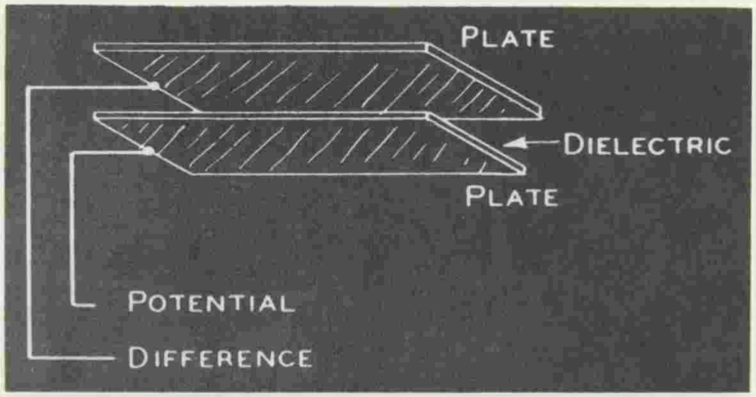

LESSON

6 R

RADIO CAPACITORS

RADIO-TELEVISION TRAINING SCHOOL, INC.

5100 SOUTH VERMONT AVENUE • LOS ANGELES 37, CALIFORNIA, U. S. A.

RADIO CAPACITORS

If you look back at the radio receiver which we built in an earlier lesson, you will find that every part may be classified as one of the following:

1. Tubes.	3. Insulators.	5. Coils or inductors.
2. Conductors.	4. Capacitors.	6. Energy sources.

When we know all about the electrical behavior of these six classes of parts, we shall know most of radio, so far as our practical work is concerned. Let's check up on where we stand in knowledge about them.

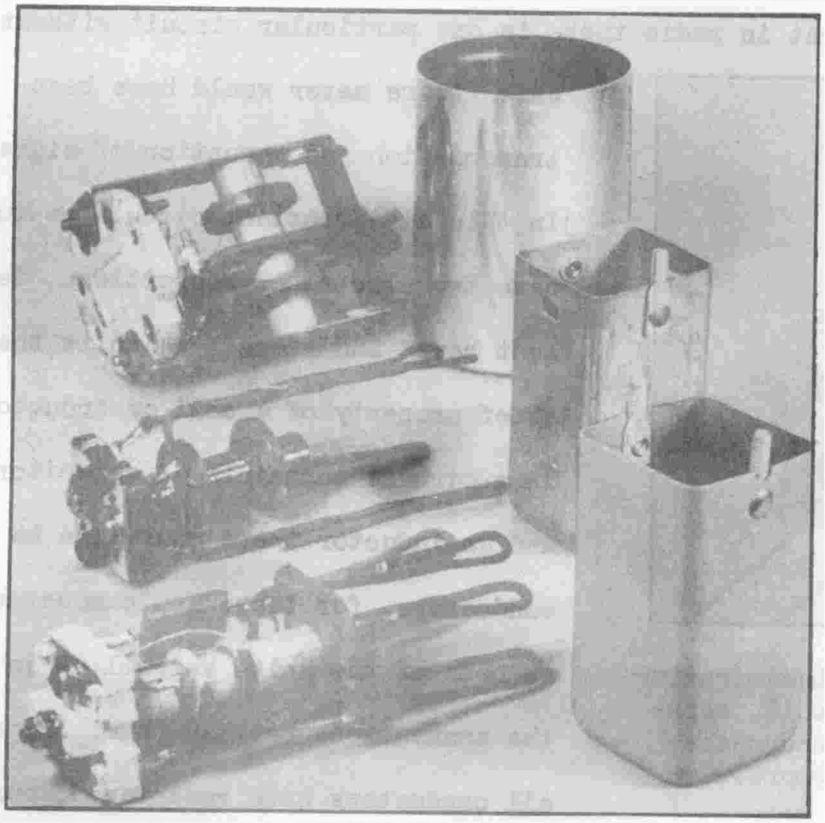

FIG. 1.
In the circuits of these intermediate-frequency transformers there are inductance, capacitance, and resistance.

1. Tubes. We have studied the basic principles relating to tubes; we understand electron flow in tubes, also, the forces that control this flow.

2. Conductors. Here we find all the metallic supports, all of the wires, and also all of the resistors—because resistors are conductors having high resistance in small space. We are thoroughly acquainted with the behavior of conductors and resistors, for we have spent much time on the relations between resistance, potential difference, and electron flow.

3. Insulation. We know that insulation does not permit any appreciable electron flow through it, and that insulation is used to confine electron flow to conductors. This was enough for our needs in earlier lessons.

4. Capacitors. So far, we do not know a great deal about the behavior of capacitors.

5. Coils or inductors. Here we are in the same position as for capacitors; we know very little about the behavior of coils.

6. Sources. We know that sources produce electrical energy, and electromotive force, from other kinds of energy. We know also that sources maintain electric charges and potential differences. This much knowledge will serve very well for the time being.

In deciding which of the six classes of radio parts should be examined next, we shall be guided by the fact that in radio there is one particular circuit without which there never would have been transmission and reception of signals. In this all-important circuit we must have two electrical properties. We must have inductance, which is the chief property of a coil or inductor. In a circuit containing a capacitor and an inductor there must also be conductors, for there are conductors in both of the units as well as in the connections between them. Since all conductors have resistance, our circuit will contain resistance as well as capacitance and inductance.

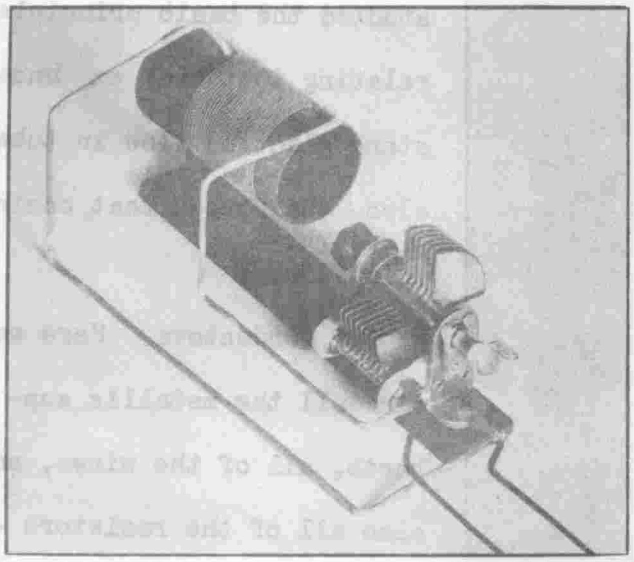

FIG. 2.

Here are the elements of a basic radio circuit: inductance in the coil, capacitance in the capacitor, and resistance in all the conductors.

We really know a lot about resistance, but we are lacking in knowledge relating to the other two elements. In this lesson we shall get acquainted with capacitors and capacitance, later with inductance, and then we shall be able to build a "resonant circuit", which is the fundamental circuit in radio.

It will be easy to learn about the behavior of capacitors, because a capacitor consists of nothing more than two conductors or sets of conductors separated by insulation. When the two conductors, called the plates of the capacitor, are given electric charges of opposite polarity, there will be a potential difference between the plates, and in whatever insulation is between the plates there will be an electric field. We already understand electric charges, potential differences, and electric fields, so the only new things will be how these act together in the arrangement called a capacitor.

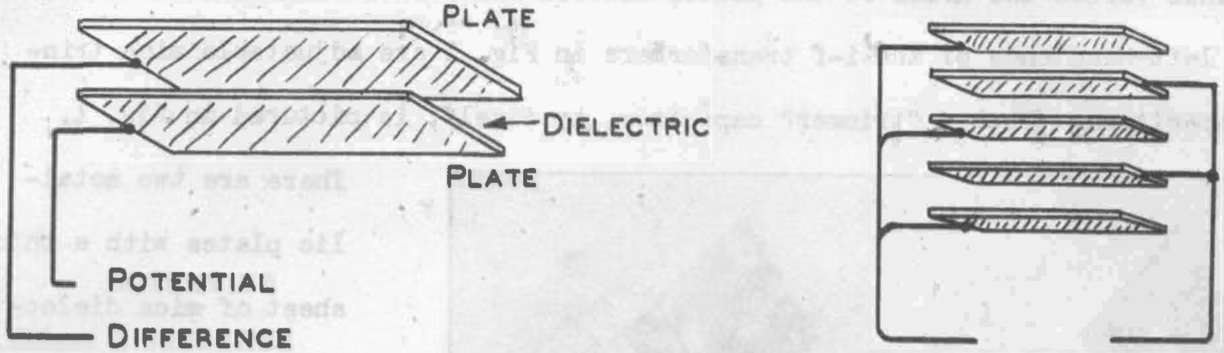

FIG.3.

The plates, and the space in which is the dielectric, of capacitors.

TYPES OF CAPACITORS

The plates and the insulation between them may be represented as in Fig. 3. The insulation between the plates of a capacitor is called the dielectric. The dielectric may be air, it may even be a vacuum, and it may be any other kind of insulating material, such as paper, mica, oil, and many others.

There may be only two plates, as at the left, with a single electric field in the dielectric between them, or there may be, as at the right, any number of interleaved plates with electric fields in the dielectric between each pair of adjacent plates. In such a construction alternate plates are joined together, thus grouping the plates into two sets which will be of opposite polarity when the capacitor is working.

Capacitors usually are specified or named in accordance with the kind of dielectric material and the purpose for which the capacitor is designed. For example, we might have an air-dielectric tuning capacitor, a paper bypass capacitor, a mica coupling capacitor, an electrolytic filter capacitor, and so on.

Capacitors are classified also as to whether or not their property called capacitance may be varied while the capacitor is in operation. If the capacitance may be varied, the unit is called a variable capacitor or an adjustable capacitor. If the capacitance cannot be altered, the unit is called a fixed capacitor. The small capacitor at the lower right in Fig. 2 is a variable air-dielectric tuning type. One set of plates, corresponding to one of the sets at the right in Fig. 3, may be rotated so that they extend to a greater or less distance between the other set. This varies the areas of the plates between which there are electric fields. On the left-hand ends of the i-f transformers in Fig. 1 are adjustable mica trimming capacitors. Such a "trimmer" capacitor, by itself, is pictured in Fig. 4.

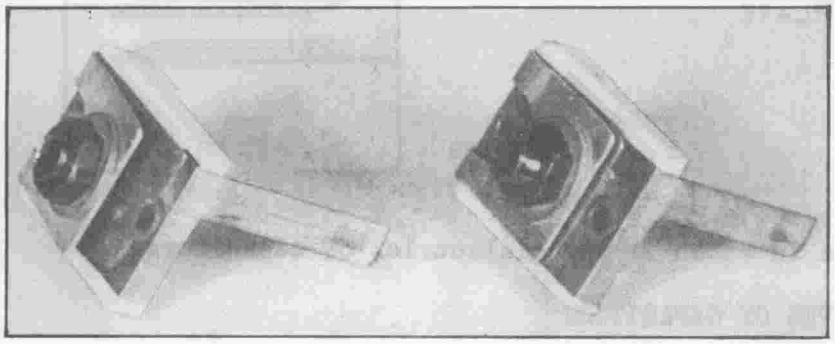

FIG.4.
A trimmer capacitor: adjusted for minimum capacitance at the left, and for maximum at the right.

There are two metallic plates with a thin sheet of mica dielectric between them. At the left the adjusting nut has been turned all the way out on the screw, thus letting one plate move as far as possible from the other to lessen the capacitance. At the right the adjustment has been changed to bring the plates close together, and to increase the capacitance.

HOW A CAPACITOR WORKS

The action of a capacitor may be compared with the action of the mechanical arrangement shown by Fig. 5. Here we have a thin, flexible rubber diaphragm held between two air chambers

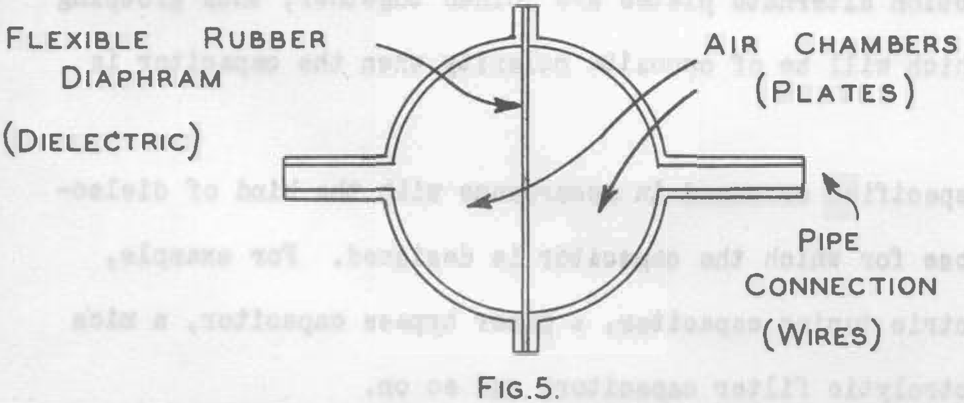

FIG.5.
A capacitor may be compared to two air chambers separated by a flexible diaphragm.

to which are made pipe connections. The rubber diaphragm represents the dielectric of the capacitor. One air chamber represents one plate, and the other chamber represents the other plate. Air will flow into and out of the chambers much as electrons flow into and out of the two plates of a capacitor. The diaphragm is stretched, or is "stressed", when there is more air in one chamber than in the other one, much as the dielectric of a capacitor is electrically stressed when there is difference between the charges on the two plates or sets of plates.

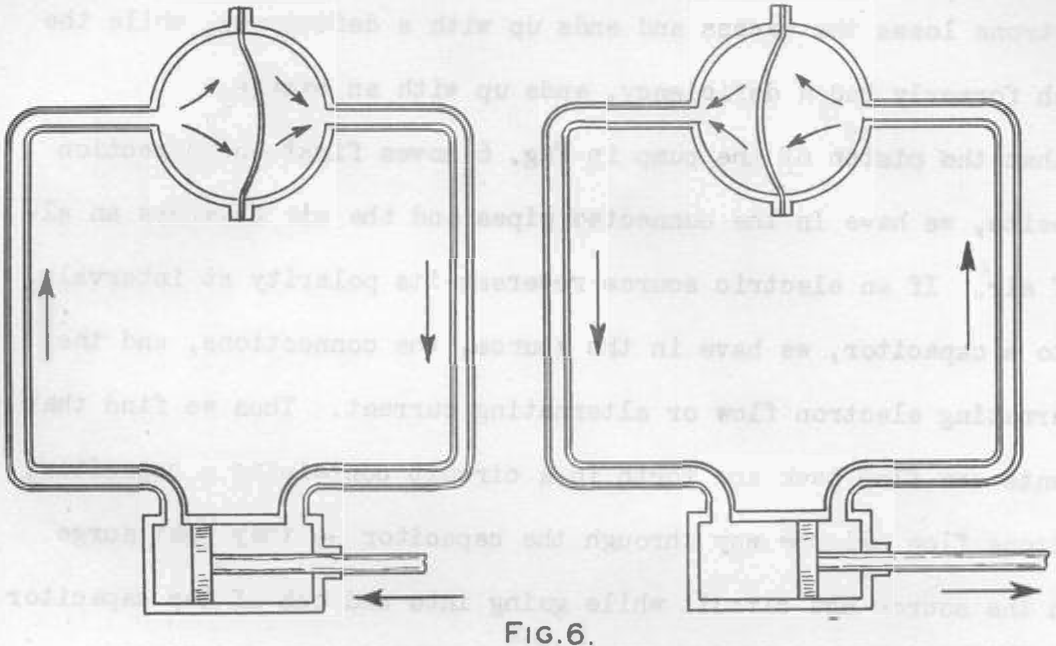

FIG.6.
The diaphragm is flexed one way and the other as air enters and leaves the chambers.

In Fig. 6 the air chambers and diaphragm are connected to a piston type of pump. In the left-hand diagram the piston is moving toward the left. The pressure developed in the pump forces air from the pump through the connecting pipe into the left-hand air chamber and the diaphragm is stretched as shown. The pump represents a source of emf whose electrical force or pressure drives electrons into one plate of a capacitor, and stresses the dielectric in one direction or polarity. When air enters the left-hand air chamber, other air leaves the right-hand chamber and goes to the pump. When electrons flow into one plate of a capacitor, an equal quantity must leave the other plate and go to the source.

No air flows all the way through the diaphragm, the flow is only into and out of the chambers. No electrons flow through the dielectric of a capacitor, the flow is only into and out of the plates.

When the pump piston reverses its direction, as in the right-hand diagram of Fig. 6, the direction of air flow is reversed. Now air enters the right-hand chamber and flows out of the left-hand chamber as the diaphragm is stretched toward the left. When there is a reversal of polarity at a source connected to a capacitor, there is a reversal of direction of electron flow, and the plate which formerly had an excess of electrons loses the excess and ends up with a deficiency, while the other plate, which formerly had a deficiency, ends up with an excess.

If we assume that the piston of the pump in Fig. 6 moves first one direction and then the opposite, we have in the connected pipes and the air chambers an alternating flow of air. If an electric source reverses its polarity at intervals, while connected to a capacitor, we have in the source, the connections, and the capacitor an alternating electron flow or alternating current. Thus we find that alternating currents can flow back and forth in a circuit containing a capacitor, although no electrons flow all the way through the capacitor — they just surge back and forth in the source and circuit while going into and out of the capacitor plates which are insulated from one another by the dielectric.

ACTION IN THE DIELECTRIC

The dielectric of a capacitor may be a gas, such as air; it may be a liquid, such as oil; or it may be a solid, such as mica. But the dielectric must be an insulator to prevent flow of electrons through it and to hold the charges on the plates.

Were we to use a piece of mica in a washer or bushing around conductors for the purpose of preventing escape of electron flow, we would speak of the mica as an insulator. Were a sheet of the same mica used in a capacitor, we would speak of it as a dielectric. We use the name dielectric when referring to action of a material in an electric field, as in a capacitor, and use the name insulator when the material is considered with reference to its ability to prevent escape of leakage of electron flow. The material may be exactly the same in both cases.

When there are charges on the plates of a capacitor, the positive charge attracts electrons which are in the atoms of the dielectric, while the negative charge repels those electrons. The electrons are not pulled out of the atoms, because in insulating substances the electrons are held too securely, but the electrons are shifted toward one side of all the atoms — toward the side that is nearest the positive change or positive plate. When the charges reverse their polarity, the electrons shift toward the opposite sides of their atoms, but they stay with the atoms. Shifting of the electrons may be called "polarization" of the dielectric material.

During polarization of a dielectric there is some actual movement of electrons as they shift in their atoms. Any movement of electrons may be called a current or an electron flow. So, in the dielectric, we have what is called a displacement current as the electrons shift back and forth. This current remains wholly within the dielectric material, while there is an entirely separate "conduction" current flowing into and out of the plates as the plates are charged and discharged.

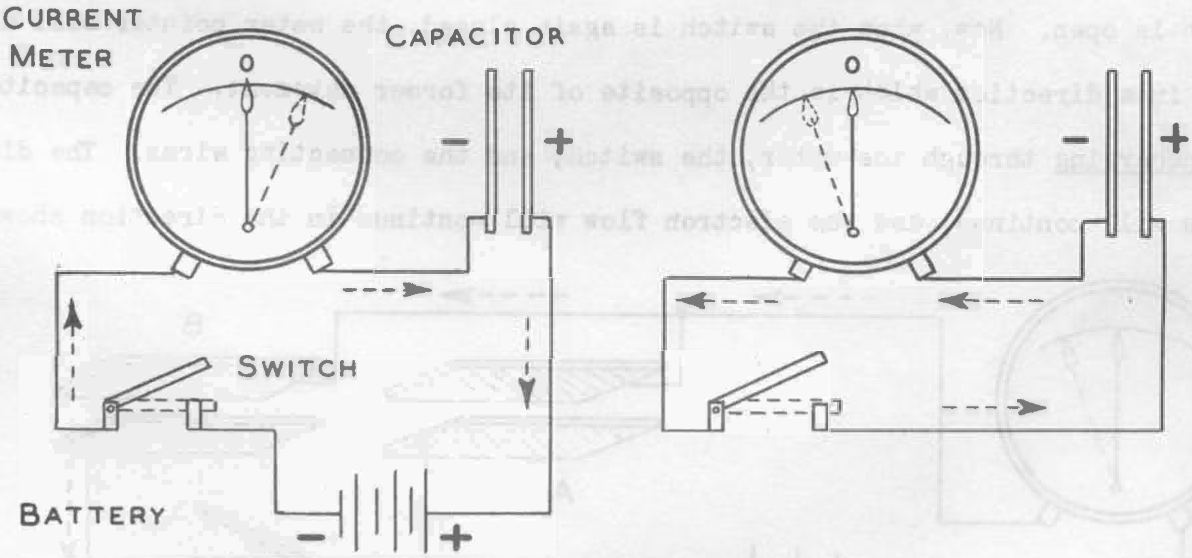

FIG. 7.
Charging and discharging of a capacitor.

CHARGE AND DISCHARGE OF A CAPACITOR

Assume that we have set up the testing circuit shown by Fig. 7. At the left we have, in series, a current meter, a capacitor, a battery, and a switch. The meter is one whose pointer remains at the center of the scale when there is no flow, and which deflects one way or the other according to the direction of flow through the meter. When we close the switch (broken lines at the left), the meter pointer will swing one way while electrons flow into one plate and out of the other plate of the capacitor. The capacitor is being charged.

While the battery is connected to the capacitor, electrons flow into one plate to give that plate an excess of electrons, which is a negative charge, and flow out of the other plate to leave a deficiency of electrons, which is a positive charge. There is a potential difference between the opposite charges. When the charges become great enough to have a potential difference equal to the potential difference of the battery, or other source, there will be no more electron flow. The meter pointer will return to zero. At the left in Fig. 7 we see that the negative charge of the capacitor is connected to the negative terminal of the battery, through the meter and switch, and that the positive charge is connected to the positive terminal of the battery. With the capacitor and battery potentials equal in strength, and with them opposed in polarity, the electron flow has to stop.

At the right in Fig. 7 the battery has been taken out of the circuit while the switch is open. Now, when the switch is again closed, the meter pointer will deflect in a direction which is the opposite of its former movement. The capacitor is discharging through the meter, the switch, and the connecting wires. The discharge will continue, and the electron flow will continue in the direction shown, until the potential difference between the capacitor plates falls to zero. Then the discharge will cease and the meter pointer will return to zero.

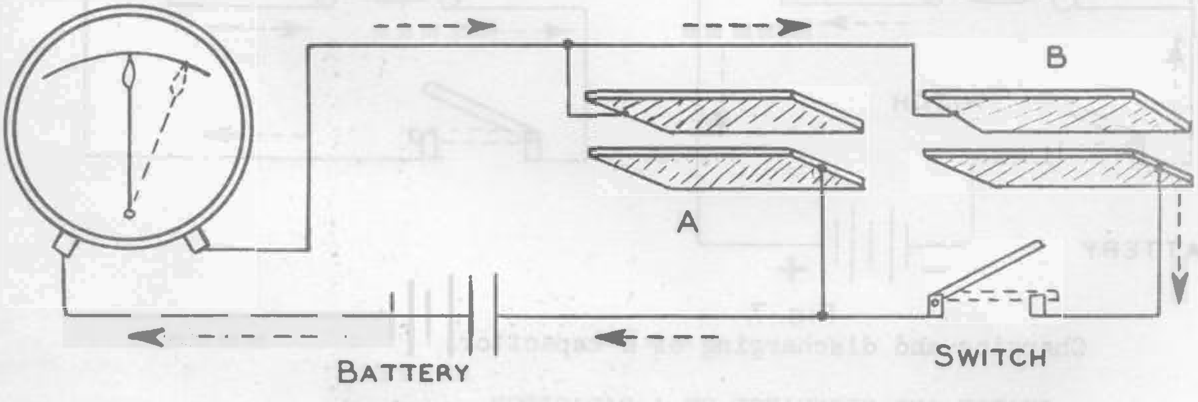

FIG. 8.
Adding to the plate area allows additional charge.

Now look at Fig. 8. Capacitor A is permanently in series with the battery and meter, consequently is charged to the full potential difference of the battery. Capacitor B may be switched into the circuit so that this second capacitor is in parallel with the first one. When the switch is closed, the meter will deflect, showing that additional electron flow is going into and out of capacitor B. What we have done is add to the areas of the capacitor plates connected to the battery. The greater the plate area which is on opposite sides of the dielectric, the more charge a capacitor or capacitors will take when all other factors remain unchanged.

Here is another experiment. Supposing that the adjustable capacitor at the left in Fig. 9 were connected to a battery through a current meter. The current meter would have a momentary deflection while the capacitor charged to the potential difference of the battery. If now the plates of this capacitor were moved closer together, as at the right, there would be an additional deflection of the meter in the same direction as the first deflection. This would show that the same capacitor is taking additional charge and is doing so with the same potential difference applied from the battery. The closer together are the plates of any given capacitor, or the thinner is the dielectric between the plates, the greater will be the charge taken by that capacitor with any given applied potential difference.

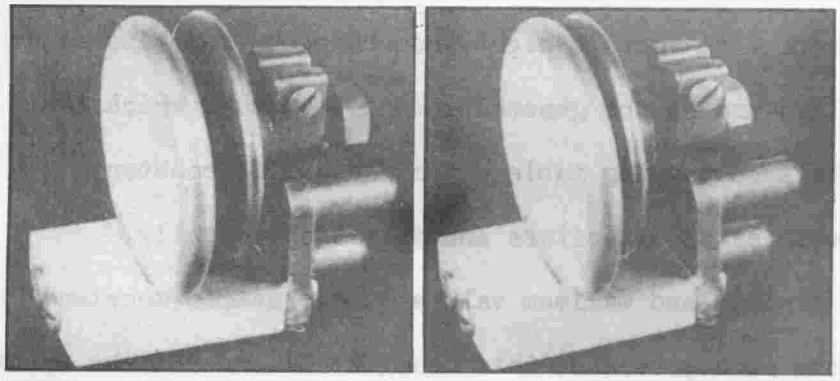

FIG. 9.

Lessening the thickness of dielectric increases the capacitance.

Supposing now that we keep the plates of our capacitor separated by the same distance as at the right in Fig. 9, which means that we have air dielectric of this thickness. Then, with the capacitor still in series with the battery and current meter, we slip between the plates a sheet of glass, as in Fig. 10. Again the meter pointer will deflect, and in the same direction as before. Thus we find that substituting glass for air as the dielectric allows the capacitor to take additional charge.

DIELECTRIC CONSTANTS

We just found that a glass dielectric of given thickness allows a capacitor to take more charge than when the dielectric is air and when the plate areas are unchanged. Were we able to make accurate measurement of the charge taken by the capacitor with air dielectric and with glass dielectric (the charge being measured in coulombs or fractions), we should find that the charge with glass dielectric is four to eight times as great as with air dielectric.

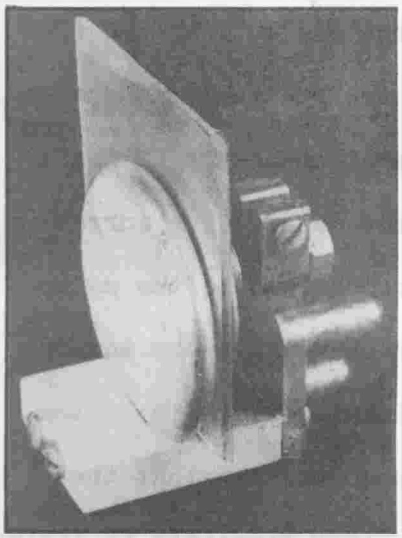

FIG. 10.
Glass instead of air for dielectric increases the capacitance.

The number of times that the charge is increased by substituting for air, or vacuum, some other substance is called the dielectric constant of that other substance. The dielectric constant of glass is anywhere from four to eight, depending on the kind of glass and on the general conditions under which the capacitor is being operated. The accompanying table gives dielectric constants for some materials used as dielectrics in capacitors and in radio generally.

The great variations between minimum and maximum values of dielectric constant for the same kind of material come about, because this constant depends on the exact grade of material, on how it is manufactured, on its purity, on the temperature, on whether the material is dry or moist, on whether the applied potential is direct or alternating, on how long the potential difference has been applied, and on other things.

Dielectric Constants of Radio Materials

Air	1.0	Porcelain, unglazed	5 to 7
Bakelite	4 to 8	Resins, synthetic	2.5 to 4
Ceramic dielectrics	85 to 90	Rubber, hard	2 to 4
Cloth, varnished	3.5 to 5	Quartz, fused	3.5 to 4.5
Fibre, hard vulcanized	5 to 8	Silk	4.6
Glass, Pyrex	4 to 5	Steatite	4.5 to 6.5
Mica	4 to 8	Titanium dioxide	90 to 170
Paper, dry, untreated	1.5 to 3	Wax, bee's	2.0 to 3.2
Paper, waxed	2.5 to 4	Wax, paraffin	1.8 to 3
Phenolic insulators	4 to 7.5	Wood, hard, dry	3 to 6

CAPACITANCE

The ability of a capacitor to take, and hold, electric charges is called the capacitance of that capacitor. The capacitance of a capacitor may be compared with the size or the cubic volumes or cubic capacities of the air chambers represented in Figs. 5 and 6. The greater the volume of the air chambers, the more air they will hold when the air is at a certain pressure. The greater the capacitance of a capacitor, the more electrons or the more charge it will hold or will take when a certain potential difference is applied to the plates.

We might measure the air capacity of our air chambers by stating the quantity of air held at some certain pressure, such as so many pounds of air per pound per square inch of pressure. In the case of a capacitor we could specify its capacitance by stating the quantity of electricity or electrons held at a certain potential difference. We might specify capacitance as so many coulombs per volt, the coulombs measuring the quantity of charge, and volts measuring the potential difference.

If a capacitor will take a charge of one coulomb when the potential difference is one volt, the capacitance is one farad. The farad is the fundamental unit of capacitance. A capacitor of one-farad capacitance would be of immense size, a thousand or more times bigger than anything used in radio. Practical capacitors are of sizes whose capacitances are measured in microfarads, one microfarad being the one-millionth part of a farad. Another common unit is the micro-microfarad, which is equal to the one-millionth part of a microfarad. An abbreviation for microfarad is <u>mfd</u>, and one for micro-microfarad is <u>mmfd</u>.

There is a set of rules or formulas applying to capacitance which is somewhat similar in general form to the Ohm's law formulas. These capacitance formulas are useful if you have much to do with computations in this field, but it is not really necessary to remember the formulas. Remember only that they can be found in this lesson in case you need them later on. When we measure capacitance in microfarads, measure potential difference in volts, and measure quantities of charge in coulombs, the three formulas are:

$$\text{Capacitance, microfarads} = \frac{\text{coulombs} \times 1{,}000{,}000}{\text{volts}}$$

$$\text{Potential difference, volts} = \frac{\text{coulombs} \times 1{,}000{,}000}{\text{microfarads}}$$

$$\text{Charge, coulombs} = \frac{\text{microfarads} \times \text{volts}}{1{,}000{,}000}$$

The third formula tells us two things of importance. First, the quantity of charge is directly proportional to the capacitance. That is, twice the capacitance means twice the charge, and half the capacitance means half the charge, when the potential difference remains unchanged. Second, the quantity of charge is directly proportional to the potential difference when the capacitance remains unchanged.

The effect of potential difference on charge may be observed with a test setup such as shown by Fig. 11. A capacitor and current meter are connected in series, with arrangements for connecting into this series circuit either one, two or three of the batteries. With the connection at A, bringing one battery into circuit, the capacitor will take a certain charge. When the connection is moved to B, placing two batteries and a greater potential difference in the circuit, the capacitor will take an additional charge; with the connection at C there will be a still further charge.

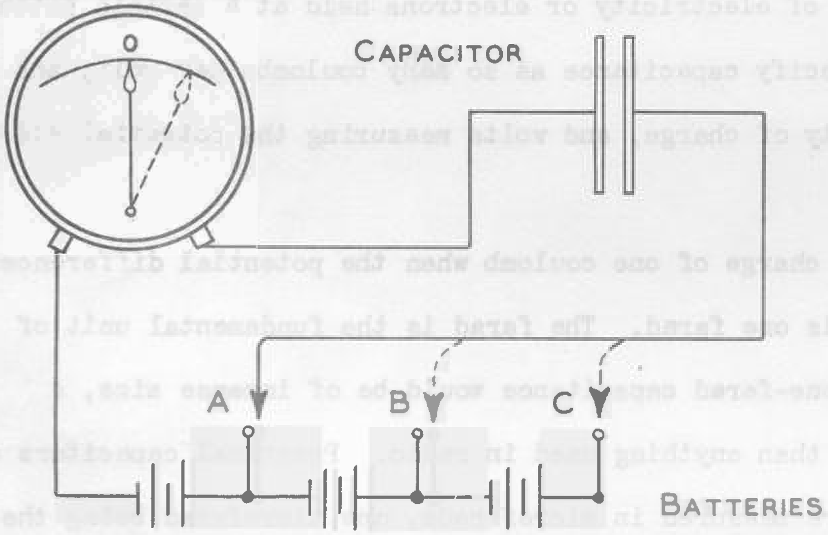

FIG. 11

Greater applied potential increases the charge with the same capacitance.

With the connection at C the capacitor is charged to a potential difference equal to that of the three batteries acting together. If the connection now is moved back to B or to A, the capacitor will discharge through the batteries or battery, because the potential difference of the capacitor is greater than the potential difference of the batteries or battery.

By going back over the several experiments or tests we find that the charge given to a capacitor is proportional to the capacitance and to the applied potential difference. We find that the capacitance itself is affected by three factors: by the areas of the plates which are on opposite sides of the dielectric, by the separation between the plates or the thickness of the dielectric, which amounts to the same thing, and by the kind of dielectric between the plates. The capacitance is affected by the kind of dielectric, because different materials have different dielectric constants.

All three factors may be put into a fairly simple formula which will give the approximate capacitance of a capacitor when we know the plate area, the number of plates, the thickness of the dielectric, and the dielectric constant of the dielectric material. Here is the formula:

$$\text{Capacitance, micro-micro-farads} = \frac{\text{area, one side of one plate, square inches} \times \text{number of plates, minus one} \times \text{dielectric constant}}{4.45 \times \text{dielectric thickness, inches}}$$

Supposing, for an example, that we have a rolled-up type of paper-dielectric capacitor having for its plates three strips of metal foil, each 1.5 inches wide and 20 inches long, with the paper between foils 3/1000 inch or 0.003 inch thick. We may assume that the dielectric constant of the paper will be 3. One item in the formula is "area, one side of one plate, square inches". The one-side area of our 1.5 by 20 inch plates is 30 square inches. We deduct one from the total number of plates, because this will give us the number of dielectric layers or electric fields which are between plates. Inserting our known values in the formula gives:

$$\text{Mmfds} = \frac{30 \times 2 \times 3}{4.45 \times 0.003} = \frac{180}{0.01335} = 13{,}500$$

Dividing this capacitance in micro-microfarads by 1,000,000, to change it to microfarads, gives 0.0135 mfd. for the assumed capacitor. Because the plates are long and narrow, the actual capacitance would be about one-fifth more than the computed value, because of the "elongation effect".

The factor which we measure as the plate area is, in reality, the area of the plates between which there is dielectric and an electric field. In variable capacitors, such as illustrated by Fig. 12, this effective area is varied by moving one set of plates with respect to the other set. The plates which remain stationary in the supports and mounting are called the stator plates. Those which are movable are called the rotor plates. All of the stator plates are electrically or conductively connected together as a set, and all of the rotor plates are conductively connected together as another set.

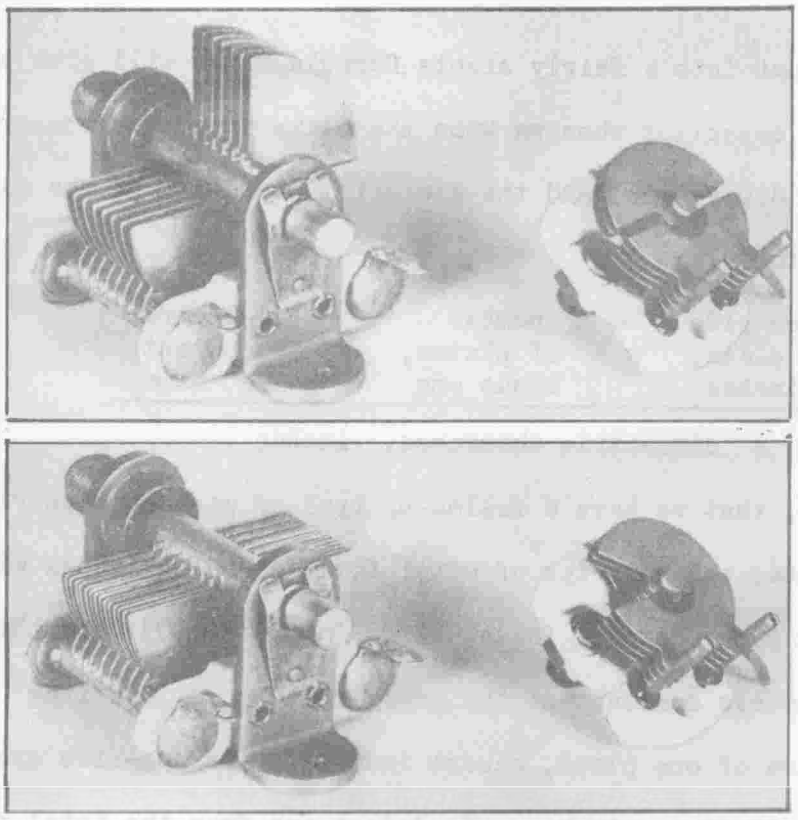

FIG.12.
Moving the rotor plates of a variable capacitor farther into or out of mesh with the stator plates alters the capacitance.

At the upper left in Fig. 12 the rotor plates are half way out of "mesh" with the stator plates, and the capacitance is about half of the maximum value which is obtainable with the rotors all the way in mesh, as at the lower left. Capacitance in the upper picture is more than half of the maximum, because there is a certain amount of non-adjustable capacitance existing between parts of the assemblies that do not change their distances apart.

At the upper right in Fig. 12 the rotor plates are all the way out of mesh, and there is the minimum possible capacitance. The capacitance is not zero, because we still have the rotors and the stators separated by the air dielectric. At the lower right the rotor plates have been turned part way into mesh, and there is more capacitance than in the picture above. These pictures show the manner in which capacitance is varied in tuning capacitors and in adjustable types used for some other purposes.

CAPACITORS IN PARALLEL

When two or more capacitors are connected together in parallel, as in Fig. 13, their capacitances add together. At the right are capacitances of 1/2, 2, and 1/4 mfd which in parallel provide a total capacitance of 2 3/4 mfds. Were all five units connected in parallel, their combined capacitance would be equal to 4 3/4 mfds.

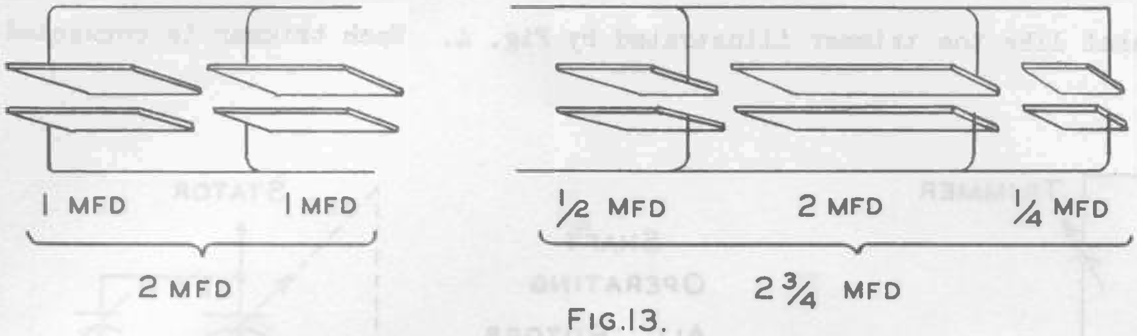

FIG.13.
Capacitances in parallel add their values.

Fig. 14 illustrates a large "ganged" tuning capacitor consisting of three separate capacitors whose three rotors are operated together by a single shaft.

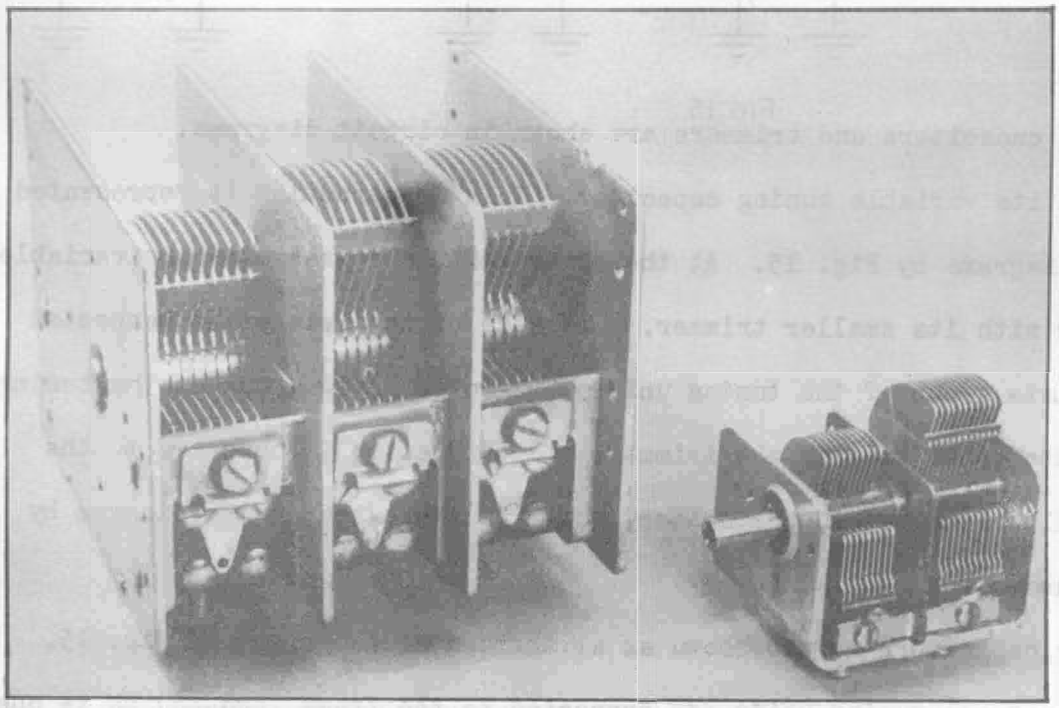

FIG. 14.
A three-gang tuning capacitor at the left, and a two-gang unit at the right.

Incidentally, although the left-hand unit in Fig. 14 is much larger than the one at the right, so far as each of the gangs is concerned, the capacitance per gang is about the same for both. This comes about because the plates of the large unit are much farther apart, or the dielectric is much thicker, than in the small unit. Also, in the smaller unit there is one more rotor and one more stator plate in each gang.

On each of the gangs in Fig. 14 are small screw-adjusted trimmer capacitors constructed somewhat like the trimmer illustrated by Fig. 4. Each trimmer is connected in parallel with its variable tuning capacitor. This construction is represented in the form of diagrams by Fig. 15. At the upper left is represented one variable tuning capacitor with its smaller trimmer. One side of the trimmer is connected to the stator plate group of the tuning unit. The rotor plate group of the tuning unit, and also the other side of the trimmer, are conductively connected to the supporting metallic frame of the capacitor, which is indicated in the diagram by symbols for ground.

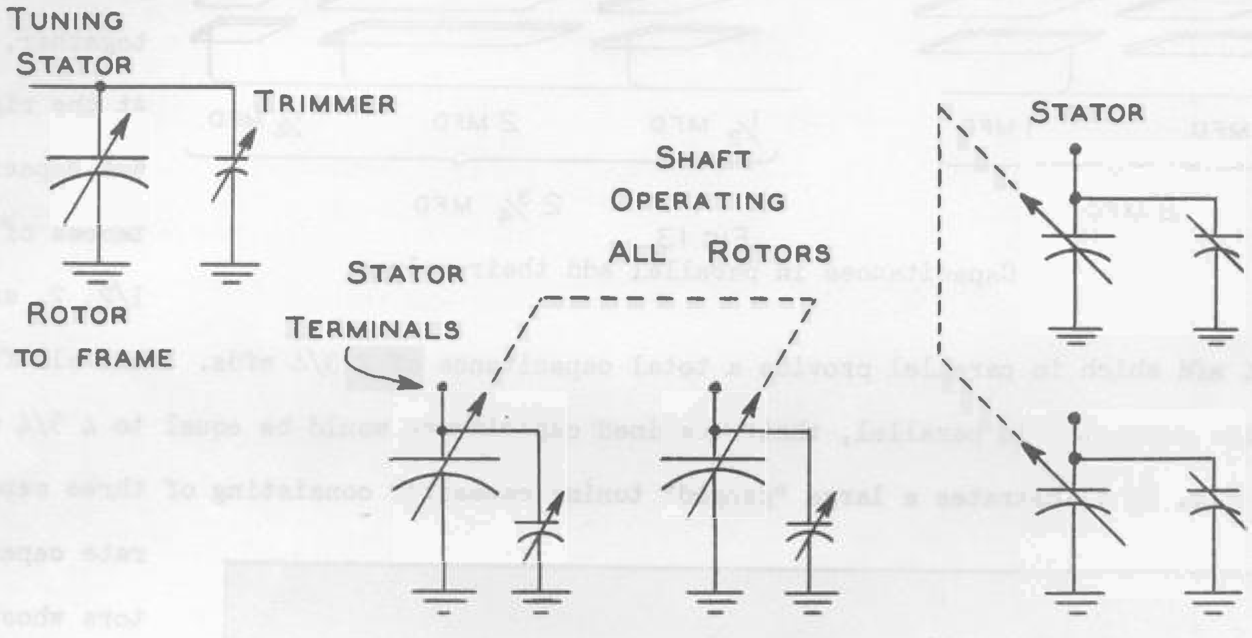

FIG.15.

How tuning capacitors and trimmers are shown in circuit diagrams.

Ganged tuning capacitors may be shown as at the center and right in Fig. 15. The rotor plates of all tuning units are connected to the frame (ground) as is one side of all the trimmers, and all of the rotors are operated together by a single shaft which is indicated by broken lines in diagrams. The stators of the tuning units are provided with individual terminals. The center and right-hand diagrams show two-gang tuning capacitors. For three or more gangs all of the arrows would be joined with broken lines to indicate the single control shafts.

With the tuning unit and its trimmer in parallel their capacitances add together. The trimmer is adjusted to make the total capacitance of the correct value when the parts are first assembled, and also when they are serviced later on, and this adjustment is not changed during operation of the tuning unit. It is only the capacitance of the tuning unit that is varied by turning the shaft.

CAPACITORS IN SERIES

At the left in Fig. 16 are represented two 50-mfd capacitors connected in series with each other and with a source furnishing a 200-volt potential difference. When the connections are first completed, the capacitors will charge. There will be electron flow from the negative terminal, A, of the source into plate B of one capacitor. We know that the excess charge (negative) on one plate of a capacitor must be equalled by the deficiency charge (positive) on the other plate of the same capacitor. Therefore, just as many electrons must leave plate C as enter plate B. All of the electrons that leave plate C must flow into plate D of the following capacitor, and as many electrons as enter plate D must leave plate E and return to the positive terminal, F, of the source. That such transfers of electrons in the capacitors must take place is evident from the fact that as many electrons must flow into the positive side of the source as leave the negative side.

Now we have equal charges on the two capacitors. The two capacitors have also equal capacitances. With equal charges in equal capacitances the potential differences across the two capacitances must be equal. The total potential difference across both capacitors is 200 volts, and if we have equal potential differences across both capacitors, the difference across each one must be 100 volts.

In the center diagram of Fig. 16 we show the 50-mfd capacitance and the 100-volt potential drop for each of the two capacitors. What is the charge, in coulombs, on each capacitor? Going back to our three capacitor formulas and using the one for charge with our known values of capacitance and voltage we have:

$$\text{Charge} = \frac{50 \times 100}{1{,}000{,}000} = \frac{5{,}000}{1{,}000{,}000} = 5/1000 \text{ or } 0.005 \text{ coulomb.}$$

This 5/1000 coulomb of electricity is the quantity that left one side of the source and entered the other side. It represents the total quantity of electricity moved in the circuit. Then the charge taken by the capacitors in series is 5/1000 coulomb.

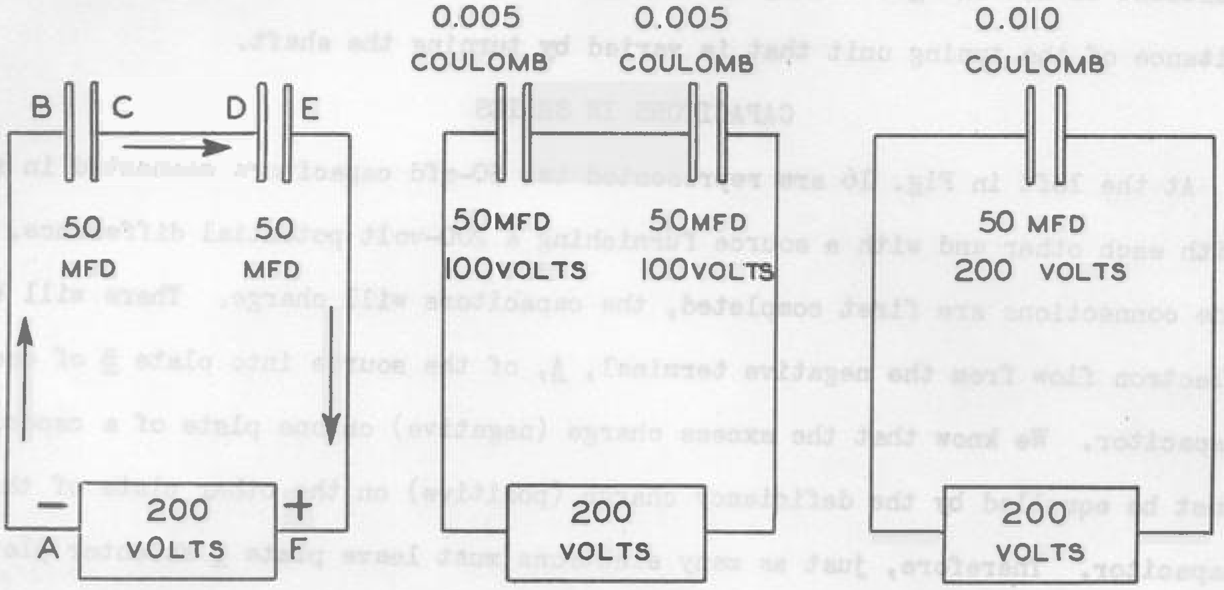

FIG. 16.

The capacitance of capacitors in series is less than the capacitance of any one of the units.

In the right-hand diagram of Fig. 16 one of the 50-mfd capacitors is connected across the 200-volt source. What is the charge given to the capacitor? Again using our formula, but with the new values of voltage and capacitance, we have:

$$\text{Charge} = \frac{50 \times 200}{1{,}000{,}000} = \frac{10{,}000}{1{,}000{,}000} = 10/1000 \text{ or } 0.010 \text{ coulomb}$$

And so we find that the one capacitor takes twice as much charge as the two of equal capacitance when they are in series. By working out any examples involving two or more than two equal capacitances in series we would arrive at this rule:

The capacitance of any number of equal capacitances connected in series is equal to one capacitance divided by the number of capacitances. For example, four 8-mfd capacitances in series would have a combined capacitance of 8/4 mfds or 2 mfds. This rule is decidedly similar to the one giving the combined resistance of resistances in parallel. The fact that we have similar rules for resistances in parallel and capacitances in series shows why, in the beginning, you should keep these important rules in a notebook rather than trusting entirely to memory. Until you have occasion to use the rules many, many times, it is better to be sure of the correct rule by referring to your notes. Later, if you feel certain that you know the rules, you may safely discard the notebook.

We had a rule for two equal or unequal resistances in parallel which may be applied to two unequal capacitances in series. Here is the rule for capacitances:

The capacitance of two equal or unequal capacitances in series is equal to the product of the separate capacitances divided by their sum.

Supposing that we have capacitances of 2 mfds and 4 mfds connected in series; this is the way to determine their combined capacitance:

$\frac{2 \times 4}{2 + 4} = \frac{8}{6} = 1\ 2/6$ or $1\ 1/3$ mfds.

If you have more than two unequal capacitances in series, you may use the method employed for more than two unequal resistances in parallel; that is, take two of the capacitances and figure out their series capacitance. Then take this series capacitance and use it with the capacitance of a third unit to find the series capacitance of the three units and so on for any number. You simply keep using the method of dividing products by sums.

The matter of capacitances in series is quite important in practical work. As an example, supposing that you require a capacitance of 2 mfds which may be subjected to 450 volts potential difference without breakdown of the dielectric, but you have on hand nothing but 6-mfd units rated for 160 volts. Looking back at Fig. 16 we observe that the overall potential difference divides equally between series capacitors which have equal capacitances. Then if you connect three of your 160-volt capacitors in series and apply an overall potential difference of 450 volts each capacitor will be subjected to only 1/3 of 450, or to 150 volts. Next, we have a rule that the combined capacitance of equal capacitances in series is equal to one capacitance divided by their number. Then the capacitances of three 6-mfd capacitors in series is equal to 6/3 or 2 mfds, just what we need to handle the present problem.

All of these rules which we are collecting are of the kind that many people call "theory". But if they are theory, they are, at the same time, highly practical. They are the rules that let good radio technicians get along with what they have in the laboratory rather than running to a supply store every day, and they are the rules that show us what may be done and what may not be done with safety. This matter of safety is well illustrated by another rule applying to capacitances or capacitors in series.

To see how this new rule works out, consider the three unequal capacitances connected in series, in Fig. 17, with a 500-volt source. First, we wish to determine the combined series capacitance. Using the rule of dividing the product by the sum, we find that the capacitance of 20 mfds and 5 mfds in series is 4 mfds.

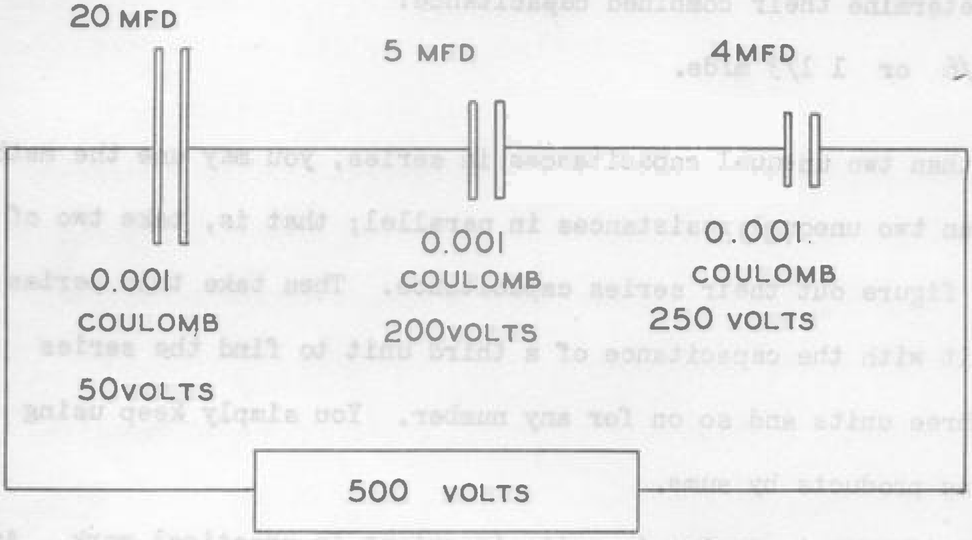

FIG.17.

The overall potential difference divides inversely as the capacitances.

Taking this combined capacitance in connection with the remaining 4-mfd capacitance, we use the rule that the capacitance of equal capacitances is equal to one capacitance divided by the number, and dividing 4 by 2 gives the overall capacitance as 2 mfds.

The total electron flow from the source, as the capacitors charge, will be that corresponding to 2 mfds and 500 volts. This will be the charge put into each capacitor. Using our formula for charge, with these known values, we have,

$$\text{Charge} = \frac{2 \times 500}{1{,}000{,}000} = \frac{1{,}000}{1{,}000{,}000} = 1/1000 \text{ or } 0.001 \text{ coulomb.}$$

Now we know the charge given to each capacitor (all three charges are equal), and we know the capacitance of each unit. Next, we use our formula for potential difference, wherein we multiply the coulombs by 1,000,000 and divide by the number of microfarads of each capacitor. Thus we learn that the potential difference across the 20-mfd unit is 50 volts, across the 5-mfd unit it is 200 volts, and across the 4-mfd unit it is 250 volts. The sum of these three potential differences is 500 volts, which is the total potential difference from the source.

The important point is this: When unequal capacitances are connected in series, the smallest capacitance is subjected to the greatest potential difference, and the largest capacitance is subjected to the least potential difference. To select capacitors having safe voltage ratings, you could make the computations, such as have just been used for Fig. 17. Or, if you are good at arithmetic, you can make use of the fact that the potential differences are inversely proportional to the capacitances, with the sum of the differences equal to the overall applied voltage. Or, you can make certain that the capacitor having least capacitance will withstand the total overall voltage — which often is the easiest and safest method to follow.

ELECTROLYTIC CAPACITORS

In all of the types of capacitors which have air, paper, mica, and other familiar materials for their dielectrics, it is impossible for current to flow in either direction through the capacitor. There is a distinctly different type of capacitor, much used in radio, wherein the dielectric prevents flow of all but a very small current in one direction, but wherein it is possible for a large flow to take place in the opposite direction. These are called electrolytic capacitors. Several such units are pictured in Fig. 18.

FIG. 18.
Various types of electrolytic capacitors.

A capacitor in which there may be current in one direction, but hardly any in the other, is entirely satisfactory where only a direct or one-way potential difference is applied. This is the condition found in filter circuits, where electron flow coming through the rectifier tube is always in one direction by the time it reaches the filter.

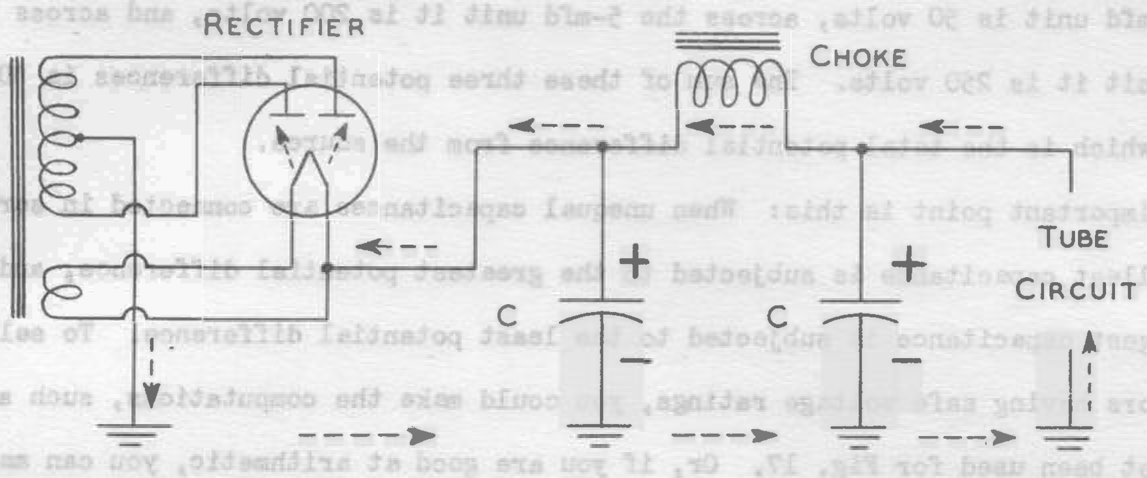

FIG.19.

Capacitors are used at positions marked "C" in a filter system.

Electrolytic capacitors are commonly used in filter circuits such as that of Fig. 19, where the two capacitors are shown on either side of the choke. The capacitors are so constructed that there can be practically no electron flow from their negative terminals to their positive terminals. The direction of electron flow in the remainder of the circuit is shown in the diagram by broken-line arrows. From the rectifier plates the flow goes through the winding of the power transformer and to ground, then through ground to the tube circuits, from the tube circuits back through the filter choke and to the filament-cathode of the rectifier tube. Practically none of this electron flow goes through the two filter capacitors, because to go through them the flow would have to be upward, negative to positive terminals of the capacitors, and there, there can be no appreciable flow in this direction. The potential differences in the circuit are in such polarities that there are no forces tending to send electrons through the capacitors from top to bottom, positive to negative.

The purpose of filter capacitors is to absorb peaks or pulses of electron flow coming from the rectifier as alternating potential is applied to the rectifier, then to give the absorbed electrons into the tube circuits between alternations of rectifier potential. Figs. 5 and 6 make this action quite clear. The capacitors permit electrons to flow into one of their plates, the negative plate, just as air flows into one side of the chambers separated by the diaphragm. Then, when the potential drops off between alternations of rectifier action, the electrons are forced back out of the negative plate of the capacitor, just as air would be forced back out of one of the air chambers. These electrons cannot go back through the rectifier, because electron flow in the rectifier can be only from cathode to plates, and so they go through the tube circuits. The filter capacitors act to smooth out the pulsating electron flow from the rectifier, and to make it a relatively even and unvarying flow in the tube circuits.

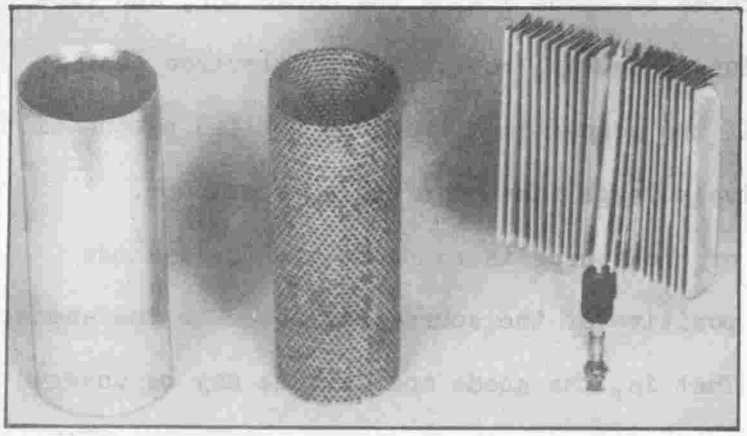

FIG.20.
The principal parts of a wet electrolytic capacitor.

The construction of one type of electrolytic capacitor is shown by Fig. 20. At the left is the cylindrical metallic can in which the parts of the capacitor are sealed. At the center is a perforated cylindrical separator, made of plastic insulating material, which fits around the inside of the can. At the right is the anode of the capacitor. Any anode is the electrode at which electron flow leaves the unit of which the anode is a part. Therefore, this anode is the "plate" of the capacitor which would be in the position marked "+" for positive in Fig. 19. The can itself is the cathode terminal in the particular style of capacitor pictured, and so the can would be the negative terminal and would be connected to ground and the negative side of the circuit in Fig. 19.

The anode is a thin sheet of aluminum, folded or corrugated so that it will go inside the separator. The can is filled, or nearly filled, with a conductive liquid which is called the electrolyte. An electrolyte commonly used in these capacitors consists of a solution of borax and boric acid in water. The terminal which you can see at the bottom of the anode in Fig. 20 extends through a rubber bushing to the outside of the lower end of the can, thus permitting external connections to be made to the anode.

After the capacitor is assembled during manufacture, a potential difference may be applied between anode and cathode, positive to the anode and negative to the cathode. At first there will be electron flow through the capacitor, but almost immediately there commences to be formed on the surface of the anode a very thin film of oxide which acts as the dielectric for the capacitor. Now there is high resistance to electron flow from cathode to anode inside the capacitor, and flow in this direction drops to a low value. However, resistance to electron flow in the opposite direction is low, and if the connections from the applied potential are reversed, there will be a relatively large flow from anode to cathode.

So long as the negative terminal of the source is connected to the cathode terminal of the capacitor, with the positive of the source connected to the anode, we have the action of a capacitor. That is, the anode and cathode may be charged like the plates of any other capacitor, and they will discharge. However, with the cathode charged negatively and the anode positively, there is some leakage or electron flow through the capacitor, and the two charges will soon neutralize each other. An electrolytic capacitor does not "hold a charge" for any length of time, because the dielectric is not an insulator, but is a conductor of very high resistance to flow of electrons in one direction. If connections from the source are reversed in polarity, and left so for any length of time, there will be a large electron flow through the capacitor. This flow will produce severe overheating of the internal elements, and the capacitor will be ruined in short order. Anodes of electrolytic capacitors are marked positive, or cathodes are marked negative, or both are marked, so that you may make correct circuit connections. When there is only a single insulated external terminal, it is for the anode, and the can is the cathode terminal.

The construction illustrated by Fig. 20 is that for one style of "wet" electrolytic capacitor, so called because the electrolyte is a free-flowing liquid inside of a can. We have also "dry" electrolytic capacitors, in which the electrolyte liquid is held absorbed by some kind of porous material. While wet electrolytics and some of the dry types are provided with metallic cans, many dry electrolytics are housed in tubular or rectangular cardboard cases which are wax-impregnated for moisture-proofing and with which space between the case the capacitor is filled with some semi-rigid insulating compound poured into place while it is melted.

The parts of one style of dry electrolytic capacitor are pictured by Fig. 21, where the assembly has been partially unrolled. Extending out toward the left is a paper-like fibrous gauze. Then comes the anode element, which is a sheet of pure aluminum. Next, there is another layer of gauze, and finally, extending toward the right, is a thin sheet of aluminum which acts as the cathode terminal. The cathode of all types of electrolytics is the electrolyte, which is on one side of the dielectric film whose other side is on the anode metal. When the electrolyte is in direct contact with an external can, as in the construction of Fig. 20, the can acts as the cathode terminal. The can is not the cathode. In the construction of Fig. 21 the electrolyte is held in the gauze. When the assembly is rolled up, we have the anode with dielectric films on both sides, and against both of these films is a layer of gauze. On the other sides of the gauze layers is the thin aluminum which acts as the cathode connection, because it is in contact with the electrolyte, which is the true cathode.

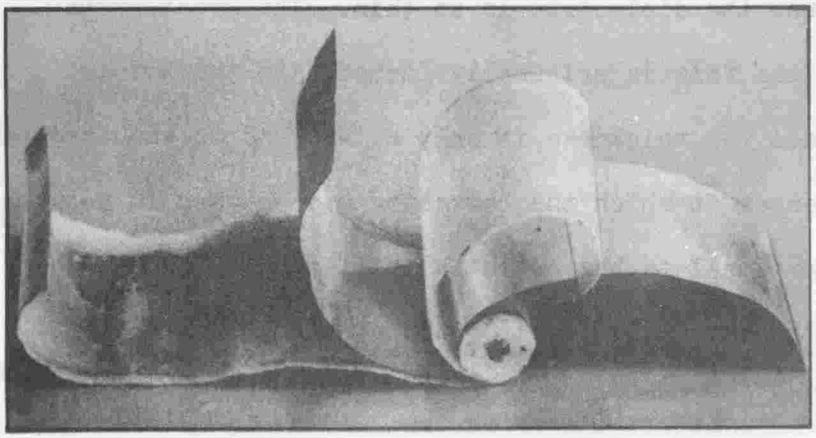

FIG. 21.
The anode, the electrolyte-absorbing gauze, and the cathode connection sheet of a dry electrolytic capacitor.

When the assembly of Fig. 21 is rolled up, connection leads are attached to the anode and to the cathode, with these leads brought through the case or else riveted to wire pigtail connections which extend out of the case.

There are numerous other constructions for dry electrolytics. In one style the electrolyte is absorbed into a paste which fills the openings of an open mesh fabric which looks somewhat like coarse cheese cloth. This fabric holds the paste in position between the anode and cathode-terminal sheets.

The capacitances of electrolytic capacitors are great as related to the dimensions of the units. This is because the dielectric is so thin. The greater the potential difference applied when the film is originally formed, the thicker is the dielectric film, but in any case the thickness is only a few hundred-thousandths of an inch. The potential differences at which the capacitor may be used in service, called working voltages, are proportional to the potential differences applied when forming the film. With the thicker dielectric for use at higher working voltages it becomes necessary to provide greater anode areas for a given capacitance, and this means longer or wider anode sheets. Thus a high-voltage electrolytic of given capacitance is larger than one for use at lower voltages.

In addition to having a "working voltage" rating, electrolytic capacitors usually have also a somewhat higher "surge voltage" rating. The working voltage is the maximum d-c potential difference which may be applied continuously, with normal surrounding temperatures. The surge voltage is the maximum potential difference which the capacitor will withstand momentarily, but which would ruin it if continued.

Electrolytic capacitors are available with one, two, three, or more units in a single can or case. The large capacitor in the upper center of Fig. 18 contains three units. The small, cylindrical, dark-colored capacitor contains two units. The others contain one unit each. The capacitances of the several units in a case may be alike or may be different. Several capacitances may be provided by placing several completely insulated capacitors in the one housing, or they may be provided by using a single long cathode connection sheet with separate anode sheets along its length, or they may be provided by using a single long anode with separate cathode sheets along the length.