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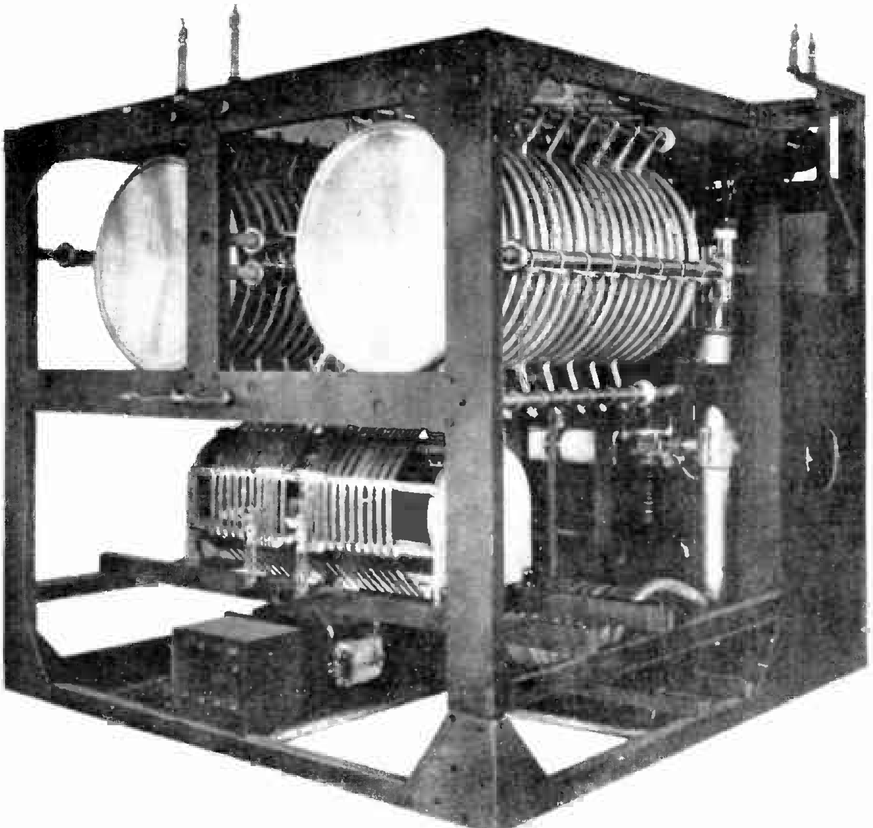

Rear View, 50-Kw. Amplifier showing tank-circuit inductance and air dielectric tuning condensers above

CAPACITANCE AND CONDENSERS

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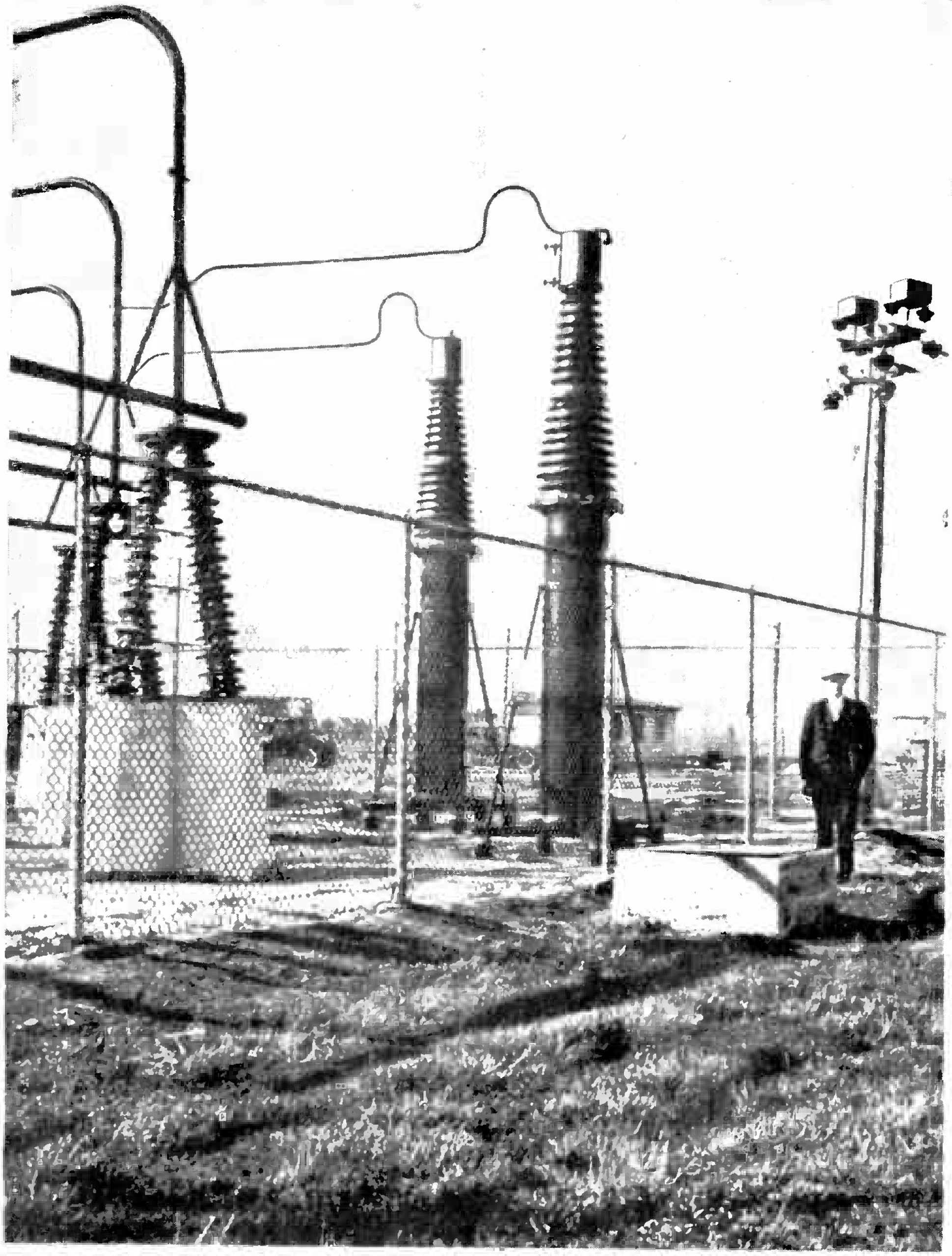

General Electric coupling capacitors for Carrier Telephony on 220,000-volt Power Transmission Line of the Southern California Edison Company

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CAPACITANCE AND CONDENSERS

What is capacity? Under what other names does it appear and where and why is it used? Capacity is the ability to receive, contain and store up energy. For example, a tank has the ability of storing water, oil and other forms of liquid. A condenser, in the electrical sense, stores electricity. It is used in power line transmission as well as in radio.

Fig. 1--Component unit of a condenser

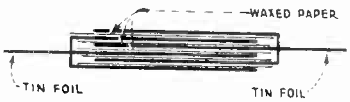


Fig. 3--Paraffined paper condenser

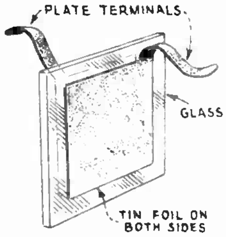


Fig. 2--Construction Details

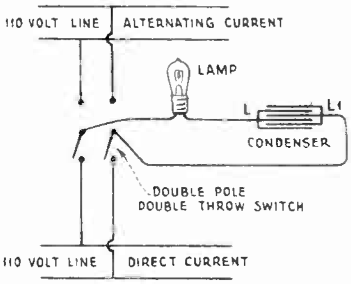


Fig. 4--Circuit used to illustrate condenser action

Capacitance is the term applied to the quality a device may have of being able to receive and store an electrostatic charge. As capacitance plays a large part in many ways and in various phases of the radio industry it may be well for you to know how simple it is to construct a device possessing capacity or capacitance. If you secure a piece of glass and two sheets of tinfoil you have the elements of a very simple condenser. Figures 1 and 2 indicate how this condenser is assembled. A large number of commercial condensers used with spark coils are made of tinfoil and paraffined paper, the tinfoil being the conductors and the paper being the insulator or dielectric, as it is called. Alternate layers of tinfoil and paper make up the condenser. A paraffined paper condenser with leads is shown in Figure 3.

Suppose we conduct an experiment, the purpose of which will assist us to visualize the effect taking place when a condenser of large capacitance is placed in a direct current circuit and then in a circuit carrying alternating current. We will use a hook-up as shown in Figure 4. Throw the double-pole double-throw switch down, thus connecting the circuit containing the condenser and lamp to the source of direct current. It is noticed that the lamp does not light. In a direct current the condenser acts as an open circuit exactly as though you had opened the circuit by cutting the wire with a pair of pliers, and this experiment proves it, for otherwise the lamp would have given off light. In tracing the circuit through the lamp you will find a connecting path for current as far as, and including, the plates marked "L", but the intervening dielectric, which is an insulator, prevents current from flowing to "L1". A potential difference does exist, however, and is available between the condenser terminals. This potential rose from zero (line disconnected) to a maximum value equal to the potential difference of the line wires, when the switch was closed. Before this value was reached, the coulombs of electricity entering the condenser per unit of time gradually decreased to zero. The lamp, if the capacitance of the condenser and resistance of the lamp were correct, might become incandescent for a fraction of a second giving a flash of light, but it would not remain illuminated. This would indicate that there was a momentary current flow after which the lamp ceased to glow.

Let us apply an alternating E.M.F. to the same circuit by throwing the switch up. The lamp at once burns at moderate incandescence and remains in this state giving off light until the circuit is opened. While we could obtain a single flash of the lamp when a direct E.M.F. was applied, we find that by applying alternating current a continuous illumination results, proving without question that a condenser, when of the correct capacity, does not produce in an a-c circuit the effect of an open circuit as it did in the direct current circuit. There is an electrical phenomenon taking place in the space between the plates of the condenser. This space together with the condenser plates constitutes capacitance. This space has the ability to receive and hold an electrical charge and is called the <u>Dielectric.</u> The plates of the condenser serve only the purpose of <u>distributing</u> the electromotive force over the dielectric.

The most common form of dielectric material is found in the shape of insulators. Air as a dielectric is frequently used, and it is from air that we base our standard for the "Specific Inductive Capacity" of the dielectric. Air, mica, glass, rubber, paper, and oil all may be utilized to form a dielectric for the condenser. As air is taken as a standard it is given the value of unity, or 1. To explain this value of Specific Inductive Capacity, suppose we determine by measurement the amount of charge a condenser using air as the dielectric will accumulate with a definite E.M.F. Then under the same conditions we will measure the amount of charge in the same condenser using glass as the dielectric. It will be found that when glass is the dielectric medium the condenser will take a charge from 5.4 to 10 times as great as the condenser having air as the dielectric, this specific inductive capacity depending upon the grade of glass used.

<u>SPECIFIC INDUCTIVE CAPACITY</u>

The following table indicates the Specific Inductive Capacity of some of the most commonly used dielectrics:

Air	has a	dielectric	constant	of	1.00		
Castor Oil	"	"	"	"	4.67		
Hard rubber	"	"	"	"	2.5	to	3.50
Glass	"	"	"	"	5.4	"	10.00
Mica	"	"	"	"	4.0	"	8.00
Paper	"	"	"	"	1.5	"	3.00

We find that when different insulating material is placed between the plates of a condenser the capacity of the condenser will be changed.

To explain the charging action of the condenser it will be well for us to review briefly the subject of conductance, insulation, and a phase of the electron theory dealing with the atomic structure. The condenser circuit is composed of the conductor plates which are usually aluminum, tinfoil or copper.

The material selected as a conductor must have a low resistance, in other words, it should offer very little opposition to the movement of electrons which, as you know, produces what is termed an electric current.

Insulation is so named because of the opposition which it offers to the electronic movement and resulting electric current. Insulation in a direct current circuit produces the effect of an open circuit, but when the same insulation is used as a dielectric of a condenser and placed in an alternating current circuit it may have the effect of being a conductor, as you learned by the lamp and condenser experiment. The condenser does not permit an actual continuous passage of electrons in one direction; it has the effect of permitting a shifting back and forth of the electrons in an otherwise conductive path. This statement may, at first appear contradictory and somewhat confusing, but the effect of the conduction of alternating current through a condenser can be readily explained and made clear if we will but consider the nature of electric current flow as set forth in the electron theory.

According to the electron theory all bodies are considered to be made up of infinitesimally small particles of matter called Atoms and, revolving about the atom, much as the earth and other planets revolve about the sun, are much smaller particles called Electrons. The atom is considered to be made up of one or more charges of positive electricity. All bodies are made up of atoms and, since the atom is considered to constitute a positive charge of electricity and the electron negative electricity, all substances possess large quantities of electricity. We found in previous lessons that like charges repel and unlike charges attract. In nearly all cases, however, the positive electrical charge equals the negative electrical charge thereby neutralizing each other and from all outward effects no electrical charges are evident. This complete balance of positive and negative electricity may be upset and we then observe electrical effects.

Negative electricity, or the electron, is considered to be the only form of motional electricity. Therefore, if we can succeed in forcing an electron to leave an atom there will be less negative charge than positive, the system becomes unbalanced, and the atom predominates in positive charge. By returning the negative electron to the atom we again produce a balance and the atom is again neutral or uncharged. Now force an electron to the balanced atom; the atom now will have an excess of negative charge thus making it negative.

In a substance which is a good conductor of electricity, such as copper and some of the other metals, the electron can be moved easily from atom to atom and this is what takes place when an electromotive force is produced by either mechanical or chemical means.

As all electrons are negative charges of electricity any electron caused to move from one atom to the next will cause an electron adjacent to it to be repelled with great force, and as long as the electromotive force is applied this repelling of electrons continues. It is this movement of electrons which results in what is called current flow.

In insulators, such as we employ as dielectric mediums of a condenser, the atom has a far more stable structure and greater electromotive force is required to drive an electron from the atom.

Now suppose we have a condenser and a source of E.M.F., the value of which is not great enough to completely dislodge or drive the electrons from the atom, but sufficiently great to strain the electron from its normal orbit without completely dislodging it from the atom, that is, to a position just short of the complete breaking away point, as the E.M.F. forces the electrons from the circuit into one condenser plate, piling them in by the millions, the electrons in the atoms of the dielectric are repelled and displaced from their normal position. The second plate, being positive, attracts the electrons in the atoms of the dielectric. It is this moving away of the electrons from their normal position in the atom that is called the displacement current, and the condenser is said to be charging; that is, charging in the sense that electrons continue, as a result of the E.M.F., to pile up in the negative plate. The displacement of the electrons has produced a strain on the whole structure of the atoms. When the holding forces of all the dielectric atoms to their electrons is equalled by the repelling force of these electrons against the electrons moved into the negative condenser plate, the potential difference between the two plates has become equal to the electromotive force applied from the external source. Then the movement of electrons out of one plate and into the other through the external circuit will cease.

This action, so far, can be illustrated by imagining a tank of proper design used to store air. Let an air pump represent an electric generator and the particles of air the electrons. On starting, the pump air at once is set in motion and is forced into the tank; the tank is under pressure and becomes strained. This strain caused by the piling up of air particles begins to exert a back pressure on the air being forced into the tank. This continues to increase with every stroke of the pump until the stored up air reaches a pressure equal to the driving pressure of the pump, when the flow of air will cease.

A similar action takes place in the electric circuit. As the applied E.M.F. decreases in the alternating current circuit the strained dielectric is relieved, allowing the electrons to again assume their normal positions about the atoms. This reverse movement of the electrons produces a displacement current in the opposite direction and the condenser is discharging. As the applied E.M.F. passes through zero value and reverses, the charging movement of electrons is toward the plate which was positive during the first half-cycle; the electrons in the dielectric atoms are displaced in the opposite direction. As the alternating E.M.F. is constantly varying in strength and direction, electrons are continually moving back and forth through the circuit tending to keep the condenser plates at the same potential difference and polarity.

It is this movement of the electrons into and out of the condenser plates which results in the current causing the lamp to glow in the experiment of Figure 4. It is therefore clear that the electrons do not actually pass through the dielectric from one plate to the other, but simply move into and out of the plates, swinging through the circuit from one plate through the generator to the opposite plate. With this knowledge of the behavior of the condenser we are enabled to make an efficient test as to the worthiness of a condenser by using direct current for the test.

From a source of direct E.M.F., such as a 45 volt "B" battery, bring out two leads as suggested in Figure 5, one lead having a suitable voltmeter in series. Touch the terminals of the condenser and at the same time observe the voltmeter. The needle will be deflected once and then return to zero. Remove the test tips and at once bring them in contact with the condenser a second time; on the second contact there will be no deflection of the voltmeter needle. This proves, first, that the condenser is charged and, second, that it will not accept a further charge with the E.M.F. of 45 volts. Third, the current will not flow entirely through the dielectric.

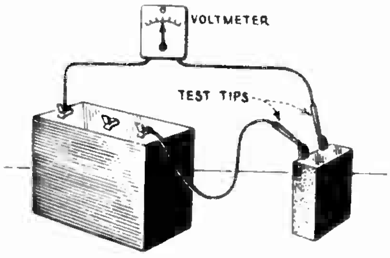


Fig. 5--Method of test-charging a condenser

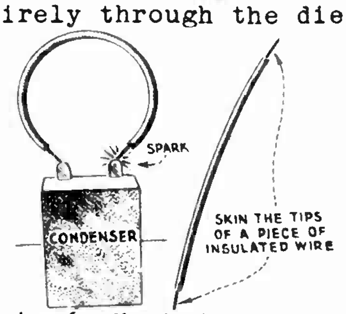


Fig. 6--Method of test-discharging a condenser

Take a piece of insulated wire, skin the ends and short circuit the condenser as shown in Figure 6. When testing certain condensers in this manner a bright spark will result, proving that the condenser held the charge until a path was offered to the charge to flow out, which it immediately did through the wire forming the circuit to the opposite plate, thus equalizing the charge until there was no difference of potential between the condenser plates.

Now secure a punctured condenser and follow the same procedure as before. The indicating needle of the meter will be deflected at every contact of the test tips indicating that the dielectric is broken down allowing current to flow directly through from one plate of the condenser to the other. A broken down condenser will not hold a charge.

A water analogy of the action of a condenser follows to illustrate displacement current. Refer to Figure 7. Here is a system of pipes "E" and "C", and a tank divided into two divisions, "A" and "B", by a rubber partition "R". A reservoir is shown at "D" (the use of which will be explained later). On filling this system with water it is clearly seen that the water will be divided and prevented from moving by the rubber partition "R". There will be the same pressure in the half of the system B-C-D as in the half A-E-D, therefore there is no distortion of the rubber partition "R" and no movement of the water through the system. The conflicting arrangement of the arrows is intended to picture the water as idle; that is, no particular direction of motion would be evident.

Figure 8 is the same arrangement but, in the reservoir "D", we have installed a centrifugal pump so designed that a continuous pressure is exerted on the water forcing it continually in one direction as long as the pump revolves. Revolving the pump in a clockwise direction the water will be forced into motion and will flow, as shown in Figure 8, from the reservoir "D" through pipe "E" and into the "A" section of the tank. Now what happens? The water cannot move beyond the rubber partition but, due to the nature of the rubber, it will stretch and become strained by the pressure of the water as shown. A displacement of water into section "A" takes place, resulting in a like displacement out of section "B".

We will assume that the pump has sufficient force to extend the partition to the limit, but not enough to rupture it. The water in "B" section of the tank will be displaced along the B-C-D half of the system by the forced distortion of the rubber partition, and will move toward reservoir "D". Now retain this: There has been a

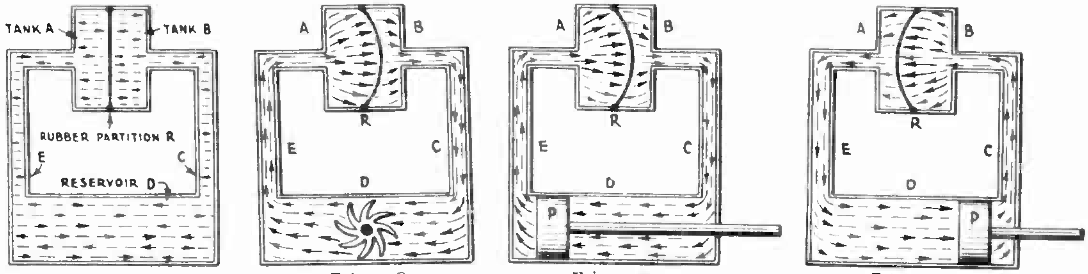


Fig. 7 Fig. 8 Fig. 9 Fig. 10

Various Water Analogies of Condenser Action

displacement of water out of "B" through "C" to "D". Do not forget the word displacement because you will have to associate it with electronic movement later. Remember also that a stress has been placed against the rubber partition and, under this stress, it has been strained and because of this strain movement results in the rubber, causing a displacement of the water in "B" section of the tank.

As the pump continues to revolve continuously in the same direction it maintains a stress upon the rubber partition and the rubber remains in a fixed strained position. As it cannot be strained further there is no further displacement of the water in "B" section when the partition has reached its limit of strain and therefore only one surge of water takes place in the B-C-D half of the system as long as the water is forced to move in the same direction.

This action is similar to the action of a condenser in a direct current circuit. There is actually one surge of displacement current through a condenser in a direct current circuit just as there was one surge of displaced water in Figure 8, but that completes it because the condenser dielectric is strained by the E.M.F. displacing electrons sufficiently to cause one surge of current.

Explaining the water analogy for the alternating current we will use Figure 9 which is the same type of arrangement as shown in Figures 7 and 8 but, instead of the centrifugal pump, we have a piston "P" which fits closely to the walls of the reservoir. Water fills the system as it did in Figure 7. It is clearly seen that if the piston "P" is moved to the left, Figure 9, it will exert a pressure on the water in the "EA" half of the system thus placing a stress on the rubber partition "R", causing it to stretch and a displacement of the water in "B" follows, which moves all the water in B-C-D. The elastic rubber partition is exerting a back pressure against the water forced against it by the piston.

When the piston is returned toward the center of "D" the strain on the partition is relieved, and its back pressure is effective in aiding such a movement of the piston because of the tendency of the partition to straighten out. Therefore the suction effect of the returning piston and the back pressure effect of the partition combine to give back into section "ED" the energy stored up in "A". At the same time the movement of the piston has forced water back up through the pipe "C" into "B" until the partition is completely straightened out and at rest. As the piston continues its movement past the center of "D" and on to the extreme right position as shown in Figure 10 the extra quantity of water moved into "B" section bulges the partition to the left, being opposed by a back pressure due to the strain in the rubber. The water in the "A" section becomes displaced into the "ED" section as shown by the arrows. With this arrangement and by a rapid forward and backward movement of the piston water will move first in one direction and then in the other.

It must be apparent that we may insert in either the "E" pipe or the "C" pipe some device operated by water flow and have work done in this device, the energy used being provided originally by the pump plunger. In like fashion we may insert an electric device, such as a lamp, in one of the electron-conducting wires between a condenser and a source of alternating E.M.F., and energy in the form of heat and light may become available at the inserted device.

CAPACITANCE

The capacitance of a condenser is a measure of the relation between the amount of a charge in the condenser and the potential difference in volts required to produce that charge. We may say that: $C = Q/V$, where Q is the quantity of electricity measured in coulombs, V the potential difference, and C is the capacitance, the unit of which is the FARAD.

In Figure 9 the volume of water displaced varied directly with the pressure, the cross-sectional area of section AB, and the elasticity of the rubber partition, but inversely with the thickness of the partition. We might write this relation as follows:

$$\text{Water Volume Displaced varies as } \frac{\text{Pressure x Area x Elasticity}}{\text{Thickness of Partition}}$$

$$\text{or } \frac{\text{Water Volume Displaced}}{\text{Pressure}} \text{ varies as } \frac{\text{Area x Elasticity}}{\text{Partition Thickness}}$$

which latter term may be considered the "capacity" of the section. In the electrical case we find a closely similar relation:

$$\frac{\text{Quantity of Charge}}{\text{Potential Difference}} \text{ varies as } \frac{\text{Area x Dielectric Constant}}{\text{Dielectric Thickness}}$$

From the preceding paragraph we know that Q/V is the capacitance of the condenser, and the exact formula for it may be written:

$$C = \frac{8.85 \times K \times A}{t \times 10^8}$$

where C = Capacitance in microfarads
K = Specific Inductive Capacity
A = Area in square centimeters of one plate of a two-plate condenser as in Figure 2.
t = thickness of dielectric in centimeters.

If, instead of a single pair of metal plates, there are N similar plates with dielectric between (Figure 3) with alternate plates connected together into two groups, we find that:

$$C = \frac{8.85 \times K \times A \times (N-1)}{t \times 10^8}$$

It will be seen that the capacitance is expressed in MICROFARADS. A condenser having a capacitance of one farad is beyond construction, it would have to be so large. Condensers in actual use have capacitances of only a very small fraction of a farad. In engineering practice, decimal parts are expressed as microfarads and micro-microfarads. Micro means "one millionth of" and micro-micro means "one million-millionth of". Hence a condenser of one microfarad has a capacitance of one-millionth of a farad, etc.

The capacity of a condenser is sometimes expressed in centimeters, one centimeter of capacity being equal to 1.1124 micro-microfarads. This unit, however, is not so frequently used as the one explained in the foregoing paragraph.

When the physical dimensions of a condenser are measured in square inches and inches instead of sq. cms. and cms. the following formula holds good:

$$C = \frac{22.4 \times K \times A \times (N-1)}{t \times 10^8}$$

The area of the plates, the number of plates and distance between the plates can easily be found. The specific inductive capacity, or "K", however, must be determined by actual test and measurement when absolute accuracy is desired. When an approximation is desired a value of "K" may be used as given in specific inductive capacity tables. For example, suppose a condenser has a total plate area of 800 square inches. The dielectric is mica, one one-hundreth (1/100) of an inch in thickness. We now have all the necessary data from which to calculate the capacity of the condenser except the specific inductive capacity (dielectric constant "K").* This can be obtained from tables giving the dielectric constant of different materials. Referring to the table given previously we find the dielectric constant for mica varies from 4.0 to 8.0, depending upon the grade of mica.

---

*(Note: specific inductive capacity (K) is more often termed the "dielectric constant").

Let us assume that the mica being used in this condenser has a dielectric constant of 5. Substituting these known values in the formula for capacity, the formula becomes:

$$C = \frac{22.4 \times 5 \times 800}{.01 \times 100{,}000{,}000}$$

$$C = \frac{89{,}600}{1{,}000{,}000}$$

$$C = .0896 \text{ mfd.}$$

Capacity effects exist between any two conductors with a dielectric between them. As you learned, air or any insulating substance is a dielectric, and there is always a capacity effect between two electrical conductors. If they are bare wires, air is the dielectric; if covered with insulation the insulation acts as a dielectric.

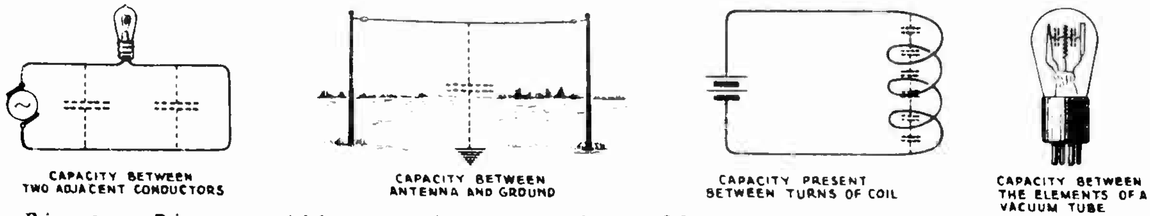


Fig.11--Diagrams illustrating capacity effects in familiar circuits

In bare wires running from pole to pole or, on a ship, from mast to mast, the air around the wires acts as a dielectric, the ground acting as one side, or plate, of a condenser while the wire is the other plate, and capacity exists there exactly as between two conductors running close to each other, or as in a condenser. Figure 11 gives an idea of capacity in circuits familiar to you.

In determining capacity it is seen that formulae for all conditions under which capacity exists would be rather a complicated work.

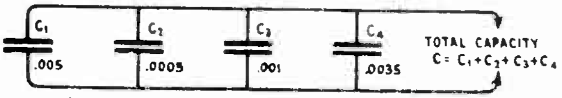


Fig.12--Parallel connection of condensers

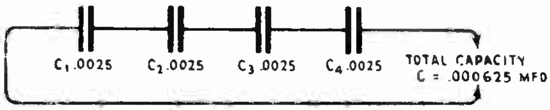


Fig.13--Series connection of condensers

CONDENSER GROUPING

Condensers are grouped to obtain various capacities and to perform certain functions. Certain circuits may call for condensers in series and others in parallel.

When condensers are connected in parallel, as shown in Figure 12, the total capacity resulting from such a connection is the sum of the individual capacities. In this instance, the different condensers in the group are shown as having capacity of .005 mf, .0005 mf, .001 mf and .0035 mf. The total capacity of such a parallel arrangement is, as stated, the sum of the individual capacities, or .01 mf.

Assume that the four condensers of Figure 13, C1, C2, C3, C4, have a capacity of .0025 each. What would be the total capacity when connected in series as shown in Figure 13? To obtain the total capacity of a number of condensers of equal value connected in series simply divide the capacity of one of the condensers by the total number of condensers in the circuit. Applying this rule to Figure 13 we obtain the answer, .000625 mfd., the total capacity of these four condensers when connected in series.

It becomes necessary under certain conditions, to employ condensers of different values in series. When this is the case the formula of reciprocals is required to solve for total capacity.

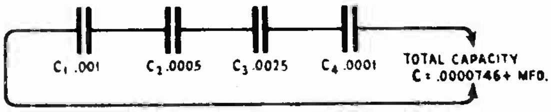


Fig. 14--Series connection of condensers having unequal values

In Figure 14 we have four condensers C1, C2, C3, C4 connected in series. What is the total capacity? The formula for condensers connected in series is as follows:

$$C = \cfrac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

Substituting our known values as stated in Figure 14, the formula becomes:

$$C = \cfrac{1}{\frac{1}{.001} + \frac{1}{.0005} + \frac{1}{.0025} + \frac{1}{.0001}}$$

$$C = \frac{1}{1000. + 2000. + 400. + 10000.} \qquad C = \frac{1}{13,400}$$

C = 13,400)1.0000000(.0000746
93800
62000
53600
84000
80400
3600

C = .0000746 mfd. (microfarads), or C = 74.6 mmfd. (micro-microfarads).

CAPACITIVE REACTANCE

The effect of capacitance in an alternating current circuit, termed capacitive reactance, will now be considered. When inductance is introduced in an alternating current circuit, the effect produced is to retard or cause the current to lag the electromotive force.

Capacitance produces exactly the opposite effect, that is, the current leads the electromotive force.

Capacitive reactance is expressed in ohms, as is inductive reactance, and is written X_c (X sub c) while inductive reactance is expressed X_l (X sub l).

The capacitive reactance in any circuit changes with a change in frequency and the greater the frequency the less effect will capacity have on the circuit. An increase in frequency, when inductance is being considered, produces a greater reactive effect.

The formula is as follows: $X_c = \dfrac{1}{6.28fC}$

X_c = capacity reactance
f = frequency
C = Capacity in farads

In a 110-v., A.C. 60-cycle circuit, we have a .0025 farad condenser connected in series with the line. What is the capacity reactance?

By formula given: $X_c = \dfrac{1}{6.28 \times f \times C}$

Substituting: $X_c = \dfrac{1}{6.28 \times 60 \times .0025}$

Multiplying the denominator

```
  6.28
    60
376.80
 .0025
188400
75360
.942000
```

then $X_c = \dfrac{1}{.942000}$

Dividing

```
.942000)1.0000000000(1.0615
         942000
          5800000
          5652000
           1480000
            942000
            5380000
            4710000
```

We find that the capacitive reactance in the circuit as given above amounts to 1.0615 ohms.

Now let us increase the frequency to 500,000 cycles using the same condenser of .0025 farads. This will show us that, with an increase of frequency, the reactance is lowered.

Again by formula $X_c = \dfrac{1}{6.28 \times f \times C}$

Substitute $X_c = \dfrac{1}{6.28 \times 500{,}000 \times .0025}$

Multiplying the denominator

```
      6.28
    500000
3140000.00
     .00 25
1570000000
628000000
7850.000000
```

```
7850)1.000000000(.00012738
     7850
     21500
     15700
      58000
      54950
       30500
       23550
        69500
        62800
         67000
```

or $X_c = .00012738$ ohms.

The purpose in working out this problem has been to show how according to the formula, capacitive reactance decreases with an increase in frequency. You found that, with a frequency of 60 cycles, a capacitive reactance of a little over one ohm reactance was present. When the frequency was increased to 500,000 cycles, however, the reactance was reduced to a fractional part of an ohm.

The table below gives the capacitive reactances of condensers of various capacitances, at frequencies commonly met with in radio practice. For other frequencies it will be easy to determine the reactance of a condenser by proportion. For instance, the reactance of a .001 mfd. condenser at 50 cycles is 3,180,000 ohms. Then the reactance at 5,000 cycles $= 3{,}180{,}000 \times \frac{50}{5000} = 31{,}800$ ohms.

CAPACITIVE REACTANCE IN OHMS

CAP. IN MFDS.	FREQUENCIES					
	POWER SUPPLY		AUDIO		BROADCAST	
	60	120	50	8,000	700,000	1,500,000
.0001	26,500,000	13,300,000	31,800,000	199,000	2,270	1,060
.00025	10,600,000	5,300,000	12,700,000	79,600	910	425
.0005	5,310,000	2,650,000	6,370,000	39,800	455	212
.001	2,650,000	1,330,000	3,180,000	19,900	227	106
.002	1,330,000	664,000	1,590,000	9,950	114	53.1
.005	531,000	265,000	637,000	3,980	45.5	21.2
.01	265,000	133,300	318,000	1,990	22.7	10.6
.02	133,000	66,400	159,000	995	11.4	5.3
.05	53,100	26,500	63,700	398	4.55	2.12
.1	26,500	13,300	31,800	199	2.27	1.06
.25	10,600	5,300	12,700	79.6	.92	.42
.5	5,310	2,650	6,370	39.8	.46	.21
1.0	2,650	1,330	3,180	19.9	.23	.11
2.0	1,330	664	1,590	9.9	.11	.05
3.0	885	443	1,060	6.6		
4.0	664	332	796	5.0	.06	.03
8.0	332	166	398	2.5		
10.0	265	133	318	2.0	.02	.01

GENERAL TYPES OF CONDENSERS

Condensers may be divided into four or five general types according to the dielectric used in their construction. The "Leyden jar" type was, at one time, a very common form of condenser used in transmitting equipment. It consists of a glass jar with walls about 1/8" thick coated inside and out to within two inches of the top with a tinfoil, copper or silver coating. This type is shown in Figure 15. The "Leyden jar" was one of the first types of electro-static condensers developed and, although it is quite efficient it has been rendered almost obsolete by more modern condensers incorporating higher efficiency and greater capacity in units of smaller physical dimensions.

The Glass Plate Condenser for use with high potentials is constructed as follows: Plate glass is used as the dielectric to which is glued tinfoil plates and, after being thoroughly dried, they are coated with shellac or hot paraffine. A single plate is shown in Figure 2.

A number of plates, depending upon the capacity desired, are connected together and immersed in an oil container as shown in Figure 16. This type of condenser is not used to any great extent due to the inconvenience of assembly and the time and work required in replacing broken plates in case of break-down.

The Compressed Air condenser is a type that will be found in use in very few radio installations because expense in construction and upkeep does not warrant its general use. Briefly, the compressed air type is constructed as follows: A metal tank contains steel plates in which half of the plates are insulated from the tank and the other half connected to the tank. The tank is pumped to a pressure of 250 pounds providing a dielectric capable of withstanding a potential of 25,000 volts. Should a break-down potential be applied to this type of condenser no damage is done because the air simply fills in again making the dielectric perfect. This type of condenser is heavy, hard to handle and, in nearly all cases, trouble is experienced in maintaining the tank air tight.

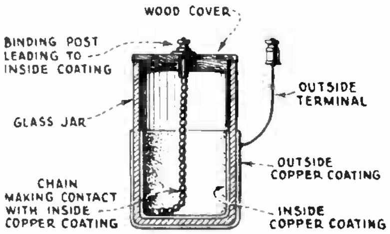


Fig. 15--"Leyden Jar" Condenser

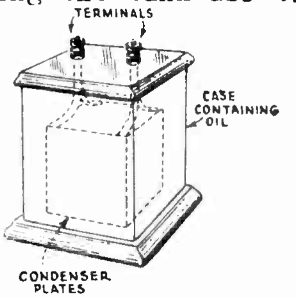


Fig. 16--Glass Plate Oil Condenser

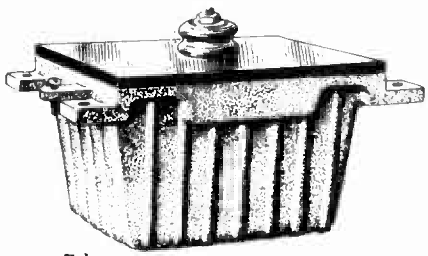


Fig. 17--Mica Transmitting Condenser

The foregoing types of condensers were rendered obsolete, as far as modern radio practice is concerned, by the mica condenser. They have been mentioned because, at the period of their development, they each represented an advancement in good practice in radio condenser construction.

The mica condenser uses sheet mica as the dielectric and the plates are made of tinfoil, or copper foil. Properly designed and constructed, this condenser will withstand the high potentials encountered in radio transmitters;—its electrical efficiency is very good and large capacities may be secured within comparatively small physical dimensions. Furthermore, it is very sturdy as compared to the fragility of condensers employing glass as the dielectric—such as the Leyden jar and the glass plate condensers.

A modern mica transmitting condenser is shown in Figure 17. The condenser is enclosed in an aluminum case, the space between the condenser and the case being filled with an insulating compound to render the condenser moisture proof and to reduce brush discharges. The metal case is used as one terminal of the condenser while the other terminal is brought out to the binding post on the bakelite cover of the case.

THE WET ELECTROLYTIC CONDENSER

(The following information on the wet type of electrolytic condenser consists chiefly of an extract of an article by Mr. H. O. Siegmund printed in the Bell System Technical Journal. The material is reprinted here with permission.)

Since the discovery about 75 years ago of the unusual polarizing effect of aluminum it has become well known that certain metals, notably aluminum and tantalum, as anodes in a suitable electrolyte become coated with a film having remarkable electrical properties. Films formed in this manner are characterized by the influence of impressed potential on their electrical resistance.

This resistance characteristic imparts to the film the capability of conducting current more freely in one direction than in the other; of breaking down as an insulation between the metallic electrode and the solution when voltages above a critical value are applied; and, in combination with the thinness of the film, of holding a substantial charge of electricity at potentials below the break-down voltage.

Each of these characteristics provides the principle around which a distinctive class of electrical apparatus has been developed. The electrolytic rectifier, widely used in small direct-current supply sets for battery charging and radio purposes, employs the uni-directional conducting characteristic. The aluminum electrolytic lightning arrester, used extensively for protection of direct-current railway equipment, depends for its operation upon the break-down characteristic of the film. And finally the aluminum electrolytic condenser, now being used in direct-current telephone and radio power plant equipment, utilizes the dielectric property of the film to provide electrostatic capacity.

There are a number of electrolytes, including various concentrations of phosphates, borates, tartrates and carbonates in which films can be formed on aluminum to withstand potentials upwards of 300 volts,at least for limited periods. If a film is formed on a piece of aluminum to this maximum voltage and the metal is then made the anode (positive electrode) in an electrolytic cell across which variable potential can be applied, a current corresponding to a density of less than one microampere per square centimeter of filmed surface will flow when a potential of one tenth of the maximum voltage is impressed.

As the potential is increased this "leakage" current will increase at a rate somewhat greater than proportionate to the voltage. As the maximum or breakdown potential is approached it will be noticed, if the room is darkened, that the anode begins to glow uniformly over the surface with a pale light and with further increases in voltage sparks begin to scintillate over the entire electrode, being noticed first at the surface of the electrolyte. The current through the cell becomes appreciable under this condition and increases more rapidly until at voltages slightly above the sparking potential the cell acts virtually as a short circuit.

Upon reduction of the voltage, however, the insulating properties of the film are restored and the current decreases with decreasing potential in substantially the same relation to voltage as before. The sparking over the surface will be observed to cease at about the same potential at which it began, the glow will disappear and the low leakage-current values will be obtained when the voltage is reduced sufficiently.

Upon reversal of potential on the aluminum electrode there is a much larger flow of current, the value of which is limited by a counter voltage of several volts, and by the low internal resistance of the cell with negative potential applied.

CAPACITY OF ALUMINUM FILMS

Like the ordinary paper or mica static condenser, the electrolytic condenser consists of two conducting surfaces separated by an insulator. The high-resistance film constitutes the insulator in the electrolytic cell, and the electrolyte on one side of the film and the metal of the film-bearing electrode on the other provide the two conducting surfaces. The cathode in this type of cell merely provides a means for making electrical contact with the electrolyte.

When a film is formed upon a smooth polished aluminum surface the coating is transparent. If observed under favorable illuminating conditions the "filmed" surface is seen to be colored and may be either green, yellow, red or blue, depending upon the thickness of the film. The actual thicknesses of films on aluminum have been determined to be from 0.001 to 0.00001 mm., depending upon conditions of formation.

Because of this extreme thinness of the dielectric and its high insulation resistance when positive potential is applied, unusually large capacities per unit area of surface can be obtained. The capacity of a film formed to 30 volts on aluminum is about 0.18 microfarad per square centimeter of dielectric surface, or about 1,000 times that of paper condensers. The capacity per unit area is approximately inversely proportional to the potential at which the film is formed, indicating that the thickness of the dielectric is proportional to the voltage of formation.

EFFECT OF IMPRESSED VOLTAGE ON CAPACITY

When an electrolytic cell with a "formed" anode has impressed on its terminals a voltage greater than the formation voltage, the film must build up to the new potential before the electrical characteristics of the cell become stable. At this higher voltage the capacity of the cell will be reduced to correspond to the increased potential. Where large plate areas are involved the direct application of a potential above the formation voltage results in a heavy flow of current, which may overheat and damage the cell if not properly limited.

If a voltage is impressed on a condenser lower than the potential applied during the formation of the film, the cell will operate satisfactorily, but the capacity will not be immediately affected and will correspond to the potential at which the film was originally formed. However, if a condenser operates for a long time at a reduced voltage the excess film will be removed slowly by the chemical action of the electrolyte, and the capacity will increase gradually to a value depending upon the operating voltage.

When the second electrode of an aluminum cell is made of a non-film forming metal, current will be conducted freely when the aluminum electrode is made the cathode (negative line terminal connected to it). Accordingly this type of cell (called "asymmetrical") is capable of holding a charge of electricity and serving as a condenser only while the aluminum is at a higher positive potential than the electrolyte.

REQUIREMENTS FOR ALTERNATING CURRENT SERVICE

A cell with a non-film forming cathode makes a suitable condenser to operate on direct-current or pulsating-current circuits, in which the aluminum always remains positively charged. On alternating-current circuits, however, such a cell will operate as a rectifier rather than as a condenser, unless two similar units are connected in a series-opposed relationship. In this case, while one cell is acting as a condenser the other cell merely acts as a series resistance; when the current reverses the functions of the two cells are interchanged.

A suitable condenser for operation on alternating current service can also be made by having two electrodes of film-forming metal in the same solution, the electrical relations between the "formed" electrodes being the same in this case as in the series-opposed arrangement of two asymmetrical cells. In either case one or other of the film-forming electrodes opposes the flow of current during each half cycle and its film therefore serves as a condenser dielectric. As the alternating potential varies between maximum values in each direction, the charge is transferred from the capacity provided by one film-forming electrode to the other, the sum of the charges on these two electrodes at every instant remaining constant.

LOSSES IN ALUMINUM CELLS

In the matter of electrical impedance characteristics, the electrolytic condenser does not approach a perfect capacitance as nearly as the more familiar forms of static condensers. Three sources of energy loss in the electrolytic condenser impart to it an equivalent series resistance, as a result of which the condenser current leads the impressed voltage by a phase angle somewhat less than 90 degrees.

The first of these losses is the dielectric hysteresis loss, which, as in the case of the paper condenser, is approximately proportional to the frequency. The second loss is the heat dissipation in the electrolyte due to its resistance and, in the case of aluminum condensers, this may be of appreciable magnitude because of the low electrical conductivity of most suitable electrolytes. This electrolyte resistance remains practically constant over a wide range of frequencies. The third possible loss is heat dissipation in the film due to its leakage-resistance, which in its effect is similar to a high resistance in parallel with the condenser. Ordinarily this loss is negligible because the leakage current is of very low magnitude.

CONDITIONS AFFECTING THE LIFE OF CONDENSERS

To be successful from a commercial point of view an electrolytic condenser must have long life and must not require frequent attention. Otherwise the advantage in the matter of mounting space and the cost per unit capacity is offset by the depreciation and maintenance costs involved. There are two common conditions affecting the life of aluminum condensers that must be controlled if the cells are to operate satisfactorily.

The first concerns the chemical action of the electrolyte on the electrodes and the film. This action, which is merely a matter of the film dissolving and forming aluminum hydroxide in the solution, takes place when the cell is off circuit as well as when potential is impressed. With impressed potential, new film forms under the influence of the leakage current to replace that which is dissolved, but in time the fluid becomes saturated with aluminum hydroxide, which may precipitate as a white jelly and adversely affect the life of the condenser.

The second consideration involves corrosion of the positive electrodes. The susceptibility of aluminum to corrosion is well known, and in the use of electrolytic condensers corrosion of the anode is the most damaging irregularity that can occur.

Obviously then an electrolyte must be chosen that does not rapidly dissolve the film, and the material for the electrodes as well as for the electrolyte must be selected and prepared to prevent serious corrosion of the "formed" aluminum plates.

A COMMERCIAL APPLICATION AND DESIGN OF ELECTROLYTIC CONDENSER

In telephone systems and radio transmitters the principal application of this device involves its use in electric wave-filters. These filters are placed in the supply circuits associated with storage batteries at central telephone offices and at radio stations (used for vacuum tube filaments) and their purpose is to eliminate noise-producing ripples and pulsations introduced by battery-charging apparatus and signalling equipment

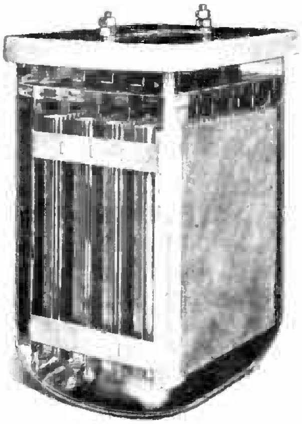


Fig. 18--Aluminum electrolytic condenser, designed for d.c. filter service

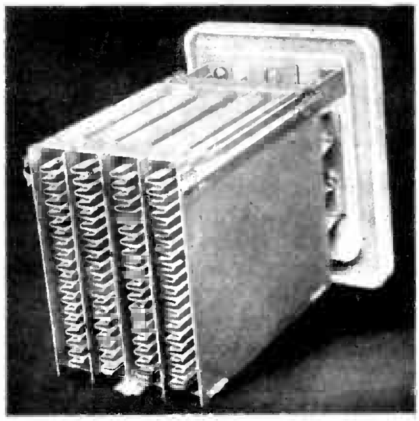


Fig. 19--Aluminum electrolytic condenser showing construction of electrodes

In Figure 18 is shown an electrolytic condenser of the type designed for direct-current filter service. When prepared for operation on 24-volt d-c circuits, the capacitance of this cell is nominally 1,000 microfarads at 1,000 cycles, and for 48 volts is about 600 mfd. at the same frequency. (The frequency of the ripple is stated because the capacity of a condenser of this type decreases with increasing frequency. This is due principally to the corrugated shape of the plates on which the film is formed).

The container for the condenser is made of heat-resisting glass which reduces possible breakage due to temperature variations. The electrodes, both of aluminum, are rigid and are bolted to a porcelain cover to keep them in proper space relation. Two supporting bolts, one from each electrode properly marked with respect to polarity, extend through the cover to provide the terminals for the condenser. A thin layer of high grade paraffine oil is used on top of the condenser fluid to prevent evaporation and to keep the inside of the cell from sweating under varying room temperature conditions. The cover is sealed to the glass jar with paraffine to provide additional protection against evaporation and to prevent dirt from getting into the cell.

ANODE CONSTRUCTION AND MATERIAL

The construction of the electrodes is shown in Figure 19. The positive electrode on which the dielectric film is formed is made of four corrugated aluminum plates, each supported by four integral ears. In an assembled condenser the positive plate surfaces are entirely immersed in the electrolyte, the ears extending up through the oil and providing contact with the positive terminal. The material for the positive plates is aluminum of special composition, selected on a basis of properties which influence the formation of the film, the leakage current, and the life of the metal. In general, the higher the purity of the aluminum the more rapid is the formation of the film and the lower is the resultant leakage current. In the matter of life, however, the purer metal seems to be more readily attacked by agencies capable of causing electrolytic corrosion.

THE NEGATIVE ELECTRODE

This consists of five rectangular flat plates, having a combined useful surface area about 35% of the total positive surface. They are also of aluminum, but they do not have a film formed on them because their sole function is to provide contact with the condenser fluid. In an ammonium borate electrolyte, such as is used in these condensers, there are a number of other materials, including tin and carbon, which can be used for the negative electrodes.

In normal operation with aluminum negatives there is a tendency for a film to occur, even though the condenser is operated on direct-current circuits, because the negative electrode becomes an anode during the interval that the condenser discharges. This disadvantage in the use of aluminum is overcome by making this negative electrode of an aluminum alloy containing other substances such as silicon which impedes the formation of a film on its surface.

WET ELECTROLYTIC CONDENSERS IN RADIO RECEIVERS

The lack of space in a radio receiver dictates that any electrolytic condenser used shall be small in volume even when there is an advantage of increased capacitance over those of the paper type. There are special construction features concerned, but the preceding information on the wet type holds good for these smaller units used in receivers. Since their external appearance is quite similar to a number of other condensers of the <u>dry</u> electrolytic type shown in Figures 23 to 30 inclusive, no particular illustrations will be presented here. It must be remembered that the wet type of condenser requires a safety valve, usually in the form of a live rubber disc with a number of pin hole vents, permitting the escape of gas, but not of liquid.

THE DRY ELECTROLYTIC CONDENSER

In our everyday experience we have become more or less acquainted with the use of the words "wet" and "dry" to distinguish between the storage battery as used for automobiles (also radio tube filament supply) and the ordinary No. 6 primary cell used for door-bell and amateur telephone systems. We can realize that both are in fact wet, since each depends for its operation on the presence of a chemical solution.

In the field of electrolytic condensers we find the same general misuse of the words "wet" and "dry" as applied to two different mechanical forms of the same electric principle. We may say that both wet batteries and wet electrolytic condensers are wet because they employ a mass of liquid as the electrolyte, whereas in dry batteries and dry electrolytic condensers the liquid electrolyte is absorbed in a chemically inactive medium. They may be considered "dry" for all practical purposes since the electrolyte will not splash around or spill.

The comparison of course does not hold in the sense of the electrical work performed. It will be remembered that in a battery electrical energy is taken from the cell as the result of a chemical or voltaic action in the cell. In a condenser the only energy given up by the condenser on discharge is the energy put into the condenser when it is charged.

In order to inform you more completely on this subject we continue with a summary of various technical articles prepared by the Aerovox Wireless Corporation on their particular make known as the Hi-Farad Dry Electrolytic Condenser. The illustrations included here as Figures 20 to 30 inclusive are reprinted by their permission. Certain technical features are found only in that particular make, but are included here for their general interest.

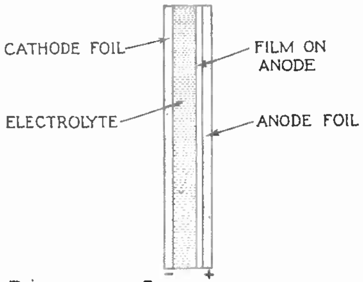


Fig. 20--Constructional detail of the Hi-Farad Dry Electrolytic Condenser

GENERAL

Essentially the Hi-Farad electrolytic condenser consists of:

1. The anode, an aluminum foil,
2. The film, formed electrochemically on the surface of the anode.
3. The electrolyte, which is the cathode proper,
4. Several layers of gauze saturated with the electrolyte, and
5. The second metallic electrode which forms the cathode terminal.

The relative disposition of these various parts is shown in Figure 20.

The foil used for anode and cathode is a particular alloy of aluminum which, in combination with a special electrolyte that does not attack aluminum, precludes any tendency for corrosion and facilitates the formation of a durable film on the anode.

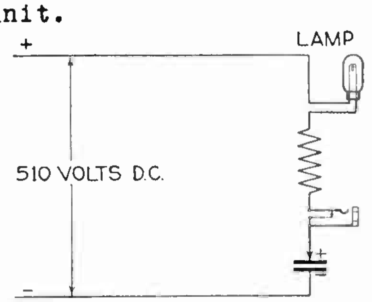
The gauze must also be devoid of any impurities which may affect the forming or the operation of the condenser. Two layers of gauze are placed between the foils. Not only do the two layers of gauze absorb the necessary amount of electrolyte, but the double layer minimizes the danger of breakdown in the case of severe overloads.

A stagger arrangement of the two foils is used for several reasons. In the first place the electrostatic field is most intense along the edges of the foil. Also the film cannot be formed on a sharp edge as effectively as it is formed on a smooth surface. The tendency for increased leakage currents and breakdown in the case of overloads is greatest along the edges, and these conditions are therefore taken care of by separating the edges by about $\frac{1}{4}$ inch.

The electrolyte ingredients are boric acid, glycerine and ammonia, either gaseous or as ammonia water. For producing the electrolyte the ingredients may be combined in the proportion of 1,000 grams of glycerine, 620 grams of boric acid and about 50 cubic centimeters of 26% ammonia water. With the use of this electrolyte, a condenser is formed in a relatively short time and it will, in use, withstand a voltage considerably in excess of 500 volts without breakdown.

WINDING THE CONDENSER

The condenser is made ready for winding by placing the gauze around the end of the cathode foil. The anode foil is then placed in position and the condenser wound up. The outer layer of foil which is the cathode affords quite complete effective electrostatic shielding and also aids in the dissipation of any heat generated within the unit.



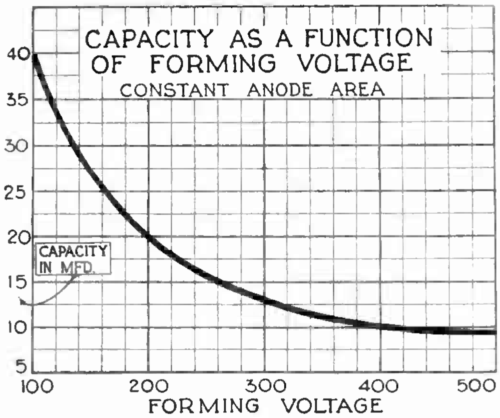


Fig. 21--Film Forming Circuit

Fig. 22--(Right) Capacity Graph

IMPREGNATION

After the condenser has been wound it is ready for impregnation in the electrolyte. As this is a liquid we can thoroughly and uniformly impregnate the sections by immersing them for a period of time in the hot electrolyte. The electrolyte has a relatively high specific resistance, but this does not appear as a disadvantage to the same extent as it would in a wet electrolytic condenser. The dry condenser has such a thin portion of electrolyte between the cathode and the film that the total series resistance is held to a comparatively low value.

FORMING

Before forming we have a unit consisting of two foils separated by two layers of gauze which is completely saturated with electrolyte. The next operation is the forming of the film on the anode. The condensers are formed at a d-c voltage somewhat in excess of that for which they will be rated to operate. Across the d-c supply there is placed in series a resistor, a small incandescent lamp and the condenser to be formed, as shown in Figure 21. Initially, that is before any film is formed, the current is limited almost entirely by the resistance of the resistor and the lamp. The lamp serves to visually indicate that the forming process is proceeding satisfactorily; it also indicates open circuits and high resistance contacts. Leakage currents are checked by means of a milliammeter inserted in series with the circuit. After removal from the forming bath the sections are individually tested for d-c leakage and capacity. They are then ready for final assembly.

The average capacity as a function of the forming voltage is shown in Figure 22.

ASSEMBLY

These condensers can be mounted in containers without any additional dipping or impregnating. Since there is no unabsorbed electrolyte they can be operated in any position and can be placed in either cardboard or metal containers.

Condensers to be mounted in cardboard containers are constructed in the same manner as for metal containers. The cardboard containers are thoroughly impregnated with wax of high melting point and the condensers with the contact tabs riveted to a fiber terminal are placed in the box. The unit is then sealed with an application of pitch over the end of the box.

When the condenser is to be mounted in a metal can the anode contact tab is secured to an aluminum stud projecting from a hard rubber cover. After the unit is mounted on the cover in this manner the section is wrapped in heavy waxed paper and assembled in the can. The grounding of the cathode tab to the can is then accomplished.

Fig. 23
Single Anode Unit
Large Size

Fig. 24
Double Anode Unit

Fig. 25
Triple Anode Unit

Fig. 26
Quadruple Anode Unit

TYPES OF CANNED CONDENSERS

In commercial practice from one to four condensers are included in a single protective can, and (in all cases of the Aerovox manufacture at least) every negative plate is connected to the can. The positive terminals are brought out to terminals on the insulating cover. Figures 23 to 26 inclusive show the external appearance of various types and sizes.

There are various methods of securing such condensers to the chassis of a radio set or other piece of apparatus where it is to be used. In Figures 27, 28 and 29 are shown several ways of mounting such condensers by means of a clamping ring. Figure 30 shows an ingenious method of securing a single-anode type condenser directly to the chassis. Through the chassis there is drilled a hole just large enough to provide clearance for the threaded section of the insulating cover. When the unit is mounted the edge of the can makes contact with the chassis, providing a negative contact thereto. The addition of a lock washer and nut to the threaded section projecting beyond the chassis makes a firm support for the condenser with the least trouble.

PAPER CONDENSERS

Practically every telephone in this country makes use of at least one condenser in which one or more thin sheets of paper act as the dielectric between two or more sheets of metallic foil. The same general type has also had a widespread use in radio receivers, particularly where low voltages are used, but an appreciable capacitance is required, as in by-passing radio frequency currents to prevent their wandering around into other circuits.

If a condenser were built up solely of tin foil and paper, the actual insulating material would be partly paper and partly air, since the paper itself includes air and in addition there are interstices between the layers of paper and foil which also contain air. The effective dielectric constant of the insulating medium of a wound paper condenser is small due to the large effect of air present. To raise this constant it has been customary to impregnate the condenser unit with a substance having a higher dielectric constant than air. Until recently paraffine has been used for this purpose.

How the mounting ring is used to mount a condenser upright above a subpanel.

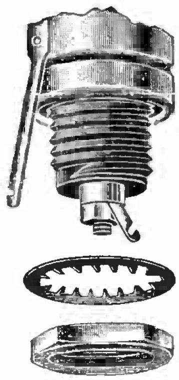
Fig. 27

In this method of inverted mounting, the cover and terminals project through the bottom of the subpanel.

Fig. 28

Showing inverted mounting with terminals on bottom of subpanel with unit partly above and partly below the subpanel.

Fig. 29



Mounting Method

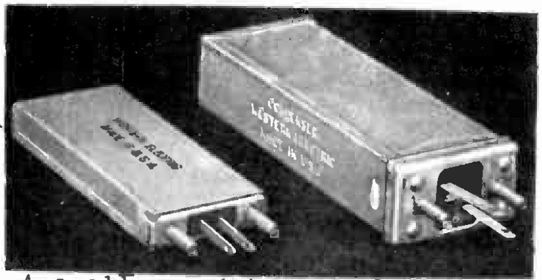
Fig. 30

Manufacturing methods in the past ten years have improved, and laboratory research has developed thin papers of high breakdown voltage, also improved impregnating compounds, particularly one called "halowax". We therefore find that very efficient and economical condensers using paper and foil are still in very good use in many of the radio and audio frequency communication systems. In Figure 31 is shown a comparison between the 1924 and 1932 models of a one mfd. condenser as used in the Bell Telephone System. The saving in space is obvious.

The actual winding process consists in rolling two sheets of tin foil and four sheets of paper so that the completed unit will have two layers of paper between adjacent layers of tin foil. After the winding operation the unit is pressed into compact shape, thoroughly dried in vacuum ovens, and then — while still in a high vacuum — is impregnated with the "halowax." Following this the unit is further pressed to the required size, which forces out all the excess wax, and soldering lugs are fastened to the metal contact strips that, at the beginning of the winding, were laid in contact with the sheets of tin foil. The unit is then ready for potting in the rectangular tin plate containers. Some manufacturers use small cardboard boxes instead of the metal. The containers are partially filled with a sealing compound which, when the condenser units are inserted, completely fills the container and seals the condenser against all entrance of moisture.

In Figure 32 is shown a view of the paper and foil sheets. Aluminum foil has come to replace the tin foil used in earlier condensers.

1932 Model



1924 Model

(Courtesy Bell Telephone Laboratories)

Fig.31--A smaller and better telephone condenser as a result of much research

AIR DIELECTRIC CONDENSERS

These are the simplest to understand, since they are merely a particular application of the fundamental principle that there exists a capacitance between any two conducting areas in air. A familiar type is the rotary variable condenser with which every one is fami-

Fig.32--Two sheets of paper between adjacent layers of aluminum foil form the elements of a telephone condenser

liar in the modern radio receivers and low-powered transmitters, an example of it being shown in Figure 33, the variation being by change in area.

An interesting example of condenser construction is that shown on the front cover, being a pair of tuning condensers for the tank circuit of a 50 k.w. radio transmitter. They are adjustable somewhat

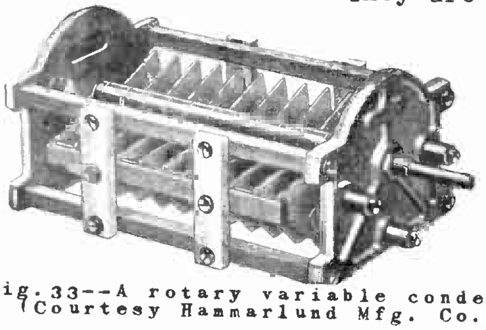


Fig.33--A rotary variable condenser (Courtesy Hammarlund Mfg. Co.)

roughly by loosening the clamps which hold the several plates fixed in position, and moving the individual plates toward or away from each other. In contrast with the preceding paragraph, this variation of capacitance is by change in the thickness of the dielectric. It is obvious that a variation of capacitance by area change could also be accomplished, by merely removing one or more plates from their supporting frame.

EXAMINATION QUESTIONS

1. What is a dielectric material?

2. Explain what happens when a condenser is placed in an A.C. circuit.

3. Describe a simple condenser.

4. What is capacitive reactance?

5. (a) Show by diagram how you would connect three condensers in series. (b) In parallel.

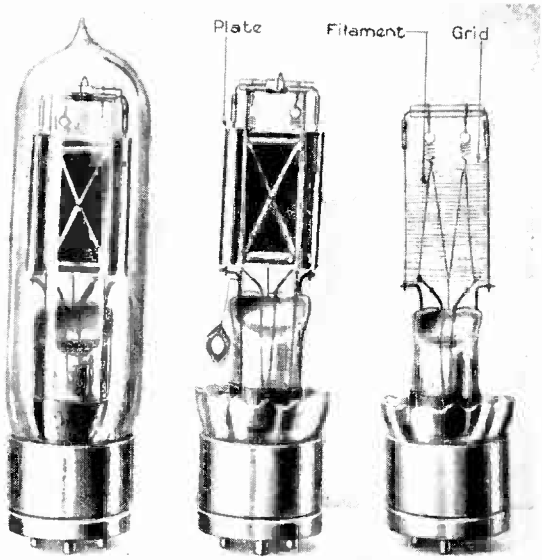
6. What is your understanding of the term "capacitance"?

7. When three condensers, each having a capacitance of .001 microfarads are connected in series what is the total capacitance?

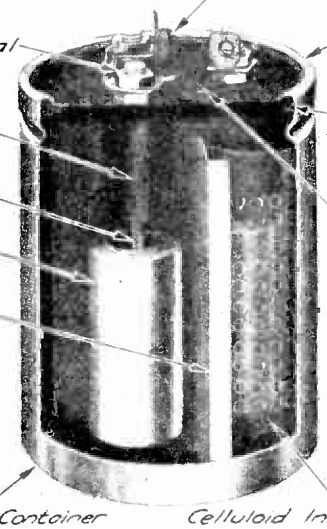
8. Describe three types of condensers.

9. What is the action of a condenser when placed in D.C. circuit?

10. When four condensers, each having a capacitance of .002 microfarads are connected in parallel what is the total capacitance?



The closely-spaced metal elements of a vacuum tube provide capacitances which are of importance in amplifier design



Interior Construction of
Amrad condenser

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