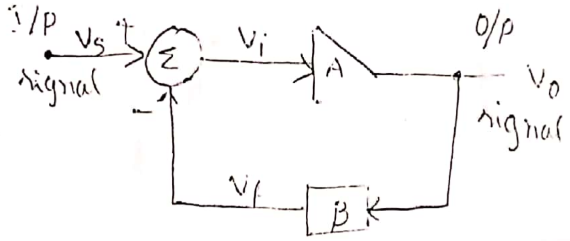
FEEDBACK AMPLIFIERS

UNIT - V

Concepts of Feedback:-

A portion of the o/p signal is taken from the o/p of the amplifier and is combined with the i/p signal is called feedback given to the circuit.



fig(1)
Block diagram of a feedback circuit

Fig (1) shows the feedback connection. The input signal V_s is applied to mixer circuit, where it is combined with a feedback signal, V_f. The differ of these signals, V_i is then the i/p signal of the amplifi.

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

Feedback networks are two types. ① Negative F.B
② Positive F.B

Negative Feedback is a portion of the o/p signal is subtracted from the input signal.

Positive Feedback is a portion of the o/p signal is added to the input signal.

If the feedback signal is opposite polarity to the i/p signal, as shown in fig (1) is called as a negative feedback while Negative feedback, results in reduce the overall gain but it is used to maintain high i/p impedance, better stabilized voltage gain, freq response, Low o/p impedance, Reducing noise etc..

Positive feedback is used in the design of osc. and in a number of other applications.

Advantages and Disadvantages of Negative Feedback:-

Advantages:- [Characteristics]

1. Gain sensitivity
2. Bandwidth extension
3. Noise sensitivity
4. Reduction of nonlinear distortion
5. Control of impedance levels

Disadvantages:-

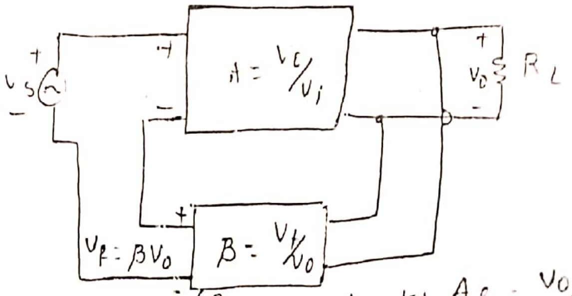
1. ~~Circuit gain~~ reduction in gain

~~2. Stability~~

Classification of Feedback Amplifiers:-

There are four basic ways of connecting the feedback signal. Both the voltage and current can be fed back to the i/p either in series or parallel.

1. Voltage series feedback
2. Voltage shunt "
3. Current series "
4. Current shunt "



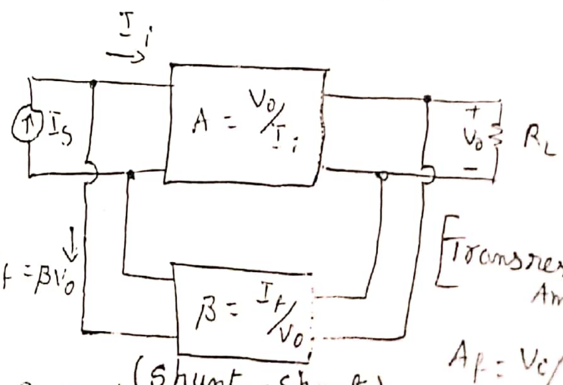
(Series - shunt) $A_f = V_o/V_s$

1. Voltage series feedback

→ Series feedback connections tends to increase the i/p impedance while shunt connections tends to decrease the i/p resistance.

→ Voltage refers to connecting the o/p voltage as input to the F.B n/w.

→ Current refers to tapping off some o/p current through the F.B n/w.



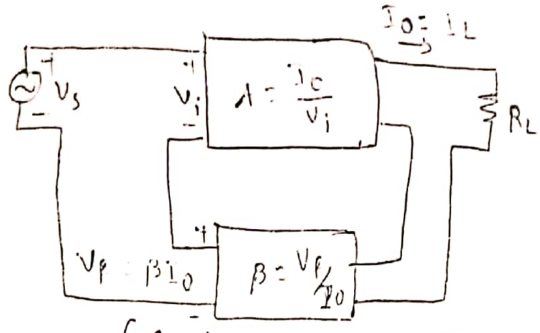
(Shunt - Shunt)

Transresi. Amp

$A_f = V_o/I_i$

2. Voltage shunt feed back

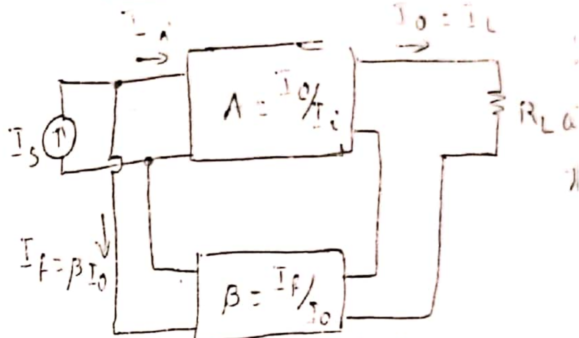
→ ~~Voltage~~ F.B tends to decrease the o/p impedance while current F.B tends to increase the o/p impedance.



(Series - Series) → Transconductance

3. Current series feed back Amp.

$$A_f = I_0/V_s$$



(shunt - series)

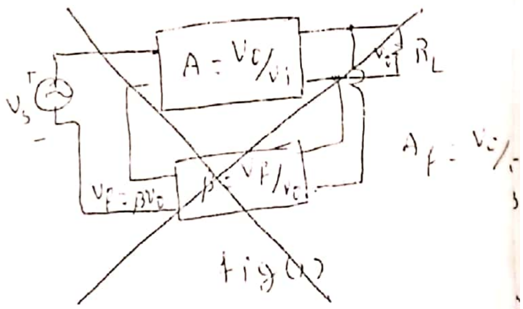
4. Current shunt feedback

$$A_f = I_0/I_s$$

~~General characteristics of Negative Feedback Amplifiers~~ :-

Effect of Feedback on Amplifier characteristics :-

① Signal Gain :-

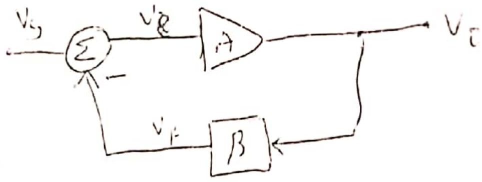


From fig (1), the o/p signal is

$$\boxed{V_o = A V_e} \quad — ①$$

where A is the amplification factor.

Feedback signal is $\boxed{V_f = \beta V_o}$ — ②



where β in this case is the feedback transfer function.

At summing node, we have $\boxed{V_e = V_s - V_f}$ — ③

where V_s is the input signal.

From eqn ① then becomes $V_o = A(V_s - V_f) = AV_s - AV_f$

$$V_o = AV_s - A\beta V_o \quad — ④$$

Closed - loop transfer function or gain, which is

$$A_f = \frac{V_o}{V_s} = \frac{AV_s - A\beta V_o}{V_s} = \frac{A}{(1 + A\beta)} \quad — ⑤$$

$$= \frac{A(V_s - \beta V_o)}{V_s} = A - A\beta\frac{V_o}{V_s}$$

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

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

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

The signals V_s, V_o, V_f and V_ε can be either currents or voltages. However, they do not need to be all voltages or all currents in a given feedback amplifier.

Eqn (5) can be written $A_f = \frac{A}{1+A\beta} = \frac{A}{1+T}$ —— (6)

where $T = \beta A$ is the loop gain.

For negative feedback, we assume T to be a positive real factor.

combining eqn (1) and (2), we obtain the loop gain relationship.

$$T = A\beta = \frac{\cancel{V_o}}{V_\varepsilon} \times \frac{V_f}{\cancel{V_o}} = \frac{V_f}{V_\varepsilon} \quad — (7)$$

Normally the error signal is small, so that the expected loop gain is large

If the loop gain is large so that $A\beta >> 1$, then from eqn (6), we have $A_f \cong \frac{A}{A\beta} = \frac{1}{\beta}$ — (8)

Hence the gain or transfer function of the feedback amplifier essentially becomes a function of the feedback network only.

The feedback circuit is usually composed of passive elements, which means that the feedback amplified gain is almost completely independent of the basic amplifier properties. Since the feedback amplifier gain is a function of the feedback elements only.

Hence, the individual transistor parameters may vary widely, and may depend on temperature and frequency, but the feedback amplifier gain is constant. So the results of -ve F.B is stability in the amp characteristics.

(or) Improved stability

② **Gain Sensitivity:- (stabilisation of Gain)**

If the loop gain $T = \beta A$ is very large, the overall gain of the feedback amp. is essentially a function of the feedback network only.

If the feedback transfer function β is constant, then taking the derivative of A_f with respect to A, from eqn ⑤, produces.

$\log x = \frac{1}{x} \cdot dx$

$u = A$, $v = \frac{1}{1+A\beta}$

$\frac{d\,uv}{dA} \Rightarrow \frac{1}{1+A\beta} + A \cdot -1($

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

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

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

taking log on both sides

$$A_f = \frac{A}{1+A\beta} \quad \text{—— ⑤}$$

$\log A_f = \log A - \log(1+A\beta)$

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

diff above eqn

$\frac{1}{A_f} dA_f = \frac{1}{A} \cdot dA - \frac{1}{1+A\beta} \cdot \beta dA$

$\frac{dA_f}{A_f} = \frac{dA}{A} - \frac{\beta dA}{1+A\beta}$

$$dA_f = \frac{dA}{(1+\beta A)^2} \quad \text{—— ⑥}$$

Dividing both sides of eqn ⑥ by closed loop gain yields

$$\frac{dA_f}{A_f} = \frac{\frac{dA}{(1+\beta A)^2}}{\frac{A}{1+A\beta}} = \frac{1}{1+\beta A} \frac{dA}{A} = \left(\frac{A_f}{A}\right)\frac{dA}{A} \quad \text{—— ⑦}$$

$= \frac{dA}{A}\left[1 - \frac{A\beta}{1+A\beta}\right]$

$= \frac{dA}{A}\left[\frac{1+A\beta - A\beta}{1+A\beta}\right)$

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

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

→ The term $\frac{dA_f}{A_f}$ represents the fractional change in amplifier voltage gain with feedback.

→ The term $\frac{dA}{A}$ denotes the fractional change in voltage gain without feedback.

→ The term $\boxed{\frac{1}{1+A\beta}}$ is called sensitivity.

Ex:- sensitivity is 0.1, the percentage change in A_f is one-tenth of the percentage variation in A.

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The sensitivity is defined as the ratio of percentage change in voltage gain with feedback to percentage change in voltage gain without feedback

$$\boxed{\text{Sensitivity} = \frac{(dA_f/A_f)}{(dA/A)} = \frac{1}{1+A\beta}}$$

The reciprocal of the term sensitivity is called desensitivity i.e $\boxed{1+A\beta}$.

③ Bandwidth Extention:-

The amplifier bandwidth is a function of feedback. Assume the frequency response of the basic amplifier is

$$A = \frac{A_0}{1+\frac{s}{\omega_H}} \quad \text{—— ①} \qquad A = \frac{A_{vm}}{1+j\frac{f}{f_H}}$$

where A_0 is the ~~low~~ mid-frequency or mid band gain, ω_H is the upper 3dB or corner frequency.

The closed loop gain of the feedback amplifier can be expressed as

$$A_f = \frac{A}{1+\beta A} \quad \text{—— ②}$$

where we assume that the feedback transfer function β is independent of frequency.

Substituting eqn ① and ②, then we can write the clossed loop gain in the form

$$A_f = \frac{\frac{A_0}{1+\frac{s}{\omega_H}}}{1+\beta\left(\frac{A_0}{1+s/\omega_H}\right)} = \frac{A_0}{1+\frac{s}{\omega_H}} \times \frac{1+\frac{s}{\omega_H}}{1+\frac{s}{\omega_H}+\beta A_0} = \frac{A_0}{1+\beta A_0}\left[\frac{1}{1+\frac{s}{\omega_H(1+\beta A_0)}}\right] \quad \text{—— ③}$$

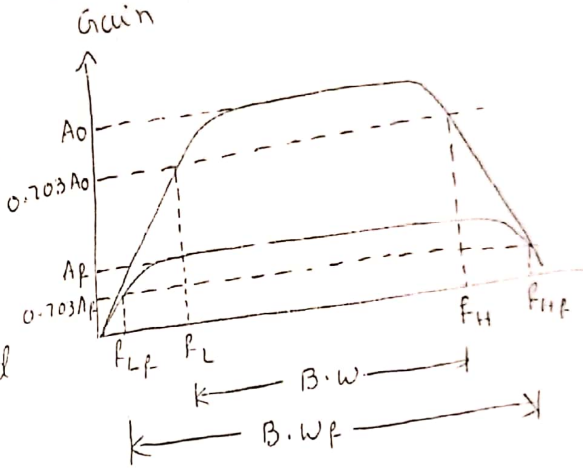
$$A_{vf} = \frac{A_{vm}}{1+j\frac{f}{f_H}} \times \frac{1+j\frac{f}{f_H}}{1+\beta A_{vm}+j\frac{f}{f_H}}$$

dividing numerator & denominator by $1+\beta A_{vm}$

$$A_f = \frac{A_{vmf}}{1+j(f/f_{Hf})}$$

$$A_{vmf} = \frac{A_{vm}}{1+\beta A_{vm}}, \quad f_{Hf} = f_H(1+\beta A_{vm})$$

From eqn (3), the low frequency closed-loop gain is smal[ler] than the open-loop gain by a factor of $(1+\beta A_0)$, but t[he] closed-loop 3dB frequency is larger than the open loop val[ue] by a factor of $(1+\beta A_0)$.



→ If we multiply the ~~low~~ high-freq open-loop gain A_0 by the b.w (3dB) W_H, we obtain $A_0 W_H$. Which is the gain-bandwidth product.

→ The product of ~~low~~ high-freq closed loop gain and closed loop b.w is

$$\boxed{\frac{A_0}{1+\beta A_0}\left[W_H(1+\beta A_0)\right] = A_0 W_H} \quad — (4)$$

→ eqn (4) states that gain-b.w product of a feedback am[p] is a constant.

$$\frac{A_{v0}}{1+\beta A_{v0}}\left[f_H(1+\beta A_{v0})\right] = A_{v0} f_H$$

(4) Noise Sensitivity:-

In any electronic system, unwanted random and extraneous signals may be present in addition to the desired signal. These random signals are called noise.

Electronic noise can be generated within an amp. or may enter the amplifier along with the i/p signal.

Negative feedback may reduce the noise level in amp., more accurately, it may increase the signal-to-noise rati[o].

The i/p signal-to-noise ratio is defined as

$$(SNR)_i = \frac{S_i}{N_i} = \frac{V_i}{V_n} \quad — (1)$$

where $S_i = V_i$ is input source signal and $N_i = V_n$ is the i/p noise signal.

(5) Reduces the frequency Distortion.

$$A_f = \frac{A}{1+A\beta} \Rightarrow \text{for -ve F.B } A\beta >> 1 \therefore A_f \simeq \frac{1}{\beta} \Rightarrow$$ A_f becomes independent [of] freq. even when A is depe[ndent] on freq.

[illegible]

$$N_f = N - A\beta N_f$$

$$N_f = \frac{N}{1+A\beta}$$

The output signal-to-noise ratio is

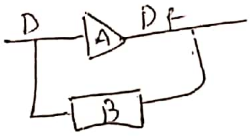
$$(SNR)_o = \frac{S_o}{N_o} = \frac{A_{Ti} S_i}{A_{Tn} N_i} \quad \text{—— (2)}$$

where the desired o/p signal is $S_o = A_{Ti} S_i$ and the o/p signal is $N_o = A_{Tn} N_i$.

→ The parameter A_{Ti} is the amplification factor that multiplies the source signal.

→ The parameter A_{Tn} is the amplification factor that multiplies the noise signal.

→ A large signal-to-noise ratio allows the signal to be detected without any loss of information. This is a desirable characteristic.



(5) Reduction of Nonlinear Distortion :-

→ Distortion in an o/p signal is caused by a change in the basic amplifier gain or a change in the slope of the basic amplifier transfer function.

D → O. Loop Dist

D_f → closed loop dist

→ The change in gain is a function of the nonlinear properties of bipolar and MOS transistors used in the basic amplifier.

$D_f = DX$ —(1)

where X = F.B factor

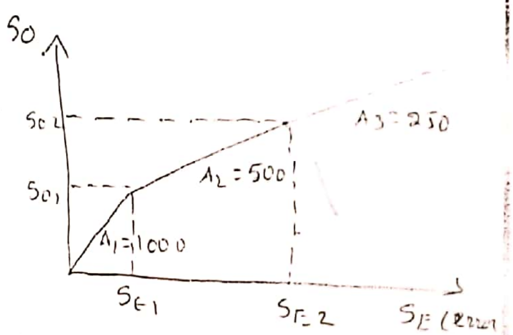
After amplification Dist becomes $A\beta DX$

it is antiphase with original D

→ Assume the basic amplifier or open-loop transfer function is shown in fig(a), which shows changes in gain as the i/p signal changes.

$\therefore D_f = D - A\beta DX$ —(2)

Comparing two eqns



(a) open loop transfer characteristics

→ When this amplifier is incorporated in a feedback circuit with a feedback transfer function of $\beta = 0.099$, the resulting closed-loop characteristics are shown in fig(b).

$DX = D - A\beta DX$

$DX(1+A\beta) = D$

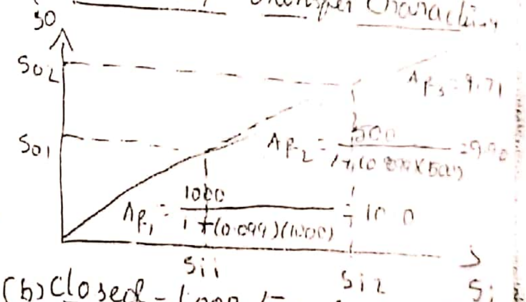
$DX = \frac{D}{1+A\beta}$

where $X = \frac{1}{1+A\beta}$

$\therefore \cancel{D_f = \frac{D}{1+A\beta}}$

$D_f = D - A\beta D_f$

$$\boxed{D_f = \frac{D}{1+A\beta}}$$



(b) Closed-Loop transfer char.

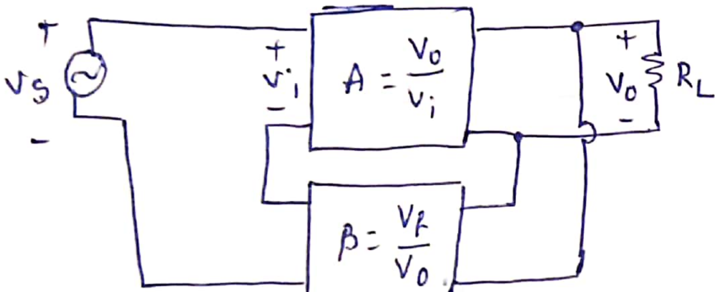
→ This transfer function also has changes in gain but, where the open-loop gain changes by a factor of 2, the closed-loop gain changes by only 1 percent and 2 percent respectively.

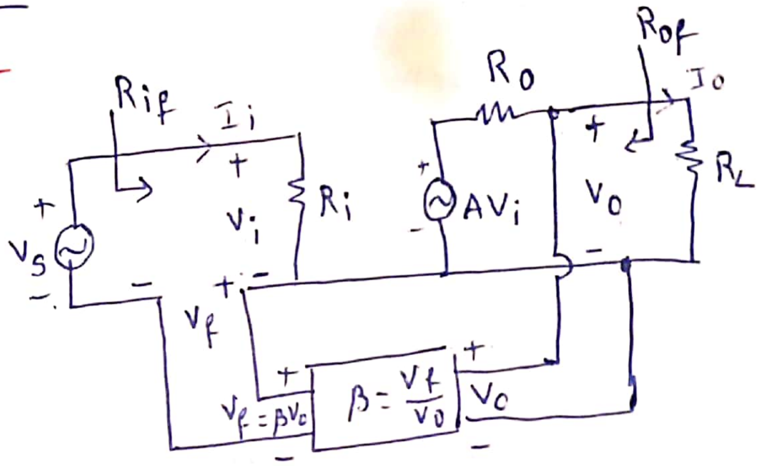
→ A smaller change in gain means less distortion in the O/p signal of the negative feedback amplifier.

is stabilized.

Classifications of FB Amplifier

Voltage Series FB Amplifier :-





$R_{if} = \frac{V_s}{I_i}$; $V_f = \beta V_0$

$V_0 = AV_i$

$V_i = V_s - V_f$

$V_s = V_i + V_f$

$= V_i + \beta V_0 = V_i + \beta A V_i$

$= V_i(1 + A\beta)$

$\therefore R_{if} = \frac{V_s}{I_i} = \frac{V_i(1+A\beta)}{I_i}$

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

$R_{of} = \frac{V_0}{I_0}\Big|_{V_s = 0}$

$V_s = V_i + V_f$

if $V_s = 0$ then $V_i = -V_f$

$V_0 = AV_i + I_0 R_0$

$I_0 R_0 = V_0 - AV_i$

$I_0 = \frac{V_0 + AV_f}{R_0}$

$= \frac{V_0 + A\beta V_0}{R_0}$

$I_0 = \frac{V_0(1 + A\beta)}{R_0}$

$\therefore R_{of} = \frac{V_0}{I_0} = \cancel{\frac{V_0(1+A\beta)}{R_0 I_0}} = \frac{V_0 R_0}{V_0(1+A\beta)} = \boxed{\frac{R_0}{1+A\beta}}$

$A_{vf} = \frac{V_0}{V_s}$

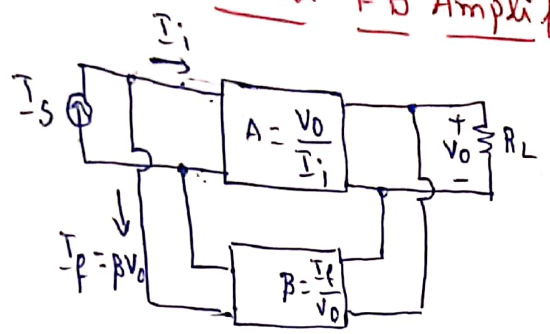
$V_s = V_i + V_f$

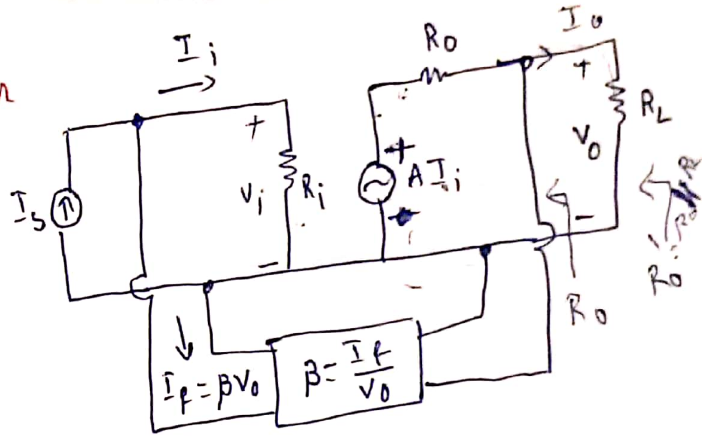
$= V_i(1 + A\beta)$

$A_{vf} = \frac{V_0}{V_i(1+A\beta)}$

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

Voltage Shunt FB Amplifier





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

$$I_i = I_s - I_f$$

$$I_s = I_i + I_f$$

$$= I_i + \beta V_o$$

$$= I_i + \beta A I_i$$

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

$$\boxed{\therefore R_{if} = \frac{V_i}{I_i(1+A\beta)} = \frac{R_i}{1+A\beta}}$$

$$R_{of} = \frac{V_o}{I_o}\Big|_{I_s=0}$$

$$V_o = AI_i + I_o R_o$$

$$I_o = \frac{V_o - AI_i}{R_o}$$

if $I_s = 0$, $I_i = -I_f$

$$\therefore I_o = \frac{V_o + AI_f}{R_o}$$

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

$$\boxed{\therefore R_{of} = \frac{\cancel{V_o} R_o}{\cancel{V_o}(1+A\beta)} = \frac{R_o}{1+A\beta}}$$

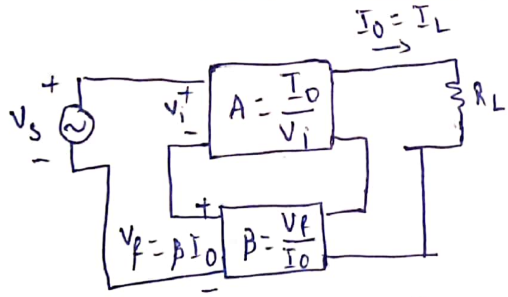
$$A_f = \frac{V_o}{I_s}$$

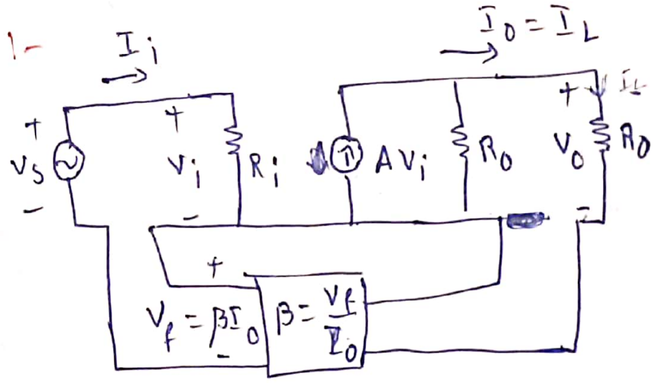
$$= \frac{V_o}{I_i + I_f}$$

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

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

(3) Current Series FB Amplifier:-





$$R_{if} = \frac{V_s}{I_i}$$

$$V_i = V_s - V_f$$

$$V_s = V_i + V_f$$

$$= V_i + \beta A V_i$$

$$= V_i(1+A\beta)$$

$$\boxed{\therefore R_{if} = \frac{V_i(1+A\beta)}{I_i} = R_i(1+A\beta)}$$

$$R_{of} = \frac{V_o}{I_o}\Big|_{V_s=0}$$

if $V_s = 0$, $V_i = -V_f$

$$I_o = AV_i + \frac{V_o}{R_o}$$

$$= -AV_f + \frac{V_o}{R_o}$$

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

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

$$= I_o(1+A\beta)$$

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

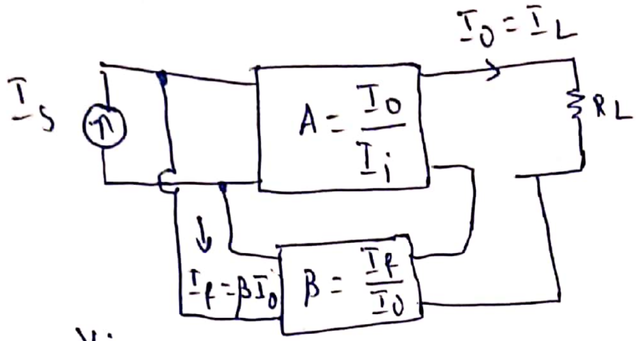
$$\therefore R_{of} = \frac{\cancel{I_o} R_o(1+A\beta)}{\cancel{I_o}}$$

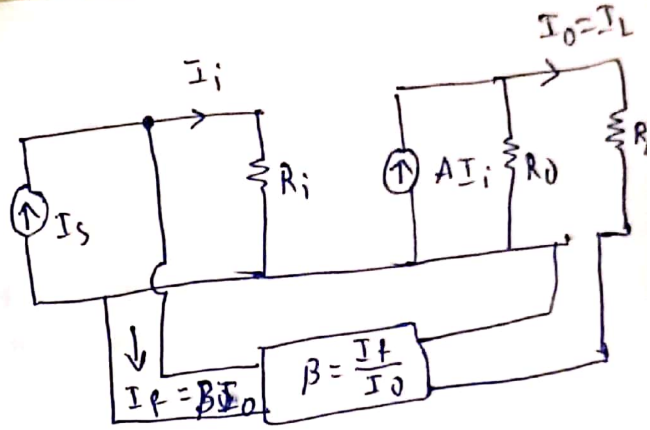
$$\boxed{R_{of} = R_o(1+A\beta)}$$

$$A_f = \frac{I_o}{V_s} = \frac{I_o}{V_i(1+A\beta)}$$

$$\boxed{\therefore A_f = \frac{A_G}{1+A_G\beta}}$$

Current Shunt FB Amplifier:-





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

$$I_i = I_s - I_f$$

$$I_s = I_i + I_f$$
$$= I_i + \beta I_0$$
$$= I_i + \beta A I_i$$
$$= I_i(1+A\beta)$$

$$\boxed{\therefore R_{if} = \frac{V_i}{I_i(1+A\beta)} = \frac{R_i}{(1+A\beta)}}$$

$$R_{of} = \frac{V_0}{I_0}\Big|_{I_s=0}$$

if $I_s = 0$, $I_i = -I_f$

$$I_0 = AI_i + \frac{V_0}{R_0}$$

$$\frac{V_0}{R_0} = I_0 - AI_i$$
$$= I_0 - A(-I_f)$$
$$= I_0 + A\beta I_0$$
$$= I_0(1+A\beta)$$

$$\therefore V_0 = I_0 R_0 (1+A\beta)$$

$$R_{of} = \frac{V_0}{I_0} = \frac{\cancel{I_0} R_0(1+A\beta)}{\cancel{I_0}}$$

$$\boxed{R_{of} = R_0(1+A\beta)}$$

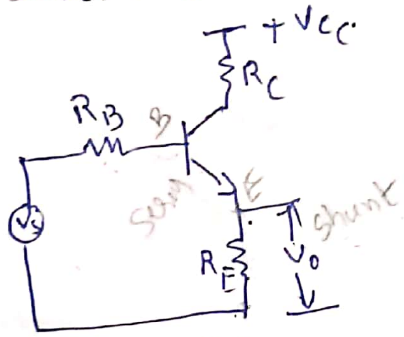
$$A_f = \frac{I_0}{I_s} = \frac{I_0}{I_i + I_f} = \frac{I_0}{I_i(1+A\beta}$$

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

Examples

① Voltage Series FB Amp — Noninverting (Op-Amp) Amp

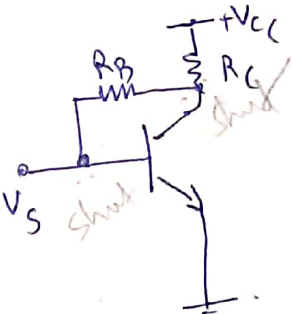
Series - shunt FB Amp



CC Amplifier

② Voltage - Shunt — Inverting Amp

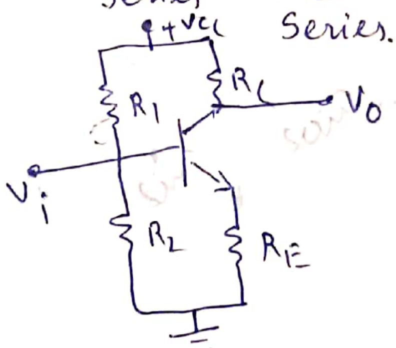
shunt - ~~shunt~~



collector to Base bias Amp.

③ Current - Series

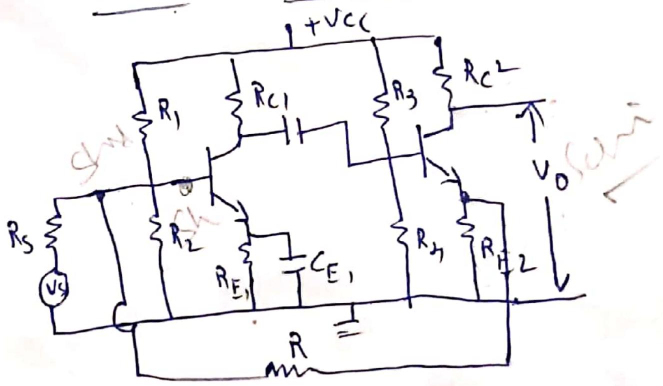
Series - ~~Shunt~~ Series.



CE Amp without bypass capacitor

④ Current - shunt

shunt - Series.



Two-stage Amplifier