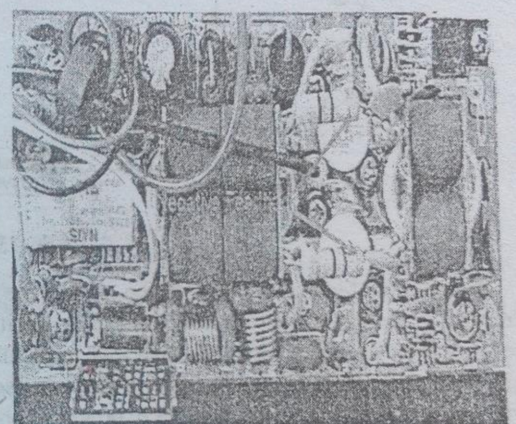
13

Amplifiers with Negative Feedback



INTRODUCTION

A practical amplifier has a gain of nearly one million *i.e.* its output is one million times the input. Consequently, even a casual disturbance at the input will appear in the amplified form in the output. There is a strong tendency in amplifiers to introduce *hum* due to sudden temperature changes or stray electric and magnetic fields. Therefore, every high gain amplifier tends to give noise along with signal in its output. The noise in the output of an amplifier is undesirable and must be kept to as small a level as possible.

The noise level in amplifiers can be reduced considerably by the use of *negative feedback* *i.e.* by injecting a fraction of output in phase opposition to the input signal. The object of this chapter is to consider the effects and methods of providing negative feedback in transistor amplifiers.

13.1 Feedback

The process of injecting a fraction of output energy of *some device back to the input is known as* **feedback**.

The principle of feedback is probably as old as the invention of first machine but it is only some 50 years ago that feedback has come into use in connection with electronic circuits. It has been found very useful in reducing noise in amplifiers and making amplifier operation stable. Depending upon whether the feedback energy aids or opposes the input signal, there are two basic types of feedback in amplifiers *viz positive feedback* and *negative feedback*.

(*i*) **Positive feedback.** When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called *positive feedback*. This is illustrated in Fig. 13.1. Both amplifier and feedback network introduce a phase shift of 180°. The result is a 360° phase shift around the loop, causing the *feedback voltage* V_f to be in phase with the input signal V_{in}.

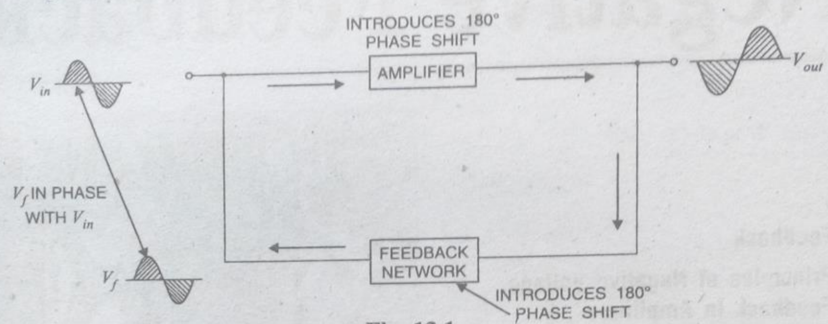


Fig. 13.1

The positive feedback increases the gain of the amplifier. However, it has the disadvantages of increased distortion and instability. Therefore, positive feedback is seldom employed in amplifiers. One important use of positive feedback is in oscillators. As we shall see in the next chapter, if positive feedback is sufficiently large, it leads to oscillations. As a matter of fact, an oscillator is a device that converts d.c. power into a.c. power of any desired frequency.

(*ii*) **Negative feedback.** When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback*. This is illustrated in Fig. 13.2. As you can see, the amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (*i.e.*, 0° phase shift). The result is that the *feedback voltage* V_f is 180° out of phase with the input signal V_{in}.

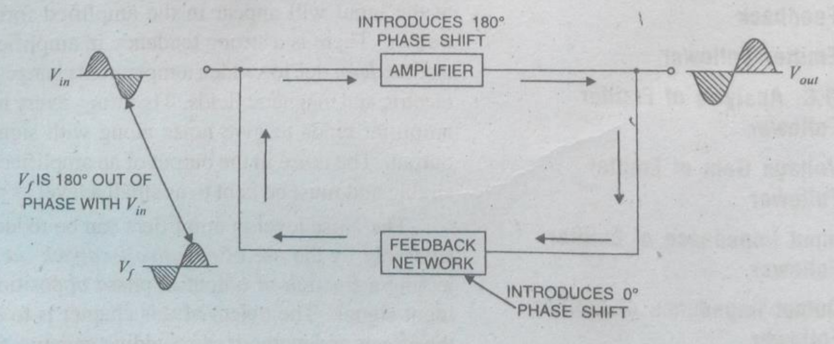


Fig. 13.2

Negative feedback reduces the gain of the amplifier. However, the advantages of negative feedback are: reduction in distortion, stability in gain, increased bandwidth and improved input and output impedances. It is due to these advantages that negative feedback is frequently employed in amplifiers.

13.2 Principles of Negative Voltage Feedback In Amplifiers

A feedback amplifier has two parts viz an amplifier and a feedback circuit. The feedback circuit usually consists of resistors and returns a fraction of output energy back to the input. Fig. 13.3 *shows the principles of negative voltage feedback in an amplifier. Typical values have been assumed to make the treatment more illustrative. The output of the amplifier is 10 V. The fraction m_v of this output *i.e.* 100 mV is fedback to the input where it is applied in series with the input signal of 101 mV. As the feedback is negative, therefore, only 1 mV appears at the input terminals of the amplifier.

Referring to Fig. 13.3, we have,

$$\text{Gain of amplifier without feedback, } A_v = \frac{10\text{ V}}{1\text{ mV}} = 10,000$$

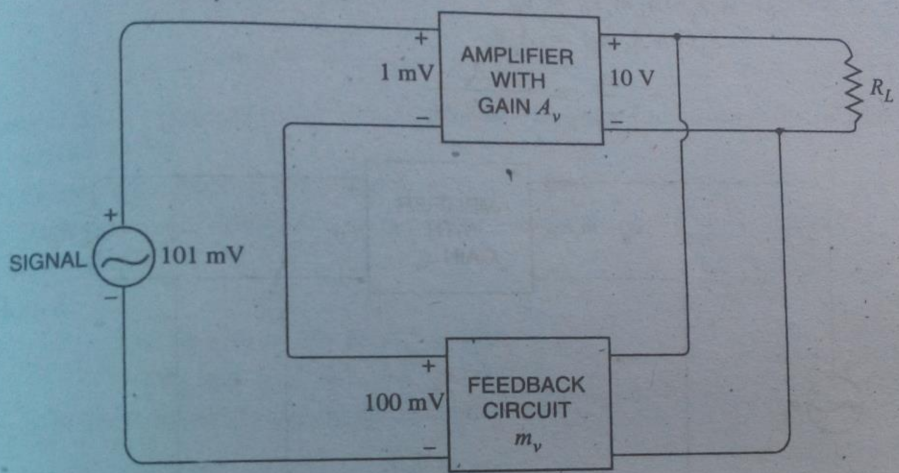


Fig. 13.3

$$\text{Fraction of output voltage fedback, } m_v = \frac{100\text{ mV}}{10\text{ V}} = 0.01$$

$$\text{Gain of amplifier with negative feedback, } A_{vf} = \frac{10\text{ V}}{101\text{ mV}} = 100$$

The following points are worth noting :

(*i*) When negative voltage feedback is applied, the gain of the amplifier is **reduced. Thus, the gain of above amplifier without feedback is 10,000 whereas with negative feedback, it is only 100.

(*ii*) When negative voltage feedback is employed, the voltage *actually* applied to the amplifier is extremely small. In this case, the signal voltage is 101 mV and the negative feedback is 100 mV so that voltage applied at the input of the amplifier is only 1 mV.

(*iii*) In a negative voltage feedback circuit, the feedback fraction m_v is always between 0 and 1.

(*iv*) The gain with feedback is sometimes called *closed-loop gain* while the gain without feedback is called *open-loop gain*. These terms come from the fact that amplifier and feedback circuits form a "loop". When the loop is "opened" by disconnecting the feedback circuit from the input, the amplifier's gain is A_v, the "open-loop" gain. When the loop is "closed" by connecting the feedback circuit, the gain decreases to A_{vf}, the "closed-loop" gain.

* Note that amplifier and feedback circuits are connected in *series-parallel*. The inputs of amplifier and feedback circuits are in *series* but the outputs are in *parallel*. In practice, this circuit is widely used.

** Since with negative voltage feedback the voltage gain is decreased and current gain remains unaffected, the power gain A_p (= $A_v \times A_i$) will decrease. However, the drawback of reduced power gain is offset by the advantage of increased bandwidth.

13.3 Gain of Negative Voltage Feedback Amplifier

Consider the negative voltage feedback amplifier shown in Fig. 13.4. The gain of the amplifier without feedback is A_v. Negative feedback is then applied by feeding a fraction m_v of the output voltage e_0 back to amplifier input. Therefore, the actual input to the amplifier is the signal voltage e_g *minus* feedback voltage $m_v e_0$ *i.e.*,

$$\text{Actual input to amplifier} = e_g - m_v e_0$$

The output e_0 must be equal to the input voltage $e_g - m_v e_0$ multiplied by gain A_v of the amplifier *i.e.*,

$$(e_g - m_v e_0) A_v = e_0$$

or $$A_v e_g - A_v m_v e_0 = e_0$$

or $$e_0 (1 + A_v m_v) = A_v e_g$$

or $$\frac{e_0}{e_g} = \frac{A_v}{1 + A_v m_v}$$

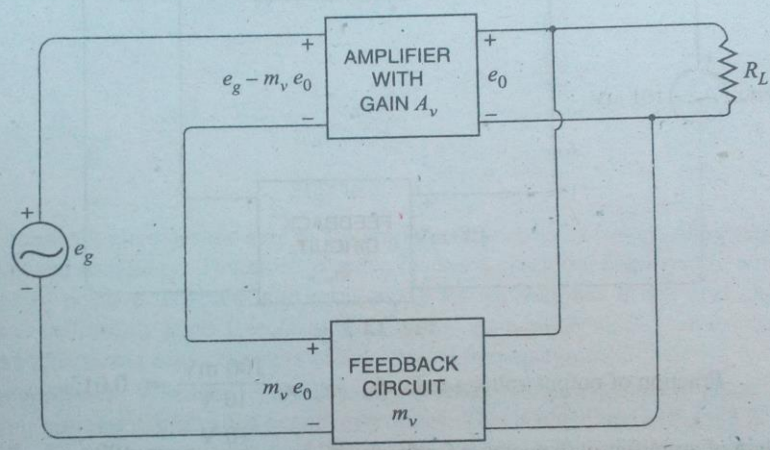


Fig. 13.4

But e_0/e_g is the voltage gain of the amplifier with feedback.

∴ Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v m_v}$$

It may be seen that the gain of the amplifier without feedback is A_v. However, when negative voltage feedback is applied, the gain is reduced by a factor $1 + A_v m_v$. It may be noted that negative voltage feedback does not affect the current gain of the circuit.

Example 13.1. *The voltage gain of an amplifier without feedback is 3000. Calculate the voltage gain of the amplifier if negative voltage feedback is introduced in the circuit. Given that feedback fraction $m_v = 0.01$.*

Solution. $A_v = 3000,\quad m_v = 0.01$

∴ Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v m_v} = \frac{3000}{1 + 3000 \times 0.01} = \frac{3000}{31} = 97$$

Example 13.2. *The overall gain of a multistage amplifier is 140. When negative voltage feedback is applied, the gain is reduced to 17.5. Find the fraction of the output that is fedback to the input.*

Solution. $A_v = 140, \quad A_{vf} = 17.5$

Let m_v be the feedback fraction. Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$17.5 = \frac{140}{1 + 140\, m_v}$$

or $$17.5 + 2450\, m_v = 140$$

$\therefore$ $$m_v = \frac{140 - 17.5}{2450} = \frac{1}{20}$$

Example 13.3. *When negative voltage feedback is applied to an amplifier of gain 100, the overall gain falls to 50.*

(i) Calculate the fraction of the output voltage fedback.

(ii) If this fraction is maintained, calculate the value of the amplifier gain required if the overall stage gain is to be 75.

Solution.

(*i*) Gain without feedback, $A_v = 100$

Gain with feedback, $A_{vf} = 50$

Let m_v be the fraction of the output voltage fedback.

Now $$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$50 = \frac{100}{1 + 100\, m_v}$$

or $$50 + 5000\, m_v = 100$$

or $$m_v = \frac{100 - 50}{5000} = \mathbf{0.01}$$

(*ii*) $$A_{vf} = 75\,; \quad m_v = 0.01\,; \quad A_v = ?$$

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$75 = \frac{A_v}{1 + 0.01\, A_v}$$

or $$75 + 0.75\, A_v = A_v$$

$\therefore$ $$A_v = \frac{75}{1 - 0.75} = \mathbf{300}$$

Example 13.4. *With a negative voltage feedback, an amplifier gives an output of 10 V with an input of 0.5 V. When feedback is removed, it requires 0.25 V input for the same output. Calculate (i) gain without feedback (ii) feedback fraction m_v.*

Solution.

(*i*) Gain without feedback, $A_v = 10/0.25 = 40$

(*ii*) Gain with feedback, $A_{vf} = 10/0.5 = 20$

Now $$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$20 = \frac{40}{1 + 40\, m_v}$$

or $$20 + 800\, m_v = 40$$

or $$m_v = \frac{40 - 20}{800} = \frac{1}{40}$$

Example 13.5. *The gain of an amplifier without feedback is 50 whereas with negative voltage feedback, it falls to 25. If due to ageing, the amplifier gain falls to 40, find the percentage reduction in stage gain (i) without feedback and (ii) with negative feedback.*

Solution. $$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$25 = \frac{50}{1 + 50\, m_v}$$

or $$m_v = 1/50$$

(*i*) **Without feedback.** The gain of the amplifier without feedback is 50. However, due to ageing, it falls to 40.

∴ $$\text{\%age reduction in stage gain} = \frac{50 - 40}{50} \times 100 = \mathbf{20\%}$$

(*ii*) **With negative feedback.** When the gain without feedback was 50, the gain with negative feedback was 25. Now the gain without feedback falls to 40.

∴ $$\text{New gain with negative feedback} = \frac{A_v}{1 + A_v\, m_v} = \frac{40}{1 + (40 \times 1/50)} = 22.2$$

∴ $$\text{\%age reduction in stage gain} = \frac{25 - 22.2}{25} \times 100 = \mathbf{11.2\%}$$

Example 13.6. *An amplifier has a voltage amplification A_v and a fraction m_v of its output is fedback in opposition to the input. If $m_v = 0.1$ and $A_v = 100$, calculate the percentage change in the gain of the system if A_v falls 6 db due to ageing.*

Solution. $$A_v = 100, \quad m_v = 0.1, \quad A_{vf} = ?$$

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{100}{1 + 100 \times 0.1} = 9.09$$

$$\text{Fall in gain} = 6db$$

Let A_{v1} be the new absolute voltage gain without feedback.

Then, $$20 \log_{10} A_v/A_{v1} = 6$$

or $$\log_{10} A_v/A_{v1} = 6/20 = 0.3$$

or $$\frac{A_v}{A_{v1}} = \text{Antilog } 0.3 = 2$$

or $$A_{v1} = A_v/2 = 100/2 = 50$$

∴ $$\text{New } A_{vf} = \frac{A_{v1}}{1 + A_{v1}\, m_v} = \frac{50}{1 + 50 \times 0.1} = 8.33$$

$$\text{\% age change in system gain} = \frac{9.09 - 8.33}{9.09} \times 100 = \mathbf{8.36\%}$$

Example 13.7. *An amplifier has a voltage gain of 500 without feedback. If a negative feedback is applied, the gain is reduced to 100. Calculate the fraction of the output fed back. If, due to ageing of components, the gain without feedback falls by 20%, calculate the percentage fall in gain with feedback.*

Solution.

$$A_v = 500 \; ; A_{vf} = 100 \; ; m_v = ?$$

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$100 = \frac{500}{1 + 500\, m_v}$$

$\therefore$ $$m_v = \mathbf{0.008}$$

Now $$A_v = \frac{80}{100} \times 500 = 400 \; ; m_v = 0.008 \; ; A_{vf} = ?$$

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{400}{1 + 400 \times 0.008} = \frac{400}{4.2} = 95.3$$

$\therefore$ $$\%\text{ age fall in } A_{vf} = \frac{100 - 95.3}{100} \times 100 = \mathbf{4.7\%}$$

Note that without negative feedback, the change in gain is 20%. However, when negative feedback is applied, the change in gain (4.7%) is much less. This shows that negative feedback provides voltage gain stability.

Example 13.8. *An amplifier has an open-loop gain $A_v = 100{,}000$. A negative feedback of 10 db is applied. Find (i) voltage gain with feedback (ii) value of feedback fraction m_v.*

Sodlution.

(*i*) *db* voltage gain without feedback

$$= 20 \log_{10} 100{,}000 = 20 \log_{10} 10^5 = 100\ db$$

Voltage gain with feedback $= 100 - 10 = 90\ db$

Now $$20 \log_{10} (A_{vf}) = 90$$

or $$\log_{10} (A_{vf}) = 90/20 = 4.5$$

$\therefore$ $$A_{vf} = \text{Antilog } 4.5 = \mathbf{31622}$$

(*ii*) $$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$31622 = \frac{100{,}000}{1 + 100{,}000 \times m_v}$$

$\therefore$ $$m_v = \mathbf{2.17 \times 10^{-5}}$$

Example 13.9. *An amplifier with an open-circuit voltage gain of 1000 has an output resistance of 100 Ω and feeds a resistive load of 900 Ω. Negative voltage feedback is provided by connecting a resistive voltage divider across the output and one-fiftieth of the output voltage is fedback in series with the input signal. Determine the voltage gain with negative feedback.*

Solution. Fig. 13.5 shows the equivalent circuit of an amplifier along with the feedback circuit.

Voltage gain of the amplifier without feedback is

...See Art. 10.20

$$A_v = \frac{A_0\, R_L}{R_{out} + R_L}$$

$$= \frac{1000 \times 900}{100 + 900} = 900$$

$$\therefore \quad A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{900}{1 + 900 \times (1/50)} = 47.4$$

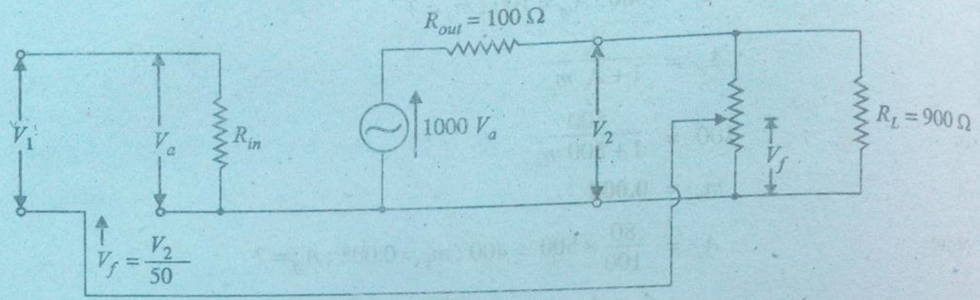


Fig. 13.5

Example 13.10. *An amplifier is required with a voltage gain of 100 which does not vary by more than 1%. If it is to use negative feedback with a basic amplifier the voltage gain of which can vary by 20%, determine the minimum voltage gain required and the feedback factor.*

Solution.

$$100 = \frac{A_v}{1 + A_v\, m_v}$$

or $\quad 100 + 100\, A_v\, m_v = A_v \quad$ ... (*i*)

Also $\quad 99 = \frac{0.8\, A_v}{1 + 0.8\, A_v\, m_v}$

or $\quad 99 + 79.2\, A_v\, m_v = 0.8\, A_v \quad$ ...(*ii*)

Multiplying eq (*i*) by 0.792, we have,

$$79.2 + 79.2\, A_v\, m_v = 0.792\, A_v \quad \text{... (iii)}$$

Subtracting [(*ii*) – (*iii*)], we have,

$$19.8 = 0.008\, A_v \quad \therefore \quad A_v = \frac{19.8}{0.008} = 2475$$

Putting the value of A_v (= 2475) in eq. (*i*), we have,

$$100 + 100 \times 2475 \times m_v = 2475$$

$$\therefore \quad m_v = \frac{2475 - 100}{100 \times 2475} = 0.0096$$

13.4 Advantages of Negative Voltage Feedback

The following are the advantages of negative voltage feedback in amplifiers :

(*i*) **Gain stability.** An important advantage of negative voltage feedback is that the resultant gain of the amplifier can be made independent of transistor parameters or the supply voltage variations.

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

For negative voltage feedback in an amplifier to be effective, the designer deliberately makes the product $A_v m_v$ much greater than unity. Therefore, in the above relation, 1 can be neglected as compared to $A_v m_v$ and the expression becomes :

$$A_{vf} = \frac{A_v}{A_v m_v} = \frac{1}{m_v}$$

It may be seen that the gain now depends only upon feedback fraction m_v *i.e.*, on the characteristics of feedback circuit. As feedback circuit is usually a voltage divider (a resistive network), therefore, it is unaffected by changes in temperature, variations in transistor parameters and frequency. Hence, the gain of the amplifier is extremely stable.

(*ii*) **Reduces non-linear distortion.** A large signal stage has non-linear distortion because its voltage gain changes at various points in the cycle. The negative voltage feedback reduces the non-linear distortion in large signal amplifiers. It can be proved mathematically that :

$$D_{vf} = \frac{D}{1 + A_v m_v}$$

where D = distortion in amplifier without feedback

D_{vf} = distortion in amplifier with negative feedback

It is clear that by applying negative voltage feedback to an amplifier, distortion is reduced by a factor $1 + A_v m_v$.

(*iii*) **Improves frequency response.** As feedback is usually obtained through a resistive network, therefore, voltage gain of the amplifier is *independent of signal frequency. The result is that voltage gain of the amplifier will be substantially constant over a wide range of signal frequency. The negative voltage feedback, therefore, improves the frequency response of the amplifier.

(*iv*) **Increases circuit stability.** The output of an ordinary amplifier is easily changed due to variations in ambient temperature, frequency and signal amplitude. This changes the gain of the amplifier, resulting in distortion. However, by applying negative voltage feedback, voltage gain of the amplifier is stabilised or accurately fixed in value. This can be easily explained. Suppose the output of a negative voltage feedback amplifier has increased because of temperature change or due to some other reason. This means more negative feedback since feedback is being given from the output. This tends to oppose the increase in amplification and maintains it stable. The same is true should the output voltage decrease. Consequently, the circuit stability is considerably increased.

(*v*) **Increases input impedance and decreases output impedance.** The negative voltage feedback increases the input impedance and decreases the output impedance of amplifier. Such a change is profitable in practice as the amplifier can then serve the purpose of impedance matching.

(*a*) **Input impedance.** The increase in input impedance with negative voltage feedback can be explained by referring to Fig. 13.6. Suppose the input impedance of the amplifier is Z_{in} without feedback and Z'_{in} with negative feedback. Let us further assume that input current is i_1.

Referring to Fig. 13.6, we have,

$$e_g - m_v e_0 = i_1 Z_{in}$$

Now

$$\begin{aligned} e_g &= (e_g - m_v e_0) + m_v e_0 \\ &= (e_g - m_v e_0) + A_v m_v (e_g - m_v e_0) \qquad [\because e_0 = A_v (e_g - m_v e_0)] \\ &= (e_g - m_v e_0)(1 + A_v m_v) \\ &= i_1 Z_{in} (1 + A_v m_v) \qquad [\because e_g - m_v e_0 = i_1 Z_{in}] \end{aligned}$$

* $A_{vf} = 1/m_v$. Now m_v depends upon feedback circuit. As feedback circuit consists of resistive network, therefore, value of m_v is unaffected by change in signal frequency.

or $$\frac{e_g}{i_1} = Z_{in}(1 + A_v m_v)$$

But $e_g/i_1 = Z'_{in}$, the input impedance of the amplifier with negative voltage feedback.

$$\therefore \quad Z'_{in} = Z_{in}(1 + A_v m_v)$$

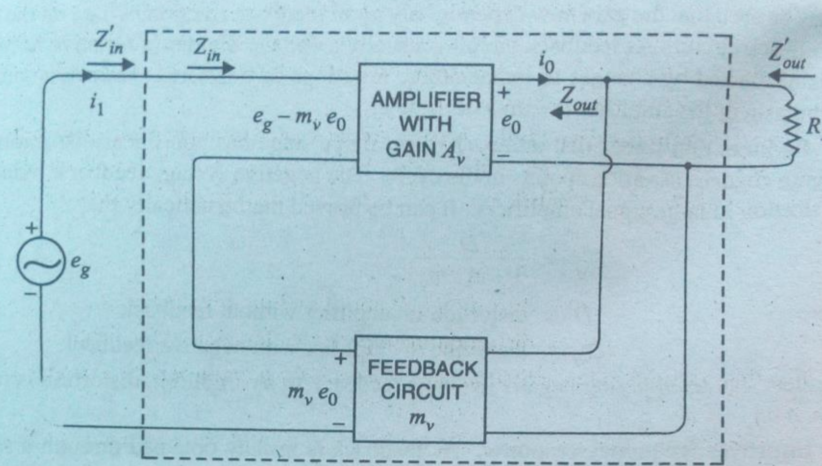


Fig. 13.6

It is clear that by applying negative voltage feedback, the input impedance of the amplifier is increased by a factor $1 + A_v m_v$. As $A_v m_v$ is much greater than unity, therefore, input impedance is increased considerably. This is an advantage, since the amplifier will now present less of a load to its source circuit.

(b) Output impedance. Following similar line, we can show that output impedance with negative voltage feedback is given by :

$$Z'_{out} = \frac{Z_{out}}{1 + A_v m_v}$$

where Z'_{out} = output impedance with negative voltage feedback

Z_{out} = output impedance without feedback

It is clear that by applying negative feedback, the output impedance of the amplifier is decreased by a factor $1 + A_v m_v$. This is an added benefit of using negative voltage feedback. With lower value of output impedance, the amplifier is much better suited to drive low impedance loads.

13.5 Feedback Circuit

The function of the feedback circuit is to return a fraction of the output voltage to the input of the amplifier. Fig. 13.7 shows the feedback circuit of negative voltage feedback amplifier. It is essentially a potential divider consisting of resistances R_1 and R_2. The output voltage of the amplifier is fed to this potential divider which gives the feedback voltage to the input.

Referring to Fig. 13.7, it is clear that :

$$\text{Voltage across } R_1 = \left(\frac{R_1}{R_1 + R_2}\right) e_0$$

$$\text{Feedback fraction, } m_v = \frac{\text{Voltage across } R_1}{e_0} = \frac{R_1}{R_1 + R_2}$$

where BW = Bandwidth of the amplifier without feedback
$BW_{(f)}$ = Bandwidth of the amplifier with negative feedback

13.6 Principles of Negative Current Feedback

In this method, a fraction of output current is fedback to the input of the amplifier. In other words, the feedback current (I_f) is proportional to the output current (I_{out}) of the amplifier. Fig. 13.10 shows the principles of negative current feedback. This circuit is called current-shunt feedback circuit. A feedback resistor R_f is connected between input and output of the amplifier. This amplifier has a current gain of A_i without feedback. It means that a current I_1 at the input terminals of the amplifier will appear as $A_i I_1$ in the output circuit *i.e.*, $I_{out} = A_i I_1$. Now a fraction m_i of this output current is fedback to the input through R_f. The fact that arrowhead shows the feed current being fed forward is because it is *negative* feedback.

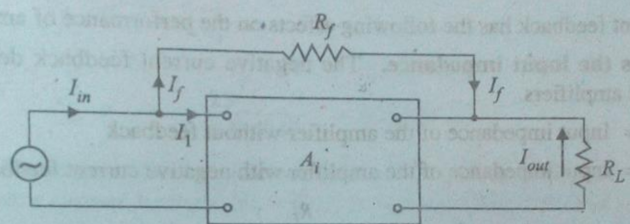


Fig. 13.10

Feedback current, $I_f = m_i I_{out}$

$\therefore$ Feedback fraction, $m_i = \dfrac{I_f}{I_{out}} = \dfrac{\text{Feedback current}}{\text{Output current}}$

Note that negative current feedback reduces the input current to the amplifier and hence its current gain.

13.7 Current Gain with Negative Current Feedback

Referring to Fig. 13.10, we have,

$$I_{in} = I_1 + I_f = I_1 + m_i I_{out}$$

But $I_{out} = A_i I_1$, where A_i is the current gain of the amplifier without feedback.

$$\therefore \quad I_{in} = I_1 + m_i A_i I_1 \qquad (\because I_{out} = A_i I_1)$$

$\therefore$ Current gain with negative current feedback is

$$A_{if} = \frac{I_{out}}{I_{in}} = \frac{A_i I_1}{I_1 + m_i A_i I_1}$$

or

$$A_{if} = \frac{A_i}{1 + m_i A_i}$$

This equation looks very much like that for the voltage gain of negative voltage feedback amplifier. The only difference is that we are dealing with current gain rather than the voltage gain. The following points may be noted carefully :

(*i*) The current gain of the amplifier without feedback is A_i. However, when negative current feedback is applied, the current gain is reduced by a factor $(1 + m_i A_i)$.

(*ii*) The feedback fraction (or current attenuation) m_i has a value between 0 and 1.

(*iii*) The negative current feedback does not affect the voltage gain of the amplifier.

Example 13.15. *The current gain of an amplifier is 200 without feedback. When negative current feedback is applied, determine the effective current gain of the amplifier. Given that current attenuation m_i = 0.012.*

Solution.

$$A_{if} = \frac{A_i}{1 + m_i A_i}$$

Here

$$A_i = 200\ ; \quad m_i = 0.012$$

$\therefore$

$$A_{if} = \frac{200}{1 + (0.012)(200)} = \mathbf{58.82}$$

13.8 Effects of Negative Current Feedback

The negative current feedback has the following effects on the performance of amplifiers :

(*i*) **Decreases the input impedance.** The negative current feedback decreases the input impedance of most amplifiers.

Let Z_{in} = Input impedance of the amplifier without feedback

Z'_{in} = Input impedance of the amplifier with negative current feedback

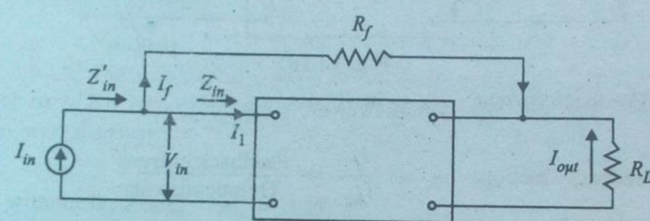


Fig. 13.11

Referring to Fig. 13.11, we have,

$$Z_{in} = \frac{V_{in}}{I_1}$$

and

$$Z'_{in} = \frac{V_{in}}{I_{in}}$$

But

$$V_{in} = I_1 Z_{in} \quad \text{and} \quad I_{in} = I_1 + I_f = I_1 + m_i I_{out} = I_1 + m_i A_i I_1$$

$\therefore$

$$Z'_{in} = \frac{I_1 Z_{in}}{I_1 + m_i A_i I_1} = \frac{Z_{in}}{1 + m_i A_i}$$

or

$$Z'_{in} = \frac{Z_{in}}{1 + m_i A_i}$$

Thus the input impedance of the amplifier is decreased by the factor $(1 + m_i A_i)$. Note the primary difference between negative current feedback and negative voltage feedback. Negative current feedback *decreases* the input impedance of the amplifier while negative voltage feedback *increases* the input impedance of the amplifier.

(*ii*) **Increases the output impedance.** It can be proved that with negative current feedback, the output impedance of the amplifier is increased by a factor $(1 + m_i A_i)$.

$$Z'_{out} = Z_{out}(1 + m_i A_i)$$

where Z_{out} = output impedance of the amplifier without feedback

Z'_{out} = output impedance of the amplifier with negative current feedback

The reader may recall that with negative voltage feedback, the output impedance of the amplifier is decreased.

(iii) **Increases bandwidth.** It can be shown that with negative current feedback, the bandwidth of the amplifier is increased by the factor $(1 + m_i A_i)$.

$$BW' = BW(1 + m_i A_i)$$

where BW = Bandwidth of the amplifier without feedback

BW' = Bandwidth of the amplifier with negative current feedback

Example 13.16. *An amplifier has a current gain of 240 and input impedance of 15 kΩ without feedback. If negative current feedback ($m_i = 0.015$) is applied, what will be the input impedance of the amplifier ?*

Solution. $$Z'_{in} = \frac{Z_{in}}{1 + m_i A_i}$$

Here $Z_{in} = 15\ \text{k}\Omega\ ;\ A_i = 240\ ;\ m_i = 0.015$

$$\therefore \quad Z'_{in} = \frac{15}{1 + (0.015)(240)} = \mathbf{3.26\ k\Omega}$$

Example 13.17. *An amplifier has a current gain of 200 and output impedance of 3 kΩ without feedback. If negative current feedback ($m_i = 0.01$) is applied; what is the output impedance of the amplifier ?*

Solution. $$Z'_{out} = Z_{out}(1 + m_i A_i)$$

Here $Z_{out} = 3\ \text{k}\Omega\ ;\ A_i = 200\ ;\ m_i = 0.01$

$$\therefore \quad Z'_{out} = 3[1 + (0.01)(200)] = \mathbf{9\ k\Omega}$$

Example 13.18. *An amplifier has a current gain of 250 and a bandwidth of 400 kHz without feedback. If negative current feedback ($m_i = 0.01$) is applied, what is the bandwidth of the amplifier?*

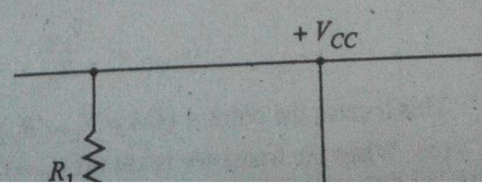
Solution. $$BW' = BW(1 + m_i A_i)$$

Here $BW = 400\ \text{kHz}\ ;\ m_i = 0.01\ ;\ A_i = 250$

$$\therefore \quad BW' = 400[1 + (0.01)\,250] = \mathbf{1400\ kHz}$$

13.9 Emitter Follower

It is a negative current feedback circuit. The emitter follower is a current amplifier that has no voltage gain. Its most important characteristic is that it has high input impedance and



13.13 OUTPUT IMPEDAMCE OF EMITTER FOLLOWER

THE OUTPUT IMPEDENCE OF A CIRCUIT IS THE IMPEDANCE THAT THE CIRCUITOFFERS TO LOAD. WHEN LOAD IS….

connected to the circuit, the output impedance acts as the source impedance for the load. Fig. 13.22 shows the circuit of emitter follower. Here R_s is the output resistance of amplifier voltage source.

It can be proved that the output impedance Z_{out} of the emitter follower is given by :

$$Z_{out} = R_E \parallel \left(r'_e + \frac{R'_{in}}{\beta} \right)$$

where $R'_{in} = R_1 \parallel R_2 \parallel R_s$

In practical circuits, the value of R_E is large enough to be ignored. For this reason, the output impedance of emitter follower is approximately given by :

$$Z_{out} = r'_e + \frac{R'_{in}}{\beta}$$

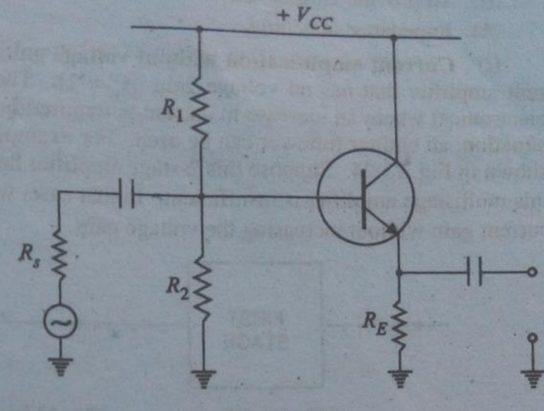


Fig. 13.22

Example 13.23. *Determine the output impedance of the emitter follower shown in Fig. 13.23. Given that $r'_e = 20\ \Omega$*

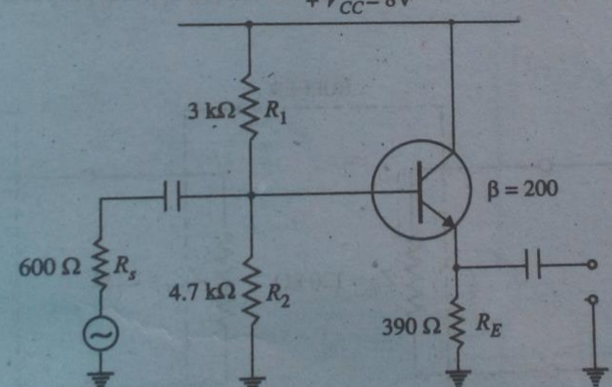


Fig. 13.23

Solution. $Z_{out} = r'_e + \dfrac{R'_{in}}{\beta}$

Now $R'_{in} = R_1 \parallel R_2 \parallel R_s$

$= 3\ \text{k}\Omega \parallel 4.7\ \text{k}\Omega \parallel 600\ \Omega = 452\ \Omega$

$\therefore \quad Z_{out} = 20 + \dfrac{452}{200} = 20 + 2.3 = 22.3\ \Omega$

Note that output impedance of the emitter follower is very low. On the other hand, it has high input impedance. This property makes the emitter follower a perfect circuit for connecting a low impedance load to a high-impedance source.

13.14 Applications of Emitter Follower

The emitter follower has the following principal applications :

$$1 + 40\, m_v$$

or $$20 + 800\, m_v = 40$$

$$m_v = \frac{40 - 20}{800} = \frac{1}{40}$$

Example 13.5. *The gain of an amplifier without feedback is 50 whereas with negative voltage feedback, it falls to 25. If due to ageing, the amplifier gain falls to 40, find the percentage reduction in stage gain (i) without feedback and (ii) with negative feedback.*

Solution.

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v}$$

or $$25 = \frac{50}{1 + 50\, m_v}$$

or $$m_v = 1/50$$

(*i*) **Without feedback.** The gain of the amplifier without feedback is 50. However, due to ageing, it falls to 40.

∴ $$\%\text{age reduction in stage gain} = \frac{50 - 40}{50} \times 100 = \mathbf{20\%}$$

(*ii*) **With negative feedback.** When the gain without feedback was 50, the gain with negative feedback was 25. Now the gain without feedback falls to 40.

∴ $$\text{New gain with negative feedback} = \frac{A_v}{1 + A_v\, m_v} = \frac{40}{1 + (40 \times 1/50)} = 22.2$$

∴ $$\%\text{age reduction in stage gain} = \frac{25 - 22.2}{25} \times 100 = \mathbf{11.2\%}$$

Example 13.6. *An amplifier has a voltage amplification A_v and a fraction m_v of its output is fedback in opposition to the input. If $m_v = 0.1$ and $A_v = 100$, calculate the percentage change in the gain of the system if A_v falls 6 db due to ageing.*

Solution. $$A_v = 100, \quad m_v = 0.1, \quad A_{vf} = ?$$

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{100}{1 + 100 \times 0.1} = 9.09$$

$$\text{Fall in gain} = 6db$$

Let A_{v1} be the new absolute voltage gain without feedback.

Then, $$20 \log_{10} A_v/A_{v1} = 6$$

or $$\log_{10} A_v/A_{v1} = 6/20 = 0.3$$

or $$\frac{A_v}{A_{v1}} = \text{Antilog } 0.3 = 2$$

or $$A_{v1} = A_v/2 = 100/2 = 50$$

$$\text{New } A_{vf} = \frac{A_{v1}}{1 + A_{v1}\, m_v} = \frac{50}{1 + 50 \times 0.1} = 8.33$$

∴ $$\%\text{ age change in system gain} = \frac{9.09 - 8.33}{9.09} \times 100 = \mathbf{8.36\%}$$