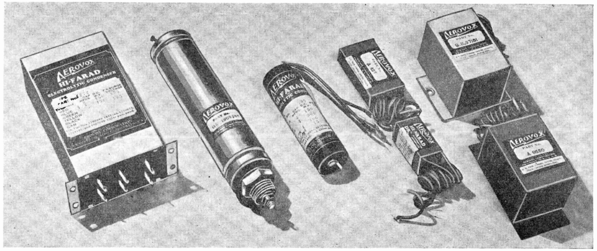

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Connecting Condensers In Series

By the Engineering Department, Aerovox Corporation

IT frequently happens that condensers are needed in a circuit which develops a high voltage while the constructor does not have available condensers of the proper voltage ratings. It is then often the practice to connect several lower-voltage condensers in series in the hope that they will serve as well as a single high-voltage condenser. When using d.c. this may result in a breakdown of all condensers—the best one going first—unless special precautions are taken.

The idea that two condensers in series will have only half the applied voltage across each of them is probably borrowed from alternating current theory or of the academic case of perfect condensers which have no leakage. Such condensers, however, have never been made yet and consequently the voltage does not divide equally across condensers with d.c. applied to them. In the following paragraphs we shall briefly review the reasons for this and suggest a cure.

SERIES CONDENSERS IN A.C. CIRCUITS

In a.c. circuits the voltage across any impedance element (a resistor, condenser, inductance or combination of these) is given by Ohm's Law for alternating current circuits:

$$E = IZ \quad (1)$$

In the case of several condensers in series, the current, I, passing through them is the same and consequently, the voltage across each one of the condensers is proportional to their impedance.

In Fig. 1 two condensers, C_1 and C_2 are connected across an alternating voltage source delivering E volts at a frequency f. First assume that $C_1 = C_2$ then, according to equation (1) the voltages e_1 and e_2 are proportional to the respective impedances or rather *reactances* of C_1 and C_2. The reactances of Cl and C are equal since their capacity is equal, therefore in this case $e_1 = e_2$.

On the other hand, suppose C_1 equals 1 mfd. and C_2 equals 5 mfd. Assume that E is 600 volts and the frequency 60 cycles. The voltages e_1 and e_2 are now found as follows.

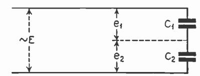

Fig. 1

Reactance of $C_1 =$

$$\frac{1}{6.28 \text{ X } 60 \text{ X } 1 \text{ X } 10^{-6}} = 2650 \text{ ohms}$$

Reactance of $C_2 =$

$$\frac{1}{6.28 \text{ X } 60 \text{ X } 5 \text{ X } 10^{-6}} = 530 \text{ ohms}$$

Total reactance in the circuit:

$$2650 + 530 = 3180 \text{ ohms}$$

$$e_1 = \frac{2650}{3180} \times 600 = 500 \text{ volts}$$

$$e_2 = \frac{530}{3180} \times 600 = 100 \text{ volts}$$

This example shows that the largest condenser has the smallest voltage across it; the voltage is inversely proportional to the capacity. The capacity of the series combination, of course, is found by the usual formula

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{1 \times 5}{1 + 5} = \frac{5}{6} \text{ mfd.}$$

The resultant capacity is therefore *smaller than the smallest* of the condensers in the series combination.

SERIES CONDENSERS IN D.C. CIRCUITS

An ideal condenser would be a device which had nothing but capacity: i.e. no resistance either in series or in parallel and no dielectric losses. If such a condenser could be made, voltages across condensers of equal capacity would indeed be equal. However, even the best condensers have a certain amount of leakage which in this case determines how the voltage is going to be divided. As soon as the initial rush of current, which charges the condensers, is over, the behaviour of condensers in a d.c. circuit is just like high resistances. The value of this resistance which is known as the insulation resistance, and its variations have been described in the Aerovox Research Worker for March 1935. If two condensers of the same capacity are employed and both are new, the insulation resistance of one may easily be twice that of the other and yet both may be perfectly good condensers which would pass any standard test. When the condensers are old, or when one is older than the other or when one has seen more service than the other, the insulation resistance of one could easily be ten times as much as that of the other and the ratio can be even worse.

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Bearing in mind these remarks, let us look what will happen when two condensers of unequal insulation resistance are connected across a d.c. voltage supply. Fig. 2 illustrates a

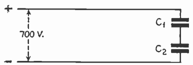

Fig. 2

power supply of 700 volts with two condensers connected across it. Assume that C_1 and C_2 are 2 mfd. each and that the insulation resistance of C_1 is 500 megohms and that of C_2, 2500 megohms. The equivalent circuit is shown in Fig. 3. Since the voltage across the condensers is now proportional to their resistances, we have:

$$e_1 = \frac{500}{2500 + 500} \times 700 = \frac{700}{6}$$
$$= 118 \text{ volts}$$

$$e_2 = \frac{2500}{2500 + 500} \times 700 =$$
$$\frac{5}{6} \times 700 = 582 \text{ volts}$$

The result is now that C_2 which is the best of the two condensers, will break down first. As soon as this has happened, all the voltage is across C_1 and that one will break down too. The

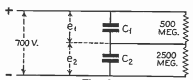

Fig. 3

breakdown may not happen immediately but since the condenser is connected to a voltage much higher than it is designed for, its life will be greatly shortened. It is variously estimated that the useful life is inversely proportional to the fifth power or the seventh power of the applied voltage. This would mean that, to apply twice the rated voltage divides the useful lifetime by 32, at least!

Taking another example: In a power supply of 1000 volts, three 400 volt condensers of equal capacity are used having insulation resistances as follows: C_1, 1000 megs; C_2, 1000 megs; C_3, 2000 megs. This makes a total of 4000 megs. Consequently the voltage across the three condensers is

$$e_1 = \frac{1000}{4000} \times 1000 = 250 \text{ volts}$$

$$e_2 = \frac{1000}{4000} \times 1000 = 250 \text{ volts}$$

$$e_3 = \frac{2000}{4000} \times 1000 = 500 \text{ volts}$$

This shows again that C_3 is overloaded and is likely to break down. Meanwhile the constructor may have imagined that his combination was good for 3 times 400 or 1200 volts.

THE REMEDY

The difficulty can be overcome by connecting resistors across the condensers. The value of the resistors

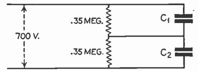

Fig. 4

should be chosen so as to be small compared to the insulation resistance of the condensers. On the other hand they should be high enough not to interfere with the operation of the circuit wherein they are used. This value will have to be determined for each case, but generally an additional drain of 1 ma. will not do any harm and will result in satisfactory division of the applied voltage.

Consider again the problem of Fig. 2, now redrawn with shunt resistors of .35 meg. each, in Fig. 4. The equivalent circuit appearing in Fig. 5. It can be considered that two resistances, one of 500 megs. and one of 350,000 ohms are across C_1 similarly, 2500 megs. and 350,000 ohms are across C_2. The resultant resistance across C_1 is then

$$\frac{500 \times .35}{500 + .35} = \frac{175}{500.35} = .3497 \text{ meg.}$$

Across C_2 there is a total resistance of

$$\frac{2500 + .35}{2500 \times .35} = \frac{875}{2500.35} = .3499 \text{ meg.}$$

The voltage now divides in proportion to these resistance values; hence, the voltage across C_1 is:

$$700 \times \frac{.3497}{.3497 + .3499} =$$
$$\frac{.3497}{.6996} \times 700 = 349.9 \text{ volts}$$

The voltage across C_2 is

$$700 \times \frac{.3499}{.3497 + .3499} =$$
$$\frac{.3499}{.6996} \times 700 = 350.1 \text{ volts}$$

This illustration shows the effectiveness of the method, since the difference is now only .2 volts. There are those who will object that this will detract from the filtering efficiency of the condenser combination. Let us see whether it does. Taking an unfavorable case, assume that both condensers were 2 mfd. condensers, then the resulting capacity is 1 mfd. If the frequency to be filtered out is 60 cycles, the equivalent series resistance corresponding to a parallel resistance of 700,000 ohms is:

$$r = \frac{Xc^2}{R} = \frac{1325^2}{700000} = 2.5 \text{ ohms}$$

The power factor due to this resistance alone would be

$$\frac{2.5}{1325} \times 100 = .19\%$$

The Research Worker for October and November 1934 amply explain the

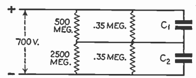

Fig. 5

unimportance of such a small amount of series resistance. In fact, the resistance across the condensers could be much smaller without seriously impairing filtering efficiency.

SUMMARY

1. Condensers can be connected in series to obtain a higher voltage rating, if all condensers are of the same capacity. This can be done with paper, oil or electrolytic condensers.

2. It is recommended that the total voltage rating of the series condensers exceed the applied voltage. for instance: It is best that 4 400 volt condensers be used for a 1200 volt power supply, 3 electrolytics of 500 volts to be connected across 1000 volts, etc.

3. As a safety measure, it is essential that resistances of equal value be connected across each condenser. These resistances should have values which are small compared to the insulation resistances of the condensers.

4. Contrary to popular opinion, these resistances are not detrimental to the operation of a filter, even if they are as low as 100,000 ohms.

5. The capacity of the combination of condensers is equal to the capacity of one condenser divided by the number of condensers in series.

The Elimination of Interference

THE public calls all radio noises "static". Before opening our discussion of this subject, we should first define what is meant by natural atmospheric static and "man-made static".

Strictly speaking, static is caused by natural discharges only, such as thunderstorms and lightning. This type of interference cannot be eliminated at the present development of the radio art and we therefore are not concerned with it in this article. All other kinds of noises and interference are caused by electrical machinery, including the radio itself; it is not static and can be eliminated in most cases, if the source can be ascertained.

This interference, or noise, also called "man-made static", can be subdivided according to its source into noises originating in the receiver itself, noises caused by someone else's receiver, and noises due to electrical discharges or sparks in electrical wiring or appliances.

Noises originating in the receiver are generally due to bad connections, defective tubes, condensers, resistors or transformers. Such an interference is of the frying and sputtering kind. Sometimes it may be intermittent and the cause is then rather hard to locate. In general, whether the noise is in the receiver or not, can be determined by disconnecting the aerial and ground, short circuiting the antenna and ground connection and, using a line filter, and then trying the receiver. If the noise persists, it originates in the set. Removing the tubes one by one will often help to find the trouble. When the noise stops as a tube is removed, the noise starts in that stage or those ahead of it.

Squeals or howls may be due to an oscillating condition in your receiver or your neighbor's receiver. It may also be caused by acoustic feedback between the speaker and some part of the set. This condition can be corrected by moving the speaker or by insulating it with sound absorbing material.

By far the greatest difficulty is encountered with noises of the third type, or those caused by electrical machinery. The cause of it all are the electric motors, switches, etc. which make or break a current suddenly, giving rise to a damped oscillatory discharge. A wave is then *propagated along* the power line as well as along any other wires or metal objects connected to the device. The energy is also being *radiated* by these conductors, so that it can be transmitted to the receiver by way of the antenna.

The part which follows the power line may be conveyed to the receiver by way of the power cord and cause noise. However, the radiated energy is picked up by every conductor in the vicinity, including the antenna, ground, as well as neighboring pipes, wires, etc. The antenna itself will bring the noises to the set, but if the antenna did not pick up the noise direct, it is still possible that it is capacity coupled to some other wire and picks it up in that way.

Obviously, the most effective remedy is to check the noise at its source, by preventing the propagation and radiation by means of a capacity filter. Electric motors, or other noise making machinery should be supplied with a filter consisting of two condensers in series across the line with the center tap grounded. It is important in this case to place the filter as close as possible to the spark so that the wires between it and the filter are not long enough to be effective radiators. Also, the centertap must be grounded to the frame of the machine, not to an independent ground for this would complete the r.f. circuit through considerable length of power wire which causes radiation. The correct circuit is illustrated in Fig. 6.

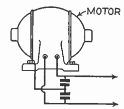

Fig. 6

When more leads leave the interfering machine, they all should be filtered in the same way, with a filter placed on the machine and grounded to the frame of the machine.

A line filter used at the receiver can of course do only half a job, because some of the interference is coming by way of the antenna circuit. In order to eliminate this too, it would be necessary to be sure that the antenna does not pick it up by placing the antenna far away from the interference source and to conduct the signal to the receiver by a lead-in which does not pick up anything. Good results can be obtained by a transposed or twisted lead-in such as those now being sold in special kits.

It is also necessary to pay more attention to the ground. A gas pipe or steam pipe travels a long way before it finally reaches ground, and underway it can have disturbances induced in it, or it can even be connected to interfering machinery. It stands to reason that this type of noise will also enter the set. A very short lead to an independent ground would be the best remedy. Unfortunately, the city dweller is not always in a position to obtain such a ground.

The small indoor antenna often picks up noise, for the reason that it is closely located among the sources of interference, and it works as an antenna coupling to neighboring conductors. All these conductors however may have noise induced in them as they are really a part of the antenna. In other words, the effective antenna will change when a lamp is switched on or off somewhere causing sudden changes in volume of the received signal. Many complaints of variations in volume are caused by such a condition.

The Thordarson Condenser Tester

To the many tools of the up-to-date service man there is now added a simple, inexpensive, practical condenser tester. Designed and sponsored by Thordarson Electric Manufacturing Company, the tester may be assembled from a foundation unit and specified components in less than an hour. The completed job, housed in a neat portable walnut instrument case, will be found useful both on the service bench and out in the field, in dealing with condenser problems and replacements. General details are contained in a special circular being mailed with this issue of the Research Worker.

Because Aerovox condensers have been chosen as standard components for this tester, and also because of our desire that condenser tests should be reasonably indicative of capacity and leakage, our engineers have assembled and checked the performance of the Thordarson condenser tester. This instrument has been found satisfactory and adequate for radio servicing requirements. The designers have struck a happy compromise between a very small investment and reasonable accuracy within the usual tolerances of service work, as contrasted with the elaborate and costly capacity measuring equipment for laboratory practice, calling for a variety of oscillators of good wave form, bridges, amplifiers, balance indicating devices, filters, and so on.

The necessary Aerovox Condenser Kit for the Thordarson Condenser capacity and leakage tester is now available. The kit comprises seven tubular and metal-case paper condensers, listing at \$5.65 for the complete kit.