6. A transistor has thermal resistance $\theta = 80°C/W$. If the maximum junction temperature is 90°C and the ambient temperature is 30°C, find the maximum permissible power dissipation.
[750 mW]

7. A power transistor dissipates 4 W. If $T_{J\,max} = 90°C$, find the maximum ambient temperature at which it can be operated. Given thermal resistance $\theta = 8°C/W$. **[58 °C]**

8. A class A transformer-coupled amplifier uses a 25 : 1 transformer to drive a 4Ω load. Calculate the effective a.c. load (seen by the transistor connected to the larger turns side of the transformer).
[2.5 kΩ]

9. Calculate the transformer turns ratio required to connect 4 parallel 16Ω speakers so that they appear as an 8 kΩ effective load. **[44.7]**

10. For a class B amplifier with $V_{CC} = 25V$ driving an 8Ω load, determine :
(*i*) maximum input power
(*ii*) maximum output power
(*iii*) maximum circuit efficiency
[(*i*) 49.7W (*ii*) 39.06W (*iii*) 78.5 %]

Discussion Questions

1. Why does collector efficiency play important part in power amplifiers ?
2. Why does the problem of distortion arise in power amplifiers ?
3. Why are power amplifiers classified on the basis of mode of operation ?
4. Why does the output stage employ push-pull arrangement ?
5. Why is driver stage necessary for push-pull circuit ?
6. Why do we use transformer in the output stage ?

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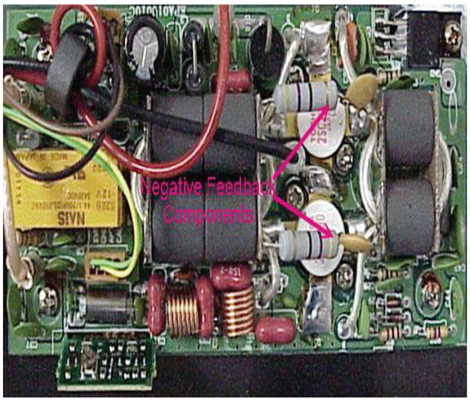
Amplifiers with Negative Feedback



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}.

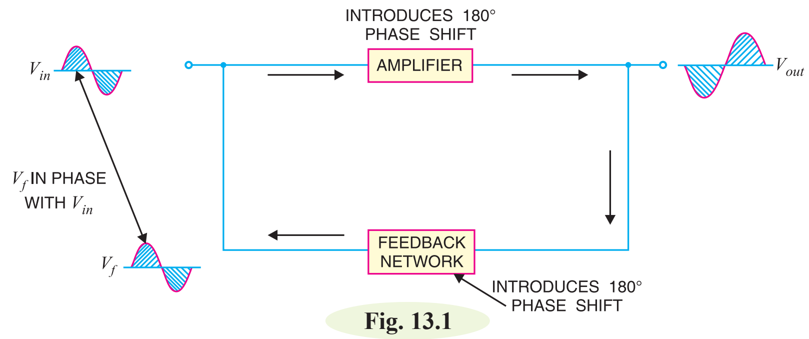


Fig. 13.1

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}.

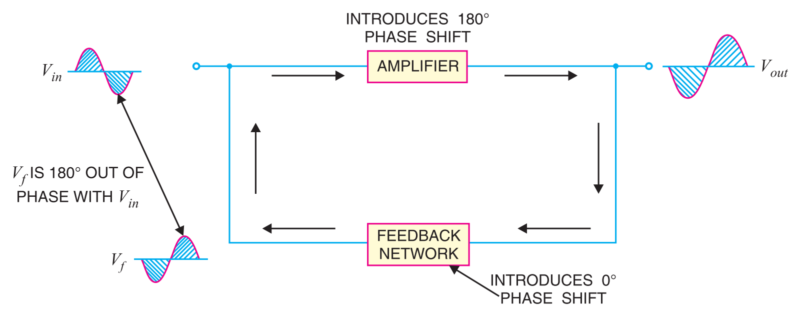


Fig. 13.2

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,

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

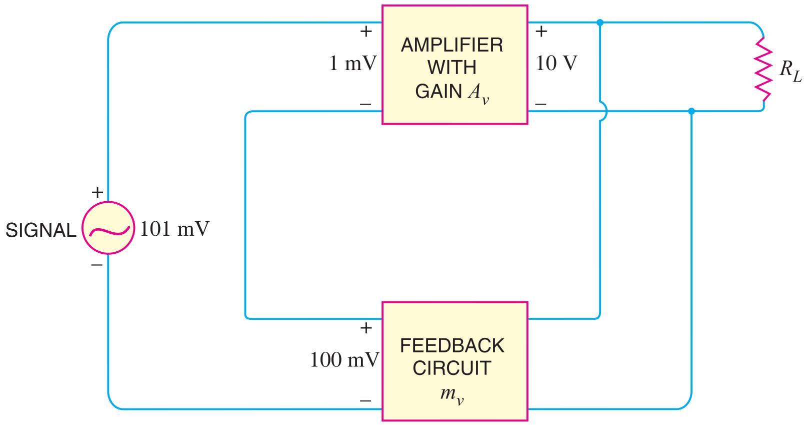


Fig. 13.3

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

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

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

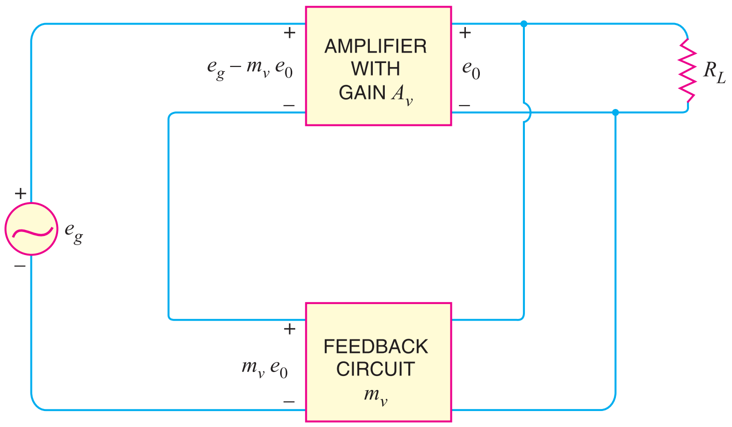


Fig. 13.4

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.

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

(*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.

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

$\therefore$ %age reduction in stage gain $= \dfrac{25 - 22.2}{25} \times 100 = \mathbf{11.2\%}$

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

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

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

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

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