The Aerovox Research Worker

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

Vol. 2 November, 1929 No. 9

Loudspeaker-Coupling Systems

Part 1

By the Engineering Department, Aerovox Wireless Corp.

THAT a chain is no stronger than its weakest link is a truism that dates back so far into antiquity that it is hoary with age. Yet it is just as applicable to radio as it ever was to any of the earlier pursuits of mankind.

Given a highly efficient receiver and audio amplifier and a well-designed loudspeaker, there is no guarantee that when these are connected together, the results will be satisfactory UNLESS proper consideration has been given to the design of the coupling between the speaker and the amplifier.

Before considering the coupling means to use between output tubes and loudspeakers, it might be mentioned that the greatest undistorted power output is obtained from an amplifier tube, when working into a load which is equal to twice the plate resistance of the tube. A detailed discussion of this subject is contained in the Cunningham Tube Data Book (a copy of which can be obtained for one dollar from E. T. Cunningham, Inc., 370 Seventh Ave., New York City) pages 16 to 20, but the general statement of the relation of load impedance to plate resistance of the tube for maximum undistorted output from the tube will suffice here.

Since the plate resistances of various tubes differ and since the plate resistance of any given tube differs under different conditions of operation, it is important that the plate resistance characteristics of the tube under the conditions under which it is operated be known, before it is possible to recommend a loudspeaker or coupling system that will give best results with a given output tube.

The A.C. Plate Resistance of the various popular output tubes under different conditions of operation, are given in Fig. 1.

The figures in the plate resistance column show that the characteristics of the CX-371A tube, when operated at 180 volts plate voltage and 40.5 volts grid bias are very similar to those of the CX-345 and the CX-350 tubes. Practically the same loudspeaker and coupling means can therefore be used for all three of these tubes, provided that the loudspeaker and coupling means are capable of handling the power output and the plate current of the tube with which they are used. The CX-112A and the CX-310 tubes, however, would require a loudspeaker and coupling combination of different characteristics while the speaker and coupling required by the CX-301A tube would be still different.

TUBE TYPE	PLATE VOLTAGE	GRID BIAS VOLTAGE	A.C. PLATE RESISTANCE
CX-301A	90	4.5	11,000
	135	9.0	10,000
CX-112A	135	9.0	5,000
	157.5	10.5	4,700
CX-371A	90	16.5	2,500
	135	27.0	2,200
	180	40.5	2,000
CX-310	250	18.0	6,000
	350	27.0	5,150
	425	35.0	5,000
CX-345	180	33.0	1,950
	250	50.0	1,900
CX-350	250	46.0	2,100
	350	63.0	1,900
	450	84.0	1,800

Fig. 1.

Accurate data on the impedance characteristics of all types of magnetic and dynamic speakers is not available, but the usual type of magnetic speaker has a coil winding having a D.C. resistance of from 1,000 to 2,000 ohms with an impedance which varies from that value at zero frequency (D.C. current flowing through the windings) up to 30,000 to 40,000 ohms at the higher frequencies up to 5,000 cycles per second. These high values of impedance for this type of loudspeaker unit are due to the comparatively high inductance of the winding which is made up of a large number of turns.

In the dynamic speaker however, the voice coil is wound with as few turns as possible to keep the weight of the moving coil very low and to prevent excessive inertia of the moving system. The small number of turns results in a practically constant load impedance over a wide range of frequencies.

In the usual types of dynamic speakers, the impedance of the moving coil may vary from approximately 6 ohms at 100 cycles to not higher than 30 ohms at 5,000 cycles.

In some dynamic speakers, the impedance of the voice coil is much less and in at least one type of speaker, in which the voice coil consists of a single turn of wire, the impedance of the coil is less than .001 ohm.

These facts should be kept in mind since they have an important bearing on the following discussion of matching the characteristics of loudspeakers to the characteristics of the output tubes.

One of the earliest methods of connecting a loudspeaker to the output of a vacuum tube is shown in Fig. 2. In this type of circuit the loudspeaker windings are connected directly in the plate circuit

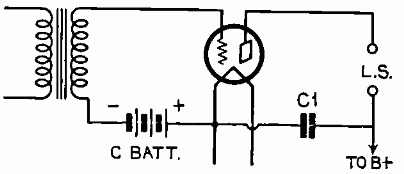


Fig. 2.

of the tube and the plate current flows in the windings. This plate current in the windings of the speaker, is small and is not a very serious factor when using tubes of the CX-301A type which require very small plate currents although the current in the windings tends to produce distortion, due to the flexing of the speaker diaphragm. When the speaker is not properly connected however, the current through the windings tends to demagnetize the permanent magnet of the speaker.

With such a connection it is desirable to use a bypass condenser of at least 2 mfds. as shown at "C1" when the source of voltage for the plate circuit is a power supply unit. While the resistance of the usual "B" batteries, even when run down is comparatively low so that the value of using a condenser as a bypass is questionable at the very low audio frequencies, such a condenser performs a useful function at the higher audio frequencies and at radio frequencies.

Since the A.C. plate resistance of a CX-301A tube is between 10,000 and 11,000 ohms under the usual conditions of operation, the load imposed by the loudspeaker should be approximately 20,000 to 22,000 ohms or more to get maximum undistorted output from the tube.

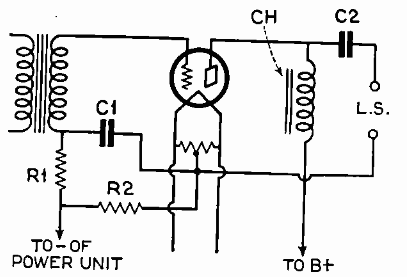
The windings of most magnetic loudspeakers do not attain that value of impedance until the frequencies reach about 1,000 to 2,000 cycles per second. This explains one of the reasons why the average type of magnetic speaker gives rather poor response on the lower frequencies.

With the gain in popularity of tubes requiring high plate voltages and drawing high plate currents, the practice of connecting the loudspeaker directly in the plate circuit, as shown in Fig. 2, came to an end, because of the danger of burning out the windings and causing too great a flexing of the diaphragm.

The type of circuit generally adopted for a single power tube in the output stage is the circuit shown in Fig. 3. By using this type of circuit, the direct current in the plate circuit is made to flow through the choke "CH" while the audio frequency signal current flows through the shunt plate-to-filament circuit consisting of the condenser "C2" and the loudspeaker windings.

There are many variations of the circuit shown in Fig. 3, but the most satisfactory is the one shown. In some cases, the series combination of condenser and loudspeaker windings is connected directly across the terminals of the choke. While such a connection serves to remove the direct current component of the plate current from the speaker windings, it does not serve to bypass the signal current to the filament and around the power supply unit, as does the connection shown in Fig. 3. Where the connection of the loudspeaker and condenser is made directly across the choke, the voltage rating of the condenser need not be very high, since the voltage applied across it is simply the voltage drop across the choke. This type of economy however is hardly worth while because of the difficulties that will be encountered due to coupling in the power supply unit, and the passing of audio frequency currents through the resistors. The best method of connection for a single output stage is as shown in Fig. 3. The capacity of the condenser should be as high as possible to avoid resonance peaks in the loudspeaker response. It should not be less than two mfds. The choke coil inductance should be as high as possible so as to offer a very high impedance to the passage of the signal current through the choke. The higher the ratio of impedance of the choke to the combined impedance of the condenser and loudspeaker, the greater will be the proportion of signal current in the loudspeaker circuit and consequently the greater the volume produced by the loudspeaker for a given signal input to the amplifier.

It can be stated as a general approximation that when two impedances are connected in parallel, one of the impedances being much larger than the other, the resultant impedance is slightly less than the impedance of the smaller of the two impedances. Thus if the combined impedances of the choke "CH" and the voltage divider resistors for any given frequency is high as compared to the combined speaker and condenser impedance, the total impedance of the system which



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constitutes the load connected to the output tube will be somewhat less than the impedance of the speaker. This is especially true if the capacity of condenser "C2" is large, at least two mfds., so that the reactance of the condenser is negligible over the greater part of the range.

We have already noted that for maximum undistorted output from the tube, the impedance of the load should be twice the A.C. plate resistance of the tube. The loudspeaker selected for use should therefore be chosen with due regard to the requirement that its impedance at the lowest frequencies to be covered be at least twice the A.C. plate resistance of the output tube.

The curve of impedance plotted against frequency of a representative type of magnetic speaker shows that the impedance of that type of speaker is approximately 2,500 ohms at 100 cycles per second, 5,000 ohms at 300 cycles, 10,000 ohms at 750 cycles, 20,000 ohms at 1,750 cycles and increases steadily as the frequency goes up until it reaches a value of somewhat over 30,000 ohms at 5,000 cycles per second.

This means that at 100 cycles per second, the impedance of 2,500 ohms of the speaker would match a tube whose A.C. plate resistance is 1,250 ohms or less; at 300 cycles it would match a tube whose A.C.

Continued on page 4, column 3

How to Increase Efficiency of Circuits by Proper Bypassing and Filtering

Part 3*

TO obtain the maximum permissible gain in radio frequency stages employing the new screen grid tubes, it is important that the output and input circuits of the tubes be isolated as completely as possible from each other. The type of construction peculiar to the screen grid tube has resulted in a remarkable decrease in interelectrod capacity. The CX-301A and CX-326 tubes have a plate to grid capacity of approximately 10 mmfds. In the screen grid tube this has been reduced down to .01 mmfds. This practically eliminates coupling between plate and grid circuits through the grid to plate capacity of the tube. The negligible grid to plate capacity eliminates the necessity for neutralization or means of suppressing oscillations in radio frequency circuits. Coupling with resultant oscillation however, can be effected either through magnetic coupling from other parts of the circuit or through conductive, inductive or capacitive coupling through elements common to input and output circuits. Magnetic coupling and to some extent capacitive coupling is usually eliminated by completely shielding the various elements of the circuit.

The only remaining important source of coupling between circuits is then the coupling which exists between those portions of the circuits or elements which are common to two or more circuits of the receiver.

The use of separate batteries in each circuit, would of course eliminate the coupling which takes place through the elements common to the grid, plate and screen grid circuits. Such a system would be impractical however, because of the expense involved and the large space required by the large number of batteries which would have to be used.

Practically the same object, namely the isolation of each circuit from all other circuits can be attained by the use of resistance-capacity filters as shown in Fig. 7. This diagram shows a completely filtered and properly bypassed screen grid tube circuit.

The general principles used to isolate the various circuits and to bypass the signal currents around the high resistance of grid bias and power supply unit resistors are similar to those used in circuits employing the CX-326 and C-327 type tubes discussed in Parts 1 and 2 of this series.

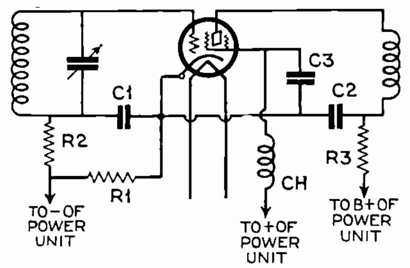

Fig. 7.

A resistor at "R2" in series with the grid bias resistor "R1", with a condenser "C1" connected as shown in Fig 7 serves to isolate the control grid circuit of the tube from the power supply circuit. The low reactance of condenser "C1", as compared to the resistance of the series combination of resistors "R1" and "R2", serves to bypass the signal current in the control grid circuit around the resistors so that only a very minute part of it flows in the shunt circuit consisting of the two resistors. This prevents the coupling which would otherwise exist between the grid circuit and the power supply circuit, if the resistor "R2" were removed and resistor "R1" connected directly across condenser "C1". The resistor "R2" also isolates the grid circuit from the plate and power supply circuits.

The plate circuit of the tube can be isolated from the power supply circuit in much the same way by connecting a resistor as shown at "R3" in Fig 7. A condenser "C2" serves to bypass the signal current in the plate circuit around resistor "R3" and the power supply unit resistors.

Due to the positive potential placed on the screen grid and the position of the screen grid with respect to the cathode of the tube, a slight current will flow in the screen grid circuit. The value of this current varies somewhat in different tubes, ranging from approximately .3 milliampere to 1 milliampere. In some extreme cases the current may run as high as 1.5 milliampere.

This variation in the current drawn by different tubes has no effect on the operation of the tube, provided that the voltage divider is designed to give good regulation, so that the difference in the current drain of the screen grid circuits is not sufficient to cause any appreciable change in the voltage applied to the screen grids.

For this reason it is advisable to use an R.F. choke ("CH") and a bypass condenser ("C3") filter in the screen grid circuit in preference to a resistance-capacity filter.

The reason for this is easily seen if we consider the effect on the screen grid voltage when using a resistor of high resistance in place of the choke "CH". If we were to use a resistor of 50,000 ohms in place of the choke, the voltage drop produced by the resistor with a current flow of .3 milliampere would be 15 volts and the voltage divider should be designed to provide a voltage of 15 volts more than the voltage required at the screen grid. If instead of drawing .3 milliampere, the tube draws 1 milliampere, the voltage drop across the resistor would be 50 volts. This means that if .3 milliampere is taken as the current drain and the tap designed to provide the required voltage making due allowance for the drop through the resistor at this current drain, the drop obtained when using a tube which has a higher screen grid current drain will result in a lower screen grid voltage and consequently in a lower response because of the volume control action of different voltages on the screen grid.

In using an R. F. choke in the screen grid lead, it is important that the choke be carefully shielded so as to avoid coupling between the screen grid circuit and other circuits of the receiver.

It is also very important to select a choke having a very low value of distributed capacity. A high value of capacity in the choke will render it useless for the purpose for which it is used.

It might be mentioned here, while we are on the subject of screen grid circuits, that the general practice of using a variation

* NOTE—Readers who are beginning their subscription with this issue and have therefore not received Parts 1 and 2 of this series, may obtain them on request. Merely write to the Aerovox Wirless Corporation and ask for the July-August and the September-October issues of the Research Worker. There is no charge or obligation.

of screen grid voltage as a volume control is hardly to be recommended. One disadvantage of this method lies in the fact that a variation of screen grid voltage affects the plate current drain of the tubes, causing variations at the other taps of the voltage divider. Another disadvantage of this system of volume control is that under certain conditions of adjustment of the screen grid voltage the radio frequency tube becomes a detector, resulting in reduced signal strength and crosstalk.

The value of resistance chosen for "R2" is not critical and may run from 25,000 to 50,000 ohms. Since this resistor does not carry any appreciable current, either signal or direct, unless the grid circuit draws current, (a condition under which the tube should not be used) the value of resistance employed does not affect any operation characteristics of the tube. A high value of resistance will naturally give better filtering action by limiting coupling between the grid circuit and the other circuits of the receiver but too high a resistance is not desirable because of the limiting factors imposed by the possibility of gas current in the grid circuit.

The value of resistance used at "R3" is limited only by the watts dissipation characteristics of the available high resistance units and by the available voltages at the power supply unit.

The maximum rating of the Aerovox Type 1098 Lavite units which are available for the purpose is three watts. In actual service under the conditions shown in the diagram for "R2" and "R3", the charging current drawn by condensers "C1", "C2" and "C3" as the receiver is turned on and off may run rather high so it is not advisable to use the resistors at more than 25 percent of their maximum watt rating or .75 watts.

The maximum current that may flow in resistor "R2" is very small so it is prefectly safe to use resistors as high as 50,000 ohms in that position.

Since the plate current drawn by the tube, 4 milliamperes, must pass through "R3", the value of resistance used at "R3" must be taken into consideration both from the standpoint of selecting a resistor capable of carrying this current safely and also because of the drop in voltage produced by the resistor, which makes it necessary to have available a source of higher voltage than the 180 volts required on the plate of the tube.

If we assume operation of the resistor at 25 percent of its maximum rating or .75 watts, it would be perfectly safe to use a resistor of 46,800 ohms or approximately 50,000 ohms. A resistor of 50,000 ohms with a current of four milliamperes flowing through it however, would produce a drop of 50,000 times .004 or 200 volts. The source of voltage would therefore have to be the 180 volts required for the plate plus the drop of 200 volts which takes place through the resistor or a total of 380 volts. If this voltage is not available, a lower value of resistor must be used.

Since we are dealing with high frequencies in all of these circuits, the capacities required at "C1", "C2" and "C3" need not be very high. If we were to use 50,000 ohm resistors at "R2" and "R3" a ratio of 1 to 1,000 between the condenser reactance and the resistor resistance could be obtained by using a condenser having a reactance of 50 ohms. A glance at the table of condenser reactance given with Part 2 of this series, shows that a condenser of between .005 and .01 mfd. would be suitable for the purpose. If exceptionally good bypassing and filtering is desired or if lower values of resistors are used, the capacities of condensers "C1", "C2" and "C3" may be increased to .1 mfd. Higher values of capacity are not necessary.

Since the voltage across condenser "C1" will never be more than the grid bias voltage and since this voltage is very small in screen grid tube circuits, a 200 volt D.C. working voltage condenser is more than ample at that point.

The voltages applied across condensers "C2" and "C3" however, depend upon conditions in the tube circuits. With the tube filament burned out or the tube out of its socket so that no current is drawn in the plate and screen grid circuits, the voltages applied across the condensers may rise to the values of the voltages at the voltage divider taps to which the free ends of resistors "R3" and "R4" are connected.

In the case of "C2", the voltage at the divider tap, using a 50,000 ohm resistor at "R3" is approximately 380 volts so that a 400-volt condenser is the minimum rating which should be used if the condenser is to be protected against the comparatively high voltage which will be applied to it if the tube is removed or the filament burned out.

In the case of condenser "C3", the voltage at the voltage divider tap will be approximately 75 volts, the recommended maximum voltage for use with the screen grid, and a condenser of 200 volts D.C. working voltage rating should be sufficient.

To protect condenser "C2" against occasional higher voltages when used with heavy duty power units having high output voltages it may even be necessary to use a higher voltage rating. The designer of the circuit must be guided by the application, the voltage drop through the filter resistor and the possible increase in voltage at the voltage divider tap under noload conditions in determining the voltage ratings of the condensers.

Continued from page 2, column 3

plate resistance is 2,500, etc.

It is easy to see that if this speaker were used with a CX-301A tube in the last stage, the speaker impedance would not reach a value of twice the A.C. plate resistance of the tube until the frequency rose to a value of almost 2,000 cycles. this of course would mean that the system would produce comparatively poor results on frequencies below 2,000 cycles. On the other hand if the speaker is used with a CX-371A tube in the last stage, the impedance of the speaker would be twice the A.C. plate resistance of the tube at 300 cycles per second and would therefore produce a better response characteristic at the lower frequencies down to 300 cycles per second.

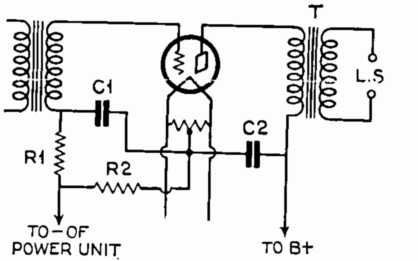

Fig. 4.

Where it is desired to have a better response characteristic and the impedance characteristics of the speaker cannot be changed, it is best to use the circuit shown in Fig. 4. In this circuit an output transformer "T" is used. This transformer should be so designed as to provide a means of matching the impedance characteristics of the speaker to the A.C. plate resistance of the tube.

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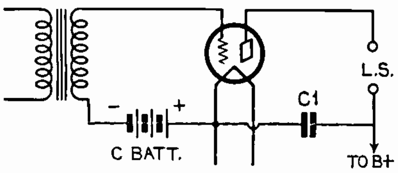

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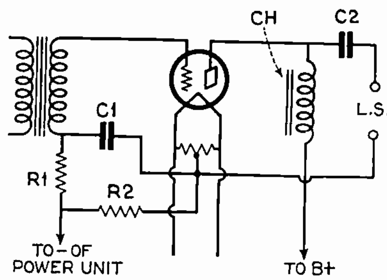

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constitutes the load connected to the output tube will be somewhat less than the impedance of the speaker. This is especially true if the capacity of condenser "C2" is large, at least two mfds., so that the reactance of the condenser is negligible over the greater part of the range.

We have already noted that for maximum undistorted output from the tube, the impedance of the load should be twice the A.C. plate resistance of the tube. The loudspeaker selected for use should therefore be chosen with due regard to the requirement that its impedance at the lowest frequencies to be covered be at least twice the A.C. plate resistance of the output tube.

The curve of impedance plotted against frequency of a representative type of magnetic speaker shows that the impedance of that type of speaker is approximately 2,500 ohms at 100 cycles per second, 5,000 ohms at 300 cycles, 10,000 ohms at 750 cycles, 20,000 ohms at 1,750 cycles and increases steadily as the frequency goes up until it reaches a value of somewhat over 30,000 ohms at 5,000 cycles per second.

This means that at 100 cycles per second, the impedance of 2,500 ohms of the speaker would match a tube whose A.C. plate resistance is 1,250 ohms or less; at 300 cycles it would match a tube whose A.C.

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