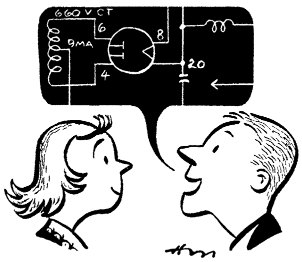
Audio Classroom

Practical Audio Design Part 3: Decoupling Networks and Voltage Regulation

BY JOSEPH MARSHALL



Noted author Joseph Marshall concludes this three-part series on power supplies by offering some effective design techniques. This article originally appeared in Audiocraft*, March 1956 (©1956 by Audiocom, Inc.).*

Every amplifier or amplifier stage must have a load in order to achieve either amplification or power delivery. The load should ideally be coupled from the output of the tube directly to ground, so that no part of the signal could be developed in an impedance between the load and ground. Unfortunately, except for cathode followers, the load must be returned to a source of voltage. And almost all power supplies, even batteries, have some internal resistance that represents an impedance to the signal frequency.

If several stages are used in cascade or series, and the main loads are returned to the same point in the power supply, some voltage from each stage would be developed across the supply because there is impedance between this point and ground. Parts of the late-stage signals would feed back to previous stages. When there are only two stages, the plate currents are out of phase; the signal fed back would result in degeneration—some loss of gain—and except for this, no great harm would result.

But when there are three stages, the signal currents of the first and third stages are in phase. The feedback would be positive, and, if it's of sufficient amplitude, instability or oscillation could occur. This instability or oscillation almost always happens at a very low frequency, because power-supply impedance increases as frequency decreases. The effect is familiarly called "motorboating," because it sounds exactly like the putt-putt of an outboard motorboat.

The condition for motorboating through a common impedance in the plate-return circuits is diagrammed in *Fig. 1*. This is a three-stage amplifier in which all the loads are returned to the same point in the power supply and therefore have a common impedance. There is usually a filter capacitor at this point to ground; there is also a series impedance consisting of the reactance of chokes and the resistance of filter resistors, as well as the rectifier.

At most frequencies, the reactance of the shunt capacitor is very low compared with either the resistance of the power supply or that of the individual stage loads. Most of the signal at point X is, therefore, bypassed through the capacitor to ground. But at low frequencies, the capacitor reactance begins to approach that of the power supply and/or the loads. Then part of the output signal will travel along the paths indicated by arrows back to the load of the input tube, producing positive feedback and low-frequency instability.

The solution to the problem involves three steps: 1) arrange things so that the loads are returned to impedances that are not common to the several stages; 2) provide capacitors of very low reactance in front of these independent impedances so as to bypass the signal to ground; 3) reduce the impedance of the power supply to the lowest possible value.

This can be done by changing the circuit in *Fig. 1* to that in *Fig. 2*. Here we have added some additional resistors (marked R_d) and capacitors (marked C_d) in the plate-supply lines. This accomplishes steps 1 and 2 specified in the previous paragraph. Each load now looks into an independent impedance, and at each point there is, so to speak, an escape path for the signal frequencies through the capacitor. There is a fairly high impedance between each stage, and a low impedance to ground from each stage.

DECOUPLING RESISTORS

It is obvious that the added resistances cause reduction of B+ voltages. To hold down this drop and thereby hold up the

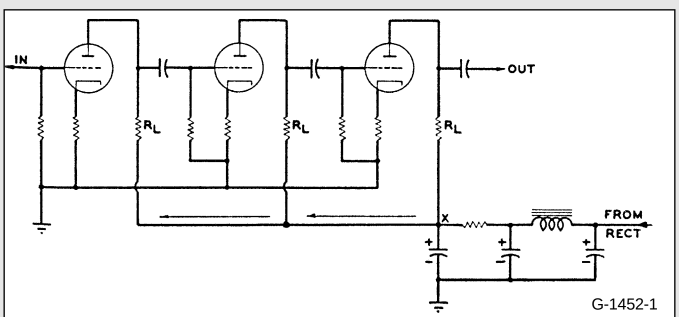


FIGURE 1: Condition for motorboating; plate loads connected to common power-supply impedance.

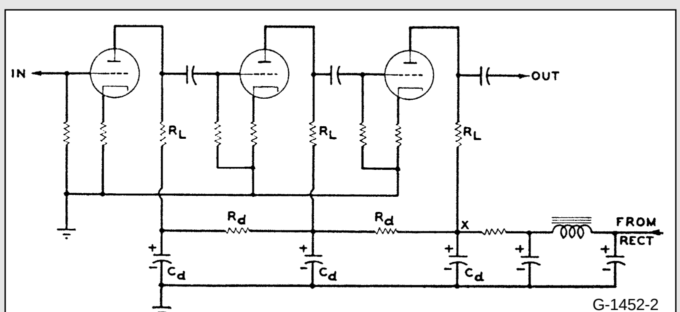


FIGURE 2: Decoupled loads.

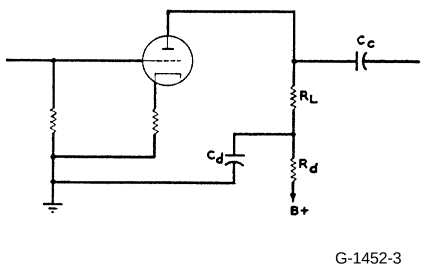


FIGURE 3: Illustrating low-frequency boost.

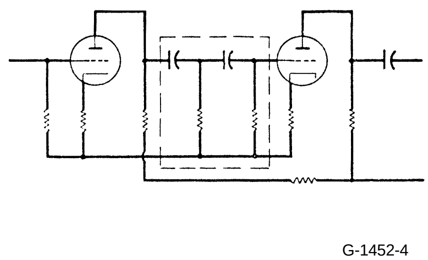


FIGURE 4: Multi-section interstage network.

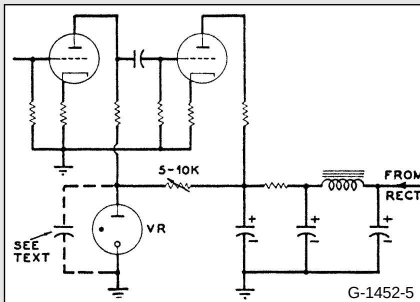


FIGURE 5: VR tube employed as decoupler.

gain, the decoupling resistors should be no greater in value than necessary. In most audio amplifiers that have a power-output stage, the voltage at point X is 100V or more higher than it need be to obtain adequate gain from the early stages; therefore you don't need to worry much about holding the decoupling resistances down except for another circumstance, illustrated in *Fig. 3*.

Here, one of the stages is redrawn. R_L represents the normal plate load, R_d the the decoupling resistor, and C_d the bypass capacitor. The actual load consists primarily of R_L, in series with the parallel combination of R_d and the reactance of C_d. At frequencies for which the reactance of C_d is very low, the effect of the decoupling network on the load is very slight. But as the frequency is lowered, the reactance of C_d increases and, after a certain point, becomes high enough so that the combination of R_d and C_d in parallel produces a total impedance that is a considerable fraction of R_L. At that point, the low frequencies will be working into a greater load than the higher frequencies, the gain will increase, and the result is a boost of lows.

This effect is sometimes employed in amplifiers to make up for low-frequency losses in the coupling capacitor (C_c) between the stages. It is quite possible to proportion the decoupling and interstage coupling capacitors so as to break even, as it were, and achieve a flat curve down to some much lower frequency than would be possible without the decoupling network. But this is rather a risky business. As might be expected, the boost in the low end means that there is more voltage that might be fed back to cause instability, and it is very seldom that you can be sure of obtaining both a better bass response and better stability in this way.

A good rule is to make R_d equal to ⅕ R_L in late stages, where the signal level is high; you may use a higher value in earlier low-level stages. The value must not be so high, however, that the voltage drop through it would result in applying too low a voltage to a preceding stage. Ordinarily, the rule given will take care of this, but, if the gain of some stage is reduced more than is desirable, it may be well to reduce the decoupling resistors.

The time constant of R_d and C_d (R in MΩ times C in µF) should not be less than .01 for any kind of audio amplifier (except possibly a speechless frequency ham or telephone amplifier); for high-quality amplifiers it should not be less than 0.1. The simplest way to improve the time constant is to increase the capacitance. Electrolytics are universally employed today, and they are good enough to cause little trouble. Occasionally, however, one is excessively leaky, and sometimes one is noisy and will be troublesome in low-level stages.

It is not a good idea to use decoupling resistors greater than 50k with electrolytic capacitors, and lower values are preferable. Electrolytics sometimes have high reactance at high frequencies, and, because of this, it is possible to have feedback through the power-supply impedances at high frequencies. You can minimize or correct this by wiring paper capacitors of from 10 to 50nF in parallel with the electrolytics. Stubborn cases of parasitic feedback at high frequencies are sometimes curable by this method.

HUM FILTERING

The decoupling network, then, is actually a part of the hum-filter network. Indeed, the same components achieve both hum filtering and decoupling. Ordinarily, the need for progressive hum filtering discussed in Part 2 of this series dictates the use of a hum decoupling element between all stages in a multiple-stage amplifier. However, if hum isn't a serious consideration, and decoupling with economy is, you can save by using decoupling filters only between odd-numbered stages. That is, the second and third stage might be fed from the same point in the power supply, while the first stage had a decoupling filter.

When the number of stages exceeds three, the decoupling problem becomes severe; even extensive decoupling may not prevent motorboating. One reason for

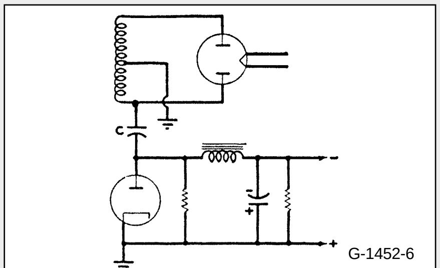


FIGURE 6: A diode of conventional type can be used for bias supply.

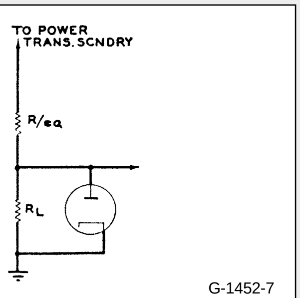


FIGURE 7: An equivalent circuit for the bias supply in *Fig. 6*. See text for explanation.

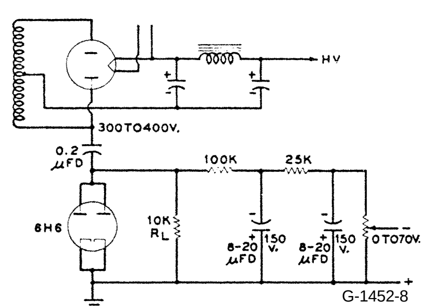


FIGURE 8: Practical variable-bias circuit.

this is that there are other paths for feedback: the plate-grid capacitances of the individual tubes; coupling by adjacent spacing of tubes or wiring; or, in most modern amplifiers, a deliberate negative feedback loop.

With so many paths for feedback, even a little feedback through the common-plate impedances may be sufficient to cause trouble. It is not wise, therefore, to attempt to use the same power supply for more than four stages at the most, and it's much safer to use one power supply for the power amplifier plus its driver and voltage-amplifying stages, and another power supply for the tone-controls, mixers, and preamplifier stages.

But if it is absolutely essential to use a single supply for many stages, it is often possible to prevent motorboating by putting sharp cutoff filters between the stages. You achieve this simply by adding another capacitor and resistor to the grid-coupling network, as in *Fig. 4*. Using this at several points may produce acceptable performance of multiple-stage units.

However, this applies only if there is no negative-feedback loop around the whole amplifier; if there is, the addition of the sharper cutoffs will only accentuate phase shift in the feedback loop and lead to more serious instability. I find the double RC-coupling network most useful between the input to the power amplifier—just ahead of the stage to which overall feedback is applied—and the preceding control unit or preamplifier.

VOLTAGE REGULATION

It has been pointed out that lowering the internal impedance of the power supply reduces the probability of instability. A power supply with voltage regulation has extremely low impedance. If you use vacuum-tube regulation, the common impedance may be so low that you need no decoupling network at all. Furthermore, a voltage regulator provides extremely effective hum filtering; a device capable of bypassing the very slow irregularities of a DC current can offer little reactance to audio frequencies.

I have had good results using gas-type voltage regulators of the OA2 and VR150 types as decoupling and hum filtering elements. As many readers know, I have incorporated them in several of my designs. They furnish a simple and effective way to obtain very good decoupling and hum filtering. Since one VR tube costs less than almost any combination of choke or resistor and capacitor, it is also an inexpensive way.

The application of VR tubes for decoupling requires very few precautions. First, the current flowing through a VR tube must be sufficient to ignite it and keep it so. You can ensure this by using a variable series resistor between the VR tube and the power supply, as shown in *Fig. 5*. You can adjust the resistor so that, with the tubes all in the circuit, a current of at least 10mA flows through the VR tube. Alternatively, if there are as many as three or four high-mu triodes drawing from 5–10mA beyond the VR tubes, a series resistor of 7,500Ω (at least 5W) will do the job.

Some VR tubes are noisy, producing a hash that might be audible in high-gain amplifiers. Some may also oscillate in the circuit. It is usually a good idea to bypass the tube with a paper capacitor of 50nF if either effect is noticed. Sometimes, though, adding this capacitor only makes matters worse! Trial-and-error changes of shunt capacitance, or tube replacement, are necessary in such cases.

BIAS SUPPLIES

The use of fixed bias on power-output tubes often makes possible a considerable increase in power output for the same voltage supplied to the plates. Bias required for modern power-output tubes ranges from –10 to –60V. There are a number of simple ways to obtain the required bias voltage.

One of the simplest is the use of a shunt rectifier, shown in *Fig. 6*. No additional winding on the power transformer is needed. If the circuit is redrawn as in *Fig. 7*, it becomes obvious that the reactance of the capacitor at 60cps (indicated by R_{eq}) and the rectifier load (indicated by R_L) comprise a voltage divider that reduces the high voltage of the power transformer. You can obtain any voltage needed simply by changing the value of the capacitor, or the value of the load resistor, or both.

The current drawn depends on the load resistance—the greater the resistance, the lower the current. A few mA is sufficient, and values of R_L around 10k are satisfactory. *Figure 8* shows values for a practical supply delivering up to –70V, enough for almost any output tube. You can obtain lower voltages either by reducing the size of C or by using a pot across the bias supply and adjusting it for whatever bias value is needed.

Note that there is a high resistance between R_L and the filter capacitors. This resistance is essential; without it, the first filter capacitor would become the bottom half of the voltage divider, and excessive current would be drawn. The rectifier may be one or both sections of a 6AL5 or 12AL5 in parallel, a 6H6 or similar tube, a small triode connected as a diode (by tying grid to plate), or the in-

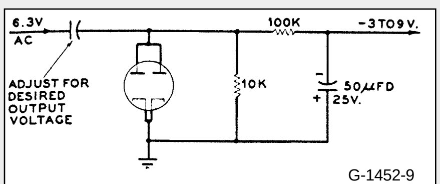


FIGURE 9: Simple low-voltage bias supply.

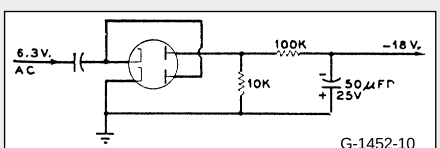


FIGURE 10: Voltage-doubler hookup, *Fig. 9*.

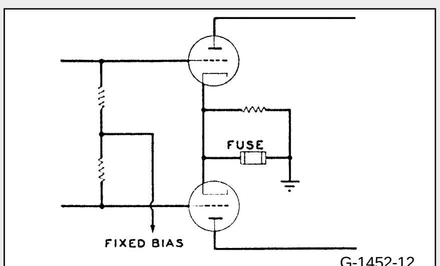


FIGURE 12: Emergency bias circuit.

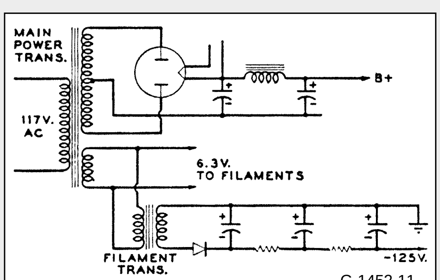


FIGURE 11: High-voltage fixed-bias circuit.

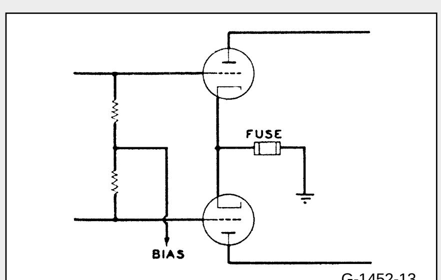


FIGURE 13: Simple protective device.

dependent diode of a multiple-section tube, provided you can ground the cathode directly.

VOLTAGE DOUBLING

When a very low bias voltage is needed (–3 to –9V), the circuit in *Fig. 9* can furnish it with only the filament voltage as a source. *Figure 10* shows a voltage-doubling version that can supply –18V from a 6.3V filament string—enough for 6V6s, EL84s, and similar tubes.

Another way to obtain bias voltage, especially when you require more than –100V (in circuits, for instance, where output tubes are directly coupled to cathode-follower drivers, and driver grid-bias voltage is needed to buck out the cathode voltage) is to use a miniature 6.3V filament transformer wired in reverse, as in *Fig. 11*, and then rectify the 117V output. Inexpensive and compact selenium rectifiers are perfectly satisfactory for this purpose. [*Today, of course, we use cheap, readily available, silicon diodes. —Ed.*] If the load resistor is kept fairly high, the bleeder current is low, and you can use a high-resistance filter to achieve adequate hum filtering.

The trouble with using fixed bias is that failure of the bias supply removes bias from the output tubes and may, in consequence, burn out the plates in a few seconds. There are at least two very simple devices to provide insurance against this, one of which will maintain operation in spite of failure. *Figure 12* shows an output stage with fixed bias. Note that there is a bias resistor in the cathode circuit, but the resistor is shorted by a ¼A, 250V fuse. Failure of the bias supply would increase current violently, causing the fuse to blow. This would remove the short on the self-bias resistor until the fault was corrected.

In *Fig. 13* there is the same fuse, but no bias resistor. Failure of bias will blow the fuse, but, in this case, the result is merely to open the cathode circuit and prevent the flow of plate current. This is not quite safe; a tube can be damaged—though it is far less likely to be—when plate and filament voltages are applied with an open cathode. But it does give immediate indication of trouble. These measures cost so little that it is foolish not to include them. ❖