"Motorboating," What It Is, and Why

The Sporting Proclivity of Resistance-Coupled Amplifiers

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"MOTORBOATING," as applied to radio, is a term used to express the action taking place in an audio-frequency amplifier, when pulsations of the current in the output circuit, if passed through the coil windings of a loud speaker, cause the latter to emit the familiar "put-put-put" sounds which are somewhat analogous to the sound of the exhaust of a distant motorboat; hence the name.

There is a distinct difference between "motorboating" and "howling"; they are not inherently the same, as some writers have claimed. One man, for instance, states that "motorboating" is a term applied to low-frequency oscillations between the limits of half a cycle per second and 50 cycles per second. He then goes on to say that, when the frequency of these oscillations goes above 50 cycles per second, "we no longer call the action 'motorboating'; we call it 'howling'."

"Howling" is "howling," and "motorboating" is "motorboating"—two inherently different actions. When an amplifier "howls" it is *oscillating at an audio frequency*. "Motorboating" is not an oscillatory action; it is a *"limiting"* or "blocking" action. "Howling" is oscillatory; "motorboating" is non-oscillatory. Our ears can distinguish oscillations as low as 30 or 40 cycles per second, but not much lower; hence, if "motorboating" were an oscillating action, how could we hear these low frequency oscillations, when they are changed from electrical oscillations to sound waves, if their frequency were lower than 30 cycles per second? The answer is; we couldn't. We do hear the "put-put-put" sounds emanating from the loud speaker at frequencies below 30 cycles when an amplifier "motorboats": hence it is a non-oscillatory condition.

SOURCES OF TROUBLE

"Motorboating" is experienced chiefly in resistance-coupled amplifiers. Under certain conditions the tendency to "motorboat" is more pronounced than under others, more favorable. For instance, when a resistance-coupled amplifier is supplied with plate voltage from a set of new "B" batteries, the tendency to "motorboat" is not pronounced. If "motorboating" should occur, it might very possibly be due to interaction between the radio-frequency and audio-frequency circuits. To overcome this, be sure to *keep all radio frequency out of the audio amplifier circuit*. Keep the radio frequency isolated. This may be done as follows:

If you consider the schematic wiring diagram in Fig. 1 you will see that there is a .002-mf. condenser C4 connected from the plate of the detector tube T1 to the negative filament terminal of the detector tube socket. The function of this condenser is to by-pass radio-frequency energy around the plate coupling resistor R1, the latter being a part of the audio-frequency coupling unit, in the input circuit of the audio amplifier.

Now, the by-pass condenser C4 may not be adequate. Part of the radio-frequency energy at this point in the circuit may pass through the by-pass condenser in question, but some radio frequency may also get into the input circuit of the first audio amplifier tube T2. To obviate this possibility, a radio-frequency choke coil RFC1 having an inductance of 85 millihenrys, is connected between the plate of the detector tube and the plate resistor R1.

Even though a resistance-coupled amplifier be supplied with plate current from a new set of "B"-batteries, "motorboating" may take place; due to no other reason than the fact that the interstage coupling condensers store up electrons on the grid side faster than the grid leak can carry them off to the negative side of the filament. When this occurs in any one coupling unit, electrons collect on the grid side of the coupling condenser faster than they leak off through the grid resistor; and the grid of the succeeding tube gradually assumes a more negative bias until it finally becomes so negative that no plate current flows in the output circuit of the tube in question. The tube is then said to be "blocked."

Now, when the plate current ceases, no more electrons are passing from filament to plate within the tube, and no more electrons are passing from filament to grid within the tube. Then the grid leak carries off the electrons accumulated on the grid side of the coupling condenser, the grid returns to normal potential, plate current flows again; and the circuit returns to normal operation, until the grid of the tube in question goes far enough negative again to "block." The frequency of this "blocking" or "motorboating" depends, among other things, upon the value of the interstage coupling condenser and the value of the grid resistance.

This effect is most apt to occur in the last audio-frequency stage, where the potential swings of the grid are greatest. One way to eliminate "motorboating" due to this cause is to decrease the resistance of the leakage path for electrons accumulating on the plate of the coupling condenser. This can be done by decreasing the value of the grid leak at this point in the circuit; but, when this is done, stability is effected at the expense of volume, for the volume is thus decreased.

AN INDUCTIVE LEAK

The best method is to use an impedance leak in the grid circuit of the last tube as shown in Fig. 1; the inductance value of this leak should be between 100 and 200 henrys. Since it is used in the grid circuit, where the current-carrying requirements are so small as to be considered negligible as far as determining the size of the wire is concerned, very small wire may be used and the actual space taken up by a choke having this amount of inductance is no greater than that required by some of our large audio-frequency transformers.

With the impedance leak, the resistance to the flow of *direct current* is so small that the electrons which flow to the grid side of the coupling condenser will be leaked off to negative filament as fast as they arrive, and the average potential of the grid will remain constant. The volume will not be impaired in this case, as it was when we decreased the value of the grid leak resistor, because even at audio frequencies the impedance of this choke is very high. Thus, most of the audio-frequency potential that is apparent across the plate resistor R5 will appear also across the impedance leak, since it and C3 are connected in series across R5. If this impedance is large compared to that of C3, most of the voltage across the combination will be apparent across the impe dance.

RESISTANCE-COUPLING PROBLEMS

In passing, the thought might be mentioned that one of the reasons for distortion in connection with resistance-coupled amplifiers is the very thing that we have just been discussing. When electrons collect on the grid side of the coupling condenser, faster than they leak off, the average potential of the grid goes further and further negative. In the extreme condition of this sort we get "motorboating" but, even before this occurs, we get distortion, due to the fact that the average potential of the grid goes below that point on the straight part of the characteristic curve which will allow for linear amplification, and we get non-linear amplification with subsequent distortion. Hence, the impedance leak is an aid to obtaining good quality amplification with a resistance-coupled amplifier.

The resistance-coupled amplifier we have been discussing has been operating on a set of new "B"-batteries. Now, as these batteries grow old, the tendency to "motorboat" is more pronounced, due to the fact that their internal resistance increases, with subsequent increase in the interstage feed-back coupling. This permits voltage-ripples or surges at one point in the circuit to be fed back in just the proper phase relation to build up in another part of the circuit, and

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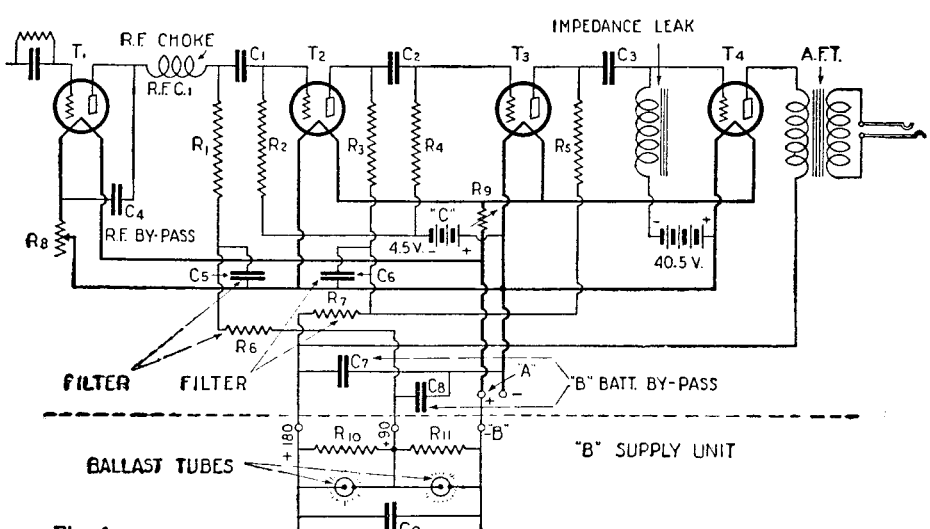

Fig. 1
By the use of an audio-frequency amplifier of a design such as that shown above, it is made practically impossible for "motorboating" to occur.

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effect this limiting or blocking action that is termed "motorboating."

The way to overcome this is to reduce the interstage feed-back coupling by connecting condensers across the "B"-battery terminals; and, if condensers are already connected across these terminals, you might increase the value of the capacity used. In the schematic diagram, Fig. 1, the by-pass condensers C7 and C8 are shown connected from the "B+180" and "B+90" terminals, respectively, to the "A—" terminal. The value of these condensers should be in the order of 1-mf. each; this should be sufficient. This is one of the most important places to operate on the circuit to eliminate "motorboating."

SOCKET-POWER OPERATION

When we use our resistance-coupled amplifier in connection with a "B" socket-power unit, the tendency to "motorboat" is increased; because the impedance between the different voltage taps on an "eliminator" unit is of high value and, unless properly by-passed, offers considerable interstage coupling. Here again, the way to eliminate this undersirable coupling, which is so apt to cause "motorboating," is to connect 1-mf. by-pass condensers from the "B"-supply terminals for the plates of the audio-frequency amplifier tubes to the negative filament terminal *right inside the amplifier unit.* Don't think that by-pass condensers across the voltage taps in your "B" unit are going to be adequate, when you run long leads from your eliminator to your amplifier.

In the case of the "B" power unit and its relation to "motorboating," we find another reason why it is apt to be the prime reason for this undesirable condition; namely, the fluctuation in the output potential of the unit. There are many reasons why the voltage output of a "B" device is apt to fluctuate. One reason is that, the greater the current drain, the lower the voltage available at the different output taps. Because of the high impedance of the rectifier tube and filter circuit, a small increase in current drain causes a large decrease in potential at the voltage-output taps. The current drain to the audio-frequency amplifier tubes is not constant. More current is drawn on the lower frequencies in the audio-frequency band than when the higher frequencies are passing through the circuit. This means that the voltage output from the eliminator is changing, since it is so susceptible to relatively large changes in voltage output with relatively small changes in current drain.

USE OF VOLTAGE REGULATORS

One way to overcome the fluctuation in output voltage from the "B" socket-power unit is to connect a UX-874 "voltage-regulator" tube from the "B+90" output tap to the negative terminal, and, if you have an 180-volt tap, connect another one of these tubes from the "B+180" terminal to the "B+90" one. The output resistors in your "B" unit should be so chosen that the voltage at the 90- and 180-volt taps is slightly over those respective values and does not fall below them as a result of the action of the "voltage-regulator" tube.

The UX-874 is a two-electrode gas-filled tube. When the potential difference across its terminals rises above 90 volts, ionization of the gas within the tube takes place, the internal impedance of the tube decreases, and enough current flows through the tube to decrease the value of the potential across its terminals to 90 volts again. It is highly desirable to have a device of this sort to regulate the voltage available at the output taps of a "B" socket-supply unit.

FILTER COMBINATIONS

Filter circuits can be used to smooth out any fluctuations in the voltage applied to the "B+" side of the plate-coupling resistors in a resistance-coupled amplifier. For instance, looking at Fig. 1, let us assume that the voltage applied to the "B+" side of the plate-coupling resistor R1 undergoes periodical ripples and surges, conducive to making the circuit "motorboat." A filter circuit, consisting of a 10,000-ohm resistor R6 and a 0.1-mf. by-pass condenser C5, can be connected as shown, to smooth out the ripples and the surges in the supply voltage. The condenser C5 acts as a reservoir, to collect energy when the D.C. supply potential surges above normal, and to dispense energy when there is a deficiency in the value of the supply voltage. This little filter circuit thus tends to equalize the D.C. potential at the "B" side of the plate-coupling resistor.

Another filter circuit, consisting of a 10,000-ohm resistor R7 and the 0.1-mf. by-pass condenser C6, can be connected in the plate-voltage supply lead for the two audio amplifier tubes T2 and T3, as also shown in Fig. 1.

Another type of filter circuit, which will primarily prevent any feed-back of audio-frequency energy from one circuit to a preceding one, with the possibility of effecting enough unstability to produce "motorboating," can be arranged by substituting audio-frequency choke coils in the two small filter circuits just described, in place of the two resistors R6 and R7.

RESISTANCE VALUES

If you are experiencing trouble from "motorboating," one easy thing to try in the course of getting rid of this undesirable action is to "stagger" the values of the resistors in the coupling units in the amplifier circuit. If the values of the coupling resistors throughout the different stages of amplification are the same, the R-C (resistance-capacity) constants will be the same throughout. This means that a "limiting" effect established in one stage would find better response in the succeeding circuit, if this succeeding circuit had the same "time-constant"; and the possibility of the limiting action being sustained in succeeding circuits would be greater.

However, if the R-C constants of the several coupling units are different, there is less chance of a periodic disturbance (established in one stage and passed on to the next) being amplified in this latter stage to a degree sufficient to cause "motorboating." With this thought in mind, you might use 50,000-ohm resistors at R1 and R2; 100,000-ohm resistors at R3 and R4; and a 200,000- or 250,000-ohm resistor at R5.

(*Editor's Note—Readers desiring a complete list of parts for the non-motorboating resistance-coupled amplifier shown in Fig.* 1 *may obtain same by writing to the "I Want to Know" Department,* RADIO NEWS, *230 Fifth Avenue, New York, N. Y. A stamped and self-addressed envelope should accompany each request for this information.*)