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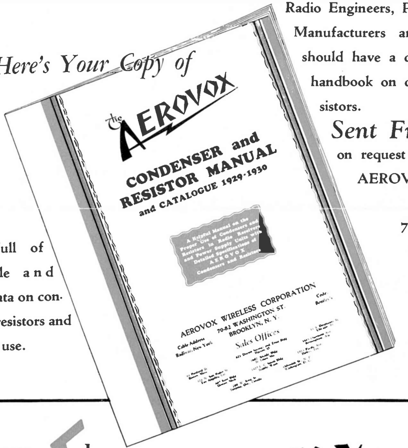

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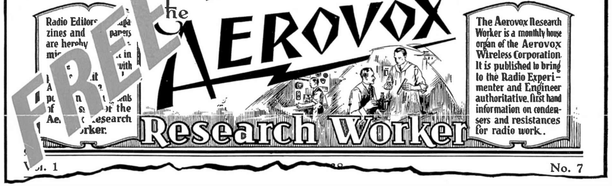

THE Aerovox Research Worker is a free publication issued monthly by the Aerovox Wireless Corporation, to keep radio experimenters, engineers and manufacturers abreast of the latest developments in radio.

Special attention is given each month to design problems in connection with radio receivers and power supply units, with special attention on the proper use of resistors and condensers.

During the past year such subjects as the "Measurement of the A.C. Component of Composite Voltages"; the "Construction of a Peak Voltmeter"; "Latest Developments in "A" Condensers"; "Notes on the Design of Filters"; "Principles of Voltage Divider Design"; "How to Test Condenser Capacities"; "Trouble Shooting in A.C. Receivers"; the "Selection of Resistors for Power Supply Work" and other such subjects have been treated in detail.

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1929-7

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The AEROVOX Research Worker

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 July-August, 1929 No. 7

How to Increase Efficiency of Circuits by Proper Bypassing and Filtering

Part 1

By the Engineering Department, Aerovox Wireless Corp.

THE subject of metal shielding to prevent coupling effects and their attendant troubles such as oscillation, distortion, motor-boating and generally poor performance of radio circuits has been given considerable attention during the past few years. The equally important subject of preventing coupling by means of filtering to keep signal currents in the circuits where they belong and out of circuits where they are bound to cause trouble has, however, been given but scant attention. In those comparatively few instances where the evils of allowing signal currents to "fraternize" with the direct and alternating currents in the power sources have been recognized, attempts to disassociate them have been more or less half-hearted and doomed to failure.

The evils following the failure to keep these currents in their proper channels were first brought home to the author by George Crom, Jr., of the American Transformer Co., makers of the Amer-Tran line of transformers and power supply units.

To get a clear picture of the effects of coupling in the various circuits of a radio receiver, due to the use of common sources of power in the various circuits, it is necessary to understand the fundamental relations existing in the circuits of a vacuum tube amplifier.

The fundamental circuit of a radio amplifier tube is shown in Fig. 1. The tube used is the type in which the cathode is indirectly heated by means of a filament placed within it, but the principle applies equally to all other types of tubes. The current from the "A" battery or A.C. line heats the filament, and the heat developed in the filament in turn heats the cathode or electron emitting element of the tube. If continuous current, such as is obtained from a storage battery is used to heat the filament, the temperature of the filament and of the cathode will attain a constant temperature, the ideal condition required for best operation of the vacuum tube.

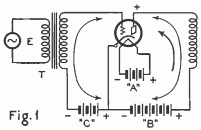

Fig. 1

A "C" battery is used in the grid circuit to maintain the grid of the tube at a constant negative potential with respect to the cathode. A "B" battery is used in the plate circuit to maintain the plate or anode, at a positive potential with respect to the cathode.

If we disregard the grid, we know that current will flow in the plate circuit as long as the "B" battery maintains the plate at a positive potential with respect to the cathode and that the current in the plate circuit will depend on the voltage of the "B" battery (which determines the extent to which the plate is positive with respect to the cathode), and the temperature of the cathode (which determines the electron emission from the cathode).

The use of the grid, however, limits the current in the plate circuit by interposing a negatively charged element between the cathode and the plate. The grid repels to some extent the negative electrons from the filament and prevents them from reaching the plate. The extent to which the grid acts as a controlling "gate" depends on its potential with respect to the cathode.

If it is very negative, its repelling power will be large. If it is only slightly negative, its repelling power will be correspondingly smaller. If it becomes positive with respect to the cathode, it will itself attract electrons instead of repelling them and in that event current will flow in the grid circuit.

The extent to which the grid must be kept negative with respect

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to the cathode is determined by the characteristic curve of the tube. This curve shows the proper operating point of the tube as regards normal negative grid bias and plate voltage which will provide operation of the tube on the straight portion of its characteristic curve, so as to give equal variations of plate current for equal variations in the signal voltage applied in the grid circuit.

The normal grid bias to be applied with any given tube is also affected by the variations or amplitudes of signal voltage which may be applied to the grid circuit of the tube.

In the circuit shown in Fig. 1, voltage fluctuations produced in circuit "E" by the A.C. generator or oscillator will produce similar voltage fluctuations in the grid circuit of the tube, coupled to circuit "E" by transformer "T". These voltage fluctuations will exercise a controlling effect on the plate current. The result is a signal current in the plate circuit being superimposed on the steady direct current which would ordinarily flow in the plate circuit when the grid is maintained at a constant negative voltage.

The alternating signal voltage in the grid circuit and the fluctuating signal current in the plate circuit are represented by curves with arrows at both ends. The steady direct current which ordinarily flows in the plate circuit is represented by a curve with an arrow at only one end.

In the grid circuit shown in Fig. 1, the "C" battery is in the circuit in which the signal voltage is applied. In the plate circuit, both the signal current and the direct current flow through the "B" battery.

These are the conditions existing in a single stage amplifier of the usual type. In a push-pull amplifier, however, conditions are somewhat different as can be seen by consulting Fig. 2. In this case, the signal voltage originating in the oscillator circuit is applied, by means of the secondary of the transformer in such a way as to make grid "G" of one tube more negative than the normal grid bias voltage and grid "G1" of the other tube less negative during one alternation of the signal voltage and then, as the current reverses in the oscillator circuit, to make grid "G" less negative while at the same time making grid "G1" more negative than the normal grid bias voltage.

Any signal voltage or current passing through the "C" battery in the upper tube is opposite in phase to a corresponding signal voltage or current in the grid circuit of the lower tube and therefore balances out, so that if the tubes and circuits are well matched, no signal voltage or current can be measured between the midtap of the secondary winding of transformer "T" and the cathodes of the tubes.

If the tube is being operated at the proper point of its characteristic curve, the effect of the difference in negative potential of the two grids is to cause an effective signal current to flow in the plate circuits as shown by the double headed arrow. The complete circuit of the signal current in the plate circuit can be considered as flowing in the circuit consisting of the center-tapped coil, the two plates and the two filaments, all of which form a series circuit, with no signal current through the "B" battery connected between the midtap of the plate coil and the cathodes of the tubes.

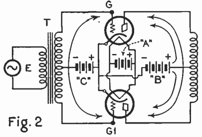

Fig. 2

The important facts brought out by this discussion thus far are that in the case of a single stage amplifier of the type shown in Fig. 1, a measurable signal voltage exists across the "C" battery or any other source of power that may be used in that position and that this signal voltage can therefore be applied to any other circuit of which the "C" battery or other source of power is a part.

In the case of the single stage push-pull amplifier shown in Fig. 2 however, due to the balancing out of the signal voltage in the circuit between the midpoint of the transformer and the cathodes of the tubes, no signal voltage exists in the power source from which the grid bias voltage is obtained, and therefore no signal voltage can be tapped off from this part of the circuit and applied to any other circuit.

A similar condition holds true in the plate circuits. In the circuit shown in Fig. 1, a signal current flows through the "B" battery and this signal current can cause trouble in other circuits which are coupled to it by the common coupling through the battery or power source, when a single battery or source of power is used for the other circuits of a receiver. However in the push-pull circuit shown in Fig. 2, since no effective signal current exists in that part of the circuit between the midpoint of the transformer coil and the cathodes of the tubes, no trouble can be experienced from that source.

Further consideration of the differences between these two circuits brings out the converse of the above statements. If an oscillator is connected across the terminals of the "C" voltage supply, the fluctuations in voltage will cause the grid of the tube to become more or less negative in step with the fluctuations. If the generator is capable of generating a sufficiently high voltage, the grid may even swing positive and cause grid current to flow in the grid circuit. The important thing to note however, is the fact that fluctuations applied in the grid circuit of the single stage amplifier shown in Fig. 1 affect the voltage on the grid and therefore cause a fluctuation in the signal current in the plate circuit which will finally be reproduced in the loudspeaker as hum, noises or distortion due to the modulation effect of this extraneous source on the signal in the grid circuit.

In the case of the push-pull circuit shown in Fig. 2, however, any fluctuating voltage applied across the "C" voltage will cause equal voltages to be applied to the two grids, causing equal but oppositely poled current fluctuations to flow through the two sections of the coil in the plate circuits of the tubes. These equal and oppositely poled impulses in the plate circuits will just balance each other out and will therefore not be transmitted on to the following circuits or to the loudspeaker.

The same thing holds true of any fluctuations which may be applied across the common plate voltage source, in the case of Figs. 1 and 2, the "B" battery. In the circuit shown in Fig. 1, fluctuating voltages or currents applied across the common "B" battery or voltage divider resistance in power supply units, will appear in the plate circuit of the tube and will be transmitted to the grid circuit of the following tube or to the loudspeaker circuit. In the case of the circuit shown in Fig. 2, however, the fluctuations impressed across the battery or voltage divider resistance will divide through the plate circuit coil and since they will be opposite in phase they will cancel out and will have no effect on following circuits.

It would seem from this discussion that the push-pull system is far superior to the straight single stage amplifier from the standpoint of eliminating coupling between different stages of a receiver and amplifier. However, it is possible by using proper filtering circuits, to reduce trouble from coupling to a negligible minimum in ordinary amplifier stages without resorting to the use of such expensive means as push-pull in all stages. Because of the comparatively large energy that must be handled in the power output stage of an amplifier, the use of a push-pull stage in that position is without doubt the most desirable. However, the use of push-pull systems in the other amplifier stages is not necessary because of the comparatively small signal voltages and currents which these other stages are called upon to handle.

In these stages, it is more economical and just as effective to use straight single tube stages with proper filtering to avoid coupling.

The subject of proper filtering is too lengthy to be taken up in the short space remaining in this issue of the Research Worker, and will therefore be left for next month's issue. As a preparation for the material which is to follow we shall take up a few important facts regarding condensers and resistances in electrical circuits in general and radio circuits in particular.

In alternating current circuits, whether of high frequency or low frequency, the opposition to the flow of current offered by a resistor is measured in the same way as in direct current, in ohms. The resistance of a resistor which does not contain inductance or capacity remains practically constant for all frequencies with the exception of a slight change due to so-called "skin effects" at high frequencies. For all practical purposes however, we may consider the resistance of a resistor as remaining constant for all frequencies.

The formula for the resistance of a resistor is given by Ohm's Law and may be expressed by the formula shown in Fig. 3A, where "R" is the resistance in ohms, "E" is the voltage in volts, across the resistor, and "I" is the current in amperes flowing through the resistor.

In the case of condensers and inductances, the opposition to the flow of current varies with the frequency. The inductive reactance offered by an inductance to the flow of current of any frequency is expressed by the formula shown in Fig. 3B, in which "Xl" is the inductive reactance in ohms, the constant 6.28 represents 2 pi, "f" is the frequency in cycles and "L" is the inductance in Henries.

$$R = \frac{E}{I}$$

Fig. 3A

$$Xl = 6.28fL$$

Fig. 3B

$$Xc = \frac{1}{6.28fC}$$

Fig. 3C

The capacitive reactance offered by a condenser to the flow of current of any frequency is expressed by the formula shown in Fig. 3C, in which "Xc" is the capacitive reactance in ohms, the constant 6.28 again represents 2 pi, "f" is the frequency in cycles and "C" is the capacity in farads.

By using these formulae it is a simple matter to determine the "impedance" offered by any resistance, capacity or inductance to the flow of a current of any given frequency, and to find out how currents in any circuit will split up in shunt circuits containing resistance, inductance and capacity.

In order to serve as an effective "bypass" across a resistor for instance, a condenser connected across the resistor must offer considerably less impedance to the flow of current of that frequency than that offered by the resistor. If we select a resistor of 2,000 ohms such as might be used as a grid bias resistor for a C-327 tube either as a radio frequency amplifier or as an audio frequency amplifier, the resistance offered by the resistor at both radio and audio frequencies remains 2,000 ohms, provided it is a non-inductive resistor.

To prove effective as a "bypass" condenser, in audio circuits, the reactance in ohms of the condenser connected across this resistor should be not more than .1 times the resistance of the resistor across which it is connected or in this particular case, 200 ohms.

The capacity required at 60 cycles to satisfy the above conditions as determined by substitution in the formula shown in Fig. 3C is found to be 13 mfds. This means that if the amplifier is designed to work to limits as low as 60 cycles, a 13 mfd. condenser would have to be connected across the 2,000-ohm grid bias resistor.

If the tube is a radio frequency amplifier, the signal frequencies will vary from approximately 500,000 to 1,500,000 cycles per second over the broadcast band. Since the lowest frequency requires the highest capacity, we can take the lower frequency in determining the proper capacity to use. It is also advisable in radio frequency circuits to use a smaller ratio of reactance of bypass condenser to resistance of resistor, usually of the order of 1 to 100 or even 1 to 1,000. By substitution in the formula of Fig. 3C we find that to obtain a ratio of 1 to 100 between the reactance of the condenser and the resistance of the resistor will require a .015 mfd. condenser at 500,000 cycles. To obtain a ratio of 1 to 1,000 would require a condenser of .15 mfd.

To obtain the required capacity in a radio frequency circuit is therefore a simple matter. Aerovox Type 1450 mica condensers for instance are made in capacities of up to .02 mfd. and are ideally suited for use in radio frequency circuits.

Where cost is a very important factor, the Types 270, 260, 207 or 200-S paper condensers may be employed in place of the mica condensers.

In the audio circuits however, it is obviously impractical to use a 13-mfd. condenser. This problem however can be solved very easily by using a capacity-resistance filter circuit which makes it possible to greatly reduce the capacity required without impairing the net result, namely of keeping the signal in the grid circuit where it belongs and out of the other circuits of the receiver and amplifier. This type of circuit also serves the purpose of keeping signal currents generated in other parts of the circuit from affecting the particular circuit which is protected by the resistance-capacity filter.