Feedback Amplifier

Basic Open-Loop Amplifier:

The block diagram of a basic open-loop amplifier is shown in Fig-1

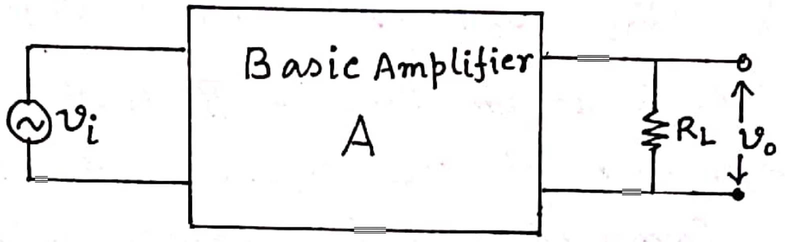

Fig-1

Let v_i be the input voltage to the amplifier and v_o is the corresponding output voltage across the load resistance R_L. The open-loop voltage of the amplifier is given by

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

Closed-loop Amplifier:

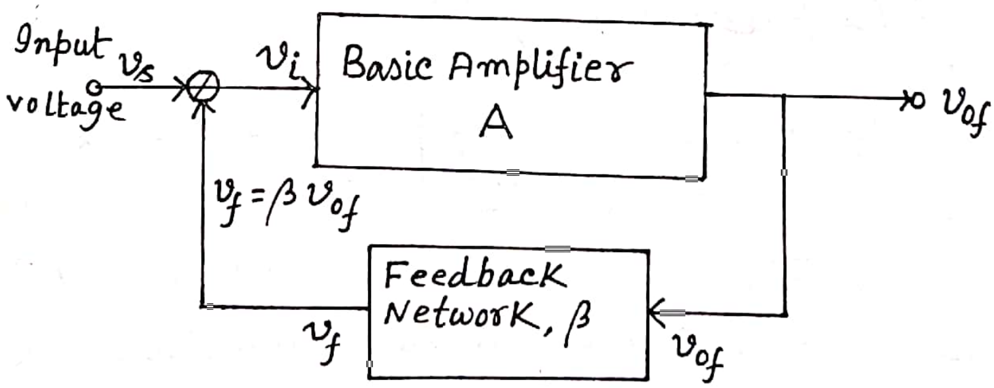

Fig-2

The block diagram of a closed-loop amplifier is shown in Fig-2. A feedback network is connected between the input and output of the basic amplifier. In presence of the feedback network a fraction β of the output voltage v_{of} is fed back to the input such that the effective input to the amplifier becomes $v_i = v_s + \beta v_{of} = v_s + v_f$. β is known as feedback ratio. The basic amplifier and the feedback network may introduce phase changes. A and β are in general complex and the feedback voltage $v_f = \beta v_{of}$ may be in phase (positive feedback) or out of phase (negative feedback) with the input signal v_s.

The output voltage of the amplifier with positive feedback is

$$v_{of} = A v_i = A(v_s + v_f) = A(v_s + \beta v_{of}) \quad \text{--(1)}$$

$$\Rightarrow v_{of} - A\beta v_{of} = A v_s$$

$$\Rightarrow v_{of}(1 - A\beta) = A v_s$$

Therefore the overall voltage gain or closed-loop voltage gain of the feedback amplifier is

$$\boxed{A_f = \frac{v_{of}}{v_s} = \frac{A}{1 - A\beta}} \quad \text{------(2)}$$

The quantity $A\beta$ is known as loop gain. If $A\beta$ is real, positive and less than unity then

$$|1 - A\beta| < 1 \text{ and } |A_f| > |A|$$

Then the feedback is known as <u>positive feedback or regenerative type</u>.

If v_s and $v_f = \beta v_{of}$ are out of phase Then from equation (1)

$$v_{of} = A v_i = A(v_s - v_f) = A(v_s - \beta v_{of})$$

$$\Rightarrow v_{of} + A\beta v_{of} = A v_s$$

$$\Rightarrow v_{of}(1 + A\beta) = A v_s$$

Therefore, The closed-loop voltage gain of The feedback amplifier is

$$\boxed{A_f = \frac{v_{of}}{v_s} = \frac{A}{1+A\beta}} \quad \text{------- (3)}$$

Thus $|1+A\beta| > 1$ and $|A_f| < |A|$. This type of feedback is known as <u>negative feedback or degenerative type</u>.

Effects or Advantages of Negative Feedback :

Though The negative feedback reduces The gain of The amplifier, at The Cost of This reduced gain it can improve many important characteristics of The amplifier as stated below:

1. Negative feedback stabilizes The gain of an amplifier
2. It can reduce nonlinear, phase and frequency distortions.
3. It Can reduce internal noise in an amplifier
4. It increases The bandwidth and Thus improves The frequency response.

5. Input and output impedances can be modified suitably by using negative feedback.

1. Gain Stability:

The gain of the amplifier may change due to a variety of causes such as supply voltage fluctuations, change in circuit parameters due to temperature or replacement etc. Using negative feedback one can improve the stability of amplifier gain.

The closed-loop voltage gain the amplifier is given by

$$A_f = \frac{A}{1+A\beta} \quad \text{------(1)}$$

where A and β are the open-loop voltage gain and feedback ratio respectively.

when $(1+A\beta) > 1$ we can approximate the relation (1) as

$$A_f \approx \frac{A}{A\beta} = \frac{1}{\beta} \quad \text{------(2)}$$

which depends on only the feedback network and is independent of any fluctuations of the basic amplifier. Thus the gain is stable.

Differentiating eqn (1) w.r.t. A we get

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

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

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

$$\therefore \boxed{\frac{dA_f}{A_f} = \frac{dA/A}{(1+A\beta)}} \quad \text{--------- (3)}$$

Now $\frac{dA}{A} = S$ measures the fractional change in voltage gain without feedback and $\frac{dA_f}{A_f} = S'$ measures the fractional change in voltage gain with feedback. Thus

$$S' = \frac{S}{1+A\beta}$$

$$\Rightarrow \frac{S'}{S} = S_A \text{ (say)} = \frac{1}{1+A\beta}$$ is known as

gain sensitivity. In negative feedback $(1+A\beta) > 1$ and $S_A < 1$. If $S_A = 0.1$ then the % change in gain with feedback is $\frac{1}{10}$ of the % change in gain without feedback. $D = 1+A\beta$ is known as gain desensitivity.

2. Input Impedance :

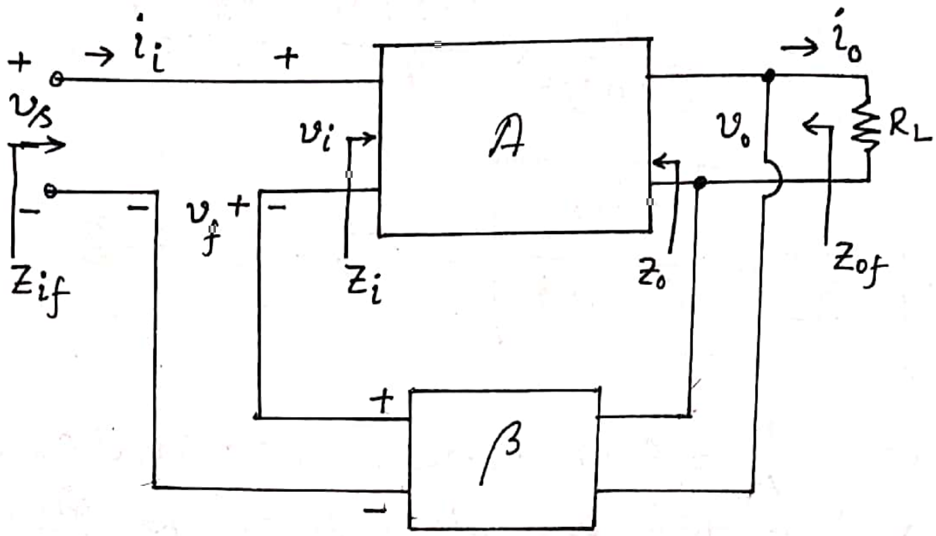

Fig-3

In the voltage series feedback circuit of Fig-3, the input impedance of the amplifier is

$$Z_i = \frac{v_i}{i_i} \quad \text{-------(1)}$$

The input impedance of the feedback amplifier is

$$Z_{if} = \frac{v_s}{i_i} \quad \text{-------(2)}$$

The externally applied input signal is

$$v_s = v_i + v_f = v_i + \beta v_o = v_i + A\beta v_i$$
$$= v_i(1+A\beta)$$

$$\Rightarrow v_s = v_i(1+A\beta)$$

Putting the value of v_s in the equation (2) we get

$$Z_{if} = \frac{v_i(1+A\beta)}{i_i} = \frac{v_i}{i_i}(1+A\beta) = Z_i(1+A\beta)$$

using (1).

$$\therefore \boxed{Z_{if} = Z_i(1+A\beta)} \quad \text{-----} (3)$$

Thus Z_{if} increases due to negative feedback.

Current-Shunt Feedback :

The circuit of Fig-4 represents a current shunt feedback configuration.

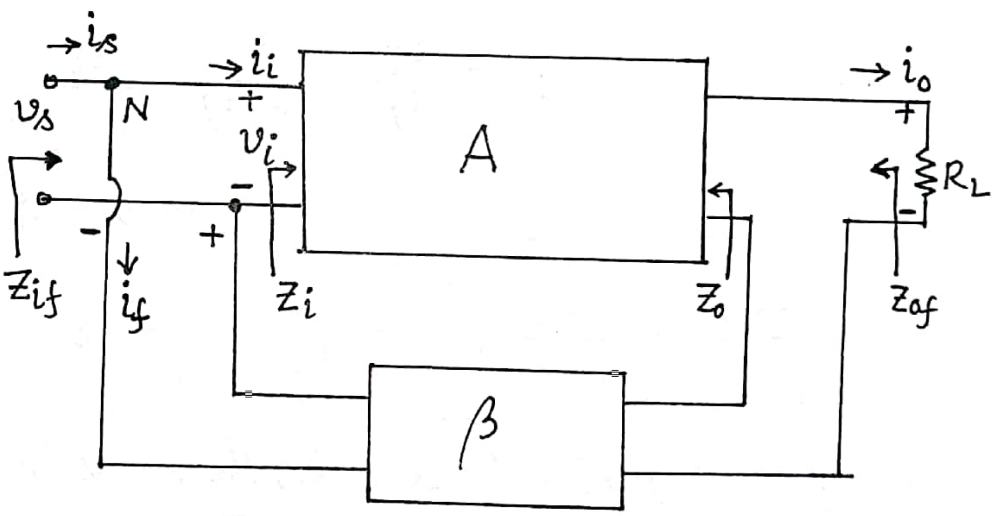

Fig-4

The current gain of the amplifier

$$A = \frac{i_o}{i_i} \quad \text{--------} (1)$$

The input impedance

$$Z_i = \frac{v_i}{i_i} \quad \text{-----} (2)$$

For feedback amplifier, the input impedance

$$Z_{if} = \frac{v_s}{i_s}$$

Applying KCL at N we get

$$i_s = i_i + i_f$$

where i_f is the feedback current. If β is the reverse transmission factor then

$$i_f = \beta i_o = A\beta i_i$$

$$\therefore \quad i_s = i_i + A\beta i_i = i_i(1+A\beta)$$

$$\therefore Z_{if} = \frac{v_s}{i(1+A\beta)} = \frac{v_i}{i_i} \cdot \frac{1}{(1+A\beta)} = \frac{Z_i}{(1+A\beta)}$$

as $v_i = v_s$

$$\therefore \boxed{Z_{if} = \frac{Z_i}{(1+A\beta)}} \quad \text{------} (3)$$

Thus for negative feedback, the input impedance of the feedback amplifier with current-shunt feedback configuration decreases the input impedance.

Output Impedance :

The output impedance of any amplifier is an important quantity because it may affect the efficiency of power amplifier for transfer of power from amplifier to load.

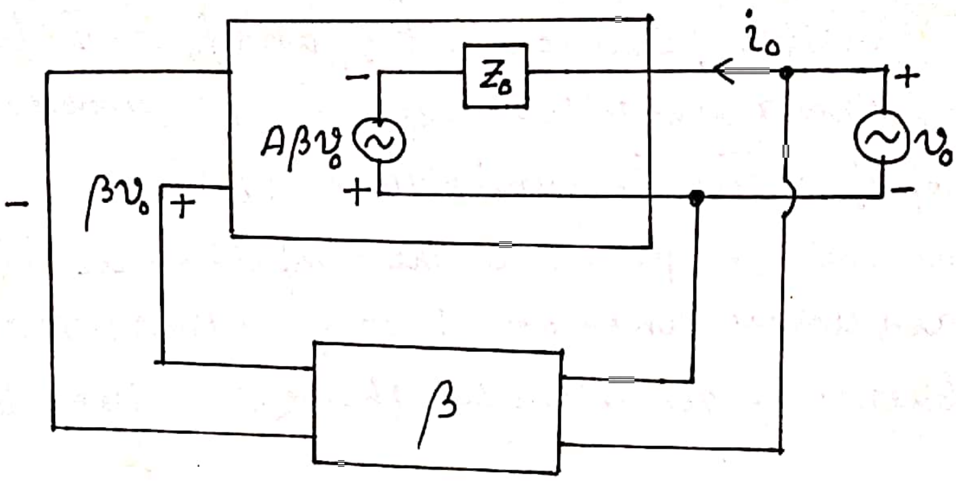

Fig-5

We consider the voltage-series feedback circuit and to find its output impedance the input is short circuited, the load is disconnected and the output is driven by a test source v_o. The resulting circuit is shown in Fig-5, where Z_o is the output impedance without feedback. Now the feedback current supplied by the test source v_o is

$$i_o = \frac{v_o + A\beta v_o}{Z_o} = \frac{v_o(1+A\beta)}{Z_o} \quad \text{---(1)}$$

Therefore the output impedance Z_{of} with feedback is

$$\boxed{Z_{of} = \frac{v_o}{i_o} = \frac{Z_o}{(1+A\beta)}} \quad \text{------(2)}$$

It shows that negative feedback decreases the output impedance.

But the current-shunt feedback increases the output impedance and is given by

$$\boxed{Z_{of} = Z_o(1+A\beta)} \quad \text{------(3)}$$

Increase of Bandwidth due to Negative Feedback:

The bandwidth of a amplifier will be increased due to negative feedback. Let f_1 and f_2 are the lower half-power and upper half-power frequencies of the amplifier then the bandwidth is $(f_2 - f_1)$

The voltage gain A of the amplifier in the low frequency range and high frequency range in absence of negative feedback are given by

$$\left.\begin{aligned} A_l &= \frac{A_m}{1 - j(f_1/f)} \quad \text{for low freq. range} \\ \text{and} \quad A_h &= \frac{A_m}{1 + j(f/f_2)} \quad \text{for high freq. range} \end{aligned}\right\} \quad \text{--(1)}$$

where A_m is the mid frequency voltage gain.

Due to negative feedback, the closed-loop voltage gain for low frequency range and high frequency range are respectively given by

$$\left.\begin{aligned} A_{lf} &= \frac{A_l}{1 + \beta A_l} \quad \text{for low-freq. range} \\ \text{and} \quad A_{hf} &= \frac{A_h}{1 + \beta A_h} \quad \text{for high freq. range} \end{aligned}\right\} \quad \text{--(2)}$$

Now $A_{lf} = \dfrac{A_l}{1 + \beta A_l}$

$$\Rightarrow A_{lf} = \frac{\frac{A_m}{1-j(f_1/f)}}{1+\frac{\beta A_m}{1-j(f_1/f)}} \quad \text{using (1)}$$

$$= \frac{A_m}{1-j\left(\frac{f_1}{f}\right)+\beta A_m}$$

$$= \frac{A_m}{(1+\beta A_m)\left[1-j\frac{1}{f}\cdot\frac{f_1}{1+\beta A_m}\right]}$$

$$= \frac{\frac{A_m}{1+\beta A_m}}{1-j\left(\frac{f_{1f}}{f}\right)} = \frac{A_{mf}}{1-j\left(\frac{f_{1f}}{f}\right)}$$

$$\therefore A_{lf} = \frac{A_{mf}}{1-j\left(\frac{f_{1f}}{f}\right)} \quad \text{-------- (3)}$$

where $A_{mf} = \frac{A_m}{1+\beta A_m}$ is closed-loop mid-frequency voltage gain and

$$f_{1f} = \frac{f_1}{1+\beta A_m} \quad \text{------ (4)}$$

is the lower half-power frequency due to negative feed back. and $f_{1f} < f_1$

Again $A_{hf} = \frac{A_h}{1+\beta A_h}$

$$\Rightarrow A_{hf} = \frac{\dfrac{A_m}{1+j(f/f_2)}}{1 + \dfrac{\beta A_m}{1+j(f/f_2)}} \qquad \text{using (1)}$$

$$\Rightarrow A_{hf} = \frac{A_m}{1+\beta A_m + j(f/f_2)}$$

$$\Rightarrow A_{hf} = \frac{\dfrac{A_m}{1+\beta A_m}}{1+j\left(\dfrac{f}{f_2(1+\beta A_m)}\right)}$$

$$\therefore A_{hf} = \frac{A_{mf}}{1+j\left(\dfrac{f}{f_{2f}}\right)} \quad \text{------} (5)$$

where $f_{2f} = f_2(1+\beta A_m)$ is the upper half-power frequency due to negative feedback and $f_{2f} > f_2$

Thus the bandwidth $(f_{2f} - f_{1f})$ with feedback is greater than the bandwidth $(f_2 - f_1)$ without feedback

For audio and video amplifiers $f_2 >> f_1$ and hence $f_2 - f_1 \approx f_2$. If we assume f_{2f} as the bandwidth of the amplifier with feedback. The gain bandwidth product is

$$A_{mf} \times f_{2f} = \frac{A_m}{(1+\beta A_m)} \cdot f_2(1+\beta A_m) = A_m f_2 \quad \text{-----} (6)$$

Thus we conclude that the negative feedback reduces the gain and increases the bandwidth but the gain bandwidth product remains constant.