core of each transformer.

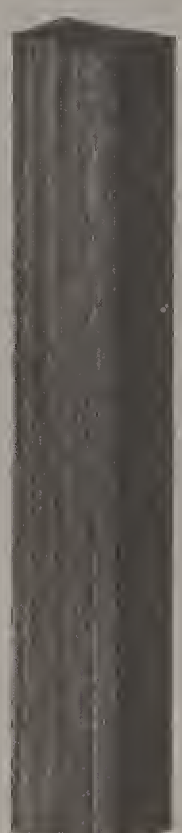


Fig. 90

Fig. 91

Fig. 92

468. **Assembled Transformer; Ready to Mount in Case** (Fig. 91): The insertion of the steel core in the coil form makes the coupling between primary and secondary coils comparatively close without actually diminishing the distance between the two so that the capacity between the coils is still very low. The capacity to the steel core is small as the coil form is quite thick and the windings are not close enough to the core to increase the capacity to any extent. Moreover, the insertion of the core greatly increases the inductance of both primary and secondary coils. Therefore the number of turns of wire on the transformer required to cover a given wave-length is much smaller than when an air core is used. The use of the steel core, therefore, still further reduces the distributed capacity of the windings by decreasing the necessary number of turns to obtain a given inductance. It is true that there are some losses inherent in a steel core high frequency transformer but these losses are much more than compensated by the elimination of capacity made possible by the use of the steel core.

469. **Transformer Case** (Fig. 92): The outer case of the transformer is made of black formica. Good insulation and strength are just as essential here as in the winding form. Con-

necting pins are rigidly fastened in the case, as shown in the photograph.

470. **Complete Transformer** (Fig. 93): The completely wound transformer is inserted in the case, the connecting wires from the coils soldered to the four pins and the case is completely filled with a special highly insulating wax so that the transformer cannot be affected by moisture. The overall dimensions of the transformer are: Height, 4″; Width, 1⅛″· Depth, 1½″.

Fig. 93

Fig. 94

471. **Plug-in Mounting** (Fig. 94): It is, of course, impossible to make a single radio frequency amplifying transformer that will operate at all the wave-lengths used in radio communication. As we have seen, radio transformers are limited by their principle of operation to a comparatively narrow band of wave-lengths. Mr. Daniel of the Radio Instrument Co. realized the limitations of a radio frequency amplifier in this respect and patented a plug-in mounting for the transformer. The four pins mounted on the back of the transformer casing plug into and make connection with four sockets on the transformer mounting. This feature makes it possible to remove transformers of one range and insert others having a different range if it is desired to hear signals on widely different wave-lengths. In this way a single amplifier can be used for reception at any wave-length merely by inserting the correct type of transformer. Only three types are required to cover the range from 200 to 3,000 meters.

472. **Voltage Amplification of DX Transformer-coupled Amplifier**: The heavy line curve of Fig. 95 shows the voltage amplification over a wide wave-length range actually obtained with a two-stage DX transformer-coupled amplifier using U.V. 201 A tubes. The two dotted-line curves show the results obtained with two other standard makes of radio frequency transformers under the same conditions.

A comparison of these three curves establishes the superiority of the DX transformer. Not only is the voltage amplification much greater at all wave-lengths within the range tested, but the range of the DX transformer is much wider than either of the other two.

The type of DX transformer with which the curve of Fig. 95 was obtained is especially designed for use with U.V. 201 A tubes for the reception of radio broadcasting on wave-lengths from 250 to 585 meters. This one type of transformer therefore covers efficiently all the wave-lengths now used in radio broadcasting.

The construction of amplifiers and complete receivers employing DX transformers is fully explained in Part 2.

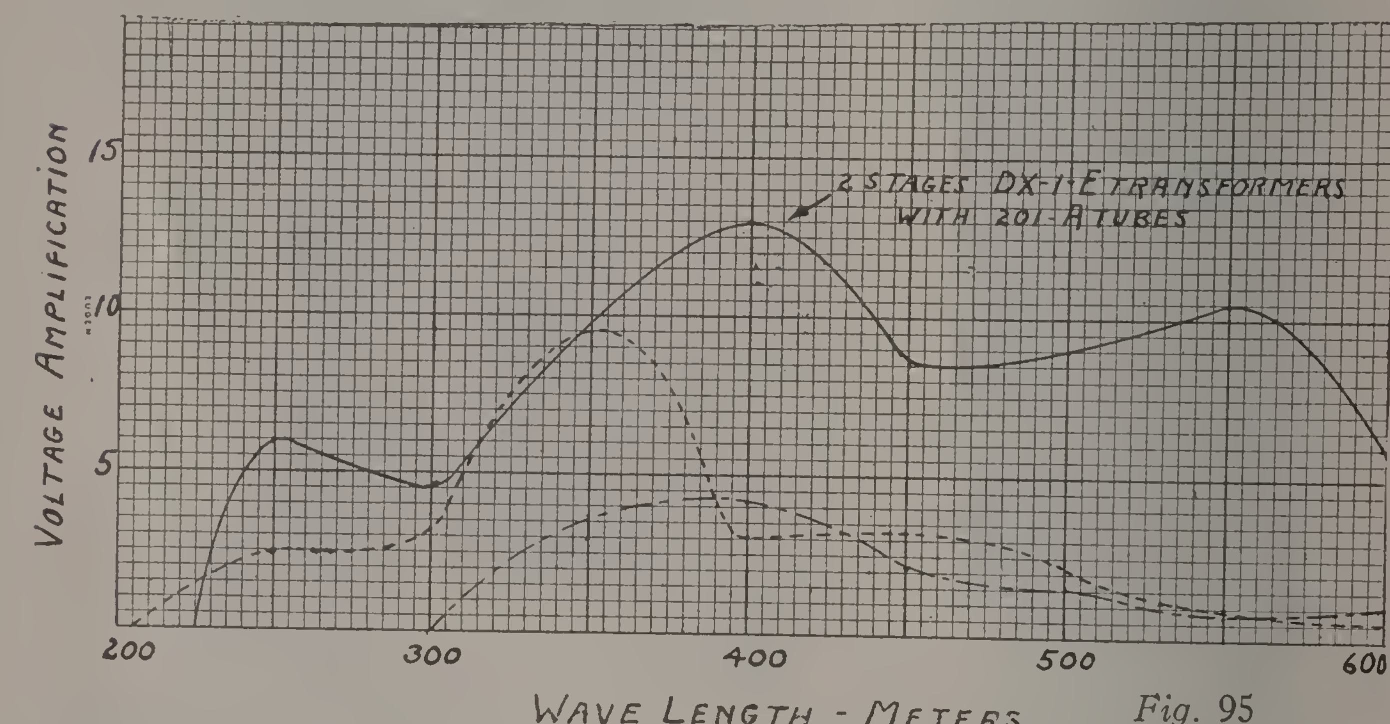


Fig. 95

CONTROLLING SELF-OSCILLATION IN A RADIO FREQUENCY AMPLIFIER.

473. In multi-stage high frequency amplifiers of all types, whether they be resistance, inductance or transformer-coupled, there is often a tendency toward self-oscillation. For the reception of damped waves and radio-telephony it is necessary, of course, to control these continuous oscillations—to prevent them from being generated.

474. To understand the methods of accomplishing this it is first essential that we comprehend how the continuous oscillations are generated. We have already explained how regeneration and self-generated oscillations are produced by the reaction of the plate circuit of a tube upon its grid circuit through inductive or capacitive coupling. However, in a multi-stage amplifier, while regeneration or self-oscillation may be produced by the feed-back of energy from the plate circuit of any tube in the amplifier back to the grid circuit of the same tube, similar results may be produced by the feeding back of energy from the plate or grid circuit of one tube to the plate or grid circuit of a **preceding** tube.

475. It does not follow, however, that if any two circuits of an r.f. amplifier are coupled together, regeneration will be

produced. The coupling may have the directly opposite effect. In other words, energy may be fed back from one circuit to another in either a positive or negative sense. This can best be understood by considering the simple case of a regenerative receiver using a tickler coil to produce regeneration or cause continuous oscillations to be generated as in Fig. 67. The energy is here fed back by inductive coupling between the plate and grid circuits. The tickler coil and the coil in the grid circuit form a transformer.

To produce regeneration and strengthen a signal oscillation, the e.m.f. induced in the grid circuit by the varying current in the tickler coil must act in the same direction as the signal oscillation. In other words, the oscillating e.m.f. induced in the grid circuit by the tickler coil must be **in phase** with the signal oscillation. If the current does not pass through the tickler coil in the proper direction—that is to say, if the connections to the coil are reversed—the oscillating e.m.f. induced in the grid circuit will be directly **out of phase** with the signal oscillation. Instead of strengthening the signal it will tend to damp it out. Instead of decreasing the resistance of the grid circuit it will increase the resistance.

476. Now, in a multi-stage radio frequency amplifier energy may be fed back from one circuit to another through various forms of coupling. Some of these couplings are inherent and cannot be avoided. For instance, there is the capacity coupling between the plate and grid of each tube, or between some of the wiring; the inductive coupling due to magnetic linkages between transformers or coils in the amplifier; resistance coupling due to the internal resistance of the plate batteries; and possibly direct magnetic coupling caused by long wires connecting to the plate batteries. These sources of coupling are either unavoidable or can only be partially avoided.

477. The energy which is fed back from one circuit to another in the amplifier through these various couplings may be either in a positive or negative sense. However, the positive feed-back is usually great enough to generate continuous oscillations in the circuits.

478. There are two methods employed to prevent the self-generation of continuous oscillations in a radio frequency amplifier so that damped waves and radio telephone signals may be received without distortion.

479. **Controlling Self-Oscillations by Negative Feed-back:** The first method, devised by the French Army during the war, is based on the principle of coupling two circuits of an amplifier together to produce a negative feed-back of energy which tends to neutralize the positive feed-back inherent in the amplifier. The two circuits are generally capacitively coupled through a small condenser.

480. Fig. 96 shows one application of this principle in a resistance-coupled amplifier. In this application, both positive and negative feed-back are controlled. Resistance-coupled amplifiers usually have less tendency towards self-oscillation than inductance or transformer-coupled amplifiers and, hence, in this

case, to produce continuous oscillations for the reception of undamped waves, a positive feed-back control is also incorporated. As the diagram shows, the grid of the first tube is connected to the movable plate of a special three-plate condenser. The two stationary plates of the "compensating" condenser are connected respectively to the plates of the second and third amplifying tubes.

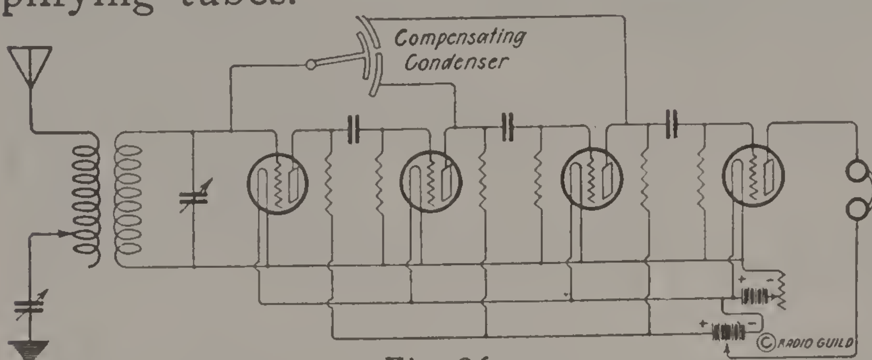


Fig. 96

481. Now, in each successive stage of a resistance-coupled amplifier the voltage is reversed in phase. That is to say, when the grid of the first tube is made positive by a signal impulse, the plate potential of the same tube drops. Consequently the grid of the second tube becomes negative and the plate positive; the potential of the third tube is then the same as the first; the fourth is the same as the second, and so on.

482. In the system of Fig. 96, therefore, one fixed plate of the compensating condenser is wired to feed back positively to the grid of the first tube and the other fixed plate is wired to feed back negatively. The respective values of these two opposing feed-backs can be altered by turning the movable plate of the condenser. There is one position of the movable plate at which the negative feed-back neutralizes the positive feed-back. At any other position one feed-back is stronger than the other. In this way regeneration can be controlled and continuous oscillations produced if desired. On the other hand, the negative feed-back can be increased to prevent self-oscillation.

483. The same principle can be used in this or other ways to neutralize the positive feed-back of inherent coupling in any type of radio frequency amplifier. Neutralizing feed-back can be produced by coupling one plate to another or one grid circuit to another.

484. For instance, in the transformer-coupled r.f. amplifying circuit of Fig. 97 (a) the plate of the second tube is coupled to the plate of the first tube by the small variable condenser C1. With the radio frequency transformer Tr connected in the manner shown, the positive feed-back from the plate of the second tube will produce regeneration or self-oscillation if C1 is varied. But if the leads to the secondary of the transformer Tr are reversed as shown in Fig. 97(b) the feed-back from the second tube is negative and will neutralize any inherent positive feed-back if C1 is properly adjusted.

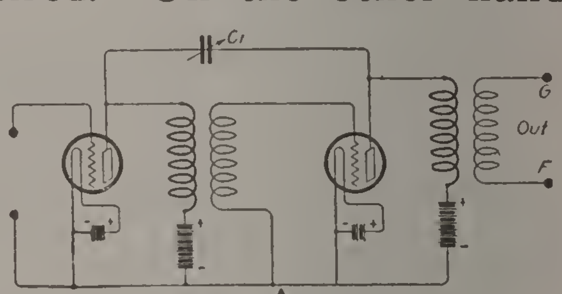


Fig. 97*A*

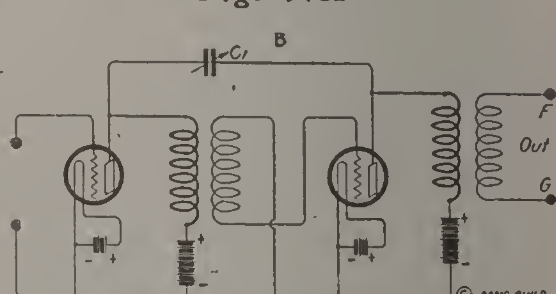


Fig. 97*B*

Fig. 98 shows a negative feed-back from the grid of one tube back to the grid of the preceding tube, based on the same principle as Fig. 97(b). Some other feed-back arrangements of this kind can be found in British patent No. 127,014, issued November 7th, 1916.

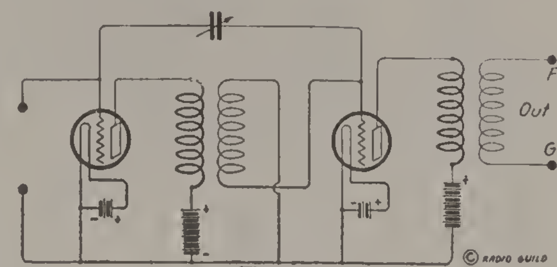


Fig. 98

485. **The Neutrodyne System:** In the opinion of the author, the functioning of the so-called "Neutrodyne" system in preventing the generation of continuous oscillations in the circuits of a radio frequency amplifier, is explained by the above paragraphs, particularly Paragraphs 483 and 484.

486. **Potentiometer Method of Controlling Self-oscillation:** The second method of controlling self-oscillation in a high frequency amplifier was developed by the British during the war and is shown in Fig. 99. Instead of connecting the grids of the amplifying tubes through the secondaries of the radio frequency transformers to a point of negative potential on the filament circuit, they are connected to the sliding contact of a potentiometer in parallel with the filament battery. By moving the potentiometer contact the normal potential of the grids with respect to the negative end of the filament can be varied from a negative value to a positive value. The principle of this arrangement was explained in Paragraph 325. The filament rheostats of the radio frequency amplifying tubes are connected between the filament and the **negative** end of the filament battery so that by moving the potentiometer contact the grids may be made either negative or positive with respect to the negative end of the tube filaments.

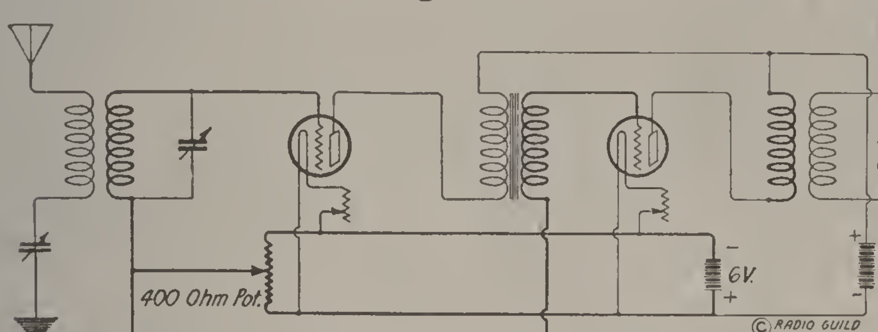


Fig. 99

487. If continuous oscillations are generated when the potentiometer contact is at the negative end of the resistance the oscillations can be damped out by moving the contact towards the positive end. As the grids become more positive with respect to the filament the impedance of the grid-filament circuits is lowered. If the impedance is lowered sufficiently the grid-filament circuit becomes conductive. In either case the amplification is diminished. More energy is consumed in the grid circuit; in other words, its resistance is increased. By properly balancing the resistance of the grid circuit against the feed-back self-oscillation can easily be controlled.

488. There is some difference of opinion as to the respective merits of the two methods of controlling regeneration and self-oscillation in a radio frequency amplifier. In either case,

the self-oscillation is controlled by increasing the resistance of the circuits; in other words, by diminishing the amplification.

489. The ideal radio frequency amplifier, of course, would be one in which all coupling between circuits (other than the coupling which repeats the signal oscillation from tube to tube) is entirely eliminated. Then there would be no feed-back in either a positive or negative sense. If this were possible any number of stages of amplification could be used and the signal oscillation enormously magnified. Regeneration could be added to still further magnify the signal.

490. In a multi-stage amplifier this, at present, is impossible of accomplishment but the designer of a radio frequency amplifier should bend every effort to reach as close to this ideal as possible. All sources of coupling in the amplifier should be reduced to a minimum. All inductances should be mutually at right angles to each other and separated. The apparatus should be arranged so that it may be connected together with very short wires—particularly the plate and grid leads. In this way the efficiency of the amplifier can be greatly improved as there is less tendency towards self-oscillation and the amplification need not be reduced to the same extent to stop self-oscillation.

491. The amplifiers and complete receivers which are described in detail in Part 2 of this book are properly designed in this way to obtain maximum possible efficiency and high amplification.

492. These sets are divided into two classes: DX transformer-coupled, and tuned radio frequency amplifying receivers. In the former class potentiometers are used to control self-oscillation. With more than one stage of DX transformer-coupled amplification this is found to be the most practical way to stabilize the operation of the amplifiers.

493. The tuned radio frequency amplifiers use the system of coupling described in Paragraphs 454-459 of this chapter, and the receivers are designed in such a way that no potentiometer or compensator is required. Continuous oscillations are not set up in the circuits; mainly because the most important source of feed-back coupling—the feed-back through the internal capacity of the tubes—is comparatively small as compared with the DX transformer-coupled amplifier. The oscillations set up across the **resonant** plate circuits of the DX transformer-coupled amplifier have a much higher amplitude than the oscillations set up across the **aperiodic** plate circuits of the tuned r.f. amplifiers. Therefore, with the latter type of amplifier the feed-back through the tube is much smaller.

All other sources of feed-back coupling are eliminated by careful design and high amplification is secured without self-generated oscillations being set up.

THE "REFLEX" SYSTEM.

494. The so-called "Reflex" circuit can be usefully employed under certain conditions. This system was used by the French

about seven or eight years ago, but has only recently been brought into prominence in this country.

495. The principle of the system is shown in the diagram of Fig. 100. The signal oscillation is applied between the grid and filament of the amplifying tube A. The radio frequency current variations in the plate circuit of this tube set up oscillations across the primary of the radio frequency transformer R.F.T. An oscillating e.m.f. is induced in the secondary of this transformer and the amplified oscillations applied between the grid and filament of the rectifying tube B. The audio frequency variations in the plate circuit of the rectifying tube induce an alternating e.m.f. across the secondary of the audio frequency transformer A.F.T. These amplified alternations are then applied between the grid and filament of the amplifying tube A and the audio frequency variations of the plate current of this tube are detected by the telephones. Tube A, then, amplifies radio and audio frequency variations simultaneously.

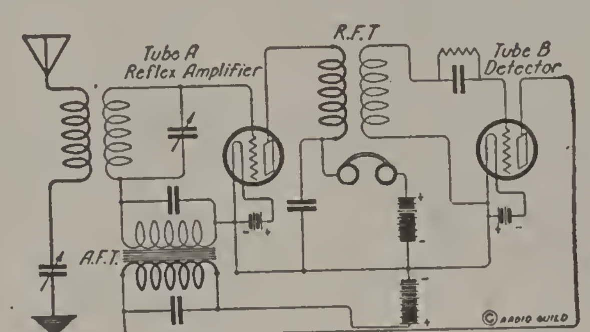


Fig. 100

496. Provided the circuit is properly arranged there is no distortion of tone. Under certain conditions the amplification of both frequencies is quite good enough to warrant the use of the system. With only one amplifying tube the circuit is very satisfactory. The amplification at both frequencies is very good. With more than one amplifying tube, each being used "twice," considerable care has to be taken to avoid losses and distortion.

497. The great advantage of the "reflex" system is the low cost of the receiver in which it is used. However, if a receiver of the very maximum sensitiveness is desired, at a somewhat greater cost, it is undoubtedly better to use separate tubes for radio and audio frequency amplification.

498. The "reflex" system cannot be used to advantage in an r.f. transformer-coupled amplifier in which a potentiometer is necessary to control self-oscillation. The audio frequency amplification is very poor when the grids of the amplifying tubes are not negative at all times with respect to the filament.

499. "Reflex" is used in the tuned radio frequency amplifying receivers described in Part 2 and this feature greatly increases their efficiency. No potentiometer is used in these receivers and the grids of the amplifying tubes are negative at all times. The radio and audio frequency amplification are both excellent. In fact, we will later describe a one-tube receiver which very successfully operates a loud speaker!

LESSON 8.

AUDIBILITY AND SELECTIVITY OF RECEIVING SYSTEMS.

500. In comparing the qualities of radio receiving systems or in determining the efficiency of a particular receiver, there are two qualities upon which judgment is mainly based, viz: "audibility" and "selectivity." We have used these expressions already but in order that there may be no misunderstanding we shall define them as follows:

501. **Definition of Audibility**: This has been defined as the ratio of the audio frequency current variations actually flowing through the telephones of a receiver to the current which must flow to make the signals just audible. For instance, if a certain signal picked up by a receiver sounds loud in the telephones, the current in the 'phones may be 100 times greater than the current which is necessary to render the signal just audible; in other words, the "audibility" is 100.

502. The audibility of a receiver is proportional to the **square** of the amplitude of the e.m.f. signal oscillations impressed on the rectifying system. This will be understood by considering the rectifying system as explained in Paragraphs 302-309.

503. When a signal oscillation is impressed on this rectifying system, increases of current are produced by positive impulses and decreases of current by negative impulses. If the increases are greater than the decreases, rectification takes place; the average current through the telephones or output circuit of the rectifying system is greater than before. But the extent of the current increase depends upon how much greater are the increases than the decreases. In other words, the effective value of the rectified current depends upon the **difference** between the increases of current produced by positive impulses of the signal oscillation and the decreases of current produced by negative impulses. If the amplitude of the signal oscillation itself is increased, this **difference** increases but they do not increase in the same proportion. For instance, if the amplitude of the signal oscillation is increased five times the effective value of the rectified current is increased about twenty-five times.

504. If a signal is so weak that there is **no** difference between the increases of current produced by positive impulses

and the decreases of current produced by negative impulses, the signal is not rectified and is inaudible. The audibility increases, however, as the square of the amplitude of the signal e.m.f. increases, until the saturation point is reached. Above a certain amplitude of signal e.m.f. the rectified current is not increased by an increase of impressed e.m.f.

505. Without either radio or audio frequency amplification, then, the audibility of a simple detecting system is greater for strong signals than weak signals. Distant stations and weak transmitters may be entirely inaudible.

506. The addition of audio frequency amplification increases the audibility of signals which are strong enough to operate the rectifier but has no effect upon the signals which are too weak to be rectified.

507. The addition of radio frequency amplification, on the other hand, increases the audibility of weak signals more than strong signals. If a signal is already so strong that it can produce the maximum possible output from the detecting system, radio frequency amplification does not increase the audibility at all. But if the signal is very weak, the radio frequency amplifier magnifies the signal oscillations and greatly increases the audibility. For instance, a two-stage DX transformer-coupled amplifier magnifies the voltage of a 400-meter signal about 13 times. This will increase the audibility of a weak 400-meter signal about 169 times (13^2).

508. **Definition of Selectivity**: This can be defined as the ratio of the frequency to which a receiver is tuned to the difference between this frequency and the frequency of another signal of the same strength which is just audible. For instance, if a receiver is tuned to resonance with a signal of 1,000,000 cycles (300 meters) and another signal of the same intensity on 750,000 cycles (400 meters) is just audible, the selectivity is given by the ratio:

$$\frac{1{,}000{,}000}{1{,}000{,}000 - 750{,}000} = 4.$$

The higher this ratio the better is the selectivity.

509. In the above case the selectivity is poor because, while the receiver is tuned to 1,000,000 cycles (300 meters), all signals of the same intensity from 750,000 cycles (400 meters) to 1,250,000 cycles (240 meters) are audible. The audibility of the 300-meter signal, of course, is greatest, since the receiver is tuned to the frequency of this signal. But another signal of greater intensity than the signal to which the receiver is tuned may be as loud or louder than the desired signal even though the frequency of the interfering signal is greater or less than the

510. In order that this may be quite clear, let us take another example: Suppose a receiver is tuned to 1,000,000 cycles (300 meters) and another signal of the same intensity on 900,000 desired signal.

cycles (333 meters) is just audible, the selectivity ratio can be written:

$$\frac{1{,}000{,}000}{1{,}000{,}000 - 900{,}000} = 10.$$

This receiver has a little better selectivity than the first (the ratio is higher). All signals of the same intensity from 900,000 cycles (333 meters) to 1,100,000 cycles (272 meters) are audible, but the 300-meter signal, of course, is loudest since the receiver is tuned to resonance with this frequency. Again, however, a stronger signal above or below the resonant frequency may be as loud or louder than the desired signal.

511. **Audibility vs. Selectivity:** While there are several practical factors which must be taken into consideration when comparing radio receiving systems—such as ease of operation, cost, etc.—it is apparent that the comparison must be largely based on the audibility and selectivity possessed by the respective systems. If a receiver has good audibility but poor selectivity, it is of little use. There is no advantage in being able to hear hundreds of stations within a range of two thousand miles or so if one hears them all at the same time. On the other hand, if a receiver has extremely high selectivity but very poor audibility it may be equally useless.

512. Sometimes these two qualities are inversely proportional to each other. If the audibility of a receiver is increased the selectivity may be decreased in the same proportion and vice versa. If this condition exists the designer or the operator of the receiver, as the case may be, should seek to obtain the highest possible selectivity compatible with reasonable audibility.

513. If the audibility of a receiver is increased by adding regeneration or radio frequency amplification the selectivity must be proportionately increased. When the audibility is increased the range of the system is widened. If the selectivity is not increased the added audibility is more of a drawback than an advantage. It merely means that more stations are heard than before; in other words, that interference is increased.

514. Suppose, for instance, that an amateur adds a radio frequency amplifier to his receiving system and the type of amplifier is such that the **audibility alone** is increased. With his old set he was using a moulded vario-coupler or some such arrangement to vary the coupling between his antenna and secondary circuits. This coupler probably afforded sufficient control of audibility and selectivity with his old set because the audibility was comparatively low. He was only able to hear stations within a radius of, say, 250 miles. Retaining the same tuning arrangement, the addition of the radio frequency amplifier widens his range of reception to include all stations within, say, 1,500 miles. Hundreds of stations he has never even heard on his old set now come in almost as strongly as the local stations. But, as the selectivity of his receiver has not been increased in any way, **he hears them all at the same time**—he cannot tune one from another. The solution is obvious. The **selectivity of the tuner which precedes the amplifier must be increased.**

RECEIVING SYSTEMS COMPARED.

515. **Single Circuit Non-Regenerative Receiver:** We saw, in Lesson 4 that the resonance curve of an oscillatory circuit demonstrates the selectivity of the circuit as well as the value of the current which flows in the circuit when an oscillating e.m.f. is induced in it. The sharper this curve the greater is the selectivity and the higher is the maximum current value at the resonant frequency. We also learned that a resonance curve is flattened out by the effect of resistance in an oscillatory circuit. The simple non-regenerative system has only one oscillatory circuit, namely the antenna circuit. The resonance curve of this circuit determines the selectivity and the audibility of the system. Owing to the comparatively high resistance of the antenna, this system has poor selectivity and poor audibility.

516. **Inductively-Coupled Non-Regenerative Receiver:** In this system, as shown in Fig. 66, there are two oscillatory circuits for tuning purposes—the antenna circuit and the secondary closed circuit. The selectivity and audibility of the system can be adjusted by varying the coupling between the two oscillatory circuits, each circuit being tuned to resonance. For a given resistance of circuits there is one low value of coupling at which the audibility is maximum (see Paragraph 276). If the coupling is made closer than this value the audibility and selectivity are both decreased; with weaker coupling the selectivity increases as the audibility decreases.

517. **Inductively-Coupled Regenerative Receiver:** In this type of receiver, as depicted in Fig. 70, there are three oscillatory circuits; the antenna, the secondary, and the tuned plate circuit. The regenerative action reduces the effective resistance of the secondary circuit. This, of course, makes the audibility and selectivity much higher than with the non-regenerative receiver of the same time.

518. The audibility and selectivity can be controlled by varying the coupling between the antenna and secondary circuits. The non-regenerative receiver may require a coupling of six or seven per cent to secure maximum audibility but the degree of coupling which gives maximum audibility with a well-designed regenerative receiver may be as low as three per cent and should never be more than five per cent. This automatically makes the inductively-coupled regenerative receiver very selective. Signals within two or three meters of the desired signal are inaudible. The coupling between the antenna and the secondary circuit is so low that interfering signals which may set up forced oscillations in the antenna circuit are not transferred to the secondary. Even if they are strong enough to be transferred, the tuning of the low resistance secondary circuit is so extremely sharp that the interfering signal is damped out.

519. And yet this very loose coupling (from three to five per cent, as the case may be) gives maximum audibility to signals of the desired frequency. If the coupling is made closer, the signal strength and selectivity are **both decreased.** Obviously, there is no advantage in making the maximum coupling

of a radio-coupler greater than five per cent if it is intended for a regenerative receiver. The only useful variation is between zero and five per cent; the coupling which gives maximum audibility can be found within these limits.

520. **Semi-tuned Transformer-coupled R.F. Amplifying Receiver:** If radio frequency amplification is used in a receiver, the signal oscillations are impressed on the amplifier and repeated from tube to tube by means of tuned or semi-tuned oscillatory circuits (except in the case of the resistance-coupled amplifier). The resonance curves of these circuits manifestly affect the audibility and selectivity of the system, while the amplifying action of the tubes greatly increases the audibility.

521. The semi-tuned transformer-coupled type of amplifier, in which DX or similar transformers are used, is inherently non-selective; in fact, it is designed to be non-selective. The whole object of the transformers is to eliminate the necessity of closely tuning each intermediate circuit of the amplifier and the transformers are purposely made to cover as broad a range of frequencies as possible. In Fig. 95 we showed the voltage amplification of a two-stage DX transformer-coupled amplifier against the wave-length range. An amplifier with these transformers magnifies all signals from 250 to 585 meters; some waves are amplified more than others, but they are all covered. Other transformers of similar design have the same effect, although they do not accomplish it so efficiently.

522. This type of amplifier, then, enormously increases the audibility of a receiver but in no way increases the selectivity. However, we are not implying that these amplifiers are inefficient. On the contrary, considerable advantage can be taken of the enormous increase in audibility they afford if the selec-

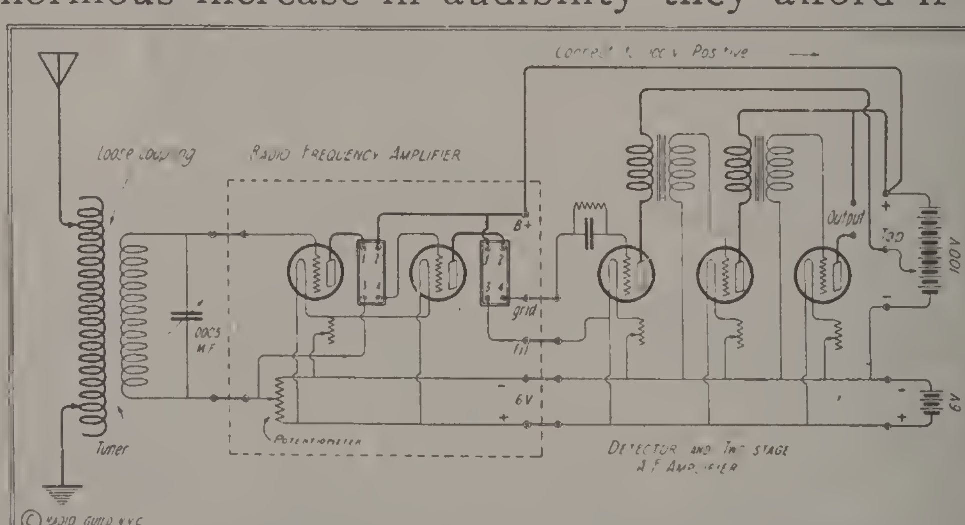


Fig. 101

tivity of the tuner which precedes the amplifier is increased. By properly designing this tuner, the selectivity and audibility can be controlled with unusual efficiency in a very simple manner.

523. Fig. 101 shows a typical receiving circuit with a tuner, a two-stage DX transformer-coupled r.f. amplifier, a detector and two-stage a.f. amplifier. This arrangement is very popular today. It is also very efficient, if the tuner is made super-selective. But if the tuner is non-selective, the tuning is so broad that the system is almost useless.

524. What type of tuner, then, should be used with a semi-tuned transformer-coupled amplifier? To be of practical use, it must be simple to operate. There would be no point in carefully eliminating the tuning of a radio frequency amplifier to reduce the controls and then using five or six controls in an elaborately selective tuner. In fact, the active controls should number not more than three.

525. The first arrangement that suggests itself is the inductively-coupled tuner with a tuned antenna circuit, tuned secondary circuit and a variable coupling between the circuits—three controls. But is this system selective enough? If an interfering signal is not damped out by the tuner, it will pass into the radio frequency amplifier and be magnified together with the desired signal. There are no sharply tuned circuits in the amplifier to diminish the interfering signal. The tuner must be ultra-selective and just pass signals of the desired frequency into the amplifier to be magnified.

526. Judging from the results obtained with vario-couplers of standard make, this is more than can be expected from the simple tuning arrangement suggested above. **But the fault lies in the design of the vario-couplers and not in the principles of the system.**

527. We have already discussed these principles. In common with the simple regenerative receiver, when an inductively-coupled tuner is followed by a radio frequency amplifier, the value of coupling between antenna and secondary circuits which gives maximum audibility is very low—three to five per cent. With both types of receivers, if the coupling is increased above the low value which gives maximum audibility, the selectivity and audibility are **both decreased**. In either case, **nothing** is gained by increasing the coupling beyond this value. But if the couplng is decreased **below** the point of maximum audibility the audibility decreases **as the selectivity increases.** If reference is made to the curve of Fig. 51, it will be seen that this decrease in audibility with proportionate increase in selectivity is very sharp between about five per cent and zero.

528. Now, the amplification of a regenerative receiver is definitely limited and the signal strength is unnecessarily diminished if the coupling is reduced below the degree which gives maximum audibility. The selectivity at this degree of coupling is quite good enough for the audibility which the regenerative receiver provides. The vario-coupler for the regenerative receiver should merely be designed to make easy the location of the degree of coupling between three and five per cent, which gives maximum audibility.

529. But whereas the amplification by regeneration reaches a definite limit, the magnification produced by the radio frequency amplifier is greatly in excess of this limit. By sacrificing a little audibility the coupling can be reduced even below three per cent to gain **extreme selectivity.** Three per cent coupling is very selective and this may be the coupling which gives maximum audibility, but below this the selectivity is incredibly high. There is no disadvantage in sacrificing some of the audibility to

increase the selectivity. The audibility is so enormously increased by the radio frequency amplifier that it is better to concentrate all the amplification on a single wave-length rather than increase the audibility and spread the amplification over a broad band of wave-lengths.

530. We can say, then, that to adjust the audibility and selectivity of either a regenerative receiver or a semi-tuned transformer-coupled radio frequency amplifying receiver with maximum efficiency, the vario-coupler must provide a variation of coupling between zero and five per cent. Moreover, it must be possible to **closely** adjust the coupling between these limits as a slight variation of coupling between zero and five per cent has a large effect upon the audibility and selectivity. The same type of coupler serves for either system of reception as the requirements for both are almost identical.

531. And now, do the ordinary vario-couplers of standard make fulfil the requirements of this type of tuning? We have tested a score or more of couplers of different makes and can unhesitatingly say that these requirements are **not** filled. With the average coupler it is **impossible** to reduce the coupling to zero, or even close to zero; moreover, the maximum coupling is usually away beyond five per cent. One reason for this is quite apparent. The couplers are usually designed so that the rotor revolves inside the primary winding with only a minute spacing between the two. When the rotor is parallel with the primary coil, the coupling, both capacitive and inductive, is maximum, and this maximum is far above five per cent—too high for regenerative or radio frequency amplifying receivers. When the rotor shaft is revolved only 90 degrees so that the rotor is at right angles to the primary coil, the inductive coupling is almost zero, **but the capacitive coupling between the coils is quite high.**

This is the most useless type of coupler. So much care and attention are devoted to polishing up the beautiful moulded forms to make the finished product look more like something good to eat than an electrical instrument that insufficient attention is paid to the electrical characteristics.

532. Other couplers are a little better designed and are suitable for non-regenerative receivers which require a closer coupling than five per cent. The rotor is not jammed up close to the primary but is fairly widely spaced from it. However, the maximum and minimum degrees of coupling are still too high for use with regenerative or r.f. amplifying receivers. Only a small portion of the rotor revolutions can be usefully employed. Why be limited to only a five or ten-degree revolution of the rotor shaft with the rest of the revolution useless and the minimum coupling too high?

533. Using even the best types of standard vario-couplers, one is limited to a minute revolution of the coupling dial to adjust one of the most important tuning controls. The slightest movement of the coupling dial may change the coefficient of coupling near the minimum point sufficiently to cut down the audibility 100 per cent. This naturally makes tuning so difficult

that it is impossible to gain selectivity or control audibility. To take advantage of the control of selectivity and audibility offered by the vario-coupler system, it must be possible to **closely** adjust the coupling from **zero** to **not more than five per cent.**

534. **The Harkness Coupler:** Realizing the need for a coupler which fills these requirements the writer designed one for the purpose. A photograph of it appears in Fig. 102. The maximum coupling afforded by this coupler is not more than five per cent, while the minimum is zero. Moreover, **it requires a 180-degree revolution (complete half-turn) of the rotor shaft to cover this range of coupling.**

Fig. 102

535. The construction of this coupler is plainly shown in the photograph. The primary is wound on the lower end of a long cylindrical form while the secondary is wound on a smaller coil which revolves inside the primary form but at the opposite end from the primary winding. The rotor shaft is set at an angle to permit a 180-degree variation of coupling.

536. When the rotor is parallel with the primary coil the coupling is maximum but, from center to center, the spacing between the two coils is almost four inches. This maximum coupling is only about five per cent. When the rotor shaft is revolved through an angle of 180 degrees the secondary coil itself turns from the parallel position until it is at right angles to the primary coil. Here the inductive coupling is zero and, owing to the wide spacing between the coils, **the capacitive coupling is also zero.**

537. With this coupler, the adjustment of audibility and selectivity is a simple matter. Instead of being restricted to a minute variation of the coupling dial **the whole 180-degree revolution can be utilized.** When the coupler is used with a regenerative receiver the **exact** coupling which gives maximum audibility with high selectivity can easily be located. When it is used with a one, two or three-stage radio frequency amplifying receiver the exact degree of coupling necessary to eliminate an interfering signal can similarly be found with ease. In actual practice the device has proved most successful.

538. The tuned plate regenerative receiver (as in Fig. 70), and the radio frequency amplifying receiver with broad resonance curve transformers are both widely used today. The efficiency of these receivers can be increased 100 per cent by the use of this specially designed coupler. There is no change in the wiring. The coupler is "hooked up" in the same way as any other vario-coupler in accordance with the wiring diagrams of standard regenerative and radio frequency amplifying receivers.

539. This special coupler is used in the DX transformer-coupled r.f. amplifying receivers described in Part 2. The use of this coupler in these sets contributes in large measure to their unusual efficiency and simplicity of operation.

540. **Tuned Transformer-coupled R.F. Amplifying Receivers:** Receivers using this method of radio frequency amplification are inherently **selective** and it is because of this selectivity that it is possible to dispense entirely with a variable coupling between the antenna circuit and secondary circuit. The radio frequency amplifier itself ensures selectivity. Each stage of the amplifier tunes quite sharply. In the two-stage amplifier of Fig. 87 there are three tuned circuits each sharply tuned to the incoming signal frequency. When these three circuits are adjusted for maximum audibility—when each is tuned accurately to resonance—the selectivity is very good.

541. For instance, if the amplifier is tuned to receive a 400-meter wave and another signal on 410 meters is impressed on the receiving antenna the 400-meter signal is **enormously magnified,** whereas the 410-meter signal is **greatly diminished** by the reactance of each of the tuned circuits. Each stage of the amplifier **increases** the amplitude of the 400-meter signal and **reduces** the amplitude of the 410-meter signal. When the two signals are finally impressed on the rectifying system the amplitude of the 400-meter signal is very much greater than the amplitude of the 410-meter signal; in fact, the latter may be completely damped out.

542. With the tuned transformer type of amplifier, then, **the selectivity increases as the audibility increases.** The more accurately the circuits are tuned to resonance, the sharper the resonance curve of each circuit; the more stages of amplification used—the greater become **both** the audibility and selectivity. Moreover, the selectivity is **automatically** increased by an increase of audibility; it is not necessary to sacrifice audibility to gain selectivity.

LOOP ANTENNA RECEPTION.

543. **Principles of Loop Reception:** The closed coil antenna, or "loop," was first used as a radio compass to determine the direction of a transmitting station and it is still principally used for this purpose today. All along the coasts radio compass stations with loop antennae greatly assist navigation by giving bearings to ships at sea. However, a loop can also be used with a radio frequency amplifier to receive radiophone broadcasts and amateur transmitters **if it is inconvenient to erect an outdoor aerial.**

544. The easiest way to understand the principles of loop reception is to consider the loop as the secondary inductance of an inductively-coupled receiving system of which the transmitting station antenna is the primary circuit. A loop is merely a large inductance coil—nothing else. Shunted by a variable condenser it forms a closed oscillatory circuit. This closed circuit is connected across the grid and filament of the first radio frequency amplifying tube in exactly the same manner as the secondary circuit of an inductively-coupled receiver; it is similarly tuned to resonance with a desired signal by means of the variable condenser. No primary antenna circuit is used at the receiving station. The transmitting antenna may be considered the primary circuit. The inductive coupling between the receiving loop circuit and the transmitting antenna circuit can be varied from zero to maximum by revolving the loop just as the rotor of a vario-coupler can be revolved to vary the coupling between the primary and secondary circuits of a loose-coupled receiver. It is this latter feature of the loop antenna which makes it extremely directional.

545. To receive any particular transmitting station the loop must be pointed in the direction of the station. If the loop is turned through an angle of 90 degrees so that it is at right angles to the direction of the transmitting station, the inductive coupling between the two stations is zero and no signals are heard.

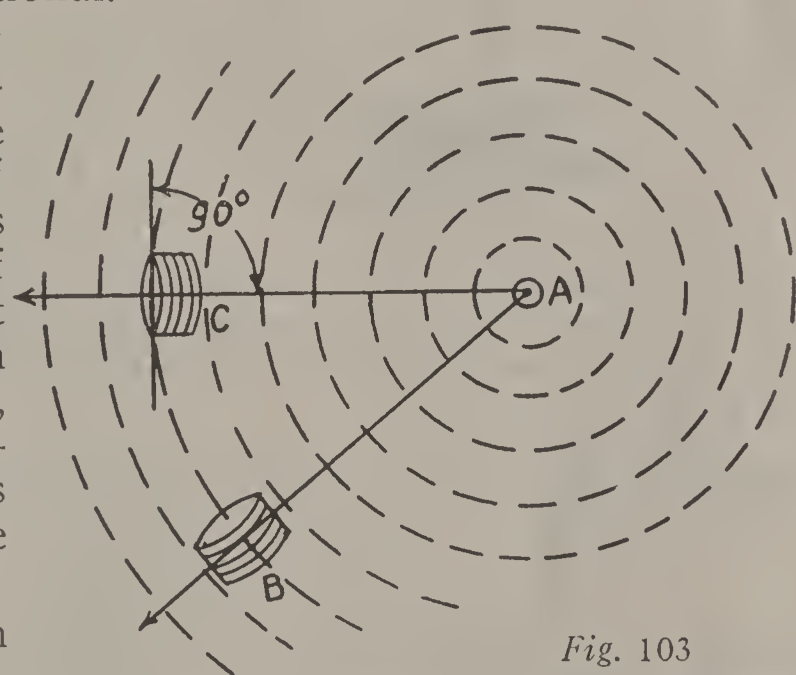


Fig. 103

546. For instance, in Fig. 103 the point A represents the transmitting antenna and the broken lines are the magnetic fields of the waves radiated by the transmitting station. The loop B is pointing in the direction of the transmitter A. The inductive coupling between A and B is maximum; therefore, the audibility of the receiver using B as antenna is maximum.

The loop C is turned at right angles to the direction of wave travel from A. The inductive coupling between A and C is zero; therefore, the audibility of the receiver using C as antenna is zero. Signals from A are inaudible.

547. Of course, the loop C may be pointing in the direction of a second transmitting station and the audibility of the signals from this second station may be maximum. In this case the signals from A do not interfere with reception. The directional characteristics of a loop may be utilized in this way to gain selectivity.

548. Figs. 104 A and 104 B show a collapsible loop antenna, designed by one of the Radio Guild engineers, which is eminently suitable for the reception of wave-lengths from 200 to 600

meters. This loop is a large inductance coil wound on a frame four feet square. An interesting feature of the design of this loop is the fact that the bakelite cross-pieces can be turned to change the loop from a solenoid to a spiral if desired. The loop can be turned in any direction.

Fig. 104*A*

549. **Efficiency of Loop Reception:** The loop has been used by many amateurs to gain selectivity. These amateurs had added radio frequency amplification to their receivers and were disappointed by the broad tuning which their sets developed. The loop antenna was suggested by radio magazines and others as a solution to this difficulty and was adopted by many. Immediately their receivers became selective again and the conclusion was reached that an outside aerial cannot be efficiently used with a radio frequency amplifier.

This conclusion, of course, was erroneous; although, until the coupler described in Paragraph 534 appeared on the market, it must be admitted there was no simple and efficient method of gaining selectivity.

550. The loop antenna undoubtedly makes possible very selective reception. It accomplishes this in two ways:

1. By its directional characteristics;
2. By enormously **decreasing** the audibility of the receiving system with which it is used.

551. The second is by far the more important factor. For instance, if an amateur adds a broad tuning radio frequency amplifier to his receiver the audibility is enormously **increased** without any increase in selectivity. With an outside aerial he hears stations within a range of 2,000 miles or so, but the selectivity of the receiver is so poor that interference renders it practically useless. To gain selectivity he uses a loop antenna. Immediately the audibility is enormously **decreased** and selective reception is made possible. But the receiving range of a two-stage radio frequency amplifier and detector with a loop antenna is little or no greater than a regenerative detector alone with an

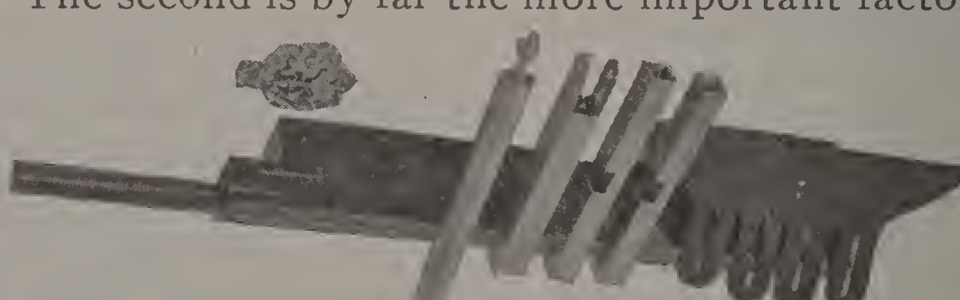


Fig. 104*B*

outside aerial. **He has gained nothing by adding the radio frequency amplifier to his receiver.**

552. However, if this amateur substitutes a Harkness Coupler for the coupler in his tuner **selective reception with an outside aerial is made possible** and **the advantages of the aerial and the radio frequency amplifier retained.** The coupler permits accurate control of audibility and selectivity. If, to eliminate an interfering signal, it is necessary to decrease the audibility of the system, the audibility can be **very gradually** decreased by revolving the coupler dial. The slightest decrease of audibility, with its proportionate increase of selectivity, may be sufficient to eliminate the interfering signal.

553. Of course, there are many occasions on which a loop **must** be used. But if the object of the radio frequency amplifier is to increase the range of a receiving system, the outside aerial must be retained and the Harkness Coupler used to gain selectivity. If a loop is used instead of an aerial the range is **not** increased (unless, of course, three or more stages of r.f. amplification are employed).

554. A loop antenna, then, should only be used when it is inconvenient to erect an outside antenna. To operate efficiently, of course, a radio frequency amplifier **must** be used with a loop or the receiving range is **very** limited.

555. Incidentally, the range of a receiving system with loop

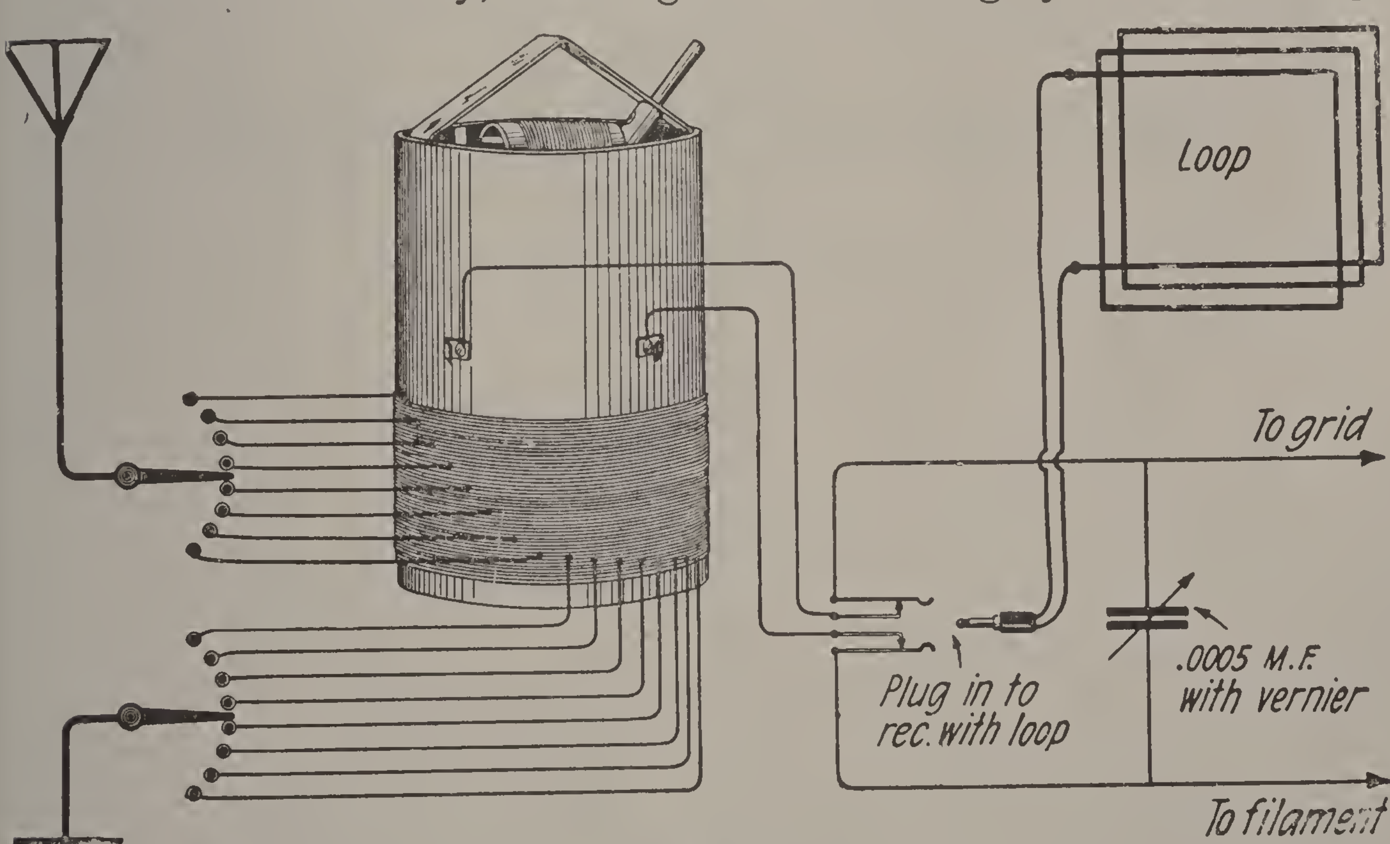


Fig. 105

antenna and radio frequency amplifier is a fairly good indication of the efficiency of the receiver. If, with a small loop antenna, one can pick up signals from stations say, one thousand miles distant, the receiver is very sensitive. If an outside aerial, with the Harkness Coupler as tuner, is used in place of the loop antenna, the range will be more than doubled.

556. **Combining Loop and Aerial Reception**: Fig. 105 shows a convenient way of combining loop reception and outside aerial

reception in one complete receiver. A telephone jack is connected in the receiver as shown in the diagram; the terminals of the loop are connected to a telephone plug. When the plug is inserted in the jack the loop takes the place of the rotor of the Harkness Coupler. The secondary tuning condenser is used in the usual manner to tune the loop circuit. When the plug is removed from the jack the rotor of the Harkness Coupler is again connected across the secondary condenser. In this way either the loop or the outside aerial can be used for reception. Fig. 106 shows the antenna circuit tuned by varying only the inductance of the coupler primary, but better results are obtained if the antenna is tuned with a variable condenser.

557. Fig 106 shows the design of a very simple loop antenna which is especially adaptable for use with the system of

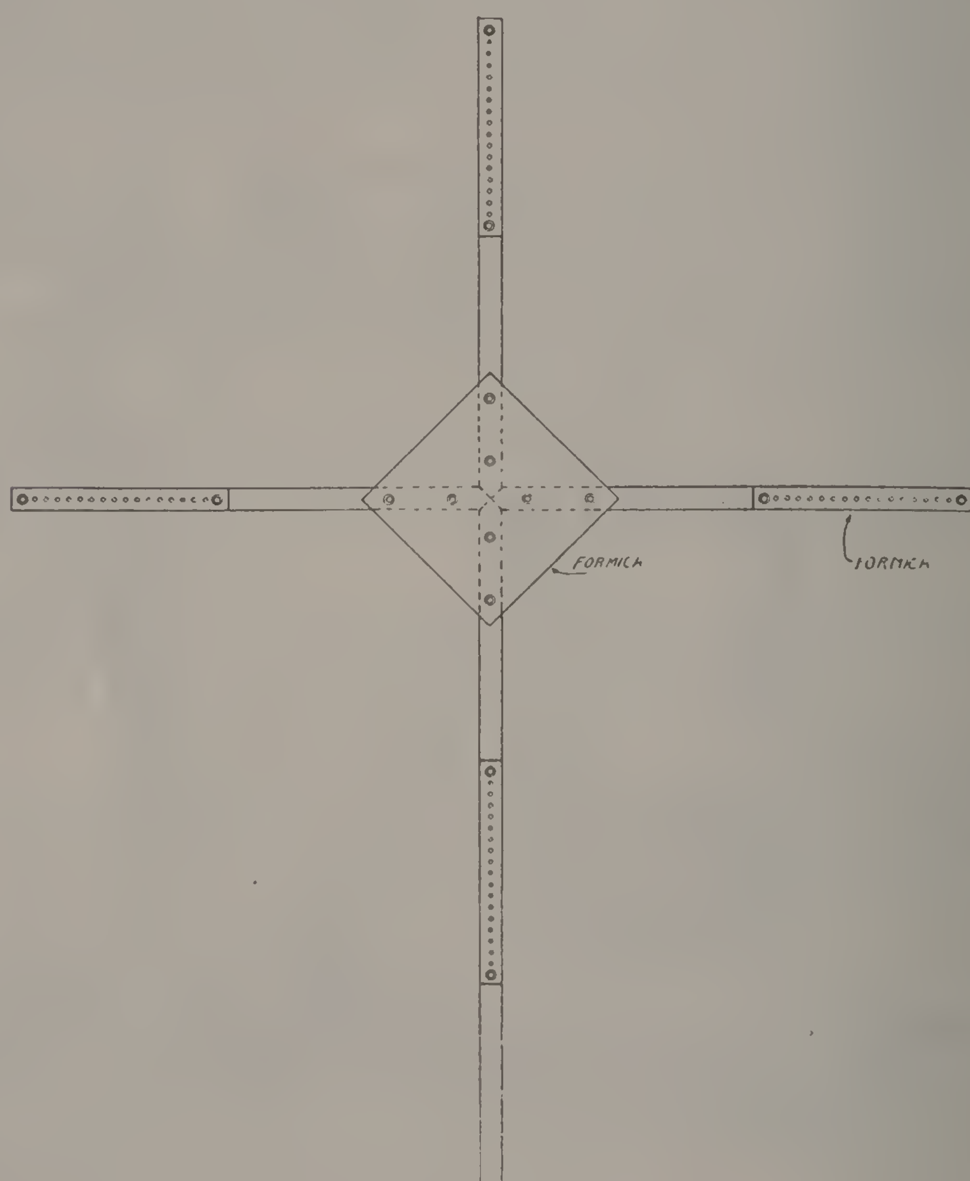


Fig. 106

Fig. 106. A telephone plug is attached to the lower end of the vertical stick. The whole loop can then be "plugged" into the jack in the receiver, the latter being secured to a shelf panel so that the loop can be supported in an upright position. The design of this loop is plainly indicated in the drawing of Fig. 107 and photographs of it appear in Part 2. The wire is wound in a spiral form on supports fastened to the bakelite strips. The ends of the wiring are brought down to the terminals of the plug.

PART 2

Construction of Radio-Audio Frequency Amplifiers and Complete Receivers

PART 2

LESSON 9.

RADIO-AUDIO FREQUENCY AMPLIFYING UNITS.

With the knowledge gained in the first part of this book of the theory of operation of different types of radio receiving systems and the comparison of their respective merits which was made in the eighth lesson, the reader should be able to reach his own conclusions regarding the system of reception which is best suited to his needs.

In these remaining lessons we are giving complete details of the construction and operation of the better types of amplifiers and receivers, the principles of which were discussed in Part 1. These sets all employ radio frequency amplification. Some are exceedingly simple and inexpensive; others are more elaborate, more sensitive and consequently somewhat more expensive. We all like to have "the best," but of necessity, the best costs more. Fortunately, even the best radio receiver can be made by the home constructor at a much lower cost than the price at which it can be purchased. By making his own receiver, the amateur eliminates many "overheads" and profits which must be charged against the completely manufactured article.

The photographs and drawings which appear on these pages will give the reader an intimate knowledge of how commercial receivers of the finest type are designed, built and wired. With the assistance of the instruction matter in the text, the duplication of these receivers in both appearance and operation should prove simple even to one with but slight mechanical ability.

We have occasionally read statements that radio frequency amplifying receivers are unstable, "liable to break into oscillation without any particular reason," and so forth. If this be true, the particular receivers described must have been improperly designed, carelessly wired or composed of cheap and unsuitable apparatus. The sets which we describe in this book have no such distressing peculiarities. They are in every way practical and simple to operate. In fact, they are more stable and simpler to operate than most types of receivers.

If good results are to be expected, the apparatus used in the construction of a radio receiver must be of the finest quality and must be designed properly **electrically** as well as mechanically. A noisy or poorly designed rheostat or a tube socket with loose spring contacts will be a constant source of trouble. A poorly designed audio frequency transformer will cause howling. The electrical losses in some types of variable condensers and other essential apparatus are quite high and may lower considerably the efficiency of the receiver. Moreover, if the receiver itself is not designed properly it will not function at its best, even if perfect apparatus is used. As we suggested in Paragraph 490 of Part 1, a radio frequency amplifier must be designed and wired in such a way that all capacitive, inductive, or resistive coupling which would feed back energy from one circuit to another must be reduced to the lowest possible minimum.

All the faults and causes of instability of highly sensitive receivers have been brought to the attention of the author in the most effective possible manner. Hundreds of receivers have passed through our hands for testing and approval. This testing work has proved most useful in the correction of faulty design or apparatus. For instance, howling was often present in the receivers with three stages of audio frequency amplification. The "howl" had to be removed from each set before it passed inspection. Almost every known make of transformer was tested in an attempt to make the receiver without the necessity of later changing it to remove howling. We are now using a transformer which gives high amplification without a trace of howling or distortion. This source of trouble was permanently corrected by the use of this transformer.

By following the instructions given in these pages and using the apparatus suggested, the amateur constructor will experience none of the difficulties suggested above. These problems have all been effectually solved and the receivers herein set forth represent the solution.

UNIT SYSTEM OF RADIO-AUDIO FREQUENCY AMPLIFIERS.

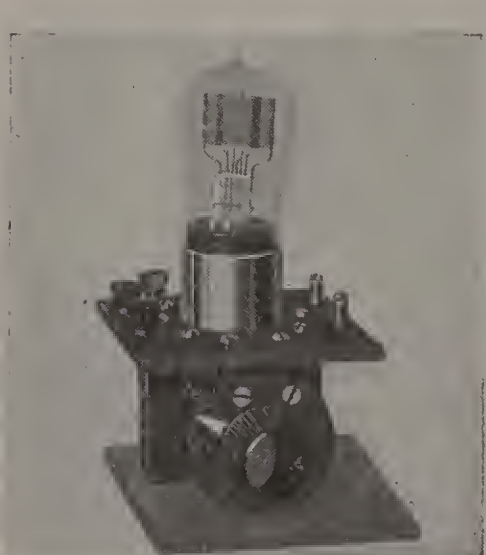


Fig. 107

The number of stages of radio or audio frequency amplification which can be usefully employed in a radio receiver is limited. If more than three stages of r.f. amplification are used, it is extremely difficult to control self-oscillation. Similarly, three stages of audio frequency amplification produce extremely loud signals—loud enough for ordinary purposes. However, a receiver may employ any intermediate number of stages, depending upon the purpose for which it is intended and the means of the constructor.

For the convenience of those who wish to make their own sets, the Radio Guild has devised a unit system of amplifiers known as "Ampli-Units" which permit any combination of radio or audio frequency amplification to be easily used in or added to any receiver. Fig. 107 shows a one-stage audio frequency amplifying unit; this photograph portrays the principles underlying the design of these units. The necessary

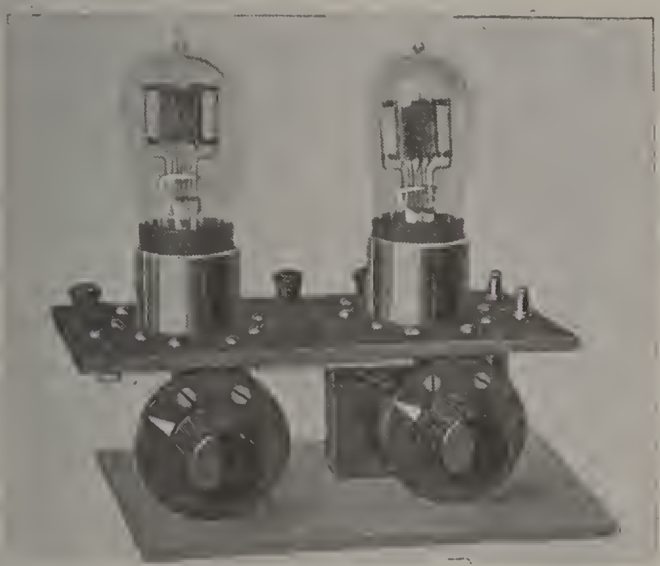


Fig. 108

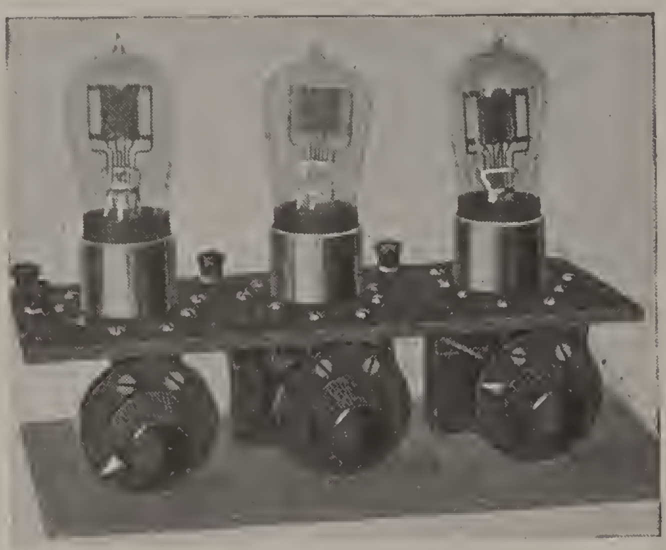


Fig. 109

apparatus is condensed into a very small space, thereby greatly improving the efficiency as the wiring to the transformer and other apparatus is made with very short leads. Fig. 108 shows a detector and one-stage audio unit and Fig. 109 a detector and two-stage audio unit. Other combinations of radio as well as audio frequency amplification are made in a similar manner. In Fig. 110, a two-stage radio, detector and one-stage audio unit is

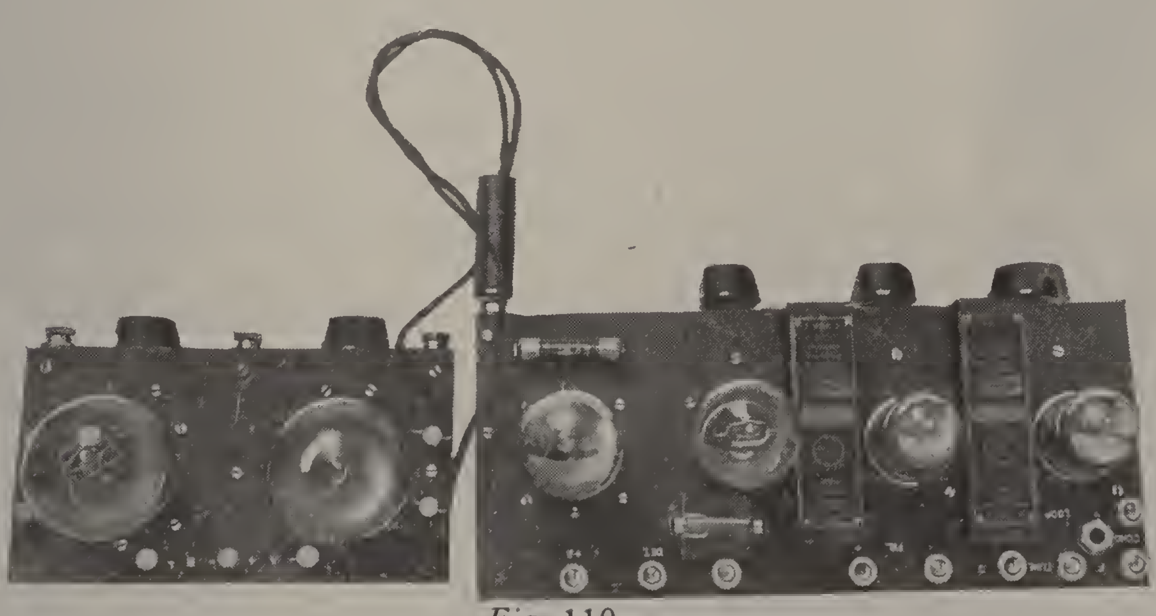


Fig. 110

shown with a two-stage audio unit. These "Ampli-Units" are completely self-contained and they can be obtained completely wired and ready for use. All apparatus is firmly attached to the horizontal panel of formica. Any unit can be used in or added to a receiver by drilling a few holes in the front panel of the set and then screwing the unit in place with a screw driver. No other tools are necessary. The unit is connected in the circuit by wiring to the binding posts on its panel.

However, being self-contained, it is not even necessary to use a front panel with the units if it is not convenient or desirable to do so.

THE R.G. 510 AMPLI-UNIT.

The R.G. 510 Ampli-Unit (so called because it is employed in the complete R.G. 510 receiver describer in the next chapter) represents a splendid adaptation of the unit system to a cascade radio and audio frequency amplifier of very high efficiency. In addition to being compact, the unit is designed to minimize plate and grid connections in both radio and audio frequency amplifying circuits. The complete unit is shown in Fig. 121.

The Circuit: The wiring diagram of the R.G. 510 unit is given in Fig. 111. The unit has two stages of DX transformer-coupled radio frequency amplification, detector and three stages of audio frequency amplification. While the wiring diagram has

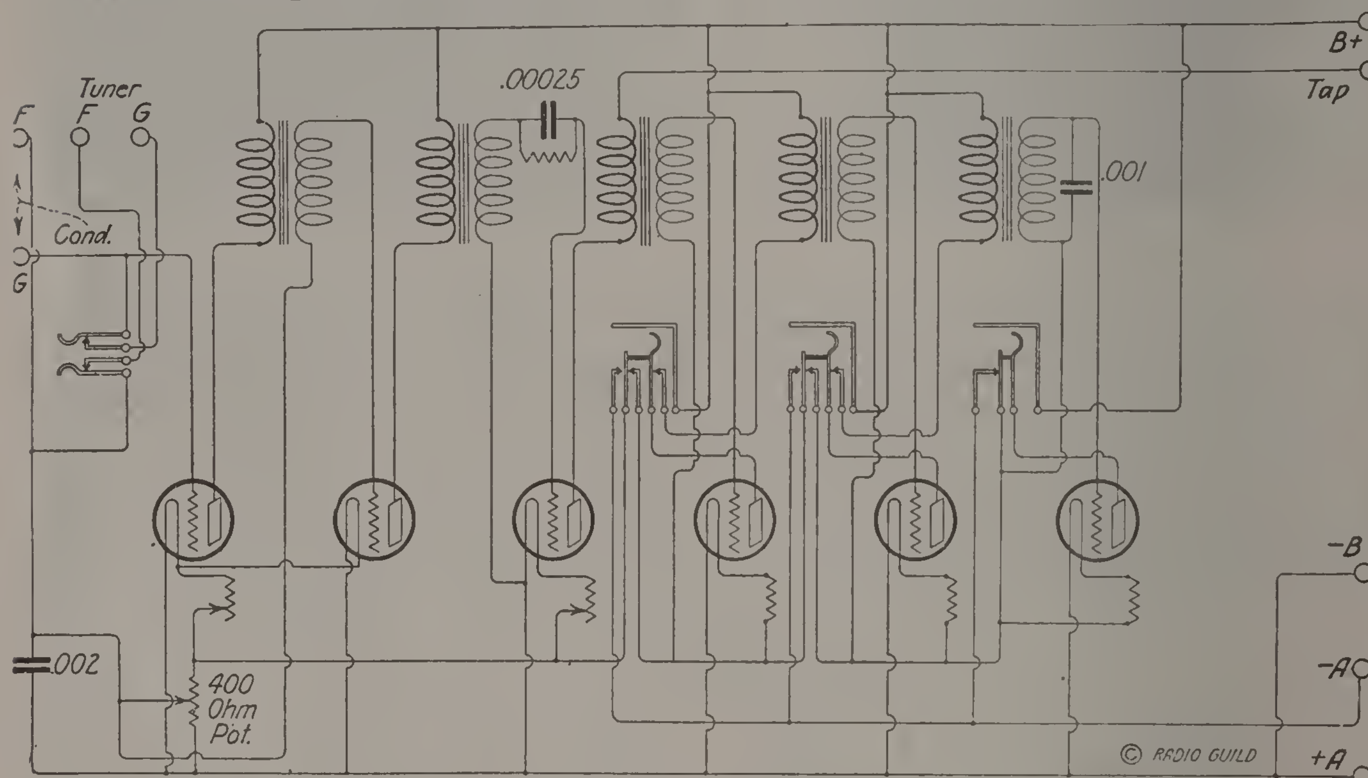


Fig. 111

a more complicated appearance than the circuits of radio and audio frequency amplifiers given in Part 1, the complications are caused by the filament wiring to the telephone jacks. The telephone jacks are arranged so that the 'phones can be plugged in the first, second, or third stage of audio frequency amplification, as desired. The jacks are of the filament control type so that only the filaments of the tubes in use are lighted when the plug is inserted in the jack. Otherwise, the circuit conforms exactly with the simple circuits of transformer-coupled radio and audio frequency amplifiers explained in Part 1. A potentiometer is used to prevent self-oscillation in the radio frequency amplifier.

The input binding-posts are arranged so that the unit may be used with a tuner in a complete antenna receiving set or with a loop as antenna. There are four binding-posts and loop jack to the left of the unit which appear at the upper left-hand corner of the diagram of Fig. 111. A variable condenser is connected to two of these binding posts and the condenser is used to tune either the loop circuit (when a loop is plugged in the jack) or the secondary circuit of the aerial tuner (when the loop is removed from the jack). The secondary inductance of the tuner is connected to the two "tuner" terminals on the unit. This system of combining aerial or loop reception in one receiver was explained in Paragraph 556 of Part 1.

Apparatus Used to Construct Unit: The following apparatus is used in the construction of this unit:

1 Formica panel measuring 5 x 17 x ¼ inches.
6 Tube sockets.
1 Potentiometer.
2 Filkostats.
3 Amperites and Mountings.
1 Grid Condenser (.00025 mfd).
1 Grid Leak (1 or 2 megohm).
1 Double Circuit Loop Jack.
3 Filament Control Telephone Jacks (1 Single Circuit, 2 Double Circuit).
2 DX Radio Frequency Transformers.
8 DX Transformer Mounting Lugs.
3 Guild Seal Audio Frequency Transformers.
2 Fixed Condenser (.001 mfd) and 1 Fixed Condenser (.002 mfd).
9 Binding-posts.
Sundry screws, brackets and wire.

The panel to which all the apparatus in the unit is firmly attached must necessarily be strong and at the same time have good insulating properties. One-fourth inch Formica is therefore used for this panel. The strength and insulating qualities of this material are well known.

Fig. 112

Special attention is called to the filament controls employed in the unit. To regulate the filament temperature of the radio frequency amplifying tubes and the detector tube, vernier filament controls of the Filkostat type, shown in Fig. 112, are used. These provide exceedingly fine regulation of the filament temperature, which is very essential if maximum efficiency is to be obtained. The Filkostats are particularly useful when tuning in a weak station. **A very close adjustment of the filament temperature is often the easiest method of controlling the sensitiveness of the radio frequency amplifying circuit.** An ordinary wire rheostat is useless for this purpose but the Filkostat gives such a very fine control of the filament temperature that it has become an almost indispensable adjunct of the radio frequency amplifier.

The filaments of the audio frequency amplifying tubes do not require such careful adjustment and to minimize the number or controls automatic self-adjusting resistances as shown in Fig. 113 are used in place of variable rheostats. These "Amperities" have proved very satisfactory in operation. They tend to keep the filament current constant at a value suited to the tube in use. The Amperites are made in different models for different types of tubes. They are inserted in mountings so that the Amperite can be suited to the tube employed. For instance, if a U.V. 201A tube is used with a six-volt filament battery, an Amperite "IA" gives the proper control of filament current.

Fig. 113

Filament control jacks, as used in the R.G. 510 Ampli-Unit are exceedingly useful in the audio frequency amplifying stages of a radio receiver. They simplify the operation and prevent the possibility of leaving the tubes alight while the set is not in use. It has been difficult, however, to locate a jack which is properly designed to withstand the wear and tear of constant use. We have chosen the jacks shown in Fig. 114 and they have given exceptional service. Receivers using these jacks have been in daily use for many months and the jacks have never failed to operate perfectly. The main reason for this lies in the design and construction; the upper spring is reinforced so that the jacks never lose their springiness.

Fig. 114

The DX radio frequency transformers employed in the units were fully described in Part 1, Lesson 7. The audio frequency transformers were also described in the same lesson. Both types of transformers are essential parts of the unit and must be used to gain satisfactory results.

Fig. 115

Dubilier fixed condensers are used in the unit. These condensers with their mica dialectric are the standard of the radio industry. Fig. 115 shows the grid condenser with its convenient grid leak mounting.

All the other apparatus in the unit, down to the last screw, is the finest that can be made or purchased. A radio frequency amplifier **must** be made with the best of material or its efficiency is greatly impaired.

Assembling the Unit: The first work of construction is the drilling of the panel to which the apparatus is attached. A scale drawing of the unit panel is given in Fig. 116 which shows the location of all holes drilled for the mounting screws and tube sockets. It is well to grain the panel on top and bottom after all the holes have been drilled.

With the possible exception of the tube sockets, the mounting of the apparatus on the panel is fairly simple. Figs. 117 and 118 show top and bottom views respectively of the completely mounted but unwired unit and clearly reveal the location of the different pieces of apparatus. The tube sockets are spun into the Formica by a special machine operation which cannot be duplicated by amateur devices. This, however, will not be a hindrance as the units may be purchased in any stage of construction. The contact springs of the tube sockets are firmly secured to the lower side of the panels.

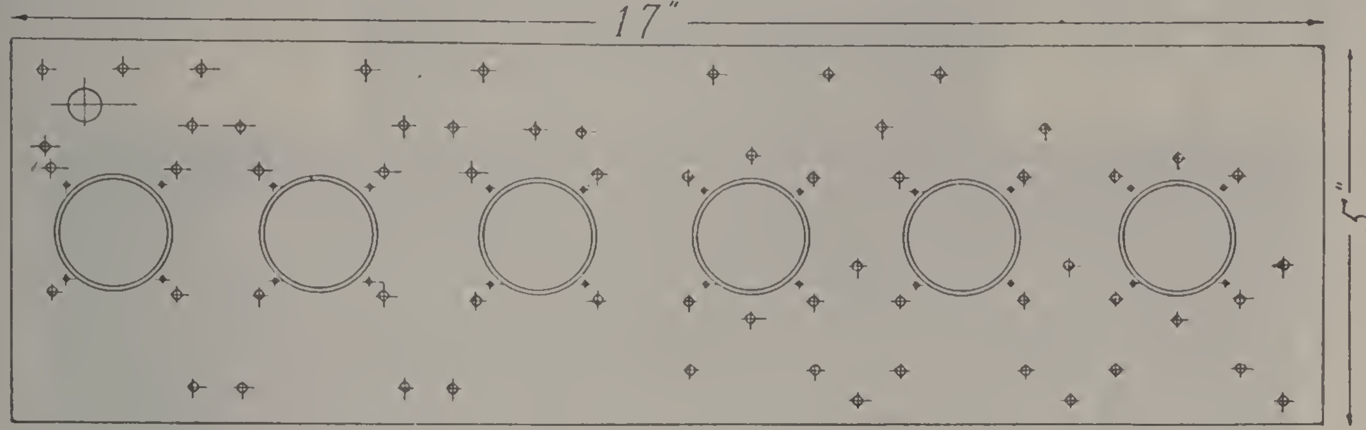


Fig. 116

In Fig. 117, between the first and second and the second and third tube sockets, may be seen the mountings for the DX transformers. To the extreme left the loop jack is visible, to-

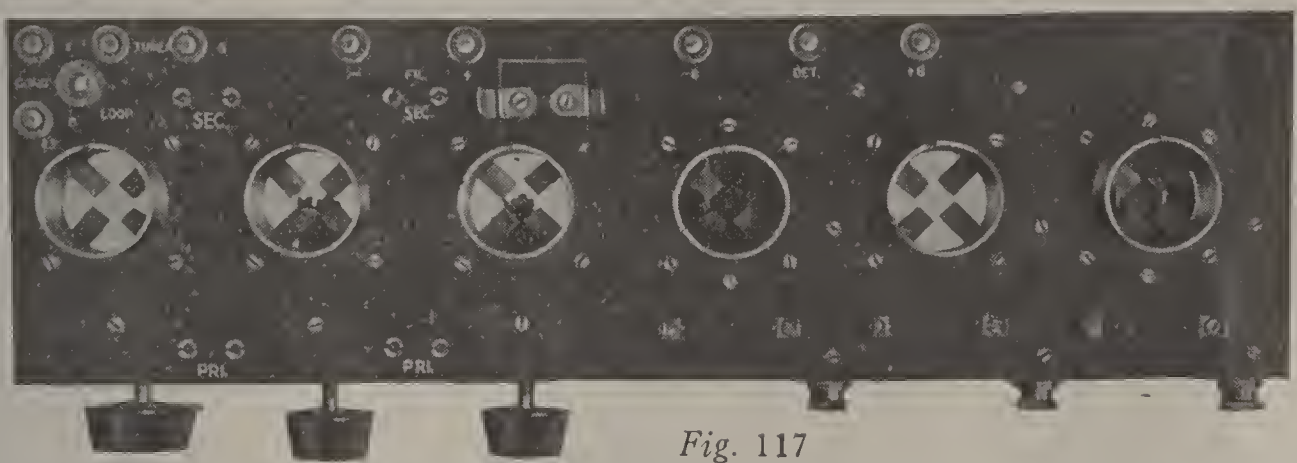


Fig. 117

gether with the condenser and tuner terminals; along the back are situated the battery terminals.

Fig. 118

It will be noted in Fig. 118 that the first audio frequency transformer is mounted directly beneath the first audio frequency tube socket. The second transformer is mounted to the rear of the second socket and the last transformer under the third socket. This staggered arrangement allows more space between the transformers and tends to prevent interaction between the circuits, which might produce howling.

Notes on Wiring: The photograph of Fig. 119 shows a lower view of the unit completely wired. With the exception of the audio frequency transformer leads, all wiring is made with square bus-bar, combining neatness and strength with efficiency. All wiring is underneath the panel. Although the circuit is more or less complicated, this mode of wiring tends to simplicity. All leads are made as short as possible and all

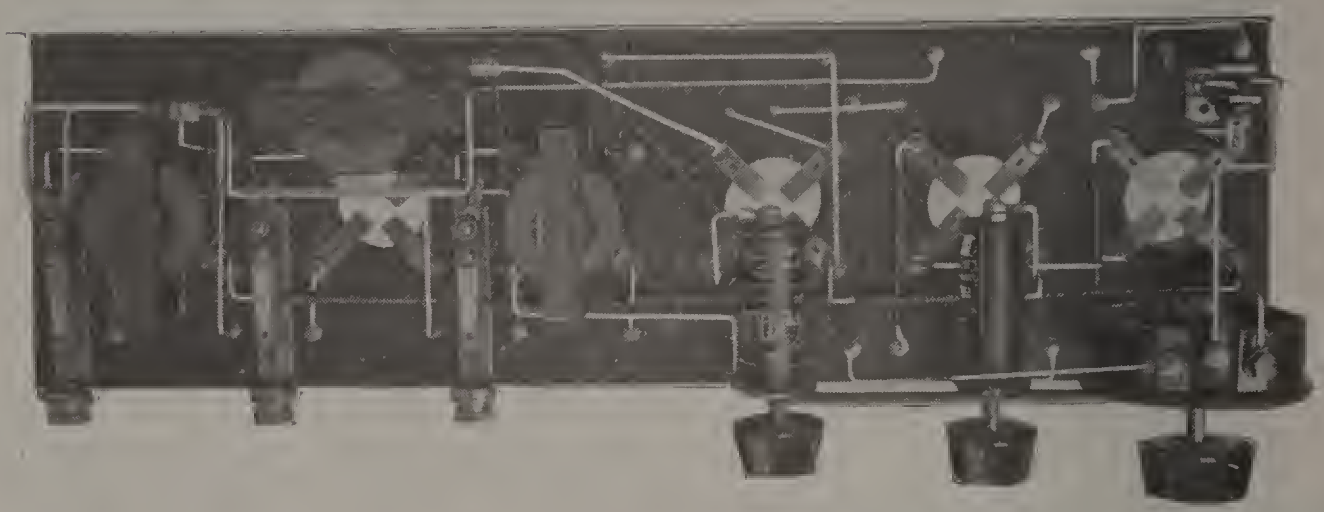


Fig. 119

joints soldered, not in a haphazard fashion but in such a manner that both electrically and mechanically the joints are perfect.

The leads from the audio frequency transformers are made with the flexible wire of the transformer coils themselves covered with the insulating tubing. Fig. 85 of Part 1 clearly shows

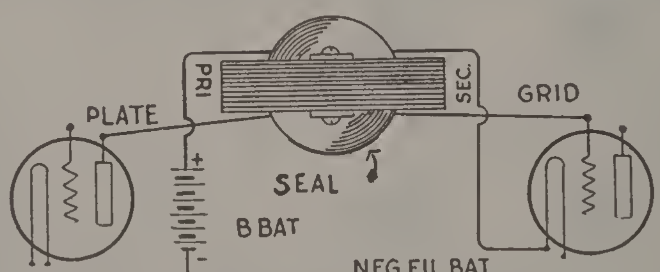


Fig. 120

how these leads are made. As the transformers are mounted directly beneath the tube sockets, the wiring to the grid and plate terminals is exceptionally short and direct. The transformers are wired so that the outside of the primary coil connects to the plate of one tube and the outside of the secondary coil to the grid of the succeeding tube, as illustrated by the sketch of Fig. 120. If this sketch is not followed, howling may be caused.

Fig. 121 is a close-up of the wiring from the condenser and tuner terminals to the loop jack. The wiring must be made in this manner to conform with the engraving of the terminals on top of the panel. When connections are made to these terminals in accordance with the engraved instructions, the "tuner" terminals are isolated from the remainder of the circuit if a loop is plugged into the double circuit jack. Additionally, when connecting the variable condenser to the marked terminals, the movable plates may be connected to the "F" or filament terminal so that body capacity effects are avoided when operating the receiver.

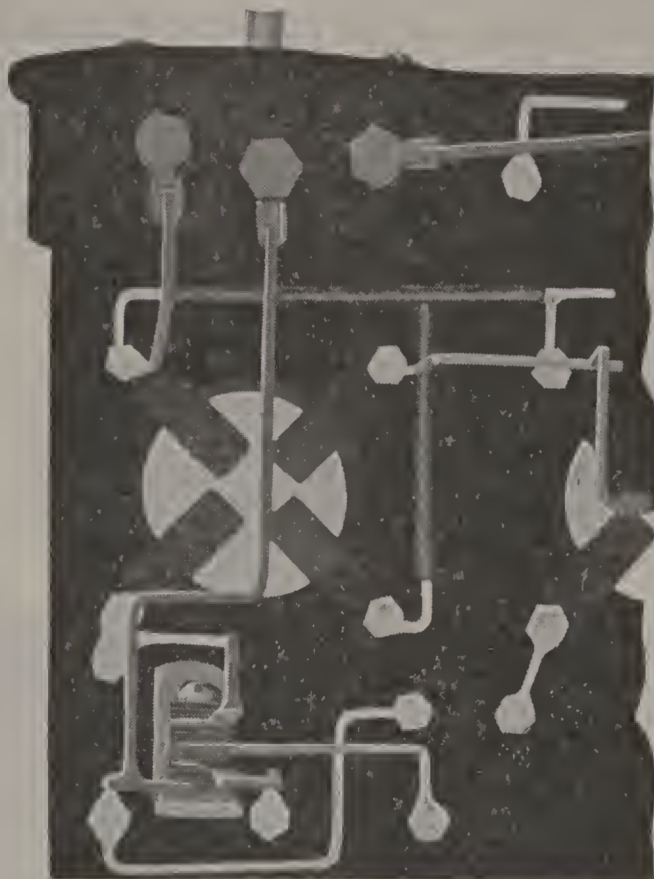


Fig. 121

INSTALLATION AND OPERATION.

The R.G. 510 unit is principally intended to be used in the construction of a complete receiver, as described in the next lesson. However, with the addition of a tuning condenser and loop antenna, the unit is a **complete receiving set in itself,** as suggested by the photograph of Fig. 122. Incidentally, this photograph shows the extreme compactness of the unit and shows how the radio frequency transformers are mounted, and the arrangement of amperites, potentiometer, Filkostats, valves, etc.

A variable condenser is shown connected to the "condenser" terminals on the unit and a loop is plugged into the loop jack. The jack acts as a support for the loop. The condenser has a separate "vernier" plate which is of assistance when tuning the loop circuit to resonance.

To install and operate this unit as a complete loop receiver the following procedure should be observed.

Installation: 1. Make all battery connections exactly as in Fig 123. As shown in this photograph, a 60-80- (or larger) ampere hour six volt storage "A" battery and two forty-five volt plate batteries are required. Connect batteries to the terminals with heavy, insulated, flexible wire. Make sure that both A and B batteries are in perfect condition.

2. Insert the radio frequency transformers, the grid leak (usually one megohm) and the three Amperites in their respective mountings (Type "1A" Amperite for ¼ Amp. and type "PT." for 1 Amp. tubes).

3. Connect a 23 plate vernier variable condenser to the "Condenser" terminals with the rotary plates to the terminal

marked "F." Insert the loop plug in the loop jack, making sure that positive contact is made.

4. Place the vacuum tubes in their respective sockets. Almost any type of vacuum tube may be used for either the radio

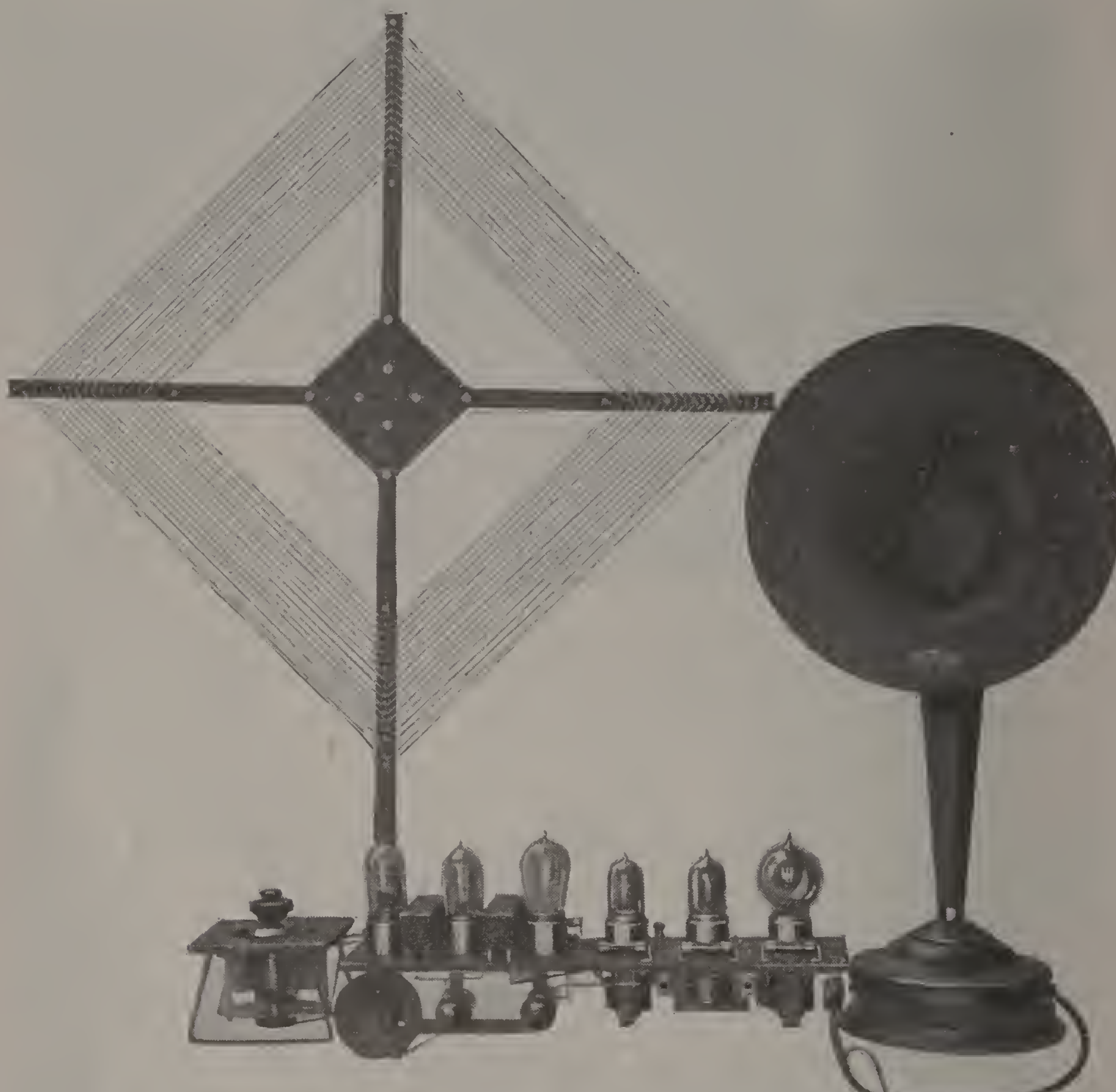


Fig. 122

or audio frequency amplifier. The best results are obtained with De Forest or similar low internal capacity tubes in the radio frequency amplifier. A U.V. 200 (or C300) tube may be used as detector although practically as good results are had with the 201A type.

Operation: 1. Insert the telephones or loud speaker plug in the center phone jack. The filaments of the tubes will automatically light, except the last audio frequency amplifier, which is then out of the circuit. Adjustment of the filaments of the radio frequency amplifying tubes is secured by manipulation of the Filkostat knob directly to the right of the potentiometer. Detector filament control is provided by the Filkostat under the detector tube. If a U.V. 200 or other gas content tube is used for the detector the Filkostat should be turned until a hissing sound is heard in the telephones. The position of the Filkostat **just below** this "hissing point" gives best retification.

2. The **tuning condenser** and the **potentiometer** are the important operating controls. A few moments actual operation of the receiver will enable anyone to obtain satisfactory results. The usual method of quickly tuning in a station is this: Turn the potentiometer to the negative side of the filament line

Fig. 123

and vary the tuning condenser between maximum and minimum until the carrier wave of a transmitting station is heard. The so-called carrier waves are discernible as two whistles on each side of a silent spot. When a broadcasting station is in action the modulated tones are heard between the two whistles. Having located the station, turn the potentiometer slowly in the opposite direction towards the positive side of the filament. At the same time make slight readjustments of the vernier of the tuning condenser to keep the station in tune. Then find the adjustment of the potentiometer with which the loudest signals are heard **without** the presence of the carrier wave.

Having tuned in a station, any one of the three jacks may be used, depending on the volume of reproduction desired. The first jack is sufficient for head 'phones. The center jack is employed for usual home entertainment with loud speaker, while by plugging in the last stage, very loud signals, suitable for a large room, are obtained.

To pick up a different station, turn the potentiometer to the negative side of the filament and proceed as outlined above. The approximate condenser positions for the different stations should be recorded for future reference.

The position of the loop is important and maximum signal strength is secured when the plane of the loop is pointed in the direction of the transmitting station to be received. The loop assists in eliminating interference from other stations which are not in the direction in which the loop is turned.

If a ground is connected to the "G" or grid terminal of the unit, the audibility of the system is greatly increased. Distant stations are easily received. When the ground is connected in this way the movable plates of the tuning condenser should also be connected to the grid post.

Performance: There is no question that a six-tube receiver of this type is excellent for long distance reception and has proved its merits on innumerable occasions. The author, in his New York studio, has frequently picked up stations 1,500 miles distant, with equipment similar to that pictured in Fig. 122. Naturally, local reception is perfect and is usually accomplished on a small three-inch coil with no outside connection whatsoever. For reliable reception of distant stations, however, it is much better to use an aerial with tuning arrangement as described in the next lesson.

LESSON 10.

RECEIVER TYPE R.G. 510.

Complete Aerial or Loop Receiver with Tuner, 2-stage Radio Amplifier, Detector and 3-stage Audio Amplifier.

There is seldom a radio amateur who is **completely** satisfied with his receiver. He starts, perhaps, with a crystal set which picks up the local stations. Soon he sells that and buys a new set that will receive farther. He hears stations two hundred miles away. But that isn't far enough. He adds an amplifier—but still, there is something just a bit better if he could only find it. There is always a "perfect" receiver to dream about and perhaps one day possess. He knows exactly what that "perfect" receiver must be able to do. It must be able to receive thousands of miles—on any wave-length. It must be absolutely selective—no interference. It must be simple to operate, etc., etc. Each individual has his own ideas as to what it should contain and it would be impossible to make a single receiver which would satisfy everybody.

We are encouraged to learn from many radio amateurs, however, that the R.G. 510 receiver described in this lesson has even transcended their most fanciful dreams of a "perfect" receiver.

We are inclined to share the enthusiasm of those who are using this receiver. We have obtained quite phenomenal results with it under test conditions. Below are a few of the practical features of this instrument which combine to form as "perfect" a receiver as can be devised:

Audibility: The R.G. 510 uses in its construction the unit described in the last lesson with two stages of radio frequency amplification, detector and three stages of audio frequency amplification. The extreme sensitiveness of a receiver with this combination of amplification is apparent. The design and apparatus used in the amplifiers ensure maximum efficiency. **Real** amplification is obtained. One cannot judge the audibility of a receiver by the **number of tubes** that are used. The thing that counts is the **amplification per stage.** The high amplification of both types of amplifiers in the R.G. 510 unit was fully explained in Lesson 7 of Part 1.

However, the audibility of any receiver must finally be judged under actual operating conditions. The results secured with the R.G. 510 under normal conditions indicate that the audibility is very high. Broadcasting stations over 1,000 miles distant are consistently received, using only a small loop as antenna. With an outdoor aerial, the receiving range is doubled and sometimes trebled. These results, of course, do not represent the greatest distances that have been covered by this receiver; they merely represent the average. One amateur in Cuba, using loop antenna, reports the reception of a California broadcasting station. Another amateur in Cuba sends a list of U. S. broadcasting stations he has heard and the list is quite comprehensive. It includes Schenectady, New York, Boston, Massachusetts; Davenport, Iowa; Atlanta, Ga., etc., etc. Still another amateur in Minneapolis, Minn., reports hearing both the Atlantic and Pacific coast stations with great regularity. From all over the United States and Canada similar reports of long-distance reception have been made.

There is a distinct fascination in possessing a receiver which is capable of picking up broadcasts from stations thousands of miles distant. Even though one rarely exercises this power, there is present a sensation of mastery in the knowledge that one **can** receive the distant stations at will. As an automobile manufacturer has declared, the buyer of an automobile preferably chooses the high-power car—the car which is capable of making a speed of 80 or 90 miles an hour. He may never drive it at a greater speed than 40 or 50 miles an hour, but when he owns the high-power car he has the "consciousness of the possession of power"—the knowledge that, if put to it, he can make a higher speed. Similarly, the buyer of a radio receiver chooses the set with high audibility—the set that **can** receive stations thousands of miles away.

Apart from the sensations of the owner, however, the buyer of the high-power car or the purchaser of a receiving set with high audibility, unconsciously makes a wise choice. One should rarely drive a car or operate a radio receiver with the maximum expenditure of power. If a car is invariably driven at the maximum speed of which it is capable, it will soon wear out. Some power should always be held in reserve. Similarly, a radio receiver should seldom be operated at the point of maximum sensitiveness; the set will not wear out any quicker but distortion is much more likely to be experienced when the set is balanced at the critical point of maximum sensitivity. The receiver should preferably have such high audibility that **it is not necessary** to bring it to the state of maximum sensitiveness to receive local stations or stations within a radius of say, 1,000 miles. The R. G. 510 is a receiver of this type. To reproduce the broadcasting of the local stations or stations within a limited radius, it is not necessary to operate the receiver with maximum output of energy. The receiver does not need to be critically adjusted to produce the maximum amplification of which it is capable. A rough adjustment serves the purpose and some amplification is "held in reserve." However, the high audibility of the receiver is there to be called upon if desired. By carefully adjusting the radio frequency amplifier, the tuner controls, and using all three stages of audio frequency amplification, the very far distant stations can be brought in loudly and clearly at will.

Selectivity: As we explained in Lesson 8, a receiver with high audibility is useless, unless, at the same time, it has high selectivity. The practicability of radio frequency amplification with an outdoor aerial has often been questioned by experimenters who have found the combination exceptionally broad in tuning. As consistent long-distance reception is only practical when some form of aerial is employed, this lack of selectivity constituted a severe objection to the use of radio frequency amplification. To gain selectivity, many amateurs resorted to the use of loop antennae but, as we explained previously, the selectivity of loop reception is chiefly gained by enormously decreasing the audibility of the receiver.

The efficient use of radio frequency amplification with an outdoor aerial is now made possible, however, by a special coupler which is described in Lesson 8.

Go back and read Lesson 8 again. It explains how this "Harkness Coupler," which is used in the R.G. 510 receiver, accurately controls the audibility and selectivity of the system; how it makes possible the reception of local or distant stations with a remarkable freedom from interference.

Simplicity: When it is said that a receiver is "simple to operate," some amateurs immediately conclude that the receiver **must** be inefficient. A common but entirely erroneous conception of an efficient receiver is one with about fifteen controls. But **simplicity of operation is as much a factor of efficiency as audibility or selectivity**. If a receiver has seven or eight controls and each control requires careful adjustment, the receiver is absolutely useless for practical purposes no matter how high the audibility or selectivity may be.

The R.G. 510, when receiving with the loop, has only **two** active controls. One control tunes the loop circuit and the other acts as a stabilizer. When receiving with the aerial there are four active controls; but tuning is not complicated. Of the four controls, two are mainly used for tuning the set to receive different stations. The remaining two controls are additional refinements for improving the audibility or selectivity of a signal when it has been located by the two main controls.

Other features: The R.G. 510 can be easily adapted to receive on any wave-length—from 200 meters to 20,000 meters. This is a decidedly unique feature for a receiver of this type employing radio frequency amplification.

Either a loop or outside aerial can be used to pick up signals. The receiving range with the aerial, of course, is much greater than with the loop; that is to say, the audibility is much higher. Moreover, reception with the aerial is even more selective than with the loop. Therefore, although provision is made for using a loop, this should only be resorted to when it is inconvenient to erect an aerial.

One, two, or three stages of audio frequency amplification can be used as desired by simply plugging in the telephones or loud-speaker in the proper jack. The jacks are of the filament control type. When the 'phone plug is removed from any jack, the filaments of **all** tubes are automatically switched off. When the 'phone plug is inserted in any jack, the filaments of the tubes **in use** are automatically lit; tubes not in use do not light.

The Circuit: The diagram of Fig. 124 shows the tuner of the R.G. 510 connecting to the amplifying unit (described in Lesson 9) which constitutes the remainder of the receiver. The wiring diagram of the unit itself was given in Fig. 111.

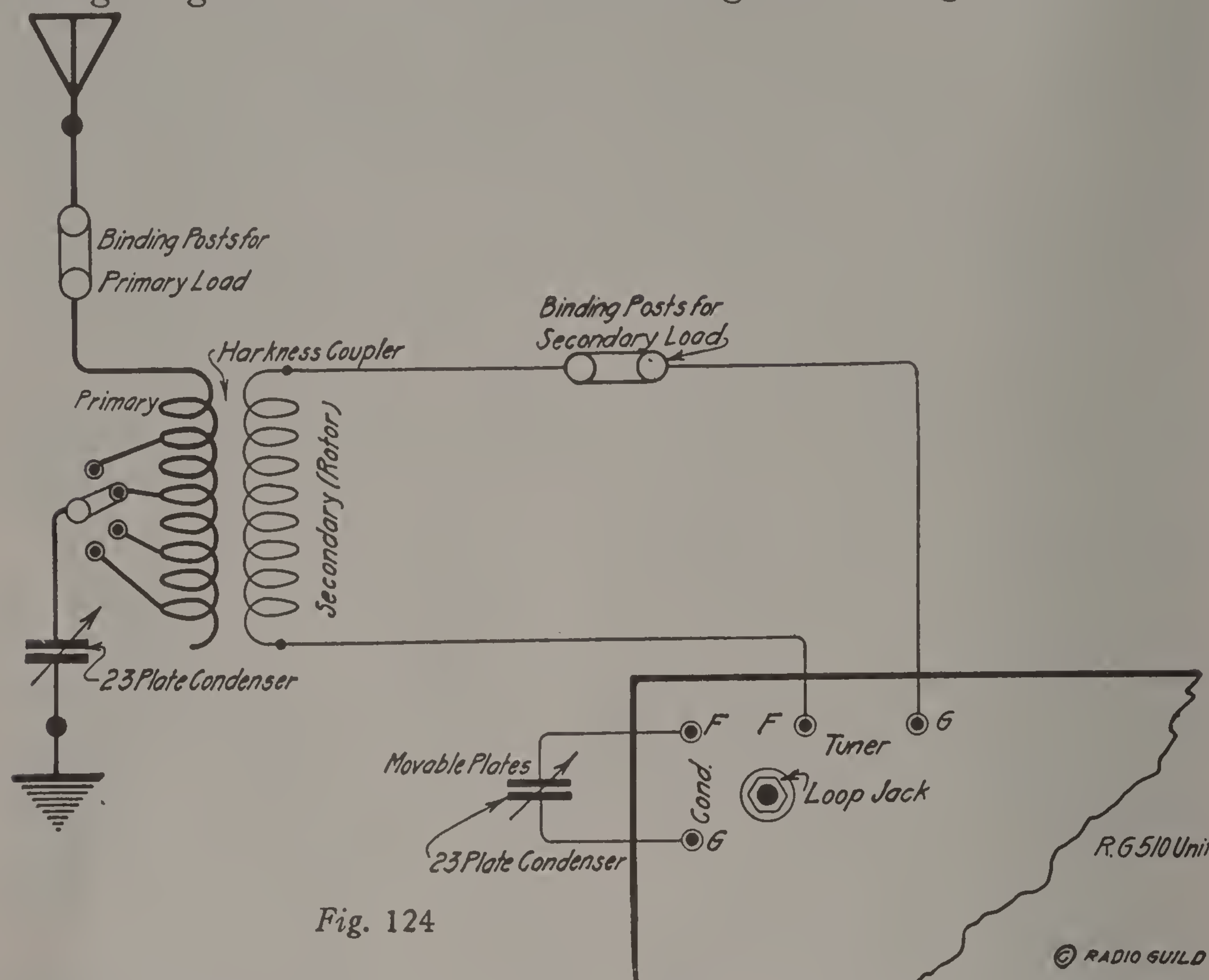


Fig. 124

The tuner is of the inductively-coupled type. The special "Harkness Coupler" (described in Lesson 8) is used. The antenna circuit is broadly tuned by varying the primary inductance of the coupler and is accurately tuned to resonance with a variable condenser in series with the ground lead. The secondary circuit is formed by the rotor of the Harkness Coupler and the secondary variable condenser. The inductive coupling between the two circuits is varied by revolving the rotor of the coupler.

If a loop is inserted in the jack on the amplifying unit, the rotor of the Harkness Coupler is disconnected and the secondary variable condenser is connected across the loop. The secondary condenser is then used to tune the loop circuit.

CONSTRUCTING THE R.G. 510.

Apparatus Used: The following apparatus is used in the construction of the R.G. 510:

1 Formica panel measuring 10½" x 26" x 3/16".
1 Harkness Coupler.
1 Inductance Switch set (including lever, 4 switch points and 2 switch stops).
2 Variable Condensers (.0005 mfd each).
1 R.G. 510 six tube Ampli-Unit (completely wired).
6 Binding Posts.
3 Dials.
1 Cabinet measuring 10½" x 26" x 9" (outside measurements). Sundry screws and wire.

Of the above apparatus, the six tube Ampli-Unit was fully described in the last lesson and the Harkness Coupler was described in Lesson 8 of Part 1.

The remaining apparatus is all standard. Attention is drawn to the variable condensers, one of which is shown in the photograph of Fig. 125. These condensers are exceedingly well made, have an excellent appearance and are designed properly to eliminate electrical losses. A pig-tail contact is used from the rotary plates.

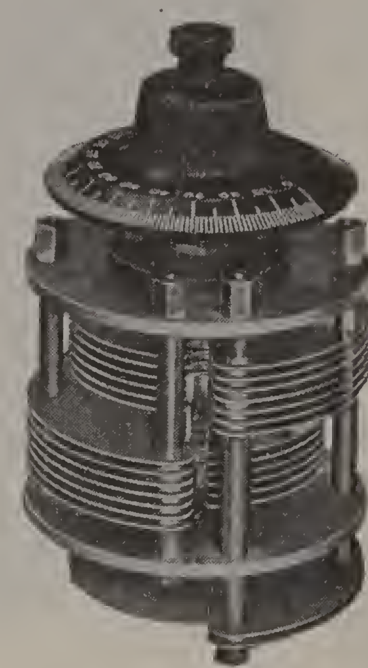


Fig. 125

Drilling of Panel: The first operation in the construction of the R.G. 510 is the drilling of the front panel. A scale drawing of this panel is given in Fig. 126 which shows the location of holes drilled for the mounting of the apparatus. The panel is grained and engraved after the holes are drilled.

Assembly and Wiring: The use of the completely wired amplifying unit in the construction of the R.G. 510 greatly simplifies the work of assembly and wiring. A soldering iron and a screw driver are the only tools required to complete the work. By following the instructions given below and with the assistance of the photographic illustrations, any amateur constructor can easily put this set together and completely wire it in about half an hour.

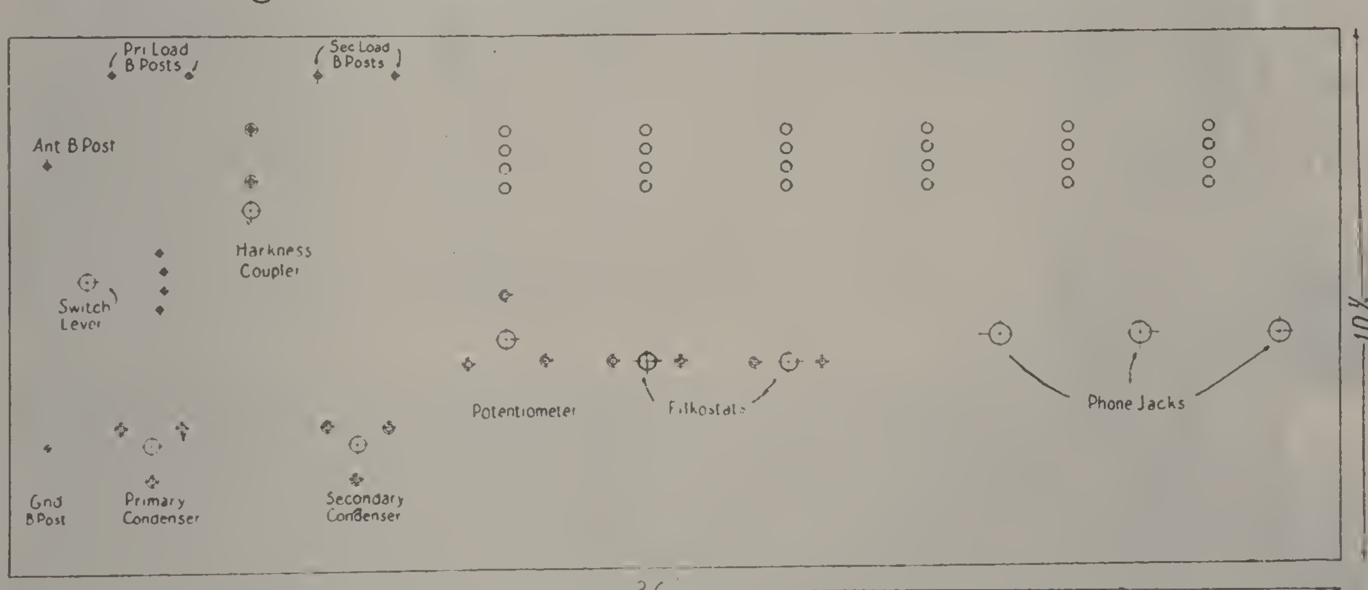


Fig. 126

1. Mount the Harkness Coupler, the two variable condensers, the inductance switch set and the six binding posts on the panel in the manner indicated in Fig. 127.

2. Completely wire the antenna circuit. Follow the wiring diagram of Fig. 124. The photograph of Fig. 127 also shows the method of wiring very clearly. Make the leads from the coupler taps to the switch points with flexible wire covered by cambric tubing. Make all other wiring with bus bar. Also connect a wire between one of the Fahnestock clips (secondary terminals) on the coupler and one of the secondary loading coil binding posts as shown in Fig. 127.

3. Remove the potentiometer and Filkostat knobs and the nuts of the telephone jacks from the amplifying unit. Then mount the unit in place on the back of the panel, as illustrated in Fig. 128.

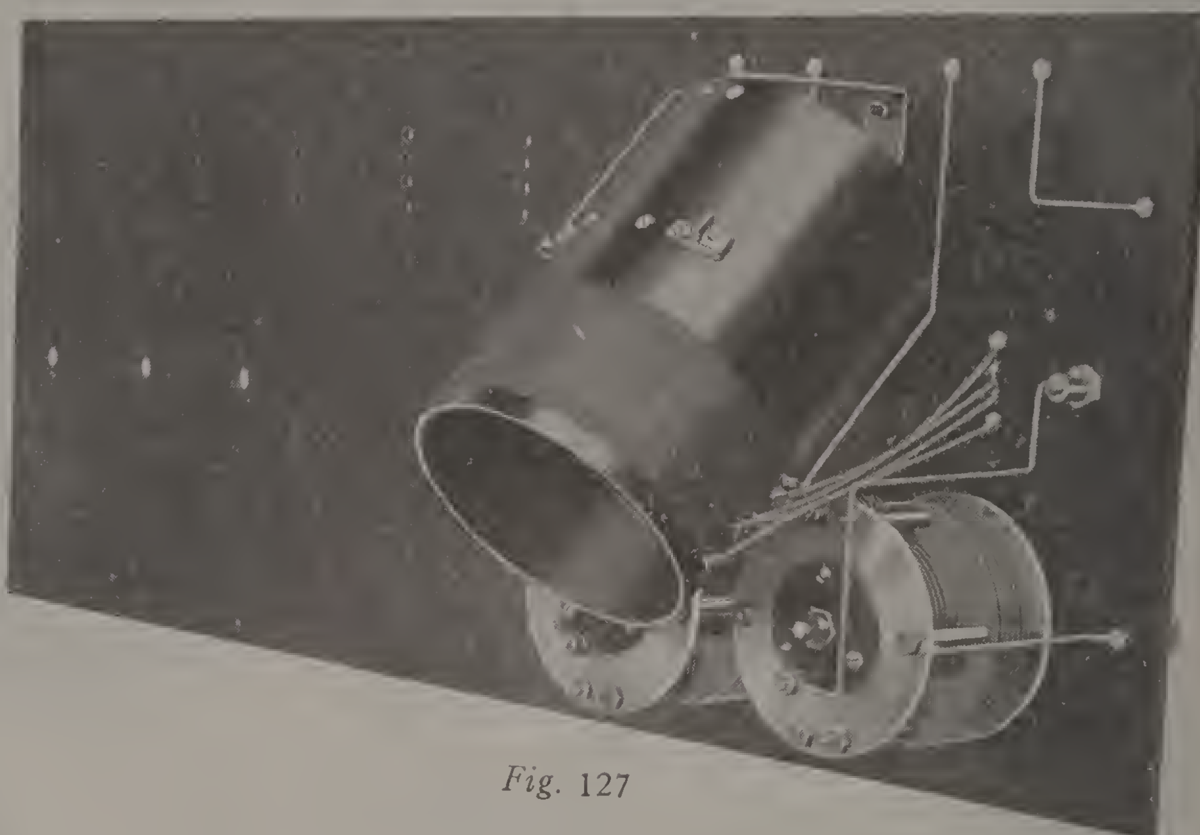


Fig. 127

4. Firmly secure the unit in place by screwing on the nuts of the telephone jacks projecting through the front of the panel and by fastening the potentiometer and Filkostats to the front panel with nuts and bolts. Fig. 129 shows a constructor in the act of tightening down on the last mounting bolt of the potentio-

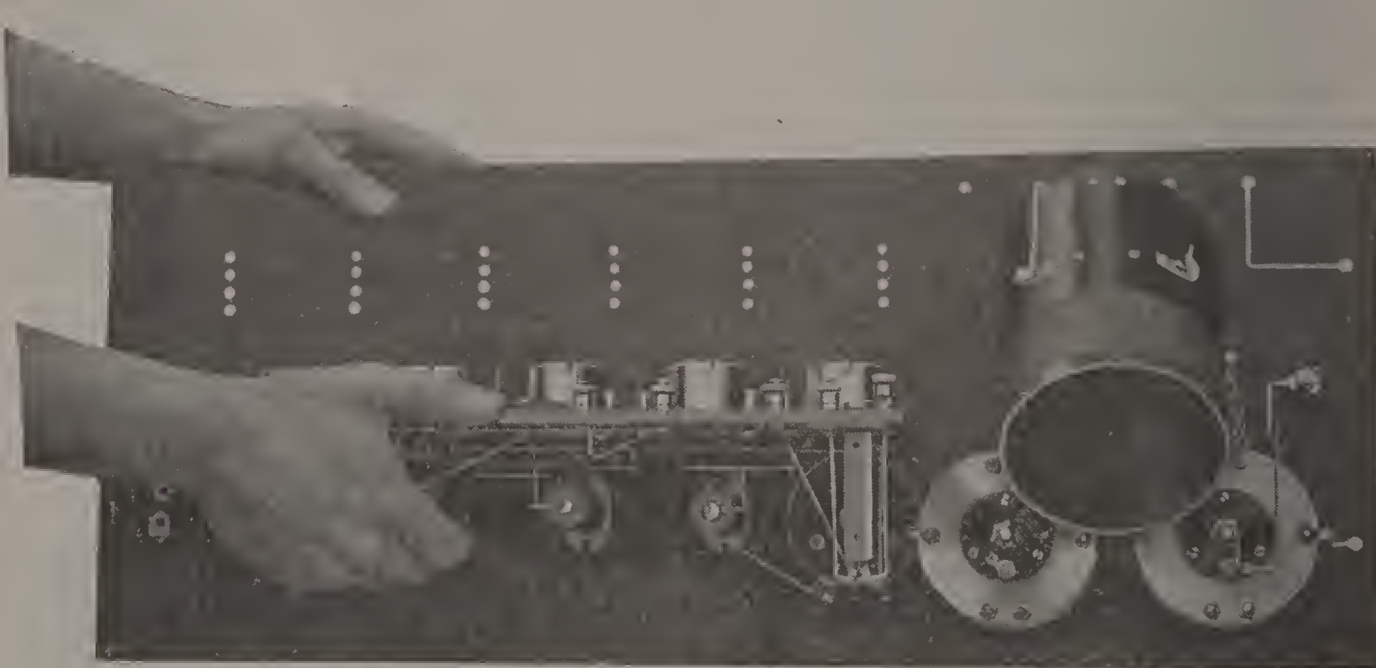


Fig. 128

meter, the mounting bolts of the Filkostats having already been fastened and the telephone jack nuts screwed on tightly. These mounting bolts and nuts easily hold the entire amplifying unit firmly in place and eliminate the necessity of brackets. This completes the assembly of the R.G. 510 receiver.

5. To finish the work of construction, make wire connections from the tuner to the binding post on the amplifying unit,

Fig. 130 shows very clearly how the connections are made. It should be noted that the movable plates of the secondary variable

Fig. 129

Fig. 130

Main Control

Fig. 131

condenser are connected to the "F" or filament side of the "condenser" terminals on the unit. The object of this is to avoid body capacity effects when operating the receiver.

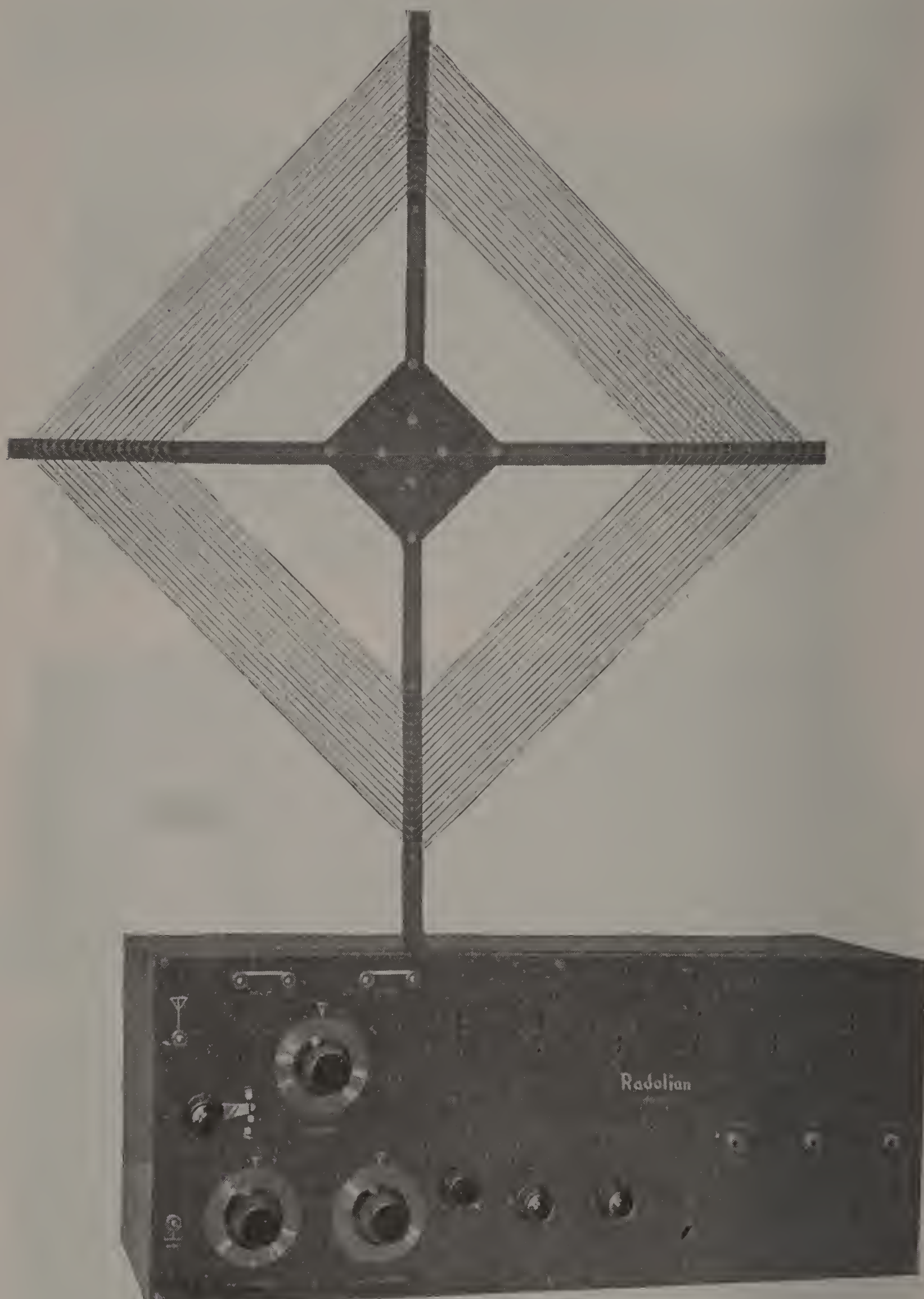


Fig. 132

6. The assembly and wiring completed, mount the three dials on the shafts of the variable condensers and Harkness Coupler projecting through to the front of the panel; also mount the potentiometer knob and the two Filkostat knobs. Then screw the finished set into its cabinet. Fig. 131 and Fig. 132 give two different views of the complete receiver.

If the above instructions are followed, the work of construction will be found exceedingly simple. As the amplifying unit can be obtained completely wired and **tested,** perfect operating results with the home-constructed set are assured.

INSTALLATION AND OPERATION.

Installation: To install the R.G. 510 receiver, proceed as follows:

1. Shunt the primary and secondary loading coil terminals with short sections of bus bar and connect the five battery terminals to both A and B batteries, as indicated in Fig. 123 of the previous lesson. Make certain that these batteries are in good condition as otherwise satisfactory operation is not possible.

2. Insert the vacuum tubes in the tube sockets and make sure that all the tubes are making positive contact with the socket springs. In the previous lesson, we gave particulars of the proper types of tubes to use with the R.G. 510. Insert the radio frequency transformers, grid leak and Amperites in their respective mountings.

3. Connect the aerial and ground to the antenna and ground posts on the front of the panel.

Operation: To receive with the loop, insert the loop through the hole in the cover of the cabinet and plug it into the jack on the unit panel. The aerial tuner is then isolated from the amplifying unit with the exception of the secondary variable condenser, which is used to tune the loop circuit. Loop reception is effected in exactly the same manner as described in Lesson 9.

To receive with the aerial, remove the loop entirely. The tuning is almost as simple as when receiving with the loop. The secondary condenser and the potentiometer are the main controls. A rough adjustment of the antenna circuit is sufficient to pick up signals which are tuned in by these two main controls. When the signal has been located, a close adjustment of the antenna circuit can be made by revolving the antenna condenser to improve the audibility. Similarly, the coupling can be varied by revolving the rotor of the coupler to improve the selectivity or audibility of the system. After a little experience anyone can easily secure maximum efficiency from the receiver. To pick up signals, the following brief outline of the procedure should be observed:

1. Adjust the radio frequency and detector Filkostat filament controls to the proper points for the vacuum tubes used.

2. Set the coupling dial at maximum; the primary inductance switch at the bottom tap to include all of the coil in the antenna circuit and set the primary condenser at an approximately half-way position.

3. With the potentiometer slider at the **negative** side of the filament, rotate the secondary condenser slowly until a station or carrier whistle is heard; keep the condenser centered about this point and move the potentiometer slider gradually towards the **positive** side of the filament, making slight readjustments of the secondary condenser to keep the station in tune.

4. Turn the coupling dial to about "50" and then revolve the primary condenser to tune the antenna circuit and thereby improve the audibility of the signal. These adjustments will

also necessitate slight readjustments of the secondary condenser.

If interference is experienced, turn the coupling dial a few degrees toward zero; that is to say, loosen the coupling between the primary and secondary circuits, then retune both the antenna and secondary circuits. Repeat this process if necessary until the interfering signal is eliminated. Variation of the potentiometer setting also assists in securing selectivity. It is advisable to keep a record of the best positions of the antenna condenser, coupling dial and secondary condenser for the most common transmitting stations.

The Filkostat filament controls will be found particularly useful when tuning the receiver for weak signals. When the position of the potentiometer has been found which gives maximum audibility of a weak signal, the audibility can often be greatly increased by slightly changing the temperature of the filaments of the r.f. amplifying tubes. A wire rheostat does not give a fine enough control of the filament current to make this useful adjustment but the Filkostat varies the filament current very gradually and evenly and therefore acts as a very valuable tuning control.

LESSON 11.

RADIO AMPLIFIER TYPE R.G. 500.

Tuner and Two-Stage Radio Frequency Amplifier for Increasing the Range of Any Receiver.

There are probably many readers of this book who appreciate the many advantages offered by the R.G. 510 receiver described in the previous lesson and who would like to possess such a receiver; but they may already have a radio receiver or a detector and audio frequency amplifier. The question which then presents itself to these amateurs has been asked by hundreds of others in a similar situation—"How can I add radio frequency amplification to my receiver?"

This question has been answered in a variety of ways but most of the suggestions offered necessitate changing the wiring or design of the receiver to which radio frequency amplification is to be added. Incidentally, many of the suggestions offered are exceedingly inefficient as **no provision is made for increasing the selectivity of the system**, although the audibility is enormously increased by adding the radio frequency amplifier.

The highly efficient tuner and two-stage radio frequency amplifier described in this lesson can be used with any radio receiver (or detector and audio frequency amplifier) **without changing any wiring or altering the receiver in any way.** In other words, the owner of either a regenerative or a non-regenerative receiver can add a thousand miles or more to his receiving range; secure exceedingly selective reception and obtain the many other desirable features of the R.G. 510, by constructing at low cost the tuner and amplifier set forth in this lesson and using it in connection with his receiver.

This tuner and amplifier (known as Type R.G. 500) can be used with any radio receiver or detecting system. When used in connection with a receiver and a two or three-stage audio frequency amplifier, the remarkable audibility and selectivity of the R.G. 510 receiver are exactly duplicated. One of the most unique features of the R.G. 500 tuner and amplifier is the key switch with which the radio frequency amplifier may be cut out of the circuit if desired. This switch connects the tuner of the R.G. 500 directly to the receiver or detecting system with which it is used and opens the filament circuit of the radio frequency amplifier. This is a distinct advantage as the radio frequency amplifier is seldom required for local reception but is ready for action at the flick of a switch.

The Circuit: The diagram of Fig. 133 shows the complete circuit of the R.G. 500 tuner and amplifier. The tuner consists of a Harkness Coupler with two variable condensers and

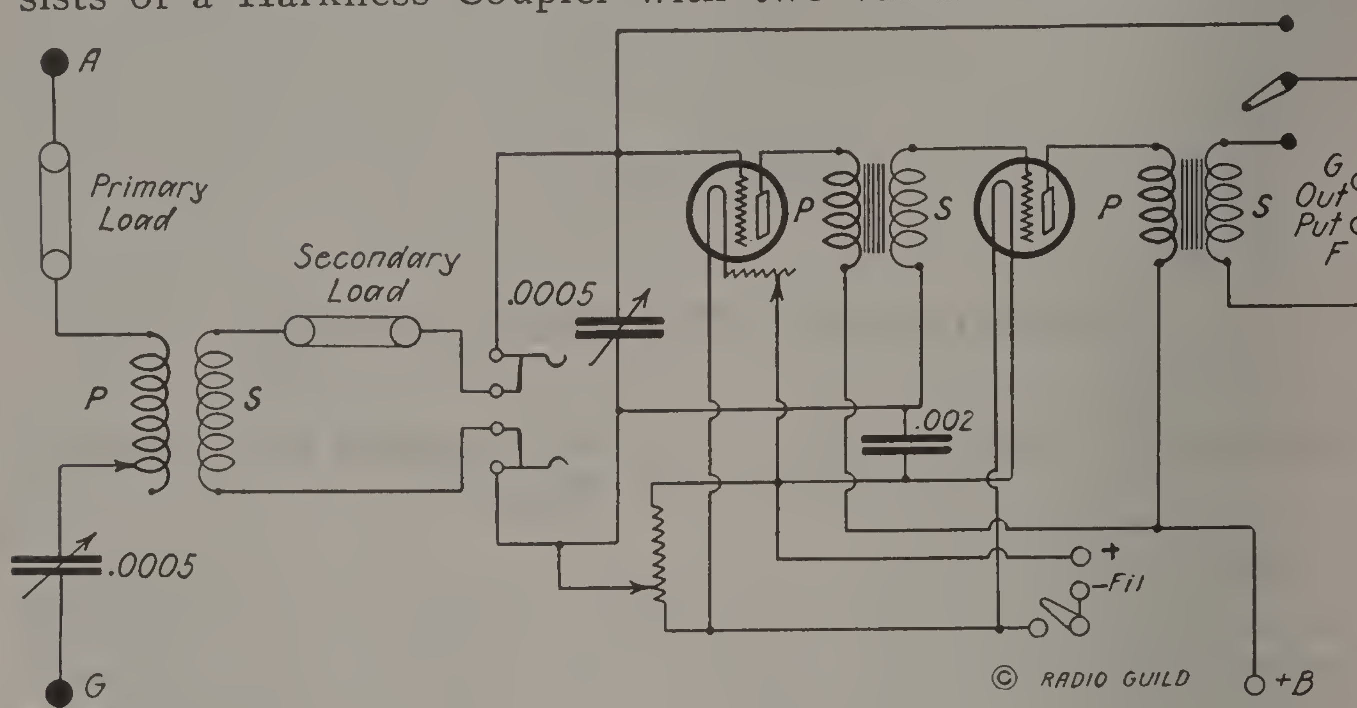


Fig. 133

is exactly similar to the tuner of the R.G. 510. The radio frequency amplifier comprises two stages of DX transformer-coupled amplification. A DX transformer is used to couple the output of the amplifier to the receiver or detecting system. A double circuit jack is provided so that either a loop or an outside aerial can be used to pick up signals.

CONSTRUCTING THE R.G. 500.

The R.G. 500 is divided into two main parts: the tuner and the radio frequency amplifier. The latter is constructed as a separate unit, which we will first describe in detail.

The Amplifying Unit: The following apparatus is used in the construction of the amplifying unit:

1 Formica panel measuring 5 x 6¾ x ¼ inches.
2 Tube Sockets.
1 Potentiometer.
1 Filkostat.
1 Double Circuit Loop Jack.
1 Anti-Capacitv Key Switch.
2 DX Radio Frequency Transformers.
8 DX Transformer Mounting Lugs.
9 Binding Posts and 1 Fixed Condenser (.002 mfd).
Sundry screws, brackets and wire.

As the R.G. 500 amplifying unit is one of the system of "Ampli-Units" described in Lesson 9, the same high quality type of apparatus is used in its construction. This is the only unit, however, in which a key switch is used. A Federal anti-capacity switch was chosen and has been found very satisfactory in operation.

Assembling the Unit: The construction of this unit is very similar to that of the other units. The Formica panel to which all the apparatus is attached is first laid out in accordance with the scale drawing of Fig. 134. All holes shown in this diagram are accurately drilled and both sides of the panel are grained.

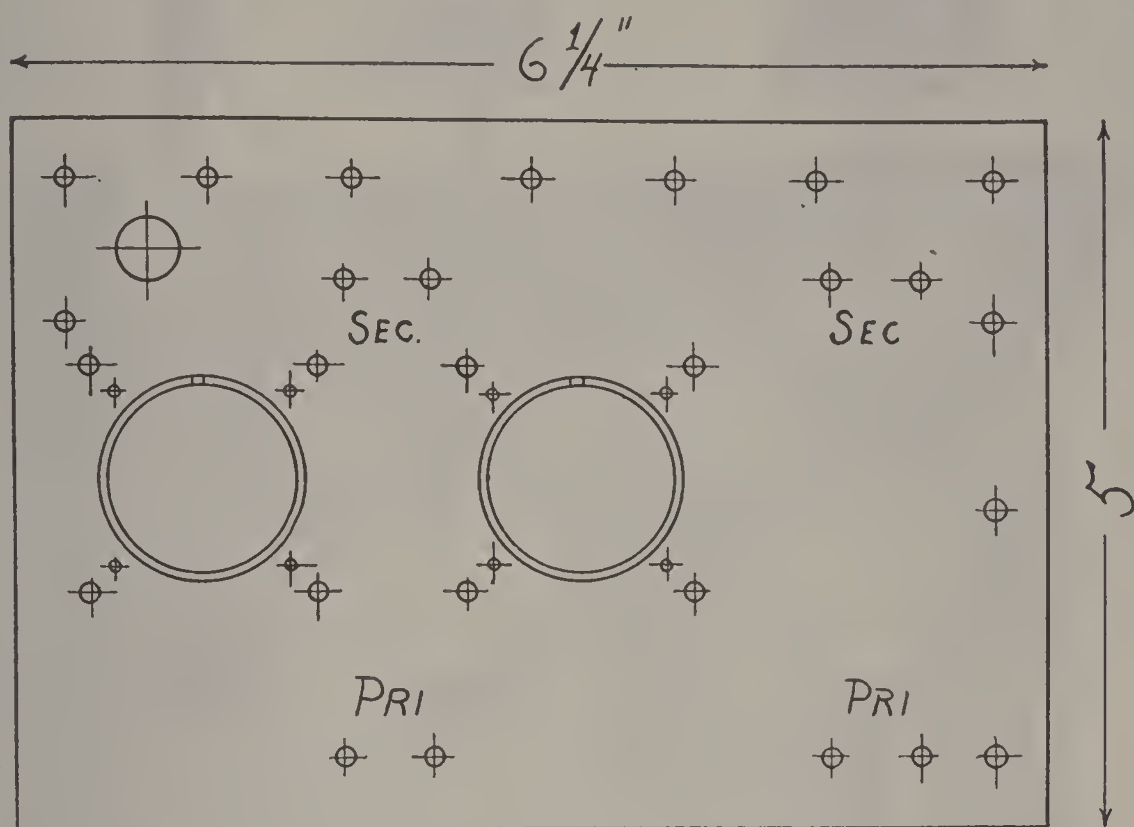


Fig. 134

The sockets are spun in and all the other apparatus is firmly mounted to the panel with 6/32 machine screws. The photo-

Fig. 135

graphs (Figs. 135 and 136) show upper and lower views of the completely mounted but unwired unit.

Wiring of Unit: A separate and complete wiring diagram of the unit itself is given in Fig. 137. The wiring is made with

Fig. 136

short direct leads in the usual manner. The design of the unit permits short grid and plate leads, which is highly desirable. Reference should be made to Fig. 121 for details of wiring to the loop jack. The importance of carefully soldering and then cleaning all joints is again emphasized. Each joint, after being

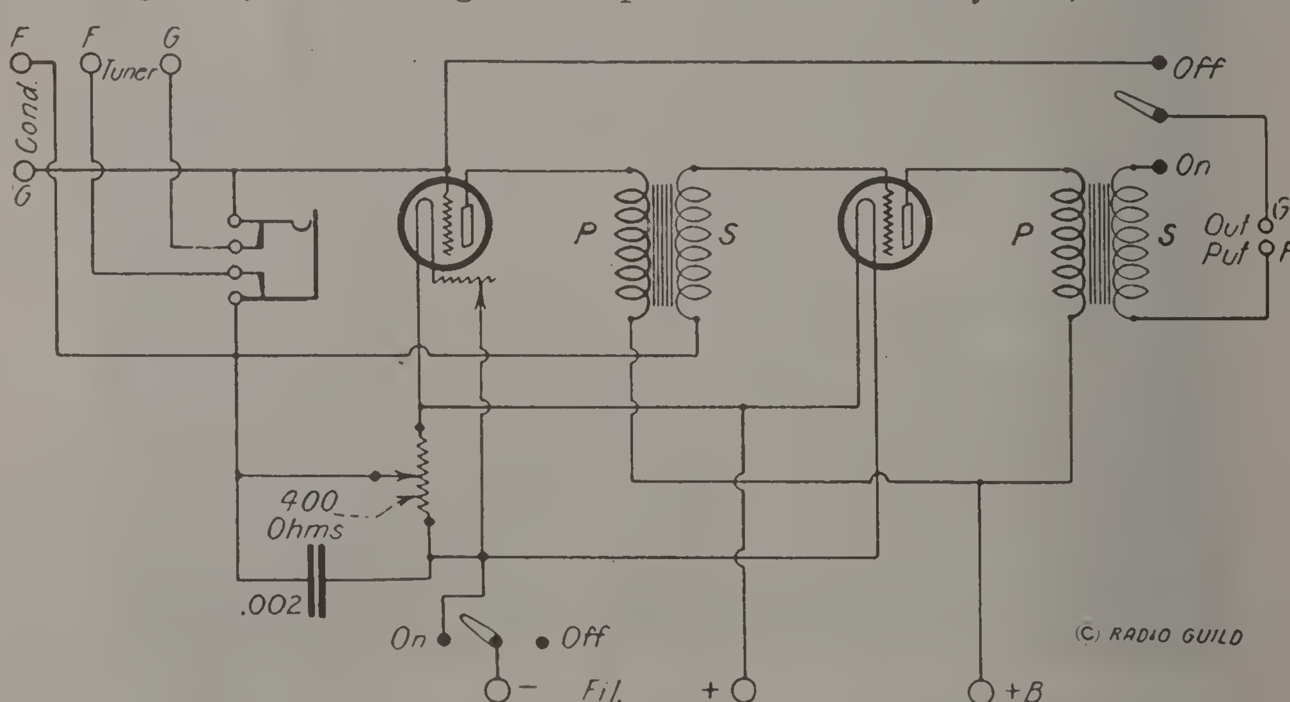


Fig. 137

carefully soldered, is wiped clean with a dry cloth, then brushed with alcohol to dissolve any remaining flux and finally rubbed spotlessly clean with a fresh cloth. Many home-made receivers and, in fact, some commercial ones, lose a great deal of efficiency by neglecting this necessary work.

Assembly of the Complete R.G. 500: The following apparatus, in addition to the completely wired amplifying unit just described, is necessary in constructing the R.G. 500:

1 Formica panel measuring 10½ x 17 x 3/16 inches.
1 Harkness Coupler.
1 Inductance Switch Set (including switch lever, four switch points and two switch stops).
2 Variable Condensers (.0005 mfd each).
8 Binding Posts.
3 Dials.
1 Cabinet, measuring 10½ x 17 x 8½ inches (outside).
Sundry screws and wire.

The above apparatus has already been fully described in previous lessons.

The construction of the R.G. 500 from this point is very similar to the construction of the R.G. 510. The front panel is first drilled in accordance with the scale drawing of Fig. 138. The panel is grained and engraved after the holes are drilled.

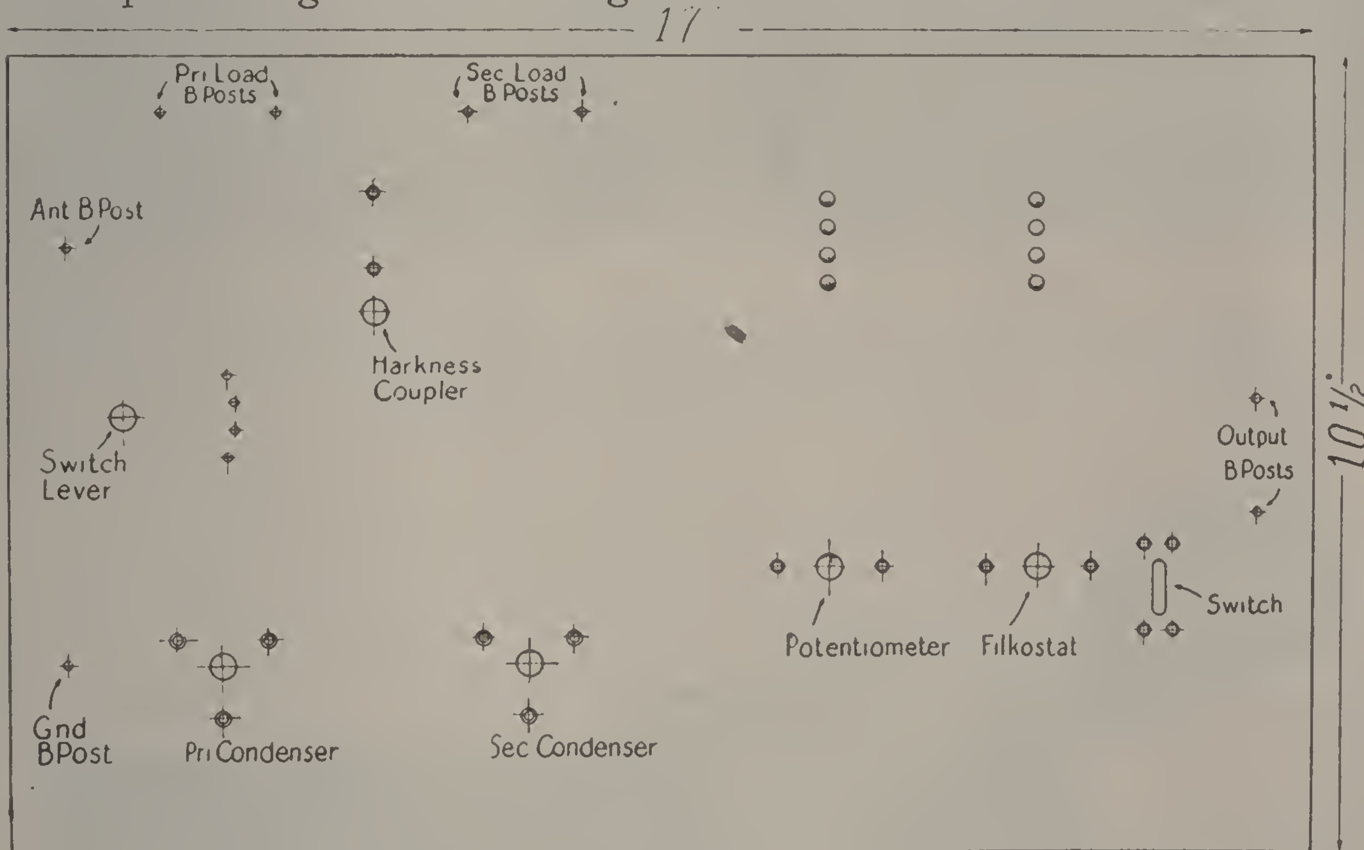


Fig. 381

With the completely wired amplifying unit in hand, the assembly and wiring of the R.G. 500 are very simple. Again a soldering iron and a screw driver are the only tools required to complete the work. The below procedure should be followed:

1. Mount the Harkness Coupler, the two variable condensers, the inductance switch set and the eight binding posts on the panel in the manner indicated in Fig. 139.

2. Completely wire the antenna circuit. Follow the wiring diagram of Fig. 133. The photograph of Fig. 139 shows how this wiring is made. Also connect a wire from one of the secondary terminals of the coupler to one of the secondary loading coil binding posts.

3. Remove the potentiometer, Filkostat and anti-capacity switch knobs; then mount the unit in place on the back of the panel as illustrated in Fig. 140.

4. Firmly secure the unit in place by screwing in the four mounting screws of the key switch, the two mounting bolts of the Filkostat and the two mounting bolts of the potentiometer. Brackets are unnecessary to hold the unit in place as these mounting screws and bolts hold the unit very securely to the front panel.

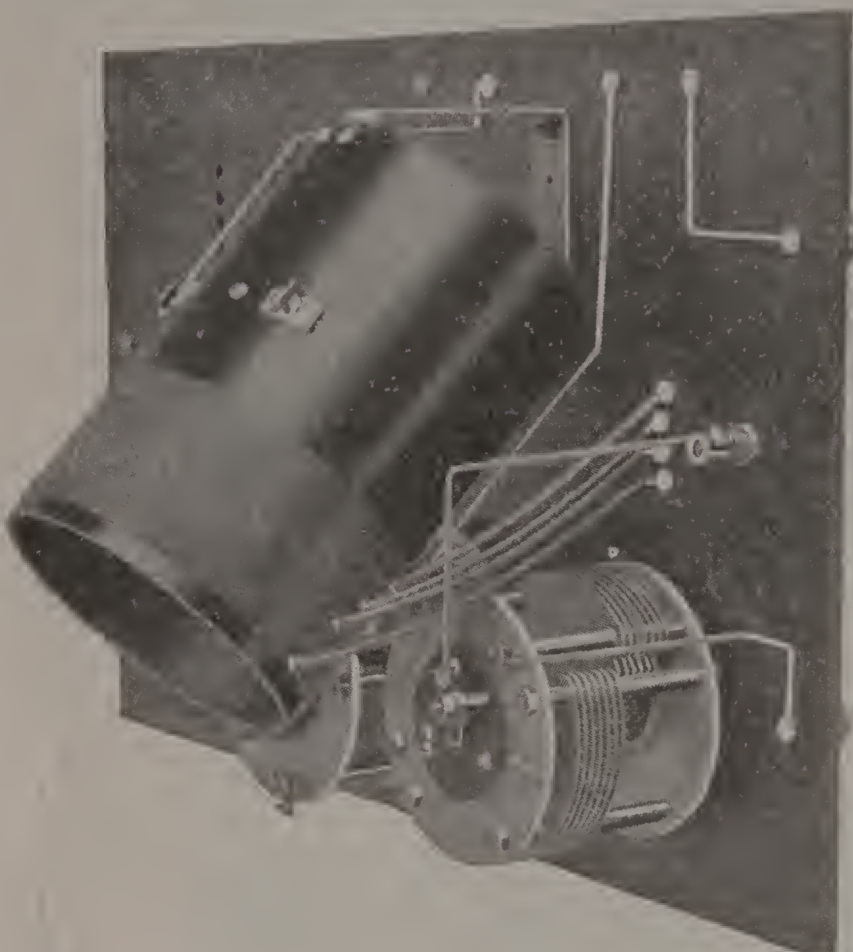


Fig. 139

5. Connect the tuner to the amplifying unit in exactly the same manner as previously shown in Fig. 130. Connect the movable plates of the secondary condenser to the "F" or filament side of the "condenser" terminals on the unit. Also wire the output terminals of the unit to the output binding posts in the front panel. Fig. 141 shows the rear view of the completely wired set.

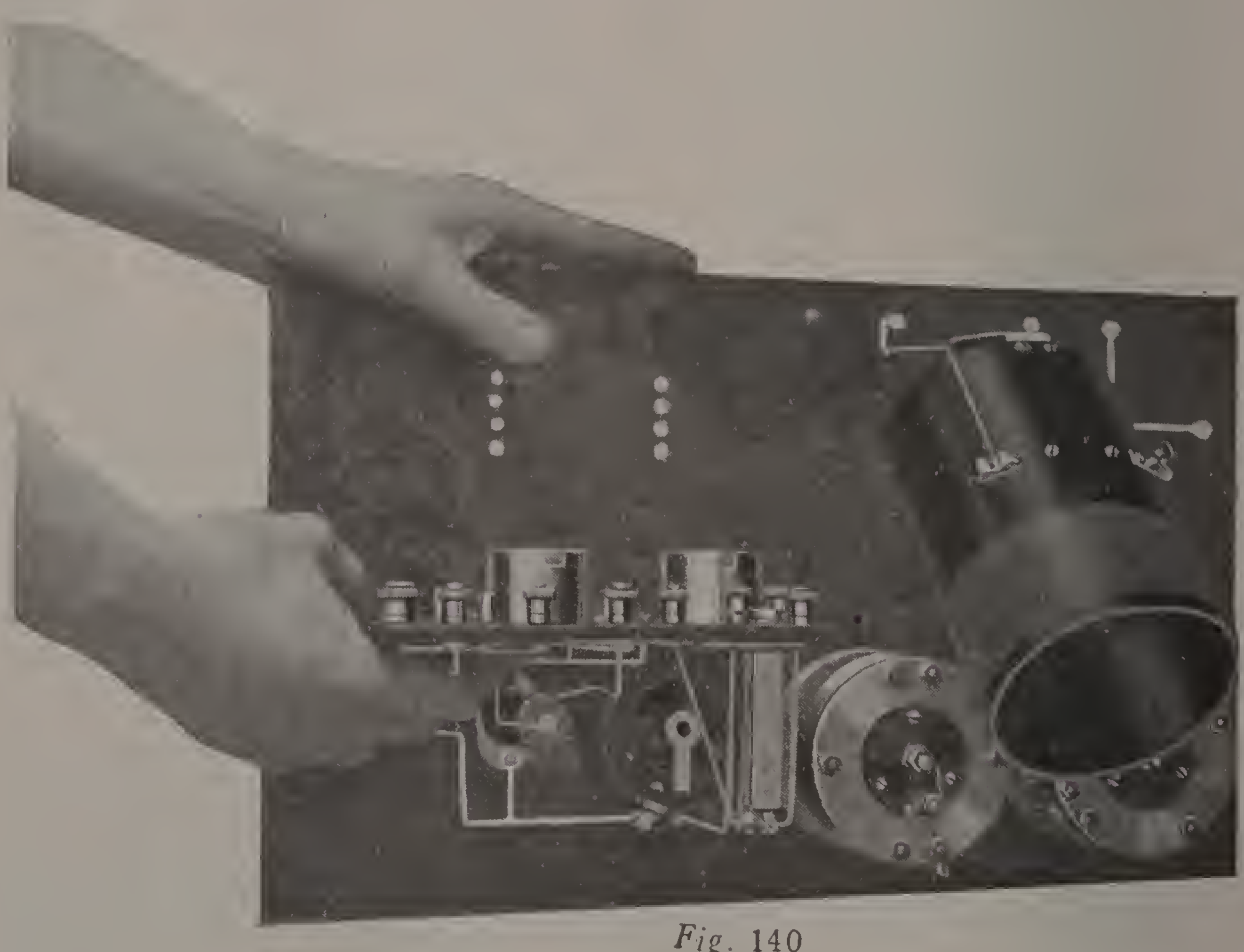


Fig. 140

6. The assembly and wiring completed, mount the three dials on the shafts of the variable condensers and Harkness

Coupler; also mount the potentiometer knob, Filkostat knob and the key switch knob. Then screw the finished set into its cabinet. Figs. 142 and 143 are front views of the complete R.G. 500.

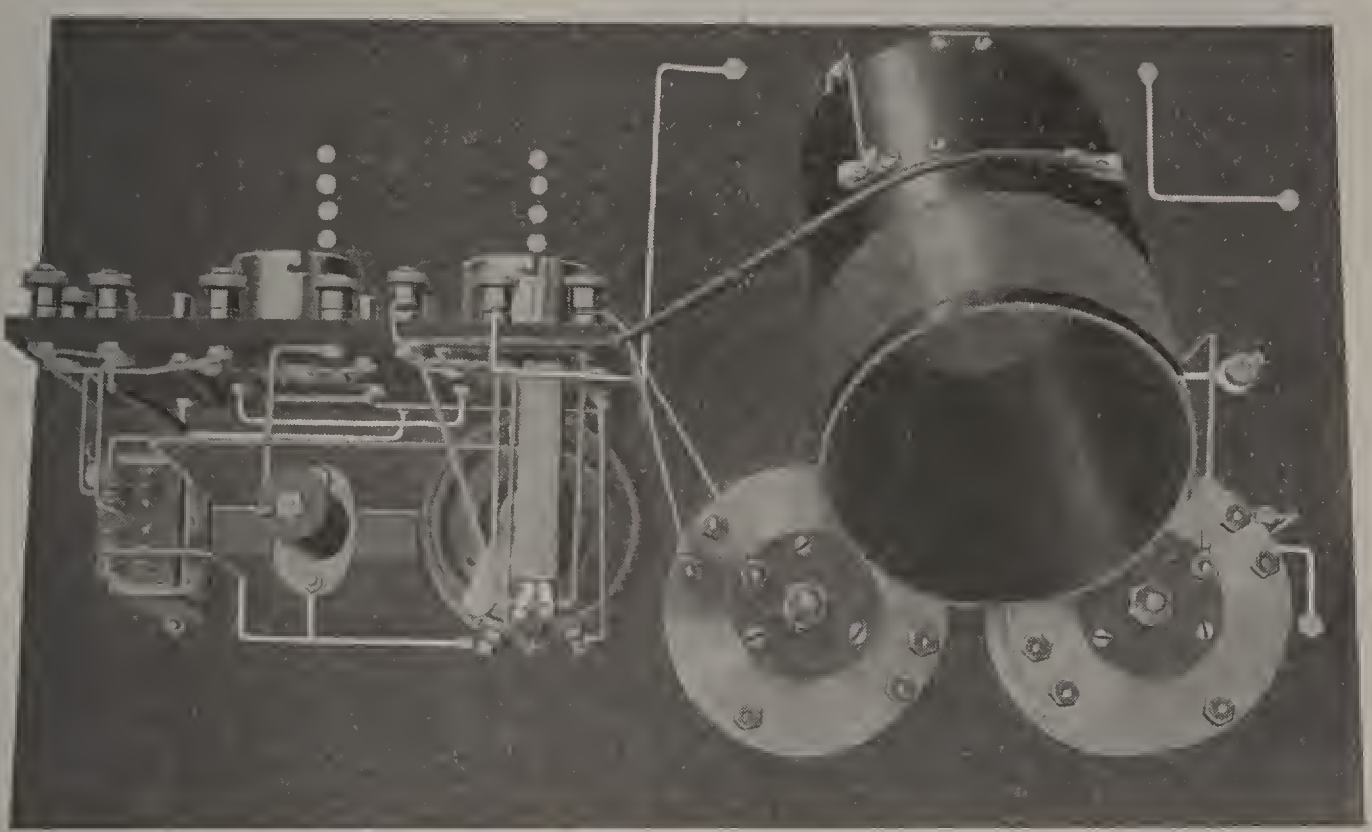


Fig. 141

INSTALLATION OF THE R.G. 500.

To install the R.G. 500 amplifier, proceed as follows:

1. Shunt the primary and secondary loading coil terminals with short sections of wire. Connect a storage battery to the "Fil" terminals on the amplifying unit and connect the positive terminal of a 90-volt plate battery to the "B Pos." post on the amplifying unit. Connect the negative end of the plate battery to the positive side of the filament battery. Make certain that the batteries are in good condition.

2. Insert the amplifying tubes in the tube sockets and make sure that the tubes are making positive contact with the socket springs. Insert the DX transformers in their mountings.

3. Connect the aerial and ground to the antenna and ground posts on the front of the panel.

The amplifier is then ready to be connected to a receiving set or simple detecting system. The R.G. 500 amplifier can be used with any of the following:

1. A plain crystal rectifier.

2. A vacuum tube rectifier.

3. A simple tuner of any type and either a crystal or vacuum rectifier.

One, two or three stages of audio frequency amplification may succeed the detecting system of any of the above three classes.

In connecting the amplifier to a detecting system under the first classification the "G" post of the output terminals is connected to one side of the crystal rectifier; the other side of the

Fig. 142

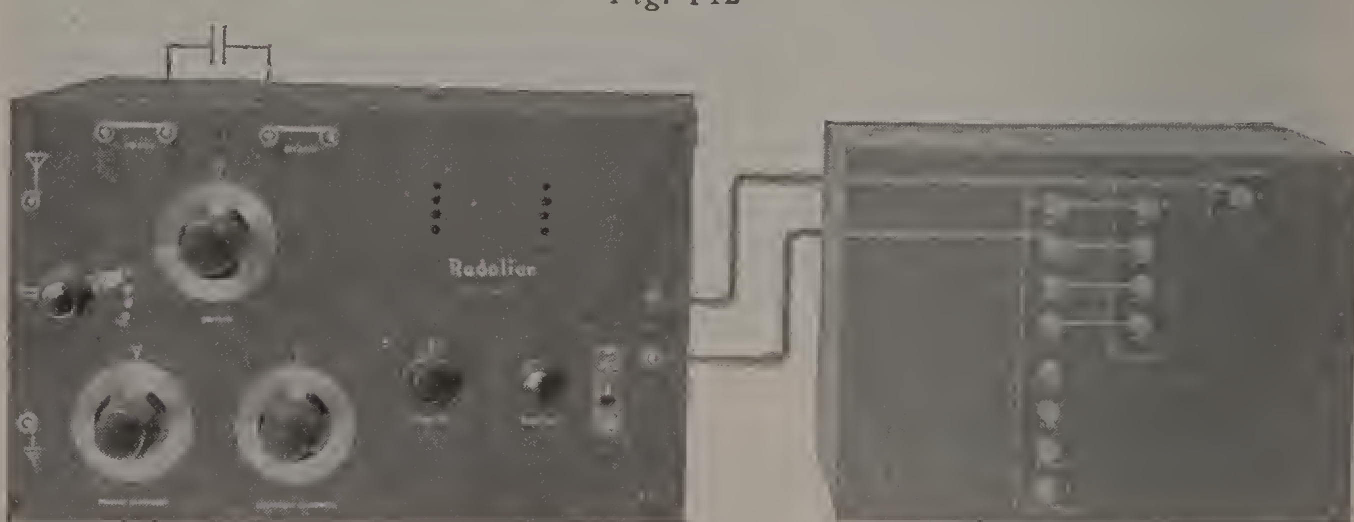


Fig. 143

crystal is connected to one telephone terminal and the remaining 'phone terminal is connected to the "F" post of the output terminals on the amplifier. If the crystal set contains a tuner of any description, the output posts of the amplifier are connected to the antenna and ground posts of the crystal receiver.

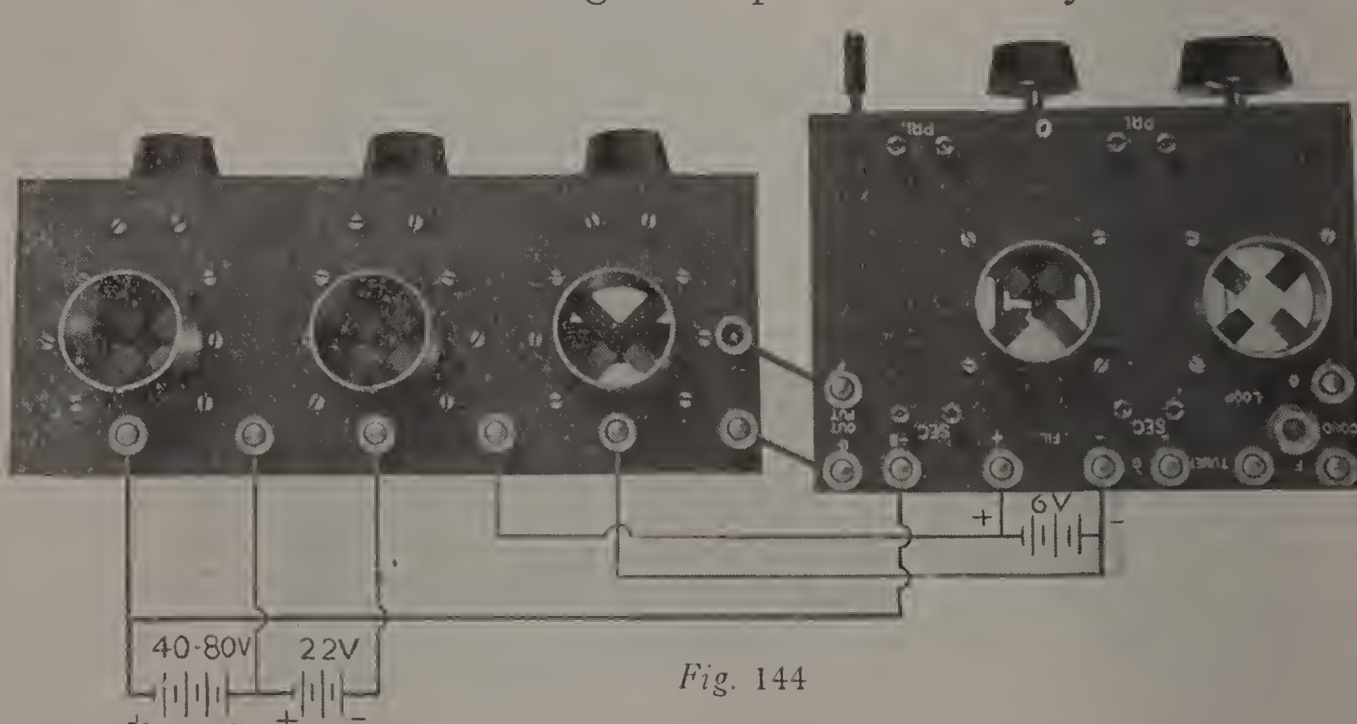


Fig. 144

With detecting systems of the second class, the output terminals of the amplifier are connected to the input posts of the detector; that is to say, the output of the radio frequency amplifier is connected across the grid and filament of the rectifying tube. The filament and plate batteries of the radio frequency amplifier can be used for the detector tube. Fig. 144 illustrates how the R.G. 500 amplifier is connected to a vacuum tube detecting system with audio frequency amplifier. Only one storage battery and one 90-volt plate battery are required.

If the amplifier is used with a simple tuner and detecting system in the third classification above, the output terminals of the amplifier are connected to the aerial and ground posts of the tuner while the battery connections are the same as described above. Fig. 143 illustrates how the amplifier is connected to a standard receiving set.

When audio frequency amplification is used with any of the above systems, the connections remain the same. The battery connections are as illustrated in Fig. 144. The use of audio frequency does not affect the tuning of a radio receiver in any way.

OPERATION.

The following general methods of reception are made conveniently possible when the R.G. 500 is used with any type of receiver or detecting system:

1. Loop reception with Radio Frequency Amplification.
2. Aerial reception with Radio Frequency Amplification.
3. Aerial reception without Radio Frequency Amplification.

Loop reception without radio frequency amplification is also possible but is only practical when receiving nearby stations.

When the anti-capacity key switch of the R.G. 500 is thrown to the down position, the circuit is changed (see Fig. 137), so that the secondary of the coupler is connected to the output terminal and the filament circuit of the amplifier is broken. When the switch is raised to the opposite position the secondary of the last radio frequency transformer is connected to the output terminal and the filament circuit of the amplifier is completed.

Therefore, to use the radio frequency amplifier for either loop or aerial reception, throw the switch up; to cut off the amplifier when receiving with the aerial, throw the switch down and slide the potentiometer to the positive side of the filament.

If the R.G. 500 is used with **either a plain crystal or vacuum tube rectifying system,** the following operating instructions should be followed:

For reception with either loop or aerial **with** radio frequency amplification (1 or 2 above), throw up the key switch to include the radio frequency amplifier in the circuit and then follow the instructions for the operation of the R.G. 510 receiver given in Lesson 10. The operation of both receivers in this respect is identical.

For reception with the aerial **without** radio frequency amplification, remove the loop, switch off the radio frequency amplifier and turn the potentiometer to the positive side of the filament. If the detecting system has a crystal rectifier, connect a small fixed or variable condenser between the primary and secondary loading coil posts as shown in Fig. 143 and then manipulate the three controls of the R.G. 500 tuner in accordance with the instructions given in previous lessons for tuning coupled circuits. However, if the detecting system has a vacuum tube rectifier, as is common, the condenser shown in Fig. 143 is not required, provided a variometer is used to tune the plate circuit of the vacuum tube detecting system. With the radio frequency ampifier switched off the R.G. 500 and a tuned plate detecting system together constitute a simple regenerative receiver exactly similar to the circuit of Fig. 71, Part 1. The antenna circuit is tuned to resonance with an incoming signal by revolving the primary condenser of the R.G. 500. The secondary circuit is tuned to resonance with the secondary variable condenser, and the plate circuit is tuned with the plate variometer. The audibility and selectivity of the system is controlled by varying the coupling between the antenna and secondary circuits. A variation of this coupling necessitates a slight readjustment of the primary and secondary condensers. When the R.G. 500 is used in this manner it will be found very helpful to use a Filkostat to control the filament current of the detector tube. This vernier adjustment of the detector filament current is very useful in controlling regeneration and greatly assists and simplifies the tuning.

If the R.G. 500 is used with some **standard type of receiving set which includes a simple tuning and detecting system**, the operating instructions given below should be followed. In these instructions, the expression "receiver" refers to the standard receiving set with which the R.G. 500 is used.

For loop reception with radio frequency amplification, insert the loop in the loop jack and set the potentiometer to the negative side of the filament. Adjust the **receiver** controls to the **approximate** wave-length to be received and vary the secondary condenser of the R.G. 500 until the station is heard. Then vary the potentiometer and secondary condenser for better results. Finally tune the **receiver** accurately for maximum signal strength.

For antenna reception with radio frequency amplification, tune the **receiver** in the manner described above; otherwise, follow exactly the operating instructions given in the last paragraphs of Lesson 10.

For antenna reception without radio frequency amplification, either switch off the radio frequency amplifier or connect the aerial directly to the antenna post of the receiver with which the R.G. 500 is used. By the former method very selective tuning can be obtained but the latter method is preferable if the receiver already has a selective tuner; the tuning is less complicated and the audibility greater.

LOADING COILS.

It will be noted that loading coil terminals for the primary and secondary circuits of the tuner are provided in both the R.G. 500 and R.G. 510. For short wave reception, these terminals are normally shorted. To receive wave lengths over 600 meters, the shorting lugs must be removed, loading coils of the proper inductance value connected to the terminals and the radio frequency transformers changed. The loading coils may be laid on top of the cabinet or special mountings may be provided for them. A variable coupling is not essential. Usually they should be placed at right angles to each other.

The following coils of the honeycomb, duo-lateral, or Giblin-Remler type may be used. The number is usually an indication of the total number of turns on the particular coil:

	Primary	Secondary
600-1500 meters	150	100
1500-3000 meters	300-400	300

To cover this range of wave-lengths, the following types of DX radio frequency transformers should be inserted in the radio frequency amplifier:

Type DXS: 400-1200 meters.
Type DX2: 900-3000 meters.

LESSON 12.

THE "NEUTRODYNE" SYSTEM

Announcements have frequently been made that radio is about to be "Revolutionized." Beyond the mere statement, nothing of a very startling nature seems to happen. From time to time these revolutionary expectations are heralded upon the publication of trick circuits which one is led to believe will immediately supersede all previous attempts at radio reception.

But like ships that pass in the night, the revolutionary circuits, which are usually old circuits with some doubtful variations, create their little uproar and pass on in their way to oblivion. Unfortunately, however, in the avalanche of "new circuits" some perfectly good circuits are overlooked. The much maligned "super-regenerative" was cast aside because too much was expected of it. It was given so much publicity and received such rough handling on the part of many of its exponents that the amateur was led to believe that with the turn of a wrist he could receive China on one tube. When he failed to realize this expectation—or one just as fantastic—the circuit was discarded.

Of late, the so-called "Neutrodyne" system has been given

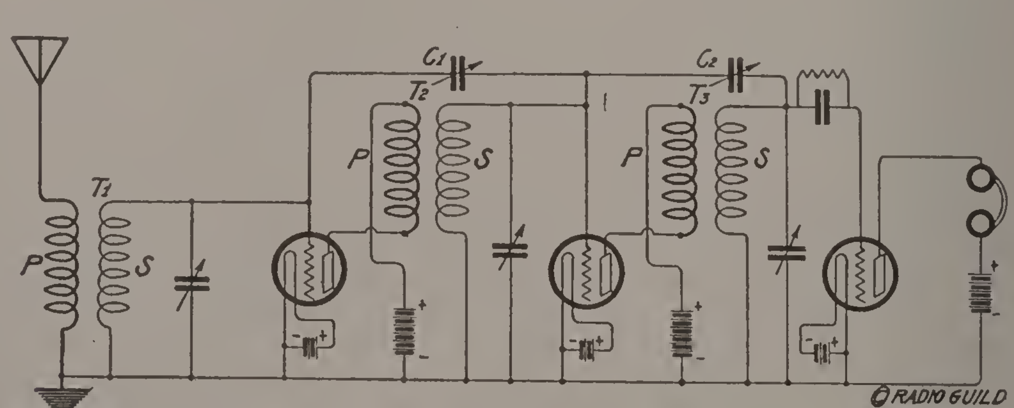


Fig. 145

some publicity and the usual claim of revolutionizing radio has been made by some. The object of the system is to prevent self-oscillation in the circuits of a radio frequency amplifier. An example of the manner in which it accomplishes this is shown in the theoretical circuit diagram of Fig. 145. This circuit shows two stages of radio frequency amplification and detector. T2 and T3 are inter-tube coupling transformers. To counteract the feed-back effect of the internal capacity of the amplifying tubes in the circuit the grid circuit of the second tube is coupled back to the grid circuit of the first tube by the condenser C1 and the secondary of the transformer T3 is coupled back to the grid circuit of the second amplifying tube by the condenser C2.

The author fails to see anything particularly "revolutionary" about this circuit. By this he does not mean that the circuit is inefficient; on the contrary, the principle of neutralizing the capacity feed-back of amplifying tubes in a radio frequency amplifier is a very good one. The circuit itself, with the exception of the neutralizing condensers, is, of course, a standard transformer coupled radio frequency amplifying circuit. This will be evident if the circuit of Fig. 145 is compared with Fig. 87 of Part 1. In paragraphs 454 to 459 we explained fully the operation of this circuit. The transformers T1, T2 and T3 of Fig. 145 are constructed as described in these paragraphs; that is to say, the primary of each transformer is made aperiodic and each secondary circuit is tuned to resonance with a variable condenser. The circuit, then, is a modified tuned radio frequency amplifying circuit.

As regards the neutralizing condensers C1 and C2, some original explanations have been given of the action of these condensers but we are content to believe that the capacity feed-back of the amplifying tubes is neutralized by the negative feed-back produced by these condensers. The manner in which self-oscillation in a radio frequency amplifier is controlled by negative feed-back action was fully explained in Paragraphs 479 to 485 of Part 1.

Fig. 146 shows a side view of an experimental "Neutrodyne" receiver constructed by the author. This set has two stages of radio frequency amplification, detector and one stage of audio. The published circuit and specifications of the Neutrodyne receiver were followed. One of the radio frequency transformers is visible in the foreground between the detector tube and the audio frequency amplifying tube. Each of the three transformers has eight turns on the primary and fifty turns on the secondary. The coils are wound on 3½" tubing. The secondary is laid over the primary and only separated from it by a small spacing. The two neutralizing condensers are visible along the back of the panel. The drawing of Fig. 147 shows how these neutralizing condensers are made. The capacity of each condenser, of course, is very small, being about equal to the capacity of the tubes in the circuit. Following specifications, the transformers were all turned at an angle of 56 degrees and supported behind the three variable condensers used for tuning the grid circuits.

In operation, the receiver was found to oscillate if the neutralizing condensers were not adjusted properly. When the neutralizing condensers were adjusted and self-oscillation thereby prevented the selectivity of the system was excellent and the audibility fair. The audibility, of course, was not nearly so good as with a receiver comprising two stages of DX transformer-coupled radio frequency amplification, detector and one stage of audio; but this was to be expected, as the efficiency of the DX transformer is very much greater than the simple type of transformer used in this receiver. Even although the secondary of each transformer is tuned accurately to resonance, this

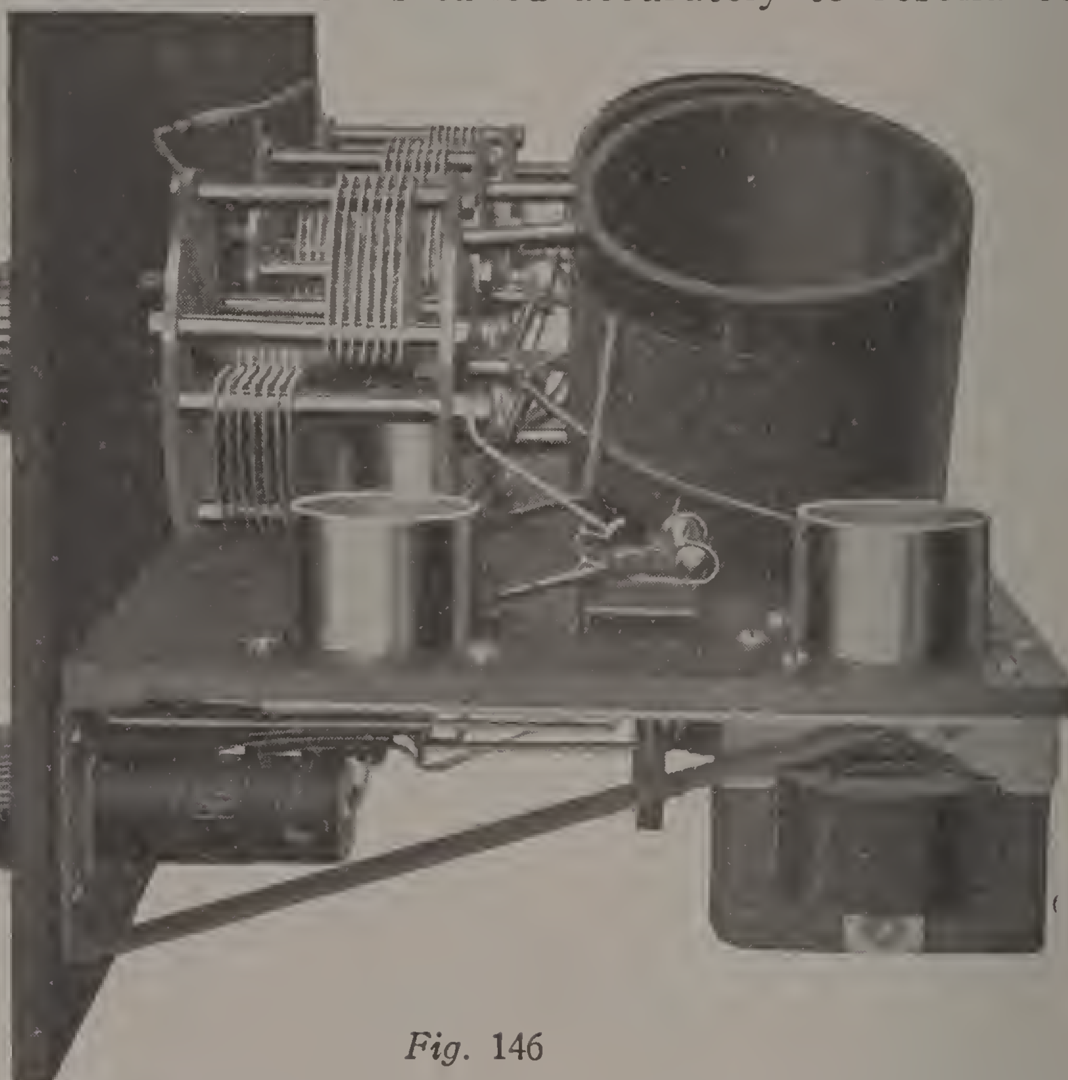


Fig. 146

does not compensate for the loss of amplification caused by the aperiodic primary. This could be remedied, of course, by tuning the primary circuits but the tuning of the system would then be so complicated that it would be impracticable.

We made numerous tests with this receiver in an endeavor

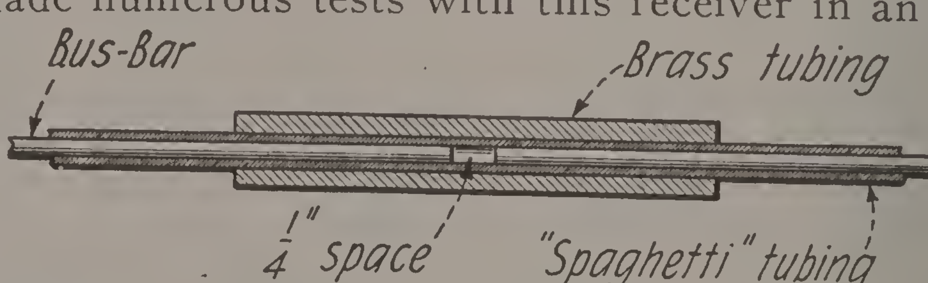


Fig. 147

to improve its audibility. Different sizes of transformers were tried and the number of turns on the primary was changed. It was found, however, that even with only six turns on the primary of each transformer, self-oscillation was produced unless the neutralizing condensers were properly adjusted. In view of the fact that, in a receiver of this type using transformers with aperiodic primaries, the most important source of feed-back—the feed-back through the internal capacity of the tubes—is very small as compared with a DX transformer coupled amplifier (See Par. 493, Part 1), it seemed to the author that there must be inductive coupling between the transformers themselves to produce self-oscillation, especially with only six turns on the primaries of the transformers. If this proved to be the case the amplification of the system, of course, must be small. As we explained in Paragraph 490 of Part 1, all sources of coupling in a radio frequency amplifier must be reduced to an absolute minimum. If there is comparatively close inductive coupling between the transformers of a radio frequency amplifier, continuous oscillations will be self-generated very easily. The only way of preventing these continuous oscillations is to reduce the amplification of the system but **the more easily the continuous oscillations are generated the greater the amplification must be reduced to stop them.**

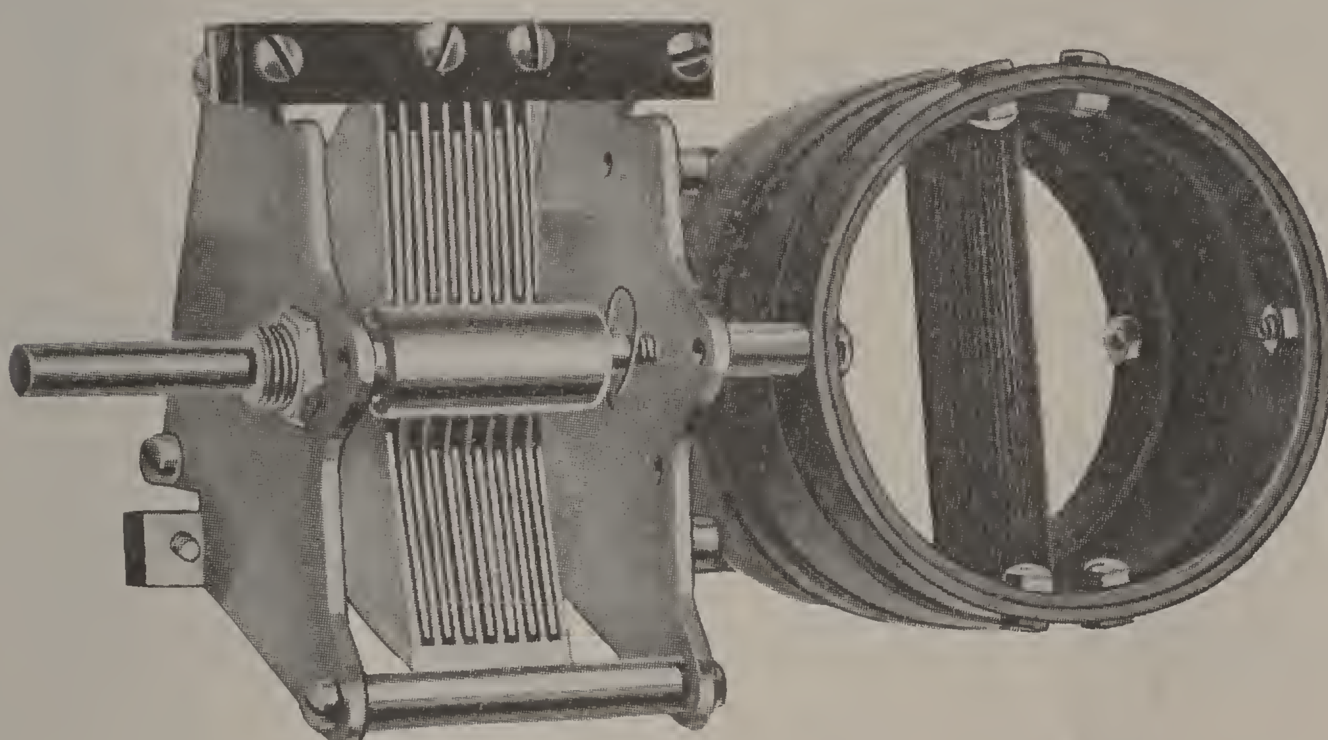


Fig. 148

THE DOUBLE-DEE R. F. TRANSFORMER.

Believing that the self-oscillation of the "Neutrodyne" receiver was chiefly caused by inductive coupling between the radio frequency transformers the Author designed a special type of transformer to eliminate this inductive coupling. This unit is known as the "Double-Dee" radio frequency transformer and consists of a special air-core transformer attached to the rear of a variable condenser as pictured in Fig. 148. It will be seen from this photograph that the transformer is composed of two sections shaped like the letter "D" and held together by bakelite rings. The coils of the transformer are wound on these two sections so that each holds one-half of the primary coil and one-half of the secondary coil, the pri-

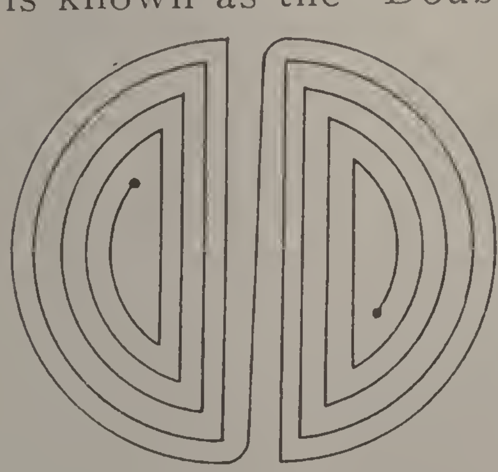


Fig. 149

mary being wound over the secondary and separated from it by a piece of heavy insulating paper. The two halves of each coil are joined together so that the winding follows the direction suggested by Fig. 149. By arranging and winding the coils in this manner a closed magnetic field is created when current flows in the transformer. The magnetic field is so concentrated that the inductive coupling between two Double-Dee transformers, separated a few inches, is practically zero.

Experiments prove that these Double-Dee transformers greatly improve the operation and stability of a tuned radio frequency amplifying receiver. The tendency towards self-oscillation caused by inductive coupling between transformers is eliminated and the Double-Dee transformer is designed so that the only remaining feed-back of importance—that produced by the capacitive coupling of the tubes—is not strong enough to generate continuous oscillations. The necessity for a potentiometer or neutralizing condensers is obviated. Moreover, the amplification of a receiver with Double-Dee transformers is higher than that of a receiver which uses transformers with ordinary solenoidal windings. The latter set "oscillates" when only 6 turns of wire are used as the primary of each transformer whereas the former set does not generate continuous oscillations although 8 turns are used on the primary of each Double-Dee transformer.

It may be mentioned that Double-Dee transformers are only intended for use in a receiver with two stages of radio frequency amplification. Ordinary transformers may be used in a receiver with only one stage of radio frequency amplification as inductive coupling can then be easily eliminated by merely turning the transformers at right angles to each other.

HOW TO BUILD A 4-TUBE RECEIVER WITH DOUBLE-DEE TRANSFORMERS.

A receiver using Double-Dee radio frequency transformers has many advantages. With high audibility and selectivity the system is easy to operate and comparatively inexpensive to construct. No troublesome adjustment of neutralizing condensers is required to prevent self-oscillation. In the remaining pages of this lesson we give particulars of a receiver of this type and sufficient constructional data to enable the reader to build the set if he so desires.

The Circuit. The diagram of Fig. 150 shows the circuit used in this receiver (known as Type R.G. 515). This circuit comprises a two stage modified tuned radio frequency amplifier, vacuum tube detector, one stage of reflex audio frequency amplification and one extra stage of audio amplification. As the grid of each amplifying tube is connected directly to the negative side of the filament the reflex system can be used to advantage. This increases the audibility of the system without increasing the number of tubes. Filament control telephone jacks are used to simplify the operation. The circuit is intended for use with U.V. 201A or C 301A tubes and Amperites are therefore employed throughout to automatically control the filament current of the four tubes. This reduces the operating controls of the

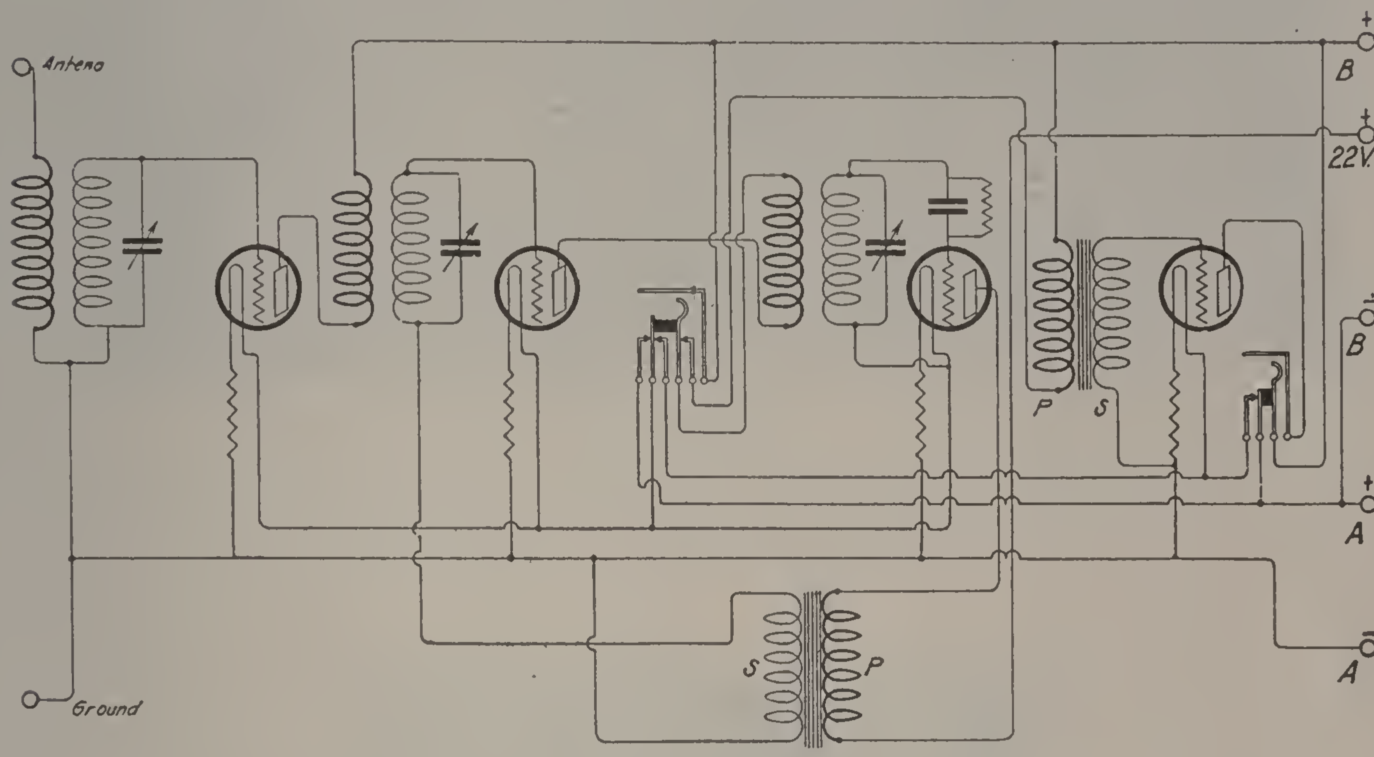


Fig. 150

receiver to the three variable condensers for tuning the three grid circuits to resonance.

CONSTRUCTION OF THE R.G. 515.

For the benefit of those who would like to build a receiver of this type we give details of the construction of this receiver below:

Apparatus Used: The following apparatus is used in the construction of the R.G. 515:

1 Formica panel measuring 19×8×3/16 inches
1 Formica panel measuring 11½ × 7½ × ¼ inches
4 tube sockets
1 grid condenser (.00025 mfd)
1 grid leak (1 megohm)
2 Filament control jacks (1 single circuit & 1 double circuit)
2 Radio Guild Audio Frequency Transformers
4 Amperites and mountings
7 Binding posts
3 Double-Dee Radio Frequency Transformers
3 Dials
1 Cabinet, measuring 20½ × 8 × 8½ inches outside measurements ½″ material
Sundry screws, brackets and wire.

Assembling and Wiring: The front and rear panels are drilled in accordance with the scale drawings of Figs. 154 and 155. In assembling the receiver, the telephone jacks and the audio frequency transformers are attached to the lower side of the rear panel. The tube sockets are spun in in the positions indicated. The grid condenser is mounted on the top of the panel near the detector tube and the mountings for the four Amperites

Fig. 151

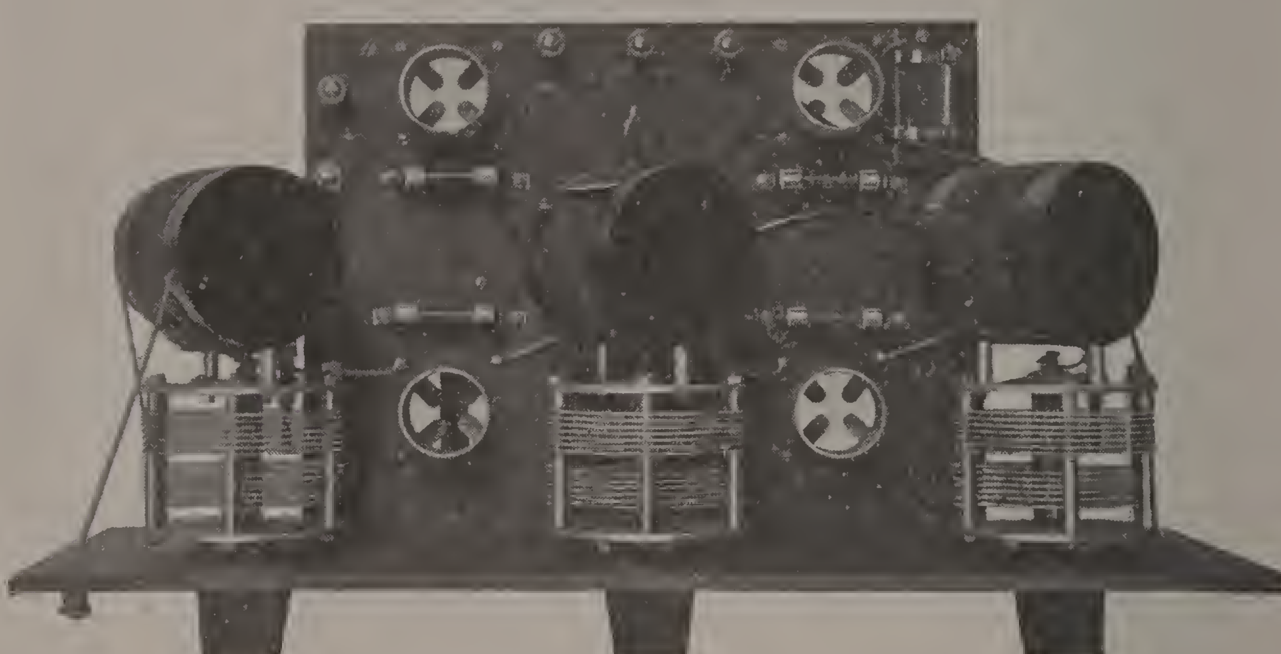


Fig. 152

Fig. 153

are also attached to the top of the rear panel. This panel is then wired separately, all the filament circuit and as much of the remainder of the circuit as possible being completed. The three Double-Dee transformers with their variable condensers are mounted on the front panel. Finally the shelf panel is mounted on the front panel with brass brackets and the wiring completed. Figs. 151 and 152 show two rear views of the receiver and Fig. 153 shows the front view.

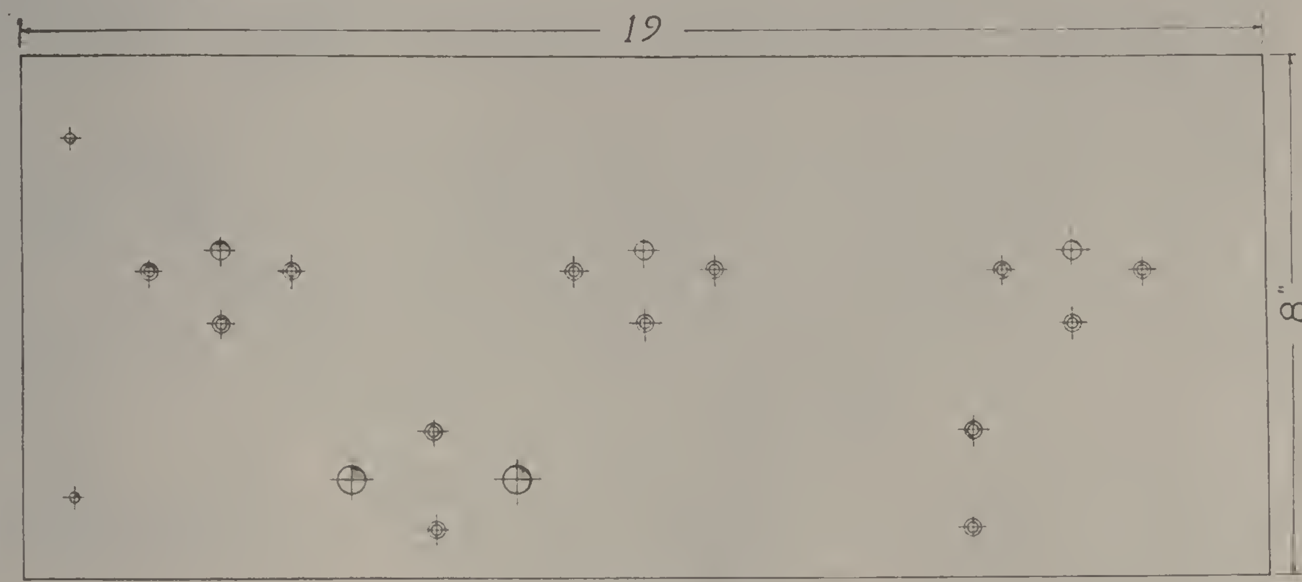


Fig. 154

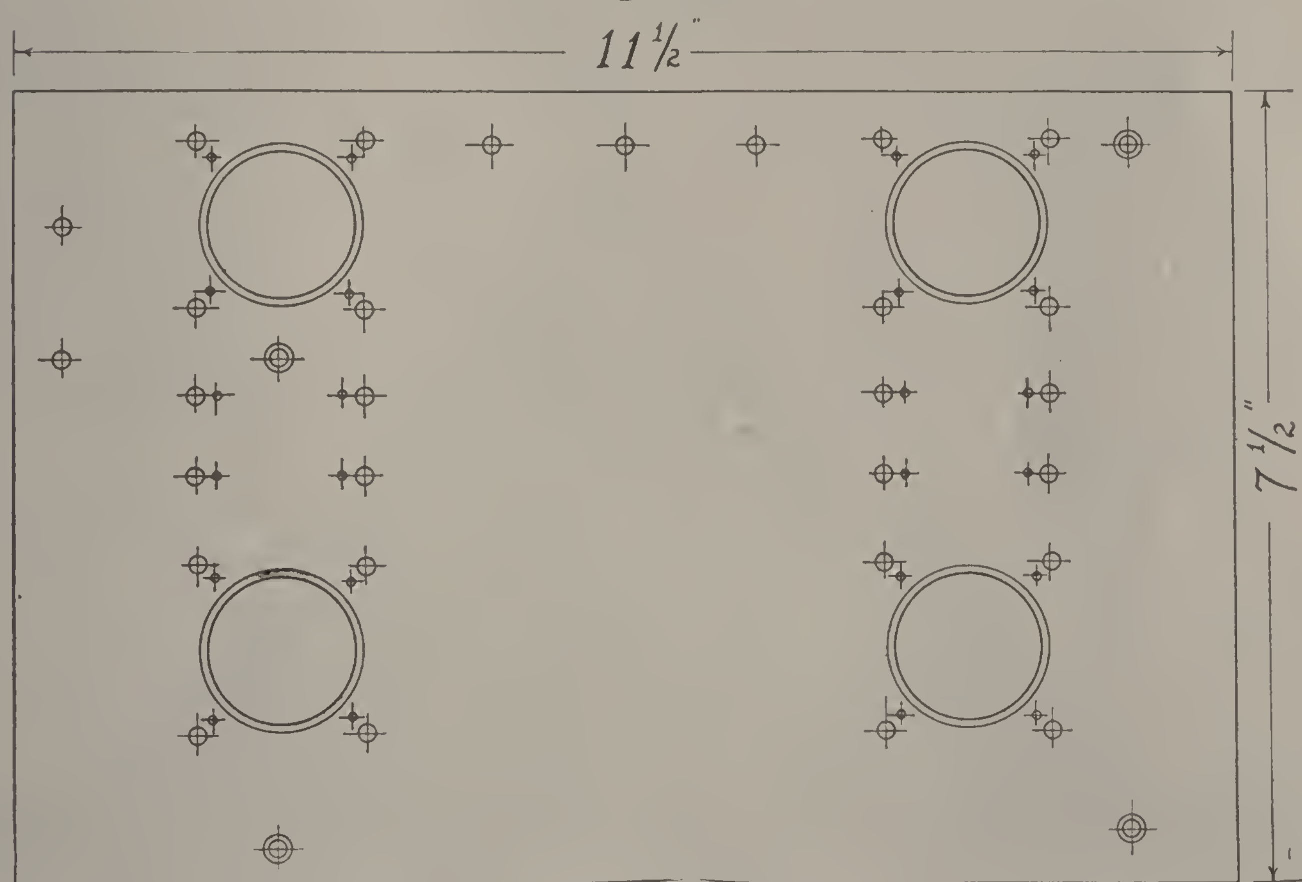


Fig. 155

Installation and Operation: To install the R.G. 515, insert four U.V. 201A tubes in the tube sockets and connect a six volt storage battery and a 90 volt plate battery to the battery terminals at the rear. Connect the antenna and ground to the binding posts on the front panel.

The operation is then exceedingly simple. There are only the three controls and each circuit is tuned independently to resonance by these controls. The three dials can be calibrated in wave-length if desired.

LESSON 13.

THE HARKNESS RECEIVER.

Models A and B.

To judge the efficiency of a radio receiver one must clearly understand the relative importance of the factors of efficiency upon which a judgment is based. Therefore, in order that the reader may easily judge and fully appreciate the advantages of the receivers which are described in this lesson we will briefly outline the relative importance of the essential qualities of a radio receiver, as graphically presented by Fig. 156.

RELATIVE IMPORTANCE OF A RADIO RECEIVER'S QUALITIES.

1. **Selectivity**: This factor is of prime importance. Above all things a radio receiver must be selective. The most useless set is one which cannot select and reproduce the broadcasting of a particular station to the exclusion of others.

2. **Audibility**: This essential quality is second in importance. For practical purposes a radio receiver must at least be sensitive enough to reproduce local stations on a loudspeaker. If the audibility be higher than this so that distant stations can also be reproduced on a loudspeaker, so much the better—provided the selectivity is proportionately high. High audibility without high selectivity is useless. (See Par. 511.)

3. **Ease of Operation**: This is a distinctly important quality in a radio receiver and is often overlooked as being a factor in determining efficiency. If one type of receiver requires three controls but has no greater selectivity and audibility than another type with only two controls, the latter set is more efficient.

4. **Cost**: The initial cost of a radio receiver is determined by the amount and quality of the apparatus required by the receiving system employed. The additional cost of the accessories and upkeep cost plainly depend upon the number of vacuum tubes the system requires. It is evident that the receiving system which requires the least amount of apparatus and the smallest number of vacuum tubes to gain a given degree of selectivity and audibility (the quality of the apparatus in all cases being equal) is the lowest in cost and is therefore the most efficient. In case the quality of the apparatus is not equal and a given degree of audibility and selectivity is gained, on the one hand, by the use of a large quantity of poorly-made apparatus and, on the other hand, by the use of a small quantity of well-made apparatus the latter is more efficient, even though the actual cost of each receiver may be identical. The receiver which uses well-made apparatus will, of

course, last longer, look better and will be less likely to develop faults than the other.

5. **Non-reradiation.** This quality, while relatively unimportant so far as the user of a radio receiver is concerned, is all-essential to the thousands of other owners of radio sets. Oscillat-

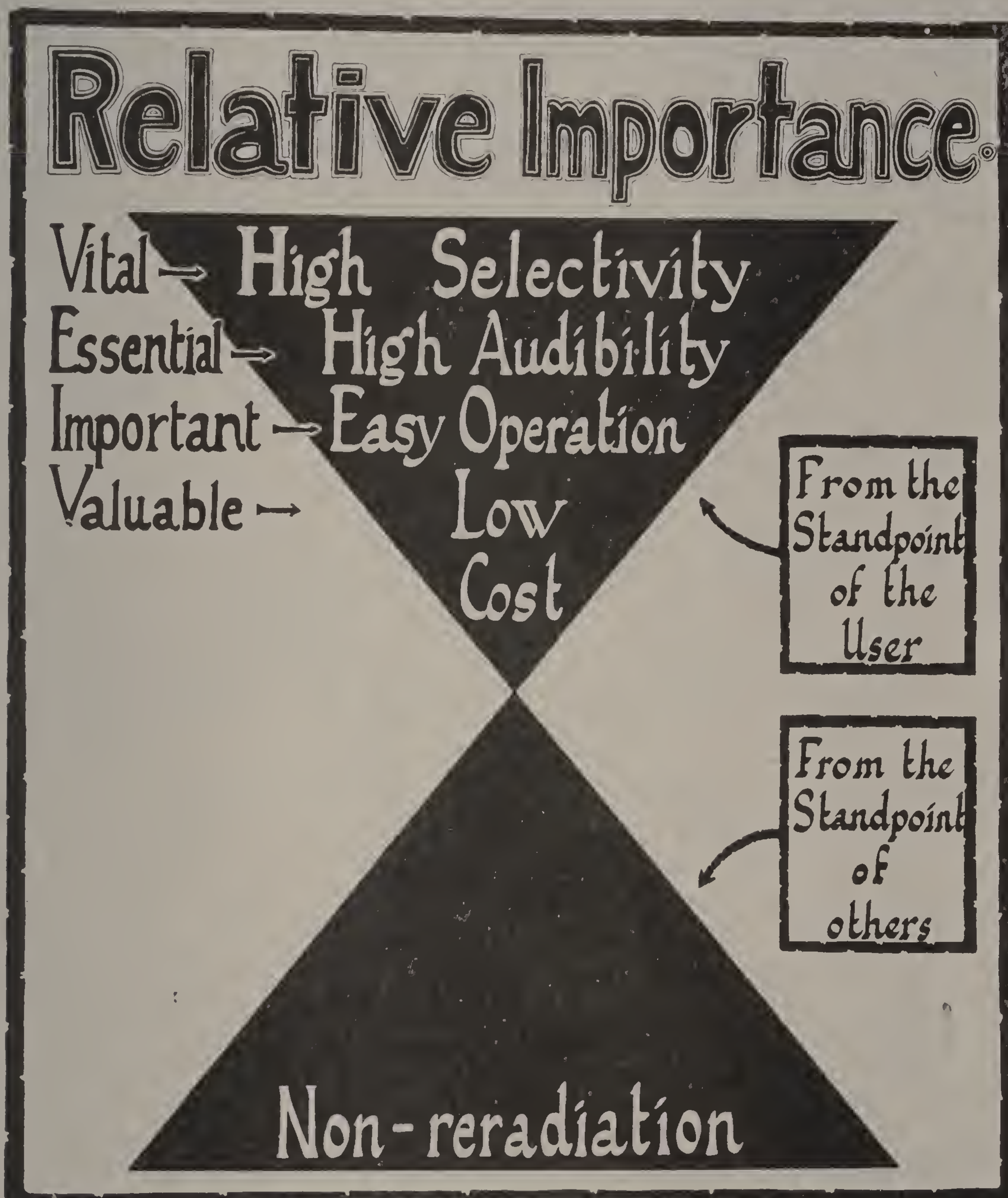


Fig. 156

ing regenerative receivers are alone responsible for the whistles and squeals which accompany the reproduction of radio broadcasting by the more modern types of non-oscillating receivers. These whistles and squeals are most objectionable and entirely preventable. If the use of oscillating receivers for broadcast reception were prohibited the quality of radio reception would be vastly improved.

THE HARKNESS RECEIVER.

The present author believed a need existed for a non-oscillating radio receiver with high selectivity and high audibility which would at the same time be inexpensive and easy to operate. After considerable experimenting he devised a circuit and designed a receiver which meets all these specifications in a surprising manner. The details of this system were initially published in the first edition of this work. The circuit has since become popular and is now generally known as the "Harkness Circuit". Receivers using the circuit are known as "Harkness Receivers".

FUNDAMENTAL HARKNESS CIRCUIT.

The fundamental Harkness Circuit is given in Fig. 157. The functioning of this circuit may be explained as follows:

An incoming signal oscillation induces an oscillating e.m.f. across the secondary of the radio frequency transformer T2. The grid circuit is tuned to resonance by means of a variable condenser and the signal oscillation applied between the grid and filament of the tube. The resulting radio frequency current variations in the plate circuit set up oscillations across the primary of the second radio frequency transformer T2. An amplified oscillation is thereby induced in the secondary of T2 which is also tuned to resonance with a variable condenser. This magnified signal oscillation is then rectified by the crystal and the audio frequency variations of the rectified current induce an alternating e.m.f. across the secondary of the audio frequency transformer, the primary of which is included in the detecting circuit. The audio frequency variations are applied between the grid and filament of the tube and the amplified variations in the plate circuit are detected by the telephones. The single tube amplifies the radio and audio frequency variations simultaneously.

Unlike most reflex receivers, the Harkness Receiver amplifies radio and audio frequency currents with full efficiency. It should be particularly noted that the grid of the reflex tube in the Harkness circuit is connected directly to the negative side of the filament. Those who have followed the contents of the previous lessons will realize the importance of this. The ordinary reflex circuit connects the grid of the amplifying tube to the center arm of a potentiometer which is shunted across the filament battery. The object of this, of course, is to control self-oscillation but while a potentiometer can be satisfactorily used for this purpose in a plain radio frequency amplifier its effect in a reflex circuit is very harmful. If the grid of a reflex amplifying tube is given a positive potential by a potentiometer the audio frequency amplification is practically reduced to zero; the audio frequency transformer might as well not be in the circuit at all and the set would probably operate a great deal better without it. (See Par. 437, Part 1.)

QUALITIES OF THE HARKNESS RECEIVER.

Audibility equal to 3-tube set: As the Harkness Receiver uses tuned radio frequency amplification and also amplifies with full efficiency at audio frequency—the grid of the single tube being connected directly to the negative side of the filament—the audibility of the receiver is consequently very high. The receiver amplifies at radio and audio frequency just as though separate tubes were used for each type of amplification. In the fullest sense the single tube does the work of two tubes. Moreover, as a crystal is used as rectifier the audibility of the receiver is actually equal to that of a receiver with three tubes. Tests have proven this to be true. To severely test the audibility of the single tube Harkness Receiver, the author constructed a 3-tube set with one stage of tuned radio frequency amplification, a tube detector and one stage of audio frequency amplification. The audibility of this receiver was accurately compared with that of

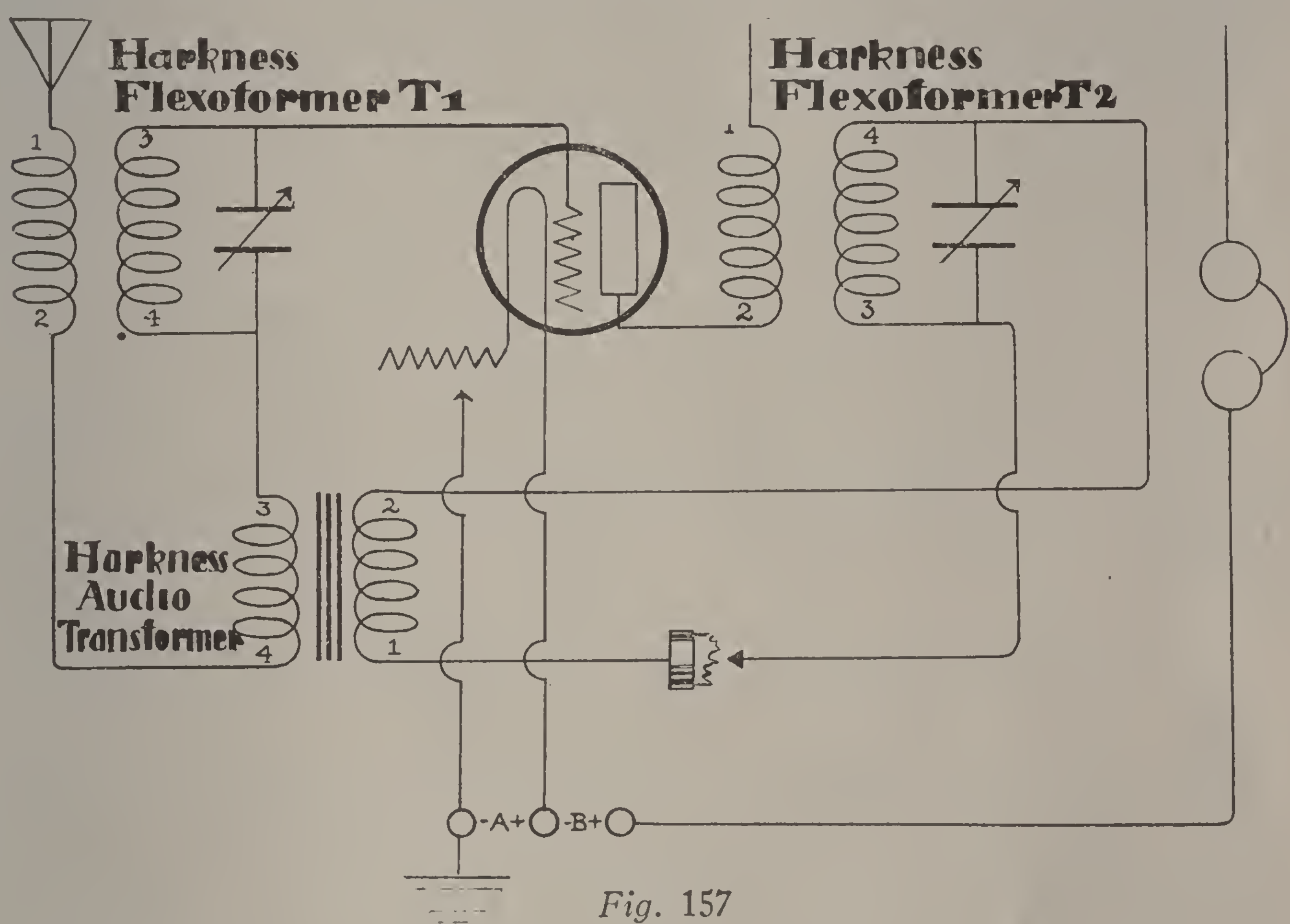


Fig. 157

single tube Harkness Receiver and the difference between the two was extremely small.

Operates Loudspeaker With One Tube: The audibility of the Harkness Receiver is so great that with only one tube it actually operates a loudspeaker with ease. With one tube the average range is 1000 to 1500 miles and hundreds of amateurs have testified that the stations within this range are often received with sufficient volume to operate a loudspeaker!

Selectivity Very High: Since the Harkness Receiver uses tuned radio frequency amplification its high audibility is not gained at a sacrifice of selectivity. As we explained in Paragraph 542 of Part 1 the selectivity of a receiver using tuned radio frequency amplification is very high and is in proportion to its audibility.

Easy to Operate: The operation of the Harkness Receiver is exceedingly simple. The circuit has only two variable controls; the set has just two dials to turn. Each control is independent of the other and the dial settings for different stations are permanently accurate. The fact that the receiver does not oscillate also greatly simplifies the operation.

Cost Remarkably Low: The cost of the Harkness Receiver is extremely low as compared with other receiving systems. The circuit and design are such that a very small amount of apparatus is required to gain high audibility and selectivity. In fact, the efficiency of the single-tube Harkness Receiver, which can be built for only twenty-five dollars, is practically equal to that of a standard 3-tube set costing three times as much.

No Whistles or Squeals—Cannot Reradiate: When built with the special apparatus designed for the circuit the Harkness Receiver does not oscillate and therefore does not generate a single whistle or squeal or cause interference to others by re-radiation.

WHY THE HARKNESS RECEIVER DOES NOT OSCILLATE.

The Harkness Receiver has no potentiometer or neutralizing condenser to stop self-oscillation and although the grid of the reflex tube is connected directly to the negative side of the filament the receiver does not generate continuous oscillations.

How is this possible? The ordinary reflex receiver requires a grid potentiometer to stop self-oscillation and other systems—notably the radio frequency amplifiers developed by the British and French during the war—use neutralizing condensers or other methods of producing negative reaction to stop self-oscillation. (See Par. 479, Part 1.) The Neutrodyne receiver uses the latter system. Why, then, does the Harkness Receiver not oscillate?

To understand the reason for this it is necessary to appreciate how self-oscillation is caused. Continuous oscillations in a radio frequency amplifier are generated by the feed-back of energy from one circuit to a preceding circuit through some form of coupling. The important sources of coupling in a radio frequenced amplifier are (1) the inductive coupling due to magnetic linkages between the radio frequency transformers and (2) the capacitive couplings between the plate and grid of each radio frequency amplifying tube. The first coupling can be avoided by correctly designing the transformers and the arrangement of the transformers in the amplifier. The second coupling cannot be avoided without using special tubes, and then only to a limited degree.

The first maxim of radio frequency amplifier design is to choose and arrange the apparatus so that all sources of coupling are reduced to an absolute minimum. (See Par. 489, Part 1.) But if the unavoidable feed-back produced by the capacitive coupling of the radio frequency amplifying tube or tubes is strong enough in itself to generate continuous oscillations these oscillations can only be controlled by using a potentiometer or neutralizing condenser.

Ordinary reflex receivers and other systems using radio frequency transformers **with tuned or semi-tuned primaries** use a potentiometer or neutralizing condenser because the strong oscillations set up across the **resonant** plate circuit of the amplifying tube feeds back sufficient energy through the self-capacity of the tube to generate continuous oscillations. Even though every precaution is taken to avoid inductive coupling between the transformers, the feed-back through the tube, which cannot be avoided, is strong enough in itself to cause self-oscillation.

But the Harkness Receiver, in common with the Neutrodyne and others, uses radio frequency transformers with **aperiodic** primaries. (See Par. 456, Part 1.) The oscillations set up across the primary of the radio frequency transformer T2 in the Harkness Receiver do not feed back sufficient energy through the tube to generate continuous oscillations. Of course, if the receiver were poorly designed and close inductive coupling existed between the transformers T1 and T2, the combined feed-back might be sufficient to cause self-oscillation, but this, of course, is not the case; the receiver is designed so that the inductive coupling between the transformers T1 and T2 is very small.

The Harkness Receiver, then, does not use any of the customary methods of preventing self-oscillating because it is not **necessary** to do so—provided the transformers T1 and T2 are correctly designed and provided also that the apparatus is arranged so that all avoidable coupling is reduced to a minimum.

As proof of this explanation we refer the reader to the previous lesson in which we demonstrated that the neutralizing condensers of the "Neutrodyne" are unnecessary. The "Neutrodyne" oscillates because inductive coupling exists between the radio frequency transformers. The feed-back of energy through the tubes is not sufficient in itself to generate continuous oscillations.

SUCCESSFUL OPERATION DEPENDS ON SPECIAL PARTS

It will be evident from the foregoing that the successful operation of the Harkness Receiver largely depends upon the design of the radio frequency transformers T1 and T2. The number of turns on the primary of T2 must be such that good amplification is obtained without causing self-oscillation. Moreover, the number of turns on the secondary of T2, the constants of T2, the capacity, resistance and losses of the variable condensers all affect the operation of the receiver. In previous publications and articles on this receiver we have given exact details of how the transformers T1 and T2 are made but we found that this led to trouble. Some amateur constructors wound coils according to our specifications but failed to achieve success with their receivers because the capacity or resistance of the condensers they used changed the constants of the circuit. We found it difficult to convince these amateurs that the fault was theirs and not ours!

To ensure the successful operation of home built sets, the Author has designed complete radio frequency transformer units for use with the Harkness Circuit. These units are known as "Harkness Flexoformers" and, being simple, they are inexpensive. The Flexoformer, as shown in Fig. 158, consists of an air core radio frequency transformer attached to the rear of a special variable condenser with extremely low electrical losses and low minimum capacity. The units are made in two types. Flexoformer T1 is used to couple the antenna circuit to the grid circuit while Flexoformer T2 is used to couple the plate circuit to

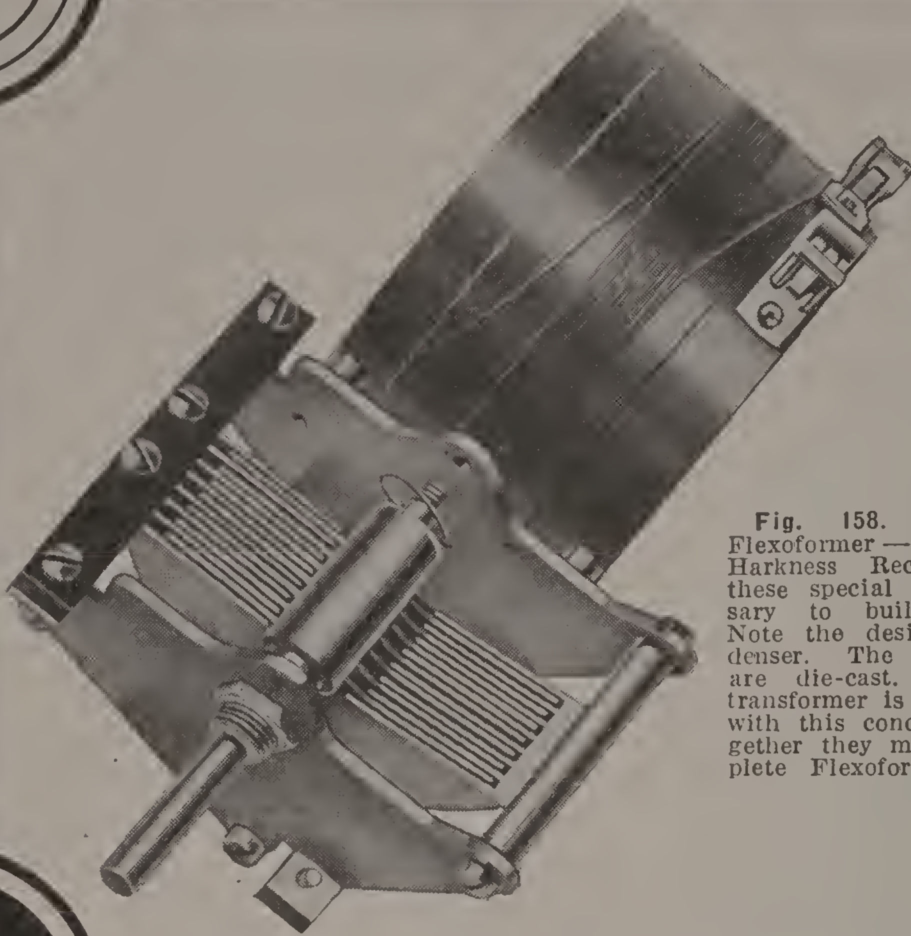


Fig. 158. The Harkness Flexoformer — Heart of the Harkness Receiver. Two of these special units are necessary to build the receiver. Note the design of the Condenser. The stator and rotor are die-cast. The air core transformer is designed for use with this condenser only. Together they make up the complete Flexoformer.

Fig. 159. The Harkness Audio Frequency Transformer is especially designed for the Harkness Receiver. This transformer is largely responsible for the high tone quality of the Harkness Receiver and its freedom from distortion.

the rectifying circuit. (See Fig. 157.) A receiver built with these two units and wired correctly is bound to operate successfully.

Special Audio Transformer Aids Quality of Reproduction: In experimenting with the Harkness Circuit we found that the design of the audio frequency transformer affected both the amplification of the system and the quality of the reproduction. Some standard makes of transformers were found to be entirely unsuitable. The Author therefore designed a special audio frequency transformer for use in the circuit and best results are had when this transformer is employed. Fig. 159 is a photograph of the transformer. While especially designed for the Harkness Circuit this transformer, of course, can also be used in any audio frequency amplifying circuit.

THE TWO MODELS OF HARKNESS RECEIVER.

Harkness Receivers are at present made in two models. Model A uses only one tube, consistent with the fundamental circuit, while Model B uses two tubes. The second tube of Model B is a plain audio frequency amplifier and the effect of this additional tube is to greatly increase the audibility of the receiver.

In the remaining pages of this lesson we show how the reader can build either of these receivers.

HOW TO BUILD THE HARKNESS RECEIVER MODEL A.

List of Parts: Below is a complete list of the parts which are required to build the single-tube Harkness Receiver, Model A:

1 Harkness Flexoformer T1
1 Harkness Flexoformer T2
1 Front Panel, 7 in. x 12 in. (See Fig. 160)
1 Shelf Panel, 4 in. x 7¾ in. with tube socket and two mounting brackets. (See Fig. 162)
1 Harkness Audio Frequency Transformer
1 Harkness Crystal Detector. (See Fig. 161)
1 Filkostat
1 Filament Control Jack (Single Circuit)
4 Binding Posts
2 Dials (4 in. in diameter)
Wire and Insulating Tubing.

The front panel is shown in Fig. 160, which also indicates how this panel is drilled. Fig. 162 shows the shelf panel with the tube socket and mounting brackets attached. Particular attention is drawn to the crystal detector, Fig. 161, which was especially designed for the Harkness Receiver. This vernier control panel-mounting crystal detector gives perfect satisfaction. A sensitive adjustment of the catwhisker can easily be found in a moment by turning the lower knob. To find a new surface the crystal itself can be revolved by turning the upper knob.

Assembly and Wiring.

The photographs and drawings which appear on Pages 165, 166 and 167 illustrate the progressive steps in the assembly and wiring of the single-tube Harkness Receiver. Clearer than words can convey these illustrations reveal the simplicity of this receiver and the ease with which it may be constructed.

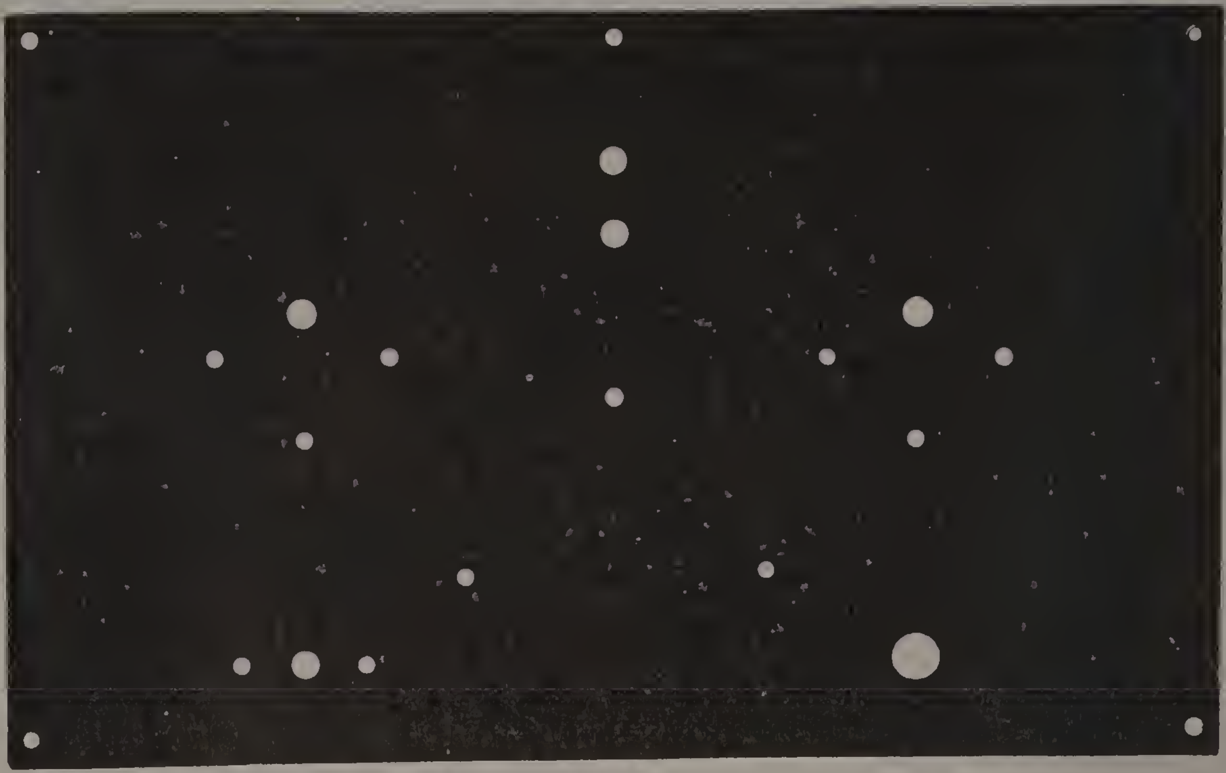


Fig. 160 (above). The front panel of the Harkness Receiver measures 7″ x 12″ and is drilled as indicated.

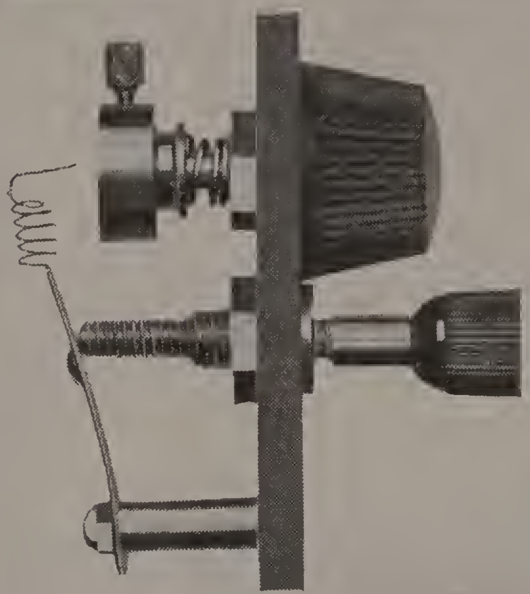
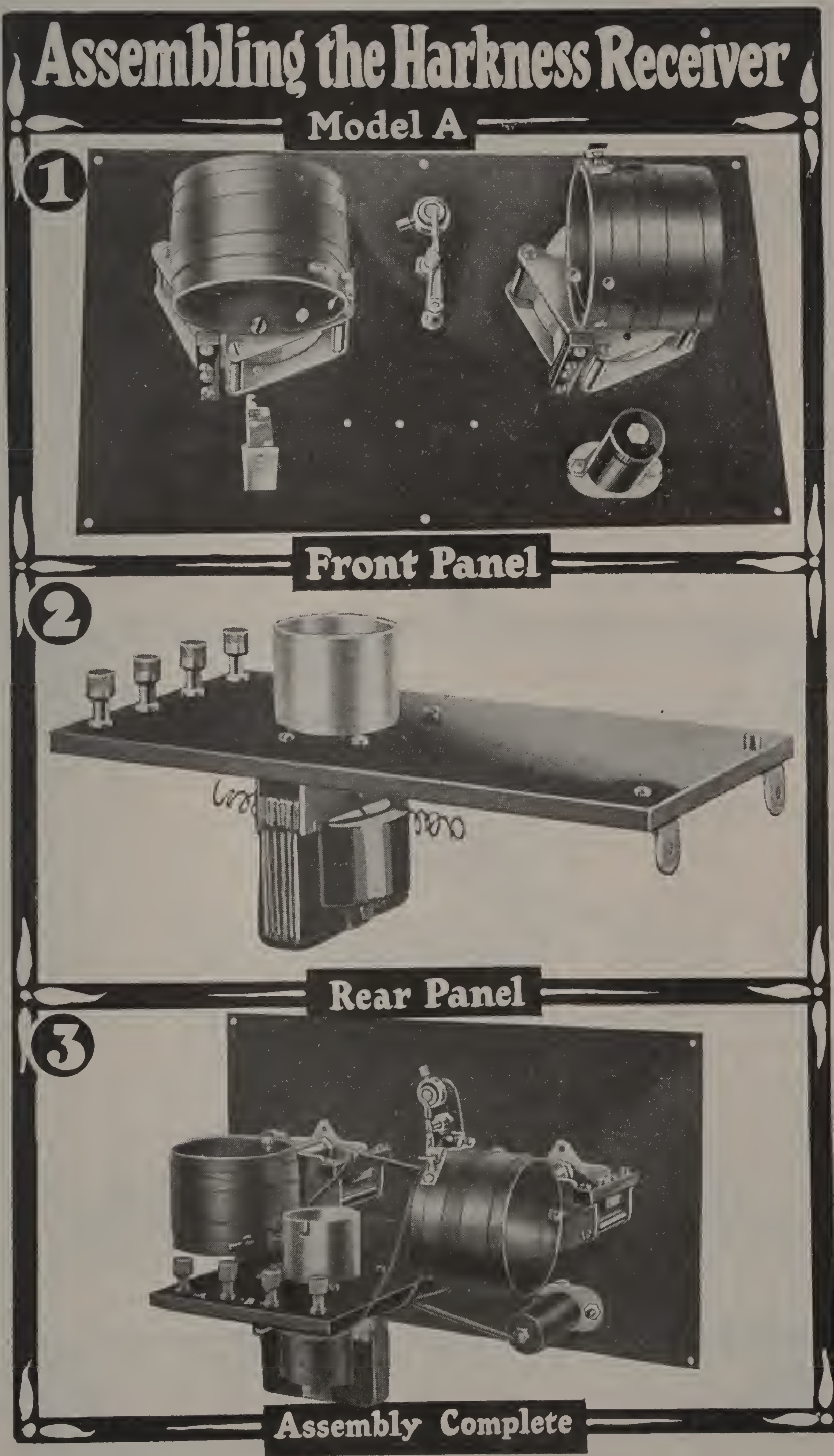


Fig. 161 (left). This crystal detector was especially designed for use in the Harkness Receiver. The design is simple and yet original. On the front of the panel there are only two little knobs visible. The upper knob revolves the crystal itself while the lower knob adjusts the tension on the catwhisker. This crystal detector makes the finding of a sensitive point a simple matter.

Fig. 162 (below). The rear panel of the 1-tube Harkness Receiver is shown in this photograph. The panel measures 4″ x 7¾″ and is used to support the tube socket, audio transformer and binding post terminals.


Assembling the Harkness Receiver
Model A
1
Front Panel
2
Rear Panel
3
Assembly Complete

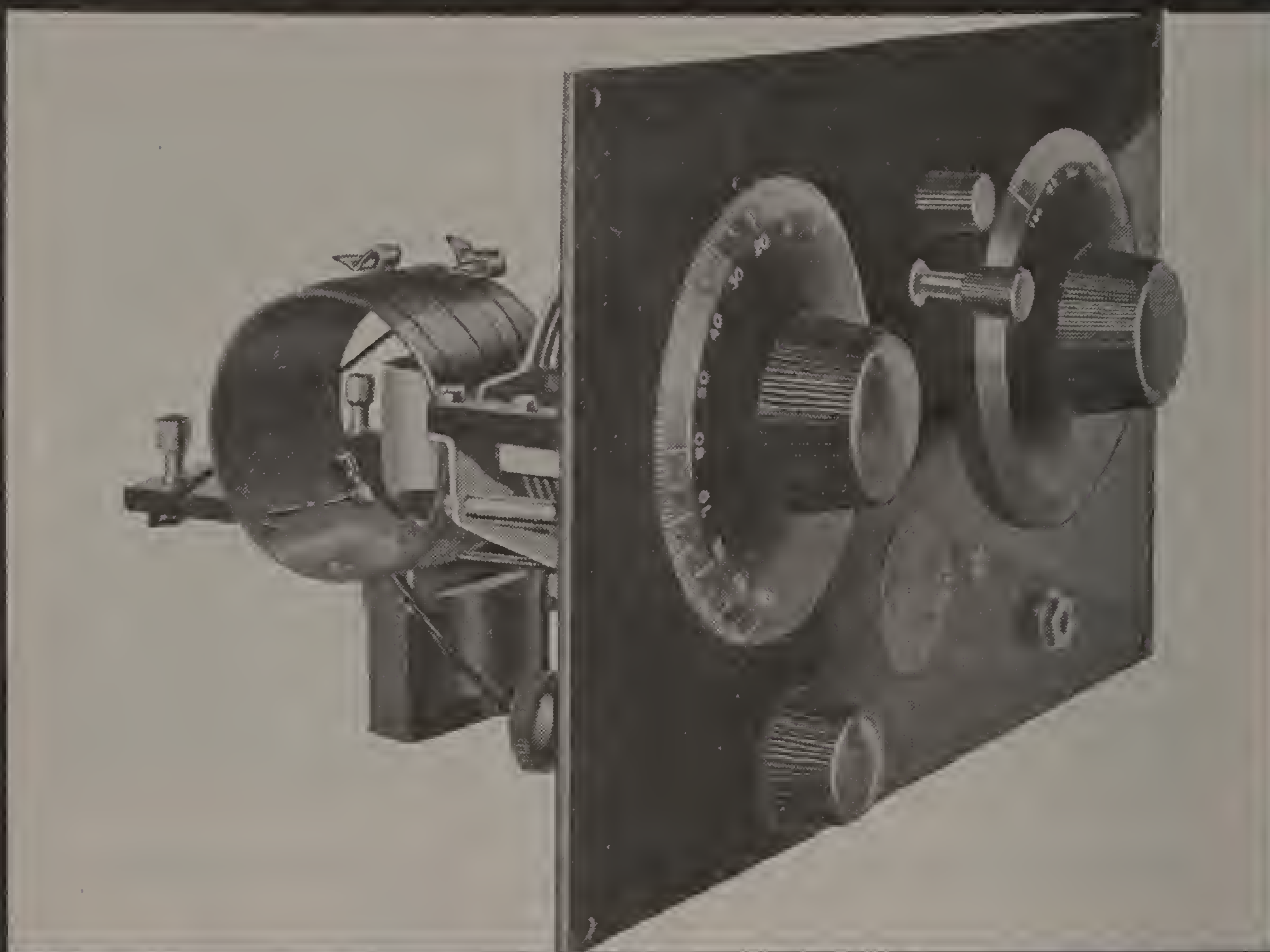


Fig. 166. This shows how the Harkness Receiver appears when it is completely assembled, the three progressive steps in assembly having been clearly set forth on the preceding page.

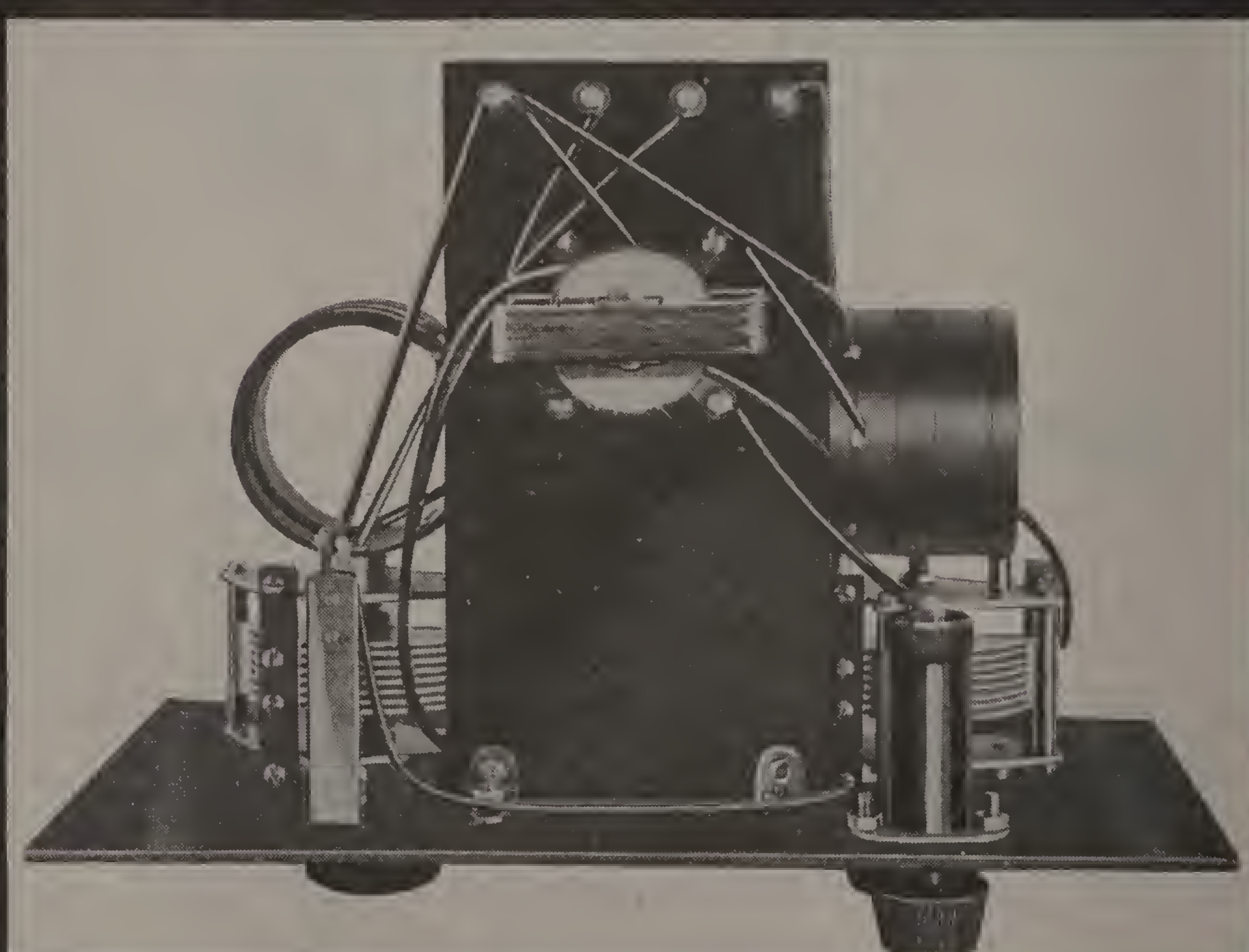
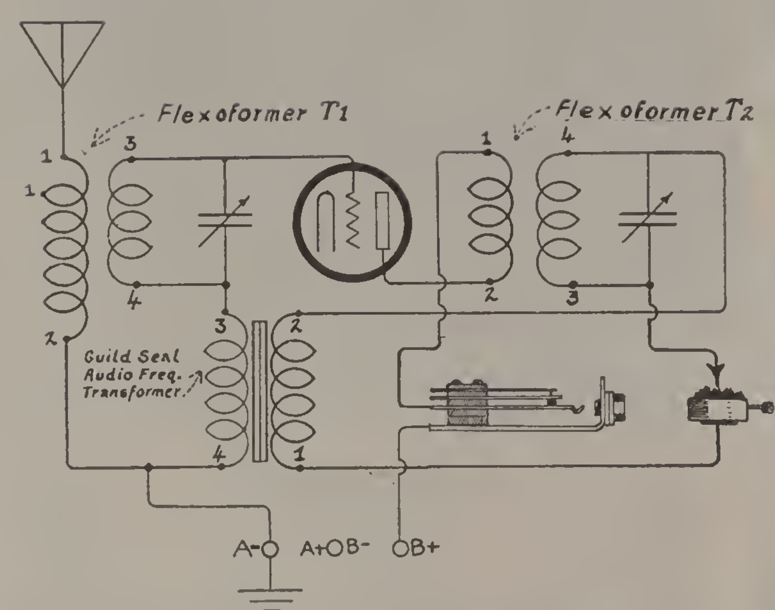


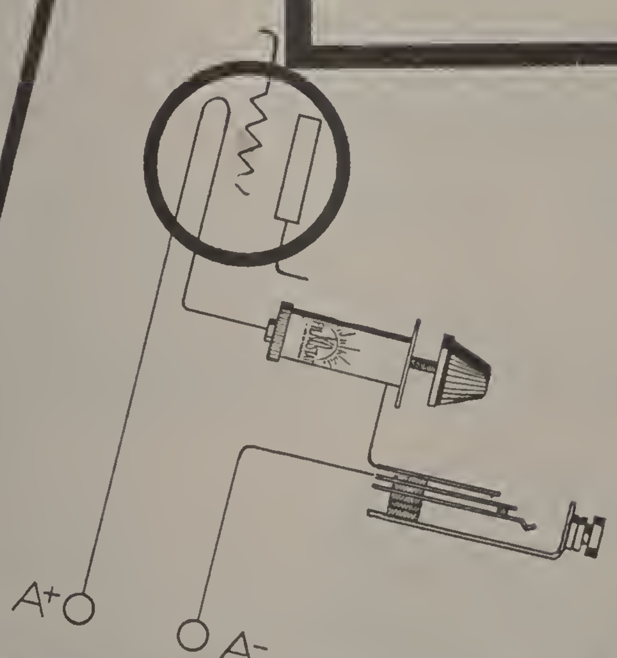
Fig. 167. This bottom view of the single-tube receiver shows how the wiring is made. Soft-drawn copper wire, covered with "spaghetti", is used for making the connections.

Wiring the Harkness Receiver

Model A

The One Tube Harkness Circuit





Figs. 168 and 169. These diagrams show how to wire the Harkness receiver Model A. The terminals of the Flexoformers and audio transformer are numbered and the connections must be made to the correct terminals. In wiring to the binding posts on the rear panel compare these diagrams with Fig. 167. The post to the extreme left of Fig. 167 is "A minus"; the second is "A plus" and "B minus" combined; the third is "B plus" while the fourth (at extreme right) is for the antenna. Connect one end of a flexible wire to the antenna post so that the other end may be connected to either of the two clips on Flexoformer T1. When wiring this receiver connect terminal No. 3 of Flexoformer T1 to the stator plates of the variable condenser.

HOW TO BUILD THE HARKNESS RECEIVER MODEL B.

The 2-tube Model of Harkness Receiver has proved to be one of the most popular applications of the circuit. This model embodies the circuit of Model A with an additional stage of audio frequency amplification. The extra tube so greatly increases the audibility of the receiver that stations within a radius of 1000 to 1500 miles are consistently received with sufficient volume to operate a loudspeaker.

List of Parts: Below is a complete list of the parts required to build Model B:

1 Harkness Flexoformer T1

1 Harkness Flexoformer T2

1 Front Panel, 7 in. x 12 in.

1 Shelf Panel 4 in. x 7¾ in. with 2 tube sockets and two mounting brackets.

2 Harkness Audio Frequency Transformers

1 Harkness Crystal Detector

1 Filkostat

1 Filament Control Jack (Single Circuit)

4 Binding Posts

2 Dials (4 in. in diameter)

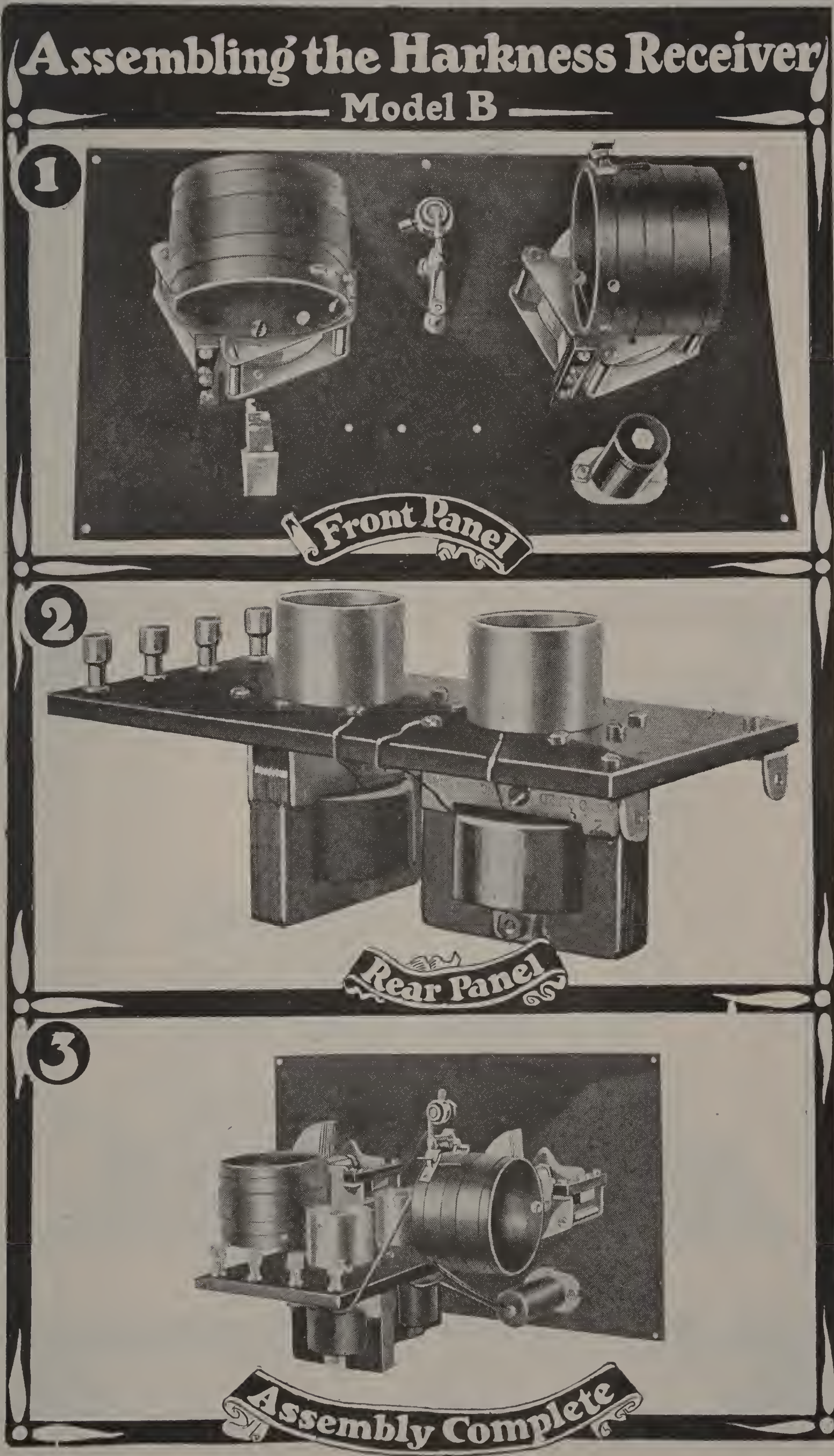
Wire and Insulating Tubing.

The front panel of Model B is exactly the same size and is drilled in the same way as the front panel of Model A. The rear panel, however, has two vacuum tube sockets turned into its surface and is drilled to support two audio frequency transformers as well as the mounting brackets and binding posts.

Assembly and Wiring.

The 2-tube Harkness Receiver is just as easy to build as the single tube model. There are three progressive steps in the work of assembly, as illustrated by the photographs appearing on the opposite page. First, the Flexoformers, crystal detector, Filkostat and telephone jack are mounted on the front panel in the positions indicated. Second, the audio frequency transformers, mounting brackets and binding posts are mounted on the rear panel. Third, the rear panel is secured to the front panel by screws passing through the front panel and tightening into the threaded mounting brackets.

The photographs and drawings on Page 170 and 171 show how to wire the completely assembled receiver.


Assembling the Harkness Receiver
Model B
1
Front Panel
2
Rear Panel
3
Assembly Complete

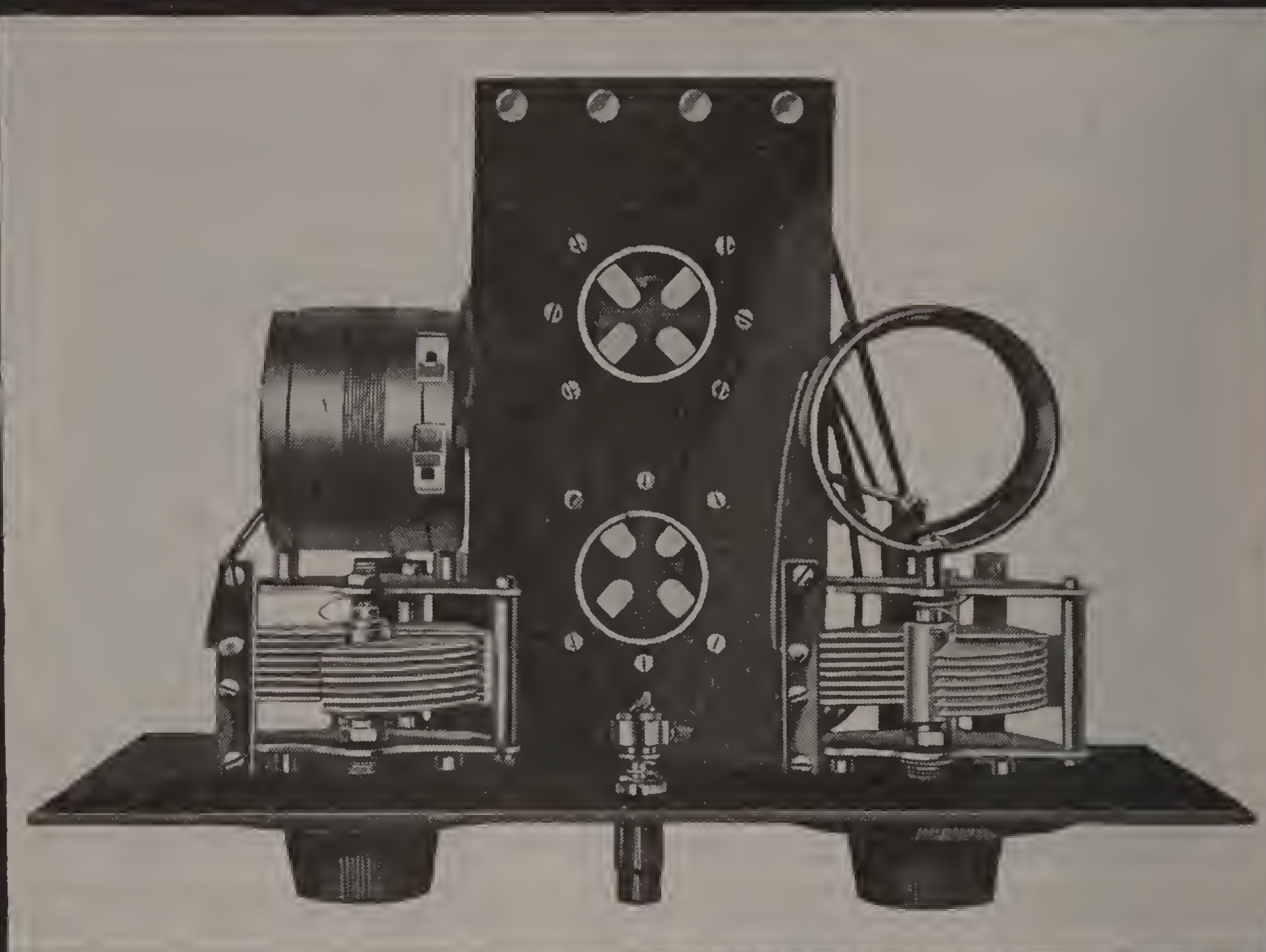


Fig. 173. This view of the completed 2-tube Harkness Receiver shows the arrangement of its parts very clearly. Flexoformer T1 appears on the left and T2 on the right.

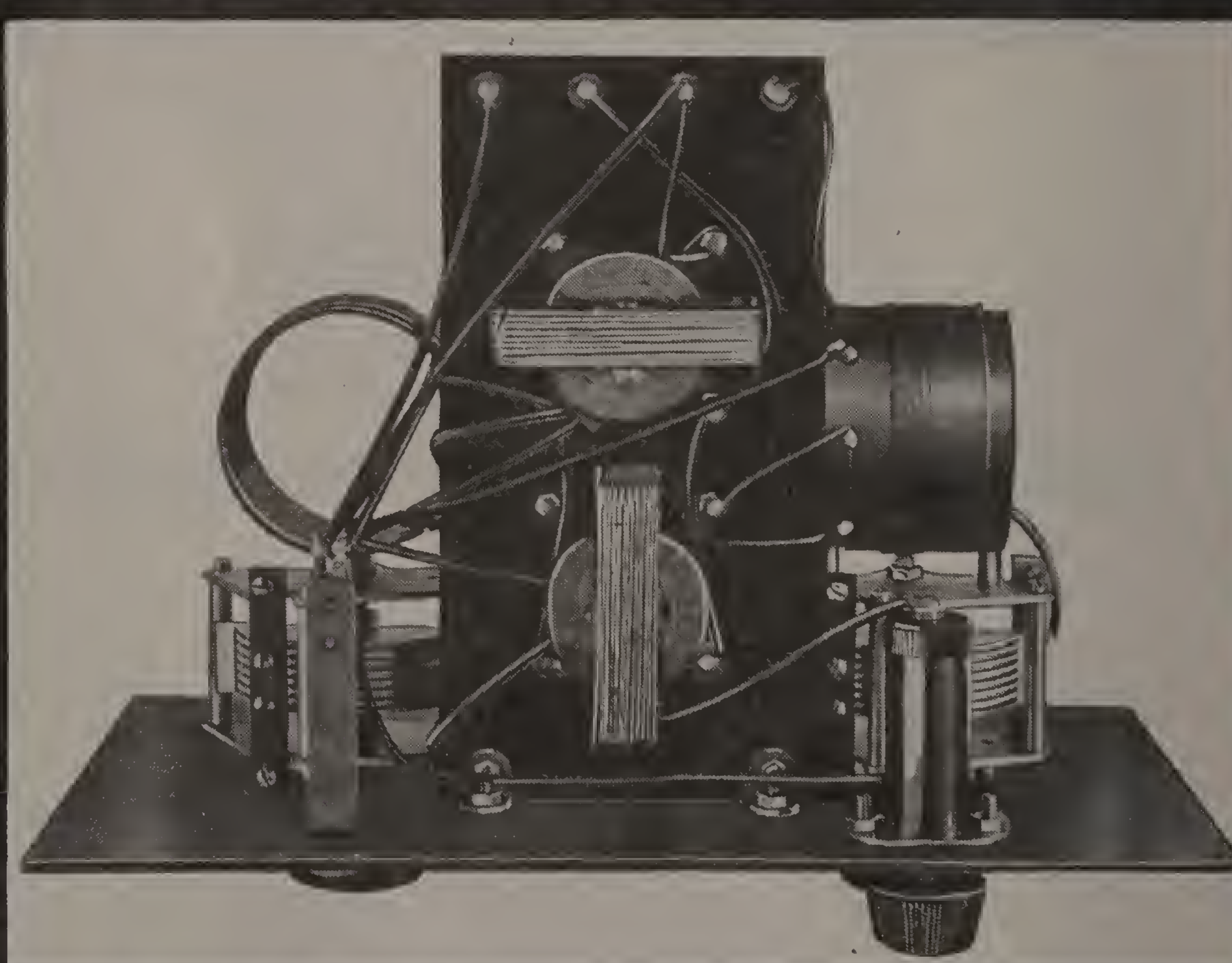
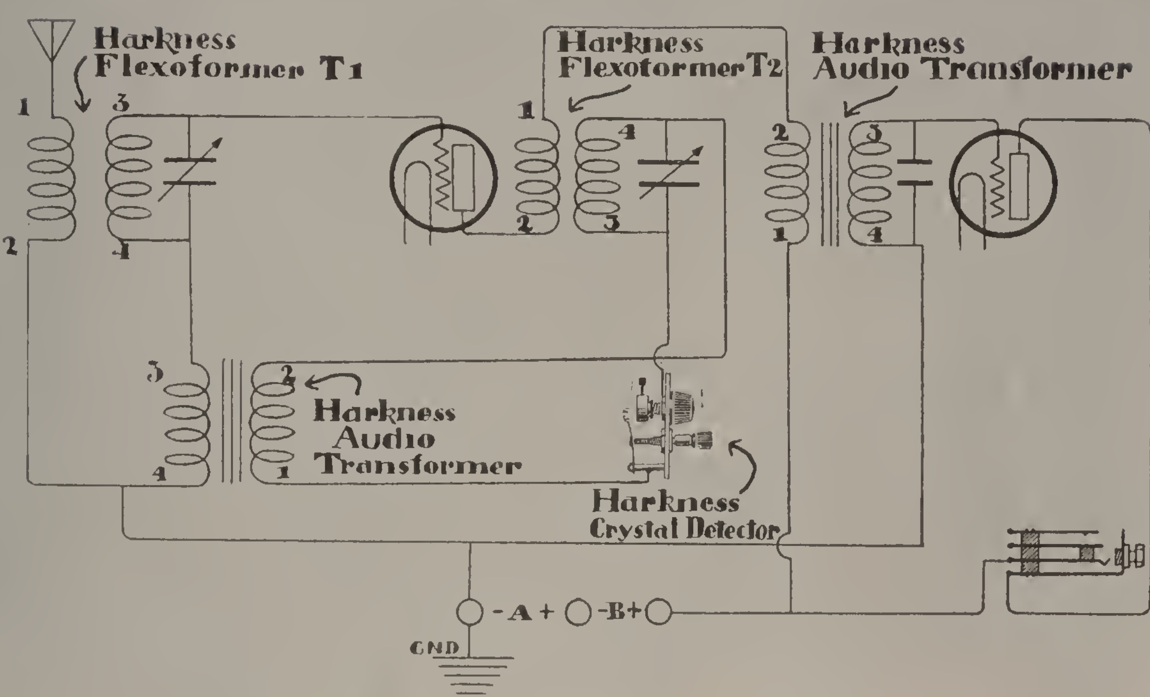
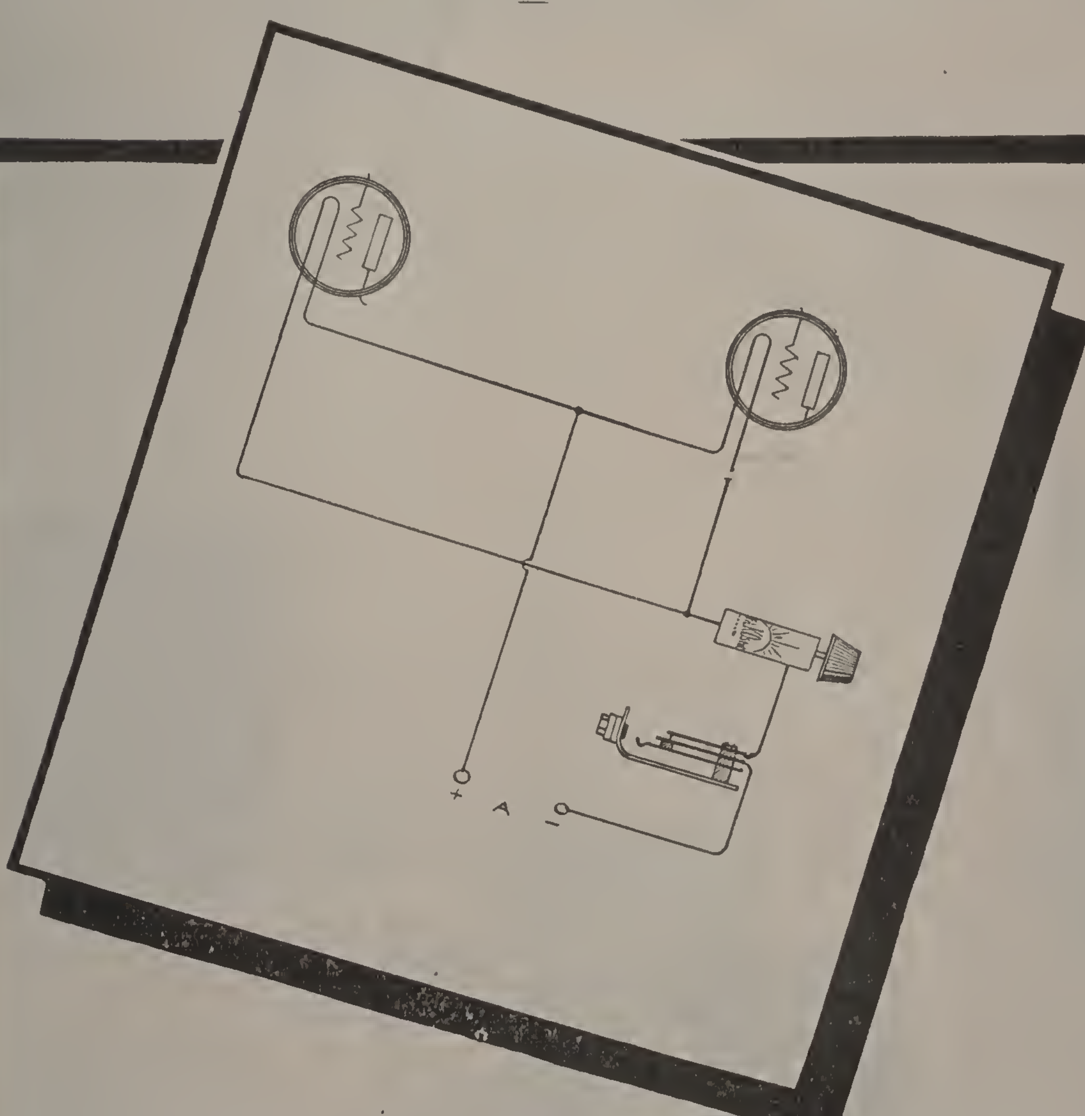


Fig. 174. This bottom view of the finished model B shows how the wiring is made. All joints are carefully soldered.

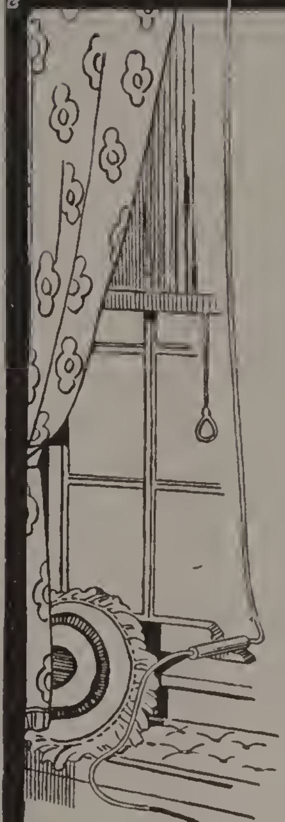
The Two Tube Harkness Circuit





Figs. 175 and 176. The wiring of the Harkness Receiver Model B is given in these two diagrams. Be sure to connect the wires to the correct numbered terminals as shown above. When wiring to the binding posts on the rear panel follow the instructions given on Page 167.

Installing



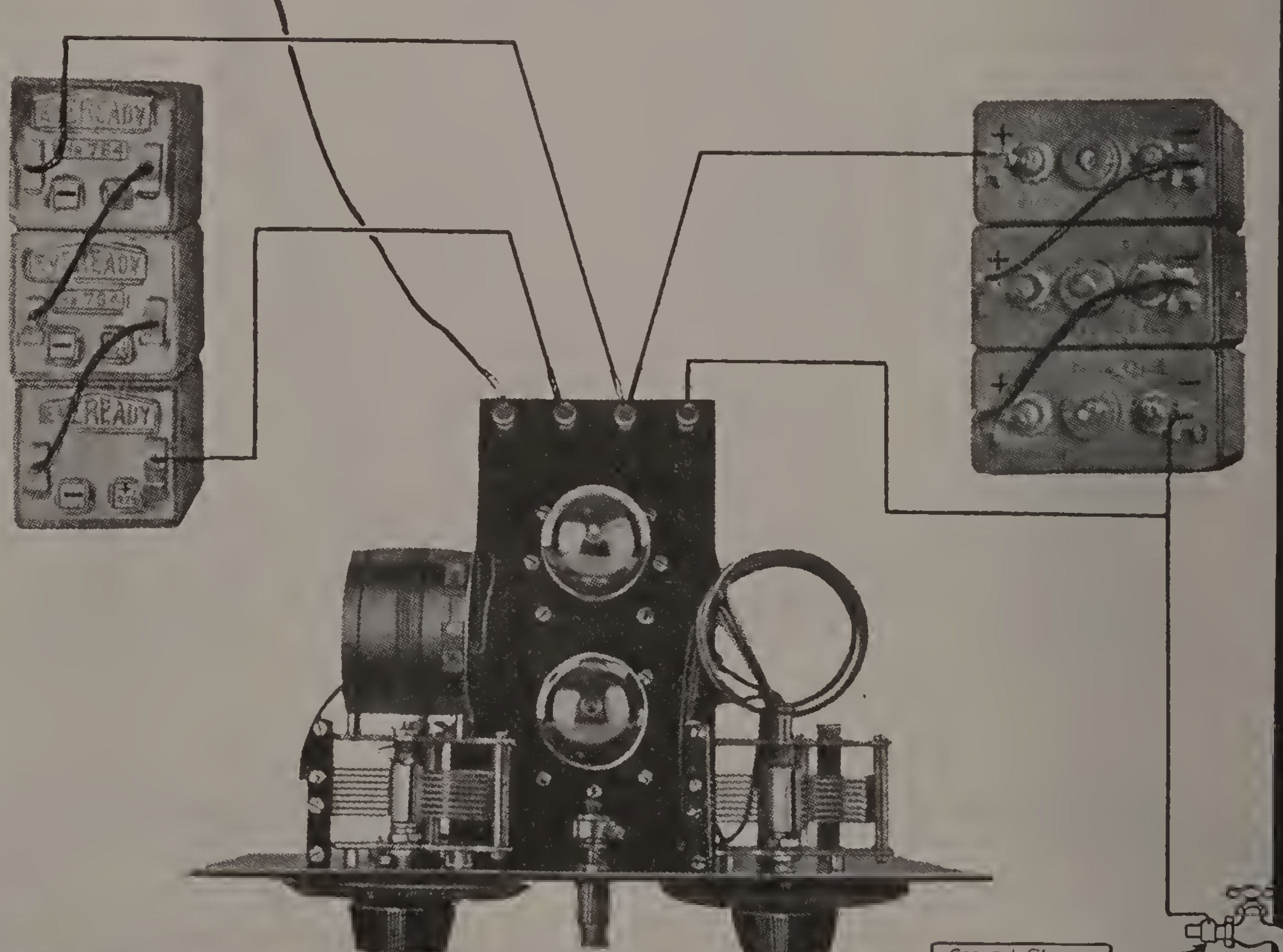
The following accessories are required to operate the Harkness Receiver Model A (1 tube):

Complete antenna equipment:
1 C 301A or U.V. 201A vacuum tube;
1 Filament Battery (6 volts);
1 Plate Battery (90 volts);
1 Pair Headphones and/or Loudspeaker.

Exactly the same accessories are required to operate Model B except that an extra tube is needed.

The filament battery may be either a small storage battery or four dry cells. The plate battery may be composed of four 22½ volt units or two 45 volt units connected in series. Dry cell tubes may be used in place of 6 volt tubes if desired although, of course, the audibility is much lower with the former. With Type C299 or U.V.199 tubes the filament battery should consist of three 1½ volt cells connected in series.

The illustration below shows how to connect the antenna, ground and batteries to the Harkness Receiver (either model). The plate battery appears on the left and the filament battery on the right. Note that the negative lead of the plate battery and the positive lead of the filament battery both connect to one binding post. Similarly the negative lead of the filament battery and the ground lead both connect to the right hand post.



Operating

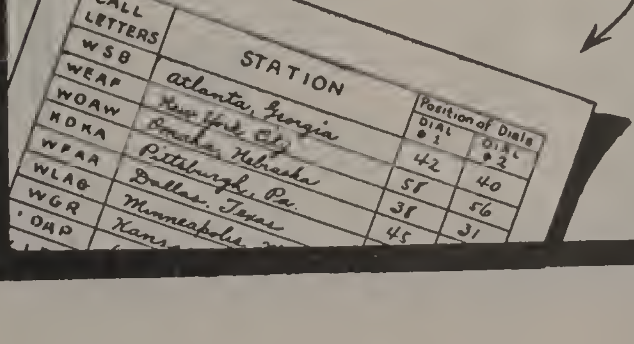
To prepare the Harkness Receiver for steady operation the following adjustments must be made, in the order given:

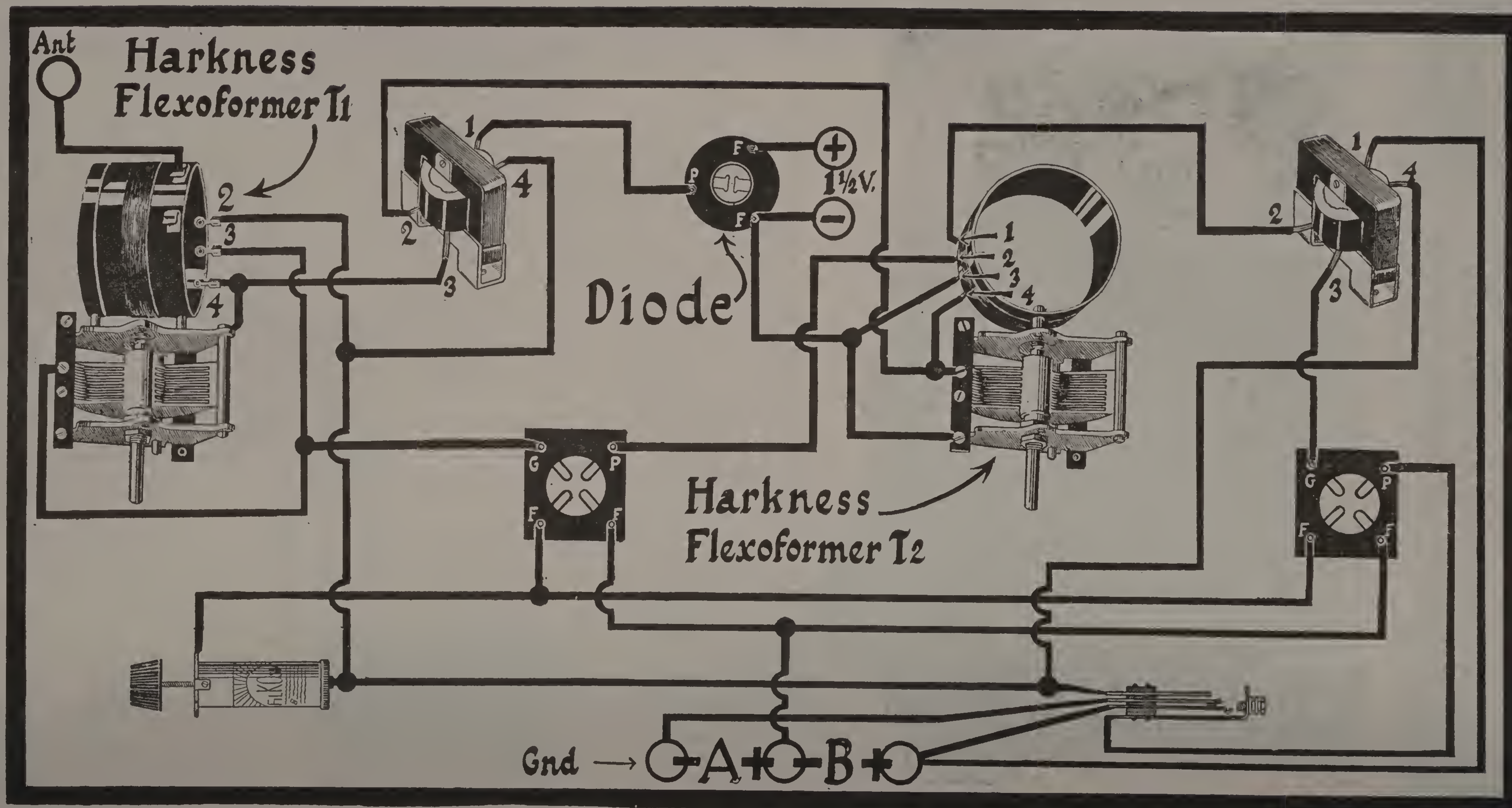
1. Turn the lower knob of the crystal detector to the left until the catwhisker is resting gently on the surface of the mineral.
2. Plug in your loudspeaker or headphones.
3. Turn both dials until a station is heard; then turn the right hand dial to the position which produces the loudest sound. Then turn the left hand dial and **reduce** the volume of sound until the station is just audible.
4. Turn the lower knob of the crystal detector to the right and left a number of times and revolve the upper knob if necessary until an adjustment of the crystal detector is found which gives loudest signals.

The receiver is then ready for steady operation. Thereafter different stations can be tuned in by merely revolving the two large dials. When seeking a station these two controls should be turned simultaneously until the signal is heard; then each dial should be turned separately until the positions are found which produce the most volume of sound. The tuning is just as simple as A-B-C.

Since the dial settings for any particular station are permanently accurate a record should be kept of the best positions of the dials for different stations. With this record to refer to, any desired station can be tuned in by merely turning the two dials to the positions indicated.

Keep a record like this of the stations you hear





Ant
Harkness
Flexoformer T1
Diode
1½V.
Harkness
Flexoformer T2
Gnd → A B

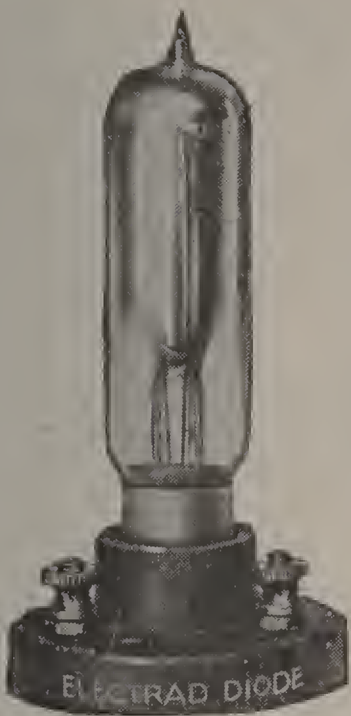


Fig. 179

ADDITIONAL OPERATING NOTES

Although the simplified controls of the crystal detector in the Harkness Receiver allow a sensitive adjustment to be quickly and easily found, it is not necessary to continually "play" with these controls. If proper care is taken the crystal detector will retain a sensitive position for several days before requiring readjustment.

The Filkostat (lower left hand knob) is often useful when tuning in weak signals, although ordinarily this control requires no adjustment. When a distant station is accurately tuned in by the two large dials the strength of the signal can be increased by gradually turning the Filkostat knob to the right until the receiver is in its state of maximum sensitiveness.

THE HARKNESS CIRCUIT WITH DIODE DETECTOR

A crystal detector is used in the Harkness Receiver, not merely because a three-electrode tube is more expensive, but because the audibility of the receiver with a crystal detector is just as good as when a vacuum tube is used as rectifier. Under these circumstances, the cost of the vacuum tube alone (without other necessary parts) being three times the cost of the complete crystal detector, there is no question that the crystal is more efficient for use in this circuit.

Still another arrangement, however, can be used and a compromise effected if desired. Instead of using either a three-electrode tube or a crystal as rectifier, a two-electrode tube can be substituted. Fig. 179 shows a tube of this type which is known as the "Diode." This rectifying tube is much less costly than a three-electrode tube, requires no plate battery and uses only a single dry cell as its source of filament current. Although the Diode is no more sensitive than the crystal in the Harkness Circuit it has the advantage of requiring no adjustment whatsoever.

For the benefit of those who would like to use this type of rectifier in preference to a crystal detector we show a complete picture diagram of the popular 2-tube Harkness Circuit with Diode detector on the opposite page.

LESSON 15.

TROUBLE-SHOOTING HINTS—CARE OF RECEIVERS—ERECTING AN AERIAL.

When a receiver has been constructed and wired it should NOT be put into operation before it is tested. If the wiring is incorrect or if two wires are shorting the filaments of the vacuum tubes may be burned out. This can be avoided by first testing the receiver.

A very convenient testing device for locating trouble in a receiving set may be made by connecting a small 25 watt lamp in series with the house supply and providing two metal terminals, with insulated handles, which will complete the circuit and light the lamp when touched together as in Fig. 180. If the two testing terminals are directly shorted the lamp will light brightly; if resistance is connected between the two terminals the lamp will glow at varying degrees of brilliancy depending upon the amount of resistance. For instance if the high resistance of the secondary of an audio frequency transformer is between the terminals only a spark will be apparent when the circuit is broken—the lamp will not glow. Obviously, if the testing terminals are connected to a supposedly complete circuit and the lamp does not light or no spark is discernible there is a break in the circuit. The location of the break can be found by testing each portion of the circuit. Similarly, if the terminals are applied to a complete circuit of high resistance and the lamp lights brightly it is evident there is a short in the circuit.

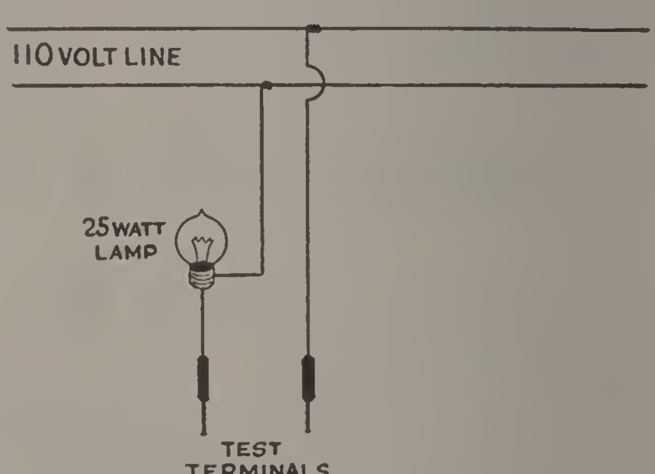


Fig. 180

When using the trouble-shooting lamp to test the circuits of a radio receiver **do not leave the vacuum tubes in the sockets; remove all ground connections and make tests quickly, applying the test terminals for the briefest possible time.**

Testing a Receiver: After a radio receiver has been completely wired, FIRST test the filament circuit by connecting the filament battery to the proper terminals on the receiver and inserting a single vacuum tube in one of the sockets. When a telephone plug is inserted in the last filament control jack and either the Amperite inserted or the rheostat revolved (as the case may be) the tube should light. If it has a rheostat this should vary the filament current of the tube. Repeat this process inserting the tube in each of the sockets. Then insert all the tubes in their respective sockets and make certain that when the telephone plug is removed from the last jack the filaments of all the tubes are extinguished. If the receiver has more than one filament control jack the telephone plug should be inserted in each jack to see if they operate properly. For instance, when testing the R.G. 510 receiver the insertion of the plug in the first jack should light the filaments of the first four tubes only; in the second jack the filaments of five tubes should light and in the last jack the filaments of all six tubes should light.

If the filaments do not light properly it is because—

1. The filament battery is connected to the wrong posts.
2. The circuit wiring is imperfect or not complete.
3. The tube socket springs are not making proper contact with the tubes.
4. The spring contacts of the filament control jacks are not bent correctly.
5. The rheostats or ballast resistances have a broken circuit.
6. Some joints which appear to be connected are not making electrical contact.
7. One or more of the tube filaments are burnt out.

The remedy in most cases is obvious and can be briefly outlined as follows:

1. Connect the filament battery to the correct terminals.

2. Trace the filament wiring with frequent reference to the wiring diagram. Correct any mistakes.

3. Bend up and clean off all socket springs.

4. Inspect each automatic filament control jack and make certain that each functions correctly. The three springs (two on the last jack) furthest from the jack frame are the ones to which the filament wiring is connected. When the telephone plug is **out** the center spring should be making contact with the spring adjacent to it nearest the frame. Test with a lamp to see that it makes contact and, if necessary, bend the spring until it makes proper contact. When the plug is **in**, the center spring should be making contact with the spring furthest from the frame only. On the last jack the two springs furthest from the frame should make contact only when the plug is inserted in this jack. Inspect the insulation between the springs of the jacks and clean off any solder flux with alcohol. If the insulation is not clean it acts as a low leakage path to both A and B battery currents.

5. Test each rheostat and ballast resistance with a lamp touching the test terminals to the wires leading to these parts, not merely to the mountings. If an open circuit is found test

directly on the rheostat or Amperite terminals. If the circuit is then complete the trouble is most likely due to the connections. The various connections should be tested and re-soldered if necessary. In the rare event that it is impossible to make a complete circuit through either the adjustable or automatic resistances replace these parts.

6. Test across the joints with the trouble-testing lamp and if the lamp does not light brightly or if an arc is formed at the break, resolder the joints, taking care to clean the parts thoroughly. This trouble is rare if proper care is taken when wiring the receiver. When it does occur it is usually found that the connections to the socket springs are not making proper contact. This can be avoided by soldering the wires to the socket springs so that solder flows over **on the spring itself** and not merely on the fastening screw or nut.

When the filament circuit functions properly, connect the negative terminal of the plate battery to its binding post. Then, **with all the vacuum tubes removed from their sockets,** touch the plate battery "detector" tap to its binding post; if no sparks take place connect it permanently; do the same with the positive plate battery connection. Then insert the telephone plug in any of the jacks and note whether the wire on the potentiometer warms up. If it does there is an error somewhere which allows the positive of the plate battery to be connected to the filament through the potentiometer. The mistake will be found in the plate circuits so inspect and check all plate circuit wiring. Make certain the plate connections are not in accidental contact with other leads. Then test the primaries of all radio and audio frequency transformers and, with all batteries removed, test for shorts between the primary and secondary windings. Also test the secondary circuits of all transformers. Similarly test the loop jack and its connections and the tuner circuits.

When all circuits are tested and found correct the receiver may be put into operation. If, **with all the exterior connections properly made**, the receiver does not then operate, the trouble may be traced to a short in the telephone plug, in the phone leads or in the telephones themselves.

CARE OF RECEIVERS.

If a radio receiver is properly built **and tested** before being put into operation it requires little attention. The cover of the cabinet should be kept closed to prevent dust from entering. Every few months the vacuum tube spring contacts should be cleaned off; the R.F. transformer and Amperite mountings inspected and all binding posts tightened up.

If a receiver which has been in successful operation suddenly ceases to function properly the fault may usually be traced to

1. RUN DOWN FILAMENT OR PLATE BATTERIES.
2. **Reversed connections to the storage battery.**
3. A burned out or "dead" vacuum tube.
4. Loose connections to the binding posts or batteries.

A radio receiver with a run down plate or filament battery is like an automobile without gas—it won't operate. Look there for the trouble FIRST. Don't start pulling the wires apart until you **know** the batteries are in good condition and that this is not the reason why the set will not operate.

Try reversing the filament battery leads. An audio frequency amplifier **will not amplify** with the filament battery leads connected the wrong way around.

Some vacuum tubes last two months—others last two years. With normal usage the vacuum tubes of a radio receiver only require renewal about once a year. An individual tube, however, may burn out in six or seven months and it should then be replaced by a new tube. A "dead" tube sometimes lights but operates very poorly.

Batteries: The only way of testing a plate battery is by connecting a volt meter across the battery. If a 45 volt battery is run down to below 35 volts **throw it out** or at least don't use it as the plate battery of a receiver. A run-down plate battery is responsible for most of the "static" in a good radio receiver. A good plate battery will last six months or more when used with a one, two or three tube receiver. When used with a four, five or six tube receiver it will rarely last more than four months—depending upon the average hourly use.

A filament storage battery requires constant re-charging. A run-down filament battery **will light the tubes of a receiver** but this does not necessarily indicate that the receiver will function properly. The voltage of the battery may be too low.

Six volt storage batteries can be obtained in different sizes. A 100-120 ampere-hour battery will last longer before it requires re-charging than a 60-80 ampere-hour battery. The length of time during which current may be drawn from a fully charged battery depends upon the **rate of discharge** and the ampere-hour capacity of the battery. In general the rate of discharge divided into the ampere-hour capacity equals the number of hours such a current may be drawn. For instance, a five Ampere current can be taken from a 100 ampere-hour battery for a total length of time of 20 hours. If the battery is used for one hour a day it will last 20 days. The rate of discharge is determined by the type and number of tubes used in the radio receiver. Six ¼ Ampere tubes (U.V. 201A-W.D.11) draw 1.5 Amperes so a fully charged 60 ampere-hour battery will last 40 hours before another charge is required. A single 1 Ampere valve (U.V. 200-201) draws one ampere so a 60 ampere-hour battery should last 60 hours before another charge is necessary.

However, a battery should never be completely discharged. It should be charged frequently. Battery chargers can be purchased for this purpose and the house electric light supply used to charge the battery. Chargers are made for either alternating or direct current; the proper type must be used.

The condition of a battery may be determined by hydrometer readings of the electrolyte according to the following table. A suitable hydrometer can easily be purchased at a small cost.

Hydrometer reading in "specific gravity"	Battery condition
1.100 to 1.150	Discharged—charge immediately.
1.200 to 1.250	One-quarter to one-half charged.
1.280 to 1.300	Fully charged

The condition of a storage battery can also be judged by testing the voltage of each cell. During the test the battery should be under normal load; that is to say, the current from the battery should be lighting the filaments of the tubes in the receiver. If a reading of 2.1 volts (per cell) is secured the battery is fully charged. A reading of 1.8 volts indicates that a recharge is necessary.

To preserve the life of a battery the following precautions should be observed:

1. The battery should never be completely discharged.
2. The electrolyte in each cell should be kept above the top of the plates by regular addition of **distilled water** (not acid) to compensate for that lost through evaporation.
3. The battery terminals should never be shorted nor should the battery be used with a greater load than stipulated by the manufacturer.
4. The charging rate should not exceed that specified by the manufacturer. The charging rate of a battery divided into the ampere hour capacity equals the time in hours such a charge must be continued. To this a twenty or thirty percent overcharge should be added.
5. The vent cups should be removed while charging and replaced immediately thereafter.
6. The battery top should be kept clean to avoid leakage losses and the terminals should be cleaned regularly.
7. Never jolt or jar the battery as the paste in the plates is apt to fall out and cause disastrous internal shorts.

ERECTING AN AERIAL.

If at all within the bounds of possibility an outside aerial should be used with a radio receiver. Granted the receiver may be so sensitive that signals can be picked up using a bed-spring, electric light line (with suitable attachment) a loop or other indoor antenna but if an outside aerial can easily be erected the receiver is not being operated with maximum efficiency and an unnecessary amount of amplification is being used for local stations.

The erection of an aerial is usually a simple matter. The following equipment is required:

100 feet #14 bare copper wire
50 feet #18 insulated lead-in wire.
3 Insulators
1 Porcelain lead-in insulator
1 Ground clamp
1 Lightning Arrester

Figs. 181-184

The drawings of Figs. 181 to 186 suggest different ways of erecting the aerial, according to the location. The wire, of course should not touch the buildings but should be held off by means of the insulators. The insulated lead-in wire should be brought into the house through the porcelain insulator and connected to the "Antenna" post of the receiver. The "Ground" post of the receiver should be connected to a water-pipe or other connection which goes to ground by means of the ground-clamp.

Fig. 185

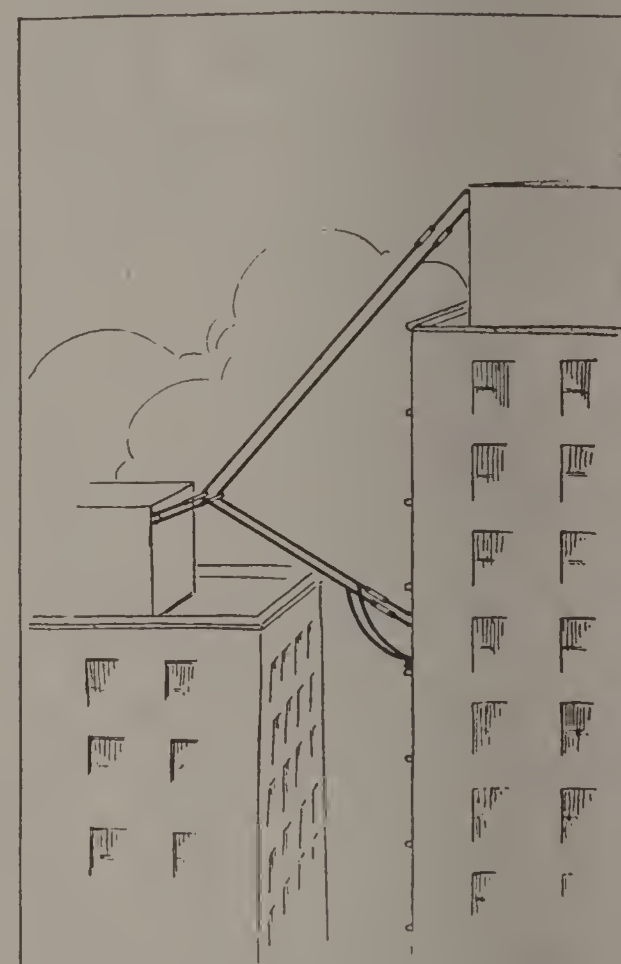


Fig. 186

The water-pipe or radiator is usually the most convenient ground; the pipe should be cleaned thoroughly before attaching the ground clamp. The wire from the "Ground" post of the receiver should be soldered to the ground clamp. A good ground is just as important as a good aerial.

The lightning arrester is connected between the antenna and ground. This must be inserted to conform with fire regulations and to protect the receiver in case lightning strikes the aerial. Incidentally, the aerial then acts as a lightning protector. If lightning does strike the aerial the house will not be damaged whereas without the aerial the lightning might strike the house itself.

Radio Guild Inc.
New York, N.Y.
REGISTERED TRADE MARK

APPARATUS

THE Radio Guild products described in the following pages have been specially selected by Mr. Kenneth Harkness because they are of particular interest to you — a reader of this book.

These products all bear the seal of the Radio Guild signifying that they have been tested and finally approved by Mr. Harkness.

Interference

The Amazing New

Harkness Coupler

makes selective reception easy

The Harkness Coupler was specially conceived, specially designed and specially built to cut out interference. That's what it was made for and **that's what it does!**

There is nothing uncanny or mysterious about it. The explanation is simple. Vario-couplers were originally designed for non-regenerative receivers. When regenerative and radio frequency amplifying sets came into use the design remained practically the same. But Kenneth Harkness realized that the coupling variation of these old-fashioned couplers was altogether too close for the modern type of receiver. With his staff of experts he set to work to devise a new coupler which would meet the new conditions. The Harkness Coupler was the result. The coupling variation of this instrument is **scientifically correct** for regenerative and radio frequency amplifying receivers. The use of this coupler enormously increases the selectivity and efficiency of a receiving set. It will banish interference from your receiver the minute you hook it up in your circuit. It will impart to your set a razor-sharp selectivity which you never dreamed possible. With just a hair's breadth turn of your dial you will be able to completely tune out an interfering station and bring in the one you want—without a trace of interference.

SPECIFICATIONS

To mount on the front panel of a receiver the Harkness Coupler requires a clearance space of 7½ inches in height, 4 inches in width and 7 inches in depth. The primary coil is wound at one end of a piece of Formica tubing 6 inches long and 4 inches in diameter. The primary coil has 5 taps. The secondary is wound on a smaller Formica tube 2⅛ inches long and 3 inches in diameter. Green double silk covered wire is used for both coils. Wave-length range of the coupler with a .0003 mfd. condenser across the secondary is 180 to 575 meters. The rotor is arranged so that a complete half turn of the coupling dial is required to vary the coupling from zero to maximum. Pig-tail connections are used from the rotor to avoid electrical losses. The heavy, durable hardware is beautifully nickel-plated. Shipping weight about 2 lbs.

STOCK NO. 300—Harkness Coupler, Type A. For use with receiver having two or more stages of untuned radio frequency amplification...... **$5.75**

STOCK NO. 306—Harkness Coupler, Type C. For use with regenerative sets or receivers with one stage of untuned radio frequency amplification ....

$5.75

Satisfaction Guaranteed

When you have DX transformers in your receiver you'll be able to pick up distant stations just as easily as you pick up the local ones now! These transformers are so perfectly designed that they bring in distant stations just as if they were next door to you.

IT PAYS TO USE THE BEST—AND THE DX TRANSFORMER IS THE BEST

After all, the most important part of your radio frequency amplifying receiver is the transformer. If you use an inferior, imitation transformer you can't expect to get good results.

Yet, do you realize that nearly every radio frequency transformer on the market today is a poor imitation of the first and original radio frequency transformer—the DX?

SUPERIOR DESIGN COVERED BY BASIC PATENTS

The DX transformer was designed by Mr. P. D. Lowell of the United States Bureau of Standards, Washington, D. C. There are basic patents on the design of the transformer, and it is this patented design—which cannot be imitated—which makes the DX transformer superior to all others.

OUR GUARANTEE PROTECTS YOU FROM ALL RISK

As manufacturer's distributors we unconditionally guarantee every DX transformer we sell. We know that these transformers will more than satisfy you. In fact, if they don't meet up with your expectations in every way; if you don't think that the DX transformers you buy from us are infinitely superior to any radio frequency transformers on the market, we will take them back and refund every cent of your money. We can't do more than this to demonstrate our confidence in this really wonderful product. When you order DX transformers from us you take absolutely no risk; we guarantee them to the hilt—and our guarantee is without a loophole.

Choose now the types of DX transformers you need for your receiver from the list on the next page—then get your order in without delay.

Radio Guild Inc. New York, N. Y.
Manufacturer's Distributors
Dealers — write for Discounts

The DX Transformer

Full instructions and circuit diagrams are enclosed with each instrument. All types have the same dimensions—Length, 4 inches; Width, 1⅛ inches; Depth, 1¼ inches. Weight, 8 ozs.

TYPE DX-12

Wave length range 220 to 550 meters. For the reception of all broadcasting.

Stock No. 312—DX-12 Transformer, with 4 mounting lugs............$6.40

TYPE DX-S

Wave-length range 400 to 1,200 meters. Particularly useful for ship and commercial radio operators.

Stock No. 318—DX-S Transformer, with 4 mounting lugs..................$6.60

TYPE DX-2

Wave-length range 900 to 3,000 meters. Receives Arlington Time Signals, etc.

Stock No. 320—DX-2 Transformers, with 4 mounting lugs.............$6.60

TYPE DX-2H FOR SUPER HETERODYNE

Especially designed for the Super-Heterodyne Receiver, this type of DX transformer, with a peak wave-length of 5,000 meters, is widely recognized as the most efficient transformer yet produced.

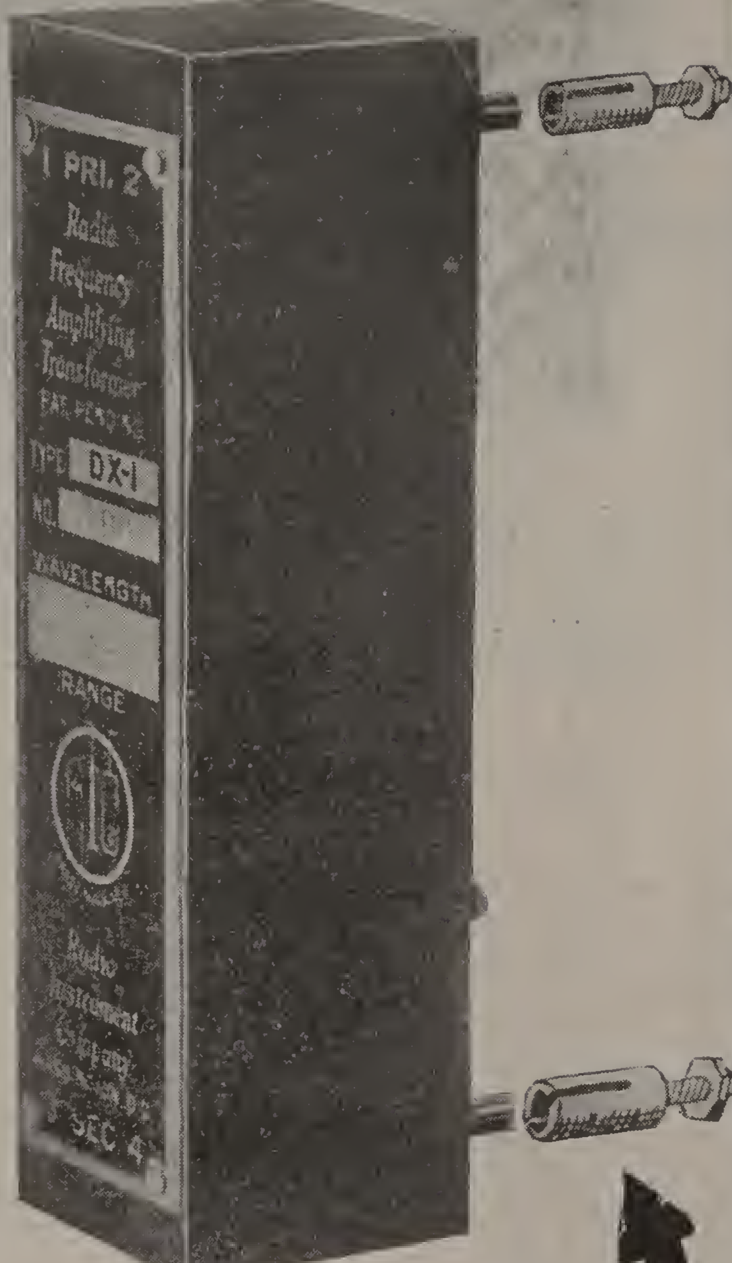
Stock No. 322—DX-2H Transformer, with 4 mounting lugs..............$6.60

TYPE DX-INPUT

Designed for the input of a Super-Heterodyne amplifier. Similar to the DX-2H except that it is tuned to the peak wave-length of the DX-2H, thereby insuring high selectivity.

Stock No. 324—DX-INPUT Transformer, with 4 mounting lugs..........$6.60

Stock No. 326—DX Mounting.....90c



Plug in Mounting Feature

The DX transformer is not only electrically perfect—it is mechanically perfect, too. If you want to change the wave-length range of your receiver, you don't have to tear it apart to do so. With the DX transformer's exclusive, patented plug-in mounting feature all you have to do is to detach the transformer of one wave length range and substitute another. No fuss—no bother; just like a plug and jack and just as speedy and simple.

If Your Dealer Cannot Supply You Promptly

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Assembled RG 510

The Supreme Creation of Radio's Foremost Designer of Receiving Apparatus

If this receiver were on your desk right in front of you, you would have at your command the power to receive every broadcasting station in the United States.

Read that again. Realize what it means to you. Imagine the fascination of plugging your phones or loud speaker in one of those jacks on the right hand side of the panel and picking up, one after another, various broadcasting stations in different parts of the country. It doesn't matter where you live. The R. G. 510 can reach out from the East to the West, from the North to the South, from wherever *you* live to the furthermost ends of the continent. With its seemingly limitless power of amplification the R. G. 510 can pick up the feeblest signal and reproduce it for you with the volume of a phonograph.

Still more important, the selectivity of the R. G. 510 is in proportion to its audibility. This set is positively the first multi-stage radio frequency amplifying receiver with which an outside aerial can be used to the fullest advantage without experiencing interference. **The R. G. 510 is just as selective with an outside aerial as it is with a loop.**

When you consider the unusual merits of the R. G. 510, the high quality of the parts used in its construction, the superfine workmanship of the Guild craftsmen who make these parts and who assemble and wire the receiver, you will agree that the price at which you can buy this set is amazingly low—only $135. This special low price is made to bring this product of the Radio Guild to the public attention. We can only supply a limited number of receivers at this price. If you are to be one of those who will take advantage of this special introductory price you must order your R. G. 510 today—NOW.

SPECIFICATIONS

Tuner: Harkness Coupler with two Radio Guild leak-proof condensers and inductance switch set. Binding posts provided for inserting loading coils. Loop jack on amplifying unit.

Amplifier: Ampli-Unit with 2 stage DX transformer coupled radio amplifier, tube detector circuit and 3 stage Radio Guild transformer coupled audio amplifier; wire potentiometer; Filkostat filament control of R. F. and detector circuit; Amperite automatic control of audio amplifier filaments; Fil. control jacks on 1st, 2nd and 3rd audio stages; battery binding posts along rear.

General: Formica panels, fully engraved; polished black composition 3½-inch dials; mahogany cabinet with highly polished finish. Length, 26 inches; Height, 10½ inches; Depth, 8¼ inches. Shipping Weight about 20 lbs.

Stock No. 510— R. G. 510 Receiver........................ **$135.00**

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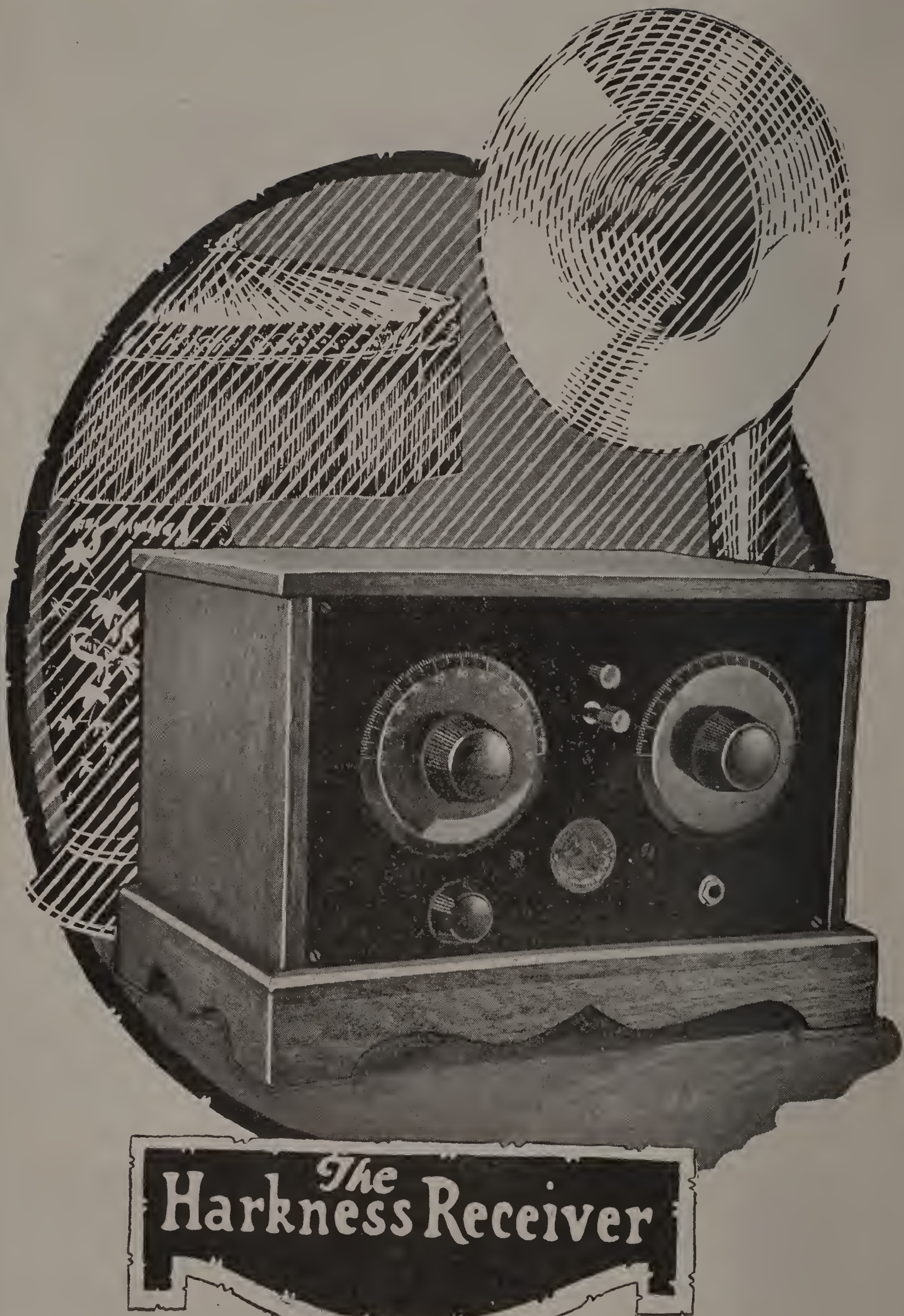
The
Harkness Receiver

Radio's Greatest Achievement

Operates a Loud Speaker with One Tube—Breaks All Receiving Records!

2,000 miles is one of the actual distance records of the amazing new Harkness Receiver! 2,000 miles! You will notice we don't say "thousands of miles"; we don't say "across the continent" or make any other vague, uncertain claim which cannot be proven. This is a specific example of what the Harkness Receiver has done and here is the proof. Mr. Stephen E. Merrill of Port Richmond, N. Y., writes:

> "Your set sure is a wonder! Station CFCN, Calgary, Alberta, over 2,000 miles away, comes in regularly. Sometimes this station is so loud that I can use my loudspeaker."

Here is another example of long distance record-breaking reception. Mr. Thos. Johnson, of Wilmington, Del., writes:

> "I have received nearly every broadcasting station in the United States and have also heard 2LO—London, England. If anyone wants to know what the Harkness Receiver will do—tell them to write me."

Our claim that the Harkness Receiver operates like other sets costing two and three times as much is corroborated by scores and scores of Harkness Receiver owners who KNOW this to be a fact. For instance, Mr. D. J. Gilbert, of Port Byron, N. Y., writes:

> "There are some 12 or 15 outfits in this locality costing from $150 to $225 each—yet my little one-tube Harkness Receiver can reach out and get stations which the others cannot touch."

Easy to Operate—No Whistles or Squeals

Most owners of Harkness Receivers are particularly impressed by the ease and simplicity with which they can receive distant stations. Below are quotations from a letter typical of hundreds of similar letters on our files:

> " . . . I could hardly believe my ears! Louder than a 2-tube set, without a single squeal or whistle and with a simplicity in tuning which is almost uncanny, I believe the Harkness Receiver to be the greatest one in its class."—H. Mohr, Cleveland, Ohio.

Go to your dealer today and ask him to show you either a one or two-tube model of Radio Guild Harkness Receiver. A demonstration will convince you. If your dealer cannot supply you, use our order form and we will ship you a Harkness Receiver with our guarantee that if it does not meet up with your expectations in every way we will refund every cent of your money.

SINGLE-TUBE HARKNESS RECEIVER, MODEL A

All parts used in the construction of this set are of the finest quality, most of them being made in our own factory. The cabinet is polished oak. Length 13 inches, Height 10 inches, Depth 7 inches. Panel 7 inches by 12 inches. Shipping Weight 10 pounds.
STOCK NO. 556—Harkness Receiver, Model A.................... **$42.50**

TWO-TUBE HARKNESS RECEIVER, MODEL B

The external appearance and dimensions same as Model A. Shipping weight 11 pounds.
STOCK NO. 566—Harkness Receiver, Model B.................... **$52.50**

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Genuine
Harkness Receiver
Parts
Miracle of Modern Radio
Complete Set of Special Standardized Parts
Harkness Receiver
Radio Guild Inc.
Complete Box of Parts
Harkness Receiver
Model A
Avoid Imitations
Radio Guild Inc.
New York, N.Y.

YOU can build a Harkness Receiver

Success Certain

The Harkness Receiver you build with the Radio Guild box of standardized parts is bound to operate successfully because with these parts you can build an exact duplicate of the remarkable receiver which Kenneth Harkness designed. Guess work is eliminated. The panels are drilled and ready for you to assemble. Each part is standardized and can only go in its proper place. Moreover each part is the correct type to use—the type which Kenneth Harkness designed as the result of months of experimentation.

Construction Easy

The Radio Guild box of standardized parts makes it easy for you to build the Harkness Receiver. Each box contains **ALL** the parts to build the set, and each part is specially prepared and standardized to simplify the work of construction. The panels are drilled; the coils are wound; the terminals are numbered; each box of parts contains every necessary item right down to the last screw. With only a screwdriver you can put the whole set together in just a few minutes.

Biggest Bargain in Radio

When you buy a box of genuine Radio Guild Harkness parts you get big value for your money. Each part is manufactured in enormous quantities under the most modern system of standardized production. It stands to reason that we can sell these parts for a very low price and still maintain the Radio Guild standard of quality.

But apart from the low price of this box of parts itself—consider also the value of the receiver which you can build with these parts. Remember—if you were to buy a receiver of any other type with the receiving range, volume and selectivity of the Harkness Receiver you would have to pay at least three or four times as much! This box of standardized parts is actually the greatest bargain in radio today. You get more real value for your money than any other investment in radio material you could possibly make.

For a limited time we are featuring the prices of the Boxes of Harkness Parts. How long these extremely low prices will last we cannot say. We may have to raise them any day. Tomorrow may be too late to buy at these bargain figures—so to take advantage of our special rock-bottom prices, buy your box of parts today—NOW!

Complete Box of Parts for One Tube Set

This attractive box contains all the parts to build the one tube Harkness Receiver, Model A, as follows: 1 Flexoformer T1; 1 Flexoformer T2; 1 Front Panel, completely drilled; 1 Shelf Panel with tube socket and two mounting brackets, panel completely drilled; 1 Harkness Audio Transformer; 1 Harkness Crystal Detector; 1 Filkostat; 1 Single Circuit Fil. Control Jack; 4 Binding Posts; 2 Dials (4 in.); 25 ft. copper wire; 2 lengths insulating tubing; Instruction Booklet. Shipping Weight, 8 lbs.

STOCK NO. 558—Complete Harkness Parts, Model A........................ **25.00 Per Box**

Complete Box of Parts for Two Tube Set

Every necessary part to build the 2-tube Harkness Receiver, Model B, is contained in this box, as follows: 1 Flexoformer T1; 1 Flexoformer T2; 1 Front Panel, completely drilled; 1 Shelf Panel with 2 tube sockets and mounting brackets, panel completely drilled; 2 Harkness Audio Transformers; 1 Harkness Crystal Detector; 1 Filkostat; 1 Single Cir. Fil. Control Jack; 4 Binding Posts; 2 Dials (4 in.); 25 ft. Copper Wire; 3 lengths Insulating Tubing; Instruction Booklet. Shipping Weight, 8 lbs.

STOCK NO. 568—Complete Harkness Parts, Model B........................ **35.00 Per Box**

If Your Dealer Cannot Supply You Promptly

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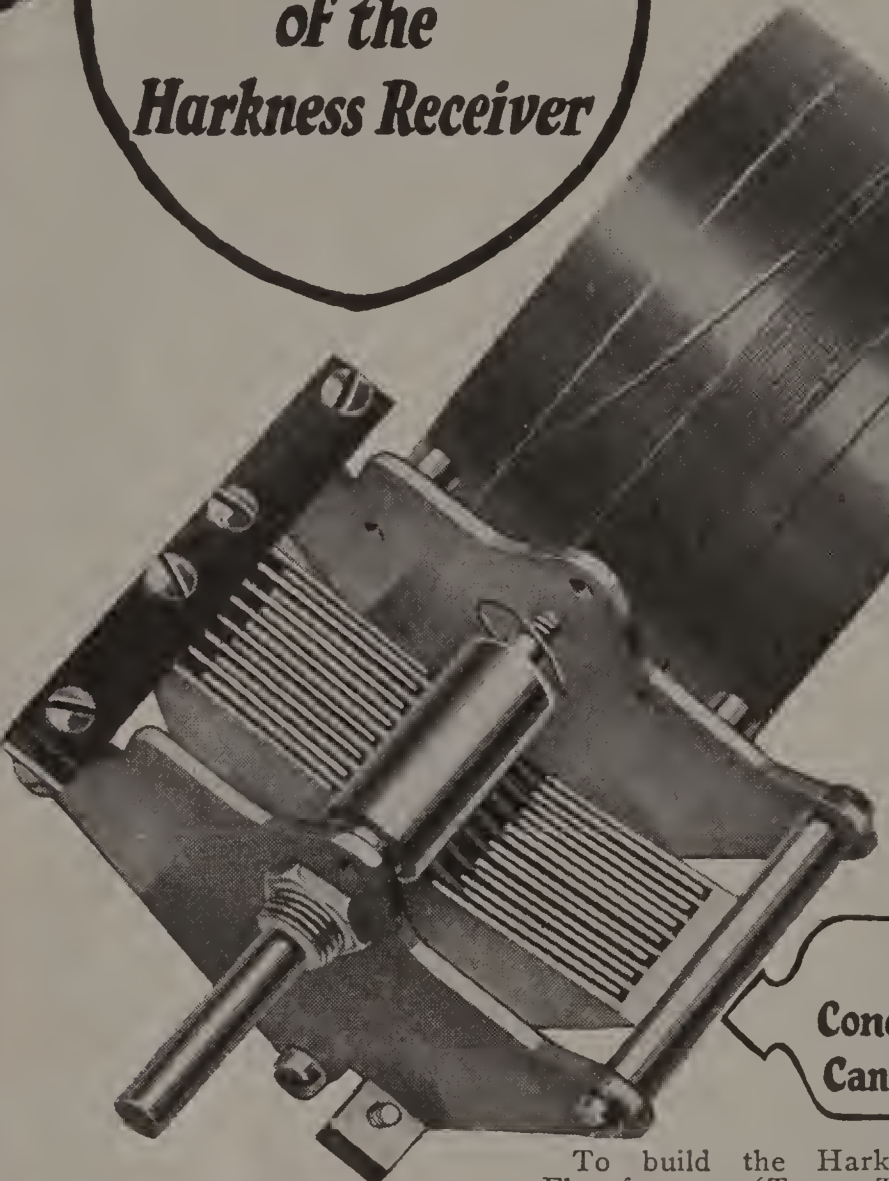
The Harkness Flexoformer

The Heart of the Harkness Receiver



Avoid worthless imitations of this product. Ask for the **Radio Guild Harkness Flexoformers** and look for the Guild Seal on the package.

Cast Metal Condenser Plates Cannot Short Circuit

$3.00 per pair Coils Only

$12.00 Per Pair

To build the Harkness Receiver a pair of Flexoformers (Types T1 and T2) are absolutely essential. The Flexoformer consists of a special air-core transformer mounted on the rear of the Radio Guild low-resistance leak-proof condenser. The whole secret of the amazing efficiency of the Harkness Receiver lies in the design of this special unit.

SPECIFICATIONS

Transformer:—Wound with green D. S. C. wire on Formica tubing 2⅝ inches diam., 2 inches long. Each terminal has soldering lug. All terminals numbered making correct wiring of receiver easy; numbered circuit diagrame accompany each Flexoformer. **Condenser:** The most perfect instrument ever produced. Resistance and other losses lower than any other. Wave length range complete Flexoformer 220 to 575 meters. Shipping weight 1½ lbs. each. Shipping weight of coils 12 ozs. per pair.

STOCK NO. 100—Harkness Coils, without condensers, per pair **$3.00**

STOCK NO. 102—Harkness Flexoformer T1, complete with Radio Guild leak-proof condenser, each **$6.00**

STOCK NO. 104—Harkness Flexoformer T2, complete with Radio Guild leak-proof condenser, each **$6.00**

If Your Dealer Cannot Supply You Promptly

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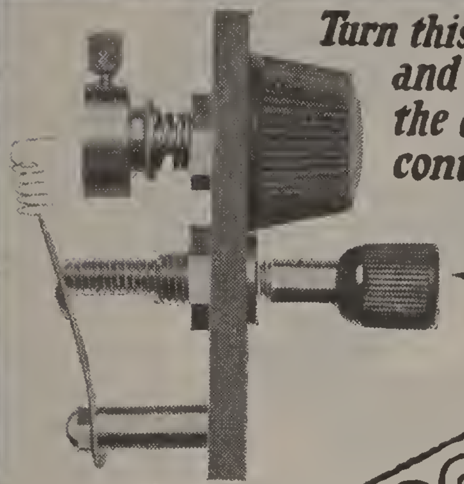
Two All Essential Items

New Radio Guild Inc. New York, N.Y. Vernier Control Crystal Detector



Turn this knob and you have the desired contact

Everything behind The Panel

$2.00 Each

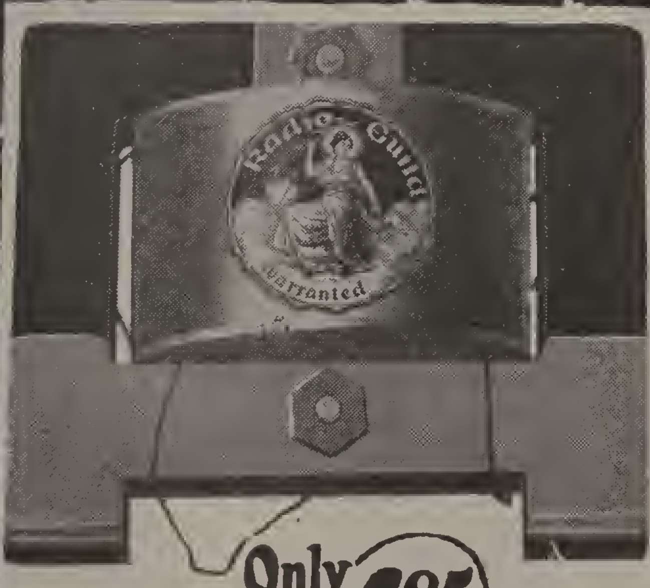
So-called permanent crystal detectors are not sensitive enough for the Harkness Receiver and adjustable detectors of the old-fashioned type are too troublesome to operate. So we designed this new panel-mounting Crystal Detector which is highly sensitive, easy to adjust and almost permanent in action. To adjust the new Radio Guild Crystal Detector you just turn two little knobs; one knob revolves the crystal itself and the other delicately adjusts the tension on the "catwhisker." A sensitive point can be found with one little twist of the lower knob—and the adjustment stays put for days at a time.

SPECIFICATIONS

This Detector is supplied completely assembled on a drilling template, as illustrated. You can mount it on your panel in just a few moments. All metal parts are nickel-plated. Total height, 2¼ inches. Depth clearance behind panel, 1¼ inches. Shipping Weight, 1 lb.

STOCK NO. 116—Crystal Detector (without mineral)....... **$2.00**

New Radio Guild Inc. New York, N.Y. Audio Frequency Transformer



Only $4.85

Especially Designed *for the* Harkness Receiver

This transformer is largely responsible for the high amplification and pure quality of reproduction for which the Harkness Receiver is famous. Other transformers may or may not function in the Harkness Circuit. If you are building a Harkness set—take no chances; use the transformer which Mr. Harkness designed especially for this circuit. The transformer, of course, can also be used in standard amplifying circuits. Its uniform amplification of all voice and musical frequencies makes it the ideal transformer for the amplifier of a radio broadcast receiver in which loud, clear, pure and undistorted reproduction is of the greatest importance. The coil windings have a ratio of 4½ to 1. Circuit diagrams showing how to use the transformer for all purposes are enclosed with each instrument. Height, 2 3/16 inches. Length, 2¾ inches. Shipping weight, 1½ lbs.

STOCK NO. 120—Audio Transformer.................... **$4.85**

If Your Dealer Cannot Supply You Promptly

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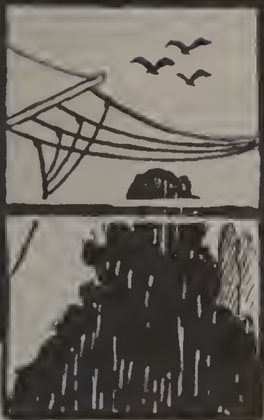
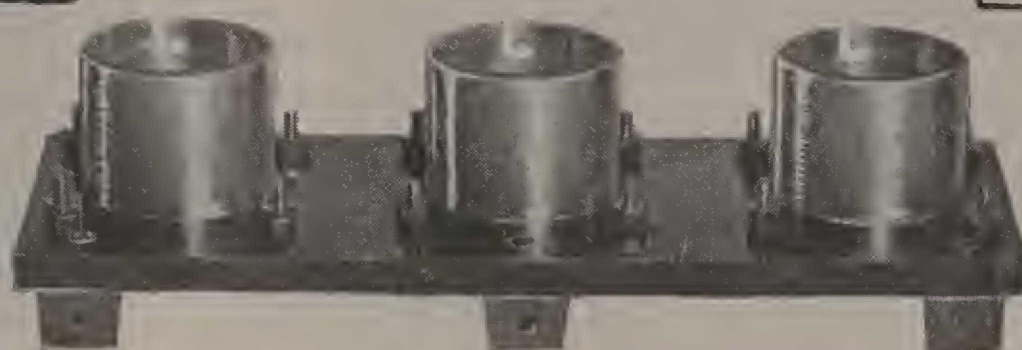


Panel or Table Mounting Sockets



Single Socket

Equip your set with the Radio Guild socket—there is none better. This socket is built to endure, built to give you lasting satisfaction. The receptacle is wedged into the quarter-inch hard-rubber base by a special process and is guaranteed to remain firm and securely in position for the life of your receiver. Panel or table mounting. Base 2⅝ inches by 3⅛ inches. Shipping Weight ½ lb.

STOCK NO. 600—Single Socket........ 85c

85¢

Triple Socket

For receiving sets employing a combination of three tubes the Triple Socket is the most satisfactory and efficient arrangement. All you need to mount this socket on tho panel of your receiver is a screw driver. Three small screws, turned into the special brackets, fasten the socket permanently to your panel. If you prefer table mounting, special washers are provided for this purpose.

SPECIFICATIONS

Metal parts are nickel-plated and highly polished. The engraved terminals insure your making correct connections. The high quality quarter-inch hard rubber base gives perfect insulation and strength. Strong contact strips made of heavy nickel-plated phosphor bronze give positive contact with the tube at all times and never lose their springiness. The tube receptacles are securely wedged into the hard rubber base by a special process; they can never become loose. Base 3 inches by 7½ inches. Mounting screws spaced 3 5/16 inches between centers. Shipping weight 1½ lbs.

STOCK NO. 602—Triple Socket.............................. $2.25

2.25

Radio Guild Inc. New York, N.Y.

If Your Dealer Cannot Supply You Promptly

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Electrad "B" Batteries

More Power—Longer Life.

Noiseless!

The finest battery on the market. The result of 20 years research and experiment.

Absolutely guaranteed uniform high voltage, long life. They insure better reception, uniformity of discharge, freedom from noises.

These batteries are made in all standard sizes. If your dealer cannot supply you promptly use our order form and we will see that you are supplied from our stock of batteries received fresh from the manufacturer each week.

Stock No. 810—22½ volt, medium size; Length, 4⅛ inches; Width, 2½ inches; Height, 2¾ inches; Weight, 1 lb. 6 ozs. $1.90

Stock No. 812—22½ volt, large size; Length, 6½ inches; Width, 3⅞ inches; Height, 3 inches; Weight, 3 lbs. 14 ozs. $2.50

Stock No. 814—45 volt, Baby size; Length, 5⅞ inches; Width, 4⅞ inches; Height, 2½ inches; Weight, 3 lbs. 9 ozs. $4.00

Stock No. 816—45 volt, Large size; Length, 7¾ inches; Width, 6½ inches; Height, 3 inches; Weight, 8½ lbs. $5.00

Stock No. 818—22½ volt, Skyscraper size; Length, 2 9/16 inches; Width, 3¼ inches; Height, 5½ inches; Weight, 2 lbs. 3 ozs. $2.25

If Your Dealer Cannot Supply You Promptly

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Save Money!
Detect The Diode Way

Use a Diode Tube as rectifier in the next receiver you build. It will cost you just a fraction of the price you would have to pay for a three-element tube and its accessories. You will not only save money—you will gain efficiency, too; especially if your receiver is a reflex. The Diode is far better than a three-element tube as rectifier in a reflex circuit. Mr. Kenneth Harkness endorses it for use in the Harkness Circuit.

The Diode is noiseless. It requires no B battery, and will operate on less than half an ampere from a single dry cell. With ordinary handling it will burn from 600 to 1,000 hours.

The terminals on the moulded socket base of the Diode are plainly marked so that you cannot make a wrong connection. Diameter of base—1¾ in. Total height, tube and socket—3⅝ in. Shipping weight—12 oz.

Stock No. 826—Diode Tube and Socket.......................................$2.50

If Your Dealer Cannot Supply You Promptly

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Lowest Minimum Capacity

SPECIFICATIONS

Maximum Cap.—.00032 MF.
Minimum Cap.—.00001 MF.
Resistance (hi. freq.)—.4 ohm.
Phase diff. (hi. freq.)—2 mins.
Plates—7 rotor, 8 stator.
End Plates—Nickeled Brass.
Revolves on ball-bearing.
Tapped holes on rear plate for mounting coil.
Width, 3⅜ inches; Height (plates open), 3 inches.
Shipping Weight, 1½ lbs.

Straight Line Variation

—and double the strength of your signals

If you could see the losses which take place in ordinary variable condensers you would understand why your signals are sometimes weak and feeble when they should be strong and clear.

The engineers of the Radio Guild have now designed a condenser in which all losses are reduced to an absolute minimum. The resistance of this condenser is so low that it actually increases the signal strength and selectivity of a receiver from 50 to 100 per cent.

The ordinary type of condenser is made up of individual plates separated by washers. This method of construction produces high resistance. The resistance of the Radio Guild condenser, however, is astonishingly low because all the movable plates are die-cast in one solid piece and all the stationary plates are cast in another solid piece of metal. The movable casting is electrically connected to the rotor terminal by a special spring pigtail which positively eliminate the resistance of friction contacts used in other condensers. Other losses caused by leakage and dielectric absorption are practically reduced to zero in the Guild condenser.

The Radio Guild condenser is intended for use in any standard circuit to take the place of the average 23-plate condenser. Although its maximum capacity is lower than that of the average 23-plate condenser its minimum capacity is also much lower. Consequently it can be used to cover the same wave length band—and with far greater efficiency.

See this condenser at your dealers. An examination will reveal its striking electrical superiority, its mechanical strength and durability, its handsome appearance and perfect proportions. If your dealer cannot supply you, use our order form and we will be glad to serve you by return mail. Every Radio Guild condenser is fully guaranteed.

STOCK NO. 110—Leak-proof Condenser (.00032 Mf.)........................**$4.50**

If Your Dealer Cannot Supply You Promptly

Use Order Form On Last Page

Order Blank

The Radio Guild Inc.
256 West 34th St.
New York City

Name ____________________ Date ____________________

Post Office ____________________ State ____________________

Shipping Point ____________________

Total amount of money sent with this order		

How to be shipped		
Express	Freight	Parcel Post

Don't Write Here	Stock Number	How Many	DESCRIPTION	Price of Each	Total (Add this col.)	Don't Write in This Col.

On request we shall be glad to supply you with a quantity of these Order Blanks.

Write your order on this Order Blank and it will be given Preferred Attention the day we receive it

Satisfaction Guaranteed or Your Money Refunded

Country of origin and production U. S A.

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