Unit-3 (Feedback Amplifier)

$$A_V = -g_m\left(\frac{R_i}{R_i + R_s}\right)R_o$$

$$= -\frac{I_o}{V_{in}}\left(\frac{R_i}{R_i + R_s}\right)R_o.$$

$$= -\frac{I_o}{V_{in}} \cdot \frac{1}{R_i} R_o \quad [\text{if } R_s = 0]$$

$$A_V = -A_I \frac{R_o}{R_i}$$

If $A_I = 100$, $R_i = 1.1\,K\Omega$, $R_o = 2.2\,K\Omega$.

$$A_V = -200$$

If $V_i = 1\,mV$

$\therefore V_o = |A_V|\, V_i$

$= 200 \times 1\,mV.$

$= 200\,mV.$

if temp ↑, A_i ↑, to 110.

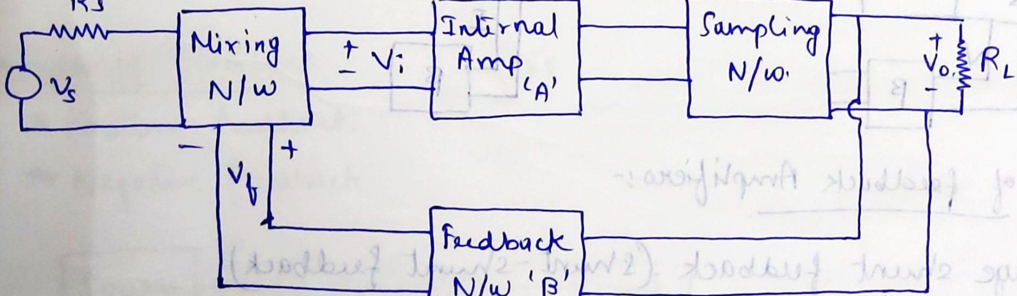
then

$$A_V = 110 \cdot \frac{2.2\,K}{1.1\,K} = 220$$

$\therefore V_o = 220 \cdot 1\,mV.$

$= 220\,mV.$

Feedback Amp. Block Diagram :-



$V_i = V_s - V_f$.

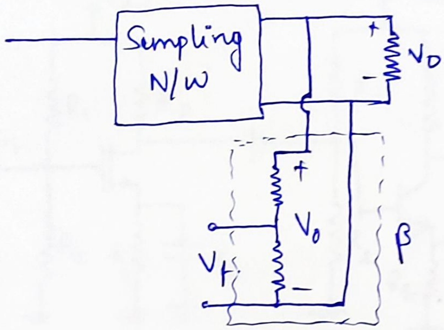
- If V_o ↑ due to any fluctuations,

  V_f ↑ $\therefore V_i$ ↓ ⇒ Brought down V_o to constant.

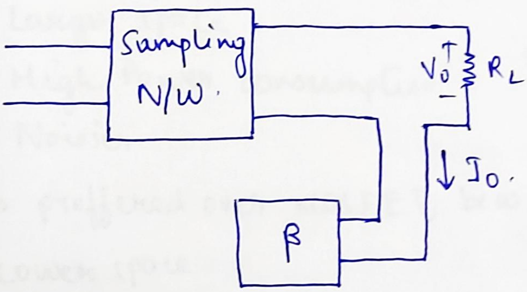
- If V_o ↓, V_f ↓, V_i ↑ ⇒ Brought down V_o to constant.

▲ Sampling N/W :-

i) Voltage Sampling :-

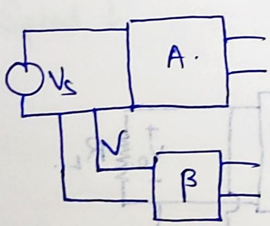


ii) Current Sampling :-

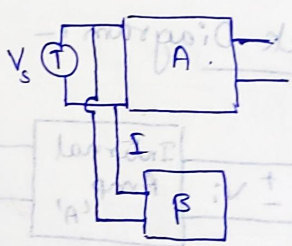


▲ Mixing N/W :-

i) Series mixing

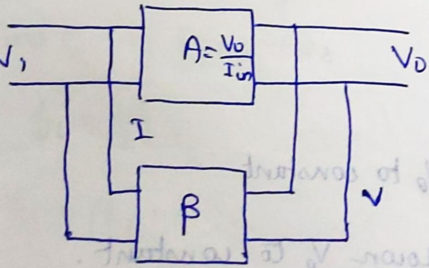


ii) Shunt mixing



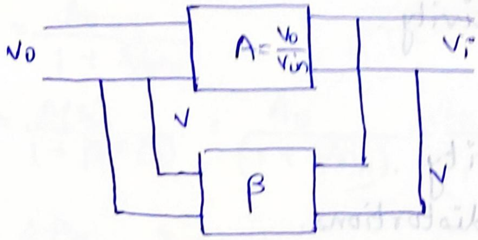
▸ Types of feedback Amplifiers :-

i) Voltage shunt feedback (Shunt-shunt feedback).
(Transresistance Amp)



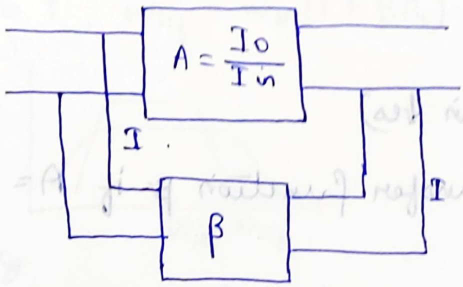
Wein bridge

2) Voltage Series Feedback (Series - shunt feedback).



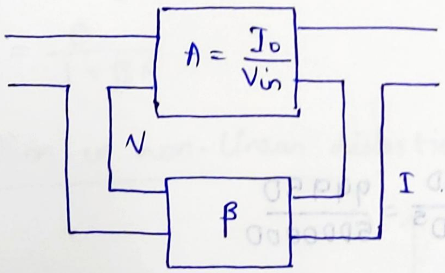
(Voltage Amp)

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



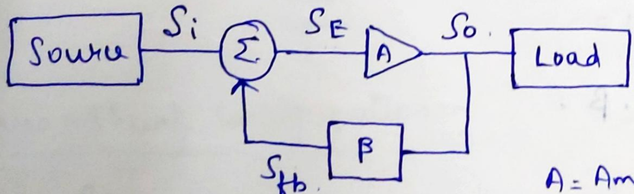
(Current Amp.)

4) Current Series Feedback (Series - series feedback).



(Transconductance Amp.)

- Types of Feedback :-
  - Positive feedback $\rightarrow A_{fb} = \frac{A}{1-A\beta}$
  - Negative feedback.



A = Amplification factor / open Loop gain

β = feedback transfer function.

OR

feedback factor.

$S_o = A \cdot S_E$.

$S_{fb} = \beta S_o$.

$S_E = S_i - S_{fb}$.

$A\beta$ = Loop Gain

$A\beta >> 1$.

$\therefore A_{fb} = \frac{A}{A\beta} = \frac{1}{\beta}$.

$S_o = A(S_i - S_{fb}) = AS_i - A\beta S_o \Rightarrow AS_i = S_o + A\beta S_o$.

$\Rightarrow A_{fb} = S_o/S_i = A/(1 + A\beta) \Rightarrow$ closed loop gain

- **Advantages of Negative feedback :-**

1) Reduction in gain sensitivity.
2) Bandwidth extension.
3) Reduction in noise sensitivity.
4) Reduction of non-linear distortions.

(A) -ve feedback has good control over input & output impedance levels.

- **Disadvantages :-**

① Reduction in gain (Gain ↓es)

Q) Calculate feedback transfer function β if $A = 10^5$, $A_f = 50$.

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

$$A_f\beta + AA_{fb}\beta = A.$$

$$\cancel{\beta(A_f + AA_f\beta) = A}$$

$$\beta AA_f + A_f = A.$$

$$\beta = \frac{A - A_f}{AA_f} = \frac{10^5 - 50}{50 \times 10^5} = \frac{99950}{5000000}$$

$$= 0.0199.$$

- **Advantages of Negative Feedback :-**

i) Reduction in Gain sensitivity :-

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

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

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

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

$$\frac{dA_f}{A_f} = \frac{dA/(1+\beta A)^2}{A/(1+A\beta)} = \frac{1}{1+A\beta}\,\frac{dA}{A}.$$

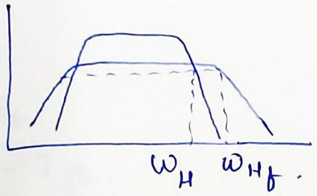
ii) Bandwidth extension:-

$$A(s) = \frac{A_0}{1 + s/\omega_H}$$

$$A_f(s) = \frac{A(s)}{1+\beta A(s)} = \frac{A_0}{(1 + s/\omega_H)} \cdot \frac{1}{\left(1 + \frac{\beta A_0}{1 + s/\omega_H}\right)}$$

$$= \left(\frac{A_0}{1+\beta A_0}\right)\left(\frac{1}{1 + s/\omega_H(1+\beta A_0)}\right)$$

i.e ω_H is ↑, $\omega_{Hf} = \omega_H(1+\beta A_0)$

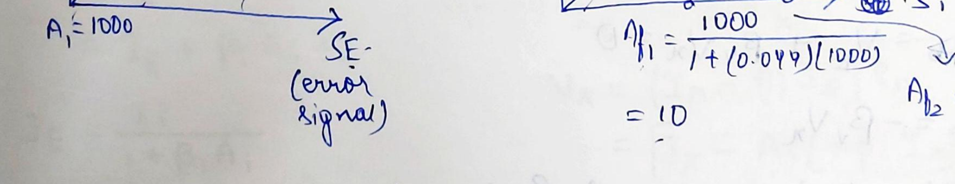


iii) Noise & distortion Reduction :-

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

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

iv) Reduction in non-linear distortion :-



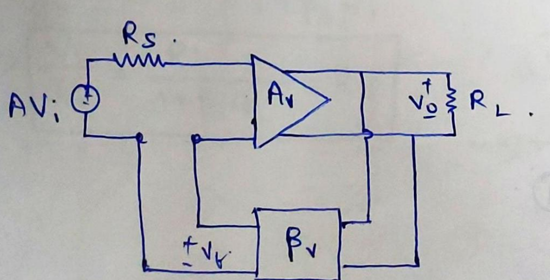
$$A_{f1} = \frac{1000}{1+(0.099)(1000)}$$

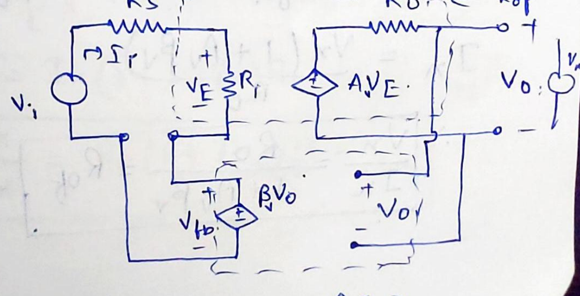
$= 10$

$$A_{f2} = \frac{500}{1+(0.099)(500)}$$

$= 9.9$

• Series-Shunt Configuration :-





P.T.O

$$V_0 = A_v V_E \quad \text{— (I)}$$

$$\& \; V_{fb} = \beta_v V_0 \quad \text{— (II)}$$

$$V_E = V_i - V_{fb}$$

$$\therefore V_0 = A_v (V_i - V_{fb}) \quad \text{— (III)}$$

$$\therefore V_0 = A_v (V_i - \beta_v V_0)$$

$$\Rightarrow V_0 = A_v V_i - \beta_v V_0 A_v$$

$$\Rightarrow V_0 (1 + A_v \beta_v) = A_v V_i$$

$$\Rightarrow \boxed{\frac{V_0}{V_i} = \frac{A_v}{1 + A_v \beta_v} = A_{vf}} \quad \text{— (IV)}$$

$$V_i = V_E + V_{fb} = V_E + \beta_v V_0$$

$$V_i = V_E + \beta_v (A_v V_E)$$

$$\Rightarrow V_i = V_E (1 + A_v \beta_v)$$

$$\Rightarrow V_E = \frac{V_i}{1 + A_v \beta_v}$$

$$I_i = \frac{V_E}{R_i} = \frac{V_i}{R_i (1 + A_v \beta_v)}$$

$$\Rightarrow \frac{I_i}{V_i} = \frac{1}{R_i (1 + A_v \beta_v)}$$

$$\Rightarrow \boxed{\frac{V_i}{I_i} = R_{if} = R_i (1 + A_v \beta_v)} \quad \text{— (V)}$$

$$V_E + V_{fb} = V_E + \beta_v V_x = 0$$

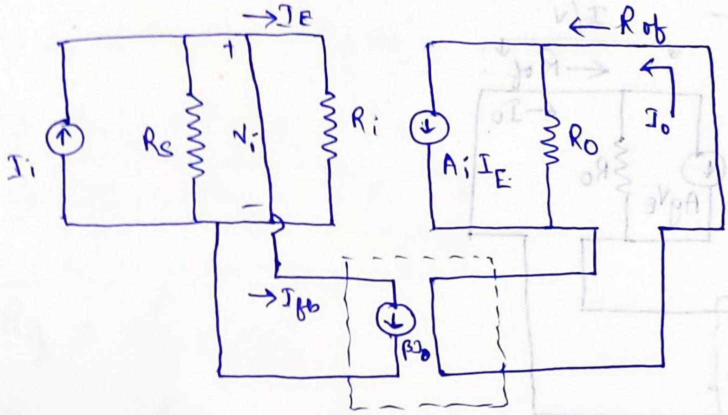
$$\therefore V_E = -\beta_v V_x$$

$$I_x = \frac{V_x - A_v V_E}{R_0} = \frac{V_x + A_v \beta_v V_x}{R_0}$$

$$I_x = \frac{V_x (1 + A_v \beta_v)}{R_0}$$

$$\therefore \boxed{\frac{V_x}{I_x} = \frac{R_0}{1 + A_v \beta_v} = R_{of}} \quad \text{— (VI)}$$

• Shunt-Series Configuration :-



Gain

$I_o = A_i I_E$

$I_{fb} = \beta_i I_o$.

$I_E = I_i - I_{fb}$.

$I_i = I_E + I_{fb}$.

$= I_E + \beta_i I_o$.

$= \frac{I_o}{A_i} + \beta_i I_o$.

$\Rightarrow I_i = \frac{I_o + \beta_i A_i I_o}{A_i}$

$\Rightarrow I_i = \frac{I_o(1+\beta_i A_i)}{A_i}$

$\cancel{\frac{I_o}{I_i} = \frac{A_i I_E}{I}}$

$\Rightarrow \boxed{\frac{I_o}{I_i} = \frac{A_i}{1+\beta_i A_i}}$

Input Impedance

$I_i = I_E + I_{fb}$.

$= I_E + \beta_i I_o$

$= I_E + \beta_i A_i I_E$.

$\Rightarrow I_E = \frac{I_i}{1+\beta_i A_i}$

$V_i = I_E R_i = \frac{I_i R_i}{1+\beta_i A_i}$

$\Rightarrow \boxed{\frac{V_i}{I_i} = \frac{R_i}{1+\beta_i A_i} = R_{if}}$

Output Impedance

Connect V_x at o/p

$I_E + I_{fb} = I_E + \beta_i I_x = 0$

$I_E = -\beta_i I_x$

$V_x = (I_x - A_i I_E) R_o$

$= [I_x - A_i(-\beta_i I_x)] R_o$

$V_x = [I_x + A_i \beta_i I_x] R_o$.

$\Rightarrow V_x = I_x(1 + A_i \beta_i) R_o$

$\Rightarrow \boxed{\frac{V_x}{I_x} = R_o(1 + A_i \beta_i) = R_{of}}$

$$V_o = A_z(I_i - I_{fb})$$

$$\Rightarrow V_o = A_z(I_i - \beta_g V_o).$$

$$\Rightarrow V_o(1+\beta_g A_z) = A_z I_i$$

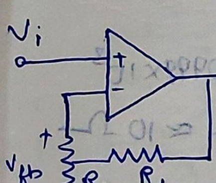
$$\Rightarrow \boxed{\frac{V_o}{I_i} = A_{zf} = \frac{A_z}{1+\beta_g A_z}}$$

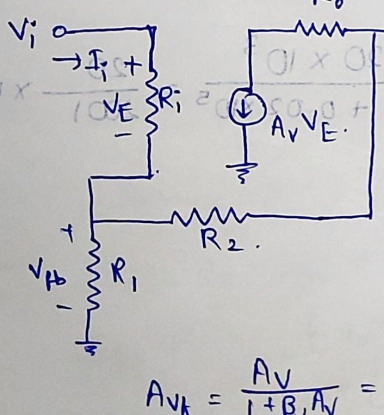
$$\boxed{R_{if} = \frac{R_i}{1+A_z\beta_g} \qquad R_{of} = \frac{R_o}{1+A_z\beta_g}}$$

Configuration	Type of Amp	Gain with feedback	I/P Imp	O/P Imp
Series - Shunt	I/P = V O/P = V Voltage Amp	$\frac{A_V}{1+\beta_V A_V}$	$R_{if} = R_i(1+\beta_V A_V)$	$R_{of} = \frac{R_o}{1+\beta_V A_V}$
Shunt - Series	I/P = I O/P = I Current Amp	$\frac{A_i}{1+\beta_i A_i}$	$R_{if} = \frac{R_i}{1+\beta_i A_i}$	$R_{of} = R_o(1+\beta_i A_i)$
Series - Series	I/P = V O/P = I. Transconductance	$\frac{A_g}{1+A_g\beta_z}$.	$R_{if} = R_i(1+\beta_z A_g)$	$R_{of} = R_o(1+\beta_z A_g)$
Shunt - shunt	I/P = I O/P = V	$\frac{A_z}{1+\beta_g A_z}$	$R_{if} = \frac{R_i}{1+A_z\beta_g}$	$R_{of} = \frac{R_o}{1+A_z\beta_g}$

- Practical feedback ckts:-

Voltage Amp:





$$A_{vf} = 1 + \frac{R_2}{R_1}$$

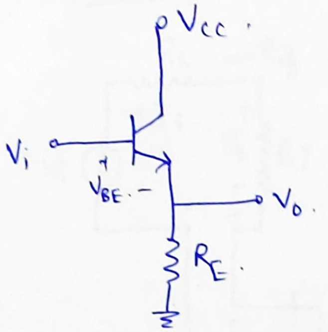
$$A\beta >> 1.$$

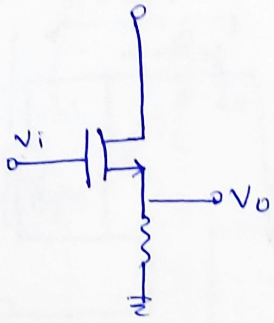
$$A_{vf} = \frac{1}{\beta_V}.$$

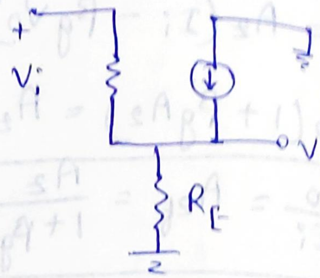
$$\text{or } \beta_V = \frac{1}{A_{vf}} = \frac{1}{1+\frac{R_2}{R_1}}$$

$$A_{vf} = \frac{A_V}{1+\beta_V A_V} = \frac{A_V}{1+\frac{A_V}{1+R_2/R_1}}$$

Discrete ckt.







$$A_v = \left(\frac{1}{r_\pi} + g_m\right) R_E = \frac{R_E}{r_e}.$$

$$R_{if} = r_\pi + (1 + h_{fe}) R_E$$

$$R_{of} = R_E \| \frac{r_\pi}{1+h_{fe}} = R_E \| r_e$$

Q) Determine i/p imp of series i/p connection and o/p imp of a shunt o/p connection for an ideal voltage amp. if $A_v = 10^5$, $A_{vf} = 50$, $R_i = 10 K\Omega$, $R_o = 20 K\Omega$.

$$A_{vf} = \frac{A_V}{1 + \beta_v A_v}.$$

$$1 + \beta_v A_v = \frac{A_v}{A_{vf}}.$$

$$\beta_v = \left(\frac{A_v}{A_{vf}} - 1\right)\frac{1}{A_v} = \frac{1}{A_{vf}} - \frac{1}{A_v}.$$

$$\beta_v = \frac{1}{50} - \frac{1}{10^5} = 0.019.$$

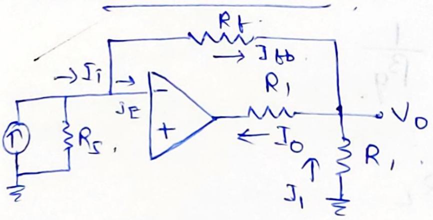
$$R_{if} = R_i(1 + \beta_v A_v) = 10\left(1 + 0.019 \times 10^5\right) \times 10^3$$

$$= 19010 \ K\Omega \approx 20 \ M\Omega.$$

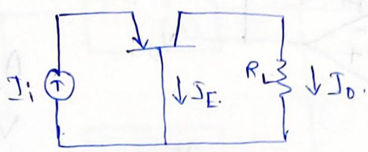
$$R_{of} = \frac{R_o}{1 + \beta_v A_v} = \frac{20 \times 10^3}{1 + 0.02 \times 10^5} = \frac{20}{2001} \times 10^3 = 0.00999 \times 10^3$$

$$= 9.9\Omega \approx 10 \Omega$$

Current Amp (Shunt Series)



CB Circuit



$V_0 = -I_{fb} R_f$

$= -I_i R_f$

$I_1 = -\frac{V_0}{R_1}$

$I_0 = I_{fb} + I_1$

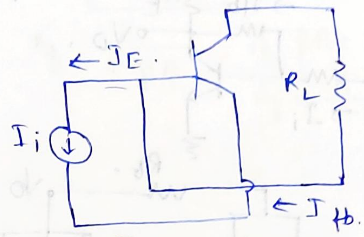
$I_0 = I_i + \left(-\frac{1}{R_1}\right)(-I_i R_f)$

$\Rightarrow I_0 = I_i \left(1 + \frac{R_f}{R_1}\right)$

$\Rightarrow \boxed{\frac{I_0}{I_i} = 1 + \frac{R_f}{R_1}}$

$A_{if} \simeq \frac{1}{\beta_i} = \frac{I_0}{I_i}$

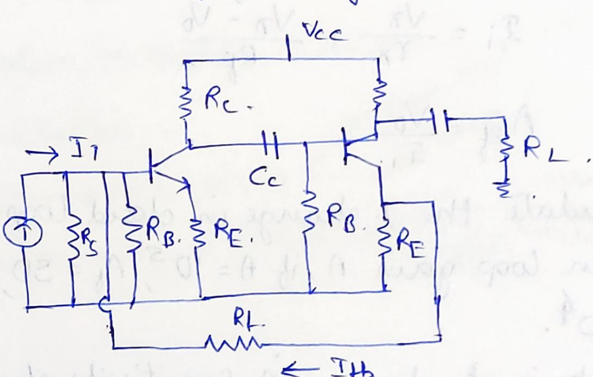
$\therefore \beta_i = \frac{1}{1 + \frac{R_f}{R_1}}$



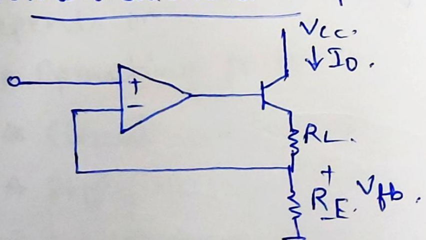
$A_i = \frac{I_0}{I_E} = h_{fe}$

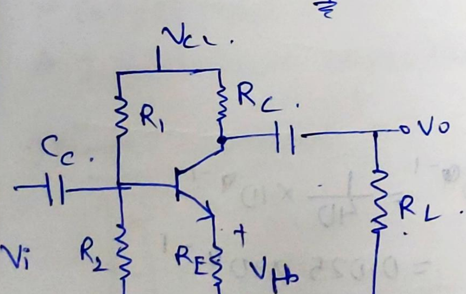
$A_{if} = \frac{h_{fe}}{1 + h_{fe}} = \frac{A_i}{1 + A_i}$

$\beta_i =$ unity.



Transconductance Amp :-





$A_{gf} = \frac{I_0}{V_i} = \frac{1}{\beta_2}$

$V_i = V_{fb} = I_0 R_E$

$A_{gf} = \frac{I_0}{V_i} = \frac{1}{R_E}$

$\beta_2 = R_E$

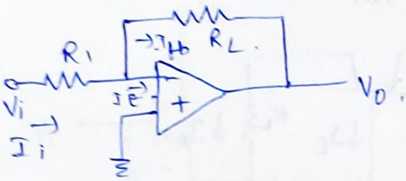
$I_0 = (-g_m V_\pi)\left(\frac{R_L}{R_C + R_L}\right)$

$V_{fb} = \left(\frac{V_\pi}{r_\pi} + g_m V_\pi\right) R_E$

$V_i = V_\pi + V_{fb} = V_\pi \left(1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right)$

$A_{gf} = \frac{I_0}{V_i} = \frac{(-g_m V_\pi)\left(\frac{R_L}{R_C + R_L}\right)}{V_\pi \left(1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right)}$

- Transresistance Amp.

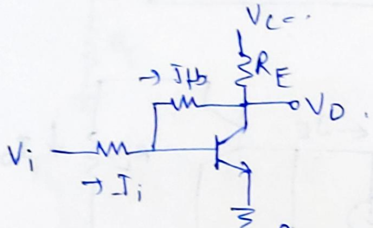


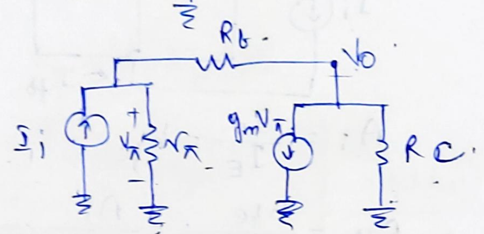
$$A_{zf} = \frac{V_o}{I_i} = \frac{1}{\beta_g}.$$

$$A_{zf} = -R_L.$$

$$V_o = -I_{fb} R_L.$$

$$\beta_g = -\frac{1}{R_L}.$$





$$\frac{V_o}{R_c} + g_m V_\pi + \frac{(V_o - V_\pi)}{R_f} = 0.$$

$$I_i = \frac{V_\pi}{r_\pi} + \frac{V_\pi - V_o}{R_f}.$$

$$A_{zf} = \frac{V_o}{I_i}$$

Q) Calculate the % change in closed loop gain A_f, given a change in open loop gain A, if $A = 10^5$, $A_f = 50$, $\beta = 0.01999$, $dA = 10^4$.

Reduction of change in sensitivity of gain

$$\frac{dA_f}{A_f} = ?$$

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

$$dA_f = \frac{50}{1+(0.01999 \times 10^5)} \cdot \frac{10^4}{10^5}.$$

$$dA_f = \frac{50}{1+1999} \times 10^{-1} = \frac{50}{2000} \times 10^{-1} = \frac{1}{40} \times 10^{-1}$$

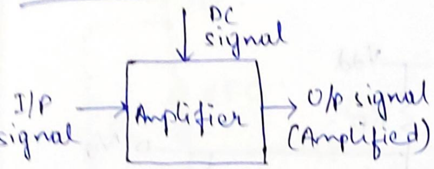
$$= 0.025 \times 10^{-1}$$

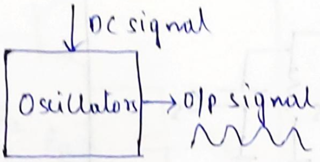
$$= 2.5 \times 10^{-3}$$

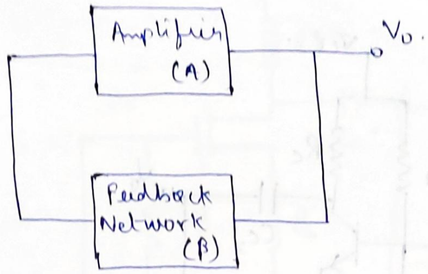
$$\Rightarrow dA_f = 2.5 \times 10^{-3}.$$

$$\frac{dA_f}{A_f} =$$

Oscillators :-







$A_f = \frac{A}{1-\beta A}$, if $\beta A = 1$

$A_f = \frac{A}{1-1} = \frac{A}{0} = \infty$

Condition for oscillation :-

$\beta A = 1 \angle 0°$

i) $|\beta A| \geq 1$
ii) $\angle \beta A = 0°$ or $360°$

} Barkhausen criteria.

Types :-

i) Sinusoidal or harmonic oscillator.
ii) Non-sinusoidal or Relaxation oscillator.

According to freq. of oscillation :-

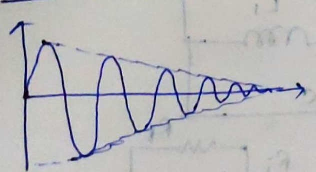
i) Audio frequency oscillator → 20 Hz - 20 KHz < RC phase shift, Wein bridge
ii) Radio frequency oscillator → Beyond 20 KHz < LC → Hartley, Colpitt, Clapp; Crystal

Frequency stability :-

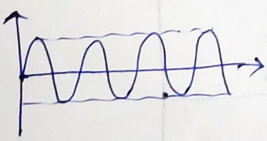
Depends on.

- Operating point.
- Circuit components.
- Supply voltage
- Output load
- Interelement capacitance and stray capacitance.

·) Damped oscillation :-

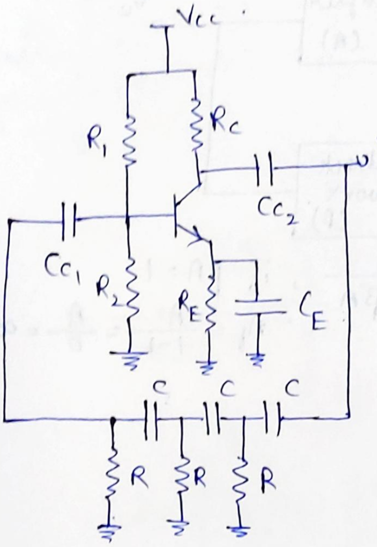


·) Sustained oscillation



→ Const amplitude
→ Const frequency

▲ RC Phase Shift Oscillator :-

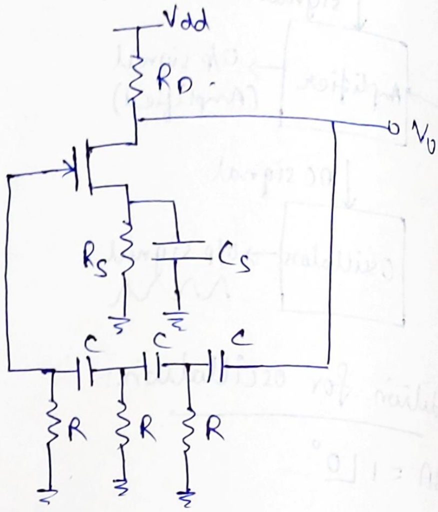


$\beta = \frac{1}{29}$

$A > 29$

$f = \frac{1}{2\pi RC} \cdot \frac{1}{\sqrt{6 + 4(R_C/R)}}$

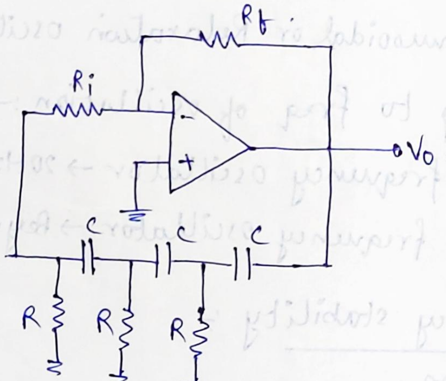
$h_{fe} > 23 + \frac{29R}{R_C} + \frac{4R_C}{R}$



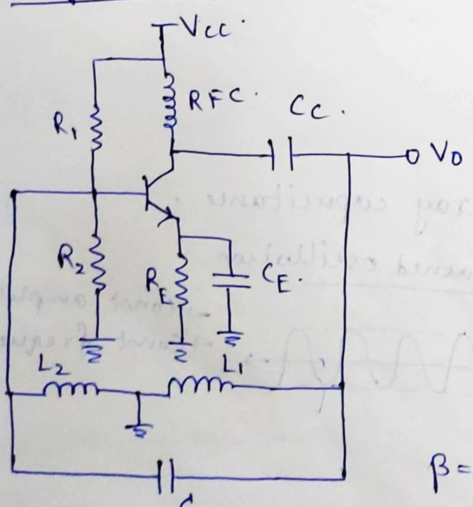
$|A| = g_m R_L$

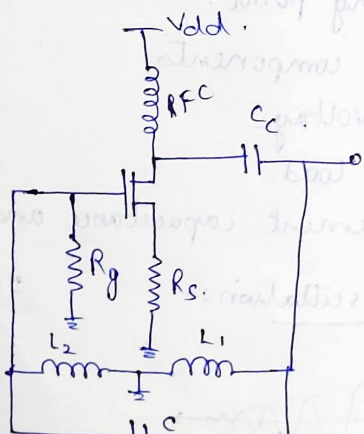
$R_L = \frac{R_D r_d}{R_D + r_d}$

$f = \frac{1}{2\pi RC\sqrt{6}}$



▲ Hartley oscillator :-

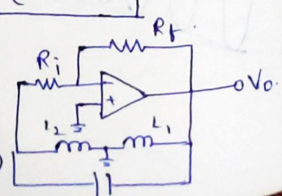




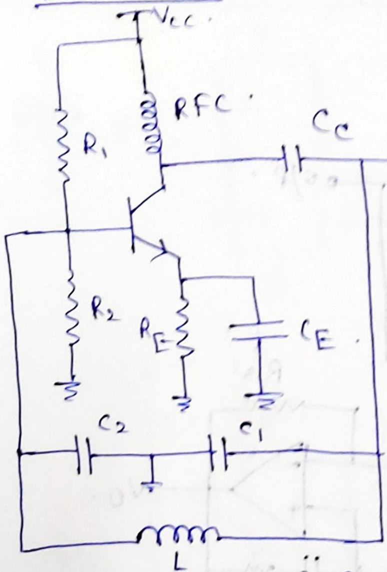
$\beta = \frac{L_2}{L_1}$

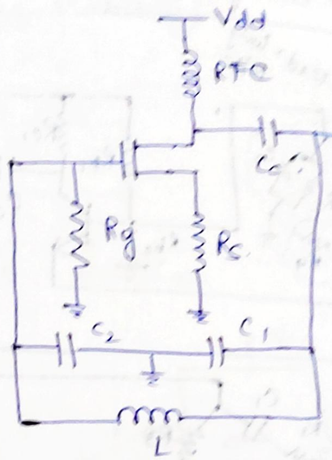
$A = L_1/L_2$. (M = mutual inductance)

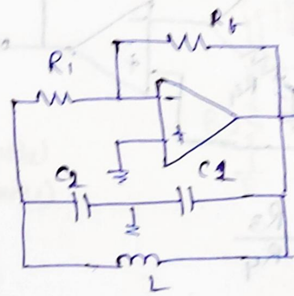
$L_{eq} = L_1 + L_2 + 2M$ $f_0 = \frac{1}{2\pi\sqrt{L_{eq} \cdot C}}$



- Colpitt oscillator :-







$$\beta = \frac{C_2}{C_1}$$

$$A = \frac{C_1}{C_2}.$$

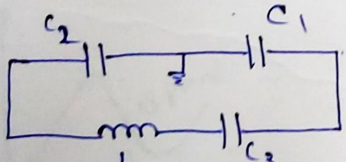
- Clapp oscillator

$$f_0 = \frac{1}{2\pi\sqrt{L C_{eq}}}$$

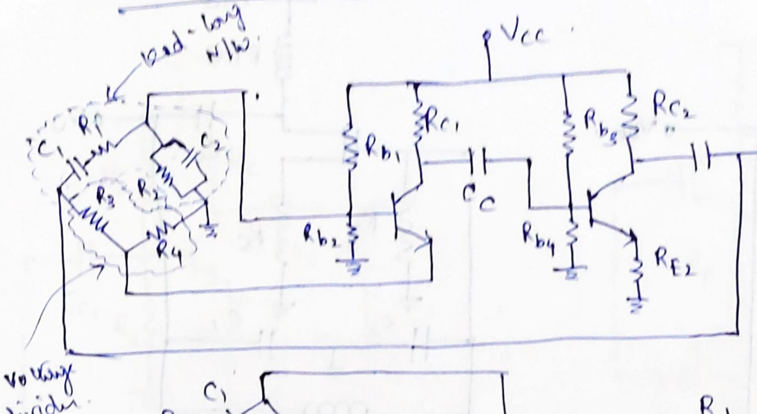
$$C_{eq} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}.$$

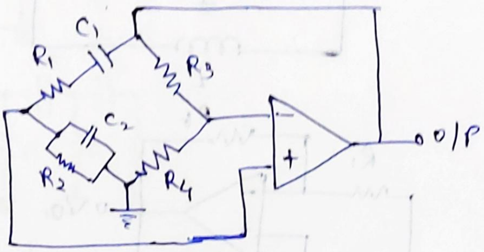
C_3 = small

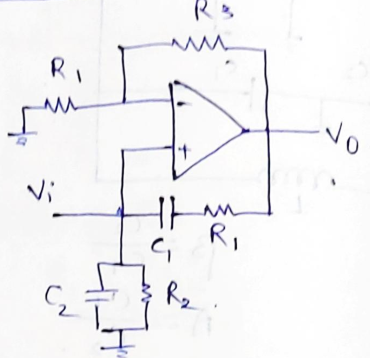
$$f_0 \simeq \frac{1}{2\pi\sqrt{LC_3}}$$



Wein Bridge Oscillator :- (20 Hz to 1 MHz)







$$A = 1 + \frac{R_3}{R_4}$$

$$\beta = \frac{Z_p}{Z_p + Z_s}$$

$$Z_p = \frac{R_2 \times \frac{1}{sC_2}}{R_2 + \frac{1}{sC_2}} = \frac{R_2}{sR_2C_2 + 1}$$

$$Z_s = R_1 + \frac{1}{sC_1} = \frac{1 + sR_1C_1}{sC_1}$$

$$T(s) = \beta A = \left(1 + \frac{R_3}{R_4}\right)\left(\frac{Z_p}{Z_p + Z_s}\right)$$

If $R_1 = R_2 = R$ and $C_1 = C_2 = C$.

$$T(s) = \left(1 + \frac{R_3}{R_4}\right)\left(\frac{1}{3 + sRC + \frac{1}{sRC}}\right)$$

Voltage divider

$$\boxed{\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1}}$$

$$\boxed{f_0 = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}}$$

$$T(j\omega_0) = \beta A = 1\angle 0^\circ$$

$$= \left(1 + \frac{R_3}{R_4}\right)\left(\frac{1}{3 + j\omega_0 RC + \frac{1}{j\omega_0 RC}}\right) = 1$$

Imaginary part = 0

$$\therefore j\omega_0 RC + \frac{1}{j\omega_0 RC} = 0$$

$$\therefore \omega_0 = \frac{1}{RC}$$

$$\therefore f_0 = \frac{1}{2\pi RC}$$

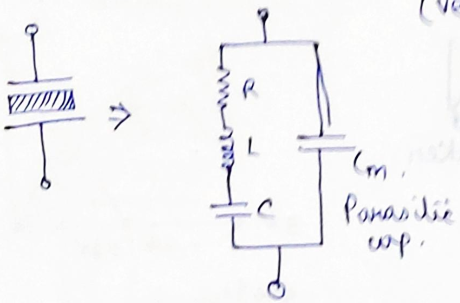
Real part,

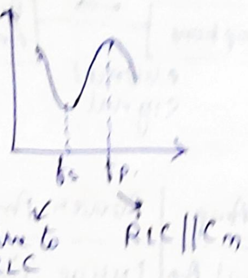
$$\left(1 + \frac{R_3}{R_4}\right)\left(\frac{1}{3}\right) = 1$$

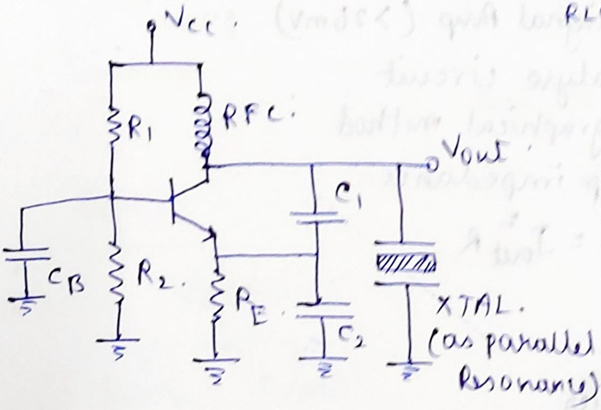
$$\therefore \frac{R_3}{R_4} = 2.$$

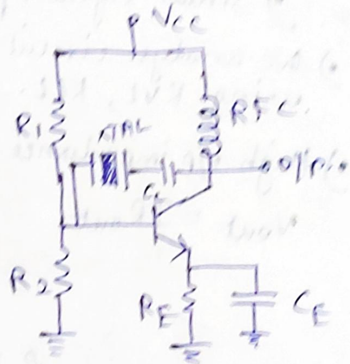
Crystal oscillator (10 KHz to 200 MHz)

(very high freq stability)

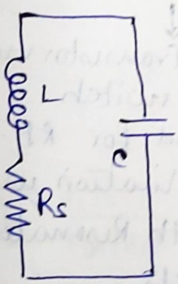




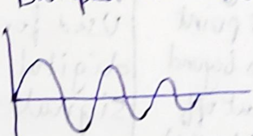




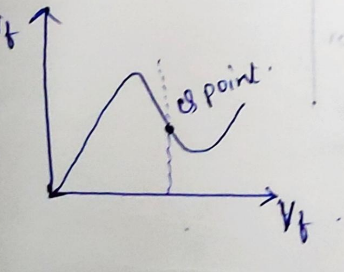
Negative Resistance Oscillator



Damped oscillations

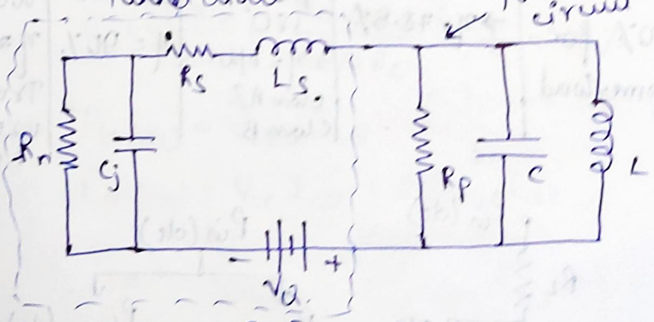


Tunnel diode.



Tunnel diode

Tuned circuit



$$R_{eq} = \frac{-R_p R_n}{R_p - R_n}$$

if $R_p > R_n$ then, $R_{eq} = -ve$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$