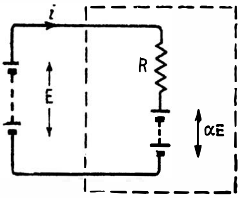


Fig. 1. This circuit is used to illustrate the calculation of resistance.

Negative Feedback

Its Effect on Input Impedance and Distortion

By E. GRIFFITHS, Grad.I.E.E.

(*Engineering Division, B.B.C.*)

READERS of *Wireless World* will be familiar by now with the use of negative feedback to modify amplifier gain and distortion characteristics. Articles have also been published on the effect of negative feedback on output impedance, but very little has been written about the modification of input impedance by negative feedback, although it has been mentioned in passing by several authors. In this article the spotlight will be concentrated on the way in which negative feedback can be used to change the input impedance of an amplifier.

First, however, it is necessary to clear our minds of the idea that resistance as measured in ohms always indicates the presence of a physical component of that value. We are so used to handling resistors marked or colour-coded in ohms that it is easy to forget that resistance is a ratio of two in-phase quantities, voltage and current, and that the input impedance of a circuit is defined as the ratio of the voltage across the input terminals to the current flowing into the terminals. As an example, consider a mysterious black box with two terminals. If a p.d. of 2 V across the terminals causes a current of 1 A to flow, the obvious conclusion is that there is a 2-Ω resistor connected between the terminals, but this does not necessarily follow. There might be a 1-Ω resistor inside the box with a 1-V battery opposing the applied e.m.f., or on the other hand, it could be a 3-Ω resistor in series with a 1-V battery aiding the applied e.m.f. If different applied voltages were tried we might conclude that there was a non-ohmic resistor inside the box, because the applied e.m.f., divided by the current flowing, would not be a constant. After a while, however, suspicion might be aroused and a voltmeter connected across the input terminals would give the answer to the problem. Suppose, however, there was a gremlin inside the box who adjusted the internal e.m..f so that it was always proportional to the applied e.m.f. Where would we be then ? The voltmeter test would show nothing, but it is obvious that the input resistance would not be equal to the value of the physical resistance inside the box.

Using the symbols shown in Fig. 1 we can calculate the input resistance as follows :

Net voltage acting round circuit

$$= E - \alpha E$$
$$= E(1 - \alpha)$$

hence

$$i = E(1 - \alpha)/R$$

so that, input resistance

$$= E/i = R/(1 - \alpha)$$

which is greater than R.

On the other hand, if the gremlin suddenly reversed the polarity of the internal e.m.f., the input resistance would fall to $R/(1 + \alpha)$.

After this slight digression we can now return to the object of this article and consider how the input impedance of an amplifier can be increased or decreased, depending on the method of connection of the feedback voltage.

With series-connected feedback the source voltage, grid voltage and feedback voltage are in series round the circuit. Fig. 2 shows the simplified circuit for an input stage with valve gain A, connected to a source of internal resistance R_1 and open-circuit output voltage e'. Assuming a grid-cathode voltage of e_g is developed across the grid resistor R_2, the output voltage will be Ae_g and, if the feedback voltage is fed back via a circuit of gain β', the feedback voltage will be $A\beta' e_g$. (It will be seen later why β' is used in preference to the usual symbol β).

By definition, the input impedance $Z_i = e/i$ and

$$e = iR_2 + A\beta' e_g$$

but

$$e_g = iR_2$$

$$\therefore e = iR_2 + A\beta' iR_2$$

whence

$$Z = e/i = R_2(1 + A\beta') \quad .. \quad .. \quad .. \quad (1)$$

and shows that the input impedance has been increased by the use of series-connected feedback.

Parallel-connected feedback is obtained when the three voltages in which we are interested are connected in parallel, as shown in Fig. 3. The feedback voltage is aiding the input voltage and the grid-circuit current is therefore increased—the input

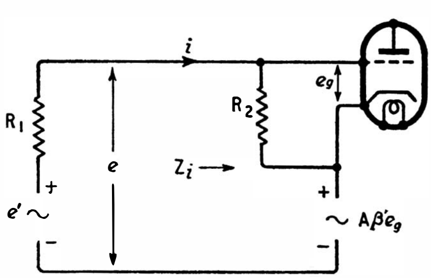
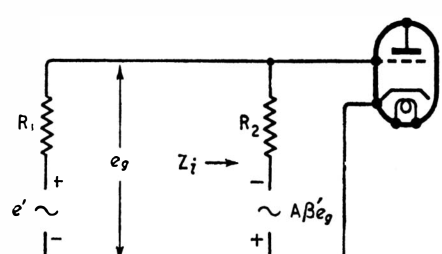


Fig. 2. (left) Showing the simplified circuit of a series-connected feedback stage.

Fig. 3. (right) Illustrating the basic parallel-connected feedback stage.



impedance is thus reduced by the application of the feedback voltage.

With this circuit the input voltage is equal to the grid voltage, so that the input impedance is given by:

$$Z_i = e_g/i$$

and

$$e_g = iR_2 - A\beta' e_g$$

from which, with a little mathematical juggling, we find:

$$Z_i = R_2/(1 + A\beta') \quad \ldots \quad (2)$$

Modern high gain a.f. amplifiers normally use a r.f. pentode for the first stage, and with such valves the maximum recommended value of grid resistor is usually of the order of 0.5 MΩ. When a crystal microphone or pickup is used, it may be desirable to use a much higher input impedance than this, and a series-connected feedback stage may then be used as a half-way house between a conventional valve stage and a cathode follower.

As an example, consider the requirement of a 5-MΩ input impedance when the grid resistor is 0.5 MΩ. The increase in input impedance required is 10 times and reference to equation (1) shows that the required value of $A\beta'$ is 9. Assuming a grid to anode gain of 200 is available, calculation shows that β' is 9/200. Fig. 4 then gives the circuit to be used. The load resistance for the valve (R) is that of the anode feed resistance R_2 and the following grid resistance R_3 in parallel and a typical value is 100 kΩ. β' is the ratio of the feedback resistance to the load resistance, and since this must have a value of 9/200, the correct value for the feedback resistance R_1 is 4,500 ohms.

Parellel-connected feedback may be used to give feedback without loss of gain, provided that the comparison is made on the basis of two amplifiers doing the same job. By this, it is meant that the comparison is between two amplifiers having the same input impedance, rather than the same amplifier with and without feedback.

Fig. 5 shows an example of parallel-connected feedback. In this circuit the value of the grid resistance is not limited by the maker's recommended value, since there is a low resistance d.c. path between grid and cathode provided by the input transformer. If the resistance R_4 is made 5 MΩ and the impedance on the secondary of the input transformer is to be 0.5 MΩ, reference to equation (2) shows that $A\beta'$ must be 9 and hence, with a grid to anode gain of 200, β' is 9/200. Assuming a value for $R_1 + R_2$ of 0.3 MΩ we have:

$$\frac{R_2}{R_1 + R_2} = \frac{9}{200}$$

and hence, $R_2 = 13{,}500$ ohms.

The Feedback Factor

It is now necessary to distinguish between β and β'. In this article, β' has been defined as the ratio of the fed-back voltage to the output voltage. β is, however, defined by the fact that $A\beta e_g$ is the feedback voltage effective between grid and cathode. This distinction is made clear by reference to Fig. 6

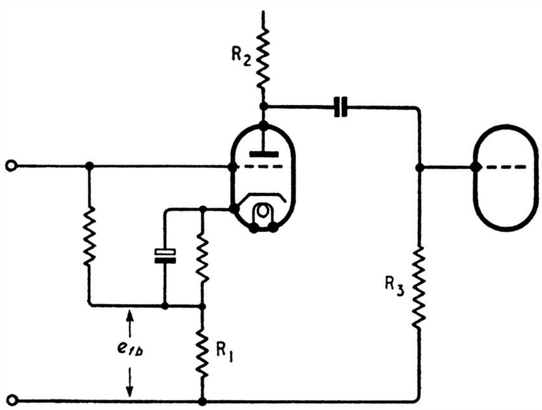
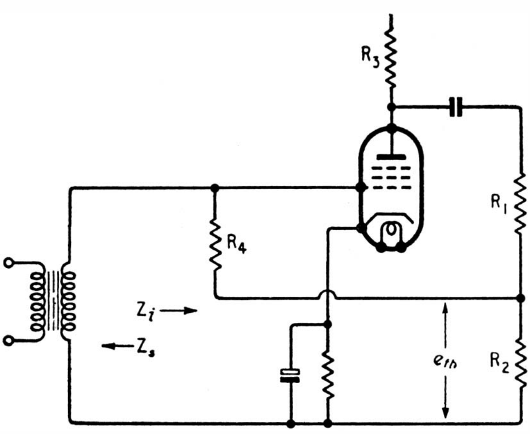


Fig. 4. Cathode feedback is one example of the series-connected type.

Fig. 5. Illustrating parallel-connected feedback with transformer input.



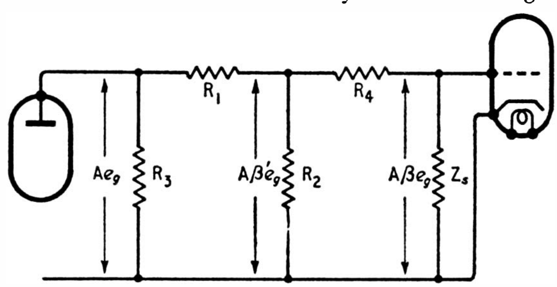
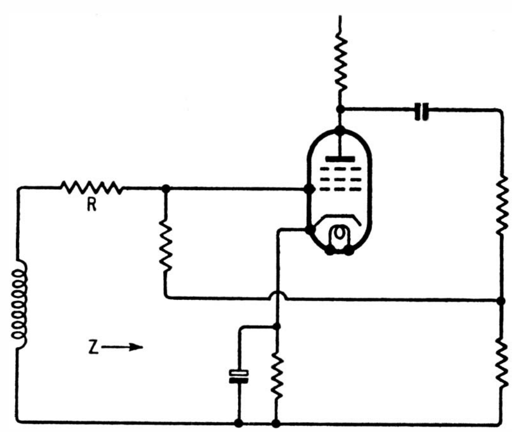


Fig. 6. This diagram is used to show the distinction between distortion reduction and gain reduction factors.

Fig. 7. This arrangement enables distortion to be reduced more than with the circuit of Fig. 5.



which is equivalent to Fig. 5 when only the feedback path is considered. The distortion-reduction factor when negative feedback is applied to a single-stage amplifier is $1/(1+A\beta)$, but the value of β' must not be substituted in this formula, since it is not the voltage $A\beta' e_g$ which is effective between grid and cathode, but $A\beta e_g$. As an example, considering the circuit shown in Fig. 5 again, we know that the resistance R_4 is 5 MΩ and β' is 9/200, and assuming that $Z_s = Z_i = 500{,}000$ ohms, and remembering that R_2 is small:

$$\beta = \frac{Z_s}{R_4 + R_s}\,\beta' = \frac{0.5}{5.5}\,\beta' = \frac{1}{11}\,\beta' = \frac{9}{11 \times 200}$$

The distortion-reduction factor with this circuit is therefore:

$$\frac{1}{1+A\beta} = \frac{1}{1 + \dfrac{200 \times 9}{11 \times 200}} \approx \frac{1}{2}$$

This circuit can therefore be used to give nearly 50% decrease in distortion without loss of gain as compared with an amplifier without feedback and with the same input resistance. The greater the change in input impedance with feedback, the nearer the distortion-reduction factor approaches a half.

This particular change in harmonic distortion is, of course, only obtained with amplifiers in which a high input impedance is reduced to the same value as the source impedance by the use of parallel-connected feedback. When the source impedance is high compared with the input impedance obtained by applying feedback the distortion will be reduced by more than 50%, because β more nearly approaches β'. The converse also applies.

When a greater reduction in distortion is required it can be obtained by using the circuit of Fig. 7. This circuit may be developed from that of Fig. 5 in the following manner. If β' is increased the value of the impedance Z will fall. The input impedance may be restored to its original value by adding the resistance R, the effective feedback factor then becomes larger, so that the distortion is reduced still more. On the other hand, the series resistance R and the apparent impedance Z, together, form a voltage-dividing network, so that the gain is reduced by the factor $Z/(R+Z)$. When cathode injection of the feedback voltage is used, the gain is reduced by the same factor as the distortion (for a given output) but when parallel-connected feedback is used the required reduction is distortion can be obtained with only about half the loss in gain that is given by the more conventional circuit.

Gain Stabilization

One advantage of negative feedback is that the overall gain is stabilized in spite of reasonable variations in valve parameters. When parallel-connected feedback is used, an easily visualized explanation for this exists. If the grid to anode gain falls, the input impedance rises and with the simple circuit shown in Fig. 5 a bigger proportion of the source voltage appears between grid and cathode. With the circuit of Fig. 7 the loss ratio of the voltage-dividing network falls, owing to the rise in the value of Z, but in this case the variation in amplifier input impedance is less, because of the padding effect of the series resistance R.

OPERATING TROLLEY-BUS POINTS

Remote Control from Driver's Cab by Induction Link

SINCE the introduction of trolley-buses in London, one of the main operational difficulties has been the changing of points on the overhead track at junctions and turning places. At present, this has to be done either by the conductor, who leaves the bus to operate a switch at the side of the road, or, in the case of a busy junction, by a man permanently on the site. To overcome the many obvious disadvantages of this procedure, a device has now been developed by Wayne Kerr for the London Transport Executive, to enable the trolley-bus driver himself to change the points by pressing a button in his cab.

It is an induced-current system, comprising a one-valve oscillator and transmitting loop on the trolley-bus, and a corresponding pick-up loop and receiver mounted on the overhead track wires. The driver switches on the oscillator as he approaches the junction, then as soon as the transmitting loop on the roof of the trolley-bus passes underneath the pick-up loop, a current is induced from one into the other. This is rectified in the receiver, and the resulting d.c. operates a sensitive relay which, in turn, closes the electrical circuits of the existing point-changing mechanism. To switch on the oscillator, the driver presses a push-button which actuates a thermal relay to give a 30-second time delay; this enables him to put the system into operation some way in advance of the junction, and so leaves his hands free for driving for the rest of the time. A signal is painted on one of the roadside pillars to tell him exactly when to press the button.

Since the transmitter radiates at a frequency of 70 kc/s (somewhere in the region of 4,000 metres) it is not likely to cause interference with reception on the long-wave band. In any case, the power radiated has been deliberately kept low in order to limit the range of the system to a few feet, so that the receiver will not be triggered by more than one transmitter at a time. The oscillator valve dissipates about 12 watts in its anode, and the tank circuit is matched to an 80-ohm coaxial line which feeds power into the transmitting loop. Heater current for the valve is obtained directly from the 24 V supply in the trolley-bus, and h.t. from the same source by means of a synchronous vibrator.

Perhaps the most interesting part of the equipment is the receiver. This consists of little more than a 5-mA Westinghouse bridge rectifier housed in a small container, which is suspended, together with the pick-up loop, on the overhead track wires. The d.c. output of the rectifier is wired across to a roadside pillar and into a weather-proof box, which contains the sensitive relay already mentioned and a heavier relay for switching the point-changing mechanism. The pick-up loop is arranged in a rectangle, 16ft × 5ft, and consists of one turn of 3-core electric light cable, with the cores connected to form three turns.

Reports from the London Transport Executive indicate that the first installation, at a road junction in Croydon, has proved very reliable and simple to operate, and four trolley-buses have, so far, been equipped with transmitters.