AEROVOX
HI-FARAD DRY ELECTROLYTIC CONDENSER


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

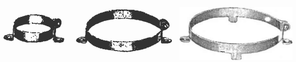

In this method of inverted mounting, the cover and terminals project through the bottom of the subpanel.

Hi-Farad Condensers Can Be Mounted in Any Position

Hi-Farad Dry Electrolytic Condensers can be used with perfect safety in any position—upright, horizontal, inverted or at any other angle.

The mounting rings furnished with Hi-Farad condensers are universal in their application. With them, Hi-Farad condensers can be mounted in upright or inverted positions above or below the subpanel or mounting base to any desired amount as shown in the photographs illustrating the condensers mounted in various positions above and below the phantom view of the subpanel.

Hi-Farad condensers are also standard in size enabling replacement changes to be made in practically all types of radio sets.


Type TAR Type TBR Type TCR

Mounting Rings for Hi-Farad Condensers


Showing mounting ring used to mount a condenser partly above and partly below subpanel.


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

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Vol. 4 October-November, 1931 No. 7

The Aerovox Hi-Farad Dry Electrolytic Condenser

By the Engineering Department, Aerovox Wireless Corporation

[*Prepared and delivered as an address through the medium of a sound motion picture at the Institute of Radio Engineers Fall Meeting, Rochester, N. Y., November 9-10.*]

THE purpose of this paper is to describe the construction and performance characteristics of the Aerovox Hi-Farad Dry Electrolytic Condenser, the condenser being referred to as "dry" to indicate that it contains no unabsorbed electrolyte. Such construction eliminates any possibility of leakage of the electrolyte. The general use of this type of filter condenser in radio receivers is due to a number of factors of which the following are probably the most important.

The first advantage, and in these days a most important one, is its low cost. See Fig. 1. An 8 mfd. 500 volt electrolytic condenser costs a set manufacturer about one-sixth as much as a paper condenser of the same rating.

A second advantage, Figs. 2 and 3, is compactness and light weight. For a given voltage and capacity the electrolytic condenser requires a comparatively small amount of space. An 8 mfd. 500 volt unit weighs but approximately 100 grams.

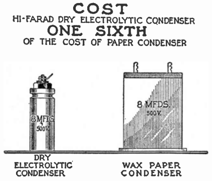

Fig. 1

A third advantage is the ability to accurately predetermine the maximum voltage the condenser will withstand.

The fourth advantage is its comparative immunity to voltage surges in excess of its rated peak voltage.

These valuable properties are primarily due to the fact that the electrolytic condenser incorporates an extremely thin film formed electro-chemically usually on the surface of the anode. Its exact thickness has not been accurately determined, but in the case of a 500 volt condenser it is the order of one hundred thousandths to one millionth of an inch thick.

The film formed on a smooth clean surface is transparent. Due to light interference effect, however, the film may sometimes appear to be tinged faintly red, yellow, green or blue, depending upon the thickness of the film. The great dielectric strength of the film enables it to withstand high voltages and its thinness makes it possible to secure high capacities per unit area. On an average, each square inch gives a capacity of approximately 0.06 mfd.

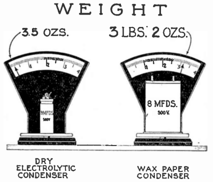

Fig. 2

These dielectric properties of the film are effective only as long as a positive potential is applied to the anode. Should the polarity be reversed the film will not oppose the flow of current and the unit ceases to function as a condenser. Hence the ordinary electrolytic condenser can be subjected only to uni-directional currents; they are not suitable in circuits with straight alternating currents, and in general where reversal of the polarity occurs.

During manufacture, the film on the anode is formed to a certain definite voltage and electrolytic condensers will operate safely on all voltages not exceeding the forming voltage. As the forming voltage can be accurately controlled during the manufacturing process, it is easy to rate the units correctly without taking recourse to large safety factors. This

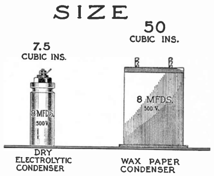

Fig. 3

AEROVOX PRODUCTS ARE BUILT BETTER

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means that the set engineer, knowing the peak voltage in his receiver, can purchase filter condensers that will safely withstand the peak voltages.

The maximum voltage to which a condenser can be formed depends upon the characteristics of the electrolyte. Whereas these condensers are normally rated at 500 volts peak and are actually formed at a somewhat higher voltage, we have, by slightly altering the electrolyte, constructed condensers which successfully withstand 600 volts peak, and which have now been on life test for several thousands hours and show no signs of deterioration.

With paper condensers over-voltages may cause permanent breakdown of the condenser. However, should momentary over-voltages be applied to the electrolytic condensers its film gives way while the surge lasts, but as soon as the excessive strain is over the film is restored for it is an oxide which is rapidly produced by the electrochemical action of the leakage current itself; in this way the condenser almost immediately regains its normal operating characteristics. Excessive voltages do not, therefore, destroy permanently the dielectric layer and this characteristic makes the condenser immune to ordinary surges.

Essentially the Hi-Farad electrolytic condenser consists of

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

The capacity effect may be considered to be produced between the surfaces of the anode and the electrolyte and is due to the film between them. See Fig. 4. The electrolyte establishes an intimate contact with the film and the second metallic electrode is in effect an extension of the electrolyte. It should be pointed out, however, that this theory of operation is not universally accepted, some engineers believing that the unit functions because of a thin layer of gas on the surface of the anode. The opinion has also been expressed that a cell consisting of two aluminum electrodes with an electrolyte which does not attack aluminum is really not an electrolytic condenser but a true electrostatic condenser in which the film of alumina is the dielectric.

Type 15-8

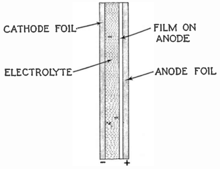


Fig. 4

Performance Characteristic

In considering the performance of the dry electrolytic condenser, the following factors are of importance.

1. Life
2. Maintenance of capacity
3. Normal leakage current
4. Leakage current after periods of idleness
5. Ability to operate over wide ranges in temperature
6. Efficiency in filter circuits

The curves given illustrate these factors. Some of these curves have been made in our own laboratory, others have been made in the laboratories of set manufacturers. Our own curves and those made by outside sources have been in close agreement. In our laboratory condensers of this type have been tested under all conditions of humidity, temperature and voltage. In some tests only d.c. was applied, in other tests 120 cycle or 60 cycle voltages were superimposed on the d.c. voltage. In general the test conditions have been much more severe than those to which the condenser will be subjected in practice.

The curve, Fig. 5-A, is of interest in showing how well the condensers perform when continuously subjected to temperatures as high as 150 degrees F. It will be noted, Fig. 5-B, that the condensers maintain their capacity during the entire 1000 hour test. In this test the condenser was weighed before and after the thousand

AEROVOX NO. 19
ELECTROLYTIC CONDENSER LIFE TEST

INITIAL WT. 112.210 GMS.
FINAL WT. 112.231 GMS.
DIFF. +0.021 GM.
LOAD OF 375 VOLTS D.C.

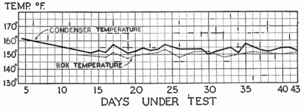


Fig. 5-A

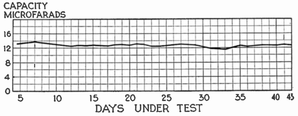


Fig. 5-B

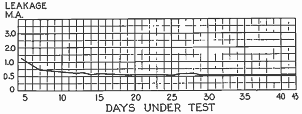


Fig. 5-C

The ingredients used for the electrolyte 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 one thousand grams of glycerine, six hundred and twenty grams of boric acid and about fifty c.c. of twenty-six per cent ammonia water or the equivalent amount of ammonia gas.

By heating the mixture to boiling and continuing until the boiling point at atmospheric pressure is about 130 degrees C. and holding the solution at this temperature for preferably at least five minutes, the preparation of the electrolyte is completed.

The resultant liquid is a fluid and will have the viscosity between 3 and 4.5.

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 without breakdown and have a high capacity per unit area of the anode plate.

Forming

Before forming we have a unit consisting of two foils separated by two layers of gauze which is completely impregnated 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 Fig. 1. 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.

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. The condensers are mounted in metal cans in the following manner.

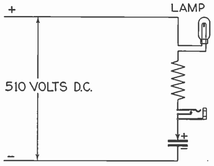


Fig. 1

Moulded in a hard rubber cover is an aluminum stud. The hole in the anode tab is placed over the projecting stud and an aluminum washer placed on top. Then, by machine, the protruding stud is spun down forcing the various pieces tightly together. In this manner a very positive, dependable connection is made between the anode terminal and the anode tab. 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 accomplished by spinning the corresponding tab on the top of the can while the cover is being sealed.

The use of an aluminum can carries out the idea mentioned previously of using no metal but aluminum. Not only is the weight held to a minimum, but there is little possibility of local galvanic action.

Condensers to be mounted in cardboard containers are constructed in the same manner as has been described. The cardboard containers are thoroughly impregnated with wax of high melting point and the condensers with the tabs riveted to a fiber terminal strip are placed in the box. The unit is then sealed with an application of pitch over the end of the box. The pitch will not flow even at temperatures considerably above 200 degrees F.

Aging and Final Testing

After assembly the condensers are aged by placing them across a d.c. voltage slightly in excess of their rated peak voltage. They are afterward given a final test for leakage and capacity. A percentage of each days production is tested more elaborately by the laboratory.

Mounting Details of Screw Mounting Type Hi-Farad Condensers

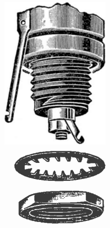
The illustration at the left shows in detail the construction of the insulated type of mounting used in the I Type cans. The thread, insulating boss and cover of the can are made of moulded bakelite.

In mounting, a clearance hole for the thread is made in the chassis. The insulating boss keeps the can clear of the chassis.

The grounded type unit is shown at the right. In this unit no insulating boss is used. When the unit is mounted, the edge of the can makes contact with the chassis. This type of unit, however can be converted into an insulated type of mounting by placing an insulating washer over the thread before mounting it on the chassis. The washer then prevents contact between the can and the chassis.

Type I—Insulated Can Mounting

Disassembled view of nut, lock washer and screw mounting designed to insulate cathode (can) from metal chassis.



Type G—Ground Can Mounting

Disassembled view of nut, lock washer and screw mounting designed to connect cathode (can) to metal chassis on mounting.

The Construction of Hi-Farad Dry Electrolytic Condensers

THE foil used for anode and cathode is an alloy of aluminum made especially for Hi-Farad condensers. This aluminum alloy in combination with our electrolyte that does not attack aluminum precludes any tendency for corrosion and facilities 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 later to be impregnated with electrolyte, 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.

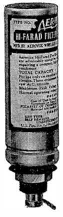
Reinforced Tabs

Vital parts of the unit are the tabs which are reinforced to increase the dependability of the condenser both mechanically and electrically. The reinforcement of the anode tab consists of an aluminum strip superimposed on and eyeletted to the foundation tab, the latter being part of the anode foil itself. In this manner a strong terminal for the section is obtained. To prevent corrosion the eyelets used for the reinforced tabs are of aluminum.


Cardboard Box
Type P5-8

Corrosion of the tab is also prevented due to the fact that our electrolyte, being a liquid, creeps along the anode tab and thereby tends to maintain a film formation on the tab.

The two foils of the Hi-Farad condenser are staggered or offset, the edges being separated by about one-quarter of an inch. This patented staggered arrangement is used for several reasons. In the first place the electrostatic field is most intense along the edges of the foil. Also the film can not be formed on a sharp edge as effectively as it is formed on a smooth surface.


Type G5-8

Therefore, the tendency for increased leakage currents arcing and breakdown in the case of overloads is always greatest along the edges. These conditions are taken care of by the separation between the edges of the two foils, an exclusive feature of the Hi-Farad condenser.

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.

The outer layer of foil is the cathode on which there is formed no film; this outer layer affords quite complete electrostatic shielding and also aids in the dissipation of any heat generated within the unit.

Impregnation

After the condenser has been wound it is ready for impregnation in the electrolyte. The selection, proportioning and treatment of the ingredients used in the preparation of the electrolyte are all important factors which determine the properties of the condenser. An electrolyte has been developed which not only does not attack aluminum but which also permits the formation of a hard durable film capable of withstanding high voltage, of remaining stable over a wide range in temperature and which gives extremely low leakage.

As the electrolyte 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 used in this condenser has a relatively high specific resistance. In general it has been found that electrolytes of low specific resistance are chemically more active and hence exhibit a greater tendency to attack the electrodes and produce corrosion. Corrosion of the anode or anode tab is the most damaging irregularity that can occur.

Neglecting corrosion, the life of an electrolytic condenser depends upon the ability of the electrolyte to retain its moisture content. In the Hi-Farad condenser a balance is maintained between moisture lost and moisture gained because the solution is hygroscopic and it readily absorbs moisture to make up for that lost through evaporation or electrolysis. For these reasons we find that the amount of electrolyte initially placed in the condensers bears little relation to the life of the condenser. Electrolytes in acqueous type condensers are non-hygroscopic and cannot absorb moisture to make up for that lost due to evaporation and electrolysis.


Cardboard Box
Type P5-88

These conditons are especially noticeable when the condensers are subjected to temperatures in the order of 140 degrees F. The deciding factor is not the amount of moisture, but the ease with which the water is evaporated or decomposed and the ability of the electrolyte to reabsorb moisture. The electrolyte used in this condenser shows a strong tendency to maintain its moisture content with the result that condensers operated for long periods at high temperatures show no loss in weight.

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hour period to determine the change in weight of electrolyte. These figures are given in Fig. 5 and show a gain in weight of approximately 0.02 grams. This gain in weight is due to the fact that the electrolyte contains a large percentage of glycerine which is hygroscopic, and in this case the absorption of moisture caused a slight increase in weight. Other condensers did not show the same change in weight, and on an average the condensers showed a negligible change in weight after operation for 1000 hours. No change in weight after 1000 hours of continuous operation at 150 degrees F. means that the condenser has an extremely long life.

This curve of Fig. 5-C also gives information on the leakage. During practically the entire test the leakage current averaged between 50 to 100 microamperes, or from 4 to 10 microamperes per microfarad. These low values of leakage current are regularly obtained under conditions of continuous operation.


Type I5-4

For a constant anode area, the capacity obtained is approximately inversely proportional to the formation voltage. With our elcctrolyte, a total formed anode surface of 156 square inches gives a capacity of 8 mfds. when the unit is formed at 500 volts; if the formation voltage is 250, then the same anode area gives a capacity of 16 mfds. These facts are illustrated by the curve, Fig. 6.


Type G5-16

Since the capacity depends upon the formation voltage, the question naturally arises of the effect which occurs when a unit formed to a certain voltage is operated on a lower voltage. Experience has indicated that under such conditions the capacity gradually increases if the unit is operated on a voltage lower than the original forming voltage. The change in capacity takes place very slowly, however. To check this point, an 8 mfd. 500 volt condenser was placed across a 45 volt circuit. The unit had an initial capacity of 8 mfds. After operation for three thousand hours at 45 volts, the capacity increased to 13 mfds. This represents the extreme condition since the operating voltage was only one-tenth of the initial forming voltage. We can conclude, therefore, that when units are operated at voltages somewhat lower than the forming voltage, the capacity will increase very slowly, and that no considerable change in capacity will occur over an operating period of several thousand hours.

In the test described, the condenser was actually used as a by-pass across a C-bias resistance in a receiver. The current in the circuit was quite limited, being about one mA and this test can therefore also be taken to show that this electrolytic condenser maintains its capacity even when the d.c. current is very limited. We have received a number of inquiries from engineers who consider that


Type G5-4

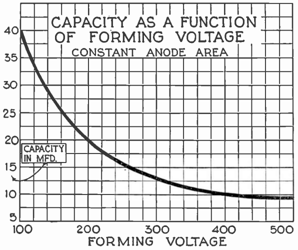

Fig. 6

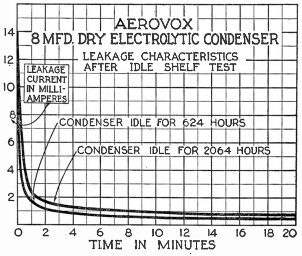

Fig. 7

if an electrolytic condenser is used as a by-pass in circuits where the current available for maintaining formation is limited to about one mil., that the unit would gradually deform and cease to act as a condenser. This test showed that such an effect does not occur, that the condenser maintains its characteristics even when the available current is extremely small.

We have also determined the leakage characteristic of the condenser after long periods of shelf life. The two curves, Fig. 7 give the leakage characteristic after idle periods of 624 and 2064 hours. These curves represent a very severe test for the idle periods were extremely long and in determining the leakage 500 volts d.c. were applied, and this voltage is considerably higher than that to which the condensers are subjected in the usual receiver.

Type E5-8

It will be noted that these two curves differ but slightly though they represent widely different idle periods. This indicates that the film structure is quite permanent and that deterioration, if there be any, takes place very slowly.

It should be noted that the current drops rapidly during the first thirty seconds after the voltage was applied.

Effect of Temperature

It is obvious that if an electrolytic condenser is to give satisfactory service it must be able to withstand both high and low temperatures. The test specifications of many companies include tests at 140 degrees F. with superimposed a.c. and d.c. Fig. 5 shows that the condenser gives excellent performance when continuously subjected to such temperatures. The curve, Fig. 8, shows the effect on capacity of temperatures from zero up to 150 degrees F. At room temperature, 75 degrees, the condensers under test have an average capacity of 8 mfds. Temperatures above this value cause an increase in capacity and temperatures below 75 degrees cause a decrease in capacity; this is characteristic of all types of condensers which we have tested. It is important to note, however, that the condenser remains operative down below zero degrees F. due to the fact that electrolyte used has a very low freezing point. Subjecting condensers to temperatures below zero F. and then allowing them to return to room temperature has shown that these low temperatures have no permanent effect on the condenser characteristic.

Type E5-4

Efficiency In Filter Circuits

The following data have been obtained from a number of measurements on filter circuits using our electrolytic condenser. These data will show that in filtering action the condenser is essentially equal in every respect to a paper condenser of the same capacity.

In the course of our research on electrolytic condensers units of various power factors were constructed and we found that as the power factor is reduced by suitably altering the electrolyte that the tendency for corrosion to take place is increased. Considerations of corrosion make it desirable therefore not to produce condensers of power factors lower than are needed to give satisfactory results. The curves and data to be shown indicate that if the power factor is 20 per cent or lower, the filtering efficiency of an electrolytic condenser is essentially equal to that of a paper condenser.

Type E5-88

In view of these facts our research was aimed to design a condenser that would

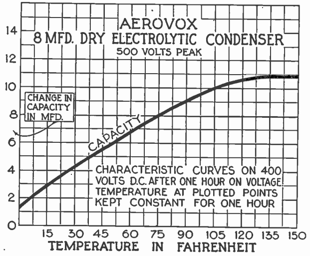

Fig. 8

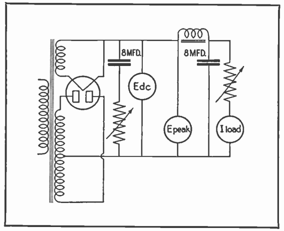

Fig. 9

contain no unabsorbed electrolyte, that would have a long life and be free from corrosion. To sacrifice any of these valuable properties to obtain a low power factor could hardly be considered sound engineering.

The tests were made using a standard filter circuit consisting of a type 280 rectifier, two 8 mfd. condensers and a single choke coil. The circuit, see Fig. 9 was arranged to use for the first condenser an 8 mfd paper condenser in series with which resistors of various values should be placed to produce a given increase in the power factor of the circuit. Using this method the effect on the filter circuit could be obtained by using condensers of various power factors. It was found that the filter condensers with power factors up to about 20 per cent produce extremely small changes in both the d.c. voltage and the ripple voltage.

Type E5-888

If we consider the a.c. ripple voltage across the first condenser to be a measure of the filtering action and also consider that a zero power factor condenser gives maximum or 100 per cent filtering action, then we can calculate the percentage decrease in filtering action which results from the use of condenser of any given power factor. The results of such calculations are shown by Fig. 10. A zero power factor condenser gives 100 per cent filtering action. As the power factor is increased the filtering efficiency drops very slowly at first and then much more rapidly. It will be noted that the curve begins to bend quite sharply for power factors beyond about 20 per cent. The decrease in filtering efficiency for power factors up to 20 per cent is slight and is in fact so small that for all practical purposes it can be neglected. These calculated results have been checked experimentally. Table I shows calculated and measured data and they both check quite clearly. The table brings out once again that power factors up to 20 per cent have a negligible effect on filtering efficiency.

Percentage Increase in A.C. Ripple,
Across First Filter Condenser,
as a Function of Power Factor

E ac for plate=350
I load=125 mA

Power Factor in Percent	*Calculated Percentage Increase in Ripple*	*Measured Percentage Increase in Ripple*
0	0	0
5	0.1	0.1
10	0.5	0.8
15	1.1	1.2
20	2.0	1.9
30	4.5	3.9

Table I

The effect of power factor on d.c. output voltage is also extremely small. These curves, Fig. 11 give d.c. output voltages of a type 280 rectifier with an 8 mfd. condenser and an a.c. plate voltage of 350 volts per anode. It will be noted that the difference in output with condensers of zero power factor and 25 per cent power factor is negligible amounting to only about 1 per cent at a load of about 120 mils. It will be obvious therefore that ordinary line voltage fluctuations will cause *greater* changes in ripple and d.c. voltage than will be caused by the use of filter condensers with power factors up to 20 per cent.

Type E5-8888

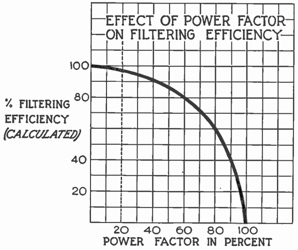

Fig. 10

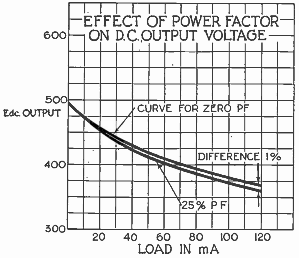

Fig. 11