Module-III Feedback amplifier & Oscillators

→ When a fraction of o/p is injected to the i/p, feedback is said to be exist.

→ Depending on the relative polarity of the signal feedback into a ckt, one may have -ve or +ve feedback.

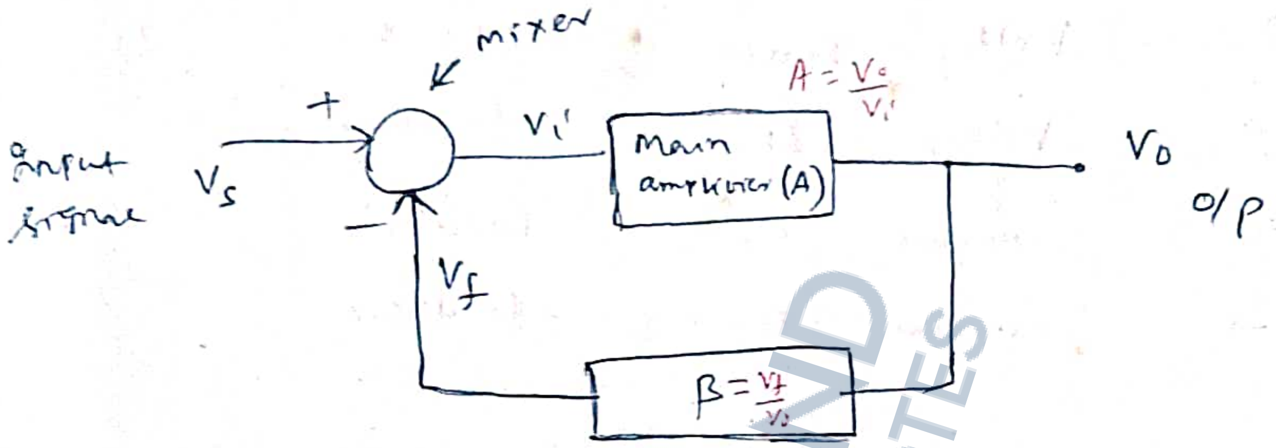
→ -ve feedback results in decreased voltage gain, for which a number of ckt features are improved.

Advantage of -ve feedback :- 2 mark BPUT

1) Stabilized voltage gain.
2) High I/P impedance
3) Low o/p impedance.
4) Reduced noise
5) Nonlinearity & distortion decreases
6) Bandwidth increases (Improved freq response)

→ +ve feedback drives a ckt into oscillation.

→ Consider the block diagram of feedback amplifier. The i/p signal is applied to a mixer n/w, where it is combined with a feedback signal, 'V_f'. The ~~feedback~~ difference of these signals, V_i is then the i/p voltage to the amplifier.



A fraction of amplifier o/p V_o is connected to the feedback n/w (β), which provides a reduced portion of the o/p as feedback signal to the i/p mixer n/w.

Types of feedback ckts:-

A feedback amplifier essentially consists of 2 parts i.e main amplifier & a feedback n/w.

The feedback may also be classified as Voltage feedback and current feedback.

Voltage feedback :-

If the signal feedback is proportional to the o/p voltage of the amplifier it is voltage feedback.

Current feedback :- If the signal feedback is proportional to the o/p current of the amplifier it is current feedback.

Both voltage & current can be feedback to the i/p either in series or in parallel resulting four basic feedback connection, given below

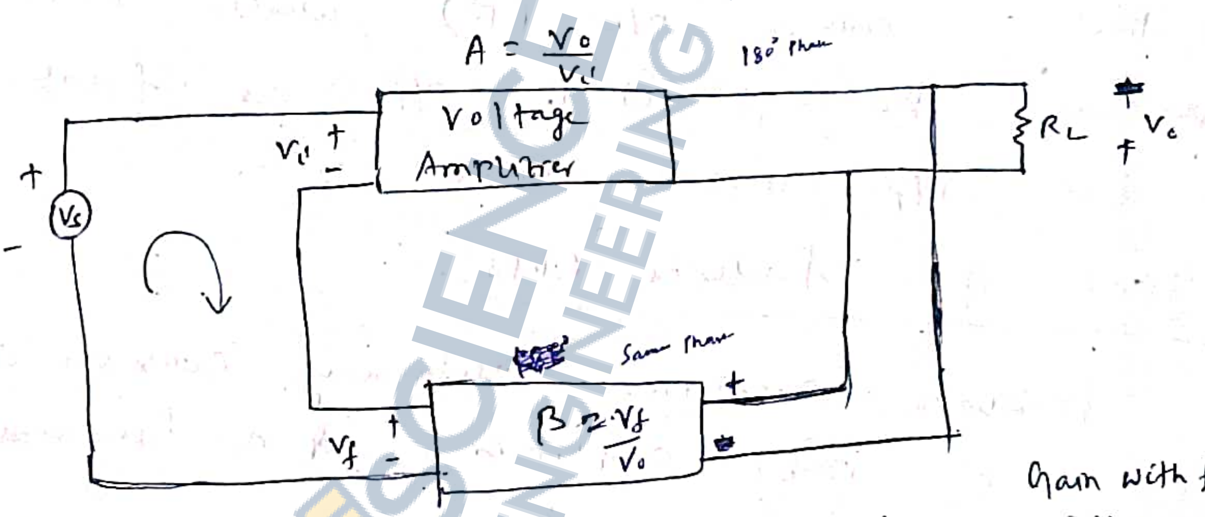
→ Voltage - series feedback.

→ Voltage - shunt feedback.

→ Current - series feedback.

→ Current - shunt feedback.

1) <u>Voltage Amplifier with voltage-series feedback</u>



$V_f = \beta V_o$,

Gain with feedback

$$A_f = \frac{V_o}{V_s} = \cancel{\text{Voltage}}$$

Fig. shows the voltage series feedback connection with a part of o/p voltage fed back in series with the i/p signal, resulting in an overall gain reduction.

<u>Gain</u>

If there is no feedback ($V_f = 0$), the voltage gain of the amplifier stage is

$$A = \frac{V_o}{V_s} = \frac{V_o}{V_i} \quad \text{——— (1)}$$

If feedback signal V_f is connected in series with the I/P, then

$$V_i = V_s - V_f \quad \text{——— (2)}$$

KVL
$V_s - V_i - V_f = 0$
$\Rightarrow V_i = V_s - V_f$

But $V_o = A V_i$

$$V_o = A(V_s - V_f) \quad \text{——— using eq}^n \text{ (2)}$$

or
$A_f = \frac{V_o}{V_s} = \frac{V_o}{V_i + V_f}$
(from eq^n (2))
$A_f = \frac{V_o}{V_i + \beta V_o} = \frac{A\cancel{V_i}}{\cancel{V_i} + \beta A \cancel{V_i}}$
$A_f = \frac{A}{1 + A\beta}$

$$V_o = A V_s - A V_f$$

$$= A V_s - A(\beta V_o) \qquad \left(\because \beta = \frac{V_f}{V_o}\right)$$

$$V_o = A V_s - A\beta V_o$$

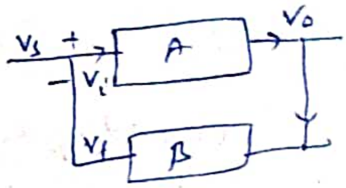
β = feedback ratio

A_f = gain with feedback.

$$\Rightarrow V_o(1 + A\beta) = A V_s$$

$$\Rightarrow \frac{V_o}{V_s} = \frac{A}{1 + A\beta}$$

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



From the above equation, it is seen that the −ve feedback reduces the amplifier gain by a factor $(1 + A\beta)$.

$$|A_f| < |A|$$

→ $(A\beta)$ is known as loop gain.
$\beta \rightarrow$ feedback fraction / feedback ratio

→ when no feedback, $\beta = 0$, $A_f = \frac{A}{1+0} = A$.

→ $A \rightarrow$ Open loop gain, A_f = Closed loop gain.

I/P Impedance :-

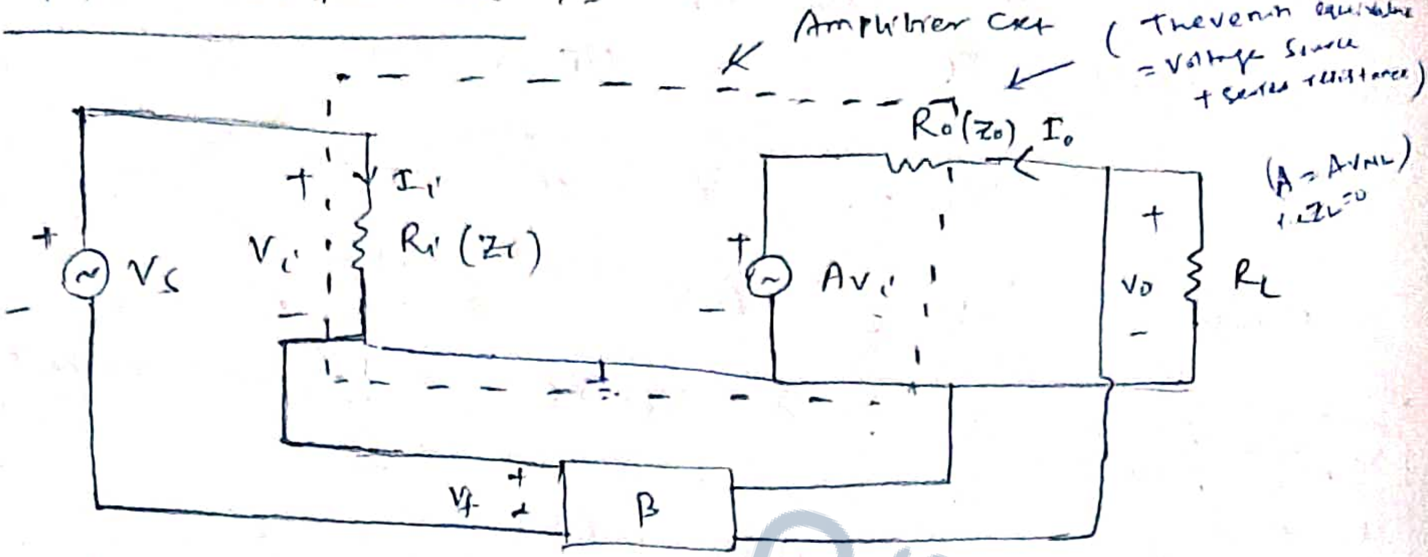


Figure shows the equivalent ckt of voltage series -ve feedback amplifier. The main amplifier has a i/p impedance i.e.

$$R_i \text{ or } Z_i = \frac{V_i}{I_i}$$

If we consider feedback n/w, the i/p impedance with feedback is represented by

$$R_{if} \text{ or } Z_{if} = \frac{V_s}{I_s} = \frac{V_s}{I_i}$$

(∵ Series system $I_s = I_i$]

$$Z_{if} = \frac{V_s}{I_i} \quad \text{——— (1)}$$

Applying KVL in the i/p loop,

$$V_s - V_i - V_f = 0$$

$$\Rightarrow V_s = V_i + V_f \quad \text{——— (2)}$$

Using eqn ② in eqn ①,

$$Z_{if} = \frac{V_i + V_f}{I_i} = \frac{V_i + \beta V_o}{I_i} \quad \left[\because \beta = \frac{V_f}{V_o}\right]$$

$$= \frac{V_i + \beta \cdot (AV_i)}{I_i} \quad \left[\because A = \frac{V_o}{V_i}\right]$$

$$Z_{if} = \frac{V_i}{I_i}(1 + A\beta)$$

$$\Rightarrow \boxed{Z_{if} = Z_i (1 + A\beta)}$$

<u>O/P impedance</u> (Z_{of}) / R_{of}.

$Z_o \to R_o \to$ O/P Resistance without feedback.

$Z_{of} \to R_{of} \to$ O/P Resistance with feedback.

<u>KVL in O/P loop,</u>

$$V_o - I_o R_o - AV_i = 0$$

$$\Rightarrow V_o = I_o R_o + AV_i \quad \text{———} \ ③$$

For O/P impedance calculation V_s ~~is~~ is taken as 0, Eqn ② becomes,

$$0 = V_i + V_f$$

$$\Rightarrow V_i = -V_f \quad \text{———} \ ④$$

Putting eqn ④, in eqn ③, we have

$$V_o = I_o R_o - AV_f$$

$$\Rightarrow V_o = I_o R_o - A(\beta V_o) \qquad \left[\because \beta = \frac{V_f}{V_o}\right]$$

$$\Rightarrow V_o(1+A\beta) = I_o R_o$$

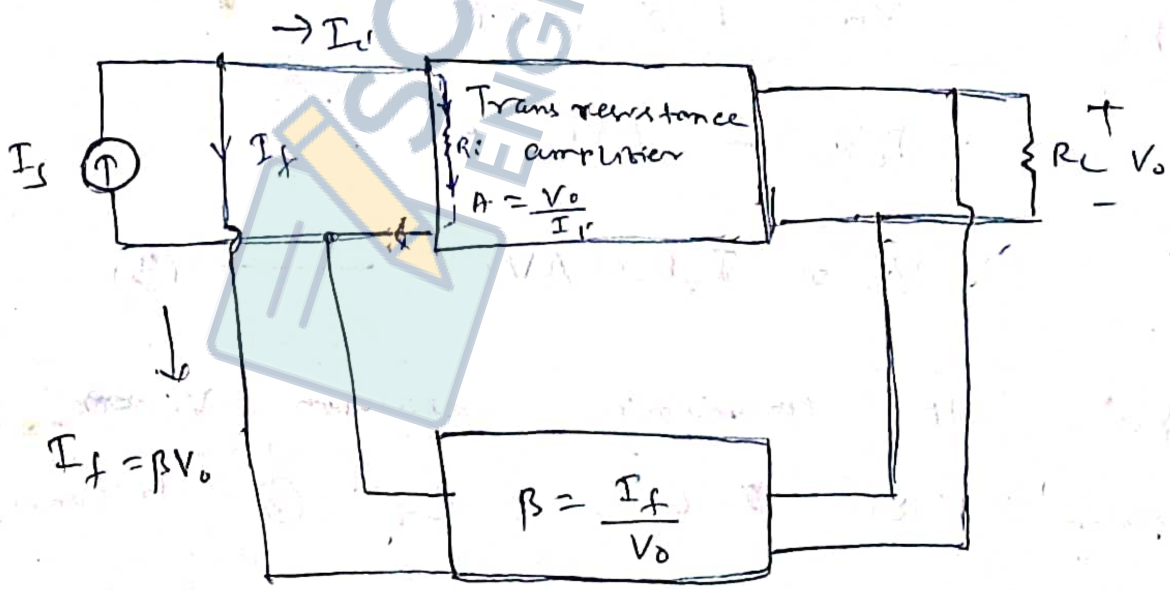
$$\Rightarrow \frac{V_o}{I_o} = \frac{R_o}{1+A\beta}$$

$$\Rightarrow Z_{of} \text{ or } \boxed{R_{of} = \frac{R_o}{1+A\beta}}$$

$\therefore$ Input impedance increases and o/p impedance decreases with feedback by a factor $(1+A\beta)$

2) Trans ~~conductance~~ resistance amplifier with Voltage shunt ~~amplifier~~ feedback :-

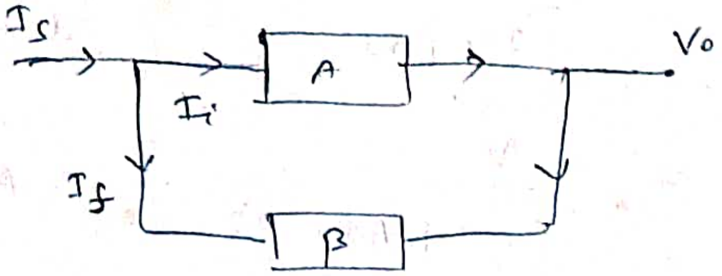
o/p voltage / i/p current



$$A_f = \frac{V_o}{I_s}$$

[Write the theory similar to as described for voltage series feedback]

Gain



$$\beta = \frac{I_f}{V_o} \quad \text{——— (1)}$$

$$I_s = I_i + I_f \quad \text{——— (2)}$$

$$A_f = \frac{V_o}{I_s} = \frac{V_o}{I_i + I_f} = \frac{V_o}{I_i + \beta V_o}$$

[using eqⁿ (1)]

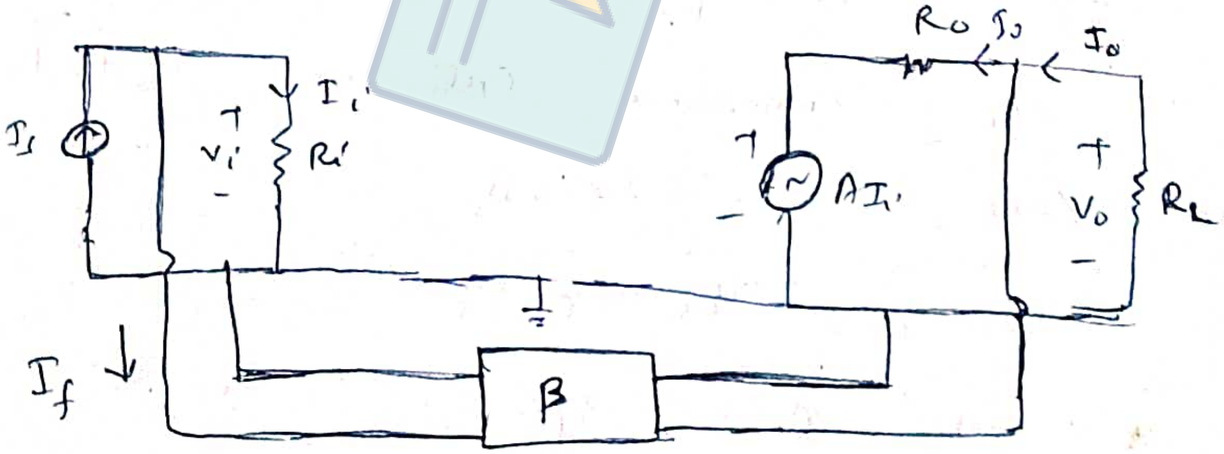
$$A_f = \frac{\cancel{AV_i}\ A\cancel{I_i}}{\cancel{I_i} + \beta A \cancel{I_i}}$$

[$\because A = \frac{V_o}{I_i}$ = Transresistance amplifier]

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

[Thevenin equivalent = Voltage source + series resistance]

I/P impedance



$$R_{if} = \frac{V_s}{I_s} = \frac{V_s}{I_i + I_f} = \frac{V_s}{I_i + \beta V_o}$$

[$\because \beta = \frac{I_f}{V_o}$]

$$\Rightarrow R_{if} = \frac{V_i}{I_i + \beta V_o} \quad \left[\because V_s = V_i \text{ due to Shunt} \right]$$

$$= \frac{V_i}{I_i + \beta A I_i} \quad \left[\because A = \frac{V_o}{I_i} \right]$$

$$= \frac{V_i}{I_i(1+A\beta)}$$

$$= R_i \left(\frac{1}{1+A\beta} \right)$$

$$\therefore \boxed{R_{if} = \frac{R_i}{1+A\beta}}$$

O/P impedance :-

KVL in O/P loop

$$V_o - I_o R_o - A I_i = 0$$

$$\Rightarrow V_o = I_o R_o + A I_i \quad \text{——— (1)}$$

$$I_s = I_i + I_f$$

For O/P impedance Calculation, V_s is taken as zero, $\therefore I_s = 0$

$$\Rightarrow 0 = I_i + I_f$$

$$\Rightarrow I_i = -I_f$$

eqn (1) becomes,

$$V_o = I_o R_o - A I_f \quad \text{——— (2)}$$

But $\beta = \frac{I_f}{V_o}$

$\Rightarrow I_f = \beta V_o$

$\therefore$ eqn (2) becomes,

$V_o = I_o R_o - A\beta V_o$

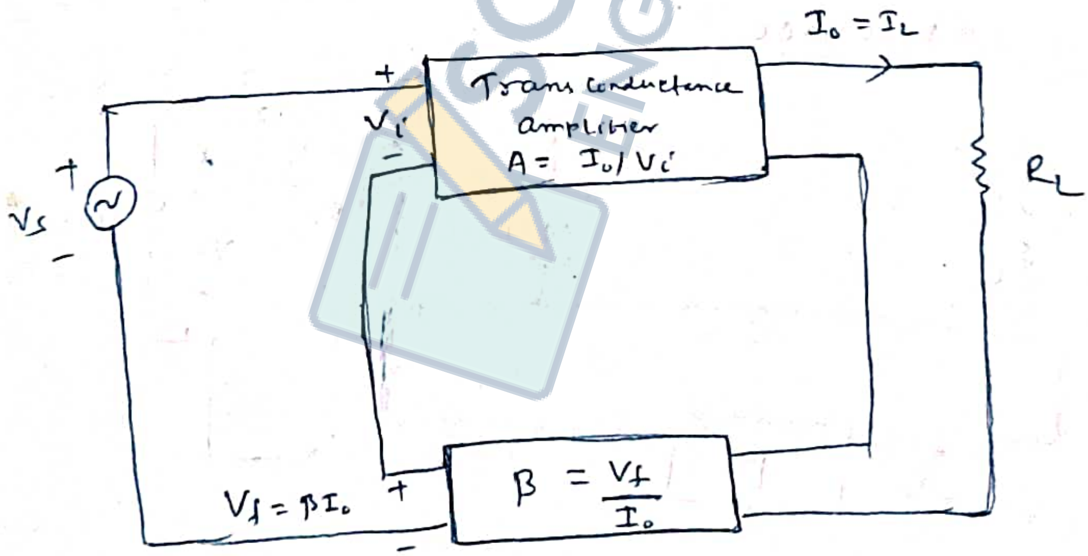
$\Rightarrow V_o(1+A\beta) = I_o R_o$

$\Rightarrow \frac{V_o}{I_o} = \frac{R_o}{1+A\beta}$

$\Rightarrow \boxed{R_{of} = \frac{R_o}{1+A\beta}}$

$\therefore$ Both i/p & o/p impedance decrease by a factor $(1+A\beta)$.

3) gmp - BPUT **Transconductance amplifier with current series feedback**

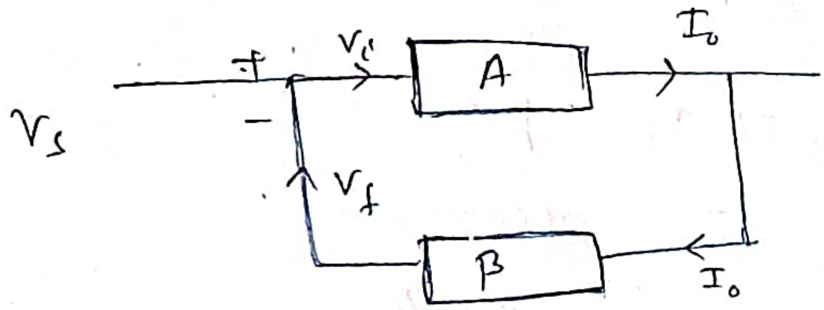


$A_f = \frac{I_o}{V_s}$

Applying KVL in the i/p loop

$V_s - V_i - V_f = 0 \Rightarrow V_s = V_i + V_f$ —(1)

Gain



$$A_f = \frac{I_o}{V_s} = \frac{I_o}{V_f + V_i} \quad \left[\text{using eq}^n\ (1)\right]$$

$$= \frac{I_o}{\beta I_o + V_i}$$

$$= \frac{A\cancel{V_i}}{\beta A\cancel{V_i} + \cancel{V_i}}$$

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

$\beta = \frac{V_f}{I_o}$

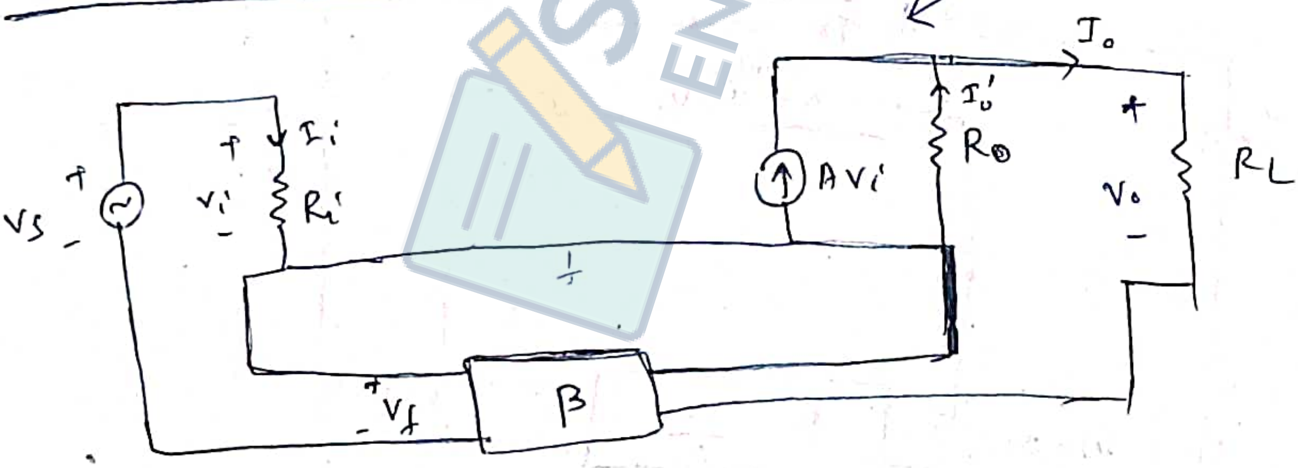
$\Rightarrow V_f = \beta I_o$

$A = \frac{I_o}{V_i}$

$\Rightarrow I_o = AV_i$

i/p impedance

(Norton equivalent = current source + parallel resistance)



KVL in the i/p loop

$$V_s - V_i - V_f = 0$$

$$\Rightarrow V_s = V_i + V_f \quad \text{——— } (1)$$

$$V_s = I_i R_i + \beta I_o$$

$$= I_i R_i + \beta A V_i$$

$$\because \beta = \frac{V_f}{I_o} \qquad A = \frac{I_o}{V_i}$$

$$V_s = I_i R_i + \beta A \cdot (I_i R_i)$$

$$V_s = I_i R_i (1 + A\beta)$$

$$\Rightarrow \frac{V_s}{I_i} = R_i (1 + A\beta)$$

$$\Rightarrow \boxed{R_{if} = R_i (1 + A\beta)}$$

O/P impedance :-

From fig

$$I_o = A v_i + I_o' \quad \text{—— (I)}$$

For calculation of R_o, V_s is made zero, $V_s = 0$,

eqn (1) becomes

$$0 = V_i + V_f$$

$$\Rightarrow V_i = -V_f$$

$$\Rightarrow I_o = A(-V_f) + \frac{V_o}{R_o} \qquad \beta = \frac{V_f}{I_o}$$

$$\Rightarrow I_o = A(-\beta I_o) + \frac{V_o}{R_o}$$

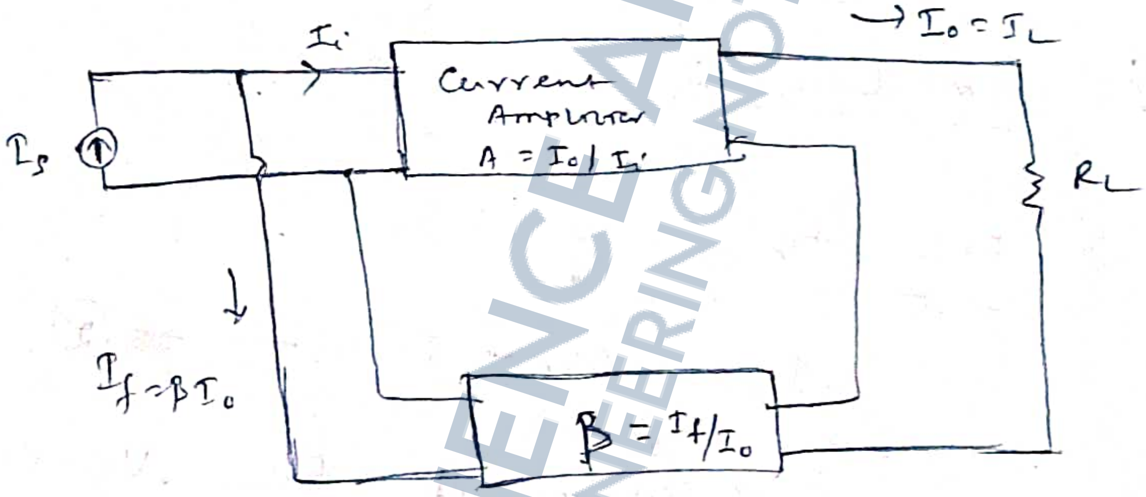
$$\Rightarrow I_o (1 + A\beta) = \frac{V_o}{R_o}$$

$$\Rightarrow V_o / I_o = R_o (1 + A\beta)$$

$$\Rightarrow \boxed{R_{of} = R_o (1 + A\beta)}$$

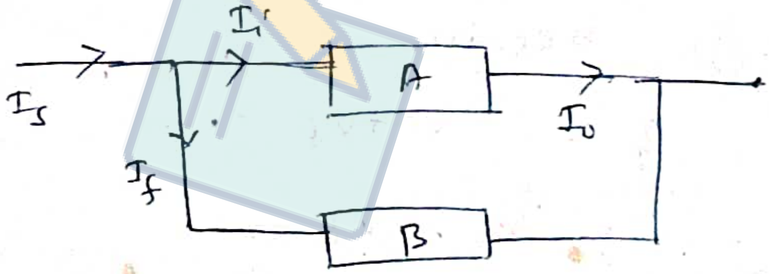
∴ Both i/p & o/p impedance increase by a factor $(1 + A\beta)$

4) <u>Current amplifier with current shunt feedback</u>



$$A_f = \frac{I_o}{I_s}$$

<u>Gain</u> :-



$$I_s = I_f + I_i$$

$$A_f = \frac{I_o}{I_s} = \frac{I_o}{I_f + I_i} = \frac{I_o}{\beta I_o + I_i}$$

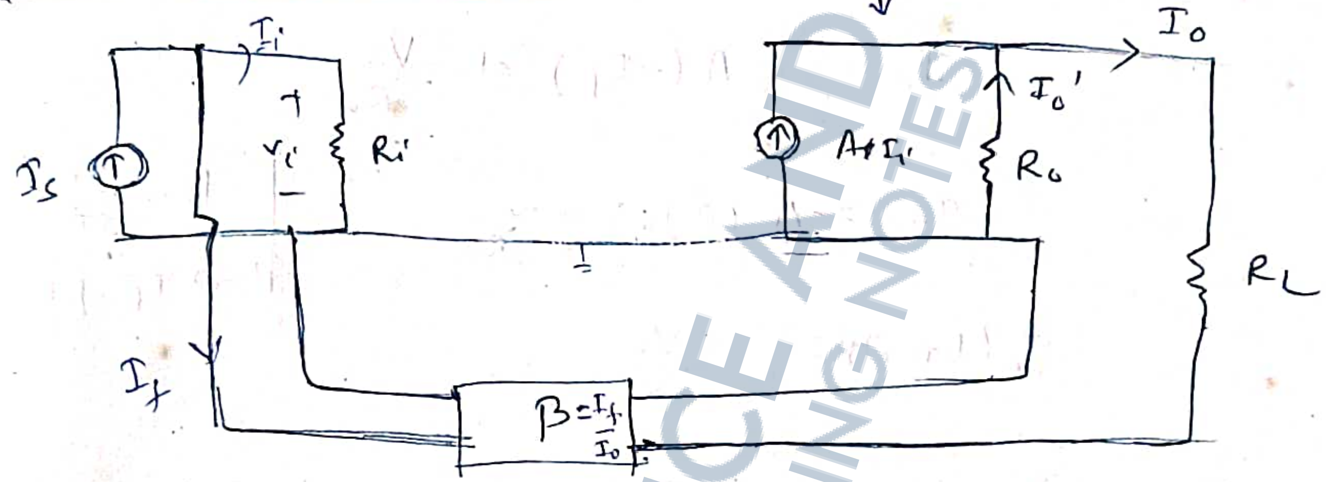
$$\because \beta = \frac{I_f}{I_o}$$

$$\therefore A_f = \frac{A \cancel{I_i}}{\beta (A \cancel{I_i}) + \cancel{I_i}} \qquad \Big| \because A = \frac{I_o}{I_i}$$

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

I/P impedance

Norton equivalent. (Current source + parallel resistance)



"shunt"

$$R_{if} = \frac{V_s}{I_s} = \frac{V_i}{I_s} = \frac{V_i}{I_f + I_i} = \frac{V_i}{\beta I_o + I_i} = \frac{V_i}{\beta (A I_i) + I_i}$$

$$\left(\because A = \frac{I_o}{I_i} \right)$$

$$R_{if} = \frac{V_i}{I_i(1+A\beta)} = \frac{R_i}{1+A\beta} \qquad \left(\because R_i = \frac{V_i}{I_i} \right)$$

$$\Rightarrow \boxed{R_{if} = \frac{R_i}{1+A\beta}}$$

O/P impedance

To find $\boxed{R_{of} = \frac{V_o}{I_o}}$

$$I_o = A I_i + I_o' \quad \text{——— (1)}$$

For calculation of O/P impedance, $V_s = 0$

$\Rightarrow I_s = 0$

But $I_s = I_f + I_i'$

$\Rightarrow 0 = I_f + I_i'$

$\Rightarrow I_f = -I_i'$

$\therefore$ Eq^n (1) becomes,

$$I_o = A(-I_f) + \frac{V_o}{R_o}$$

$$I_o = -A(\beta I_o) + \frac{V_o}{R_o}$$

$\beta = \frac{I_f}{I_o}$

$\Rightarrow I_f = \beta I_o$

$$\Rightarrow I_o(1+A\beta) = \frac{V_o}{R_o}$$

$$\Rightarrow \frac{V_o}{I_o} = R_o(1+A\beta)$$

$$\Rightarrow \boxed{R_{of} = R_o(1+A\beta)}$$

$\therefore$ I/P impedance decreases & O/P impedance increases by a factor $(1+A\beta)$

Summary :-

1) In all the 4 cases $\boxed{A_f = \frac{A}{1+A\beta}}$

2)

	Voltage-Series	Voltage-Shunt	Current-Series	Current Shunt
$R_{if} \rightarrow$	$R_i(1+A\beta)$	$\frac{R_i}{1+A\beta}$	$R_i(1+A\beta)$	$\frac{R_i}{1+A\beta}$
$R_{of} \rightarrow$	$\frac{R_o}{1+A\beta}$	$\frac{R_o}{1+A\beta}$	$R_o(1+A\beta)$	$R_o(1+A\beta)$

Practical feedback circuits

1) Voltage-series feedback

Fig shows an FET amplifier stage with voltage-series feedback. A part of the o/p signal (V_o) is obtained using a feedback n/w of resistor R_1 & R_2. The feedback voltage V_f is connected in series with source signal V_s, their difference being the i/p signal V_i.

without feedback the amplifier gain is

$$A = \frac{V_o}{V_i} = -g_m R_L \quad \text{—} \; (1)$$

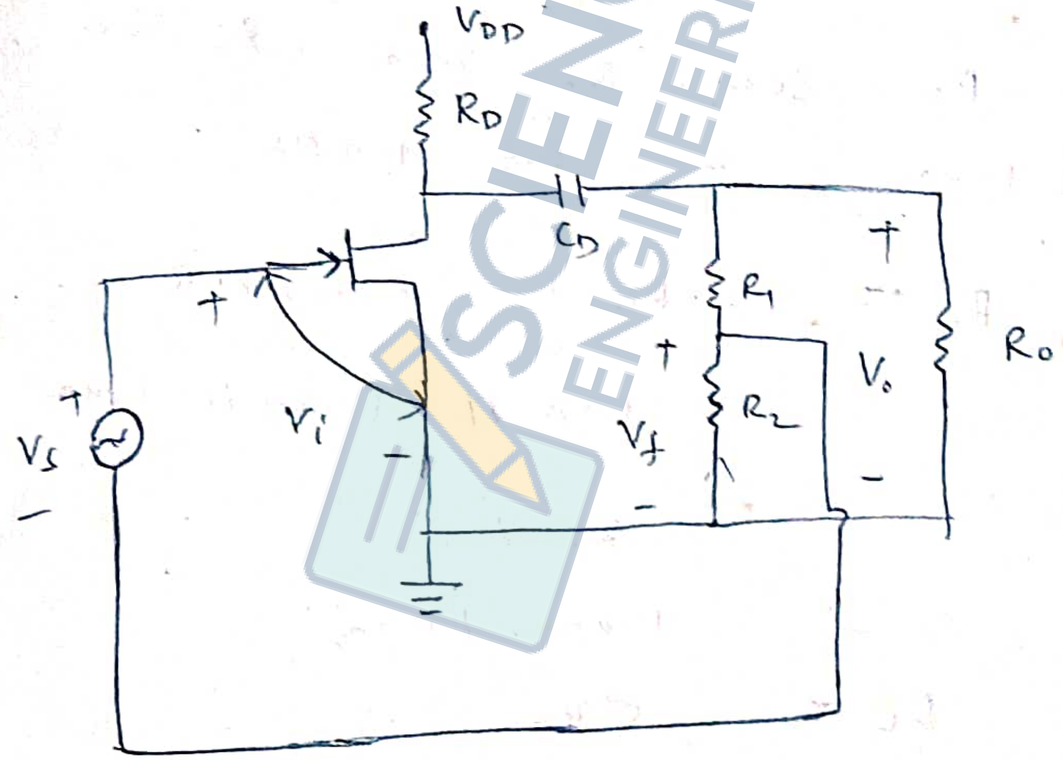


fig:- FET amplifier stage with voltage-series feedback

$$R_L = R_D \,//\, (R_1 + R_2) \,//\, R_o$$

$$\beta = \text{feedback factor} = -\frac{R_2}{R_1 + R_2}$$

[-ve sign shows, V_f is 180° out of phase w.r.t V_s]

$$\therefore A_f = \frac{A}{1+A\beta} = \frac{-g_m R_L}{1+(-g_m R_L)\left[\frac{-R_2}{R_1+R_2}\right]}$$

$$A_f = \frac{-g_m R_L}{1+\left[\frac{R_2 R_L}{R_1+R_2}\right] g_m}$$

If $A\beta >> 1$

$$A_f = \frac{\cancel{A}}{\cancel{A}\beta} = \frac{1}{\beta} = -\frac{R_1+R_2}{R_2}$$

Ex:- 35 Calculate the gain without & with feedback for the FET amplifier circuit.

Given $R_1 = 80k\Omega$, $R_2 = 20k\Omega$, $R_o = 10k\Omega$, $R_D = 10k\Omega$, and $g_m = 4000\ \mu S$

Ans :-

$$R_L \simeq R_D \,//\, (R_1+R_2) \,//\, R_o$$

$$= 10k\Omega \,//\, 100k\Omega \,//\, 10k\Omega$$

$$\simeq R_D \,//\, R_o$$

$$\simeq 10k\Omega \,//\, 10k\Omega$$

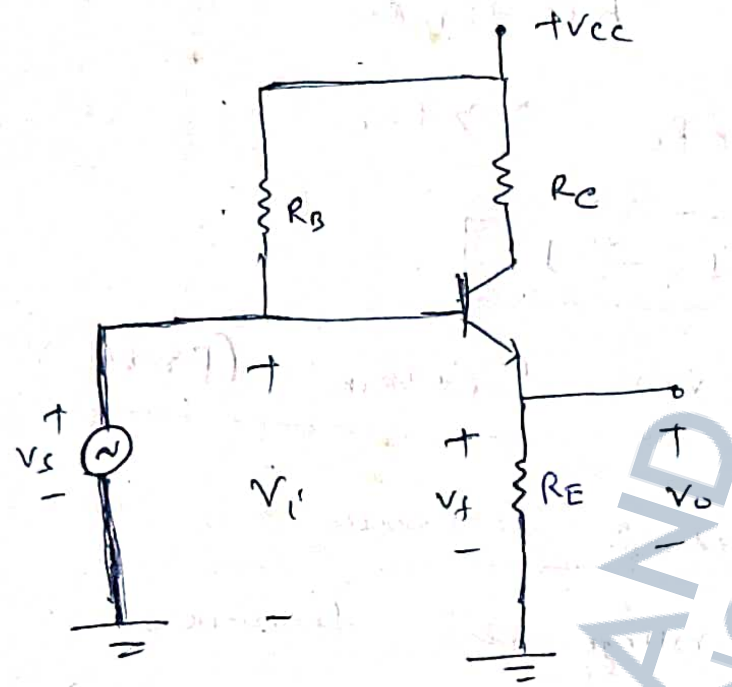
$$R_L \simeq 5k\Omega$$

$$A_2 \; -g_m R_L = -4000 \times 10^{-6} \times 5 \times 10^3 = -20$$

$$\beta = \frac{-R_2}{R_1+R_2} = \frac{-20}{80+20} = -0.2$$

$$A_f = \frac{A}{1+A\beta} = \frac{-20}{1+(-20)(-0.2)} = \frac{-20}{1+4} = -4$$

Voltage-series feedback (using emitter follower)



The emitter follower ckt, provides voltage-series feedback. The signal voltage V_s is the i/p voltage V_i. The o/p voltage V_o is also the feedback voltage in series with i/p voltage.

The operation of the ckt without feedback provides $V_f = 0$, so that

$$A = \frac{V_o}{V_s} = \frac{h_{fe} I_b \cdot R_E}{V_s} = \frac{h_{fe} \cdot R_E \left(\frac{V_s}{h_{ie}}\right)}{V_s}$$

$$A = \frac{h_{fe} R_E}{h_{ie}} \quad \text{——} (1)$$

$$\beta = \frac{V_f}{V_o} = 1$$

The operation with feedback,

$$A_f = \frac{V_o}{V_s} = \frac{A}{1+A\beta} = \frac{\frac{h_{fe} R_E}{h_{ie}}}{1+\left(\frac{h_{fe} R_E}{h_{ie}}\right) \cdot 1}$$

$$A_f = \frac{h_{fe} R_E}{h_{ie} + h_{fe} R_E}$$

For $h_{fe} R_E >> h_{ie}$

$$\boxed{A_f \simeq 1}$$

Advantages of -ve feedback (Proof)

1) **Input Impedance increases**

Derived in voltage-series feedback.

$$R_{if} = R_o(1+A\beta)$$

2) **O/P impedance decreases**

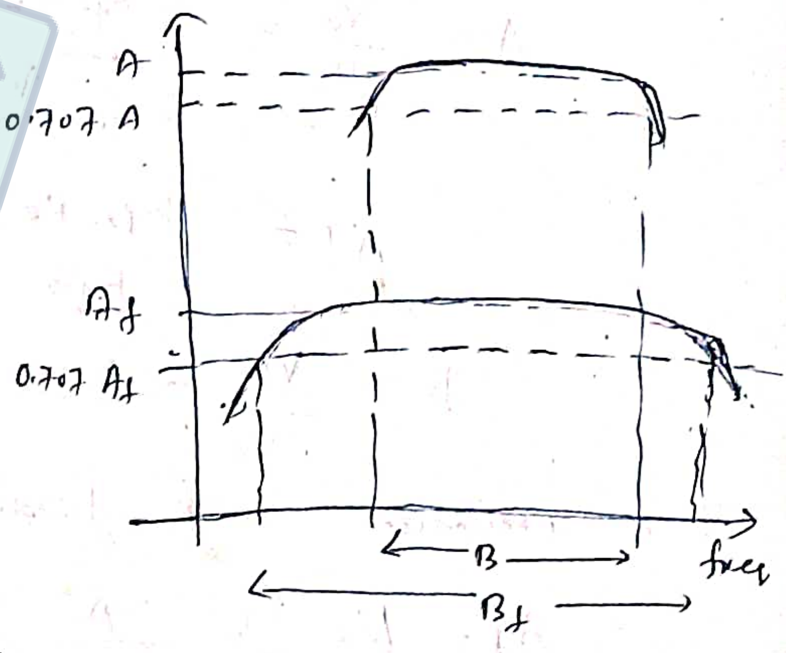
Derived in voltage-series feedback

$$R_{of} = \frac{R_o}{1+A\beta}$$

3) **Bandwidth increases :-**

Always the product of gain & BW is a Const.

Bandwidth means the difference betn the lower & upper cutoff freq.



$$A \times B = A_f \times B_f$$

$$\Rightarrow B_f = \frac{AB}{A_f}$$

$$= \frac{AB}{\left(\frac{A}{1+A\beta}\right)}$$

$$\Rightarrow B_f = \frac{\cancel{A}B \times (1+A\beta)}{\cancel{A}}$$

$$\Rightarrow \boxed{B_f = B(1+A\beta)}$$

$\therefore$ Bandwidth of feedback amplifier increases by a factor of $(1+A\beta)$.

4) Stabilization of gain with -ve feedback

The variation in temperature, supply voltages, aging of components or variation in transistor parameters with replacement are some of the factors that affect the gain of the amplifier and cause it to change.

However, the overall gain of the amplifier can be made independent of these variations if -ve feedback is used.

$$\rightarrow A_f = \frac{A}{1+A\beta}, \quad \text{if } A\beta \gg 1, \text{ then}$$

$$A_f \simeq \frac{\cancel{A}}{\cancel{A}\beta} = \frac{1}{\beta}$$

$\therefore$ The gain is thus independent of internal gain of the amplifier & depends on the passive elements such as resistors.

[Ex:- β (feedback ratio) $= -\frac{R_2}{R_1+R_2}$ in FET feedback amplifier]

The value of resistors remains fairly constant because they can be chosen very precisely with almost zero temp. coefficient of resistance. Thus the gain is stabilized.

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

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

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

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

Dividing both the sides by A_f

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

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

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

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

Since $1+A\beta >> 1$, $\frac{1}{1+A\beta}$ is a fraction.

$$\Rightarrow \frac{dA_f}{A_f} < \frac{dA}{A}$$

i.e % Change in gain with feedback is less than % Change in ~~to~~ gain without feedback.

∴ The -ve feedback improves the gain stability of the amplifier.

Ex:- 36 If the amplifier with gain of -1000 & feedback of $\beta = -0.1$ has a gain change of 20% due to temperature, Calculate the change in gain of the feedback amplifier.

Ans.
$$\frac{dA_f}{A_f} = \left(\frac{1}{1+A\beta}\right) \cdot \frac{dA}{A} \simeq \frac{1}{A\beta} \cdot \frac{dA}{A}$$

$$\Rightarrow \frac{dA_f}{A_f} = \frac{1}{(-1000)\times(-0.1)} \times \frac{20\%}{\cancel{100}} = \frac{20}{\underset{5}{100}} \%$$

$$\Rightarrow \boxed{\frac{dA_f}{A_f} = 0.2\%}$$