RADIO CONDENSERS AND HOW THEY WORK

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STUDY SCHEDULE NO. 7

For each study step, read the assigned pages first at your usual speed. Reread slowly one or more times. Finish with one quick reading to fix the important facts firmly in your mind, then answer the Lesson Questions for that step. Study each other step in this same way.

☐ 1. How a Condenser Stores a Charge .... Pages 1-8

Here is the fascinating story of how it is possible to cause electrons to redistribute themselves on the plates of a condenser and thus make this important part store a charge. The voltage applied and the capacity determine the amount of charge. The capacity in turn depends on the physical dimensions of the condenser. Answer Lesson Questions 1 and 2.

☐ 2. Typical Radio Condensers .... Pages 8-18

This section is crammed full of practical information. You study the difference between types, learn to recognize them and see how the way they are made causes them to have certain defects. You'll find plenty of use for this information in your radio work. Answer Lesson Question 3.

☐ 3. Connecting Condensers Together .... Pages 18-21

Condensers are frequently connected in series or in parallel to get the proper capacity. The effects are exactly opposite to those obtained with coils or resistors. Also, you are introduced to leakage and its effects on voltage distribution. Answer Lesson Question 4.

☐ 4. How a Condenser Works with A. C. .... Pages 21-24

This short section describes an important but little understood action—how a. c. can "flow" through a condenser. Read this several times carefully. Answer Lesson Questions 5 and 6.

☐ 5. A Simple Condenser-Resistor Circuit .... Pages 24-30

When a condenser and resistor are connected together, several important actions occur. The condenser takes longer to charge and, with a. c., a phase shift occurs. Here is more about vectors. Answer Lesson Question 7.

☐ 6. Voltage Division with R, L and C .... Pages 30-36

Here is the "heart" of the lesson. You are introduced to some of the basic circuits you will find in every radio device and find out how condenser defects upset them. You will get more details later, but you should study and restudy this section. Answer Lesson Questions 8, 9, and 10.

☐ 7. Mail your Answers for this Lesson to N. R. I. for Grading.

☐ 8. Start Studying the Next Lesson.

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RADIO CONDENSERS AND HOW THEY WORK

How a Condenser Stores a Charge

CONDENSERS are one of the four corner-stones of radio. Like coils, resistors and tubes, condensers are found in every radio—even the tiniest. In fact, there are usually more condensers than there are of any other type of part. These condensers (acting in combination with other parts) are used to tune the set, to furnish the right power for operating the various sections, to keep the currents in the proper paths, and to perform many other important tasks which must be done for the radio to operate properly. You'll be meeting these useful devices all through your N.R.I. Course, but we should first study the types and basic actions of condensers before we take up their uses in combination with other parts. You'll want to learn about the defects occurring in condensers, as they cause more radio breakdowns than any other part, except possibly tubes. Hence, this lesson gives practical facts about condensers and their troubles.

What a Condenser Is. A condenser* is a device for storing electricity. Any condenser, no matter what type it is, consists essentially of two or more conducting surfaces separated by an insulator. The conducting surfaces are usually called plates, and the insulator is known as a "dielectric" (pronounced die-eh-LECK-trick).

▶ As you'll learn in this lesson, there are a great many types of condensers. They differ in construction, in kinds and shapes of plates, and in the dielectrics used, but basically they all work the same way to store electricity. So before taking up the various types and their uses, let's see just how a condenser works.

CHARGING A CONDENSER

Let's first take the simple case of a condenser which has absolutely nothing—a perfect vacuum—between its plates. When such a condenser is connected to a battery, as in Fig. *1*, the battery voltage makes electrons rush from the negative terminal of the battery through wire *a* to plate *A*. *There the electrons stop, because they cannot flow through the vacuum which separates them from plate B.**

But although these electrons cannot move across the vacuum, their *effect* can. As you learned in an earlier lesson, electrons repel one another—that is, they try to drive one another away. This repelling action occurs even when the electrons are a considerable distance apart, and are separated by a perfect vacuum.

Thus, the electrons which have collected on plate *A* repel an equal number of electrons from plate *B*. The electrons from plate *B* then flow into

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* A *condenser* does not "condense" anything. This is just the popular name for the part, which is more correctly called a *capacitor* by radio engineers. Similarly, *capacitance* is more proper than *capacity*. However, radio men have used these terms so long that they are accepted as correct.

* The electrons normally do not have sufficient energy to escape from the plate and jump the gap. Later you will learn that if the voltage is too high, they can jump the gap between the plates.

wire *b*, and through the wire to the positive terminal of the battery.

We thus have an electron flow, or current, from the battery to plate *A*, and an equal current from plate *B* to the battery *but no flow between plates A and B*. The flow of electrons onto plate *A* makes it *negative*, because it has an excess of electrons. The flow of electrons away from plate *B* makes this plate *positive*, because it has a scarcity of electrons. Thus, a difference in potential, or a voltage, exists between plates *A* and *B*.

▶ The electron flow continues until plate *A* is just as negative as the negative battery terminal, and plate *B* is just as positive as the positive battery terminal. As electrons do not flow across the gap, there can be no continuous flow of current. The electrons just flow long enough to make the condenser charge up so the condenser voltage equals the battery voltage.

Notice the polarity of this voltage, shown in Fig. *2*. As you go around the circuit, you find the condenser voltage opposes (bucks) the battery voltage. Therefore, when the condenser voltage is equal to the battery voltage, it cancels the battery voltage and the flow of electrons stops. That is, after a condenser is charged, it does not act like a load—it resembles a source of voltage. Hence, we have the effect of two sources of voltage connected so as to buck each other out, leaving no voltage to maintain electron flow. When the condenser voltage is equal to the voltage of the battery, we say the condenser is fully charged.

The Charged Condenser. Many people believe that a charged condenser contains more electrons than an uncharged one. But what you have just learned shows that this idea is not accurate. It is true that the negative plate has many more electrons than normal on it; however, each of these extra electrons has forced another electron out of the positive plate, so the *total* number of electrons on the condenser plates is unchanged. In charging a condenser, we increase the number on one plate and decrease those on the other—the same as if we transferred some electrons from one plate to the other around the circuit. The number of electrons added to the negative plate (and, of course, subtracted from the positive plate) is called the "charge" on the condenser.

▶ You may wonder what good it does to charge a condenser, since we don't change the total number of electrons on it by so doing. Well—suppose we disconnect the condenser from the battery. The electrons on the negative plate must remain there, because they have no other place to go. Thus we have an unbalanced condition inside the condenser, with more electrons than normal on one plate and fewer than normal on the other.

As you know, nature always tries to correct an unbalance of this sort. If we provide a path, the extra electrons on the negative plate will rush to the positive plate. In other words, if we connect the plates of our charged condenser with a wire, a current will flow through the wire. (Of course, it will flow only for the time necessary for all the excess electrons to reach the positive plate).

Thus, you might consider a condenser to be a kind of storage battery, or an electrical reservoir. Within limits, we can put electricity into a condenser whenever we wish, and draw it out again whenever we wish. This makes a condenser a highly useful device in radio circuits.

Amount of Charge. The charge on any particular condenser—which, as you just saw, is the number of electrons moved around the circuit—depends on the voltage of the battery used to charge it. The higher the battery voltage, the more the charge will be. However, the voltage alone does not determine the amount of charge we can store in a condenser. The *capacity* of the condenser is just as important as the charging voltage. Let's see what is meant by this term "capacity."

CAPACITY

If we divide the amount of charge on any condenser by the voltage necessary to give it this charge, the result shows us the amount of charge that can be stored on that condenser by an applied voltage of one volt. This is called the "capacity" (sometimes "capacitance") of the condenser. We can express capacity by the equation $C = Q/V$, where C is the capacity of the condenser, Q is the charge it takes, and V the charging voltage.

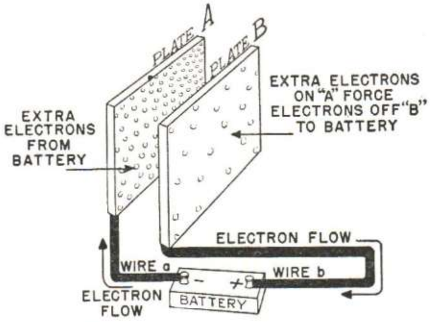

FIG. 1. When a condenser is connected to a battery, electrons collect on the negative plate, driving others off the positive plate as shown here.

The capacity of a condenser is really a measure of its ability to store electricity. A condenser with high capacity can store a great deal of electricity for a given voltage, while less can be stored in a condenser of lower capacity. For this reason, its capacity is usually the first thing a radio man wants to know about any condenser he uses.

Units of Capacity. Just as ohms are the units of resistance and henrys the units of inductance, so *farads* (pronounced FAIR-ads) are the units of capacity. A condenser which stores 6.3 million million million more electrons (which is called a "coulomb" of charge) on its negative plate than on the positive plate when one volt is applied to it has a capacity of one farad. Of course, a farad is a very large unit, so large in fact, that it is not practical for radio work. Instead, two smaller units are used:

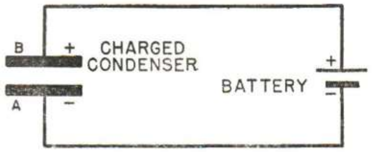

FIG. 2. No current flows when the condenser is charged to a voltage equal to the battery voltage. The condenser voltage then acts as a "bucking" voltage by being equal and opposite to the battery voltage as you progress around the circuit.

1. The microfarad, equal to one millionth of a farad. It is abbreviated *µf.*, *mf.*, or *mfd.*

2. The micro-microfarad, equal to one millionth of a microfarad. Its abbreviations are *µµf.*, *mmf.*, or *mmfd.*

All six abbreviations are frequently used in radio, so you should learn them all. The sign µ is the Greek letter "mu" (pronounced MEW).

Sometimes it will be necessary for you to change a value in microfarads to its equivalent value in micro-microfarads, and vice versa. Learn these two simple rules, and you'll find it easy to make the change:

Rule 1. To change mfd. to mmfd., move the decimal point six places to the right.

Rule 2. To change mmfd. to mfd., move the decimal point six places to the left.

For example, suppose we have a capacity of .001 mfd. and we want to know its value in micro-microfarads. We can write .001 as .001000. Then, moving the decimal point six places to the right (Rule 1) gives us 001000 mmfd., or 1000 mmfd. Similarly, to express 250 mmfd. in microfarads, we would first write 250 as 000250, then move the decimal point six places to the left (Rule 2). This gives us .000250, or .00025 mfd.

Incidentally, radio men usually pronounce .001 mfd. as *point double oh one* microfarad, or as *point zero zero one* microfarad. They would pronounce .00025 mfd. as *point triple oh two five* microfarad, or as *point triple zero two five* microfarad.

WHAT DETERMINES CAPACITY

Many times in your future radio work, you will use condensers whose capacities can be changed. So you will understand how and why such condensers work, let's now take up the important subject of what determines the capacity of a condenser.

The ability to store a charge depends on the amount of repelling effect we can develop between the condenser plates, so we must either increase the number of repelling electrons or increase the repelling effect of the electrons to store a greater charge. It has been found that the capacity of any condenser depends on just four things—the *area* of the plates, the *number* of plates, the *spacing* of (distance between) the plates, and the *dielectric* used. Let's see just how each factor affects capacity.

1. Area. Besides acting across space to repel electrons from the positive plate, the electrons collected on the negative plate repel each other. For a particular voltage, only a certain number can be made to collect on a plate of fixed size, because they refuse to crowd too closely together. Increasing the area of the plates allows more "standing room" for electrons on the negative plate, so a greater charge is stored for the same voltage. If we double the overlapping area of the plates of a condenser, we double its capacity; if we triple the overlapping area, we triple the capacity; and so on. Notice that it is the *overlapping* area which is important—any section of the negative plate of a condenser which is not directly over a section of the positive plate does not greatly affect the capacity. You will see the practical use of this fact when we come to variable condensers a little farther along in this lesson.

2. Number of Plates. Suppose we have three plates instead of two, arranged as shown in Fig. *3A*. There will be a certain capacity formed between plates A_1 and B, and another capacity between A_2 and the other side of B. As A_1 and A_2 are the same size and connected together, they act like a single plate twice the size of either alone. Since both sides of plate B are used, the effective area is also twice that of one side of B. We thus have twice the effective plate area by adding one more plate. As you just learned, doubling the area doubles the capacity.

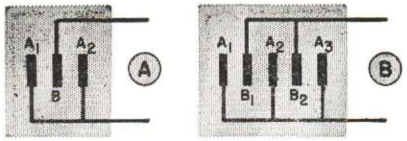

FIG. 3. Adding plates increases capacity.

The capacity can be further increased by adding more plates. In Fig. *3B*, we have capacities between A_1 and B_1, B_1 and A_2, A_2 and B_2, and B_2 and A_3. Here we have four times the capacity that would be formed by one pair of the same size plates. Thus, the total capacity is equal to the capacity of one pair of plates, multiplied by a number which is *one* less than the number of plates. For example, if a condenser has a capacity of 10 mmfd. between each pair of plates and has 7 plates, the capacity will be 10 times 6 (7 plates minus one) or 60 mmfd.

3. Plate Spacing. The distance over which the repelling effect must work is important. The smaller the distance, the stronger the force between the plates. This makes it easier to overcome the desire of the electrons to remain on the positive plate, so more are forced away, permitting more to collect on the negative plate. Thus, varying the plate spacing will affect the amount of charge per volt, and so vary the capacity. If we make the distance between the plates of a condenser only half what it was, we double the capacity; if we make the distance a third, we triple the capacity; and so on. This fact, too, has a practical use, as you will find when we treat trimmer condensers in a later section of this lesson.

4. Dielectric. So far, we have been talking about a condenser which has a perfect vacuum between its plates—that is, a condenser which uses a vacuum as a dielectric. If, instead, we used mica as a dielectric between the plates, we would increase the capacity as much as 6 to 8 times. Other substances would give different capacity increases.

Since most condensers use some dielectric other than a vacuum, and since a great many of your service problems will be caused by dielectric failures, let's see just what effects dielectrics have on condensers.

EFFECTS OF A DIELECTRIC

You recall that electrons flowing onto the negative plate of our vacuum dielectric condenser repelled electrons from the positive plate and thus allowed the condenser to become charged. What happens to this repelling effect when we put a solid dielectric between the plates?

The two pictures in Fig. *4* show the answer. A dielectric, as you know, is an insulator. Like everything else in the world, it is made up of atoms, which consist of electrons whirling around positive charges. Fig. *4A* shows an atom which has a positive charge at its center and one electron revolving around it in a circle. (Actually, atoms of all but one of the known elements have more than one whirling electron, but for simplicity we'll assume we are dealing with an atom which has only one.)

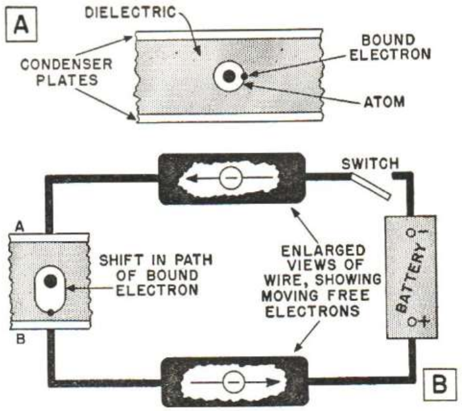

FIG. 4. Electrons in the dielectric are bound to their atoms. They do not "flow", instead their paths are shifted so they come closer to the positive plate and thus transfer the effect of the extra electrons gathered on the negative plate.

As you learned in an earlier lesson, a *conductor* has a large number of free electrons, which can move easily when even a low voltage is impressed across the conductor. But this is not true of an *insulator*. When a voltage is impressed across an insulator, nearly all the electrons within the insulator tend to keep whirling around their central positive charges, because they are bound tightly within their atoms; normally, they will break away only when acted on by a very high voltage. For this reason, the electrons in an insulator are called "bound" electrons.

Now, let's close the switch in the circuit shown in Fig. *4B*. Electrons start to pile up on the negative plate of the condenser. These electrons repel the bound electrons of the dielectric. Unless this repelling force is extremely large, the bound electrons do not break away from their atoms; however, the force does change their paths within their atoms from the circle shown in Fig. *4A* to the oval shown in Fig. *4B*. This brings the bound electrons closer to the positive plate of the condenser; they then exert a repelling effect of their own on the free electrons of plate *B*, driving them out of the plate into the battery.

In this manner, the repelling effect of the electrons on the negative condenser plate is relayed right through the dielectric. Placing the dielectric material between the plates provides bound electrons within the space, and so provides a better transfer medium. This increases the capacity.

Dielectric Constant. You learned a moment ago that any other dielectric gives a condenser a higher capacity than does a vacuum. However, experiments show that the increase in capacity is very slight when air or any other gas under normal pressure is used as the dielectric. In fact, the difference can be detected only by the finest laboratory equipment, so for all practical purposes we can say that a condenser using air as a dielectric has the same capacity it would have with a vacuum dielectric.

If we divide the capacity of a condenser using any given dielectric by the capacity of the *same* condenser using air as a dielectric, we get a number which shows how much the dielectric increases capacity. This number is called the *dielectric constant*[*] of the dielectric material.

You can readily see that condensers using dielectrics which have a high dielectric constant have a higher capacity than condensers using materials with a low dielectric constant. The dielectric constants of various common materials used in condensers are air = 1; paper = 1.5 to 3; paraffin = 2 to 3; mineral oil = 2.5; rubber = 2 to 4; mica = 4 to 8; glass = 4 to 10; castor oil = 4.7; porcelain = 5 to 7. Ceramic materials now coming into use have dielectric constants as high as 1500. Thus a condenser which has a capacity of 10 mmfd. using air as a dielectric would have a capacity between 40 and 80 mmfd. with a mica dielectric, and as much as 15,000 mmfd. with one of the new ceramic dielectrics.

VOLTAGE RATINGS

We have shown how increasing the voltage applied to a condenser will increase the charge stored on it. However, there are limits to the amount of voltage we can safely apply to the condenser. For example, when the voltage gets too high for the plate spacing of an air dielectric condenser a spark will jump between the plates. Thus, the amount we can increase the capacity of an air condenser by decreasing the distance between its plates is limited by the voltage to be applied to the condenser.

The same thing is true for condensers using other dielectrics. If we apply too high a voltage, the bound electrons of the dielectric escape from their atoms and start a flow of current through the condenser. This burns a hole right through the dielectric. When this happens, we say the condenser "breaks down"; the voltage which is just high enough to cause the condenser to break down is called the "breakdown voltage" rating of the condenser. The value of breakdown voltage for any given condenser depends on the dielectric used in it and the dielectric thickness.

Working Voltage. Condenser manufacturers almost always specify the *"working voltage"* of a condenser. This is the *maximum* voltage that can safely be applied to the condenser for long periods of time. Working voltage ratings for solid dielectric condensers, such as paper or mica, are always less than half the breakdown voltage. That is, over twice the working voltage can be applied to solid dielectric condensers before they will break down.

This rating does not mean you *have* to apply the working voltage to the condenser—this is just the *maximum* that *can* be applied safely. Thus, you can use a 400-volt condenser in a 10-volt circuit, or in any circuit having not more than 400 volts applied to it.

If a condenser is used in a d.c. circuit, we can put a voltmeter across it to make sure the working voltage is not being exceeded. But, as you have already learned, an a.c. voltmeter used on an a.c. circuit reads *effective* voltage; this meter reading must be multiplied by 1.4 (approximately) to get the actual peak voltage in the circuit. For example, if the meter shows that 110 volts a.c. is across the condenser, you would multiply this value by 1.4 to find the peak voltage. Since 1.4 times 110 equals 154 volts, the condenser would have to have a working voltage of at least 154 volts to be used in the circuit. Actually, a radio man would use at least a 200-volt condenser, and possibly a 400- or 600-volt type, as these are easily obtained standard sizes and allow an extra amount of safety factor.

▶ Some solid dielectric condensers also have a "peak voltage" rating. This is twice the working voltage; it is therefore just under the breakdown voltage, and represents the maximum voltage the condenser can stand for short periods of time.

Condenser Life. When the condenser has a solid dielectric, like paper or mica, a breakdown ruins the condenser, because a conductive "hole" has burned through the dielectric. Liquid dielectrics are not damaged unless the breakdown is too frequent, in which case the liquid may carbonize and become conductive.

Even when the safe working voltage limits are never exceeded, condensers using solid dielectrics will not last forever. The constant voltage stress on the bound electrons in the dielectric finally forces them out of their atoms and causes breakdown, just as constant bending of a bar of iron will eventually break the iron. Good solid dielectric condensers, used at or below their working voltage, should last from 10,000 to 20,000 working hours—usually much longer than a radio receiver will last.

Condensers must be kept cool to have such long service life. Exposing the condenser to heat speeds up the breakdown process, because bound electrons escape much more readily from their atoms when heated. For this reason, designers usually position condensers in radio equipment so they will not be exposed to too much heat. That brings up a practical hint for your service work—*if possible, always put a replacement condenser in the same place the designer put the*

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[*] Scientists sometimes call the dielectric constant the "specific inductive capacity" of the material; both names mean the same thing. Don't confuse this term with inductance, a property of coils, as there is no relationship.

original, or in an equally cool place.

Air condensers will last almost indefinitely. Unlike condensers using solid dielectrics, air condensers are not particularly harmed by breakdown, because the air dielectric is "self-healing" (that is, more air immediately rushes in to replace the air broken down by the voltage). However, they should always be kept dry to minimize the number of breakdowns suffered because, although the condenser itself is usually not injured by breakdown, other parts in the circuit may be harmed by the sudden flow of excess current.

Typical Radio Condensers

So far, we have learned that the condenser is basically a means of storing electricity; that the condenser capacity depends on the area, number and spacing of the plates as well as the dielectric, and that a condenser can withstand just so much voltage before breaking down. Now let us learn something about the types of condensers used in radio, so you can recognize them when you meet them in receivers. Let's also study their weaknesses, so you can see just how and why they become defective, as they so often do.

▶ Condensers whose capacities cannot be changed are called "fixed" condensers. They are usually classified according to their dielectrics. Thus there are paper, mica, oil, gas-filled, cellulose acetate, polystyrene, electrolytic (in these a chemical deposit is the dielectric), ceramic, rubber and even glass fixed condensers. They are usually in some kind of case, which might be a metal, paper or cardboard box or cylinder, or a molded plastic covering.

▶ Radio men also use two types of condensers whose capacities can be changed — "variable" and "adjustable." Variable condensers—for example, the tuning condenser of a radio—almost always use air as a dielectric. Their name comes from the fact that their capacities can be varied easily, usually just by turning a control knob.

Adjustable condensers are usually used to make corrections or minor adjustments in the capacity of other condensers. For this reason, they are often called "trimmer" or "padder" condensers. They usually have air, or air and some other insulator, as their dielectrics. Their capacities are generally varied by changing the separation of the plates, usually by turning a screw. When they have been adjusted to the desired capacities, they are ordinarily left alone.

Let us now go on to some of the more common types, to see how they are put together and what they look like.

PAPER CONDENSERS

Fig. *5* shows you the important steps in making typical paper condensers. When the condenser is in the form shown in Fig. *5C*, it is thoroughly dried in a vacuum to remove air and moisture, then impregnated with wax to keep moisture and air out. Finally, the unit is housed in a cover of some kind—often a waxed cardboard cylinder. Condensers so housed are called "cartridge" condensers because of their appearance. Many paper condensers, especially the larger ones, are housed in metal cases.

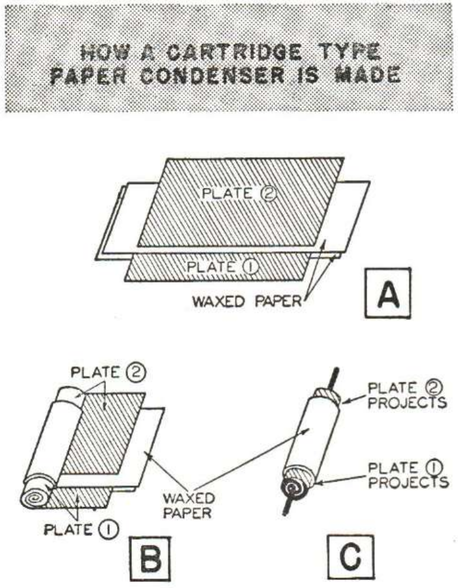

HOW A CARTRIDGE TYPE PAPER CONDENSER IS MADE

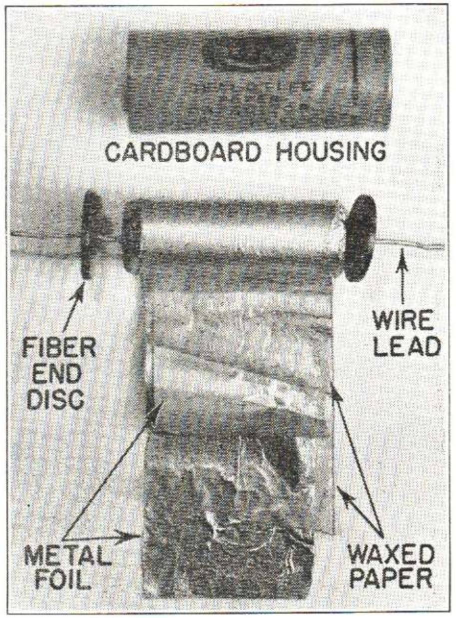
FIG. 5. How paper condensers are made. Waxed paper sheets separate the plates, which are tin or aluminum-foil sheets. After the condenser is rolled up, the projecting ends of the plates are crimped around the spirals formed by the connecting wires. The wires are soldered to tin-foil plates but cannot be soldered to aluminum-foil plates. Instead, the wire spiral is filled with solder and is pressed tightly into the foil. This mechanical joint is held only by wax and the container, so frequently comes apart.

If the condenser leads are merely clamped to the foils instead of being soldered, heating of the condenser when in use may make one lead separate from its foil. This will, of course, disconnect the condenser from the circuit. Such an "open" may occur intermittently or permanently; either condition is something you will meet quite frequently in your servicing. If you service a radio which gives alternately good and bad reception, remember that an intermittent open in a condenser may be the cause.

Voltage Rating. The voltage a paper condenser can withstand depends on the thickness of the waxed paper between the foil sheets. Of course, a thicker dielectric gives a higher voltage rating but also separates the foil sheets more, giving less capacity per unit length of foil. A condenser with a higher voltage rating but the same capacity as another will be larger physically, as longer sheets of foil and paper are needed to give the same capacity because, for a fixed dielectric thickness, the capacity is determined by the plate area, which depends on the length and width of the foil sheets used.

Standard radio receiver condensers of the paper type have ratings of 200, 400, 600 and 1000 volts, with capacities between .0005 mfd. and 2 mfds. Transmitting condensers have much higher voltage ratings.

Inductive and Non-Inductive Types. The method of rolling up the condenser shown in Fig. *5*, with all of one edge of each foil sheet fastened to a lead, is known as a "non-inductive" winding. Electrons coming through each wire can move almost directly to any point on the corresponding foil sheet.



This picture shows the details of a paper condenser.

Fig. *6* shows an "inductive" winding. In this condenser, the leads are soft metal ribbons, projecting from each foil sheet. When electrons enter the condenser through a ribbon, they have to flow around and around inside the condenser to get to the other end of the plate. This makes the condenser have an inductive effect like a coil, which is often undesirable in high-frequency radio circuits. For this reason, these condensers are found only in power supply and audio circuits, and then only where the convenience of having both leads come from the same end of the condenser is an important factor.

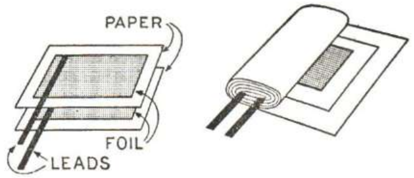


FIG. 6. The "inductive" winding shown here is rarely found in radio, as it can be used only in power packs and audio amplifiers. The non-inductive type shown in Fig. 5 can be used throughout radio receivers or transmitters, so is more commonly found.

Condenser Casings. Fig. *7A* shows the final appearance of the condenser constructed as in Fig. *5*. It is cased in a waxed cardboard tube, with the pigtail leads coming out each end through eyelets in a round cardboard or fiber disc (or through a plug of hard wax).

The condenser may also be cased in a square or rectangular metal box like those shown in Figs. *7B* and *7C*. The leads extend through the housing but are insulated from it. These condensers are usually provided with mounting brackets, so they can be bolted, riveted or soldered to the radio chassis.

High-voltage paper condensers which can stand 1000 to 2000 volts (and even 50,000 volts in some special types) are made by using several strips of high-grade waxed linen paper as a dielectric between strips of aluminum foil. The unit is mounted in a container filled with insulating oil. The terminal leads are brought out through porcelain stand-off insulators. Such a condenser is shown in Fig. *7D*.

MICA CONDENSERS

Mica is a far better dielectric than waxed paper where very high-frequency currents are involved, as in the r.f. signal circuits of receivers and transmitters. Mica condensers are considerably bigger than paper condensers of equal capacity, so are usually used only where low capacities are required. Mica condensers are generally made in capacities ranging from 10 to 10,000 mmfds. Larger units are available, but are quite expensive.

Fig. *8* shows how a fixed mica condenser is assembled. Thin, clear sheets of mica (only a few thousandths of an inch thick) are stacked in between sheets of copper, lead or aluminum foil. As in the paper condenser, these sheets of foil form the condenser plates. When the desired number of plates have been stacked up, a thicker piece of mica is placed at top and bottom for extra strength, the foil ends are bent over at each end, and a combination lug and clamp is squeezed over each end while the unit is held under pressure. Bakelite is then molded over the unit, leaving only the terminal lugs exposed, as shown in the bottom picture of Fig. *8*. This gives the condenser a neat, water-proof insulated housing. Frequently the condenser is then impregnated with wax to seal any tiny cracks which may have formed in the bakelite.

In this condenser the plate area is kept small, but a number of plates are used. This method of manufacture has the advantage of making all except the two outside plates do double duty.

What Practical Condensers Look Like

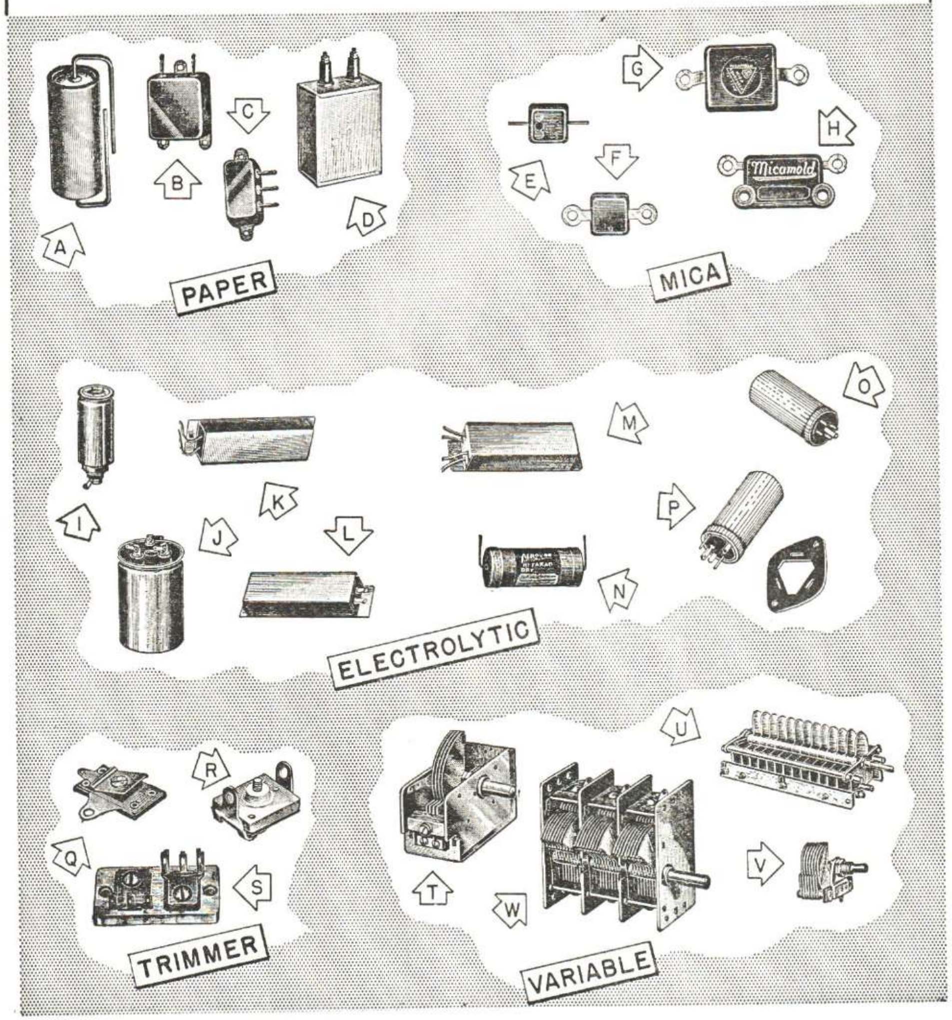


FIG. 7. Here are pictured some of the many condensers you will find in radio apparatus.
A = Tubular paper condenser.
B and C = Metal housing used for moisture and heat protection.
D = High-voltage type used in transmitters.
E and F = Postage-stamp size mica condensers.
G = Larger size having higher capacity.
H = Mounting holes are provided here so condenser can be rigidly fastened.
I and J = Wet electrolytics; single and triple units.
K, L, M, N = Typical dry electrolytics, differing only in the number of units and lead arrangement.
O and P = Plug-in dry electrolytics.
Q, R = Top and bottom views of a typical trimmer.
S = Dual trimmer unit.
T, U, V = Variable condensers differing in size and number of plates.
W = A three-gang variable condenser.

In the condenser shown in Fig. *8*, plates *2* and *1* are really one condenser, and plates *2* and *3* are another. Since plates *1* and *3* project out the same side and are connected by the lug clamp, this gives the whole condenser a capacity equal to twice the capacity of each individual condenser. Therefore, using only *three* plates, we have a capacity double what we would have by using *two* plates of the same size and separation.

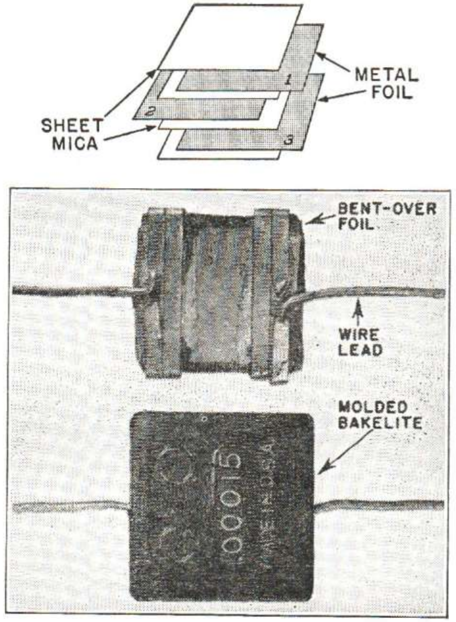


FIG. 8. Mica condensers are made of alternate layers of mica and metal plates, as shown at the top. The leads are clamped over the foil projections, then the unit is molded in a bakelite housing.

When mica condensers are made with many plates, all the foils sticking out at each end are usually soldered together, instead of just being held with a clamp. This makes a better electrical connection.

▶ Figs. *7E, F, G* and *H* show some typical fixed mica condensers in their bakelite housings. The terminals of these condensers are strong enough to support the condensers without need for other mounts. When the condenser is to be bolted to the chassis or when several condensers are to be bolted together, units like that in Fig. *7H*, with mounting holes molded in the bakelite housing, are used.

▶ Since mica is a very good insulator, mica condensers have amazingly high working voltages for their size. Receiver types are all 500 to 600 volts, while transmitters use slightly larger sizes rated as high as 2500 volts.

ELECTROLYTIC CONDENSERS

The electrolytic condenser shown in Fig. *9* consists of an aluminum rod placed in a metal container filled with a conductive chemical solution. The solution is called an "electrolyte" (pronounced *e-LECK-troh-light*). The rod is called the "anode," which is the general term for the positive part or terminal of any device.

To make the condenser, the positive terminal of a d.c. voltage source is connected to the anode, and the negative source terminal to the metal container. In a few hours, electrochemical action produces a thin, high-resistance film of aluminum oxide on the anode. The condenser is then said to be "formed," and is ready for use.

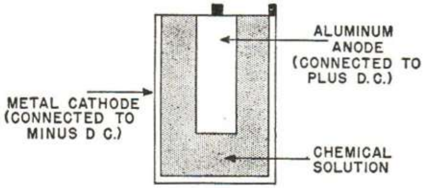
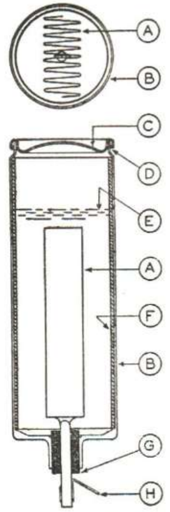


FIG. 9. Electrolytic condensers depend on the formation of an aluminum oxide film on the anode as the dielectric, then the anode rod and the electrolyte form the "plates" of the condenser. The can is called the cathode, as it is the means of making connection to the electrolyte which is the true negative plate.

The anode is one plate of the finished condenser, the aluminum oxide film is the dielectric, *and the surface of the electrolyte which is in contact with the dielectric film is the other plate*. The metal container acts only as a container and as a lead from the outside circuit to the electrolyte; it is *not* a plate of the condenser. (The container is usually called the "cathode," which is the general name for the negative part or terminal of an electrical device.)

▶ Using a rod as the anode limits the capacity, as the area of the rod surface is limited. More modern condensers obtain greater surface areas. A cross-section of a typical electrolytic condenser is shown in Fig. *10*. Here the anode is a sheet instead of a rod, and is folded back and forth within the container. This increases the surface area of the anode, and so gives higher capacity. In this particular condenser, the anode is "crimped" so it will take up as little space as possible; in other types, the anode is often wound in a spiral for the same reason. Frequently the anode is also chemically etched so that it has a rough surface, and therefore more surface area.



Courtesy Sprague Products Company

FIG. 10. Top and side views of a typical wet electrolytic condenser.

A = Anode, a plain or etched aluminum foil sheet folded in a zig-zag or crimped manner and riveted to a support rod.
B = Cathode, an aluminum can.
C = Aluminum cover.
D = Semi-porous gasket under cover, which prevents leakage of liquid electrolyte yet allows gases to escape.
E = Level of electrolyte.
F = Insulating material, which prevents short circuits between anode and cathode.
G = Insulating gasket which separates anode terminal from cathode and seals container at this point.
H = Connection to anode.

The thin dielectric and large plate area allow an electrolytic condenser to be physically rather small and yet have a very high capacity. In fact, electrolytics (as radio men call them) can have a much higher capacity for a given size than any other kind of condenser, with the possible exception of the new ceramic type. (As an example of comparative sizes, an electrolytic condenser of about the same dimensions as a 2-mfd. paper condenser might have a capacity of around 60 mfd.) This fact, and their relatively low cost, are the chief reasons electrolytics are used so much in radio circuits.

▶ Electrolytics which have a fluid electrolyte are often called "wet" electrolytics to distinguish them from two other types—semi-dry and dry electrolytics. Semi-dry electrolytics are like wet electrolytics except that a thickening material is added to the electrolyte, making it jelly-like and almost spill-proof.

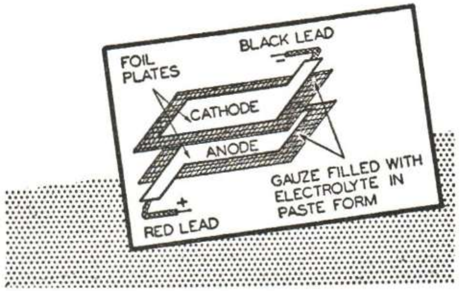


FIG. 11. How dry electrolytics are made.

The dry electrolytic condenser is today taking the place of the semi-dry type. Fig. *11* shows how dry electrolytics are made. Here the cathode is a sheet of pure aluminum, while the anode is a sheet of aluminum which has been "formed," so that it is covered with a thin dielectric film. The two electrodes are separated by strips of cheesecloth, paper or cellophane, which have been filled with an electrolyte in paste form. The four strips of material are rolled into a compact cylinder, flexible wire leads are attached to each electrode, the unit is mounted in a cardboard or other container, and the whole condenser is dipped in hot wax several times to make it air-tight. Sometimes dry electrolytics are sealed in metal cans similar to the containers for wet types.

Capacity of Electrolytics. The thickness of the dielectric film of an electrolytic depends on the voltage used to form it. High forming voltages give fairly thick dielectric films, while low voltages give thinner films. As you have already learned, the thinner the dielectric the closer the plate spacing and the higher the capacity will be. So, other things being equal, the electrolytic formed at a low voltage will have a higher capacity than one formed at a high voltage.

The forming voltage also determines the breakdown voltage of the condenser, since a voltage higher than that used to form the dielectric film cannot be applied to it without breaking the dielectric down. On the other hand, the ability of the condenser to maintain the dielectric film depends on the applied d.c. voltage. That is, the dielectric film becomes thinner as the applied voltage is decreased, so the capacity and working voltage ratings are not reliable unless the applied voltage is near the forming voltage. Hence, the working voltage rating of an electrolytic is usually about 90% of the forming voltage. Notice this means the breakdown voltage is only slightly higher than the working voltage. The electrolytic condenser thus differs from those using solid dielectrics in the relationship of its voltage ratings. These condensers should be used in circuits having voltages close to their working voltage ratings, although they can be used on lower voltages if the increased capacity will not matter.

The highest standard working voltage for electrolytic condensers is 450 to 475 volts. These condensers will break down if the applied voltage exceeds about 525 volts. (One manufacturer has produced a condenser with a breakdown rating of about 600 volts.) Capacities up to 60 mfds. are available in the 450-volt electrolytics, and capacities as large as 125 mfds. may be found in condensers with working voltages around 50 volts.

Service Notes on Electrolytics. Unlike all other common forms of condensers, *electrolytics must always be connected into a circuit with the proper polarity.* The anode must always be connected to the positive terminal of the circuit, and the cathode must be connected to the negative terminal. Now you see why the terminals are so named. Condensers with solid dielectrics do not have polarity so the leads can be interchanged at will.

Dry electrolytic condenser leads are labeled or colored, so the proper connections can be made. An identifying code or table is stamped on the case of most replacement types. Thus, you may find a red lead is the anode (+) and a black lead is the cathode (—) connection for a single-section dry condenser. When in a cylindrical container, the case may be marked (+) near the positive lead.

The metal container of wet and semi-dry electrolytics is the cathode, and so is connected to the negative terminal of the circuit. The other condenser terminal (usually in the center of the condenser) is the anode, and should go to the positive part of the circuit.

If you connect electrolytics into a circuit with the wrong polarity, the dielectric will break down almost at once. This is usually not too harmful with wet electrolytics, because they are self-healing—that is, the dielectric will repair itself within a short time after the connections are corrected. But dry and semi-dry electrolytics do not have this property; if broken down, they are ruined.

▶ The fact that electrolytics must be connected with proper polarity means they can be used only on d.c. or on d.c. mixed with a.c. In the latter case, the d.c. part of the voltage must be larger than the a.c. part, so that the polarity of the applied voltage will never be reversed by the a.c. variations. For example, it is all right to connect an electrolytic with a suitable working voltage to a circuit which furnishes 110 volts d.c. and 40 volts (peak) a.c., provided the positive terminal of the condenser is connected to the positive terminal of the d.c. voltage. Then the voltage applied to the positive terminal of the condenser will vary from 110 minus 40 to 110 plus 40, or from plus 70 to plus 150, but will always be positive, so the condenser will not break down. If the circuit furnishes 40 volts d.c. and 110 volts (peak) a.c., however, the voltage on the positive terminal of the condenser will vary from 40 plus 110 to 40 minus 110, or from plus 150 to *minus* 70, and the condenser will break down when the voltage reverses polarity.

▶ As you will learn a little later, electrolytics are often used in circuits where d.c. and a.c. are mixed. When you use one in such a circuit, you must be sure not only that the circuit does not reverse polarity, but that the peak value of the a.c. added to the value of the d.c. does not exceed the working voltage of your condenser. Electrolytics break down very quickly when the working voltage is exceeded. As with breakdowns caused by wrong polarity of connections, a voltage breakdown does not usually cause permanent harm to wet or semi-dry electrolytics, but ruins dry electrolytics. Servicemen usually play safe when replacing condensers by being sure the replacement has a working voltage rating equal to or greater than the original part.

▶ One disadvantage of electrolytics is that the aluminum oxide film which forms their dielectric is not a true insulator, so some electrons can flow through the condenser. This is called a *leakage current,* as it "leaks" through the dielectric. Since the electrolyte (through which the leakage current must flow) has some resistance, the flow of leakage current through it creates heat within the condenser. This heat drives gas out of the electrolyte. Normally, the vent on the top of wet and semi-dry electrolytics allows this gas to escape; if the vent becomes plugged for any reason, the condenser may blow up.

The escaping gas carries a certain amount of electrolyte with it. In time, this action disturbs the chemical balance within the condenser, increasing the resistance of the electrolyte; also, since the electrolyte forms one plate of the condenser, and lowering its level is the same thing as decreasing the plate area, lowering the electrolyte level reduces the condenser capacity. The added resistance of the electrolyte increases the heating effect of the flow of leakage current, thus speeding up the destructive process. Eventually, this combination of actions ruins the condenser. From 2000 to 10,000 hours of service can be expected from a good wet electrolytic.

▶ Much the same effect occurs in dry and semi-dry electrolytics, in which the heat caused by the flow of leakage current tends to dry out the paste electrolyte. In fact, these types will not usually last as long as wet electrolytics; dry electrolytics are used in preference to wet electrolytics in radio circuits only because they are usually much smaller in size, may be mounted in any position, and cost less.

Of course, heat from any source is as bad for electrolytics as the internal heat caused by leakage current. Keep electrolytics away from tubes, transformers and large resistors that may radiate considerable heat.

Identifying Electrolytics. Sometimes it is hard to tell just what type an electrolytic is by looking at it. If the condenser is in a metal can with water-tight gaskets around the terminals, and a rubber nipple through which gas can escape, you are usually safe in assuming it is a wet or semi-dry type. Pick such a condenser up and shake it—if you hear a swish, it is a wet electrolytic. Dry electrolytics usually have flexible leads and are cased in cardboard containers or in sealed metal cans which have no vent to permit gas to escape.

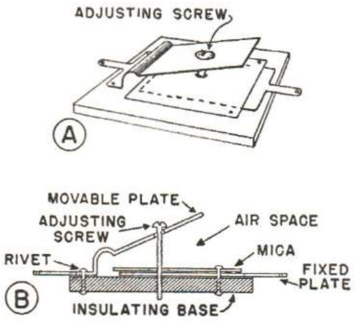


FIG. 12. Two views of a typical trimmer.

Figs. *7I* and *J* show two kinds of wet electrolytics. (Semi-dry would look exactly the same.) A single unit is shown in *I*. The triple unit in *J* has three terminals on the top of the can as the positive terminals, while the can is the common cathode.

Six common types of dry electrolytics are shown in Figs. *7K* through *7P*. The terminals of condenser *7O* come out to a plug mounted on the end of the condenser. This condenser is connected into the circuit by being plugged into a receptacle. Type *7P* is also a plug-in condenser, with flat terminal pins which fit into the special wafer mounting shown beside it. These pins are twisted after the condenser is plugged in; this both makes a good electrical connection and holds the condenser firmly in place.

TRIMMER CONDENSERS

A trimmer condenser is used to make a small adjustment in the capacity of a circuit. A typical trimmer is shown in Fig. *12*.

Air and mica are used as dielectrics. One plate is riveted to the bakelite base of the unit, and the other plate, usually made of spring brass or phosphor bronze, is moved close to or away from the fixed plate by turning the adjusting screw. When the two plates are close together, the mica sheet is the dielectric, and the capacity is a maximum. When the two plates are farther apart, both air and mica are between them and the capacity is less. In some condensers, the adjusting screw makes electrical contact with the movable plate: in others it is insulated from the movable plate; it is always insulated from the fixed plate. When a trimmer with large capacity is wanted, several pairs of plates are used, with alternate plates connected together.

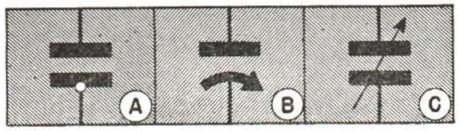


FIG. 13. Adjustable condenser symbols used in wiring diagrams. The one at A is used for trimmer condensers. The other two are used for variable tuning condensers usually, although sometimes they are used to indicate trimmers too.

▶ Trimmer condensers are also called "equalizing," "neutralizing," "aligning," "phasing" or "padding" condensers, depending on how they are used in the radio circuit. Fig. *13A* shows the symbol used in your N.R.I. Course and by many radio manufacturers to indicate a trimmer, while *13B* and *C* show the ordinary symbols for a variable condenser, which some authors and manufacturers also use for trimmers.

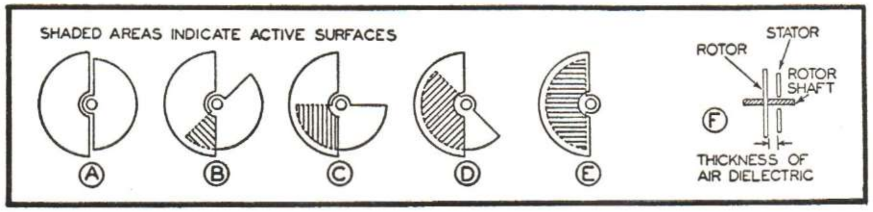


FIG. 14. How a variable air condenser works.

▶ Typical trimmers are shown in Figs. *7Q* through *7S*. Because these trimmers open like a book, they are often called "book type" trimmers.

VARIABLE CONDENSERS

The series of pictures in Fig. *14* show the working principle of the variable air condensers used to tune many modern radios. (For clearness, only one set of plates is illustrated, but most such condensers have several sets, as shown in Fig. *15*.) The plate at the left in *A*, *B*, *C*, *D* and *E* is a fixed plate, called the "stator." The smaller plate is pivoted on a shaft so that it may be rotated; this plate is called the "rotor."

When the plates are in the position shown in *A*, the condenser has a minimum capacity, because, as you learned earlier in this lesson, only the *overlapping* parts of plates have a capacity between them. As the rotor is turned past the stator, more and more of the plates overlap, as shown by the shaded areas, and the capacity of the condenser increases. When the plates reach position *E*, the capacity is a maximum. Relatively high-capacity variable condensers are made by using large plates or by adding additional rotors and stators. When this latter is done, the rotor plates are connected together electrically by the shaft to which they are attached, and the stators are electrically connected by a metal bar built into (but insulated from) the condenser frame.

▶ Several typical variable condensers are shown in Figs. *7T* through *7W*. Those pictured in *T*, *U* and *V* are similar, differing only in size. Unit *W* is really three separate condensers with the rotors mounted on the same shaft, so that the capacity of all three condensers is varied at the same time. Each condenser stator is insulated from the other two, and separate connections are made from each to the radio circuit it is used in. This kind of unit, in which the capacities of two or more condensers are varied by turning one shaft, is called a "gang" condenser. The one pictured in *W* is a three-gang condenser.

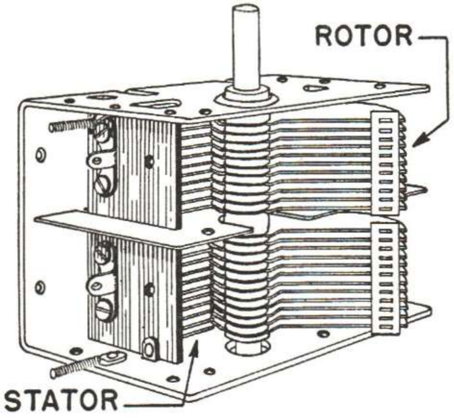


FIG. 15. What a variable condenser looks like.

▶ Although the condensers in a gang

are carefully made, manufacturing tolerances result in slight differences in capacity. To correct this and make the capacities of condensers in the gang "line up" with each other and with the circuits with which they are used, a trimmer condenser is usually connected to each condenser. The trimmer is adjusted to get exactly the right capacities in each section. Thus, the trimmer is a "corrector" and once adjusted is left alone until some change makes it necessary to repeat the adjustment.

Connecting Condensers Together

Now that you know what condensers are and how they work, let's consider a very practical point—what happens when condensers are connected together. Very frequently, you may need a certain capacity and find you do not have the right value, but have several condensers of other sizes to choose from. What is the effect on capacity when condensers are connected in parallel or in series?

CONDENSERS IN PARALLEL

Going back to Fig. *3A*, you will see that the condenser plates A_1 and A_2 are connected together so that the capacity A_1-B is in *parallel* with the capacity B-A_2. (There is a separate path from one terminal to the other through each condenser.) This parallel connection increases the capacity in this one condenser and would also increase the capacity if these were separate condensers. So if one condenser doesn't have enough capacity for the use to which you want to put it, you can connect another condenser to it *in parallel* to get a higher capacity. The capacity of a combination of two or more condensers connected in parallel is equal to the *sum* of the capacities of the individual condensers.

Fig. *16* shows why. Since they are connected in parallel, each condenser has the full line voltage across it. Each stores the amount of charge it usually does with such a voltage across it, so the amount of charge stored is the sum of that in all the condensers. As the capacity is equal to the charge divided by the voltage, this adding of charges means the capacity of the combination is equal to the capacity of all three condensers added together. Thus, the capacity of the combination in Fig. *16* is 33 mmfd. (10 mmfd. plus 11 mmfd. plus 12 mmfd. equals 33 mmfd.).

CONDENSERS IN SERIES

When condensers are connected in series, as in Fig. *17*, the capacity of the combination is *less* than the capacity of the smallest condenser in the group. Since plates *b* and *c* in Fig. *17A* are connected by a wire, the same charge must be on each of them; similarly plates *d* and *e* have equal charges. Hence, we can consider the series combination to be really one condenser with plates *a* and *f* and a dielectric equal in thickness to the sum of the thicknesses of the dielectrics of all three condensers (Fig. *17B*). Naturally, the greater dielectric thickness makes the capacity of the combination less than that of any one of the individual condensers.

From this you can readily see that if several condensers having equal capacities are connected in series, the total capacity of the group equals the capacity of one condenser divided by the number in the group. For example, if all three condensers in Fig. *17A* are identical, then the equivalent condenser shown in Fig. *17B* will have the same plate area as any one of the condensers and three times the dielectric thickness. Its capacity will therefore be one-third that of any one of the condensers (or C/3, where C is the capacity of one condenser). The total capacity of four identical condensers in series would be C/4, of five in series C/5, and so on.

▶ This method of finding the capacity of a series combination can be applied only to condensers of equal capacity. But there is a simple rule for finding the capacity of any two condensers connected in series, whether they have the same capacity or not; just divide the product of the two capacities by the sum of the two capacities. Using symbols:

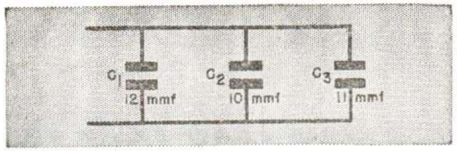


FIG. 16. **Condensers in parallel give more capacity.**

$$C = \frac{C_1 \times C_2}{C_1 + C_2}$$

where C is the capacity of the series combination, C_1 the capacity of one condenser, C_2 the capacity of the other condenser, with all capacities expressed in mfd. or all in mmfd.

▶ If you have more than two unequal condensers connected in series, find the combined capacity of two of them by this equation. Then treat this combined capacity as C_1 in the equation, take the third condenser as C_2, and again solve for C. You can keep this up for as many condensers as you have in the series circuit and your final answer will be the combined capacity of all of them. Notice—the combined capacity of condensers in *series* is found in exactly the same way that you learned to find the combined resistance of resistors in *parallel.*

VOLTAGE RATINGS FOR CONDENSER COMBINATIONS

When condensers are connected in parallel, each has the source voltage across it. Therefore, each condenser must have a working voltage *at least equal to the source voltage.*

While each condenser in a series combination has only part of the source voltage applied to it, still the safest thing is to make sure all of them can stand the full source voltage. But sometimes you won't be able to get condensers with high enough working voltages to observe this rule. Let's take a practical problem and see the simple trick you can use to solve it.

Suppose you have a d.c. source with a voltage of 1000 volts which must be used with a 2-mfd. capacity. (This is a problem which often comes up in transmitters and high-voltage power packs.) You have two 4-mfd. paper condensers, which will give the 2-mfd. you want if put in series. But suppose the working voltage rating of each condenser is only 500 volts.

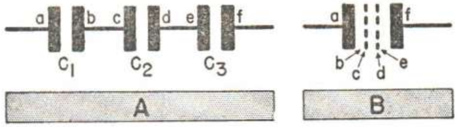


FIG. 17. **Condensers in series give less capacity.**

▶ If you can be sure each condenser will get no more than 500 volts across it, you'll be safe in using them in series. But how can you be sure?

Leakage Current. A perfect condenser (excluding electrolytics) will pass no d.c. However, no solid dielectric condenser is perfect; there are always some free electrons in even the best dielectric and, when a voltage is applied across the condenser, these electrons will flow through the dielectric. (Of course, this flow of current is much smaller than that necessary to cause breakdown.) Further, there is always some flow of current between the leads across the surface of the case of the condenser; in fact, this current is usually considerably higher than the current through the dielectric.

FIG. 18. A practical condenser acts like a perfect condenser in parallel with a high resistance.

The amount of current that flows from one terminal of the condenser to the other when a d.c. voltage is placed across the condenser is known as the "leakage current." Condensers having impurities in the dielectric, or so made that moisture can get in, will have much higher leakage currents than well-made ones. Condenser manufacturers always test the leakage of their solid dielectric condensers; those which pass too much current are rejected. For most purposes, the leakage current is so small it is ignored altogether.

▶ Where the leakage is important, we can take leakage current into account by considering a practical condenser to be a perfect condenser with a high resistance shunted across it, as shown in the cutaway section in Fig. *18*. This way of picturing a practical condenser is often very useful.

The high resistance shunting the condenser is called the "leakage resistance" of the condenser. Naturally, **a condenser with a high leakage resistance will pass less d.c. than one with a lower leakage resistance.**

▶ **Since the perfect condenser won't pass d.c., it must be the current passing through the leakage resistance which determines the I × R drop (or voltage) across the condenser.**

Now if one of the 4-mfd. condensers has a leakage of 50 megohms and the other has a leakage resistance of 200 megohms, as shown in Fig. *19A*, the total resistance is 250 megohms. Using Ohm's Law, you could figure the current flow and resulting voltage division. You would find that the line voltage will divide according to the ratio of the resistances. Thus, the condenser with 50 megohms will get 50/250 or ⅕ the source voltage. This puts 200 volts (⅕ of 1000) across this condenser and leaves 800 volts across the other condenser. Since the 800 volts across the latter condenser is considerably more than its safe working voltage rating of 500 volts, it will break down fairly soon. Then the full 1000 volts will be applied to the other condenser, breaking it down almost at once.

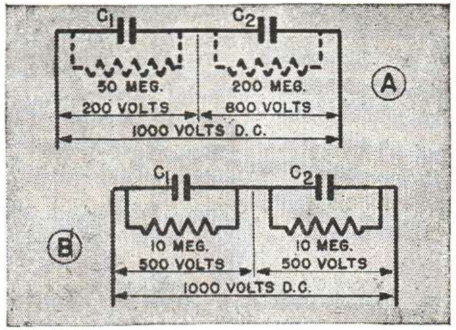


FIG. 19. Unequal leakage resistance values may cause an improper voltage division, as at A. By shunting the condensers with equal resistances which are much less than the leakage values, an equal drop can be obtained, as at B.

If the condensers are used in a circuit where a small current flow will not matter, you can solve this problem very easily by putting a 10-megohm resistor across each condenser. These added resistors are in parallel with, and considerably lower in ohmic value than the leakage resistances of the condensers. As you learned in your lesson on resistors, combining two resistors of widely different values in parallel gives a combined resistance just about equal to the smaller of the two. Therefore, the total resistance of each condenser-resistor combination will be about that of the added resistors, as shown in Fig. *19B*. Thus the resistances are made equal, so the voltage will divide about evenly across the combinations, and each condenser will be operating at its working voltage.

The same trick can be used if your condensers are electrolytics, but since electrolytics have much lower leakage resistances than paper condensers, you'll have to use lower shunting resistors. Between 10,000 ohms and 50,000 ohms will be satisfactory. (If you connect two electrolytics in series, remember that the *positive* terminal of one must connect to the *negative* terminal of the other.)

These extra resistors act as "bleeders," drawing or "bleeding" an extra current from the source of such value that they determine the voltage division. Naturally, this method of getting an even split of voltage across two condensers can be used only if this extra current is not objectionable in the circuit.

How a Condenser Works with A.C.

So far, we have dealt with the charging action of a condenser when a d.c. voltage is connected across it. You have learned that leakage current is the only current flow through a condenser when a d.c. source is used, and this flow can be ignored in most instances. Ordinarily, when a d.c. voltage is applied to a fixed condenser, the condenser charges up to the source voltage value, as long as the voltage does not exceed the safe working voltage rating of the condenser. When the charge on the condenser has reached its maximum, the movement of electrons in the circuit stops, so all current flow ceases until a different voltage is applied or until the condenser is discharged.

The nature of an alternating current provides a different action, however. As you will recall, electrons do not flow always in one direction when acted on by an a.c. voltage. Instead, they move a short distance in one direction in the wire; then, when the voltage reverses, they move in the other direction. This back-and-forth motion of the electrons in the circuit permits us to say that alternating current flows through a condenser. Let's examine this action more closely.

HOW ALTERNATING CURRENT FLOWS THROUGH A CONDENSER

When electrons are moving back and forth in the circuit due to an a.c. source, electrons must flow in and out of the plates of the condenser. When the electrons flow into one plate, the bound electrons in the dielectric are forced away from that plate and force electrons out of the other condenser plate.

When the a.c. voltage reverses, the electrons are forced back into the second plate of the condenser. And now the electrons on the second plate act just the way the electrons on the first plate did a moment before—they push the bound electrons in the dielectric away and the movement of the bound electrons now pushes the electrons out of the first plate.

This action is shown in Fig. *20*. At *A*, we start with the electrons at rest in the dielectric. Then, as electrons are forced into plate *1*, the path for the bound electrons in the dielectric shifts, forcing electrons out of plate *2* as shown at *B*.

This movement of electrons causes the condenser charge to reach a maximum when the a.c. voltage reaches a maximum on this half cycle. Then, as the a.c. voltage decreases, the electrons redistribute themselves about the circuit, allowing the electrons in the dielectric to return to their neutral position as shown in Fig. *20C*. As the cycle reverses, electrons begin to flow into plate *2*, forcing a movement in the dielectric in the opposite direction so that electrons are forced out of plate *1* as shown at *D*. This action reaches a maximum, charging the condenser in this reversed direction. Then the voltage decreases toward zero, allowing the bound electrons to return to the neutral position shown at *A*, after which the cycle is repeated over and over. Fig. *21* shows the points on an a.c. cycle corresponding to this action. The condenser charges between *A* and *B*, discharges between *B* and *C*, charges with the opposite polarity between *C* and *D*, discharges again between *D* and *A*, and repeats the cycle over and over.

From the foregoing, you can see that there is a back-and-forth motion of the bound electron paths in the dielectric when acted on by a.c., just as there is a back-and-forth movement of free electrons in the conductor. Therefore, around the complete circuit there is a back-and-forth motion of electrons and we are perfectly justified in saying that an alternating current passes through a condenser. Scientists call this current within the dielectric a "displacement current." This new name is given the current flow because there is no actual electron movement from plate to dielectric or from dielectric to plate. Instead, there is a displacement of electrons within the dielectric which passes on the current flow action of the entire circuit.

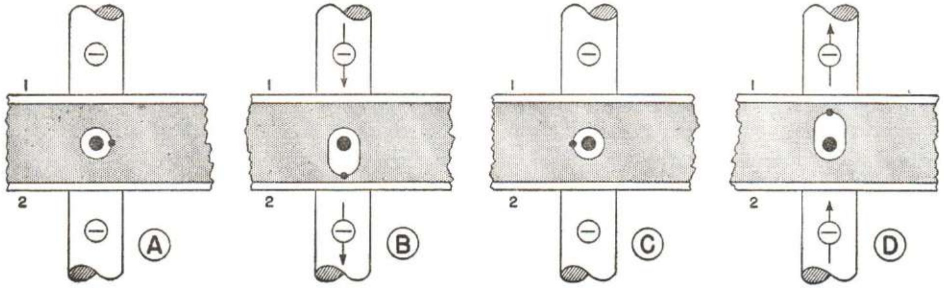


FIG. 20. When a.c. is applied, the bound electrons move first one way, then the other, so, in effect, an alternating current flows through the condenser.

It is important that you get the idea clearly that an alternating current is just a movement back and forth of electrons, and further, this actual amount of movement is over an astonishingly short distance. However, when electrons move in the circuit, it is not the distance they travel that is important, it is the number of electrons which actually do move within a given period of time which gives us a measure of current flow.

CAPACITIVE REACTANCE

Although a condenser permits a flow of alternating current through the circuit, it also restricts the current flow. Work must be done to move the bound electrons in the dielectric, so there is an opposition to the flow of current. Actually, the charge-storing ability will limit the current flow.

Now, the larger the condenser, the greater its ability to store a charge. As the current flow depends on the number of electrons in the charge, we see that the larger the capacity, the less the opposition to current flow.

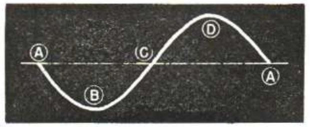


FIG. 21. The points on the cycle corresponding to the electron path shifts shown in Fig. 20.

The opposition of a condenser to an alternating current is called reactance, just as it is for a coil. This reactance, as is that of a coil, is measured in ohms. However, notice this important difference—for a condenser, *the larger the condenser the less the reactance*, while for coils, *the larger the inductance the greater the reactance.*

Furthermore, frequency changes also have an inverse effect upon condenser reactance. That is, the higher the frequency, the less the reactance of a condenser, whereas with a coil, the higher the frequency the greater the reactance. As you will soon see, these are very important differences.

You can figure out the reactance of a condenser by this simple method:

> *Multiply the frequency of the current in cycles per second by the capacity of the condenser in microfarads, then divide the number 159,000 by this result.*

The equation for this is:

$$X_C = \frac{159{,}000}{f \times C}$$

Where X_C is the capacitive reactance in ohms, f is the frequency in cycles per second, and C is the capacity in mfd.

Another way we might express this is:

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

where C is in farads. (Compare this with the equation for inductive reactance you learned in your lesson on coils.)

▶ Let's take a few practical examples, to see just what these important equations mean. We will use only the first equation, since its units are more convenient. (The second equation, of course, is exactly the same as the first one; the difference in units is what makes them look different.)

Suppose we have a condenser of 10-mfd. capacity fed by a source supplying 100-cycle current. Then:

$$X_C = \frac{159{,}000}{f \times C} = \frac{159{,}000}{100 \times 10}$$

$$= \frac{159{,}000}{1{,}000} = 159 \text{ ohms}$$

so the a.c. reactance of our condenser is 159 ohms. (Remember, this a.c. reactance has nothing to do with the d.c. leakage resistance; a condenser has a reactance only when it is used in an a.c. circuit.)

Now if we supply the same condenser from a source which furnishes 1000-cycle current:

$$X_C = \frac{159{,}000}{f \times C} = \frac{159{,}000}{1000 \times 10}$$

$$= \frac{159{,}000}{10{,}000} = 15.9 \text{ ohms}$$

so *increasing* the frequency of the current *decreases* the reactance of our condenser. Notice that the increase in frequency causes a proportionately equal decrease in reactance; *increasing* the frequency 10 times *decreases* the reactance 10 times.

If we keep the frequency at 100 cycles and increase the capacity of the condenser to 100 mfd:

$$X_C = \frac{159{,}000}{f \times C} = \frac{159{,}000}{100 \times 100}$$

$$= \frac{159{,}000}{10{,}000} = 15.9 \text{ ohms}$$

so *increasing* the capacity of the condenser *decreases* its reactance. Just as the increase in frequency did in the previous example, the increase in capacity causes a proportionately equal decrease in reactance; increasing the capacity 10 times decreases the reactance 10 times.

▶ Let us sum up what we have just learned in one easily remembered rule: *An increase in frequency or an increase in capacity will cause a decrease in the reactance of a condenser.*

Of course, the reverse effect is also true; *a decrease in frequency or capacity causes an increase in reactance.*

Since a drop in reactance means it is easier for a.c. current to pass through the condenser, you can readily see that high-frequency currents pass through a condenser much more easily than do low-frequency currents; also, that a current of any frequency flows more easily through a condenser of high capacity than through one of low capacity. You will see how extremely important these facts are a little later on in this lesson, when we discuss some practical condenser circuits.

A Simple Condenser-Resistor Circuit

Now we know that a condenser will store a charge when a d.c. voltage is applied, and that condensers permit a.c. current to flow in the circuit, limiting the current flow by their reactance. What happens when we connect other parts with condensers? Let's combine a resistor with a condenser and consider the action both for d.c. and a.c. sources. We'll start with a d.c. source.

TIME CONSTANT

With the resistor and condenser connected to a d.c. source, as shown in Fig. *22*, a very interesting action occurs. If the condenser were connected by itself directly to the source, the condenser would charge to the full source voltage almost immediately. However, when we put a resistor in the circuit, we find that it takes longer—the charging time increases to as much as several minutes, if the resistor and condenser are large enough. Let's learn more about this action.

The *effective* voltage in this circuit—that is, the voltage which acts to cause current flow—is equal at any time to the source voltage minus the back, or bucking, voltage of the condenser. When the circuit is first closed, there is no charge on the condenser and therefore no voltage across it, so the effective voltage is equal to the full source voltage. The current flow in the circuit is then equal to the source voltage divided by the value of resistor *R*. As this current flows through the circuit, however, the condenser begins to store a charge, and voltage builds up across it. This, of course, makes the effective (or current-moving) voltage less than the full source voltage, so the current through the resistor and circuit must drop. As the condenser continues to charge, the effective voltage becomes less and less, making the circuit current continually smaller. Eventually, when the condenser voltage equals the source voltage, there is no effective voltage and all current flow stops.

▶ The effect of the resistor is to increase the time necessary to charge the condenser. Even a very large condenser will charge almost at once if there is a sufficient current flow into it, but when, as in this circuit, the current flow is limited to a small initial value by the resistor, and then grows even smaller, it may take a considerable time for enough electrons to flow into the condenser to charge it completely.

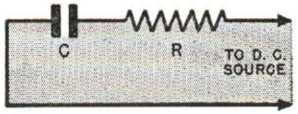


FIG. 22. The condenser charges through the resistor more slowly than it would if the resistor were not used.

The amount of time it takes for the condenser to charge up with a resistance in series with it is an important factor in the action of many radio circuits. It has been found that multiplying the capacity of the condenser in mfd. by the value of the resistor in megohms gives a figure equal to the time in seconds that it takes the condenser voltage to reach about 63% (actually 63.3%) of its final value. This time is called the "time constant" of the condenser-resistor combination. The time it takes a condenser to reach its full voltage is many times this special value, but comparing time constants directly is often a useful way to compare the action of one radio circuit with that of another.

Fig. *23* is a graph showing how the condenser voltage increases with time. Notice the rapid rise at first, followed by a gradual tapering off until the final condenser voltage is reached a relatively long time later on. As shown, the time constant is the amount of time it takes to reach about 63% of full charge.

You will meet time constants frequently in later lessons, for they have much to do with such important things as the ability of an amplifier to amplify signals without distortion. For the present, just remember that the time constant of a condenser-resistor combination is the time in seconds required to charge the condenser to about 63% of the charging voltage. Further, this time can be obtained directly from the condenser and resistor values by multiplying the capacity of the condenser in mfd. by the ohmic value of the resistor in megohms. Thus, a 10-mfd. condenser and a 5-megohm resistor have a time constant of 10 × 5 or 50 seconds, or almost a minute to charge to 63% of the source voltage, while a .05-mfd. condenser and a .1-meg (100,000 ohms) resistor will charge to this same value in .05×.1, or .005 second, thus, the larger the resistor or the condenser, the longer the time constant.

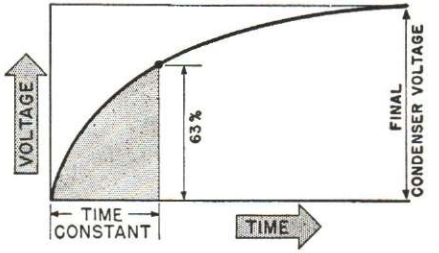


FIG. 23. This curve is more steep at the beginning and then gradually flattens out. This shows the condenser voltage builds up rapidly at first, then more slowly as time passes. The time in seconds required for the condenser to reach about 63% of its final charge is known as the time constant.

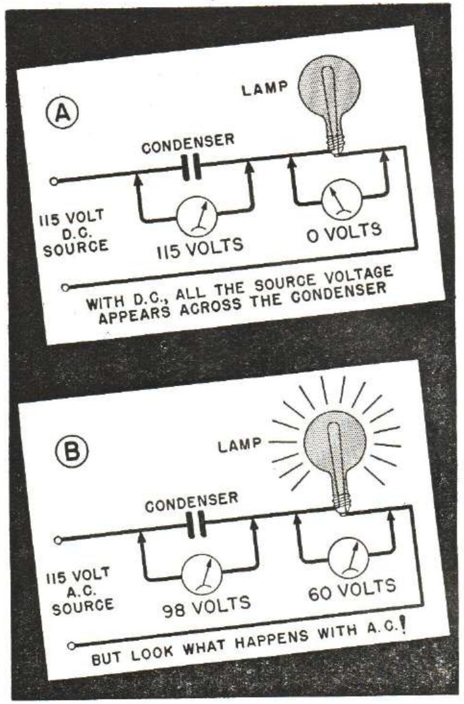


FIG. 24. How the voltages are divided when d.c. is applied at A. The division for a.c. is shown at B.

ACTION WITH A. C.

You recall that in the lesson on coils, we compared the action of a coil and a lamp in series on a.c. with their action on d.c. Let's make the comparison again, this time substituting a condenser for the coil. Of course, the lamp represents a resistor, so we have the same circuit as Fig. *22*. However, the lamp shows when current flows by lighting.

Starting first with a d.c. source, as shown in Fig. *24A*, we find that the lamp will not light. This indicates that no d.c. flows through the condenser. Actually, there is an initial flow of current when the circuit is first completed, but this current flows for too short a time to light the lamp even momentarily. When the condenser is charged, the entire d.c. voltage is across the condenser and none across the lamp. The d.c. voltage drops in the circuit check with Kirchhoff's Voltage Law, as 115 volts across the condenser added to zero lamp volts equal the 115-volt source voltage.

Suppose we now change to a 115-volt a.c. source, as in Fig. *24B*. With a.c. voltmeters being used now to measure the voltage drops, we find that the two voltage drops add up to 158 volts, which is much higher than the source voltage. Clearly, we cannot apply Kirchhoff's Voltage Law directly to this circuit. Once again we have met the subject of *phase*.

The voltage drops across the condenser and lamp in Fig. *24B* do not add up to the a.c. source voltage because these a.c. voltage drops *do not reach corresponding peak values at the same instant of time in each cycle.* In other words, one a.c. voltage may be at the zero point in its cycle at the instant when the other a.c. voltage is at its maximum or peak value. We encounter this situation whenever we use coils or condensers along with resistors in radio circuits, and radio men say that there is a *phase difference* between these a.c. voltage drops.

The only time we can add directly the a.c. voltages which a.c. meters measure is when these voltages are in phase with each other (when all reach corresponding peak values in each cycle at the same instant of time, and all drop to zero together). This occurs only when all the parts in the circuit are identical (all are perfect resistors, all are perfect coils or all are perfect condensers).

The a.c. meters do not show the *instantaneous* voltages; they show the *effective* values over a period of time. If they could show the instantaneous values, we would find they would add up properly at all times. Instead, we must combine the meter readings in a way which will take phase into account in order to see just what goes on. Let us now see how phase enters into the picture when the a.c. circuit has a condenser in it.

Phase. You remember that voltage and current are always in phase in a purely resistive a.c. circuit, and that they are always 90° out of phase in a purely inductive a.c. circuit, with the current lagging behind the voltage. In a capacitive a.c. circuit the current and voltage are again 90° out of phase, but here the voltage lags behind the current—or, to put it another way, the current leads the voltage.

The reason why is easy to see. You learned in your study of time constant that, when the circuit is closed, the maximum current flows at once and the voltage across the condenser is zero. As current continues to flow, the condenser voltage builds up and, at the same time, the current decreases. When the condenser is fully charged—the voltage across it is a maximum—the current is zero.

When a.c. is applied, this same action occurs during one quarter of the cycle. Then, as the voltage decreases, electrons begin to flow off the condenser plates. By the time the voltage across the condenser reaches zero again, the condenser is completely discharged, and again a maximum current flow is taking place, this time in the opposite direction from the original flow.

Thus the circuit current and the condenser voltage are 90° out of phase in a capacitive circuit fed by a.c.; the circuit current is always a maximum when the voltage across the condenser is zero, and vice versa. Since the current is maximum first, the current leads the voltage.

Vector Diagrams. You remember that we had to use voltage vectors to combine the voltages across a coil and a lamp, because the two voltages were out of phase. Since the voltages across the condenser and resistor in Fig. *24B* are also out of phase, we must also use voltage vectors and a vector diagram to combine these voltages.

First, we can see that the same alternating current flows through both the condenser and the lamp as these parts are in series, so we will use the current as a reference value. We start by drawing our current reference vector, as shown in Fig. *25A*. Remember—in a vector diagram the *length* of any vector is proportional to the *amount* of current or voltage the vector represents. Further, the *position* of any current or voltage vector with respect to the circuit current reference vector we have just drawn shows how much the current or voltage is out of phase with the circuit current.

FIG. 25. The starting or reference position is shown at A. Each complete revolution of a vector represents one a.c. cycle. By general agreement among radio and electrical men, vectors are always assumed to be rotating counter-clockwise, opposite to the direction in which the hands of a clock move. Furthermore, the starting or reference position for all vectors is the vector position shown at A, which is a line going to the right horizontally from the center (O) of the vector diagram. In a series circuit, we almost always use current for our reference vector. To make the vector A represent the circuit current, we make the length of the vector proportional to the effective current value which would be indicated by an a.c. ammeter. We then put on the arrow head, and label it with the capital letter I to indicate that it represents current. As the resistor voltage drop is in phase with the current, its position will be the same as the reference line, so we draw it right on top of the current line, as at B.

Since the resistor voltage drop is in phase with the circuit current, we draw the resistance voltage vector V_R right over the current vector, as shown in Fig. *25B*.

We must now draw the vector for the condenser voltage drop. We just learned that voltage lags the current in a condenser by 90°, so we will have to draw the voltage vector V_C 90° *behind* our reference current vector, or straight *down* from the point of origin (O), as shown in Fig. *26A*. Then we complete the rectangle, as shown in Fig. *26B*, and draw a diagonal line from the point O to the opposite corner of our rectangle. This diagonal, vector E, then represents the source voltage. Since it is behind the circuit current vector I, we know that the source voltage lags behind the circuit current in a capacitive circuit.

If we draw V_R and V_C to scale so that every inch along them represents a certain number of volts, the length of line E will be equal to the source voltage figured on the same scale. Thus, Kirchhoff's Voltage Law applies to our capacitive a.c. circuit when we use a vector diagram to take phase into account.

Impedance. You have learned that resistors have resistance, while coils and condensers have reactance. Now reactance and resistance are somewhat alike, in that both act to oppose the flow of current. In other words, current flow through either of them produces a voltage drop equal to the product of the current multiplied by the resistance or reactance. However, as you know, the voltage drops produced differ in phase from one another.

Thus, the voltage drop produced by current flow through resistance is in phase with the current. The drop produced by current through an inductive reactance leads the current by 90°. The drop produced by current through a capacitive reactance lags the current by 90°.

You have already learned how to represent these phase differences in voltage drops by vector diagrams. In each diagram, a voltage vector represents the product of the circuit current multiplied by the resistance or reactance of the part concerned. Thus, V_R really equals $I \times R$, while V_C equals $I \times X_C$ and V_L equals $I \times X_L$. Now, since the *current is the same in each of these voltage drops* if the parts are in series (because the same current flows through each part of a series circuit), we might just as well ignore it, and draw our vector diagram to represent our resistance or reactances only.

How do we do this? First, we draw our resistance vector R horizontal, making its length in inches proportional to its value in ohms. Then we draw our capacitive reactance vector X_C straight down, also making its length in inches proportional, on the same scale, to the ohmic value of the capacitive reactance. If we have a coil in the circuit instead of the condenser, we draw its inductive reactance vector X_L straight up, again making the vector length proportional to the ohmic value of the reactance.

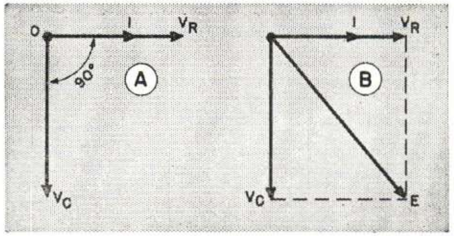


FIG. 26. The condenser voltage drop lags one-quarter of a cycle or 90° behind the current, so is drawn one-quarter of a revolution clockwise from the reference line, as at A. We can now complete the rectangle as at B and draw the diagonal E, which represents the source voltage. This tells the complete story of the voltage and current phase relationships in the circuit of Fig. 24B.

Figs. *27A* and *B* show how these vectors look when drawn this way. Notice—in each diagram, the rectangle has been completed and a diagonal vector Z drawn. What does this vector represent?

You know that, in the similar diagrams drawn for voltages, this diagonal vector represented the source voltage—the vectorial sum of all the voltage drops in the circuit. In these resistance-reactance diagrams, the diagonal vector similarly represents the vectorial sum of the reactance and the resistance in the circuit. It is called the "impedance" of the circuit; its symbol is "Z"; it is measured in ohms.

The impedance of a circuit represents the *combined opposition of all the parts of the circuit to the flow of a.c.* We can't add resistance to reactance directly, we must follow the same rules we do for their voltage drops. However, when we have the impedance, the product of the ohmic value of the impedance multiplied by the value of the circuit current in amperes equals the source voltage in volts.

Since this is true, we substitute impedance for resistance when we apply Ohm's Law to a.c. circuits. The three ways of writing the law then are:

OHM'S LAW FOR A. C.

$$I = \frac{E}{Z}$$

$$Z = \frac{E}{I}$$

$$E = IZ$$

As you will notice, they are exactly like the Ohm's Law forms for d.c., except that impedance is substituted for resistance.

Thus, if we know them, we can use impedance and the source voltage to figure the circuit current, and use this current with the resistance and reactance values to find the voltage drops across the parts. Or, if we already know the voltages across each part, we can add them vectorially to find the source voltage, as we did in Fig. *26*. Either method will give us the right answer, but one will usually be more convenient than the other, as we shall see later.

CONDENSER LOSSES

Losses in the dielectric of a condenser keep it from being 100% efficient. You have already learned that there's a certain amount of leakage through the dielectric. This leakage provides a discharge path which will allow the charge to "leak off" and prevents the condenser from keeping its charge forever. The better the condenser is, the lower *leakage loss* it has.

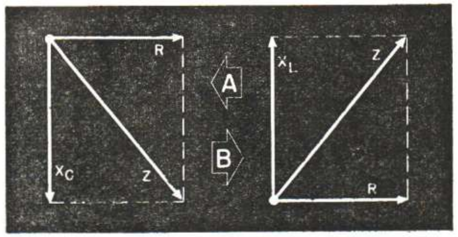


FIG. 27. Combining resistance with either inductive or capacitive reactance by means of vectors gives the impedance or total opposition to alternating current flow.

You can get some idea of how good a fairly large paper condenser is by connecting it to a 200- to 400-volt d.c. source long enough to charge it, breaking the connection, waiting two or three minutes, then shorting the condenser terminals with a screwdriver. If you get a strong spark, you know the condenser has low leakage and is therefore of good quality. (This test is useful only for paper condensers larger than .25 mfd.)

Another dielectric loss is caused by the fact that the dielectric absorbs some energy from the charging operation which it does not give back at once upon discharge. The reason is that when a condenser is charged, then discharged suddenly, all the bound electrons do not return at once to their normal orbits. If you wait a moment or two, then short the condenser again, there will be another (smaller) discharge. This effect is called "absorption." In an a.c. circuit, absorption is given the technical name of "dielectric hysteresis" (*di-eh-LECK-trick HISS-ter-E-sis*).

Both leakage loss and hysteresis loss can be lumped together and called the dielectric loss of the condenser. For simplicity, we can consider their combined effects as either a low resistance in *series* with a perfect condenser, or

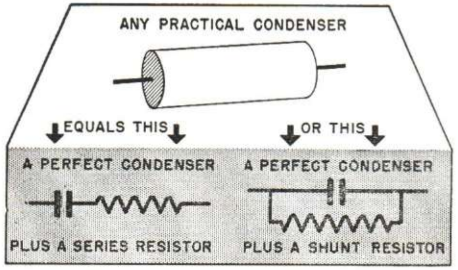


FIG. 28. Dielectric losses are in series with the condenser, while leakage losses are across the condenser. One or the other may be ignored, or both can be lumped together and shown by either of these methods.

as a high resistance in parallel with a perfect condenser. Both ways of picturing losses are shown in Fig. *28*.

The losses in a condenser go up as the frequency goes up, so condensers do not work as well at higher frequencies unless carefully made. Certain kinds of condensers cannot be used at high frequencies, particularly electrolytic condensers, due to the high amount of loss in these condensers.

Power Factor. Another way of expressing the losses in a condenser is in terms of "power factor." The power factor of a condenser shows the per cent of applied electrical power that is wasted by the resistance of the condenser. It is usually expressed in per cent. A perfect condenser would have a power factor of zero, while one with a high loss would have a fairly high power factor. As you can readily see, the lower the power factor of a condenser, the more efficient it is.

Test instruments are available that measure the power factor of condensers directly. Such instruments are used in radio service work, for they are very helpful in telling whether a condenser has such high resistance in series (high power factor) that it should be replaced. Usually such a test is necessary only on electrolytic condensers. You'll learn more about these instruments when you study service equipment in later lessons. For now, just remember power factor tells how much loss there is in a condenser.

Voltage Division with R, L and C

We have now reached the point where we can combine what we have learned about the action of resistors, coils and condensers into some of the basic circuits which you will meet time after time in radio receivers and other radio equipment. This section is a preview of circuits you will study again in later lessons. Several readings now, and later when you encounter similar circuits are recommended.

▶ In radio circuits we may have d.c. alone; we may have d.c. mixed with an alternating current; we may have d.c. with many different a.c. frequencies, or we may have different a.c. frequencies together. Regardless of what we have, we must have a means of combining and separating the different a.c. frequencies, as well as combining any or all frequencies with d.c., in order to obtain the radio actions we shall study later.

In addition to making the proper combination and separation, we must consider the necessity of supplying the right voltage for the particular reaction we want to occur.

▶ Right now, we are going to start off with some very simple circuits. However, complex radio circuits can be "boiled down" into simple circuits so that the actions in a radio receiver are easy to understand. We will leave the subject of complete radio circuits for later lessons, where you can pick them up one by one, analyze them into their basic elements, and thus reach a complete understanding of just what goes on in a radio. This thorough understanding of the actions which occur in a set will lead you directly into an understanding of what might go wrong, how it can go wrong, and what is necessary to clear up trouble when it arises.

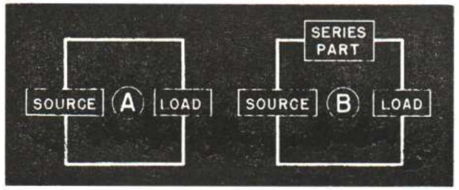


FIG. 29. When the source voltage is exactly correct for the load, they can be connected together as at A. However, a series part may be needed as at B, to lower the voltage, separate d.c. from a.c., or to separate different a.c. frequencies.

▶ Suppose we start with a source and "load" connected as shown in Fig. *29A*. (We call the device to which the source is connected a "load" because it uses the energy from the source.) For us to be able to connect a source of voltage directly to any radio part like this, the source must deliver voltage of exactly the right amount and right frequency for that radio part.

If the source furnishes too much voltage or voltages with the wrong frequency, this condition is often corrected by using the proper part in series with the load, as shown in Fig *29B*. The exact size and kind of series part to use depends on the correction needed.

SERIES RESISTANCE

Let us assume that our load is a resistor R_L, as shown in Fig. *30*, and that the voltage source supplies more voltage than we want to apply to R_L. Now, suppose we put resistor R in series with R_L. As you have already learned, the source voltage will divide, part appearing across R, the rest across R_L. This same division will occur whether the source supplies a.c. or d.c., and the frequency of the source makes no difference. Thus, the effect of resistor R is to reduce the amount of voltage available for the load R_L. The amount of reduction depends on the relative resistance of R and R_L. *Therefore, by adjusting the value of resistor R, we can adjust the voltage across R_1 to the desired value.* However, resistor R will affect only the *amount* of voltage. It has no effect on the frequency of the source voltage, and cannot separate frequencies, so the source must deliver the correct frequency.

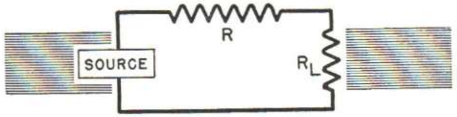


FIG. 30. The series resistor can reduce the voltage to the right amount for the load but cannot separate frequencies.

SERIES INDUCTANCE

Now, suppose we use an inductance L instead of resistor R, as shown in Fig. *31*. We have again made up a voltage-dividing circuit, but one which acts in an entirely different manner.

▶ Suppose the source produces d.c. The normal resistance of the coil is relatively low, so there will be very little d.c. voltage drop in coil L. Nearly all the d.c. voltage will appear across R_L. As far as d.c. is concerned, the coil L has practically no effect in this circuit.

▶ Now suppose the source furnishes a.c. of both low and high frequencies. The coil has a low reactance at low frequencies, so very little low-frequency voltage is dropped across it. But the reactance of coil L is very much greater at high frequencies, so most of the high-frequency voltage supplied by the source is dropped across the coil, and only a little appears across R_L. Thus, the series coil acts as a *frequency separator*. It passes d.c. and low-frequency a.c., but tends to exclude high frequencies from the load. The larger the reactance, compared to the value of R_L, the greater the tendency to exclude high frequencies.

As low frequencies find less opposition in the coil, this circuit might be called a low-pass filter, because it passes low frequencies but filters out the higher frequencies.

▶ Again, as in Fig. *30*, the division of voltage between the load and the series coil depends on the relative opposition each offers to current flow. If the ohmic value of the coil reactance is high compared with the ohmic value of load resistance, more voltage will be dropped across the coil than across the resistor. And remember, the reactance of the coil depends upon both its electrical size and the frequency of the source. It is quite possible for the reactance of the coil to be much smaller than the resistance of the resistor at low frequencies and much higher at high frequencies. The coil reactance may be large because of high inductance, high source frequency, or both.

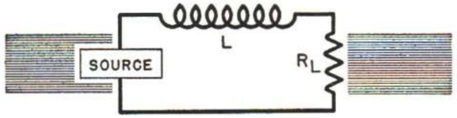


FIG. 31. The coil has greater reactance as frequency is increased, so higher-frequency voltages are divided so most of the drop is across the coil. The coil thus tends to separate frequencies, excluding the higher ones.

SERIES CAPACITY

Now let's change the circuit to that shown in Fig. *32*, with a condenser C as the series part.

We know that if the source is a d.c. voltage, there will be an initial charging current, the duration of which depends on the time constant of C and R_L. However, once the condenser is charged, there will be no further d.c. flow through the circuit (except for a tiny leakage current, which is so small that we can normally ignore it). Therefore, we can say that the condenser *blocks* the d.c. flow because, as soon as the condenser is charged, there is no current in the circuit and no d.c. voltage across R_L. All the voltage supplied by the source appears across condenser C.

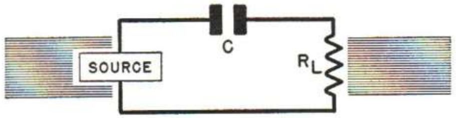


FIG. 32. The condenser blocks d.c. and, as its reactance decreases as the frequency is increased, it passes higher frequencies with less opposition, exactly opposite to the action of a coil.

▶ We have learned that a.c. does flow through a condenser, however. Further, we know that the higher the frequency, the *lower* the condenser opposition to a.c. flow.

Thus, the action of a series condenser is opposite to the action of a series coil. For low-frequency a.c., there is a large voltage drop across the condenser, leaving less voltage for the load resistance. At higher frequencies, less and less voltage is dropped across the condenser and more of the source voltage appears across the load resistance.

Again, the relative opposition of the condenser and the load to current flow determines the voltage division between them. The larger the capacity, or the higher the source frequency, the lower the condenser reactance—and the greater the voltage applied to the load.

Fig. *32* is one of the most common radio circuits you will meet later on. Condenser C is sometimes called a *blocking condenser*, because it prevents d.c. from flowing. As it will pass a.c. to the load, it is also called a *coupling condenser*, because it "couples" an a.c. voltage from one circuit to another. The name used depends upon which action is more important in the circuit.

A Typical Circuit. Fig. *33* is a typical radio circuit where a condenser is used both as a blocking and a coupling condenser. Battery B causes a d.c. flow through tube VT_1 and through resistor R_1. Condenser C prevents direct current flow from battery B through resistor R_2. However, a.c. signals in the circuit of tube VT_1 are passed on to R_2 through condenser C, where they operate tube VT_2.

Of course, we don't expect you at this point to understand all about how this circuit works. There are a few practical facts you can see, though. If condenser C becomes "open" (disconnected by a break where the lead is fastened to the foil), no signal energy will be passed on to the next tube, because the circuit is broken so the condenser is effectively not there. This may make the receiver dead.

On the other hand, if condenser C becomes leaky or short circuited, d.c. will flow through this condenser and through resistor R_2, where it is not wanted. As you will learn in a later lesson, this will cause distortion.

Thus, a properly operating condenser C blocks d.c. and couples the **a.c.** signal to the next tube. A defective condenser C may prevent the passage of signal energy, or may permit the passage of d.c.

Summary. Fig. *34* shows in chart form the action of a resistor, coil and condenser individually. You will find this chart helpful in summarizing the information given to you so far.

▶ Now, having learned how these parts will act when in series with the load, let us consider a few more basic circuits using condensers.

BY-PASSING AND FILTERING

Suppose we go back to our resistive circuit shown in Fig. *30* for a minute. You will recall that the voltage division depends on the relative resistance values, but the same division occurs regardless of frequency. This circuit cannot separate d.c. from a.c., nor can it separate alternating currents of different frequencies.

▶ There are plenty of cases where we want d.c. in the load without a.c., or want low-frequency a.c. and no high frequencies. We can add a condenser in parallel with the load, as in Fig. *35*, and will again have a frequency-separating circuit—one of the most useful in radio.

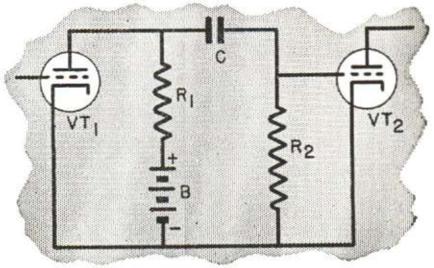
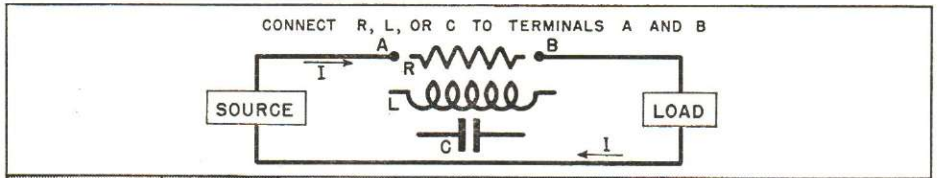


FIG. 33. A typical resistance-capacitance circuit utilizing the basic circuit actions of Fig. 32.

As you know, there is no d.c. path through the condenser. If we apply a



APPEARANCE	SYMBOL	DOES IT CONTROL D.C. CURRENT?	DOES IT CONTROL A.C. CURRENT?	WHAT HAPPENS WHEN THE ELECTRICAL SIZE IS INCREASED?	WHAT HAPPENS WHEN FREQUENCY OF A.C. IS INCREASED?
 RESIS-TOR		YES	YES	OPPOSITION INCREASES	NO CHANGE IN OPPOSITION
 COIL		NO (CURRENT PASSES)	YES	OPPOSITION INCREASES	OPPOSITION INCREASES
 CONDENSER		NO (NO CURRENT PASSES)	YES	OPPOSITION DECREASES	OPPOSITION DECREASES

FIG. 34. This chart summarizes the actions of a resistor, coil or condenser when used in the simple circuit shown above. (Because a condenser completely blocks the flow of d.c., some engineers say that it does control d.c. to this extent.)

d.c. source, condenser C charges through resistor R, after which there is no further direct current flow in the condenser section of the circuit. Of course, the load R_L provides a d.c. path, so a direct current flows through resistors R and R_L, and the condenser might as well not be there, so far as d.c. is concerned.

▶ When low-frequency a.c. is applied to this circuit, the capacitive reactance is high, and if it is much higher than the resistance of load R_L, very little a.c. flows through the condenser, most of it going through the load R_L.

As the frequency is increased, however, the reactance of the condenser decreases. Condenser C and resistor R begin to divide the source a.c. voltage, with a greater and greater drop occurring across resistor R as the frequency increases. Therefore, less and less a.c. voltage is available across C and the load R_L. This circuit can be considered a low-pass filter, because low-frequency currents flow through R_L, while higher frequencies do not.

Notice—this action is exactly opposite to that of the circuit in Fig. *32*. The circuit in Fig. *32* permitted only higher frequencies to pass, while that in Fig. *35* permits only lower frequencies to pass. Hence, Fig. *35* is acting much like the coil circuit of Fig. *31*.

▶ Sometimes we may use a coil as a filter, sometimes a condenser. By putting the coil or condenser in the proper place in the circuit, we can get either a low-pass or a high-pass action for a.c. The condenser has the advantage of blocking direct current flow when in series, and has no effect on d.c. when in parallel, so the condenser is often more desirable in circuits where d.c. is also present. You will usually find coils used more commonly in circuits containing only a.c. frequencies.

▶ Notice how the parts *work together* to give the desired actions. Without the series R in Fig. *35*, an entirely different action would occur. The condenser would then act just as it does alone and would serve only as an *additional load* on the source. It would not have any control over the R_L voltage unless the source contained enough impedance to replace the action of the series R. Of course, in practice, the source *will have appreciable impedance* so some a.c. drop will occur.

By-pass Action. The condenser connection shown in Fig. *35* is very frequently called a "by-pass" because it "by-passes" high-frequency currents so they do not flow through the resistor R_L. This action is also called "filtering," because the effect is one of "filtering out" certain frequencies. Which name we use depends upon the exact action required in the circuit, as you will learn later. Usually, the term "by-passing" is used whenever we want to provide an easy path for a.c. and at the same time keep this a.c. out of another circuit.

Fig. *36A* shows a typical by-passing circuit. Battery B causes d.c. to flow through the source, through R_L and through R_B. Condenser C has no effect on this action.

The source produces a.c., which we may want to keep out of battery B. This a.c. flows through R_L and condenser C, rather than through R_L, R_B and the battery, because the opposition to a.c. in the path through condenser C is very low, causing the a.c. voltage to divide between R_L and C. Since most of this voltage is across R_L there is little voltage across C, and as R_B and B are in parallel with C, they have the same low a.c. voltage across them.

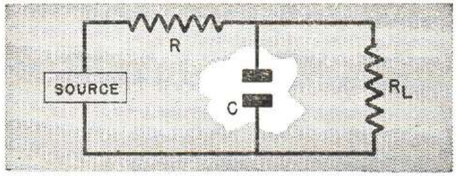


FIG. 35. Another important condenser circuit. Here, the condenser acts with resistor R to keep the higher frequencies from affecting the load R_L.

▶ The practical radio equivalent of this filter circuit is shown in Fig. *36B*, where the tube VT acts as the source of the a.c. signal. Again, we include this circuit just to show you a practical use for one of our simple circuits. Much more information will be found in later lessons on this subject.

▶ From what you've already learned, however, you can see that if condenser C in Fig. *36* becomes leaky, it provides a path for d.c. from battery B through R_B. As the leakage resistance becomes lower, there will be a greater drop across R_B and less voltage will be available for the tube and R_L. In other words, the d.c. path becomes R_B-C, rather than R_B-R_L-VT. Thus, a leaky condenser can stop the operation of the circuit. On the other hand, if the condenser becomes disconnected (open), the a.c. has no by-passing path and must flow through the battery, where it can produce undesirable effects, as we shall study later.

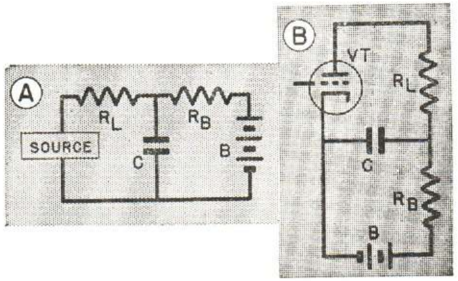


FIG. 36. This typical by-pass circuit uses the basic actions of Fig. 35.

COMBINING L AND C

So far, we have discussed using a coil or condenser with a resistor. What happens when we combine a coil and condenser?

Let us first consider the circuit shown in Fig. *37*. We know that the coil tries to exclude higher frequencies from R_L, because it offers a greater opposition to higher frequencies. We also know that condenser *C* has less reactance at higher frequencies, and so tends to "by-pass" the higher frequencies.

Thus, both elements of this combination try to exclude higher frequencies from the load, *L* by offering high reactance and *C* by offering low reactance to the high frequencies. The practical result of combining these two parts in this circuit is that the high frequencies are cut off quite abruptly, instead of dropping off gradually as they do when either the coil or the condenser is used alone. This is a low-pass circuit, since only low frequencies reach the load.

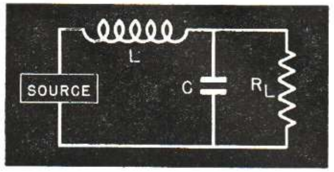


FIG. 37. Using a coil and condenser together this way gives a low-pass filter, which "passes" low frequencies to the load but sharply cuts off higher frequencies.

By interchanging the two parts as shown in Fig. *38*, we produce the opposite condition. Condenser *C* offers greater opposition to low frequencies, and coil *L* acts as a "by-pass" element. Therefore, the circuit in Fig. *38* cuts off low frequencies, and is thus a high-pass circuit.

The actual frequency where this "cut-off" action occurs depends on the values chosen for *L* and *C* in both circuits. When you take up filtering later on, you will find that coil and condenser combinations of these types are quite commonly used where it is necessary to separate high and low frequencies abruptly.

Looking Ahead. In radio, we will find circuits which contain resistance only. Circuits of this type will act the same regardless of the frequency. In other circuits, we introduce a coil or condenser to discriminate against either low or high frequencies. Then there are other combinations of coils, condensers and resistors which pass some frequencies but reject those higher or lower. Another group will reject a band of frequencies but allow higher and lower frequencies to pass.

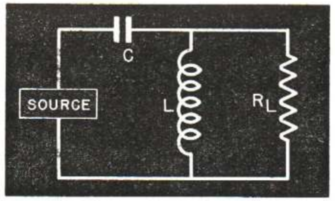


FIG. 38. Reversing the coil and condenser positions gives a high-pass filter which excludes low frequencies from the load.

Exactly when and how we do this will be the subject of many of your future lessons.

▶ In your next lesson you will take up the interesting and important subject of vacuum tubes and how they operate. You will then be ready to put together resistors, coils, condensers and tubes to form actual radio circuits.

Lesson Questions

Be sure to number your Answer Sheet 7FR-3.

Place your Student Number on *every* Answer Sheet.

***Send in your set of answers for this lesson immediately after you finish them,* as instructed in the Study Schedule. This will give you the greatest possible benefit from our speedy personal grading service.**

1. Name the four factors that determine the capacity of a condenser.

2. What is meant by the "working voltage" of a condenser?
[illegible] VOLTAGE THAT CAN SAFELY BE APPLIED.

3. Is it necessary to consider polarity when connecting electrolytic condensers?
YES

4. How would you connect two condensers together to get an increased capacity?

5. When the frequency is *decreased*, does the capacitive reactance: *1, increase; 2, decrease; or 3, remain the same?*

6. When the capacity is increased, does the capacitive reactance: *1, increase; 2, decrease; or 3, remain the same?*

7. When a resistor is connected in series with a condenser, does the charging time: *1, increase; 2, decrease; or 3, remain the same?*

8. Suppose you want to exclude d.c. from a load. What part would you use in series with the load to do this? CONDENSER

9. Suppose a condenser is in series with a resistive load, as shown in Fig. *32*. Will a larger-capacity condenser permit *more* or *less* a.c. voltage to be applied to the load?

10. Suppose distortion occurs due to a d.c. voltage across resistor R_2 of Fig. *33*. Choose the *two* following conditions of condenser *C* which could cause this: *1, leaky; 2, open; 3, short-circuited; 4, normal condition.*

SUCCESS AND HAPPINESS

I would like to have you feel, as you read these short personal messages, that you are seated right alongside my desk. Years of experience with thousands of ambitious men proved to me that a word of advice or cheer can go a long way toward speeding your progress. As I see it, my responsibility goes farther than just giving you the *very best* training in radio—my duty is to help you get the very most out of *life*—to attain *real happiness.*

You, in common with all other N.R.I. men, desire success. You think that success will bring happiness, but this is not necessarily true. I believe that a man must train himself for happiness, just as he must train himself for success!

The first thing you must understand is this: *Happiness comes from within!* There is no guarantee that material things—money, success, friends and possessions—will make you happy, for happiness is a state of mind. You must learn to be happy within yourself.

In these one-minute chats, then, I am going to teach you how to get the most happiness out of the success which is in store for you.

J. E. Smith