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HOME RADIO HOME STUDY

RADIO SERVICE FUNDAMENTALS

LESSON IV

CAPACITANCE AND CAPACITIVE REACTANCE

RADIO SERVICE FUNDAMENTALS
LESSON IV
PR-2493-4

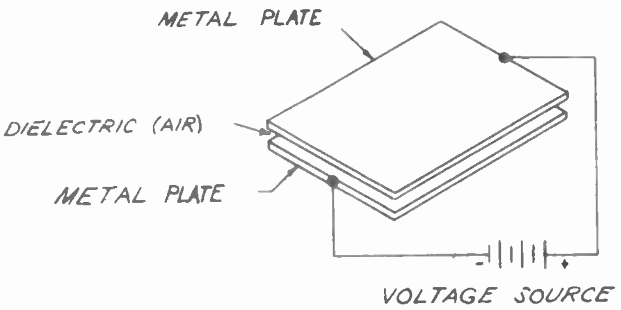

Figure 1. Basic Type of Capacitor Using Air Dielectric

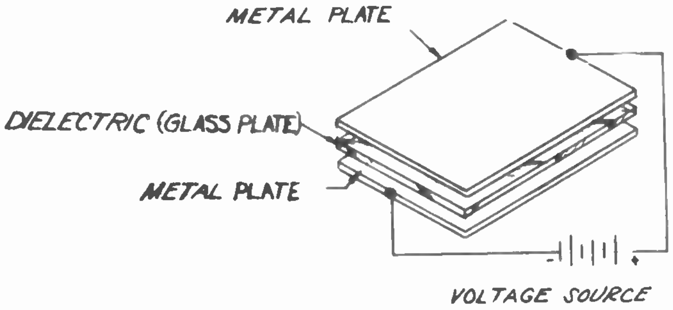

Figure 2. Basic Type of Capacitor Using Glass Dielectric

INTRODUCTION

1. The three fundamental properties which exist in every electrical circuit are resistance, inductance, and capacitance. Two of these properties, resistance and inductance, have been studied in previous lessons. This lesson will therefore be devoted to the study of the third basic property of electrical circuits, capacitance.

THE CAPACITOR

2. As stated above, capacitance exists in every electrical circuit. In some instances the presence of capacitance is highly undesirable, and numerous methods are employed to minimize it, but it can never be completely eliminated. On the other hand, there are numerous occasions where capacitance performs a highly important function, and its presence is essential to the proper performance of a circuit. In these cases an electrical device called a capacitor is used to obtain the desired amount of capacitance.

3. A basic type of capacitor is illustrated in figure 1. Such a capacitor consists of two metal surfaces or plates which are separated by an insulator. This insulator, more often called the *dielectric,* consists of air, as in figure 1, or a thin sheet of insulating material. A basic type of capacitor using glass as the dielectric is shown in figure 2. Capacitors are capable of storing an electric charge when a voltage is applied to their terminals, the actual amount of the charge which may be stored in a given capacitor being determined by the total area of the plates, the thickness and type of dielectric used, and the value of the applied voltage.

CAPACITOR ACTION

4. In their normal or uncharged state, the conductors in a capacitor are in a condition of electrical balance. That is, there is neither an excess nor a deficiency of electrons on either conductor. However, when a potential is applied across a capacitor, this will cause a difference of potential to exist between the two conductors; this difference of potential acts to establish an excess of electrons on one side of the capacitor and a deficiency on the opposite side. If the applied potential is then disconnected, the capacitor is left in a charged condition, since the presence of the dielectric prevents the electrons from re-establishing the original state of electrical balance between the conductors. The conductor having a deficiency of electrons is left with a positive charge, and the other conductor, having an excess of electrons, is negatively charged. However, the conductors not only act as storage places for the collection of electrons, but the charges thereby accumulated also result in the application of electric lines of force, or an *electrostatic field,* to the dielectric. This field, which acts upon the capacitor's dielectric, as illustrated in figure 3, plays a very important part in the action of the capacitor.

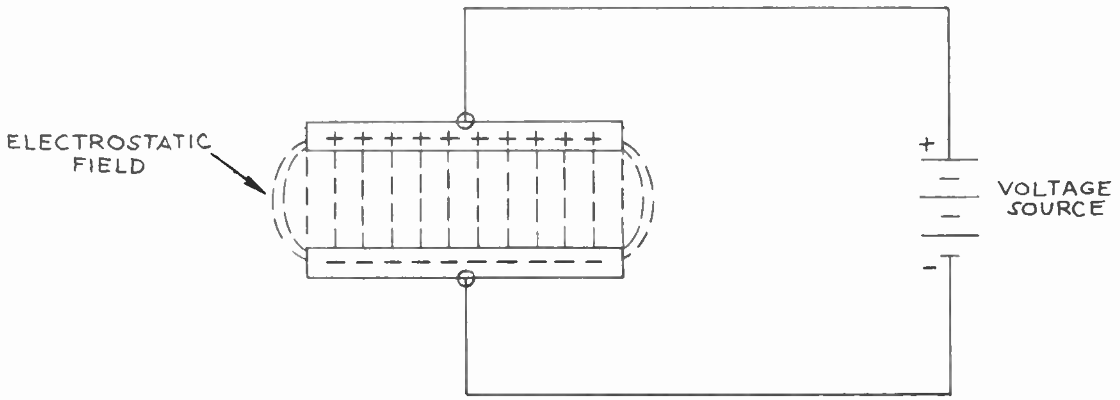

Figure 3. Electrostatic Field in a Capacitor

THE ELECTROSTATIC FIELD

5. In order to understand what is meant by an electrostatic field, and the important part which the dielectric plays in the action of a capacitor, it is necessary to reconsider some basic concepts which were discussed in the lesson on electron theory. In this earlier lesson it was learned that in a conductor, the atoms have their outer electrons loosely bound to the nuclei, so that these electrons are quite easily dislodged by the application of a difference of potential. It is the motion of these loosely bound electrons from one orbit to another, under the influence of an applied e.m.f., which constitutes a flow of current. On the other hand, in an insulator the electrons are tightly bound to their nuclei, and are very difficult to dislodge from their orbits. The higher the potential required to dislodge electrons, the better the insulator. Since the dielectric of a capacitor is usually an excellent insulator, there will be no current flow through the dielectric when an e.m.f. is applied to the conductors. However, as previously mentioned, when an e.m.f. is applied to the capacitor there will be a flow of electrons from one plate around through the external circuit to the other plate. This causes a deficiency of electrons on one side of the capacitor and an excess on the other. The accumulation of electrons on one plate builds up a negative charge on it which exerts a repelling force on the electrons of the atoms within the dielectric. At the same time, the deficiency of electrons, or positive charge, on the opposite plate of the capacitor exerts a strong force of attraction on the electrons of the dielectric. The combined forces of repulsion and attraction acting upon the dielectric of a capacitor is called an *electrostatic* force or field.

6. Because the electrons of the atoms comprising the dielectric are tightly bound to their nuclei, they cannot, under the stress exerted by the electrostatic field, break out of their orbits and cause a flow of current. However, as a result of the force exerted by the electrostatic field, the orbits of the electrons are distorted. The greater the value of the applied voltage, the greater will be the forces tending to distort the electron orbits.

7. The condition which exists in a capacitor before an e.m.f. is applied is shown in figure 4. Each of the conductors contains its regular number of electrons, while the electrons of the atoms in the dielectric continue to rotate in their normal orbits around the nuclei.

8. A different condition exists in a capacitor when a d-c potential is applied. Under the influence of the applied voltage, the electrons flow from one side of the capacitor around to the other, leaving one plate with a deficiency and the other plate with an excess of electrons. Because of the strong repelling effect of the negative charge on one side of the capacitor and the strong pulling effect of the positive charge on the opposite plate, the electrons within the dielectric, while still holding onto their individual atoms, have their orbits distorted under the stress, as shown in figure 5. But because of this distortion of their orbits, some of the electrons in the dielectric are brought closer to the plate having the positive charge, thus adding considerably to the repelling force on the negative plate and forcing many more electrons off the positive plate and around through the external circuit and on to the negative plate. If, after all possible electrons have been forced around to the negative plate, the applied e.m.f. is disconnected, the stresses which have been set up will remain and the capacitor is "charged." This charge represents stored electrical energy.

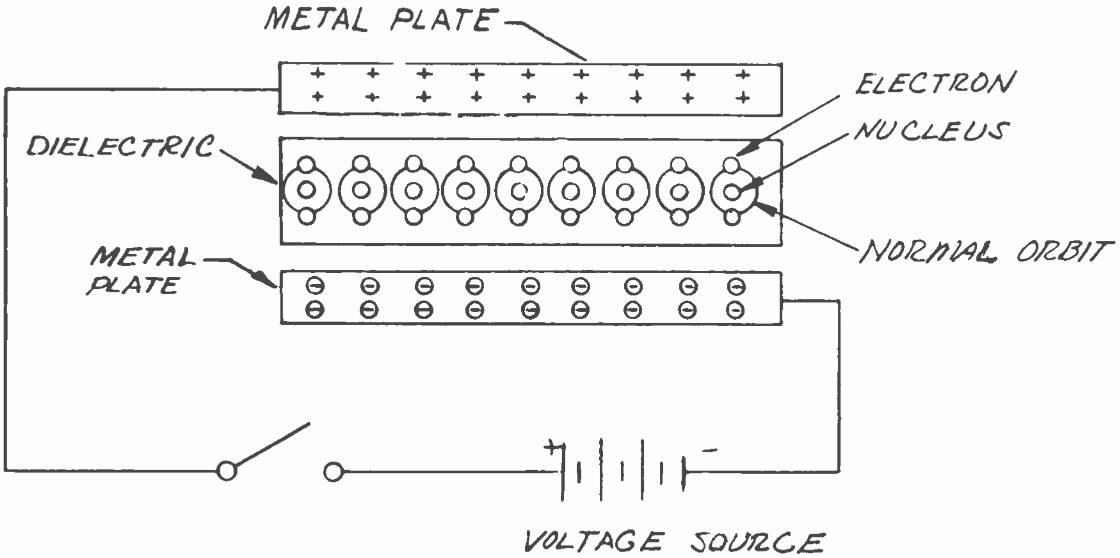

Figure 4. Normal Orbits of Electrons in Dielectric of Uncharged Capacitor

9. If the capacitor terminals are shorted together after the capacitor has been given a charge, the electrons on the negative plate will then flow back to the positive plate, until the normal state of electrical balance is restored.

10. The condition which exists when an alternating e.m.f. is applied to a capacitor is shown in figure 6. Electrons will flow through the external circuit from one plate to the other during one half of the cycle, then reverse and flow in the opposite direction on the next half-cycle. This action is repeated over and over with each alternation of the applied e.m.f., thereby producing an alternating flow of current in the external circuit between the plates, without any transfer of electrons through the dielectric itself. When such an alternating e.m.f. is applied to a capacitor, the rapidly reversing electrostatic field will result in a steady straining of the electrons in the dielectric and a distortion of their orbits in both directions, as shown in the illustration.

UNIT OF CAPACITANCE—THE FARAD

11. Capacitance, like all electrical quantities, requires a unit by which it can be measured. It has previously been mentioned that the quantity of electrons or electric charges which can be stored in a given capacitor is dependent not only upon the total conductor area and the nature of the dielectric, but also upon the value of the applied e.m.f. One farad is that capacitance which has a potential of one volt when one caulomb (6.28×10^{18} electrons) is stored.

12. Since the farad is an impractically large quantity for most uses, much smaller sub-units, the microfarad (μf.) which is equal to one-millionth farad, and the micromicrofarad ($\mu\mu$f.), equal to one millionth-millionth of a farad, are used in most practical applications.

DIELECTRIC CONSTANT

13. It has been previously stated that the amount of charge which may be stored in a capacitor is greatly dependent upon the type of dielectric employed. In order to provide a means of comparison for the many types of dielectric materials suitable for use in capacitors, air has been taken as the standard, and has been given the arbitrary value of 1. The ratio of the capacitance of a given size capacitor employing a particular dielectric, to the capacitance which the same capacitor would have if air were the dielectric is called the *dielectric constant*, or K, of the dielectric.

14. It is the number of electrons which can be distorted in their orbits under the influence of the electrostatic field that determines the K of a given dielectric. Since the various dielectric materials have different atomic structures, each type of material will affect the capacitance differently when used as a dielectric.

DIELECTRIC LEAKAGE

15. So far it has been assumed that the dielectric material used in capacitors is a perfect insulator. In practice, however, this is not true, since all dielectric materials will conduct slightly. Such conduction through the dielectric effectively is a loss of charge, since it permits electrons to go directly from the negative plate to the positive one. Although the conduction in most dielectrics is rather slight, even a small amount will act to weaken the electrostatic field. Such a loss of energy is called leakage. Theoretically, there would be not limit to the length of time a capacitor could remain in a charged condition if there were no dielectric leakage. In practice however, capacitors using even the best of dielectrics will lose their charge within a relatively short time.

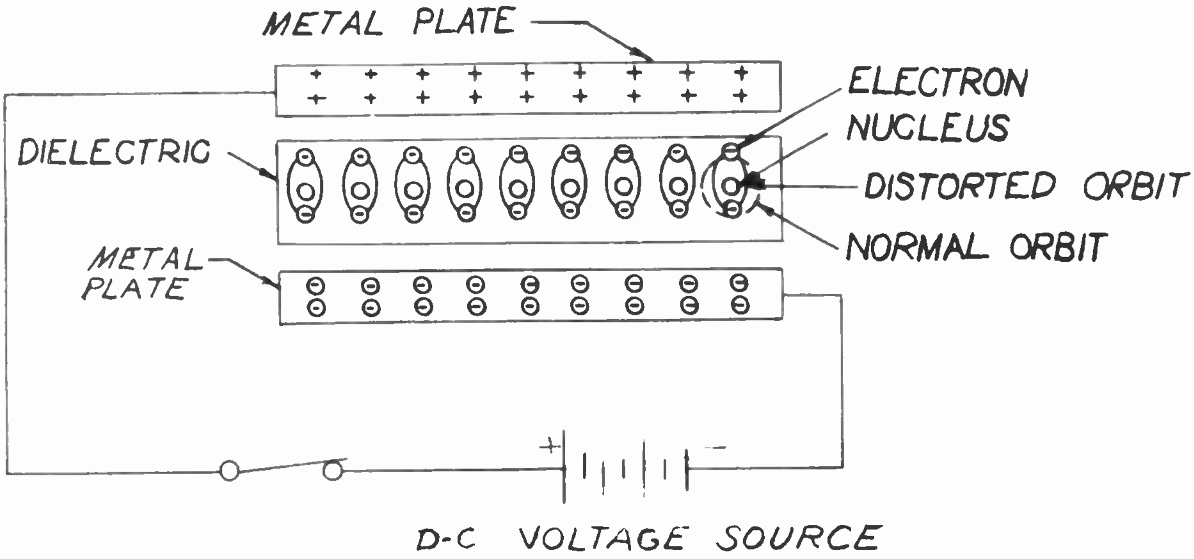

Figure 5. Distortion of Electron Orbits in Capacitor Dielectric Under Influence of D-C Applied Voltage

BREAKDOWN VOLTAGE

16. It has previously been shown how the orbits of the electrons in a dielectric are distorted under the stresses of the electrostatic field. The higher the value of the potential impresed upon the capacitor, the greater will be the stress to which the dielectric is subjected and the greater the charge which can be accumulated. There is a limit, however, beyond which this straining cannot be carried. For every dielectric there is some value of voltage which places such a severe strain upon the dielectric that the electrons can no longer be held in their orbits. When the voltage is increased beyond this point the electrons are torn from their orbits, the insulating properties of the dielectric are destroyed, and a conducting path is formed between the capacitor plates. The heavy current which flows as a result of this rupture of the dielectric is usually sufficient to wreck the capacitor. The value of the e.m.f. at which the dielectric ruptures is called the *breakdown voltage*.

17. Although it is the value of the applied potential which primarily determines the point at which a given dielectric will rupture, time is also a frequent factor in capacitor breakdown. Thus, for example, a capacitor which might operate satisfactorily for a minute or two when subjected to an excessive voltage, would be more than likely to break down if subjected to the same excessive voltage for a longer period.

18. Since every dielectric will have a different breakdown voltage, the value of which is dependent largely upon the structure of the material, practically all capacitors have markings which, in addition to indicating the capacitance, also show the value of the potential which may safely be applied to the capacitor for an indefinite period. This value is ordinarily given in terms of what is known as the "d-c working voltage" (d.c.w.v.); that is, the highest d-c voltage which may be applied steadily to the capacitor without harm.

19. In a circuit carrying a pure direct current, a capacitor can be subjected to the full value of the d-c working voltage for which it is rated. However, in a circuit through which an alternating current is flowing, a different situation exists. In an a-c circuit the voltage rises from zero to its *peak* value twice in every cycle. Because the peak value of a sine-wave alternating current is 1.41 times its *effective* value (the d-c voltage equivalent), a capacitor to be used in a-c applications must be selected on the basis of the peak value of the a-c voltage to which it will be subjected, rather than the effective value (which would be indicated on an a-c voltmeter) or the d.c.w.v. rating.

CAPACITOR TYPES

20. In order to meet the varied requirements of innumerable applications in the electrical and electronic fields, capacitors are made in many types, depending upon the required capacitance, breakdown voltage, etc. All of these forms, however, may be grouped into two general classifications, fixed capacitors and variable capacitors.

21. Fixed capacitors have a fixed value of capacitance, and most of the capacitors used in electrical work are of this type. A great many forms of construction are used, depending largely upon the required safe voltage rating and the amount of leakage permissible in the dielectric. Capacitors having a fixed value of capacitance are usually rated in accordance with the type of dielectric employed. The principal types of fixed capacitors are mica capacitors, paper capacitors, and electrolytic capacitors. In addition, various other types such as ceramic and oil-dielectric capacitors are in common use.

22. Mica capacitors are employed in those circuits where very low leakage is a very important requirement. While mica is one of the best types of dielectric material available, it is also relatively expensive;

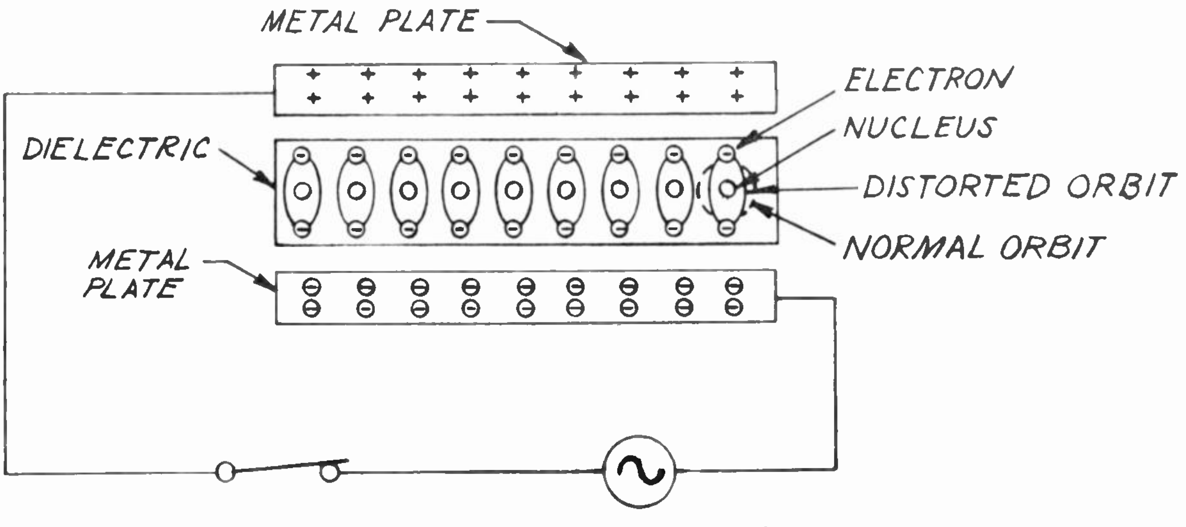

Figure 6. Distortion of Electron Orbits in Capacitor Dielectric Under Influence of A-C Applied Voltage

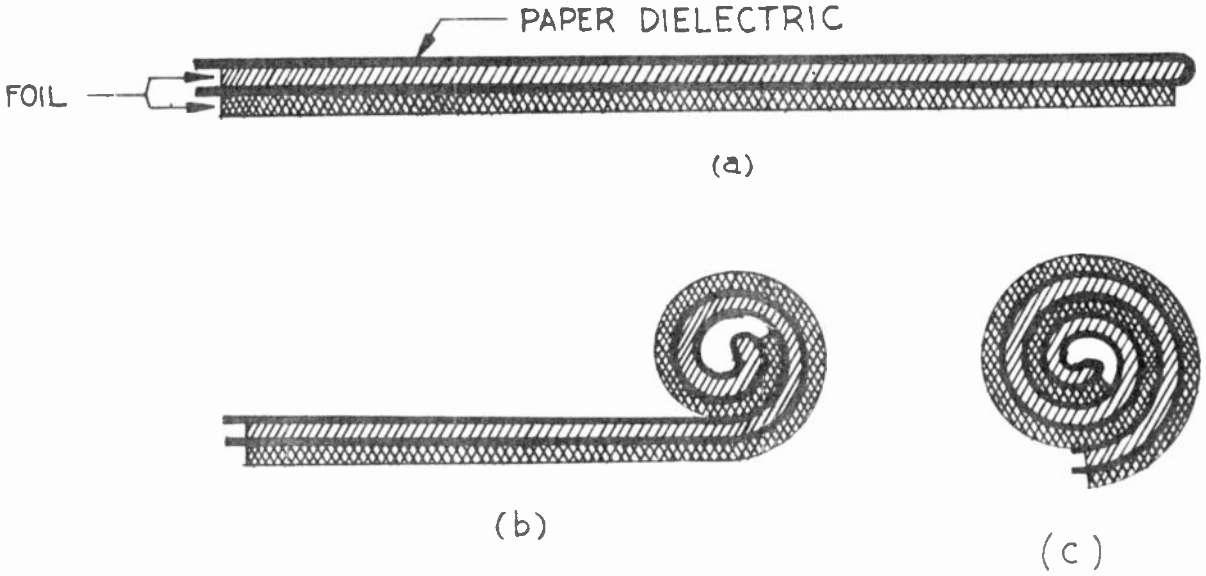

Figure 7. Internal Construction of Paper-Dielectric Capacitor

hence the use of mica capacitors is confined mainly to applications where less expensive types are unsuitable. Mica capacitors seldom are made in capacitance values greater than .05 μf., but generally have higher voltage ratings than other types.

23. Paper capacitors are made of thin metal foil and a dielectric of a special type of paper, tightly rolled together and impregnated with various special compounds to exclude moisture. This form of construction is illustrated in figure 7. Paper capacitors are very extensively used in the electronics field, because they are smaller for a given capacitance value and less expensive than the type using mica dielectric. But, since they have higher losses than the mica type, their most frequent application is in circuits where extremely low leakage is not of primary importance.

24. In the electrolytic type of capacitor, the dielectric consists of an extremely thin film of oxide which is formed on one of the surfaces by an electrochemical process. See figure 8. When a capacitor made of certain metals, such as aluminum, is immersed in a solution called an electrolyte, which permits the flow of an electric current, and a source of d-c voltage is connected to the capacitor terminals, the temporary passage of current results in a nonconducting film being formed on the positive plate of the capacitor. The effect therefore is to cause the electrolyte itself to act as the negative surface of the capacitor, separated from the positive capacitor surface by the extremely thin film of dielectric. Because of the extreme thinness of this insulating film, or dielectric, the electrolytic-type capacitor provides very high values of capacitance in a small physical size. However, because the insulating film is not as good an insulator as mica, paper, etc., the leakage current of an electrolytic capacitor is considerably more than that of other types. Hence electrolytic capacitors are most frequently used in those applications where such leakage can be tolerated, such as in radio receiver power supplies, etc.

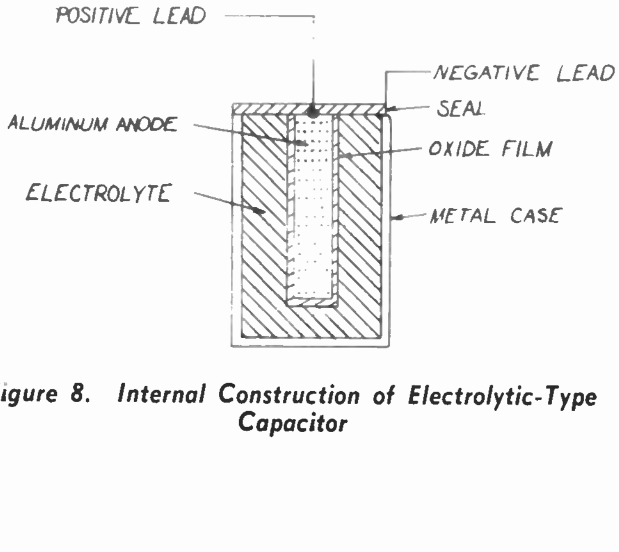

Figure 8. Internal Construction of Electrolytic-Type Capacitor

25. Electrolytic capacitors are polarized; that is, they must be connected to the d-c source in the same polarity as that which was used when the film was initially formed. Since the film acts as a non-conductor in only one direction, if the capacitor is connected incorrectly, the heavy flow of current which will result will ruin the capacitor.

26. Variable capacitors, which practically always use air as the dielectric, find their greatest application in the tuning circuits of radio receivers and transmitters. Most capacitors of this type consist of a number of stationary (stator) plates which are arranged in a manner which permits another group of plates (rotor) to be turned on a shaft and to mesh with the first set of plates without touching. This is

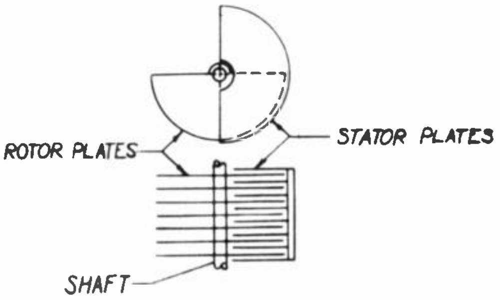

Figure 9. Construction of Variable Capacitor

illustrated in figure 9. The air spaces between the two sets of plates act as the dielectric. When both sets of plates are completely meshed, maximum capacitance is obtained. When they are fully unmeshed, minimum capacitance exists. By rotating the capacitor shaft, more or less of the plate areas are exposed to each other, so that any intermediate value of capacitance between maximum and minimum can be obtained. By properly designing the shape of the rotor plates, any desired rate of change of capacitance per degree of shaft rotation necessary for a particular application can be obtained.

27. The breakdown voltage of variable capacitors depends mainly on the spacing between the two sets of plates. For high-voltage applications, such as in radio transmitters, the spacing of the capacitor plates is considerably greater than, for example, in an ordinary home radio. Of course, the greater the spacing between plates the less capacitance the capacitor will have for a given number of plates. Hence, in a wide-spaced variable capacitor it is necessary to use more plates or a larger plate area to obtain a given capacitance.

CAPACITORS IN PARALLEL

28. Two capacitors connected in parallel are shown in figure 10. It can be seen that both upper plates are connected together, as are both of the lower plates. Since both capacitors are connected across the same voltage source, the two capacitors will charge up until the stored potential in each is equal to the applied voltage.

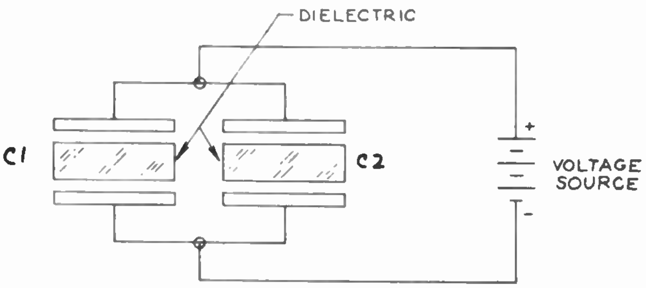

Figure 10. Parallel Connection of Capacitors

29. Assuming that the two capacitors have the same plate area, dielectric, etc., the effect of connecting them in parallel is to double the capacitance, since the plate area has effectively been doubled. In other words, any number of capacitors may be connected in parallel to give an effective capacitance value equal to the sum of all of the capacitance values. Thus for example, if a .0005 μf., a .001 μf., and a .01 μf. capacitor were connected in parallel, the total capacitance of the combination would be .0115 μf.

30. If a number of capacitors having dissimilar voltage ratings are connected in parallel, the maximum voltage which may be applied to the combination is limited by the safe working voltage rating of the capacitor which has the lowest voltage rating.

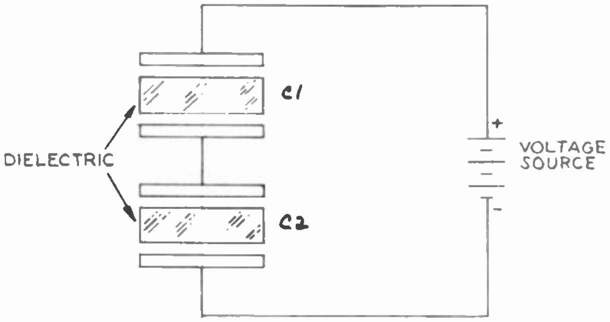

Figure 11. Series Connection of Capacitors

CAPACITORS IN SERIES

31. In figure 11 two capacitors are shown connected in series. In this method of connection the two outside plates are connected across the applied voltage, with the two inner plates connected to each other. This procedure effectively acts to increase the thickness of the dielectric; therefore the resultant capacitance of the combination is decreased, while at the same time, the safe working voltage that may be applied to the combination is increased. In other words, combining capacitors in series serves to reduce the capacitance, and makes the combination able to safely withstand higher voltages without breaking down. The total capacitance of capacitors connected in series *will always be less* than the value of the smallest capacitor in the group. The total capacitance of a number of capacitors in series can be determined from the formula

$$C_{Total} = \cfrac{1}{\cfrac{1}{C_1} + \cfrac{1}{C_2} + \cfrac{1}{C_3} \quad \ldots}$$

Thus, for example, if three .01-μf., 400 d.c.w.v., capacitors are connected in series, the resultant capacitance will be: $\cfrac{1}{\cfrac{1}{.01} + \cfrac{1}{.01} + \cfrac{1}{.01}} = \cfrac{1}{\cfrac{3}{.01}} = .0033\ \mu f.$

In the particular case where only two capacitors are connected in series, the formula may be simplified as follows:

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

32. When capacitors of the same type and of equal capacitance are connected in series, the voltage which is impressed across the combination will divide equally across each of the capacitors. Thus, in the example previously given, where three 400 d.c.w.v. capacitors were connected in series, the combination would have an effective rating of 1200 d.c.w.v. When the capacitors connected in series are not of the same type and capacitance, variations in insulation resistance, etc., will affect the voltage distributions across the individual capacitors, complicating the calculation of the safe working voltage of the combination. In practice, resistors of high value, connected across each of the capacitors, will assist somewhat in equalizing the voltage distribution.

PHASE RELATIONSHIP OF VOLTAGE AND CURRENT IN A CAPACITIVE CIRCUIT

33. The relationship that exists between the voltage and current in a capacitor which is connected to a source of a-c voltage is illustrated in figure 12. This figure shows the condition for each quarter of one cycle. The voltage across the capacitor is represented by the solid line, while the dotted line represents the current. The zero, or reference point for both the voltage and current is the line running through the center. The time of the cycle in terms of electrical degrees is marked off on the bottom line.

34. At the beginning of the first quarter-cycle (0° to 90°), figure 12 (a), the voltage is just starting from zero and moving in a positive direction. At the same time, because the voltage is now changing at its greatest rate, and because there is nothing to oppose the electrons which are moving off one plate and onto the opposite plate of the capacitor, the flow of current is at a maximum. As the voltage continues to increase, however, more and more electrons are accumulated on the negative plate, building up an increasingly greater negative charge, which exerts an opposition to the electrons that are being forced in by the now more slowly rising voltage. The closer the voltage approaches to its maximum value, the smaller its rate of change becomes, and the more the flow of current is decreased by the heavy charge already on the capacitor. When the voltage finally reaches its maximum value at 90°, the applied e.m.f. and the charge on the capacitor are equal, and there is no further movement of electrons from one capacitor plate to the other. The current at 90° is therefore zero.

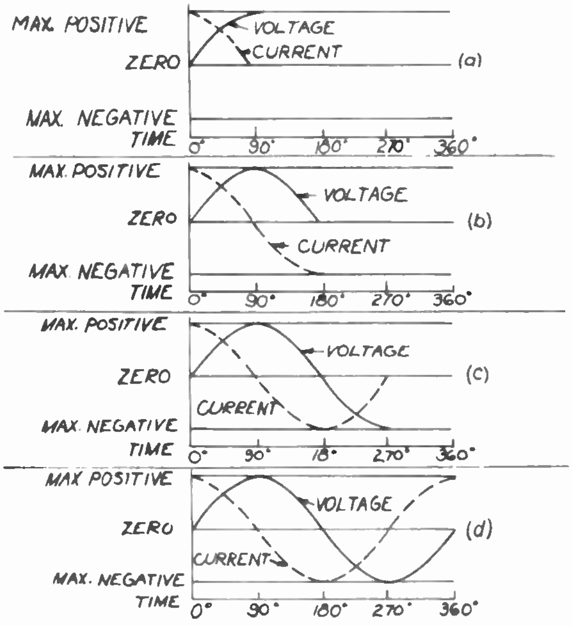

Figure 12. Phase Relationship Between Voltage and Current in a Capacitive Circuit

35. At the start of the second quarter-cycle (90° to 180°), figure 12 (b), the alternating voltage, which had previously been increasing in the positive direction, begins to decrease. Although it has not changed in polarity and is still a positive voltage, to the capacitor the decrease in voltage means that the plate which previously had an excess of electrons must now begin to lose some of them. The current therefore reverses and starts flowing in the opposite (negative current) direction. At 180° the impressed voltage has again fallen to its minimum value and the current has risen to a maximum.

36. Just after 180° the voltage reverses polarity and starts building up to its maximum negative value. During this third quarter-cycle (180° to 270°), figure 12 (c), the rate of voltage change again gradually diminishes as the capacitor builds up to its maximum charge at 270°. At this point, because the capacitor is once more fully charged, there is no further movement of electrons, and the current is zero. Thus, the conditions are exactly the same as at the end of the first quarter-cycle, but the polarity is reversed.

37. After 270° has been passed, the impressed voltage once again starts to decrease, and the capacitor must begin losing the electrons it has accumulated. Starting at a minimum rate of flow and rising to a maximum, the discharging action continues through the final quarter-cycle (270° to 360°), figure 12 (d), until the impressed voltage has dropped to zero. After 360° has been reached the entire cycle begins all over again.

38. From an examination of the curves in figure 12 it can easily be seen that, because of the charging and discharging action, the current in a capacitive circuit always arrives at a given point in the cycle 90 degrees ahead of the voltage. The time and place relationship between the voltage and the current in a capacitive (or inductive) circuit is called the *phase relationship.* The voltage-current relationship in a capacitive circuit is exactly opposite that in an inductive circuit. *The voltage across a capacitor leads the current through the capacitor by 90°*

CAPACITIVE REACTANCE

39. In the preceding study of the phase relationships in a capacitive circuit, it was shown how a capacitor offers a very real opposition to the flow of current. This opposition, which is known as *capacitive reactance* (X_c), is greatly dependent upon the actual value of the capacitance. This is because the capacitance, or storage ability, determines the number of electrons, or amount of current, which can flow from one plate onto the other. As the capacitance is increased, a greater number of electrons change plates every cycle, and (since current is a measure of the number of electrons which pass a given point in a given period of time) the current is increased.

40. The frequency, that is, the number of alternations which occur in one second, also plays a very important part in determining the reactance which a given capacitor will offer. For example, an increase in frequency will decrease the opposition offered by a capacitor, because the number of electrons which the capacitor can handle will flow through the external circuit more often in a given period of time: hence, there is greater current flow.

41. From the above it can be seen that the opposition which a capacitor offers to an alternating current is inversely proportional to frequency and to capacitance. In other words, capacitive reactance decreases as frequency increases, and also (for a given frequency) decreases as capacitance increases. The formula for capacitive reactance is therefore as follows:

$$X_c = \frac{1}{2\pi fc}$$

where:

X_c = capacitive reactance, in ohms
f = frequency, in cycles per second
c = capacitance, in farads
$2\pi = 2 \times 3.1416$, or 6.28

EXPERIMENT NO. 1

OBJECTIVE

To determine capacitor values.

MATERIAL REQUIRED

1. Two paper-dielectric capacitors. These may be of the type used in radio receivers, and should have a rating of about 400 d.c.w.v. Each should also have a different value of capacitance; for example, .25 μf. and .1μf.

2. Resistor rated at 1 watt or more, and having a resistance value of 500 ohms.

3. A-C voltmeter having ranges of about 10 volts full scale and 150 volts full scale (or a multimeter set to similar a-c ranges).

4. 110—125-volt, 60-cycle, a-c source.

PROCEDURE

1. Connect one capacitor, the a-c voltmeter (set to the 10-volt range), and the resistor as shown in figure 13 (a).

2. Insert the power-cord plug into the a-c receptacle. Then read and record the value indicated on the a-c voltmeter.

3. Using Ohm's law, determine the current through the resistor ($I = \frac{E}{R}$). Record this value.

4. Remove the power-cord plug from the a-c receptacle. Then disconnect the a-c voltmeter from the resistor, set it to the 150-volt a-c range, and connect it across the capacitor as shown in figure 13 (b).

5. Insert the power-cord plug into the a-c receptacle. Then read and record the value indicated on the a-c voltmeter. Remove the power-cord plug from the a-c receptacle.

6. It has been previously observed that the current is equal in all parts of a series circuit. Therefore, since the capacitor and the resistor are connected in series, the same amount of current flowing through the resistor will also flow in the capacitor. Knowing the voltage appearing across the capacitor and the current flowing in it, use the formula $X_c = \frac{E}{I}$ to

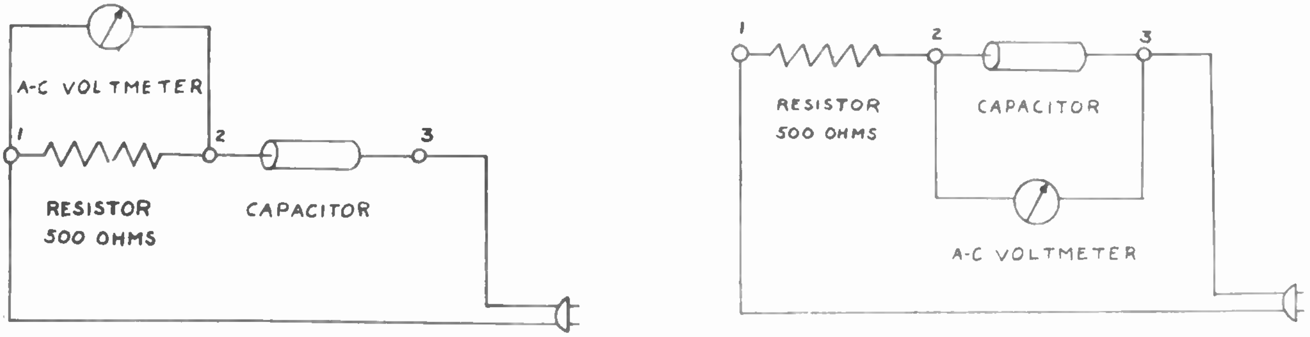

Figure 13. Experiment No. 1

determine the capacitive reactance. Record the value obtained. The resistor has very little effect upon the total current flowing in the circuit, because its value is so small in comparison with the total impedance of the circuit that its effect can be ingnored. Consequently, the capacitor may be considered as the only circuit element which controls or limits the current flowing in the circuit.

7. Having determined the value of X_c, use the formula $X_c = \dfrac{1}{2\pi fC}$ to determine the value of the capacitor, and record the value obtained. For example, assume that X_c, as determined in step 6 above, has a value of 10,000 ohms. From the formula $X_c = \dfrac{1}{2\pi fC}$, it is found that $C = \dfrac{1}{2\pi fX_c}$

and, since

$$X_c = 10{,}000 \text{ ohms}$$
$$2 = 6.28$$
$$f = 60 \text{ cycles}$$

Therefore

$$C = \frac{1}{6.28 \times 60 \times 10{,}000}$$
$$= .00000026 \text{ farad, or } .26 \text{ microfarad.}$$

8. Disconnect the capacitor which has just been measured. Then, using the second capacitor on hand, repeat the procedure given in steps 1 through 7, above, to determine the capacitance of the second capacitor. Record the value obtained.

9. The capacitance values of the two capacitors which have just been determined should be retained for further use in the experiments which follow.

CONCLUSION

The capacitance of a capacitor may be determined from the formula $C = \dfrac{1}{2\pi fX_c}$ once the value of X_c has been found by measurement of capacitor current and the voltage drop across the capacitor.

EXPERIMENT NO. 2

OBJECTIVE

To show the effects of capacitances in series.

MATERIAL REQUIRED

1. Two capacitors having known values of capacitance, as determined in experiment No. 1, and a 500-ohm, 1-watt resistor.

2. A-C voltmeter having ranges of about 10 volts full scale and 150 volts full scale (or a multimeter having similar a-c ranges).

3. 110—125-volt, 60-cycle, a-c source.

PROCEDURE

1. Connect the two capacitors, the resistor, and the a-c voltmeter (which has been set to the 10-volt range) as shown in figure 14.

2. Insert the power-cord plug into the a-c receptacle. Then read and record the value indicated on the a-c voltmeter.

3. Using Ohm's law, determine the current through the resistor ($I = \dfrac{E}{R}$). Record this value.

4. Remove the power-cord plug from the receptacle. Then disconnect the a-c voltmeter from across the resistor, and connect it between points 2 and 4. Set the voltmeter to the 150-volt range.

5. Insert the power-cord plug into the a-c receptacle.

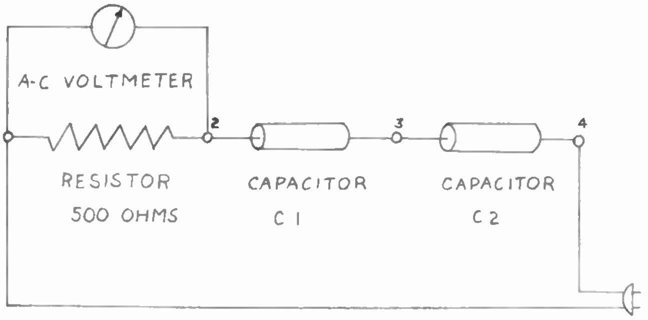

Figure 14. Experiment No. 2

Then read and record the value indicated. Remove the power-cord plug from the a-c receptacle.

6. The capacitors and the resistor are connected in series; therefore, the same amount of current flowing in the resistor will also flow in the capacitors. Knowing the voltage appearing across the two capacitors in series and the current which is flowing, use the formula $X_c = \frac{E}{I}$ to determine the capacitive reactance. Record the value obtained.

7. Having determined the effective value of X_c, use the formula $C = \frac{1}{2\pi f X_c}$ to determine the effective capacitance, and record the value obtained. As an example, assume that the effective capacitive reactance, as determined in step 6, above, has a value of 20,000 ohms.

Since

$X_c = 20{,}000$ ohms
$2 = 6.28$
$f = 60$ cycles

Therefore

$$C = \frac{1}{6.28 \times 60 \times 20{,}000}$$
$$= .00000013 \text{ or } .13 \text{ microfarad.}$$

8. Using the capacitance values of C1 and C2, as determined in experiment No. 1, for the C1 and C2 values in the following formula, calculate the effective capacitance of the series combination:

$$C_{eff} = \frac{C1 + C2}{C1 \times C2}$$

9. Using the calculated value of effective capacitance as determined in step 9, calculate the effective value of reactance by means of the formula

$$X_c = \frac{1}{2\pi fC}.$$

10. Compare the measured value of effective reactance, as determined in step 6, with the calculated value obtained in step 9.

11. Compare the measured value of effective capacitance, as determined in step 7, with the calculated value obtained in step 8.

12. Connect the a-c voltmeter between points 2 and 3, insert the power-cord plug into the a-c receptacle, and read the voltage drop across C1. Remove the power-cord plug.

13. Connect the a-c voltmeter across points 3 and 4, insert the power-cord plug into the a-c receptacle, and read the voltage drop across C2. Remove the power-cord plug.

14. Compare the two readings obtained in steps 12 and 13. Does the greatest voltage drop occur across the larger or smaller capacitance?

CONCLUSIONS

1. When two capacitors are connected in series, the total effective capacitance will be less than the capacitance value of either of the two alone.

2. When two capacitors are connected in series, one larger than the other, the greatest voltage drop will occur across the smaller capacitance.

3. When two capacitors are connected in series, the total reactance will be greater than the reactance of either capacitance alone.

EXPERIMENT NO. 3

OBJECTIVE

To show the effects of capacitances in parallel.

MATERIAL REQUIRED

1. Two capacitors having known values of capacitive reactance and capacitance, as determined in experiment No. 1.

2. One 500-ohm, 1-watt resistor.

3. A-C voltmeter having ranges of about 10 volts full scale and 150 volts full scale (or a multimeter having similar ranges).

4. 110—125-volt, 60-cycle, a-c source.

PROCEDURE

1. From the data taken in experiment No. 1, obtain the values of capacitive reactance and capacitance of each of the capacitors to be used in this experiment.

2. Connect the two capacitors, the resistor, and the a-c voltmeter (set to the 10-volt range) as shown in figure 15.

3. Insert the power-cord plug into the a-c receptacle. Then read and record the value indicated on the a-c voltmeter. Remove the power-cord plug.

4. Using Ohm's law, determine the current through the resistor ($I = \frac{E}{R}$). Record this value.

5. Disconnect the a-c voltmeter from across the resistor, and connect it between points 2 and 3. Set the voltmeter to the 150-volt range, insert the power-cord plug into the a-c receptacle, and then read and record the value indicated on the voltmeter. Remove the power-cord plug from the a-c receptacle.

6. Knowing the voltage appearing across the paralleled capacitors and the current which is flowing, use the formula $X_c = \frac{E}{I}$ to determine the effective capacitive reactance of the two in parallel. Record the value obtained.

7. Having determined the effective value of X_c, use the formula $C = \frac{1}{2\pi f X_c}$ to determine the effective capacitance of the parallel combination. Record the value obtained.

8. Disconnect the a-c voltmeter from points 2 and 3. Then connect it between points 1 and 2, and set it to the 10-volt range. Disconnect either capacitor C1 or C2, whichever has the larger capacitance value, from points 2 and 3.

9. Insert the power-cord plug into the a-c receptacle. Then read and record the value obtained. Disconnect the power-cord plug from the a-c receptacle.

10. Using Ohm's law, ($I = \frac{E}{R}$) determine the current in the circuit with only the smaller of the two capacitors connected.

11. Comparing the individual reactances of C1 and C2, as determined in experiment No. 1, with the reactance value of the two in parallel, as determined in step 6, above, is the total reactance of the parallel combination more or less than the reactance of either capacitor alone?

12. Comparing the individual capacitances of C1 and C2, as determined in experienment No. 1, with the capacitance value of the two in parallel, as determined in step 7, above, is the total capacitance of the parallel combination more or less than the capacitance of either capacitor alone?

13. Comparing the value of current which flowed when both capacitors were connected in parallel, in step 3, above, with the current which flowed when only the smaller capacitance of the two was connected in the circuit, as in step 10, above, does a larger current flow in a capacitor having a larger or smaller capacitance?

CONCLUSIONS

1. With two capacitances connected in parallel, the total reactance will be less than the reactance of either capacitance alone.

2. With two capacitances connected in parallel, the total capacitance will be more than the capacitance of either alone, the total capacitance being equal to the sum of the two.

3. With two capacitors connected in parallel, the greater current will flow in the capacitor having the greater capacitance (smaller reactance).

4. With two capacitors connected in parallel, the total current flowing in the circuit is the sum of the currents through both capacitors.

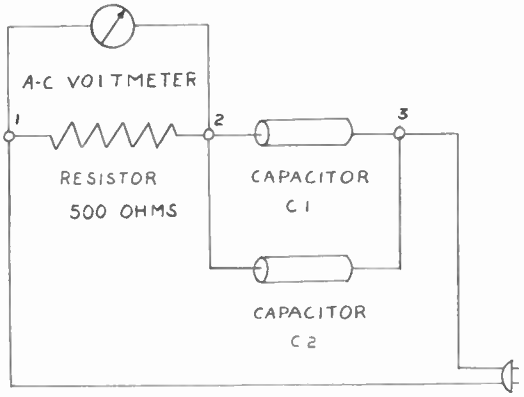

Figure 15. Experiment No. 3

REVIEW QUESTIONS

1. What are the three fundamental properties which exist in every electrical circuit?
Ans. Page 3, Paragraph 1.

2. Can capacitance ever be completely eliminated from an electrical circuit?
Ans. Page 3, Paragraph 2.

3. What is the name given to the electrical device used to obtain capacitance?
Ans. Page 3, Paragraph 3.

4. What name is given to the insulator in the electrical device used to obtain capacitance?
Ans. Page 3, Paragraph 3.

5. What is the property of a capacitor?
Ans. Page 3, Paragraph 3.

6. What factors determine the amount of charge stored in a capacitor?
Ans. Page 3, Paragraph 3.

7. What condition exists in an uncharged capacitor?
Ans. Page 3, Paragraph 4.

8. What condition exists in a capacitor when an e.m.f. is applied to it?
Ans. Page 3, Paragraph 4.

9. What condition exists in a capacitor when the applied e.m.f. is disconnected?
Ans. Page 3, Paragraph 4.

10. What is an electrostatic field?
Ans. Page 3, Paragraph 4.

11. What is the effect of the electrostatic field on the orbits of the electrons in a dielectric?
Ans. Page 4, Paragraph 8.

12. What does the charge stored in a capacitor represent?
Ans. Page 4, Paragraph 8.

13. What occurs when the terminals of a charged capacitor are connected together?
Ans. Page 5, Paragraph 9.

14. What condition exists in a capacitor when an alternating e.m.f. is applied?
Ans. Page 5, Paragraph 10.

15. What is the unit of capacitance called?
Ans. Page 5, Paragraph 11.

16. How is the unit of capacitance defined?
Ans. Page 5, Paragraph 11.

17. What sub-units of capacitance values are in common use?
Ans. Page 5, Paragraph 12.

18. What substance has been taken as the standard of comparison for dielectric materials?
Ans. Page 5, Paragraph 13.

19. What is meant by *dielectric constant?*
Ans. Page 5, Paragraph 13.

20. What determines dielectric constant?
Ans. Page 5, Paragraph 14.

21. Is it true that all dielectric materials are perfect insulators?
Ans. Page 5, Paragraph 15.

22. What determines the length of time a capacitor will retain a charge?
Ans. Page 5, Paragraph 15.

23. What is the effect upon the dielectric of increasing the applied e.m.f.?
Ans. Page 6, Paragraph 16.

24. What is the name given the value of applied e.m.f. at which a capacitor's dielectric ruptures?
Ans. Page 6, Paragraph 16.

25. What other factor determines the point at which a capacitor's dielectric ruptures?
Ans. Page 6, Paragraph 17.

26. What is meant by "d.c.w.v."?
Ans. Page 6, Paragraph 18.

27. What value of e.m.f. can be applied to a capacitor in a direct-current circuit?
Ans. Page 6, Paragraph 19.

28. When a capacitor is to be used in an a-c circuit, for what value of the voltage must it be rated?
Ans. Page 6, Paragraph 19.

29. Into what general classifications may various types of capacitors be grouped?
Ans. Page 6, Paragraph 20.

30. What usually determines the voltage rating given to fixed capacitors?
Ans. Page 6, Paragraph 21.

31. What are some of the principal dielectric materials used in fixed capacitors?
Ans. Page 6, Paragraph 21.

32. What is an advantage of using mica dielectric capacitors?
Ans. Page 6, Paragraph 22.

33. What advantage do paper capacitors have over other types?
Ans. Page 7, Paragraph 23.

34. What does the dielectric consist of in an electrolytic capacitor?
Ans. Page 7, Paragraph 24.

35. How does the leakage of an electrolytic capacitor compare with that of other types?
Ans. Page 7, Paragraph 24.

36. Where do electrolytic capacitors find their most frequent application?
Ans. Page 7, Paragraph 24.

37. How must electrolytic capacitors be connected in a circuit?
Ans. Page 7, Paragraph 25.

38. What is the most frequently used dielectric in variable capacitors?
Ans. Page 7, Paragraph 26.

39. What is the most frequent application of variable capacitors?
Ans. Page 7, Paragraph 26.

40. Upon what does the breakdown voltage of variable capacitors primarily depend?
Ans. Page 8, Paragraph 27.

41. What is the effect of connecting two capacitors in parallel?
Ans. Page 8, Paragraph 28.

42. If two identical capacitors are connected in parallel, what is the effect upon the capacitance of the combination?
Ans. Page 8, Paragraph 29.

43. If two or more capacitors are connected in parallel, what is the effective capacitance of the combination equal to?
Ans. Page 8, Paragraph 29.

44. If a number of capacitors having dissimilar voltage ratings are connected in parallel, what is the maximum voltage which may be applied to the combination?
Ans. Page 8, Paragraph 30.

45. What is the effect of connecting two capacitors in series?
Ans. Page 8, Paragraph 31.

46. What is the effect upon the total capacitance when two or more capacitors are connected in series?
Ans. Page 8, Paragraph 31.

47. What is the formula for determining the total value of capacitors connected in series?
Ans. Page 8, Paragraph 31.

48. When two or more identical capacitors are connected in series, how will an applied voltage divide across them?
Ans. Page 9, Paragraph 32.

49. In a capacitive circuit, during what part of the cycle is the voltage changing at its greatest rate?
Ans. Page 9, Paragraph 34.

50. In a capacitive circuit, during what part of the cycle is current flow at a maximum?
Ans. Page 9, Paragraph 34.

51. What is the phase relationship between the voltage and current in a capacitive circuit?
Ans. Page 10, Paragraph 38.

52. What name is given to the opposition which a capacitor offers to the flow of current?
Ans. Page 10, Paragraph 39.

53. Why does frequency affect the capacitive reactance of a capacitor?
Ans. Page 10, Paragraph 40.

54. What is the formula for determining capacitive reactance?
Ans. Page 10, Paragraph 41.

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