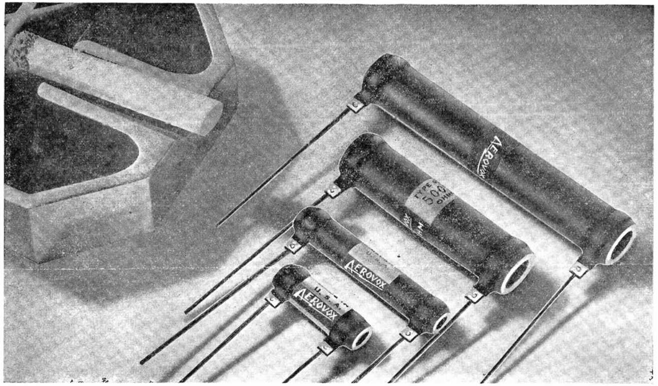

H L HOOVER

Radio Editors of magazines and newspapers are hereby given permission to reprint in whole or in part, with proper credit to the Aerovox Corporation, the contents of this issue of the Aerovox Research Worker.

The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 7, No. 4 APRIL, 1935

50c per year in U.S.A.
60c per year in Canada

The Use of Condensers in Radio Receivers

By the Engineering Department, Aerovox Corporation

THE use of condensers in radio work has become so common that more thought should be given to their function in various circuits. The average radio man is probably taken by surprise to have someone ask: "What is a condenser and what is it good for?" and most likely he will find it hard to give a concise answer to the question.

In this article it is proposed to point out the characteristics or properties of condensers and to show how these are utilized in radio receiver construction.

PROPERTIES OF CONDENSERS

The name "condenser" is really a misnomer since it is not an instrument to "condense" anything. As far as we can determine, to "condense" is to transform a substance from the gaseous to the liquid state and this certainly does not happen in the kind of condenser we are referring to. For this reason, the more appropriate and less popular name of "capacitor" has been given to it.

It is not the intention to go into any long and learned discussion on the behaviour of the condenser. It is sufficient to consider it from a practical standpoint and to state that a condenser has the property to store electrical energy in the form of an electrostatic charge and can return the greater part of this energy to the circuit when the impressed voltage is removed. As a result, three important usable qualities can be enumerated:

1. The condenser does not pass direct current but provides a path for alternating current, the impedance of which is inversely proportional to the capacity.

2. When used in alternating current circuits, the reactance can be expressed in equivalent ohms and the reactance is inversely proportional to the frequency as well as inversely proportional to the capacity.

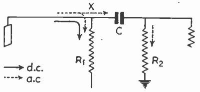

Fig. 1

3. There is a phase difference of 90 degrees for a perfect condenser, the current leading the voltage.

The various applications of condensers can now be classified according to which one of the three qualities are being utilized. For instance, where a condenser is used as a coupling element in a resistance coupled amplifier, it is the first property alone which makes it suitable for the purpose. The second and third are present, of course, but they are not doing any good, in fact, they are not desirable in that particular application.

The first group of applications—those utilizing property 1—include: coupling condensers, bypass condensers across bias resistors or voltage dividers, and in plate, screen and grid circuits.

Group 2, applications utilizing both property 1 and 2, include all those where frequency discrimination is desired. The common tone control and some forms of resistance-capacity filters are the examples.

Group 3 includes applications where all three of the mentioned qualities are utilized, such as filters consisting of inductances and condensers and in tuned circuits, some of which are used with fixed condensers, for instance in tone compensating networks.

APPLICATIONS OF GROUP 1A-COUPLING CONDENSERS

One of the best examples of coupling condensers is in resistance-coupled amplifiers where it is desired to transfer the signal (alternating voltage) from the plate circuit of one tube to the grid of the next without getting the high plate voltage on the grid. A typical circuit is shown in Fig. 1. The plate current, being direct current, can only flow through the resistor R_1. The tube can be considered as a generator of alternating current and this will flow through R_1 as well as through the condenser C and the resistor R_2. It is desired, of course, to transfer as much of the signal voltage as possible to the grid and to transfer an equal amount at all frequencies so as not to introduce frequency distortion.

In order to make the voltage across R_2 as high as possible, the reactance of C should be small compared to the resistance of R_2, because the voltage divides in proportion to the im-

Printed in U. S. A.

pedance of these two elements. This can be done by having a large condenser, the larger the better, for the reactance is smaller for larger condensers. There is, however, an economical limit, for instance, when the voltage across the resistor R_2 is 99 percent of the voltage between X and ground, it should be satisfactory. There is a complication: the reactance of C becomes larger for lower frequencies, making the voltage across R_2 smaller for the low notes.

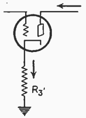

Fig 2

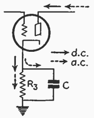

Fig. 3

In order to illustrate this, let us take an example. Suppose R_2 is 250,000 ohms, the grid leak of some power tube and let us figure the percentage of the total signal voltage appearing across R_2 for different values of C and for different frequencies.

	Percent of signal voltage across R_2 at:				
C(mfd.)	50c.	100c.	1000c.	5000c.	10,000c.
.001	7.8	15.5	84.5	99.2	99.9
.005	36	61.5	99.2	pract'ly	100%
.01	61.5	84.5	99.9	pract'ly	100%
.05	95.5	99.2	practically 100%		
.1	99.2	practically 100%			

This table illustrates that the efficiency drops rapidly at low frequencies when the condenser is too small and also that it does not pay to go above a given size of condenser. In our particular example, a .1 mfd. condenser will give good bass response. If the resistance of R_2 had been larger, all values of capacity would have shown up better. For a 1 megohm grid leak, .025 would give the same percentage as .1 does in the above table.

For those who are interested in calculating these percentages themselves, we give the equations below:

$$\% = \frac{R_2}{\sqrt{R_2^2+X_c^2}} \times 100$$

$$X_c = \frac{1,000,000}{6.28\,f\,C}$$

where C is in microfarads and f in cycles.

There is still another complication which shifts the phase of the alternating voltage applied to the grid of the next tube. Due to property (3) mentioned above, the current through the condenser C and the resistor R_2 is not in phase with the voltage between X and the chassis; the current leads the voltage—rather, the impressed voltage—and the voltage across R_2 is in phase with this current. Therefore, the voltage across R_2 leads the voltage across the combination C and R_2, the phase is shifted forward, so to say. This amount of phase shift varies again with the frequency, it is larger for low frequencies than for high ones. According to leading authorities, phase shift cannot be noticed by the human ear, hence, in this particular application, the effect is not of much practical importance.

1B—BYPASS CONDENSERS

There are many places in the radio receiver where bypass condensers are used. In nearly all cases, the effect desired is to provide an easy path for the signal voltage around some resistance or impedance where it might cause undesirable feedback; the frequency discrimination a condenser affords is generally not desired, but it should be taken in consideration when studying or designing the circuit.

Several examples of bypassing come to mind, for instance the condensers used across bias resistors, sections of voltage dividers, in plate, screen and grid circuits. Consider first the condenser across a bias resistor.

Fig. 2 shows a part of an amplifying stage employing a triode. This may represent either an audio or radio-frequency amplifier, and the same will hold as well for other tubes employing bias resistors.

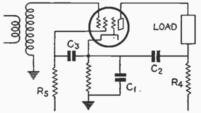

Fig. 4

It is understood that the bias resistor, R_3, serves to obtain the required grid bias for the tube. The plate current, flowing in the direction of the arrow, causes a voltage drop across the resistor R_3, making the cathode positive with respect to the chassis. Since the grid return is connected to the chassis also, the cathode becomes positive with respect to the grid, or, the grid becomes negative with respect to the cathode. The value of the resistor to get just the right amount of bias is found by dividing the required grid bias in volts by the normal plate current in milliamperes and multiplying by 1000.

For the sake of being able to give numerical examples, assume that the tube of Fig. 2 is a 56, then the plate current would be 5 ma., the grid bias 13.5 volts, which makes the resistor R_3 2700 ohms. When the tube is in operation the alternating current, flowing in the plate current, has to pass through the resistor R_3 and will develop an alternating voltage (a part of the amplified signal voltage) across the bias resistor. This alternating voltage is also applied to the grid in such a sense as to decrease the amplification. This can be proven easily, for, during the first half cycle, when the grid becomes positive, the plate current increases, making the cathode somewhat more positive than it was. This results in the grid being slightly more negative, an action opposite to that of the impressed signal voltage. A similar reasoning can be made for the other half cycle. The magnitude of this alternating voltage across R_3 is proportional to the resistance R_3. So it follows that in order to make the alternating voltage as small as possible, the impedance to alternating current from cathode to ground should be nearly zero, but for direct current it should remain 2700 ohms. This condition is met by connecting a condenser of suitable size across the bias resistor. Fig. 3 illusrates the circuit, also showing by arrows the path of the alternating current. The alternating current will divide, some of it passing through the resistor, and some through the condenser. The amount of current through the two branches is inversely proportional to their impedance. So, making the impedance of the condenser very low, (using a large condenser), the current through the other branch, R_3, can be made negligible. The table below illustrates this; it is assumed here, that the total alternating current remains the same and the table shows to what percentage the current in R_3 is cut down for different sizes of condensers, all values being calculated for 1000 cycles.

C	d.c. in R_3	a.c. in R_3	a.c. in C
none	5 ma	100 %	
.001	5 ma	99.8%	6.4%
.01	5 ma	98.7%	16.6%
.1	5 ma	51 %	86 %
1	5 ma	5.9%	99.8%

The larger the condenser, the less current through the bias resistor. Note that the percentage of current in the resistor and that in the condenser does not add up to 100 percent. This is because the one is out of phase with the other and their vectorial sum adds up to 100 percent.

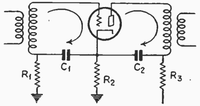

Fig. 5

The figures in the table were calculated for 1000 cycles only; unfortunately they change with frequency. At 100 cycles, the condenser has to be ten times as large to get the same results. In the following table this is illustrated for a 1 mfd. condenser with this same bias resistor of 2700 ohms for different frequencies.

f	d.c. in R_3	a.c. in R_3	a.c. in C.
50	5 ma	75.5%	65.5%
100	5 ma	51 %	86 %
500	5 ma	11.7%	99.2%
1000	5 ma	5.9%	99.8%
5000	5 ma	1.7%	100 %
10000	5 ma	.84%	100 %

This table shows that for very low frequencies the 1 mfd. condenser is really not large enough. More favorable conditions are obtained when the resistor R_3 is smaller. This explains the reason for using larger capacity, low voltage condensers for bypassing bias resistors.

The ratio of currents in the two branches can be calculated from the following equations.

Current through the resistor

$$\% = \frac{2\pi f C}{\sqrt{R^2+(2\pi fC)^2}} \times 100$$

Current through the condenser

$$\% = \frac{R}{\sqrt{R^2+(2\pi fC)^2}} \times 100$$

Bypassing of voltage divider sections rests on the same prinicple as the bias resistor bypassing. If a section of a voltage divider is common to two or more circuits it may give rise to instability and it may be necessary to employ a resistance capacity filter in addition to the bypass condenser.

Bypassing of plate, screen or grid supply leads is generally done by means of a resistance capacity filter or a choke and condenser combination. First consider the resistance capacity filter. Two of these are illustrated in Fig. 4; a pentode, employed as an r.f. or i.f. amplifier might be used in such a circuit. Here the resistor R_4 in the plate circuit cannot be made too large because the voltage drop across it lowers the plate voltage. A value often used is 1000 ohms; since the plate current of the tube is generally below 5 ma., the voltage drop cannot be more than five volts with this value of resistor.

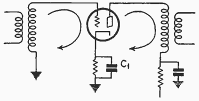

Fig. 6

Below is another little table of the effectiveness of bypass condenser C_2 when different sizes are used. The table shows the reactance of the condenser at 500kc. From the previous table it should be clear that if the reactance of the condenser becomes less than one twentieth of the resistance, the bypassing action is such that a negligible amount of the signal passes through R_4. If this is not sufficient, it may be necessary to employ two sections.

C	X_c at 500 kc.
.001	320 ohms
.01	32 ohms
.1	3.2 ohms

The latter value, .1 mfd. has become quite popular in modern receivers with high gain stages. It is often used for all three condensers C_1, C_2 and C_3. In reality, it is possible to use a somewhat smaller condenser for C_3 because the resistor R_5 is generally 15000 or 25000 ohms. So the ratio of current in the two branches, (condenser and resistor) is 25 times more favorable than in the R_1-C_2 filter.

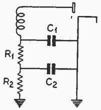

Fig. 7

Chokes can be used in both positions, instead of R_4 and R_5, and assuming that the choke is a choke at the frequency under consideration, greater efficiency of filtering can be obtained. This type of filter has been discussed at length in the Research Worker for October and November 1934.

Another system of bypassing the same circuits, which is used in high class audio amplifiers, is illustrated in Fig. 5, while still another way is shown in Fig. 6 where everything is bypassed to ground instead of to the cathode. The superiority of both circuits of Fig. 4 and 5 over the one in Fig. 6 is immediately apparent when one follows the path of the plate circuit and the grid circuit. In Fig. 6, the alternating current component of the plate current, when it has passed through the plate bypass condenser has to go through the cathode bypass condenser in order to return to the cathode This cathode bypass condenser is also in the grid circuit, providing some element of coupling. Furthermore, in Fig. 5, the condenser C_1, which closes the grid circuit, does not have to be so large as the condenser C_1 in Fig. 6, because in Fig. 5 it is in parallel with the two resistors R_1 and R_2 (in series) and R_1 can usually be made large, in the order of 50,000 ohms.

Finally we come to a form of bypassing which really belongs to our group 2 because a frequency discrimination is desired and obtained. However, this filter is very similar in design and construction to the ones just shown. We refer to the filter used in the detector circuit to eliminate the r.f. component without affecting the audio component. Unfortunately, the simple network usually employed does not make such a sharp distinction, as we shall see. The function of the condensers C_1 and C_2 with the resistor R_1, is to return the r.f. component to the cathode preventing it from passing through R_2 and further amplification in the audio amplifier. R_2 is generally of a value anywhere between 100,000 and 1 meg, while R_1 might be from 25,000 to 250,000 ohms. When such high impedances are bypassed by condensers of from 100 to 250 mmfd each, the higher audio notes will be greatly attenuated.

For instance, the table below shows the reactance of different values of condensers at 500 kc and at 10,000 cycles. Supposing the condenser C_2 has these values, it will be clear that the path through the condenser at 10 kc. is very much easier than through the resistor R_2, resulting in a loss of that frequency.

C_2 (mmfd)	X_c at 500 kc.	X_c at 10 kc.
25	12700	638000
50	6400	319000
75	4250	212500
100	3200	160000
200	1600	80000
250	1270	63800

Values of 100 mmfd. are quite common for C_2. If the resistor is ¼ or ½ megohm it stands to reason that a great part of the signal voltage is lost at 10 kc. Therefore, if it is necessary to have "high fidelity," such an arrangement could not be used. The remedy would be to make R_2 smaller or C_2 smaller or both. It might also be remedied by employing a choke in series with the resistor R_2, which would raise the impedance of the R_2-plus-choke-branch at the higher frequencies.

When the resistor R_1 is replaced by a choke, the action is more efficient and eliminates this difficulty as far as C_1 is concerned but C_2 will still be across a high resistance thus attenuating the high frequencies.

Further applications of the condensers, where frequency discrimination is utilized and the applications of group three, will be discussed in the next installment. This part will deal with tone control and tone compensating networks.