Chapter 8

Feedback Amplifiers

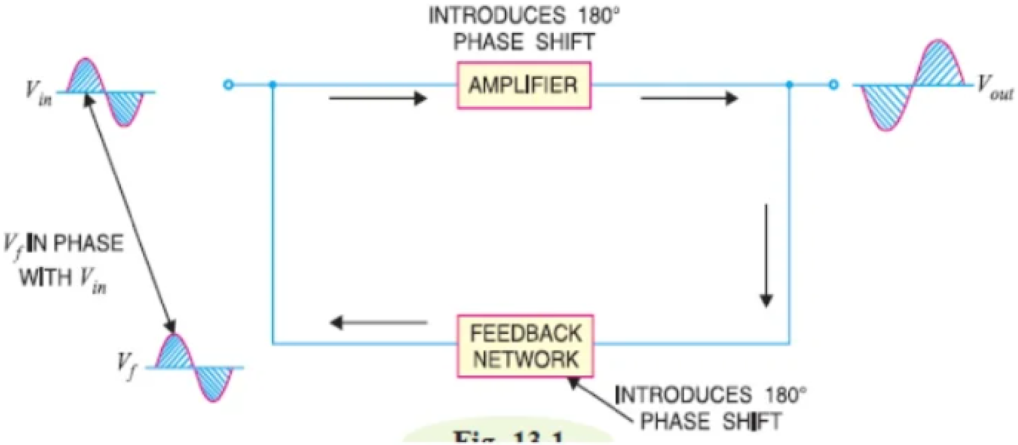
What is Feedback?

- 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 process of injecting a fraction of output energy of some device back to the input is known as **feedback.**
- 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*

1) *Positive feedback*
2) *Negative feedback.*

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.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}.

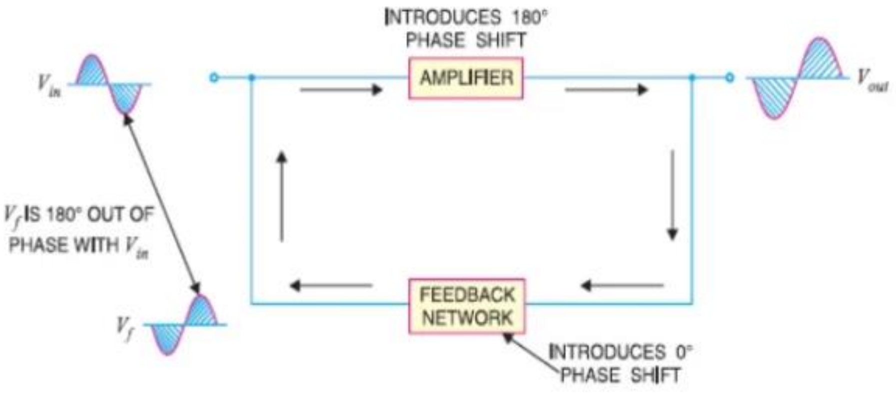


Positive feedback

- 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.

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.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}.



Negative feedback

- 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.

11.3 ADVANTAGES OF NEGATIVE FEEDBACK

There are numerous advantages of negative feedback which outweigh its only drawback of reduction in gain. Among the advantages are:

1. **Gain Stability.** The voltage gain of an amplifier with negative feedback is given as $A_f = A/(1 + A\beta)$. If $A\beta >> 1$ then the expression becomes $A_f = \frac{1}{\beta}$ *i.e.*, overall gain of feedback amplifier A_f is independent of internal gain and depends only on feedback ratio β, and β in turn depends on the passive elements such as resistors. Resistors remain fairly constant and so the gain is stabilised.
2. **Reduced Nonlinear Distortion.** A large signal stage has nonlinear distortion which is reduced by a factor $(1 + A\beta)$ when negative feedback is used.
3. **Reduced Noise.** There is always a noise voltage in the amplifier which is reduced by a factor $(1 + A\beta)$ when negative feedback is used.
4. **Increased Bandwidth (or Improved Frequency Response).** The bandwidth (BW) of an amplifier without feedback is equal to the separation between 3-dB frequencies f_1 and f_2. If A is the gain then gain-bandwidth product is $A \times BW$. With the negative feedback the amplifier gain is reduced and since gain bandwidth product has to remain constant in both cases, so obviously the bandwidth will increase to compensate for the reduction in gain.
5. **Increased Input Impedance.** The input impedance of the amplifier with negative feedback is increased by a factor $(1 + A\beta)$.
6. **Reduced Output Impedance.** The output impedance of the amplifier with negative feedback is reduced by a factor $(1 + A\beta)$.

Advantages of a negative feedback

- It has fewer harmonics distortion
- It has less phase distortion
- More linear operation
- It has less frequency distortion
- It has less amplitude distortion
- Gain is more stable

- **Disadvantages of a negative feedback amplifier:**
- Its reduction in gain
- It increases output resistance in the case of shunt and current series feedback amplifiers

For Negative Feedback :

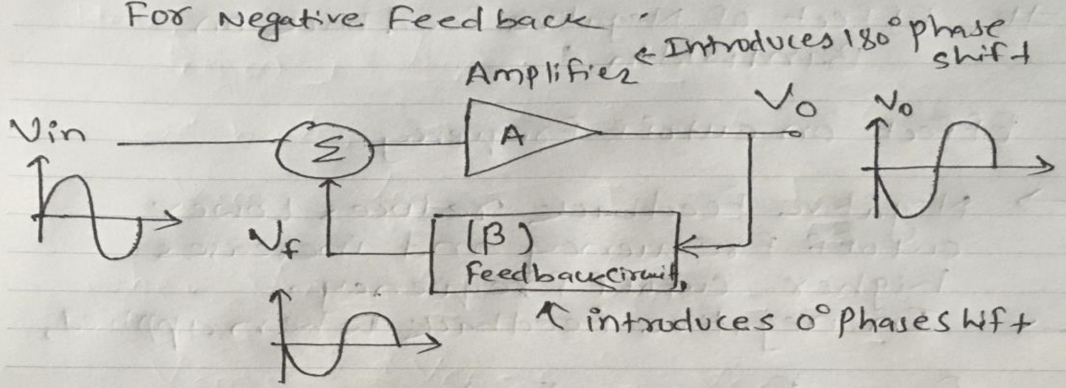


figure: - Negative feedback.

Here, $V_o = A(V_{in} - V_f) - ①$ { For 2nd cycle
where $V_f = \beta V_o - ②$ $\left[\beta = \frac{V_f}{V_o}\right]$ }

From ① & ②

$$V_o = A(V_{in} - \beta V_o)$$

$$\Rightarrow V_o(1 + A\beta) = A V_{in}$$

$$\therefore \left[\frac{V_o}{V_{in}} = A_f = \text{Gain} = \frac{A}{(1+A\beta)}\right]$$

where, A_f = closed Loop gain for negative feedback.

Barkhausen criteria for oscillation

consider basic inverting amplifier with an open loop gain . The feedback network attenuation factor is less than unity. As basic amplifier is inverting, it produces a phase shift of between input and output as shown in the figure.

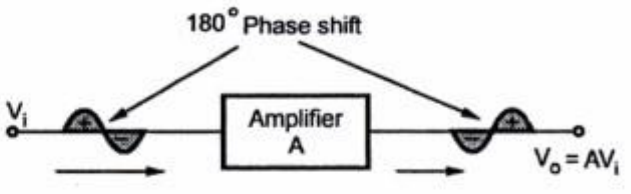


Fig. 4.2 Inverting amplifier

Now the input applied to the amplifier is to be derived from its output using feedback network. But the **feedback must be positive** i.e. the voltage derived from output using feedback network must be in phase with . Thus the feedback network must introduce a phase shift of while feeding back the voltage from output to input. This ensures positive feedback.

Consider a voltage applied at the input of the amplifier. Hence we get,

$$V_0 = A V_i$$

The feedback factor β decides the feedback to be given to input,

$$V_f = \beta V_0$$

$$\Rightarrow V_f = A\beta V_i$$

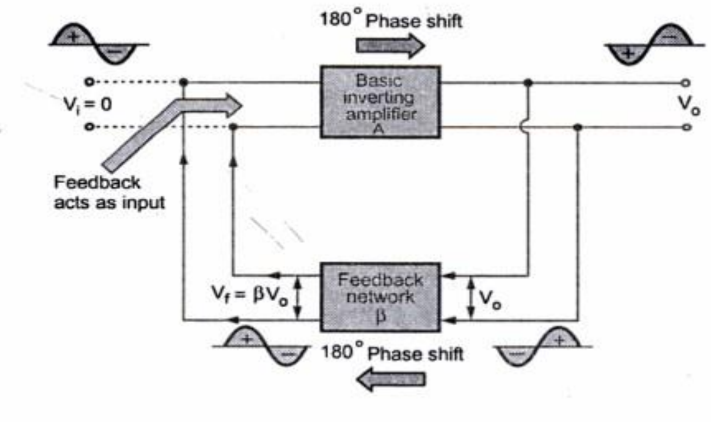


Fig. 4.3 Basic block diagram of oscillator circuit

For the oscillator, we want that feedback should drive the amplifier and hence V_f must act as V_i.

$$\Rightarrow \boxed{A\beta = 1}$$

And the phase of V_f is same as V_i i.e. feedback network should introduce 180° phase shift in addition to 180° phase shift introduced by inverting amplifier. This ensures positive feedback. So total phase shift around a loop is 360°.

The **two conditions** discussed above, required to work the circuit as an oscillator are called **Barkhausen Criterion** for oscillation.

- The total phase shift around a loop, as the signal proceeds from input through amplifier, feedback network back to input again, completing a loop, is precisely or .
- The magnitude of the product of the open loop gain of the amplifier and the magnitude of the feedback factor is unity.

In reality, no input signal is needed to start the oscillations. In practice, Aβ is made greater than 1 to start the oscillations and then circuit adjusts itself to get Aβ = 1, finally resulting into self sustained oscillations.

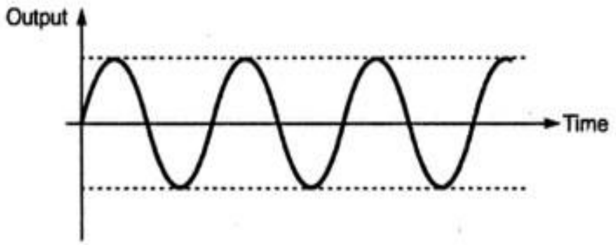


Fig. 4.5 Sustained oscillations

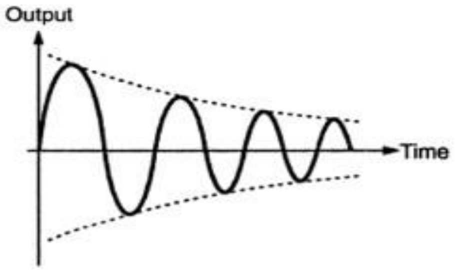
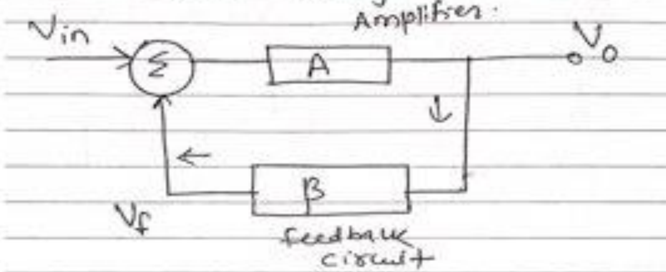
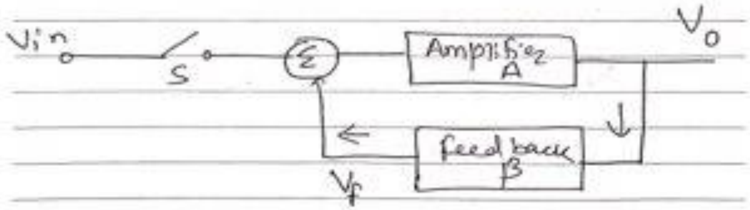


Fig. 4.6 Exponentially decaying oscillations

Principle of oscillation / Barkhausen criteria

→ An oscillator is Amplifier with positive feedback where feed back factor 'β' must be slightly greater than ~~unit~~ unity.





first apply Vin to the circuit and open switch 'S'. [in ~~sesco~~ second stage (time) Vf Feedback voltage acts as I/P ~~&~~ voltage no I/p Vin is given]..

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→ An op-amp with proper positive feedback will work as an Oscillator.

→ once oscillation is ~~stro~~ started, no external source is needed.

→ In order to get undamped O/P, the following condition must be meet.

$V_o = V_{in} A \quad \left[A = \frac{V_o}{V_{in}} \right]$

$\beta = \frac{V_f}{V_o} \quad \therefore V_f = \beta V_o$

~~Since~~, when 'S' is opened,

$V_{in} = V_f$

$V_{in} = \beta V_o = V_{in} A\beta$

$V_{in}(1 - A\beta) = 0$

Since, $V_{in} \neq 0$.

$\therefore (1 - A\beta) = 0$

$\boxed{\therefore A\beta = 1}$

[Here, A = amplifier gain
β = feedback ratio]

To get oscillation,

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1. Positive feedback should occur. i.e total phase difference between O/P and I/P should be zero. i.e $\Delta\phi = 0°$ ~~or (360°)~~.

2. Total Loop gain should be equal to unity. i.e $A\beta = 1$ „

This criteria is known as Barkhausen criteria.

11.4 STABILIZATION OF GAIN WITH NEGATIVE FEEDBACK

The variations in temperature, supply voltages, ageing of components or variations in transistor parameters with replacement are some of the factors that affect the gain of an amplifier and cause it to change. However, the overall gain of the amplifier can be made independent of these variations if negative feedback is used. This is an important advantage of negative feedback.

From Eq. (11.4), the voltage gain with negative feedback is given as

$$A_f = \frac{A}{1+\beta A} \simeq \frac{A}{\beta A} \simeq \frac{1}{\beta} \quad (11.4) \quad ...(11.6)$$ if $A\beta$ is made much larger than unity

The gain is thus independent of internal gain of the amplifier and depends on the passive elements such as resistors. The values of resistors remain fairly constant because they can be chosen very precisely with almost zero temperature coefficient of resistance. Thus the gain is stabilized.

Even if open-loop gain A is not very large, some improvement in gain stability can be achieved. Differentiating Eq. (11.4) w.r.t. A we have

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

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

Dividing above equation by Eq. (11.4) we have

$$\frac{dA_f}{A_f} = \frac{dA}{A} \times \frac{1+\beta A}{(1+\beta A)^2} = \frac{1}{(1+\beta A)}\,\frac{dA}{A} \qquad ....(11.7)$$

In negative feedback $(1 + \beta A) >> 1$, the percentage change in gain with negative feedback is less than the percentage change in gain without feedback. Thus negative feedback improves the gain stability of the amplifier.

Effect of Negative feedback on Bandwidth :

Effect on cutoff frequency.

→ Negative feedback reduces Lower cutoff frequency and increases higher cutoff frequency.

→ In negative feedback when applied,

$$f_{Lf} = \frac{f_L}{(1+A\beta)}$$

[where, f_{Lf} → Feedback amplifier lower cutoff freq.]

$$f_{uf} = f_u(1+A\beta)$$

[f_{uf} → upper cutoff freq. of feedback amplifier]

∴ Bandwidth = Upper cutoff frequency − Lower cutoff frequency

$$BW = f_{uf} - f_{Lf}$$

$$= f_u(1+A\beta) - \frac{f_L}{(1+A\beta)}$$

[Neglecting the smaller term, $f_L/(1+A\beta)$]

$$\therefore BW = f_H(1+A\beta)$$

∴ In negative feedback closeloop bandwidth is greater than openloop bandwidth.

∴ Gain and Bandwidth product with or without feedback remain same.

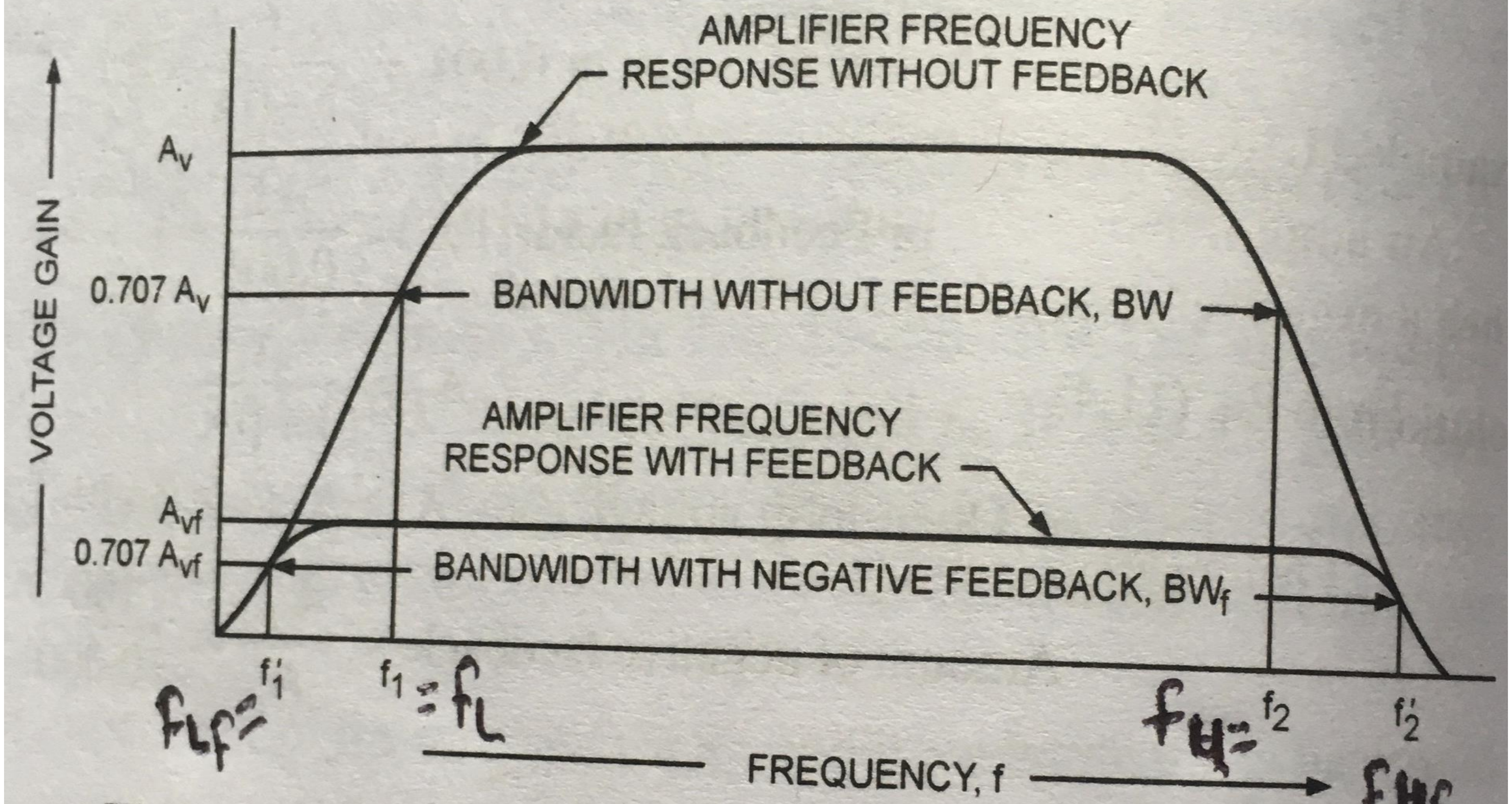

Fig. 11.4 *Amplifier Frequency Response With and Without Negative Feedback*

Example 11.1. The voltage gain of an amplifier without feedback is 3,000. Calculate the voltage gain of the amplifier if the negative feedback is introduced in the circuit. Given that feedback fraction $m = 0.01$.

[*Pb. Technical Univ. Analog Electronics, May-2006*]

Solution: Open-loop voltage gain (voltage gain without feedback),

$$A = 3{,}000$$ Here, ($\beta = m$)

Feedback fraction, $\beta = 0.01$

Voltage gain with negative feedback $A_f = \frac{A}{1+\beta A} = \frac{3{,}000}{1+0.01\times 3{,}000} = \frac{3{,}000}{31} = 96.774$ **Ans.**

Example 11.2. Calculate the gain of a negative feedback amplifier with an internal gain $A_v = 75$ and feedback fraction $m_v = \frac{1}{15}$. What will be the gain if A_v doubles ? [*Pb. Technical Univ. Analog Electronics, December-2005*]

Solution: Internal gain (open-loop voltage gain), $A = 75$

Feedback fraction, $\beta = \frac{1}{15}$

Voltage gain with negative feedback, $A_f = \frac{A}{1+\beta A} = \frac{75}{1+\frac{1}{15}\times 75} = 12.5$ **Ans.**

When A_v doubles *i.e.*, when $A' = 2 \times 75 = 150$

$$A'_f = \frac{A}{1+\beta A'} = \frac{150}{1+\frac{1}{15}\times 150} = 13.64 \text{ Ans.}$$

Example 11.3. An amplifier has a voltage gain of 40. The amplifier is now modified to provide a 10% negative feedback in series with the input. Calculate (*i*) voltage gain with feedback, (*ii*) amount of feedback in dB, (*iii*) loop gain. [*Rajasthan Univ., 2003*]

Solution: Open-loop voltage gain, $A = 40$

Feedback ratio, β = 10% or 0.1

(*i*) Voltage gain with feedback, $A_f = \frac{A}{1+\beta A} = \frac{40}{1+0.1\times 40} = 8$ **Ans.**

(*ii*) Amount of feedback in dB $= 20\log_{10}\left|\frac{1}{1+\beta A}\right| = 20\log_{10}\left|\frac{1}{1+40\times 0.1}\right| = 20\log_{10} 0.2 = -13.98$ **Ans.**

(*iii*) Loop gain $= A\beta = 40 \times 0.1 = 4$ **Ans.**

Example 11.4. An amplifier with voltage gain of 60 dB uses $\frac{1}{20}$ of its output in negative feedback. Calculate the gain with feedback in dB.

Solution: Open-loop voltage gain, A = 60 dB or antilog $\frac{60}{20} = 1{,}000$

Feedback ratio, $\beta = \frac{1}{20} = 0.05$

Gain with feedback, $A_f = \frac{A}{1+\beta A} = \frac{1{,}000}{1+0.05\times 1{,}000} = 19.6$ or $20\log_{10} 19.6$ dB $= 25.85$ dB **Ans.**

Example 11.5. If the gain of an amplifier is 90 dB and 60 dB without and with feedback respectively, find the feedback factor of the amplifier.

[*B.P. Univ. of Technology Basic Electronics, 2008*]

Solution: Voltage gain of amplifier without feedback, A = 90 dB or 31,622.8

Voltage gain of amplifier with feedback, A_f = 60 dB or 1,000

Voltage gain with feedback is given as

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

or feedback factor, $\beta A = \frac{A}{A_f} - 1 = \frac{31{,}622.8}{1{,}000} - 1 = 30.6$ **Ans.**

Example 11.6. A single stage transistor amplifier has a voltage gain of 600 without feedback, and 50 with feedback. Calculate the percentage of output which is fed back to the input.

Solution: Voltage gain without feedback, $A = 600$

Voltage gain with feedback, $A_f = 50$

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

$$\therefore 50 = \frac{600}{1+600\beta}$$

or $\beta = 0.01833$

Percentage of output voltage that is fed back to the input $= \frac{V_f}{V_{out}} \times 100 = \beta \times 100 = 0.01833 \times 100 = 1.833\%$ **Ans.**

Example 11.7. An amplifier with negative feedback gives an output of 12.5 volts with an input of 1.5 V. When feedback is removed, it requires 0.25 V input for the same output. Find (*i*) value of voltage gain without feedback, and (*ii*) value of β, if the input and output are in phase and β is real.

[*Rajasthan Technical Univ. Analog Electronics, 2009*]

Solution: (*i*) Voltage gain without feedback,

$$A_v = \frac{\text{Output voltage}}{\text{Input voltage}} = \frac{12.5}{0.25} = 50$$ ∵ Output voltage is same with and without feedback

Voltage gain with feedback, $A_{vf} = \frac{\text{Output voltage}}{\text{Input voltage}} = \frac{12.5}{1.5} = 8.333$

Since, $A_{vf} = \frac{A_v}{1+\beta A_v}$,

Feedback ratio, $\beta = \frac{\frac{A_v}{A_{fv}} - 1}{A_v} = \frac{\frac{50}{8.333} - 1}{50} = \frac{6-1}{50} = 0.1$ or 10% **Ans.**

Example 11.8. An amplifier gain changes by ± 10%. Using negative feedback, the amplifier is to be modified to yield a gain of 100 with ± 0.1% variation. Find the required open-loop gain of the amplifier and the amount of negative feedback.

Solution: Variation in open-loop gain, $\dfrac{dA}{A} = \dfrac{10}{100} = 0.1$

Variation in closed-loop gain, $\dfrac{dA_f}{A_f} = \dfrac{0.1}{100} = 0.001$

From Eq. (11.7)
$$\frac{dA_f}{A_f} = \frac{1}{(1+\beta A)} \cdot \frac{dA}{A}$$

$$\text{or } 0.001 = \frac{1}{1+\beta A} \times 0.1$$

$$\text{or Feedback factor, } \beta A = \frac{0.1}{0.001} - 1 = 99$$

From Eq. (11.4)
$$A_f = \frac{A}{1+\beta A}$$

or Open-loop voltage gain, $A = A_f\,(1 + \beta A) = 100\,(1 + 99) = 10{,}000$ **Ans.**

Amount of negative feedback $= \dfrac{A_f}{A} = \dfrac{100}{10{,}000} = \dfrac{1}{100}$ **Ans.**

Example 11.9. An R-C coupled amplifier has $A_m = 50{,}000$; $f_H = 20$ kHz ; $f_L = 30$ Hz. A resistive voltage negative feedback is added such that $\beta = 5 \times 10^{-5}$. Find A_{mf}, f_{Hf} and f_{Lf}.

Solution: Open-loop gain, $A_m = 50{,}000$

Feedback ratio, $\beta = 5 \times 10^{-5}$

$$A_{mf} = \frac{A_m}{1+\beta A_m} = \frac{50{,}000}{1+5\times10^{-5}\times 50{,}000} = 14{,}285.7 \text{ Ans.}$$

Upper cutoff frequency with feedback, $f_{Hf} = f_H(1+\beta A_m) = 20 \times 10^3 (1 + 5 \times 10^{-5} \times 50{,}000) = 70$ kHz **Ans.**

$$\text{Lower cutoff frequency with feedback, } f_{Lf} = \frac{f_L}{1+\beta A_m} = \frac{30}{1+5\times10^{-5}\times 50{,}000} = 8.57 \text{ Hz Ans.}$$

Example 11.10. Derive an expression for the overall gain of a voltage series feedback amplifier.

An amplifier has the midband gain of 1,500 and a bandwidth of 4 MHz. The midband gain reduces to 150 when a negative feedback is applied. Determine the value of feedback factor and the bandwidth.

Solution: Midband gain $A_{vm} = 1{,}500$

$$\text{Midband gain with feedback, } A_{vmf} = \frac{A_{vm}}{1+\beta A_{vm}}$$

Substituting the value of $A_{vmf} = 150$ and $A_{vm} = 1{,}500$ in above equation, we have

$$150 = \frac{1{,}500}{1+\beta A_{vm}}$$

$$\text{or Feedback factor, } \beta A_{vm} = \frac{1{,}500}{150} - 1 = 9 \quad \text{Ans.}$$

Bandwidth with feedback, $BW_f = (1+\beta A_{vm}) \times$ Bandwidth without feedback $= (1+9)\times 4 = 40$ MHz **Ans.**