$$R_{out2} = \frac{R_{e2}\left[R_{th} + h_{fe} r_e'\right]}{R_{th} + h_{fe}(r_e' + R_{e2})}$$

$$= \frac{R_{e2}\left[\frac{R_{th}}{h_{fe}} + r_e'\right]}{R_{e2} + \left(\frac{R_{th}}{h_{fe}} + r_e'\right)}$$

$$= R_{e2} \parallel \left(\frac{R_1 \parallel R_2 \parallel R_s}{h_{fe}} + r_e'\right)$$

$R_{L2} = 0$, $R_{L2} = \alpha$.

Determination of the Values of capacitances C_b, C_c, C_{e1} and C_{e2}

$$Z_b = \sqrt{\{R_s + R_{in}(total)\}^2 + X_b^2}$$

$$X_b = \frac{1}{2\pi f_{smin} R_b}$$

$$X_b = \frac{1}{2\pi f_{smin} C_b} \leq 0.1\left[R_s + R_{in}(total)\right]$$

$$Z_b = \sqrt{\{R_s + R_{in}(total)\}^2 + X_b^2}$$

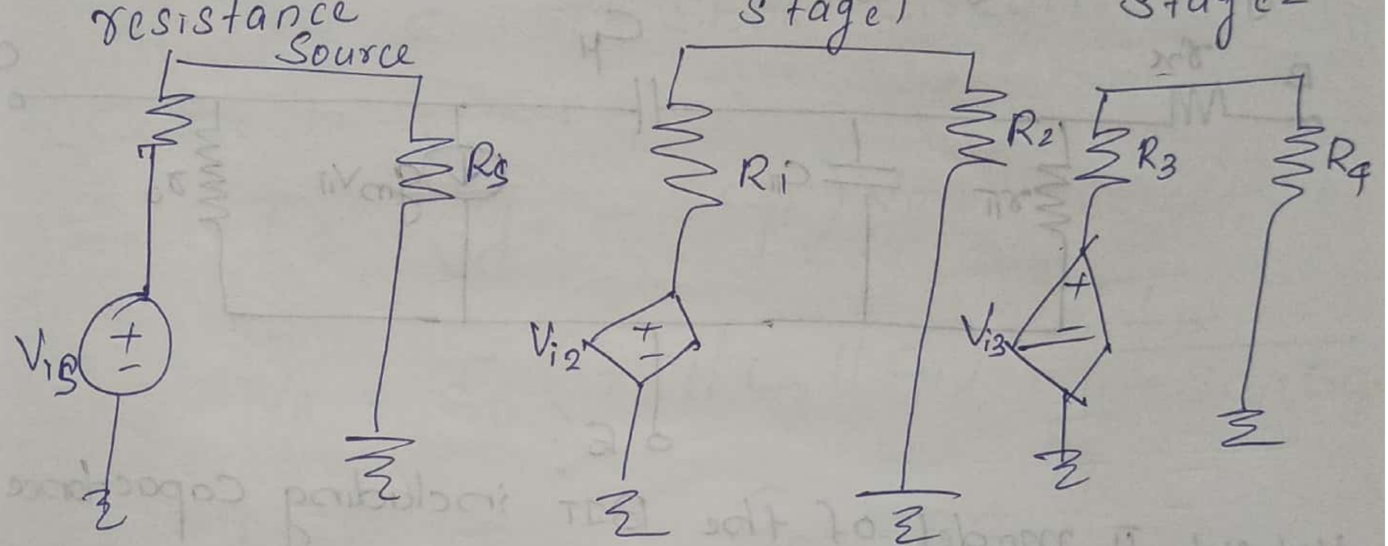
$$= \sqrt{1.01\{R_s + R_{in}(total)\}^2}$$

$$\simeq \underline{\underline{Z_s}}$$

$$X_c = \frac{1}{2\pi f_{smin}}$$

Cascade Amplifiers:-

To meet given amplifier specification the need to design amplifier as cascade of two or more stages. Stages may not be identical. First stage is usually having large input resistance & final stage with low output resistance



$$V_o = A_{Vo} \cdot V_i \frac{R_L}{R_L + R_o}$$

$$A_V = \frac{V_o}{V_i} = A_{Vo} \cdot \frac{R_L}{R_L + R_o}$$

$$V_i = V_s \cdot \frac{R_i}{R_i + R_s}$$

$$\frac{V_o}{V_s} = A_{Vo} \cdot \frac{R_i}{R_i + R_s} \cdot \frac{R_L}{R_L + R_o}$$

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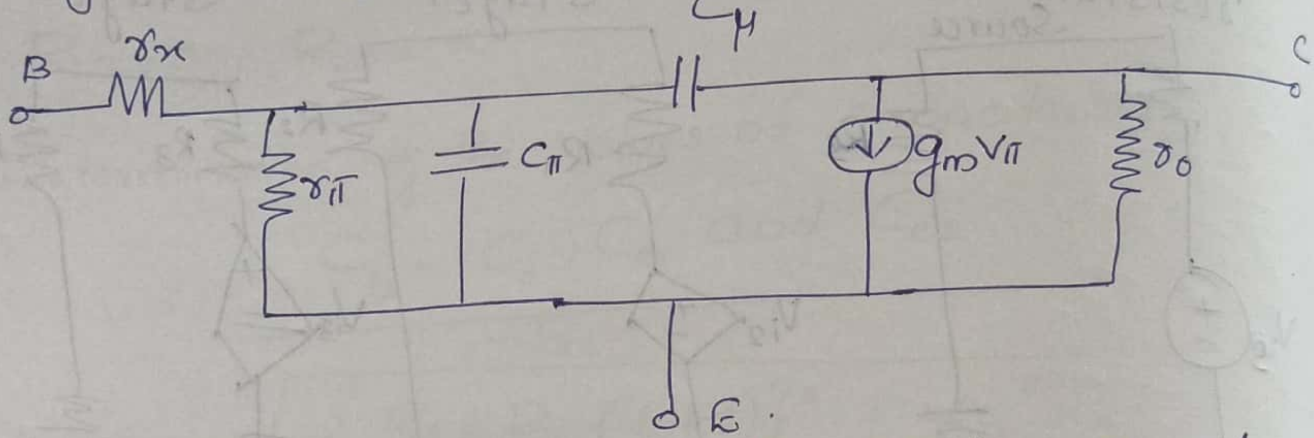
Module - III

High Frequency Equivalent Circuits of BJT

Transistors exhibit charge storage phenomenon that limit speed and frequency of their operation. Charge storage effects that take place in BJT and take them into account by adding capacitances to the hybrid π model.

High Frequency Hybrid π Model:-



Hybrid π model of the BJT including capacitance

Emitter base capacitance

$$C_\pi = C_{de} + C_{je}$$

$C_{de} \longrightarrow$ Small Signal diffusion Capacitance

$C_{je} \longrightarrow$ depletion layer capacitance.

Collector - base capacitance C_μ

The values of hybrid π equivalent circuit parameters. r_x is a few ten of ohms

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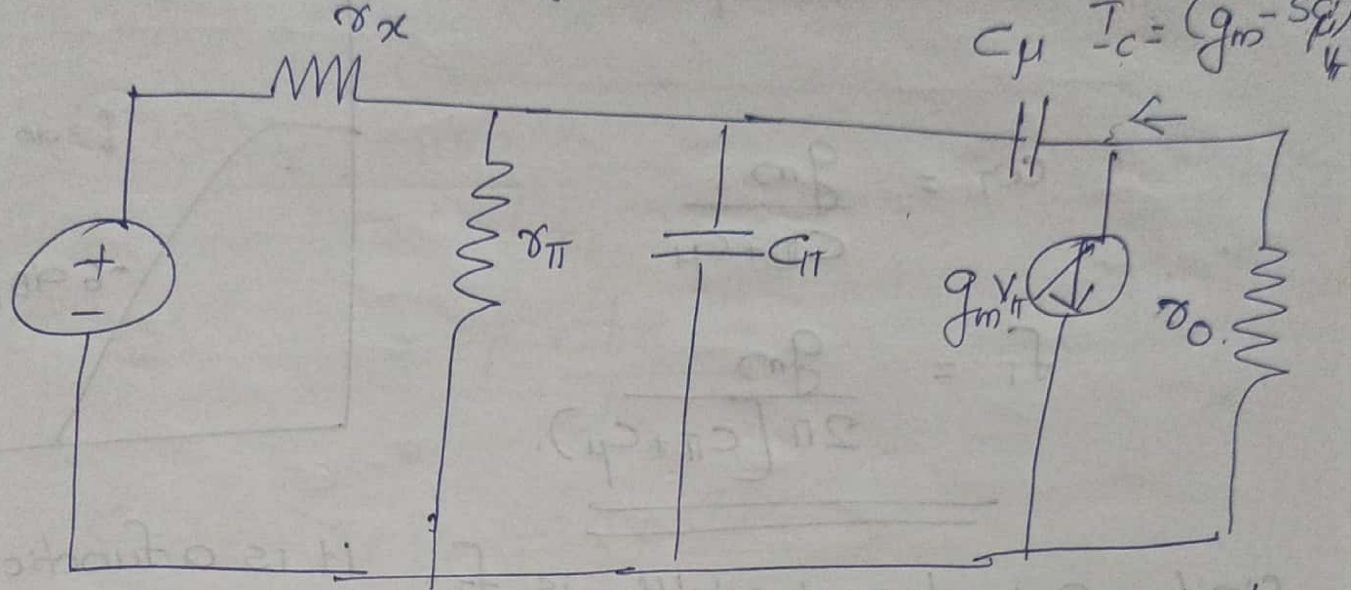
Cut off frequency



At node C, the short circuit collector current I_c as

$$I_c = (g_m - sC_\mu)V_\pi$$

$$V_\pi = I_b (r_\pi \,||\, C_\pi \,||\, C_\mu) = \frac{I_b}{\frac{1}{r_\pi} + sC_\pi + sC_\mu}$$

$$h_{fe} = \frac{I_c}{I_b} = \frac{(g_m - sC_\mu)}{\left[\frac{1}{r_\pi} + sC_\pi + sC_\mu\right)}$$

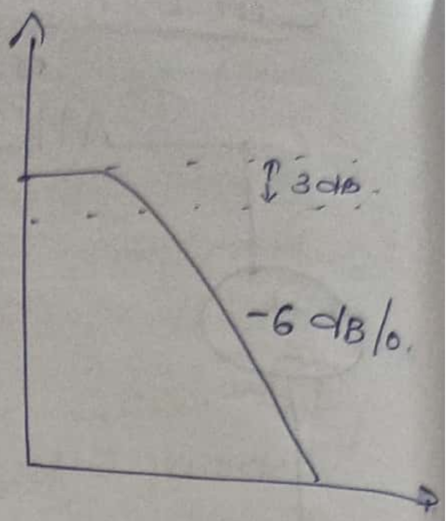
If $g_m >>> \omega C_\mu$

$$h_{fe} \cong \frac{I_c}{I_b}$$

$$h_{fe} \cong \frac{g_m r_\pi}{1 + s[C_\pi + C_\mu)r_\pi}$$

$$\omega_\beta = \frac{1}{[C_\pi + C_\mu)r_\pi}.$$

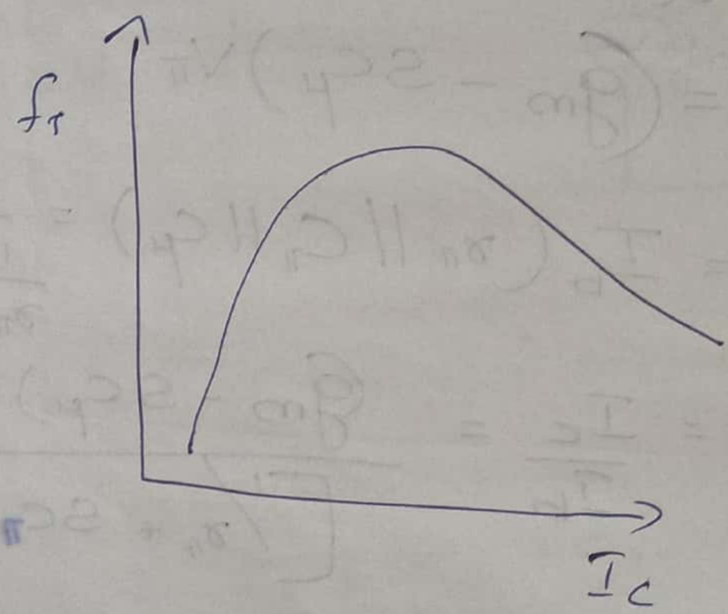
$$\omega_T = \beta_0 \, \omega_\beta .$$



$$\omega_T = \frac{g_m}{C_\pi + C_\mu}$$

$$f_T = \frac{g_m}{2\pi (C_\pi + C_\mu)}.$$

Unity gain band width is f_T. It is a function of I_c and V_{CE}.



Base Charging / Diffusion Capacitance C_{de} :-

when transistor is operating in active or Saturation modes, minority carrier charge is stored in base region.

$$Q_n = \frac{W^2}{2D_n} i_C = \tau_F i_C .$$

τ_f is the device constant $\tau_f = \dfrac{W^2}{2D_n}$.

$$C_{de} = \frac{dQ_n}{dV_{BE}}$$

$$= \tau_f \frac{di_c}{dV_{BE}}$$

$$C_{de} = \tau_f g_m = \tau_f \frac{I_C}{V_T}.$$

Base Emitter Junction Capacitance C_{je} :-

$$C_{je} = \frac{C_{jeo}}{\left(1 - \frac{V_{BE}}{V_{oe}}\right)^m}$$

C_{jeo} is the value of C_{je} at zero voltage

$$C_{je} \cong 2 C_{jeo}.$$

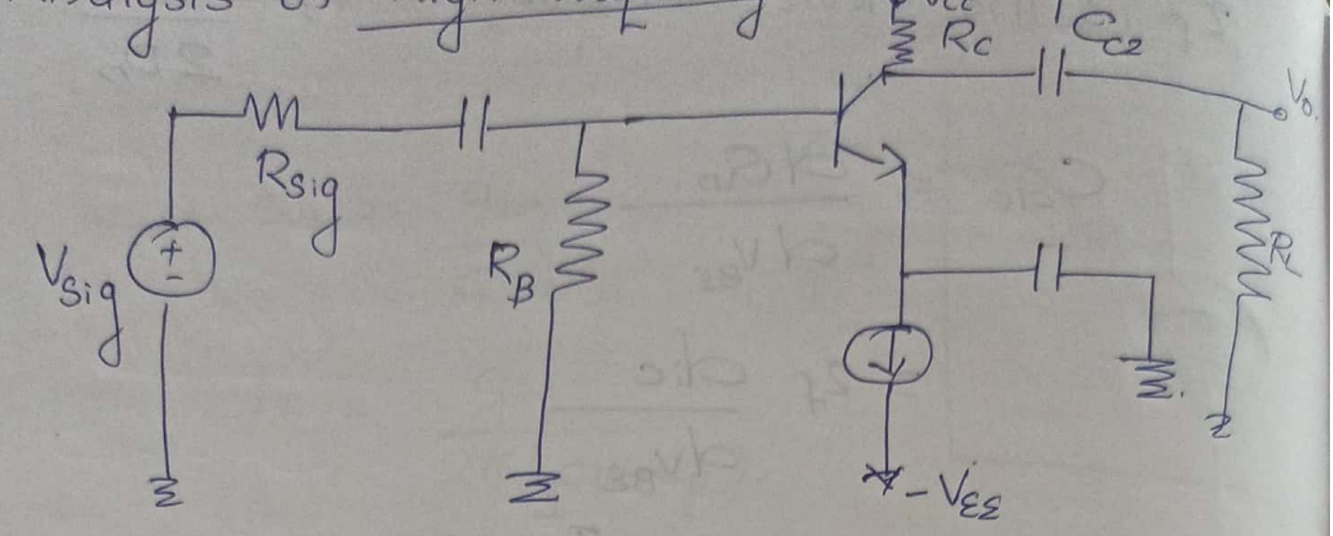
Collector-Base Junction Capacitance C_μ

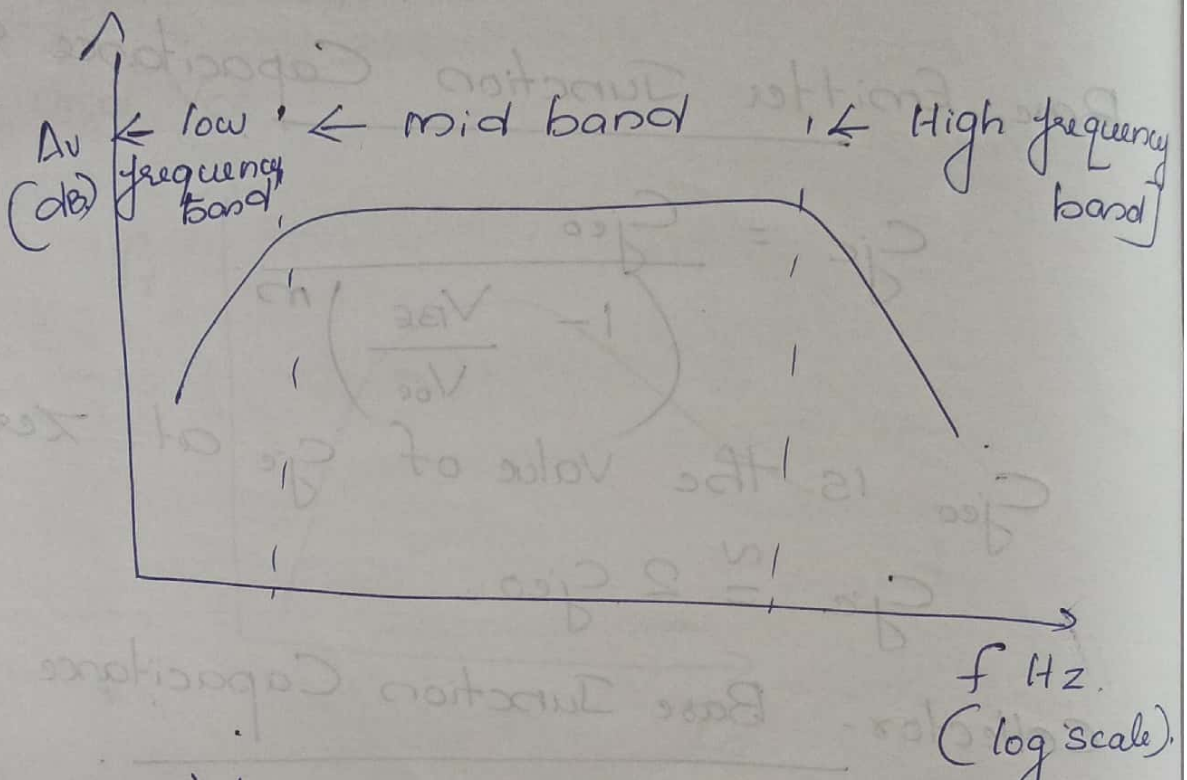
$$C_\mu = \frac{C_{\mu o}}{\left[1 + \frac{V_{CB}}{V_{oc}}\right]^m}$$

$C_{\mu o} \longrightarrow$ zero Voltage capacitance.

$m \longrightarrow$ grading Coiefficent.

Analysis of high frequency CE Amplifier:-



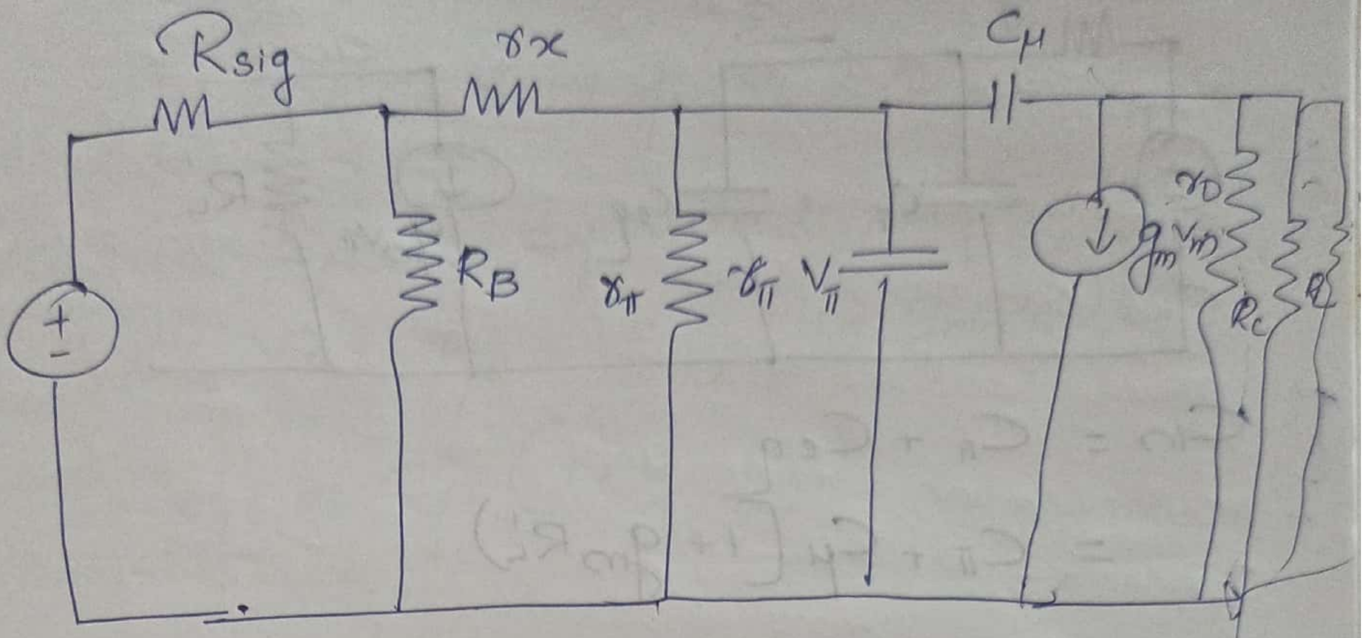


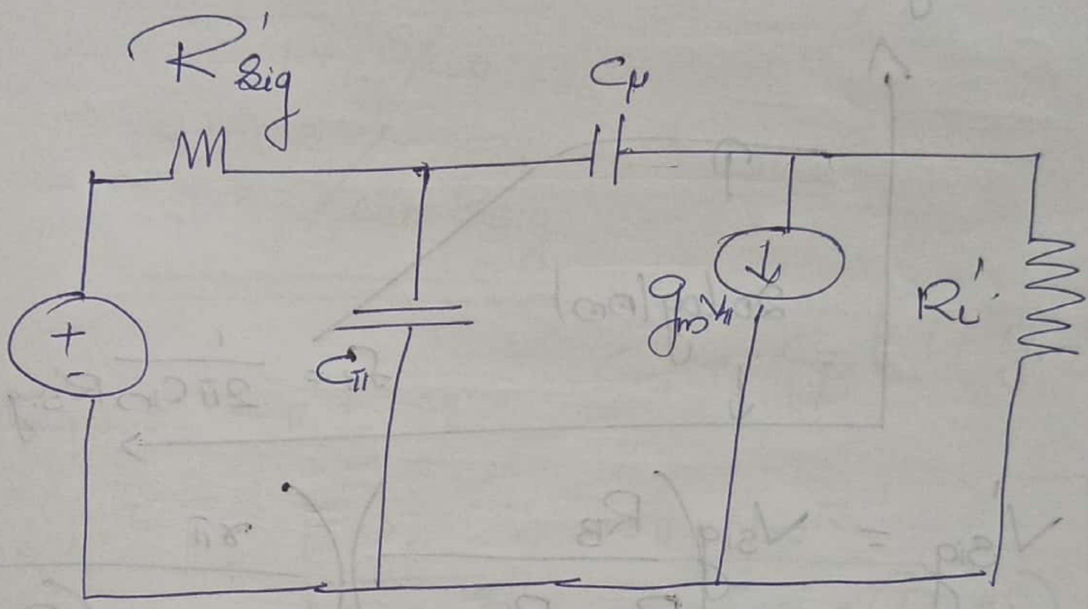
$$A_M = \frac{V_o}{V_{sig}} = -\frac{(R_B \| r_\pi)}{(R_B \| r_\pi) + R_{sig}} g_m (r_o \| R_C \| R_L)$$

Gain fall off in low frequency band

$$BW = f_H - f_L$$

$$BW \simeq f_H$$

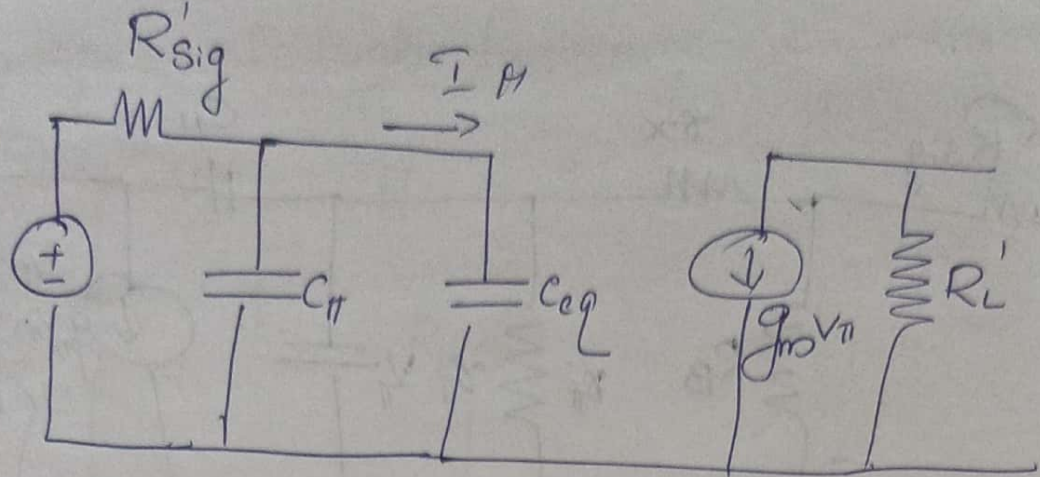




$$V'_{sig} = V_{sig}\left(\frac{R_B}{R_B + R_{sig}}\right)\left(\frac{r_\pi}{r_\pi + r_x + (R_{sig} \| R_B)}\right)$$

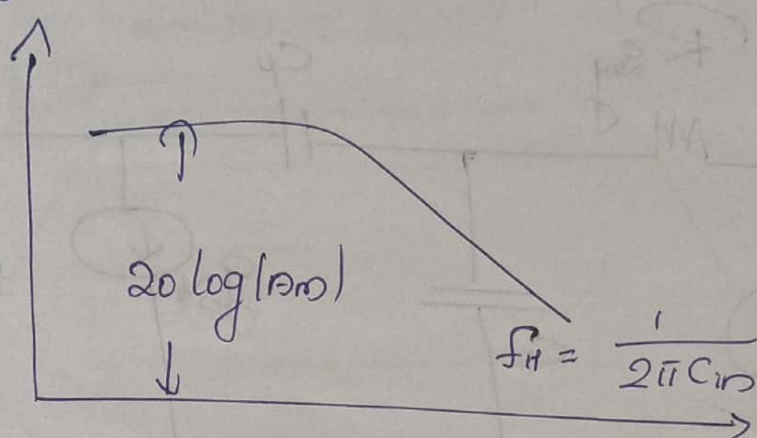
$$R'_{sig} = \frac{r_\pi}{r_x + \| \left[r_x + R_B / R_{sig} \right]}$$

$$R_L' = r_o \| R_C \| R_L$$



$$C_{in} = C_\pi + C_{eq}$$
$$= C_\pi + C_\mu\left[1 + g_m R_L'\right).$$

$$V_o = -g_m R_L' V_\pi.$$



$$f_H = \frac{1}{2\pi C_{in} R'_{sig}}$$

$$V'_{sig} = V_{sig}\left(\frac{R_B}{R_B + R_{sig}}\right)\left(\frac{r_\pi}{r_\pi + r_x + (R_{sig} \| R_B)}\right)$$

$$R'_{sig} = r_\pi \,\|\, \left[r_x + (R_B \,\|\, R_{sig})\right).$$

Load current is $(g_m V_\pi - I_\mu)$.

$$V_o = -g_m V_\pi R_L = -g_m R_L' V_\pi.$$

Current I_μ

$$I_\mu = s C_\mu (V_\pi - V_o)$$

$$= sC_\mu \left[V_\pi - (-g_m R_L' V_\pi) \right].$$

$$I_\mu = sC_\mu (1 + g_m R_L') V_\pi$$

Replace C_μ by equivalent Capacitance C_{eq}

$$s C_{eq} V_\pi = I_\mu = s C_\mu \left[1 + g_m R_L' \right) V_\pi$$

$$C_{eq} = C_\mu (1 + g_m R_L')$$

$$V_\pi = \frac{V_{sig}'}{1 + s/\omega_0}$$

$$\omega_0 = 1/C_{in} R_{sig}'$$

$$C_{in} = C_\pi + C_{eq} = C_\pi + C_\mu \left[1 + g_m R_L' \right)$$

$$\frac{V_o}{V_{sig}} = -\left(\frac{R_B}{R_B + R_{sig}} \; \frac{r_\pi \cdot g_m R_L'}{r_\pi + r_x + (R_{sig} \| R_B)} \right] \left(\frac{1}{1 + \frac{s}{\omega_0}} \right)$$

$$\frac{V_o}{V_{sig}} = \frac{A_m}{1 + \frac{s}{\omega_0}}$$

$$f_H = \frac{\omega_0}{2\pi} = \frac{1}{2\pi C_{in} R_{sig}'}$$

. Upper 3-dB frequency is determined by R'_{sig} and C_{in}. If $R_B \ggg R_{sig}$ and $r_x \lll R_{sig}$.

. Input capacitance C_{in} is dominated by C_{eq} which inturn is made large by multiplication effect that C_μ undergoes.

. Multiplication effect and C_μ undergoes conned connected to node by $(1 + g_m R'_L)$ to have larger capacitance is called Miller capacitance.

Low Frequency Response:-

To determine the low frequency gain of CE amplifier

$$V_\pi = V_{sig} \cdot \frac{(R_B \parallel r_\pi)}{(R_B \parallel r_\pi) + R_{sig} + \frac{1}{sC_{C1}}}$$

$$V_o = -g_m V_\pi (R_C \parallel R_L)$$

$$\frac{V_o}{V_{sig}} = \frac{(R_B \parallel r_\pi)\, g_m (R_C \parallel R_L)}{(R_B \parallel r_\pi) + R_{sig}} \left[\frac{s}{s + \frac{1}{C_{C1}\left[(R_B + r_\pi) + R_{sig}\right]}}\right]$$

$$\omega_{P1} = \frac{1}{C_{C1}\left[(R_B \parallel r_\pi) + R_{sig}\right]}$$

Reflecting r_e and C_E to base

$$I_b = V_{sig} \cdot \frac{R_B}{(R_B + R_{sig})} \frac{1}{\left[(R_B \| R_{sig}) + (1+\beta)\left(r_e + \frac{1}{sC_E}\right)\right]}$$

$$V_o = -\beta I_b (R_C \| R_L)$$

$$= \frac{-R_B}{(R_B + R_{sig})} \frac{\beta (R_C \| R_L)}{(R_B \| R_{sig}) + (1+\beta)\left(r_e + \frac{1}{sC_E}\right)} V_{sig}.$$

$$\frac{V_o}{V_{sig}} = \frac{-R_B \quad \beta (R_C \| R_L)}{(R_B + R_{sig})(R_B \| R_{sig}) + (1+\beta)\left(r_e + \frac{1}{sC_E}\right)}$$

$$\omega_{P3} = \frac{1}{C_{C2} (R_C + R_L)}$$

$$\frac{V_o}{V_{sig}} = -A_M \left[\left(\frac{S}{(S + \omega_{P1})}\right)\left(\frac{S}{S + \omega_{P2}}\right)\left(\frac{S}{S + \omega_{P3}}\right)\right]$$

Emitter follower At High frequencies:

$$G_s' V_s = \left[G_s' + g_{be}' + s(C_c + C_e) V_i' \right) - (g_{b'e} + sC_e) \Big] V_e$$

$$0 = -(g + sC_e) V_i' + \left[g + \frac{1}{R_L} + s(C_e + C_L) \right] V_e$$

$$G_s' = \frac{1}{R_s + r_{bb'}} \qquad g = g_m + g_{b'e}$$

If V_i' is eliminated, voltage gain

$$\frac{V_e}{V_s} = \frac{g_m V_{b'e}}{\frac{1}{R_L} + j\omega C_L} = \frac{g_m R_L (V_i' - V_e)}{1 + j\omega C_L R_L}$$

$$K = \frac{g_m R_L}{1 + g_m R_L} \cdot \frac{1}{1 - j(f/f_H)}$$

$$K_0 = \frac{g_m R_L}{1 + g_m R_L} \cong 1$$

$$f_H = \frac{1 + g_m R_L}{2\pi C_L R_L} \cong \frac{g_m}{2\pi C_L}$$

$$= \frac{f_T C_e}{C_L}$$

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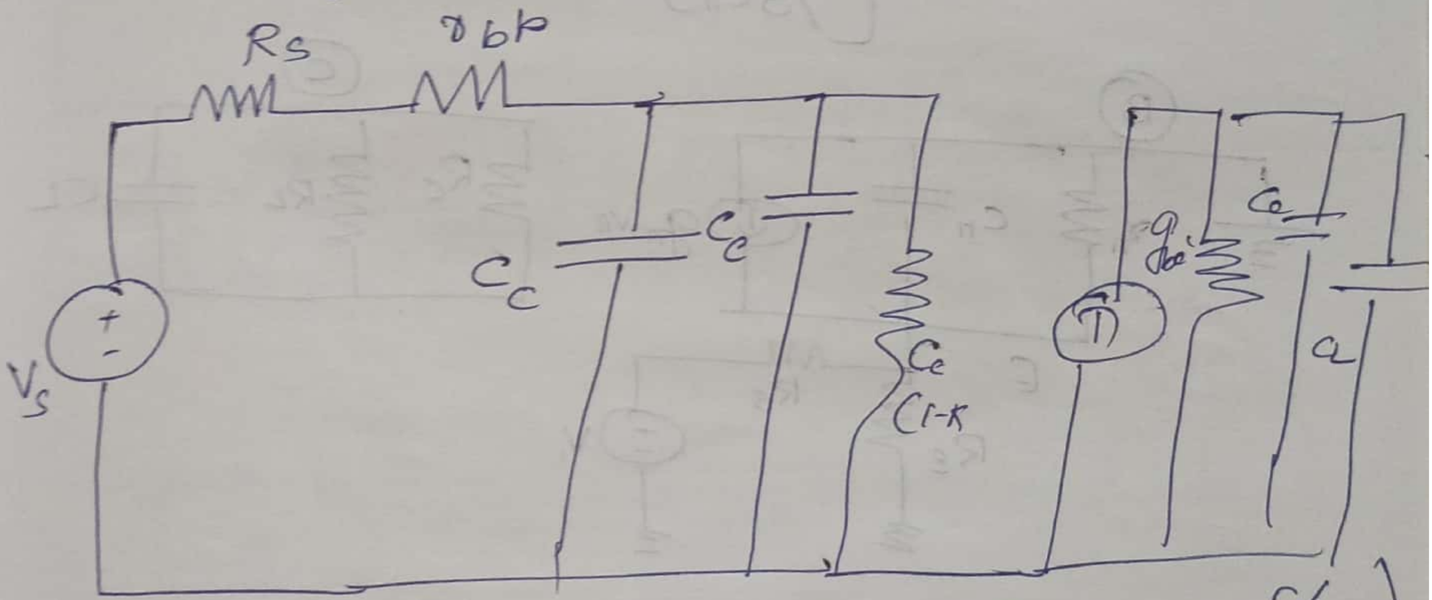
$$f_T = \frac{g_m + g_{b'e}}{2\pi (C_c + C_e)}$$

Input Admittance :-

$$Y_i' = \frac{I_b}{V_i'} = j\omega \left[C_c + (1-K) C_e \right] + [1-K] g_{b'e}$$

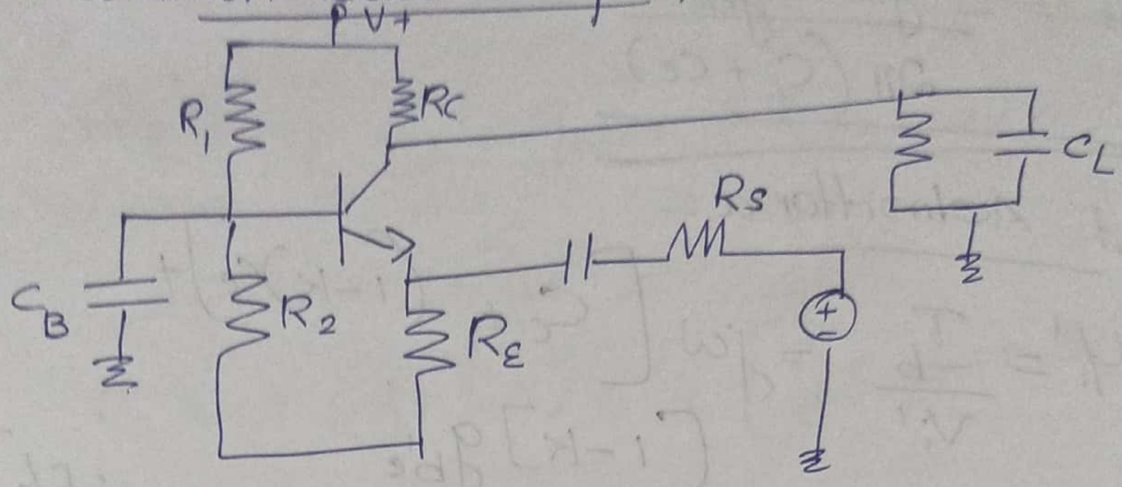
$$Y_i' = j 2\pi f C_c + (g_{b'e} + j 2\pi f C_e) \left(\frac{1 - K_0 + j f/f_H}{1 + j f/f_H} \right)$$



$$Y_i' = j 2\pi f C_e + (g_{b'e} + j 2\pi f C_e) \left(\frac{1 - K_0 + j f/f_H}{1 + j f/f_H} \right)$$

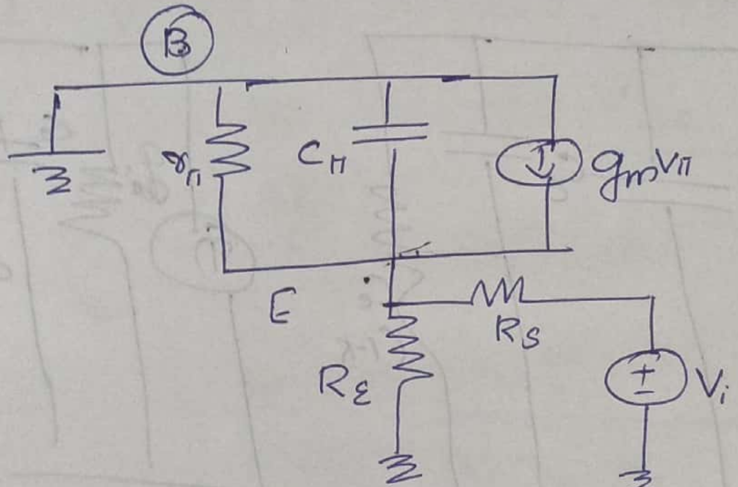
$$Y_i' = j 2\pi f \left[C_c + (1 - K_0) C_e \right] + g_{be} (1 - K_0) + j g_{b'e} \frac{f}{f_H} - \frac{2\pi f^2 C_e}{f_H}$$

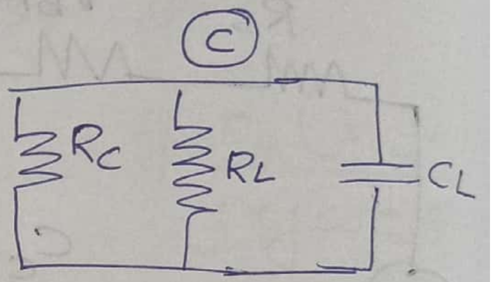
Common Base Amplifier :-

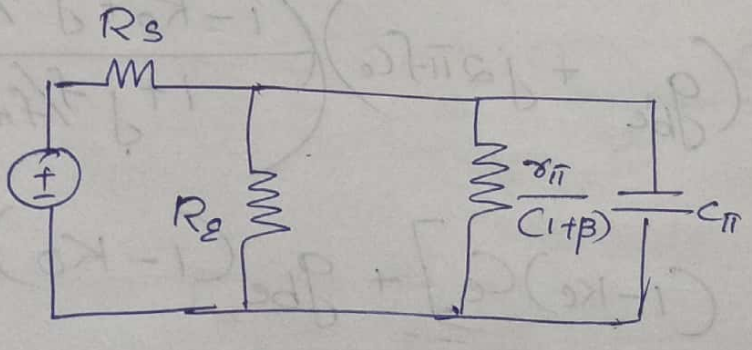


writing KCL

$$I_e + g_m V_\pi + \frac{V_\pi}{\left[1/sC_\pi\right]} + \frac{V_\pi}{r_\pi} = 0$$







$$V_\pi = -V_e$$

$$\frac{I_e}{V_e} = \frac{1}{Z_i} = \frac{1}{r_\pi} + g_m + sC_\pi$$

$$\frac{1}{Z_i} = \frac{1}{r_\pi} + g_m + sC_\pi$$

$$\frac{I_e}{V_e} = \frac{1}{Z_i}$$

$$\frac{1}{Z_i} = \frac{1 + r_\pi g_m}{r_\pi} + sC_\pi$$

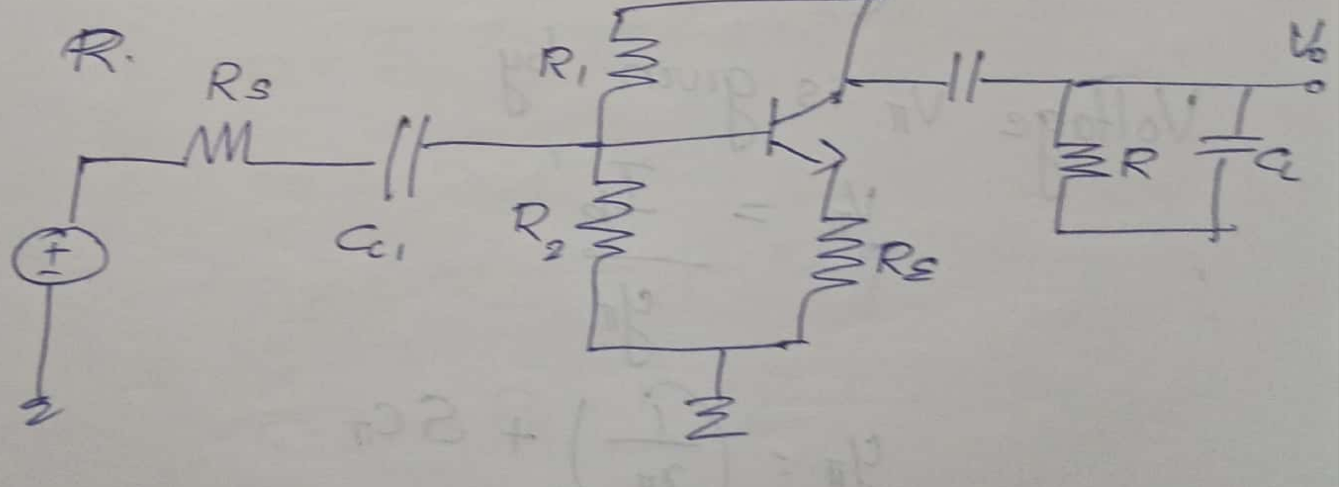
$$\frac{1}{Z_i} = \frac{(1+\beta)}{r_\pi} + sC_\pi$$

$$\boxed{f_{H\pi} = \frac{1}{2\pi \tau_{p\pi}}}$$

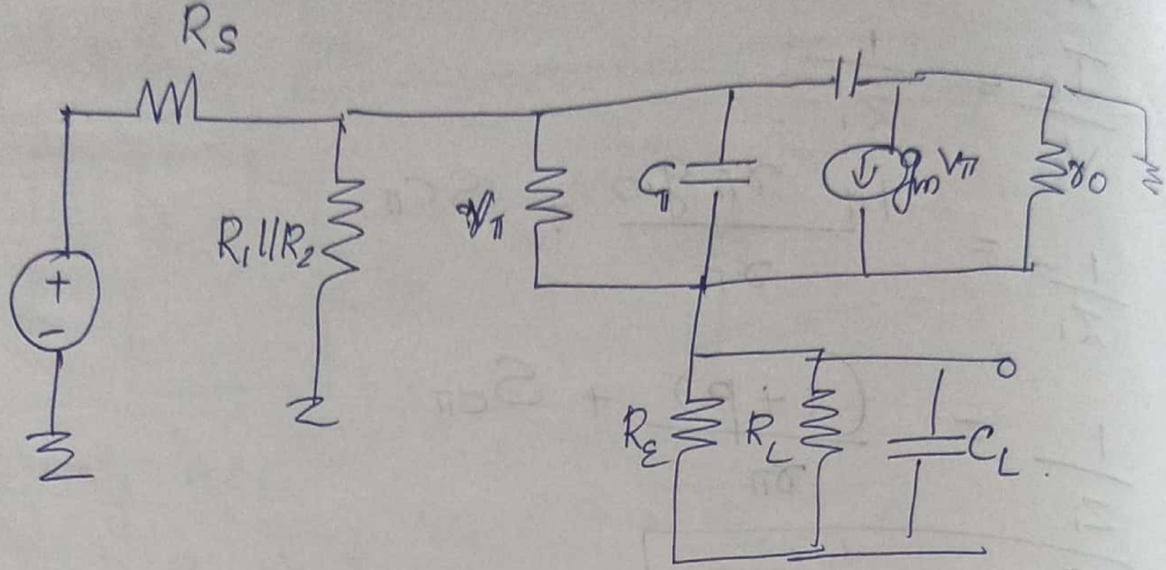
$$\tau_{p\pi} = \left(\left(\frac{r_\pi}{(1+\beta)}\right) \parallel R_E \parallel R_s\right) \cdot C_\pi$$

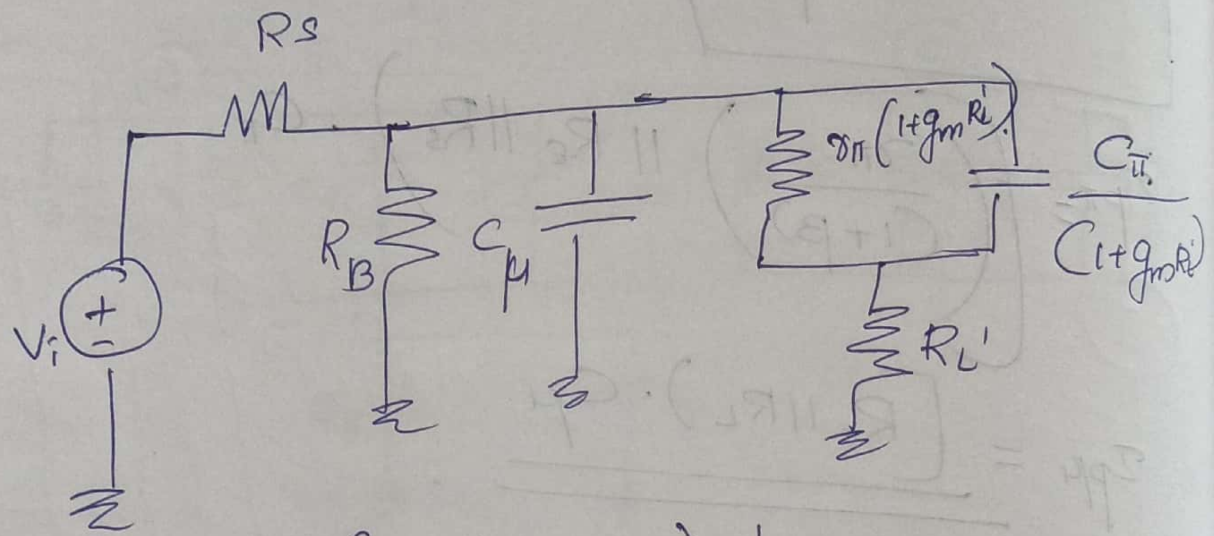
$$\tau_{p\mu} = \underline{\left[R_c \parallel R_L\right) \cdot C_\mu}.$$

Emitter Follower Circuits:-



$R_L' = R_E \parallel R_L \parallel r_o$





$$V_o = \left(I_b' + g_m V_\pi\right) R_L'$$

Voltage V_π is given by

$$V_\pi = \frac{I_b'}{y_\pi}$$

$$y_\pi = \left(\frac{1}{r_\pi}\right) + S C_\pi$$

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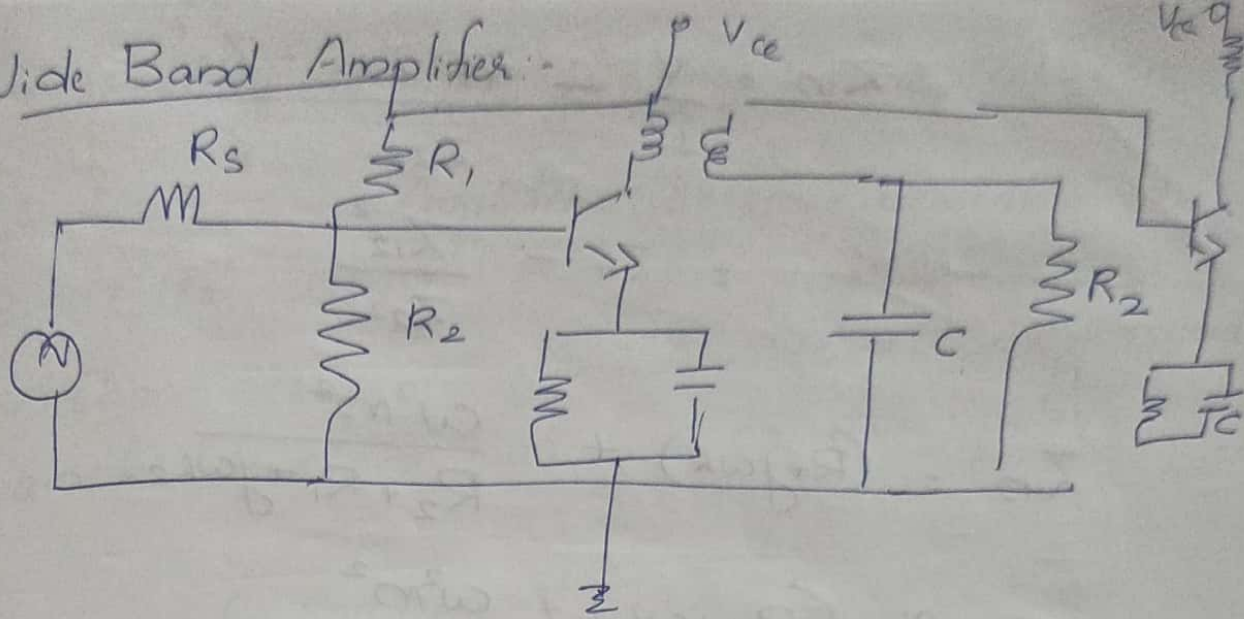
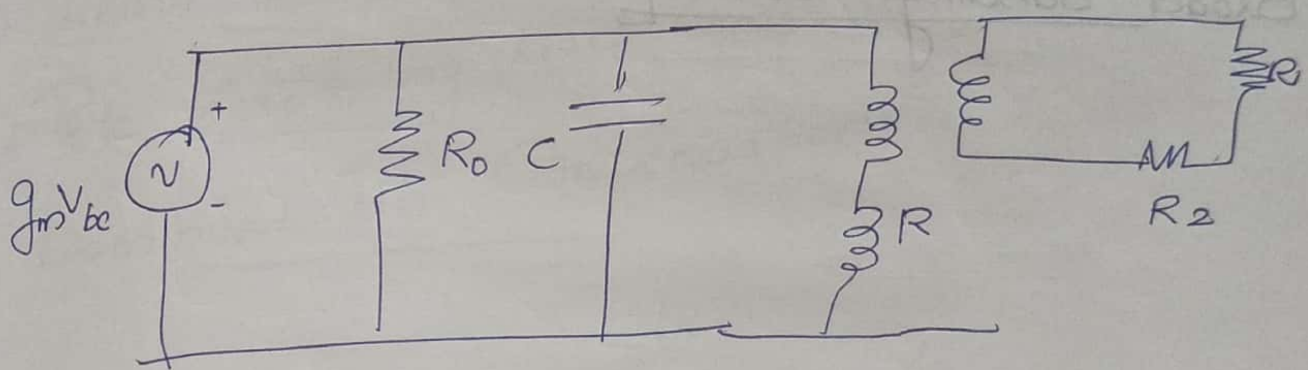
Wide Band Amplifier :-



Equivalent open Circuit



Applying Kirchoff law

$$V = I_1 Z_{11} + I_2 \cdot Z_{12}$$

$$0 = I_1 \cdot Z_{21} + I_2 \cdot Z_{22}$$

$$Z_{11} = R + j\omega L$$

$$Z_{12} = Z_{21} = j\omega M$$

$$Z_{22} = R_2 + R_i + j\omega L_2$$

$$I_1 = \frac{V \cdot Z_{22}}{Z_{11} Z_{22} - Z_{12}^2}$$

$$Z_{in} = \frac{V}{I_1} = \frac{Z_{11} Z_{22} - Z_{12}^2}{Z_{22}}$$

$$= Z_{11} - \frac{Z_{12}^2}{Z_{22}}$$

$$Z_{in} = (R + j\omega L) + \frac{\omega^2 M^2}{R_2 + R_1 + j\omega L_2}$$

$$Z_{in} \cong (R + j\omega L) + \frac{\omega^2 M^2}{R_1}$$

Broad Banding Techniques:-

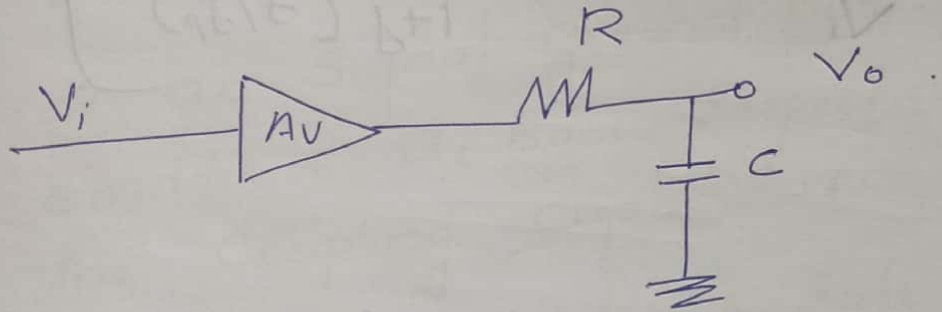
Low frequency & High frequency Compensation:-

Amplifier becomes unstable if $A\beta = 1 \angle 180°$. Using resistive feedback, this condition occurs if the A network or forward transfer function has two or more poles.

The methods of Compensation:-

1) Dominant pole or lag compensation.
2) Lead Compensation.
3) Pole Zero / Lag Lead Compensation.

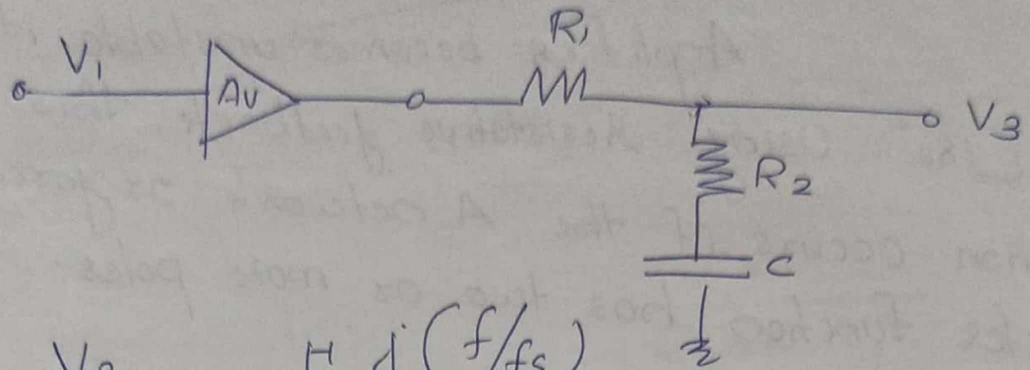
Dominant Pole Compensation:-



$$A_v' = \frac{1}{1+j(f/f_0)} \cdot A_v$$

Loop Gain is Zero dB.

Pole - Zero Compensation :-

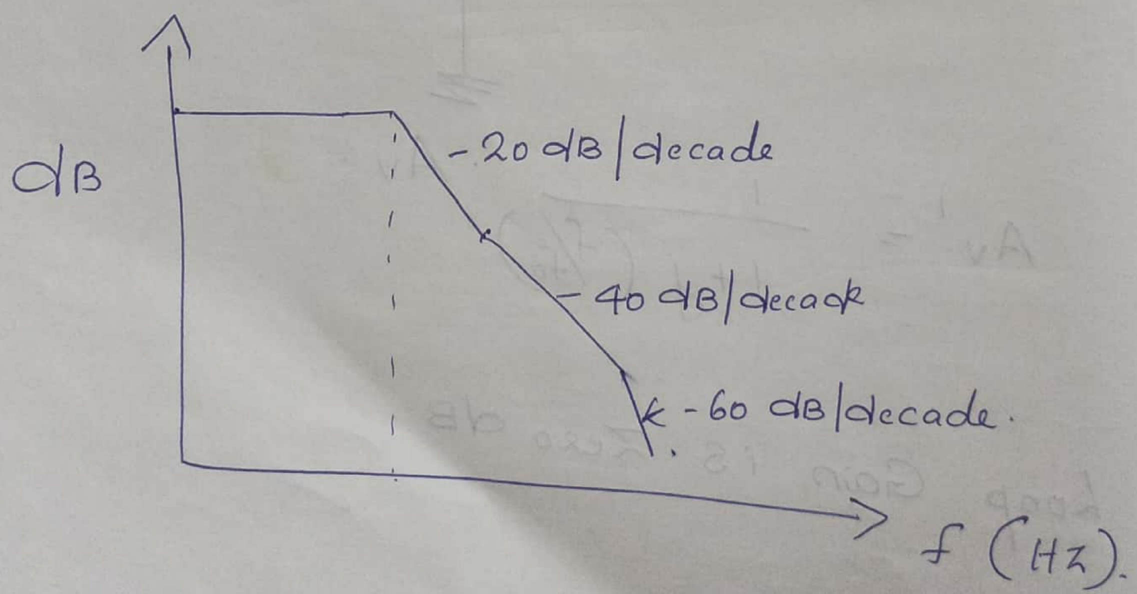


$$\frac{V_2}{V_1} = \frac{H\, j(f/f_s)}{1 + j(f/f_p)}.$$

$$f_z = \frac{1}{2\pi R_2 C}.$$

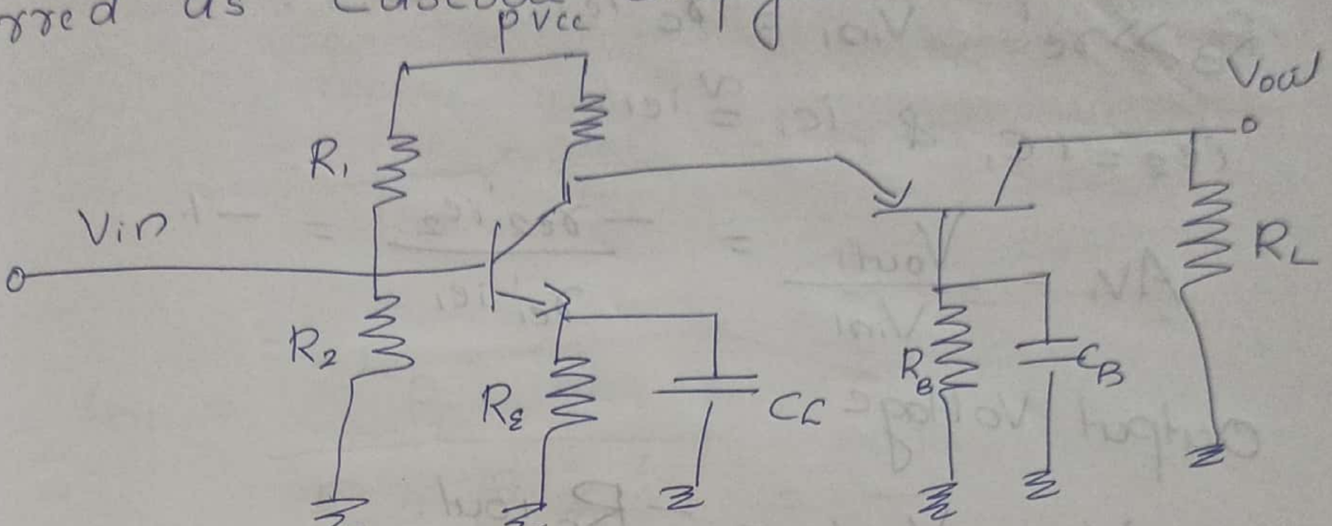
$$f_p = \frac{2}{2\pi (R_1 + R_2) C}.$$

$$A_v' = \frac{V_s}{V_i} = A_v \left[\frac{1 + j(f/f_2)}{1 + j(f/f_p)} \right]$$



Cascode Amplifier:-

The CE-CB Configuration generally referred as cascode amplifier.



DC Analysis:-

R_1, R_2 and R_3 form a bias network for a transistor Q_1 and Q_2: C_{S1} and C_{S2} Provide ac signal ground paths from the Q_1 emitter & Q_2 base, respectievely. C_{in} is the Coupling capacitor

Applying voltage divider rule

$$V_{B1} = V_{CC} \times \frac{R_1}{(R_1 + R_2 + R_3)}$$

$$V_{E1} = V_{B1} - V_{BE1} = \frac{V_{CC} \cdot R_1}{R_1 + R_2 + R_3} - V_{BE1}$$

$$I_{E1} = \frac{V_{E1}}{R_E} = \frac{\frac{V_{CC} R_1}{[R_1 + R_2 + R_3]} - V_{BE1}}{R_E}$$

Ac Analysis :-

Voltage Gain :-

$R_B \gg r_e'$ $\quad V_{in1} = r_e' i_{e1}$ $\quad V_{out} = -r_{e2}' i_{e2}$

$i_{e2} = i_{C1}$ & $i_{C1} \simeq i_{e1}$

$$AV_1 = \frac{V_{out1}}{V_{in1}} = \frac{-r_{e2}' i_{e2}}{r_{e1}' i_{e1}} = -1.$$

Output Voltage

$$V_{out} = V_{out2} = -R_c\, i_{out}.$$

$$I_{out} = i_{C2} = i_{e2} \quad ; \quad i_{e2} = -\frac{V_{out1}}{r_{e2}'}$$

$$V_{out} = -R_c \times -\frac{V_{out1}}{r_{e2}'}$$

$$= \frac{R_c}{r_{e2}'}$$

$$AV_2 = V_{out}$$

$$A_V = \frac{V_{out}}{V_{in1}} = A_{V1} \times AV_2$$

$$= -1 \times \frac{R_c}{r_{e2}'}$$

$$= \frac{-R_c}{r_{e2}'}$$

Current Gain:-

$$A_i = \frac{i_{out}}{i_{in}} = \frac{i_{b1}}{i_{n1}} \times \frac{i_{e1}}{i_{b1}} \times \frac{i_{e2}}{i_{e1}} \times \frac{i_{c2}}{i_{e2}}$$

$$= \frac{i_{b1}}{i_{in}} \times \frac{i_{e1}}{i_{b1}}$$

$$i_{b1} = \frac{R_B \cdot i_{n1}}{R_B + \beta_{ac} r_{e1}'}$$

$$\boxed{A_i = \frac{\beta_{ac} R_B}{R_B + \beta_{ac} r_{e1}'}}$$

Input Resistance:-

$$V_{in1} = i_{e1} r_{e1}' = \beta_{ac} r_{e1}' i_{b1}.$$

$$V_{in} = \beta_{ac} r_{e1}' \times \frac{R_B\, i_{n1}}{R_B + \beta_{ac} r_{e1}'}.$$

$$R_{in} = \frac{V_{in}}{i_{n}} = \frac{\beta_{ac} r_{e1}' R_B}{R_B + \beta_{ac} r_e'}$$

Verified
20/9/16

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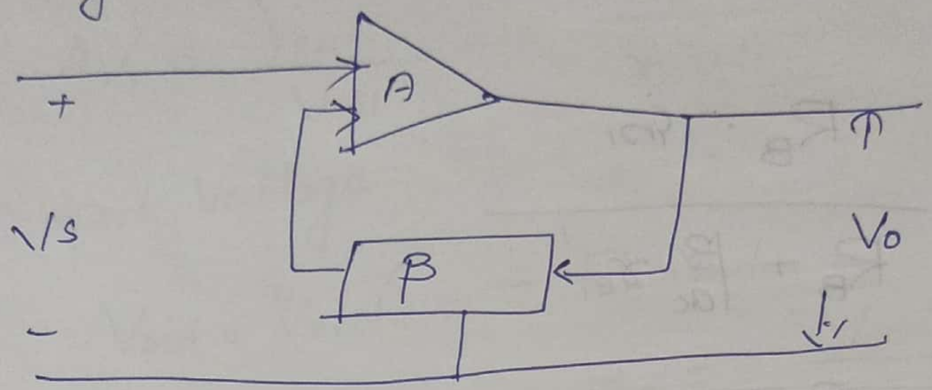
Module IV

Feedback Amplifiers :-

The process of combining a fraction of output energy back to input is called feedback. When feedback voltage increase input, it is known as positive feedback, if voltage decreases, it is known as negative feedback.



$$V_{in} = V_s + V_f$$

$$V_{in} = V_s - V_f$$

Classification of Amplifiers :.

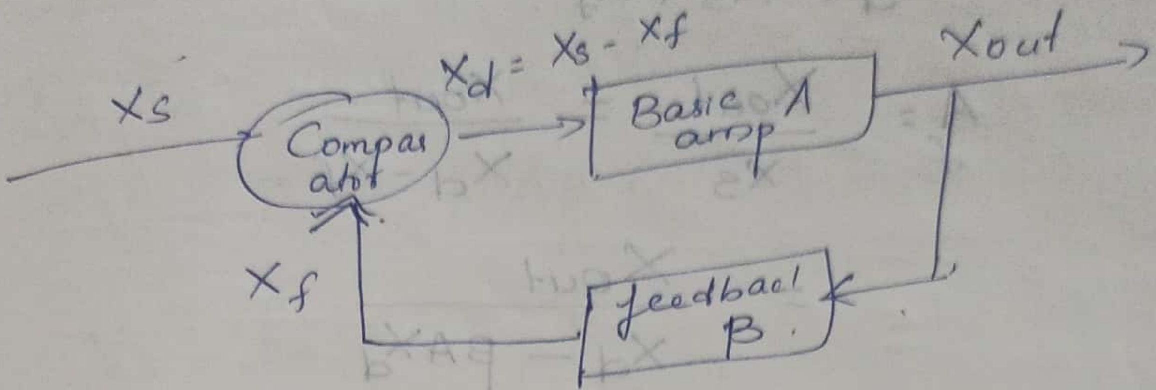
Gain of basic amplifier is unstable because of

1) change in parameter
2) Ageing
3) Distortion
4) More noise
5) Less Bandwidth.

Amplifiers can be classified as

. Voltage Am

Effect of feedback on Gain:-



For -ve feedback

$$X_d = X_s - X_f.$$

$$A = \cancel{\frac{X_{out}}{X_s}} = \frac{A X_d}{X_s} = \frac{A X_d}{X_d + X_f}.$$

$$= \frac{A}{1 + \frac{X_f}{X_d}}$$

$$X_s = X_d + X_f.$$

$$= X_d + \beta X_{out}.$$

$$= X_d + A\beta X_d.$$

$$X_s = X_d [1 + A\beta].$$

$$\frac{X_d}{X_s} = \frac{1}{[1 + A\beta]}.$$

$$X_d = X_s - X_f = X_{in}$$

$$\cancel{X_s = X_d =}$$

$$A_f = \frac{X_{out}}{X_s} = \frac{X_{out}}{X_{in} + X_f}.$$

$$= \frac{A X_{in}}{X_{in} + \beta A X_{in}}.$$

$$= \frac{A \cancel{X_{in}}}{\cancel{X_{in}} [1 + A\beta]}$$

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For +Ve feedback

$$x_d = x_s + x_f$$

$$A_f = \frac{x_{out}}{x_s} = \frac{x_{out}}{x_d - x_f}$$

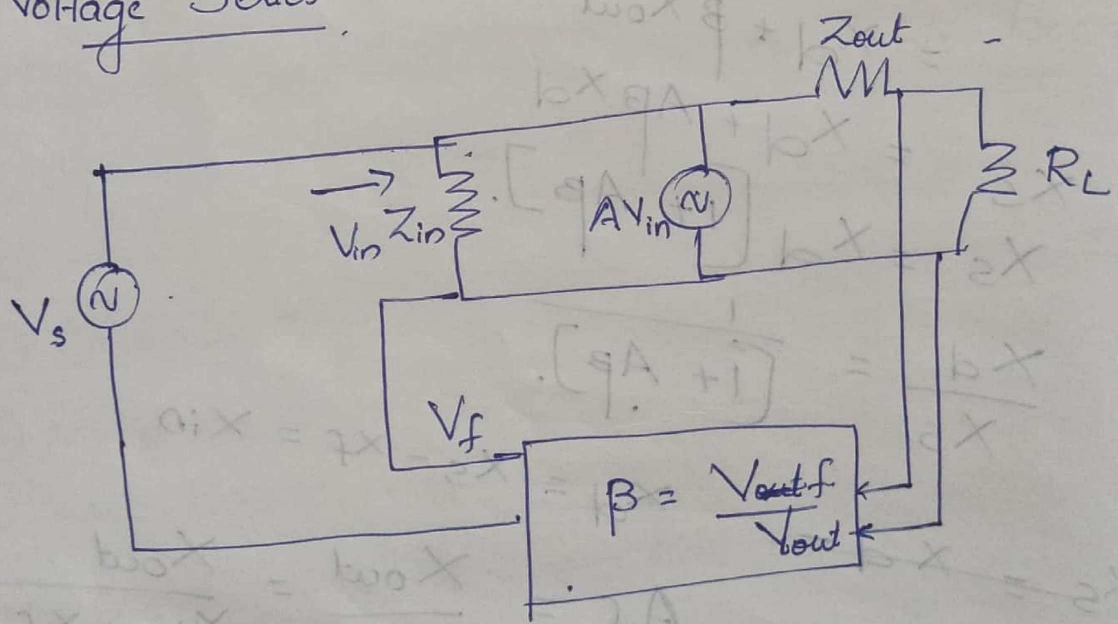
$$= \frac{x_{out}}{x_d - \beta A x_d}$$

$$= \frac{x_{out}}{x_d[1 - A\beta]}$$

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

Effect of feedback topologies on Input Impedance:

Voltage Series:-



$$V_{in} = V_s - V_f$$

$$Z_{in} = \frac{V_{in}}{I_{in}} = \frac{V_s - V_f}{I_{in}} = \frac{V_s - \beta V_{out}}{V_{in} I_{in}}$$

$$I_{in} Z_{in} = V_s - \beta V_{out}$$

$$I_{in} Z_{in} = V_s - \beta A V_{in}$$

$$V_s = I_{in} Z_{in} + A\beta V_{in}$$

$$V_s = I_{in} Z_{in} + A\beta I_{in} Z_{in}$$

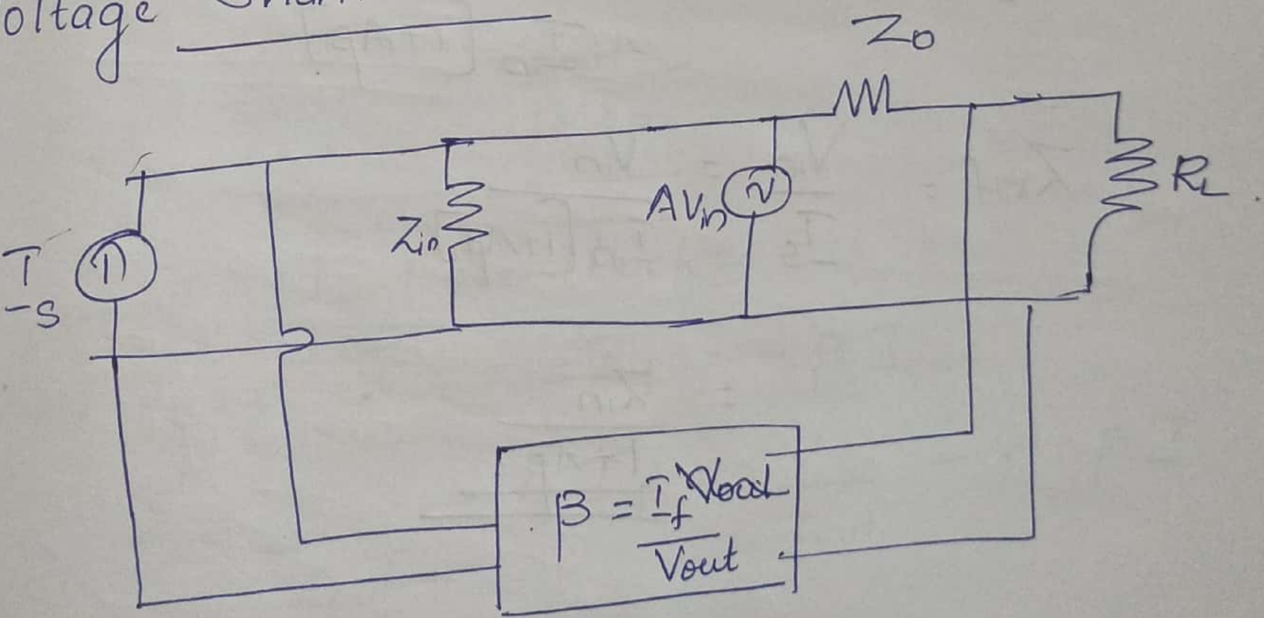
$$V_s = I_{in} Z_{in} [1 + A\beta]$$

$$\frac{V_s}{I_{in}} = Z_{in} [1 + A\beta]$$

$$Z_{inf} = Z_{in} [1 + A\beta]$$

This will be same for ~~no~~ current series also.

Voltage Shunt Feedback :-



$$I_{in} = I_s - I_f.$$

$$= \cancel{I_s - \beta V_{out}}$$

$$= \cancel{I_s - \beta A}.$$

$$Z_{inf} = \frac{V_{in}}{I_s} = \frac{V_{in}}{I_{in} + I_f} = \frac{V_{in}/I_{in}}{\frac{I_{in}}{I_{in}} + \frac{I_f}{I_{in}}}$$

$$= \frac{Z_{in}}{1 + \beta \frac{V_{out}}{I_{in}}}$$

$$= \underline{\underline{\frac{Z_{in}}{1 + A\beta}}}.$$

Current Shunt Feedback:

$$I_s = I_{in} + I_f = I_{in} + A\beta I_{in}$$

$$= I_{in}[1 + A\beta]$$

$$Z_{inf} = \frac{V_{in}}{I_s} = \frac{V_{in}}{I_{in}[1+A\beta]}$$

$$= \underline{\frac{Z_{in}}{1+A\beta}}$$

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Effect of negative feedback on output Impedance

It is advantageous to an amplifier, so is low output impedance with lower o/p impedance, the amplifier is suited to drive a low impedance load.

Voltage Series feedback:

The input terminal is short circuited so that $-V_f$ is now the only input impedance to the amplifier

$$V_{out} = I_{out} Z_{out} + A V_{in}$$

$$= I_{out} Z_{out} - A V_f$$

$$= I_{out} Z_{out} - A\beta V_{out}$$

$$V_{out} [1 + A\beta] = I_{out} Z_{out}$$

$$Z_{outf} = \frac{V_{out}}{I_{out}} = \frac{Z_{out}}{1 + A\beta}$$

Current - Shunt feedback:

With $I_s = 0$ $\quad I_{in} = -I_f = -\beta I_{out}$

$$I = \frac{V}{Z_{out}} - A I_f = \frac{V}{Z_{out}} - A \times \beta I$$

$$I [1 + A\beta] = \frac{V}{Z_{out}}$$

$$Z_{outf} = \frac{V}{I} = Z_{out} [1 + A\beta]$$

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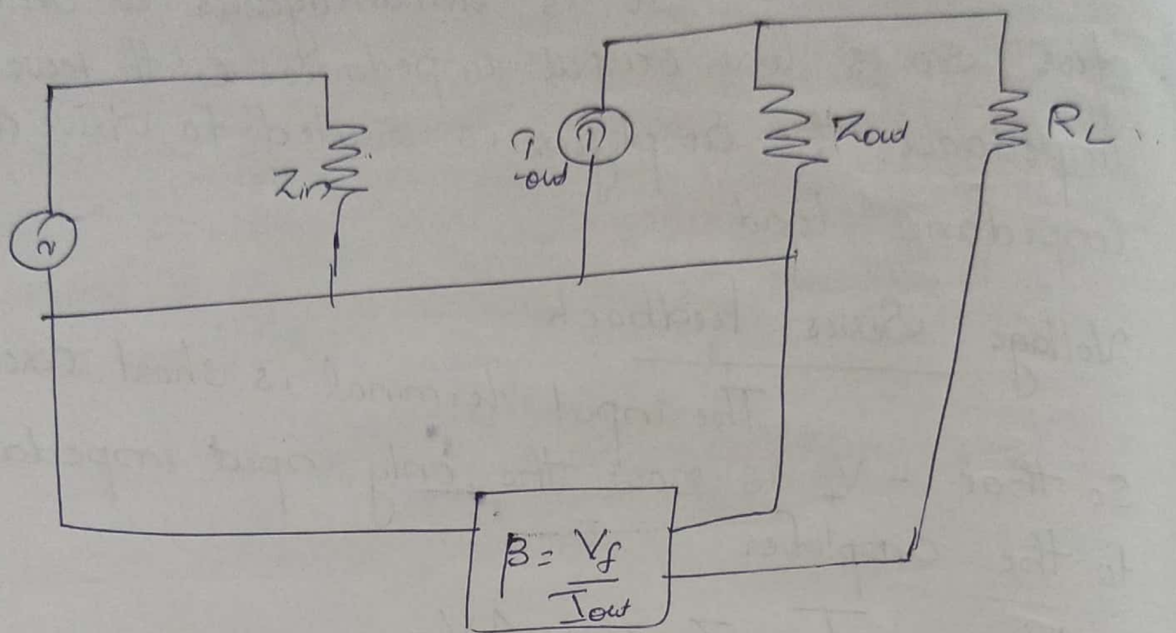
Current Series feedback:-



$$I = \frac{V}{Z_{out}} - AV_{in}$$

$$= \frac{V}{Z_{out}} - AV_f = \frac{V}{Z_{out}} - A\beta I_{out}$$

$$Z_{out} I [1 + A\beta] = V$$

$$Z_{outf} = \frac{V}{I} = Z_{out}[1 + A\beta]$$

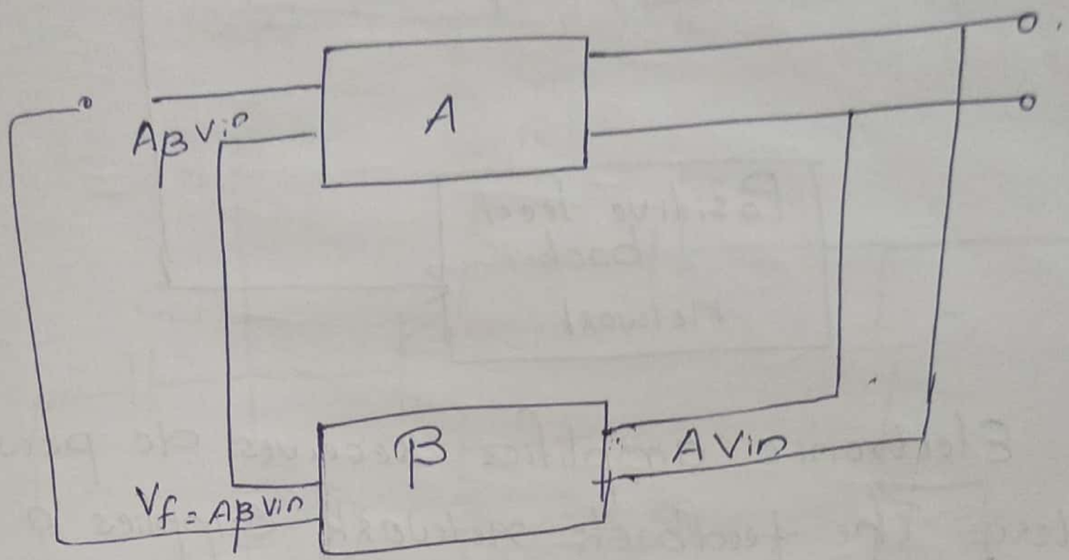
Oscillators:-

Oscillator is the basic element of all ac Signal Sources and generates Sinusoidal Signals of known frequency and amplitude.

· Portable & Cheap in cost.

Operation of Oscillators:-

The use of positive feedback that results in a feedback amplifier having closed loop gain A_f exceeding unity and satisfies the phase condition.



Barkhausen Criteria

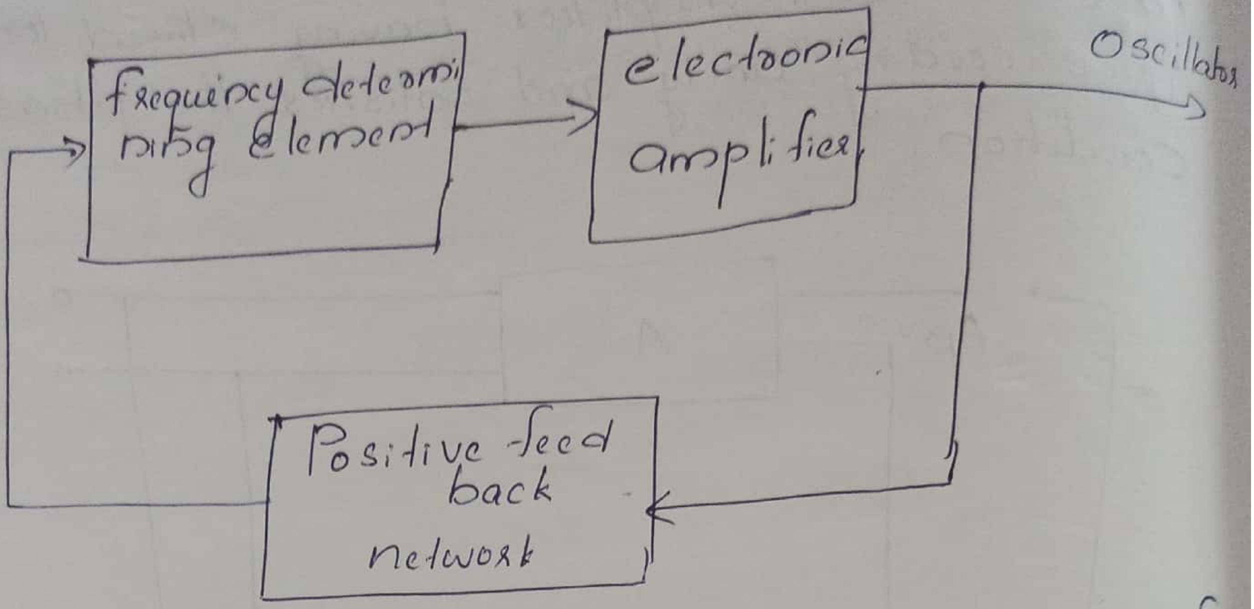
$$|A\beta| = 1.$$

$$A\beta(j\omega) = 1 \angle \pm 360^\circ = 1 + j0.$$

Essentials of an oscillatory Circuit

- oscillatory circuit / frequency determining element.
- Amplifier.
- Positive feedback Network.

Block Diagram:-



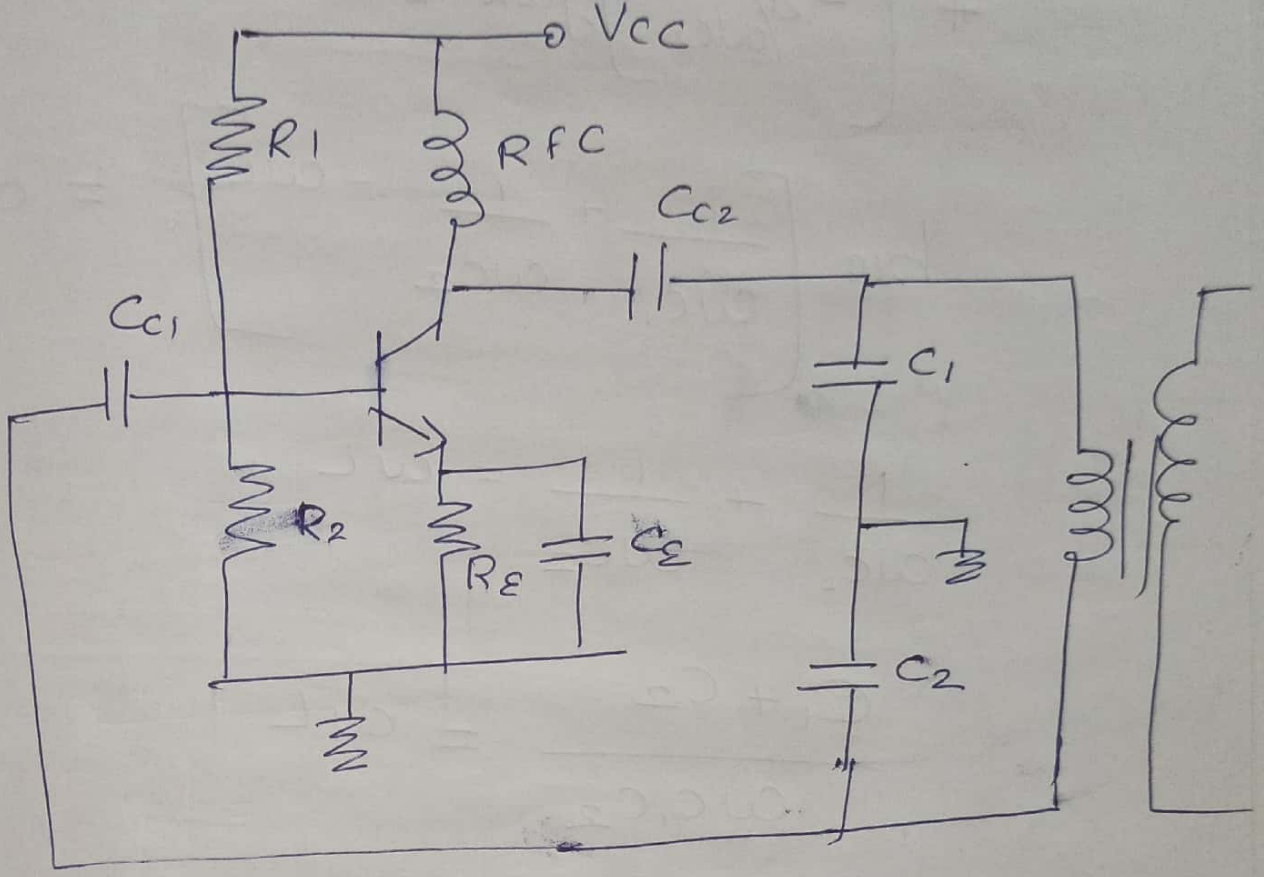
Electronic amplifier receives dc power from battery. The feedback network supplies a part of output power to the frequency determining element in correct phase.

Types:-

Wien Bridge Oscillator	1Hz - 1MHz
Phase Shift Oscillator	1 Hz - 10 MHz
Hartley oscillator	10 KHz - 100 MHz.
Colpitt's oscillator	10KHz - 100MHz.
Negative Resistance oscillator	> 100 MHz
Crystal Oscillator	Fixed frequency.

Colpitt's Oscillator:-

is a superb circuit and is widely used in commercial signal generators upto 100 MHz



$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC_1} + \frac{1}{LC_2}}.$$

oscillation across C_2 are applied to base emitter junction.

Frequency:-

$$Z_1 = \frac{1}{j\omega C_1} = \frac{-j}{\omega C_1}.$$

$$Z_2 = \frac{1}{j\omega C_2} = -j/\omega C_2$$

$Z_3 = j\omega L$

$$h_{ie}\left[\frac{-j}{\omega C_1} - \frac{j}{\omega C_2} + j\omega L\right] + \left[\frac{-j}{\omega C_1} \; \frac{-j}{\omega C_2}\right](1+h_{fe})$$

$$+ \left[-j/\omega C_2\right] j\omega L = 0.$$

$$h_{ie}\left[\frac{1}{\omega C_1} + \frac{1}{\omega C_2} - \omega L\right] = 0.$$

$$\frac{1}{\omega C_1} + \frac{1}{\omega C_2} = \omega L.$$

$$\frac{C_1 + C_2}{\omega C_1 C_2} = \omega L$$

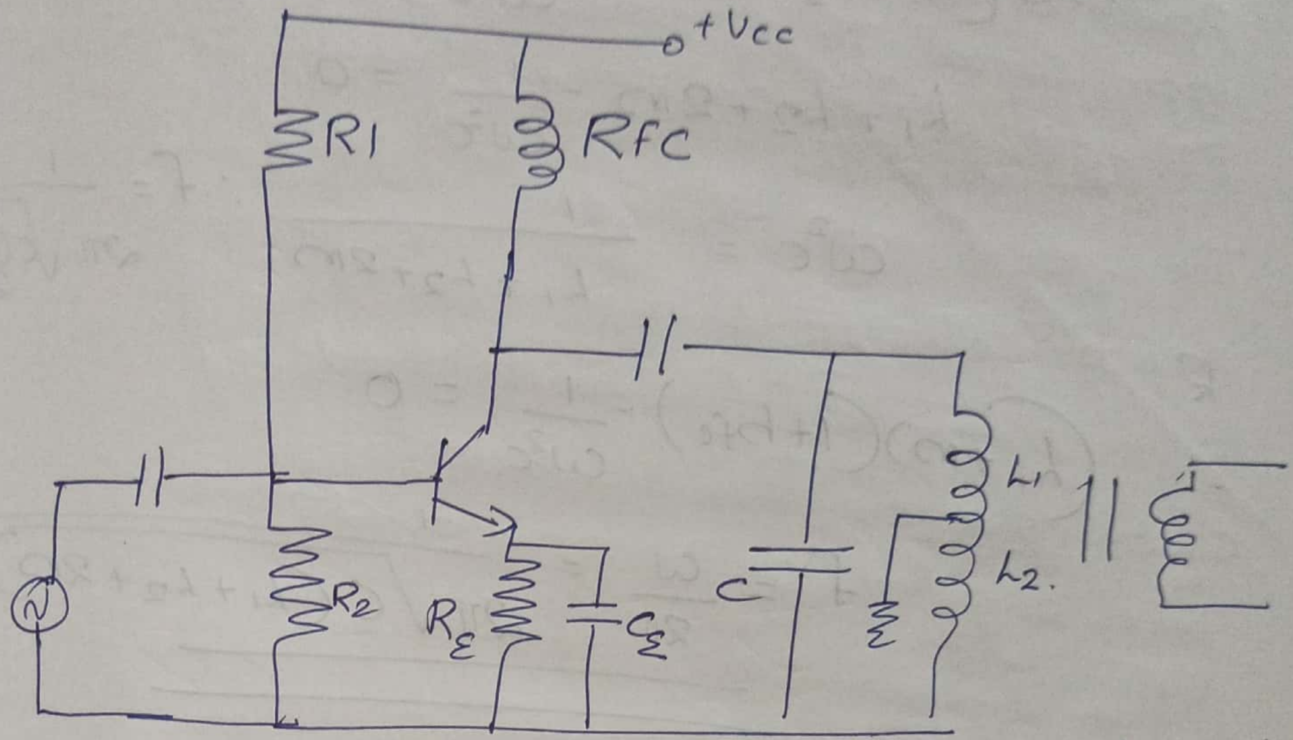
$$\omega^2 = \frac{C_1 + C_2}{L C_1 C_2}.$$

$$\omega = \sqrt{\frac{C_1 + C_2}{L C_1 C_2}}.$$

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC_1} + \frac{1}{LC_2}}$$

Hartley Oscillator:-

Hartley oscillator is a local oscillator in radio receivers.



Considering the fact that there are L_1 and L_2 wound on same core

Effective inductance $L = L_1 + L_2 + 2M$.

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

Frequency of oscillation

General equation is

$$h_{ie}[Z_1+Z_2+Z_3] + Z_1Z_2[1+h_{fe}) + Z_2Z_3 = 0$$

Here $Z_1 = j\omega L_1 + j\omega M$. $Z_2 = j\omega L_2 + j\omega M$, $Z_3 = 1/j\omega C$

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$h_{ie}\left[(j\omega L_1 + j\omega M) + (j\omega L_2 + j\omega M) - j/\omega C\right) + \left[(j\omega L_1 + j\omega\right.$

$\left.(j\omega L_2 + j\omega M)(1 + h_{fe})\right] + (j\omega L_2 + j\omega M)(-j/\omega C) = 0.$

Equating real & imaginary

$$h_{ie}\left[L_1 + L_2 + 2M - \frac{1}{\omega^2 C}\right] = 0.$$

$$L_1 + L_2 + 2M - \frac{1}{\omega^2 C} = 0$$

$$\omega^2 C = \frac{1}{L_1 + L_2 + 2M} \qquad \therefore f = \frac{1}{2\pi\sqrt{C(L_1+L_2+2M)}}$$

&

$$(L_1 + M)(1 + h_{fe}) - \frac{1}{\omega^2 C} = 0.$$

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

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Module V

Power Amplifier:-
A power amplifier can be ~~divided~~ defined as a device that converts dc power into ac power and whose action is controlled by the input signal. The transistors employed in power amplifiers are power transistors.

- The base is made thicker.
- Area of collector is large.
- Emitter & base layers are heavily doped.

Classification of Power Amplifiers:-
Power amplifiers are primarily divided into two categories:-

Class A Power Amplifier:-
The output current flows for the entire cycle of the input signal. Thus the operating point is selected in such a way that transistor operates only in linear region of its load line.

Class B Power Amplifier:-
The output current flows for only a single half cycle of input signal. It is biased at cut off region.

Class AB
Current flows in cycles between 180° & 360°.

Class C Power Amplifier:-

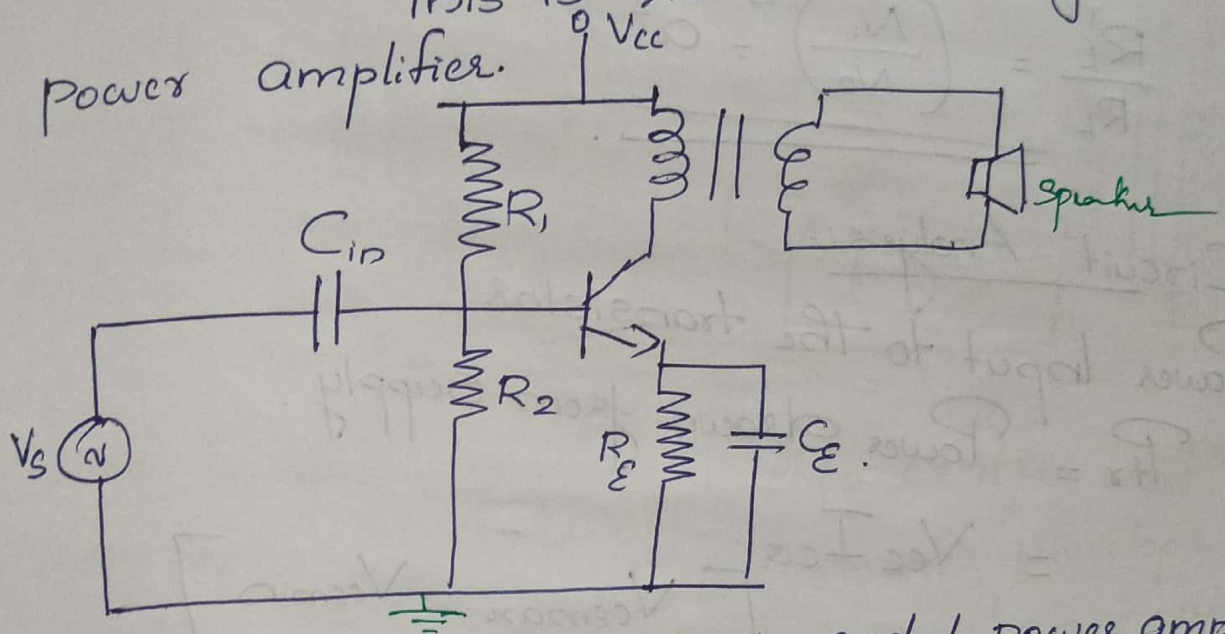
Amplifier is biased for operations in cycles less than 180°.

class D power Amplifier:-

are designed to operate with digital or pulse type Signals.

Class A Power Amplifier Transformer Coupled:-

This is referred as single ended power amplifier.

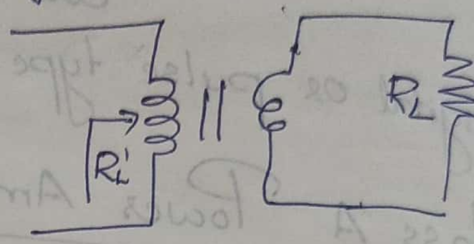


* They are known as Single ended power amplifier
* The quiscent Current flows through the collector resistive load and cause large wastage of dc power in it.
* It is advisable to pass the dc through the output device Such as in voice coil of a loud Speaker.
* Primary has negligible dc Resistance.
* Ac power is magnetically coupled across the transformer.

* The power transferred to load will be maximum only if amplifier output impedance equals to the load impedance R_L.

* The transformer matching is maximum.

$$\frac{R_L'}{R_L} = \frac{V_1/I_1}{V_2/I_2}$$



$$\frac{R_L'}{R_L} = \left(\frac{N_1}{N_2}\right)^2 = a^2$$

Circuit Analysis:-

Power Input to the transistor

P_{tr} = Power drawn from supply.

$$= V_{cc} I_{CQ}$$

$$V_{rms} = \frac{1}{\sqrt{2}}\left[\frac{V_{CEmax} - V_{CEmin}}{2}\right]$$

$$= \frac{V_{cc}}{\sqrt{2}}$$

$$I_{rms} = \frac{I_{cmax}}{2\sqrt{2}} = \frac{I_{CQ}}{\sqrt{2}}$$

$$P_{out} = V_{rms} I_{rms} = \frac{V_{cc} I_{CQ}}{2}$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{cc} I_{CQ}}{2 V_{cc} I_{CQ}}$$

$$= \frac{1}{2} = 50\%$$

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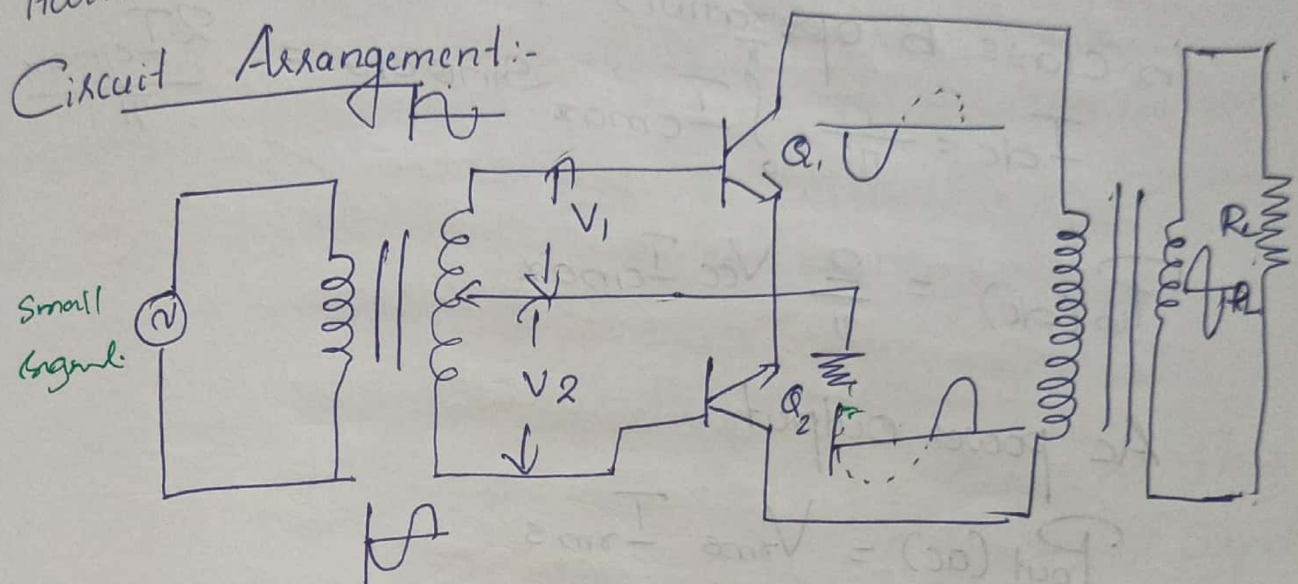
Class B Push pull Amplifier:-

* The Circuitry for the Class B push pull operation is same as that of class B operation.
* It have higher operating Efficency (theoretical 78.5%)
* Harmonic distortion is more.

Circuit Arrangement:-



Circuit Operation:-

* When input signal is applied to centre tapped secondary of the input transformer develops two signals which are identical but in phase opposition
* The transistors Q_1, Q_2 are driven by two signals
* The Collector current in Q_1 increases from zero and Q_2 becomes negative.
* The effect of two half cycles in seperates halves of the primary of output transformer is to produce a magnetic flux in the transformer core, which flows first in one direction.

Conversion Efficiency of class B Amplifier:

Power provided to the load R_L coupled to the amplifier is drawn from dc power supply V_{cc} and is considered an input dc power.

$$P_{in}(dc) = V_{cc} I_{dc}.$$

In class B operation

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} I_{cmax} \sin\theta \, d\theta = \frac{2I_{cmax}}{\pi}$$

$$P_{in}(dc) = \frac{2}{\pi} V_{cc} I_{cmax}$$

Ac power output

$$P_{out}(ac) = V_{rms} \cdot I_{rms}$$

$$= \frac{V_{cc}}{\sqrt{2}} \cdot \frac{I_{cmax}}{\sqrt{2}}$$

$$= \frac{V_{cc} I_{cmax}}{2}.$$

$$\eta_{overall} = \frac{P_{out}(ac)}{P_{in}(dc)} = \frac{V_{cc}\frac{I_{cmax}}{2}}{\frac{2V_{cc}I_{cmax}}{\pi}} = \pi/4$$

$$= 0.785$$

$$\eta = 78.5\%$$

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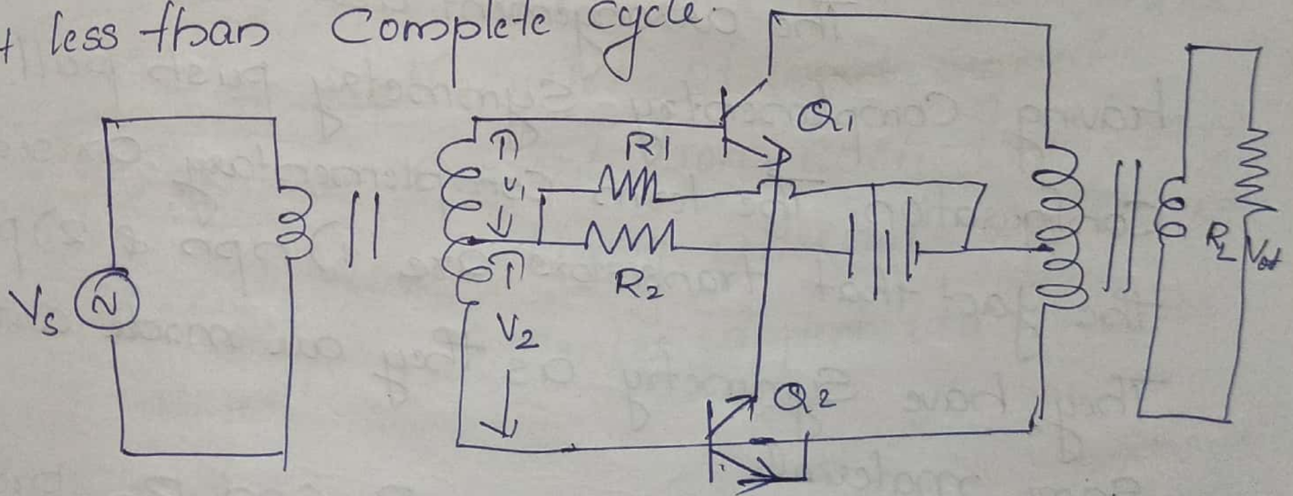
Cross Over Distortion:-

In addition to distortion due to the non linearity of collector characterstics and due to nonmatching of two transistors, there is a source of distortion.

Silicon transistors must have atleast 0.5 V to 0.6 V of forward base emitter bias before they go to conduction. In class B due to this a dead band is formed and produces crossover distortion.

Class AB Push Pull Amplifier:-

In class AB, the collector current flows for more than half the cycle of the input signal but less than complete cycle.



* It uses two identical transistors Q_1 and Q_2
* Emitters are connected together.
* Input transformer is centertapped.

When base current of one Q_1 is being driven positive with respect causing a decreasing collector current

A current flowing through primary winding is in same direction. As I_{C1} increases I_{C2} decreases. Hence name push pull amplifier.

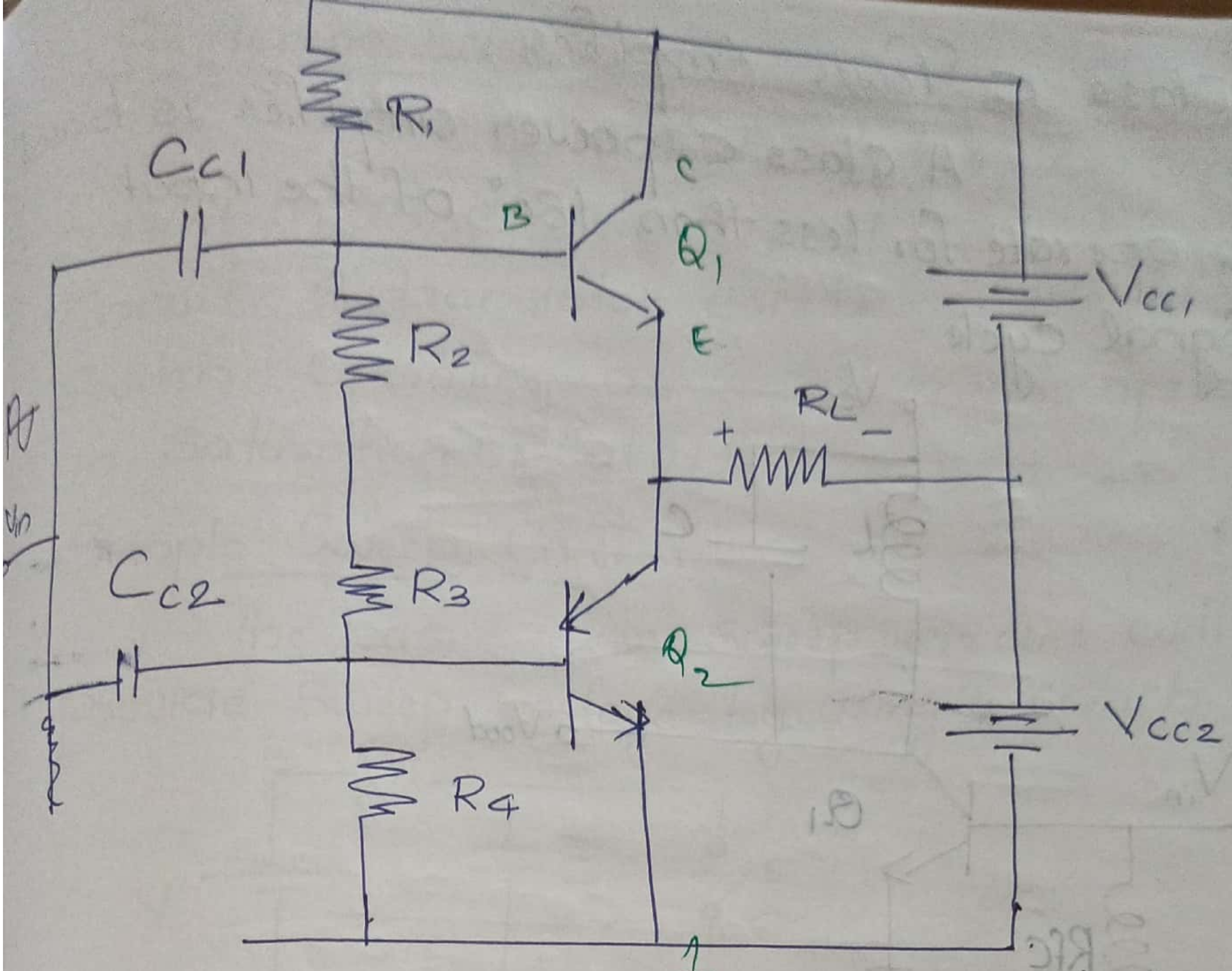
Transformerless class B Power Amplifier

The use of transformers at input aswell as output ends makes push pull amplifiers bulky and expensive. The transformer has to be tapped.

To overcome this limitations push pull amplifiers are replaced by complementary symmetry pushpull amplifier.

The arrangement uses two transistors having complementary symmetry push pull configuration. The term complementary arises from the fact that transistors are 1) npn & 2) pnp. They have symmetry as they are made with same material.

The resistors R_1 and R_2 provide the voltage divider bias to forward bias the emitter base junction of Q_1 & R_3 and R_4 provide bias for Q_2.



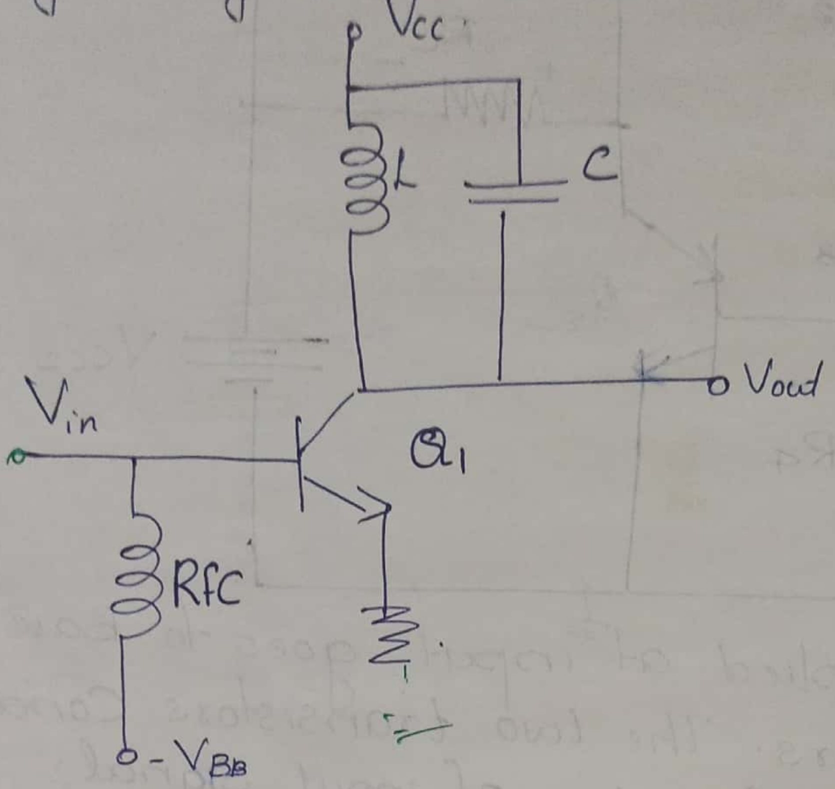
The Signal applied at input goes to base of both transistors. The two transistors Conduct in opposite half cycles of input Signal. Since collector current from each transistor flows through load during alternate cycles of input signal, no center tapped transformer is required.

Draw back:-

* Two power Supplies required.
* Unbalance in transistor Characteristic.
* Non linear distortion.

Class C Power Amplifier :-

A class C power amplifier is biased to operate for less than 180° of the input signal cycle.



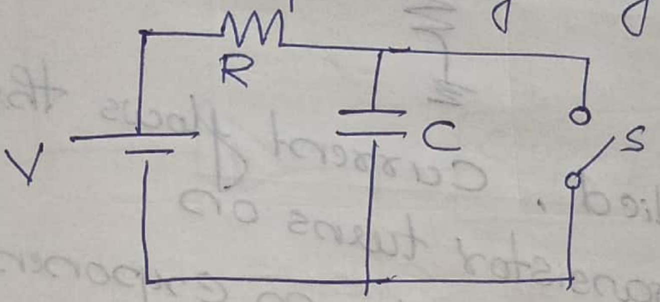
* The tuned circuit in output, provide a full cycle of output signal for fundamental reasonant frequency of LC tank circuit.
* The use of such amplifier is limited for a fixed frequency.
* operation of class C is intended for Communication circuits.
* It provide large signal amplification.

Switching Circuits :-

A circuit that can turn ON and OFF current in an electric circuit is switching circuit. A transistor can be employed as a switch. Operating as switch means operating in saturation or cut off.

Simple Sweep Circuit :-

The basic R-C sweep circuit will provide sweep voltage by using a switch



The waveform generated will not be exactly linear.

Applying Kirchoff's law to above circuit.

$$V - iR - V_c + V_a = 0.$$

$$iR = V \quad \text{if } V_a = V_c$$

$$\Rightarrow i = V/R.$$

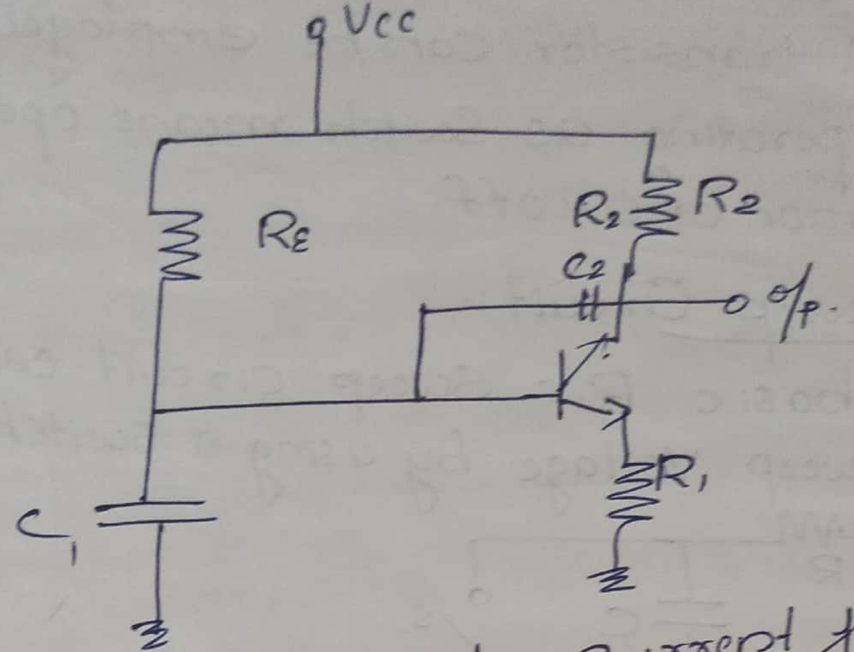
The charging current i is independent of capacitor C

$$V_c = \frac{q_c}{C} = \frac{1}{C}\int i.dt$$

$$= \frac{1}{C}\int \frac{V}{R} dt = \frac{V}{RC} \cdot t$$

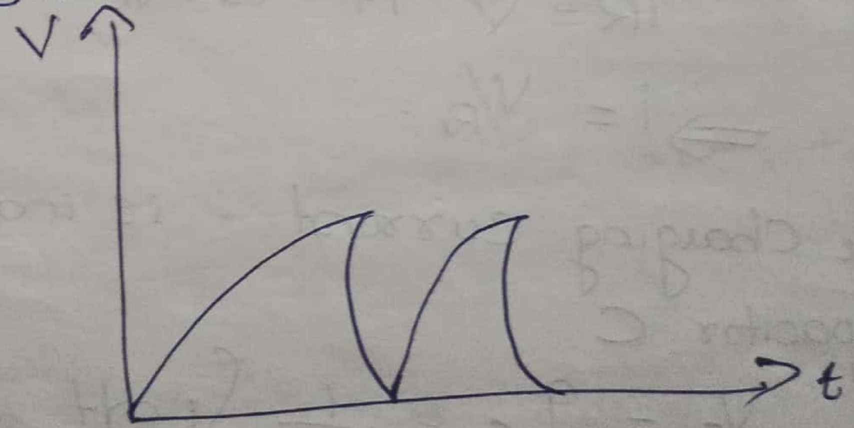
Boot Strap Sweep Circuit:-

is used to generate a sawtooth wave.



When Vcc is applied, current flows through R_E and the transistor turns on. Capacitor C_2 charges into an exponential waveform.

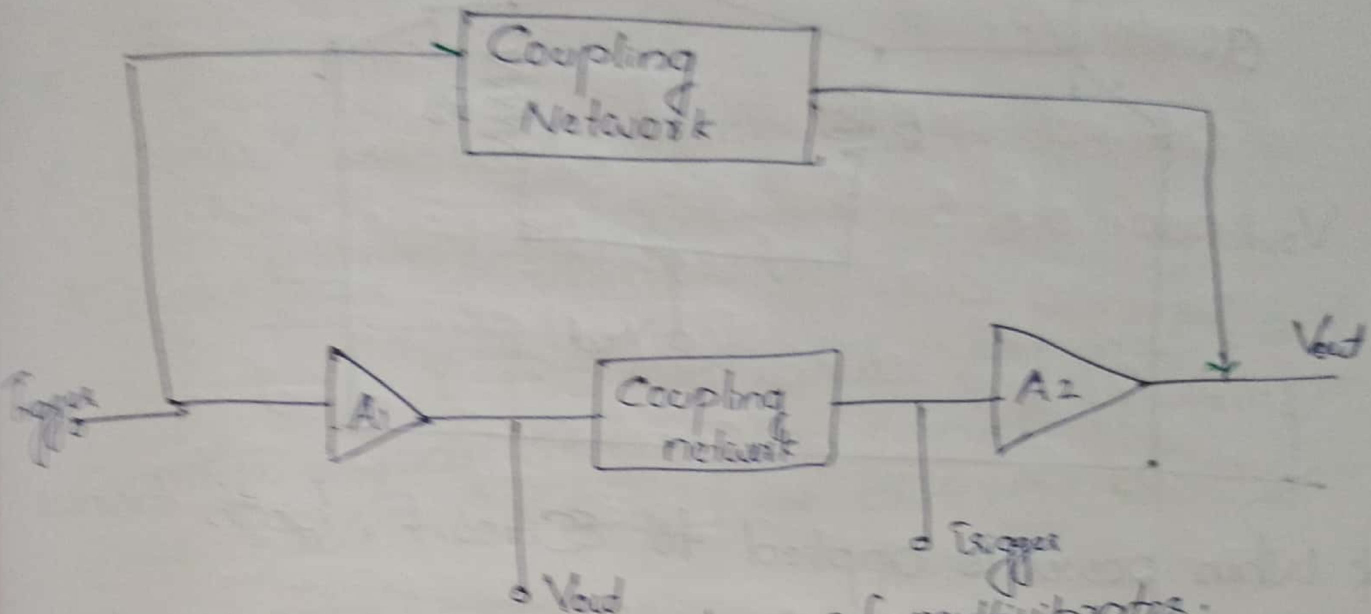
When transistor is reverse biased, the capacitor C_2 discharges through R_1 and voltage starts decreasing.



A Sweep wave will be generated.

Multivibrators :-

A multivibrator is basically a two stage RC coupled amplifier with positive feedback from circuit output amplifier to input amplifier. multivibrator is a switching circuit that creates non sinusoidal waves

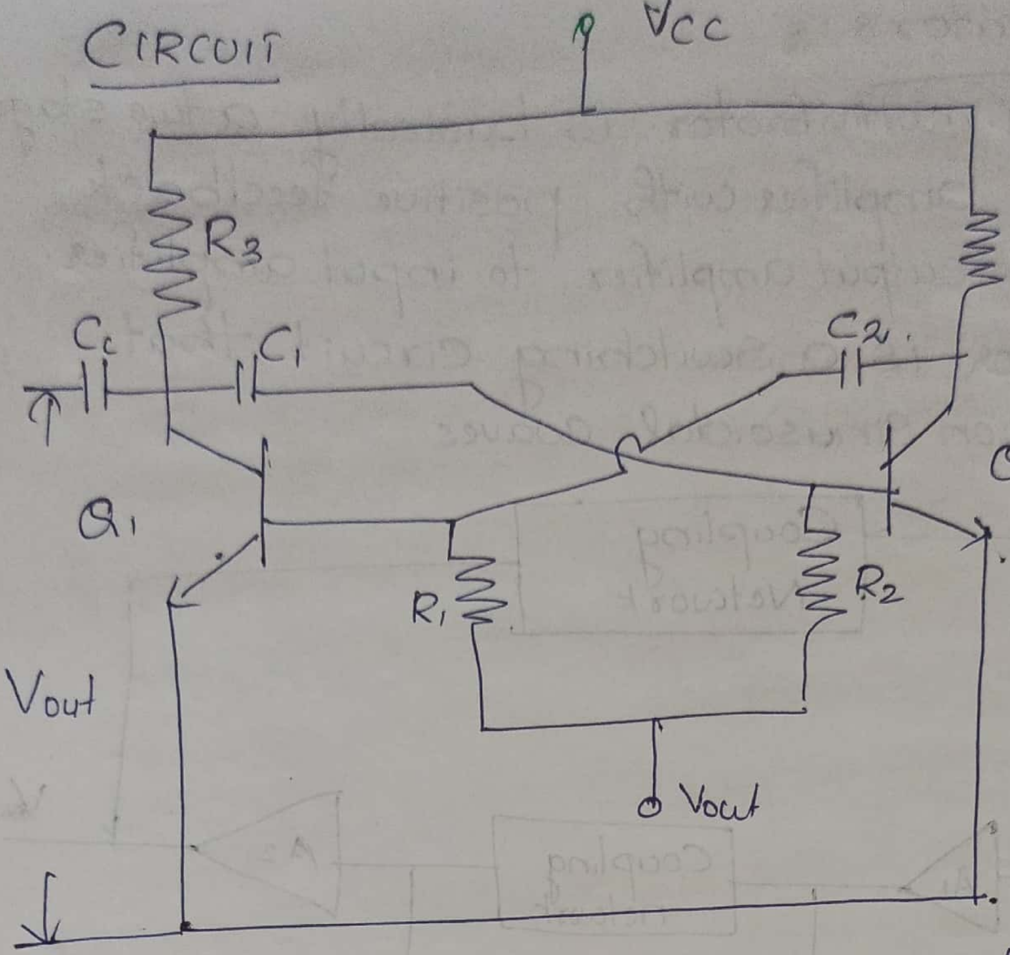


Basic Configuration of multivibrator.

Astable Multivibrator :-

Astable multivibrator is also called free running multivibrator. It is essentially a two stage RC coupled amplifier with the output of first stage coupled to input of second stage and output of 2nd stage coupled to input of first stage. As the phase of signal is reversed when amplified by a single stage CE amplifier. it comes to orginal phase

CIRCUIT



* When power is applied to circuit, both transistors start conducting.

* Because of small operating differences one transistor conduct more than other.

* Assume Q_1 conducts more than Q_2. This causes collector voltage of Q_1 falls to drop more rapidly than Q_2.

* Resulting negative signal is fed to Q_2 through C_1 and drives Q_2 to cut off.

* This change in collector voltage of Q_2 is fed to base of Q_1 through C_2.

C_1 does not get a chance to discharge and voltage appears across R_2.

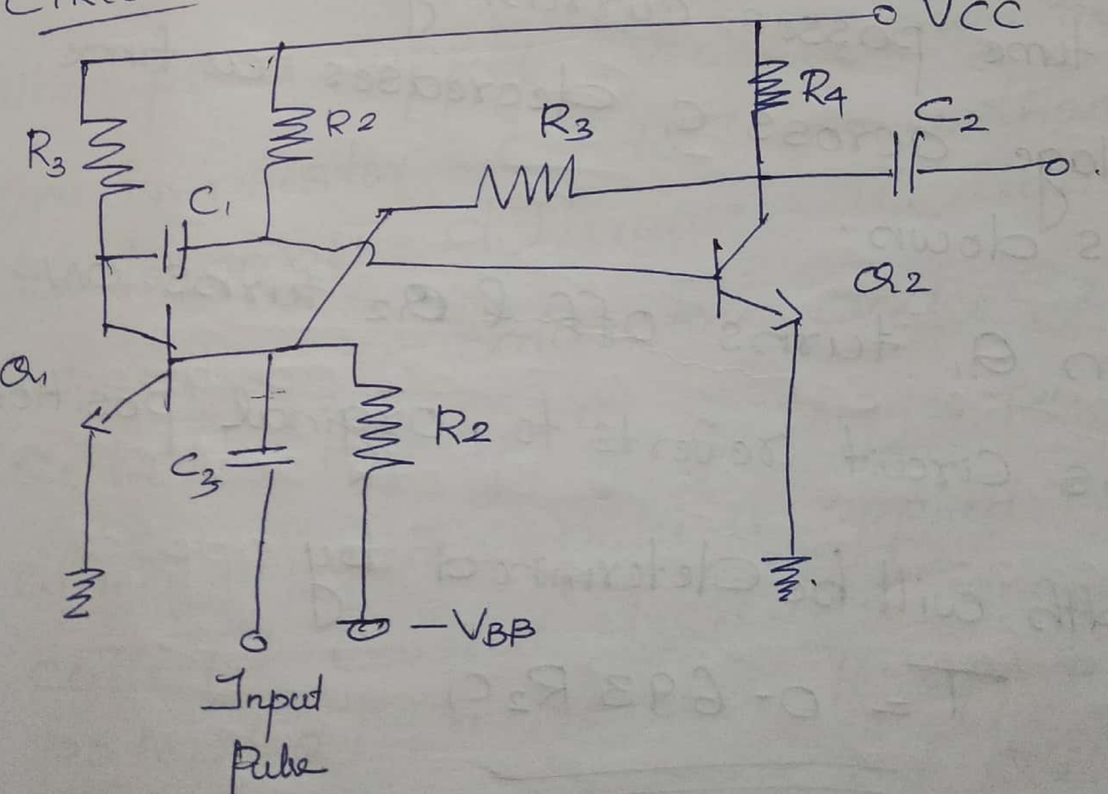
When C_1 discharges and tend to zero Q_2

* begins to conduct.
* As Q_2 conducts it collector voltage decreases and signal is fed to Q_1 & Q_1 turns off.
* The cycle repeats.
* output will be square wave.

Monostable Multivibrator :-

It has two states one stable and another quasi stable. The circuit remains in quasi stable for a period determined by components.

CIRCUIT



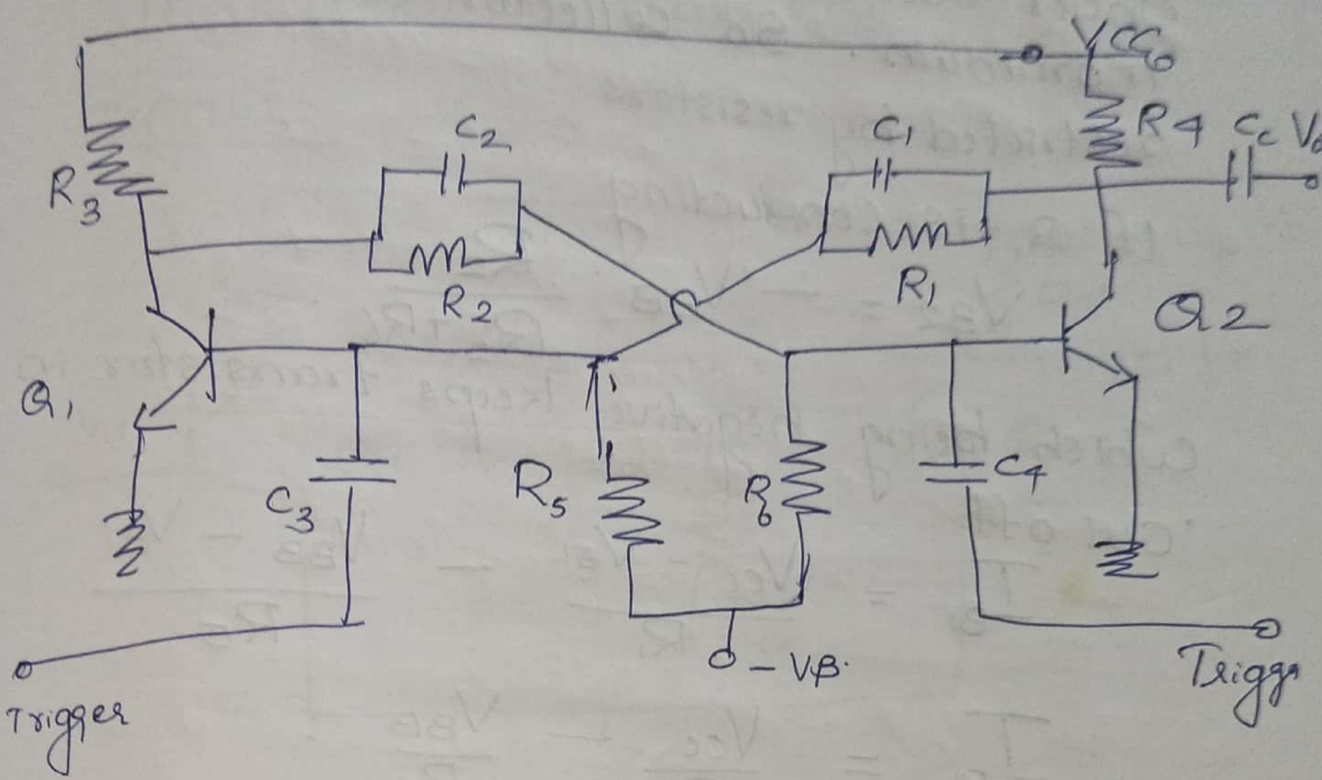
When power Supply is switched ON

* Input pulse is applied to turn ON Q_2
* It is forward biased by V_{cc}.
* Transistor Q_1 will be in cutoff
* C_1 is connected to Q_1 and will charge upto V_{cc}.
* When a positive trigger is applied to base of Q_1 through capacitor, it overrides reverse bias of emitter base junction of Q_1 and gives forward bias.
* Thus Q_1 starts conducting and potential of Q_1 comes to ground.
* Charge on C_1 will not disappear instantly
* As time passes current flows onto C_1.
* Voltage across C_1 decreases as time pass down.
* Then Q_1 turns off & Q_2 turns ON.
* Thus circuit reverts to orginal position.
* ~~puls~~ Width will be determined by

$$T = 0.693 R_2 C_1$$

Bi stable Multivibrator:-

It has two stable states. It can stay in one state for indefinite period. It can be used as flip flop.



when power supply Vcc is switched ON one transistor conduct more than other due to small differances in transistors. Let Q_1 is in saturation and Q_2 is in cut off by applying trigger pulse. when negative pulse is applied to Q_1 the collector current decreases and collector potential increases. It appears across emitter base junction of Q_2 and is connected to collector terminal through

C_1.

Under cut off V_{CC} appears across the transistor and this restricts the supply to order of volts.

Under saturation collector current is maximum. So collector current should be restricted by resistors.

If Q_1 is conducting

$$V_{B2} = -V_{BB} \cdot \frac{R_2}{R_2 + R_6}$$

which being negative keeps transistor in cut off.

$$I_{B1} = \frac{V_{CC} - V_{B1}}{R_1} - \frac{V_{BB} - V_{B1}}{R_5}$$

$$I_{B1} = \frac{V_{CC}}{R_1} - \frac{V_{BB}}{R_2}.$$

To keep Q_1 conducting

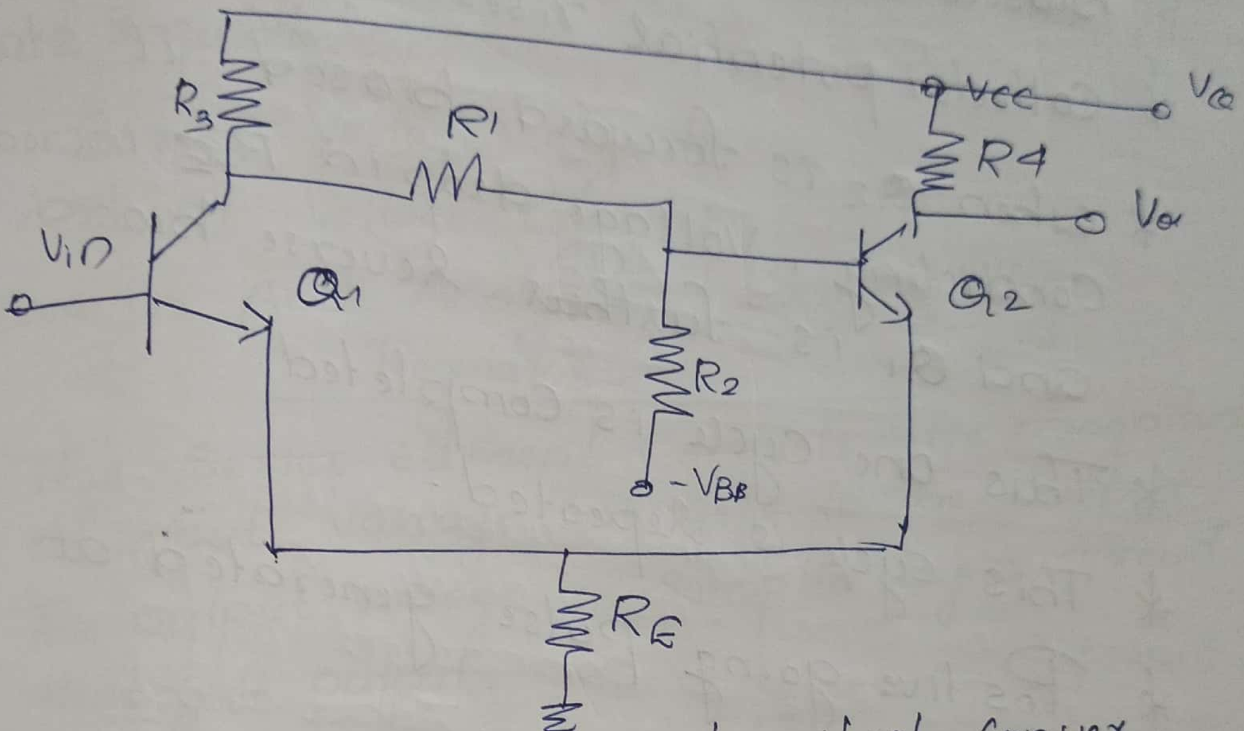
$$I_{B1} \geq \frac{I_{C1}}{h_{fe}}$$

Values of V_{CC}, V_{BB}, R_1, R_2, R_3 and R_4 are selected to satisfy a stable operation which exist with Q_2 in cut off and Q_1 in saturation. Pulse need to be applied in sufficant time only.

Schmit trigger is a form of bistable multivibrator except

- Coupling from output terminal C_2 of Q_2 to input is missing.
- It is a binary oscillator.

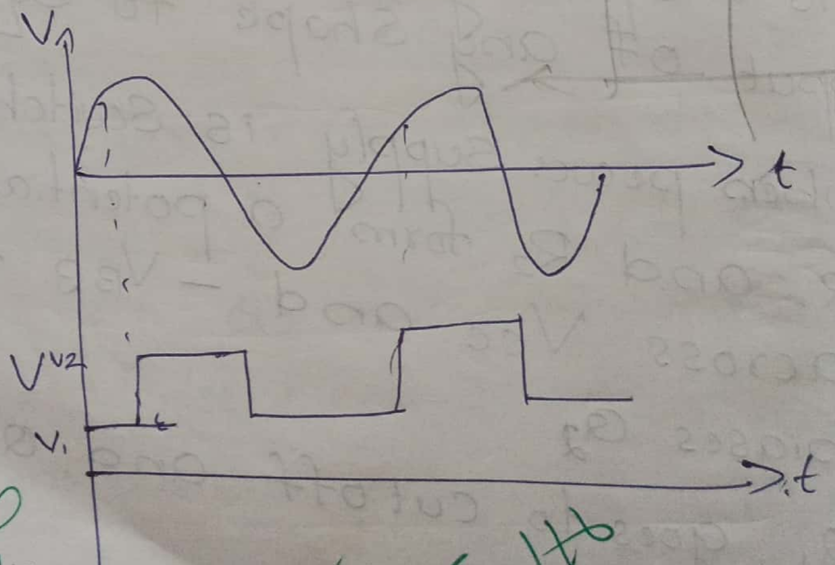
CIRCUIT :-



- It is a squaring circuit which conver input of any shape to square pulses.
- when power supply is switched ON, R_3, R_1 and R_2 form a potential divider across Vcc and $-V_{BB}$ forward biases Q_2
- Q_1 goes to cutoff and Q_2 goes to saturation.
- Input ac signal is applied to base of transistor

Potential of Q_1 rises to Vcc

* positive going signal appears at Collector emitter junction.
* After half a cycle of input signal, Q_1 is negative going. Q_1 will be reverse biased, Collector voltage rises to Vcc
* Collector potential rises to Vcc.
* when Q_2 is forward biased, it starts Conducting, Voltage drop in R_E increases and Q_1 is further reverse biased.
* Thus one cycle is Completed.
* This cycle is repeated.
* Positive going pulse generated at output.



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Module - VI

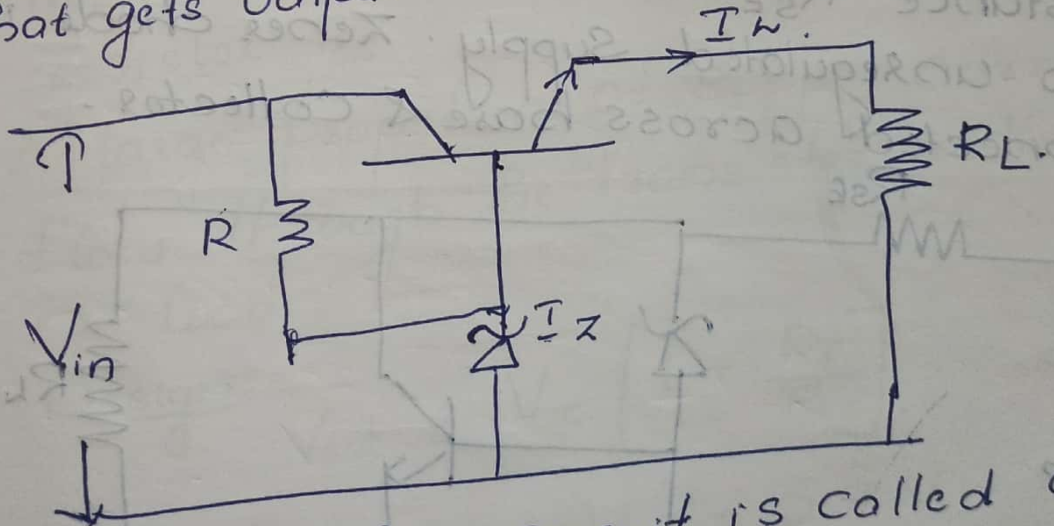
Transistor based Voltage Regulator:-

Regulator is a circuit which is capable of maintaining constant dc output voltage. It also rejects ac ripple voltages. The regulator may also include protective functions such as short circuit protection, current limiting overvoltage protection etc. There are two types of regulators.

- Series Voltage Regulator.
- Shunt Voltage Regulator.

Design And Analysis of Series Voltage Regulator:-

The series element controls the magnitude of input voltage that gets to the output. The output voltage is sampled by a circuit that gets output.



This circuit is called an emitter follower voltage regulator. because Q is connected in emitter follower configuration

$$\text{Stability factor} = \frac{\Delta V_o}{\Delta V_i}$$

$$= \left(\frac{R_1 + R_2}{R_2}\right) \frac{\left((R_1 \| R_2) + h_{ie2} + (1+h_{fe2})R_z\right)}{h_{fe2} R_3}$$

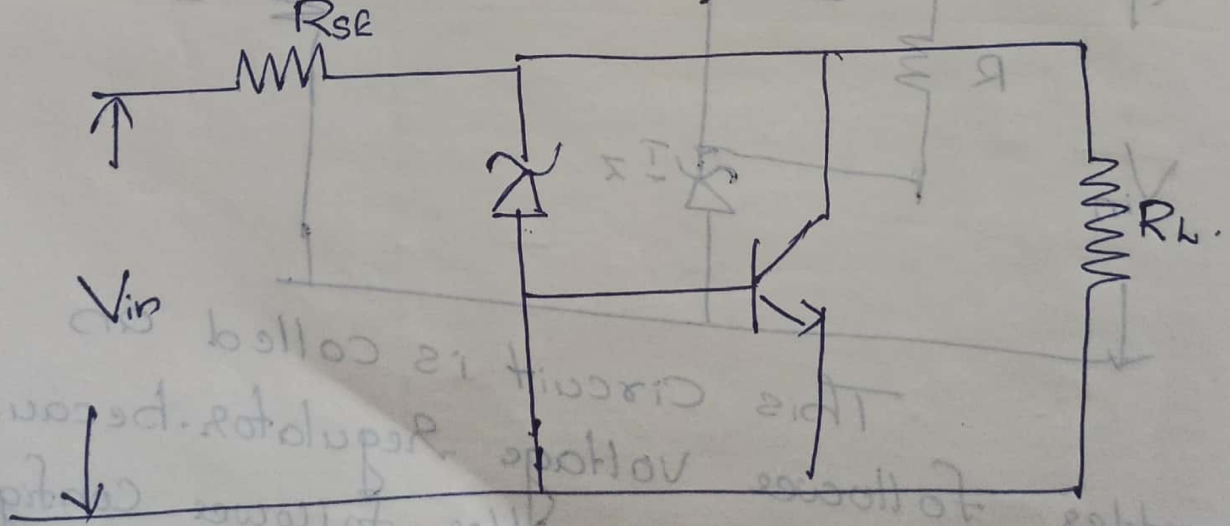
R_z = Zener diode resistance.

$$R_o = \frac{r_o + \frac{R_3 + h_{ie1}}{1 + h_{fe1}}}{1 + G_m (R_3 + r_o)}.$$

$$G_m = \frac{\Delta I_c}{\Delta V_o}.$$

Shunt Regulator :-

A shunt regulator uses an NPN transistor and zener diode. A series resistance R_{SE} is connected in series with unregulated supply. Zener diode is connected across base & collector.



unregulated voltage is reduced, due to voltage drop in series resistance R_{SE}, by an amount that depends on the current supplied to the load R_L. The voltage across the load is fixed by the zener diode and transistor base emitter voltage V_{BE}.

output voltage is given as

$$V_{out} = V_Z + V_{BE} = V_{in} - IR_{SE}$$

Since both V_Z and V_{BE}

~~V_{out} =~~

Since both V_Z and V_{BE} remain nearly constant.

$$I_C = \beta I_B$$

If the input voltage increases, it causes increase V_{out}

Limitations:-

- There is considerable power loss in series resistor R_{SE}
- A large propotion of supply current I flow through the transistor rather than no load.

Design:-

$$V_{out} = V_Z \left[1 + \frac{R_f}{R_1}\right].$$

$$V_{op\text{-}amp} = V_{out} + 0.7\,V.$$

$$V_{in} \geq V_{out} + 2$$

$$\beta \geq \frac{I_{out}}{I_{opamp\,max}}$$

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Line Regulation And Load Regulation:-

The ratio of $\left(\frac{V_{HL} - V_{LL}}{\text{Nominal load Voltage}}\right) \times 100$

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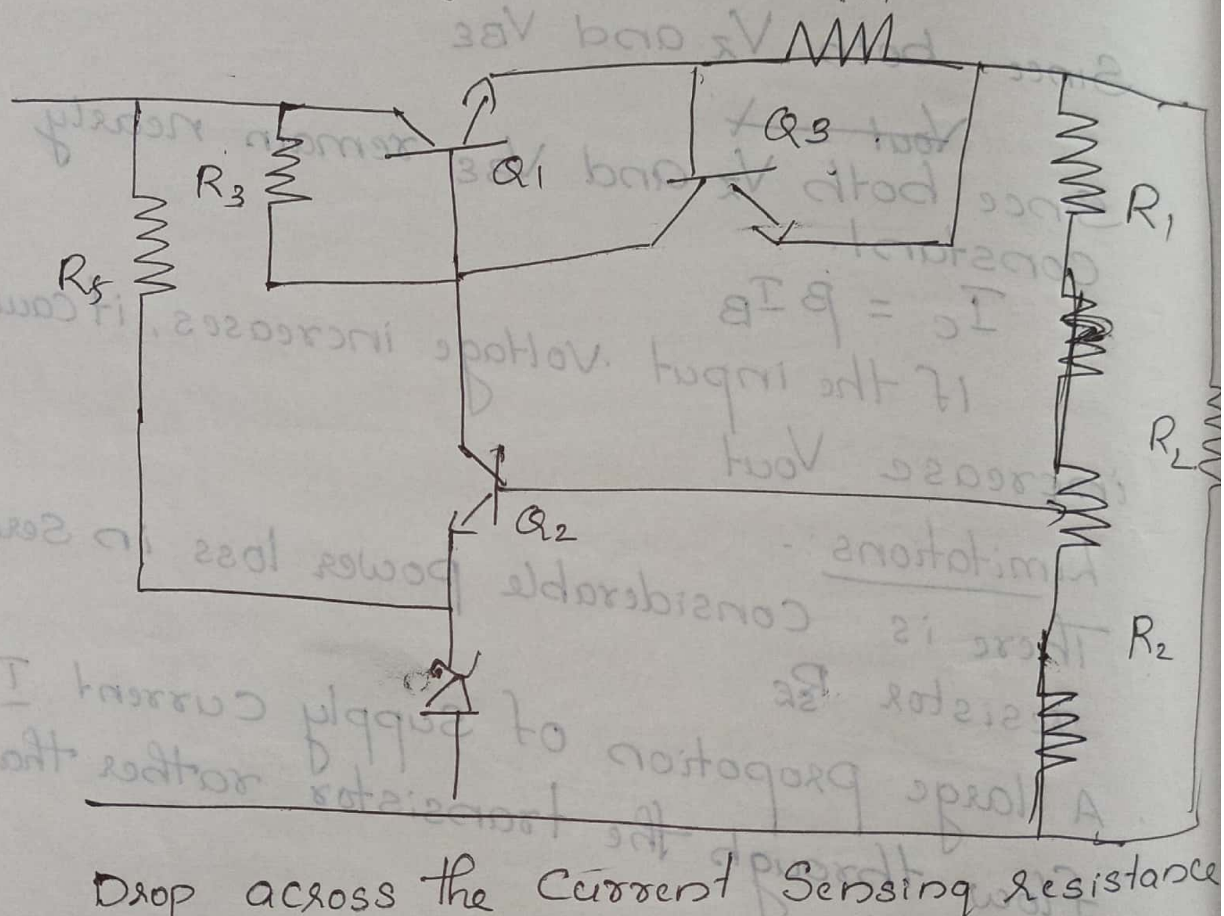
$\beta = 120$

15

Voltage Regulator with Short Circuit Protection

A Simple Current limiting Circuit is Constructed using a transistor & a resistance R_4.



Drop across the current Sensing resistance R_4 is applied to the base emitter of Q_3.

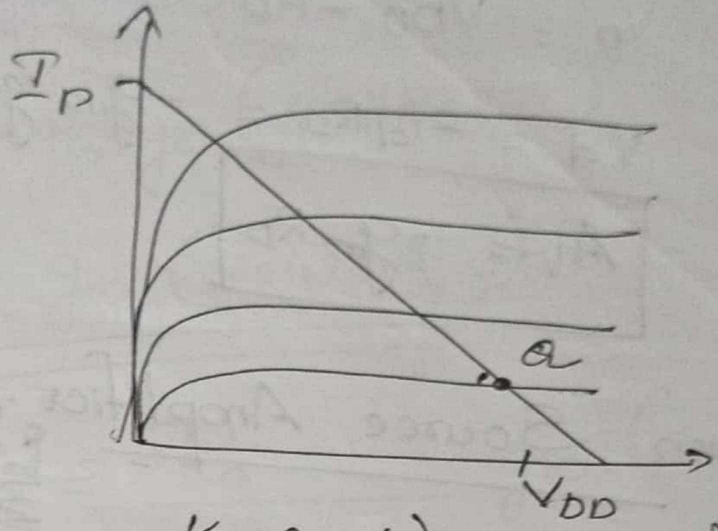
$$V_{BE} = I_{SL} R_4.$$

$$I_{SL} = \frac{V_{BE}}{R_4}.$$

$$R_{min} = \frac{V_{reg}}{I_{SL}}$$

Mosfet Amplifier :-

To operate as an amplifier Mosfet has to be biased in saturation mode. Device is biased at a point at middle of the curve



$$I_D = \frac{1}{2} k_n (W/L)(V_G - V_t)^2$$

$$V_D = V_{DD} - I_D R_D$$

$$V_D > V_{GS} - V_t$$

$$v_{GS} = V_{GS} + v_{gs}$$

$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right)(V_{GS} + v_g - V_t)^2$$

$$= \frac{1}{2} k_n' (W/L)(V_{GS} - V_t)^2 + \frac{1}{2} k_n' (W/L) v_g^2$$

$$+ k_n' (W/L)(V_{GS} + v_{gs}) V_t$$

$$v_{gs} <<< 2(V_{GS} - V_t)$$

$$i_D \cong I_D + i_d$$

$$g_m = \frac{i_d}{V_{gs}} = k_n'(W/L)(V_{GS} - V_t).$$

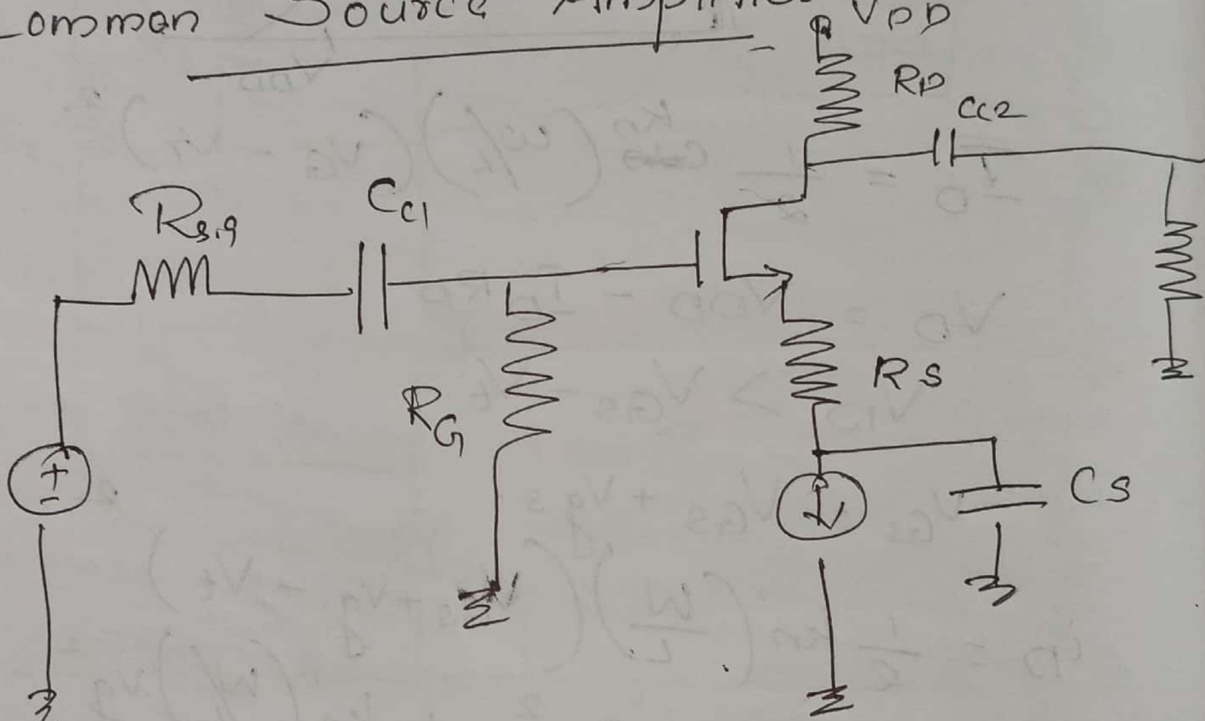
$$V_D = V_{DD} - i_D R_D.$$

$$V_D = V_{DD} - R_D(I_D + i_d)$$

$$V_d = -i_d R_D = -g_m V_{gs} R_D.$$

$$\boxed{A_V = -g_m R_D}$$

Common Source Amplifier



$$R_{in} = R_i = R_G$$

$$V_i = V_{sig}\frac{R_G}{R_G + R_{sig}}$$

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$$V_{gs} = V_i \frac{1/g_m}{\frac{1}{g_m} + R_S}$$

$V_i \cong V_{sig}$

$V_{gs} = V_i$

$V_o = -g_m V_{gs} (r_o \| R_D \| R_L)$

$$A_V = -g_m (r_o \| R_D \| R_L)$$

$$G_V = -\frac{R_G}{R_G + R_{sig}} g_m (r_o \| R_D \| R_L)$$

$$R_{out} = r_o \| R_D \| R_L$$

Cascaded Amplifier