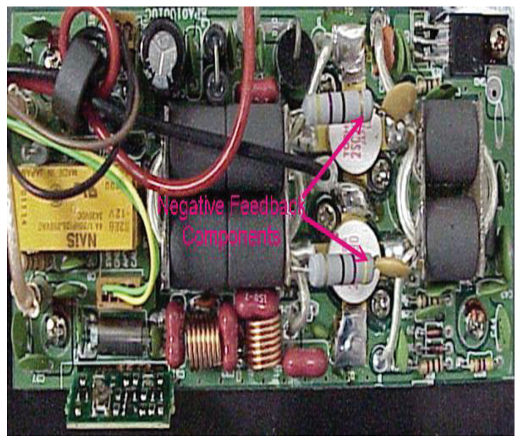
13

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}.

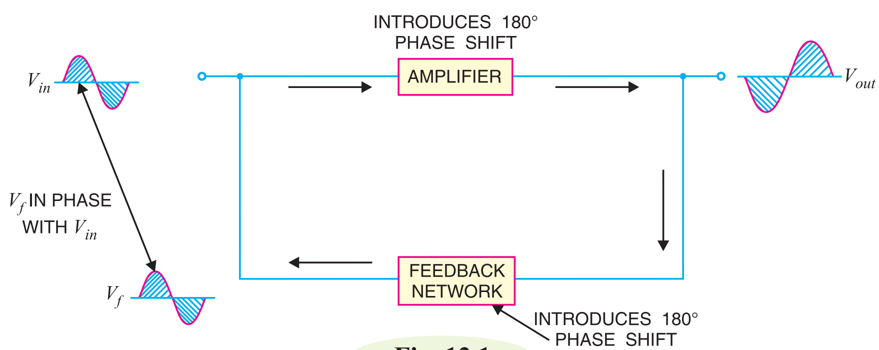


Fig. 13.1

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}.

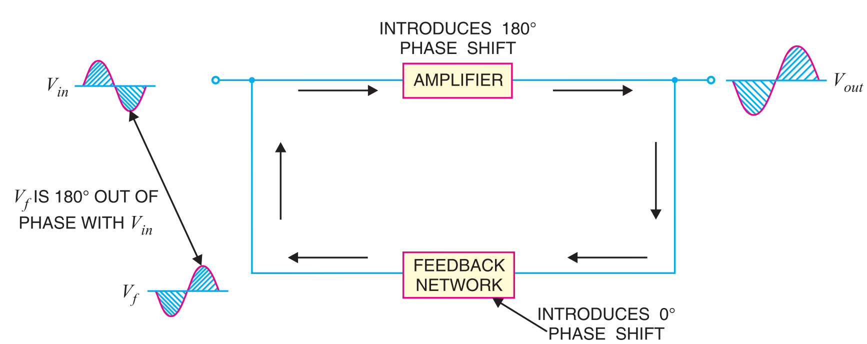


Fig. 13.2

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,

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

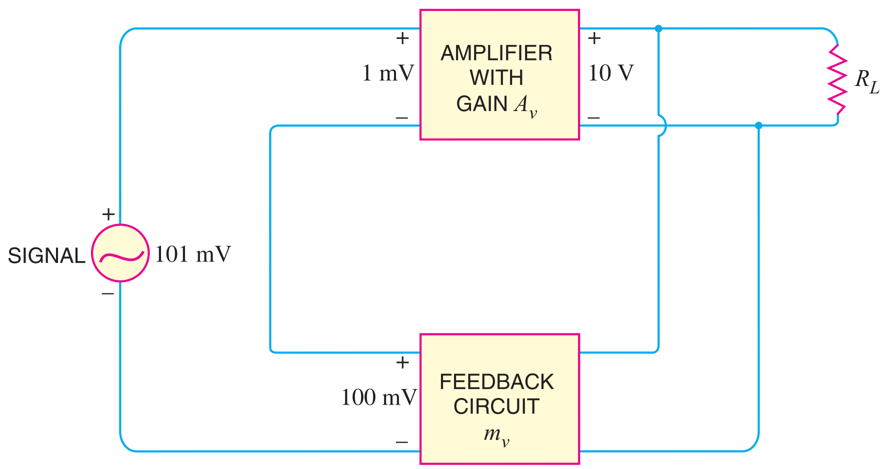


Fig. 13.3

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

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

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

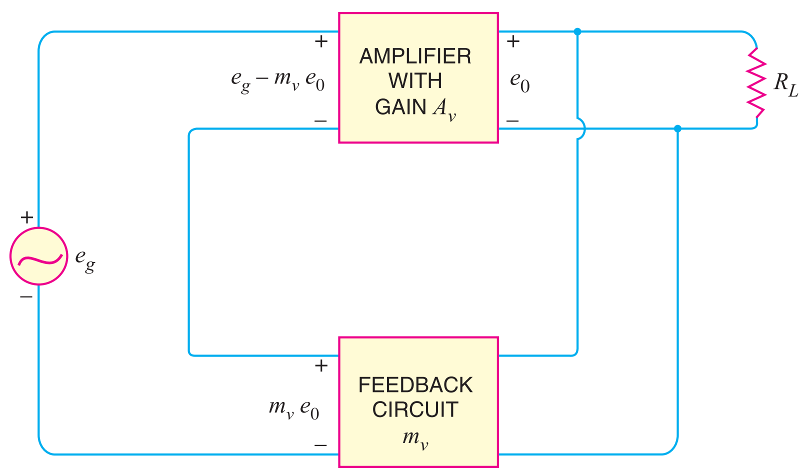


Fig. 13.4

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

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

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 $$17.5 + 2450 m_v = 140$$

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

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, $A_v = 10/0.25 = \mathbf{40}$

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

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

∴ $$m_v = \mathbf{0.008}$$

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

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

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

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

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

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

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

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

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

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

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

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

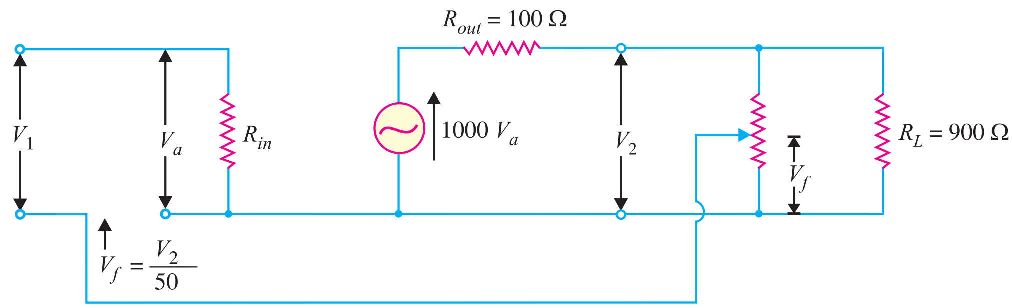


Fig. 13.5

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,

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

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

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

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

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.

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.

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

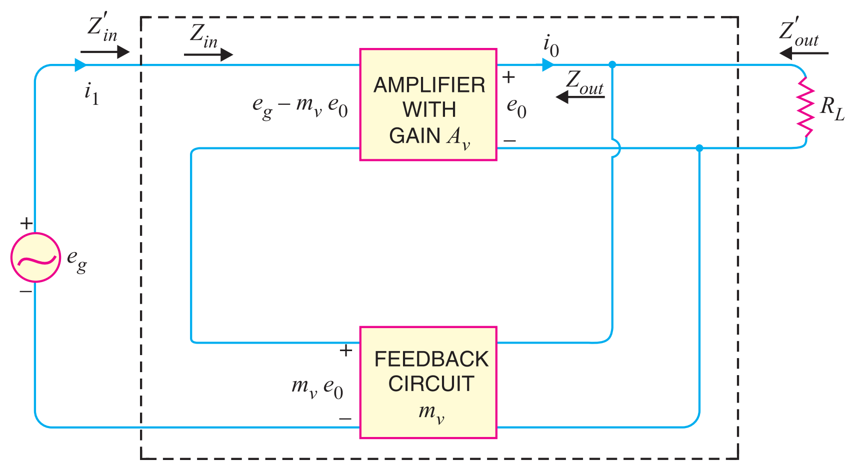


Fig. 13.6

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 :

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

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

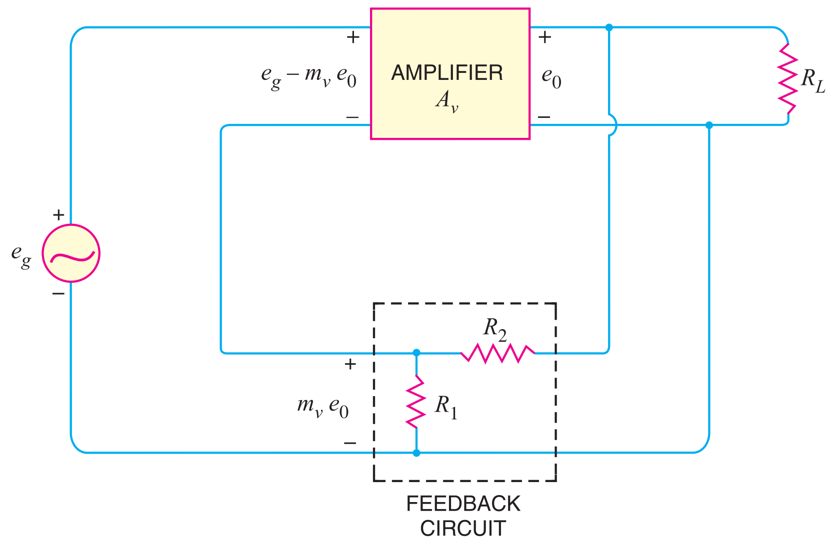


Fig. 13.7

Example 13.11. *Fig. 13.8 shows the negative voltage feedback amplifier. If the gain of the amplifier without feedback is 10,000, find :*

(i) feedback fraction (ii) overall voltage gain (iii) output voltage if input voltage is 1 mV.

Solution. $A_v = 10{,}000, \quad R_1 = 2\text{ k}\Omega, \quad R_2 = 18\text{ k}\Omega$

(i) Feedback fraction, $m_v = \dfrac{R_1}{R_1 + R_2} = \dfrac{2}{2+18} = \mathbf{0.1}$

(ii) Voltage gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{10{,}000}{1 + 10{,}000 \times 0.1} = \mathbf{10}$$

(iii) Output voltage $= A_{vf} \times$ input voltage

$= 10 \times 1\text{ mV} = \mathbf{10\ mV}$

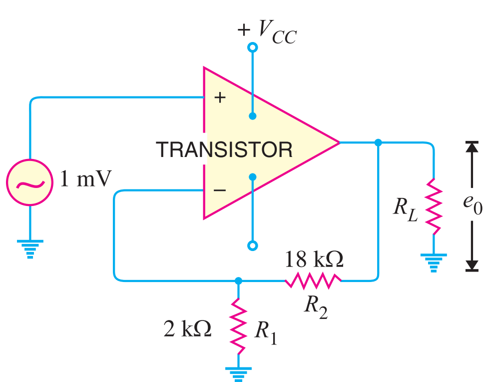


Fig. 13.8

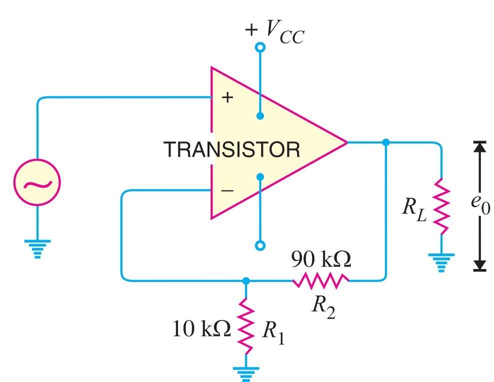


Fig. 13.9

Example 13.12. *Fig. 13.9 shows the circuit of a negative voltage feedback amplifier. If without feedback, $A_v = 10{,}000$, $Z_{in} = 10\text{ k}\Omega$, $Z_{out} = 100\ \Omega$, find :*

(i) *feedback fraction* (ii) *gain with feedback*
(iii) *input impedance with feedback* (iv) *output impedance with feedback.*

Solution.

(*i*) Feedback fraction, $m_v = \frac{R_1}{R_1 + R_2} = \frac{10}{10 + 90} = \mathbf{0.1}$

(*ii*) Gain with negative feedback is

$$A_{vf} = \frac{A_v}{1 + A_v\, m_v} = \frac{10,000}{1 + 10,000 \times 0.1} = \mathbf{10}$$

(*iii*) With negative voltage feedback, input impedance is increased and is given by :

$$\underset{(feedback)}{Z'_{in}} = (1 + A_v\, m_v)\, Z_{in}$$
$$= (1 + 10,000 \times 0.1)\ 10\ \text{k}\Omega$$
$$= 1001 \times 10\ \text{k}\Omega$$
$$= \mathbf{10\ M\Omega}$$

(*iv*) With negative voltage feedback, output impedance is decreased and is given by ;

$$\underset{(feedback)}{Z'_{out}} = \frac{Z_{out}}{1 + A_v\, m_v} = \frac{100\ \Omega}{1 + 10,000 \times 0.1} = \frac{100}{1001} = \mathbf{0.1\ \Omega}$$

Example 13.13. *The gain and distortion of an amplifier are 150 and 5% respectively without feedback. If the stage has 10% of its output voltage applied as negative feedback, find the distortion of the amplifier with feedback.*

Solution.

Gain without feedback, $A_v = 150$

Distortion without feedback, $D = 5\% = 0.05$

Feedback fraction, $m_v = 10\% = 0.1$

If D_{vf} is the distortion with negative feedback, then,

$$D_{vf} = \frac{D}{1 + A_v\, m_v} = \frac{0.05}{1 + 150 \times 0.1} = 0.00313 = \mathbf{0.313\%}$$

It may be seen that by the application of negative voltage feedback, the amplifier distortion is reduced from 5% to 0.313%.

Example 13.14. *An amplifier has a gain of 1000 without feedback and cut-off frequencies are f_1 = 1.5 kHz and f_2 = 501.5 kHz. If 1% of output voltage of the amplifier is applied as negative feedback, what are the new cut-off frequencies ?*

Solution. $A_v = 1000$; $m_v = 0.01$

The new lower cut-off frequency with feedback is

$$f_{1(f)} = \frac{f_1}{1 + A_v\, m_v} = \frac{1.5\ \text{kHz}}{1 + 1000 \times 0.01} = \mathbf{136.4\ Hz}$$

The new upper cut-off frequency with feedback is

$$f_{2(f)} = f_2\,(1 + m_v\, A_v) = (501.5\ \text{kHz})\,(1 + 1000 \times 0.01) = \mathbf{5.52\ MHz}$$

Note the effect of negative voltage feedback on the bandwidth of the amplifier. The lower cut-off frequency is decreased by a factor $(1 + m_v\, A_v)$ while upper cut-off frequency is increased by a factor $(1 + m_v\, A_v)$. In other words, the bandwidth of the amplifier is increased approximately by a factor $(1 + m_v\, A_v)$.

$$BW_{(f)} \simeq BW\,(1 + m_v\, A_v)$$

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.

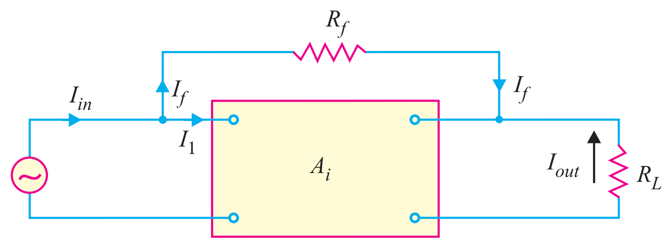


Fig. 13.10

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

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

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.

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

∴ 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 $A_i = 200\ ;\quad m_i = 0.012$

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

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

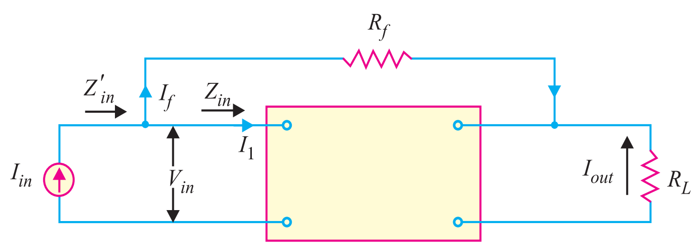


Fig. 13.11

Referring to Fig. 13.11, we have,

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

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

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

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

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 kΩ ; A_i = 240 ; m_i = 0.015

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

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 kΩ ; A_i = 200 ; m_i = 0.01

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

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 kHz ; m_i = 0.01 ; A_i = 250

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

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 low output impedance. This makes it an ideal circuit for impedance matching.

Circuit details. Fig. 13.12 shows the circuit of an emitter follower. As you can see, it differs from the circuitry of a conventional *CE* amplifier by the absence of collector load and emitter bypass capacitor. The emitter resistance R_E itself acts as the load and a.c. output voltage (V_{out}) is taken across R_E. The biasing is generally provided by voltage-divider method or by base resistor method. The following points are worth noting about the emitter follower :

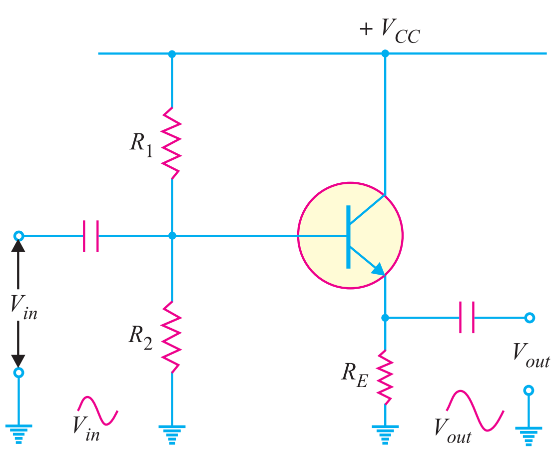


Fig. 13.12

(*i*) There is neither collector resistor in the circuit nor there is emitter bypass capacitor. These are the two circuit recognition features of the emitter follower.

(*ii*) Since the collector is at *ac* ground, this circuit is also known as *common collector* (*CC*) *amplifier.*

Operation. The input voltage is applied between base and emitter and the resulting a.c. emitter current produces an output voltage $i_e R_E$ across the emitter resistance. This voltage opposes the input voltage, thus providing negative feedback. Clearly, it is a negative current feedback circuit since the voltage fedback is proportional to the emitter current *i.e.*, output current. It is called emitter follower because the output voltage follows the input voltage.

Characteristics. The major characteristics of the emitter follower are :

(*i*) No voltage gain. In fact, the voltage gain of an emitter follower is close to 1.

(*ii*) Relatively high current gain and power gain.

(*iii*) High input impedance and low output impedance.

(*iv*) Input and output *ac* voltages are in phase.

13.10 D.C. Analysis of Emitter Follower

The d.c. analysis of an emitter follower is made in the same way as the voltage divider bias circuit of a CE amplifier. Thus referring to Fig. 13.12 above, we have,

$$\text{Voltage across } R_2,\ V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2$$

$$\text{Emitter current, } I_E = \frac{V_E}{R_E} = \frac{V_2 - V_{BE}}{R_E}$$

$$\text{Collector-emitter voltage, } V_{CE} = V_{CC} - V_E$$

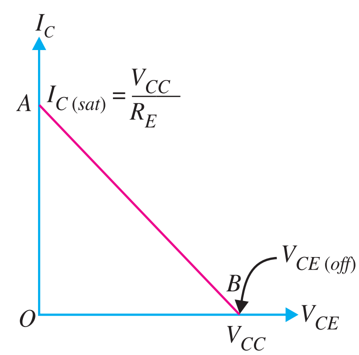


Fig. 13.13

D.C. Load Line. The d.c. load line of emitter follower can be constructed by locating the two end points *viz.*, $I_{C(sat)}$ and $V_{CE(off)}$.

(*i*) When the transistor is saturated, $V_{CE} = 0$.

$$\therefore \quad I_{C(sat)} = \frac{V_{CC}}{R_E}$$

This locates the point *A* ($OA = V_{CC}/R_E$) of the d.c. load line as shown in Fig. 13.13.

(*ii*) When the transistor is cut off, $I_C = 0$. Therefore, $V_{CE(off)} = V_{CC}$. This locates the point *B* ($OB = V_{CC}$) of the d.c. load line.

By joining points *A* and *B*, d.c. load line *AB* is constructed.

Example 13.19. *For the emitter follower circuit shown in Fig. 13.14 (i), find V_E and I_E. Also draw the dc load line for this circuit.*

Solution.

$$\text{Voltage across } R_2,\ V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{18}{16 + 22} \times 22 = 10.42 \text{ V}$$

$$\text{Voltage across } R_E,\ V_E = V_2 - V_{BE} = 10.42 - 0.7 = \mathbf{9.72\ V}$$

$$\text{Emitter current, } I_E = \frac{V_E}{R_E} = \frac{9.72 \text{ V}}{910\ \Omega} = \mathbf{10.68\ mA}$$

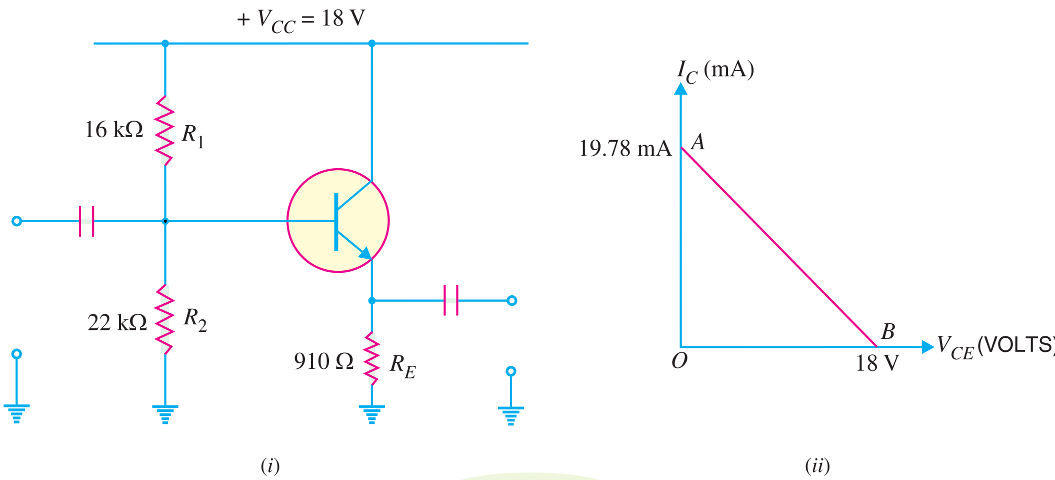


Fig. 13.14

D.C. load line
$$I_{C\,(sat)} = \frac{V_{CC}}{R_E} = \frac{18 \text{ V}}{910\ \Omega} = 19.78 \text{ mA}$$

This locates the point A (OA = 19.78 mA) of the d.c. load line.

$$V_{CE(off)} = V_{CC} = 18 \text{ V}$$

This locates point B (OB = 18 V) of the d.c. load line.

By joining points A and B, d.c. load line AB is constructed [See Fig. 13.14 (*ii*)].

13.11 Voltage Gain of Emitter Follower

Fig. 13.15 shows the emitter follower circuit. Since the emitter resistor is not bypassed by a capacitor, the *a.c.* equivalent circuit of emitter follower will be as shown in Fig. 13.16. The ac resistance r_E of the emitter circuit is given by :

$$r_E = r'_e + R_E \qquad \text{where } r'_e = \frac{25 \text{ mV}}{I_E}$$

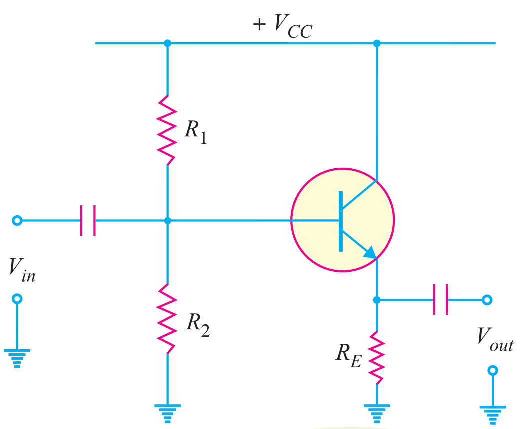


Fig. 13.15

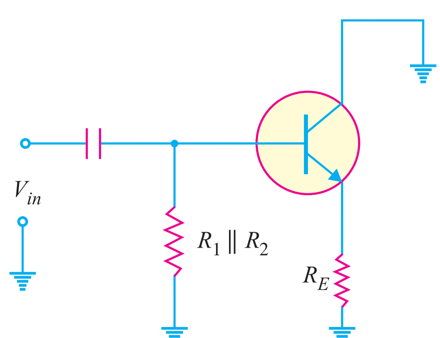


Fig. 13.16

In order to find the voltage gain of the emitter follower, let us replace the transistor in Fig. 13.16 by its equivalent circuit. The circuit then becomes as shown in Fig. 13.17.

Note that input voltage is applied across the *ac* resistance of the emitter circuit *i.e.*, ($r'_e + R_E$). Assuming the emitter diode to be ideal, Output voltage, $V_{out} = i_e R_E$

Input voltage, $V_{in} = i_e (r'_e + R_E)$

∴ Voltage gain of emitter follower is

$$A_v = \frac{V_{out}}{V_{in}} = \frac{i_e R_E}{i_e (r'_e + R_E)} = \frac{R_E}{r'_e + R_E}$$

or $$A_v = \frac{R_E}{r'_e + R_E}$$

In most practical applications, $R_E >> r'_e$ so that $A_v \simeq 1$.

In practice, the voltage gain of an emitter follower is between 0.8 and 0.999.

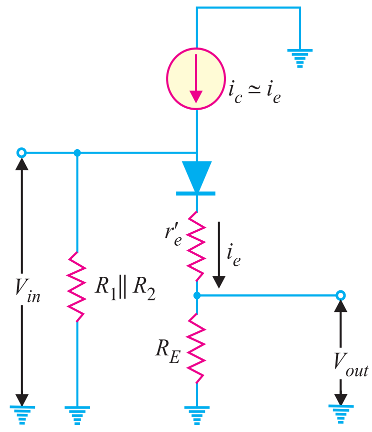


Fig. 13.17

Example 13.20. *Determine the voltage gain of the emitter follower circuit shown in Fig. 13.18.*

Solution.

Voltage gain, $$A_v = \frac{R_E}{r'_e + R_E}$$

Now $$r'_e = \frac{25 \text{ mV}}{I_E}$$

Voltage across R_2, $$V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{10}{10 + 10} \times 10 = 5 \text{ V}$$

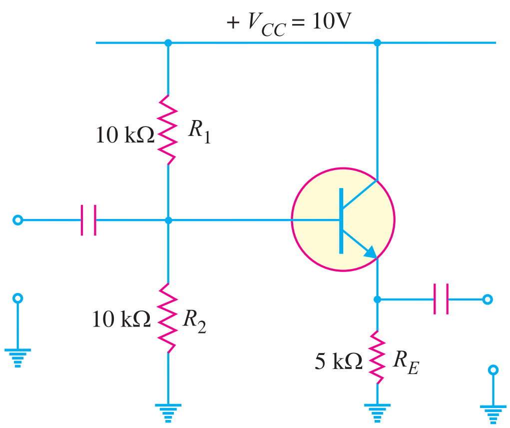


Fig. 13.18

Voltage across R_E, $V_E = V_2 - V_{BE} = 5 - 0.7 = 4.3$ V

∴ Emitter current, $$I_E = \frac{V_E}{R_E} = \frac{4.3 \text{ V}}{5 \text{ k}\Omega} = 0.86 \text{ mA}$$

∴ $$r'_e = \frac{25 \text{ mV}}{I_E} = \frac{25 \text{ mV}}{0.86 \text{ mA}} = 29.1 \ \Omega$$

∴ Voltage gain, $$A_v = \frac{R_E}{r'_e + R_E} = \frac{5000}{29.1 + 5000} = \mathbf{0.994}$$

Example 13.21. *If in the above example, a load of 5 kΩ is added to the emitter follower, what will be the voltage gain of the circuit ?*

Solution. When a load of 5 kΩ is added to the emitter follower, the circuit becomes as shown in

Fig. 13.19. The coupling capacitor acts as a short for a.c. signal so that R_E and R_L are in parallel. Therefore, the external emitter resistance R_E changes to R'_E where

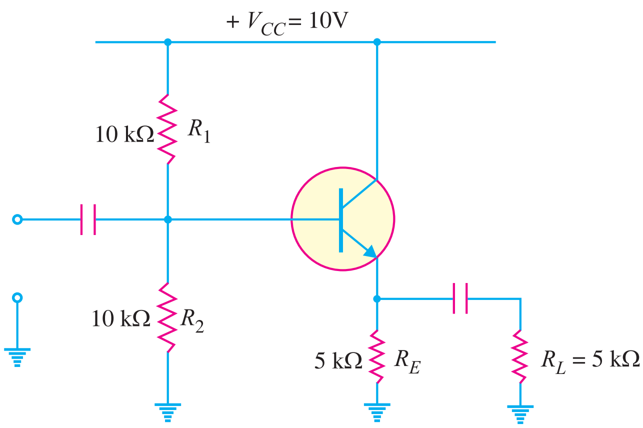


Fig. 13.19

$$R'_E = R_E \,||\, R_L = 5\text{ k}\Omega \,||\, 5\text{ k}\Omega = 2.5\text{ k}\Omega$$

$$\text{Voltage gain, } A_v = \frac{R'_E}{r'_e + R'_E} = \frac{2500}{29.1 + 2500} = \mathbf{0.988}$$

Comments. This is the same example as example 13.20 except that load is added. Note the loading effect on the voltage gain of an emitter follower. When load is added to the emitter follower, the voltage gain drops from 0.994 to 0.988. This is really a small change. On the other hand, when a CE amplifier is loaded, there is drastic change in voltage gain. This is yet another difference between the emitter follower and CE amplifier.

13.12 Input Impedance of Emitter Follower

Fig. 13.20 (*i*) shows the circuit of a loaded emitter follower. The a.c. equivalent circuit with T model is shown in Fig. 13.20 (*ii*).

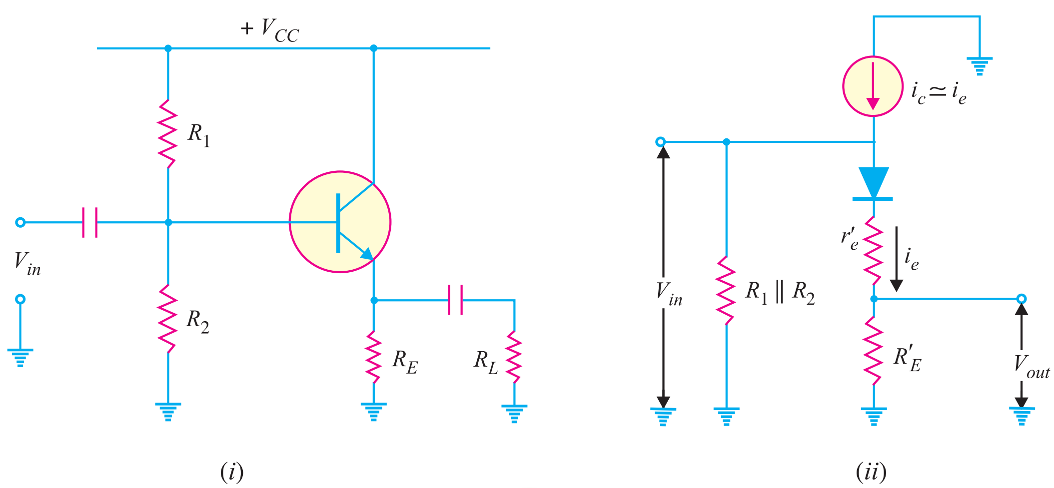


Fig. 13.20

As for CE amplifier, the input impedance of emitter follower is the combined effect of biasing resistors (R_1 and R_2) and the input impedance of transistor base [Z_{in} (*base*)]. Since these resistances are in parallel to the *ac* signal, the input impedance Z_{in} of the emitter follower is given by :

$$Z_{in} = R_1 \,||\, R_2 \,||\, Z_{in(\text{base})}$$

where $$Z_{in\,(base)} = \beta\,(r'_e + R'_E)$$

Now $$r'_e = \frac{25\text{ mV}}{I_E} \quad \text{and} \quad R'_E = R_E \,||\, R_L$$

Note. In an emitter follower, impedance of base [*i.e.*, Z_{in} (*base*)] is generally very large as compared to $R_1 \,||\, R_2$. Consequently, Z_{in} (*base*) can be ignored. As a result, approximate input impedance of the emitter follower is given by :

$$Z_{in} = R_1 \,||\, R_2$$

Example 13.22. *For the emitter follower circuit shown in Fig. 13.21, find the input impedance.*

Solution.

$$\text{Voltage across } R_2,\ V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{10}{10+10} \times 10 = 5\text{ V}$$

$$\text{Voltage across } R_E,\ V_E = V_2 - V_{BE} = 5 - 0.7 = 4.3\text{ V}$$

$$\therefore \quad \text{Emitter current, } I_E = \frac{V_E}{R_E} = \frac{4.3\text{ V}}{4.3\text{ k}\Omega} = 1\text{ mA}$$

$$\therefore \quad \text{A.C. emitter resistance, } r'_e = \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{1\text{ mA}} = 25\ \Omega$$

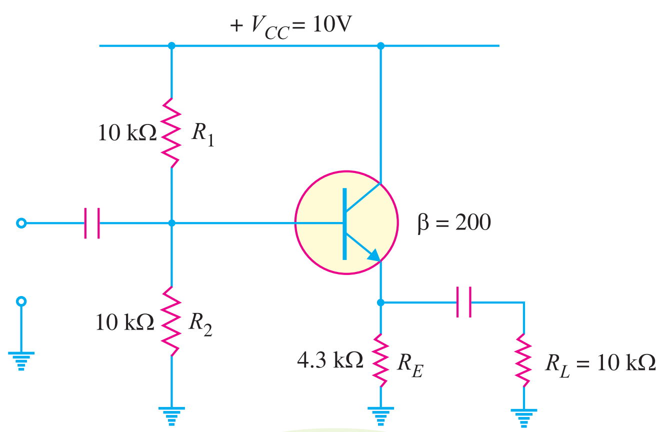


Fig. 13.21

Effective external emitter resistance is

$$R'_E = R_E \,||\, R_L = 4.3\text{ k}\Omega \,||\, 10\text{ k}\Omega = 3\text{ k}\Omega$$

$$\therefore \quad Z_{in\,(base)} = \beta\,(r'_e + R'_E) = 200\,(0.025 + 3) = 605\text{ k}\Omega$$

$\therefore$ Input impedance of the emitter follower is

$$Z_{in} = R_1 \,||\, R_2 \,||\, Z_{in\,(base)}$$
$$= 10\text{ k}\Omega \,||\, 10\text{ k}\Omega \,||\, 605\text{ k}\Omega$$
$$= 5\text{ k}\Omega \,||\, 605\text{ k}\Omega = \mathbf{4.96\text{ k}\Omega}$$

Note. Since 605 kΩ is much larger than $R_1 \,||\, R_2$ (= 5kΩ), the former can be ignored. Therefore, approximate input impedance of emitter follower is given by :

$$Z_{in} = R_1 \,||\, R_2 = 10\text{ k}\Omega \,||\, 10\text{ k}\Omega = 5\text{ k}\Omega$$

13.13 Output Impedance of Emitter Follower

The output impedance of a circuit is the impedance that the circuit offers to the 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.

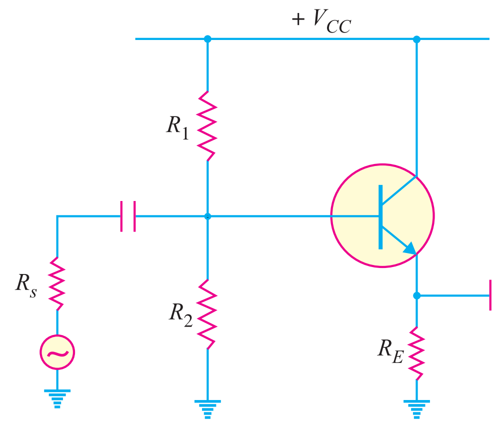


Fig. 13.22

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 $R'_{in} = R_1 \,||\, R_2 \,||\, R_s$

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 :

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

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

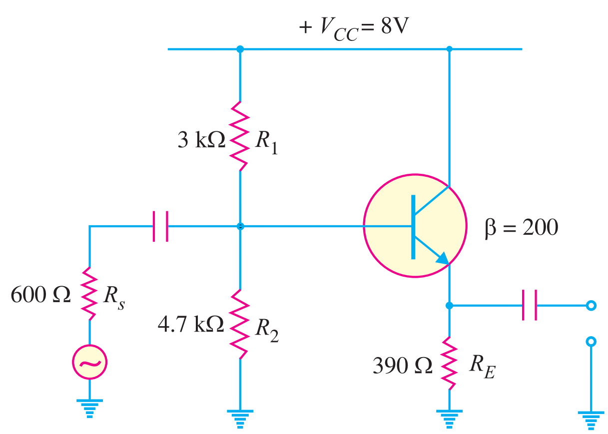


Fig. 13.23

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

Now $$R'_{in} = R_1 \parallel R_2 \parallel R_s$$
$$= 3\text{ k}\Omega \parallel 4.7\text{ k}\Omega \parallel 600\ \Omega = 452\ \Omega$$

∴ $$Z_{out} = 20 + \frac{452}{200} = 20 + 2.3 = \mathbf{22.3\ \Omega}$$

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 :

(*i*) To provide current amplification with no voltage gain.

(*ii*) Impedance matching.

(*i*) Current amplification without voltage gain. We know that an emitter follower is a current amplifier that has no voltage gain ($A_v \simeq 1$). There are many instances (especially in digital electronics) where an increase in current is required but no increase in voltage is needed. In such a situation, an emitter follower can be used. For example, consider the two stage amplifier circuit as shown in Fig. 13.24. Suppose this 2-stage amplifier has the desired voltage gain but current gain of this multistage amplifier is insufficient. In that case, we can use an emitter follower to increase the current gain without increasing the voltage gain.

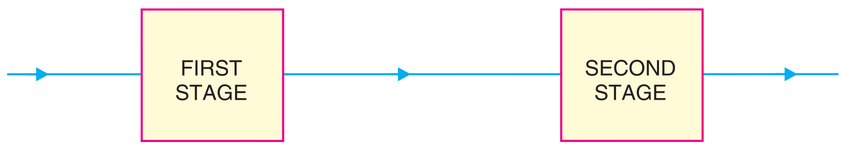


Fig. 13.24

(*ii*) Impedance matching. We know that an emitter follower has high input impedance and low output impedance. This makes the emitter follower an ideal circuit for impedance matching. Fig. 13.25 shows the impedance matching by an emitter follower. Here the output impedance of the source is 120 kΩ while that of load is 20 Ω. The emitter follower has an input impedance of 120 kΩ and output impedance of 22 Ω. It is connected between high-impedance source and low impedance load. The net result of this arrangement is that maximum power is transferred from the original source to the original load. When an emitter follower is used for this purpose, it is called a *buffer amplifier*.

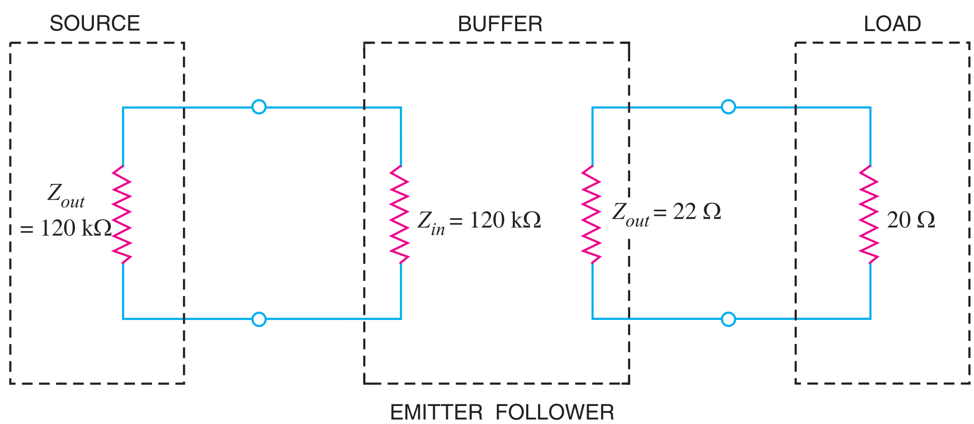


Fig. 13.25

It may be noted that the job of impedance matching can also be accomplished by a transformer. However, emitter follower is preferred for this purpose. It is because emitter follower is not only more convenient than a transformer but it also has much better frequency response *i.e.*, it works well over a large frequency range.

13.15 Darlington Amplifier

Sometimes, the current gain and input impedance of an emitter follower are insufficient to meet the requirement. In order to increase the overall values of circuit current gain (A_i) and input impedance, two transistors are connected in series in emitter follower configuration as shown in Fig. 13.26. Such a circuit is called *Darlington amplifier*. Note that emitter of first transistor is connected to the base of the second transistor and the collector terminals of the two transistors are connected together. The result is that emitter current of the first transistor is the base current of the second transistor. Therefore, the current gain of the pair is equal to product of individual current gains *i.e.*

$$*\beta = \beta_1 \beta_2$$

Note that high current gain is achieved with a minimum use of components.

The biasing analysis is similar to that for one transistor except that two V_{BE} drops are to be considered. Thus referring to Fig. 13.26,

$$\text{Voltage across } R_2,\ V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2$$

$$\text{Voltage across } R_E,\ V_E = V_2 - 2V_{BE}$$

$$\text{Current through } R_E,\ I_{E2} = \frac{V_2 - 2V_{BE}}{R_E}$$

Since the transistors are directly coupled, $I_{E1} = I_{B2}$. Now $I_{B2} = I_{E2}/\beta_2$.

$$\therefore \quad I_{E1} = \frac{I_{E2}}{\beta_2}$$

Input impedance of the darlington amplifier is

$$Z_{in} = \beta_1\beta_2 R_E \quad \text{... neglecting } r'_e$$

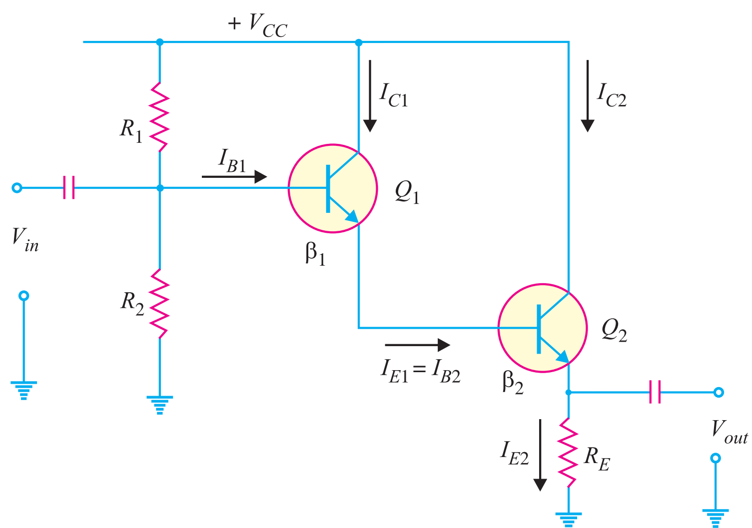


Fig. 13.26

In practice, the two transistors are put inside a single transistor housing and three terminals *E*, *B* and *C* are brought out as shown in Fig. 13.27. This three terminal device is known as a Darlington transistor. The Darlington transistor acts like a single transistor that has high current gain and high input impedance.

* $I_{E1} = \beta_1 I_{B1} \quad (\because I_{E1} \simeq I_{C1})$

Now I_{E1} is the base current of Q_2 *i.e.* $I_{E1} = I_{B2}$.

Now $I_{E2} = \beta_2 I_{B2} = \beta_2 I_{E1} = \beta_2 \beta_1 I_{B1}$

$$\therefore \text{Overall current gain, } \beta = \frac{I_{E2}}{I_{B1}} = \frac{\beta_1 \beta_2 I_{B1}}{I_{B1}} = \beta_1 \beta_2$$

Characteristics. The following are the important characteristics of Darlington amplifier :

(*i*) Extremely high input impedance (MΩ).

(*ii*) Extremely high current gain (several thousands).

(*iii*) Extremely low output impedance (a few Ω).

Since the characteristics of the Darlington amplifier are basically the same as those of the emitter follower, the two circuits are used for similar applications. When you need higher input impedance and current gain and/or lower output impedance than the standard emitter follower can provide, you use a Darlington amplifier. Darlington transistors are commonly available. Like standard transistors, they have only three terminals but they have much higher values of current gain and input impedance.

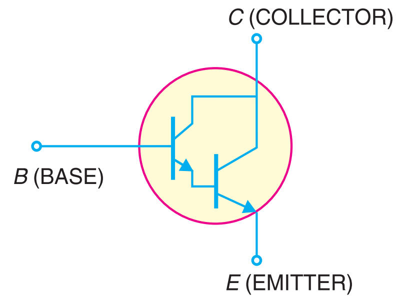


Fig. 13.27

Example 13.24. *Determine (i) d.c. value of current in R_E (ii) input impedance of the Darlington amplifier shown in Fig. 13.28.*

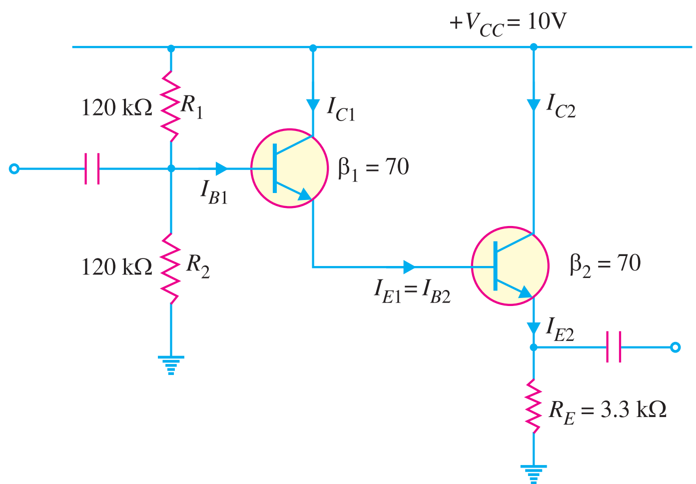


Fig. 13.28

Solution.

(*i*) Voltage across R_2, $V_2 = \dfrac{V_{CC}}{R_1 + R_2} \times R_2 = \dfrac{10\text{V}}{120\text{ k}\Omega + 120\text{ k}\Omega} \times 120\text{ k}\Omega = 5\text{V}$

D.C. current in R_E, $I_{E2} = \dfrac{V_2 - 2V_{BE}}{R_E} = \dfrac{5\text{V} - 2 \times 0.7\text{V}}{3.3\text{ k}\Omega} = \dfrac{3.6\text{V}}{3.3\text{ k}\Omega} = \mathbf{1.09\ mA}$

(*ii*) Input impedance, $Z_{in} = \beta_1 \beta_2 R_E$

$= (70)(70)(3.3\text{ k}\Omega) = \mathbf{16.17\ M\Omega}$

This example illustrates that the input impedance of Darlington amplifier is much higher than that of an ordinary transistor.

Example 13.25. *For the Darlington amplifier in Fig. 13.29, find (i) the d.c. levels of both the transistors and (ii) a.c. emitter resistances of both transistors.*

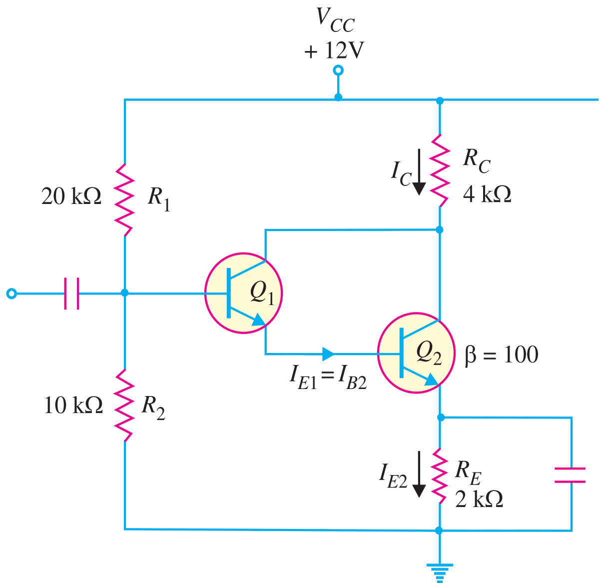


Fig. 13.29

Solution.

(*i*) D.C. Bias Levels

$$\text{Base voltage of } Q_1,\ V_{B1} = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{12\text{V}}{20\text{ k}\Omega + 10\text{ k}\Omega} \times 10\text{ k}\Omega = \mathbf{4V}$$

$$\text{Emitter voltage of } Q_1,\ V_{E1} = V_{B1} - V_{BE} = 4\text{V} - 0.7\text{V} = \mathbf{3.3V}$$

$$\text{Base voltage of } Q_2,\ V_{B2} = V_{E1} = \mathbf{3.3V}$$

$$\text{Emitter voltage of } Q_2,\ V_{E2} = V_{B2} - V_{BE} = 3.3\text{V} - 0.7\text{V} = \mathbf{2.6V}$$

$$\text{Emitter current of } Q_2,\ I_{E2} = \frac{V_{E2}}{R_E} = \frac{2.6\text{V}}{2\text{ k}\Omega} = \mathbf{1.3\ mA}$$

$$\text{Emitter current of } Q_1,\ I_{E1} = \frac{I_{E2}}{\beta} = \frac{1.3\text{ mA}}{100} = \mathbf{0.013\ mA}$$

(*ii*) A.C. Analysis

$$\text{A.C. emitter resistance of } Q_1,\ r'_{e1} = \frac{25\text{ mV}}{I_{E1}} = \frac{25\text{ mV}}{0.013\text{ mA}} = \mathbf{1923\Omega}$$

$$\text{A.C. emitter resistance of } Q_2,\ r'_{e2} = \frac{25\text{ mV}}{I_{E2}} = \frac{25\text{ mV}}{1.3\text{ mA}} = \mathbf{19.23\Omega}$$

MULTIPLE-CHOICE QUESTIONS

1. When negative voltage feedback is applied to an amplifier, its voltage gain ....
(*i*) is increased (*ii*) is reduced
(*iii*) remains the same
(*iv*) none of the above

2. The value of negative feedback fraction is always ....
(*i*) less than 1 (*ii*) more than 1
(*iii*) equal to 1 (*iv*) none of the above

3. If the output of an amplifier is 10 V and

100 mV from the output is fed back to the input, then feedback fraction is ....
(*i*) 10 (*ii*) 0.1
(*iii*) 0.01 (*iv*) 0.15

4. The gain of an amplifier without feedback is 100 *db*. If a negative feedback of 3 *db* is applied, the gain of the amplifier will become ....
(*i*) 101.5 *db* (*ii*) 300 *db*
(*iii*) 103 *db* (*iv*) 97 *db*

5. If the feedback fraction of an amplifier is 0.01, then voltage gain with negative voltage feedback is approximately ....
(*i*) 500 (*ii*) 100
(*iii*) 1000 (*iv*) 5000

6. A feedback circuit usually employs .... network.
(*i*) resistive (*ii*) capacitive
(*iii*) inductive (*iv*) none of the above

7. The gain of an amplifier with feedback is known as .... gain.
(*i*) resonant (*ii*) open loop
(*iii*) closed loop (*iv*) none of the above

8. When voltage feedback (negative) is applied to an amplifier, its input impedance ....
(*i*) is decreased (*ii*) is increased
(*iii*) remains the same
(*iv*) none of the above

9. When current feedback (negative) is applied to an amplifier, its input impedance ....
(*i*) is decreased (*ii*) is increased
(*iii*) remains the same
(*iv*) none of the above

10. Negative feedback is employed in ....
(*i*) oscillators (*ii*) rectifiers
(*iii*) amplifiers (*iv*) none of the above

11. Emitter follower is used for ....
(*i*) current gain
(*ii*) impedance matching
(*iii*) voltage gain (*iv*) none of the above

12. The voltage gain of an emitter follower is ...
(*i*) much less than 1
(*ii*) approximately equal to 1
(*iii*) greater than 1 (*iv*) none of the above

13. When current feedback (negative) is applied to an amplifier, its output impedance ......
(*i*) is increased
(*ii*) is decreased
(*iii*) remains the same
(*iv*) none of the above

14. Emitter follower is a .... circuit.
(*i*) voltage feedback
(*ii*) current feedback
(*iii*) both voltage and current feedback
(*iv*) none of the above

15. If voltage feedback (negative) is applied to an amplifier, its output impedance ....
(*i*) remains the same
(*ii*) is increased (*iii*) is decreased
(*iv*) none of the above

16. When negative voltage feedback is applied to an amplifier, its bandwidth ....
(*i*) is increased (*ii*) is decreased
(*iii*) remains the same
(*iv*) insufficient data

17. An emitter follower has ..... input impedance.
(*i*) zero (*ii*) low
(*iii*) high (*iv*) none of the above

18. If voltage gain without feedback and feedback fraction are A_v and m_v respectively, then gain with negative voltage feedback is ....
(*i*) $\dfrac{A_v}{1 - A_v m_v}$ (*ii*) $\dfrac{A_v}{1 + A_v m_v}$
(*iii*) $\dfrac{1 + A_v m_v}{A_v}$ (*iv*) $(1 + A_v m_v) A_v$

19. The output impedance of an emitter follower is ....
(*i*) high (*ii*) very high
(*iii*) almost zero (*iv*) low

20. The approximate voltage gain of an amplifier with negative voltage feedback (feedback fraction being m_v) is ....
(*i*) $1/m_v$ (*ii*) m_v
(*iii*) $\dfrac{1}{1 + m_v}$ (*iv*) $1 - m_v$

21. If A_v and A_{fb} are the voltage gains of an amplifier without feedback and with negative feedback respectively, then feedback fraction is ....

(i) $\frac{1}{A_v} - \frac{1}{A_{fb}}$ (ii) $\frac{1}{A_v} + \frac{1}{A_{fb}}$

(iii) $\frac{A_v}{A_{fb}} + \frac{1}{A_v}$ (iv) $\frac{1}{A_{fb}} - \frac{1}{A_v}$

22. In the expression for voltage gain with negative voltage feedback, the term $1 + A_m m_v$ is known as ....

(i) gain factor (ii) feedback factor
(iii) sacrifice factor (iv) none of the above

23. If the output impedance of an amplifier is Z_{out} without feedback, then with negative voltage feedback, its value will be ....

(i) $\frac{Z_{out}}{1 + A_v m_v}$ (ii) $Z_{out}(1 + A_v m_v)$

(iii) $\frac{1 + A_v m_v}{Z_{out}}$ (iv) $Z_{out}(1 - A_v m_v)$

24. If the input impedance of an amplifier is Z_{in} without feedback, then with negative voltage feedback, its value will be ....

(i) $\frac{Z_{in}}{1 + A_v m_v}$ (ii) $Z_{in}(1 + A_v m_v)$

(iii) $\frac{1 + A_v m_v}{Z_{in}}$ (iv) $Z_{in}(1 - A_v m_v)$

25. Feedback circuit .... frequency.

(i) is independent of
(ii) is strongly dependent on
(iii) is moderately dependent on
(iv) none of the above

26. The basic purpose of applying negative voltage feedback is to ....

(i) increase voltage gain
(ii) reduce distortion
(iii) keep the temperature within limits
(iv) none of the above

27. If the voltage gain of an amplifier without feedback is 20 and with negative voltage feedback it is 12, then feedback fraction is ....

(i) 5/3 (ii) 3/5
(iii) 1/5 (iv) 0.033

28. In an emitter follower, we employ ...... negative current feedback.

(i) 50% (ii) 25%
(iii) 100% (iv) 75%

29. An amplifier has an open loop voltage gain of 1,00,000. With negative voltage feedback, the voltage gain is reduced to 100. What is the sacrifice factor ?

(i) 1000 (ii) 100
(iii) 5000 (iv) none of the above

30. In the above question, what will happen to circuit performance ?

(i) distortion is increased 1000 times
(ii) input impedance is increased 1000 times
(iii) output impedance is increased 1000 times
(iv) none of the above

31. The non-linear distortion of an amplifier is D without feedback. The amplifier has an open-loop voltage gain of A_v and feedback fraction is m_v. With negative voltage feedback, the non-linear distortion will be ....

(i) $D(1 + A_v m_v)$ (ii) $D(1 - A_v m_v)$

(iii) $\frac{1 + A_v m_v}{D}$ (iv) $\frac{D}{1 + A_v m_v}$

32. The output and input voltages of an emitter follower have a phase difference of ....

(i) 180º (ii) 90º
(iii) 0º (iv) 270º

33. It is most necessary to control signal-to-noise ratio at ....

(i) initial stage (ii) driver stage
(iii) output stage (iv) detector stage

34. In order to obtain good gain stability in a negative voltage feedback amplifier (A_v = voltage gain without feedback ; m_v = feedback fraction), ...

(i) $A_v m_v = 1$ (ii) $A_v m_v >> 1$
(iii) $A_v m_v < 1$ (iv) none of the above

35. Emitter follower is also known as ....

(i) grounded emitter circuit
(ii) grounded base circuit
(iii) grounded collector circuit
(iv) none of the above

Answers to Multiple-Choice Questions

1. (*ii*)	**2.** (*i*)	**3.** (*iii*)	**4.** (*iv*)	**5.** (*ii*)
6. (*i*)	**7.** (*iii*)	**8.** (*ii*)	**9.** (*i*)	**10.** (*iii*)
11. (*ii*)	**12.** (*ii*)	**13.** (*i*)	**14.** (*ii*)	**15.** (*iii*)
16. (*i*)	**17.** (*iii*)	**18.** (*ii*)	**19.** (*iv*)	**20.** (*i*)
21. (*iv*)	**22.** (*iii*)	**23.** (*i*)	**24.** (*ii*)	**25.** (*i*)
26. (*ii*)	**27.** (*iv*)	**28.** (*iii*)	**29.** (*i*)	**30.** (*ii*)
31. (*iv*)	**32.** (*iii*)	**33.** (*i*)	**34.** (*ii*)	**35.** (*iii*)

Chapter Review Topics

1. What do you understand by feedback ? Why is negative feedback applied in high gain amplifiers ?
2. Discuss the principles of negative voltage feedback in amplifiers with a neat diagram.
3. Derive an expression for the gain of negative voltage feedback amplifier.
4. What is a feedback circuit ? Explain how it provides feedback in amplifiers.
5. Describe the action of emitter follower with a neat diagram.
6. Derive the expressions for (*i*) voltage gain (*ii*) input impedance and (*iii*) output impedance of an emitter follower.

Problems

1. An amplifier has a gain of 2×10^5 without feedback. Determine the gain if negative voltage feedback is applied. Take feedback fraction $m_v = 0.02$. **[50]**
2. An amplifier has a gain of 10,000 without feedback. With negative voltage feedback, the gain is reduced to 50. Find the feedback fraction. **[$m_v = 0.02$]**
3. A feedback amplifier has an internal gain $A_v = 40db$ and feedback fraction $m_v = 0.05$. If the input impedance of this circuit is 12 kΩ, what would have been the input impedance if feedback were not present ? **[2kΩ]**
4. Calculate the gain of a negative voltage feedback amplifier with an internal gain $A_v = 75$ and feedback fraction $m_v = 1/15$. What will be the gain if A_v doubles ? **[12.5 ; 13.64]**
5. An amplifier with negative feedback has a voltage gain of 100. It is found that without feedback, an input signal of 50 mV is required to produce a given output, whereas with feedback, the input signal must be 0.6 V for the same output. Calculate (*i*) gain without feedback (*ii*) feedback fraction. **[(i) 1200 (ii) 0.009]**

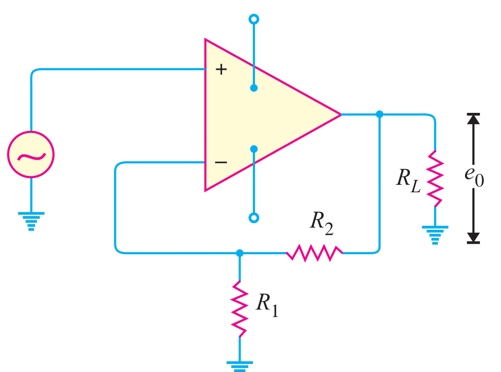


Fig. 13.30

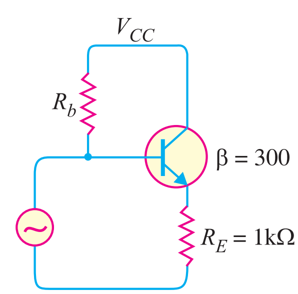


Fig. 13.31

6. Fig. 13.30 shows the negative feedback amplifier. If the gain of the amplifier without feedback is 10^5 and $R_1 = 100\ \Omega$, $R_2 = 100\ k\Omega$, find (*i*) feedback fraction (*ii*) gain with feedback. **[(i) 0.001(ii) 1000]**

7. In Fig. 13.31, if input and output impedances without feedback are 2 MΩ and 500 Ω respectively, find their values after negative voltage feedback. **[302MΩ; 1.6Ω]**
8. An amplifier has a current gain of 240 without feedback. When negative current feedback is applied, determine the effective current gain of the amplifier. Given that current attenuation m_i = 0.015. **[52.7]**
9. An amplifier has an open-loop gain and input impedance of 200 and 15 kΩ respectively. If negative current feedback is applied, what is the effective input impedance of the amplifier? Given that current attenuation m_i = 0.012. **[4.41 kΩ]**
10. An amplifier has A_i = 200 and m_i = 0.012. The open-loop output impedance of the amplifier is 2kΩ. If negative current feedback is applied, what is the effective output impedance of the amplifier ? **[6.8 kΩ]**

Discussion Questions

1. Why is negative voltage feedback employed in high gain amplifiers ?
2. How does negative voltage feedback increase bandwidth of an amplifier ?
3. Feedback for more than three stages is seldom employed. Explain why ?
4. Why is emitter follower preferred to transformer for impedance matching ?
5. Where is emitter follower employed practically and why ?
6. What are the practical applications of emitter follower ?

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