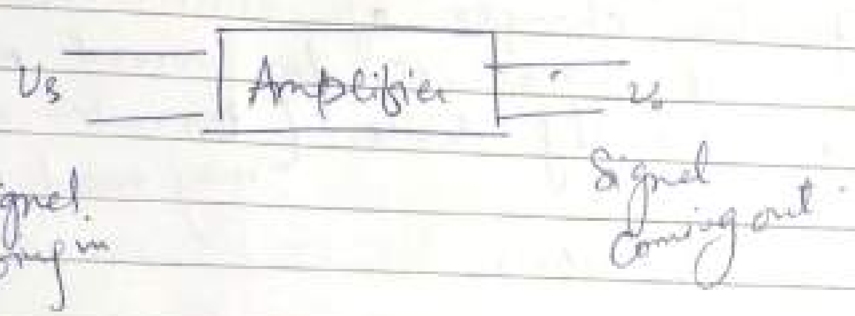
Feedback in Amplifiers

Positive and Negative feedback, Effect of negative feedback on I/P impedence, o/P impedence, Gain, Stability, Distortion and Noise.

What is feedback? What kind of feedback we can use?

FEEDBACK



Purpose of Amplifier is to amplify the signal without changing its characteristics except the magnitude.

∴ Output of Amplifier is a func" of I/P.

If O/P is not influenced by I/P, The ckt is called Open loop having no feedback ie
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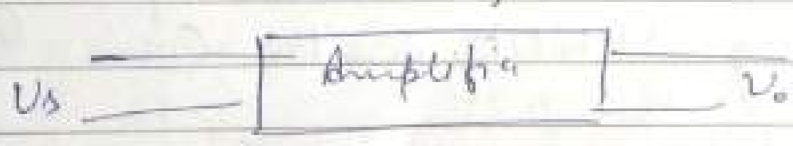


Here, no O/P is not feedback to I/P.

But this is not a good ckt ∵ performance of the amplifier will change if the situations such as temp" variation will change.

In an Open loop Amplifier

Voltage gain $A = \frac{V_o}{V_s}$ or $V_o = A V_s$

If gain changes i.e. If A becomes A + ΔA then o/p will change i.e. $v_o + \Delta v_o$

$$\Delta v_o = \Delta A \cdot v_s$$

Any change in gain of amplifier will reflect change in o/p voltage which is not accepted

Gain may change from
① Temperature changes of environment
② Aging (Use of a ckt for several months/years)
③ Replacement of device. ('transistor or resistor' may need change)
④ Voltage fluctuations

We are supposed to design a ckt which will not be affected by above mentioned changes in Gain. This is acheived by feedback.

feedback → A fraction of o/p voltage is mixed with I/P.

∴ Real I/P is Geometrical sum of applied signal and the fraction which we are feeding back. This will bring stability in the Gain

Two types of Feedbacks :-

① Positive feedback
Input = $v_s + v_f$ where v_f = Return signal fraction of o/p being fed to input.
Hence, O/P will also Increase and these steps cumulate and ultimately the gain will become very high and lead to "Instability" to the ckt. This is known as positive feedback. Positive feedback is

avoided in Amplifier, but used in oscillator circuits.

② Negative feedback

o/p phase is opposite to I/p phase in -ve feedback.

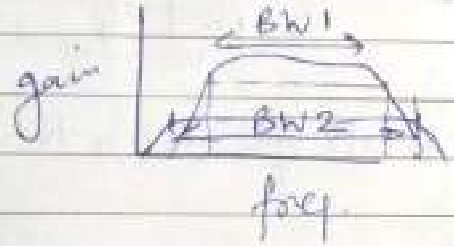
Net I/p to the amplifier is $= v_s - v_f$

-ve feedback can modify ckt. performance such as

① Stability of gain against all source of variation

② Reduces non-linear distortions

③ Increases the Bandwidth (BW)



BW1 < BW2

BW1 → without -ve feedback

BW2 → with -ve feedback

④ -ve feedback modifies (increase or decrease) the I/p and o/p impedance

One has to pay the price for all these advantages i.e. the disadvantage of negative feedback is that it reduces the gain of the amplifier.

Hence, multistage amplifier is used to increase the overall gain amplifier i.e.

gain $A_1 = \frac{v_2}{v_1}$ $A_2 = \frac{v_3}{v_2}$ $A_3 = \frac{v_4}{v_3}$

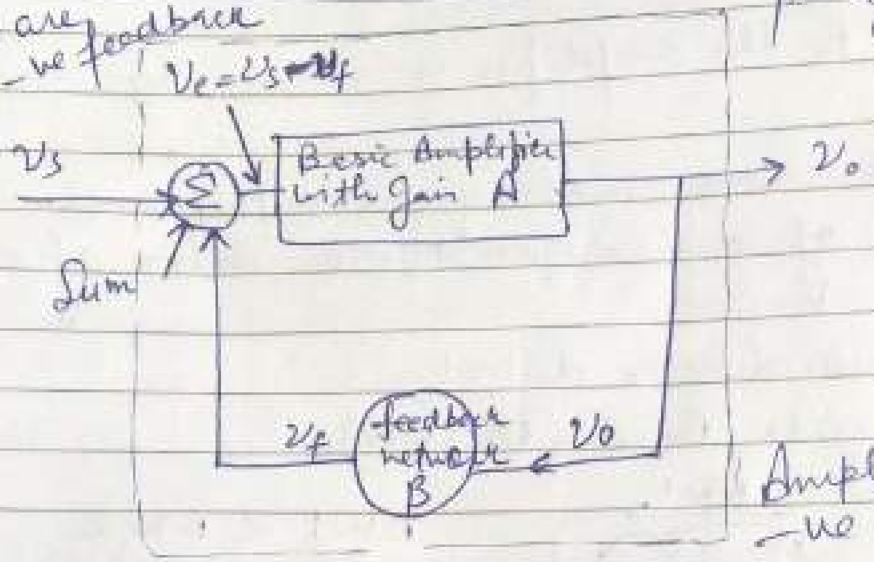
Overall gain of Amplifier $A = \frac{v_4}{v_1} = A_1 \times A_2 \times A_3 = \frac{v_2}{v_1} \times \frac{v_3}{v_2} \times \frac{v_4}{v_3}$

∴ Gain Reduction in Negative feedback is not a big problem. It can be boosted with by using Multistage Amplifiers.

General feedback Relation:

A = Gain of Basic Amp
β - Gain of feedback network

Here we are considering -ve feedback



feedback network usually consists of one or two resistors

Various Quantities involved.

A = Open loop gain of amplifier
i.e. gain without feedback

β = feedback factor or Gain of feedback circuit
i.e., $\beta = \frac{\text{Output voltage}}{\text{I/P voltage}}$

i.e. $\beta = \frac{v_f}{v_o}$

where v_f = feedback voltage
v_o = O/P "
v_e = error signal / error voltage

From above figure

$v_o = A v_e$ ①

$v_e = v_s - v_f$ ②

$v_f = \beta v_o$ ③

Substitute v_f from (3) into (2)

i.e. $v_e = v_s - \beta v_o$

Substitute this value of v_e into Eqn (1)

$v_o = A(v_s - \beta v_o)$

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

Gain of Amplifier with feedback $A_{FB} = \frac{v_o}{v_s} = \frac{A}{1+\beta A}$

(A_{FB} → Gain with feedback)

$$A_{fB} = \frac{A}{1+\beta A}$$ for Negative feedback

$$A_{fB} = \frac{A}{1-\beta A}$$ for Positive feedback

βA → called as "LOOP GAIN"

(1) GAIN STABILITY

(O/P voltage donot change due to any ckt modifications).

$$A_{fB} = \frac{A}{1+\beta A}$$

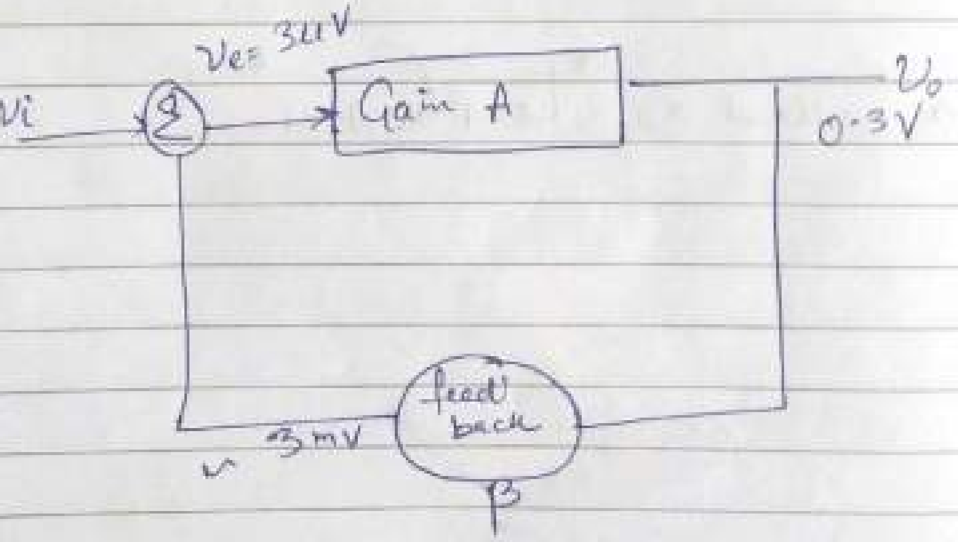
If $\beta A >> 1$

$$A_{fB} \simeq \frac{A}{\beta A} = \frac{1}{\beta}$$

i.e. $\boxed{A_{FB} = \frac{1}{\beta}}$ ∴ Gain of feedback amplifier is totally independent of A

∴ -ve feedback provides high stability to the feedback amplifier.

Example



find
Open loop Gain A
Closed loop Gain A_{fB}
Gain of feedback circuit β

Soln :- $A = \frac{0.3V}{3\mu V} = 10^5$

$$\beta = \frac{v_f}{v_o} = \frac{3mV}{0.3V} = 10^{-2}$$

$$A_{FB} = \frac{A}{1+\beta A} = \frac{10^5}{1+(10^{-2})(10^5)} = \frac{10^5}{1+10^3} \approx 10^2 = 100$$

(2) Reduction in Non-linear distortion

Distortion finally comes in form of voltage fluctuation.

For Eg:- If a ckt incorporates distortion of the order of 10% without feedback, this means that if the o/p voltage is 10V, it will be 9V or 10V.

By incorporating -ve feedback it can be minimized to 1% or 2%

Let's define Distortion as $D = \frac{\text{change in gain}}{\text{gain}}$

Here D corresponds to open loop.

$$D = \frac{\text{change in gain}}{\text{gain}} = \frac{\Delta A}{A}$$

for small change $\Delta A \to dA$

$$\therefore D = \frac{dA}{A} \quad (1)$$

In the same way $D_{FB} = \frac{dA_{FB}}{A_{FB}}$ (2)

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Rel^n b/w D and D_{fB}

$$A_{fB} = \frac{A}{1+\beta A} \quad (3)$$

Differentiating wrt gain A, we get

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

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

Since $\frac{1}{1+\beta A} = \frac{A_{fB}}{A}$ from (3)

$$\therefore dA_{fB} = \frac{dA}{(1+\beta A)} \cdot \frac{A_{fB}}{A}$$

$$\frac{dA_{fB}}{A_{fB}} = \frac{dA}{A} \cdot \frac{1}{1+\beta A}$$

Using (1) & (2)

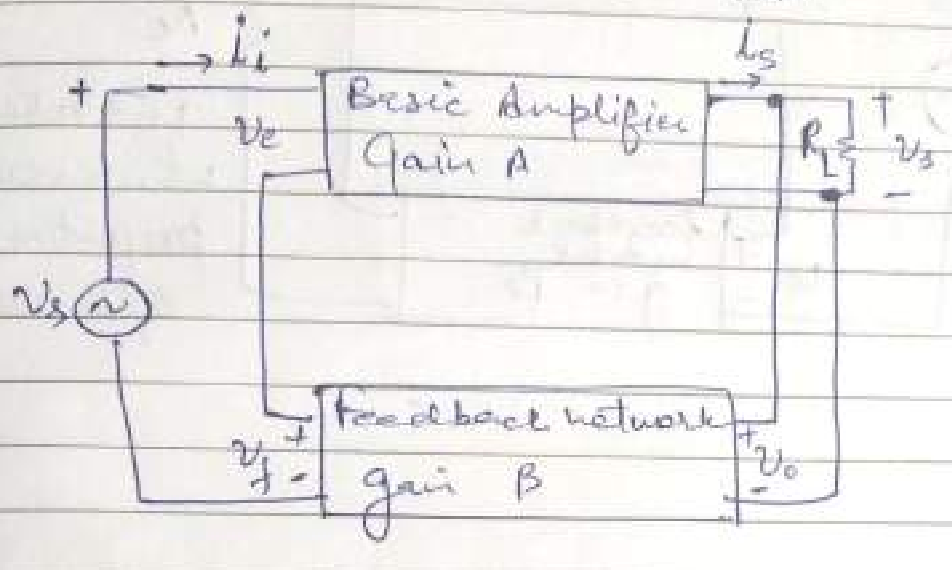
$$\boxed{D_{fB} = \frac{D}{1+\beta A}}$$

$\therefore$ Distortion reduces due to -ve feedback.

Different types of -ve feedback.

(1) Voltage Series feedback.
(o/p) (I/p)

Also called as Series - Shunt feedback.
(I/p) (o/p)



At the I/P the ckt has series connection
" " O/P " " " Shunt (parallel) connection

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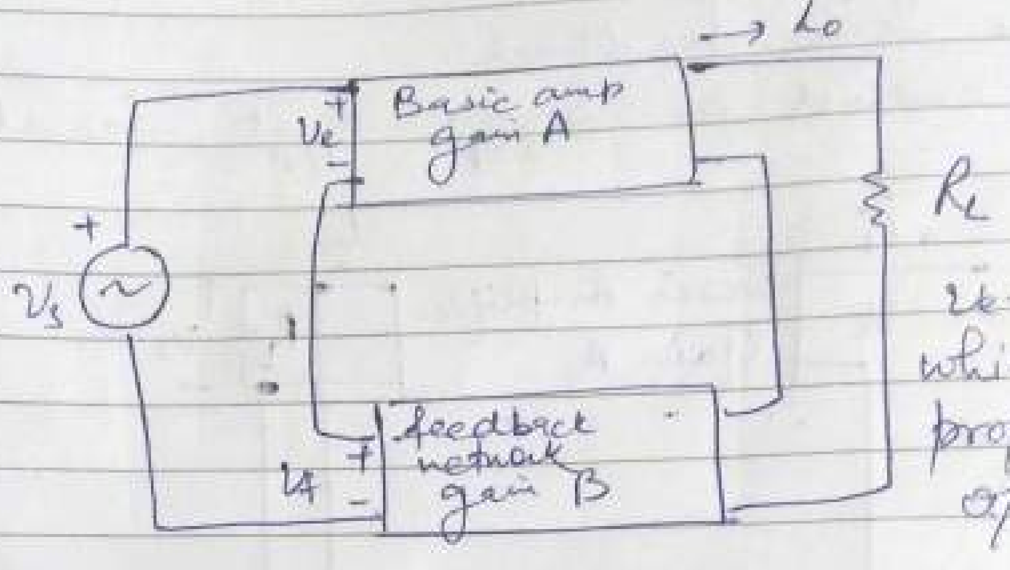
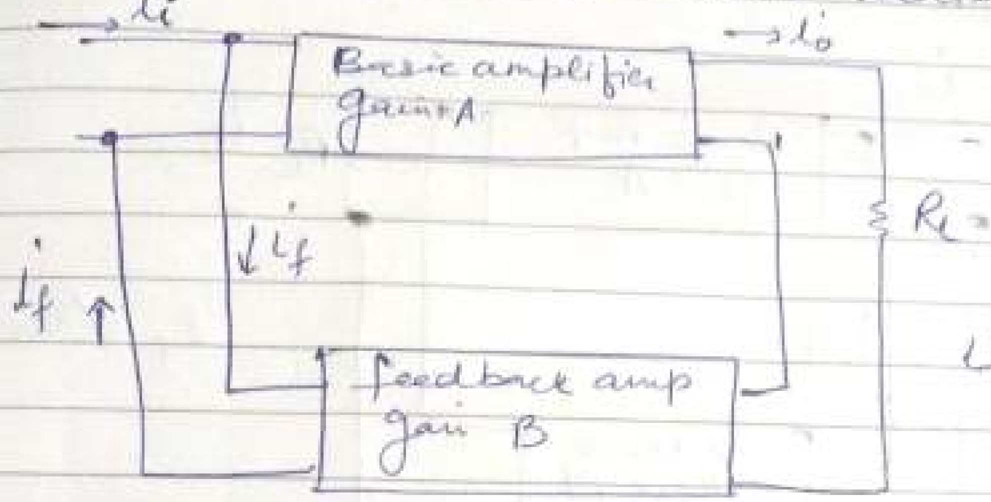
(2) Current Series feedback or Series-Series feedback



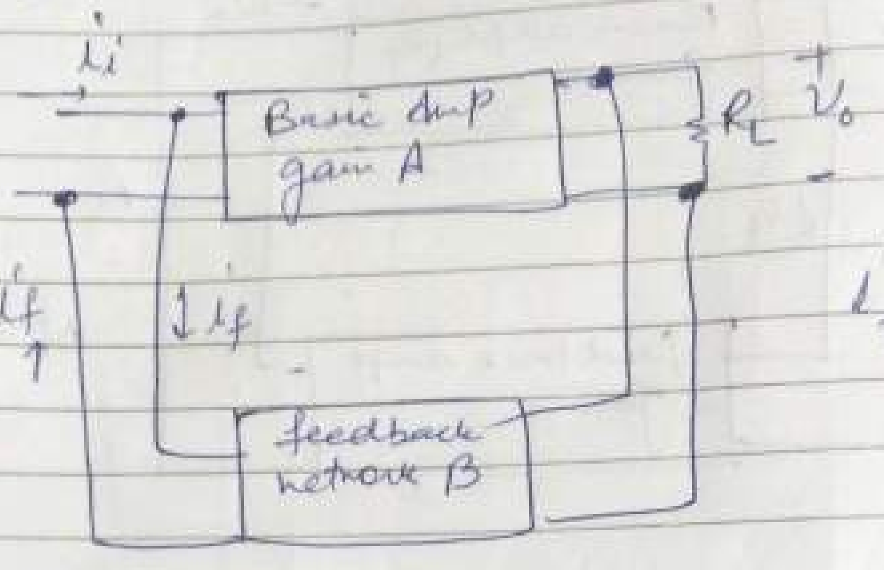
V_f → return signal which varies in proportion to the O/P current.

(3) Current Shunt feedback or Shunt-series feedback.



$i_f \propto i_o$

(4) Voltage - Shunt feedback or Shunt-Shunt feedback



$i_f \propto V_o$

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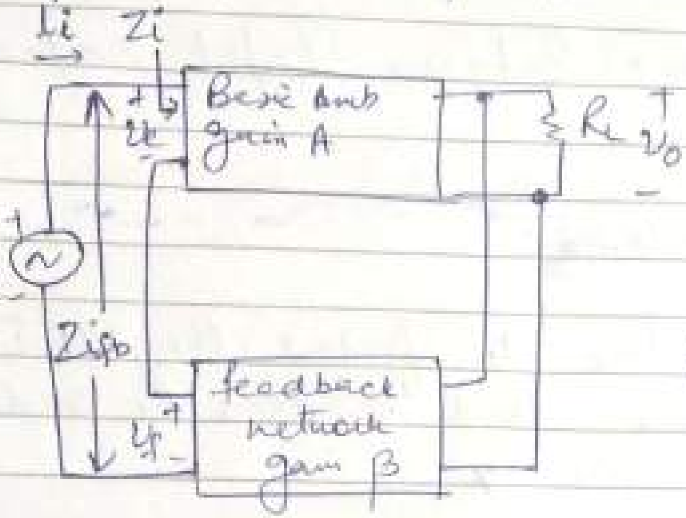
Effect of -ve feedback on Input and Output Impedances of an amplifier.

We are doing it for Voltage Series negative feedback Amplifier

If the input impedance of open loop amplifier $= Z_i$

I/P Impedance



$\beta = \frac{v_f}{v_o}$

Input Impedance for Open loop amp" $Z_i = \frac{v_e}{i_i}$

For feedback ckt $Z_{ifB} = \frac{v_s}{i_i}$

As $v_e = v_s - v_f$ and $\beta = \frac{v_f}{v_o}$

$\therefore v_f = \beta v_o$

$\therefore v_e = v_s - \beta v_o$

$v_s = v_e + \beta v_o$

Also $A = \frac{v_o}{v_e}$

or $v_o = A v_e$

$\therefore v_s = v_e + \beta A v_e$

$v_s = v_e (1 + \beta A)$

Dividing both sides by i_i

$\frac{v_s}{i_i} = \frac{v_e}{i_i}(1+\beta A) \Rightarrow \boxed{Z_{ifB} = Z_i(1+\beta A)}$

$\therefore$ I/P impedance increases by a factor of $(1+\beta A)$ during -ve feedback.

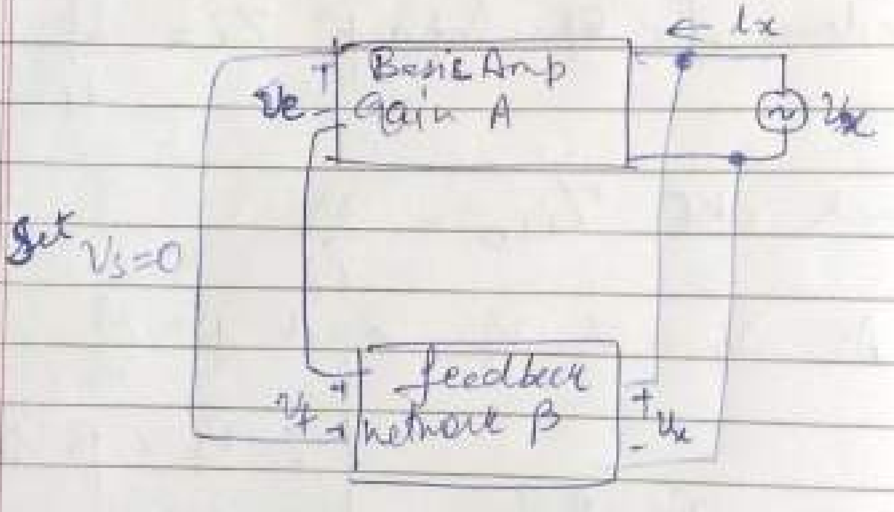
eg: If $Z_i = 1k\Omega$
Let $\beta A = 100$

$Z_{i_{fb}} \approx 100 k\Omega$

Negative feedback Enhances Input Impedance.

Output Impedance

Whenever we have to find out the O/P Impedance we have to remove load resistance R_L and instead add voltage source V_x



$$Z_{o_{fb}} = \frac{V_x}{i_x}$$

$V_e = V_s - V_f$ Since $V_s = 0$

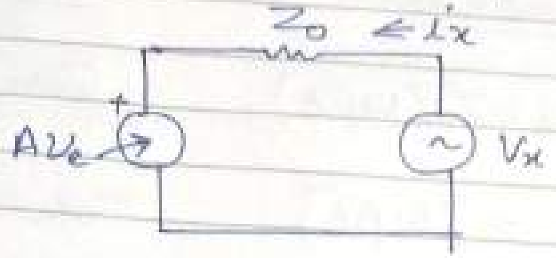
$V_e = -V_f$

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

$V_f = \beta V_x$

$\therefore V_e = -\beta V_x$

From the equivalent circuit for the output port



$$i_x = \frac{V_x - A V_e}{Z_o}$$

$$i_x = \frac{V_x + \beta A V_x}{Z_o} \quad \text{Because } V_e = -\beta V_x$$

$$i_x = \frac{V_x (1+\beta A)}{Z_o}$$

$$Z_{ofB} = \frac{V_x}{i_x} = \frac{Z_o}{1+\beta A}$$

$$\boxed{Z_{ofB} = \frac{Z_o}{1+\beta A}}$$

O/P impedance reduces by the factor of $\frac{1}{1+\beta A}$

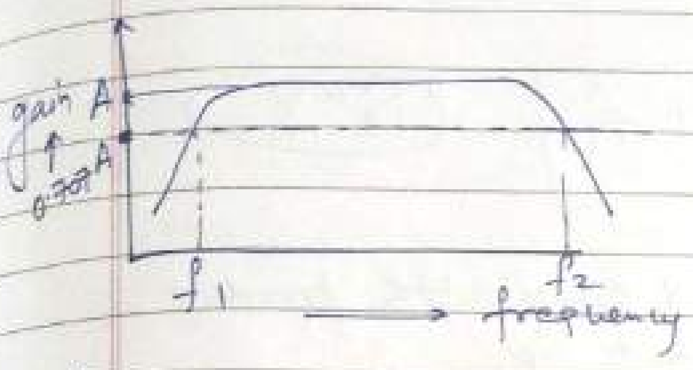
For other 3 types of feedbacks Z_{ifB} and Z_{ofB} has to be found out by yourself.

Z_i = I/P Impedance without feedback
Z_o = O/P " "

Feedback Configuration	I/P Impedance	O/P Impedance
(1) Voltage - Series FB	$Z_{ifB} = Z_i(1+\beta A)$	$Z_{ofB} = \frac{Z_o}{1+\beta A}$
(2) Current-Series FB	$Z_{ifB} = Z_i(1+\beta A)$	$Z_{ofB} = Z_o(1+\beta A)$
(3) Voltage Shunt FB	$Z_{ifB} = \frac{Z_i}{1+\beta A}$	$Z_{ofB} = \frac{Z_o}{1+\beta A}$
(4) Current - Shunt	$Z_{ifB} = \frac{Z_i}{1+\beta A}$	$Z_{ofB} = Z_o(1+\beta A)$

Depending upon the requirement apart from Stability, any one of the configuration with required Impedances could be used.
when the connection of I/P and ~~or~~ feedback network is in series then the resistance will increase.
When the connection feedback network is connected in parallel then the resistance will decrease.

(3) Effect of -ve feedback on Bandwidth of the amplifier.

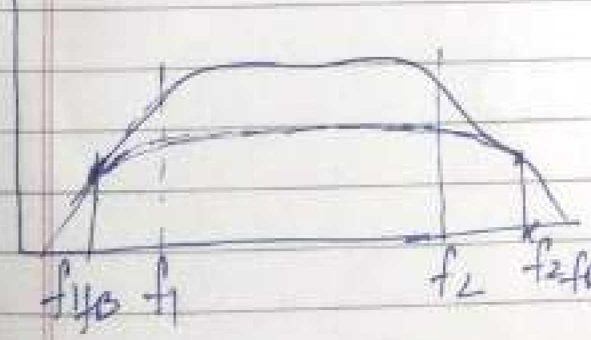


$f_1 \rightarrow$ lower Cut off frequency without feedback
$f_2 \rightarrow$ Upper Cut off frequency " "

$f_2 - f_1$ = Bandwidth

Effect of -ve feedback is to resist any change in circuit performance.
$\therefore f_{1_{FB}}$ will lie to the left of f_1 (without feedback)

and $f_{2_{FB}}$ " " " " Right of f_2 (")



$$f_{1_{FB}} = \frac{f_1}{1+\beta A}$$

i.e. $f_{1_{FB}}$ reduces by a factor of $\frac{1}{1+\beta A}$.

and $f_{2_{FB}} = (1+\beta A) f_2$
i.e. $f_{2_{FB}}$ enhances by a factor of $(1+\beta A)$

Often $f_2 >> f_1$

Bandwidth BW = $f_2 - f_1$
Since $f_2 >> f_1$

$BW = f_2$

or $$\boxed{f_{2fB} = (1+\beta A) f_2}$$ (Eqⁿ X)

Proof :-
for all amplifiers Gain X Bandwidth product is constant ie.

Gain X Bandwidth = Constant = f_T (Eqⁿ Y)

f_T — upper cutoff frequency at which gain falls to unity

We can write Eqⁿ Y for any frequency

If A → Gain of Internal / basic amplifier

$$A \cdot f_2 = f_T.$$

for feedback :

$$A_{fB} f_{2fB} = f_T$$

Since $A_{fB} = \frac{A}{1+\beta A}$

$$\left(\frac{A}{1+\beta A}\right) f_{2fB} = f_T$$

or $$\left(\frac{A}{1+\beta A}\right) f_{2fB} = A f_2$$

Hence, $$\boxed{f_{2fB} = (1+\beta A) f_2}$$

Eg If $1+\beta A = 50$

$A = 10000$

$A_{fB} = \frac{10000}{50} = 200$

But Bandwidth will increase due to negative feedback.

If $f_2 = 10kHz$

$f_{2FB} = (1+\beta A) f_2$

$= 50 \times 10 kHz$

$= 500 kHz$

Only thing we sacrifice using negative feedback is gain. $(1+\beta A)$ → Sacrifice factor.