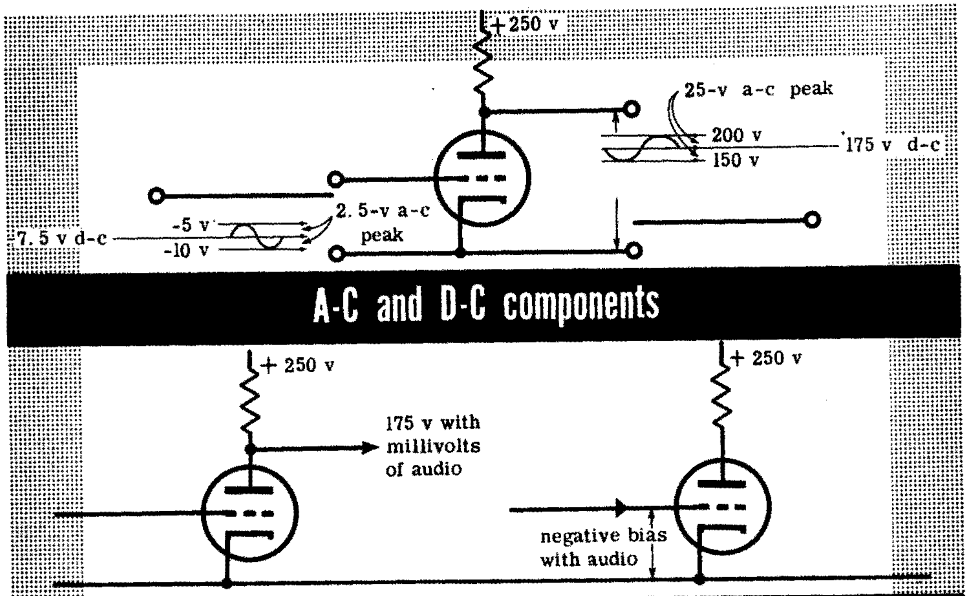
A-C and D-C Components

Thus far we have shown how smaller voltage or current fluctuations can, by using tubes or transistors, cause bigger voltage or current fluctuations. This is the essence of amplification, but one thing more is necessary to be able to make use of amplification.



How do we pass on the millivolts of audio, and give the grid of the next stage the right combination of d-c bias and audio (a-c)?

In the first practical amplifier stage discussed, an input fluctuation of 5 volts at the grid produced an output fluctuation of 50 volts at the plate. We did not pay much attention to the fact that these fluctuations do not conveniently start from zero or the negative bias required by the grid of a following stage. The grid circuit fluctuation could be regarded as being 2.5 volts away from an average (d-c) bias of 7.5 volts. The plate output is a fluctuation of 25 volts each way from an average (d-c) component of 175 volts.

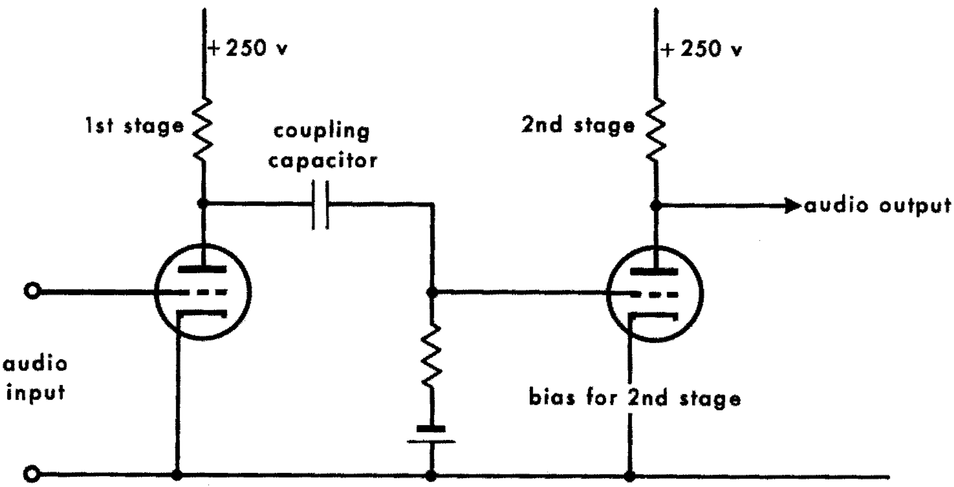
This would, of course, run in proportion. If we start from a microphone, the voltage fluctuations will only be measured in millivolts, or thousandths of a volt. The first stage of amplification would raise this to tens of millivolts—still a rather small signal that would require more amplification to make it useful.

The easiest way to eliminate the d-c components in the output is to use a capacitor. Current does not flow from one plate to the other of a coupling capacitor, but current can flow *to* the plates, producing a charge on them, accompanied by a difference in voltage between them.

Coupling Capacitors

In the absence of fluctuations (audio), the plate or foil of the capacitor connected to the grid resistor takes the grid bias voltage. If there is any charge that would produce a different voltage, it flows away through the resistor, so that the voltage is again equalized. The same thing happens at the foil connected to the plate of the previous tube— it is at the same voltage as the tube's plate.

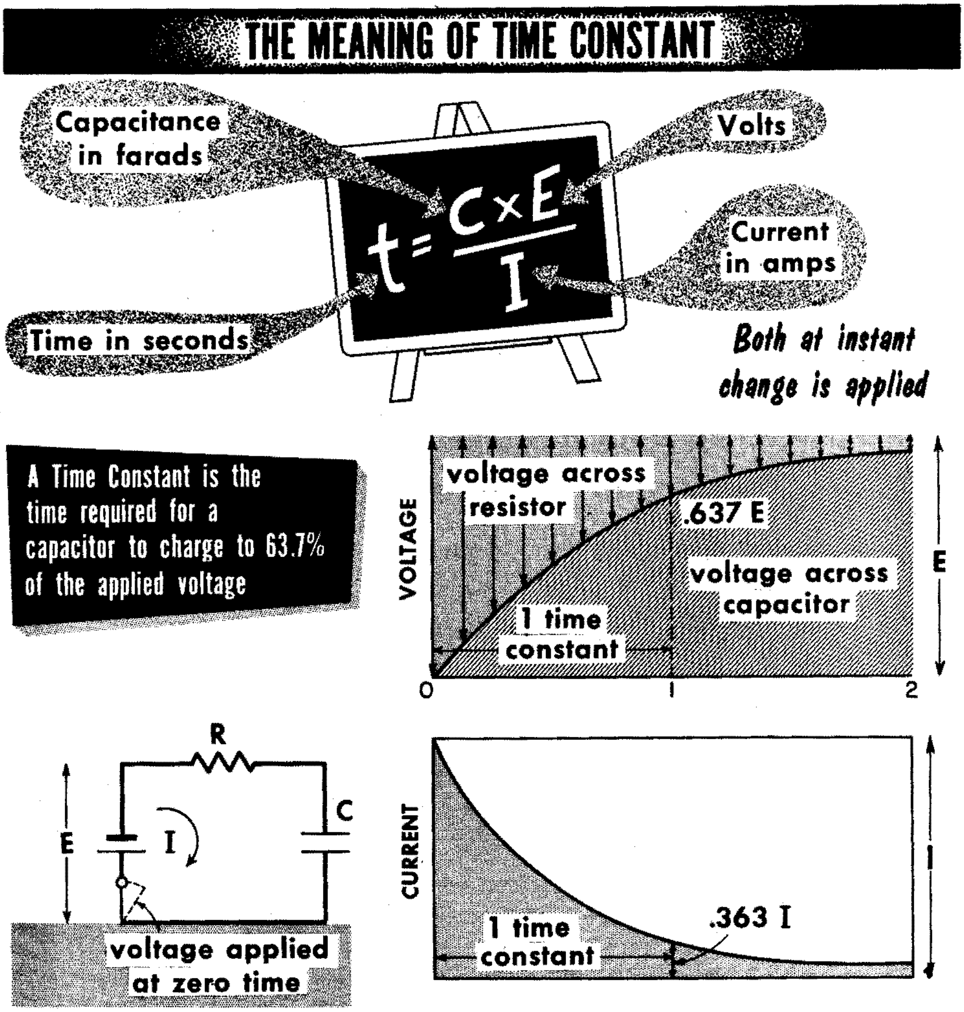
USE OF A COUPLING CAPACITOR



The COUPLING CAPACITOR prevents the d-c voltage from reaching the grid of the next stage while passing on the audio fluctuations

When audio signals come along, the voltage at the plate goes up and down from its steady resting point. Because the grid resistor is so large, the charge on the capacitor does not have time to change, hence the voltage across the capacitor does not change. This means the voltage at the grid fluctuates up and down from its steady voltage in exactly the same way as the previous tube plate. (The capacitor acts as a short-circuit for the fluctuations, while isolating the d-c components at plate and grid.) If the voltage at the previous tube plate changed permanently, the charge on the capacitor would also change, so that the potential on the grid side would be the same as ground potential, while that at the plate side assumed the new plate potential. This process (as we have shown) takes a time dependent on the size (value) of the capacitor.

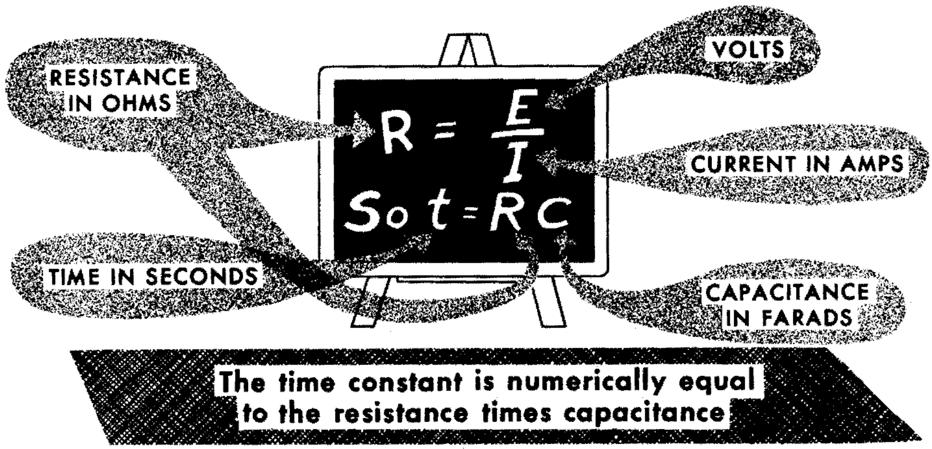
Time Constants



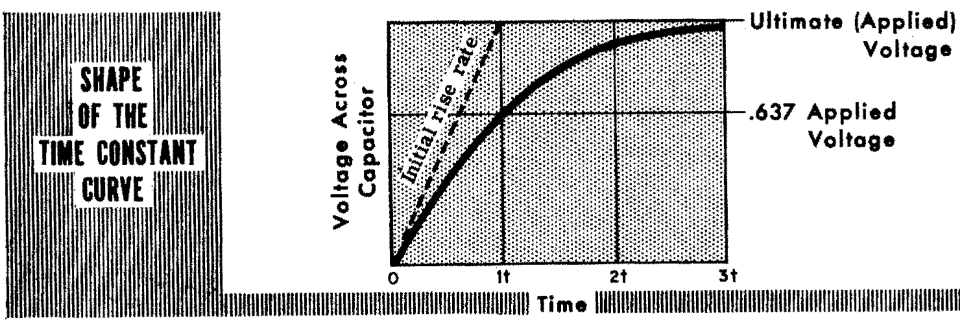
To understand the way in which a coupling capacitor operates, we need to know about time constants. When the voltage between the terminals of a resistance-capacitance combination (such as the coupling capacitor and grid resistor) changes, the charge across the capacitor does not change immediately. Therefore the voltage across the capacitor is initially the same as before the change. Current immediately *starts* to flow in the resistor, because all the change in voltage appears across it. This will determine the initial current according to $I = E/R$. If a current of this size continued to flow, it would take a certain time to change the charge on the capacitor, equalizing the voltage across it. In seconds, the time would be given by $t = C \times E/I$.

Time Constants (contd.)

Because the current is also determined by the voltage change, E, that started it, the time can be written as t = RC. This now eliminates both E and I from the formula, which shows that the time would be the same whatever the voltage change involved. (A larger voltage change would produce a larger current, hence the time for the charge to change would be the same.)



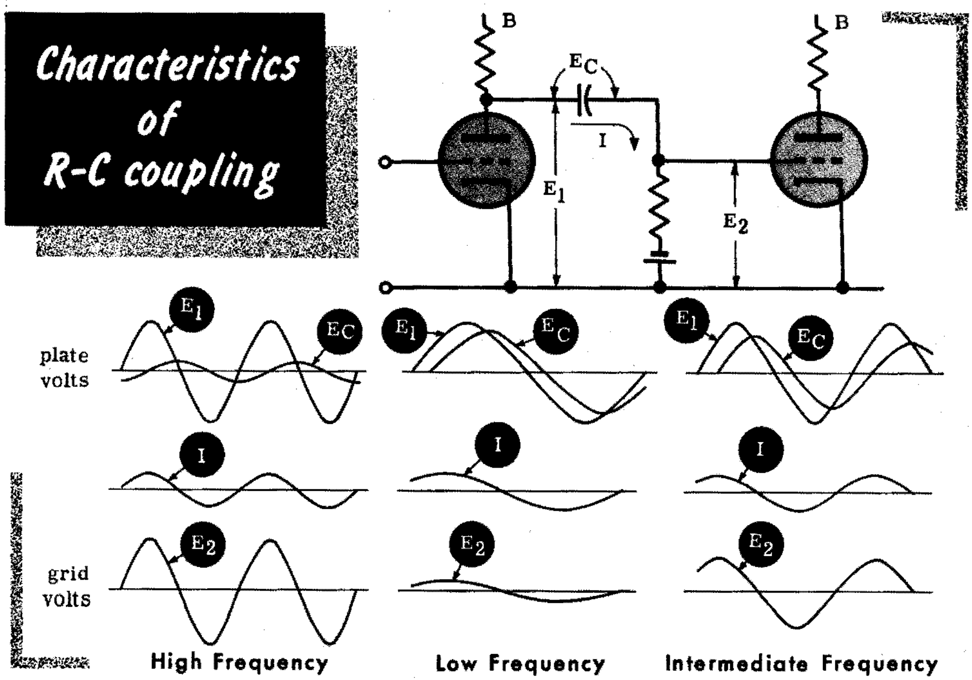
However, the current does not remain constant until the voltage equalizes, and then stops. The flowing of current causes a rise in the voltage across the capacitor and a corresponding fall in the voltage across the resistor. This, in turn, causes the current in the resistor to decrease. The current thus drops off gradually before the change in voltage is complete. In fact, in the time it would take to make the whole change if the starting current were maintained, the change actually reaches only 0.637 of its complete change. In theory it never does quite reach the complete change, because the current keeps falling off indefinitely, and so does the voltage difference.



R-C Coupling

At higher frequencies, the charge on the capacitor hardly changes at all during an audio-frequency fluctuation. At low frequencies, however, there is time for the charge to change, which changes the voltage across the capacitor. If the frequency is low enough, the voltage across the capacitor changes as much as the plate potential, and the potential of the grid of the second tube hardly changes at all. At intermediate frequencies, the voltage at the second-stage grid fluctuates by an intermediate amount.

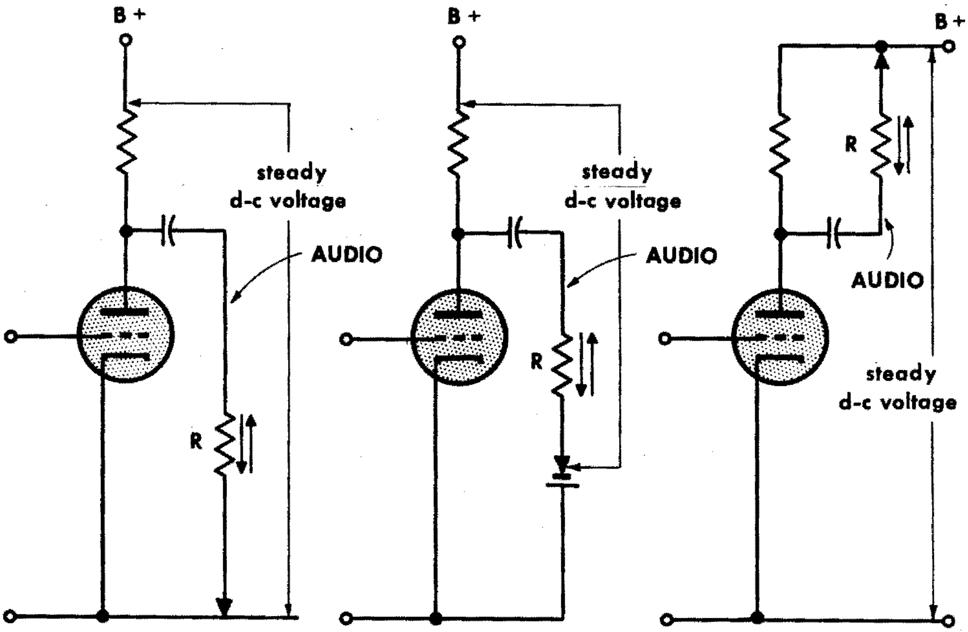
At the higher frequencies, the current through the grid resistor, due to the audio fluctuations, is the same as if the resistor were connected directly to the plate, without the steady d-c voltage difference being there. Where does this audio current come from? The plate circuit of the tube has to supply it. When the plate fluctuates negative, due to momentarily greater current through the coupling resistor, the grid of the following stage goes negative as the result of current flow through the grid resistor from grid to ground, adding to the momentary plate current. We use the term *coupling resistor* for the component that feeds B plus to the plate. Some call it the *plate resistor,* which must be carefully distinguished from plate resistance. Many call it the *load* resistor, which can be misleading. As we have just seen, current fluctuations related to stage amplification divide between this resistor and the grid resistor coupled to it by the coupling capacitor. So, at most frequencies, the *load* for the tube's plate is these two resistors effectively in parallel. We will call this the *load resistance.*



R-C Coupling (contd.)

Because this increase in plate current is controlled by the voltage applied to the grid, this extra current means that the rise in current *through the coupling resistor* will not be so great as before the capacitor and grid resistor were connected. The effect is the same as if the grid resistor were connected in parallel with the load resistor.

Taking Audio Fluctuations from the Plate Circuit



No matter where the other end of resistor R is connected, it takes the same current and voltage fluctuations from the plate

Whether the resistor to which the output side of the capacitor is connected goes to ground or to B+ will only make a difference to the charge on the capacitor and the steady voltage across it. The *fluctuations* across the capacitor and the audio currents will be the same either way because B+ is always a fixed voltage difference from the ground.

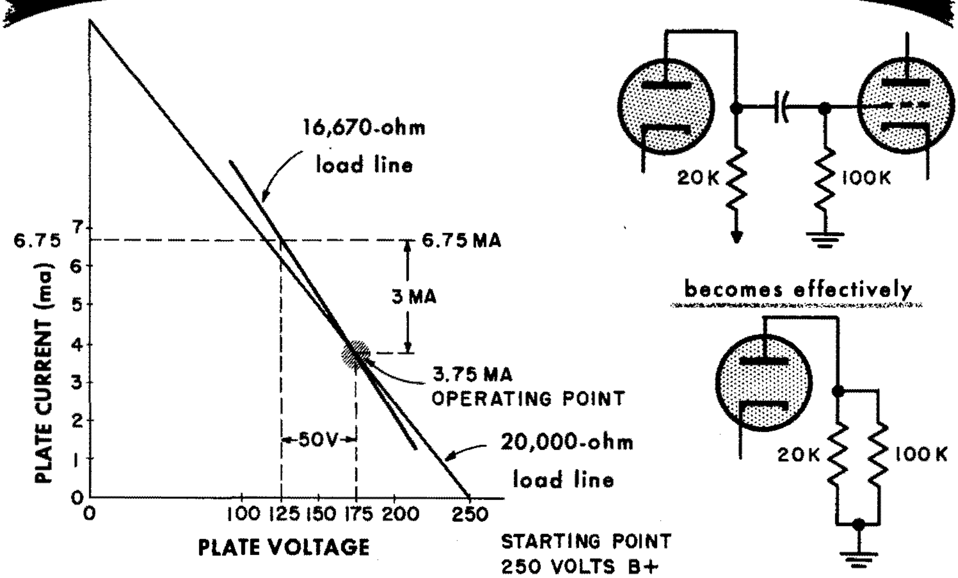
Constructing The New Load Line

We can apply these facts to the load line. The actual load resistor connected between B+ and the plate controls the steady operating point, according to the steady grid bias voltage. This operating point is found by using the load line corresponding to the coupling resistor, starting from the B+ voltage used.

Audio fluctuations cause the plate current and voltage to fluctuate in a manner that can be indicated by drawing a load line through the operating point, at a slope representing the combined resistances of the coupling resistor and grid resistor in parallel.

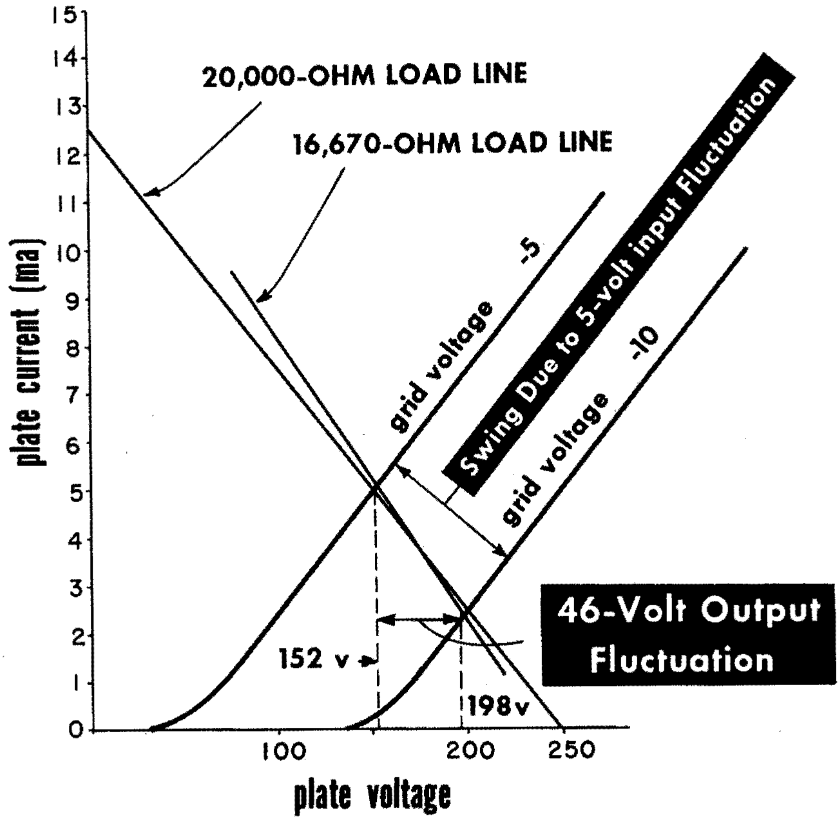
In the example we used before, the plate coupling resistor was 20,000 ohms. If we use a grid resistor of 100,000 ohms, the *effective* resistance of these two working in parallel for (audio only) is (20,000 × 100,000)/(20,000 + 100,000) or 16,670 ohms. Drawing a line representing this resistance, through the 175-volt/3.75-milliampere operating point, can be achieved as follows: three milliamps through 16,670 ohms will produce a voltage drop across it of 50 volts. Hence 6.75 milliamps on this load line will correspond with 175—50 or 125 volts.

Constructing the Dynamic Load Line



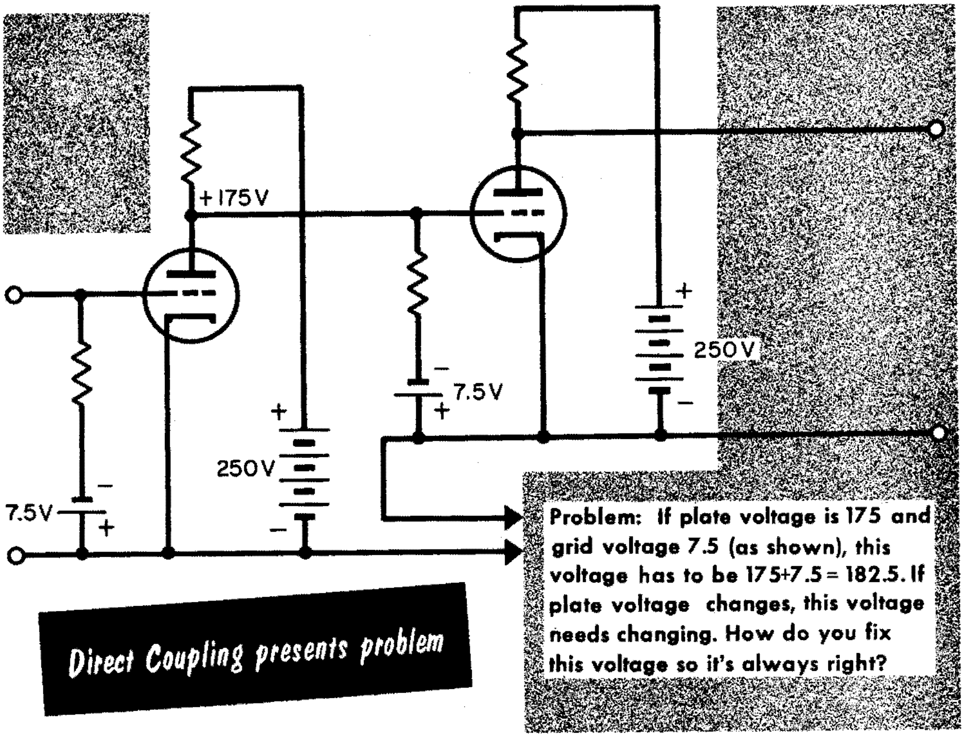
Constructing The New Load Line (contd.)

THE COMPLETE DYNAMIC LOAD LINE



Joining these points and extending the line we can find the new values of plate voltage corresponding to fluctuation of grid voltage between —5 and —10. The new voltages, instead of 150 and 200, as on the 20,000-ohm load line, are now 152 and 198 volts. Thus a 5-volt input fluctuation yields a 46-volt output fluctuation. The gain is 46/5 or 9.2, instead of the 10 obtained before.

Direct Coupling



An alternative to resistance-capacitance coupling is direct coupling. This system requires several separate supply voltages, however, and there is a problem in getting them all set—and maintained—at their right values. For example, if the working plate voltage of the first tube is 175 volts and the next stage needs 7.5 volts bias, the second-stage cathode must be exactly $175 + 7.5 = 182.5$ volts positive from the first-stage cathode. This voltage must be maintained in addition to the *voltage supplies* needed to provide plate current.

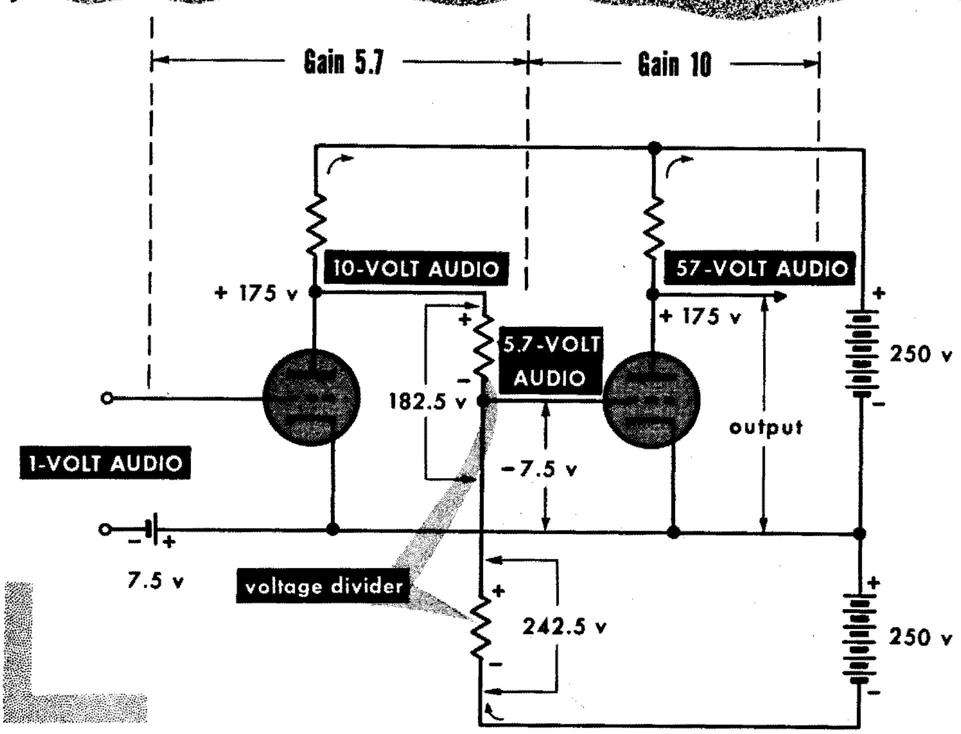
If the plate voltage should happen to be 170 volts and the second cathode is still positive 182.5 volts, its bias will become 12.5 volts, which is too much. When more stages are added to this system, a very small error in voltage at the input end can result in later stages being biased completely out of operation.

The problem then is that a number of supplies are needed, and they have to be very accurately controlled to the right value—which may vary with room temperature or a number of other things.

Such designs have been developed for computor applications, which are not audio and therefore will not be discussed here.

Direct Coupling (contd.)

A TWO-STAGE AMPLIFIER USING RESISTANCE COUPLING



Another system that uses resistance coupling has just two supplies, one positive and one negative. To bring the voltage at one plate down to a suitable level for the following grid, two resistors are used as a voltage divider. Of course these resistors will divide the available fluctuation at the plate as well as dropping the steady voltage.

Suppose the gain of the previous stage is 10 (as calculated at first), and the plate potential is 175 volts. If the negative supply is 250 volts, like the positive supply, the resistors that give the correct steady voltage for the following grid must give —7.5 volts at their junction, or be in the ratio of 182.5 : 242.5. The fluctuations will be divided by $(182.5 + 242.5)/242.5 = 1.75$. The gain from the grid of the first stage is now 10/1.75 or 5.7, being first multiplied by 10 in the tube, then divided by 1.75 in the resistance coupling. Resistance-capacitance coupling gives better results than direct coupling. Its main disadvantage is that it ceases to be effective at some low frequencies, fixed by the time constant of the resistor-capacitor combination.