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Condenser Leakage and Its Effects

By the Engineering Department, Aerovox Corporation

SERVICEMEN, engineers and experimenters are generally supplied with instruments which will tell them whether a condenser is shorted or open and what the capacity is. Yet this tells not enough and there is a trend towards more complicated condenser testers which will give an indication of insulation resistance or leakage. Assuming that such an instrument were available, where shall we set our minimum of insulation resistance — in other words, how much shall we let it leak?

Some people have set a limit with the result that servicemen have found that certain condensers which should be unsatisfactory according to this rule, are still performing their duty perfectly. Also, there are condensers which test o.k. and yet do not give satisfactory service. As a matter of fact, a single practical limit cannot be given, since it will vary with the service the condenser has to perform. There are condensers which have to satisfy very rigid requirements in regard to leakage and there are others which may have some leakage without causing any harm. It all depends on where these condensers are to be used. It is the purpose of this article to point out the reason for this strange fact and to calculate the effect of a given insulation resistance on the performance of condensers used in various circuits of a radio receiver.

First it is necessary to remember that a "perfect" condenser of the tubular (paper dielectric) type may have an insulation resistance of 15000 megohms. When the outside carton is damp, this may decrease to 1000 megohms. If the leagage of a condenser is *very* bad, the insulation resistance may fall to 100 megohms. It will be shown that so low a resistance will be fatal for certain uses of a condenser, but for others it is quite unimportant.

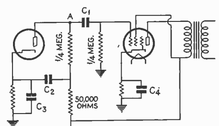


FIG. 1

That the leakage has very little to do with bypassing efficiency has already been shown in the Research Worker for October 1934 but we shall return to this later. First this discussion shall be restricted to d.c. phenomena caused by leakage.

CRITICAL LOCATIONS OF A CONDENSER

Blocking condensers are used in resistance coupled amplifier circuits in order to prevent the high voltage from reaching the grid of the next amplifier tube. This is illustrated in Fig. 1, where a voltage amplifier tube is resistance coupled to a power pentode. C_1 is the condenser in question. Suppose that the current drawn by the voltage amplifier tube is .2 ma, then the voltage drop in the load resistance and the filter resistance will be

$$300{,}000 \times .0002 = 60 \text{ volts}$$

The voltage at the point A is then 300 — 60 = 240 volts with respect to the chassis. When C_1 has some leakage, it can be considered as another resistor for purposes of d.c. calculations. The remaining 240 volts will now divide across the condenser and the gridleak in direct proportion to their resistance. In general, the leakage current will be small in comparison to the current drawn by the voltage amplifier tube. It shall be considered that the voltage at the point A does not vary appreciably. In that case, the voltage drop across the gridleak will be

$$E = \frac{1}{4\ L} \times 240 \text{ volts}$$

where L is the leakage resistance. Substituting for L values of 15000 megohms, 10,000 megohms, 1000 megohms, 500 megohms, 100 megohms and 50 megohms, the corresponding values of E are:

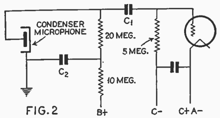


FIG. 2

L	E
15000 meg	.004 volts
10000 meg	.006 volts
1000 meg	.06 volts
500 meg	.12 volts
100 meg	.6 volts
50 meg	1.2 volts

The voltage E is applied to the grid in opposition to the bias and causes an increase in plate current as well as easier overload of the tube, accompanied with distortion. The example just quoted is one of the most favorable (for the condenser) because the gridleak had so low a value. But suppose the next tube had been a voltage amplifier tube, with a gridleak of 1 or 2 megohms and a bias of but 3 volts. If the gridleak is 1 megohm, the values of E become four times as high as in the previous example, in the case of a 2 megohm gridleak they become eight times as high. An insulation resistance of 100 megohm would then place a positive voltage of 4.8 volts on the grid in opposite sense to the grid bias. If the bias were 3 volts, this would leave the grid 1.8 volt positive. Even 500 megohm insulation resistance will cause trouble in this case. It is clear that the higher the voltage at A and the higher the value of the gridleak, the higher will be the positive voltage applied to the grid.

An even more critical service for a blocking condenser is in the pre-amplifier for a condenser microphone. This circuit is illustrated in Fig. 2. These are very high resistance circuits and the B voltage might be very high — up to 500 volts. Assuming that the voltage of the B supply is again 300 volts and that the condenser C2 does not have any leakage, the drop across a 5 megohm gridleak would be

$$E = \frac{5}{L - 35} \times 300 \text{ volts}$$

Substituting again several values for L, we have:

L	E
15000 megs	.1 volt
10000 megs	.15 volt
5000 megs	.3 volt
1000 megs	1.5 volts

The tube used in this circuit, probably has a bias of but 1.5 volts which makes a condenser of 1000 megohm insulation resistance useless. Yet this same condenser could still be employed with the power tube circuit of Fig. 1. This also illustrates why the blocking condensers in such preamplifiers must be protected against moisture.

Another critical location for a condenser is in a.v.c. circuits because resistances are high. A typical circuit is illustrated in Figure 3; it shows a circuit where the second diode plate takes care of the a.v.c. circuit and is independent of the diode detector. The resistor values of R1 and R2 are generally in the neighborhood of ½ to 1 megohm. In order not to lose any of the previous a.v.c. voltage the total leakage of C_1, C_2, C_3 and C_4 should be small, the total resistance should be large compared to R_1, say 100 times as much. This would set a lower limit of 400 megohms for each condenser. Perhaps a greater loss than 1% is permissible, but this service requires good condensers.

NON-CRITICAL LOCATIONS OF CONDENSERS

Condensers used for bypassing plate, screen, and cathode circuits do not have to satisfy such rigid requirements and sometimes the insulation resistance can be quite low without any trouble turning up. The condenser C_2 in Fig. 1 for instance, when passing any current will pass this current through the bias resistor of the voltage amplifier tube, thereby raising the bias. The value of this resistor might be as high as 5000 ohms. The increase in bias due to this cause would then be

$$E = \frac{5}{1000\ L} \times 300 \text{ ohms}$$

where L is again the insulation resistance. In this equation the drop across the 50,000 ohms has been neglected for convenience sake. This does not cause any serious error. Substituting values for L, we find

L	E
15000 megs	.0001 volt
1000 megs	.0015 volt
100 megs	.015 volt
10 megs	.15 volt
1 meg	1.5 volt

If the bias resistor had half the resistance of 5000 ohms, these figures for E will be half as much. It is seen that although the magnitude of E is much smaller for a given leakage, the practical limit is somewhere near 100 megohms. If C_2 had been connected from the B supply to the chassis, instead of to the cathode this effect of raising the bias would not take place no matter how much leakage there was. In such a case the amount of current should be considered, this is generally very low and would not upset the operation of the receiver as

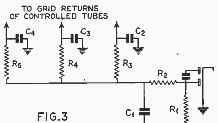


FIG. 3

long as the current itself is not sufficient to raise the temperature of the condenser thereby hastening its destruction. If the plate supply voltage is 300 volts, the following table shows the current drawn by condensers of different insulation resistance and the third column shows the amount of power dissipated.

L	I	P
15000	.02 micro amp	6 microwatts
1000	.3 micro amp	90 microwatts
100	3. micro amp	.9 milliwatts
10	30. micro amp.	9 milliwatts
1	.3 ma.	.09 watts

This table is for a 300 volt potential difference across the condenser. The current is of course proportional to this voltage and the power is proportional to the square of the voltage.

The case of C_3 and C_4 is again a bit different. These condensers are connected across low voltages and their leakage is not important even when the insulation resistance is as low as 1 megohm. In fact, electrolytic condensers are quite customary for the service of C_4.

There remains the use of condensers in the screen supply circuit, illustrated in Fig. 4. They are customarily used in two ways as at A and at B.

At A the condenser C_1 is connected across the lower half of a voltage divider. If this voltage divider does not supply any other circuit but that screen, its resistance may be quite high, sometimes as much as 50,000 ohms. Placing a leaky condenser across it amounts to lowering the effective value of R_1 and lowering the screen voltage. It becomes rather tedious to compute the exact amount of this variation, but it can be seen, that a 1 megohm resistor across R_1 would lower the total resistance only 5% and the screen voltage by less than that.

The circuit of B requires somewhat better condensers for the value of R_2 may be as high as one megohm. A condenser with an insulation resistance of 100 megohms (a bad one) will not cause any appreciable drop in screen voltage, but one of 10 megohm would.

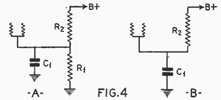
CONDENSERS IN R.F. AND A.F. CIRCUITS

So far, the standpoint of direct current only was considered However, condensers C_2, C_3 and C_4 of Fig. 1 pass a.f. currents while the condensers in Fig. 3 pass r.f. currents. It might be thought that an amount of leakage which was found to be harmless in our previous discussion may cause trouble due to less efficient filtering or losses in the r.f. circuit. To be sure, there is such a loss but it is so small that it is negligible compared to the reactance in the circuit and compared to the d.c. resistance of i.f. coils.

The equivalent series resistance for a given shunt resistance is found from the equation

$$R_s = \frac{X_c^2}{R_{sh}}$$

Taking the case of Fig. 3, when the condensers have a capacity of .1 mfd. and the frequency might be 450 kc., the reactance of the condenser is



$$X_c = \frac{1000000}{2\pi fC} = \frac{1000000}{6.28 \times 450000 \times .1}$$
$= 3.5$ ohms approx.

Substituting this value in the above equation and taking various values for the shunt resistance (insulation resistance), the following equivalents are found

R (shunt)	R (series)
15000 megs	.000 000 000 81 ohms
1000 megs	.000 000 012 ohms
100 megs	.000 000 12 ohms
10 megs	.000 0012 ohms
1 meg	.000 012 ohms

These resistance values are negligible compared to the resistance of the coil.

In a.f. circuits, the reactance of the condenser is larger and consequently the effect is somewhat more pronounced, but the series resistance is still very small compared to the reactance of the condenser. For instance, let the bypass condenser have a capacity of 1 microfarad and let the frequency be 100 cycles, then the reactance is 1600 ohms. Substituting this value in the equation again and finding the equivalent series resistance;

R shunt	R series
15000 megs	.000 17 ohms
1000 megs	.002 6 ohms
100 megs	.026 ohms
10 megs	.26 ohms
1 meg	2.6 ohms

When expressed in power factor, the last and worst shunt resistance comes to .16 percent.

It is believed that the above examples are sufficient to prove our point as well as to enable the reader to calculate the result of leakage in other circuits he might encounter.

SUMMARY

1. Insulation resistance has a very small bearing on power factor, practically negligible even when the insulation resistance has come down to very low values. When a bad power factor is present, it is due to other causes, not to leakage.

2. All difficulties due to leakage are d.c. phenomena, mostly because the leakage current is added or subtracted from the current through some resistor which controls the voltage at a tube element.

3. Due to the varied uses of condensers, it is impossible to set up fixed limits for the insulation resistance. They would have to be determined for each service individually.

4. The highest requirements for condensers are encountered in circuits where they are connected in series with relatively high resistances.

5. It was shown how the effect of leakage can be calculated in various circuits which will enable the user to establish his own lower limits of insulation resistance in each individual case.