Let's Get Started 29:

THE CATHODE FOLLOWER

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In the last two articles of this series we have entered the realms of electronic circuitry, as distinct from those of pure radio. As you will have realised, there is little basic difference between these techniques, except that valves are used for purposes other than merely amplifying a signal.

As this is the last article of this series (another one is starting next month), a circuit has been selected which finds considerable application in both worlds; in fact it is useful in most applications where valves play a part.

The advent of television in the middle thirties demanded a circuit which would isolate valve amplifying stages from one another, and present a high input impedance to the output of the previous stage, and if possible a low impedance to the next stage. The invention of the cathode follower was the result of this requirement.

Coupling

Before getting involved with the circuit itself, we will quickly recap. the question of amplifier response.

You will remember that the stray capacities from the anode of a valve to earth are effectively in parallel with the anode load resistor. The decreasing reactance of this capacitance as the frequency rises causes a loss of gain at higher frequencies. Now this stray capacity is formed by the anode to earth capacity of the valve, the wiring, and the grid to earth capacity of the next valve. If the wiring were carried out with very great care, the wiring capacities may be considerably reduced. The anode to earth capacity may also be very small, but the grid to earth capacity of the next stage could be considerable, say 10 or 20pF.

At audio frequencies this would not be particularly important, but in television the frequencies contained in the video, i.e. the picture waveforms, may be as high as 3Mc/s. At 3Mc/s, 20pF represents a reactance of only 5kΩ. If the anode load of the valve driving this grid capacitance were 5kΩ also, the gain would be halved at 3Mc/s, because the anode load has been effectively halved.

If we could insert a circuit between these stages which had a very low input capacitance, but had a very low output impedance to present to the strays, the required result could be achieved, without reducing the anode load. Reduction of the anode load would, of course, mean a level response at higher frequencies, but a lower gain at all frequencies.

The cathode follower has the attributes of high input impedance and low output impedance. Its basic circuit is shown in Fig. 1.

Gain

The circuit is certainly simple, but it is not immediately obvious why it should operate as suggested above. It has also, in common with every other device, a snag. In this case it is gain. The gain of the circuit shown in Fig. 1 can never be more than one, and in practice is always less than one.

This comes about in the following way:

The current in the valve is:

$I_a = gmV_{gk}$, where gm is the mutual conductance of the valve

but $V_{gk} = V_i - V_o$

$$\therefore I_a = gm\,(V_i - V_o) \qquad (1)$$

The output voltage is the product of valve current and R_k, across which the output is taken, i.e.:

$V_o = I_aR_k$, and substituting for I_a from (1) above:

$$V_o = gm\,(V_i - V_o)R_k$$

$$\therefore V_o\,(1 - gmR_k) = gmV_iR_k$$

and the gain $A = \frac{\text{output voltage}}{\text{input voltage}} = \frac{V_o}{V_i}$

$$\therefore \quad A = \frac{gmR_k}{1 + gmR_k} \qquad (2)$$

Now A, the gain, can never be greater than one, because whatever value gm and R_k have, the additional plus one in the denomination will always make it larger than the numerator. However, if we could make gmR_k much larger than 1, the gain would become

$$A \simeq \frac{gmR_k}{gmR_k} = 1$$

So the larger gmR_k becomes, the nearer the gain will be to one. A high gm value is obviously desirable; but a gm above 10 mA/volt is rare, so to make gmR_k large enough to ignore the additional one in the denominator of expression (2), R_k would have to be, say, 10kΩ. This would represent a gain of 0.99. There is, however, one little difficulty. In the circuit of Fig. 1 a 10kΩ cathode resistor would produce a rather excessive grid bias. If we were to choose a more reasonable resistor, from the bias point of view, of, say, 500Ω, it would reduce the gain to 0.83.

(Admittedly, "gain" is hardly the word when dealing with cathode followers; "loss" would be more appropriate, but everyone is so used to calling the output-input ratio of voltages in valves "gain," that the idea has stuck.)

A more practical form of cathode follower in which the bias conditions are correct, and the gain may be nearly unity, is shown in Fig. 2. Here the grid leak is returned to a point down the cathode load. In this way, R_k may be made reasonably high, but the bias voltage developed across R_b is correct for class A operation of the valve.

the change across R_k will be 100V. The input V_i to produce this must be $100+5+1=106$ volts. But the change of voltage across R_g will be $106-100=6$ volts. The current flowing in R_g will therefore be 6μA. This current must be provided by the input signal, i.e. 106 volts. The apparent resistance as seen by the input voltage supply will be

$$R_i = \frac{106 \text{ volts}}{6 \ \mu A} \simeq 18M\Omega.$$

Therefore, in spite of the fact that a one megohm resistor is clearly connected in the circuit, the input resistance is 18MΩ. The gain of the circuit is $\frac{105}{106} \simeq 0.99$. Fig. 3 shows all these voltages around the circuit.

The input capacity is dealt with in rather a similar manner. The voltage across this capacitor is very small and the current taken by it is small also. The reason for the small voltage across it is of course that the cathode "follows" (hence the name) the grid. We have seen that the gain may be very nearly one. The cathode to grid voltage hardly changes, therefore, and the output is in phase with the input, unlike a normal amplifier where there is a 180° phase shift.

Returning to the input capacity (Cgk in Fig. 3), an improvement in input capacity of 10 or more times is easily achieved. From

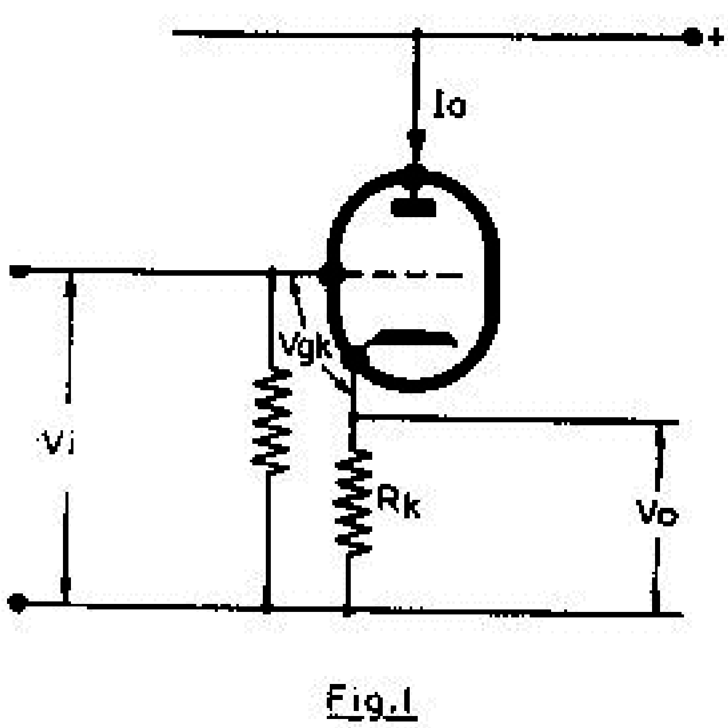

Fig.1

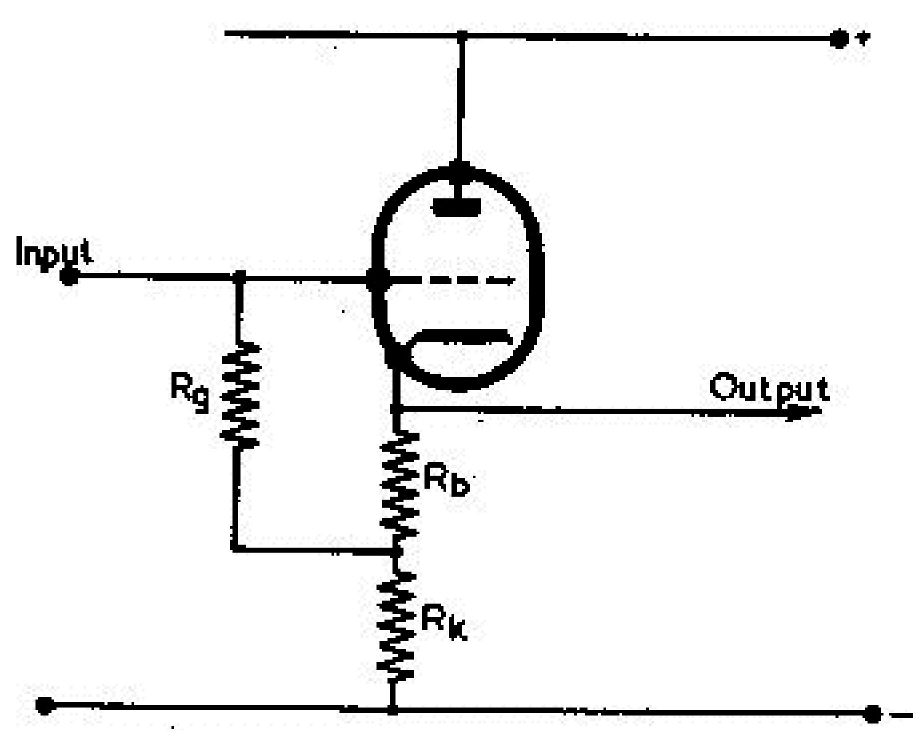

Fig.2

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Input Impedance

Now to the real point of the circuit; the input impedance. First we will consider the input resistance. To demonstrate the improvement let us assume the following values: $R_g=1M\Omega$, $R_b=1k\Omega$, $R_k=20k\Omega$; $I_a=5mA$, $gm \simeq 5mA/volt$.

If an input signal is applied which changes the grid to cathode voltage by one volt, the change of volts across R_b will be equal to the gm × one volt × $R_b=5$ volts. Similarly,

the input standpoint, the cathode follower is obviously useful. The input resistance is increased, and the input capacity decreased.

Output Impedance

There is another useful feature of this circuit, and that is the low output impedance. This can be shown to be approximately $\frac{1}{gm}$

In our original valve, the output impedance would be 200Ω, therefore. This is particularly useful because relatively high capacities may be placed in parallel with the output without ruining performance at high frequencies.

Fig. 4 shows a cathode follower between two stages of a video amplifier. The anode load of V_1 is now relieved of the grid capacities of V_3, and only has to feed the low input capacity of the cathode follower, V_2. At the same time, the grid capacities of V_3 are fed from the very low output impedance of V_2. The high frequency performance will be considerably improved, as a result.

The bias resistor in V_2 may be decoupled if required, but little is gained by this. Another way of regarding the cathode follower is as an amplifier with heavy negative feedback. This, of course, implies that the circuit is very stable and comparatively free from changes in operation, due to valve deterioration and changes in supply voltages.

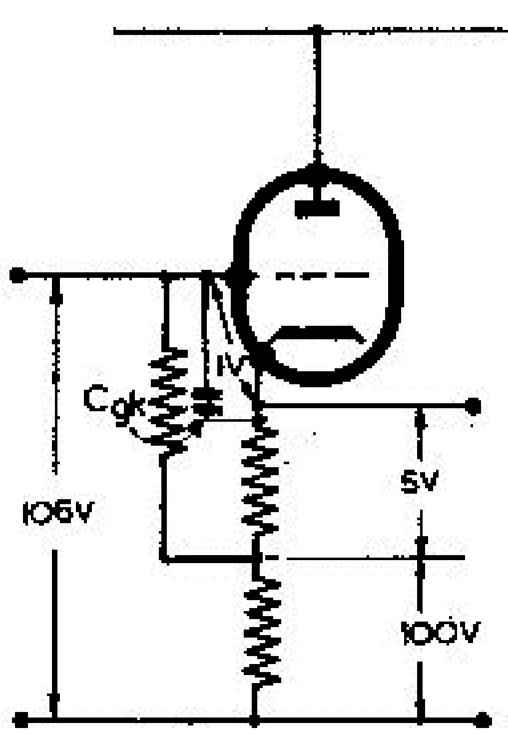

Fig. 3

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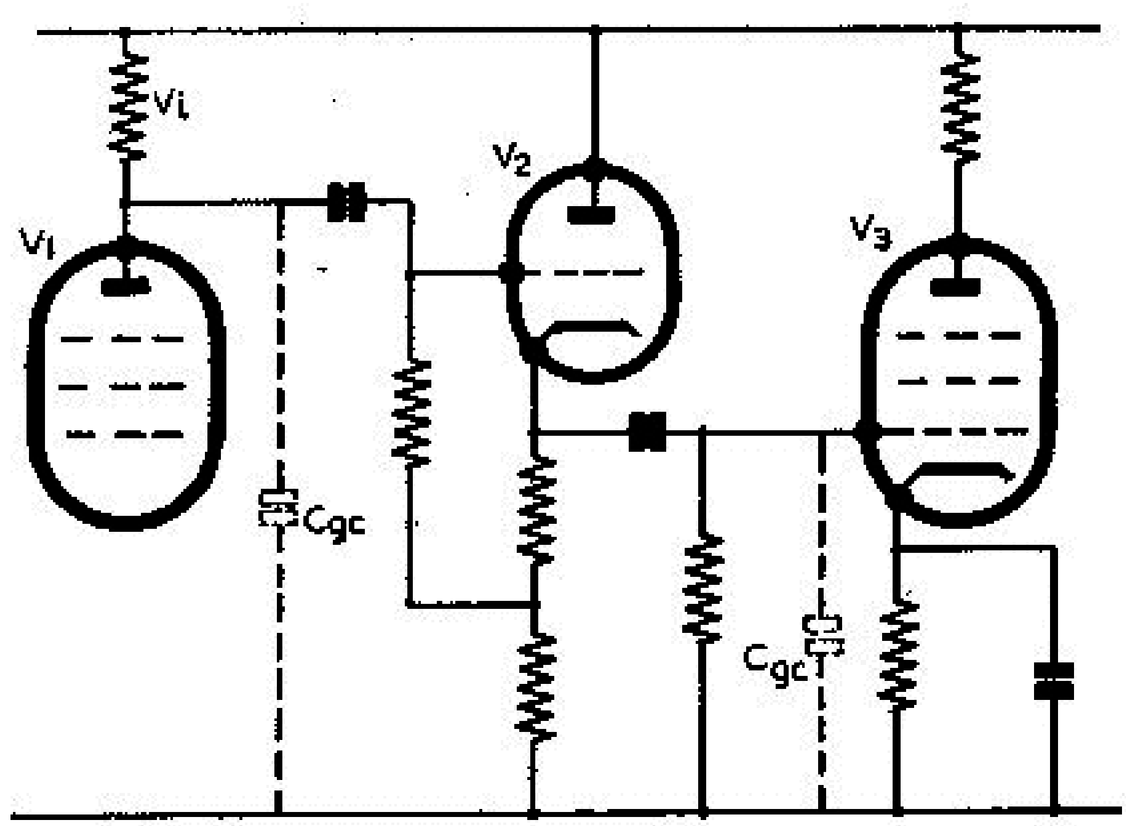

Fig. 4

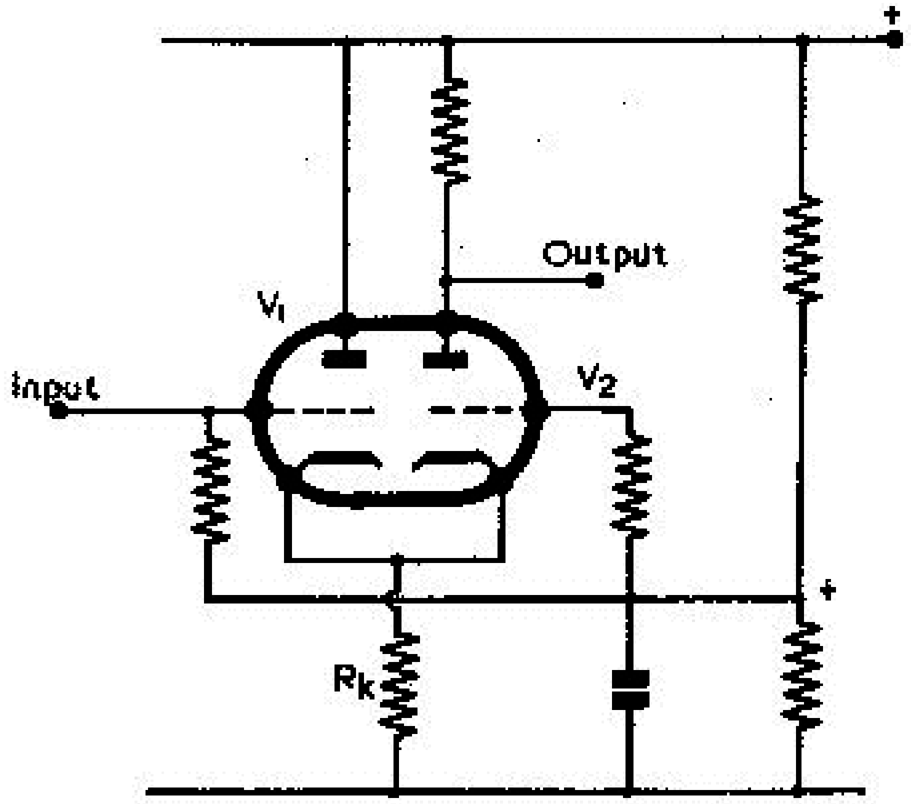

Fig. 5

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Applications

As already mentioned, there are many applications of the cathode follower. A useful one is feeding an amplifier from a high impedance microphone or pick-up when the two are a considerable distance apart. It is often found that screened lead is ineffective in avoiding hum pick-up in a case like this, especially if the microphone or pick-up are of the crystal type.

The cathode follower input is, of course, connected to the microphone and the output to the long lead of the amplifier. As we have seen, the loss of signal may be very small, provided R_k is 10 to 20kΩ, and the impedance presented to the microphone is very high and does not therefore load it. It is worth mentioning that the cathode follower is essentially a wideband circuit, that is its frequency response is very good. A transformer could be used in a case like this one, but the large step-down ratio required to match the crystal into the lead would be very great. There would be a considerable loss in signal, therefore. The cathode follower achieves the same result without loss of signal.

Sometimes, in television work particularly, an amplifier is required which produces an output in phase with the input. The circuit of such an amplifier is shown in Fig. 5. V_1 is a cathode follower, the output of which (R_k) is connected to the cathode of V_2. Imagine a signal is applied to the grid of V_1. A signal of approximately the same amplitude will appear across R_k. If the signal were to make the grid of V_1 more positive, the cathode would become more positive also. The cathode of V_2 would become more positive, therefore, and the current in the valve V_2 would decrease. This would mean a smaller drop in voltage across its anode load, the anode becoming more positive. The output is, therefore, in phase with the input.

Of course, the same result would be achieved if a signal were connected to the cathode of any valve providing the cathode bias resistor were by-passed. The difficulty would be that the impedance at the cathode is so low that the anode load of the previous valve would be shunted by it and very little gain would be obtained in that valve. That is where the cathode follower comes into use, in matching the output of the previous valve into the cathode of V_2.

Finally, a very stable valve voltmeter may be designed using the cathode follower. The circuit is shown in Fig. 6. V_1 and V_2 are cathode followers. If these two valves are similar, R_1 and R_2 are of the same value, and the currents in the valves the same; the voltages at the points to which the meter is connected will also be the same. The meter will read zero, therefore. If a d.c. potential of -1V is applied to the grid of V_1, the cathode will also drop approximately 1 volt, and the meter will be deflected.

The input impedance is, of course, high, which is essential in a valve voltmeter. The right-hand valve, V_2, is also a cathode follower in effect, but its main purpose is to provide a balancing potential for the meter to be returned to. A resistor could be used in place of V_2, but thermal changes in V_1 would unbalance the meter and zero drift would result. By using V_2, thermal drifts should be cancelled.

An advantage of using the cathode follower principle is that range changing may be carried out by switching R_3. The grid base of V_1 is very long, because any voltage applied to the grid causes an almost equal change at the cathode. The *grid to cathode* voltage therefore changes very little.

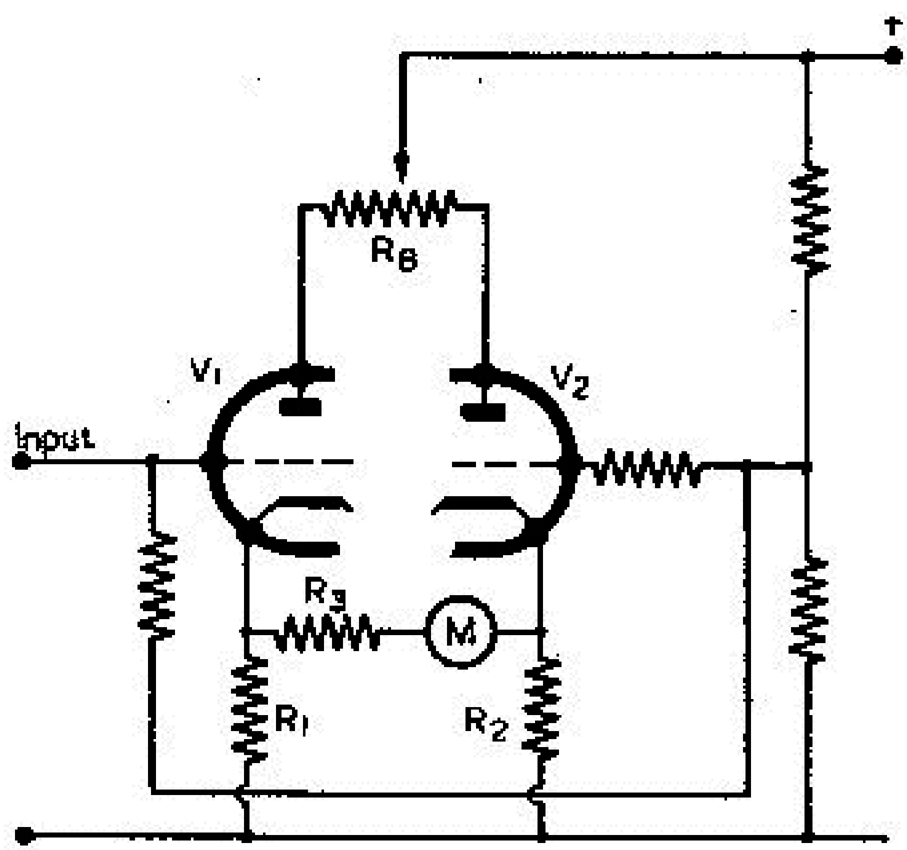

Fig. 6

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So quite a large voltage may be applied to the grid before the grid-to-cathode voltage becomes near to cut-off.

The two grids are returned via their grid leaks to a potential slightly negative with respect to the cathode, so that correct grid operating conditions are obtained.

Initial balance or zero setting is achieved by adjustment of R_8.

These are a few of the applications of this versatile and useful circuit, but many more will be found in the pages of radio and electronic books everywhere.