

## PART 5. LF AMPLIFICATION

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**W**E SAW LAST MONTH THAT THE VALVE could be used as an amplifier of electrical disturbances. Although we only spoke of one-valve amplifiers, we did mention that requirements do exist where a greater number of valve stages are necessary.

In these cases we are faced with the problem of coupling the stages together, and we shall now consider how this may be done. Many methods have been used in audio amplifiers, but most of them have been discarded in favour of the modern practice of "resistance capacity" coupling. We shall, therefore, concentrate on this type but a brief glance at some of the other methods would be useful, and can be saved for later on.

### R.C. Coupling

At first sight, one may wonder what all the fuss is about. It seems simple enough; if the anode is the output of the valve and the grid is the input, surely the anode of valve No. 1 merely has to be connected to the grid of valve No. 2? True, this sounds perfectly logical, but take a look at Fig. 1.

Now the anode voltage of  $V_1$  is, say, +100 volts, but the correct grid bias voltage for  $V_2$  is -2V. Clearly then, we cannot connect points A and B together, because the grid (point B) would become positive with respect to its cathode and excessive grid current would flow and overheat the grid.

The voltages at A and B are both d.c. voltages; they are supplied by h.t. and grid bias batteries. Now, if we apply a signal to the grid of  $V_1$ , an enlarged or amplified version of this signal will appear at the anode of the valve. You will remember, however, that this signal is necessarily of an alternating character, as we pointed out in a previous article. At the anode of  $V_1$ , then, we have an alternating voltage superimposed on a d.c. voltage. So what we want is a component that will pass the a.c. voltage to the grid of  $V_2$ , but will *not* pass the d.c. Fortunately, someone has already thought about this, and such a component is readily available: the capacitor. Incidentally, the

capacitor is often called a "condenser," but the former term is becoming more common nowadays.

The circuit of Fig. 1 may be connected as shown in Fig. 2. Any number of stages may be now "cascaded" in this way. This is the most common way of coupling audio stages together: by "resistance capacity" coupling.

### Transformer Coupling

Another type of component which will pass a.c. but not d.c. is the transformer. Fig. 3 shows one method of connecting a transformer between two valve stages. Very briefly, the current in  $V_1$  flows through the primary winding of the transformer. This current sets up a magnetic field which interacts with the secondary and induces a voltage into it, which is applied to the grid of  $V_2$  as shown. The important thing is that a d.c. current in the primary produces no voltage across the secondary, but an alternating current in the primary does produce a secondary voltage.

One advantage of the transformer is that more volts may be obtained at the secondary than are applied at the primary. If, for example, there are five times as many turns of wire on the secondary as there are on the primary, then 5 volts will appear across the secondary for every one applied to the primary.

This means that a stage of valve amplification might be saved by using a transformer instead of R.C. coupling.

Another way of connecting a transformer is shown in Fig. 4. This has the advantage that the standing current in the valve does not flow through the transformer as it is blocked off by the capacitor. The a.c. or signal will, however, still be fed to the transformer via the coupling capacitor.

### Choke Capacity

A method of coupling rarely used nowadays, but still worthy of mention, is shown in Fig. 5. An iron cored choke takes the place of the usual anode load resistor. The advantage is that a lower h.t. voltage may

be used because the choke has a low d.c. resistance and few volts are dropped across it by the flow of standing anode current.

If the choke has a high inductance, say 20 henrys, or so, it will have a high reactance down to relatively low frequencies, and the gain of the stage could be as high as with a normal resistor. The capacitor C couples the anode to the next grid in the same manner as R.C. coupling.

### Advantages

The advantages and otherwise of the methods of coupling illustrated are as follows:

1. R.C. coupling provides a system where the gain of the whole amplifier is constant over the widest band of frequencies. That is, the distortion is low.

2. Transformer coupling does not give such low distortion as R.C. coupling unless the transformer is elaborate, bulky and expensive. It does have the advantage of voltage "gain" from primary to secondary if required.

3. Choke coupling does not give low

distortion either. If the distortion can be tolerated, the efficiency of the stage may be higher than for R.C. coupling.

So much for the moment on the matter of interstage couplings. However, later we will return to the R.C. method and examine its "frequency response"; that is, whether all frequencies are treated as equals in that circuit.

### Grid Bias

In all the circuits in this article so far, this grid bias has been indicated by a vague arrow marked "G.B." This, of course, indicates that a battery is connected there. Grid bias batteries have been in use for years, but most modern designs make use of other ways of obtaining the operating bias for the valves.

Fig. 6 shows how an ordinary grid bias battery might be connected to an amplifier. The positive end of the battery is connected to earth and the grids are connected to the appropriate negative voltages. In early battery-driven receivers, this system was widely used, but in some later types

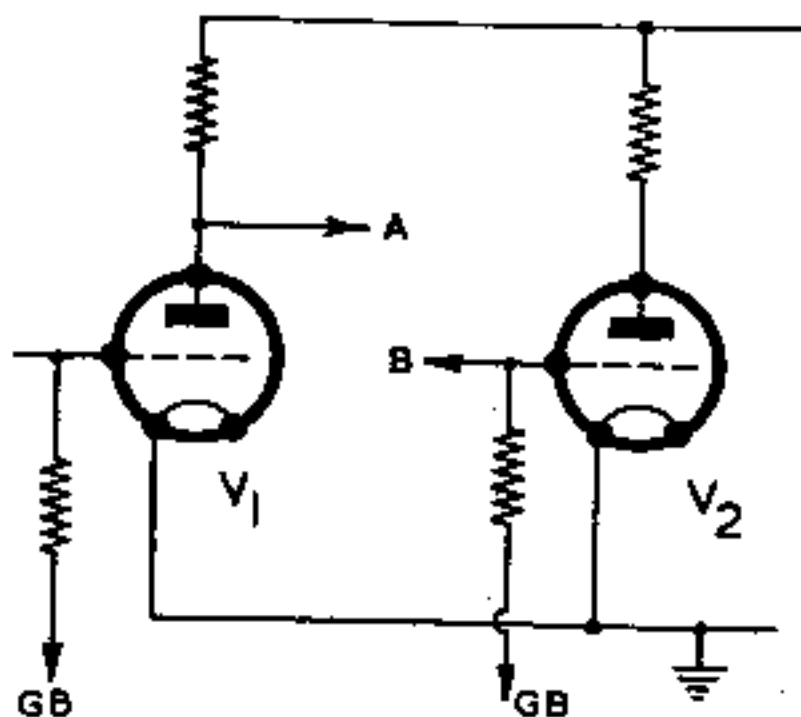


FIG. 1.

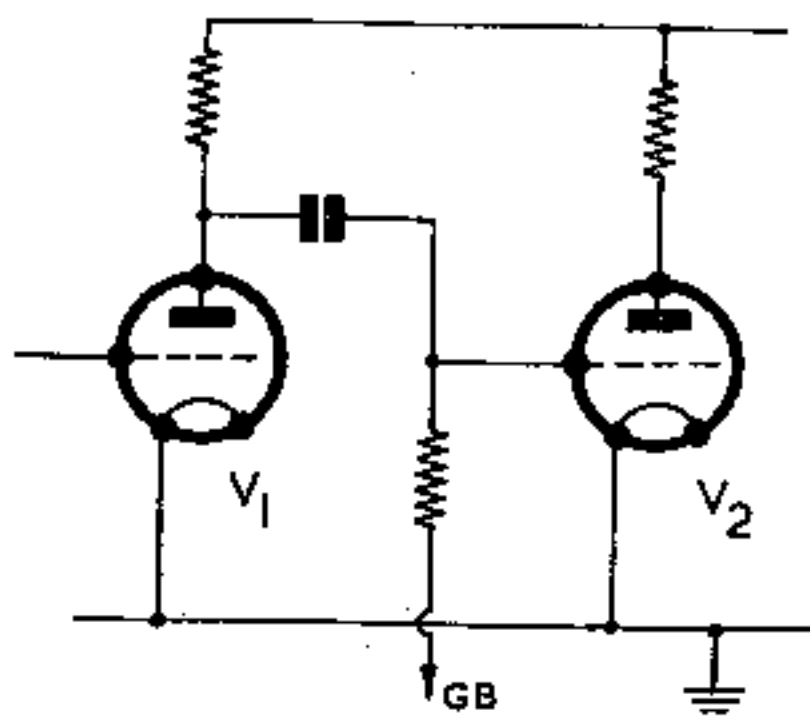


FIG. 2.

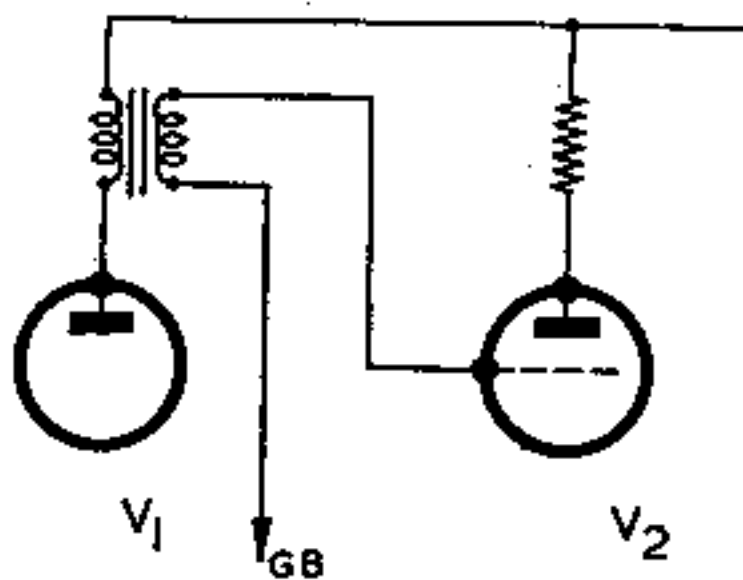


FIG. 3.

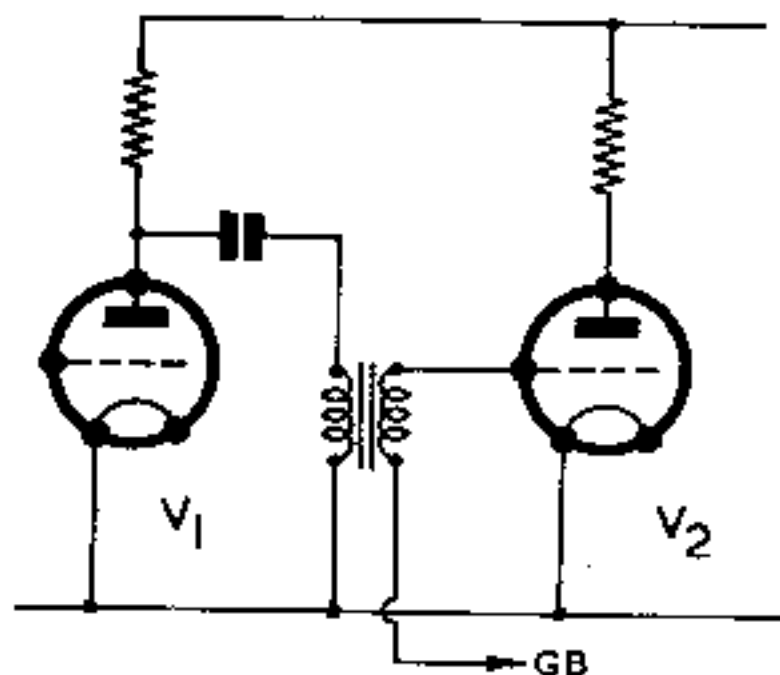


FIG. 4.

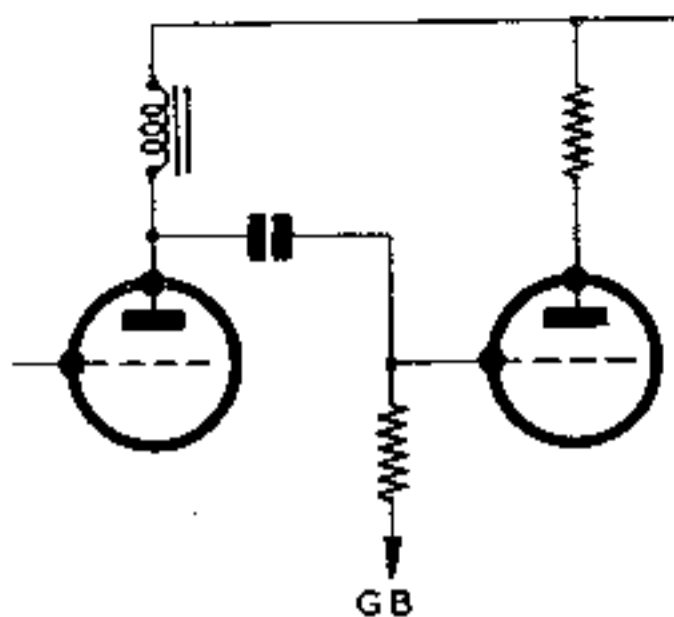


FIG. 5.

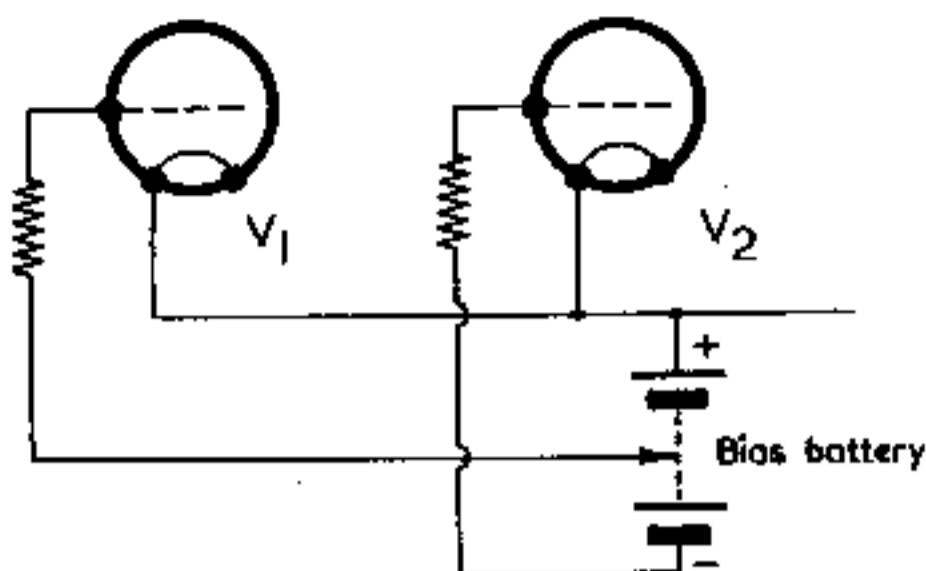


FIG. 6.

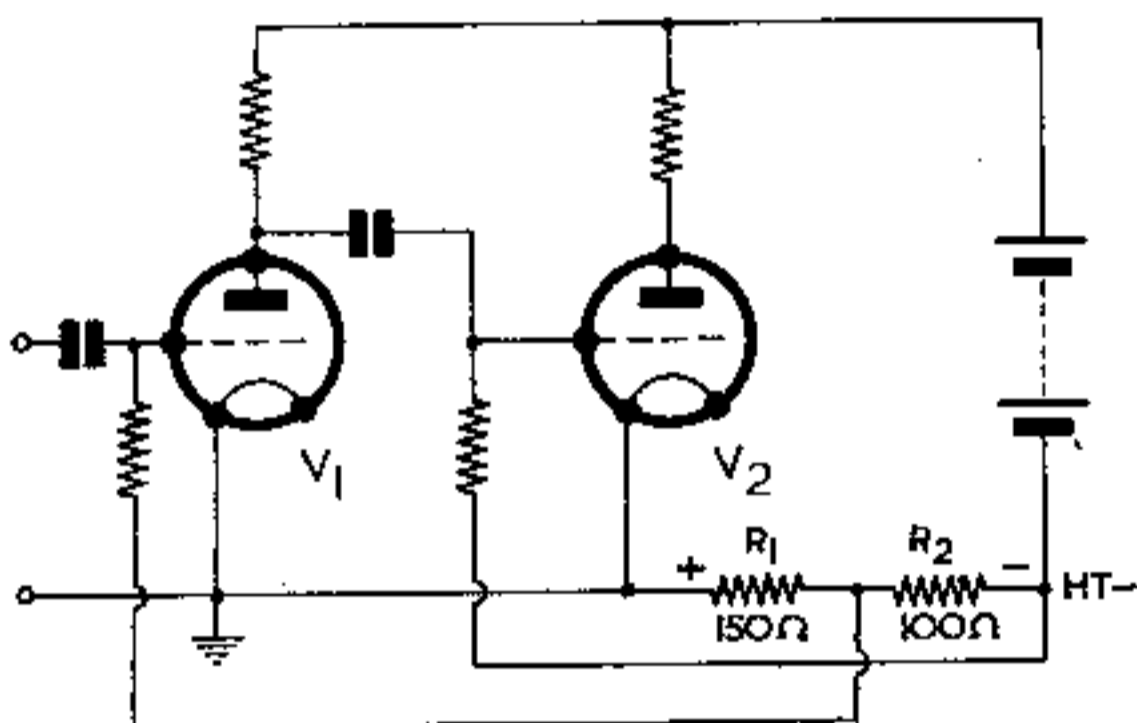


FIG. 7.

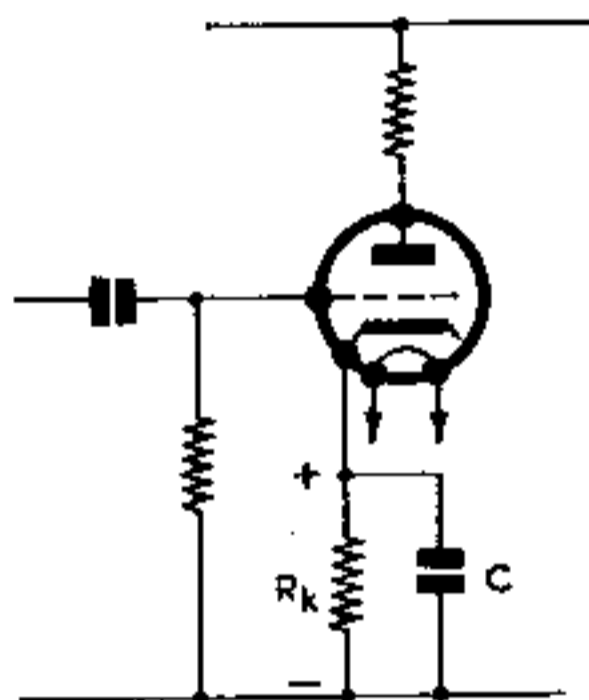


FIG. 8.

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an "auto bias" circuit appeared. The total valve h.t. current is caused to flow through a series of resistors as shown in Fig. 7. This means that the filaments are *positive* with respect to h.t.—, due to the valve current producing a voltage across  $R_1$  and  $R_2$ . The grids can now be connected to the points shown which are *negative* with respect to the filaments.

Say, for example, that the total valve current were 20mA and  $V_2$  required a grid bias of 5 volts. Then the total resistance ( $R_1 + R_2$ ) would be by Ohms Law:

$$R = \frac{E}{I} = \frac{5}{0.02} = 250\Omega;$$

but if  $V_1$  only required a bias of 3 volts, a resistance of

$$R = \frac{3}{0.02} = 150\Omega$$

would be required.

Therefore  $R_1$  would be 150Ω and  $R_2$  100Ω, thus making the total of 250Ω for

the bias of  $V_2$ . The arrival of indirectly heated valves produced another "automatic" biasing system. First, however, it should be explained that the indirectly heated valve is so called because the surface emitting the electrons is a tubular cathode placed around the filament. This enables an a.c. voltage to be used for the filament, as the cathode is electrically insulated from the filament. If a.c. were applied to the filament of a directly heated valve, some of the a.c. would be superimposed on the signal, resulting in an objectionable hum.

The method of automatic bias mostly used with indirectly heated valves to-day is shown in Fig. 8. The principle of operation is rather similar to that of Fig. 7. Here, however, only the current in individual valves is used to produce the bias voltage. The current flowing in  $R_k$  produces a voltage which is positive at the cathode. The grid, which is returned via its grid leak to the other end of  $R_k$ , is therefore negative with respect to the cathode.

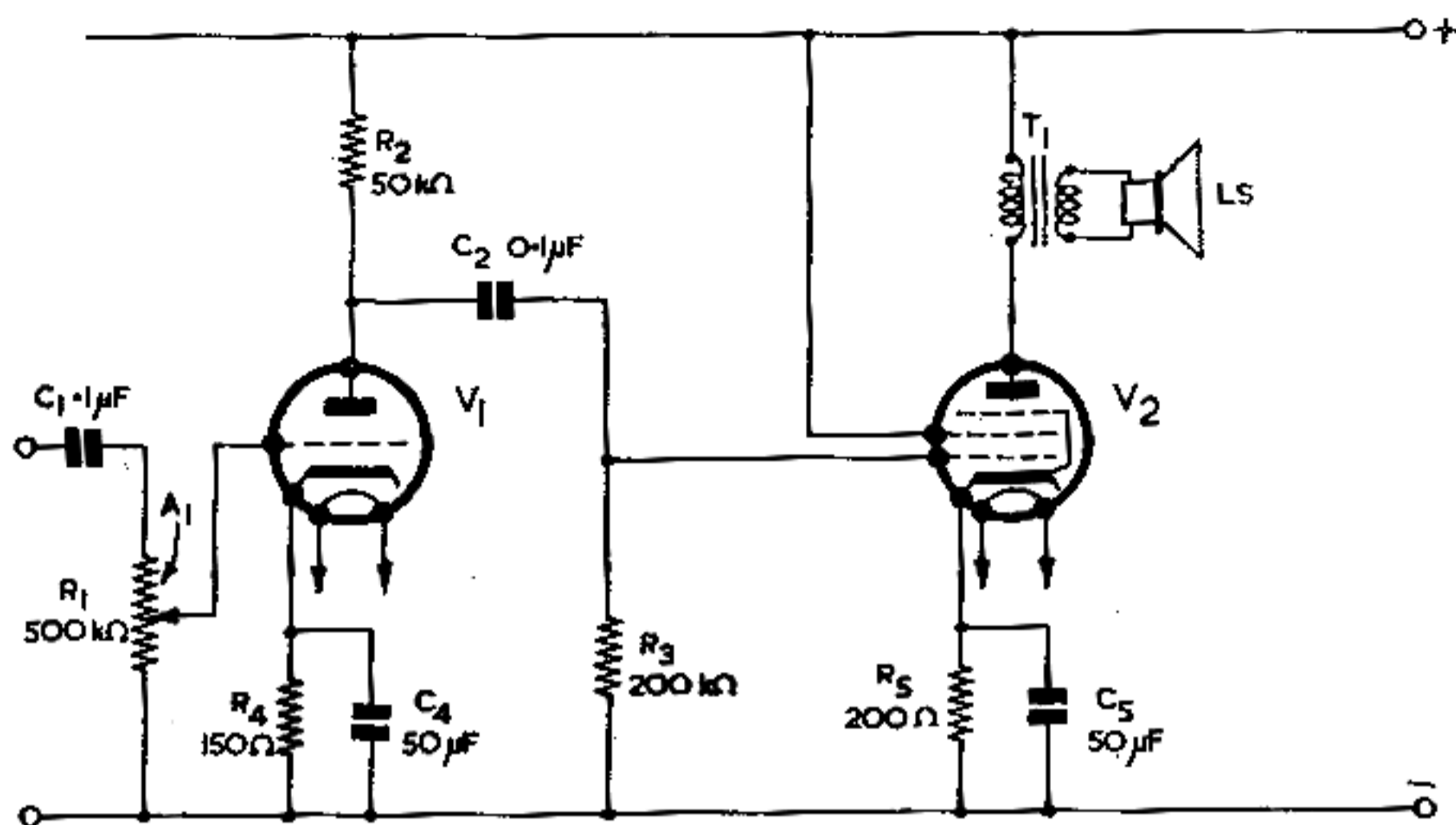


FIG. 9.

### Decoupling

There still remains one component in Fig. 8 which has not been mentioned—the capacitor, C.

If we recall that the current in the valve varies with the applied signal, then the bias voltage will vary also. For example, if the grid signal momentarily became more positive, the current in the valve would increase. The voltage drop across  $R_K$  would therefore increase also, thus increasing the bias on the valve, i.e. making the grid more negative and decreasing the current in the valve. The result is a loss of gain in the stage because the change in current in the valve, and therefore the output voltage, are partially cancelled by the changing bias voltage.

The remedy is to "bypass" the cathode resistor with a capacitor, as shown in Fig. 8. If we remember that the reactance of a capacitor decreases with increasing frequency, a large value of C in the figure will effectively short out the cathode resistor, but only to a.c. As no d.c. flows in a capacitor, placing C across the cathode resistor will have no effect upon the voltage developed across it, but any rapid changes of voltage, such as those caused by a signal, will not occur because the capacitor will bypass them to earth.

There are many other uses for bypassing components as we shall see. The technique is often called "decoupling."

### An Amplifier

As we are now in a position to couple stages together and derive bias for them, the next step is to see how all this looks when combined in a simple amplifier. Fig. 9 shows a low power output amplifier which might find typical application as a gramophone amplifier.

The R.C. coupling circuit and biasing arrangements are exactly as already described, but there are one or two features not touched upon so far.

The first is  $R_1$ , the volume control. The action is simple enough. The signal is applied across the two ends of the potentiometer  $R_1$  and the position of the "wiper" connected to the grid of  $V_1$  fixes the amount of resistance between the grid and earth. Now, the signal will cause a current to flow in  $R_1$  so the signal reaching the grid will be the current multiplied by the resistance between the wiper and earth. When the wiper is at position  $A_1$  all the signal will be fed to the grid. As the wiper is moved toward earth, less and less signal will be transferred.

The "output" stage  $V_2$  is a pentode. The pentode is a higher gain valve than the triode, but the distortion it introduces is a little higher than the triode.

In the anode of  $V_2$  a transformer is used to couple the valve to the loudspeaker. There is very little choice about this. In moving coil loudspeakers the impedance

of the coil is of the order of 2 to 15 ohms. This is so because it is necessary to have as little wire on the coil as possible in order that it may be light enough to move easily.

Now every valve has a recommended "load" to work into for maximum power output. It may have values anywhere from  $2,000\Omega$  to  $20,000\Omega$  or higher, dependent upon type. If the speech coil of the speaker were connected direct to the anode of the valve, very low power output would result. It is a property of the transformer that it can "match" one impedance to another. Therefore the transformer is connected as shown. Unfortunately, the transformer is one of the weakest parts of amplifier circuits, unless they are very well designed. Their weakness is the distortion they produce.

### Voltage and Power

The two stages in Fig. 9, although providing gain, have in one respect different roles to play.  $V_1$  is purely a voltage ampli-

fier, taking the input voltage and amplifying it as we have seen earlier.  $V_2$ , however, has to produce *power* into the loudspeaker. For this reason the output stage is often called the power amplifier.

The output of amplifiers is usually specified in watts. This forms a measure of the loudness of the sound produced. For ordinary domestic purposes, the minimum required is about 1 watt, but larger powers are usually provided, up to 10 watts in some cases. In the interests of quality of reproduction it is advisable to have a little in hand; that is to say, if the amplifier is to produce 3 watts for comfortable listening, a 5 watt amplifier is required.

This article, of course, leaves a lot still unsaid about amplifiers. What would happen, for example, if  $C_3$  in Fig. 9 were changed to  $0.01\mu\text{F}$ , and why has  $200\text{k}\Omega$  been chosen for  $R_3$ ? But these questions bring us closer to the question of the design, rather than the mere operation of the circuit.