Feedback Amplifiers

Introduction:

The amplifier in which a part of o/p is sampled and fedback to the i/p of the amplifier is called feedback amplifier.

∴ At input we have two signals: Input signal and part of the o/p which is fed back to the input.

When these input signals are in phase, the feedback is called positive feedback. When they are in out of phase, the feedback is called negative feedback.

Positive feedback - Results in oscillations - Used in oscillator.

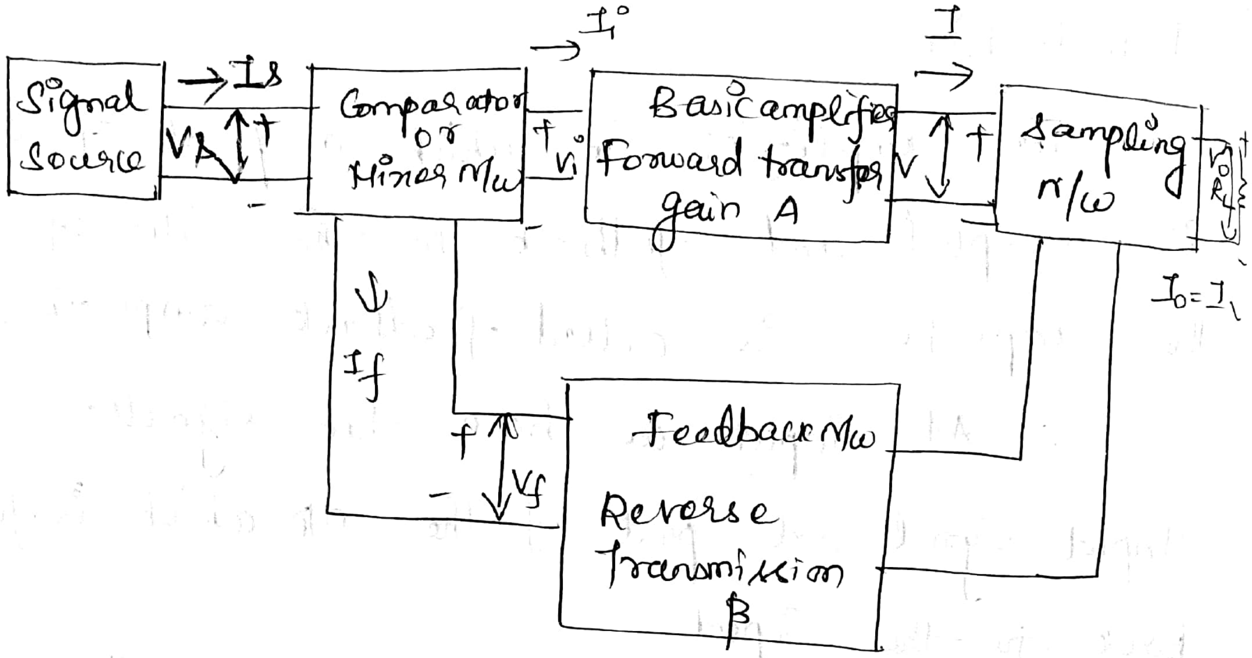
Negative feedback - gives stability - Used in Amplifiers.

Block diagram of amplifier with feedback

The feedback Connection has three networks

→ sampling network
→ Feedback network
→ Mixer network.

Block diagram



The feedback network samples the o/p voltage or current by means of a suitable sampling network and applies this signal to the i/p through a feedback two port network.

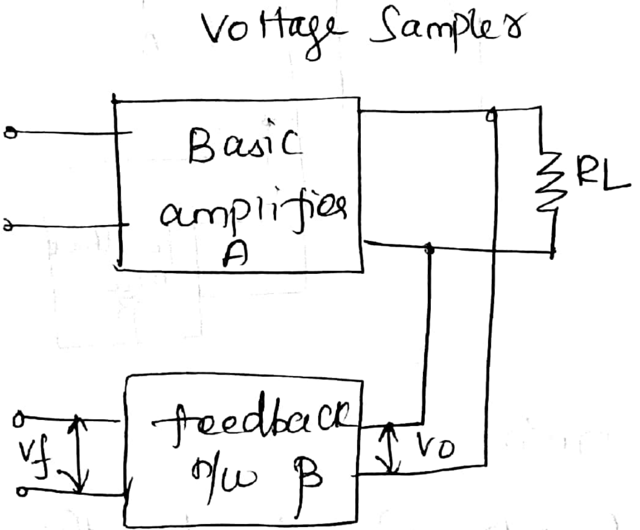
At the i/p the feedback signal is combined with the i/p signal through a mixer network and is fed into the amplifier.

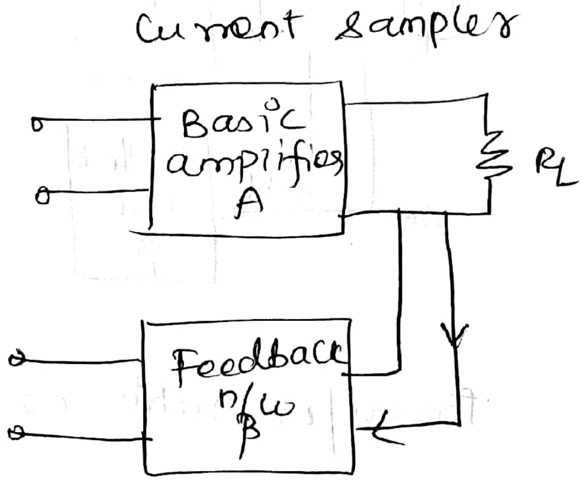
Sampling network:-

There are two ways to sample the o/p, according to the sampling parameter either voltage or current. The

O/P voltage is sampled by connecting the feedback network in shunt across the output. This type of connection is referred to as voltage or node sampling.

The O/P current is sampled by connecting the feedback network in series with the output. This type of connection is referred to as current or loop sampling.





Feedback network :-

It may consists of resistors, capacitors and Inductors. It provides reduced portion of the O/P as feedback signal to the i/p mixer network. It is given as

$$V_f = \beta V_o.$$

where β → feedback factor (or) Ratio

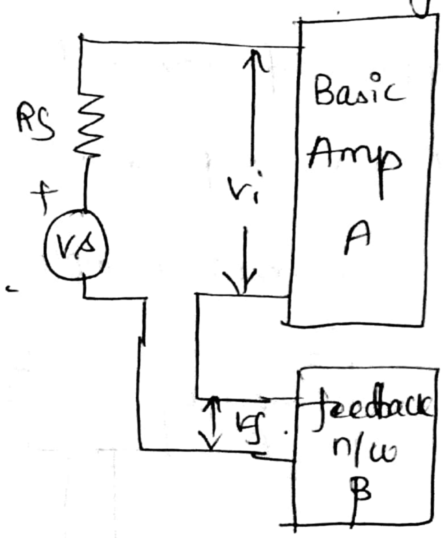
β lies btw 0 and 1.

Mixer network:

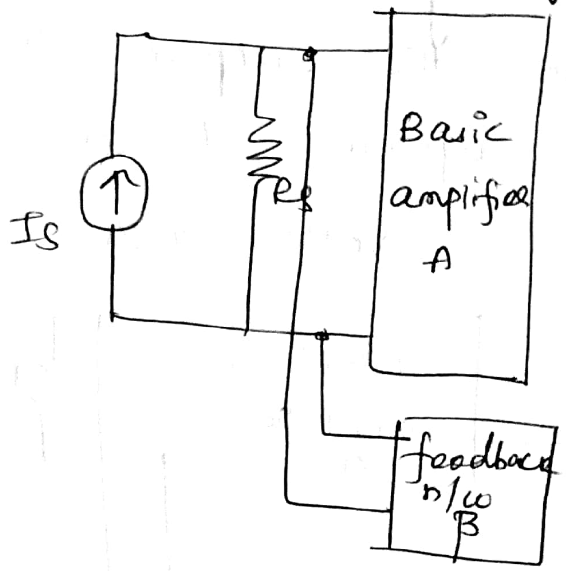
There are two ways of mixing feedback signal with the i/p signal.

1) series i/p Connection
2) shunt i/p Connection.

Series mixing



shunt mixing.



Transfer ratio or Gain:-

The ratio of o/p signal to the i/p signal of the basic amplifier is called as Gain. It is denoted by A.

voltage gain $A_V = \frac{V}{V_i}$

Current gain $A_i = \frac{I}{I_i}$

Transconductance $G_m = \frac{I}{V_i}$

Transresistance $R_m = \frac{V}{I_i}$

These four quantities are called transfer gain of the amplifier without feedback.

The gain with feedback is represented by the symbol Af :

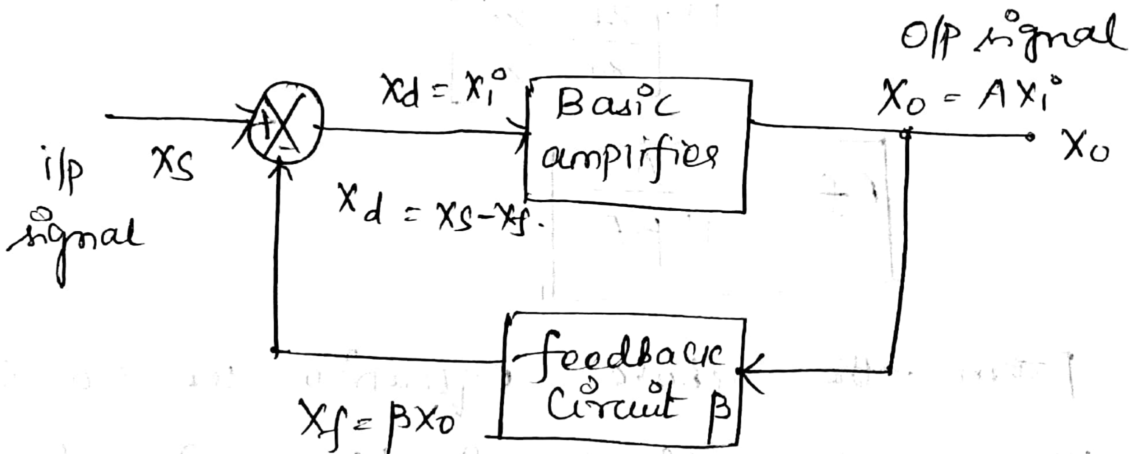
$\therefore$ $A_f = \frac{V_o}{V_s}$ = voltage gain with fb.

$A_{If} = \frac{I_o}{I_s}$ = current gain with fb.

$G_{mf} = \frac{I_o}{V_s}$ = Transconductance with fb.

$R_{mf} = \frac{V_o}{I_s}$ = Transresistance with fb.

Schematic Representation of feedback amplifier.



Gain with feedback :

A → Represents transfer gain of the basic amplifier without feedback.

Af → Transfer gain of the basic amplifier with feedback.

$A = \frac{X_o}{X_i}$ $\quad$ $A_f = \frac{X_o}{X_s}$

As it is a negative feedback, the relation between x_i and x_s is given as

$$x_i = x_s + (-x_f)$$

$x_f \rightarrow$ feedback voltage (or) current.

$$A_f = \frac{x_o}{x_s} = \frac{x_o}{x_i + x_f}$$

Dividing numerator and denominator by x_i

$$A_f = \frac{x_o / x_i}{1 + x_f / x_i}$$

$$\because A = \frac{x_o}{x_i}$$

$$= \frac{A}{1 + \left[\frac{x_f}{x_o} \cdot \frac{x_o}{x_i}\right]}$$

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

From the above equation we can say that gain without feedback is always greater than gain with feedback

$$\boxed{A >> A_f}$$

For voltage amplifier, gain with negative feedback is given as

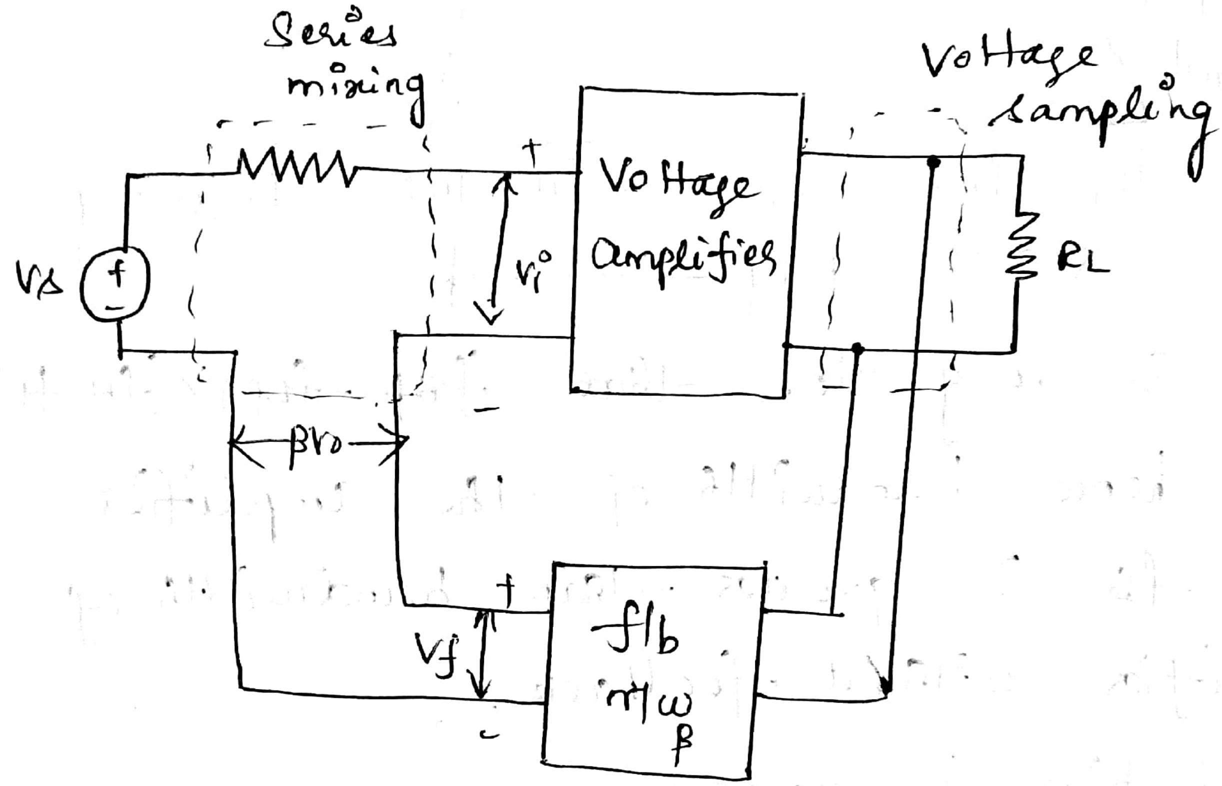
$$\boxed{A_{vf} = \frac{A_v}{1 + \beta A_v}}$$

The negative feedback amplifiers has the following advantages

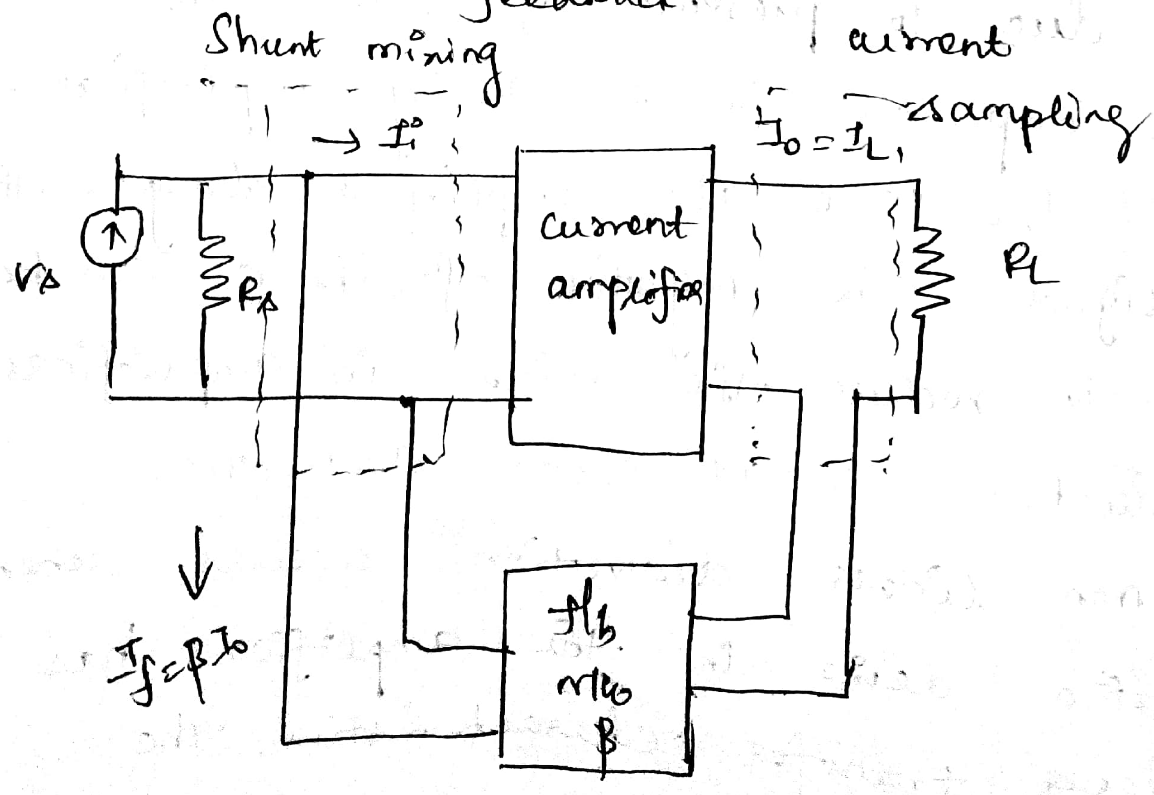
1. Improved stability
2. Reduction in gain
3. Reduction in distortion
4. Reduction in noise
5. Increase the input impedance
6. Decrease the output impedance
7. Increase in bandwidth.

Basic feedback topologies :-

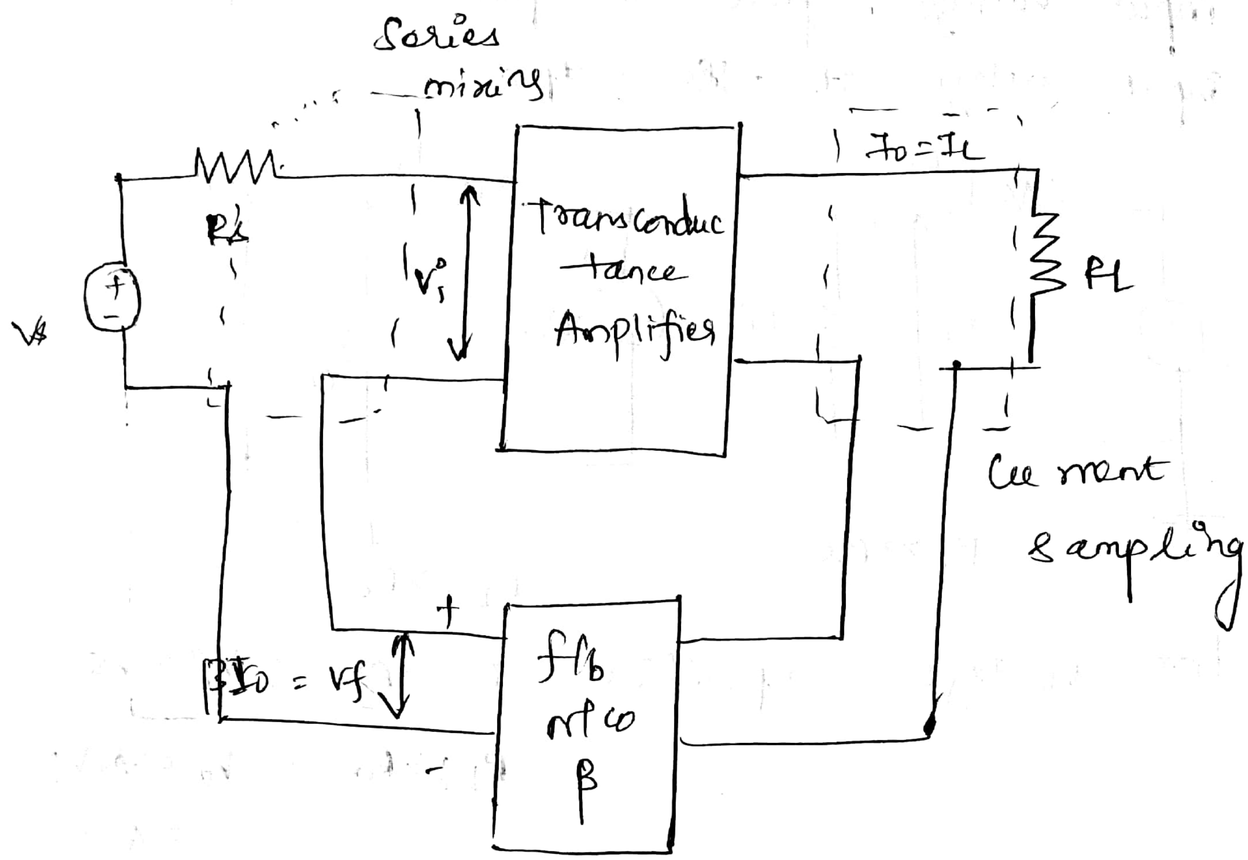
Voltage amplifier with voltage series feedback.



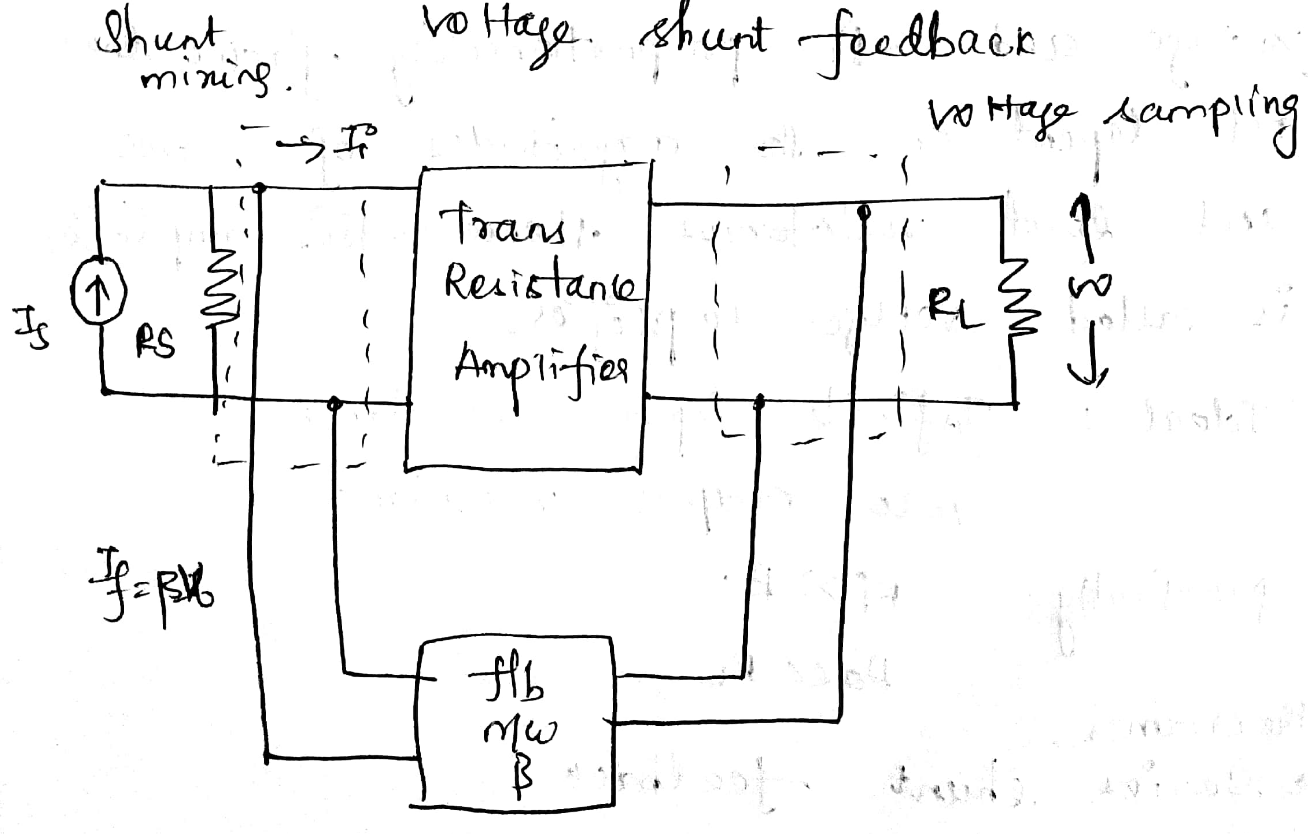
current amplifier with current shunt feedback.



Transconductance amplifier with current series feedback

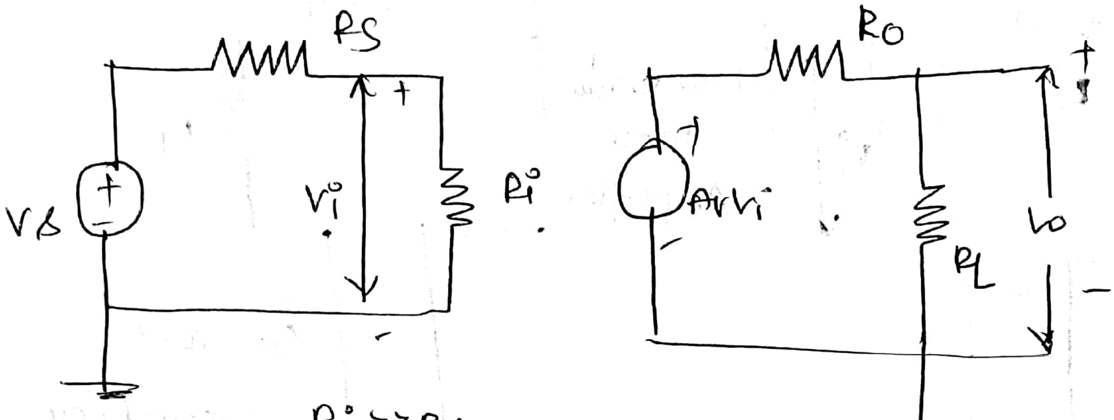


Transresistance amplifier with voltage shunt feedback



Voltage amplifier:

Voltage amplifiers are used to amplify input voltage signal and provide amplified input voltage at the output.



$R_i >> R_s$

$R_L >> R_o$

For voltage amplifier $R_i >> R_s$ $\therefore V_i \approx V_s$

$R_L >> R_o$ $\therefore V_o \approx A_v V_i$

$= A_v V_s$.

Such amplifier circuit provides a output voltage proportional to the input voltage and the proportionality factor does not depend on the magnitudes of source and load resistances. Hence this amplifier is called voltage amplifier.

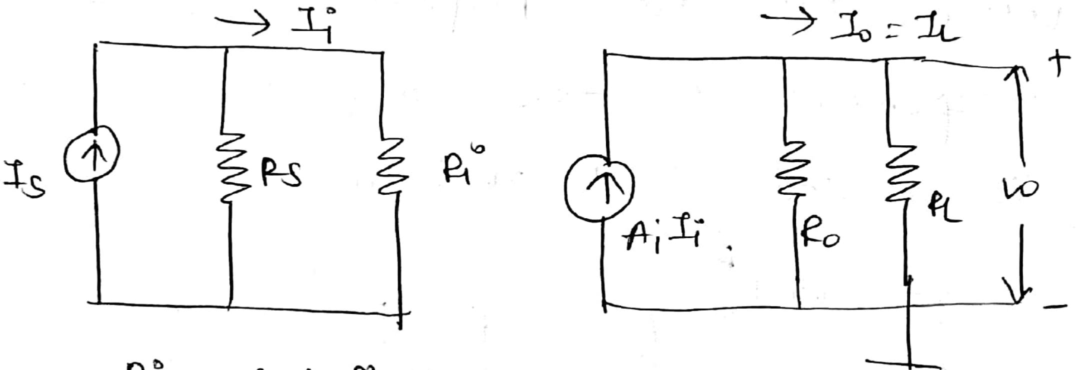
Ideal : Infinite input resistance
zero output resistance.

practically: $R_i >> R_s$
$R_o << R_L$

other names:
→ Series shunt feedback
→ Voltage series feedback.

Current Amplifier:

current amplifiers are used to amplify input current signal and provide amplified output input current at the output.



$R_i \to 0$ (or) $R_i << R_s$ $\qquad$ $R_L << R_o$ (or) $R_o \to \infty$

For current amplifier $\quad R_i << R_s \;\therefore\; I_i \approx I_s$

$R_o >> R_L \;\therefore\; I_L \approx A_i I_i$

such amplifier provides a current output proportional to the input current and the proportionality factor is independent on source and load resistances. This amplifier is called current amplifier.

Ideal : zero input resistance

Infinite output resistance.

practically : $R_i << R_s$

$R_o >> R_L$

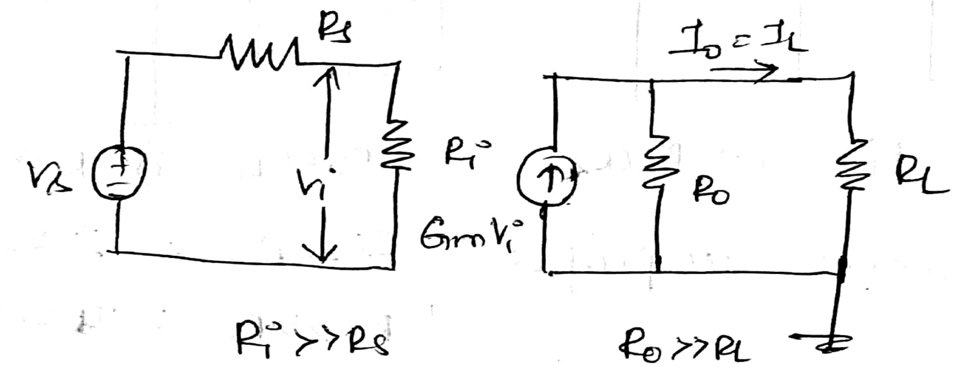
other names :-

→ shunt series feedback

→ current shunt feedback.

Transconductance amplifier :-

In this amplifier the output current is proportional to the input signal voltage and the proportionality factor is independent of the magnitudes of the source and load resistances.



Ideal : Infinite input resistance
Infinite output resistance.

practically : $R_i >> R_s$ $\quad V_i \approx V_s$

$R_o >> R_L$ $\quad I = G_m V_i$

$= G_m V_s$

$\therefore G_m = \frac{I_L}{V_s}$.

other names :-

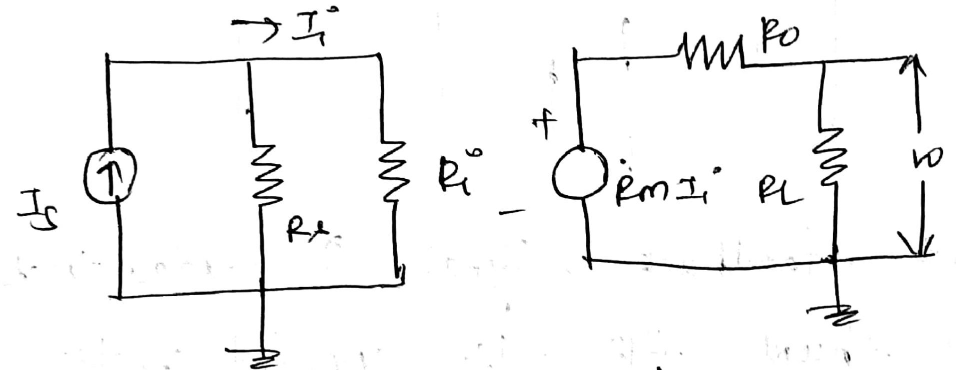
1) series - series feedback
2) current series feedback.

Transresistance amplifier:

In this amplifier an output voltage is proportional to the input signal current and the proportionality factor is independent on the source and load resistances. Ideal : zero i/p resistance & o/p resistance

practically : $R_i << R_s$ $I_i \simeq I_s$

$R_o << R_L$ $V_o = R_m I_i$



$R_i << R_s$ $R_o << R_L$

$V_o = R_m I_s$

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

other names :-

1) shunt - shunt feedback
2) voltage shunt feedback.

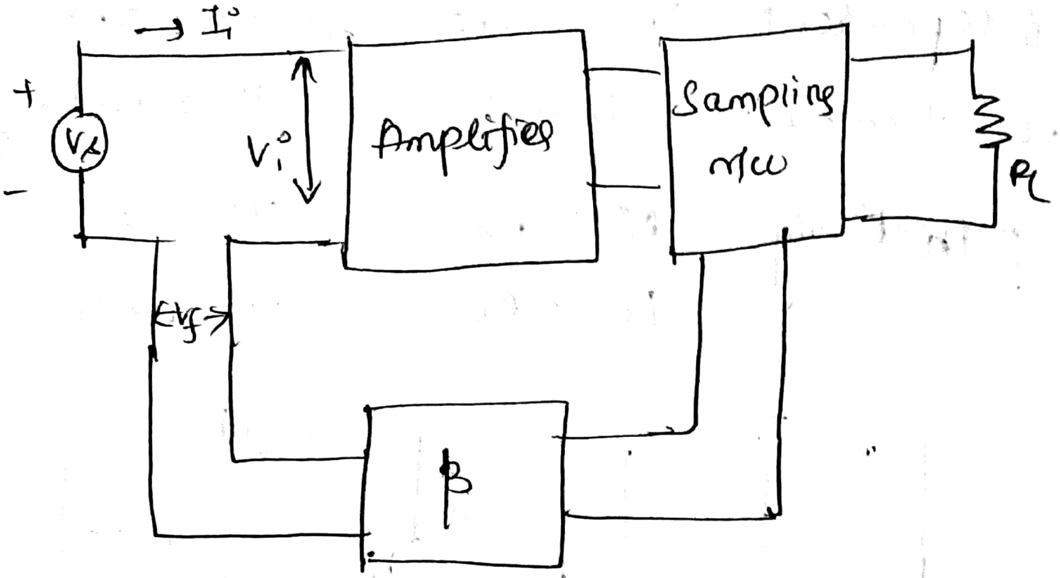
Effect on Input and output resistance of negative feedback.

Input resistance :-

If the feedback signal is added to input in <u>series</u> with the applied voltage it increases the input resistance

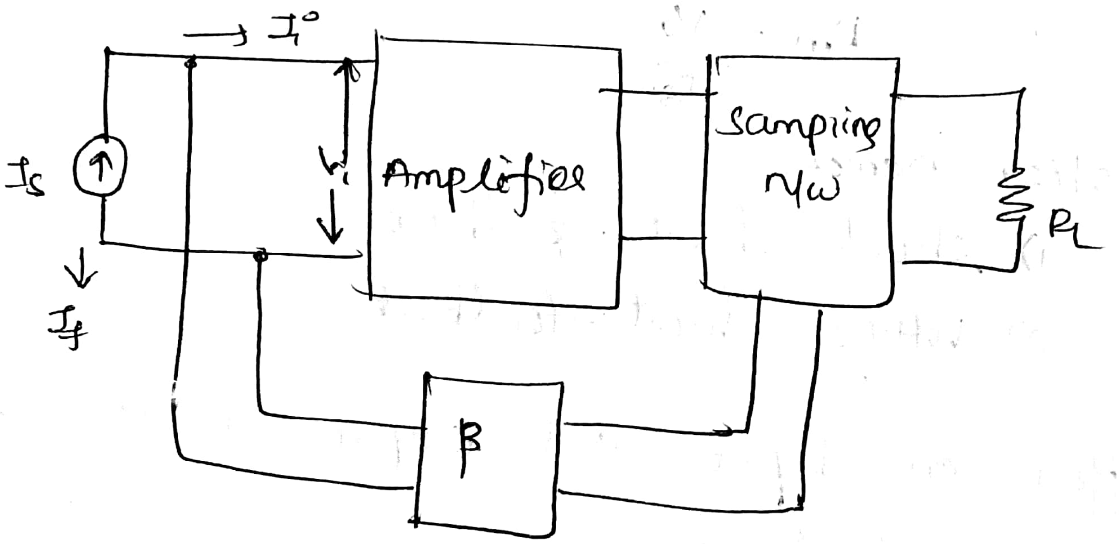
$\therefore R_{if} = \frac{V_s}{I_i}$

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



If the feedback signal is added to the i/p in shunt with the applied voltage it decreases the input resistance.

since $I_s = I_i + I_f$



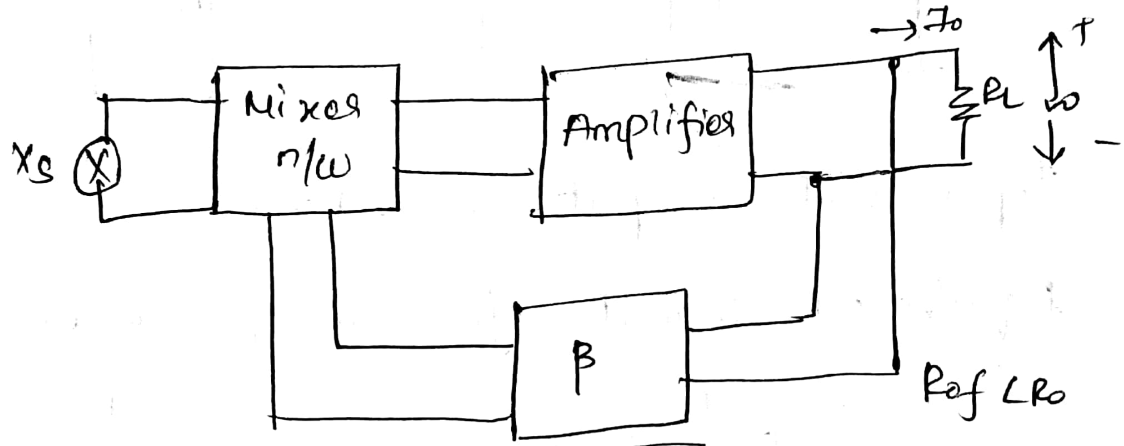
∴ Input resistance with feedback

$R_{if} = \dfrac{V_i}{I_s}$ is decreases.

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

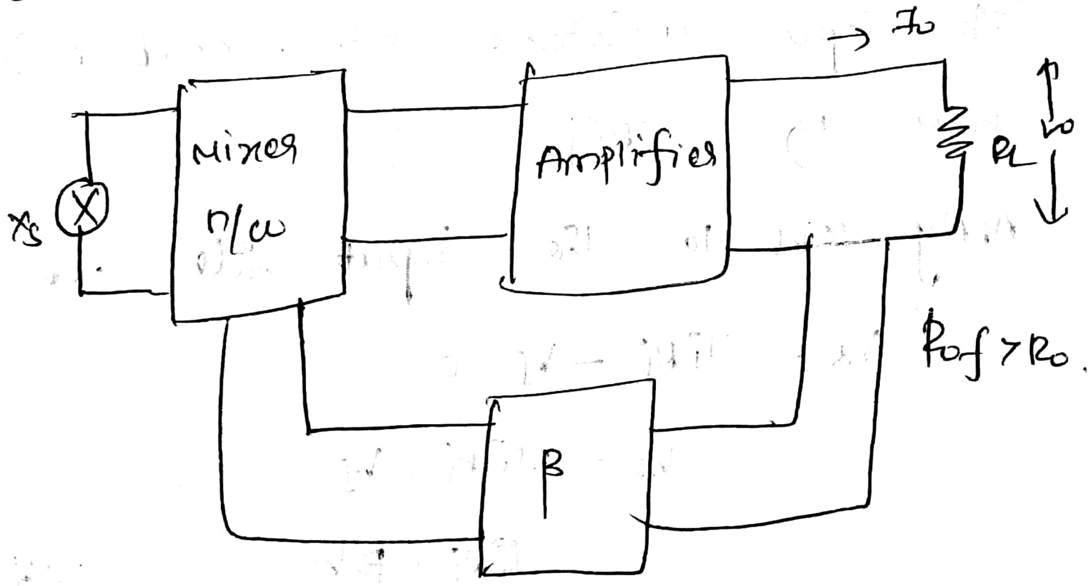
output resistance:-

The negative feedback which samples the o/p voltages tends to decrease the output resistance.



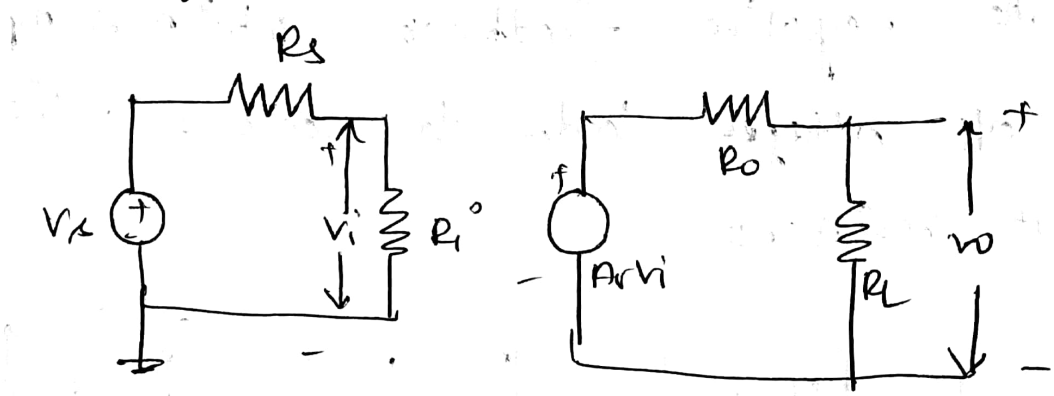
$R_{of} << R_o$

on the other hand, the negative feedback which samples the o/p current tends to increase the output resistance.



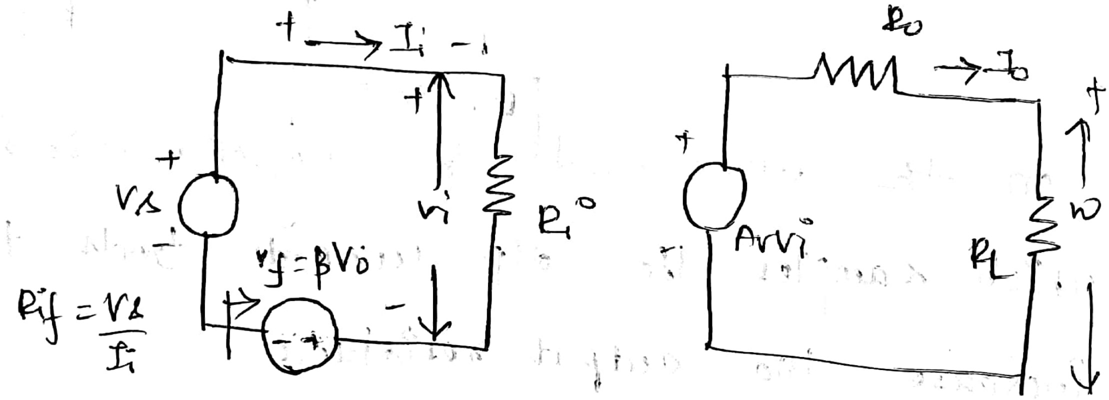
$R_{of} >> R_o$

1) Voltage series Feedback Amplifier:



Input and output resistances:

Equivalent circuit for voltage series amplifier



The input resistance with feedback is given as $R_{if} = \frac{V_s}{I_i}$

Apply KVL to the input side, we get

$$V_s - I_i R_i - V_f = 0$$

$$V_s = I_i R_i + V_f$$

$$= I_i R_i + \beta V_o \qquad \because V_f = \beta V_o$$

$$\boxed{V_s = I_i R_i + \beta V_o} \quad \text{--- (1)}$$

The O/P voltage V_o is given as

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

particular R / Total R

$$V_o = A_V V_i \qquad \because A_v = \frac{A_V R_L}{R_o + R_L}$$

$$V_o = A_v I_i R_i \quad \text{—(2)} \qquad V_i = I_i R_i$$

Input resistance R_{if} :-

Substitute the value of V_o from eqn (2) in eqn (1) we get.

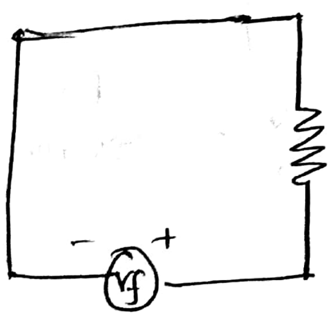
$$V_s = I_i R_i + \beta(A_v I_i R_i)$$

$$R_{if} = \frac{V_s}{I_i} = \frac{I_i R_i + \beta A_v I_i R_i}{I_i}$$

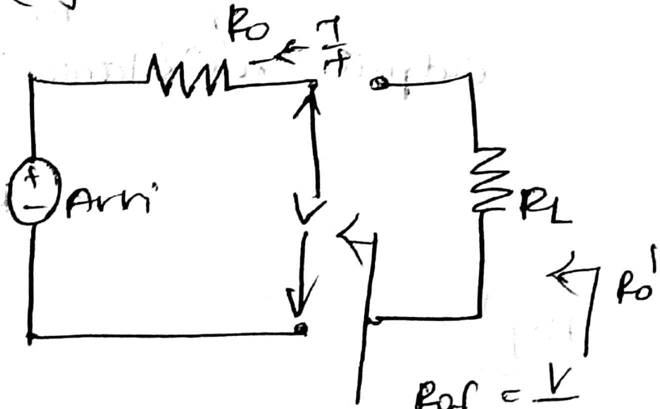
$$= R_i + \beta A_v R_i$$

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

Output resistance (R_{of}) :-



$V_f = \beta V$



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

The o/p resistance can be measured by shorting the input source $V_s = 0$ and looking into the output terminals with R_L disconnected.

Apply KVL to the o/p side we get

$$A_V V_i + IR_o - V = 0$$

$$IR_o = V - A_V V_i$$

$$I = \frac{V - A_V V_i}{R_o} \quad \text{--- (1)}$$

The input voltage is given as

$$V_i = V_f = -\beta V \quad \text{--- (2)}$$

substitute the value of V_i from eqn (2) in eqn (1) we get

$$I = \frac{V - A_V(-\beta V)}{R_o}$$

$$= \frac{V + A_V \beta V}{R_o}$$

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

output resistance $R_{of} = \frac{V}{I}$

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

<u>R_{of}'</u>

$$R_{of} = R_{of} \parallel R_L$$

$$= \frac{R_{of} \times R_L}{R_{of} + R_L} = \frac{\frac{R_o}{1+\beta A_V} \times R_L}{\frac{R_o}{1+\beta A_V} + R_L}$$

$$= \frac{\frac{R_o R_L}{1+\beta A_V}}{\frac{R_o + R_L(1+\beta A_V)}{1+\beta A_V}} = \frac{R_o R_L}{R_o + R_L + \beta A_V R_L}$$

Dividing numerator and denominator by $(R_o + R_L)$ we get

$$R_{of}' = \frac{\frac{R_o R_L}{R_o + R_L}}{\frac{R_o + R_L + \beta A_V R_L}{R_o + R_L}} = \frac{R_o R_L / R_o + R_L}{1 + \frac{\beta A_V R_L}{R_o + R_L}}$$

$$\boxed{R_{of}' = \frac{R_o'}{1+\beta A_V}}$$

$\because R_o' = \frac{R_o R_L}{R_o + R_L}$

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

Input resistance

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

output resistance

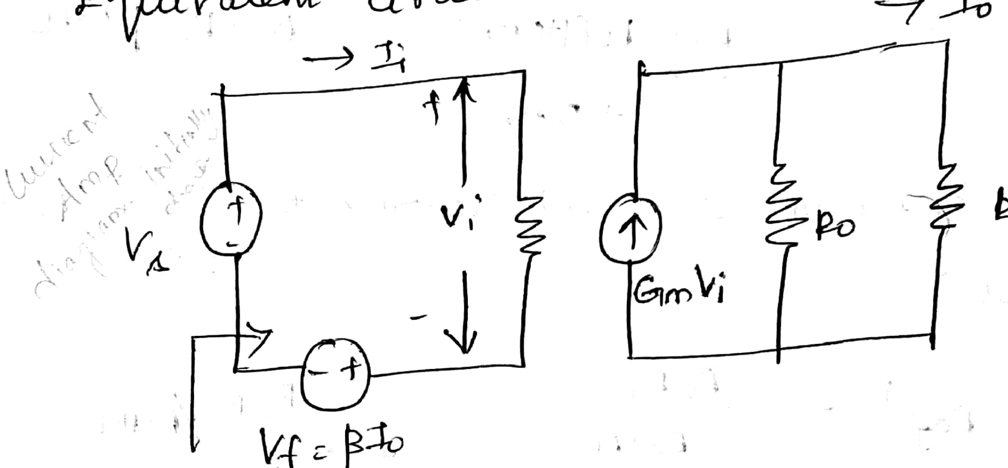
$$R_{of} = \frac{R_o}{(1+\beta \cdot A_V)}$$

Output resistance

$$R_{of}' = \frac{R_o'}{1+\beta A_V}.$$

current series feedback Amplifier :-

Equivalent circuit :-



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

The Input circuit is represented by thevenin's equivalent circuit and o/p circuit by norton's equivalent circuit.

Input resistance (R_{if})

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

Apply KVL to the input side we get

$V_s - I_i R_i - V_f = 0$

$$V_s = V_f + I_i R_i$$

$$= I_i R_i + \beta I_o \quad \text{--- (1)} \qquad \because V_f = \beta I_o$$

The o/p current I_o is given as

$$I_o = \frac{R_o G_m V_i}{R_o + R_L} \qquad \frac{\text{opp } R \times \text{applied } I}{\text{total } R}$$

$$I_o = G_M V_i \quad \text{--- (2)} \qquad \because G_M = \frac{G_m R_o}{R_o + R_L}$$

Substitute the value of I_o from eqn (2) to eqn (1) we get

$V_s = I_i R_i + \beta G_M V_i$

$V_s = I_i R_i + \beta G_M I_i R_i$ $\quad \because V_i = I_i R_i$

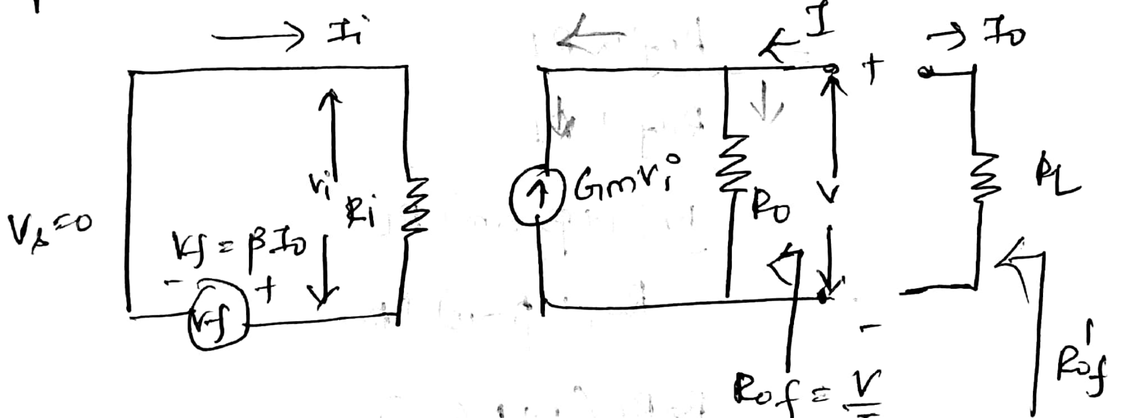
$R_{if} = \frac{V_s}{I_i}$

$= \frac{I_i R_i + \beta G_M I_i R_i}{I_i}$

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

output resistance :-

Equivalent circuit :-



The o/p resistance can be measured by shorting the i/p source $V_s = 0$ and looking into the o/p terminals with R_L disconnected.

Apply KCL to the o/p node we get.

$$I = \frac{V}{R_o} - G_m V_i \quad \text{--- (1)}$$

Input voltage is given as

$$V_i = -V_f = -\beta I_o = +\beta I \quad \text{--- (2)} \qquad \because I_o = -I$$

substitute the value of V_i from eqn (2) to eqn (1) we get

$$I = \frac{V}{R_o} - G_m \beta I$$

$$\frac{V}{R_o} = I + G_m \beta I$$

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

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

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

R_{of}' :-

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

$$= \frac{R_{of} \times R_L}{R_{of} + R_L}$$

$$= \frac{R_o(1+\beta G_m) R_L}{R_o(1+\beta G_m) + R_L}$$

$$= \frac{R_o R_L (1+\beta G_m)}{R_o + R_o \beta G_m + R_L}$$

$$= \frac{R_o R_L (1+\beta G_m)}{R_o + R_L + R_o \beta G_m}$$

Dividing numerator and denominator by $R_o + R_L$ we get

$$R_{of}' = \frac{\dfrac{R_o R_L (1+\beta G_m)}{R_o + R_L}}{\dfrac{R_o + R_L + R_o \beta G_m}{R_o + R_L}}$$

$$= \frac{R_o'(1+\beta G_m)}{1+\beta \frac{G_m R_o}{R_o+R_L}}$$

$\because R_o' = \frac{R_o R_L}{R_o + R_L}$

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

$$R_{of}' = \frac{R_o'(1+\beta G_m)}{1+\beta G_M}$$

Input resistance

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

output resistance

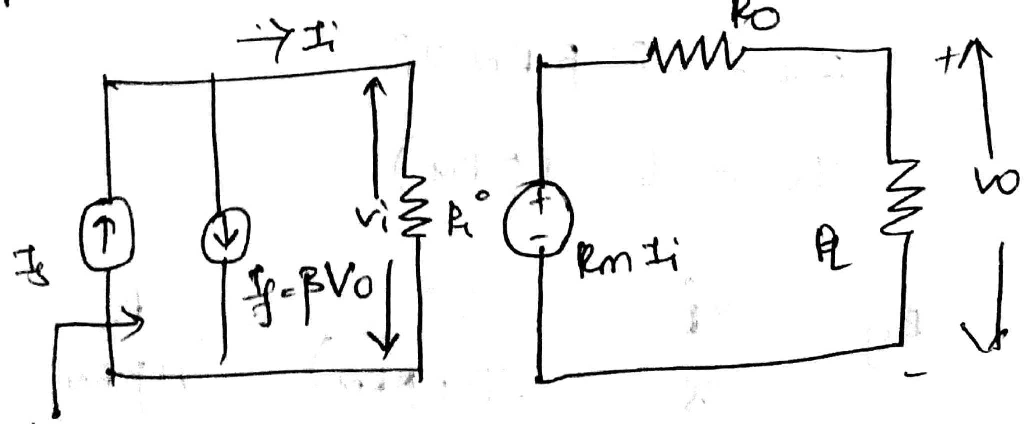
$$R_{of} = R_o(1+\beta G_M)$$

output resistance

$$R_{of}' = \frac{R_o'(1+\beta G_M)}{1+\beta G_M}$$

Voltage shunt feedback Amplifier :-

Equivalent Circuit :-



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

Input resistance (R_{if}):-

The input circuit is represented by norton's equivalent circuit and o/p circuit is represented by thevenin's equivalent.

Apply KCL at the i/p node we get

$$I_s = I_i + I_f$$

$$= I_i + \beta V_o \quad \text{--- (1)} \qquad \because I_f = \beta V_o$$

the output voltage Vo is given as

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

$$V_o = R_M I_i \quad \text{--- (2)} \qquad \because R_M = \frac{R_m R_L}{R_o + R_L}$$

R_{if} :-

substitute the value of V_o from eqn (2) in eqn (1) we get.

$$I_s = I_i + \beta R_M I_i$$

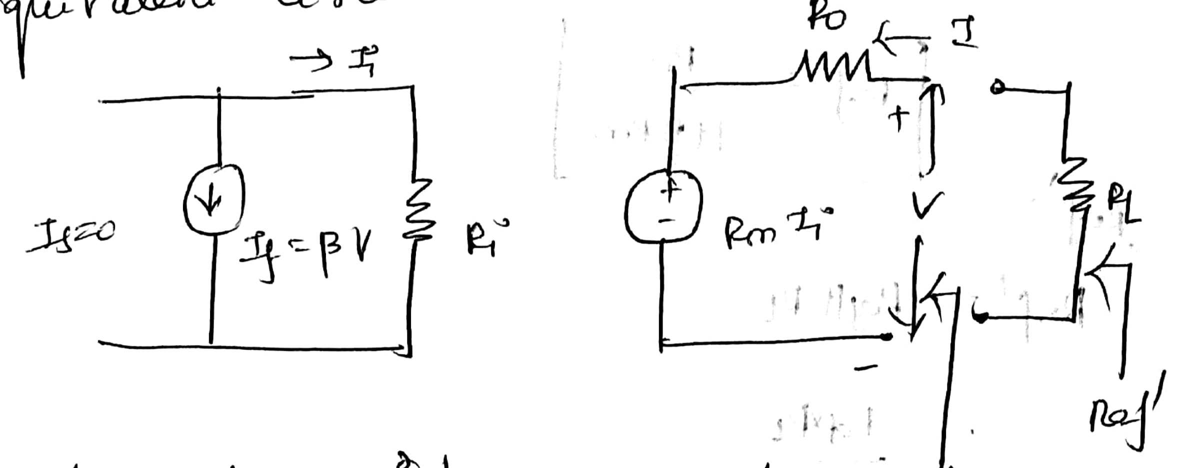
$$I_s = I_i (1 + \beta R_M)$$

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

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

Output resistance :-

Equivalent circuit :-



The o/p resistance can be R_{of}.
measured by making $I_s=0$ and looking into the o/p terminals with R_L disconnected.

Apply KVL to the output side get.

$$R_m I_i + IR_o - V = 0$$

$$IR_o = V - R_m I_i$$

$$I = \frac{V - R_m I_i}{R_o} \quad \text{--- (1)}$$

The input current is given as

$$I_i = -I_f = -\beta V \quad \text{--- (2)}$$

Substitute the value of I_i from eqn (2) to eqn (1) we get

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

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

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

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

<u>R_{of}'</u> :-

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

$$= \frac{R_{of} \times R_L}{R_{of} + R_L}$$

$$= \frac{\frac{R_o \times R_L}{1+\beta R_m}}{\frac{R_o}{1+\beta R_m} + R_L} = \frac{\frac{R_o R_L}{1+\beta R_m}}{\frac{R_o + R_L(1+\beta R_m)}{1+\beta R_m}}$$

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

Dividing numerator & denominator by $(R_o + R_L)$ we get

$$R_{of}' = \frac{\frac{R_o R_L}{R_o + R_L}}{1 + \frac{\beta R_m R_L}{R_o + R_L}}$$

$$\boxed{R_{of}' = \frac{R_o'}{1+\beta R_M}}$$

$$\because R_o' = \frac{R_o R_L}{R_o + R_L}$$

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

Input resistance

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

output resistance

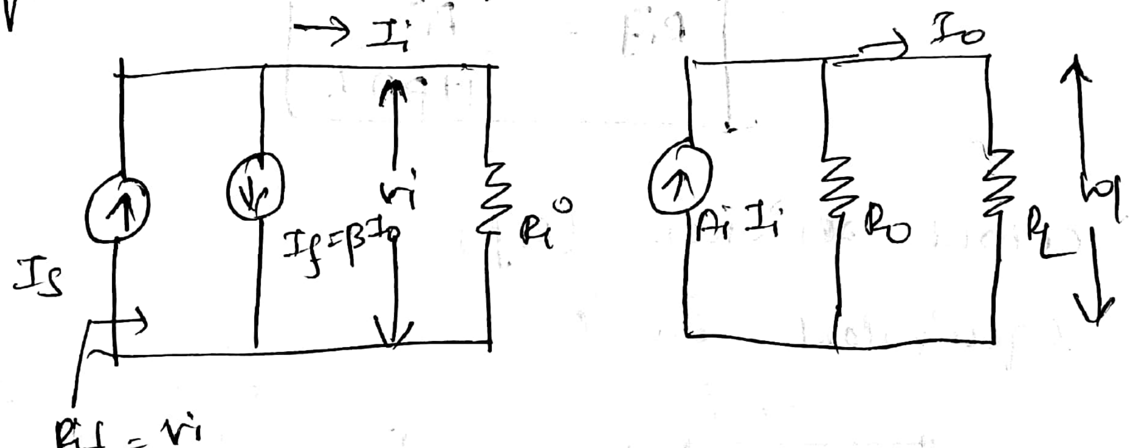
$$R_{of} = \frac{R_o}{1+\beta R_M}$$

output resistance

$$R_{of}' = \frac{R_o'}{1+\beta R_M}.$$

4) current shunt feedback amplifier :-

Equivalent circuit :-



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

Input resistance: R_{if}

The input and output circuits are repraced by Norton's equivalent circuit.

Apply KCL to the input node we get

$$I_s = I_f + I_i \qquad \because I_f = \beta I_o$$

$$= \beta I_o + I_i \quad \text{---} ①$$

The o/p current I_o is given as

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

$$I_o = A_I I_i \quad -② \qquad \because A_I = \frac{A_i R_o}{R_o + R_L}$$

substitute the value of I_o from eqn ②

to eqn ① we get

$$I_s = I_i + \beta A_I I_i$$

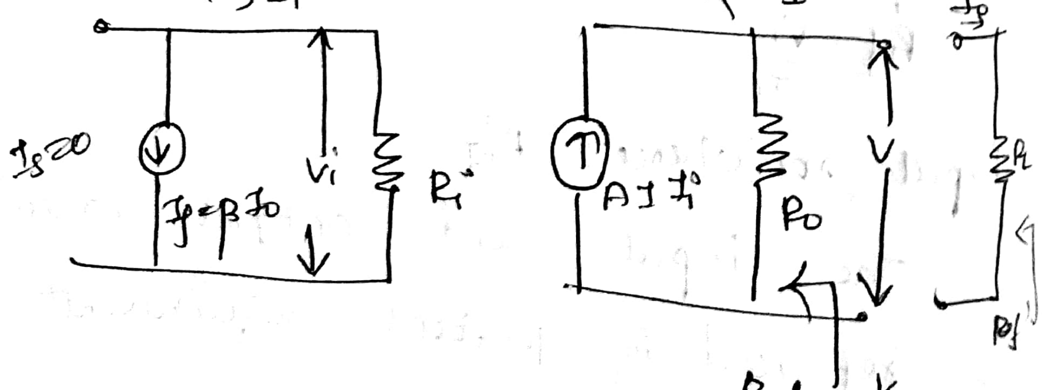
$$I_s = I_i(1+\beta A_I)$$

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

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

Output resistance : (R_{of})

Equivalent circuit



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

The output resistance can be measured by open circuiting the i/p source $I_s = 0$ and looking into the o/p terminal with R_L disconnected.

Apply KCL to the output node we get,

$$I = -A_i I_i + \frac{V}{R_o} \quad \text{—} ①$$

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

The input current is given as

$$I_i = -I_f$$
$$= -\beta I_o$$
$$= \beta I. \quad \text{—} ②$$

$I_o = -I.$

substitute the value of I_i from eqn ② to eqn ① we get.

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

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

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

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

<u>R_{of}'</u>

$$R_{of}' = R_{of} \parallel R_L$$
$$= \frac{R_{of} \times R_L}{R_{of} + R_L}$$
$$= \frac{R_o(1 + \beta A_i)R_L}{R_o(1 + \beta A_i) + R_L} = \frac{R_o R_L(1 + \beta A_i)}{R_o + R_L + R_o \beta A_i}$$

Dividing numerator and denominator by $(R_o + R_L)$ we get.

$$R_{of}' = \frac{\dfrac{R_o R_L (1+\beta A_i)}{R_o + R_L}}{1 + \dfrac{\beta A_i R_o}{R_o + R_L}}$$

$$\boxed{R_{of}' = \frac{R_o' (1+\beta A_i)}{1+\beta A_I}}$$

$$R_o' = \frac{R_o R_L}{R_o + R_L}$$

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

Input resistance

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

Output resistance

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

output resistance

$$R_{of}' = \frac{R_o' (1+\beta A_i)}{1+\beta A_I}.$$

Summary of Effect of negative feedback on Amplifier.

parameter	voltage series	current series	current shunt	voltage shunt
Gain with feedback	$A_{vf} = \frac{A_V}{1+\beta A_V}$ decreases	$G_{mf} = \frac{G_m}{1+\beta G_m}$ "	$A_{if} = \frac{A_i}{1+\beta A_i}$ "	$R_{mf} = \frac{R_m}{1+\beta R_m}$ "
Stability	Improves	Improves	Improves	Improves
Frequency Response	Improves	Improves	Improves	Improves
Frequency distortion	Reduces	Reduces	Reduces	Reduces
noises nonlinear distortion	Reduces	Reduces	Reduces	Reduces
I/p Resistance	$R_{if} = R_i(1+\beta A_V)$ $\Uparrow$	$R_{if} = R_i(1+\beta G_M)$ $\Uparrow$	$R_{if} = \frac{R_i}{1+\beta A_I}$ $\Downarrow$	$R_{if} = \frac{R_i}{1+\beta R_M}$ $\Downarrow$
O/p resistance	$R_{of} = \frac{R_o}{1+\beta A_V}$ $\Downarrow$ $R_{of} = \frac{R_o'}{1+\beta A_V'}$	$R_{of} = R_o(1+\beta G_M)$ $\Uparrow$ $R_{of}' = \frac{R_o'(1+\beta G_M)}{1+\beta G_M}$	$R_{of} = R_o(1+\beta A_I)$ $\Uparrow$ $R_{of}' = \frac{R_o'(1+\beta A_i)}{1+\beta A_I}$	$R_{of} = \frac{R_o}{1+\beta R_m}$ $\Downarrow$ $R_{of}' = \frac{R_o'}{1+\beta R_M}$

Advantages of negative feedback:

→ Low output resistance of a voltage amplifier can be lowered.

→ High output resistance of a voltage amplifier can be made higher.

→ The transfer gain A_f of the amplifier with feedback can be stabilised against variations of the h or hybrid parameters of the transistor.

→ There is a significant improvement in the linearity of operation of the feedback amplifier.

problems:-

Important formulae:-

1) $A_f = \dfrac{A}{1+\beta A}$ (Gain with feedback)

2) $A_f = \dfrac{V_o}{V_s}$ (with feedback) $\quad A = \dfrac{V_o}{V_{in}}$ (without feedback)

3) $V_f = \beta V_o$

4) $A_V = \dfrac{V_o}{V_{in}}$ (Gain without feedback)

5) Desensitivity $D = 1+\beta A \Rightarrow \dfrac{A_V}{A_{Vf}}$

6. $B_{wf} = B_w(1+\beta A)$

7. $f_{Lf} = \dfrac{f_L}{1+\beta A}$

8. $f_{Hf} = f_H(1+\beta A)$

1. In a negative feedback amplifier $A = 100$, $\beta = 0.04$ and $V_s = 50\text{ mV}$. Find

a) Gain with feedback

b) output voltage

c) Feedback factor

d) feedback voltage.

Given: $A = 100$, $\beta = 0.04$, $V_s = 50\text{ mV}$.

a) Gain with feedback

$$A_f = \frac{A}{1+\beta A} = \frac{100}{1+0.04\times100} = \frac{100}{5} = 20$$

c) Feedback factor

$$\beta = 0.04$$

b) output voltage

$$V_o = ?$$

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

$$V_o = A_f \times V_s = 20 \times 50\text{ mV}$$
$$= 1\text{ V}$$

d) Feedback voltage: $V_f = \beta V_o = 0.04 \times 1 = 40\text{ mV}$

2) The voltage gain without negative feedback is 80 dB. What is the new voltage gain if 3% negative feedback is introduced?

Given :- $A_V = 80$ dB.

$$20 \log A_V = 80 \text{ dB.}$$

$$A_V = 10000$$

$$\beta = \frac{3}{100} = 0.03$$

$$A_{vf} = \frac{A_V}{1+\beta A_V} = \frac{10000}{1+0.03 \times 10000}$$

$$= \frac{10000}{1+300}$$

$$= \frac{10000}{301}$$

$$\boxed{A_{vf} = 33.22}$$

3) Calculate the closed loop gain of a negative feedback amplifier if its open loop gain is 100000 and feedback factor is 0.01.

Given : $A = 100000$, $\beta = 0.01$

$$A_{vf} = \frac{A_V}{1+\beta A_V} = \frac{100000}{1+0.01 \times 100000} = \frac{100000}{1+1000}$$

$$= \frac{100000}{1001} = 99$$

$$\boxed{A_{vf} = 99.9}$$

4. An amplifier has a voltage gain of 1000. With negative feedback, the voltage gain reduces to 10. Calculate the fraction of the o/p, that is fedback to the i/p

Given : $A_v = 1000$, $A_{vf} = 10$.

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

$$10 = \frac{1000}{1+\beta(1000)}$$

$$[1+\beta(1000)]10 = 1000$$

$$10 + \beta \times 10000 = 1000$$

$$10000\beta = 1000 - 10$$

$$10000\beta = 990$$

$$\beta = \frac{99\cancel{0}}{1000\cancel{0}}$$

$$\boxed{\beta = 0.099}$$

$A_f = 93.33$

$\beta = 0.02$

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

$$93.33 = \frac{A}{1+0.02A}$$

$93.33 + 1.8666A = A$

$1.8666A - A = -93$

$0.8666A =$

5. An amplifier has a midband gain of 125 and a bandwidth 250 KHz.

1) If 4% negative feedback is introduced, find the new bandwidth and gain.

2) If the bandwidth is to be restricted to 1MHz, find the feedback ratio.

Given: $A_V = 125$, $BW = 250\,KHZ$

$\beta = 0.04$

i) $A_{Vf} = \dfrac{A_V}{1+\beta A_V}$

$= \dfrac{125}{1+(0.04 \times 125)} = \dfrac{125}{1+5} = \dfrac{125}{6}$

$\boxed{A_{Vf} = 20.83}$

$BW_f = BW(1+\beta A_V)$

$= 250 \times K\,(6)$

$= 1500 \times K$

$\boxed{BW_f = 1.5\,MHZ}$

ii) $BW_f = 1\,MHZ$

$1 \times 10^6 = BW(1+\beta A_V)$

$10^6 = 250 \times 10^3 (1+\beta A_V)$

$1+\beta A_V = \dfrac{10^6}{250 \times 10^3}$

$= \dfrac{10^3}{250} = \dfrac{1000}{250} = 4$

$\beta A_V = 3$

$\beta = \dfrac{3}{A_V} = \dfrac{3}{125}$

$\boxed{\beta = 0.024}$

Q) A single RC coupled amplifier has a midband gain of 1000 is made into a negative feedback amplifier by feeding 10% of the O/P voltage in series with input opposing.

i) what is the ratio of half power frequencies with feedback to those without feedback?

ii) If $f_L = 20$ Hz and $f_H = 50$ KHz for the amplifier without feedback, find the corresponding values after fb is incorporated.

Given: $A_v = 1000$, $\beta = \frac{10}{100} = 0.1$

i) $$\frac{f_{Hf}}{f_H} = (1+\beta A_v) = 1+0.1\times1000 = 101$$

$$\frac{f_{Lf}}{f_L} = \frac{1}{1+\beta A_v} = \frac{1}{1+0.1\times1000} = \frac{1}{101} = 0.0099$$

ii) $f_L = 20$ Hz, $f_H = 50$ KHz

$$f_{Lf} = \frac{f_L}{1+\beta A_v} = 20\times0.0099 = 0.198\,Hz$$

$$f_{Hf} = f_H(1+\beta A_v) = 50K\times101 = 5.05\,MHz.$$

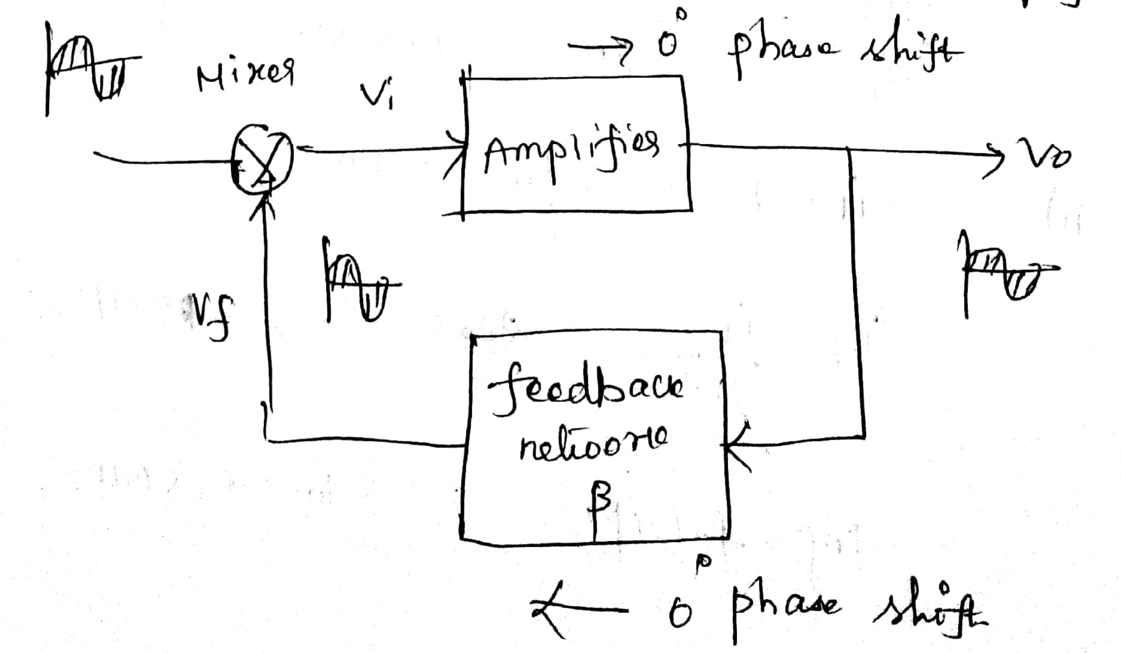
Oscillator:

The device which works on the principle of positive feedback is called an oscillator.

It does not require any input signal. It is a circuit which basically acts as a generator, generating the o/p signal which oscillates with constant amplitude and desired frequency.

Basic theory of oscillator:

The feedback is a property which allows to feedback the part of the o/p to the same circuit as the input such a fb is said to be positive whenever the part of the o/p is fed back to the amplifier as its i/p, is in phase with the original signal applied to the amplifier.



The amplifier gain

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

This is called open loop gain of the amplifier.

Closed loop gain is denoted as A_f

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

I/P voltage $V_i = V_s + V_f$

$$V_f = \beta V_o$$

$$V_i = V_s + \beta V_o$$

$$V_s = V_i - \beta V_o$$

$$A_f = \frac{V_o}{V_i - \beta V_o}$$

Dividing both numerator and denominator by V_i

$$A_f = \frac{V_o / V_i}{\frac{V_i - \beta V_o}{V_i}}$$

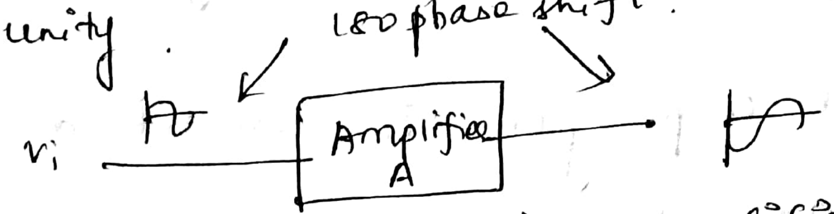
$$\boxed{A_f = \frac{A}{1 - \beta A}}$$

The gain with feedback increases as the amount of positive fb increases.

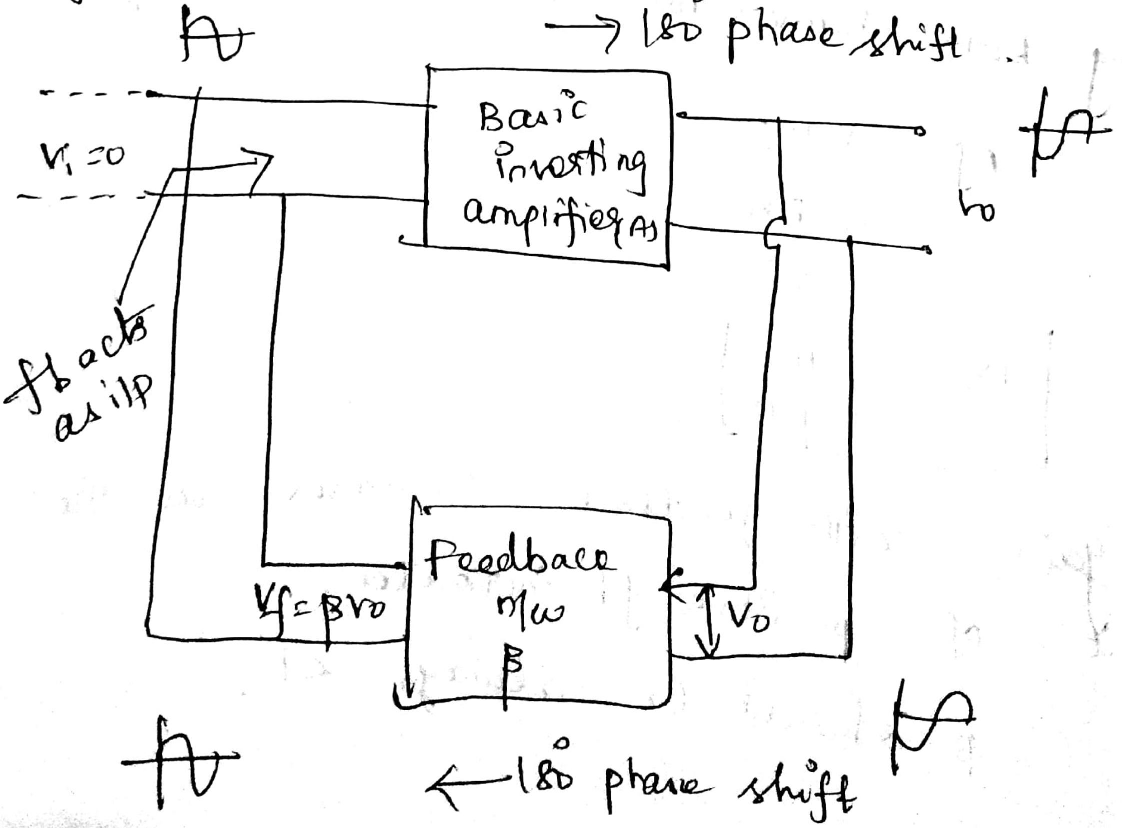
β should be always < 1.

Barkhausen criterion:-

Consider a basic inverting amplifier with an open loop gain A. The feedback network attenuation factor β is less than unity.



Since it is inverting amplifier, it produces 180° phase shift. But the fb must be positive (ie) the voltage derived from output using feedback n/w must be in phase with v_i. Thus the feedback network must introduce a phase shift of 180° while feeding back the voltage from o/p to i/p. This ensures positive feedback.



Consider a fictitious voltage V_i applied at the input of the amplifier.

$$V_o = AV_i \quad \text{—①}$$

The feedback factor β decides the feedback to be given

$$V_f = -\beta V_o \quad \text{—②}$$ (– indicates 180° phase shift)

Substitute ① in ②

$$V_f = -\beta(AV_i)$$

$$V_f = -A\beta V_i$$

Here $V_f = V_i$

$$\therefore V_i = -A\beta V_i$$

$$\boxed{-A\beta = 1}$$

This condition is called barkhausen criterion.

$$A\beta = -1 + j0$$

$$|A\beta| = |-1+j0|$$

$$|A\beta| = 1$$

The phase of V_f must be same as V_i.
(i.e) fb n/w should introduce 180° phase shift in addition to 180° phase shift introduced by inverting amplifier. This ensures positive feedback. so total phase shift around a loop is 360°.

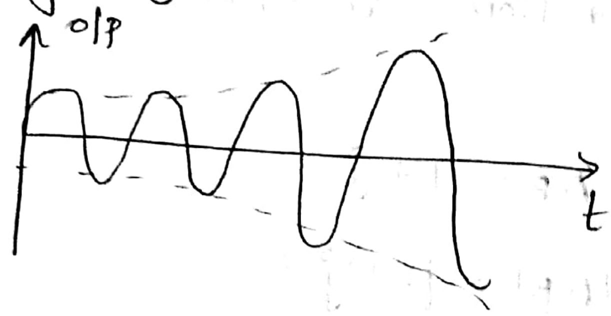
Barkhausen criterion states that

1. The total phase shift around a loop as the signal proceeds from input through amplifier, fb n/w back to again, completing a loop is 0° or 360°.

2. The magnitude of the product of the open loop gain of the amplifier and the fb factor β is unity (ie) $|A\beta| = 1$.

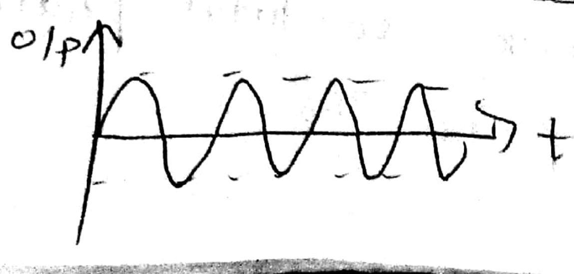
$A\beta > 1$

When total phase shift around a loop is 0° or 360° and $|A\beta| > 1$, then the o/p oscillates but the oscillations are of growing type.



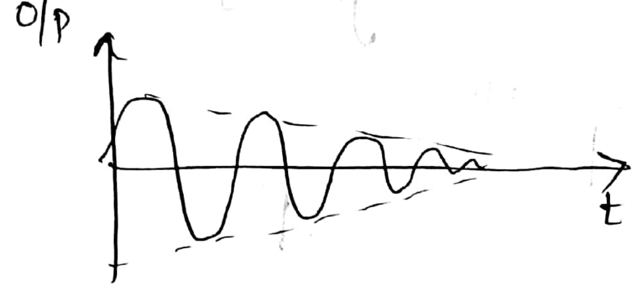
$|A\beta| = 1$

When total phase shift around a loop is 0° or 360° ensuring positive fb and $|A\beta| = 1$ then the oscillations are with constant frequency and amplitude called sustained oscillations.



$|A\beta| < 1$

when total phase shift around a loop is $0°$ or $360°$ but $|A\beta| < 1$ then the oscillations are of decaying type (b) such oscillation amplitude decreases exponentially and the oscillations finally cease.



Starting voltage :-

Every resistance has some free electrons. Under the influence of normal room temperature these free electrons move randomly in various directions. Such a movement of the free electrons generate a voltage called noise voltage across the resistance.

Such noise voltages present across the resistance are amplified. Hence to amplify such small noise voltages and to start the oscillations, $|A\beta|$ is kept greater than unity at start. Such amplified voltage appears at the o/p terminals.

Classification of Oscillators

The oscillators are classified based on the

1) nature of o/p waveform
2) parameters used
3) Range of frequency
4) Based on ~~the~~ type of fb.

Oscillators

- Based on o/p waveform
  - Triangular
  - Sinusoidal
  - Rectangular
- Based on circuit Component
  - R&C
  - C&L
  - crystal
- Based on range of frequency
  - R-C: low frequency, 20HZ-200KHZ
  - L-C: High frequency, >300KHZ
- Based on Type of fb.
  - UJT relaxation oscillator in which bias not used

Rc phase shift Oscillator

Rc phase shift oscillator basically consists of an amplifier and a fB network consisting of resistors and capacitors arranged in ladder fashion.

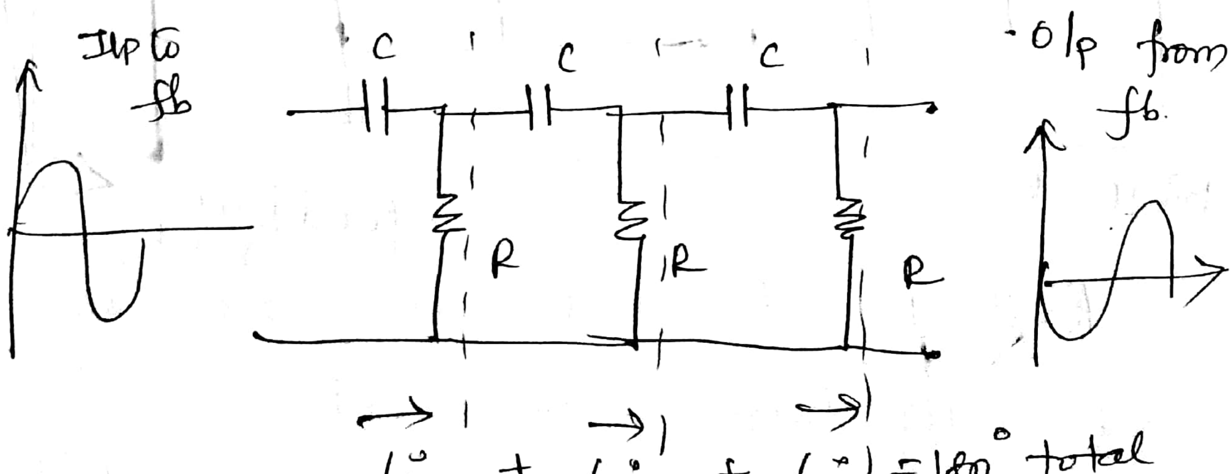
Hence such an Oscillator is also called Ladder type RC phase shift oscillator.

RC feedback network:-

RC network is used in feedback path. In oscillator fb network must introduce a phase shift of 180° to obtain total phase shift around a loop as 360°.

Thus if one RC network produces phase shift of $\phi = 60°$ then to produce phase shift of 180° such three RC networks must be connected in cascade.

Hence in RC phase shift oscillator, the feedback network consists of three RC sections each producing a phase shift of 60°, thus total phase shift due to fb is 180°.

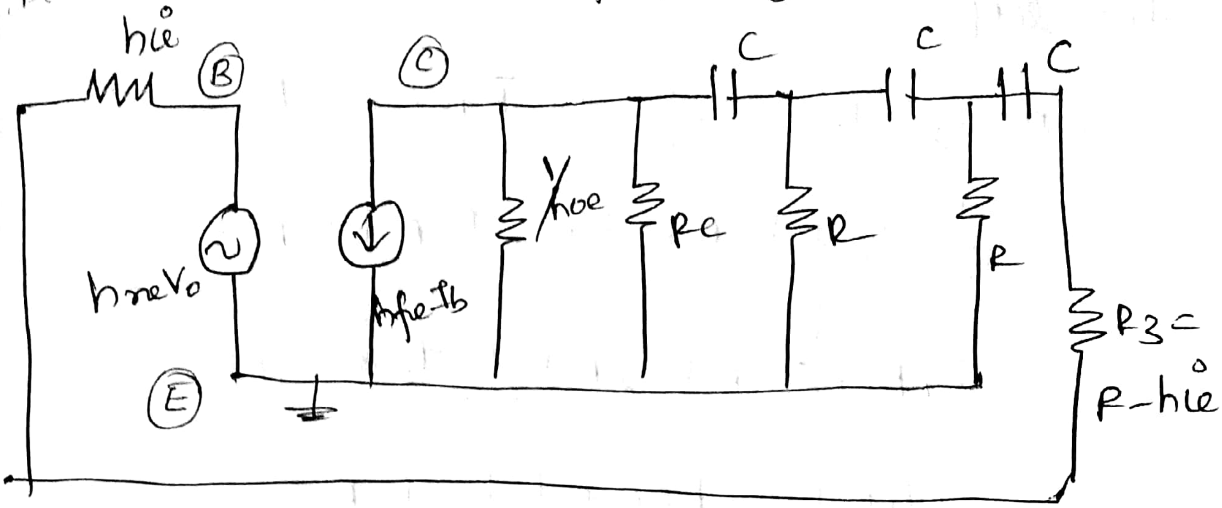


$60° + 60° + 60° = 180°$ total phase shift

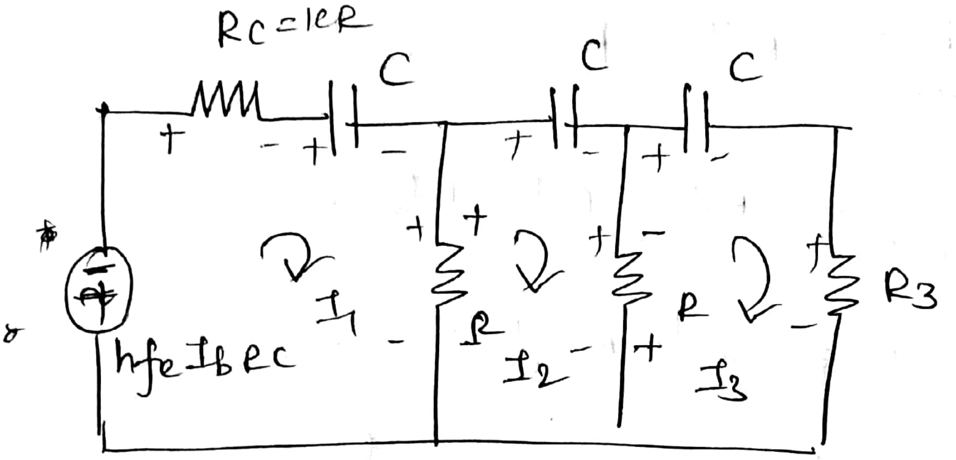
The network is also called ladder network.

All the resistance values and all capacitance

Derivation for the frequency of oscillations



H model of transistorised RC oscillator



$$K = \frac{R_c}{R}$$

Simplified equivalent circuit.

Apply KVL for the various loops in the above equivalent circuit

For loop 1,

$$-h_{fe} I_b R_c - I_1 R_c - \frac{1}{j\omega C} I_1 - R(I_1 - I_2) = 0$$

Replace R_c by KR

$$I_1 R_c + \frac{1}{j\omega C} I_1 + R(I_1 - I_2) = -h_{fe} I_b R_c$$

$$I_1 KR + \frac{1}{j\omega C} I_1 + I_1 R - I_2 R = -h_{fe} I_b KR$$

$$I_1 \left[(K+1) R + \frac{1}{SC}\right] - I_2 R = -h_{fe} I_b KR \quad \text{--- (1)}$$

For loop 2

$$-R(I_2 - I_1) - \frac{1}{j\omega C} I_2 - R(I_2 - I_3) = 0$$

$$-\frac{1}{j\omega C} I_2 - I_2 R + I_1 R - I_2 R + I_3 R = 0$$

$$-I_1 R + I_2 R + I_2 R + \frac{1}{j\omega C} I_2 - I_3 R = 0$$

$$-I_1 R + I_2 \left[2R + \frac{1}{sC}\right] - I_3 R = 0 \quad \text{--- (2)}$$

For loop 3

$$-\frac{1}{j\omega C} I_3 - R I_3 - R(I_3 - I_2) = 0$$

$$-\frac{1}{j\omega C} I_3 - R I_3 - R I_3 + R I_2 = 0$$

$$-I_2 R + I_3 \left[2R + \frac{1}{sC}\right] = 0 \quad \text{--- (3)}$$

Using cramer's rule to solve for I_3

$$D = \begin{vmatrix} (K+1)R + \frac{1}{sC} & -R & 0 \\ -R & 2R + \frac{1}{sC} & -R \\ 0 & -R & 2R + \frac{1}{sC} \end{vmatrix}$$

$$= \left[(K+1)R + \frac{1}{sC}\right]\left\{\left(2R + \frac{1}{sC}\right)^2 - R^2\right\} - R(-R)\left(2R + \frac{1}{sC}\right)$$

$$= \left[(K+1)R + \frac{1}{sC}\right]\left(2R + \frac{1}{sC}\right)^2 - R^2\left((K+1)R + \frac{1}{sC}\right)$$

$$- R^2\left(2R + \frac{1}{sC}\right)$$

$$= \frac{[sRC(k+1)+1]}{sC}\left[\frac{2Rsc+1}{sC}\right]^2 - R^2\left[\frac{kRsC+RsC+1}{sC}\right] - \frac{R^2(1+2RsC)}{sC}$$

$$= \frac{(sRCk+sRC+1)}{sC}\left[\frac{4R^2s^2C^2+1+4RsC}{s^2C^2}\right] - \left[\frac{R^3ksC+R^3sC+R^2}{sC}\right] - \left[\frac{R^2+2R^3sC}{sC}\right]$$

$$= \frac{4kR^3s^3C^3+sRCk+4kR^2s^2C^2+4R^3s^3C^3+sRC+4s^2R^2C^2+4R^2s^2C^2+1+4RsC}{s^3C^3} - \left[\frac{R^3ksC+R^3sC+R^2+R^2+2R^3sC}{sC}\right]$$

$$= \frac{s^3R^3C^3(4k+4)+s^2R^2C^2(4+4+4k)+sRC(k+5)+1}{s^3C^3} - \left[\frac{2R^2+3sR^3C+tR^3ksC}{sC}\right]$$

$$= \frac{s^3R^3C^3(4k+4)+s^2R^2C^2(4k+8)+sRC(5+k)+1-2R^2s^2C^2-3s^3R^3C^3-kR^3s^3C^3}{s^3C^3}$$

$$= \frac{s^3R^3C^3(3k+1)+s^2R^2C^2(4k+6)+sRC(5+k)+1}{s^3C^3}$$

now

$$D_3 = \begin{vmatrix} (k+1)R + \frac{1}{sC} & -R & -h_{fe} I_b R k \\ -R & 2R + \frac{1}{sC} & 0 \\ 0 & -R & 0 \end{vmatrix}$$

$$= -h_{fe} I_b R k \,(R^2)$$

$$= -k\, h_{fe} I_b R^3$$

$$I_3 = \frac{D_3}{D}$$

$$= \frac{-k\, h_{fe} I_b R^3}{\dfrac{s^3C^3R^3(3k+1) + s^2C^2R^2(4k+6) + sRC(5+k) + 1}{s^3C^3}}$$

$$I_3 = \frac{-k\, h_{fe} I_b R^3 s^3 C^3}{s^3C^3R^3(3k+1) + s^2C^2R^2(4k+6) + sRC(5+k) + 1}$$

I_3 = o/p current of the fb circuit

I_b = i/p current of the amplifier.

$I_c = h_{fe} I_b$ = i/p current of the fb circuit

$$\beta = \frac{\text{O/P of fb circuit}}{\text{i/p of fb circuit}} = \frac{I_3}{h_{fe} I_b}$$

$$A = \frac{\text{O/P of amp circuit}}{\text{i/p of amp circuit}} = \frac{I_3}{I_b} = h_{fe}.$$

$$A\beta = h_{fe} \times \frac{I_3}{h_{fe} I_b}$$

$$A\beta = \frac{I_3}{I_b}$$

$$A\beta = \frac{-kR^3 h_{fe} s^3 c^3}{s^3 c^3 R^3 (3k+1) + s^2 c^2 R^2 (4k+6) + sRC(5+k) + 1}$$

put $s = j\omega$

$$A\beta = \frac{-(j\omega)^3 k R^3 c^3 h_{fe}}{(j\omega)^3 c^3 R^3 (3k+1) + (j\omega)^2 R^2 c^2 (4k+6) + j\omega RC(5+k) + 1}$$

$$= \frac{-j\omega^3 k R^3 c^3 h_{fe}}{-j\omega^3 c^3 R^3 (3k+1) - \omega^2 R^2 c^2 (4k+6) + j\omega RC(5+k) + 1}$$

Seperate real and imaginary parts

$$A\beta = \frac{j\omega^3 k R^3 c^3 h_{fe}}{(1 - 4k\omega^2 R^2 c^2 - 6\omega^2 R^2 C^2) - j\omega\left[\omega^2 C^3 R^3 3k + \omega^2 C^3 R^3 - 5RC - kRC\right]}$$

diving numerator & denominator by $-j\omega^3 R^3 C^3$

$$A\beta = \frac{kh_{fe}}{\left\{\frac{1-4k\omega^2C^2R^2-6\omega^2C^2R^2}{j\omega^3R^3C^3}\right\} - \left\{\frac{j\omega(3k\omega^2R^2C^3+\omega^2C^3R^3 - 5RC - kR\ldots}{j\omega^3R^3C^3}\right\}}$$

Replacing $-1/j = j$

$$A\beta = \frac{kh_{fe}}{j\left\{\frac{1}{\omega^3R^3C^3} - \frac{4k}{\omega RC} - \frac{6}{\omega RC}\right\} + \left\{3k+1 - \frac{5}{\omega^2R^2C^2} - \frac{k}{\omega^2R^2C^2}\right.}$$

Replacing $\frac{1}{\omega RC} = \alpha$.

$$A\beta = \frac{kh_{fe}}{(3k+1 - 5\alpha^2 - k\alpha^2) + j(\alpha^3 - 4k\alpha - 6\alpha)}$$

As per barkhausen criterion $\angle A\beta = 0°$.

$$\alpha^3 - 4k\alpha - 6\alpha = 0$$

$$\alpha(\alpha^2 - 4k - 6) = 0$$

$$\alpha^2 = 4k + 6$$

$$\alpha = \sqrt{4k+6}$$

$$\frac{1}{\omega RC} = \sqrt{4k+6}$$

$$\frac{1}{\omega} = \frac{\cancel{Rc}}{RC\sqrt{4K+6}}$$

$$\omega = \frac{1}{RC\sqrt{4K+6}}$$

$$\omega = \frac{1}{RC\sqrt{4K+6}}$$

$$2\pi f_0 = \frac{1}{RC\sqrt{4K+6}}$$

$$\boxed{f = \frac{1}{2\pi RC\sqrt{4K+6}}}$$

Advantages :-

1) The circuit is simple to design

2) can produce o/p over audio frequency range.

3) produces sinusoidal output waveform

4) It is a fixed frequency oscillator.

Disadvantages :-

Frequency stability is poor due to the changes in the values of various components due to effect of temperature, aging etc.

LC oscillator:

The oscillators which uses the elements L and C to produce the oscillation are called LC oscillator.

The circuit using elements L and C is called tank circuit or oscillatory circuit which is an important part of LC oscillator. This circuit is also referred as resonating circuit or tuned circuit.

Frequency range from 200KHZ upto few GHZ.

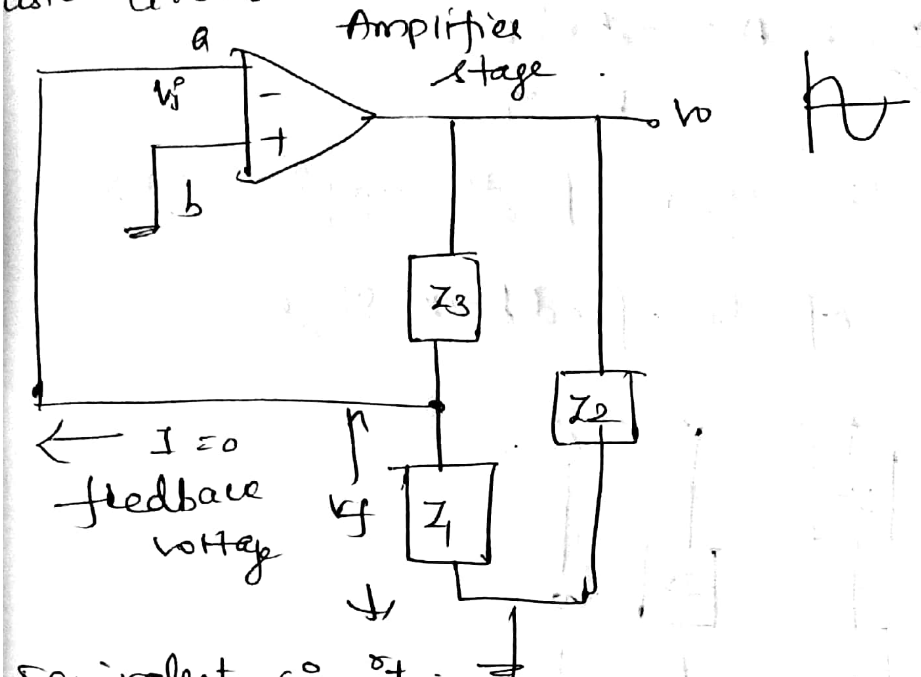
Basic form of LC oscillator:

LC tuned circuit forms the feedback network while an Op-amp, FET or bipolar junction transistor can be active device in the amplifier stage.

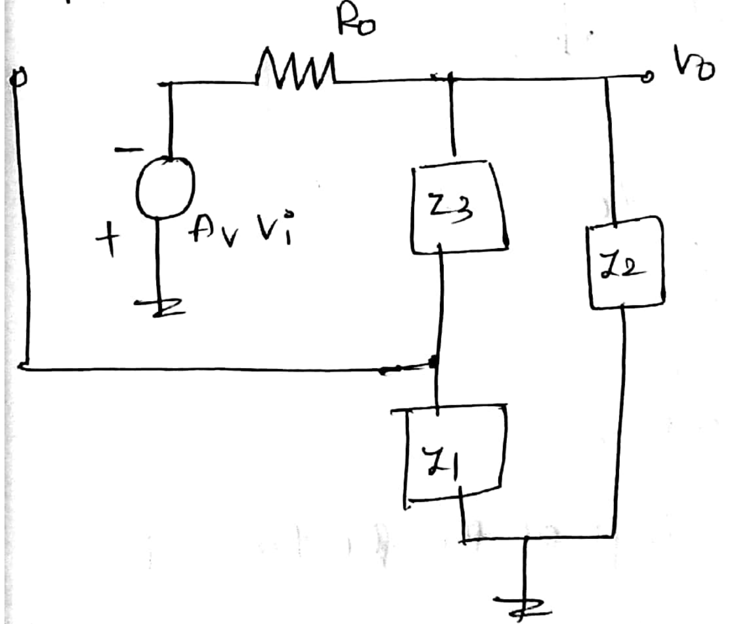
Consider an amplifier which is having gain AV and output feeds the network consisting of impedances Z_1, Z_2 and Z_3.

Amplifier provides a phase shift of 180°, while fb network provides an additional phase shift of 180°, to satisfy the required condition.

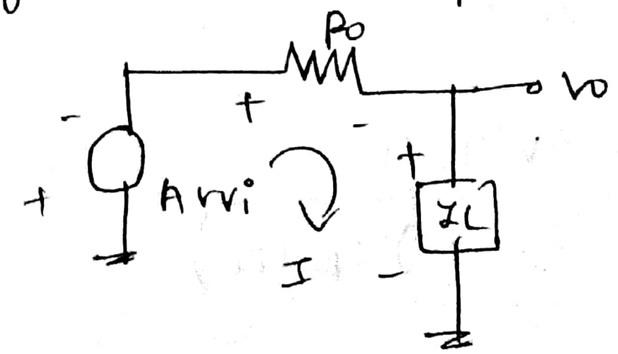
asic circuit :-



Equivalent circuit :-



Analysis of the amplifier stage :-



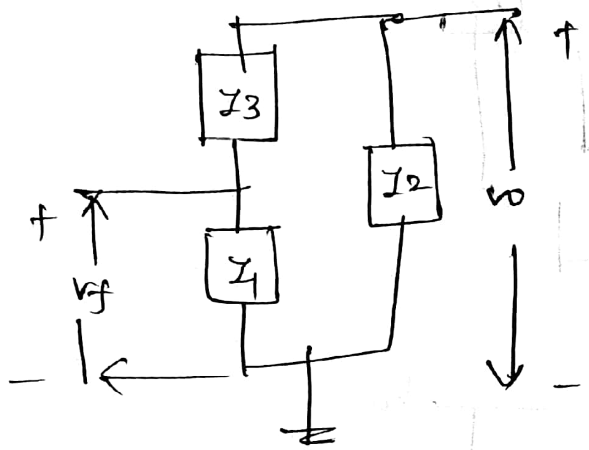
$$I = \frac{-A_v v_i}{R_o + Z_L}$$

$$V_o = I Z_L \Rightarrow V_o = \frac{-A_v V_i Z_L}{R_o + Z_L}$$

$$\frac{V_o}{V_i} = A = \frac{-A_V Z_L}{R_o + Z_L}.$$

A is the gain of the amplifier stage.

ii) Analysis of the feedback stage:



$$V_f = \frac{Z_1}{Z_1 + Z_3} V_o$$

$$\frac{V_f}{V_o} = \beta = \frac{Z_1}{Z_1 + Z_3}$$

But the phase shift of the fb network is 180°.

$$\beta = \frac{-Z_1}{Z_1 + Z_3}$$

$$-A\beta = \frac{-A_V Z_L Z_1}{(Z_1 + Z_3)(R_o + Z_L)}$$

$$Z_L = (Z_1 + Z_3) \parallel Z_2$$

$$Z_L = \frac{Z_2 (Z_1 + Z_3)}{Z_1 + Z_2 + Z_3}$$

$$-A\beta = \frac{-AvI_1\left[\dfrac{Z_2(Z_1+Z_3)}{Z_1+Z_2+Z_3}\right]}{\left[R_o+\dfrac{Z_2(Z_1+Z_3)}{Z_1+Z_2+Z_3}\right](Z_1+Z_3)}$$

Dividing numerator and denominator by $\dfrac{Z_1+Z_3}{Z_1+Z_2+Z_3}$

$$-A\beta = \frac{-AvZ_1Z_2}{\left[\dfrac{R_o(Z_1+Z_2+Z_3)+Z_2(Z_1+Z_3)}{Z_1+Z_2+Z_3}\right](Z_1+Z_3)}$$

$$= \frac{-AvZ_1Z_2}{R_o(Z_1+Z_2+Z_3)+Z_2(Z_1+Z_3)}$$

put $Z_1 = jX_1$ $\quad Z_2 = jX_2$ $\quad Z_3 = jX_3$

$X = \omega L$ $\quad X = \dfrac{-1}{\omega C}$

$$-A\beta = \frac{-Av(jX_1)(jX_2)}{R_o(jX_1+jX_2+jX_3)+jX_2(jX_1+jX_3)}$$

$$= \frac{+AvX_1X_2}{-X_2(X_1+X_3)+jR_o(X_1+X_2+X_3)}$$

Equate $\quad X_1+X_2+X_3 = 0 \quad \Rightarrow \quad X_1+X_3 = -X_2$

$$-A\beta = \frac{-AvX_1X_2}{X_2(X_1+X_3)}$$

$$-A\beta = \frac{-A_v X_1 X_2}{X_2(-X_2)}$$

$$= \frac{+A_v X_1}{X_2}$$

$$-A\beta = A_v\left(\frac{X_1}{X_2}\right)$$

According to the barkhausen Criterion $-A\beta$ must be positive and must be greater than or equal to unity.

As A_v is positive, the $-A\beta$ will be positive only when X_1 and X_2 will have same sign.

This indicates that X_1 and X_2 must be of same type of reactances, either both inductive or capacitive.

$$X_3 = -(X_1 + X_2)$$

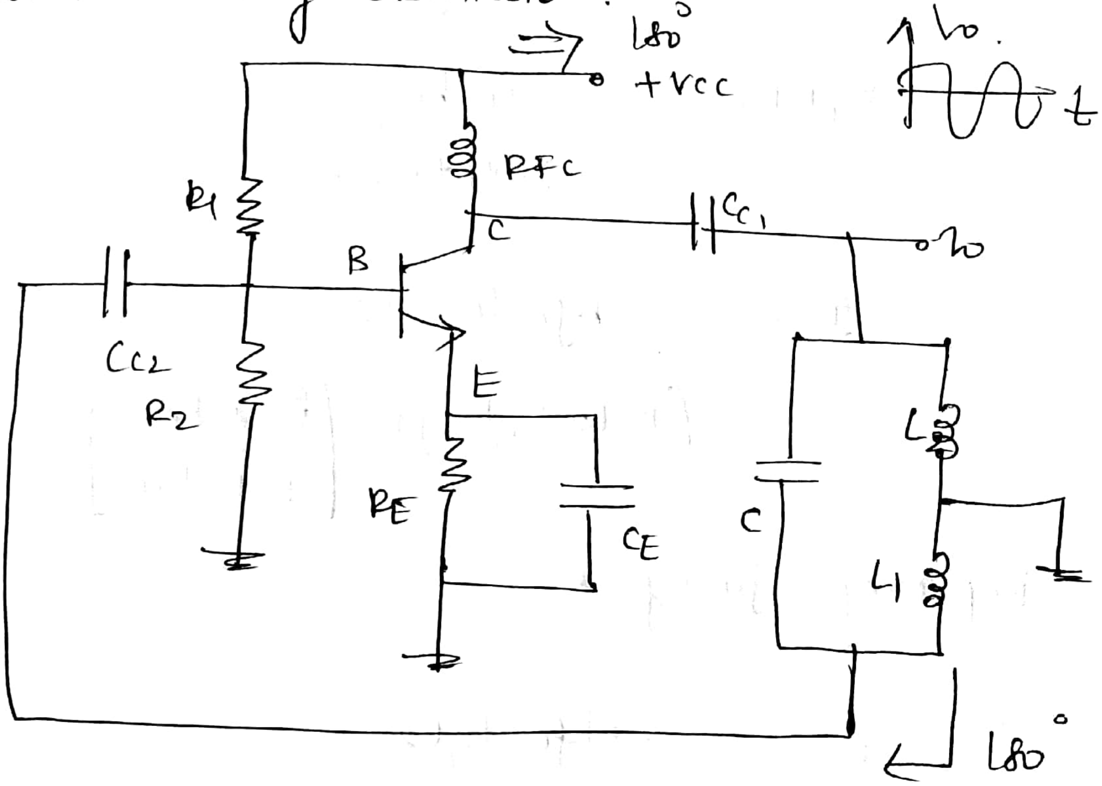
if X_3 is capacitive, x_1 and x_2 should be inductive. &

if X_3 is Inductive, x_1 and x_2 should be capacitive.

	X_1	X_2	X_3
Hartley Oscillator	L	L	C
Colpitts Oscillator	C	C	L

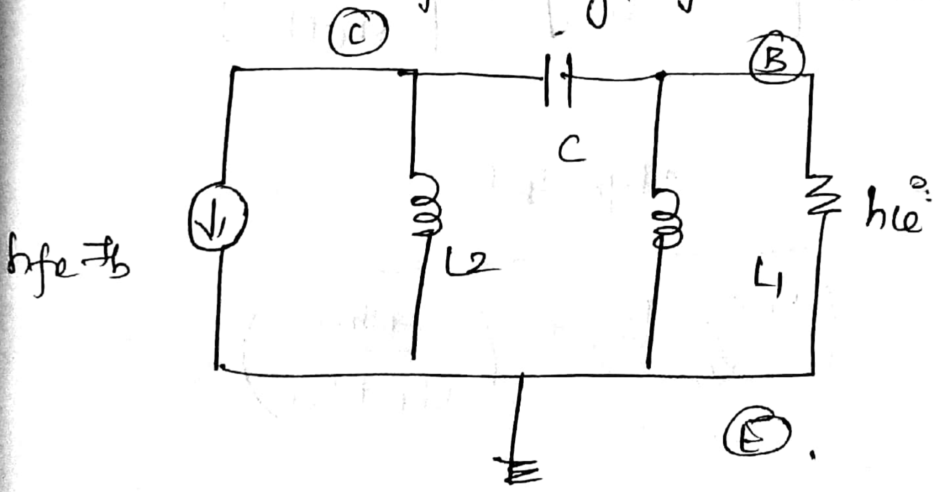
Hartley oscillator :-

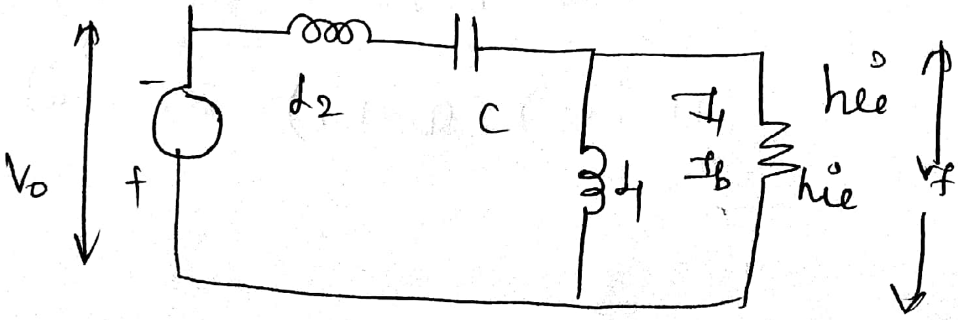
An LC oscillator which uses two inductive reactances and one capacitive reactance in its feedback network is called Hartley oscillator.



Derivation of frequency of oscillations : $\frac{I_c}{I_b} = h_{fe}$

$I_c = h_{fe} I_b$





$$V_o = h_{fe} I_b X_{L2} = h_{fe} I_b j\omega L_2$$

$$I = \frac{-V_o}{(X_{L2} + X_C) + (X_{L1} \parallel h_{ie})}$$

$$X_{L2} + X_C = j\omega L_2 + \frac{1}{j\omega C}.$$

$$X_{L1} \parallel h_{ie} = \frac{j\omega L_1 \, h_{ie}}{j\omega L_1 + h_{ie}}.$$

$$I = \frac{-h_{fe} I_b j\omega L_2}{\left(j\omega L_2 + \frac{1}{j\omega C}\right) + \left[\frac{j\omega L_1 \, h_{ie}}{j\omega L_1 + h_{ie}}\right]}$$

Replacing $j\omega$ by s

$$I = \frac{-s h_{fe} I_b L_2}{\left[sL_2 + \frac{1}{sC}\right] + \left[\frac{sL_1 h_{ie}}{sL_1 + h_{ie}}\right]}$$

$$= \frac{-s h_{fe} I_b L_2}{\left(\frac{1 + s^2 L_2 C}{sC}\right) + \left(\frac{sL_1 h_{ie}}{sL_1 + h_{ie}}\right)}.$$

$$= \frac{-s h_{fe} I_b L_2 (sC)(sL_1 + h_{ie})}{(1 + s^2 L_2 C)(sL_1 + h_{ie}) + sC(sL_1 h_{ie})}$$

$$= \frac{-s^2 h_{fe} I_b L_2 C \, (sL_4 + h_{ie})}{sL_4 + h_{ie} + s^3 L_1 L_2 C + h_{ie} s^2 L_2 C + s^2 C L_4 h_{ie}}$$

$$= \frac{-s^2 h_{fe} I_b L_2 C (sL_4 + h_{ie})}{s^3 L_1 L_2 C + s^2 C h_{ie} (L_1 + L_2) + sL_1 + h_{ie}}.$$

By Current division rule.

$$I_b = \frac{X_{L1}}{X_{L1} + h_{ie}} I$$

$$= \frac{I j\omega L_1}{j\omega L_1 + h_{ie}}$$

$s = j\omega.$

$$I_b = I \times \left[\frac{sL_1}{sL_1 + h_{ie}}\right]$$

$$I_b = \frac{-s^2 h_{fe} I_b L_2 C (\cancel{sL_1 + h_{ie}})}{s^3 L_1 L_2 C + s^2 C h_{ie}(L_1 + L_2) + sL_1 + h_{ie}} \times \frac{sL_1}{\cancel{sL_1 + h_{ie}}}$$

$$= \frac{-s^3 h_{fe} I_b C L_1 L_2}{s^3 L_1 L_2 C + s^2 C h_{ie}(L_1 + L_2) + sL_1 + h_{ie}}.$$

$$1 = \frac{-s^3 h_{fe} C L_1 L_2}{s^3 L_1 L_2 C + s^2 C h_{ie}(L_1 + L_2) + sL_1 + h_{ie}}.$$

put $s = j\omega$ $\quad s^3 = (j\omega)^3 = -j\omega^3, \; s^2 = -\omega^2.$

$$1 = \frac{j\omega^3 h_{fe} C L_1 L_2}{h_{ie} - \omega^2 C h_{ie}(L_1 + L_2) + j\omega L_1 (1 - \omega^2 L_2 C)}$$

$$I = \frac{j\omega^3 h_{fe} C L_1 L_2}{h_{ie} - \omega^2 C h_{ie}(L_1+L_2) + j\omega L_1(1-\omega^2 L_2 C)}$$

$$= \frac{j\omega^3 h_{fe} C L_1 L_2 \left[\left(h_{ie} - \omega^2 C h_{ie}(L_1+L_2)\right) - j\omega L_1(1-\omega^2 L_2 C)\right]}{\left[h_{ie} - \omega^2 C h_{ie}(L_1+L_2)\right]^2 + \omega^2 L_1^2 (1-\omega^2 L_2 C)^2}$$

Equate imaginary part $= 0$.

$$I = \frac{\omega^4 h_{fe} C L_1^2 L_2 C(1-\omega^2 L_2 C) + j\omega^3 h_{fe} L_1 L_2 C(h_{ie} - \omega^2 C h_{ie} (L_1+L_2))}{\left[h_{ie} - \omega^2 C h_{ie}(L_1+L_2)\right]^2 + \omega^2 L_1^2 (1-\omega^2 L_2 C)^2}$$

$$\omega^3 h_{fe} L_1 L_2 C\left(h_{ie} - \omega^2 C h_{ie}(L_1+L_2)\right) = 0$$

$$\omega^3 h_{fe} h_{ie} L_1 L_2 C\left(1 - \omega^2 C(L_1+L_2)\right) = 0$$

$$1 - \omega^2 C(L_1+L_2) = 0$$

$$\omega^2 C(L_1+L_2) = 1$$

$$\omega^2 = \frac{1}{C(L_1+L_2)}$$

$$(2\pi f)^2 = \frac{1}{C(L_1+L_2)}$$

$$f^2 = \frac{1}{4\pi^2 C(L_1+L_2)}$$

$$f = \frac{1}{2\pi\sqrt{C(L_1+L_2)}}$$

$$f = \frac{1}{2\pi C\sqrt{L_1 + L_2}}$$

$$\boxed{f = \frac{1}{2\pi C\sqrt{L_{eq}}}}$$

$$\boxed{h_{fe} = \frac{L_1}{L_2}}$$

Mutual inductance $= M$.

$$\therefore \quad h_{fe} = \frac{L_1 + M}{L_2 + M}$$

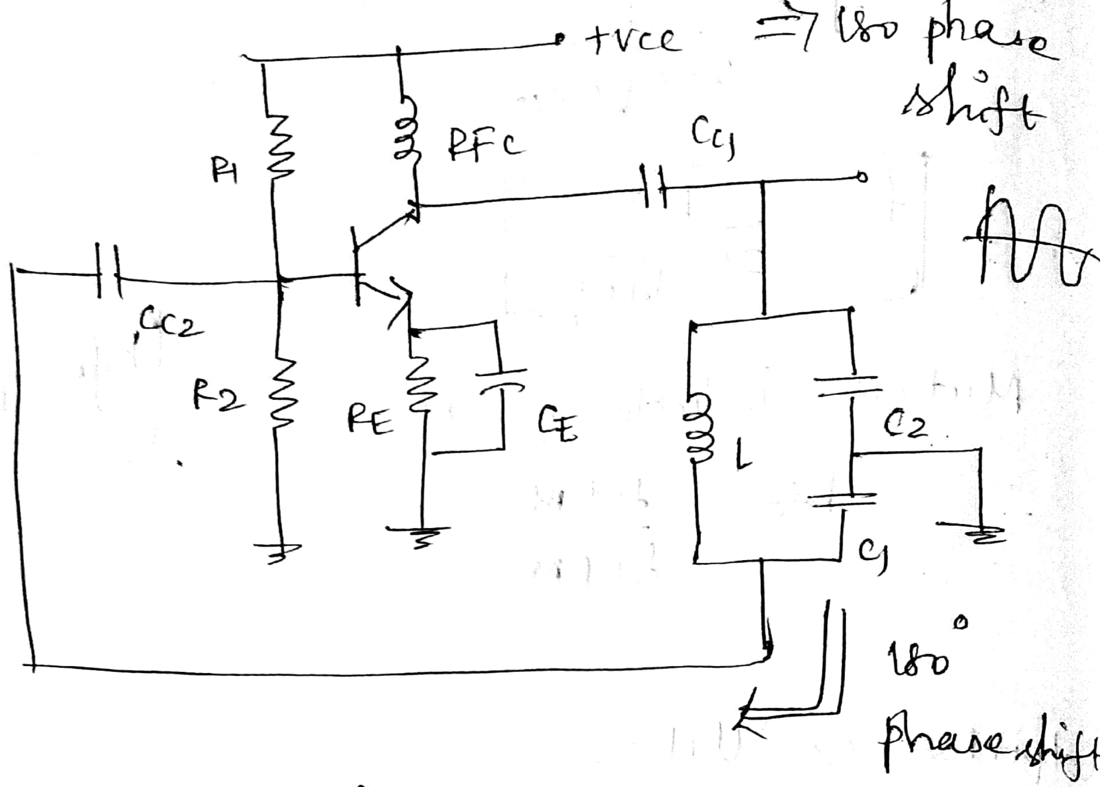
Colpitts oscillator:-

An oscillator which uses two capacitive reactances and one inductive reactance in ~~the~~ feedback n/w is called colpitts oscillator.

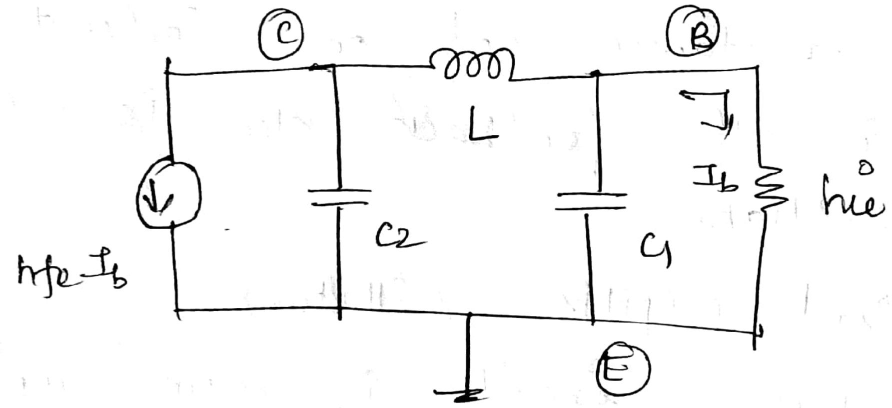
Transistorised colpitts oscillator:-

The basic circuit is same as transistorised hartley oscillator, except the tank circuit.

The CE amplifier causes a phase shift of 180°, while the tank circuit adds further 180° phase shift, to satisfy the oscillating conditions.



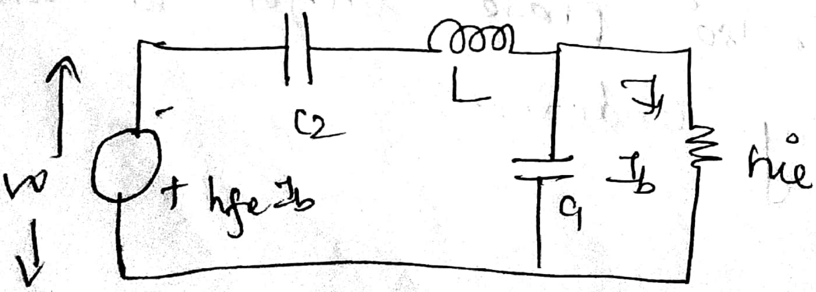
Derivation of frequency of oscillation.



$h_{fe} I_b$ ⇒ Input to the fb network.

I_b ⇒ o/p current of tank circuit.

h_{ie} ⇒ i/p impedance of the amplifier.



$$V_0 = h_{fe} I_b X_{C2} = h_{fe} I_b \frac{1}{j\omega C_2}$$

$$I = \frac{-V_0}{(X_{C2} + X_L) + (X_{C1} \parallel h_{ie})}$$

$$X_{C2} + X_L = \frac{1}{j\omega C_2} + j\omega L$$

$$X_{C1} \parallel h_{ie} = \frac{X_{C1}\, h_{ie}}{X_{C1} + h_{ie}} = \frac{\frac{1}{j\omega C_1} h_{ie}}{\frac{1}{j\omega C_1} + h_{ie}}$$

$$\therefore \quad I = \frac{-h_{fe} I_b \frac{1}{j\omega C_2}}{\left(\frac{1}{j\omega C_2} + j\omega L\right)\left(\frac{\frac{1}{j\omega C_1} h_{ie}}{\frac{1}{j\omega C_1} + h_{ie}}\right)}$$

put $s = j\omega$

$$I = \frac{-h_{fe} I_b \frac{1}{sC_2}}{\left(\frac{1}{sC_2} + sL\right)\left(\frac{\frac{1}{sC_1} h_{ie}}{\frac{1}{sC_1} + h_{ie}}\right)}$$

$$= \frac{-h_{fe} I_b \left(\frac{1}{sC_2}\right)}{\frac{(1 + s^2 L C_2)}{sC_2} \; \frac{\left(\frac{1}{sC_1} h_{ie}\right)}{\frac{1 + sC_1 h_{ie}}{sC_1}}}$$

$$= \frac{-h_{fe} I_b \left(\frac{1}{sC_2}\right)}{\frac{(1+s^2LC_2)(1+sC_1 h_{ie}) + h_{ie} sC}{(1+sC_1 h_{ie}) sC_2}}$$

$$= \frac{-h_{fe} I_b \left(\frac{1}{sC_2}\right) sC_2 (1+sC_1 h_{ie})}{1+sC_1 h_{ie} + s^2 LC_2 + s^3 LC_1C_2 h_{ie} + h_{ie}sC}$$

$$I = \frac{-h_{fe} I_b (1+sC_1 h_{ie})}{s^3 LC_1C_2 h_{ie} + s^2 LC_2 + s h_{ie}(C_1+C_2) + }$$

According to current division rule.

$$I_b = \frac{X_{C1}}{X_{C1}+h_{ie}} \times I$$

$$= \frac{\frac{1}{j\omega C_1}}{h_{ie}+\frac{1}{j\omega C_1}} \times I$$

$$I_b = \frac{\frac{1}{sC_1} \times I}{h_{ie}+\frac{1}{sC_1}}$$

$$= \frac{\frac{I}{sC_1}}{\frac{1+h_{ie}sC_1}{sC_1}} = \frac{I}{1+h_{ie}sC_1}$$

$$I_b = \frac{-h_{fe} I_b (1 + sC_1 h_{ie})}{s^3 LC_1C_2h_{ie} + s^2LC_2 + sh_{ie}(C_1+C_2)+1} \times \frac{1}{(1+h_{ie}sC_1)}$$

$$I_b = \frac{-h_{fe} I_b}{s^3 LC_1C_2 h_{ie} + s^2 LC_2 + s h_{ie}(C_1+C_2)+1}.$$

$$1 = \frac{-h_{fe}}{s^3 LC_1C_2 h_{ie} + s^2 LC_2 + s h_{ie}(C_1+C_2)+1}$$

Replace s by $j\omega$

$$1 = \frac{-h_{fe}}{(j\omega)^3 LC_1C_2 h_{ie} + (j\omega)^2 LC_2 + j\omega h_{ie}(C_1+C_2)+1}$$

$$1 = \frac{-h_{fe}}{-j\omega^3 LC_1C_2 h_{ie} - \omega^2 LC_2 + j\omega h_{ie}(C_1+C_2)+1}$$

$$1 = \frac{-h_{fe}}{(1-\omega^2 LC_2) + j\omega h_{ie}(C_1+C_2-\omega^2 LC_1C_2)}$$

Equate Imaginary part $= 0$

$$\omega h_{ie}(C_1+C_2-\omega^2 LC_1C_2) = 0$$

$$C_1+C_2-\omega^2 LC_1C_2 = 0 \qquad C_{eq} = \frac{C_1C_2}{C_1+C_2}$$

$$\omega^2 LC_1C_2 = C_1+C_2$$

$$\omega^2 = \frac{C_1+C_2}{LC_1C_2}$$

$$\omega^2 = \frac{1}{L\left[\frac{C_1C_2}{C_1+C_2}\right]}$$

$$\omega = \frac{1}{\sqrt{L\left(\frac{C_1C_2}{C_1+C_2}\right)}}$$

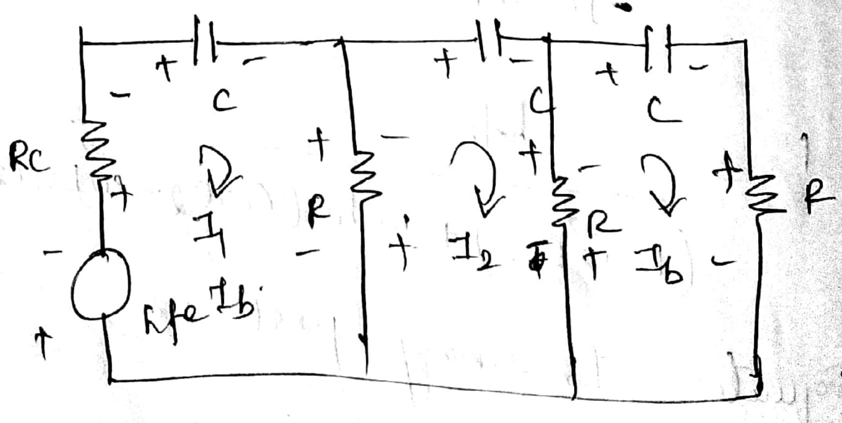
$$\omega = \frac{1}{\sqrt{LC_{eq}}}$$

$$2\pi f = \frac{1}{\sqrt{LC_{eq}}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{LC_{eq}}}}$$

$$\boxed{h_{fe} = \frac{C_2}{C_1}}$$

RC phase shift oscillator :-



For loop 1 :-

$$-h_{fe}I_bR_c - R_cI_1 + jX_cI_1 - R(I_1 - I_2) = 0.$$

$$-h_{fe}I_bR_c - R_cI_1 + jX_cI_1 - RI_1 + RI_2 = 0.$$

$h_{fe} I_b R_c + R_c I_1 - jX_c I_1 + R I_1 - R I_2 = 0.$

$$(R + R_c - jX_c) I_1 - R I_2 + h_{fe} I_b R_c = 0 \quad -①$$

For loop 2 :-

$$-R(I_2 - I_1) + jX_c I_2 - R(I_2 - I_b) = 0.$$

$$-R I_2 + R I_1 + jX_c I_2 - R I_2 + R I_b = 0$$

$$-R I_1 + R I_2 + R I_2 \mp jX_c I_2 \mp R I_b = 0$$

$$-R I_1 + I_2(2R \mp jX_c) - R I_b = 0 \quad -②.$$

For loop 3 :-

$$-R(I_b - I_2) + jX_c I_b - R I_b = 0.$$

$$-R I_b + R I_2 + jX_c I_b - R I_b = 0$$

$$R I_b - R I_2 + R I_b - jX_c I_b = 0.$$

$$-R I_2 + I_b(2R - jX_c) = 0 \quad -③.$$

$$\begin{bmatrix} R + R_c - jX_c & -R & h_{fe} R_c \\ -R & 2R - jX_c & -R \\ 0 & -R & 2R - jX_c \end{bmatrix} \cdot \begin{bmatrix} I_1 \\ I_2 \\ I_b \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\begin{vmatrix} R + R_c - jX_c & -R & h_{fe} R_c \\ -R & 2R - jX_c & -R \\ 0 & -R & 2R - jX_c \end{vmatrix} = 0$$

$$(R_C + R - jX_C)\left[(2R - jX_C)^2 - R^2\right] + R((-R)(2R - jX_C)) + h_{fe} R_C R^2 = 0.$$

$$(R_C + R - jX_C)\quad (4R^2 - X_C^2 - R^2 - j4RX_C) + R(-2R^2 + RjX_C) + h_{fe} R_C R^2 = 0$$

$$(R_C + R - jX_C)\quad (3R^2 - X_C^2 - j4RX_C) - 2R^3 + jR^2X_C + h_{fe} R_C R^2 = 0.$$

$$j4RR_CX_C + 3R_CR^2 - R_CX_C^2 + 3R^3 - RX_C^2 - jX_C3R^2 + jX_C^2 j - 4RX_C^2 - j4R^2X_C - 2R^3 + jR^2X_C + h_{fe}R_CR^2 = 0.$$

$$\cancel{R^3 + R_CR^2(3+h_{fe})}$$

$$3R_CR^2 - R_CX_C^2 + 3R^3 - RX_C^2 - 4RX_C^2 - 2R^3 + h_{fe}R_CR^2 - j4RR_CX_C - jX_C3R^2 + jX_C^2\, j4R^2X_C + jR^2X_C = 0.$$

$$R^3 + R_CR^2(3+h_{fe}) - 5RX_C^2 - R_CX_C^2 - jX_C(4RR_C + 3R^2 + 4R^2 - X_C^2 - R^2) = 0.$$

$$R^3 + R_CR^2(3+h_{fe}) - 5RX_C^2 - R_CX_C^2 - jX_C(6R^2 + 4RR_C - X_C^2) = 0.$$

Equate img part $= 0$.

$$6R^2 + 4RR_C - X_C^2 = 0$$

$$X_C^2 = 6R^2 + 4RR_C$$

$$X_C = \sqrt{6R^2 + 4RR_C}$$

$$\frac{1}{2\pi f C} = \sqrt{6R^2 + 4RR_C}$$

$$\frac{1}{f} = 2\pi C\sqrt{6R^2 + 4RR_C}$$

$$f = \frac{1}{2\pi C\sqrt{6R^2 + \frac{4R^2R_C}{R}}}$$

$$= \frac{1}{2\pi CR\sqrt{6 + 4\frac{R_C}{R}}}$$

$$\boxed{f = \frac{1}{2\pi RC\sqrt{6+4K}}} \qquad K = \frac{R_C}{R}.$$

To <u>find h_{fe} :-</u>

Real part $= 0$.

$$R^3 + R_CR^2(3 + h_{fe}) - X_C^2(5R + R_C) = 0.$$

$$R^3 + R_CR^2(3 + h_{fe}) - (6R^2 + 4RR_C)(5R + R_C) = 0.$$

$$R^3 + R^2R_C3 + R_CR^2h_{fe} - \left[30R^3 + 6R^2R_C + 20R^2R_C + 4RR_C^2\right] = 0.$$

$$R^3 + 3R^2R_C + R^2R_Ch_{fe} - 30R^3 - 6R^2R_C - 20R^2R_C - 4RR_C^2 = 0.$$

$$-29R^3 - 23R^2R_C + h_{fe}R^2R_C - 4RR_C^2 = 0.$$

$$h_{fe}\, R^2 RC = 29R^3 + 23R^2RC + 4RRc^2$$

$$h_{fe} = \frac{29R^3 + 23R^2RC + 4RRc^2}{R^2RC}$$

$$= 29\frac{R}{RC} + 23 + \frac{4Rc}{R}$$

$$\boxed{h_{fe} = 23 + \frac{29}{k} + 4k}$$

Problems :-

1) A voltage series feedback amplifier has a voltage gain with fb as 83.33 and feedback ratio as 0.01. Calculate the voltage gain of the amplifier without

2) An amplifier has a voltage gain of 1000. with negative fb, the voltage gain reduces 10. Calculate the fraction of the o/p that is feedback to the i/p.

3) In a RC phase shift oscillator if $R_1 = R_2 = R_3 = 200\,k\Omega$ and $C_1 = C_2 = C_3 = 100\,pF$. Find f.

4) In a hartley oscillator $L_1 = 0.2\,mH$, $L_2 = 0.3\,mH$ $C = 0.003\,\mu F$. Calculate the frequency of its oscillations.

5) An amplifier has a voltage gain with fb as 100. If the gain without fb changes by 20% and the gain with fb should not vary 2%. determine A and β.