Semiconductor Devices and Circuits

Chapter-III : Feedback Amplifiers

III B.Sc Physics
V Semester

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Chapter 3

Feedback Amplifiers

3.1 Introduction

An ideal amplifier in the mid-frequency range provides an output which is an exact replica of the input signal. However this is not possible practically because of the non-linearity of transistor characteristics, variations of the parameter values, effect of temperature etc., Hence to overcome these defects the principle of feedback is used in amplifiers.

Feedback: Generally feedback refers to a process wherein a portion of the output of a device is taken and injected back to the input. This feedback process helps in controlling the device output to a desired level.

Feedback Amplifiers: The amplifiers in which a portion of the output is taken and injected back to the input are called as *feedback amplifiers*. A feedback amplifier consists of two parts, namely (i) an amplifier circuit and (ii) a feedback network.

Types of Feedback: Depending on the changes in the output signal when a feedback is applied, we have two different types of feedback, namely (i) positive or regenerative feedback and (ii) negative or degenerative feedback.

3.1.1 Positive Feedback

Here the fraction of the voltage or current is fed back in such a way that the output increases tremendously. To achieve this the current or voltage fed back should have the same phase as that of the amplifier AC input signal.

Note 1: As positive feedback increases the output it may produce excessive distortion. Hence this type of feedback is never employed in amplifier circuits.

Note 2: A positive feedback is however used to produce oscillations. Hence they are employed in oscillator circuits.

3.1.2 Negative Feedback

Here the fraction of the voltage or current is fed back in such a way that the output decreases very much. To achieve this the current or voltage fed back should differ in phase with that of the amplifier AC input signal by π radians or 180^o.

Note: As negative feedback reduces the output it causes the amplifier to have a stable output over a large range of input AC signal frequencies.

3.2 Principle of Feedback

Let us consider a block diagram of an amplifier as shown in Fig. 3.1. Let the input voltage be v_i and the output voltage be v_o.

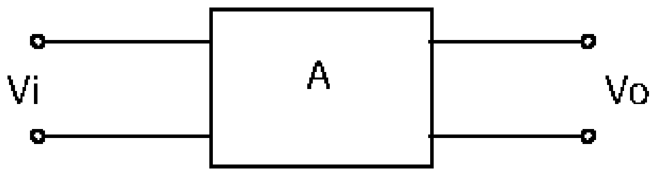

FIGURE 3.1: Block diagram of an amplifier without feedback.

Let the voltage gain of the amplifier be given by

$$A = \frac{v_o}{v_i}. \tag{3.1}$$

This gain is called as the *open loop gain.*

Let us consider a portion, say β, of the output voltage v_o is taken by a feedback network and applied to the input as shown in Fig. 3.2.

Due to the feedback, the input voltage gets changed from v_i to v_i', such that

$$v_i' = v_i \pm \beta v_o. \tag{3.2}$$

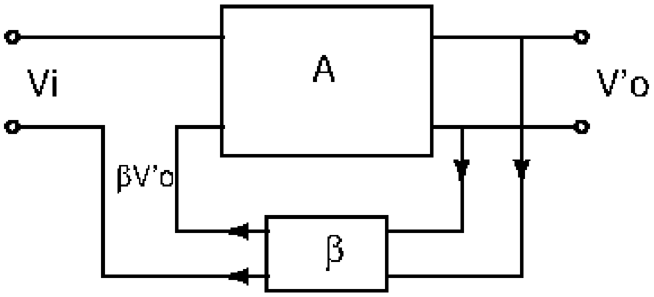

FIGURE 3.2: Block diagram of an amplifier with feedback. Here $\beta v_o'$ is the fraction of the output voltage that is fed back.

Here β is called as the *feedback ratio* or *feedback fraction*.

In this Eqn. (3.2) the $+ve$ sign denotes *positive feedback*. This is because the voltage fed back is in phase with the AC input signal. On the other hand, the $-ve$ sign denotes *negative feedback*. This is because the feedback voltage is out of phase with the AC input signal by π radians or 180^o.

The gain of the amplifier after the feedback is applied becomes

$$A = \frac{v_o'}{v_i'}$$

Substituting Eqn. (3.2) in the above equation, we have

$$A = \frac{v_o'}{v_i \pm \beta v_o'}$$

Rearranging this gives

$$A\left[v_i \pm \beta v_o'\right] = v_o'$$

or

$$v_o'\left[1 \mp \beta A\right] = Av_i$$

or

$$\boxed{v_o' = \frac{Av_i}{[1 \mp \beta A]}} \tag{3.3}$$

Though the input voltage as seen by the amplifier is v_i', the original AC input signal is v_i only. Hence the gain after feedback is applied is given by

$$A' = \frac{v_o'}{v_i}$$

Substituting Eqn. (3.3) in the above equation gives

$$A' = \frac{Av_i}{[1 \mp \beta A]} \left(\frac{1}{v_i}\right)$$

or

$$A' = \frac{A}{[1 \mp \beta A]} \tag{3.4}$$

The above equation, Eqn. (3.4) gives the expression for the *closed loop gain*, that is the gain of the amplifier when a feedback is applied.

Note: Due to the rearrangement and algebraic manipulation, the $-ve$ sign in the above equation now denotes the closed loop gain for positive feedback while the $+ve$ sign denotes that for a negative feedback.

3.2.1 Positive Feedback Gain

The gain for a positive feedback amplifier is given by

$$A' = \frac{A}{[1 - \beta A]} \tag{3.5}$$

Example Problem: If the open loop gain and the feedback fraction of a positive feedback amplifier are given as $A = 90$ and $\beta = 0.01$, find the closed loop gain due to positive feedback.

Solution:
We know that the closed loop gain of a positive feedback amplifier is given by

$$A' = \frac{A}{[1 - \beta A]}$$

Substituting $A = 90$ and $\beta = 0.01$ in this equation gives

$$\begin{aligned} A' &= \frac{90}{[1 - 0.01 \times 90]} \quad \text{or} \\ A' &= \frac{90}{[1 - 0.9]} \quad \text{or} \\ A' &= \frac{90}{0.1} \quad \text{or} \\ A' &\simeq 900 \end{aligned}$$

Note 1: In general as $|1 - \beta A| \ll 1$, $A' \gg A$ for positive feedback. As positive feedback increases the gain of the amplifier it is called as *regenerative feedback*.

Note 2: If $|\beta A| = 1$, then $A' \longrightarrow \infty$. Mathematically this means that there is an output voltage even in the absence of an input signal. However according to the law of conservation of energy, this is not possible. What happens in this case is that the amplifier starts to behave as an oscillator circuit, producing self-oscillations.

3.2.2 Negative Feedback Gain

The gain for a negative feedback amplifier is given by

$$A' = \frac{A}{[1 + \beta A]} \tag{3.6}$$

Example Problem: If the open loop gain and the feedback fraction of a negative feedback amplifier are given as $A = 90$ and $\beta = 0.01$, find the closed loop gain due to negative feedback.

Solution:
We know that the closed loop gain of a negative feedback amplifier is given by

$$A' = \frac{A}{[1 + \beta A]}$$

Substituting $A = 90$ and $\beta = 0.01$ in this equation gives

$$\begin{aligned} A' &= \frac{90}{[1 + 0.01 \times 90]} \quad \text{or} \\ A' &= \frac{90}{[1 + 0.9]} \quad \text{or} \\ A' &\simeq \frac{90}{2.0} \quad \text{or} \\ A' &\simeq 45 \end{aligned}$$

Note 1: In general for a negative feedback amplifier, $A' < A$. This means that the gain of the amplifier gets reduced as a result of the negative feedback. Hence this feedback is called as *degenerative feedback*.

Note 2: When $|\beta A| \gg 1$, then $|1 + \beta A| \simeq \beta A$. Hence Eqn. (3.6) tells that the closed loop gain does not depend on the variations in temperature or the parameter values of the components but depends purely on the AC input signal applied. Hence a negative feedback increases the stability in gain of an amplifier.

3.2.3 Advantages of Negative Feedback

The advantages of negative feedback in amplifiers are

1. higher fidelity of operation, that is, the input is faithfully obtained at the output after the desired amplification
2. highly stabilized gain
3. increased bandwidth, that is, the gain of an amplifier is constant over a very large range of frequencies
4. less distortion at the output (these include distortion in amplitude, harmonicity, phase and frequency)
5. reduced noise (unwanted signals)
6. modification of the input and output impedances as desired.

3.3 Gain in Stability of a Negative Feedback Amplifier

For a negative feedback amplifier, the closed loop gain is given as

$$A' = \frac{A}{1 + \beta A} \tag{3.7}$$

Taking logarithms on both the sides of the above equation, gives

$$log_e A' = log_e A - log_e (1 + \beta A) \tag{3.8}$$

Differentiating the above equation, gives

$$\begin{aligned}
\frac{dA'}{A'} &= \frac{dA}{A} - \frac{\beta dA}{(1+\beta A)} \\
&= \left[\frac{1}{A} - \frac{\beta}{1+\beta A}\right] dA \\
&= \left[\frac{1+\beta A - \beta A}{A\,(1+\beta A)}\right] dA \qquad \text{or} \\
\frac{dA'}{A'} &= \frac{1}{(1+\beta A)} \left(\frac{dA}{A}\right). \qquad (3.9)
\end{aligned}$$

The above Eqn. (3.9), relates the fractional change in the closed-loop gain of the negative feedback amplifier namely $\left(\dfrac{dA'}{A'}\right)$ with the fractional change in its open-loop gain, namely $\left(\dfrac{dA}{A}\right)$.

3.3.1 Sensitivity of the Negative Feedback Amplifier (S)

The *sensitivity* of the negative feedback amplifier is defined as the ratio of the percentage change in the voltage gain with feedback to the percentage change in the voltage gain without feedback, that is the sensitivity is given as

$$S = \frac{dA'/A'}{dA/A} \qquad (3.10)$$

But Inverting the above Eqn. (3.9), we have

$$\frac{dA'/A'}{dA/A} = \left(\frac{1}{1+\beta A}\right). \qquad (3.11)$$

Substituting Eqn. (3.11) in Eqn. (3.10) gives the expression for the sensitivity as

$$S = \left(\frac{1}{1+\beta A}\right). \qquad (3.12)$$

> *Note:* When the sensitivity of a negative amplifier is small, its stability of gain will be large and vice-versa.

Example Problem: An amplifier has an open loop gain of 800 and a feedback ratio of 0.05. If the closed loop gain changes by 20% due to temperature, find the percentage change in the closed loop gain.

Solution: We know that the percentage change in the closed loop gain is given by

$$\frac{dA'}{A'} = \frac{1}{(1+\beta A)}\left(\frac{dA}{A}\right).$$

From the problem given, $A = 800$, $\beta = 0.05$ and $dA/A = 20\%$ or $dA/A = 20/100$. Substituting these in the above equation gives

$$\begin{aligned} \frac{dA'}{A'} &= \frac{1}{(1+0.05\times 800)}\left(\frac{20}{100}\right), \\ &\simeq \frac{1}{200}, \qquad \text{or} \\ \frac{dA'}{A'} &\simeq 0.5\% \end{aligned}$$

Thus the percentage change in the closed loop gain of the negative feedback amplifier is 0.5%.

Note: The fact that the percentage change in the closed loop gain of a negative feedback amplifier is small when compared to its percentage change in the open loop gain, (as seen in this numerical example problem) tells us that the gain stability of the amplifier is increased because of negative feedback.