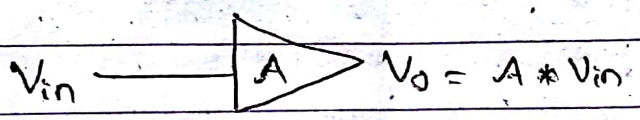
Ch 8 Feedback Amplifiers

A practical amplifier has a gain of certain times the input i.e. o/p is much more times the i/p. So even a small disturbance/noise at i/p will appear in the amplified form at o/p. The noise in the o/p of amplifier is undesirable & must be kept to as small a level as possible. The noise level in amplifier can be reduced considerably by use of -ve (negative) feedback.

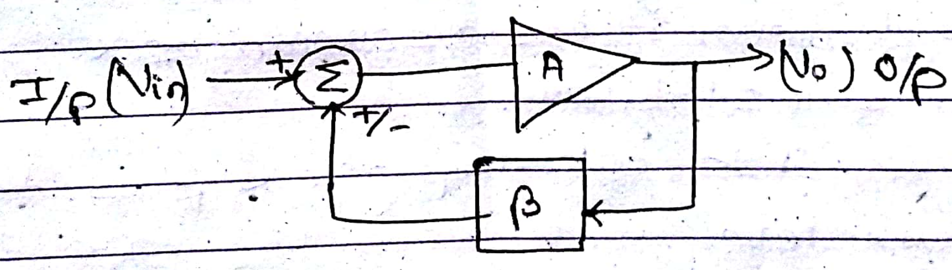
The process of injecting a fraction of o/p energy of some device back to the i/p is known as feedback.

An amplifier without feedback can be represented as,



Most of the characteristics such as gain, i/p and o/p impedance, bandwidth are required to be controlled, which can be achieved by using feedback technique.

The process in which a fraction of o/p is feedback to the i/p ckt is said to be feedback. Thus feedback amplifier are those that implements feedback technique.



There are 2 types of feedback in an amplifier which are as given below:

1) Positive feedback
2) Negative feedback

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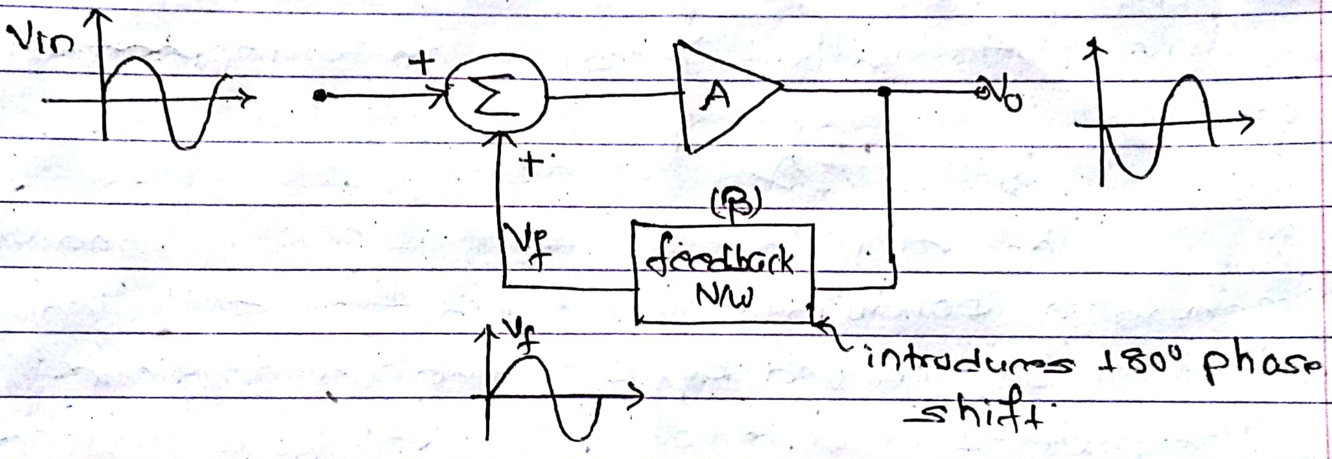
1) Positive Feedback

If the feedback signal is applied to increase the i/p signal (i.e. the signal applied is in phase with i/p signal), it is called +ve feedback. It is also called direct or regenerative feedback.

Both amplifier & feedback n/w introduce a phase shift of 180°. So the result is 360° phase shift around the loop, causing feedback voltage V_f to be in phase with the i/p signal V_{in}.



Positive feedback have capabilities to increase the power of original signal. So it is used in oscillator circuits. However it has disadvantages of increased distortion & instability.

In above fig, A is open-loop gain & β is feedback ratio. We have,

$$V_o = (V_{in} + V_f) A \text{ —— (i)}$$

where, $V_f = \beta V_o$ —— (ii)

From eq^n (i) & (ii)

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

or, $(1 - A\beta) V_o = A V_{in}$

or, $$\frac{V_o}{V_{in}} = \frac{A}{1 - A\beta}$$

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or, $A_F = \frac{V_o}{V_{in}} = \frac{A}{1-A\beta}$, which is closed loop gain for +ve feedback amplifier.

where, $A\beta$ is feedback factor

& $1-A\beta$ = loop gain.

2) Negative Feedback

If the feedback signal is applied to reduce the i/p voltage (i.e. feedback signal is out of phase with i/p signal), it is called -ve feedback. It is also called inverse or de-generative feedback.

The amplifier introduces a phase shift of 180° into the circuit, while the feedback n/w is so designed that it introduces no phase shift (i.e. 0° phase shift).

Thus it results that the feedback voltage V_f is 180° out of phase with the input signal V_{in}.

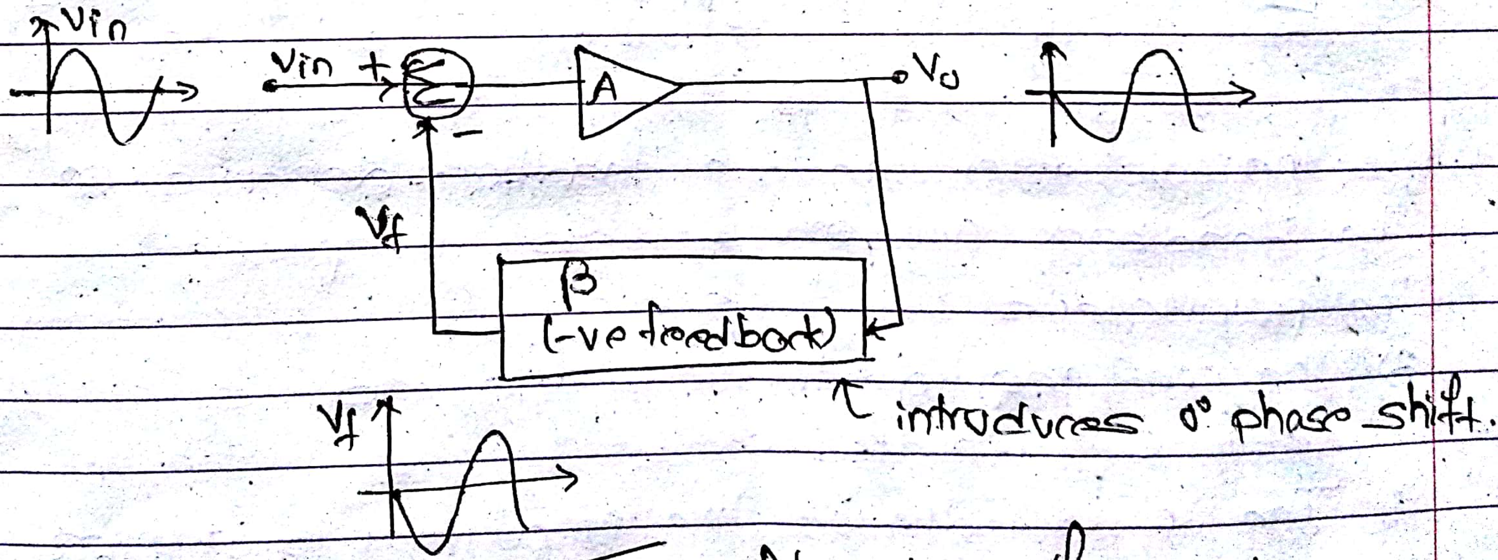

Fig: Negative feedback.

We have,

$$V_o = A \times (V_{in} - V_f) \quad \text{——(i)}$$

where $V_f = \beta V_o$ ——(ii)

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From eqn (i) & (ii)

$$V_0 = AV_{in} - A\beta V_0$$

or, $V_0(1 + A\beta) = AV_{in}$

or, $$\frac{V_0}{V_{in}} = \frac{A}{1+A\beta}$$

$$\therefore A_f = \frac{V_0}{V_{in}} = \frac{A}{1+A\beta} \quad \left(\text{or, } A_{vf} = \frac{A_v}{1+A_v \cdot m_v}\right)$$

where A_f is ~~closed~~ loop gain for -ve feedback amplifier.

Advantages of Negative feedback:

The negative feedback reduces the gain of amplifier. However it has many ~~me~~ advantages so that it is frequently used in amplifier circuits, which are as given below:

1) It increases the gain stability.

As we know that,

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

Since $A\beta >>> 1$, $\Rightarrow \left[A_f = \frac{A}{1+A\beta} \approx \frac{A}{A\beta} = \frac{1}{\beta}\right]$

$$A_f \cong 1/\beta$$

i.e. the gain after the -ve feedback depends on the feedback n/w only & it is independent of the parameters of transistor.

2) The non-linear distortion is reduced by a factor of $(1+A\beta)$.

3) The bandwidth of the amplifier is extended by approximately $(1+A\beta)$ times.

4) The signal to noise ratio is improved.

5) The i/p impedance is increased & o/p impedance is decreased by $(1+A\beta)$ times for the voltage

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series feedback configuration.

6) The frequency distortion is reduced with the negative feedback.

Gain Stabilization with Negative feedback

[The open loop gain ~~+ve fe~~ of an amplifier varies due to variation in tempr, source voltage, variation in the transistor parameters etc. We can control these variation by using -ve feedback.]

The gain of an amplifier with negative feedback is given by,

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

On differentiating eqn (i) w.r.to A,

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

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

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

On dividing both sides by A_f,

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

or, $$\frac{dA_f}{A_f} = \frac{dA}{(1+A\beta)^2} \times \frac{(1+A\beta)}{A} \qquad \left[\because A_f = \frac{A}{1+A\beta}\right]$$

$$\text{or, } \frac{dA_f}{A_f} = \frac{dA}{A} \times \frac{1}{(1+A\beta)} \quad \text{——— (ii)}$$

Since $(1+\beta A) >> 1$, the % change in gain with negative feedback is less than the % change in gain without feedback.
The -ve feedback improves the gain stability of the amplifier.

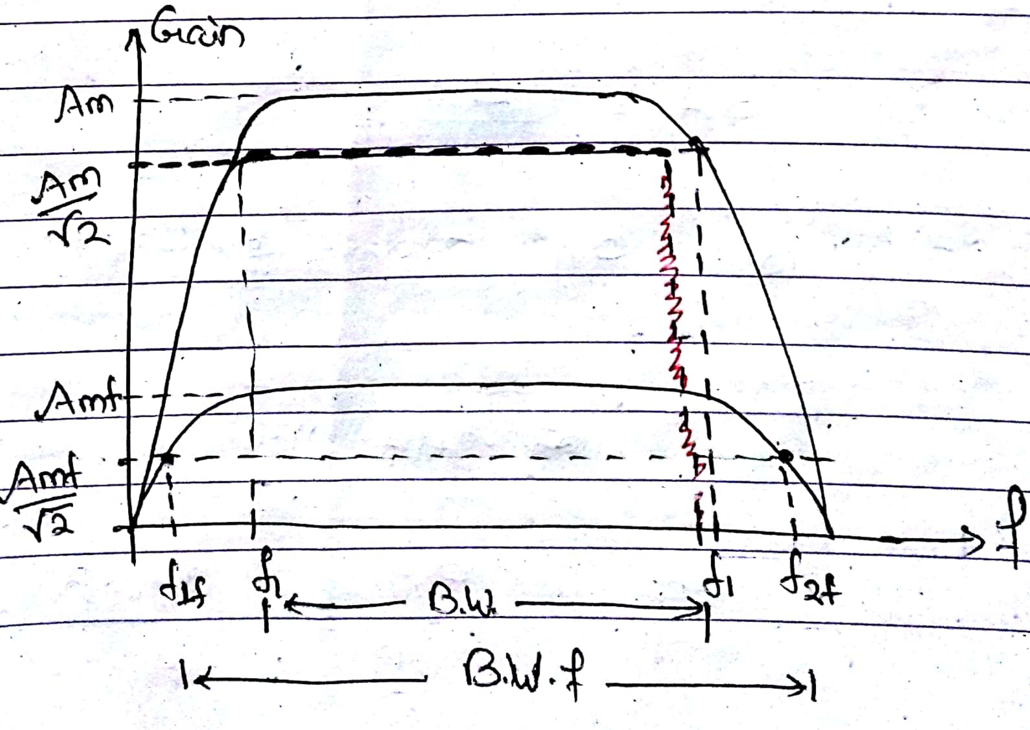
[∵ $\frac{dA_f}{A_f}$ = % change in gain with feedback

$\frac{dA}{A}$ = % change in gain without feedback]

Effect of Negative feedback on Bandwidth

(Negative feedback extends Bandwidth)

If f_L & f_H are lower & upper cut-off frequency of an amplifier without feedback then the value of f_L decreases & f_H increases by a factor of $(1+A\beta)$ if negative feedback is used.
The plot of gain & frequency of an amplifier is as shown



Here, without feedback,

$$BW = f_2 - f_1$$

where, f_1 = lower cut-off frequency
f_2 = upper cut-off frequency

After the -ve feedback, the mid-band gain (A_m) reduces by $(1+A_m\beta)$, the lower cut-off freq reduces by $(1+A_m\beta)$ & upper cut-off frequency increases by $(1+A_m\beta)$

Again,

$$BW = f_2 - f_1 = f_2 \quad (\because f_1 \text{ is very small})$$

And, BW with -ve feedback is,

$$BW_f = f_{2f} - f_{1f}$$

$$= f_2(1+\beta A_m) - \frac{f_1}{(1+\beta A_m)}$$

$$= f_2(1+\beta A_m) \quad \left[\because \frac{f_1}{(1+\beta A_m)} \text{ is very small}\right]$$

or, $BW_f = BW * (1+\beta A_m) \quad [\because BW = f_2 - f_1 \approx f_2]$

i.e. $BW_f = BW(1+\beta A_m) = BW(1+A\beta)$

Thus -ve feedback extends bandwidth & improve frequency response of the amplifier.

Proof:

The voltage gain at frequency f in the high frequency range of the RC coupled amplifier is given as,

$$A_h = \frac{A_m}{\left(1+j\frac{f}{f_2}\right)}$$

When negative voltage is applied

$$A_{hf} = \frac{A_h}{(1+\beta A_h)} = \frac{\frac{A_m}{(1+jf/f_2)}}{1+\beta \cdot \frac{A_m}{(1+jf/f_2)}} = \frac{A_m}{\left(1+j\frac{f}{f_2}+\beta A_m\right)}$$

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$$\text{or, } A_{hf} = \frac{A_m}{1+\beta A_m + j\frac{f}{f_2}} = \frac{A_m}{(1+\beta A_m)\left[1+j\frac{f}{f_2(1+\beta A_m)}\right]}$$

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

$$\text{where, } A_{mf} = \frac{A_m}{(1+\beta A_m)}$$

$$\text{or, } A_{hf} = \frac{A_m}{1+j\frac{f}{f_2'}}$$

$$\text{where, } f_2' = f_2(1+\beta A_m)$$

Thus, we see that upper cut-off freq with the feedback is increased by $(1+\beta A_m)$ times the upper cut off freq without feedback.

Similarly, the lower cut-off freq f_1 is reduced by $(1+\beta A_m)$ with negative feedback. Thus bandwidth extends with -ve feedback.

However, the gain reduces by the same factor. Thus the gain bandwidth product almost remains constant.

Effect of Negative Feedback on Signal to Noise Ratio

Let us consider a negative feedback system as shown in figure below, where V_s is the signal, V_n is the noise signal, A_2 is the gain of noise free amplifier & β is feedback ratio.

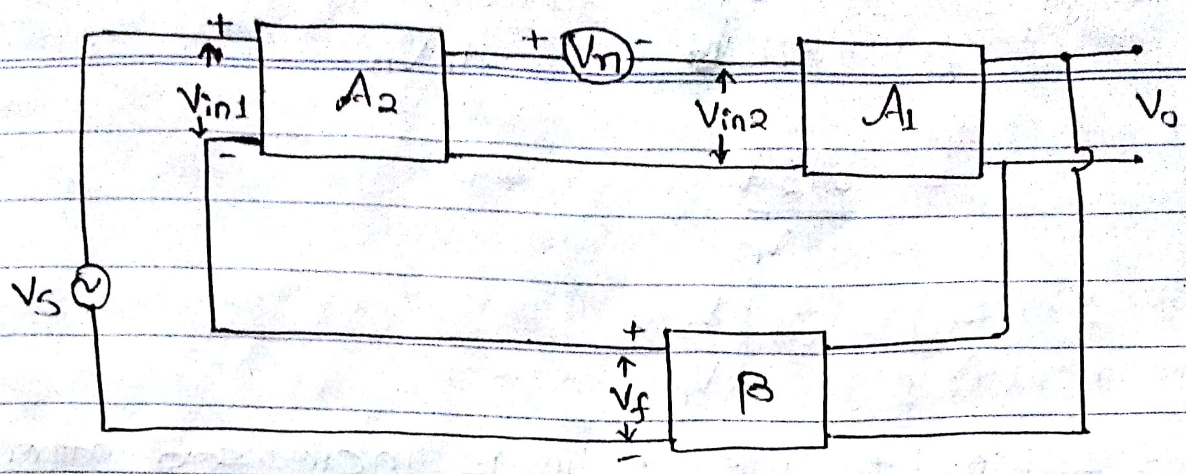
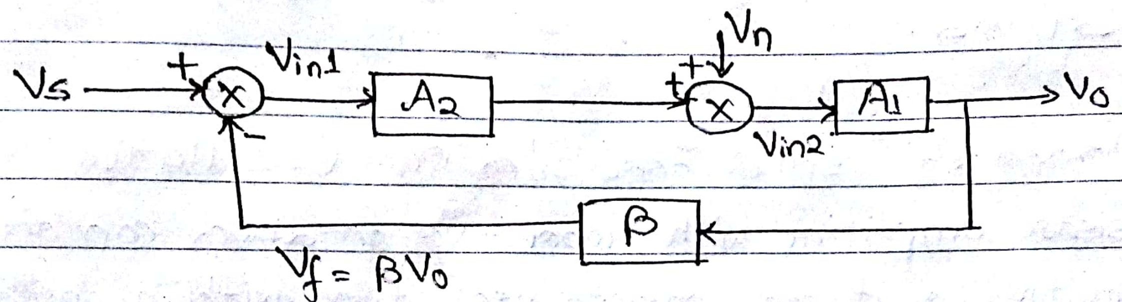


fig: Negative feed back



Here,

$$V_{in1} = V_S - V_f = V_S - \beta V_0$$

$$V_{in2} = A_2 V_{in1} + V_n$$
$$= A_2 (V_S - \beta V_0) + V_n$$
$$= A_2 V_S - A_2 \beta V_0 + V_n$$

And,

$$V_0 = A_1 V_{in2} = A_1 (A_2 V_S - A_2 \beta V_0 + V_n)$$

or, $V_0 = A_1 A_2 V_S - A_1 A_2 \beta V_0 + V_n A_1$

or, $V_0 (1 + A_1 A_2 \beta) = A_1 A_2 V_S + V_n A_1$

or, $V_0 = \dfrac{A_1 A_2 V_S + V_n A_1}{1 + A_1 A_2 \beta}$

or, $V_0 = \underbrace{\left(\dfrac{A_1 A_2}{1 + A_1 A_2 \beta}\right)}_{[\text{Signal}]} V_S + \underbrace{\left(\dfrac{A_1}{1 + A_1 A_2 \beta}\right)}_{[\text{Noise}]} V_n$

Thus signal to Noise ratio after negative feedback is,

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$$(S/N)_f = \left(\frac{A_1 A_2 V_s}{1+A_1A_2\beta}\right) \times \left(\frac{1+A_1A_2\beta}{A_1 V_n}\right)$$

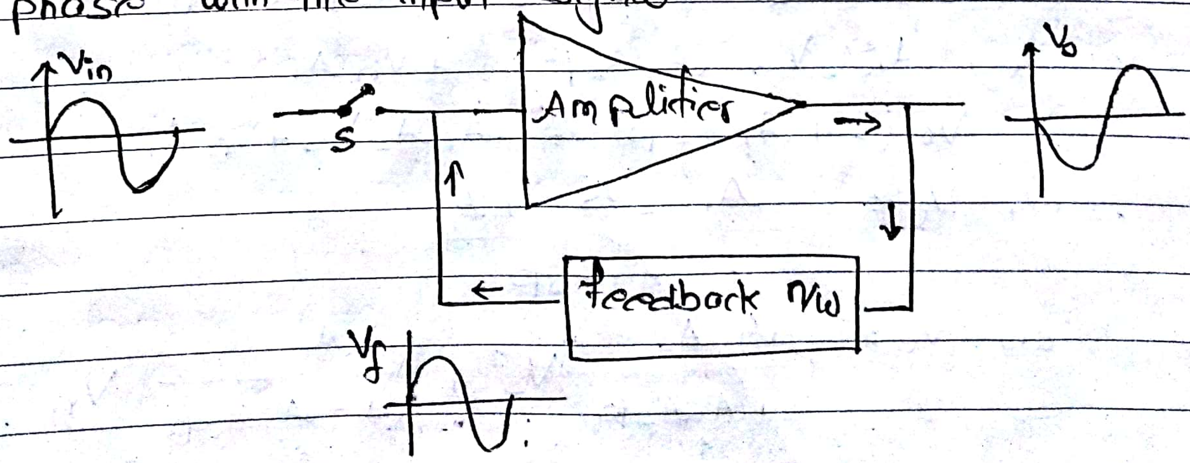
$$= \frac{A_2 V_s}{V_n}$$

$$\Rightarrow \left(\frac{S}{N}\right)_f = A\left(\frac{V_s}{V_n}\right)$$

Thus signal to noise ratio is increased after the -ve feedback. i.e. for fixed i/p signal, noise will be reduced.

Importance of Positive feedback on Oscillation

A transistor amplifier with proper +ve feedback can act as an oscillator i.e. it can generate oscillations without any external source. The +ve feedback is useful for producing oscillators. The condition for +ve feedback is that a portion of the output in combined in phase with the input. A phase shift of 180° is produced by the amplifier & a further phase shift of 180° is introduced by feedback n/w. Consequently, the signal is shifted by 360° & fed to the i/p i.e. feedback voltage is in phase with the input signal.



1) When switch 'S' is closed, the above ckt is producing an oscillations at o/p. However, this ckt has an i/p signal. This is

inconsistent with our definition of an (amplifier) oscillator i.e. an oscillator is a ckt that produces oscillations without any external signal source.

2) When switch 'S' is open, it means the i/p signal is removed. However, V_f (which is in phase with the original signal) is still applied to the i/p signal. The amplifier will respond to this signal in the same way that it did to Vin i.e. V_f will be amplified & sent to the o/p. The feedback n/w sends a portion of the o/p back to the i/p. Therefore, amplifier receive another i/p cycle & another o/p cycle is produced. This process will continue so long as the amplifier is turned on. Therefore, the amplifier will produce a sinusoidal o/p with no external signal source & its expression is given by,

$$A_{V_f} = \frac{A_V}{1 - A_V \cdot m_V} \quad \left(\text{or, } A_f = \frac{A}{1 - A\beta} \right)$$

$A_f = A_{V_f}$ = closed loop gain for +ve feedback Amp.
$\beta = m_V$ = feedback ratio, $A\beta$ = feedback factor.

Practically, the gain which applies at low signal amplitude will be reduced until the o/p amplitude reaches some constant value. However, that limiting value will be independent of i/p, allowing the ckt to produce a desired o/p. This is the important feature of +ve feedback on oscillation.

The voltage gain of an amplifier without feedback is 3000. Calculate the voltage gain of the amplifier if negative feedback is introduced in the ckt. Given feedback fraction = 0.01.

Soln: Here, voltage gain ($A_v = A_V$) = 3000
feedback fraction ($\beta = m_V$) = 0.01

Now, voltage gain with negative feedback is,

$$A_f = \frac{A}{1+A\beta} = \frac{3000}{1+3000\times 0.01} = \frac{3000}{31} = 97.$$

The overall gain of an multistage amplifier is 140. When negative voltage feedback is applied, the gain is reduced to 17.5. Find the fraction of the o/p that is feedback to the i/p.

Soln:

Here, Voltage gain (A) = 140

closed loop gain (A_f) = 17.5

Let β be the feedback fraction that is feedback to the i/p. Then the voltage gain with -ve feedback is,

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

or, $17.5 = \frac{140}{1+140\beta}$

or, $17.5 + 2450\beta = 140$

$\Rightarrow \beta = \frac{122.5}{2450} = \frac{1}{20}$

The voltage gain of an amplifier without feedback is 60dB. It decreases to 40dB with feedback. Calculate the % of o/p which is feedback to the i/p.

Soln:

Here, Open loop gain (A) = 60dB

closed loop gain (A_f) = 40dB

i.e, $20\log_{10}(A) = 60\,dB$

$\Rightarrow A = 10^3 = 1000$

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and, $20\log_{10}(A_f) = 40$

$\Rightarrow A_f = 10^2 = 100$

Now, we have,

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

or, $100 = \frac{1000}{1+1000\beta}$

or, $1+1000\beta = 10$

$\Rightarrow \beta = \frac{9}{1000} = 0.009$

Thus the percentage of o/p which is feedback to the i/p is $= 0.009 \times 100\% = 0.9\%$

A negative feedback of 0.2% is applied to an amp. gain of 60dB. Calculate the % change in the overall gain of feedback amplifier if the internal amplifier is subjected to a gain of the reduction of 15%.

[$\log_a y = x \Rightarrow y = a^x$]

Soln:

Here, Open loop gain (A) = 60dB

or, $20\log_{10} A = 60$

$\Rightarrow A = 10^3 = 1000$

Now, the % change in the gain after negative feedback is given by,

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

where, $dA/A = 15\%$ & $\beta = 0.2\% = 0.002$

$\therefore \frac{dA_f}{A_f} = \frac{1}{(1+1000\times0.002)} \times 15\% = 5\%$

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An amplifier has the midband gain of 1500 & BW of 4MHz. The midband gain reduces to 150 when a negative feedback is applied, Determine the value of feedback & BW.

Soln:

Here, midband gain, $A = 1500$

$BW = 4MHz$

Midband gain with -ve feedback, $A_f = 150$

We have,

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

or, $$150 = \frac{1500}{1+1500\beta}$$

or, $1+1500\beta = 10$ or, $1500\beta = 9$

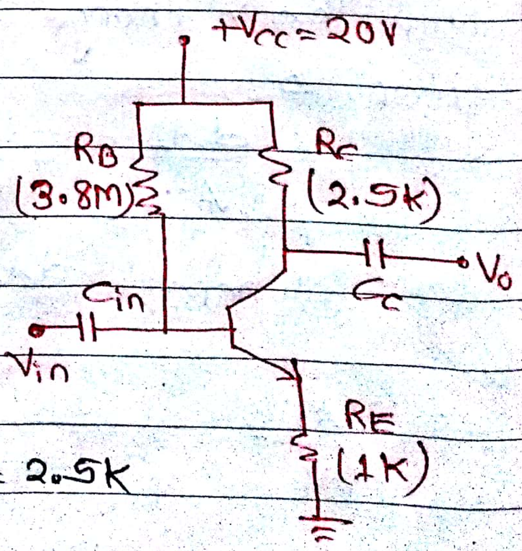
$$\Rightarrow \beta = \frac{9}{1500} = 0.006$$

$\therefore$ feedback ratio, $\beta = 0.006$

and, BW with feedback is,

$$BW_f = BW \times (1+A\beta)$$
$$= 4 \times (1+1500 \times 0.006)$$
$$= 4 \times (1+9)$$
$$= 40 MHz$$

Find feedback ratio, feedback factor, voltage gain without feedback & voltage gain with feedback, for the ckt given. Assume $\beta = 200$ & neglect V_{BE}.



Soln:

Here, Collector load resistance $R_C = 2.5K$

Emitter load resistance, $R_E = 1K$

Let $h_{ie} = 1.1K$

& $h_{fe} = \beta = 200$

Then, voltage gain without feedback is,

$$A = \frac{-h_{fe}}{h_{ie}} \times R_c = \frac{-200}{1.1K} \times 2.5K = -455$$

voltage gain with feedback,

$$A_f = \frac{-R_c}{R_E} = \frac{-2.5}{1} = -2.5$$

Also, we have,

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

where β = feedback ratio

or, $A_f + A_f A\beta = A$

$$\Rightarrow \beta = \frac{A - A_f}{A A_f} = \frac{455 - 2.5}{455 \times 2.5} = 0.398$$

$\therefore \beta = 0.398$

And,

feedback factor $= A\beta = 455 \times 0.398 = 181$.

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