NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

Radio-Trician

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

LESSON TEXT No. 3

(3rd Edition)

TUNING RADIO RECEIVING CIRCUITS

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

"Shallow men believe in luck. Nothing great was ever achieved without enthusiasm, and self-trust is the first secret of success."

—*Ralph Waldo Emerson.*

HAVE A CERTAIN TIME FOR STUDYING

A Personal Message from J. E. Smith

Be regular. Be systematic. Have a schedule for studying and live up to it. Some students assign a certain part of each day for study and a few really do accomplish it. A better plan is to use the week as a basis and decide upon the number of hours in each week which are to be used for study. Then if you see that you are running behind your schedule, give an hour or two extra each day to your studies until you get on your regular schedule again.

Remember that your studies are extremely valuable to you, and that you cannot afford to give up to anything else the time that belongs to them. You can make better progress on your studies in the early morning than you can in the evening when you are all tired out. If possible, get up a little earlier in the morning and give this extra time to your studies and you will find that you will be greatly benefited by it. Only fifteen minutes in the morning spent in reviewing the work done the night before will greatly help to fix it in your memory.

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

Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

TUNING RADIO RECEIVING CIRCUITS

It is intended, in this practical radio course to present the first six lessons in such a manner, that when the student has finished studying them he will have a very fair working knowledge of radio. After these first six lessons, we shall begin the study of the details of the theory of radio and the construction of apparatus. By studying the course in this way, the student will have an advantage over others who have attacked the subject from a different angle. It is to be expected that the study of these details is a little more difficult than merely obtaining a "bird's-eye view" of the radio *situation*. But by the time the student comes to these advanced radio subjects, he will be better prepared for them,

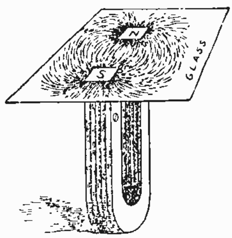


Fig. 1—Illustration Showing How Iron Filings on a Piece of Glass Arrange Themselves When a Magnet is Placed Under it.

by reason of having this all-around conception of radio; the phrases which will be introduced will not be new to him, and the ideas presented will be merely the details of what he has learned before.

We have succeeded in giving to you, in the first two lessons of this course, an idea of what radio is about; you have learned what "tuning" means, and you have learned something about the flow of electrical currents in electrical circuits.

Probably, the only thing about all this that is not yet clear is *how* the coil takes the energy from the circuit, during the discharge of the condenser. We shall now explain how this is done, but you must not forget what we have just said. We shall come back to it in a little while, but for a few moments we will start on another path of thinking.

Do you remember, in our first lesson, when we were talking about the door-bell circuit, we learned that if we had a current flowing in a wire, and an ordinary compass needle were held next to the wire, the compass needle would turn around, and rest at right angles with the wire? Well, we know that if we had two compasses, and placed them near each other, the needles would *attract* each other, and we would find the point of one needle pulling on the opposite point of the other needle. You must clearly understand that the wire carrying an electric current is acting just like a magnetic compass. We can illustrate this in several other ways; look at Fig. 1. This shows an ordinary horse-shoe magnet, which is being held up to a pane of glass. Upon the pane of glass we have sprinkled a lot of iron filings, and by tapping the glass we can see these iron filings gradually arrange themselves in the manner shown in the illustration. They seem to form lines from one pole of the magnet to the other pole. None of these lines cross each other, but all seem to go in the same direction.

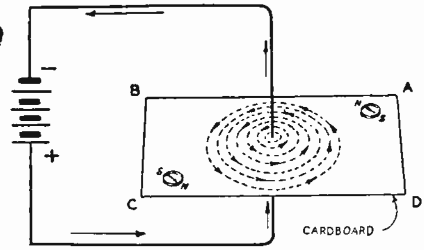


Fig. 2—Using Compasses to Illustrate the Magnetic Field Around a Wire Carrying an Electric Current.

MAGNETIC EFFECT OF CURRENTS

In Fig. 2 we see a sheet of cardboard, through which passes a wire carrying a heavy electrical current. On sprinkling iron filings on the cardboard and tapping it gently, the iron filings will arrange themselves in circles about the wire, the wire being at the center of the circles. The wire with the electric current is acting just like the magnet, excepting in the shape of the lines formed by the iron filings. If, instead of using a horse-shoe magnet for our illustration we had stretched the horse-shoe out and had made a simple bar magnet out of it, and then had placed just one of the poles under the glass, we should have obtained circles of iron filings very similar to the ones formed about the wire carrying the current.

You now know that a current flowing in a wire gives rise to *magnetism*. If we would take the wire in Fig. 2 and wind it up into the form of a coil, we would find the magnetic effect greatly increased. We have done this in Fig. 3, and have slipped into the coil another piece of cardboard sprinkled with iron filings. On tapping the cardboard gently the iron filings arrange themselves in the pattern shown in the illustration, showing that the magnetism comes out of one end of the coil, goes around and returns to the coil at the other end. The space around a wire which carries an electrical current, and within

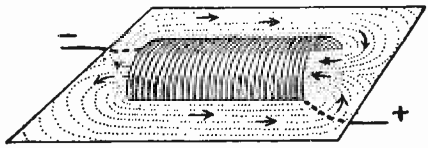


Fig. 2-A—The Sketch Above Illustrates the Magnetic Stress Surrounding an Inductance (Coil of Wire).

and around a coil carrying a current, and the space near a magnet, is called a *magnetic field.* It is called so because *magnetic energy* resides in this space, or *field.*

When a current, therefore, flows in a coil, that part of the electric energy in the current which is not used up in the resistance of the coil, is utilized in establishing a *magnetic field* in and about the coil. The energy which it so takes, in order to establish this magnetic field, is *stored* in this field in the form of *magnetic energy,* or the energy of magnetism.

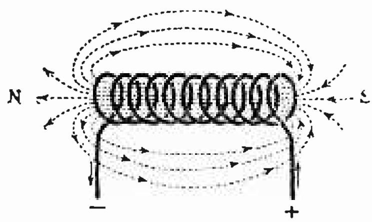


Fig. 3—Lines of Force About a Coil of Wire.

The *strength* of the magnetic field, or the amount of magnetism in the field, depends upon the strength of the current, and the number of turns of wire in the coil. The greater the strength of the electrical current flowing in the coil, the stronger will be the magnetic field; the greater the number of turns to the coil, the greater will be the amount of magnetic energy stored in the field in and about the coil.

We are now in a position to understand how the coil takes energy from the circuit during the discharge of a condenser in the circuit. The flow of electrons from one plate of the condenser to the other forms an electrical current. As the current flows through the coil which is connected to the condenser, some of the energy in the current is taken by the coil in establishing the magnetic field. But we must now learn how this coil gives back this energy to the circuit when the current is decreasing, that is, when the condenser discharge slows down.

Suppose we try the same stunt with the coil and iron filings shown in Fig. 3, but this time do not have any current flowing in the coil. We can tap the cardboard till doomsday, trying to make the iron filings arrange themselves in any certain pattern, but they will not do so. They simply travel to where we make them travel by tapping the cardboard. Therefore it is plain, there are no magnetic effects

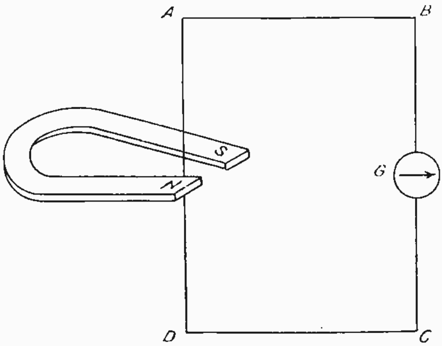


Fig. 4

excepting when the coil carries a current. It is also clear that if the coil was first carrying an electric current, and had a magnetic field established in it, when we stopped the current by breaking the circuit, the magnetic field must certainly disappear. In other words, the energy in the magnetic field of the coil had gone elsewhere. But where? That is the next question.

It will be a very simple matter to reason in this manner: certainly, if a current flowing in a wire or in a coil can establish a magnetic field, then a magnetic field ought to be able, on the other hand, to establish an electric current in the coil. Such is the actual case, excepting that you must always remember there must be *motion* of some kind. In order to create a magnetic field, the electrons in the wire or coil must be in motion—that is, a *current* must be flowing. On the other hand, in order for a magnetic field to create a current in a wire or in a coil, the *magnetic field* must be *moving*, not necessarily from one point to another, but at least must be changing in strength.

We have a state of affairs like this in an ordinary electric dynamo or generator. There is a magnetic field established by a current flowing in some coils. Another set of coils is rotated in this magnetic field by a machine of some kind. As the coils are rotated in the field a voltage is created in the moving coils, and an electrical current made to flow in them.

Suppose we had a simple wire circuit, A, B, C, D, such as we see in Fig. 4, and in this circuit we had a very sensitive instrument, G, for detecting a flow of current. On quickly moving a magnet up to the wire, the instrument would indicate that a small current was flowing as long as we had the magnet in motion. On withdrawing the magnet, that is, upon pulling it away rapidly, it would be seen that a current is again flowing, but when we merely hold the magnet still, no current would flow. A current will flow only when the strength of the magnetic field *is being changed.*

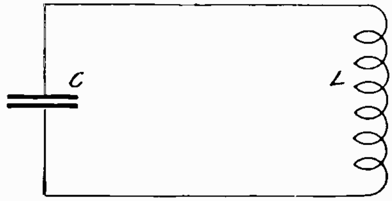


Fig. 5—Closed Circuit Consisting of a Condenser (C) and Inductance Coil (L) Connected in Series.

Now, if we have a coil carrying an electrical current, having a magnetic field established in and around the coil, and then when we stop the current by breaking the circuit the magnetic field disappears, it is clear that the strength of the magnetic field has changed. It has changed from the strength it had *down to nothing.* Consequently, this change will cause a voltage to be established (or *induced*) in the winding of the coil, and this voltage will cause a current to flow, even for a very slight instant after we break the circuit. Sometimes, if the current in the circuit is strong enough, or if the magnetic field is sufficiently intense, we shall see a small spark at the point where we break the circuit, indicating that the current flows for a very short time after the break.

At any rate, it is not necessary to entirely break the circuit, or to have the current entirely stop flowing, in order to obtain this effect, for even a small change of the magnetic field will *induce* a voltage in the coil.

Now we are able to see more clearly what is going on in the circuit of Fig. 5, which shows a condenser "C" in series with a coil "L." The condenser has been charged, and begins to discharge. At the beginning of the discharge there is a rush of current from one plate to the other. As the current flows it establishes a magnetic field inside and outside the coil. While the magnetic field is being *built up* in strength, its strength is changing, and consequently it *induces* a voltage back into the circuit which *opposes* the original current, trying to make it flow more slowly, so that it will last a longer time. When the current has reached its greatest strength the magnetic field strength is greatest; then the current begins to decrease, and with it the magnetic field begins to decrease in strength. As it decreases in strength it again induces a voltage back into the circuit, but this time it is in the *same direction* as the current, so that it tries to *keep up* the current as it decreases. Thus, once again we see that the coil tries to make the current continue flowing for a longer time. When the current reverses, that is, when the condenser begins to discharge again in the opposite direction, the whole process repeats itself, over and over again, until the oscillations finally die away.

Let us go back to the spring and weight illustration in Lesson Text No. 2. Suppose we did not have the spring to hold up the weight by its tension. The weight would then simply drop to the ground, and there would be no oscillations. Suppose again, that we did not have the weight hanging on the spring. If we would then pull down the spring and let go, it would simply fly up, and probably jump off the hook; again there would be no oscillations. The same is true of the coil and condenser circuit of Fig. 5. There can be no electrical oscillations unless we have both the condenser and the coil.

Let us think what would happen if we give a little push to the weight and help it along in its travels up and down. That is, when the weight is traveling upward, we give it a little push upward, and when it is traveling downward, a little push downward. Evidently, the weight would continue to oscillate, and would not slow down. The slight amount of energy that is lost in friction or in fanning the air, would be made up by the pushes my hand gives the weight. Not only that, but the pushes will actually cause the weight to oscillate *more strongly.* That is exactly what hap-

37

pens when we *tune* a radio circuit. We adjust the coil and condenser, either separately or together, to *naturally* vibrate at the same rate as incoming radio signals so that as the current oscillates in the radio receiver circuits, the incoming oscillations give them a *boost* each time, making the oscillations continue, as well as make them stronger. As we have seen before, the adjustment of the circuit so that it oscillates at the same rate as the incoming signals, is called *tuning to resonance.* You now see the reason for this tuning, and understand fairly well how it is done.

CAPACITY

We have said before that a condenser is composed of a number of plates of metal placed alongside of each other. Look at Fig. 6. Here we have a condenser formed by two plates, and these plates are connected to a source of electrical energy, which in this case is represented by a simple battery. *You must remember,* that batteries are not used in radio receivers for the purpose of charging condensers, but we shall

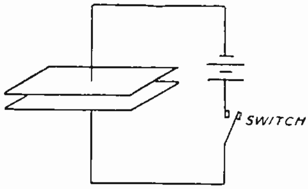


Fig. 6—Circuit Consisting of Condenser Battery and Switch Connected in Series

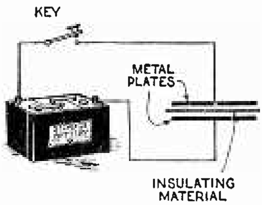


Fig. 6-A—Pictorial View of Apparatus **in Fig. 6 Connected Together.**

use them frequently in our explanations in order to simplify these explanations. We have seen that when a condenser is connected to a source of electrical energy like this, that the electrons in the circuits and on the plates of the condenser, become re-arranged in the circuit. One of the plates of the condenser acquires quite a few of these electrons, and the other plate loses just as many. The question to be answered is, "How many electrons are stored up on the one plate and lost by the other?"

This is a very complicated question to answer, so we will not try to answer it directly. But we will try to find out something about it. You remember that when the condenser is so charged, a voltage is established between the plates of the condenser. When the circuit is first closed by pressing the switch a considerable current flows in the circuit, which after a very short interval of time decreases and finally stops altogether.

This is called the charging current. At any instant during the time this charging current is flowing there is a certain charge taken by the condenser. How great this charge is depends on several things, the main ones being the size of the condenser plates and the voltage of the battery.

Now suppose, after say, one ten-thousandth of a second the size of the plates and the voltage of the battery were such that a voltage of 3 volts was established on the condenser plates. On opening the switch the charge will remain on the condenser, as we explained before. Suppose, again, that the condenser plates were suddenly made twice the size. We

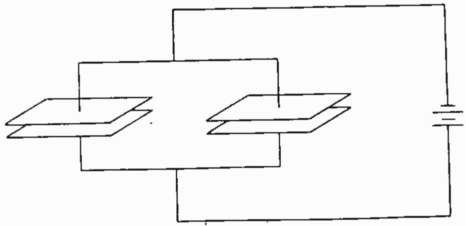


Fig. 7—Two Condensers Connected in Parallel and Connected in Series with a Battery.

originally had a certain number of electrons on the plates, and these produced the voltage in the condenser. Now, when we double the size of the plates, these electrons are only half as crowded as they were before, so that the voltage of the condenser at this instant is now less than what it was. In other words, the condenser now has a greater *capacity* than it had before; its *capacity* to hold a charge is greater; it can hold a greater charge at the same voltage, or even at a lower voltage. This word "*capacity*" is used to indicate the ability of the condenser to hold a charge. Just think of a water tank; the larger

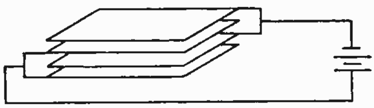


Fig. 8—Illustrating How Alternate Plates of a Condenser are Connected Together.

it is the greater the amount of water it can hold. The same thing is true of condensers; the larger the plates of the condenser the greater the charge it can hold.

Now, suppose that instead of making the plates twice as large, we used the same size of plate, but had twice as many of them, as shown in Fig. 7. Notice that the plates are connected in *parallel*. The same effect is found as before; the charge divides equally between the two sets of plates, and the capacity of the condenser is doubled by doubling the number of plates. There is one thing peculiar about this arrangement, however, and that is the outsides of the two outside plates are not used. The electric charge is held on the insides of the plates, on the sides which are next to each other. Now look at Fig. 8. In this figure we have taken the two sets of plates shown in Fig. 7 and have sandwiched the plates in between each other. Each set of plates is connected in parallel, which gives us a condenser which has quite a large capacity, but occupies only a small space, instead of spreading out, as in Fig. 7.

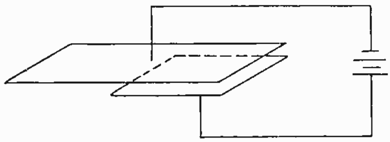


Fig. 9—Illustrating the Useful Overlapping Area of Condenser Plates.

The useful part of the condenser is the part that *overlaps*. For instance, in Fig. 9, the part of the upper plate that *does not* overlap the lower plate is useless, as far as furnishing capacity to the condenser is concerned. The capacity of the condenser is determined by the *overlapping area* of the plates. Consequently we can easily make a condenser whose capacity we can change or *vary*. This can be done very simply by having a set of plates which can be moved in and out of another

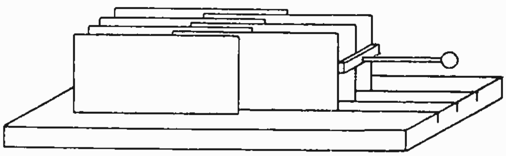
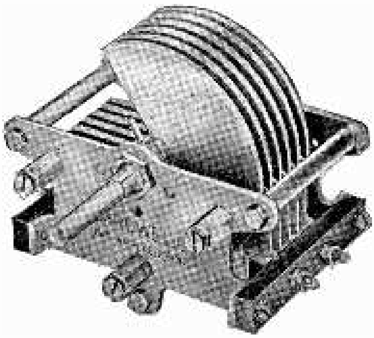


Fig. 10—Early Form of Variable Condenser.

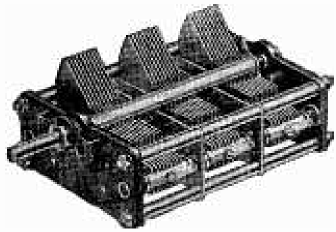
set of plates. A picture of one of these condensers is shown in Fig. 10. This is composed of a set of plates anchored in a base of insulating material, such as dry wood, and another set of plates, which do not touch the others, slides in and out in grooves in the wood. This is one of the earliest forms of variable condenser which was used in radio receivers. Of course this style of *variable* condenser is large and clumsy, so that nowadays condensers are made so that one set of *rotor* plates moves between another set of *stator* plates. Such condensers are shown in Fig. 11. These styles occupy much less space, and provide a much greater capacity for the same space.

The variable condensers shown in Fig. 11 are made of semi-circular plates. There are other shapes of plates used for special purposes in radio receivers, but we will reserve the study of these until later on. In the semi-circular plate condenser, it is clear that if we move the rotor plates a certain distance and then move them the same distance again, that we increase the *overlapping area* of the plates and consequently have increased the capacity of the condenser. In other words, the capacity increase is in proportion to the area of the rotor and stator plates enmeshed.

Now just keep all this in mind, and we shall see how the coils can be made to change the conditions in the radio circuits.



Variable Condenser.



Three Gang Condenser.

Fig. 11

Of course, it is not necessary to vary both the condenser and the coils, as the same effect can be produced by varying one or the other, as if produced by varying both, but we shall have to consider this in order to learn how the coil acts.

INDUCTANCE

In this lesson we learned that when a coil carries an electric current, that this current establishes what is known as a *magnetic field* in and about the coil. We also learned that if we had a magnetic field to begin with, and that if this magnetic field was changing, or if we passed a coil through it, that a voltage would be *induced* in the coil, due to the energy in the magnetic field.

Now suppose we had a magnetic field of a certain strength, and that we passed rapidly through it a coil of a certain number of turns. There would be a certain voltage induced in the coil. Suppose again that we passed another coil through the same magnetic field, but that the second coil has just twice as many turns of wire as the first coil. It would be found then that the voltage induced in the second coil would be just twice that induced in the first coil. It is clear then that the number of turns of wire in the coil determines how it is going to act. There are other things, however, which must be taken into consideration, and some of these are the diameter, size of wire, and so forth. We shall learn more about this later. The subject of coils is a rather difficult one, perhaps a little more difficult than the subject of condensers, so the student will have to take many things for granted at the present time, until we get to the lesson in which we shall study them in detail.

At any rate, there is a certain property of coils which we called *"inductance."* The amount of inductance of a coil gives us an idea of the ability of this coil to create a magnetic

Fig. 12—Various Types of Fixed Condensers.

field when a current flows in it, or—just the opposite—the ability a certain magnetic field has of creating or *inducing* in the coil a voltage, when the coil is passed through it or when the magnetic field varies in strength. The greater the number of turns, the greater the inductance of the coil; the greater the diameter of the turns, the greater the inductance; the smaller the wire, the greater the inductance.

In the case of condensers, the larger the plates, the greater the capacity; the closer the plates the greater the capacity. There are other things which determine the inductance of coils and the capacity of condensers, and these are the materials inside them. If we place a sheet of glass between the plates of a condenser, instead of merely allowing them to be separated by air, the capacity of the condenser will be very much increased. If we place an iron core inside a coil of wire, the inductance of the coil will be very much greater than if we had only air—that is, inside the tube upon which the coil is wound.

As a rule, air core coils are used in tuned radio circuits, and the condensers used for tuning do not have anything but air between their plates. But there are small condensers used in modern receivers, known as *fixed* condensers, which have mica sheets between the plates. These are called fixed condensers, because the plates cannot be moved. Several of these are shown in Fig. 12. We shall learn what these are used for later on.

With regard to condensers and coils, therefore, you must remember the following:

The capacity of a condenser increases as

(*a*) *the overlapping area of the plates is increased;*

(*b*) *the distance between the plates is decreased;*

(*c*) *and depends upon the material between the plates.*

The material between the plates is called the *dielectric.* It may be air, mica, paper, glass, bakelite, or any good insulating material.

The inductance of a coil increases as

(*a*) *the number of turns of wire is increased;*

(*b*) *the diameter of the coil is increased;*

(*c*) *the diameter of the wire is decreased;*

(*d*) *and depends on the material of which the core is made.*

The core material may be air or iron. Iron causes the coil to have a great deal more inductance than if an air core is used. Furthermore, it depends on the kind of iron used. Permanent magnets are made of hard steel. The cores for electromagnets, which we want to be magnetic only when a current is passing through the coil, are made of soft iron. Often these cores are made of thin sheets laid upon each other called *laminations. Silicon steel* is the grade of steel often used for these laminated cores. We shall learn a great deal about this later on when we study transformers and choke coils for Power Supply Units, etc.

To get back to the ideas of tuning. Remember, in our previous lesson, we described how a weight hung on a spring oscillated up and down after it was once started? Well, we have the same picture in Fig. 13. Let us give the weight a downward push, and count how many times a minute it oscillates up and down. Now let us take off the weight and put in place of it a heavier one. Then start it going and count once again. You will find this time that the heavier weight oscillates more slowly than did the lighter one.

Let us try something else. Suppose instead of changing the weight, we let it alone, and changed the tension of the spring. That is to say, suppose we used a spring which had been coiled up more tightly and had more tension. We would find that increasing the tension of the spring, or its "springiness," as it were, would cause the weight to oscillate more rapidly. Its *frequency* would be greater. In other words, it is possible to control the frequency of oscillation by changing either the load on the spring, or its elasticity (or tension) or both.

Now, to go a step further in our analogy, suppose, instead of the weight, we had a can hung on the end of the spring, and we also had a lot of lead shot that we could pour into the can. Let us pour a little bit in—an amount sufficient so that if we started the can oscillating it would do so at the rate of say, twenty times a minute.

Now we will go a step further. With the can at rest, let us start our hand oscillating up and down, away from the can and spring, at the rate of say, fifteen times a minute, or with any frequency which is different from that at which the can and spring oscillate by themselves. While keeping the hand thus oscillating, bring it closer and closer to the can; eventually it will touch the can and cause it to start on its downward journey. (Don't let the hand follow the can on its journey, but merely give it a push.)

Now, remember, the can oscillates *naturally* 20 times a minute, while the hand is oscillating fifteen times a minute. It is clear that the can will return on its upward journey before the hand has completed its downward journey. It is clear then, that the two motions will interfere, and the hand will prevent the weight from going through its motions as it should.

Now add some lead shot to the weight in the can. The can will oscillate more slowly. Keep on adding the shot until you find that the can oscillates *naturally* at the same rate as the hand—fifteen times a minute. When you have it just right you will find that every time the hand starts its downward journey, the can is starting its downward journey also, so that there will be no interference between the two at any time. Each time the can goes downward, so does the hand; the hand gives the can a slight push or boost, as it were, and helps the can along in its journey. As a matter of fact, we can make the can oscillate as strongly as we please by pushing it as hard as we please, but we must always push at the right instant. When the rate of pushing is exactly the same as the natural rate of the can there will be no interference between the two. We have *tuned* the can and spring to the frequency of the hand, by loading it up with lead shot. Once the can is started going, it is an easy matter to keep it going, but it is quite difficult to keep it going when the two frequencies are not the same.

Let us see what this has to do with radio. The weight represents the coil's inductance. The spring represents the capacity of the condenser. The rate at which the can is vibrating (or oscillating) is the frequency. The hand represents the radio waves being received by the radio receiver. This received wave may have any frequency; that is, up to the

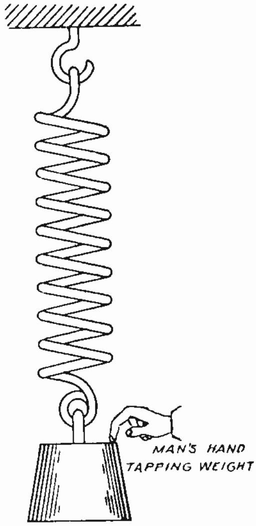


Fig. 13

station sending the waves. We must make the receiver capable of oscillating at the same frequency by tuning it. Just as we loaded up the weight on the spring by adding shot, or by changing the elasticity of the spring, in order to tune it to the same frequency as the hand, so in the radio circuit we can change the inductance (which corresponds to the weight), or the capacity (corresponding to the spring). Or, if we please, we can change both of these a little. Generally, we are content to change only the capacity of the condenser, as this simplifies the construction of the receiver.

So now we know the process of tuning. At least we have an idea of what it is all about. The radio waves are sent out by the broadcasting station, which cause electrical oscillations, or electrical currents which reverse in direction with great frequency. The radio receiver is tuned so that it is capable of oscillating at this same frequency, and when so tuned the incoming waves cause it to respond with little difficulty. It is clear that the smaller the losses (or the resistances) in the circuits, the weaker need be the incoming waves in order to make the receiver respond. This means that when the losses are smaller, the receiver can respond to weaker signals, which may be coming from a broadcasting station farther away.

Having covered the subject of tuning, by coils and condensers, we must learn something about the electron tubes. We learned that these electron tubes have a filament, just like the filaments in an incandescent lamp. Of course, the filaments in the electron tubes are very much smaller, and do not give out much light. The filaments are heated by electric currents, just as are the filaments of the incandescent lamps, but the voltage required to light them is very much lower, from 1.5 to 7.5 volts, instead of 110 volts.

The current required to heat the filament may be obtained from storage batteries, as you learned in a previous lesson, although in most modern receivers they are heated by the alternating current obtained from a transformer which is connected to the house lighting circuits. This matter was also explained in a preceding lesson, and will be discussed more at length later on. The student must remember that the filament can be heated by either method, because for the present, at least in these earlier lessons the circuit diagrams, as Fig. 14 will show, storage batteries for heating the filament in order to simplify matters.

When studying our first lesson you learned that there were such things as electrons, and you also learned that these electrons exist in everything, no matter where this thing may be, or its condition. Whether hot or cold, soft or hard, electrons are contained in it. In fact, the latest theory of the scientists is that everything is made of electrons, and the number of electrons, and the way they are arranged makes the difference between various materials, as, for instance, lead, iron, salt, air and so forth.

We also learned before that an electric current is the same thing as a flow or movement of these electrons. The problem in radio, therefore, is to make use of these electrons by making them flow where we want them to flow, and make them do what we want them to do.

It is well known that when materials are heated to a sufficiently high temperature, perhaps a few hundred degrees, that they let go of the electrons which they have in them. For instance, the very filament in the electron tube which we are studying, has electrons in it, and when we heat up this filament by passing through it an electric current from a battery, its electrons jump away from it. They jump away in the thousands, perhaps the millions, in a second. They fill the space around the filament within the glass walls of the bulb in which the filament is located.

But now that we have gotten these electrons out of the metal of the filament, the next thing to do is to make them work for us. As learned a little way back when we were studying about condensers, when we have a lot of electrons, they can be attracted to the positive pole of a battery if this battery is connected to the place where the electrons are crowded. In other words, the electron is supposed to be *an extremely small negative electric charge,* and according to the law of electricity, *opposites attract.* Therefore, if we connect the positive pole of a battery to the place where the negative electrons are, the positive pole will attract the negative electrons, and we will have an electrical current flowing. This is actually what we do in an electron tube.

ACTION OF THE VACUUM TUBE

In Fig. 14 we have an electron tube, the glass bulb having in it a filament and a plate. The glass bulb is known as the *envelope* of the tube. The plate is thin and small and may be made of tungsten, or nickel, or some other metal. The filament is lighted by means of the filament six volts lighting battery. This battery is known as the "A" battery. There is another battery, called the "B" battery, which has its positive terminal connected to the plate.

What has been said about the filament of the tube being heated by either direct current as furnished by a battery or by alternating current as furnished by a transformer, applies as well to the "B" supply, although this must always be direct current and *not* alternating current. When the power for the "B" supply is obtained from a transformer in the form of alternating current, this must be rectified by means of a special rectifier tube, and the *ripples* or *hum* must be filtered out of it. This has been explained in an elementary manner in a preceding lesson, and will be discussed in great detail later on. Although, for the sake of simplicity, the diagrams in this lesson show "A" and "B" batteries for their source of power supply. It must be remembered that these can be, and are generally, replaced by a *power-pack*, which includes a rectifier and filter, operated directly by the A. C. house lighting power.

The filament, being heated by the "A" battery, shoots off a great multitude of electrons, and the plate, which is located in the space where these electrons are, and being charged positive by being connected to the positive terminal of the "B" battery, attracts the negative electrons. Now since the electrons come from the filament, and pass on to the plate, they must keep on passing somewhere, as they cannot pile up as they

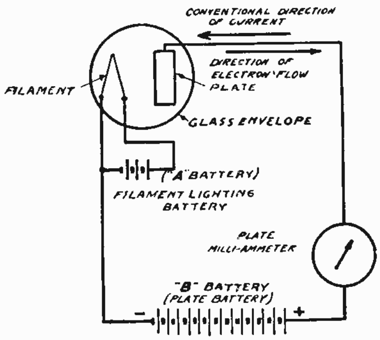


Fig. 14—Filament and Plate Circuit Connections of a Two Element Vacuum Tube.

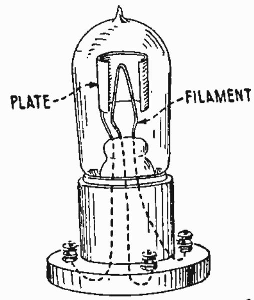


Fig. 14-A—Pictorial View of a Two Element Vacuum Tube, Showing Connections to Filament and Plate (Cut Away) Through Socket and Tube Base.

do on the plates of a condenser. The small plate in the tube is too small to hold many of them. Furthermore, we want these electrons to flow around through a complete circuit so that we can make them work for us. And finally, if we did not furnish some means of replacing the electrons that are taken from the filament, the filament would soon lose all the electrons it had. So we connect the negative pole of the "B" battery to the filament.

The electrons, therefore, flow in a complete circuit; they jump out of the filament into the space within the tube; then they are gathered up by the plate with its positive charge; next they pass through the "B" battery, and finally come back to the filament. They continue going over and over this path without a stop, as long as the filament is lighted and as long as the batteries hold out. The electrons lost by the filament are supplied by the "B" battery, and it is this that gradually uses up this battery. There are also the resistance losses in the system, which must be taken care of by the "B" battery. So now we have a source of electrons, the electrons themselves, and a means

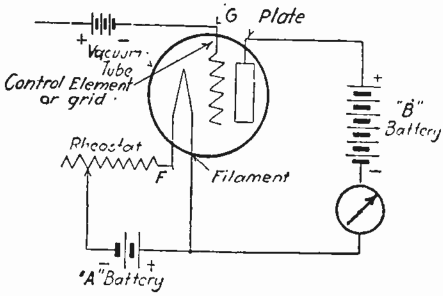


Fig. 15—Illustration Showing Position of Filament, Grid and Plate in a Vacuum Tube.

of making them work for us. We now have to see how they can be made to do work for us in a radio receiver, so that we can receive very weak signals.

It is clear that Fig. 14 is not by itself a radio circuit; there are no condensers or coils in it, and these are necessary for tun-

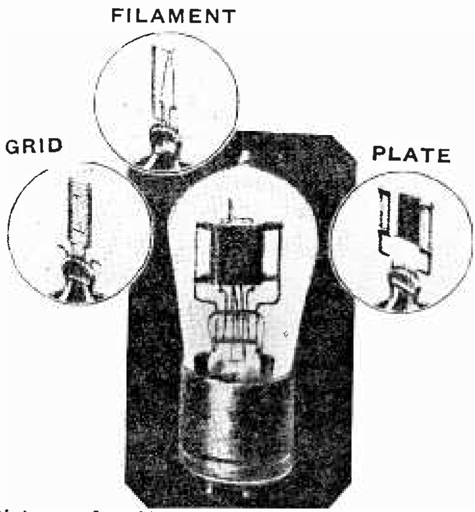


Fig. 16—Picture of a Vacuum Tube Showing Details of Grid, Filament and Plate.

ing. We must include this electron tube, with its "A" and "B" batteries in a tuning circuit with a condenser and coil. But before we do this we must find out how we can *control* the electron flow.

Glancing at Fig. 15, we see how this can be done. If we had another plate, or one or more wires in between the filament and the plate, we might make this *rob the plate* of some of the electrons, or even make it *help the plate* get more electrons. In other words it will act as a control *element,* and such it is actually called. But the popular name for it is "*grid,*" since it is constructed like a grid. This is shown in Fig. 15. A photograph of an actual electron tube—and the three elements—is shown in Fig. 16.

Now let us see what this control element or grid does in the electron tube. Ordinarily, although the grid is right in the path of the electrons as they travel from the filament to the plate of the electron tube, it does not obstruct or block the passage of many of these electrons, since nearly all of them can

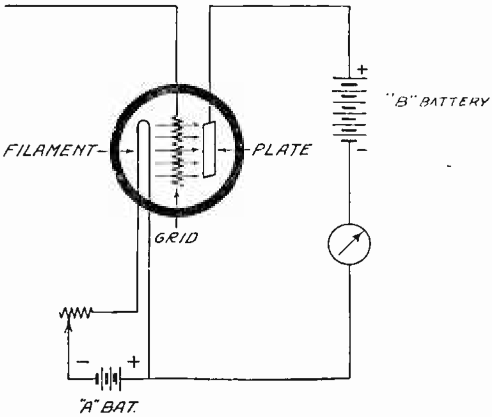


Fig. 17-A—Illustrating the Electron Emission from the Filament to the Plate of a Vacuum Tube.

pass through the open spaces of the grid. The construction of the grid makes this possible, since it consists of nothing more than an open network, or mesh, of fine wires. It does, however, gather in some of the electrons, so that it usually acquires a slight negative charge, just as any piece of conducting material when electrons collect on it. But at the present time this effect is not important; we are now mainly concerned with the fundamental operation of the tube, and will come back to the other later on. For the present let us suppose that *all* of the electrons normally go *through* the grid on their way from the filament to the plate.

This being the case, there will be a certain current flowing in the *plate circuit* of the tube, that is, the circuit (see Fig. 15) from the filament, to the plate, through the "B" battery and the current indicator, then the "A" battery and the rheostat to the filament.

NOTE:—*Before the discoveries were made that led to the electron theory, physicists believed that the current flowed from the positive terminal of a circuit, back to the negative terminal. These two theories are, therefore, in contradiction to one another, but due to the fact that the whole foundation and operating principles in the development of electrical engineering were founded on the old theory, this custom cannot well be changed in all cases, so we must still speak of the current as flowing from the positive terminal to the negative in some cases, covering the action of motors, generators, transformers, batteries, etc., but it is well to bear in mind that the thing that really flows in the wire or circuit is a stream of negative electrons from the negative to the positive terminal.*

It is hoped that this will clear up in the student's mind the

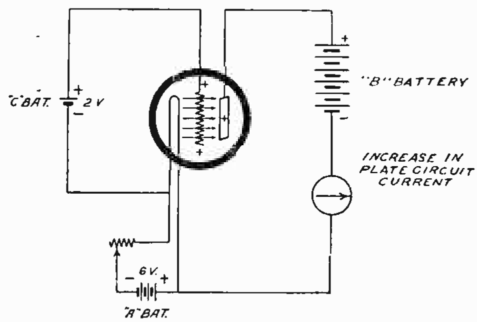


Fig. 17-B—Illustrating the Result of the "C" Battery Placing a Positive Charge on the Grid.

much talked of contradiction which has sprung up regarding the flow of current in radio circuits.

At any rate, let us say that we have a certain amount of current flowing in the plate circuit of the tube, due to the *emission,* or sending forth, of electrons from the filament to the plate. We have represented this in the diagram, Fig. 17-A, where we have also shown the way in which the electron tube is generally drawn in wiring diagrams. The number of arrows drawn from the filament to the plate represent a number of electrons traveling that way. All of them pass through the grid, and we have a certain amount of current flowing through the current indicator, in the plate circuit.

Now suppose we place a positive charge of electricity on the grid, or control element, of the tube. See Fig. 17-B. As we have said before, opposite charges attract, so that this charge on the grid will attract more electrons from the filament. Some of these electrons will stay on the grid, since the positive charge will try to hold them, but the greater part of them will fly through the open spaces of the grid to the plate. There is, therefore, a much greater number of electrons passing from the filament to the plate, and as a consequence the current in the plate circuit is increased.

Now, on the other hand, suppose we had a negative charge of electricity on the grid. (See Fig. 17-C). Since opposites attract, it is clear that charges which are *like* or the same, must repel each other. Therefore, the grid with its negative charge repels many of the electrons from it. Some of these are forced back into the filament from which they came; others are scattered out into the space within the glass bulb. When this happens, the current in the plate circuit of the tube must be less than it was before.

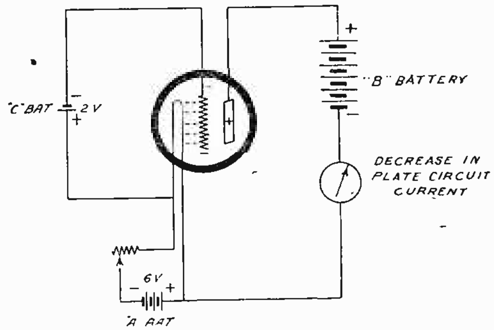


Fig. 17-C—Illustrating the Result of the "C" Battery Placing a Negative Potential on the Grid.

Now we see that the current in the plate circuit of the tube can be controlled by the charge on the grid. These changes in the plate current can be made to work for us, for it is a simple matter to place a pair of headphones, in the plate circuit, instead of the current indicator or galvanometer and hear what is going on. This is the principle of radio reception, so you see that we are rapidly making progress in our study, and things are gradually becoming clearer and clearer.

There are two ways to change the amount of current flowing in the plate circuit of a vacuum tube.

First, by increasing or decreasing the voltage applied to the grid of the tube.

Second, by increasing or decreasing the voltage applied to the plate of the tube.

Either of these two methods will cause a change in the plate current. This is very important because the *amplification factor* of a vacuum tube, represents the maximum number of times the tube is capable of amplifying the signal that is impressed upon its grid. The value of the amplification factor varies according to the ratio of the change in plate voltage, to the small change in grid voltage which produces an equal variation in plate current. By using the proper measuring instruments in the grid, filament and plate circuits it can be found that a very small negative or positive charge on the grid of the tube will produce quite a large change in the plate current. The reason for this can be explained as follows: Suppose we have 90 volts in our "B" supply. This is the same thing as saying that the positive terminal of the "B" battery or unit is 90 volts higher than the negative terminal.

Now, since the plate of the tube is connected to the *positive* and the filament of the tube to the *negative* terminal of the "B" battery, we must have the same voltage between the plate and the filament, that is 90 volts. In other words, the plate is 90 volts higher than the filament.

This being the case, the positive charge on the plate, of 90 volts, can attract just so many electrons, and produce only a certain amount of current in the plate circuit.

Now suppose we increase the plate voltage by 5 volts, making the total plate voltage 95 volts, and that this change of voltage increases the plate current by say 1/1000th of an ampere, which is usually called a *milliampere*, this change of 5 volts in the plate circuit will cause only a slight change in the plate current.

However, a change of 5 volts, say for example, from — 5 to 0 or from 0 to + 5, applied to the grid of the tube will cause a very great change in plate current. Suppose this 5 volts change in grid voltage causes a change of 10 milliamperes in plate current, we might find it necessary to increase the plate voltage to 40 volts (90 + 40) to obtain the same plate current change obtained by only a 5 volt change of grid voltage.

Thus it would require eight times the change of plate voltage as of grid voltage to obtain the same result in plate current change. The amplification factor of such a tube would be 8. To find the amplification factor of a tube we divide the number of volts change of "B" supply required to produce a certain increase in plate current by the number of volts change on the grid to produce the same increase of plate current. The quotient is the amplification factor of the tube in this case $\frac{40}{5}$ equals 8.

The amplification factor of different tubes is different, varying from about 3 to 20 or even higher, depending upon the construction of the tube in regards to the spacing of the elements and the size of wires in the grid, that is, the closer the spacing the greater the screening effect of the grid. In later text books more information will be given on the characteristics of vacuum tubes.

Now we have next to learn where and how we get the positive and negative voltages, so that we can place them on the grid of the tube. You will remember that the tuning circuit of a radio receiver consists of a coil having inductance, connected in series with a condenser having capacity. An electric current flows in this circuit whenever a signal is picked up by the antenna or aerial, and this charges and discharges in and out of the condenser, the energy being transferred during each reversal of the current back and forth from the condenser to the coil and vice-versa. This happens many times a second, depending upon the frequency of the current, or the wave length of the radio waves.

You have also learned that when a condenser becomes charged it has a voltage established between its plates; that is, each time the condenser is charged, one plate is so many volts higher than the other plate. One plate is therefore *positive* and the other is *negative*. When the condenser charges in the opposite direction, after the current has reversed, the voltage is reversed; the plate of the condenser which was negative is now positive, and the plate which was positive is now negative. So you see that we have here in the condenser the positive and negative charges which we can place on the grid of the electron tube.

You will see what we have now if you look at Fig. 18. We are fast approaching a complete wiring diagram of a radio receiver. We have a coil L connected in series with a condenser C. As the current in this circuit reverses with great *frequency,* the voltage in the condenser C reverses in step with the current. At one instant, therefore, we have the grid connected to a plate of the condenser which is positive, and the next instant that plate is negative, so that the voltage between the grid and filament reverses each time the high frequency radio current in the tuning circuit reverses. At one instant, therefore, when the grid is positive, the plate current increases, and the next instant, when the grid is negative, the plate current decreases. These increases and decreases of plate current are in step also with the high frequency radio currents in the tuned circuit. Furthermore, this varying current in the plate circuit is much greater than the current in the tuning circuit, due to the amplification by the tube.

FUNDAMENTAL RADIO CIRCUIT

The circuit shown in Fig. 18 is the fundamental circuit of the radio receiver. Although many circuits differ from one another in details, the tuning circuits in all radio receivers are based on this diagram. The grid and filament connections to the tube are called the *input* connections, and the plate and

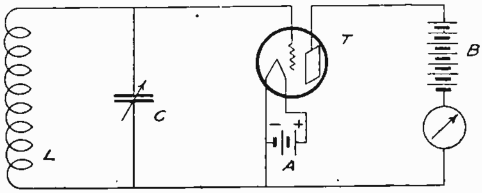


Fig. 18—Fundamental Vacuum Tube Circuit of a Radio Receiver.

filament connections are called the *output* connections of the tube. There is often a *tuned circuit* connected to the input of the tube. The output of the tube may be connected to several different circuits, depending upon how the tube is being used. If you will remember, we spoke of detector tubes and amplifier tubes in our first lesson, and we also spoke of two kinds of amplifiers—audio and radio frequency amplifiers. The radio frequency amplifiers amplify the high frequency radio currents. The detector tube operates on these high frequency currents so that it is possible to hear them when we pass them into headphones or a loud speaker. If these are yet too weak to hear comfortably we can amplify them still further in an audio frequency amplifier. The operation of the tube in all these cases is very much the same, as we shall see when we study these various operations separately and in detail.

Now let us see how far we have gone. First we have the radio wave sent out by the transmitting station. This radio wave when passing over the antenna of the receiving station establishes or *generates* a voltage in the antenna which causes a current to flow in it. This current is a *high-frequency* current, that is, it oscillates back and forth in the circuit at a very high frequency, this frequency corresponding to the frequency of the radio waves. We have seen that in order to *tune* the circuits to this frequency, we must have a tuning circuit composed of coils and condensers. Then the high frequency current in this tuning circuit causes a voltage to be established between the terminals of the condenser, and this voltage is then applied to the input of an electron tube. The electron tube *amplifies* these voltages, which reverse in polarity each time the high frequency current reverses, and we have in the output circuit of the tube a highly magnified current which oscillates at the same rate as the original currents in the antenna.

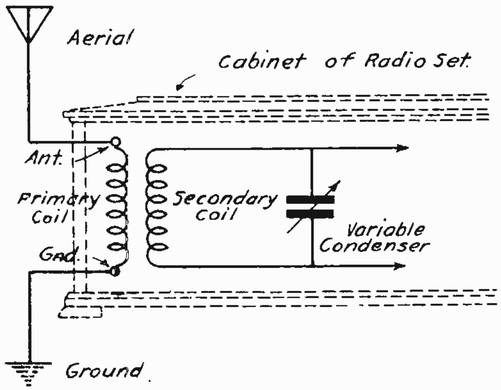


Fig. 19—Antenna Circuit of a Radio Receiving Set, Including Primary Coil, and Showing Connections to Secondary Coil and Variable Condenser.

AERIAL AND GROUND CONNECTIONS

But we have passed over a "missing link" in our story, and that is to find out how the current in the antenna causes a similar current to flow in the tuned circuit. Let us look at Fig. 19. We have shown in that figure an antenna, using the usual shorthand method of representing it, connected in series with a small coil. This is the complete antenna circuit, as generally used in up-to-date radio receivers. This may not look very much like a complete circuit to you, but you will soon see that it is. As a matter of fact the antenna is a condenser, or at least it is one plate of a condenser, and the ground or earth is the other plate. The antenna which is generally used for receiving broadcast concerts is merely a single wire, from 40 to 100 feet long, connected to two insulators and stretched above the roof of a house, or between two poles or trees.

Located somewhere inside or on the cabinet of the radio receiver are two binding posts labeled "ant" and "gnd". These abbreviations stand for antenna and ground, and show where the wires from the antenna and from the ground are to be connected.

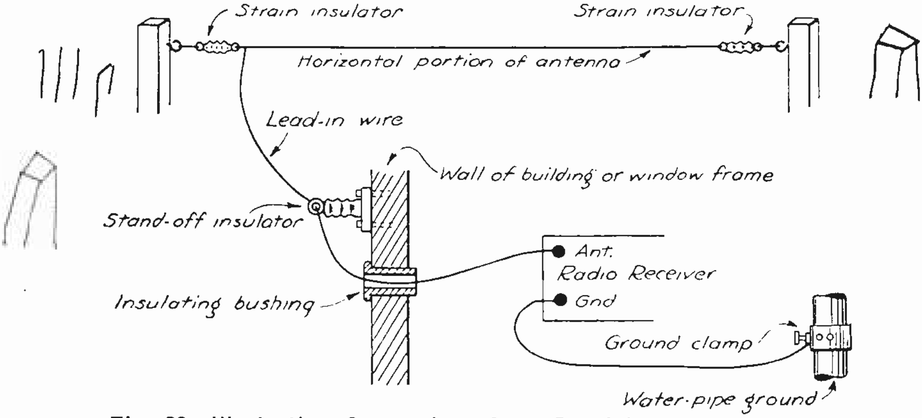
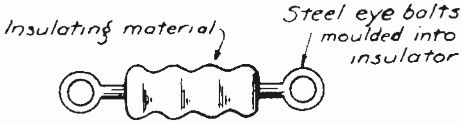


Fig. 20—Illustrating Connections from Receiving Set to Antenna and Ground.

COMPLETE AERIAL INSTALLATION

Figure 20 shows a complete installation, all excepting the batteries. The wire from this horizontal portion of the antenna is called the "lead-in" wire. This ground wire is connected to a cold-water pipe by means of a "ground-clamp" or it may be soldered to the pipe.

The insulator shown in Fig. 21 is made of some material, like glass or bakelite, which has extremely high resistance.



Strain Insulator
Fig. 21

As we stated before, when the radio waves pass over the antenna they *"induce"* a voltage in the antenna which causes a current to flow in it. A coil is connected in the antenna circuit of the radio receiver. We also stated that the antenna wire and the earth form a large condenser, the wire acting as one plate of this condenser and the ground acting as the other.

This is shown in Fig. 22. We can see that this is a simple series circuit the only thing left out of it being the radio waves themselves. We cannot at the present time explain how the waves act on this circuit, as it is a long story, but we will devote some time to it later on, so you must take it for granted, for the present at least, that the radio waves act like a generator or dynamo connected in series in this

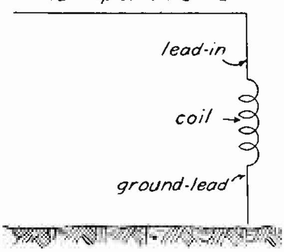


Fig. 22

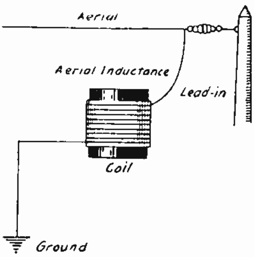


Fig. 22-A—Pictorial View of Circuit as Shown in Fig. 22.

circuit. The whole antenna circuit therefore acts like the circuit shown in Fig. 23, and since it contains both a condenser and a coil, it acts just like the tuned circuits we were discussing a little while before.

Having a generator, or a source of electrical energy, acting on the circuit, a current will flow in the circuit. This current must likewise flow through the coil in the circuit. Now we come back to the old idea that when we have a current flowing through a coil, and this current is varying or changing, that a magnetic field is established in and about the coil which changes in strength corresponding to the current. We have just such a situation here. The current in the antenna is changing at a great rate, not only in strength, but also in direction, since it is a high-frequency radio current. Therefore, the magnetic field of the coil is varying likewise. Now, as we learned before, if we place a wire, on another coil of wire, in this changing magnetic field, a voltage will be *induced* in this second coil which will cause a current to flow through it when the circuit is completed.

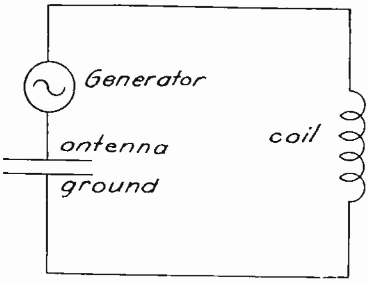


Fig. 23

We have the whole thing shown in Fig. 24. The antenna is connected to a small coil called the "*primary*" coil. The changing current in this coil establishes a changing magnetic

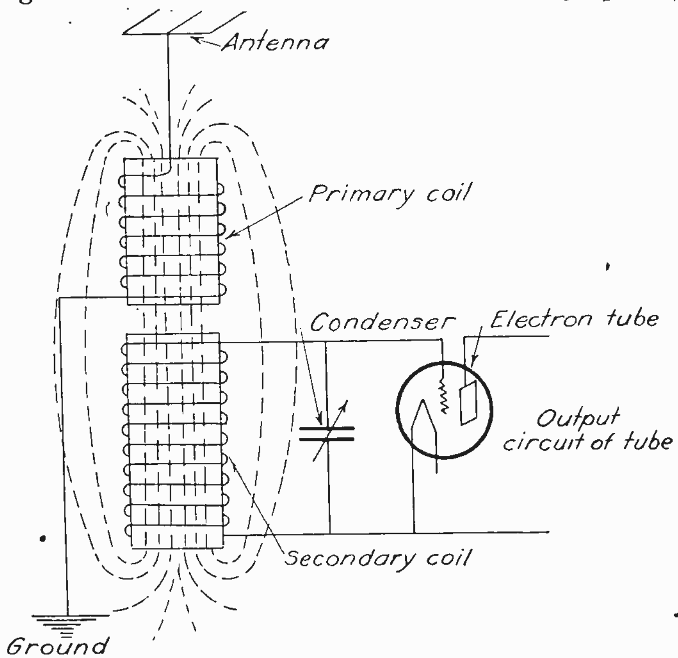


Fig. 24

field as shown by the shading in the picture. This magnetic field "cuts" or "links" another coil, which is called the *secondary coil*. The changing magnetic field *induces* a voltage in the

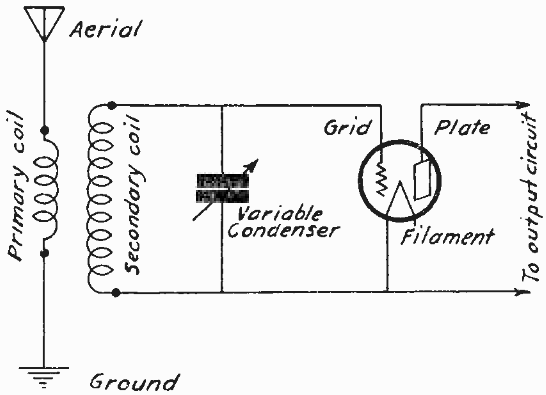


Fig. 25—Usual Way of Representing Circuit Shown in Fig. 24

secondary coil, and when the circuit of this secondary coil is completed, say, by connecting it to a variable condenser (as shown in Fig. 24), a current will flow in this circuit.

Now we have brought the radio oscillations from the antenna and into the tuned circuit; next they pass on to the electron tube, where they are amplified, and so we have oscillations of greater strength in the output circuit of the electron tube.

We have now covered a great deal of ground in our study, probably more than you at first expected to cover in three lessons. We have a great deal more to learn however, so carefully absorb all that you can from each lesson.

TEST QUESTIONS

Number Your Answer Sheet 3—3 and add Your **Student Number** ________________

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Upon what does the strength of a magnetic field of a coil depend?
2. What is the effect on the capacity of a condenser when the size of the plates is increased?
3. What happens when a coil of wire is passed through a magnetic field?
4. State two ways in which the inductance of a coil may be increased.
5. What metals may be used for the plate of an electron tube?
6. What is the effect on the plate current of an electron tube when a negative charge is placed on the grid?
7. Draw a diagram illustrating the fundamental circuit of a Radio receiver.
8. Explain the purpose of the coils and condensers in a Radio receiver.
9. Draw a simple diagram showing how the connections to the antenna, lead-in wire, receiver and ground should be made. Also show where the insulators should be placed.
10. Draw a diagram showing how the primary and secondary coils and the electron tube are connected in a complete circuit.

RADIO BY MAIL

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