UNIT – III

FEEDBACK AMPLIFIERS and OSCILLATORS

Part : A Feedback Amplifiers

Part : B Oscillators.

PART : A

Topics to be Covered:

1. Transistor parameters affecting gain of an amplifier & Need to stabilize gain.
2. Concept of Feedback. & Methods of FB
3. Types of Feedback with Feedback.
4. Derivation for gain with Feedback and Explanation
5. General characteristics of Negative Feedback and Explanation input and output impedances.
5. Classification of amplifiers based on input and output impedances.
6. classification of -ve FB amplifier, Sampling and Mixing networks.
7. Block diagram of -ve FB amplifier Topologies and Assumptions made for Analysis.
8. Negative FB amplifier Topologies and input and output impedances.
9. Effect of Negative Feedback on input and output impedances.
10. step-by-step procedure for the Analysis of -ve FB amplifiers.
11. Analysis of Voltage-series FB amp.
12. Analysis of Voltage-shunt FB amp.
13. Analysis of current-series FB amp.
14. Analysis of Current-shunt FB amp.
15. Problems
16. Effect of -ve FB on Lower and upper cutoff frequencies.

① Effect of Transistor Parameters on gain :

We know the transistor amplifier parameters are given by

$$A_I = \frac{-h_{fe}}{1+h_{oe}R_L}$$

$$R_i = h_{ie} + h_{re} A_I R_L$$

$$A_V = A_I \frac{R_L}{R_i}$$

$$Y_0 = h_{oe} - \frac{h_{fe} h_{re}}{R_s + h_{ie}}$$

The values of h-parameters are not constant, if h-parameter values changes then all the amplifier parameters will be affected. If we design an amplifier for a given value of gain, the gain should be constant irrespective of variations in h-parameters, but in practice, the gain changes due to the following reasons.

① change in temperature
② Aging effect of the active device (BJT)
③ Active device replaced with new device.

So, if the gain of the amplifier is made independent of transistor parameters then gain is said to be stabilized.

The use of negative feedback stabilizes the gain.

Note: ① Normally it is convenient to represent voltage sources using Thevenin's model and current sources with Norton's model. So, in this unit the same notations are to be followed.

(P.T.O.)

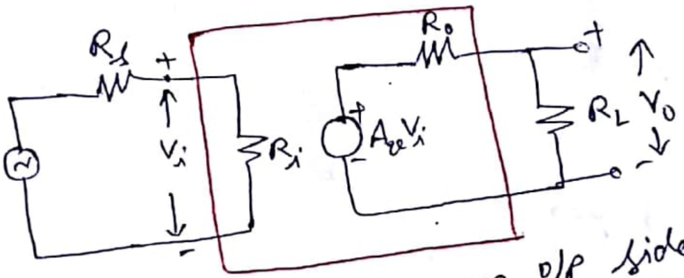
⑥ classification of Amplifiers (based on R_i & R_o)

Based on the magnitudes of R_i and R_o relative to R_s and R_L, amplifiers are classified as

① Voltage Amplifier (Voltage gain $A_V = \frac{V_o}{V_s}$)
② Current Amplifier (Current gain $A_I = \frac{I_o}{I_L}$)
③ Trans Conductance Amplifier (Transconductance gain $G_M = \frac{I_o}{V_s}$)
④ Transresistance Amplifier (Transresistance gain $R_M = \frac{V_o}{I_s}$)

① Voltage Amplifier: ($A_V = \frac{V_o}{V_s}$)

A voltage amplifier with Thevenins equivalent circuit can be shown as below.



on i/p side

$$V_i = \frac{v_s R_i}{R_s + R_i}$$

if $R_i >> R_s$ then

$$V_i \simeq v_s$$

on o/p side

$$V_o = A_v V_i \times \frac{R_L}{R_o + R_L}$$

if $R_L >> R_o$ or $R_o << R_L$ then

$$V_o \simeq A_v V_i \simeq A_v v_s$$

Therefore

if $R_i >> R_s$ and $R_o << R_L$ then

$$V_o \simeq A_v v_s$$

$\Rightarrow \boxed{V_o \propto v_s}$ then the voltage gain is independent of R_s and R_L magnitudes. Then the amplifier approaches ideal voltage amplifier characteristics.

(P.T.O.)

For an ideal voltage amplifier $R_i = \infty$ and $R_o = 0$.

In general the voltage is given by

$$A_V = \frac{V_o}{V_i}$$

$$= \frac{A_{ve} \cancel{V_i}}{\cancel{V_i}} \frac{R_L}{R_o + R_L}$$

$$A_V = A_{ve} \frac{R_L}{R_o + R_L}$$

$$\lim_{R_L \to \infty} A_V = \lim_{R_L \to \infty} A_{ve} \frac{R_L}{R_o + R_L} = \lim_{R_L \to \infty} A_{ve} \frac{1}{1 + \frac{R_o}{R_L}}$$

$$= A_{ve}$$

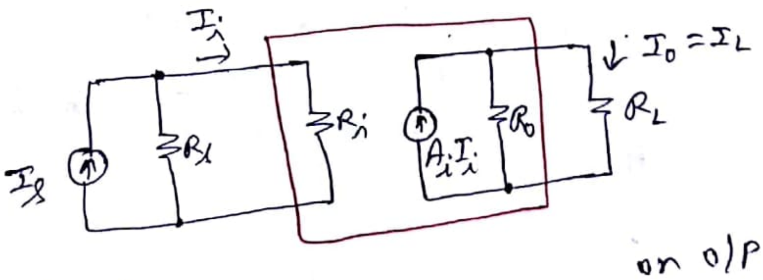
$A_{ve} \rightarrow$ called as open-circuit voltage gain (i.e. $R_L = \infty$)

$A_V \rightarrow$ called as voltage gain with R_L.

when $R_L = \infty$ then the circuit is said to be open-ckted.

(2) Current Amplifier: $\left(A_I = \frac{I_o}{I_s}\right)$

A current amplifier with Norton's equivalent is shown below.



On input side

$$I_i = I_s \frac{R_s}{R_s + R_i}$$

if $R_i << R_s$ then

$$I_i \simeq I_s$$

on o/p side

$$I_o = A_i I_i \frac{R_o}{R_o + R_L}$$

if $R_o >> R_L$ then

$$I_o \simeq A_i I_i \simeq A_i I_s$$

If $R_i << R_s$ and $R_o >> R_L$ then

$$I_o \simeq A_i I_s$$

$\Rightarrow \boxed{I_o \propto I_s}$ then the current gain is independent of R_s and R_L. Then the amplifier approaches ideal current amplifier characteristics. For an ideal current amplifier $R_i = 0$ & $R_o = \infty$.

In general the current gain is given by

$$A_I = \frac{I_o}{I_i}$$

$$= \frac{A_i \cancel{I_i}}{\cancel{I_i}} \frac{R_o}{R_o + R_L}$$

$$A_I = A_i \frac{R_o}{R_o + R_L}$$

$$\lim_{R_L \to 0} A_I = \lim_{R_L \to 0} A_i \frac{R_o}{R_o + R_L} = A_i$$

$R_L = 0 \Rightarrow$ short circuit

$A_i \rightarrow$ short circuit current gain (i.e. $R_L = 0$)

$A_I \rightarrow$ current gain with load resistance R_L.

when $R_L = 0$ then the circuit is said to be short-circuited.

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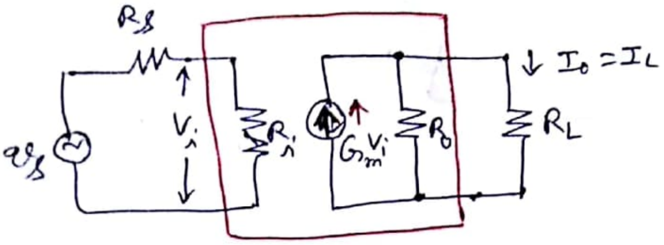
③ Trans Conductance Amplifier: $\left(G_M = \frac{I_o}{V_s}\right)$

A transconductance amplifier is as shown below.



on i/p side

$$V_i = v_s \frac{R_i}{R_i + R_s}$$

if $R_i >> R_s$ then

$$V_i \simeq v_s$$

on o/p side

$$I_o = G_m V_i \times \frac{R_o}{R_o + R_L}$$

if $R_o >> R_L$ then

$$I_o \simeq G_m V_i \simeq G_m v_s$$

Therefore

if $R_i >> R_s$ and $R_o >> R_L$ then

$$I_o \simeq G_m v_s$$

$\therefore \boxed{I_o \propto v_s}$ then the Trans Conductance gain is independent of R_s and R_L magnitudes. Then the amplifier approaches ideal transconductance amplifier characteristics.

For an ideal Trans Conductance amplifier $R_i = \infty$ & $R_o = \infty$.

In general the TransConductance gain is given by

$$G_M = \frac{I_o}{v_s} = \frac{G_m \cancel{V_i}}{\cancel{V_i}} \frac{R_o}{R_o + R_L}$$

$$G_M = G_m \frac{R_o}{R_o + R_L}$$

$$\lim_{R_o \to \infty} G_M = \lim_{R_o \to \infty} G_m \frac{R_o}{R_o + R_L}$$

$$= \lim_{R_o \to \infty} G_m \frac{1}{1 + \frac{R_L}{R_o}}$$

$$\therefore \lim_{R_o \to \infty} G_M = G_m$$

$R_L = \infty \Rightarrow$ open-circuited

$G_m \rightarrow$ open circuited TransConductance gain

$G_M \rightarrow$ TransConductance gain with R_L.

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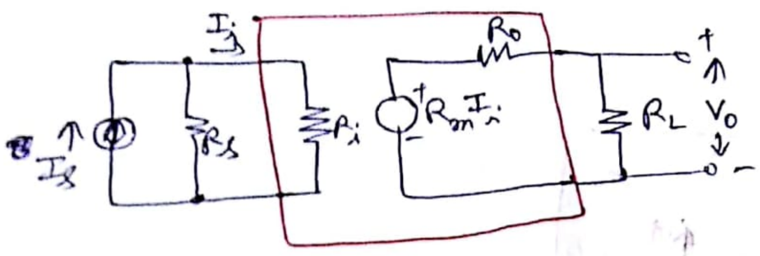
④ Transresistance amplifier : $\left(R_M = \frac{V_o}{I_s}\right)$

The transresistance amplifier is as shown



On i/p side

$$I_i = I_s \times \frac{R_s}{R_s + R_i}$$

if $(R_s >> R_i)$ then $\rightarrow R_i << R_s$

$$I_i \simeq I_s$$

On o/p side

$$V_o = R_m I_i \times \frac{R_L}{R_o + R_L}$$

if $R_o << R_L$ then

$$V_o \simeq R_m I_i \simeq R_m I_s$$

Therefore

if $R_s >> R_i$ and $R_o << R_L$ then

$$V_o \simeq R_m I_s$$

$\Rightarrow \boxed{V_o \propto I_s}$ then the transresistance amplifier is independent of R_s and R_L, then the amplifier approaches ideal ~~voltage~~ ~~Transconductance~~ Transresistance amplifier characteristics.

For an ideal transresistance amplifier $R_i = 0$ & $R_o = 0$

In general, the trans~~cond~~resistance amplifier the gain is

$$R_M = \frac{V_o}{I_i} = \frac{R_m \cancel{I_i} \times \frac{R_L}{R_o + R_L}}{\cancel{I_i}}$$

$$R_M = R_m \frac{R_L}{R_o + R_L}$$

$$\lim_{R_L \to \infty} R_M = \lim_{R_L \to \infty} R_m \frac{R_L}{R_o + R_L} = \lim_{R_L \to \infty} R_m \frac{1}{1 + \frac{R_o}{R_L}} = R_m$$

$R_m \rightarrow$ Open-circuit Transresistance gain

$R_M \rightarrow$ Transresistance gain with R_L.

(P.T.O.)

2 & 3 Concept of Feedback:

In an electronic circuit, when some portion of output signal is sampled and applied back at the input then feedback is said to be present in the circuit.

Definition: The process of applying a fraction of output signal at the input is called as feedback.

Two methods of FB

1. LOCAL FB: If ~~the~~ a fraction of o/p of a ckt is applied back at the input of the same ckt then it is said to be local FB.
2. GLOBAL FB: If ~~the~~ a ~~o/p~~ fractional ~~of~~ o/p of a ckt is applied back at the input of another ckt is applied back at the input of another circuit then it is said to be global FB.

TWO TYPES of FB

1. Positive FB & 2. Negative FB.

1. Positive FB:

When the feedback signal is in phase with external input signal then the effective input signal to the basic amplifier increases and ~~hence~~ output also increases, hence gain increases. This type of feedback is called as +ve FB.

With +ve FB:
1. Feedback signal and External signal are in phase.
2. Gain of the ~~op~~ amplifier ckt increases
3. The circuit becomes unstable and falls into oscillations.

Note: In oscillators circuits +ve FB is used.

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② Negative FB:

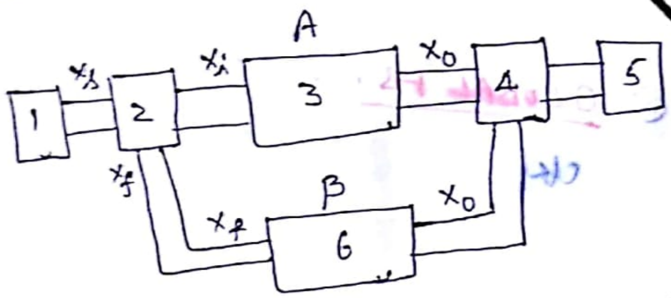
If the FB signal is out of phase with External input signal then the effective input signal decreases and output also decreases, hence gain decreases, this type of Feedback is called as negative feedback.

With -ve Feedback: ① FB signal and external input signal are out of phase by 180°.

② Gain decreases.

③ The circuit becomes more stable and hence -ve FB is used in all amplifiers.

Block diagram of FB amplifier.



1 → Source (or) External Source signal x_s (V_s or I_s)

2 → Comparator or Mixing network
its o/p $x_i = x_s \pm x_f$

3 → Basic amplifier with gain $A = \frac{x_0}{x_i}$

4 → Sampling Network, samples o/p signal V_0 or I_0

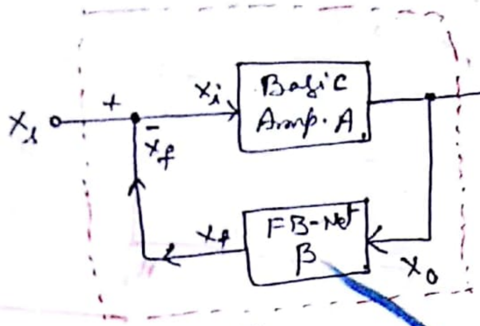
5 → Load R_L to the amplifier

6 → Feedback network with $\beta = \frac{x_f}{x_0}$ where β is called as feedback factor or feedback network factor.

(P.T.O.)

(4) Derivation for gain with –ve feedback:

The simple block diagram with –ve feedback is shown below



The gain with –ve Feedback (A_f) is defined as

$$A_f = \frac{x_o}{x_s}$$

from the figure we know

$$x_i = x_s - x_f$$

$$\therefore x_s = x_i + x_f \qquad \left[\because \beta = \frac{x_f}{x_o}\right]$$

$$\text{but } x_f = \beta x_o$$

$$\text{and } x_o = A x_i \qquad \left[\because A = \frac{x_o}{x_i}\right]$$

$$\therefore x_s = x_i + \beta x_o$$

$$= x_i + A\beta x_i$$

$$x_s = x_i (1 + A\beta)$$

$$\therefore A_f = \frac{x_o}{x_s} = \frac{x_o}{x_i(1+A\beta)} = \frac{A}{1+A\beta}$$

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

$A_f \rightarrow$ gain with feed back

$A \rightarrow$ transfer gain of the amplifier including the loading effect of β-net, R_L and R_s.

$\beta \rightarrow$ Feedback network factor.

(P.T.O.)

If $|A_f| < |A|$ then the feedback is called as negative or degenerative where the gain decreases by a factor of $\boxed{D = 1 + A\beta}$, called as desensitivity factor.

- Sensitivity is equal to the reciprocal of D.

$$\therefore \boxed{\text{Sensitivity} = \frac{1}{D} = \frac{1}{1+A\beta}} = \frac{A_f}{A}$$

Hence sensitivity can be defined as "the ratio of % change in gain with FB to the % change in gain without FB."

Loop gain : $-A\beta$ $(A \times \beta \times -1)$ is called as loop gain or return ratio

Desensitivity : (1 − return ratio) is called as desensitivity or return difference.

$$\therefore D = 1 + A\beta$$

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

∴ The amount of Feedback introduced into the amplifier is given by

$$\frac{A_f}{A} = \frac{1}{1+A\beta}$$, if expressed in dB

$$N = 20\log\left(\frac{A_f}{A}\right) = 20\log\left(\frac{1}{1+A\beta}\right)$$

for negative feedback N is a negative number & for positive feedback N is a positive number.

(P.T.O.)

5 General characteristics of Negative Feedback Amplifiers:

or

Merits and Demerits of -ve FB.

or

Advantages and disadvantages of -ve FB

The only disadvantage of negative feedback is reduction of transfer gain. But -ve FB has significant advantages in contrary to the reduction in gain.

The general characteristics (or) Advantages of -ve FB are as follows:

(a) Desensitization of transfer gain (or) stabilization of gain
(b) Reduction of Non-linear distortion
(c) Reduction of Noise
(d) Reduction of frequency distortion
(e) Improved frequency response (or) Bandwidth increases
(f) Modified input and output impedances.

a) Stabilization of transfer gain:

The gain of the amplifier with negative FB is given by

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

differentiate both sides with A

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

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

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

where $\frac{dA_f}{A_f} \rightarrow$ Fractional change in gain with FB

$\frac{dA}{A} \rightarrow$ Fractional change in gain without FB.

(P.T.O.)

always $\left|\frac{dA_f}{A_f}\right| < \left|\frac{dA}{A}\right|$.

Hence the fractional change in gain with FB is reduced, by a factor of Desensitivity $D=(1+A\beta)$, to that of without Feedback.

(b) Reduction of Non-linear Distortion:

Due to non-linearity of the active device, harmonic distortion will be introduced at the output terminals of the amplifier, this is also called as non-linear distortion or amplitude distortion. When negative FB is introduced this distortion will be reduced by a factor of D.

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

where D is the total non-linear distortion. If only second harmonic distortion is considered then

$$\boxed{B_{2f} = \frac{B_2}{1+A\beta}}$$

where B_2 is the second harmonic distortion without feedback and B_{2f} is the second harmonic distortion with feedback.

(c) Reduction of Noise:

There are many sources of noise in an amplifier, specifically in the active device, this noise will also be amplified along with external signal. When negative feedback is employed then the total noise N will be reduced by factor of desensitivity.

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

(P.T.O.)

(d) Reduction of frequency Distortion:

The gain with -ve FB is given by

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

If $|A\beta| >> 1$ then $1+A\beta \simeq A\beta$

$$\therefore A_f \simeq \frac{A}{A\beta}$$

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

The gain with -ve FB is almost equal to reciprocal of feedback network factor β. In negative feedback amplifiers β network consists of only resistive components which are independent of frequency. So, the gain with -ve FB is almost constant for the entire frequency range.

(e) Increment in Bandwidth:

When negative FB is employed in an amplifier the lower and upper cut off frequencies will be modified such that the overall Bandwidth more than that of without feedback. The Bandwidth with -ve FB is given by

$$\boxed{BW_f = BW \times (1+A\beta)}$$

where A is the mid band gain without feedback.

(P.T.O.)

Note: student should be careful in understanding the reduction of frequency distortion, this means, for the given Bandwidth the frequency response is almost constant, but the upper cut off and lower cut of frequencies are controlled by internal and external capacitances only.

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(f) Modified input and output impedances:

When negative FB is employed, the feed back signal is mixed with the external input signal. This mixing either in series or in shunt. If the mixing is in series the net input impedance increases by a factor D.

$$\therefore R_{if} = R_f (1+A\beta)$$ where $R_f \rightarrow$ input impedance without FB.

If the mixing is in shunt the net input impedance decreases by a factor of D.

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

The output impedance of a negative feedback amplifier depends the signal sampled. If output voltage (node sampling) is sampled then the output impedance decreases by a factor of D.

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

If the output current is sampled (loop sampling) then the output impedance increases by a factor of $(1+A\beta)$

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

(P.T.O.)

Note: The proof of these 4 expressions will be discussed in the later sections.

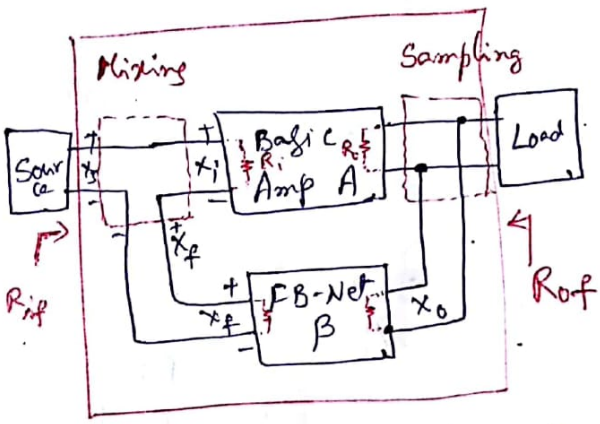
P.T.O.

(7) & (8) Negative Feedback amplifier Topologies and Block diagrams

The four negative Feedback amplifier topologies are

1. Voltage-Series FB
2. Voltage-Shunt FB
3. Current-Series FB
4. Current-Shunt FB.

(1) Voltage-Series FB amplifiers [$x_o = V_o$, $x_s = V_s$, $A = A_v = \frac{V_o}{V_i}$]



(1) Sampling → Node Sampling or Voltage Sampling
indicate the o/p variable is Voltage V_o

(2) Mixing → Series mixing
indicate the input variable is voltage V_i

(3) $A_v = \frac{x_o}{x_i} = \frac{V_o}{V_i}$

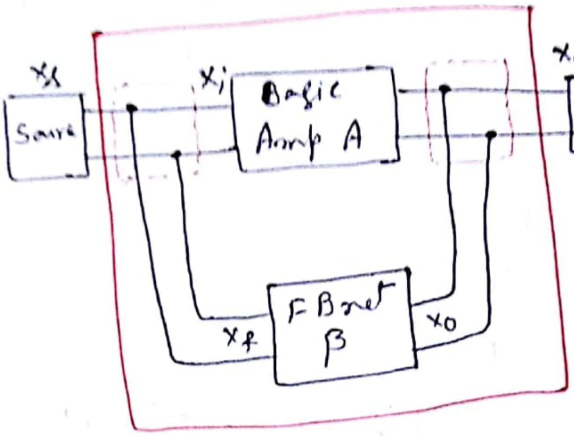
(4) $\beta = \frac{x_f}{x_o} = \frac{V_f}{V_o}$

(5) $A_{vf} = \frac{x_o}{x_s} = \frac{V_o}{V_s} = \frac{A_v}{1+A_v\beta}$

(6) $R_{if} = R_i(1+A_v\beta)$ & $R_{of} = \frac{R_o}{(1+A_v\beta)}$.

② Voltage-shunt FB amplifier $\left[x_0 = V_0,\ x_s = I_s,\ A = \frac{x_0}{x_i} = \frac{V_0}{I_i}\right]$

Feed Back amp.



Sampling → Node sampling or voltage sampling indicate o/p variable is voltage V_0.

Mixing → shunt mixing indicate o/p variable is Current I_i

$$A \rightarrow R_M = \frac{x_0}{x_i} = \frac{V_0}{I_i}$$

$$\beta \rightarrow \beta = \frac{x_f}{x_0} = \frac{I_f}{V_0}$$

$$A_f \rightarrow R_{Mf} = \frac{x_0}{x_s} = \frac{V_0}{I_s} = \frac{R_M}{1+R_M\beta}$$

$$R_{if} = \frac{R_i}{1+R_M\beta} \quad \& \quad R_{of} = \frac{R_0}{1+R_M\beta}$$

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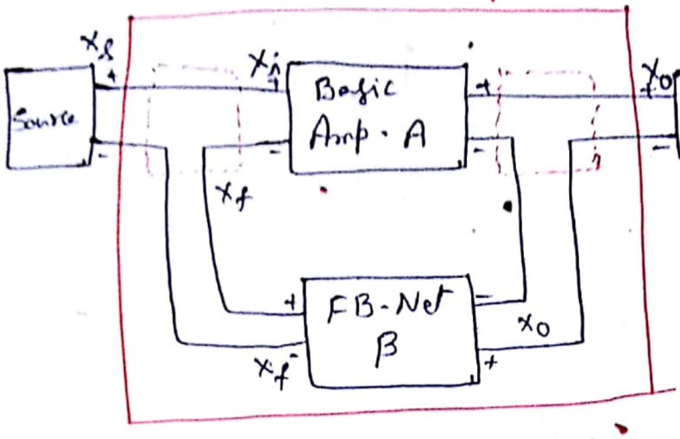
(3) Current-series FB amplifier $\left[X_o = I_o,\ X_i = V_i,\ A = G_M = \frac{I_o}{V_i}\right]$

Feedback amp.



(1) Sampling → Loop sampling or current sampling indicate the o/p variable is current I_o

(2) Mixing → series mixing indicates the input variable is voltage V_i

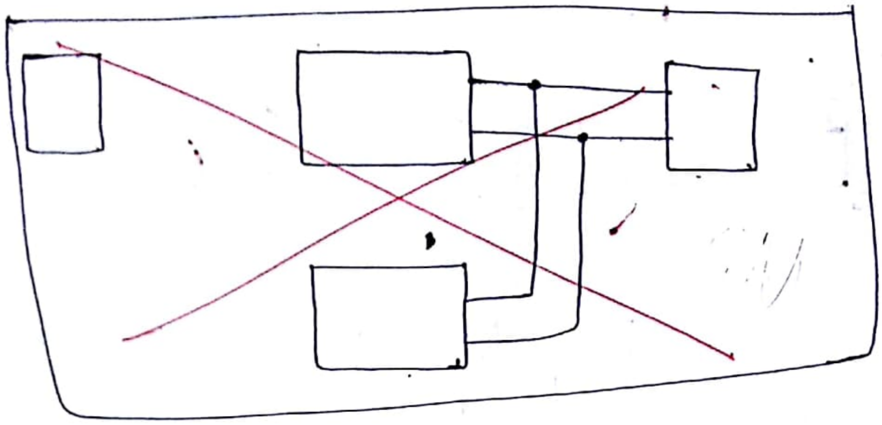
(3) $A \rightarrow G_M = \frac{X_o}{X_i} = \frac{I_o}{V_i}$

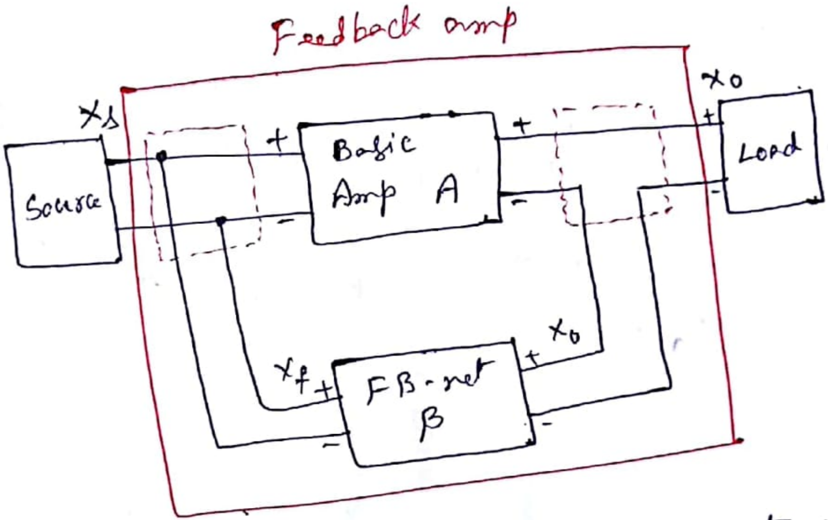
(4) $\beta \rightarrow \beta = \frac{X_f}{X_o} = \frac{V_f}{I_o}$

(5) $A_f \rightarrow G_{Mf} = \frac{X_o}{X_s} = \frac{I_o}{V_s} = \frac{G_M}{(1+G_M\beta)}$

(6) $R_{if} = R_i(1+G_M\beta)$ & $R_{of} = R_o(1+G_M\beta)$

④ Current-Shunt Feedback amplifier $\left[x_o = I_o,\ x_i = I_i,\ A = A_I = \frac{I_o}{I_i}\right]$





① Sampling → Loop sampling or current sampling
indicate output variable is current I_o

② Mixing → shunt mixing
indicate input variable is current ~~voltage~~ I_i

③ $A \rightarrow A_I = \frac{x_o}{x_i} = \frac{I_o}{I_i}$

④ $\beta \rightarrow \beta = \frac{x_f}{x_o} = \frac{I_f}{I_o}$

⑤ $A_f \rightarrow A_{If} = \frac{x_o}{x_s} = \frac{I_o}{I_s} = \frac{A_I}{(1+A_I\beta)}$

⑥ $R_{if} = \frac{R_i}{(1+A_I\beta)}$ & $R_{of} = R_o(1+A_I\beta)$

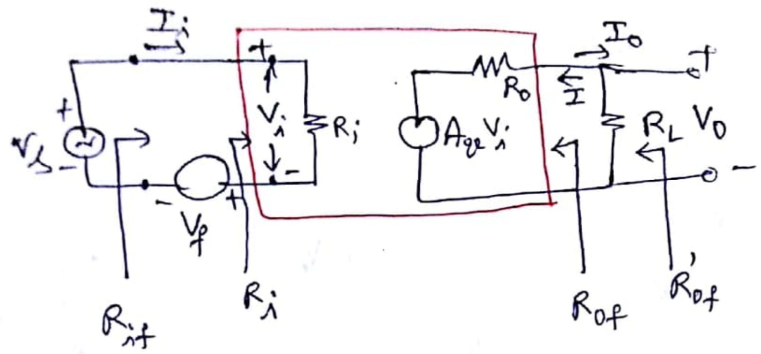
(P.T.O.)

(9) Effect of Negative Feedback on input and output impedances:

Derivation of R_{if} and R_{of} for 4 topologies:

(a) Voltage series feedback topology:

The linear circuit with voltage series feedback is as shown below.



① input impedance (R_{if}) : we know $R_i = \frac{V_i}{I_i}$

~~we~~ R_{if} is defined as

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

from o/p ckt we have

$$V_s = V_i + V_f \qquad \left(\because \beta = \frac{X_o}{X_f} = \frac{V_o}{V_f}\right)$$

$$= V_i + \beta V_o \qquad \left(\because A_v = \frac{A_v R_L}{R_L + R_o}\right)$$

$$= V_i + A\beta V_i$$

$$V_s = V_i(1 + A_v\beta)$$

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

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

② Output impedance (R_{of}) : we know $R_o = \frac{V_o}{I_o} = \frac{V_o}{I}$

The o/p impedance is defined as the ~~ratio~~ ratio of voltage(V) impressed between o/p terminals to the current(I) flowing through o/p terminals when $R_L = \infty$ and $V_s = 0$ (or $I_s = 0$).

(P.T.O.)

Let a voltage V is impressed between o/p terminals ($V = V_o$) and the current through o/p terminals is I and R_L is disconnected (i.e. $R_L = \infty$). $R_{of} = \frac{V}{I}$

Then the current I is given by

$$I = \frac{V - A_v V_i}{R_o}$$

from o/p KVL we have

$$V_s - V_i - V_f = 0$$

set $V_s = 0$

$$\therefore V_i = -V_f = -\beta V_o$$

$$V_i = -\beta V$$

$\left[\therefore \cancel{\beta = \frac{x_f}{x_o} = \frac{V_f}{V_o} = \frac{V_f}{V}} \right]$

$$\beta = \frac{x_f}{x_o} = \frac{V_f}{V_o} = \frac{V_f}{V}$$

$$\therefore I = \frac{V + A_v \beta V}{R_o}$$

$$I = \frac{V(1 + A_v \beta)}{R_o}$$

$$\therefore R_{of} = \frac{V}{I} = \frac{\cancel{V} R_o}{\cancel{V}(1 + A_v \beta)}$$

$$\boxed{\therefore R_{of} = \frac{R_o}{1 + A_v \beta}}$$

With R. Load Resistance R_L the o/p impedance is R'_{of}

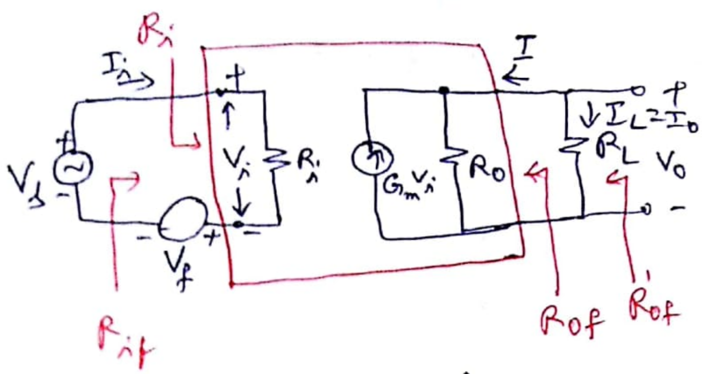
$$R'_{of} = R_{of} \parallel R_L$$

$$\boxed{R'_{of} = \frac{R'_o}{1 + A_v \beta}}$$

Note: $R_{if} >> R_i$ and $R_{of} << R_o$ hence this amplifier ~~behaves~~ a functions as a very good voltage amplifier.

(P.T.O.)

(b) Current-series FB topology:



① **input impedance (R_{if})** we know $\boxed{R_i = \frac{V_i}{I_i}}$

R_{if} is defined as

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

from i/p ckt we have

$$V_s - V_i - V_f = 0$$

$$\therefore V_s = V_i + V_f$$

$$= V_i + \beta I_o$$

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

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

$$V_s = V_i + G_m \beta V_i$$

$$\therefore V_s = V_i (1 + G_m \beta)$$

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

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

② **Output impedance (R_{of})**

The o/p impedance is defined as the ratio of voltage (V), impressed between o/p terminals, to the current (I) flowing into o/p terminals when $R_L = \infty$ and $V_s = 0$ (or $I_s = 0$).

Let a voltage V is impressed between o/p terminals ($V = V_0$) and the current through o/p terminals is I and R_L is disconnected. Now R_{of} is defined as

$$R_{of} = \frac{V_0}{I} = \frac{V}{I}$$

KCL to the o/p node gives

$$I = \frac{V}{R_0} - G_m V_i$$

from i/p loop we have

$$V_s - V_i - V_f = 0$$

set $V_s = 0$

$$\therefore V_i = -V_f$$

$$= -\beta I_0$$

$$= +\beta I$$

$$\left[\because \beta = \frac{X_f}{X_0} = \frac{V_f}{I_0}\right]$$

$$\left[\because I = -I_0\right]$$

$$\therefore I = \frac{V}{R_0} - G_m \beta I$$

$$\therefore \frac{V}{R_0} = I(1 + G_m\beta)$$

$$\therefore R_{of} = \frac{V}{I} = R_0(1 + G_m\beta)$$

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

Note: $R_{if} >> R_i$ and $R_{of} >> R_0$ hence this amplifier functions as a very good transconductance amplifier.

$$R'_{of} = R_{of} \| R_L = \frac{R_{of} R_L}{R_{of} + R_L} = \frac{R_0 R_L (1 + G_m\beta)}{R_0 + R_0 G_m \beta + R_L}$$

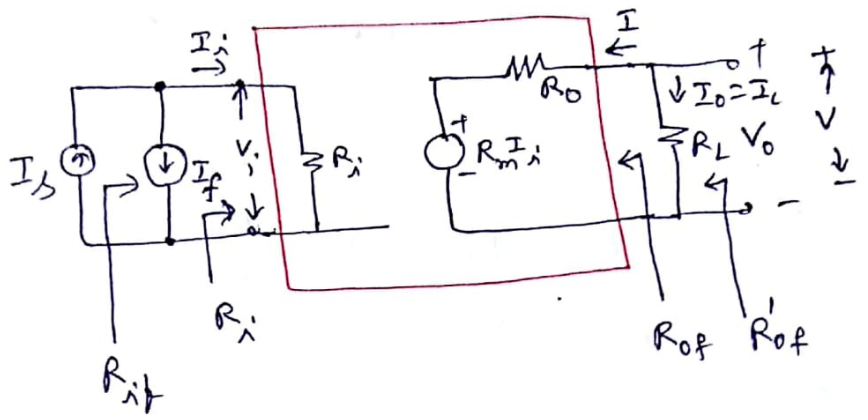
$$= \frac{R_0 R_L (1 + G_m\beta)}{(R_0 + R_L)\left[1 + \frac{G_m \beta R_0}{R_0 + R_L}\right]}$$

$$\boxed{\therefore R'_{of} = \frac{R'_0 (1 + G_m\beta)}{(1 + G_M\beta)}}$$

(P.T.O.)

(c) Voltage-shunt FB amplifier:

The linear ckt of a Voltage-shunt FB amplifier is shown below.



(1) Input impedance (R_{if}):

We know $R_i = \frac{V_i}{I_i}$ and R_{if} is defined as

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

~~from~~ KCL to i/p node gives

$$I_s - I_f - I_i = 0$$

$$\therefore I_s = I_i + I_f$$

$$= I_i + \beta V_o$$

$$= I_i + \beta R_M I_i$$

$$I_s = I_i (1 + R_M \beta)$$

$$\beta = \frac{x_f}{x_o} = \frac{I_f}{V_o}$$

$$\because V_o = R_m I_i \times \frac{R_L}{R_L + R_o}$$

$$= R_M I_i$$

where $R_M = R_m \frac{R_L}{R_L + R_o}$

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

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

(2) ~~current shunt~~

Output impedance : R_{of} =

The o/p Impedance is defined as the ratio of voltage (V), impressed between o/p terminals, to the current (I) flowing into o/p terminals when $R_L = \infty$ and $V_s = 0$ ($I_s = 0$)

Let a voltage V is impressed between o/p terminals ($V = V_o$) and the current through o/p terminals is I and R_L is disconnected (i.e. $R_L = \infty$). Now R_{of} is defined as

$$R_{of} = \frac{V_o}{I} = \frac{V}{I}$$

from o/p ckt

$$I = \frac{V - R_m I_i}{R_o}$$

from input node we have

$$I_s - I_i - I_f = 0$$

set $I_s = 0$

$$\therefore I_i = -I_f$$

$$= -\beta V_o$$

$$I_i = -\beta V$$

$$\left[\beta = \frac{x_f}{x_o} = \frac{I_f}{V_o} \quad \because V = V_o \right]$$

$$\therefore I = \frac{V + R_m \beta V}{R_o}$$

$$I = \frac{V(1 + R_m\beta)}{R_o}$$

$$\therefore R_{of} = \frac{V}{I} = \frac{R_o}{1 + R_m\beta}$$

$$\boxed{\therefore R_{of} = \frac{R_o}{1 + R_m\beta}}$$

$$\therefore R'_{of} = R_{of} \parallel R_L = \frac{R_{of} R_L}{R_{of} + R_L} = \frac{R_o R_L}{R_o + R_L(1 + R_m\beta)}$$

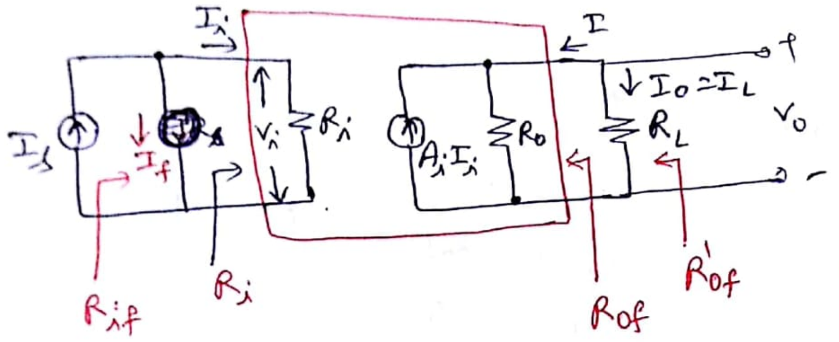
$$= \frac{R_o R_L}{R_o + R_L + R_m \beta R_L} = \frac{R_o R_L}{(R_o + R_L)\left[1 + \frac{R_m R_L \beta}{R_o + R_L}\right]} = \frac{R'_o}{1 + R_M \beta}$$

$$\boxed{\therefore R'_{of} = \frac{R'_o}{1 + R_M\beta}}$$

(P.T.O.) .. (14)

(d) Current-shunt FB topology : $A_I = \frac{I_o}{I_i}$

The linear circuit for current-shunt FB amplifier is shown below.



(1) Input impedance (R_{if})

We know $R_i = \frac{V_i}{I_i}$ and

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

KCL to i/p node gives

$$I_s - I_f - I_i = 0$$

$$\therefore I_s = I_i + I_f \qquad \beta = \frac{x_f}{x_o} = \frac{I_f}{I_o}$$

$$I_s = I_i + \beta I_o$$

but $I_o = A_i I_i \times \frac{R_o}{R_o + R_L}$

$$\therefore I_o = A_I I_i$$

$$\therefore I_s = I_i + A_I \beta I_i = I_i (1 + A_I \beta)$$

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

$$\boxed{R_{if} < R_i}$$

(P.T.O.)

Output impedance (R_{of}):

The o/p impedance is defined as the ratio of voltage (V), impressed between o/p terminals, to the current flowing into o/p terminals when $R_L = \infty$ and $V_s = 0$ ($I_s = 0$)

Let a voltage V is impressed between o/p terminals ($V_o = V$) and the current through o/p terminals is I and R_L is disconnected. Now R_{of} is defined as

$$R_{of} = \frac{V_o}{I} = \frac{V}{I}$$

from the o/p ckt

$$I = \frac{V}{R_o} - A_i I_i$$

from o/p node we have

$$I_s - I_f - I_i = 0$$

put $I_s = 0$

$$\therefore I_i = -I_f$$

$$= -\beta I_o$$

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

but $I_o = -I$

$$\therefore I_i = +\beta I$$

$$\therefore I = \frac{V}{R_o} - A_i \beta I$$

$$\therefore \frac{V}{R_o} = I(1 + A_i \beta)$$

$$\therefore R_{of} = \frac{V}{I} = R_o(1 + A_i \beta)$$

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

$$\boxed{R_{of} >> R_o}$$

$$\therefore R'_{of} = R_{of} \| R_L = \frac{R_{of} R_L}{R_{of} + R_L} = \frac{R_o(1 + A_i \beta) R_L}{R_o + R_L + A_i \beta R_o}$$

$$= \frac{R_o R_L (1 + A_i \beta)}{(R_o + R_L)\left[1 + \frac{A_i \beta R_o}{R_o + R_L}\right]} = R'_o \frac{(1 + A_i \beta)}{(1 + A_I \beta)}$$

$$\boxed{\therefore R'_{of} = R'_o \frac{1 + A_i \beta}{1 + A_I \beta}}$$

(P.T.O.)

16 Effect of -ve FB on Frequency response :

We know the gain with feedback is given by

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

The frequency response of an amplifier with feedback is to be studied in Mid, Low and High frequency regions, and the Band width of the amplifier depends on the cut off frequencies.

Case 1 : Mid Frequency Region :

We know the gain in Mid frequency region is independent of frequency and represented with A_{mid}. Therefore the gain in Mid band region with feedback is given by

$$\boxed{A_f = \frac{A_{mid}}{1+A_{mid}\beta}}$$

Case 2 : Low Frequency Region :

We know the gain in Low frequency region is given by

$$A_{LF} = A_{L freq} = \frac{A_{mid}}{1-j\frac{f_L}{f}}$$

So in the expression of A_f, A is to be replaced with A_{LF}.

major changes!

(P.T.O.)

$$\therefore A_{LFf} = \frac{A_{LF}}{1+A_{LF}\beta}$$

$$= \frac{A_{mid}}{\left[1-j\frac{f_L}{f}\right]\left[1+\frac{A_{mid}\beta}{\left(1-j\frac{f_L}{f}\right)}\right]}$$

$$= \frac{A_{mid}}{1+A_{mid}\beta - j\left(\frac{f_L}{f}\right)}$$

$$= \frac{A_{mid}}{1+A_{mid}\beta} \cdot \frac{1}{\left[1-j\frac{f_L}{f(1+A_{mid}\beta)}\right]}$$

$$\boxed{\therefore A_{LFf} = \frac{A_f}{1-j\left(\frac{f_{Lf}}{f}\right)}}$$

where $A_f = \dfrac{A_{mid}}{1+A_{mid}\beta}$ &

$$\boxed{f_{Lf} = \frac{f_L}{1+A_{mid}\beta}}$$

$$\boxed{f_{Lf} < f_L}$$

Case 3: High Frequency Region

We know the gain in High frequency Region is given by

$$A_{HF} = \frac{A_{mid}}{1+j\left(\frac{f}{f_H}\right)}$$

So, in the expression of A_f, A is to be replaced with A_{HF}, to obtain the gain with feedback in High frequency region.

(P.T.O.)

$$\therefore A_{HFf} = \frac{A_{HF}}{1 + A_{HF}\beta}$$

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

$$= \frac{A_{mid}}{1 + A_{mid}\beta + j\cdot\frac{f}{f_H}}$$

$$= \frac{A_{mid}}{(1 + A_{mid}\beta)} \times \frac{1}{\left[1 + j\frac{f}{f_H(1 + A_{mid}\beta)}\right]}$$

$$\therefore A_{HFf} = \frac{A_f}{1 + j\left(\frac{f}{f_{Hf}}\right)}$$

where

$$\boxed{A_f = \frac{A_{mid}}{1 + A_{mid}\beta}} \quad \&$$

$$\boxed{f_{Hf} = f_H(1 + A_{mid}\beta)}$$

$$\boxed{f_{Hf} > f_H}$$

Case : 4 Effect on Band width.

Bandwidth of an amplifier is defined as

$$B.W = f_H - f_L \simeq f_H$$

with Feedback

$$(B.W)_f = f_{Hf} - f_{Lf} \simeq f_{Hf}$$

$$\therefore (B.W.)_f \simeq f_{Hf} = f_H(1 + A_{mid}\beta)$$

$$= (B.W.) \times (1 + A_{mid}\beta)$$

$$\boxed{\therefore B.W._f = B.W. \times (1 + A_{mid}\beta)}$$

(P.T.O.)

Case : 5 Gain Band width product with feedback

The gain BW product of an amplifier with FB is given by

$$(GBP)_f = (Gain)_f \times (B.W.)_f$$

$$= A_f \times f_{Hf}$$

$$= \frac{A_{mid}}{\cancel{(1+A_{mid}\beta)}} \times f_H \cancel{(1+A_{mid}\beta)}$$

$$= A_{mid} \times f_H$$

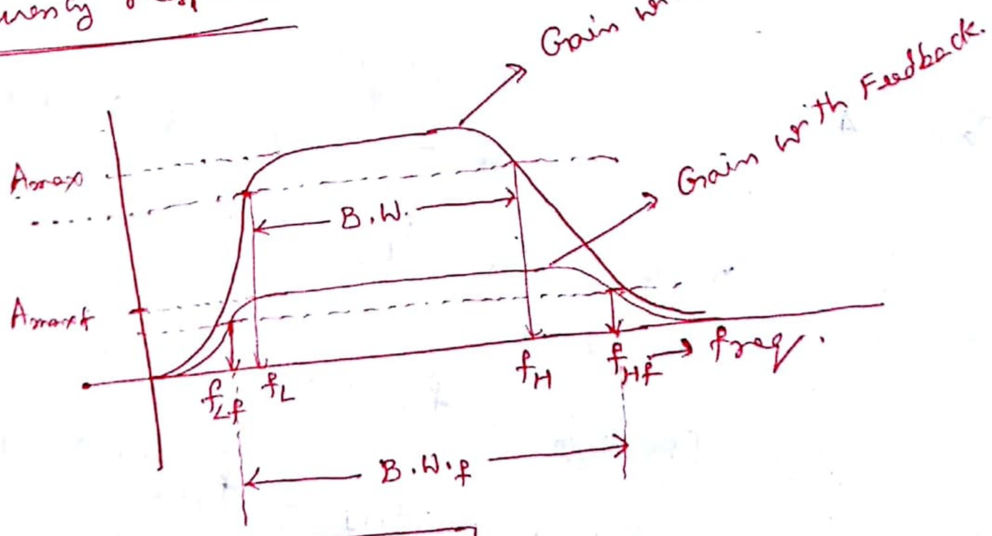
$$= G.B.P \text{ without feedback}$$

$$\therefore (GBP)_f = G.B.P$$

$$\boxed{\therefore GBP_f = GBP_{wof}}$$

Note: Negative feedback does not (change) effect the gain Band width product. The decreament in gain with feedback is compensated with increament in Band width.

Frequency Response:



$$\boxed{B.W_f > B.W}$$

(P.T.O)

10. Step-by-step procedure for the Analysis of -ve FB Amplifiers:

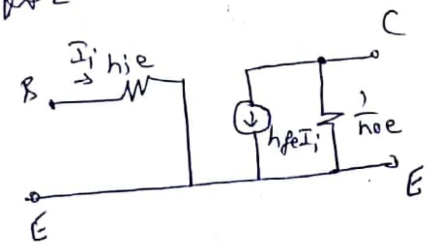
Note: There are 3 fundamental assumptions ~~are~~ made for simplifying the Analysis procedure. These are.

1. The input signal is Transmitted to the output through the basic Amplifier A and not through the β-network.

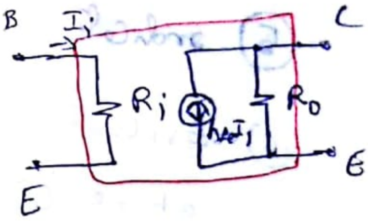
2. The feedback signal is Transmitted from output to input through the β-network and not through the amplifier.

3. The reverse Transmission factor β is independent of Load resistance (R_L) and Source resistance (R_s).

By Considering the above assumption 1 & 2 the model for BJT to be ~~is~~ used is given below.



(or)



PROCEDURE

1. Identify the topology,
   a. Is the feedback signal x_f a voltage (or) Current [in other words, is x_f applied in series or in shunt with x_s]
   b. Is the sampled signal x_o a voltage or Current? [in other words, is the sampled signal taken from output node or output loop?]

2. Draw the basic amplifier circuit without feedback ~~a~~ but taking the loading effect of β-network in to account, as explained below.

(P.T.O)

(a) To find the input circuit:

(1) Set $V_o = 0$ for voltage sampling i.e. short circuit o/p node

(2) Set $I_o = 0$ for current sampling i.e. open ckt o/p loop

(b) To find the output circuit:

(1) Set $V_i = 0$ for shunt comparision i.e. short ckt i/p node

(2) Set $I_i = 0$ for series comparision i.e. ~~op~~ open the i/p loop

(3) Use a Thevenin's source if x_f is a voltage and a Norton's source if x_f is a current.

(4) Replace each active device by the proper model, [h-parameter model for low frequencies (or) hybrid-π model at high frequencies.]

(5) Indicate x_f and x_o on the a.c equivalent obtained above.

(6) Evaluate $\beta = \frac{x_f}{x_o}$ and A by applying KVL or KCL to the above circuit.

(7) From A and β, find D, A_f, R_{if}, R_{of} and R'_{of}.

Table for Feedback amplifier Analysis.

	Characteristic	Topology: Voltage-series	Current-series	Voltage-shunt	Current-shunt
(1)	Source (Signal)	Thevenin	Thevenin	Norton	Norton
(2)	$\beta = x_f/x_o$	V_f/V_o	V_f/I_o	I_f/V_o	I_f/I_o
(3)	$A = x_o/x_i$	$A_V = V_o/V_i$	$G_M = I_o/V_i$	$R_M = V_o/I_i$	$A_I = I_o/I_i$
(4)	$D = 1 + A\beta$	$1 + A_V\beta$	$1 + G_M\beta$	$1 + R_M\beta$	$1 + A_I\beta$
(5)	$A_f = \frac{A}{D}$	A/D	G_M/D	R_M/D	A_I/D
(6)	R_{if}	$R_i D$	$R_i D$	R_i/D	R_i/D
(7)	R_{of}	$\frac{R_o}{1+A_{vo}\beta}$	$R_o(1+G_m\beta)$	$\frac{R_o}{1+R_m\beta}$	$R_o(1+A_i\beta)$
(8)	R'_{of}	$\frac{R'_o}{D}$	$\frac{R'_o}{D}(1+G_m\beta)$	$\frac{R'_o}{D}$	$\frac{R'_o}{D}(1+A_i\beta)$

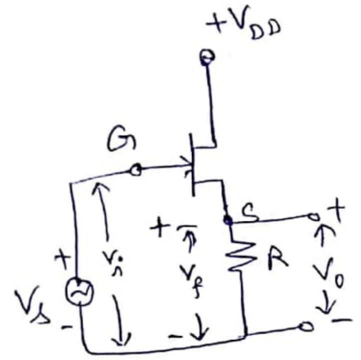
(11) Analysis of Voltage-Series FB Amplifier

(a) FET Source Follower
(b) The Emitter Follower

} These two circuits are the examples for voltage-series FB amps.

(a) Source-Follower:

The circuit is as shown below



Hint: KVL to i/p loop

$V_s - V_{gs} - V_o = 0$

o/p voltage is appearing on o/p side, there fore it is voltage sampling, and the o/p voltage is appearing in the loop hence it is series mixing.

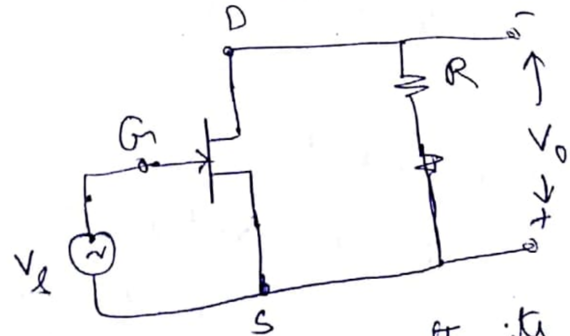
step 1: identify the topology:

The output voltage V_o is appearing in the input loop and the voltage across R (V_f) is fed back. There fore the topology of the circuit is voltage series.

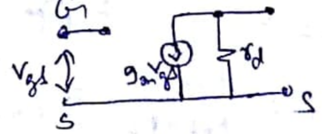
Hence $X_o = V_o$; $X_i = V_i$ & $X_f = V_f$

step 2: To obtain input ckt set $V_o = 0$ and To obtain output ckt set $I_i = 0$ (open gate terminal)

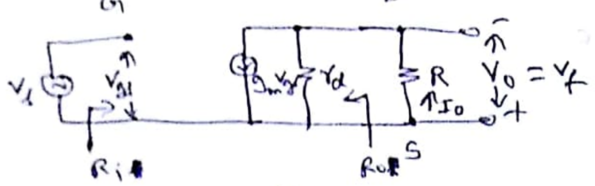
Then obtain the ac equivalent circuit without feedback and including the loading effect of β network (R).



step 3: Replace the FET with its low frequency model.



(P.T.O.)



Step 4:

(a) $\therefore \beta = \dfrac{x_f}{x_o} = \dfrac{V_f}{V_o} = 1$

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

(b) $A_V = \dfrac{X_o}{X_i} = \dfrac{V_o}{V_i} = \dfrac{V_o}{V_{gs}} = \dfrac{V_o}{V_s}$

$$= \frac{g_m V_{gs}\, r_d R}{(r_d + R)\, V_{gs}}$$

$$\boxed{\therefore A_V = \frac{\mu R}{r_d + R}}$$

(c) $\therefore D = 1 + A_V \beta = 1 + \dfrac{\mu R}{r_d + R}$

$\therefore D = \dfrac{r_d + R + \mu R}{r_d + R} = \dfrac{r_d + R(1+\mu)}{r_d + R}$

(d) $\therefore A_{vf} = \dfrac{A_V}{D}$

$$= \frac{\dfrac{\mu R}{r_d + R}}{\dfrac{r_d + R(1+\mu)}{r_d + R}}$$

$$\boxed{\therefore A_{vf} = \frac{\mu R}{r_d + R(1+\mu)}}$$

(e) For this circuit $R_i = \infty$

$\therefore R_{if} = R_i D = \infty$

(f) We know R_{of} for voltage series FB amp given by

$R_{of} = \dfrac{R_o}{1 + \beta A_v}$ where $R_o = r_d$ and $A_v = \lim_{R_L \to \infty} A_V = \mu = g_m r_d$

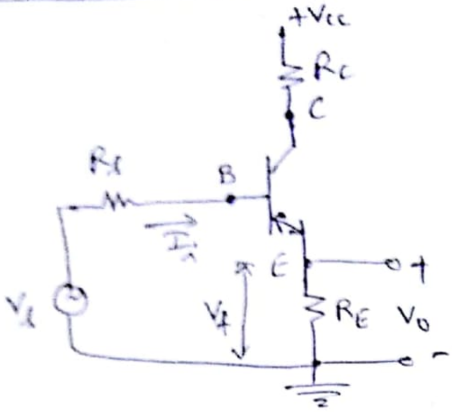
$\therefore R_{of} = \dfrac{R_o}{1+\mu} = \dfrac{r_d}{1+\mu}$

(g) $R'_{of} = R_{of} \| R_L = \dfrac{R_{of} R_L}{R_{of} + R_L} = \dfrac{R_o R_L}{R_o + R_L + \mu R_L} = \dfrac{R_o R_L}{(R_o + R_L)\left[1 + \dfrac{\mu R_L}{R_o + R_L}\right]} = \dfrac{R'}{1 + A_V}$.

where $R_L = R$, $R' = R_o \| R_L = r_d \| R$

P.T.O.. (19)

(b) The Emitter Follower:

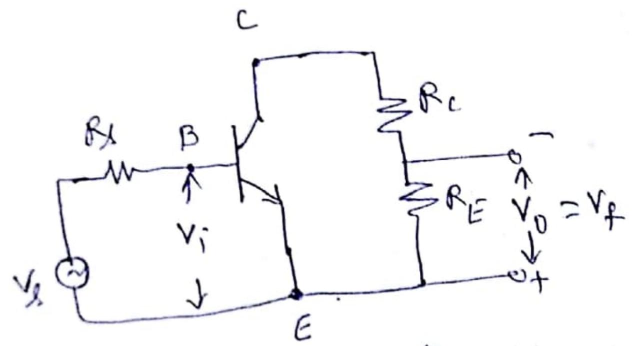


Step 1: Identify the topology:

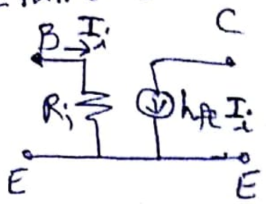
The output voltage V_o is appearing in the input loop and the voltage across R (V_f) is fed back. Therefore the circuit is performing voltage series feedback.

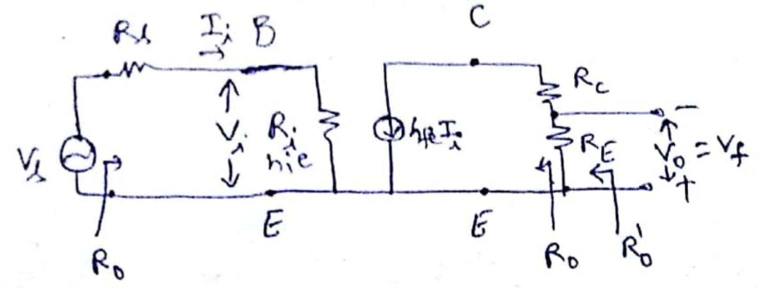
Hence: $X_o = V_o$; $X_i = V_i$, $X_f = V_f$ & $X_s = V_s$

Step 2: To obtain input ckt set $V_o = 0$ and to obtain output ckt set $I_i = 0$ (open gate terminal). Then obtain the ac equivalent circuit without feedback and including the loading effect of β-network.



Step 3: Replace BJT with its approximate h-parameter model.





(P.T.O.)

step 4 : ⓐ $\beta = \frac{x_f}{x_o} = \frac{V_f}{V_o} = 1$ $\boxed{\therefore \beta = 1}$

ⓑ $A_v = \frac{x_o}{x_i} = \frac{V_o}{V_i} = \frac{V_o}{V_s}$ $\left[\because A_v = A_{vs} \text{ in FB amplifiers}\right]$

$\therefore A_v = h_{fe} I_i R_E$

but $I_i = \frac{V_s \cancel{h_{ie}}}{R_s + h_{ie}}$

$$\boxed{\therefore A_v = \frac{h_{fe} R_E}{R_s + h_{ie}}}$$

ⓒ $\therefore D = 1 + A_v \beta = 1 + \frac{h_{fe} R_E}{R_s + h_{ie}} \cdot 1 = \frac{R_s + h_{ie} + h_{fe} R_E}{R_s + h_{ie}}$

ⓓ $\therefore A_{vf} = \frac{A_v}{D} = \frac{h_{fe} R_E}{R_s + h_{ie} + h_{fe} R_E}$

ⓔ $R_i = \frac{V_s}{I_i} = R_s + h_{ie}$

$\therefore R_{if} = R_i D = \cancel{(R_s + h_{ie})} \times \frac{R_s + h_{ie} + h_{fe} R_E}{\cancel{(R_s + h_{ie})}}$

$$\boxed{\therefore R_{if} = R_s + h_{ie} + h_{fe} R_E}$$

ⓕ $R_o = \infty$; $\therefore R_{of} = \frac{R_o}{D} = \infty$ but the amplifier ~~is~~ has a finite output impedance. So, to obtain R_{of} first calculate R'_{of} and then take $\underset{R_L \to \infty}{Lt} R'_{of}$ to get R_{of}.

$\therefore R'_{of} = \frac{R'_o}{D} = \frac{R_E}{D}$ $\left[\because R'_o = R_E\right]$

$$\boxed{R'_{of} = \frac{R_E (R_s + h_{ie})}{(R_s + h_{ie} + h_{fe} R_E)}}$$

$\therefore R_{of} = \underset{R_E \to \infty}{Lt} R'_{of}$

$= \underset{R_E \to \infty}{Lt} \frac{R_E (R_s + h_{ie})}{R_s + h_{ie} + h_{fe} R_E}$

$$\boxed{\therefore R_{of} = \frac{R_s + h_{ie}}{h_{fe}}}$$

~~END~~

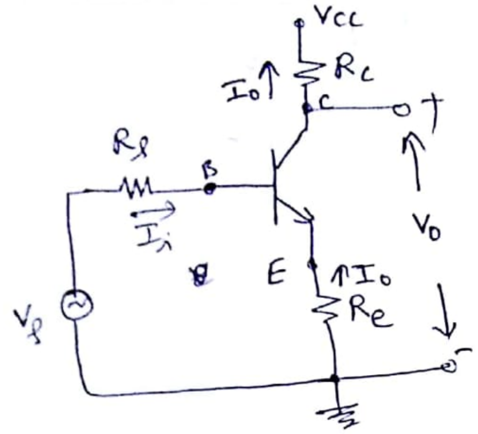
Note: Can also obtain R_o

$R_{of} = \frac{R_o}{D} \Rightarrow R_o = R_{of} D = \frac{\cancel{(R_s + h_{ie})}}{h_{fe}} \times \frac{(R_s + h_{ie} + h_{fe} R_E)}{\cancel{(R_s + h_{ie})}}$?

$R_o = \frac{R_s + h_{ie} + h_{fe} R_E}{h_{fe}}$

P.T.O. ..

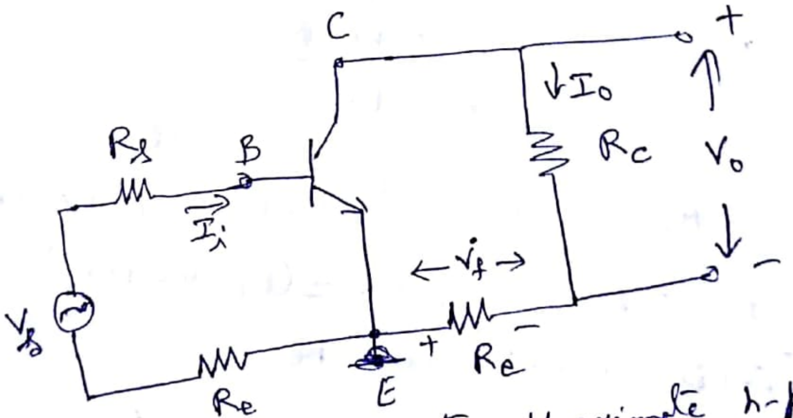
(13) Analysis of current-series FB amp:



Hint: KVL to i/p loop
$V_s - I_i R_s - V_{be} - (I_o R_e) = 0$
o/p current is appearing on i/p side
o/p current is sampled and hence o/p current is sampled and
I_o is appearing in the loop
hence it is series mixing.

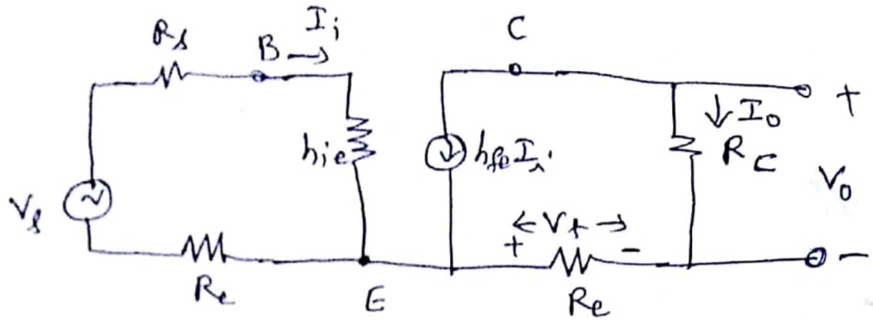
Step 1: Identify the topology:
The output current is appearing in input loop hence
The circuit is conforming current-series FB topology.
Hence $X_o = I_o$, $X_i = V_i$; $X_s = V_s$ & $X_f = V_f$

Step 2: To obtain input ckt set $I_o = 0$, so open at Collector terminal and to obtain output equivalent circuit set $I_i = 0$ (series mixing), so, open Base terminal.
Draw the ac equivalent ckt



Step 3: Replace BJT with its approximate h-parameter model.

(P.T.O.)



step 4:

(a) $\beta = \frac{x_f}{x_o} = \frac{V_f}{I_o} = \frac{-R_e I_o}{I_o} = -R_e \quad \therefore \boxed{\beta = -R_e}$

(b) $A = \frac{x_o}{x_i} = \frac{x_o}{x_s} = \frac{I_o}{V_s} = G_M$

$\therefore G_M = \frac{I_o}{V_s}$

$= \frac{-h_{fe} I_b}{V_s}$

$= \frac{-h_{fe} \cancel{I_b}}{\cancel{I_i}(R_s + h_{ie} + R_e)}$

$$\boxed{\therefore G_M = \frac{-h_{fe}}{(R_s + h_{ie} + R_e)}}$$

(c) $D = 1 + G_M \beta$

$= 1 + \frac{h_{fe} R_e}{R_s + h_{ie} + R_e}$

$$\boxed{\therefore D = \frac{R_s + h_{ie} + (1 + h_{fe}) R_e}{R_s + h_{ie} + R_e}}$$

(d) $\therefore G_{Mf} = \frac{G_M}{D} = \frac{-h_{fe}}{R_s + h_{ie} + (1 + h_{fe}) R_e}$

(e) $R_{if} = R_i D \quad ; \quad R_i = (R_s + h_{ie} + R_e)$

$$\boxed{\therefore R_{if} = R_s + h_{ie} + (1 + h_{fe}) R_e}$$

(f) $R_o = \infty$ then $R_{of} = R_o D = \infty$ if

$R'_{of} = R_{of} \| R_C = R_C$

alternate formula for R'_{of} is given by

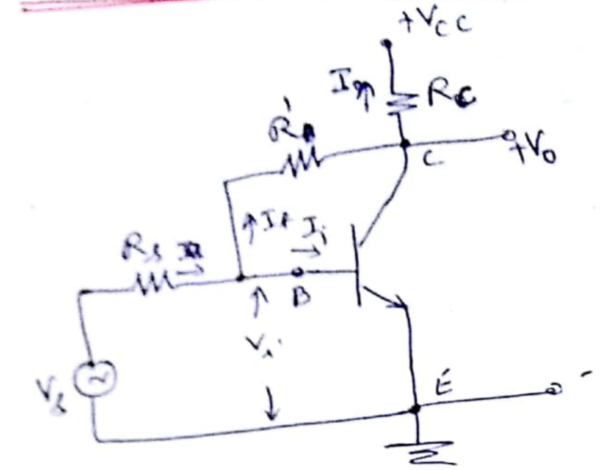
$R'_{of} = R'_o \frac{1 + G_m \beta}{1 + G_M \beta}$

we know $G_m = \underset{R_L \to 0}{Lt}\ G_M = G_M \quad [\because G_M \neq f(R_L)]$

$$\boxed{\therefore R'_{of} = R'_o = R_L.}$$

P.T.O. ... (21)

(12) Analysis of Voltage shunt FB Amp:



Hint: KCL to i/p node

$I_s - I_i - I_f = 0$

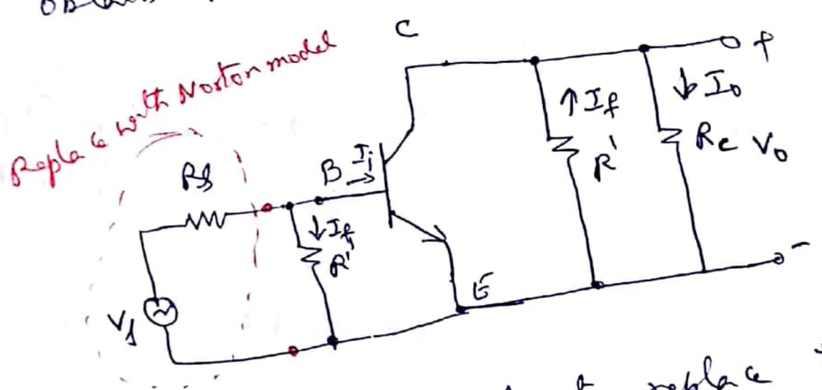
$I_s - I_i - \left(\frac{-V_o + V_i}{R'}\right) = 0$

o/p voltage is appearing in i/p KCL, hence ~~o/p~~ voltage sampling and shunt Mixing.

Step 1: identify the topology:

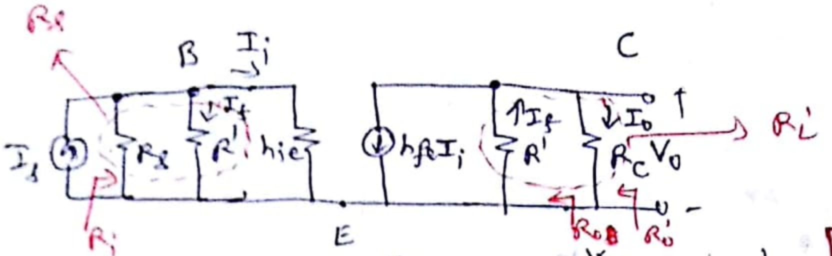
Feedback is taken from output node hence it is ~~output~~ voltage sampling. the mixing at Base is in shunt hence shunt mixing. Therefore the ckt Confirms voltage - shunt Feedback topology.

Step 2: To obtain i/p equivalent ckt set $V_o = 0$, So short o/p node.
To obtain o/p equivalent ckt set $V_i = 0$, So short i/p node.



Step 3: Since the mixing is shunt, replace the Source with its equivalent Nortons model and Replace BJT with its approximate h-parameter model.

(P.T.O.)



Step 4: (a) $\beta = \dfrac{x_f}{x_o} = \dfrac{I_f}{V_o} = \dfrac{-V_o}{R' V_o} = -\dfrac{1}{R'}$ $\qquad \boxed{\therefore \beta = -\dfrac{1}{R'}}$

(b) $A = \dfrac{x_o}{x_i} = \dfrac{x_o}{x_s} = \dfrac{V_o}{I_s} = \dfrac{-h_{fe} I_i R_L'}{I_s}$ where $R_L' = R' \| R_C$

but $I_i = I_s \times \dfrac{R_s'}{R_s' + h_{ie}}$

$$\therefore A = -\frac{h_{fe} R_s' R_L'}{(R_s' + h_{ie})} = R_M$$

$$\boxed{\therefore R_M = -\frac{h_{fe} R_s' R_L'}{R_s' + h_{ie}}}$$

(c) $D = 1 + R_M \beta = 1 + \dfrac{h_{fe} R_s' R_L'}{R'(R_s' + h_{ie})}$

$$\therefore D = \frac{h_{fe} R_s' R_L' + R'(R_s' + h_{ie})}{R'(R_s' + h_{ie})}$$

(d) $\therefore R_{Mf} = \dfrac{R_M}{D} = -\dfrac{\dfrac{h_{fe} R_s' R_L'}{(R_s' + h_{ie})}}{\dfrac{h_{fe} R_s' R_L' + R'(R_s' + h_{ie})}{R'(R_s' + h_{ie})}}$

$$\boxed{\therefore R_{Mf} = -\frac{h_{fe} R_s' R_L' R'}{(h_{fe} R_s' R_L' + R_s' R' + h_{ie} R')}}$$

(e) $R_{if} = \dfrac{R_i}{D} = \dfrac{R_s \| R' \| h_{ie}}{D}$

(f) $R_o = R'$ and $R_{of} = \dfrac{R_o}{1 + R_m \beta}$

Now R_m is to be calculated as $R_m = \lim\limits_{R_C \to \infty} R_M$

$\therefore R_m = -\dfrac{h_{fe} R_s'}{R_s' + h_{ie}} \times \lim\limits_{R_C \to \infty} R_L'$ $\qquad$ but $R_L' = R_C \| R'$
as $R_C \to \infty$ $R_L' \to R'$

$$\therefore R_m = -\frac{h_{fe} R_s' R'}{R_s' + h_{ie}}$$

$$\therefore 1 + R_m \beta = 1 + \frac{h_{fe} R_s' \cancel{R'}}{(R_s' + h_{ie}) \cancel{R'}} = \frac{R_s'(1 + h_{fe}) + h_{ie}}{(R_s' + h_{ie})}$$

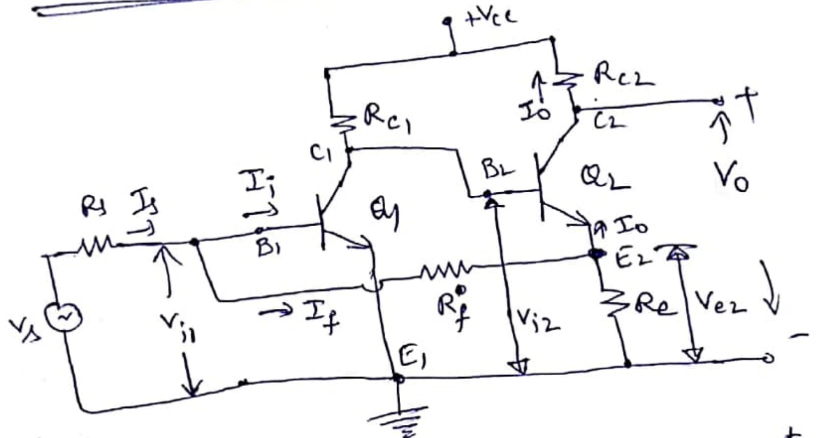
(P.T.O.)

$$\therefore R_{of} = \frac{R_o}{1+R_m\beta} = \frac{R'(R'_s+h_{ie})}{R'_s(1+h_{fe})+h_{ie}}$$

$$\boxed{\therefore R_{of} = \frac{R'(R'_s+h_{ie})}{R'_s(1+h_{fe})+h_{ie}}}$$

$$\boxed{\therefore R'_{of} = R_{of} \parallel R_C}$$

(14) Analysis of Current-Shunt FB Amp:



Hint: KCL to i/p node

$I_s - I_i - I_f = 0$

but $-I_f = (-I_o)\frac{R_e}{R_e+R'}$ [$\because V_{i1} = 0$]

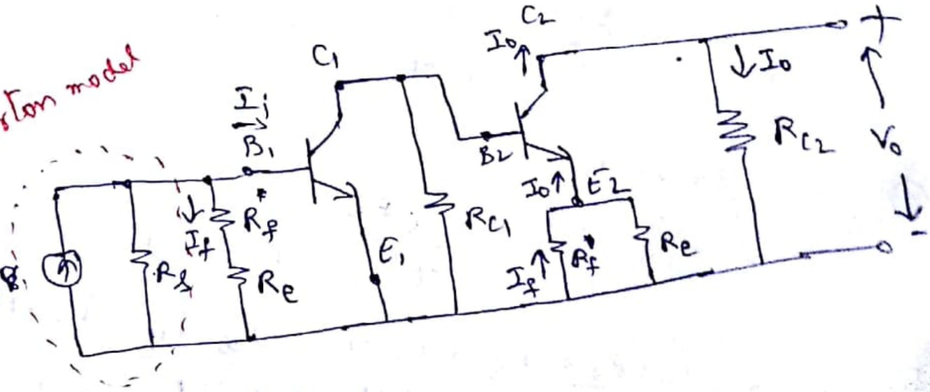
$\therefore I_s - I_i - I_o\frac{R_e}{R_e+R'} = 0$

So, I_o is sampled and Mixing is in shunt.

Step 1: Feedback signal is taken from output loop, hence it is current sampling and feedback signal is mixing in shunt with source, hence shunt mixing. Therefore the ckt conforms current-shunt topology.

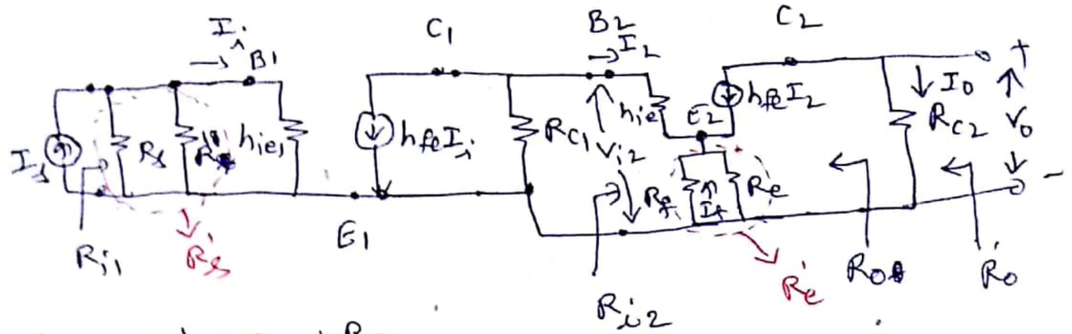
Step 2: To obtain the o/p circuit set $I_o = 0$, so open at C2 terminal and to obtain the o/p ckt set $V_i = 0$

Norton model



(P.T.O.)

Step ③: Replace BJT's with approximate h-parameter models.



where $R' = R_f + R_e$

$R_s' = R_s \| R'$

$R_e' = R_f \| R_e$

Step 4: ⓐ $\beta = \frac{x_f}{x_o} = \frac{I_f}{I_o} = \frac{R_e}{R_e + R_o}$ $\quad\quad$ $\because I_f = I_o \times \frac{R_e}{R_e + R_f}$

ⓑ $A_I = \frac{I_o}{I_s} = \frac{I_o}{I_2} \times \frac{I_2}{I_i} \times \frac{I_i}{I_s}$

$I_o = -h_{fe} I_2 \Rightarrow \frac{I_o}{I_2} = -h_{fe}$

$I_2 = -h_{fe} I_i \times \frac{R_{C1}}{R_{C1} + R_{i2}}$ $\quad\quad$ where $R_{i2} = \frac{V_{i2}}{I_2}$

$V_{i2} = h_{ie} I_2 + (1 + h_{fe}) I_2 R_e'$

$\therefore \frac{I_2}{I_i} = -\frac{h_{fe} R_{C1}}{R_{C1} + R_{i2}}$ $\quad\quad$ $\therefore \frac{V_{i2}}{I_2} = h_{ie} + (1 + h_{fe}) R_e'$

$I_i = I_s \times \frac{R_s'}{R_s' + h_{ie}}$

$\therefore \frac{I_i}{I_s} = \frac{R_s'}{R_s' + h_{ie}}$

$\therefore A_I = \left[-h_{fe}\right] \times \left[\frac{-h_{fe} R_{C1}}{R_{C1} + R_{i2}}\right] \times \left[\frac{R_s'}{R_s' + h_{ie}}\right]$

$A_I = h_{fe}^2 \times \frac{R_{C1}}{R_{C1} + R_{i2}} \times \frac{R_s'}{R_s' + h_{ie}}$

ⓒ $D = 1 + A_I \beta$

$= 1 + \frac{h_{fe}^2 R_{C1} R_s' R_e}{(R_{C1} + R_{i2})(R_s' + h_{ie})(R_e + R_f)}$

$\therefore D = \frac{h_{fe}^2 R_{C1} R_s' R_e + (R_{C1} + R_{i2})(R_s' + h_{ie})(R_e + R_f)}{(R_{C1} + R_{i2})(R_s' + h_{ie})(R_e + R_f)}$

(d) $A_{If} = \dfrac{A_I}{D}$

$$A_{If} = \frac{h_{fe}^2 R_{c1} R_s' (R_e + R_f)}{h_{fe}^2 R_{c1} R_s' R_e + (R_{c1} + R_{i2})(R_s' + h_{ie})(R_e + R_f)}$$

(e) $R_i = R_s \| R' \| h_{ie}$

$\therefore R_{if} = \dfrac{R_i}{D}$

(d) $R_{of} = R_o D$ but $R_o = \infty$; $\therefore R_{of} = \infty$

$R_{of}' = R_{of} \| R_L = R_{c2}$

$R_o' = R_o \| R_L = R_{c2}$

$\therefore R_o' = R_{of}' = R_{c2}$.