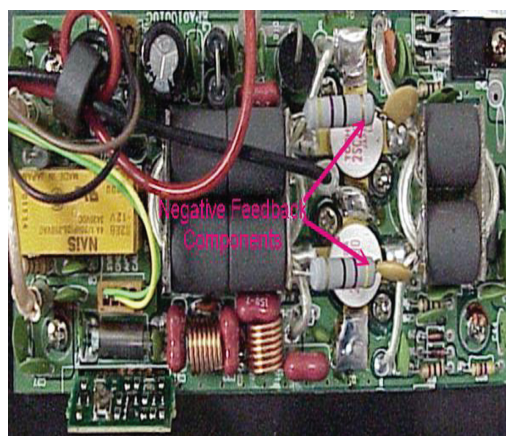


# 13

## Amplifiers with Negative Feedback

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### 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

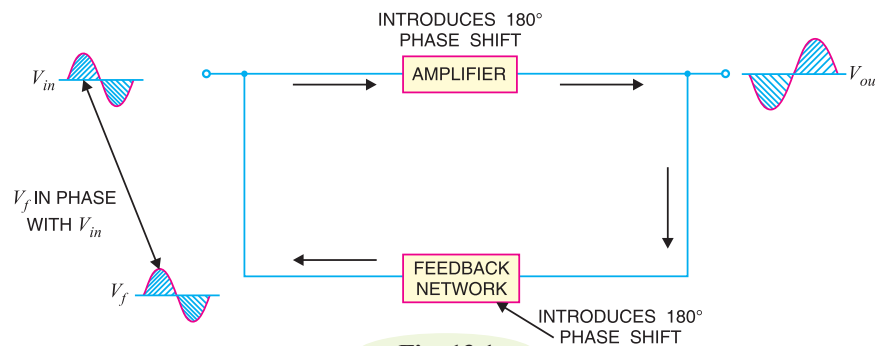
*The process of injecting a fraction of output energy of*

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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**.

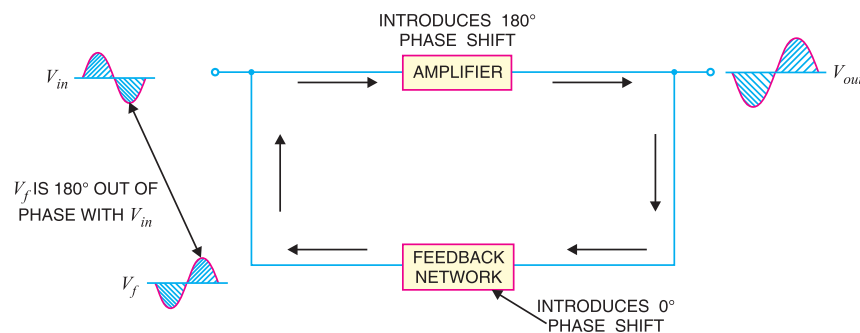
**(i) Positive feedback.** When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called **positive feedback**. This is illustrated in Fig. 13.1. Both amplifier and feedback network introduce a phase shift of  $180^\circ$ . The result is a  $360^\circ$  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  $180^\circ$  into the circuit while the feedback network is so designed that it introduces no phase shift (i.e.,  $0^\circ$  phase shift). The result is that the **feedback voltage**  $V_f$  is  $180^\circ$  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 fed back 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,

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

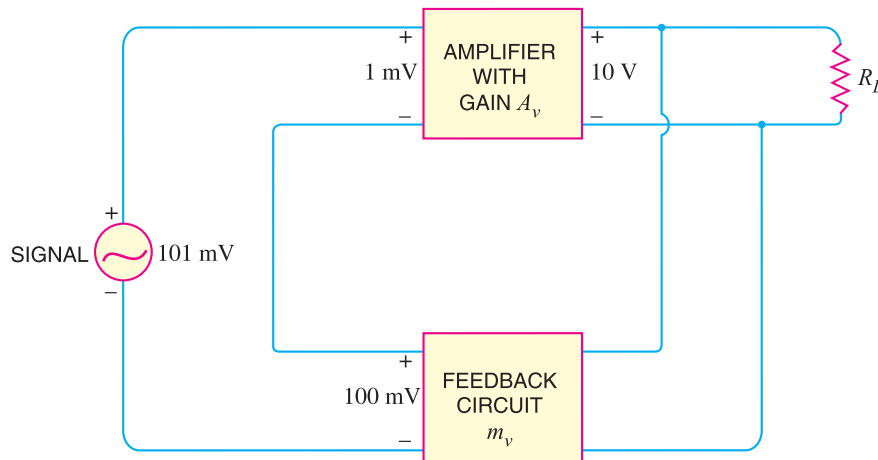


Fig. 13.3

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

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

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.,

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

$$\text{or} \quad A_v e_g - A_v m_v e_0 = e_0$$

$$\text{or} \quad e_0 (1 + A_v m_v) = A_v e_g$$

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

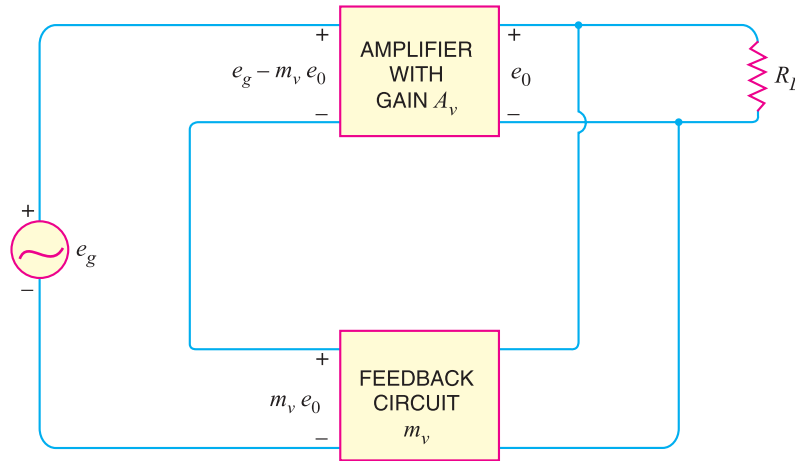


Fig. 13.4

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.**  $A_v = 3000, m_v = 0.01$

∴ 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 feedback to the input.

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

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 feedback.

(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 feedback.

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

(ii)  $A_{vf} = 75$ ;  $m_v = 0.01$ ;  $A_v = ?$

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

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

or  $75 + 0.75 A_v = A_v$

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

**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,  $A_{vf} = 10/0.5 = 20$

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$$\begin{aligned}\text{Now} \quad A_{vf} &= \frac{A_v}{1 + A_v m_v} \\ \text{or} \quad 20 &= \frac{40}{1 + 40 m_v} \\ \text{or} \quad 20 + 800 m_v &= 40 \\ \text{or} \quad m_v &= \frac{40 - 20}{800} = \frac{1}{40}\end{aligned}$$

**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.**

$$\begin{aligned}A_{vf} &= \frac{A_v}{1 + A_v m_v} \\ \text{or} \quad 25 &= \frac{50}{1 + 50 m_v} \\ \text{or} \quad m_v &= 1/50\end{aligned}$$

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

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

**(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.

$$\begin{aligned}\therefore \text{ New gain with negative feedback} &= \frac{A_v}{1 + A_v m_v} = \frac{40}{1 + (40 \times 1/50)} = 22.2 \\ \therefore \text{ \%age reduction in stage gain} &= \frac{25 - 22.2}{25} \times 100 = \mathbf{11.2\%}\end{aligned}$$

**Example 13.6.** An amplifier has a voltage amplification  $A_v$  and a fraction  $m_v$  of its output is fed back 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.**

$$\begin{aligned}A_v &= 100, \quad m_v = 0.1, \quad A_{vf} = ? \\ A_{vf} &= \frac{A_v}{1 + A_v m_v} = \frac{100}{1 + 100 \times 0.1} = 9.09\end{aligned}$$

Fall in gain = 6db

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

$$\begin{aligned}\text{Then,} \quad 20 \log_{10} A_v / A_{v1} &= 6 \\ \text{or} \quad \log_{10} A_v / A_{v1} &= 6/20 = 0.3 \\ \text{or} \quad \frac{A_v}{A_{v1}} &= \text{Antilog } 0.3 = 2 \\ \text{or} \quad A_{v1} &= A_v / 2 = 100/2 = 50 \\ \therefore \text{ New } A_{vf} &= \frac{A_{v1}}{1 + A_{v1} m_v} = \frac{50}{1 + 50 \times 0.1} = 8.33 \\ \therefore \text{ \% age change in system gain} &= \frac{9.09 - 8.33}{9.09} \times 100 = \mathbf{8.36\%}\end{aligned}$$

**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.**

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

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

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

$$\therefore m_v = 0.008$$

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

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

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

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  $m_v$ .

**Solution.**

(i) db voltage gain without feedback

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

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

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

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

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

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

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

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

**Example 13.9.** An amplifier with an open-circuit voltage gain of 1000 has an output resistance of 100  $\Omega$  and feeds a resistive load of 900  $\Omega$ . Negative voltage feedback is provided by connecting a resistive voltage divider across the output and one-fiftieth of the output voltage is fed back 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

$$A_v = \frac{A_0 R_L}{R_{out} + R_L} \quad \dots \text{See Art. 10.20}$$

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

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

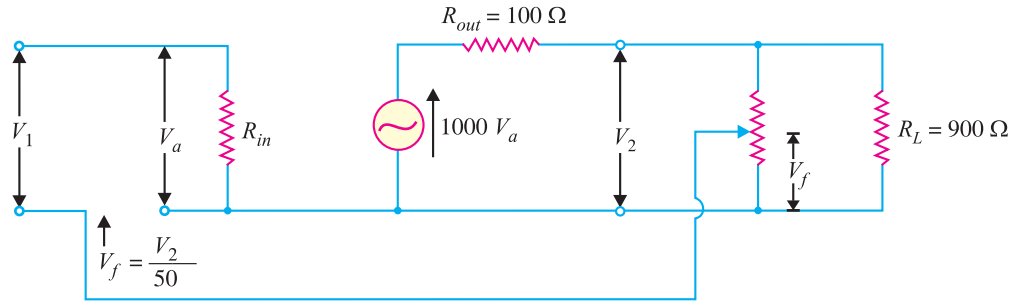


Fig. 13.5

**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.**

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

$$\text{or } 100 + 100 A_v m_v = A_v \quad \dots (i)$$

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

$$\text{or } 99 + 79.2 A_v m_v = 0.8 A_v \quad \dots (ii)$$

Multiplying eq (i) by 0.792, we have,

$$79.2 + 79.2 A_v m_v = 0.792 A_v \quad \dots (iii)$$

Subtracting [(ii) – (iii)], we have,

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

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

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

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

### 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

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

\*  $A_{vf} = 1/m_v$ . 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.

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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.

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

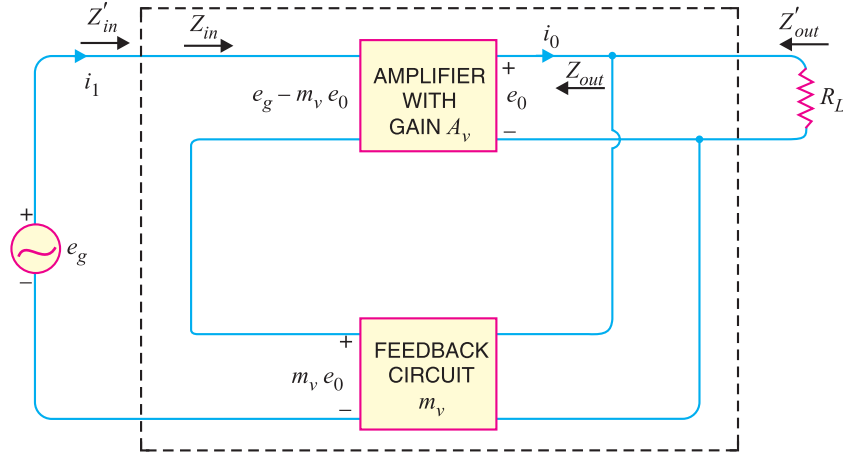


Fig. 13.6

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 :

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

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