"RG" should therefore be selected with due consideration to the manner in which the tube is being used. In radio frequency amplifiers and in grid bias detectors where the likelihood of overloading is very slight, resistors as high as 100,000 ohms may be used to advantage. In the audio stages with 327, 326 and 324 tubes the use of 25,000 and 50,000 ohms units are satisfactory. In the power stage it is customary to use resistors of not more than 25,000 ohms for 371-A, 310 and 345 tubes and 10,000 ohms for 350 tubes.

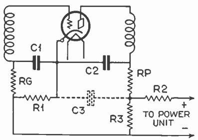

Fig. 6 A

The resistors used at "RG" should be of the heavy duty type such as the Aerovox Lavite resistors which have a maximum rating of three watts. While it is true that the current ordinarily flowing in these resistors is so minute as to be negligible, the current taken by the charging of the condensers at "C1" is fairly high. Unless the resistors are of the heavy duty type the surges which they are called upon to handle as the amplifier is turned on and off may be sufficient to cause trouble.

In the plate circuits, the use of the resistance capacity filter consisting of resistor "RP" and condenser "C2" in each plate circuit, (Figs. 6A and 6B) effectively bypasses the signal current in the plate circuit from the "B+" end of the transformer primary to the cathode of the tube. Further bypassing and filtering can be accomplished by using a condenser at "C3" as shown by the dotted lines although this is not absolutely essential.

The use of a condenser at "C3" (this should be connected as shown between the tap on the voltage divider of the power supply unit and the cathode of the tube filters out practically all of the signal current which passes through resistor "RP".

The use of resistor "RP" increases the effectiveness of "C2" as a bypass condenser and also acts as a barrier to coupling between the various stages of an amplifier whose plate circuits are tied together to a common tap such as the "B+" tap of the voltage divider.

Since there is an appreciable current (the plate current drawn by the tube) in this resistor, it is important to select a resistor capable of carrying that current safely without undue heating or change in resistance.

In the case of resistors used in the grid circuits, such as "R1" the value of resistance used is not critical since there is no current in the resistor to cause a voltage drop. In the plate circuit however, the current flowing in the plate circuit determines the voltage drop through the resistor and the value of this resistance determines the voltage drop between the tap of the voltage divider and the primary winding of the transformer. A C-327 when used as an amplifier with 90 volts on the plate and a negative bias of 6 volts on the grid, will draw 3 milliamperes plate current. If we use a resistor of 10,000 ohms at "RP", the voltage drop across the resistor will be 30 volts. If a 25,000 ohm resistor is used at "RP", the voltage drop with a current of 3 milliamperes will be 75 volts. It is therefore necessary to consider the voltage drop through the resistor when designing the voltage divider. Without any filtering resistor "RP", the voltage at the tap of the voltage divider should be 90 volts in this particular case at a current drain of 3 milliamperes. When a 10,000 ohm resistor is used at "RP" the voltage at the tap should be 90 volts plus the drop through the resistor (30 volts) or 120 volts. When a 25,000 ohm resistor is used at "RP" the voltage at the tap should be 90 volts plus the drop through the resistor (75 volts) or 165 volts.

A glance at the table of characteristics of the Aerovox Lavite resistors shows that a 10,000 ohm Lavite will easily pass 12.1 milliamperes at a very conservative rating of .75 watts, (25% of the maximum watt rating of this type of resistor). Its use at 3 milliamperes will therefore give long service without change in resistance value.

The table also shows that a 25,000 ohm resistor will easily pass 7.6 milliamperes at the same conservative rating of .75 watts, so that this value could also be used to advantage.

The lower value of resistance will give more conservative operation of the resistor and more constant voltage because of better regulation (less change of voltage with fluctuations in plate current drain). The higher value of resistance gives better filtering action but requires the use of a higher voltage tap on the voltage divider and results in somewhat poorer regulation.

The voltage ratings of the condensers used at "C1" and "C2" depend on the peak voltages which may be applied across them.

The voltage developed across condenser "C1" depends on the resistance of resistor "R1" and the current flowing through "R1". With no current flowing through "R1", that is before the tube heats up, the voltage across the condenser is zero. As the tube heats up and more and more current begins to flow in the plate circuit until the maximum plate current flow is reached, the voltage drop across resistor "R1" increases as the current flow through the resistor increases and the maximum voltage drop is reached when the maximum current flows through the resistor. Since the maximum grid bias voltage used with receiving and amplifier tubes is less than 100 volts D. C. the use of a condenser rated at 200 volts D. C. working voltage is ample for all grid bias bypass requirements.

In the plate circuits however, due consideration must be given to the characteristics of the receiver, amplifier and power supply circuits.

In the case of some circuits using heater type tubes in the R. F. and A. F. stages with 345 tubes in the power stage, (tubes which have an appreciable time lag before plate current is drawn and a load imposed on the power supply unit)

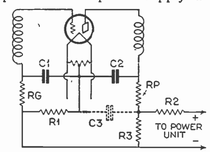

Fig. 6 B

the voltages applied to all condensers, including bypass condensers such as "C2" may be the full voltage of the output of the power supply unit and the condensers must be rated sufficiently high to meet such temporary conditions of high voltage.

Further examples of the use of bypassing and filtering to improve the efficiency of circuits will be given in the next issue of the Research Worker.

1929-8

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The Aerovox Research Worker

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Vol. 2 September-October, 1929 No. 8

How to Increase Efficiency of Circuits by Proper Bypassing and Filtering

Part 2*

By the Engineering Department, Aerovox Wireless Corp.

In the last instalment of this series, the push-pull type of circuit was analyzed in terms of its requirements from the standpoint of proper bypassing and filtering. It was found that when well-matched tubes and circuits were used, no necessity for bypassing or filtering existed in the grid and plate circuits.

If the tubes or circuits are not matched, it is desirable to use some form of equalizing circuit which will permit such equalization. This object can be attained either by a difference in the grid bias applied to each tube or by applying different plate voltages to the two tubes so as to compensate for differences in the characteristics of the tubes.

The formula used to obtain the capacitive reactance of a condenser at various frequencies was also discussed. In this issue, the table shown in Fig. 4 gives the reactance of a number of standard capacities of from .00005 to 15 mfds. at the frequencies used in common practice.

The frequencies of 500,000 and 1,500,000 cycles per second (500 to 1,500 kilocycles per second) give the two limits of frequencies used in broadcasting. The frequencies of 50 and 10,000 cycles per second take in the extremes of audio frequencies covered by a good audio amplifier and loudspeaker combination. The 25, 60 and 120 cycles per second frequencies cover the frequencies obtained from standard power supply units. A power supply line which delivers 25 cycle current will deliver 50 cycle current if a full wave rectifier is employed with it. Half wave rectification should never be used on 25 cycle current because of the difficulty encountered in filtering such a supply to eliminate hum. The reactances of the condensers with a frequency of 50 cycles per second can be obtained from the 50-cycle column under the heading "Audio Frequencies". A 60-cycle power source will give a 60-cycle output with a half-wave rectifier and a 120-cycle output with a full-wave rectifier.

This table will be found valuable in selecting the proper capacities for bypass and filter use.

The usual arrangement of the grid and plate circuit in the average heater type radio frequency amplifier, grid bias detector or audio frequency amplifier tube is shown in Fig. 5A. A similar arrangement for a standard type of amplifier in which the filament also acts as the cathode is shown in Fig. 5B.

The grid bias resistor "R1" in both cases is bypassed by a condenser "C1". The bypass condenser "C2" used in the plate circuit is usually placed at the power supply unit, connecting between the "B+" tap of the voltage divider and the "—" lead of the power supply unit.

We can now proceed to investigate the paths taken by the signal voltages and currents in both the grid and plate circuits.

The value of resistance required for a grid bias resistor at "R1" will vary somewhat with different types of tubes and plate voltages used but 2,000 ohms is a good average for use with a single tube and 1,000 ohms is a good average for use with two tubes.

Now let us see how efficient a 1 mfd. condenser is in bypassing and filtering resistor "R1".

If the tube is being used as a radio frequency amplifier the frequencies in the grid circuit will range from approximately 500,000 to 1,500,000 cycles per second.

A glance at the table shown in Fig. 4 gives the value of reactance for a 1 mfd. condenser at 500,000

*Note: Readers who are beginning their subscription with this issue and have therefore not received Part 1 of this series, may obtain Part 1 on request. Merely write to the Aerovox Wireless Corporation and ask for a copy of the July-August issue of the Research Worker. There is no charge or obligation.

cycles as .32 ohm and that for 1,500,000 cycles as .11 ohm. It would seem that a 1 mfd. condenser at "C1" is certainly more than sufficient to bypass the radio frequency current in the grid circuit across resistor "R1" as far as the radio frequency currents are concerned. As a matter of fact a ratio of 1 to 100 or 1 to 1,000 is sufficient for this purpose. For a resistor of 2,000 ohms at "R1", a condenser having a reactance of 20 ohms giving a ratio of 1 to 100 or one having a reactance of 2 ohms giving a ratio of 1 to 1,000 would be sufficient for the purpose. A glance at the table shows that at the lowest frequency of the broadcast range (500,000 cycles per second) a reactance of approximately 20 ohms is obtained by the use of a condenser having a capacity of .015 mfd. while a reactance of approximately 2 ohms can be obtained by using a condenser of between .1 and .25 mfd.

It should be noted, however, that the use of a condenser across resistor "R1" while effectively bypassing the radio frequency currents across the resistor, does not however, prevent the application of extraneous disturbing potentials across the resistor, resulting in regeneration, modulation of the signal in the grid circuit and distortion..

The elimination of these faults can only be obtained by proper filtering of the circuit, in the manner to be described later.

If the tubes shown in Figs. 5A and 5B are audio frequency amplifiers, the frequency of the currents in the grid circuits may go as low as 50 cycles. The usual value of condenser recommended as a grid bias resistor bypass is 1 mfd. The chart in Fig. 4 shows that a 1 mfd. condenser has a reactance of 3,184 ohms at 50 cycles, the lower limit of the frequencies met with in audio amplifier circuits. In view of this the use of a 1 mfd. condenser to bypass a 2,000 or even 1,000 ohm resistor is of course hardly to be recommended in audio circuits. The high reactance of such a condenser at the lower frequencies accounts for the fact that practically no difference is noted in audio circuits when a 1 mfd. condenser is connected or disconnected across the grid bias resistor.

To obtain a ratio of at least 1 in 10 between the reactance of the condenser and the resistance of 2,000 ohms would require a condenser having a reactance of approximately 200 ohms at 50 cycles. To satisfy this requirement a 15 mfds. condenser would have to be used.

Even if such a value of capacity were practical, the same objection of leaving the grid circuit unfiltered and subject to the action of extraneous voltages would still hold true.

It will also be noted that the plate circuit bypass condenser is connected between the "B+" tap and the "—" lead of the power supply unit. While this type of connection is used generally, the bypass condenser being included in the filter condenser block with all condensers connected to a single common lead, the practice has nothing to recommend it except a slight convenience in connections. With the connection of "C2" as shown in Figs. 5A and 5B, the condenser merely bypasses across the resistances of the voltage divider of the power unit. The signal current in the plate circuit flows through the primary of the coupling transformer, through the condenser "C2" (provided the condenser has sufficient capacity to provide a path of low reactance around the resistance of the voltage divider system and the power supply unit) and thence through the parallel combination of condenser "C1" and resistor "R1". The combination of "C1" and "R1" provides a means therefore of coupling the plate and grid circuits together resulting in regeneration, modulation and generally poor tone quality.

Fortunately, these faults of the

CAP. IN MFDS.	FREQUENCY IN CYCLES PER SECOND						
	Broadcast Radio Frequencies		Audio Frequencies		Power Supply Frequencies		
	500,000	1,500,000	50	10,000	25*	60	120
	CAPACITIVE REACTANCE IN OHMS						
.00005	6,369.4	2,123.1	63,694,267	318,471	127,388,534	53,078,503	26,539,252
.0001	3,184.7	1,061.6	31,847,133	159,235	63,694,267	26,539,252	13,269,626
.00025	1,273.8	424.6	12,738,853	63,694	25,477,706	10,615,600	5,307,850
.0005	636.9	212.3	6,369,426	31,847	12,738,853	5,307,850	2,653,925
.001	318.5	106.2	3,184,713	15,924	6,369,427	2,653,925	1,326,963
.005	63.7	21.2	636,943	3,185	1,273,885	530,785	265,393
.01	31.8	10.6	318,471	1,592	636,943	265,393	132,696
.015	21.2	7.1	212,314	1,061	424,629	176,929	88,464
.02	15.9	5.3	159,235	796	318,471	132,697	66,348
.05	6.4	2.1	63,694	318	127,389	53,078	26,539
.1	3.2	1.1	31,847	159	63,694	26,539	13,270
.25	1.28	.42	12,739	64	25,478	10,616	5,308
.5	.64	.21	6,369	32	12,739	5,308	2,654
1.0	.32	.11	3,184	15.9	6,369	2,654	1,327
2.0	.16	.05	1,592	7.9	3,184	1,327	663
4.0	.08	.03	796	3.9	1,592	664	332
6.0	.05	.02	531	2.6	1,062	442	221
8.0	.04	.01	398	2.0	796	332	166
10.0	.03	.01	318	1.6	637	265	133
15.0	.02	.01	212	1.1	425	177	88

*Full wave rectification of 25-cycle current is equivalent to 50-cycle column under "Audio Frequencies". Half wave rectification of 25-cycle should never be used because of hum.

Fig. 4

average radio or audio frequency amplifier can be corrected very easily without any large expenditure.

The wiring diagrams in Figs. 6A and 6B show how the circuits of Figs. 5A and 5B can be converted into efficient, well-filtered and properly bypassed amplifier and detector circuits, simply by inserting two resistances "RG" and "RP"

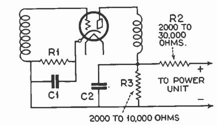

Fig. 5 A

in the grid and plate circuits of the tubes and connecting the circuits as shown.

In these circuits, resistors "RG" and "RP" are 10,000 to 50,000 ohm resistors. A short analysis of these circuits will show how vastly they differ from the circuits of Figs. 5A and 5B from the standpoint of operating efficiency.

Condenser "C1" now serves as a bypass across the series combination of resistors "RG" and "R1". With a resistor of 10,000 ohms for "RG" and one of 2,000 ohms for "R1", the total resistance of the two resistors will be 12,000 ohms instead of the 2,000 ohms of the single resistor "R1" of Fig. 5A. In this case therefore if we wish to maintain a ratio of 1 to 100 between the reactance of the condenser and the combined resistance of the series arrangement of "R1" and "RG", a condenser of approximately .0025 mfd. which would have a reactance of approximately 120 ohms would be sufficient while if we wish to keep a ratio of 1 to 1,000, a condenser of approximately .025 mfd. would be sufficient. As a matter of fact the use of resistors of 25,000 to 50,000 ohms is recommended for this service with a mica condenser such as the Aerovox Type 1450, .002 to .02 mfd. as the bypass condenser at "C1".

The arrangement of resistors shown at "RG" and "R1" in Figs. 6A and 6B not only makes it possible to use a lower capacity at "C1" with comparatively greater bypassing effectiveness but it also isolates the grid circuit from the effects of any extraneous voltages and fluctuations. In the arrangement shown in Figs. 5A and 5B, varying voltages and surges applied across resistor "R1" were introduced into the grid circuit of the tube by the coupling provided by the parallel combination of resistor "R1" and condenser "C1".

In the circuit arrangement shown in Figs. 6A and 6B, any voltage developed across resistor "R1" has only a small percentage of it introduced into the grid circuit.

Close inspection of the circuit will show that the grid of the tube is connected through the secondary of the R. F. or A. F. transformer, to the point where resistor "RG" joins condenser "C1". Resistor "RG" and condenser "C1" form in effect two legs of a voltage divider connected across resistor "R1" across which the extraneous voltage is applied. If the amplifier circuit in question is a radio frequency amplifier the lowest frequency will be of the order of 500,000 cycles per second. If resistor "RG" were not used, the full voltage developed across resistor "R1" would be introduced into the grid circuit to cause distortion. Since the reactance of a condenser of let us say .02 mfd. would be only 15.9 ohms at 500,000 cycles, as against a resistance of from 10,000 to 50,000 for resistor "RG" it is easily seen that only a very minute portion of the disturbing potential would be introduced into the grid circuit.

If the circuit is an audio frequency amplifier designed to function efficiently on frequencies as low as 50 cycles, the same principles will hold true. In this case we are dealing with very low frequencies and the reactance of a condenser of any given size naturally increases. At 50 cycles the reactance of a 1 mfd. condenser is 3,184 ohms. The folly of using such a condenser as a bypass across a 2,000 ohm resistor is obvious. Even a 4 mfd. condenser having a reactance of 796 ohms at 50 cycles is hardly sufficient as a bypass since it gives a ratio of condenser reactance to resistor resistance of only 1 to 3.

While a comparatively low capacity condenser connected directly across a grid bias resistor performs at least a real bypassing function in radio frequency circuits, although it leaves much to be desired from a filtering standpoint, a large capacity condenser directly across a grid bias resistor in the audio frequency stages does not even perform a satisfactory bypass function.

When a high resistance of from 10,000 to 50,000 ohms is placed at "RG" however, the picture changes. With a 10,000 ohm resistor at "RG" and a 1 mfd. condenser at "C1" the ratio of condenser reactance to resistor resistance is reduced from approximately 1.3 to 1 down to 1 to 4.5 at 60 cycles. At 10,000 cycles, the ratio is only 1 to 800. With a 50,000 ohm resistor at "RG", the ratio at 60 cycles is approximately 1 to 20 while at 10,000 cycles it reduces down to approximately 1 to 3,250.

With a 4 mfd. condenser at "C1" and a resistor of 10,000 ohms at "RG", the ratio is approximately 1 to 18 at 60 cycles and 1 to 3,200 at 10,000 cycles. The use of a 1 mfd. condenser with a resistor of 50,000 ohms at "RG" therefore gives practically the same bypassing ratio, although with a somewhat higher total impedance in the grid circuit, as a 4 mfd. condenser with a resistor of 10,000 ohms.

It might seem that the introduction of resistors such as "RG" of such high values as 10,000 to 50,000 ohms might reduce the efficiency of the grid circuit. Such however is far from being the case, since the use of condenser "C1" as shown in Figs. 6A and 6B effectively forms a low-impedance connecting link between the grid return lead of the transformer secondary and the cathode of the tube.

The use of a resistor such as "RG" in the grid circuit between the grid bias resistor and the grid does not affect the negative bias applied to the grid of the tube because the only current flowing in "RG" is an extremely minute signal current due to the shunt connec-

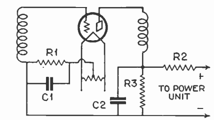

Fig. 5 B

tion of "RG" and "R1" across condenser "C1". Under such conditions the voltage drop through "RG" is negligible.

The only time when any appreciable current would be made to flow through "RG" would be under overload conditions brought on by a very strong signal which would cause the grid to swing positive and draw grid current.

The value of resistance used at