5.1 FUNDAMENTAL CONCEPT OF FEEDBACK

The term feedback means transfer of energy from the output of a system to its input. If a portion (or the whole) of the output signal of an amplifier is feedback and superimposed on the input signal, the performance of the amplifier changes significantly. The amplifier is then said to be a feedback amplifier.

The feedback concept can be explained with basic feedback configuration shown in Fig. 5.1.1,

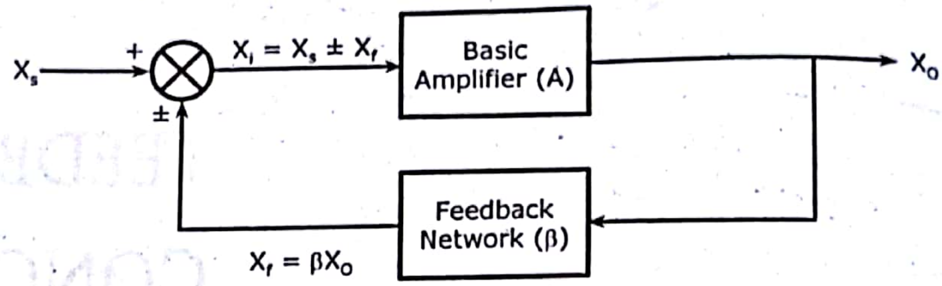


Fig. 5.1.1 Basic Feedback Configuration

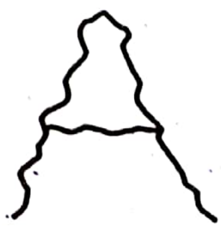
There are two types of feedback used in electronic circuits,

(1) If the feedback signal (X_f) is in phase with input signal (X_s) and adds to its magnitude, then the feedback is called "Positive or Regenerative" feedback, i.e., $X_i = X_s + X_f$

(2) If the feedback signal (X_f) is opposite in phase to the input signal (X_s) and opposes it, then the feedback is called "negative or degenerative" feedback, i.e., $X_i = X_s - X_f$

The feedback signal can be either a voltage or a current, being applied in series or shunt respectively. Feedback is the concept used not only in amplifiers, but is also inherently applicable in our daily life also.

You may not have realized it, but even we use feedback in the process of learning. When a child is asked to write a letter A, he will probably write it as shown in Fig. 5.1.2(a),



(a)

When he finds that the stroke is not going in the correct direction, the information goes to his brain through the eyes. The brain immediately orders the hand to correct the direction of the stroke. With much effort and with constant feedback, the child writes the letter 'A' as shown in Fig. 5.1.2(b),

(b)

Fig. 5.1.2 Concept of Feedback in Process of Learning

5.1.1 Block Diagram of Feedback Amplifier

Several characteristics of the amplifier such as input resistance, output resistance, linearity and bandwidth can be improved by incorporating negative feedback. This can be achieved by feeding back a part of the output into the input. Such amplifiers are called *feedback amplifiers*. The block diagram of a typical feedback amplifier is shown in Fig. 5.1.3,

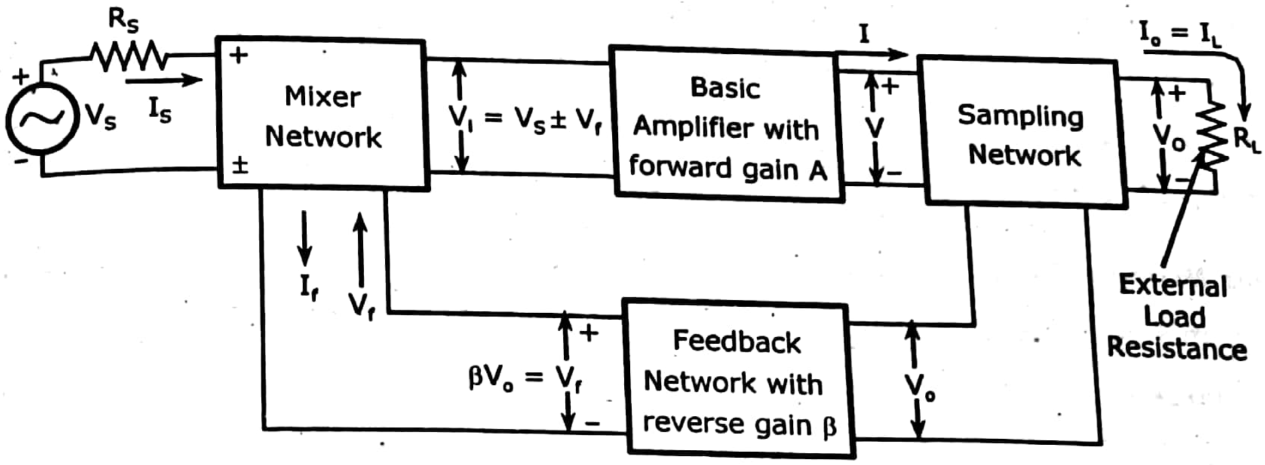


Fig. 5.1.3 Block Diagram of Feedback Amplifier

The basic configuration of feedback amplifier is shown in Fig. 5.1.3 has following building blocks,

(1) Signal source.

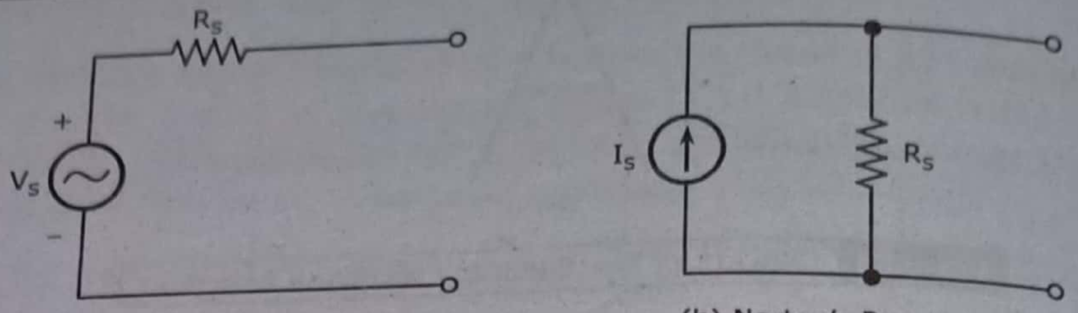
(2) Mixer network.

(3) Basic amplifier block.

(4) Sampling block.

5.1.1.1 Signal Source

The signal source is either a voltage source or a current source depending on the type of amplifier. A voltage source is represented by a signal source V_s in series with a source resistance R_s, commonly known as Thevenin's representation. A current source is represented by a signal source I_s in parallel with a source resistance R_s, commonly known as Norton's representation. These representations are shown in Fig. 5.1.4,



(a) Thevenin's Representation of Voltage Source

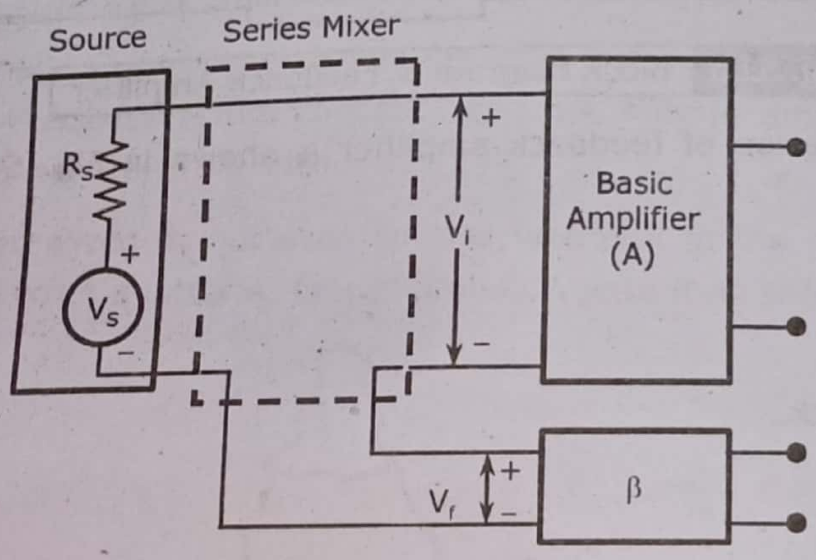
(b) Norton's Representation of Current Source

Fig. 5.1.4 Signal Source Representation

5.1.1.2 Mixer or Comparator Block

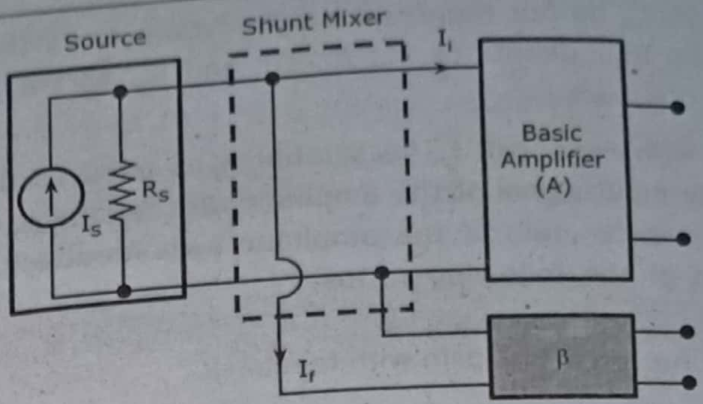
Mixer or comparator block is used to combine the source signal with the signal from the feedback network. There are two types of combining the source signal with the feedback signal depending upon the type of source and feedback signal namely, Shunt mixing and Series mixing.

(1) **Series Mixing :** When the source signal and feedback signals are both voltages, then series mixing is used. In this method, the feedback signal from feedback network is mixed with input signal in series i.e., loop formation as shown in Fig. 5.1.5(a),



(a) Series Mixing

(2) **Shunt Mixing :** When the source signal and the feedback signals are both currents, then shunt mixing is used. It is also called as parallel mixing or nodal mixing. Here, the sampled signal from the feedback amplifier is mixed in nodal form or shunted with input signal I_S, as shown in Fig. 5.1.5(b),



(b) Shunt Mixing

Fig. 5.1.5 Feedback Connection of the Input of a Basic Amplifier

5.1.1.3 Basic Amplifier Block

The basic amplifier block with forward gain A is shown in Fig. 5.1.6,

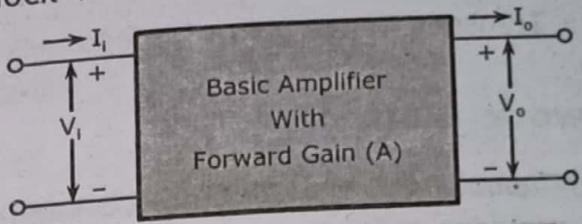


Fig. 5.1.6 Basic Amplifier Block

The forward gain or transfer ratio of amplifier block is defined as the ratio of output signal to the input signal and the amplifier gain depends on the type of amplifier the block represents.

(1) **Gain of Amplifier without Feedback :** If the block represents a voltage amplifier, then A is the voltage gain, given by,

$$A_V = \frac{V_o}{V_i} \quad \text{... (5.1.1)}$$

If the block represents a current amplifier, A is the current gain, given by,

$$A_I = \frac{I_o}{I_i} \quad \text{... (5.1.2)}$$

If the block represents a transconductance amplifier, A is the transconductance, given by,

$$G_M = \frac{I_o}{V_i} \quad \text{... (5.1.3)}$$

If the block represents a transresistance amplifier, A is the transresistance, given by,

$$R_M = \frac{V_o}{I_i} \quad \text{... (5.1.4)}$$

Actually G_M and R_M do not represent amplification. Nevertheless, it is convenient to refer each of the four quantities A_V, A_I, G_M and R_M as transfer gain of the basic amplifier without feedback.

(2) Gain of Amplifier with Feedback : The symbol A_f is used to define the ratio of the output signal to the input signal of the amplifier with feedback as shown in Fig. 5.1.1 and is called the transfer gain of the amplifier with feedback. Hence A_f is used to represent any one of the following ratios,

$$\frac{V_o}{V_s} = A_{V_f} = \text{Voltage gain with feedback}$$

$$\frac{I_o}{I_s} = A_{I_f} = \text{Current gain with feedback}$$

$$\frac{I_o}{V_s} = G_{M_f} = \text{Transconductance gain with feedback}$$

$$\frac{V_o}{I_s} = R_{M_f} = \text{Transresistance gain with feedback}$$

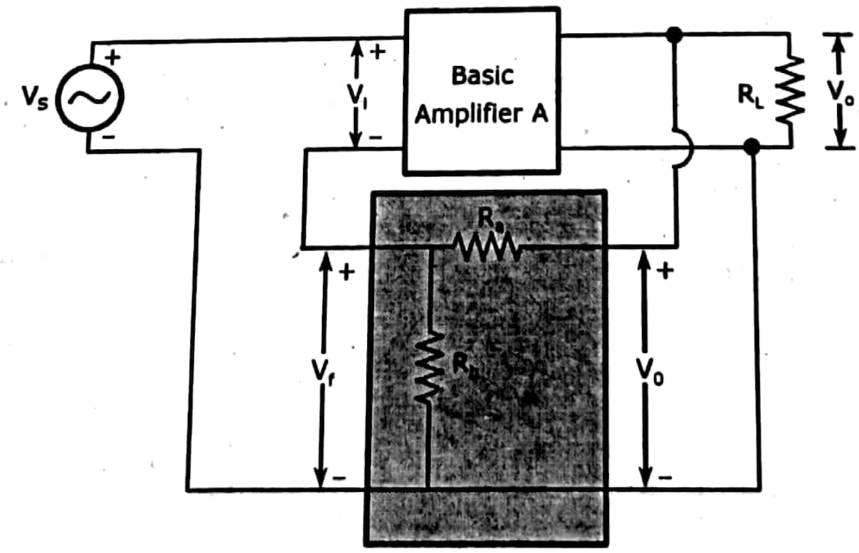
5.1.1.4 Feedback Network Block

The feedback network is usually a passive two-port network consisting of resistors, capacitors and inductors. It provides a fraction of the output voltage as feedback signal V_f to the input mixer network. The feedback voltage is given by,

$$V_f = \beta V_o$$

Where β is a feedback ratio or feedback factor or reverse transmission factor. It lies between 0 and 1.

The feedback signal can be derived from the output voltage by means of a simple voltage divider network as shown in Fig. 5.1.7,



Feedback Network

Fig. 5.1.7 Voltage-Sampling and Series Mixing Configuration

The feedback signal or output voltage of the feedback network in Fig. 5.1.7 is obtained as follows,

Applying voltage-division rule to feedback network, we get,

$$V_f = \left[\frac{R_b}{R_a + R_b}\right] V_o$$

$$\therefore \quad \frac{V_f}{V_o} = \frac{R_b}{R_a + R_b} \qquad \text{....(5.1.5)}$$

By definition,

....(5.1.6)

$$\beta = \frac{V_f}{V_o} = \frac{R_b}{R_a + R_b}$$

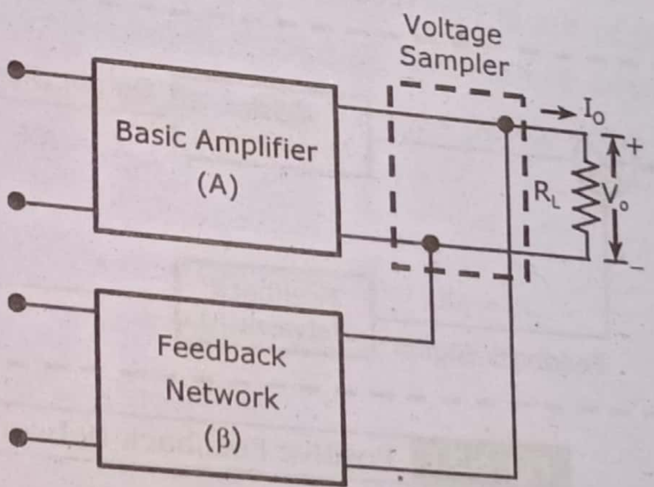
Observe that β does not have units in this case. This is not always true, for instance when current is sampled and voltage is derived from the feedback network, the feedback factor has the unit of ohms.

....(5.1.7)

5.1.1.5 Sampling Block

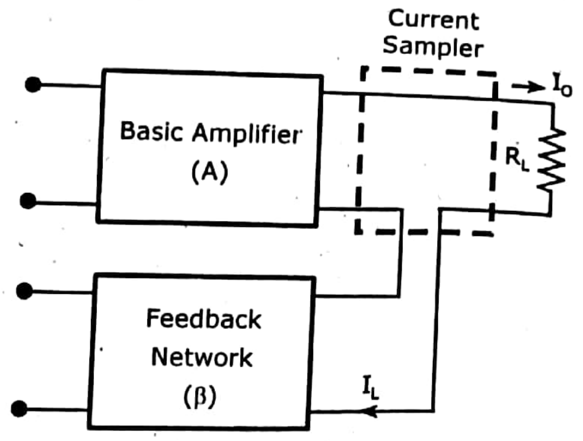
Sampling block is used to sample the output signal of the basic amplifier. There are two ways to sample the output, depending on the sampling parameters either voltage or current.

(1) Voltage Sampling : If the output voltage is sampled by connecting the feedback network in shunt across the output, the type of connection is called voltage or node sampling as shown in Fig. 5.1.8(a),



(a) Voltage or Node Sampling

(2) Current Sampling : If the output current is sampled by connecting the feedback network in series with the output, the type of connection is called current or loop sampling as shown in Fig. 5.1.8(b),



(b) Current or Loop Sampling

Fig. 5.1.8 Sampling Network

5.2 TYPES OF FEEDBACK

Depending upon whether the feedback signal aids (or) opposes the input signal, there are two types of feedbacks i.e.,

(1) Positive feedback.

(2) Negative feedback.

5.2.1 Positive Feedback

Fig. 5.2.1 shows the schematic representation of single loop positive feedback amplifier.

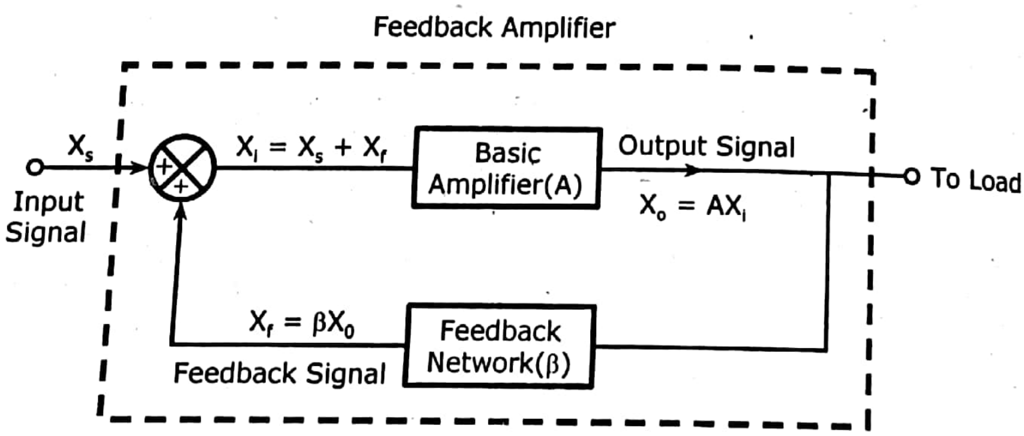


Fig. 5.2.1 Positive Feedback Network

If the feedback signal X_f (either voltage or current) is in phase with input signal X_s and adds to its magnitude, then the feedback is called positive feedback. Because of positive feedback, the resultant input to the amplifier becomes,

$$X_i = X_s + X_f$$

ADVANTAGES

Advantages of positive feedback network are as follows,

(1) It increases the gain of the amplifier.

(2) If positive feedback is sufficiently large, it leads to oscillations. So it used in oscillators.

DISADVANTAGE

Disadvantage of positive feedback network is, it increases the distortion and instability.

5.2.2 Negative Feedback

Fig. 5.2.2 shows the schematic representation of single loop negative feedback amplifier.

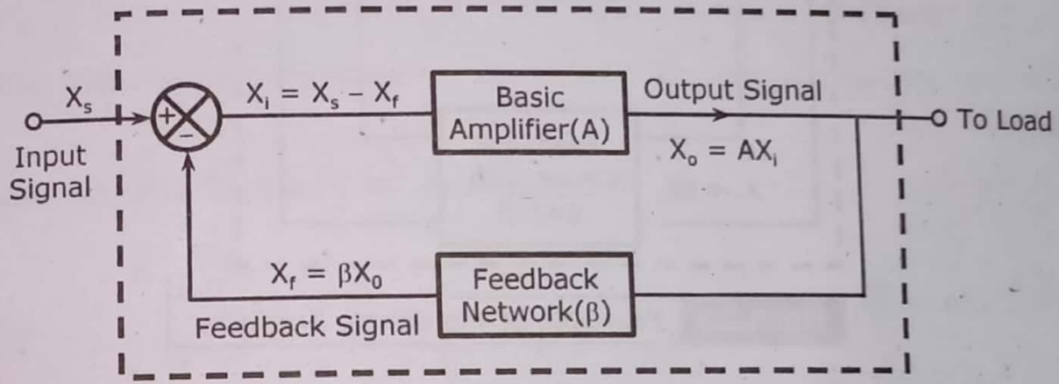


Fig. 5.2.2 Negative Feedback Network

If the feedback signal X_f (either voltage or current) is out of phase with input signal X_s and diminishes from its magnitude, then the feedback is called negative feedback.

Because of negative feedback, the resultant input, X_i to the basic amplifier block is,

$$X_i = X_s - X_f$$

ADVANTAGES

Advantage of negative feedback network are as follows,

(1) It stabilizes the gain of the amplifier.

(2) It reduces the distortion and noise.

(3) It reduces the output impedance.

(4) It increases the input impedance.

(5) It increases the range of uniform amplification or bandwidth.

DISADVANTAGES

Disadvantage of negative feedback network is, it reduces the gain of amplifier.

But due to the large number of advantages of negative feedback, it is usually employed in the amplifiers.

5.2.3 Transfer Gain with Feedback

The general theory of feedback can be understood with the help of block diagram shown in Fig. 5.2.3,

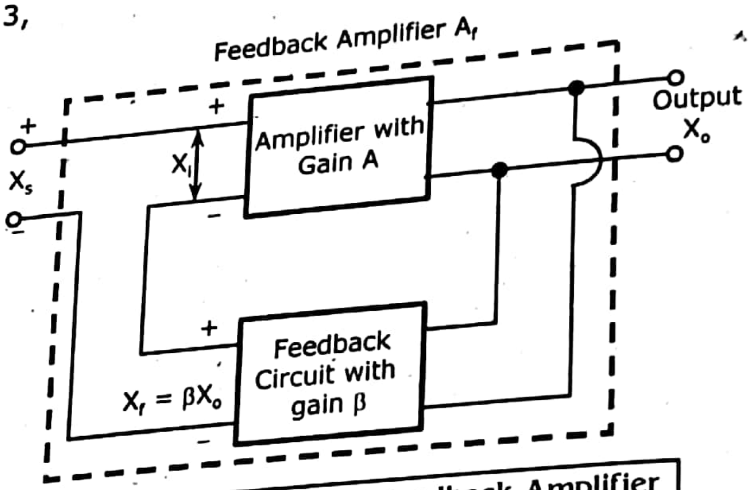


Fig. 5.2.3 Principle of Feedback Amplifier

The feedback amplifier has two parts i.e., amplifier and feedback circuit. The feedback circuit usually consists of resistors. This returns a fraction (say β) of the output back to the input. Let A be the gain of the amplifier i.e., the ratio of output X_o to the input X_i i.e., $A = X_o/X_i$. This is the gain of the amplifier without feedback. The feedback network extracts $X_f = \beta X_o$ from the output X_o of the amplifier. This is added (for positive feedback) or subtracted (for negative feedback) from the signal X_s. Now,

$$X_i = X_s + X_f = X_s + \beta X_o \text{ (Positive feedback)}$$

$$X_i = X_s - X_f = X_s - \beta X_o \text{ (Negative feedback)}$$

The quantity $\beta = X_f/X_o$ is called as feedback ratio or feedback fraction or reverse transfer ratio.

The whole system in the dashed box in Fig. 5.2.3 constitute the feedback amplifier. The overall gain, A_f (gain with feedback) is defined as the ratio of the output signal X_o to the applied signal X_s, that is,

$$A_f = \frac{\text{Output Signal}}{\text{Input signal}} = \frac{X_o}{X_s}$$

Transfer Gain with Negative Feedback : Consider the case of negative feedback, then $X_i = X_s - X_f$.

But, gain without feedback is given by,

$$A = \frac{X_o}{X_i}$$

$$X_o = AX_i$$

$$\Rightarrow \quad X_o = A(X_s - X_f)$$

$$\Rightarrow \quad X_o = AX_s - A\beta X_o \qquad (\because X_f = \beta X_o)$$

$$\Rightarrow \quad X_o(1 + A\beta) = AX_s$$

$$\Rightarrow \quad \boxed{A_f = \frac{X_o}{X_s} = \frac{A}{1 + A\beta}} \qquad \text{... (5.2.1)}$$

$\therefore$

Eq. (5.2.1) represents the transfer gain with negative feedback.

Transfer Gain with Positive Feedback : Consider the case of positive feedback, then $X_i = X_s + X_f$

But, gain without feedback is given by,

$$A = \frac{X_o}{X_i}$$

$$X_o = AX_i = A(X_s + X_f) = A(X_s + \beta X_o)$$

$$\Rightarrow \quad X_o - A\beta X_o = AX_s$$

$$\Rightarrow \quad X_o(1 - A\beta) = AX_s$$

$$\Rightarrow$$

$$\therefore \quad \boxed{A_f = \frac{X_o}{X_s} = \frac{A}{1 - A\beta}} \qquad \text{... (5.2.2)}$$

Eq. (5.2.2) represents the transfer gain with positive feedback.

From Eq. (5.2.1) and Eq. (5.2.2), it can be noticed that,

(1) For positive feedback, $|A_f| > |A|$.

(2) For negative feedback, $|A_f| < |A|$.

Considering the case of positive feedback, if $A\beta = 1$ then $A_f = \infty$. This is only possible when input is zero. Thus the amplifier is then capable of producing output even when input is zero. Under this situation, an amplifier works as an oscillator. In case of negative feedback, if $A\beta >> 1$, gain reduces with feedback, this is a major drawback of negative feedback.

(1) Loop Gain : Loop gain is defined as the path traced by input signal through the feedback loop.

Let us now trace the path of X_i through the feedback loop. The signal X_i gets,

(i) Multiplied by A in the basic amplifier.

(ii) Multiplied by β in the feedback network.

(iii) Multiplied by −1 in the mixer (for a negative feedback).

Hence, the loop gain or return ratio is $-A\beta$. Subtracting the loop gain from unity, we get the return difference defined by,

Return difference = 1 − (loop gain) ... (5.2.3)

$$\Rightarrow \quad D = 1 + A\beta$$

Thus from Eq. (4.1.8), we have gain with negative feedback as,

$$|A_f| = \frac{|A|}{|D|} \quad \text{... (5.2.4)}$$

Gain with feedback in decibels is,

$$20 \log_{10}|A_f| = 20 \log_{10}|A| - 20 \log_{10}|D| \quad \text{... (5.2.5)}$$

$$\Rightarrow \quad 20 \log_{10}|A| = 20 \log_{10}|A_f| + 20 \log_{10}|D| \quad \text{... (5.2.6)}$$

∴ Gain without feedback (dB) = Gain with feedback (dB) + Gain lost to negative feedback (dB)

(2) Amount of Feedback : The amount of feedback in dB = −Gain lost due to negative feedback.

Let N be the feedback in dB.

$$\therefore \quad N = -20 \log_{10}|D|$$

$$= 20 \log_{10}\frac{1}{|D|} \quad (\because \log a = \log(a^{-1}) = \log(1/a)) \quad \text{... (5.2.7)}$$

Substituting for D from Eq. (5.2.4), we have amount of feedback as,

$$\boxed{N = 20 \log_{10}\left|\frac{A_f}{A}\right|} \quad \text{... (5.2.8)}$$

(or) $$\boxed{N = 20 \log_{10}\frac{1}{|1 + A\beta|}} \quad \text{... (5.2.9)}$$

EXAMPLE PROBLEM 1

An amplifier has a voltage gain of 200. This gain is reduced to 50 when negative feedback is applied. Determine the reverse transmission factor and express the amount of feedback in dB.

SOLUTION

Given data : Gain without feedback (A) = 200

Gain with feedback (A_f) = 50

Gain with negative feedback is given by,

$$A_f = \frac{A}{1+\beta A}$$

$$50 = \frac{200}{1+\beta \cdot 200}$$

$$\Rightarrow \qquad \beta = 0.015$$

Amount of feedback in decibels is,

$$N = 20\log_{10}\left|\frac{A_f}{A}\right| = 20\log_{10}\left[\frac{1}{1+\beta A}\right]$$

$$= 20\log_{10}\left(\frac{1}{1+200\times 0.015}\right) = 20\log_{10}\left(\frac{1}{4}\right)$$

$$= 20\ \log_{10}\ (0.25) = 20 \times (-0.602)$$

$$= -\ 12.042\ \text{dB}$$

5.3 PROPERTIES OF NEGATIVE FEEDBACK AMPLIFIERS

Negative feedback introduces the following modifications of the amplifier characteristics,

(1) The gain is reduced and stabilized with respect to the variations in transistor parameters like h_{fe}.

(2) The nonlinear distortion is less so that the signal handling capacity of the amplifier increases.

(3) The input impedance can be changed by suitably combining the feedback signal with the externally applied input signal. The output impedance of the amplifier can also be changed by suitably extracting the feedback signal from the output.

(4) The bandwidth of the amplifier increases and the frequency distortion becomes less.

(5) The phase distortion is reduced.

(6) The noise level is lowered.

5.3.1 Stability of Gain

Temperature variation, aging, replacement of the circuit components and transistors (or FET's) result in variations of the characteristics of the circuit components and transistors. This, in turn, causes corresponding lack of stability of amplifier transfer gain.

Sensitivity of transfer gain is defined as the ratio of fractional change in amplification with feedback to the fractional change without feedback.

$$\text{Sensitivity} = \frac{\text{Fractional change in gain with feedback}}{\text{Fractioncal change in gain without feedback}}$$

$$= \frac{|dA_f / A_f|}{|dA / A|} = \frac{1}{1 + A\beta} \qquad \text{... (5.3.1)}$$

We know that gain with negative feedback as,

$$A_f = \frac{A}{1 + A\beta} \qquad \text{... (5.3.2)}$$

Differentiating Eq. (5.3.2) with respect to A, we get,

$$dA_f = \left[\frac{(1 + A\beta)1 - A\beta}{(1 + A\beta)^2}\right] \cdot dA = \frac{1}{(1 + A\beta)^2} \cdot dA \qquad \text{... (5.3.3)}$$

Dividing both sides of Eq. (5.3.3) by A_f, we obtain,

$$\frac{dA_f}{A_f} = \frac{1}{(1 + A\beta)^2} \cdot \frac{dA}{A_f}$$

$$= \frac{1}{(1 + A\beta)^2} \cdot \frac{dA}{\left(\frac{A}{1 + A\beta}\right)}$$

$$\Rightarrow \qquad \frac{dA_f}{A_f} = \frac{dA}{A} \frac{1}{(1 + A\beta)}$$

The magnitude of resulting equation is,

$$\left|\frac{dA_f}{A_f}\right| = \left|\frac{dA}{A}\right| \cdot \frac{1}{|1 + A\beta|}$$

Therefore, sensitivity of the transfer gain is,

$$\therefore \qquad \boxed{S = \frac{\left|\frac{dA_f}{A_f}\right|}{\left|\frac{dA}{A}\right|} = \frac{1}{|1 + A\beta|}}$$

Where,

$\frac{dA_f}{A_f}$ = Fractional change in gain with feedback.

$\frac{dA}{A}$ = Fractional change in gain without feedback.

Here, $\frac{1}{1 + A\beta}$ is sensitivity. The reciprocal of the sensitivity is called the densensitivity (D). The term desensitivity indicates the factor by which the voltage gain has been reduced due to feedback.

Desensitivity,

$$D = 1/\text{sensitivity} = [1/(1/1 + A\beta)] = 1 + A\beta \quad \text{... (5.3.5)}$$

We have, gain with negative feedback as,

$$A_f = \frac{A}{1 + A\beta} = \frac{A}{D} \quad \text{... (5.3.6)}$$

Thus densensitivity may also be defined as,

$$D = \frac{A}{A_f}$$

If $|A\beta| >> 1$, then,

$$A_f = \frac{A}{1 + A\beta} = \frac{A}{A\beta}$$

$$\boxed{A_f = \frac{1}{\beta}} \quad \text{... (5.3.7)}$$

Hence the gain may be made to depend entirely on the feedback network. If the feedback network contains only stable passive elements, the improvement in stability may indeed be pronounced.

Since A represents either A_V, A_I, G_M or R_M, then A_f represents the corresponding transfer gain with feedback. Either A_{Vf}, A_{If}, G_{Mf} or R_{Mf} signifies that,

For voltage-series feedback, $A_{Vf} = \frac{1}{\beta}$ voltage gain is stabilized.

For current-series feedback, $G_{Mf} = \frac{1}{\beta}$ transconductance gain is stabilized.

For voltage-shunt feedback, $R_{Mf} = \frac{1}{\beta}$ transresistance gain is stabilized.

For current-shunt feedback, $A_{If} = \frac{1}{\beta}$ current gain is stabilized.

EXAMPLE PROBLEM 1

An amplifier has an open-loop gain of 1000 and a feedback ratio of 0.04. If the open loop gain changes by 10% due to temperature, find the percentage change in gain of the amplifier with feedback.

SOLUTION

Percentage change in gain of the amplifier with feedback is given by,

$$\frac{dA_f}{A_f} = \frac{dA}{A}\frac{1}{(1+A\beta)} = 10 \times \frac{1}{1+1000 \times 0.04} = 0.243\%.$$

5.3.2 Reduction in Non-linear Distortion

Negative feedback reduces the amount of noise signal (such as power supply hum) and nonlinear distortion. Nonlinear distortion results in the production of terms such as harmonics, which are present in the input.

Consider a non-feedback amplifier as shown in Fig. 5.3.1,

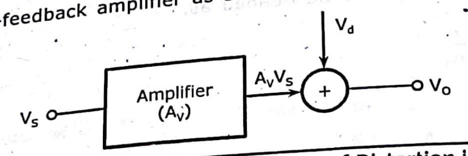


Fig. 5.3.1 A Model used to Represent the Effect of Distortion in an Amplifier

Suppose that a large amplitude signal is applied to an amplifier so that the operation of the device extends slightly beyond its range of linear operation. As a result the output signal is slightly distorted. The output of the amplifier is,

$$V_o = A_V V_S + V_d \qquad \dots (5.3.8)$$

Where V_d represents the distortion signal such as harmonics.

The distortion is given by,

$$D = \frac{V_d}{A_V V_S} \qquad \dots (5.3.9)$$

If a negative feedback is introduced as shown in Fig. 5.3.2 the input signal is increased by the same amount by which the gain is reduced, so that the amplitude of the output signal remains the same. Since the output signal operates at the same levels in both cases, the distortion signals are same and hence $V'_d = V_d$,

The output of the amplifier with the feedback is,

$$V'_o = \frac{A_V}{1+A_V\beta} V'_s + \frac{V'_d}{1+A_V\beta} \qquad \dots (5.3.10)$$

The distortion due to negative feedback is,

$$D' = \frac{V'_d}{A_V V'_S} \qquad \dots (5.3.11)$$

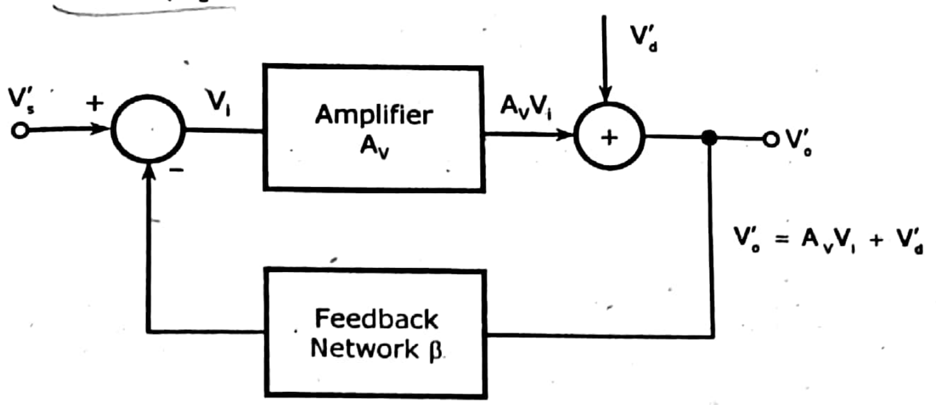


Fig. 5.3.2 The Model of Feedback Configuration

Taking the ratio of Eq. (5.3.9) and Eq. (5.3.11),

We get, $$\frac{D'}{D} = \frac{V_S}{V'_S} \quad \text{(since } V_d = V'_d\text{)} \qquad \dots (5.3.12)$$

The input signals V_S and V'_S (without and with feedback) must be adjusted so that the input signals are equal. For the output signals given in Eq. (5.3.10) and Eq. (5.3.8), if the signal components are equal then we must have,

$$A_V V_S = \frac{A_V}{1 + A_V\beta} V'_s \qquad \dots (5.3.13)$$

$$\Rightarrow \qquad V_s / V'_S = 1/1 + A_V\beta$$

Substituting (V_s/V'_S) in Eq. (5.3.12),

We get, $$\frac{D'}{D} = \frac{1}{1 + A_V\beta}$$

$$\therefore \qquad \boxed{D' = \frac{D}{1 + A_V\beta}} \qquad \dots (5.3.14)$$

Thus, the distortion has been reduced by the amount $(1 + A_V\beta)$ due to negative feedback.

5.3.3 Reduction of Noise

If V_n is the noise voltage at the input of an amplifier of voltage gain A in the absence of feedback, the noise voltage at the output of amplifier is,

$$V_{on} = AV_n \qquad \dots (5.3.15)$$

In the presence of feedback with feedback fraction β, the gain reduces to $A_f = A/(1 + A\beta)$, so that the output noise voltage becomes,

$$V_{onf} = \frac{AV_n}{1 + A\beta} = \frac{V_{on}}{1 + A\beta} \quad \cdots (5.3.16)$$

For negative feedback $|1 + A\beta| > 1$. Therefore, $V_{onf} < V_{on}$.

Eq. (5.3.16) shows that the noise reduces by a factor of $1 + A\beta$ in the presence of negative feedback.

COMMENT : ***Signal-to-noise ratio of the amplifier output is not improved since the negative feedback reduces the signal as well as noise by the same factor 1 + Ab.***

5.3.4 Reduction of Frequency Distortion

The gain of an amplifier becomes a function of frequency due to internal device capacitances, associated coupling and bypass elements such as capacitors and transformers. As a result, different frequency components are amplified to different extents.

We have seen that the gain of an amplifier with negative feedback is given by,

$$A_f = \frac{A}{1 + A\beta}$$

If $|A\beta| >> 1$, then,

$$A_f \approx \frac{A}{A\beta}$$

$$\therefore \quad A_f = \frac{1}{\beta}$$

Under this condition, A_f depends only on β. If the feedback network is purely resistive, the overall gain is then not a function of frequency even though the basic amplifier gain is frequency dependent. Under these conditions a substantial reduction in frequency and phase distortion is obtained.

5.3.5 Effect of Feedback on Input Resistance

The effect of negative feedback on input impedance depends on the nature of mixing (regardless of whether the feedback is obtained by sampling the output voltage or current). It is observed that,

1) Negative feedback using series mixing, regardless of the method of sampling, tends to increase the input resistance.

2) Negative feedback using shunt mixing, regardless of the method of sampling, tends to decrease the input resistance.

Series Mixing Increases Input Resistance : Consider a input stage of feedback amplifier with series mixing as shown in Fig. 5.3.3,

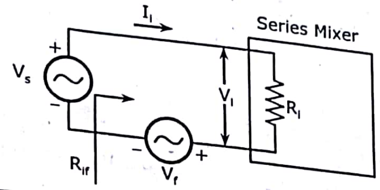


Fig. 5.3.3 Input Stage of Feedback Amplifier with Series Mixing

From Fig. 5.3.3, the input resistance without feedback, R_i is given by,

$$R_i = \frac{V_i}{I_i} \qquad \text{... (5.3.17)}$$

While the input resistance with feedback R_{if} is given by,

$$R_{if} = \frac{V_s}{I_i} \qquad \text{... (5.3.18)}$$

In the presence of negative feedback, V_f is in opposite polarity with respect to V_s and hence I_i with negative feedback is less (i.e., $I_i = (V_s - V_i - V_f)/R_i$) than that with feedback. Hence, R_{if} is greater than R_i.

Shunt Mixing Decreases Input Resistance : Consider a input stage of a feedback amplifier with shunt mixing as shown in Fig. 5.3.4,

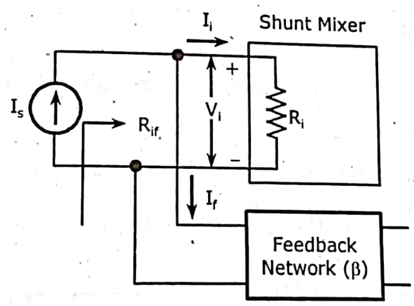


Fig. 5.3.4 Input Stage of Feedback Amplifier with Shunt Mixing

Observe that the feedback appears in parallel with the input terminal of the amplifier. From Fig. 5.3.4 input resistance without feedback is,

$$R_i = \frac{V_i}{I_i} \qquad \text{... (5.3.19)}$$

And in the presence of negative feedback, the input resistance is,

$$R_{if} = \frac{V_i}{I_s}$$

But, $I_s = I_i + I_f$

$$\therefore \quad R_{if} = \frac{V_i}{I_i + I_f} \quad \text{... (5.3.20)}$$

From Eq. (5.3.19) and Eq. (5.3.20), it is clear that R_{if} is less than R_i, since denominator of Eq. (5.3.20) is greater than denominator of Eq. (5.3.19)

5.3.6 Effect of Feedback on Output Resistance

The effect of feedback on output resistance depends on the nature of sampling (regardless of the method of mixing). It has been observed that,

(1) Negative feedback using output voltage sampling regardless of the method of mixing, tends to decrease the output resistance.

(2) Negative feedback using output current sampling, regardless of the method of mixing, tends to increase the output resistance.

Voltage Sampling Reduces the Output Resistance : Consider the output circuit of a typical voltage amplifier shown in Fig. 5.3.5. From Eq. (5.3.7), we have,

$$A_f = \frac{1}{\beta} \text{ (for } A\beta >> 1)$$

Implying that A_f is independent of both source and load resistances. Thus, ideally the output voltage V_o would remain the same irrespective of changes in load resistance R_L in the presence of negative feedback. This is obviously possible only if $R_{of} = 0$ or $R_{of} << R_L$ in the circuit of Fig. 5.3.5. Thus ***voltage sampling reduces the output resistance.***

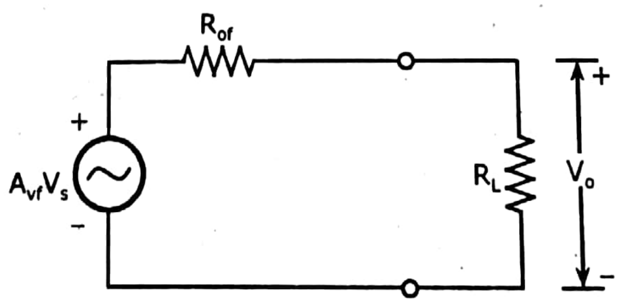


Fig. 5.3.5 Output Stage of a Feedback Amplifier with Voltage Sampling

Current Sampling Increases the Output Resistance : The circuit to analyze the effect of negative feedback on a current sampling circuit is shown in Fig. 5.3.6,

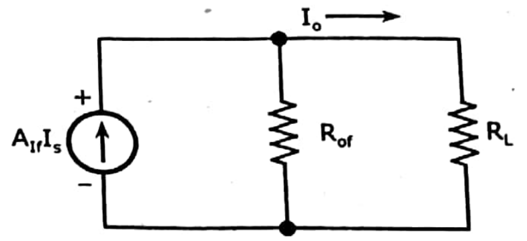


Fig. 5.3.6 Output Stage of a Feedback Amplifier with Current Sampling

In this case, under stabilization through negative feedback the current I_o in R_L remains unchanged with changes in R_L, since, A_{If} is independent of source and load resistance under negative feedback. This is obviously possible only if $R_{of} = \infty$ or $R_{of} >> R_L$ in the circuit of Fig. 5.3.6, in which case $I_o = A_{If}I_s$. Thus ***current sampling increases the output resistance.***

5.3.7 Increase in Bandwidth

The bandwidth of an amplifier is defined as the difference between the upper cut-off frequency f_H and the lower cut-off frequency f_L.

Lower Cut-off Frequency with Feedback (f_{Lf}) : The low frequency gain of a single stage RC coupled amplifier is given by,

$$A_L = \frac{A_m}{1 - j\left(\frac{f_L}{f}\right)} \quad \text{... (5.3.21)}$$

Where,

A_m = Mid frequency gain

f_L = Lower cut-off frequency.

After the application of negative feedback, Low frequency gain becomes,

$$A_{Lf} = \frac{A_L}{1 + \beta A_L} \quad \text{... (5.3.22)}$$

Substituting Eq. (5.3.21) in Eq. (5.3.22),

We get, $$A_{Lf} = \frac{A_M}{1 + \beta A_M - j\frac{f_L}{f}} = \frac{A_M}{1 + \beta A_M\left(1 - \frac{jf_L}{(1+\beta A_M)f}\right)}$$

$$\Rightarrow \quad A_{Lf} = \frac{A_{Mf}}{1 - j\left(\frac{f_{Lf}}{f}\right)}$$

Where,

$$A_{Mf} = \frac{A_M}{1 + \beta A_M} = \text{(mid - frequency gain with feedback)}$$

$$f_{Lf} = \frac{f_L}{(1 + \beta A_m)} = \text{(lower cut - off frequency with feedback)}$$

Since negative feedback implies $|1 + \beta A_m| > 1$. So that,

$$f_{Lf} < f_L$$

i.e., *negative feedback decreases the lower cut-off frequency.*

Higher Cut-off Frequency with Feedback (f_{Hf}) : The high-frequency gain of a single stage RC coupled amplifier is,

$$A_H = \frac{A_M}{1 - j\left(\frac{f}{f_H}\right)} \quad \dots (5.3.23)$$

After the application of negative feedback, high frequency gain becomes,

$$A_{Hf} = \frac{A_H}{1 - \beta A_H}$$

substituting Eq. (5.3.23) in Eq. (5.3.24), we get high frequency gain feedback as,

$$A_{Hf} = \left[\frac{\dfrac{A_M}{1 - j\left(\frac{f}{f_H}\right)}}{1 + \beta\left[\dfrac{A_M}{1 - j\left(\frac{f}{f_H}\right)}\right]}\right] = \frac{A_M}{1 + \beta A_M - j\left(\frac{f}{f_H}\right)}$$

$$= \frac{A_M}{1 + \beta A_M\left(1 - j\dfrac{f}{f_H(1 + \beta A_M)}\right)} = \frac{\left[\dfrac{A_M}{1 + \beta A_M}\right]}{\left[1 - j\left(\dfrac{f}{f_H(1 + \beta A_M)}\right)\right]}$$

$$= \frac{A_{Mf}}{1 - j\dfrac{f}{f_{Hf}}}$$

Where,

$$A_{Mf} = \frac{A_M}{1 + \beta A_M} = \text{(mid frequency gain with feedback)}$$

$$f_{Hf} = f_H(1 + \beta A_M) \text{ and}$$

Since for negative feedback $(1 + A\beta) >> 1$, so that,

$$f_{Hf} > f_H$$

Therefore, ***negative feedback increases the higher cut-off frequencies.***

Bandwidth with Negative Feedback : As bandwidth is equal to difference of higher and lower cut-off frequencies. Thus, bandwidth of amplifier with feedback is given by,

$$B.W = f_{Hf} - f_{Lf}$$

As from the above analysis, lower cut-off frequency due to feedback reduces and on the other hand upper cut-off frequency due to negative feedback increases. Hence, negative feedback increases the bandwidth of the amplifier.

Fig. 5.3.7 shows the effect of negative feedback on the frequency response curve,

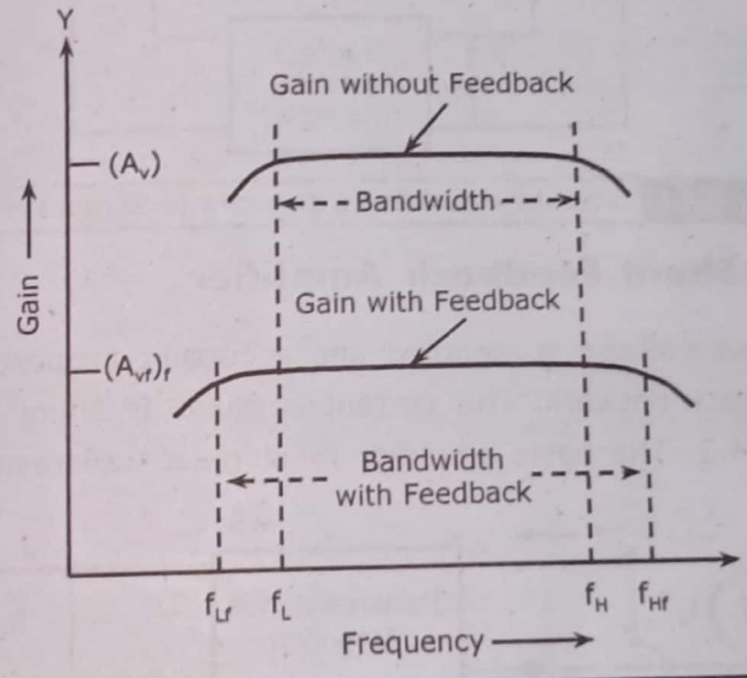


Fig. 5.3.7 Effect of Negative Feedback on Frequency Response Curve

5.4 CLASSIFICATION

We have studied two types of sampling, either current or voltage sampling independent of two types of mixer blocks (either shunt or series mixer). Thus, with two types of sampling and two types of mixers, there could be four feedback amplifier topologies.

They are,

(1) Voltage-series feedback.

(2) Voltage-shunt feedback.

(3) Current-series feedback.

(4) Current-shunt feedback.

5.4.1 Voltage-Series Feedback Amplifier

Here the output voltage V_0, is sampled and a feedback voltage (V_f) proportional to this output voltage (V_0) is derived in the feedback network. This voltage, V_f is mixed in series with the source voltage as shown in Fig. 5.4.1. Hence the basic amplifier block must be a voltage amplifier. (As input is voltage source and output is also a voltage).

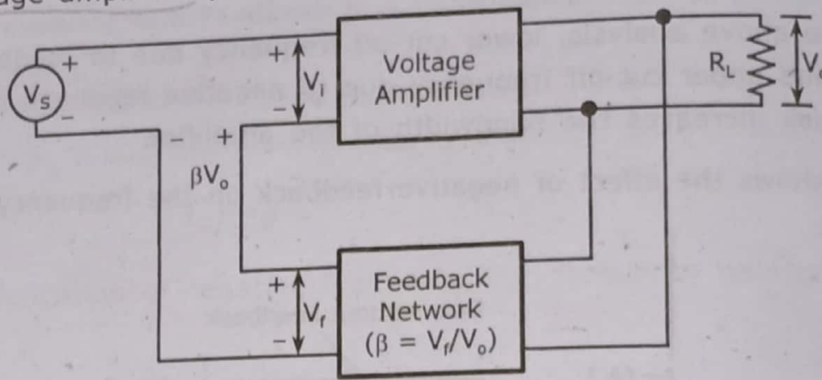


Fig. 5.4.1 Voltage Amplifier with Voltage-Series Feedback

5.4.2 Voltage-Shunt Feedback Amplifier

Here, the output voltage is sampled and a current proportional to this voltage is derived in the feedback network. This current is mixed in shunt with the source current as shown in Fig. 5.4.2. The basic amplifier must be a transresistance amplifier.

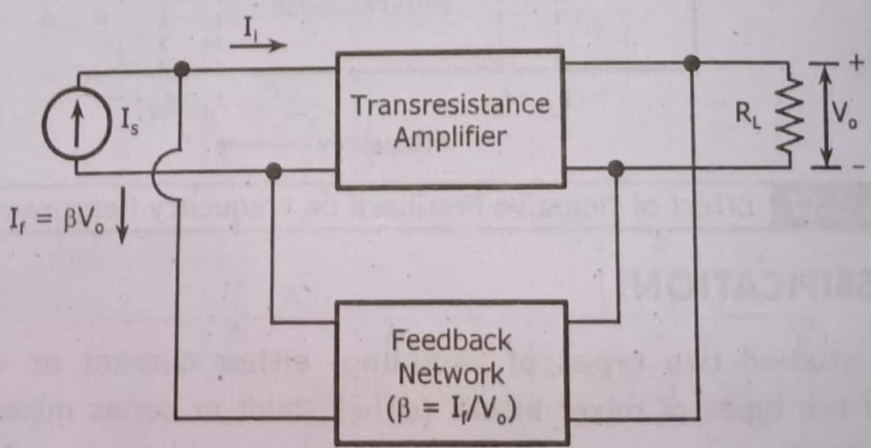


Fig. 5.4.2 Transresistance Amplifier with Voltage-Shunt Feedback

5.4.3 Current-Series Feedback Amplifier

In this feedback amplifier, output current is sampled and a voltage proportional to the current is derived in the feedback network. This voltage is mixed in series with the source voltage as shown in Fig. 5.4.3. The basic amplifier must be a transconductance amplifier.

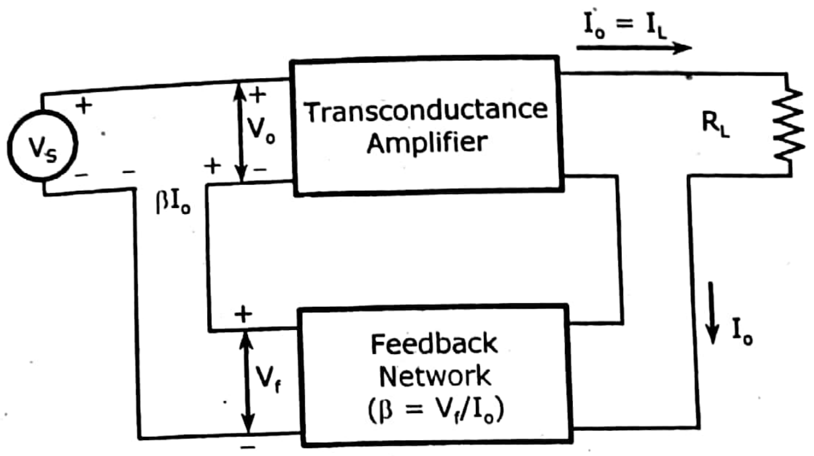


Fig. 5.4.3 Transconductance Amplifier with Current-series Feedback

5.4.4 Current-Shunt Feedback Amplifier

Here, the output current is sampled and current (I_f) proportional to this current (I_o) is derived in the feedback network. This current is mixed in shunt with the source current as shown in Fig. 5.4.4. Hence the basic amplifier must be a current amplifier.

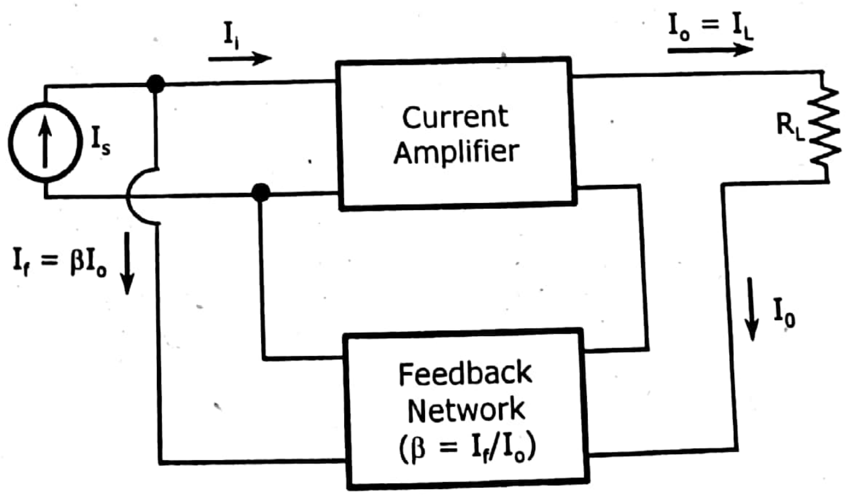


Fig. 5.4.4 Current Amplifier with Current-Shunt Feedback

Table 5.4.1 summarizes the feedback amplifier topologies.

Table 5.4.1 Summary of Feedback Topologies

Parameter \ Topology	Voltage Series	Voltage Shunt	Current Series	Current Shunt
Output (X_o)	Voltage	Voltage	Current	Current
Input (X_s)	Voltage	Current	Voltage	Current
Amplifier	Voltage Amplifier	Transresistance Amplifier	Transconductance Amplifier	Current Amplifier
Gain	$A_V = \frac{V_o}{V_i}$	$R_M = \frac{V_o}{I_i}$	$G_M = \frac{I_o}{V_i}$	$A_I = \frac{I_o}{I_i}$
Gain with Feedback	$A_{Vf} = \frac{V_o}{V_s} = \frac{A_V}{D}$	$R_{Mf} = \frac{V_o}{I_s} = \frac{R_M}{D}$	$G_{Mf} = \frac{I_o}{V_s} = \frac{R_M}{D}$	$A_{If} = \frac{I_o}{I_s} = \frac{A_I}{D}$
Feedback Factor (β)	$\beta = \frac{V_f}{V_o}$	$\beta = \frac{I_f}{V_o}$	$\beta = \frac{V_f}{I_o}$	$\beta = \frac{I_f}{I_o}$

5.5 PARAMETERS OF NEGATIVE FEEDBACK AMPLIFIERS

The negative feedback amplifiers having some of the parameters like input impedance, output impedance, voltage gain, increase bandwidth etc. These parameters are already discussed in the Section 5.3. So simply, refer the Section 5.3.

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