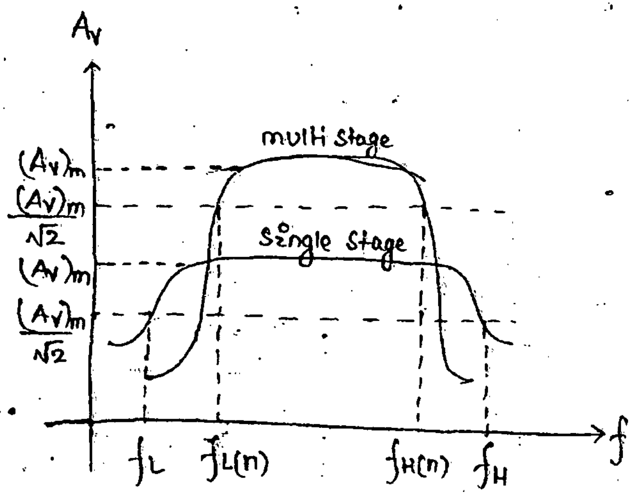
INTEGRATED ELECTRONICS (OP-AMP)

MULTI STAGE AMPLIFIERS.

→ EFFECT OF CASCADING ON BANDWIDTH (Identical Stages)



Higher cut-off frequency.

$$(A_V)_h = \frac{(A_V)_m}{1 + j\left(\frac{f}{f_H}\right)}$$

Single Stage

$$\left|\frac{(A_V)_h}{(A_V)_m}\right| = \frac{1}{\sqrt{1+\left(\frac{f}{f_H}\right)^2}}$$

n identical stage

$$\left|\frac{(A_V)_h}{(A_V)_m}\right|^n = \left|\frac{1}{\sqrt{1+\left(f/f_H\right)^2}}\right|^n$$

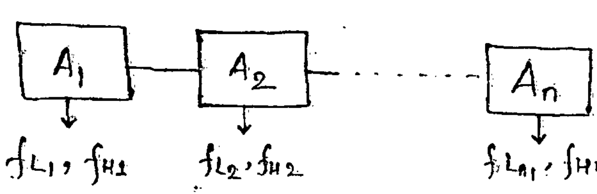
When $f \to f_{H(n)}$ –

$$\left|\frac{(A_V)_h}{(A_V)_m}\right|^n = \frac{1}{\sqrt{2}} \Rightarrow \frac{1}{\sqrt{1+\left(\frac{f_{H(n)}}{f_H}\right)^2}} = \frac{1}{\sqrt{2}}$$

$$\Rightarrow \boxed{f_{H(n)} = f_H\sqrt{2^{1/n}-1}} \qquad \text{|||y} \qquad \boxed{f_{L(n)} = \frac{f_L}{\sqrt{2^{1/n}-1}}}$$

→ EFFECT OF CASCADING ON BANDWIDTH (non identical Stages)

Ex →



$$A_l = \frac{(A)_m}{1 - j\left(\frac{f_L}{f_H}\right)}$$

$$A^n = A_1 \cdot A_2 \cdots\cdots A_n$$

$$A_l^n = A_{l1} \cdot A_{l2} \cdots\cdots A_{ln}$$

$$\frac{A^n}{\sqrt{1+\left(\frac{f_L^n}{f}\right)^2}} = \frac{A_1}{\sqrt{1+\left(\frac{f_{L1}}{f}\right)^2}} \cdot \frac{A_2}{\sqrt{1+\left(\frac{f_{L2}}{f}\right)^2}} \cdots\cdots \frac{A_n}{\sqrt{1+\left(\frac{f_{Ln}}{f}\right)^2}}$$

$$\sqrt{1+\left(\frac{f_L^n}{f}\right)^2} = \sqrt{1+\left(\frac{f_{L1}}{f}\right)^2+\left(\frac{f_{L2}}{f}\right)^2+\cdots\cdots+\left(\frac{f_{Ln}}{f}\right)^2+\underbrace{\left(\frac{f_{L1}\cdot f_{L2}}{f^2}\right)^2+\cdots}_{\text{Neglected}}}$$

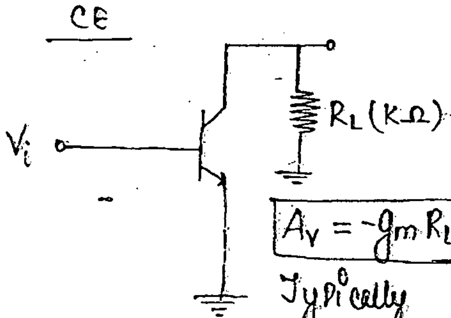
$$\boxed{f_L^n = \sqrt{f_{L1}^2 + f_{L2}^2 + \cdots + f_{Ln}^2}} \qquad \boxed{f_A^n \approx \frac{1}{\sqrt{\frac{1}{f_{H1}^2} + \frac{1}{f_{H2}^2} + \cdots + \frac{1}{f_{Hn}^2}}}}$$

☐ POPULAR CASCADING DESIGN.

1. CASCODE (CE-CB) AMPLIFIERS / WIDE BAND AMPLIFIER.
2. Darlington pair / High input impedance. (CC-CC)

1. CASCODE AMPLIFIERS | WIDE BAND AMPLIFIER. (CE-CB)

CE



$\boxed{A_V = -g_m R_L}$

Typically

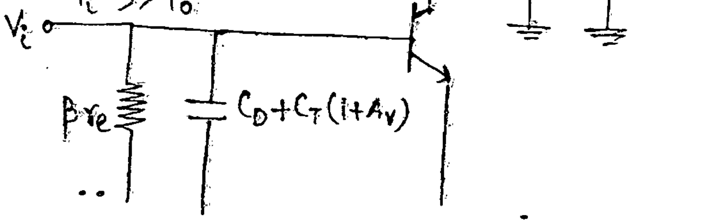
$A_V = 10^3$

$\boxed{W_{BW} = \frac{1}{T}}$

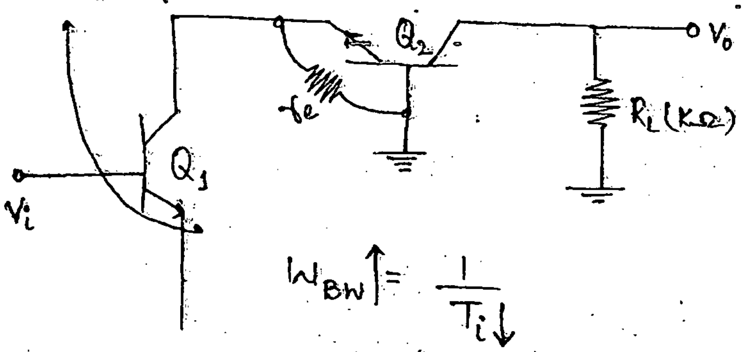
$T = T_i + T_o$

$T_i \gg T_o$

$T_i = \beta r_e \{C_D + C_T(1+10^3)\}$



$\tau_i = \beta r_e \{C_D + C_T(1+1)\}$



$W_{BW}\uparrow = \dfrac{1}{\tau_i \downarrow}$

$A_{V_1} = -g_m R_L$

$= -g_m r_e$

$A_{V_1} = -1$

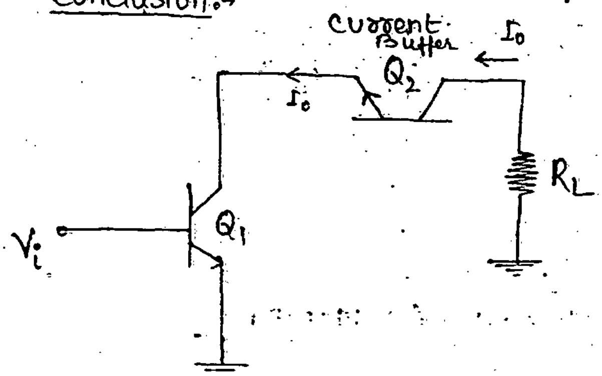
$A_{V_2} = g_m R_L$

$A_{cascode} = A_{V_1} \cdot A_{V_2}$

$= -1 \times g_m R_L$

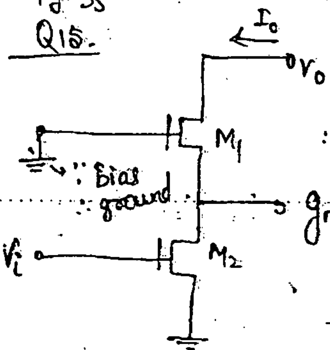
$\boxed{A_{cascode} = -g_m R_L}$

Conclusion:→



$g_m \text{ cascode} = \dfrac{I_o}{V_i} = g_{m\,CE}$

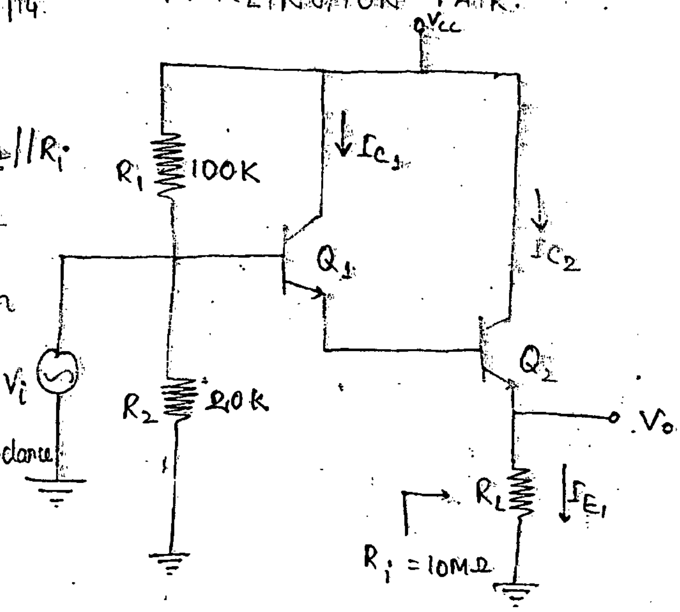
Pg-35
Q15.



$g_m \text{ cascode} = g_m \text{ of } M_2$

05/11/14. 2. DARLINGTON PAIR.

$R_1 \| R_2 \| R_i$
$= R_2$
⇓
Problem again low i/p impedance



1) $A_I = A_{I_1} \times A_{I_2} = \beta^2 \; (\beta^2 \text{ rule})$

$A_{I_1} = \frac{I_{E_1}}{I_{B_1}}$, $A_{I_2} = \frac{I_{E_2}}{I_{B_2}}$

$= \frac{I_{B_1} + I_{C_1}}{I_{B_1}} = 1+\beta \simeq \beta$

$= (1+\beta)$

$\simeq \beta$

2) $A_V = A_{V_1} \cdot A_{V_2}$

$= 1 \cdot 1 = 1$ (Buffer)

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

$1 = A_I \frac{R_L}{R_i}$

$\boxed{R_i = A_I R_L}$

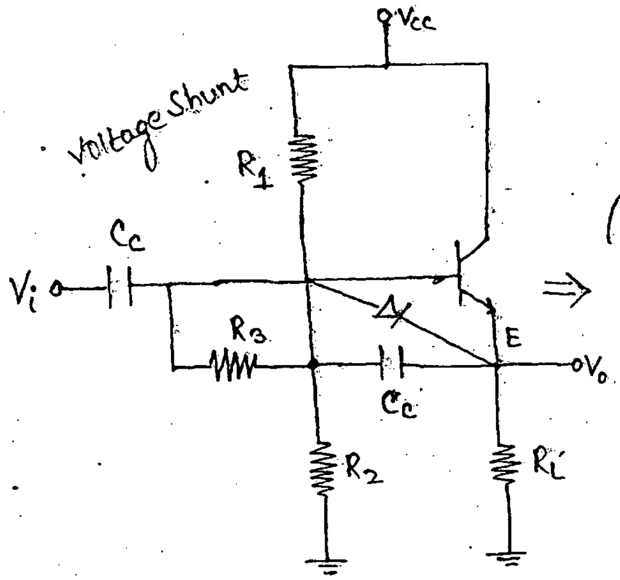
$R_i = A_I R_L \quad [A_I = \beta^2]$

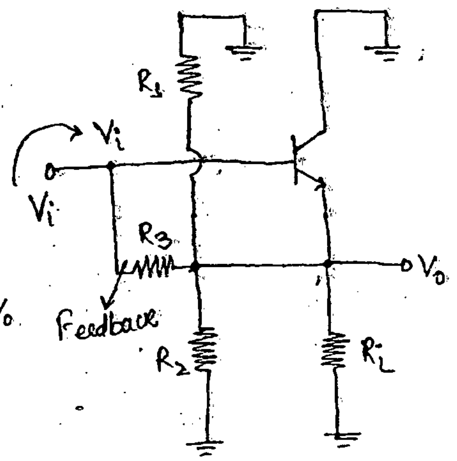
$R_i = \beta^2 R_L \quad [\beta = 100]$

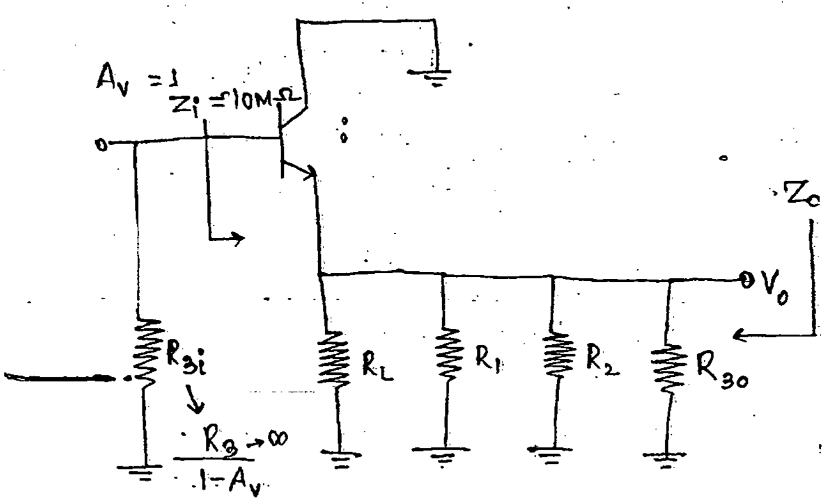
$R_i = [10 M\Omega] \quad [R_L = 1 M\Omega]$
↳ High i/p impedance.

4. $Z_o = R_L \| r_e$
$= r_e$ [impedance matching]

Modified ckt (~~Boat Shap Strap ckt~~) :



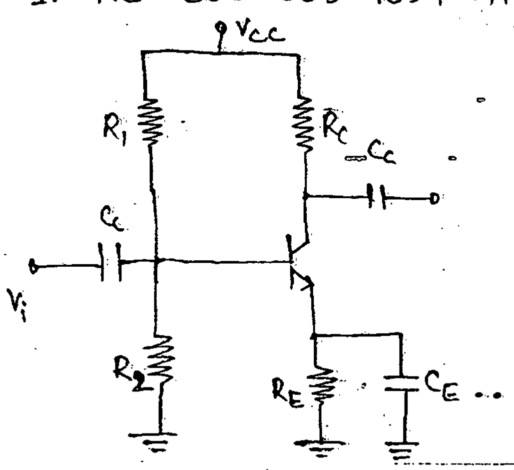




$$Z_o = R_L || R_1 || R_{30} || r_e || R_2$$
$$= r_e$$

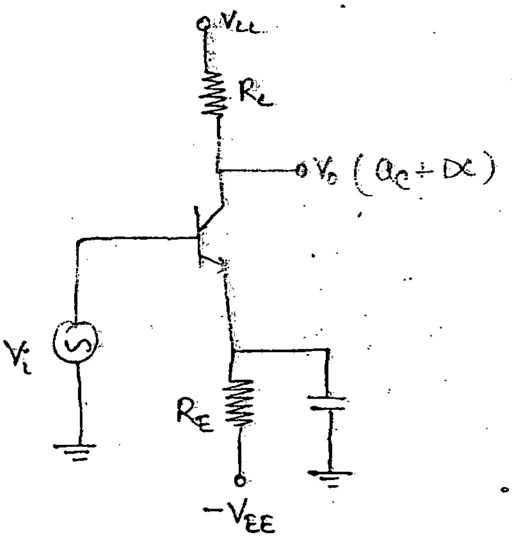
□ COUPLING DESIGN.

1. RC COUPLED BJT AMPLIFIERS.



* Low gain
* Size is more

2. DIRECT COUPLED BJT AMPLIFIERS



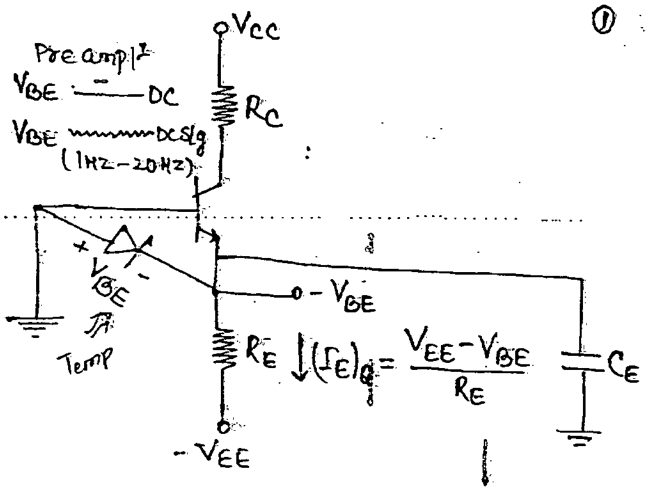
* High gain
* Small Size.

INTEGRATED AMPLIFIERS.

Requirement of Integrated amplifier
(1) High gain. (2) Small Size.

☐ DIRECT COUPLED BJT AMPLIFIER (PROBLEMS).

DC Model



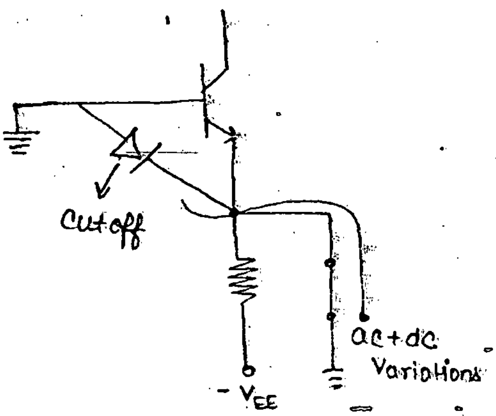
① $\frac{dV_{BE}}{dT} = -2.5\, mV/^\circ C$

unstable $(I_E)_Q = \frac{V_{EE} - V_{BE}}{R_E}$ ← Temp

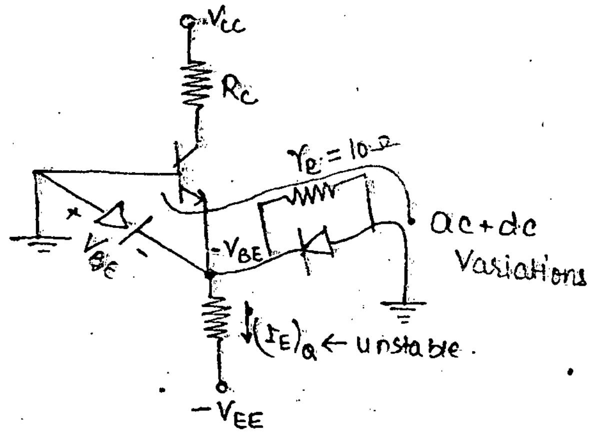
② $f_{min} = \frac{1}{2\pi C_E R_E}$ (DC signal)

$f_{min} \rightarrow$ 1 Hz. $C_E R_E \rightarrow \infty$

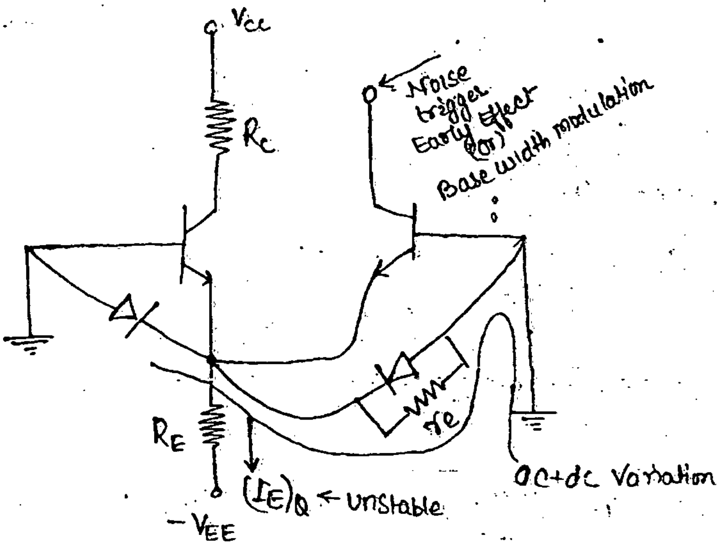
Method-1



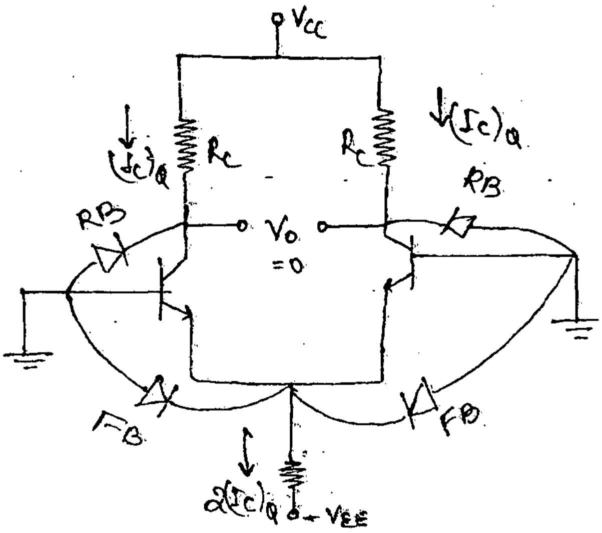
METHOD-2



METHOD-3

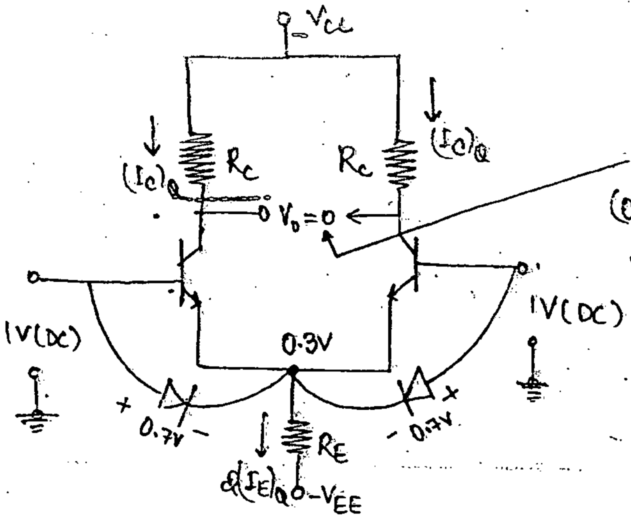


METHOD-4 . (DIFFERENTIAL AMPLIFIER)



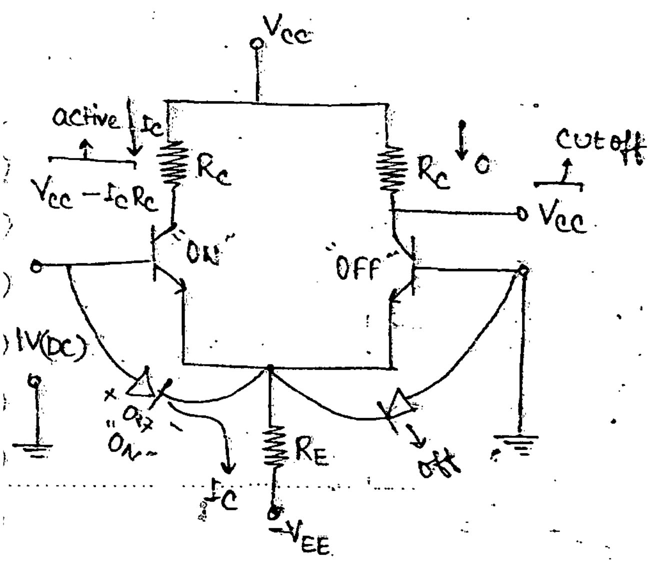
Testing of Differential Amplier.

Common Input :→



Common Signals (or) DC signals (or) Interference signal (or) Noise Signals are eliminated by differential amplifiers.

Large difference Input :→



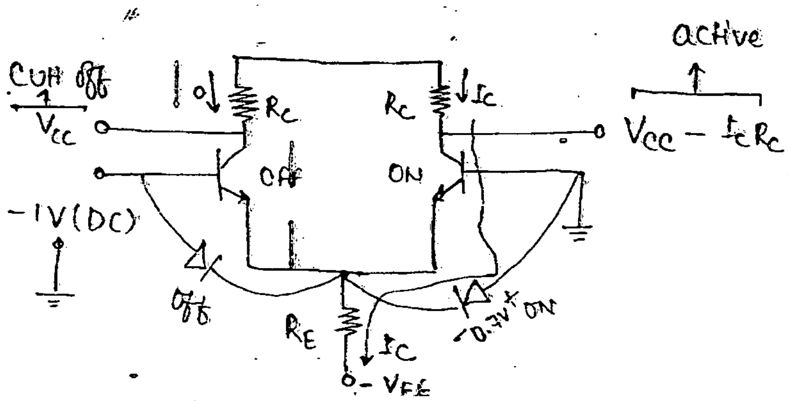
ECL (Emitter coupled Logic)

(or)

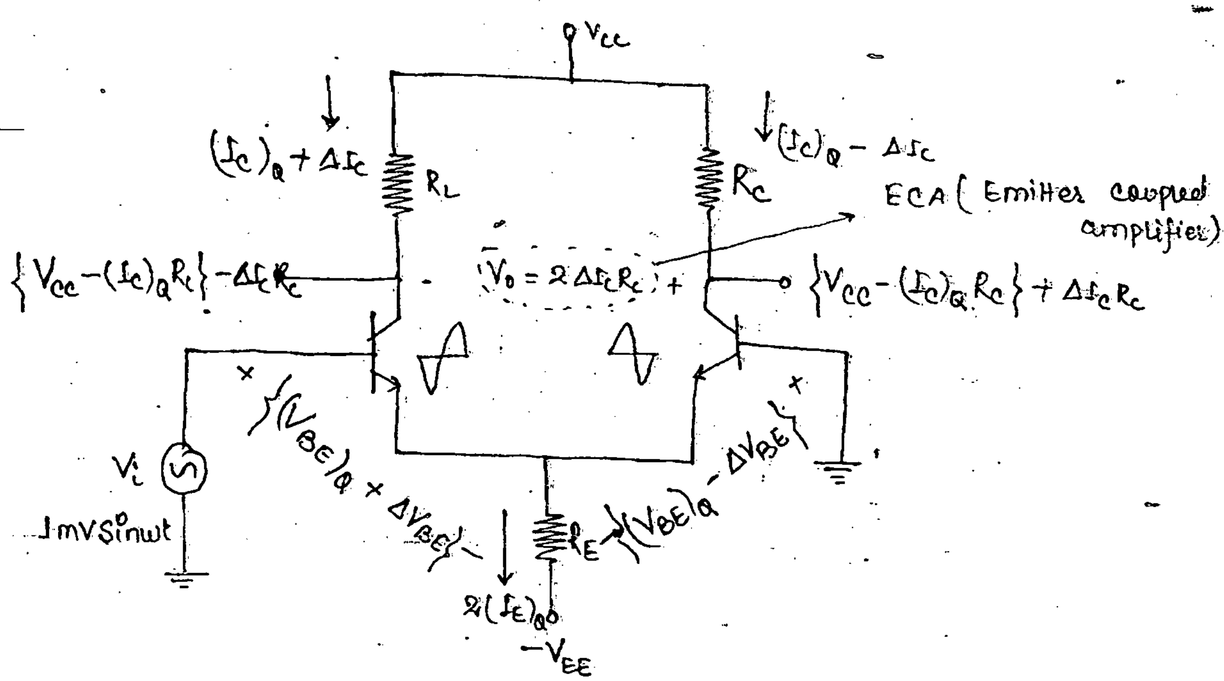
CML (current mode Logic)

⇓

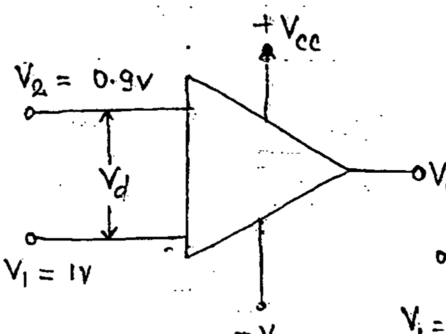
Fastest Switch.



Small Difference i/p

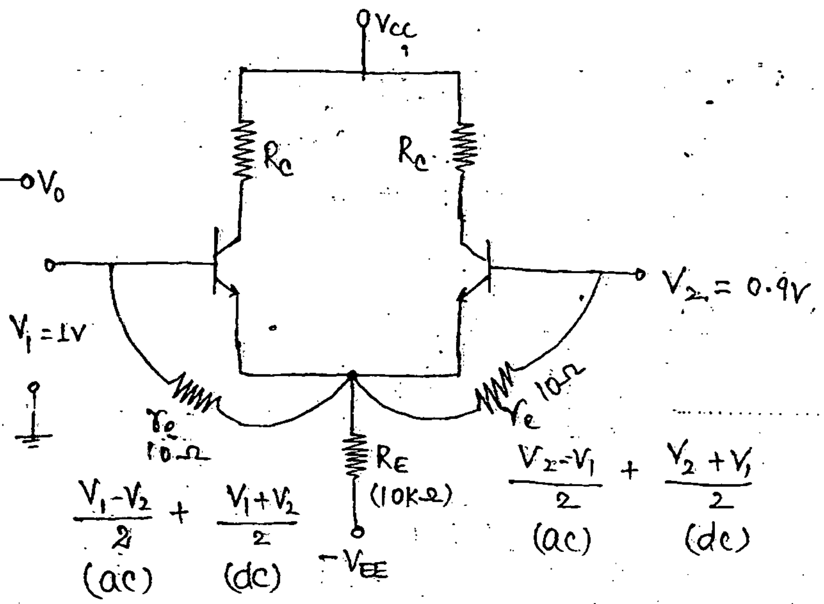


☐ MATHEMATICAL ANALYSIS OF DIFFERENTIAL AMPLIFIER



$V_d = V_1 - V_2$

$= 0.1V$



$\frac{V_1 - V_2}{2}$ (ac) $+ \frac{V_1 + V_2}{2}$ (dc)

$\frac{V_2 - V_1}{2}$ (ac) $+ \frac{V_2 + V_1}{2}$ (dc)

$V_1 = \frac{V_1 - V_2}{2} + \frac{V_1 + V_2}{2}$

$= \frac{1 - 0.9}{2} + \frac{1 + 0.9}{2}$

$= \frac{0.1}{2}$ (ac) $+ 0.95$ (dc)

$V_2 = \frac{V_2 - V_1}{2} + \frac{V_2 + V_1}{2}$

$= \frac{0.9 - 1}{2} + \frac{0.9 + 1}{2}$

$= -\frac{0.1}{2}$ (ac) $+ 0.95$ (dc)

$V_d = V_1 - V_2$

$= \frac{0.1}{2} + 0.95 - \left(-\frac{0.1}{2}\right) - 0.95$

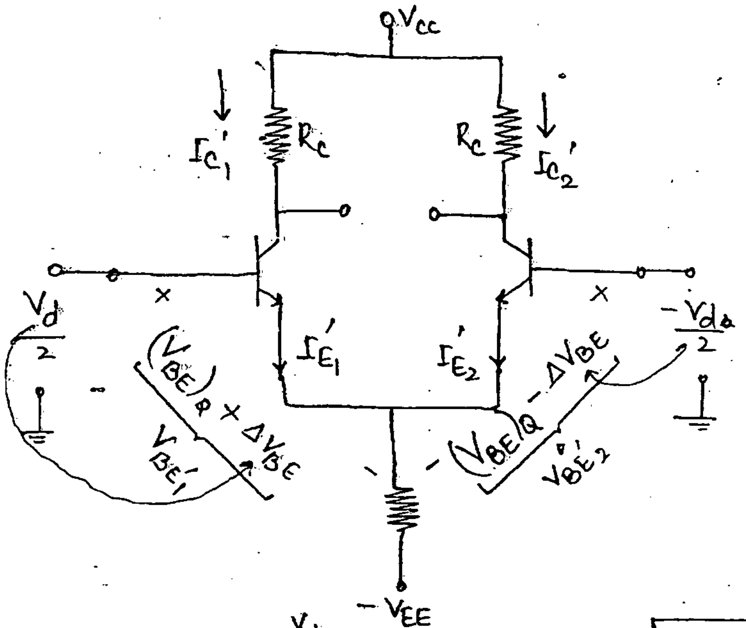
$= 0.1V$

Conclusion:- $V_d = V_1 - V_2$ (Differential voltage).

$V_c = \frac{V_1 + V_2}{2}$ (Common mode voltage).

$$\boxed{V_1 = \frac{V_d}{2} + V_c \; ; \; V_2 = -\frac{V_d}{2} + V_c}$$

TRANSFER CHARACTERISTICS OF OP-AMP.



$I_{E_1}' = (I_E)_Q + \Delta I_E$

$I_{E_2}' = (I_E)_Q - \Delta I_E$

$V_{BE_1}' = (V_{BE})_Q + \Delta V_{BE}$

$V_{BE_2}' = (V_{BE})_Q - \Delta V_{BE}$

$I_{E_1}' = I_{E_0}\, e^{V_{BE_1}'/V_T}$

$I_{E_2}' = I_{E_0}\, e^{V_{BE_2}'/V_T}$

$$\frac{I_{E_1}'}{I_{E_2}'} = e^{\overbrace{(V_{BE_1}' - V_{BE_2}')}^{V_d}/V_T} \Rightarrow \boxed{\frac{I_{E_1}'}{I_{E_2}'} = e^{V_d/V_T}}$$

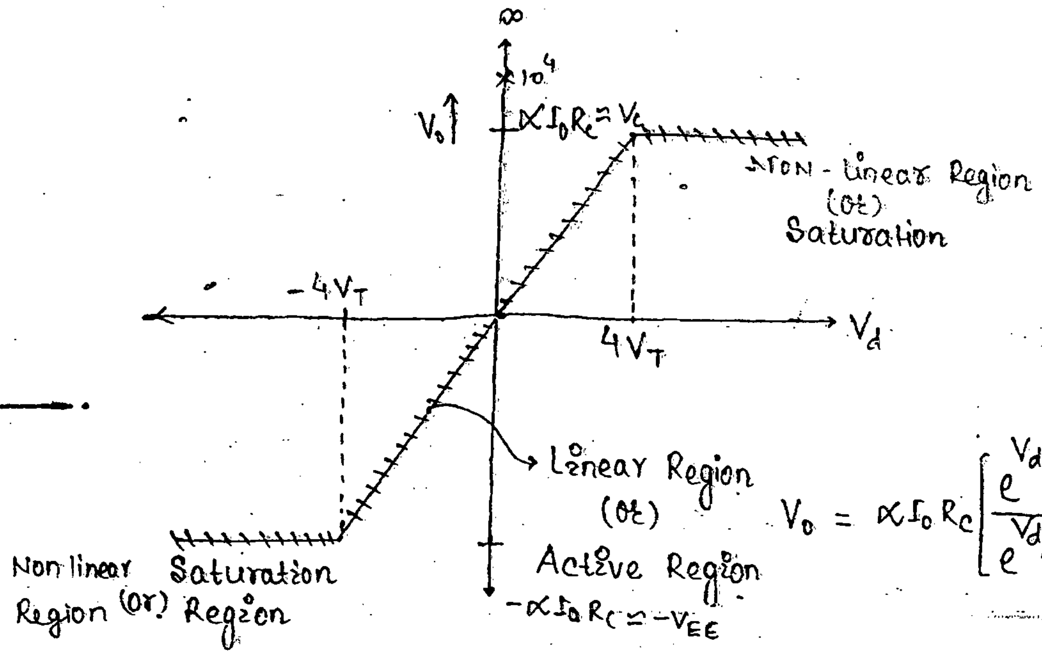
$$\frac{x}{y} = r \Rightarrow \frac{x-y}{x+y} = \frac{r-1}{r+1}$$

$$V_d = V_T \ln\left(\frac{I_{E_1}'}{I_{E_2}'}\right) \; ; \; \frac{I_{E_1}' - I_{E_2}'}{I_{E_1}' + I_{E_2}'} = \frac{[e^{V_d/V_T} - 1]}{[e^{V_d/V_T} + 1]}$$

$$I_{E_1}' - I_{E_2}' = \frac{I_{C_1}' - I_{C_2}'}{\alpha}$$

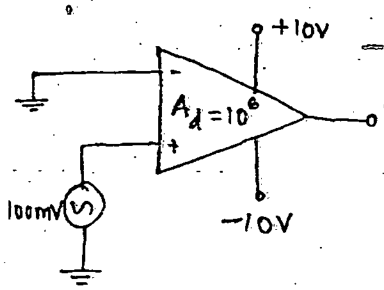
$$I_{E_1}' + I_{E_2}' = I_o (\alpha)$$

$$\frac{\overbrace{R_c(I_{C_1}' - I_{C_2}')}^{V_o}}{\alpha I_o} = \frac{(e^{V_d/V_T} - 1) R_c}{e^{V_d/V_T} + 1} \Rightarrow \boxed{V_o = \frac{\alpha I_o R_c (e^{V_d/V_T} - 1)}{(e^{V_d/V_T} + 1)}}$$



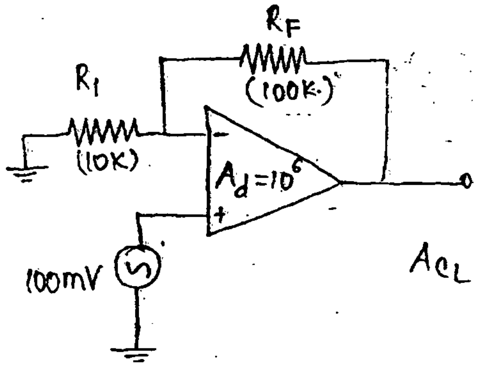
$$V_o = \alpha I_0 R_c \left[\frac{e^{V_d/V_T} - 1}{e^{V_d/V_T} + 1} \right]$$

<u>Open Loop Opamp</u> (Non - Linear)



$$V_o = A_d V_d$$
$$= 10^6 \times 10 \times 10^{-3}$$
$$= 10^4 V = 10V$$
X

Negative Feed back (Linear)
↳ amplifies.



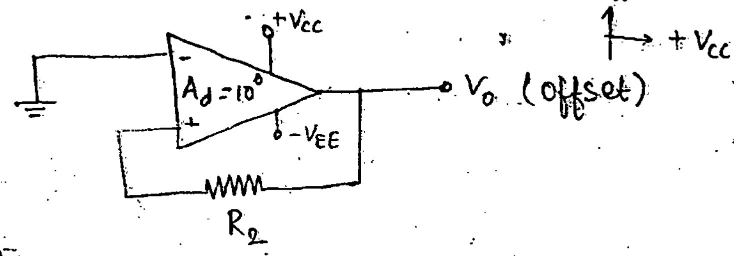
$$V_o = A_{CL} \times V_d \rightarrow 10 \times 10 \times 10^{-3}$$

$$A_{CL} := 1 + \frac{R_f}{R_1} = \cancel{1 \times 10 \times 10 \times 10^{-3}}$$

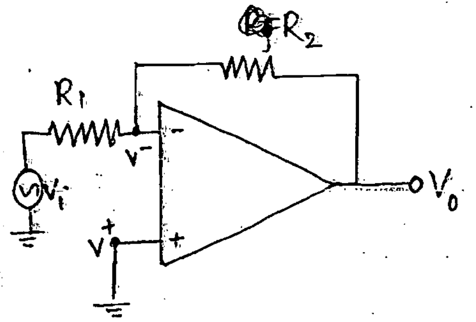
$$= 1 + \frac{100}{10K}$$

$$= 1 + 10 \approx 10$$

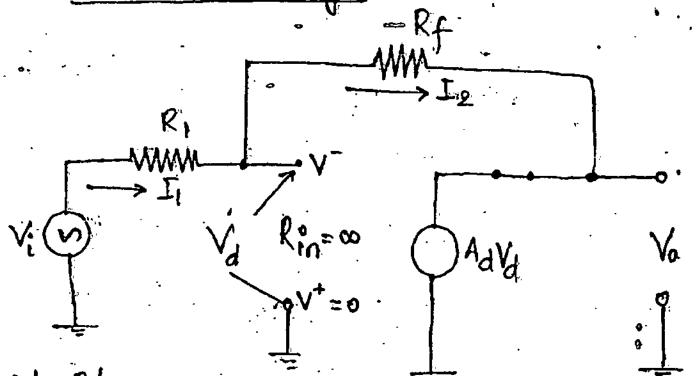
Positive Feedback (Non-Linear)



☐ VIRTUAL GROUND THEORY (VALID FOR NEGATIVE FEEDBACK)



Ideal Theory



KCL at i/p

$I_1 = I_2$

$$\frac{V_i - V^-}{R_1} = \frac{V^- - V_0}{R_2}$$

$$\frac{V_i - 0}{R_1} = \frac{0 - V_0}{R_2}$$

$$\boxed{\frac{V_o}{V_i} = -\frac{R_2}{R_1}}$$

KVL at o/p

Ideal	Practical
$V_0 = A_d V_d$	$V_o \simeq A_d V_d$
$V_d = \frac{V_0}{A_d} = \frac{V_0}{\infty} = 0$	$V_d \simeq \frac{V_0}{A_d} \simeq \frac{V_0}{10^8} \simeq 0$
$V_d = V^+ - V^- = 0$	$V_d \simeq V^+ - V^- \simeq 0$
$\boxed{V^+ = V^-}$	$\boxed{V^+ \simeq V^-}$

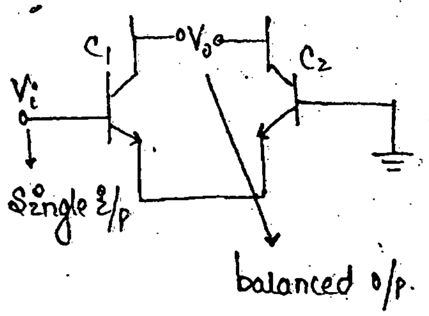
CONCLUSION :- Virtual Ground is acceptable only for (-)ve feedback.

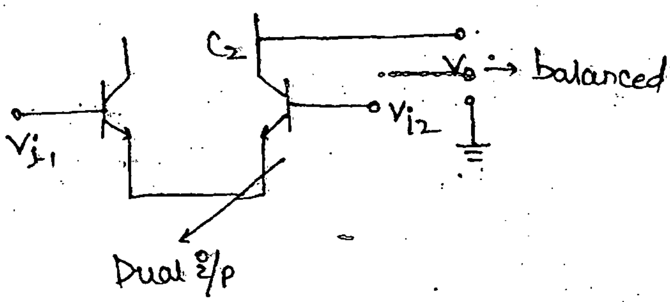
☐ DIFFERENTIAL AMPLIFIER CONFIGURATION.

At the i/p side, we have :- → Single i/p
→ Dual i/p

At the o/p side, we have :- → Balanced o/p
→ Unbalanced o/p

<u>Configurations</u> :- → Single i/p balanced o/p.
→ Single i/p unbalanced o/p
→ Dual i/p balanced o/p.
→ Dual i/p unbalanced o/p





☐ PROBLEMS IN DIFFERENTIAL AMPLIFIERS.

Q1. Calculate the voltage gain of single i/p Balanced o/p (or) Dual I/p balanced o/p differential amplifier with $R_C = 1k\Omega$ $(I_E)_Q = 26mA$.

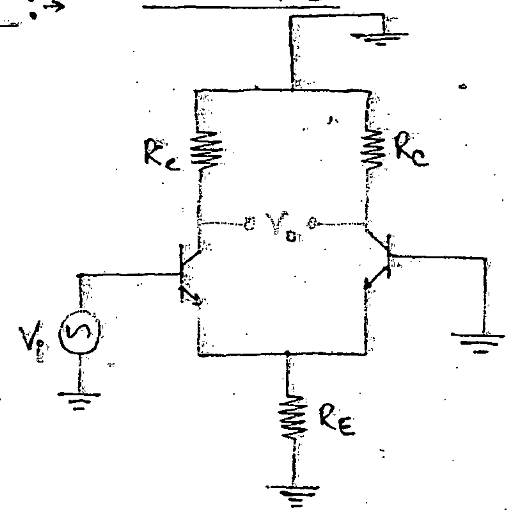
Q2. Calculate the voltage gain of single i/p unbalanced o/p (or) Dual i/p unbalanced o/p differential amplifier with $R_C = 1k\Omega$ and $(I_E)_Q = 26mA$.

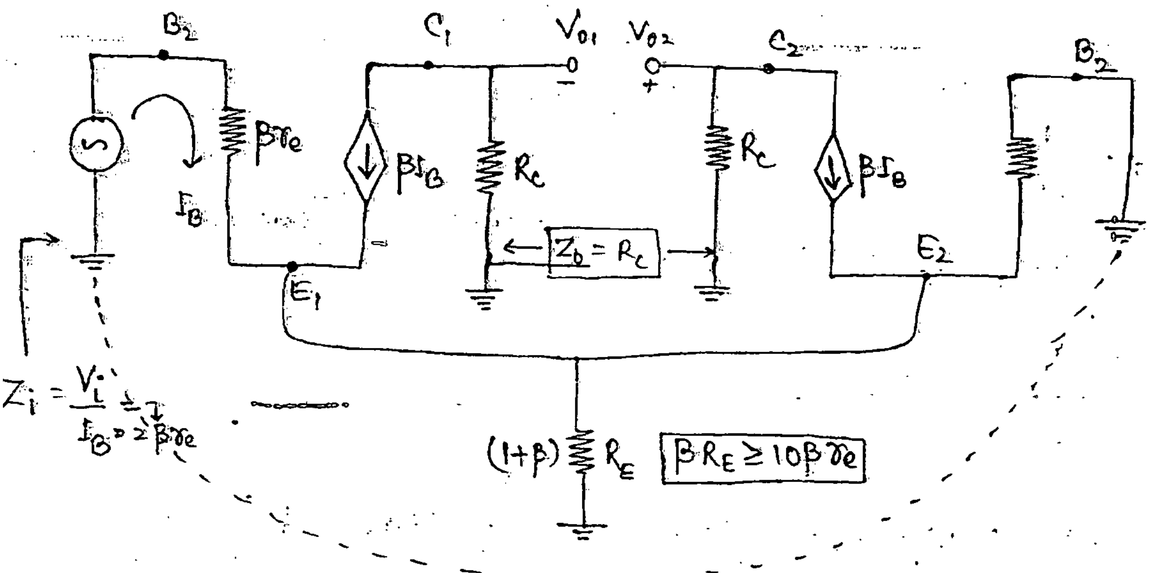
Q3. Calculate the i/p impedance of a differential amplifier with $\beta = 50$ and $(I_E)_Q = 26mA$.

Q4. Calculate the o/p impedance of a differential amplifier with $R_C = 1k\Omega$.

Q5. Design the operating point for a differential amplifier ckt.

Sol: → AC ANALYSIS





$Z_i = \dfrac{V_i}{I_B} = 2\beta r_e$

$$V_{o1} = -\beta I_B R_C$$
$$= -\beta \cdot \frac{V_i}{2\beta r_e} \cdot R_C$$

$$\boxed{A_{d_1} = \frac{V_{o1}}{V_i} = -\frac{R_C}{2r_e}}$$

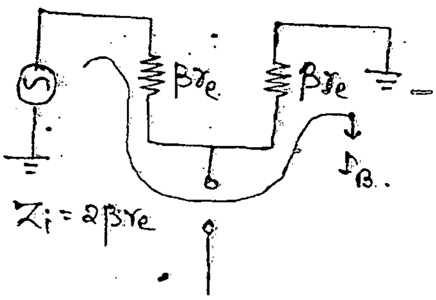
Unbalanced gain

$$\boxed{A_d = \frac{R_C}{r_e}}$$

Balanced gain.

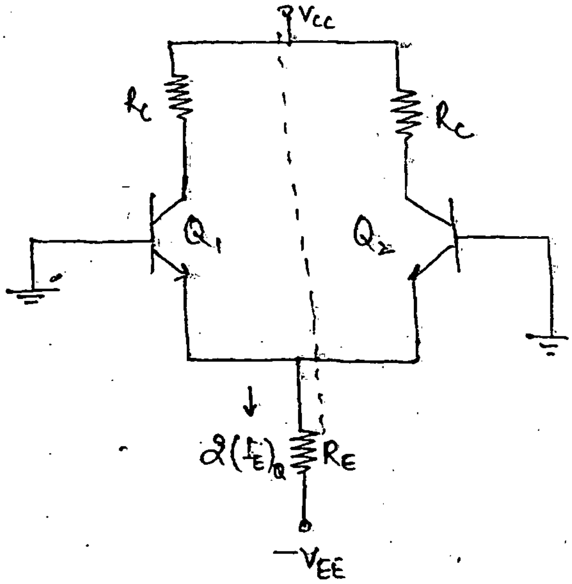
$$\boxed{A_{d_2} = \frac{V_{o2}}{V_i} = +\frac{R_C}{2r_e}}$$

Unbalanced gain



$Z_i = 2\beta r_e$

DC ANALYSIS



Q_i

$V_{EE} - V_{BE} = -2(I_E)_Q R_E$

$$\boxed{(I_E)_Q = \frac{V_{EE} - V_{BE}}{2R_E}}$$

Q1. Balanced o/p

$$A_d = \frac{R_C}{r_e}$$

$$r_e = \frac{V_1}{(I_E)_Q} = \frac{26mV}{26mA} = 1\Omega$$

$$A_d = \underline{10^3}$$

Q3. $Z_i = \beta r_e$

$= 2 \times 50 \times 1$

$= 100\Omega.$

Drawbacks :- 1. Voltage gain is not stable because of the dynamic resistance r_e.

2. The i/p impedance is low.

→ Swamping Resistor Technique :-

$$A_d = \frac{R_C}{r_e} \text{ (unstable)}$$

↓

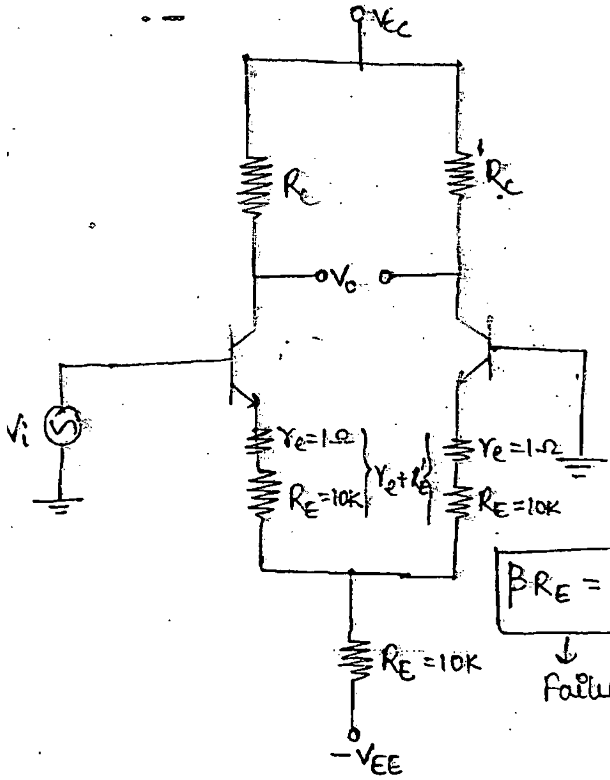
Swamping Technique

$r_e \longrightarrow r_e + R_E'$

$$A_d \doteq \frac{R_C}{r_e + R_E'}$$

$R_E' >> r_e$

$$\boxed{A_d = \frac{R_C}{R_E'}} \longrightarrow \text{Stable.}$$

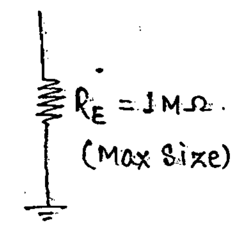


$\boxed{\beta R_E = \beta R_E'}$
↓
Failure

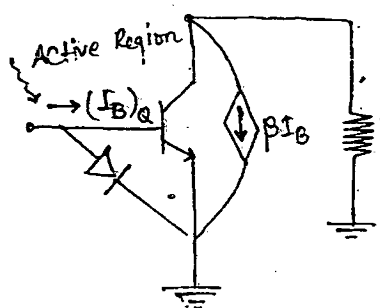
$Z_i = 2\beta r_e$ (Low Impedance)
↓
Swamping technique
$r_e \rightarrow r_e + R_E'$

$Z_i = 2\beta R_E'$
$= 2\times 50 \times 10k\Omega$
$= 1M\Omega$ (high i/p impedance)

> Replacing Resistor R_E by a transistor which gives resistance of $1M\Omega$.

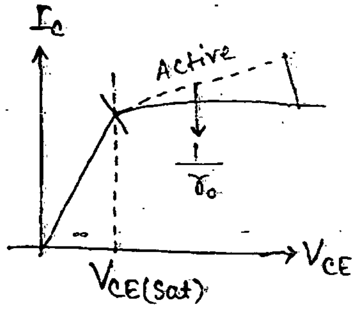


⇒

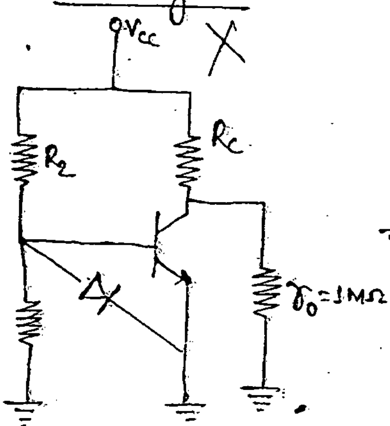


$r_o = \dfrac{V_A}{(I_C)_Q} = 1M\Omega.$

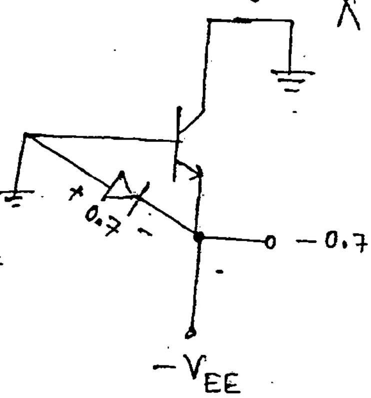
Suppose $V_A = 1000$
$(I_C)_Q = 1mA.$



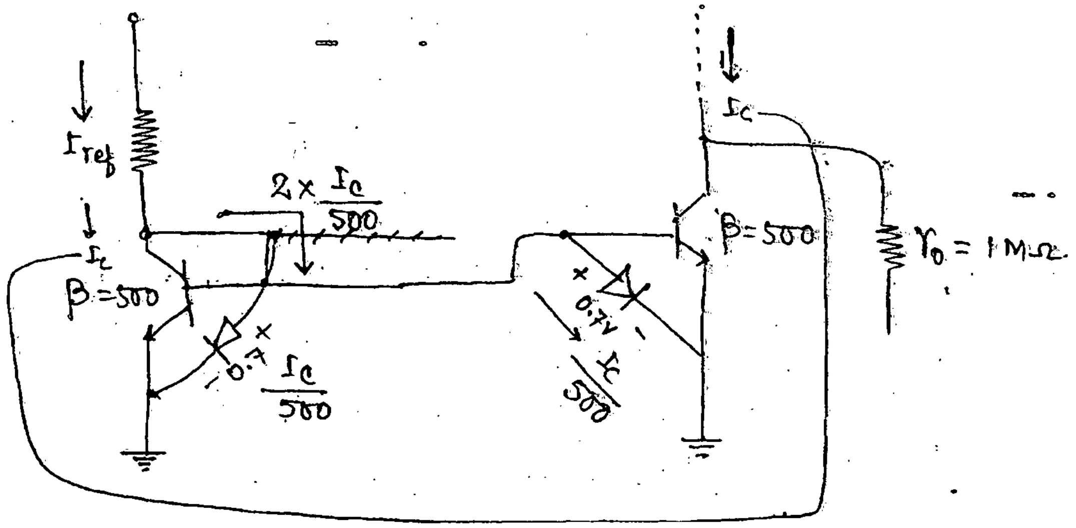
Biasing 1 ~~X~~

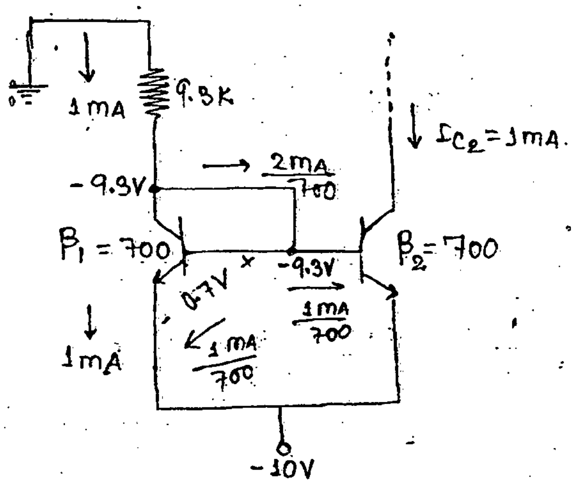


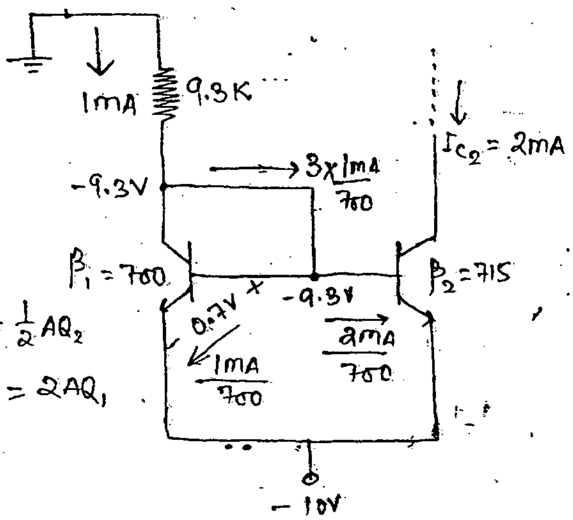
Biasing 2 ~~X~~



☐ CURRENT MIRROR BIASING. (VLSI)







$A_{Q_1} = \frac{1}{2} A_{Q_2}$

$A_{Q_2} = 2 A_{Q_1}$

Q_1			Q_2		
A_E	A_B	A_C	$2A_E$	$2A_B$	$2A_C$

$$I_E = I_0 \, e^{V_{BE}/V_T} \rightarrow Q_1$$

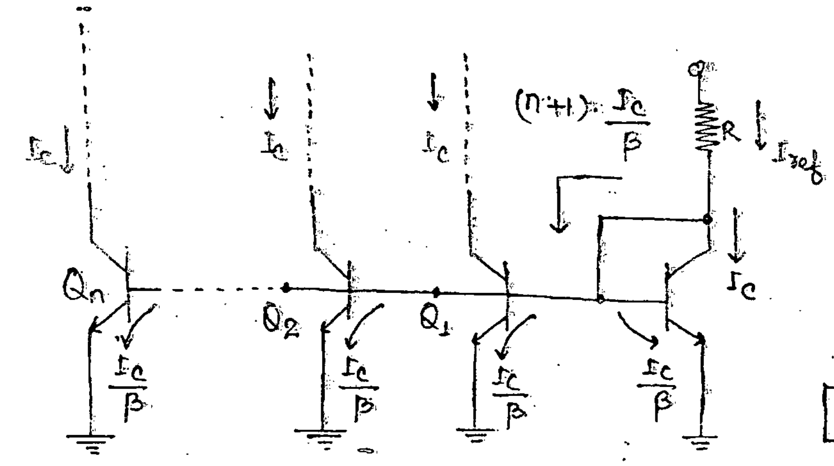
$$2I_E = 2I_0 \, e^{V_{BE}/V_T} \rightarrow Q_2$$

$$I_0 = A q \left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A} \right] n_i^2$$

$I_0 \propto$ Area.

$2I_0 \propto 2$ Area.

DRAWBACKS OF SINGLE CURRENT MIRROR.



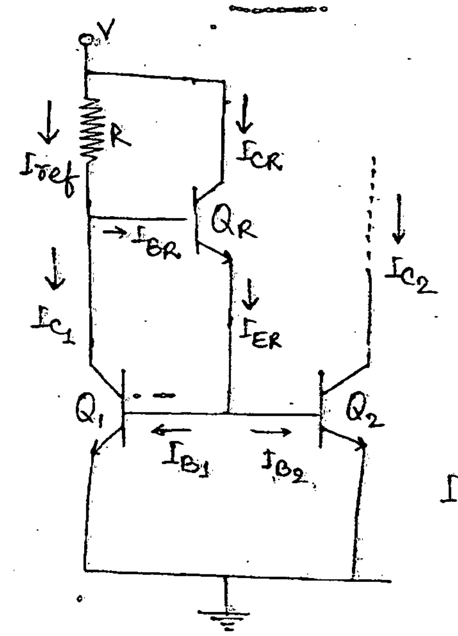
$$I_{ref} = I_C + (n+1)\frac{I_C}{\beta}$$

$$I_{ref} = I_C\left[1 + \frac{n+1}{\beta}\right]$$

$$\boxed{I_C = \frac{I_{ref}}{1 + \frac{(n+1)}{\beta}}}$$

$\boxed{n < 10}$

MODIFIED CURRENT MIRROR.



$\boxed{n > 10}$

$$I_{ref} = I_{C_1} + I_{BR}$$
$$= I_{C_1} + \frac{I_{ER}}{1+\beta}$$
$$= I_{C_1} + \frac{I_{B_1} + I_{B_2}}{1+\beta}$$

Current mirror :
$Q_1 = Q_2$

$I_{C_1} = I_{C_2}$; $I_{B_1} = I_{B_2}$; $\beta_1 = \beta_2$

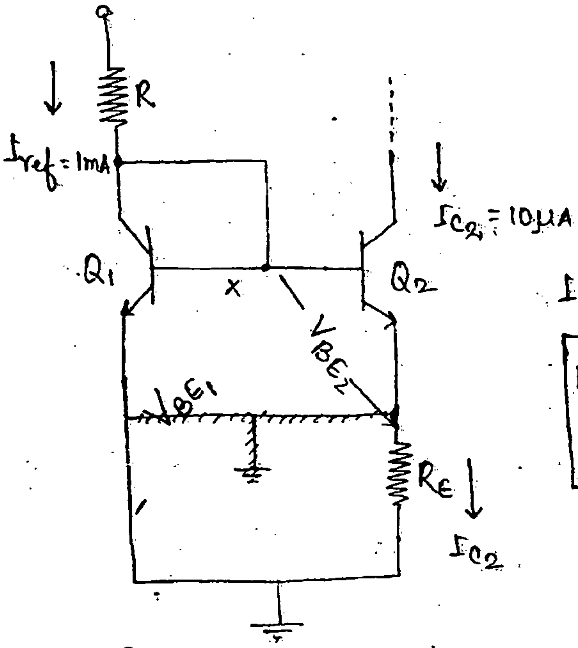
$$I_{ref} = I_{C_2} + \frac{2I_{B_2}}{1+\beta}$$
$$= I_{C_2} + \frac{2I_{C_2}}{\beta(1+\beta)}$$

$$\Rightarrow I_{ref} = I_{C_2}\left[1 + \frac{2}{\beta + \beta^2}\right] \Rightarrow \boxed{I_{C_2} = \frac{I_{ref}}{1 + \frac{2}{\beta^2}}}$$

$$\boxed{I_{C_i} = \frac{I_{ref}}{1 + \frac{(n+1)}{\beta^2}}}$$ $i = 1, 2, 3 \ldots n$

WIDLAR CURRENT SOURCE.

$$\boxed{I_{ref} \gg I_{C_2}}$$



$$V_{BE_1} = V_{BE_2} + I_{C_2} R_E$$

$$I_{C_2} R_E = V_{BE_1} - V_{BE_2}$$

$$V_{BE_1} = V_T \ln \left(\frac{I_{ref}}{I_0} \right)$$

$$V_{BE_2} = V_T \ln \left(\frac{I_{C_2}}{I_0} \right)$$

$$I_{C_2} R_E = V_T \ln \left(\frac{I_{ref}}{I_{C_2}} \right)$$

$$\boxed{R_E = \frac{V_T \ln \left(\frac{I_{ref}}{I_{C_2}} \right)}{I_{C_2}}}$$

$$R_E = \frac{0.026 \ln \left(\frac{1mA}{10\mu A} \right)}{10\mu A} = k\Omega.$$

CMRR (COMMON MODE REJECTION RATIO).

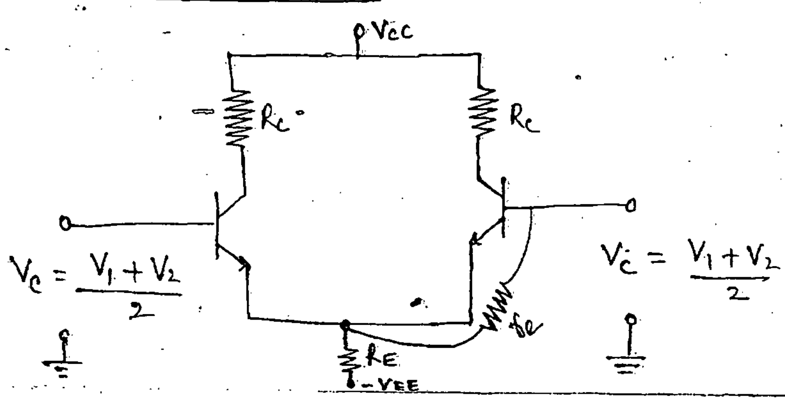
$$\boxed{CMRR = \frac{A_d}{A_c} = 10^6}$$

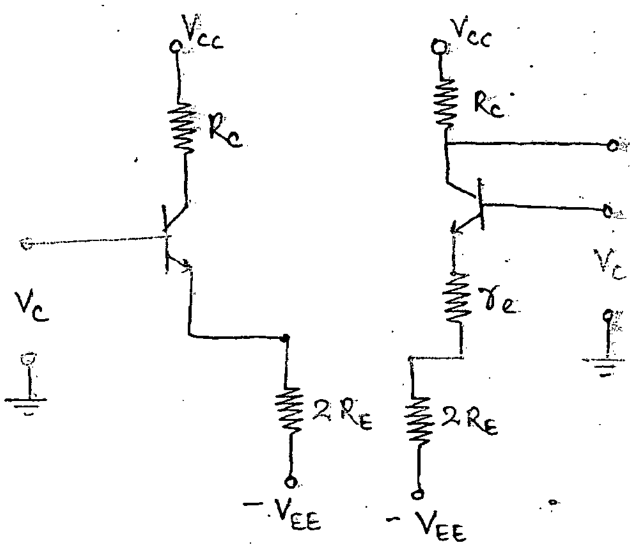
$$|CMRR|_{dB} = 20 \log \frac{A_d}{A_c}$$

$$= 20 \log 10^6$$

$$\boxed{|CMRR|_{dB} = 120 dB}$$

COMMON MODE GAIN AC





$$A_c = \frac{-R_C}{r_e + 2R_E}$$

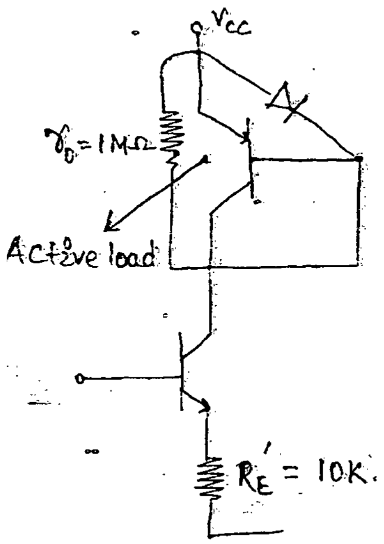
$$\boxed{A_c = \frac{-R_C}{2R_E}} \rightarrow \text{unbalanced}$$

$$\boxed{A_d = \frac{-R_C}{2r_e}} \rightarrow \text{unbalanced}$$

$$CMRR = \frac{A_d}{A_c} = \frac{-R_C/2r_e}{-R_C/2R_E} = \frac{R_E}{r_e}$$

$$\boxed{CMRR = \frac{R_E}{r_e} = g_m R_E}$$

DIFFERENTIAL GAIN IMPROVEMENT BY ACTIVE LOAD.



Passive load R_C.

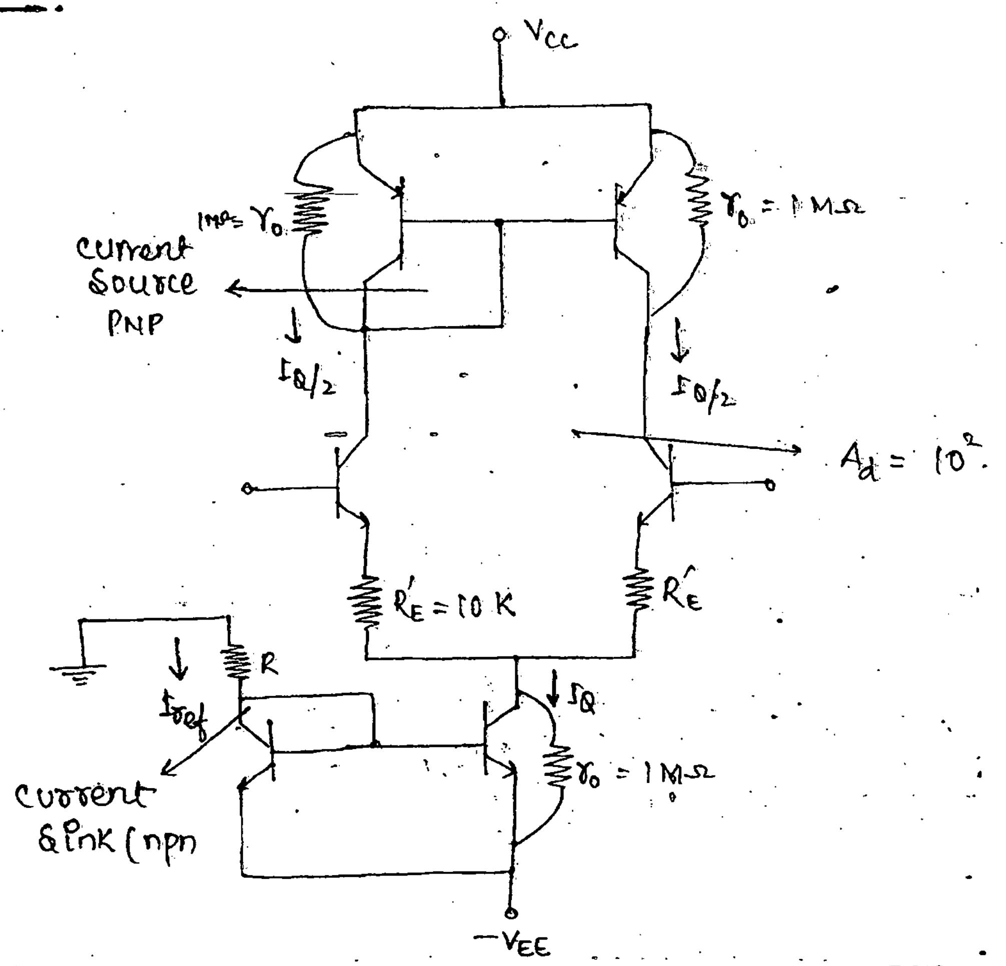
$$A_d = \frac{R_C}{R_E'} = \frac{10K}{10K\Omega} = 1.$$

Active load r_o

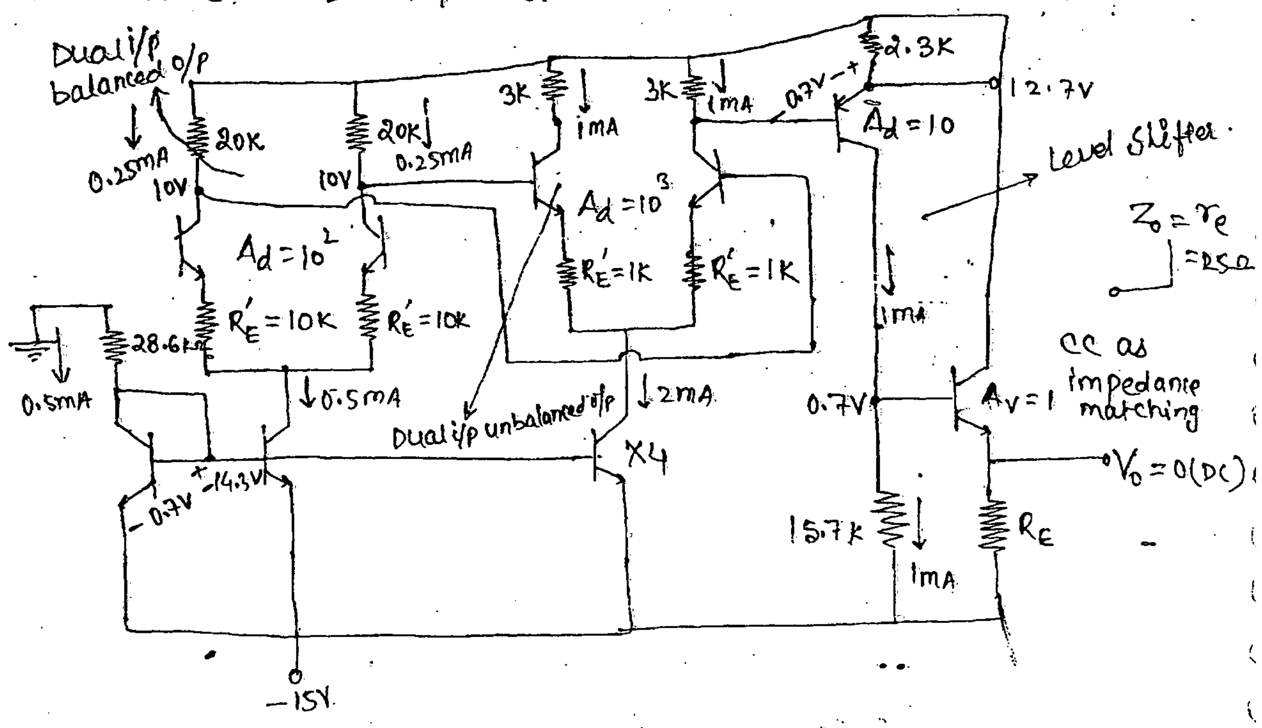
$$A_d = \frac{R_C}{R_E'} = \frac{r_o}{R_E'} = \frac{1M\Omega}{1K\Omega} = 100.$$

INTEGRATED IC DIFFERENTIAL AMPLIFIER

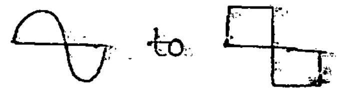
INTEGRATED IC DIFFERENTIAL AMPLIFIER

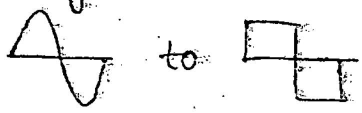


TYPICAL DESIGN OF AN OP AMP.



NON LINEAR APPLICATIONS.

→ ZCD (Zero Crossing Detector). 

→ Schmitt Trigger. 

→ Bistable ~~Trigger~~ Multivibrator (Flip Flop).

→ Astable Multivibrator (oscillator). Function Generator.

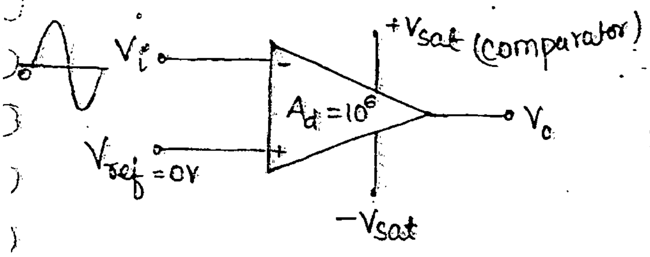
→ RC oscillators ⟶ (a) RC phase shift oscillator } audio frequ. oscillat.
(b) Wein bridge oscillators

→ LC oscillators ⟶ (a) Harthey } Radio Frequency oscillators
(b) Colpits

→ Monostable Multivibrator. (Pulse generator)

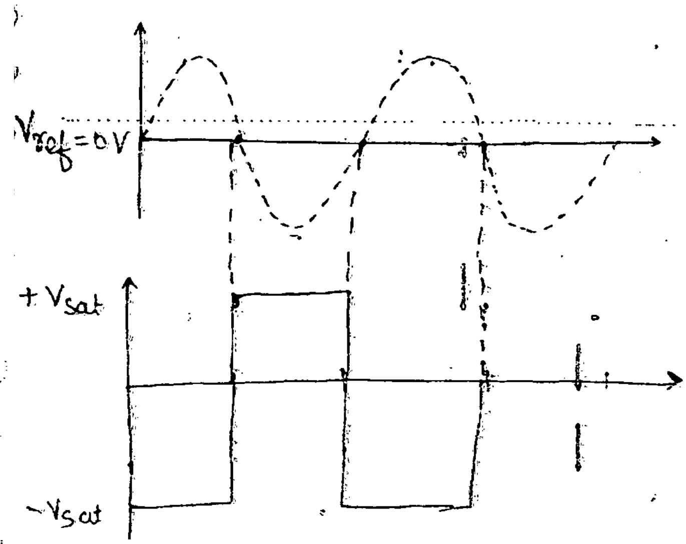
→ 555 timer.

ZCD (ZERO CROSSING DETECTOR)



$V_i < V_{ref} \rightarrow V_d$ (+)ve $\rightarrow V_o = (+) V_{sat}$

$V_i > V_{ref} \rightarrow V_d$ (−)ve $\rightarrow V_o = -V_{sat}$.

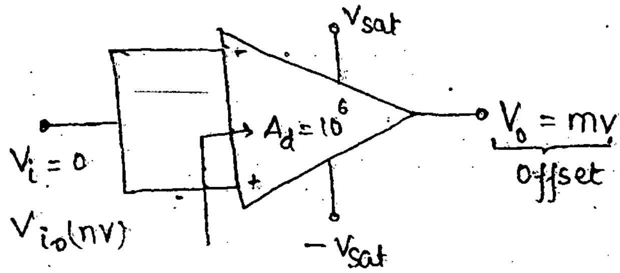


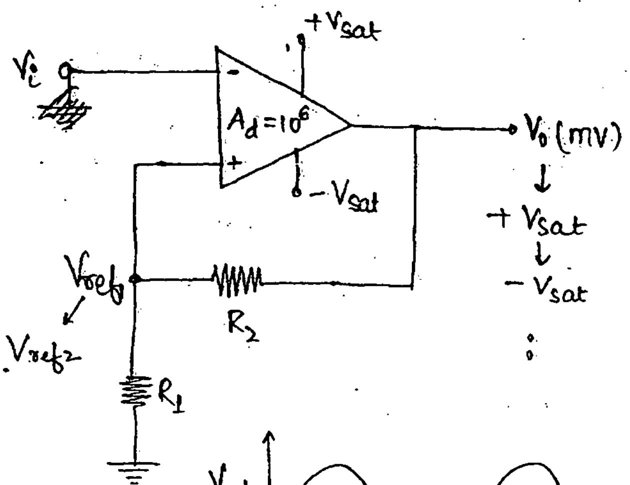
SCHMITT TRIGGER

OFFSET

V_{io} = i/p offset voltage

I_{io} = i/p offset current.





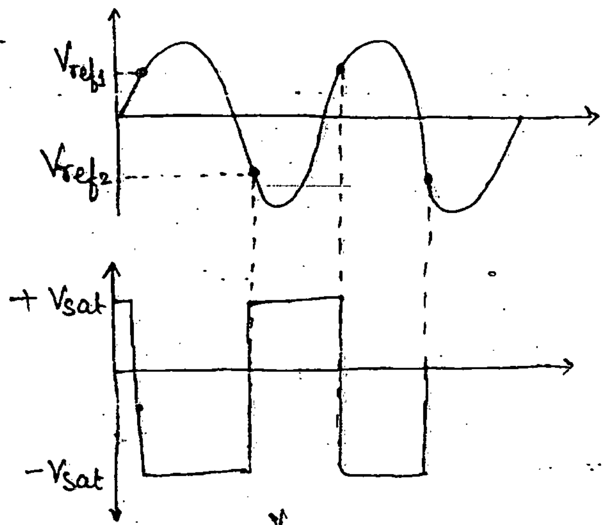
$$\underline{V_0 = (+)V_{sat}}$$

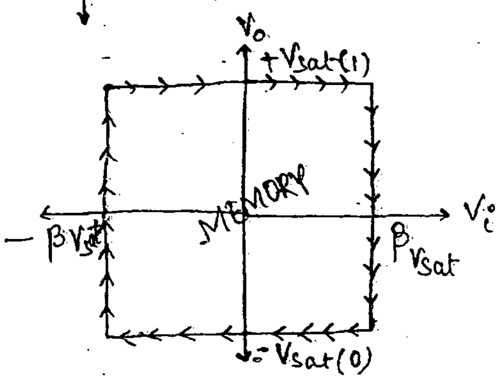
$$V_{ref_1} = +V_{sat} \times \frac{R_1}{R_1+R_2}$$

$$\underline{V_0 = -V_{sat}}$$

$$V_{ref_2} = -V_{sat} \times \frac{R_1}{R_1+R_2}$$

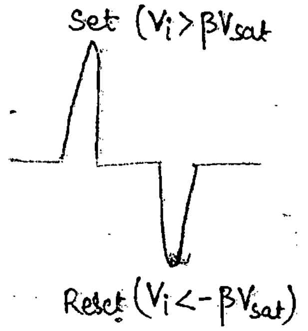
* Schmitt trigger creates V_{ref} itself.

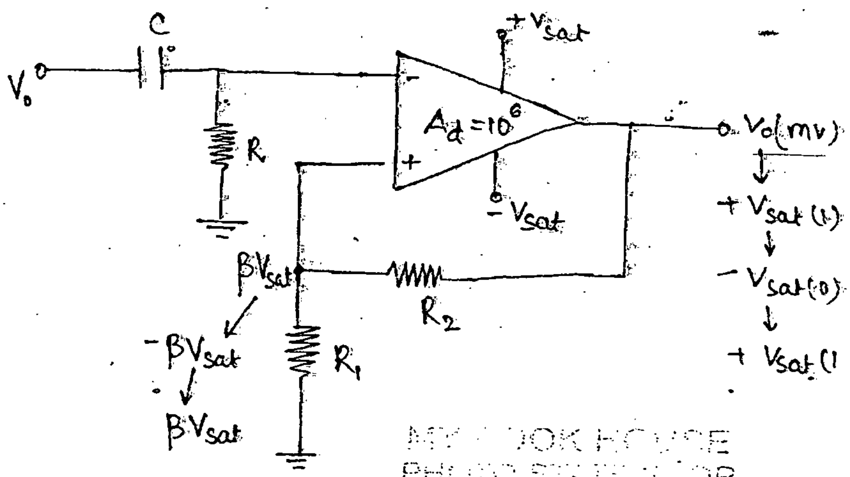




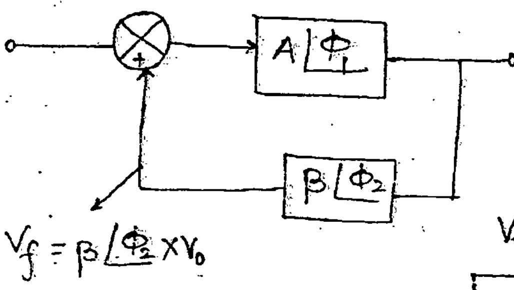
BISTABLE MULTIVIBRATOR.

(Flip flop)





OSCILLATORS.



$$V_0 = A\angle\Phi_1 \left\{ V_i + V_0 \beta \angle\Phi_2 \right\}$$

$$V_0 = A\angle\Phi_1 V_i + A\beta \angle\Phi_1+\Phi_2 \cdot V_0$$

$$V_0(1 - A\beta\angle\Phi_1+\Phi_2) = A\angle\Phi_1 \cdot V_i$$

$$\boxed{\frac{V_0}{V_i} = \frac{A\angle\Phi_1}{1 - A\beta\angle\Phi_1+\Phi_2}}$$

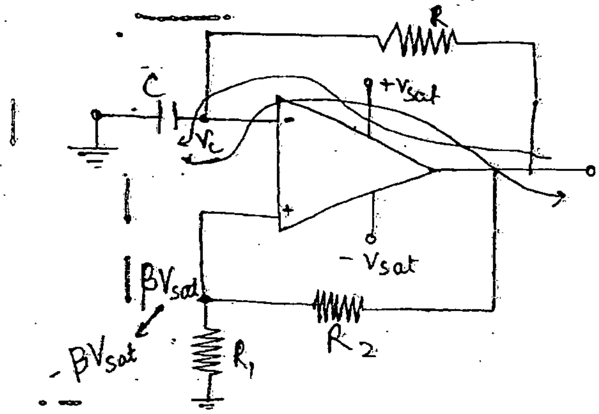
$0 \leftarrow$ $\quad$ $\rightarrow 0$

$$1 - A\beta\angle\Phi_1+\Phi_2 = 0$$

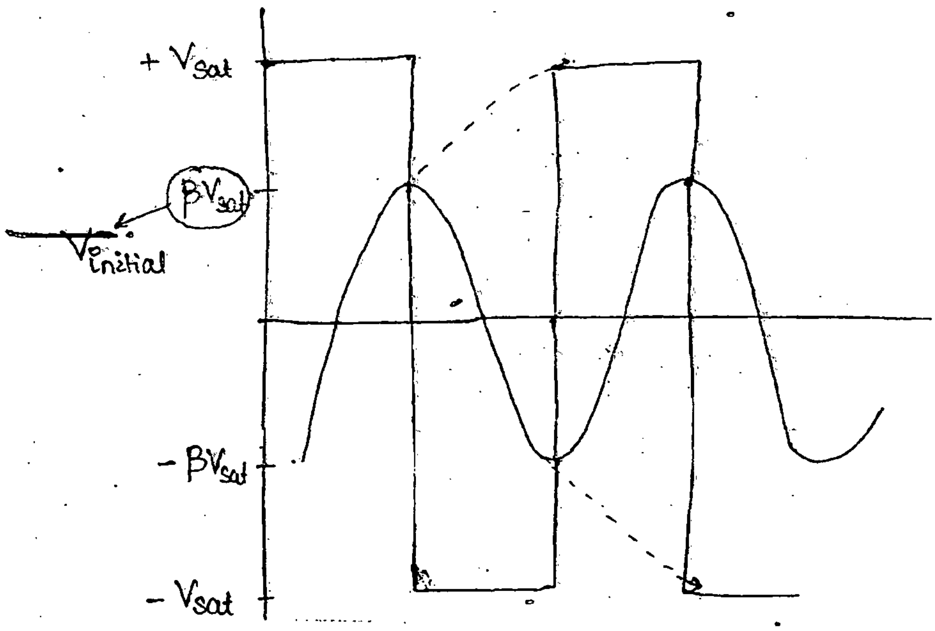
(1) $A\beta = 1$
(2) $\angle\Phi_1+\Phi_2 = 0^\circ$ (or) multiples of 2π

} Barkhausen Criteria.

~~B~~ ASTABLE MULTIVIBRATOR.



$V_0 = +V_{sat}$
$\downarrow$
$-V_{sat}$



$$V_c = V_{final} + [V_{initial} - V_{final}]\, e^{-t/RC}$$

AT: $T = T_2$

$$-\beta V_{sat} = -V_{sat} + (\beta V_{sat} + V_{sat})\, e^{-T_2/RC}$$

$$(1-\beta)\, V_{sat} = (1+\beta)\, V_{sat}\, e^{-T_2/RC}$$

$$T_2 = RC \ln\left(\frac{1+\beta}{1-\beta}\right)$$

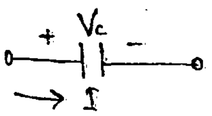
$$T_1 = RC \ln\left(\frac{1+\beta}{1-\beta}\right)$$

$$T = 2RC\ln\left(\frac{1+\beta}{1-\beta}\right) \Rightarrow \boxed{f = \frac{1}{2RC\ln\left(\frac{1+\beta}{1-\beta}\right)}}$$

where $\beta = \dfrac{R_1}{R_1+R_2}$

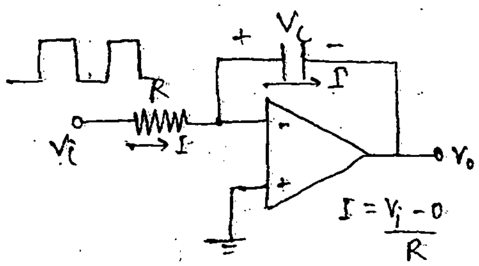
▣ TRIANGULAR WAVE GENERATOR.

INTEGRATOR.



$$\boxed{V_c = \frac{-1}{C}\int I\,dt}$$

V_0 V_i



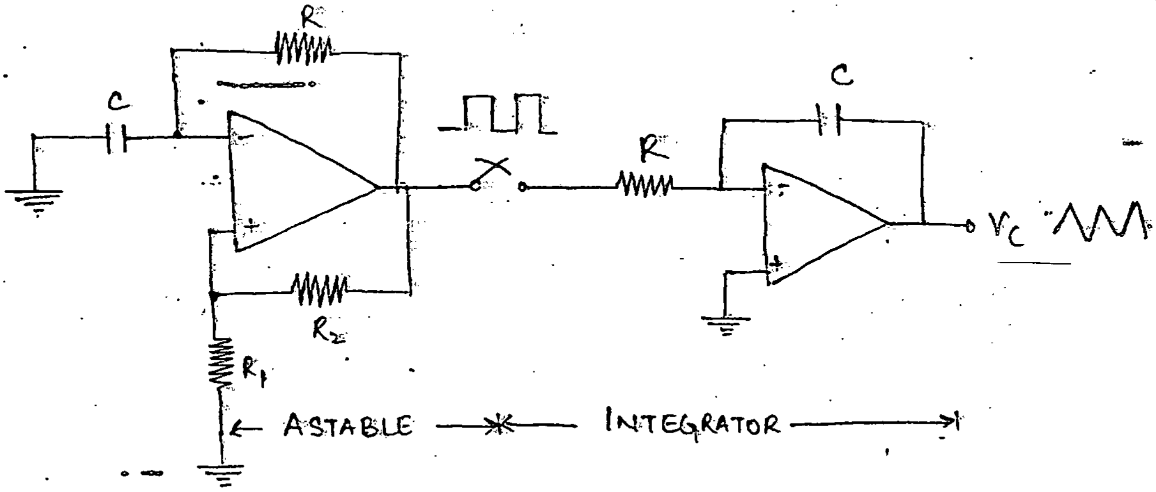
$$I = \frac{V_i - 0}{R}$$

$$\Rightarrow 0 - V_0 = V_c$$

$$\Rightarrow V_0 = -V_c$$

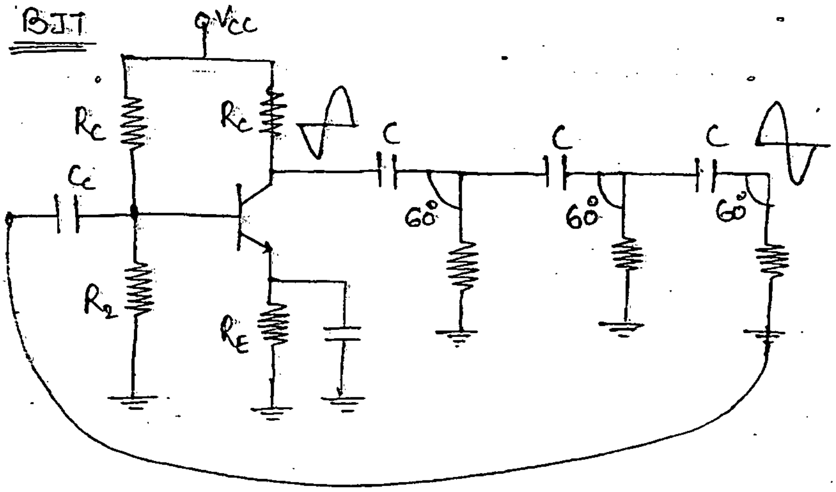
$$V_0 = \frac{-1}{C}\int I\,dt$$

$$\boxed{V_0 = -\frac{1}{RC}\int V_i\,dt}$$



RC PHASE SHIFT OSCILLATOR.

BJT



(1) $\underset{180^\circ}{\phi} + \underset{180^\circ}{3 \text{ sets of RC}} = 360^\circ$

(2) $f = \dfrac{1}{2\pi RC\sqrt{6+4K}}$

where $K = R_c/R$

$K = 1$ $\quad f = \dfrac{1}{2\pi RC\sqrt{10}}$

$K << 1$ $\quad f = \dfrac{1}{2\pi RC\sqrt{6}}$

(3) $-h_{fe}\dfrac{R_c}{R} = -29 - 23K - 4K^2.$

$K << 1$

$\boxed{A = -29}$ $\quad \boxed{\beta = -\frac{1}{29}}$ $\quad \phi = 180^\circ$

(4) $h_{fe\,min} = 44.5$

$h_{fe} = \dfrac{29}{K} + 23 + 4K$

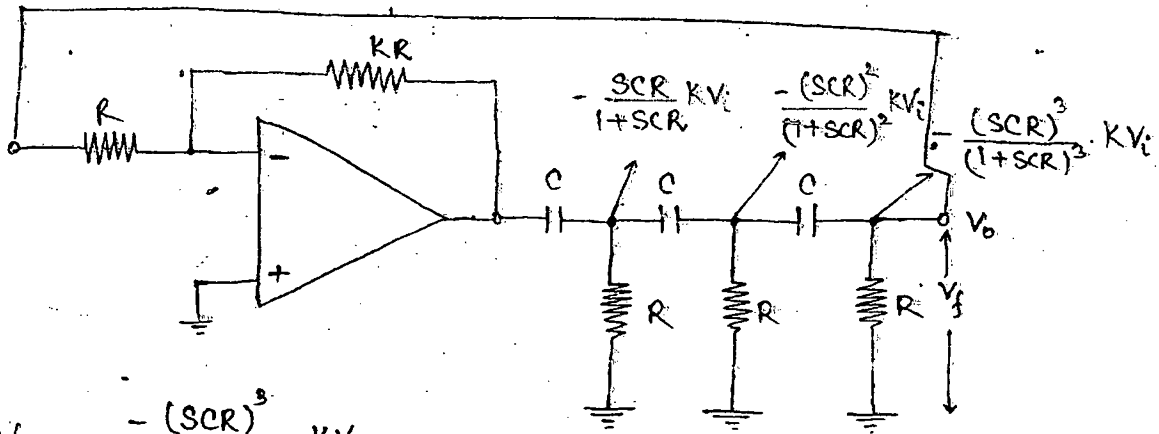
d.w.r. to K

$\dfrac{\partial h_{fe}}{\partial t} = -\dfrac{29}{K^2} + 4 = 0$

$K = 2.8$

$h_{fe} = 44.5.$

OP-AMP



CONV.

$$V_f = \frac{-(SCR)^3}{(1+SCR)^3} \cdot KV_i$$

$$\Rightarrow V_i = \frac{-(SCR)^3}{(1+SCR)^3} KV_i$$

$$\Rightarrow (1+SCR)^3 + (SCR)^3 K = 0$$

$$\Rightarrow 1 + 3S^2C^2R^2 + 3SCR + (SCR)^3(K+1) = 0$$

$$\Rightarrow 1 - 3\omega^2C^2R^2 + 3j\omega CR - j\omega^3R^3C^3(K+1) = 0.$$

Real part

$$\Rightarrow 1 - 3\omega^2C^2R^2 = 0$$

$$\boxed{\omega_0 = \frac{1}{\sqrt{3}RC}}$$

$$\boxed{f_0 = \frac{1}{2\pi RC\sqrt{3}}}$$

Imaginary part.

$$3 - \omega_0^2C^2R^2(K+1) = 0$$

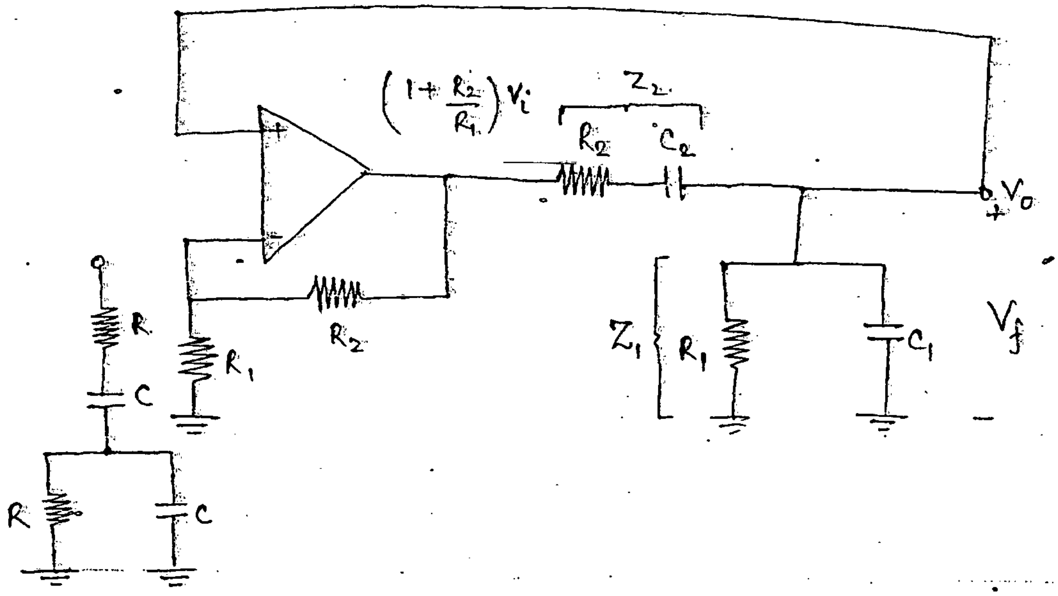
$$3 - \frac{1}{3R^2C^2} \cdot C^2 \cdot R^2 (K+1) = 0$$

$$K+1 = 9 \Rightarrow \boxed{K = 8}$$

CONCLUSIO DRAWBACKS:- 1. RC Phase Oscillator can be used for audio frequency (20Hz - 20KHz) because quality factor of RC N/W is multiples of 10.

2. This CKt can't be used for variable frequency operation because the β is depending on phase.

WEIN BRIDGE OSCILLATOR.



$$V_f = \left(1+\frac{R_2}{R_1}\right)V_i \times \frac{Z_1}{Z_1+Z_2}$$

$$= \left(1+\frac{R_2}{R_1}\right)V_i \cdot \frac{1}{1+Z_2Y_1}$$

$$V_i = \frac{\left(1+\frac{R_2}{R_1}\right)V_i}{1+\left[R_2+\frac{1}{sC_2}\right]\left[\frac{1}{R_1}+sC_1\right]}$$

$$V_i = \frac{\left(1+\frac{R_2}{R_1}\right)V_i}{1+\frac{R_2}{R_1}+\frac{C_1}{C_2}+\frac{1}{sC_2R_1}+sC_1R_2}$$

$$1 = \frac{\left(1+\frac{R_2}{R_1}\right)}{1+\frac{R_2}{R_1}+\frac{C_1}{C_2}+j\left(\omega C_1R_2-\frac{1}{\omega C_2R_1}\right)}$$

Imaginary part $= 0$.

$$\Rightarrow \omega C_1R_2 = \frac{1}{\omega C_2R_1} \qquad f_0 = \frac{1}{2\pi RC}$$

$$\Rightarrow \omega^2 = \frac{1}{R_1R_2C_1C_2}$$

$$\omega_0 = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$R_1 = R_2 = C$

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

$$1 + \frac{R_2}{R_1} = 3$$

$$\boxed{R_2 = 2R_1}$$

↓

Bridge balance

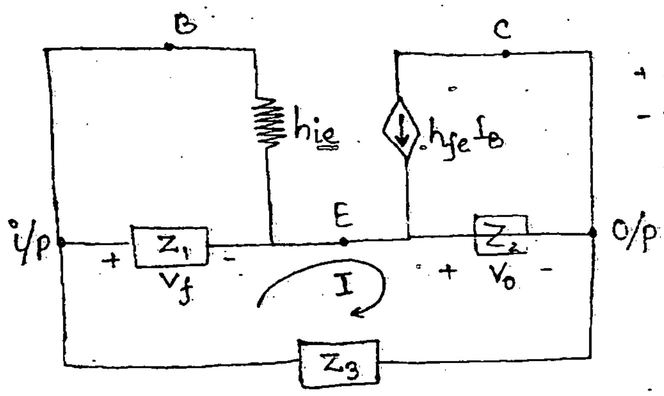
$\Phi = 0^\circ$.

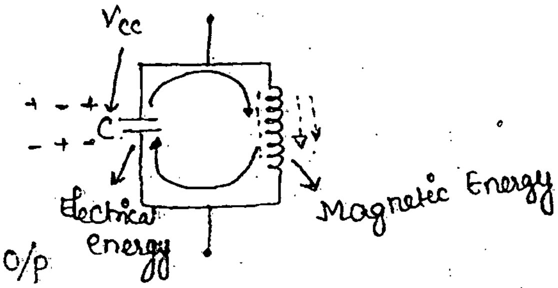
$$1 + \frac{R_2}{R_1} = 1 + \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

$$\boxed{A_v = 3}$$

09/11/14.

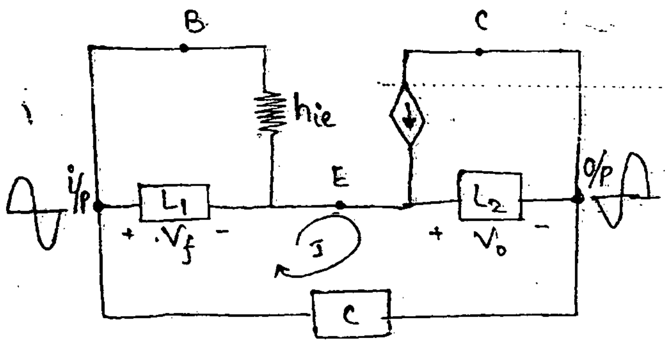
LC OSCILLATORS.
(Two port Network).





Quality factor, $\boxed{Q = n \times 100}$

Hartely oscillator (MHZ)



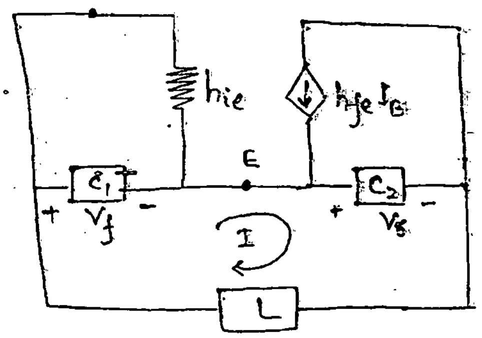
$$f = \frac{1}{2\pi\sqrt{L_T C}}$$

$$L_T = L_1 + L_2$$

$$\beta = \frac{V_f}{V_o} = \frac{I \times L_1}{I \times L_2} = \frac{L_1}{L_2}$$

$$\boxed{A = \left|\frac{L_2}{L_1}\right.}$$

Colpitts oscillators.
(MHZ)



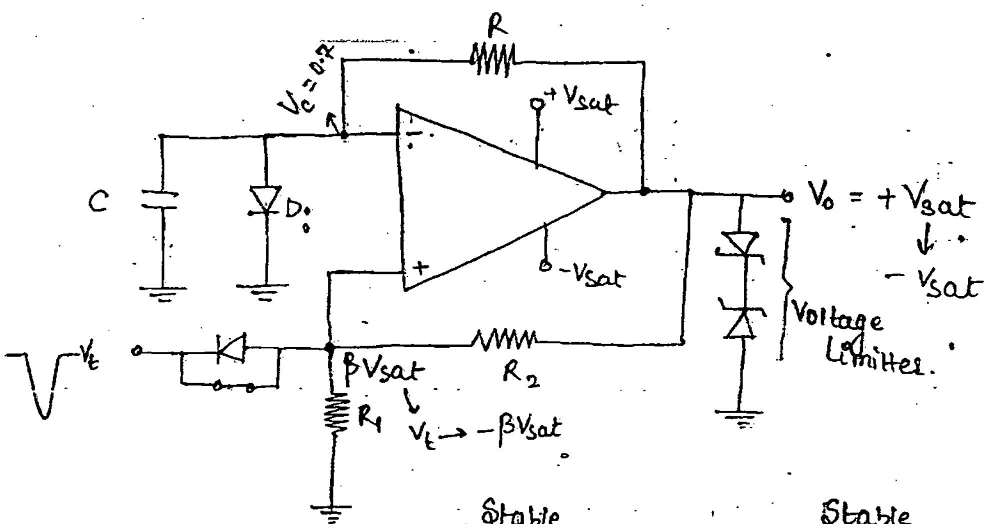
$$f = \frac{1}{2\pi\sqrt{LC_T}}$$

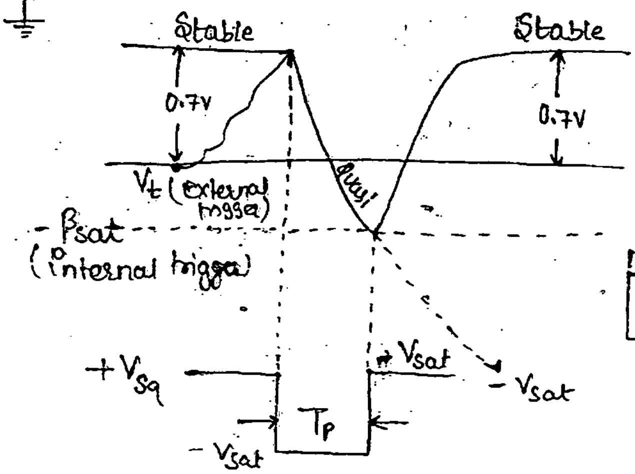
$$C_T = \frac{C_1C_2}{C_1+C_2}$$

$$\beta = \frac{V_f}{V_o} = \frac{I\times C_1}{I\times C_2} = \frac{C_2}{C_1}$$

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

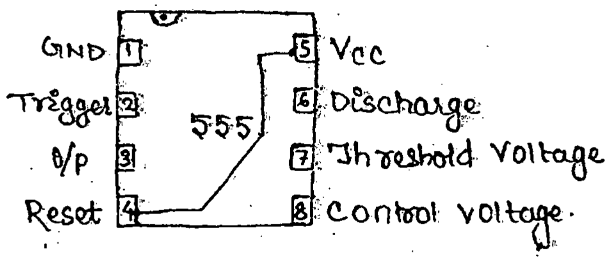
MONOSTABLE MULTIVIBRATOR.





$$\boxed{T_p = 0.693RC}$$

555 TIMER



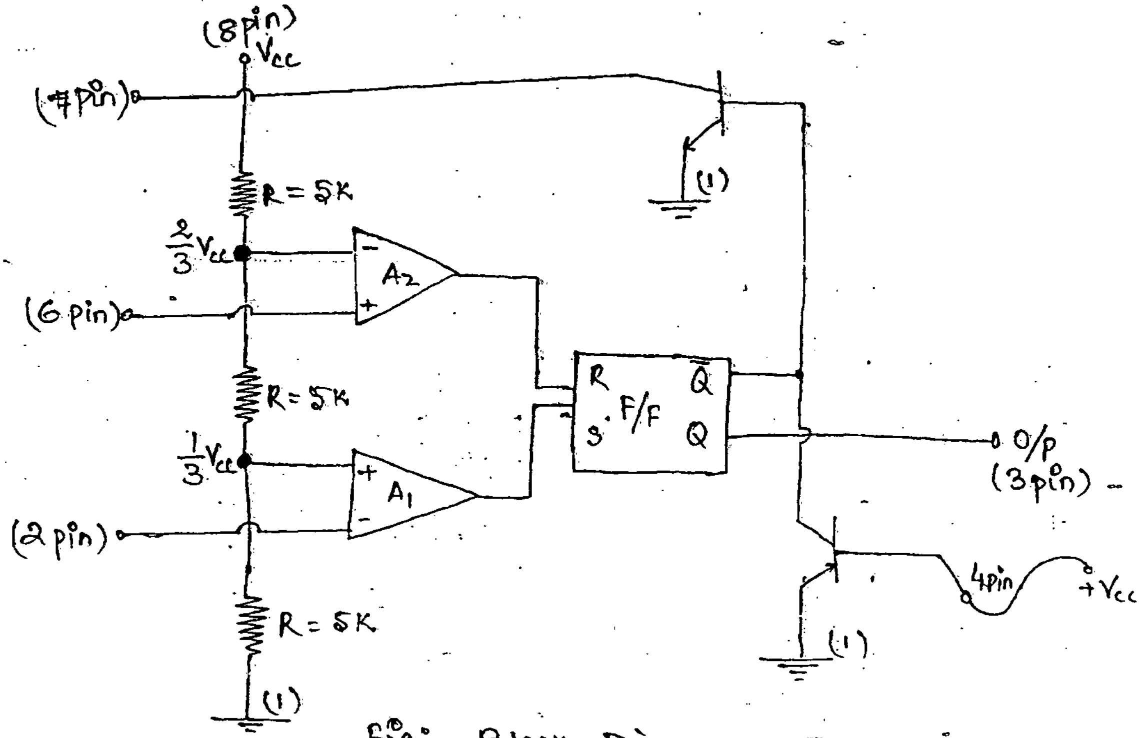
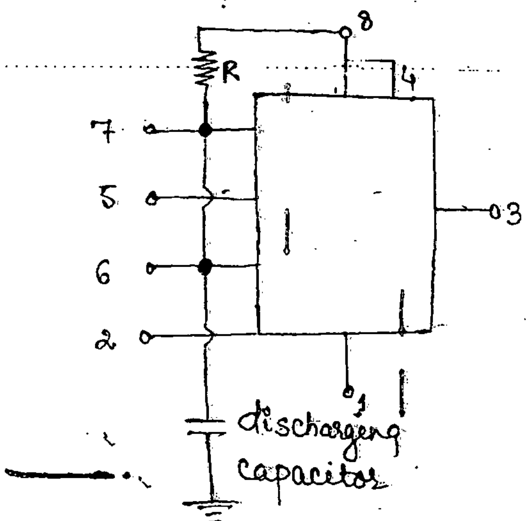
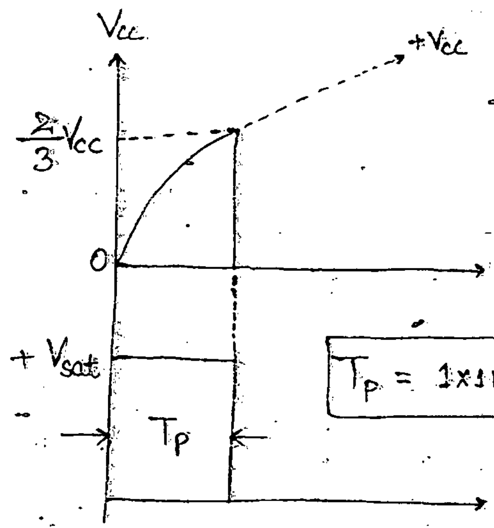


Fig:- Block Diagram

MONOSTABLE 555 TIMER :-

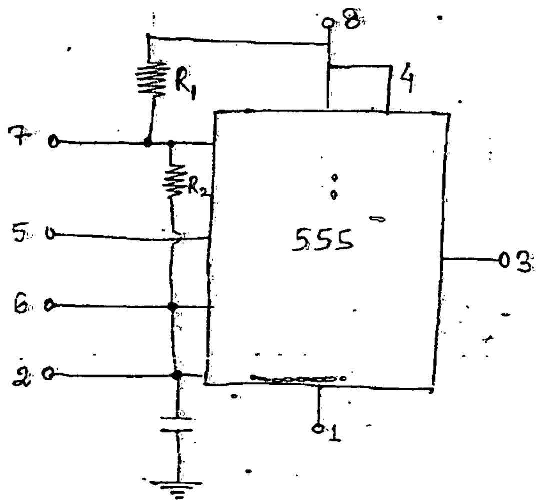


condition	Q	$\overline{Q}$	O/p	capacitor Position
Standby	0	1	0	$V_c = 0$ (Stable)
Trigger < $\frac{1}{3}V_{cc}$	1	0	1	$V_c = \frac{2}{3}V_{cc}$ (Quasi)
$V_c > \frac{2}{3}V_{cc}$	0	1	0	$V_c = 0$ (Stable

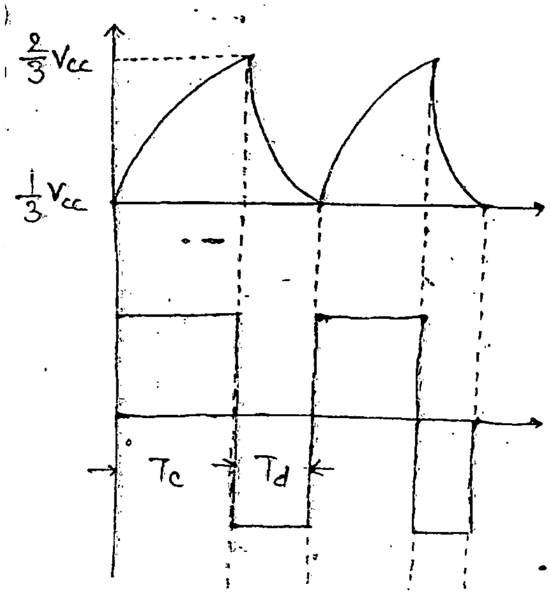


$\boxed{T_p = 1x1RC}$

ASTABLE 555 TIMER.



condition	Q	$\overline{Q}$	O/P	capacitor position
Standby	0	1	0	$V_c = \frac{1}{3}V_{cc}$
$V_c < \frac{1}{3}V_{cc}$	1	0	1	$V_c = \frac{2}{3}V_{cc}$
$V_c > \frac{2}{3}V_{cc}$	0	1	0	$V_c = \frac{1}{3}V_{cc}$



$$T_c = 0.693\,(R_1 + R_2)\,C$$

$$T_d = 0.693\,R_2 C$$

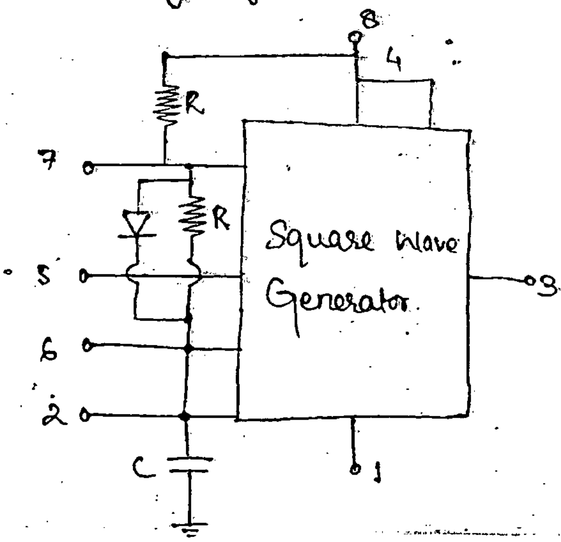
$$T = T_c + T_d = 0.693\,(R_1 + 2R_2)\,C$$

$$\boxed{D.C = \frac{T_c}{T} = \frac{R_1 + R_2}{R_1 + 2R_2}}$$

Duty cycle.

Question :- Design a square wave generator using Astable multivibrator (555 timer) with a duty cycle 50%.

Solution :- $D.C = \dfrac{R_1 + R_2}{R_1 + 2R_2}$



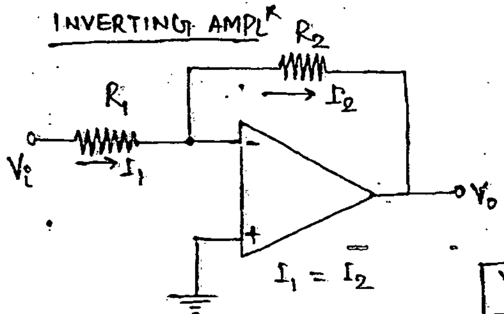
Charging time, $T_c = 0.693\, R_1 C$

discharging Time, $T_d = 0.693\, R_2 C$

$D.C = \dfrac{R}{R+R} = 50\%$

☐ LINEAR APPLICATIONS.

INVERTING AMPL^R

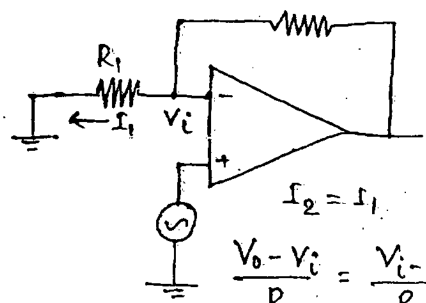


$I_1 = I_2$

$\dfrac{V_i - 0}{R_1} = \dfrac{0 - V_0}{R_2}$

$\boxed{\dfrac{V_0}{V_i} = \dfrac{-R_2}{R_1}}$

NON-INVERTING AMPL^R.

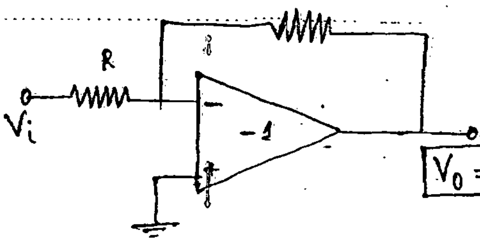


$I_2 = I_1$

$\dfrac{V_0 - V_i}{R_2} = \dfrac{V_i - 0}{R_1}$

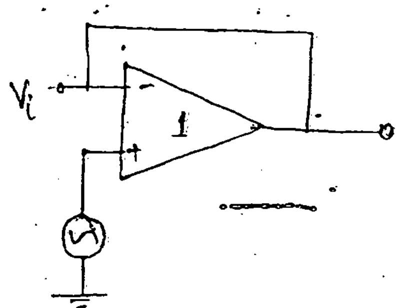
$\boxed{\dfrac{V_0}{V_i} = 1 + \dfrac{R_2}{R_1}}$

PHASE SHIFT



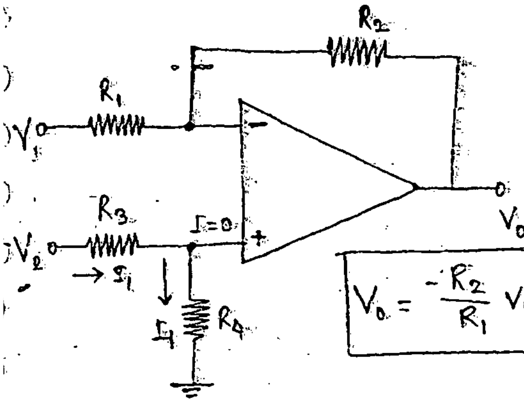
$\boxed{V_0 = -V_i}$

VOLTAGE FOLLOWER

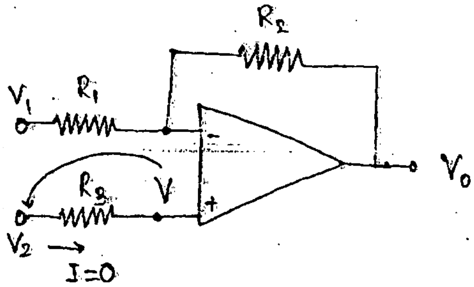


$\boxed{V_0 = V_i}$

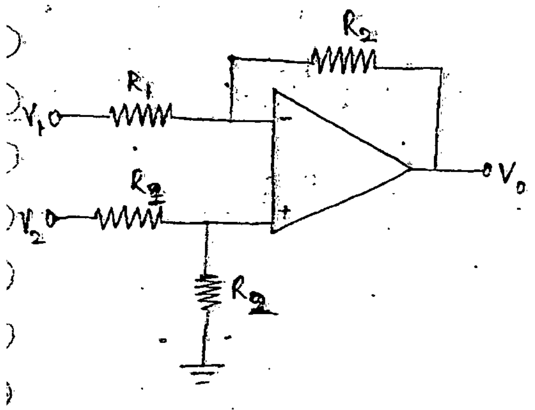
DIFFERENTIAL AMPLIFIER



$$\boxed{V_0 = -\frac{R_2}{R_1} V_1 + \left(1+\frac{R_2}{R_1}\right) V_2 \times \frac{R_4}{R_3+R_4}}$$



$$\boxed{V_0 = -\frac{R_2}{R_1} V_1 + \left(1+\frac{R_2}{R_1}\right) V_2}$$

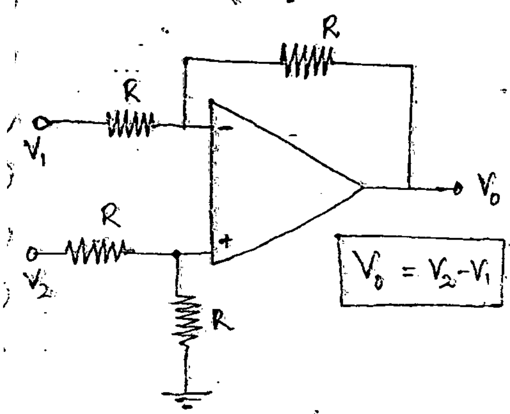


$$V_0 = -\frac{R_2}{R_1} V_1 + \left(1+\frac{R_2}{R_1}\right) V_2 \times \frac{R_2}{R_1+R_2}$$

$$= -\frac{R_2}{R_1} V_1 + \frac{\cancel{R_1+R_2}}{R_1} \cdot V_2 \times \frac{R_2}{\cancel{R_1+R_2}}$$

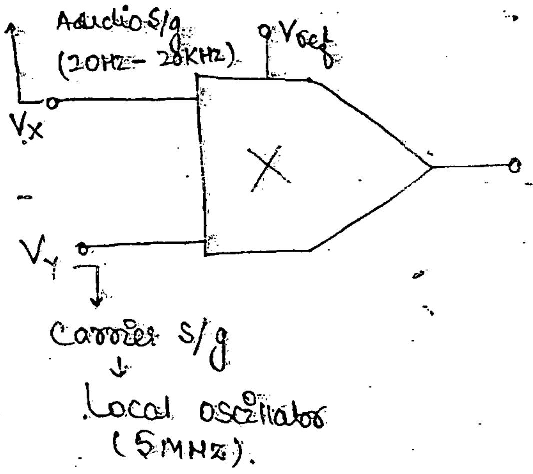
$$\boxed{V_0 = \frac{R_2}{R_1}(V_2 - V_1)}$$

SUBTRACTOR



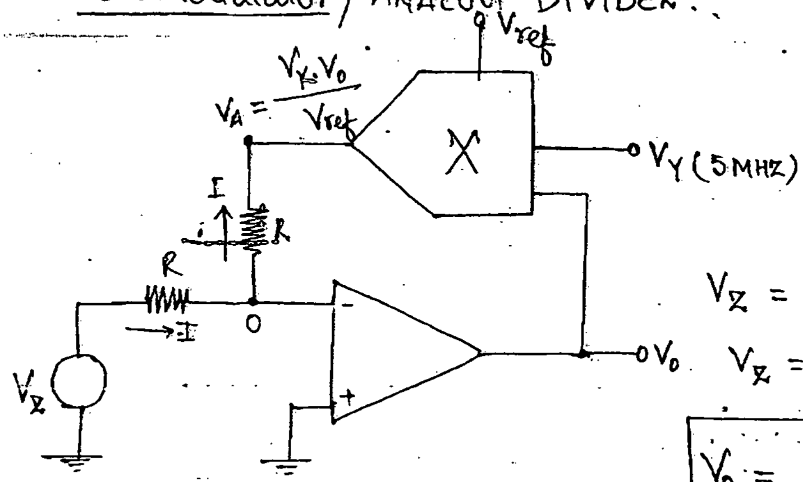
$$\boxed{V_0 = V_2 - V_1}$$

Modulator



$$\frac{V_X \cdot V_Y}{V_{ref}}$$

Demodulator / ANALOG DIVIDER.



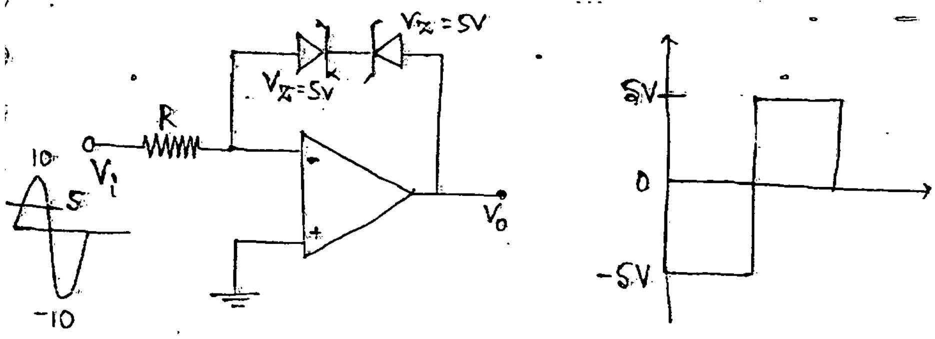
$$V_Z = -V_A$$

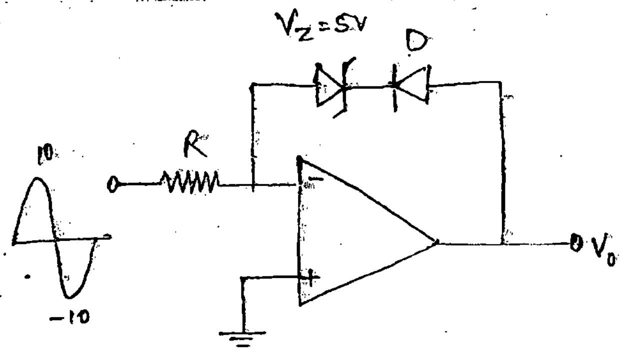
$$V_Z = -\frac{V_Y \cdot V_0}{V_{ref}}$$

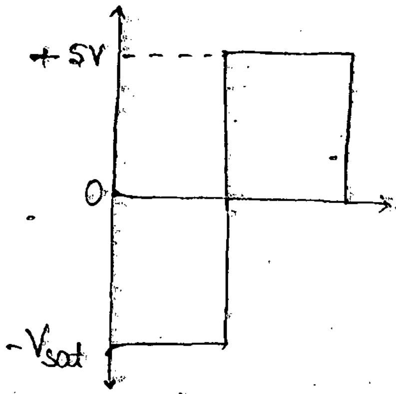
$$\boxed{V_0 = -V_{ref}\left(\frac{V_Z}{V_Y}\right)}$$

$$|V_0| = \frac{V_{ref}}{V_Y} \cdot \frac{V_X \cdot V_Y}{V_{ref}} = V_X \text{ (Audio)}$$

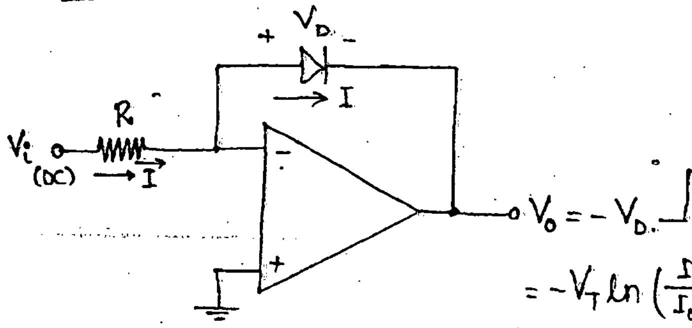
- VOLTAGE LIMITERS.







LOGARTHMIC AMPL^R

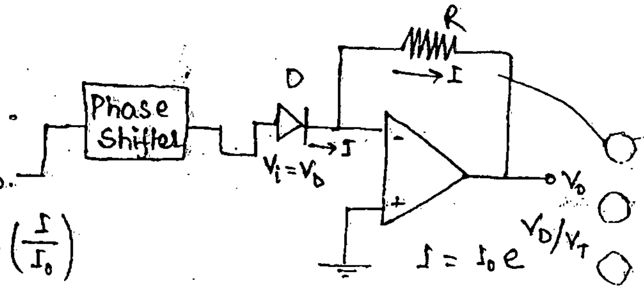


$V_0 = -V_D$

$= -V_T \ln\left(\frac{I}{I_0}\right)$

$$\boxed{V_0 = -V_T \ln\left(\frac{V_i}{I_0 R}\right)}$$

ANTILOGARTHMIC AMPL^R

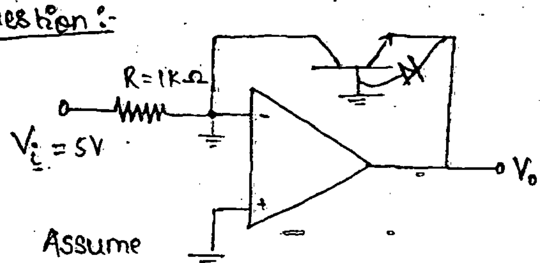


$I = I_0 e^{V_D/V_T}$

$\frac{0 - V_0}{R} = I_0 \cdot e^{V_i/V_T}$

$$\boxed{V_0 = -I_0 R e^{V_i/V_T}}$$

Question :-

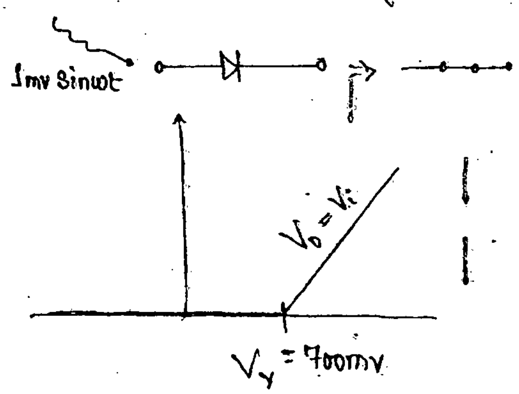


$V_0 = -V_{BE}$

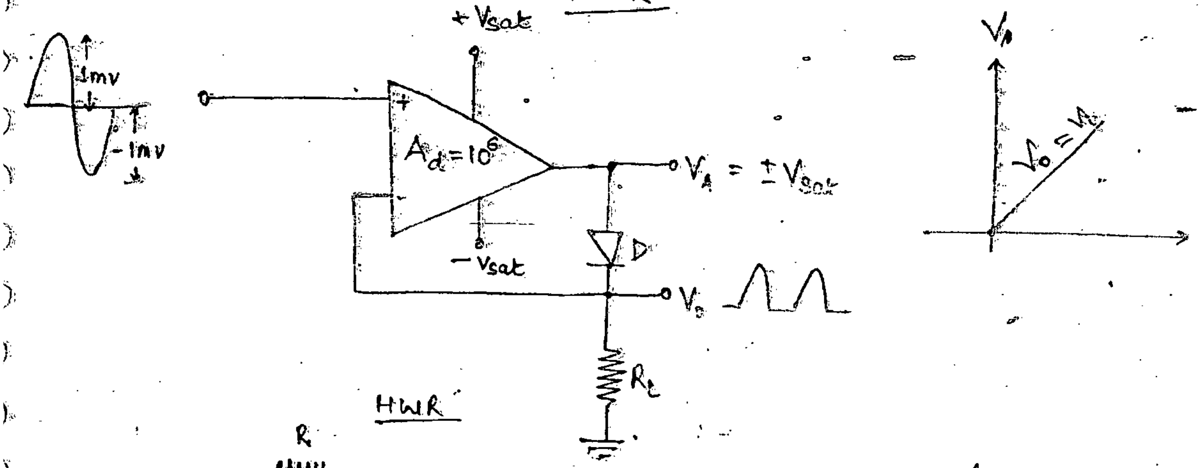
$= -0.7V$

Assume $V_{BE} = 0.7V$

☐ PRECESSION RECTIFIER.

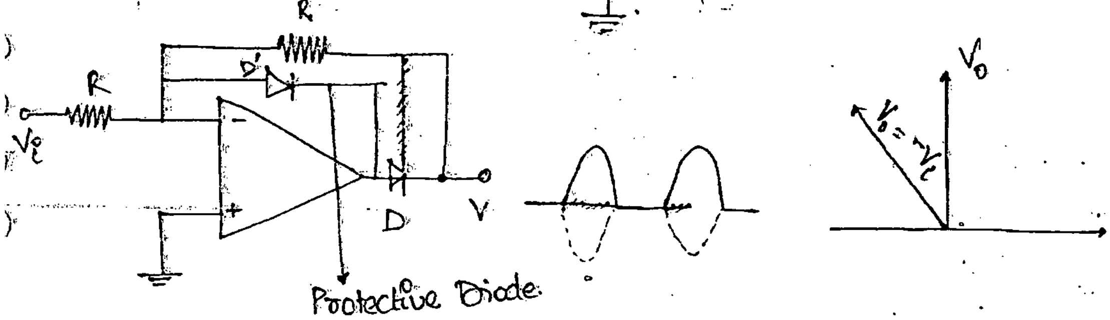


HWR



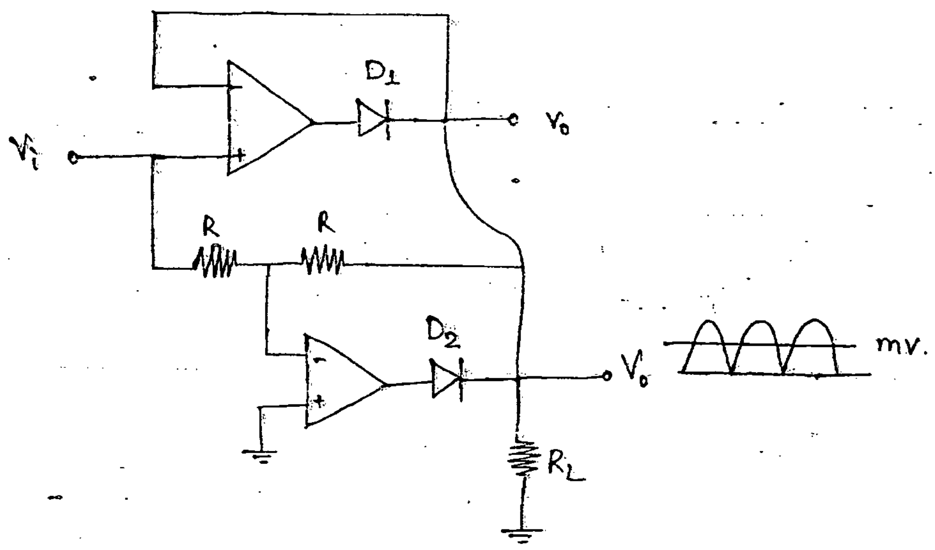
+Vsat
1mV
-1mV
$A_d = 10^6$
$V_A = \pm V_{sat}$
-Vsat
D
V_o
R_L
V_o
$V_o = V_i$

HWR



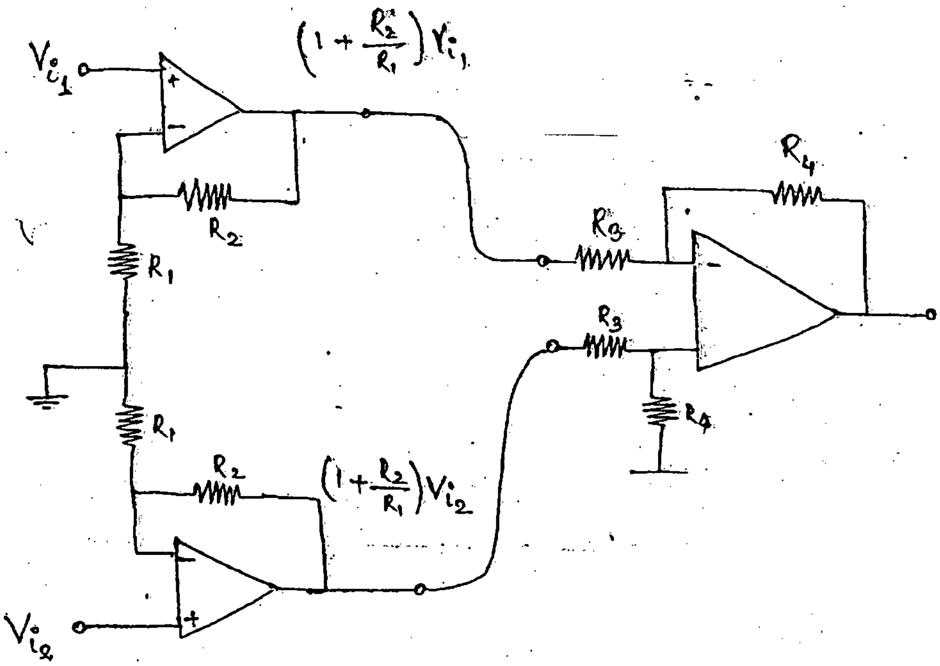
R
R
D'
V_i
D
V
Protective Diode
V_o
$V_o = -V_i$

FWR.



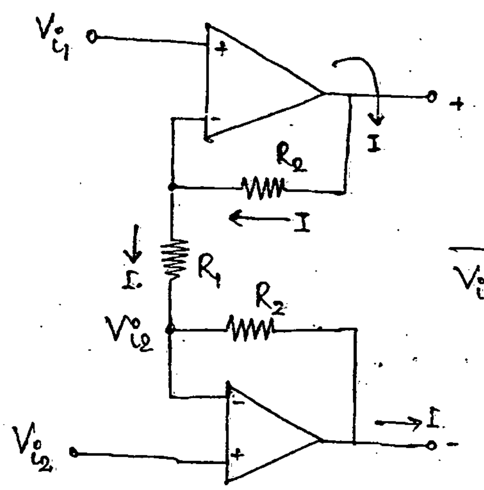
D_1
V_o
V_i
R
R
D_2
V_o
mV.
R_L

INSTRUMENTATIONAL AMPLIFIER.



$$A_d = \frac{R_4}{R_3}\left(1+\frac{R_2}{R_1}\right).$$

MODIFIED CIRCUIT.

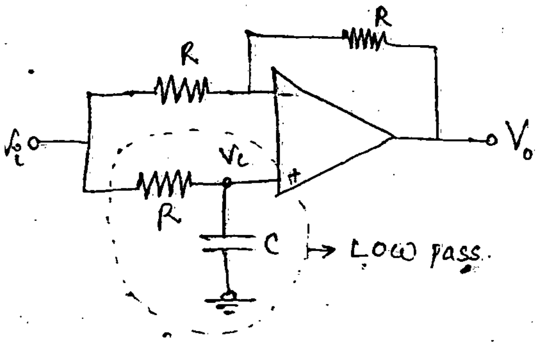


$$A_d = \frac{V_0}{V_{i_1} - V_{i_2}} = ?$$

$$\frac{V_0}{V_{i_1}-V_{i_2}} = \frac{I(R_1+2R_2)}{IR_1} = 1+\frac{2R_2}{R_1}$$

Imp.

ALL PASS FILTER (ACTIVE FILTER)

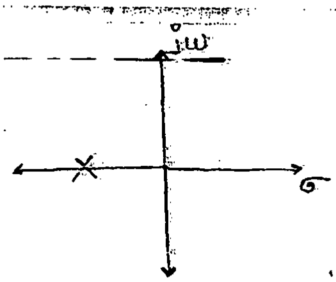


$$V_0 = -\frac{R}{R}V_i + \left(1+\frac{R}{R}\right)V_c$$

$$= -V_i + 2V_i \frac{-jX_c}{R-jX_c}$$

$$= V_i\left[-1+\frac{2}{1+j2\pi fRC}\right]$$

$$\frac{V_o}{V_i} = \frac{1 - j2\pi f RC}{1 + j2\pi f RC}$$



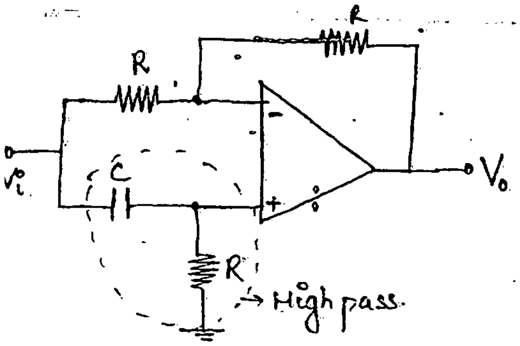
$$\left|\frac{V_o}{V_i}\right| = 1$$

$$\boxed{\phi = -2\tan^{-1} 2\pi f RC}$$

$\boxed{-180^\circ \text{ to } 0^\circ}$ → for 1st order.

• For 2nd order

$$\frac{V_o}{V_i} = \frac{s^2 - as + b}{s^2 + as + b} \qquad \boxed{-360^\circ \text{ to } 0^\circ}$$

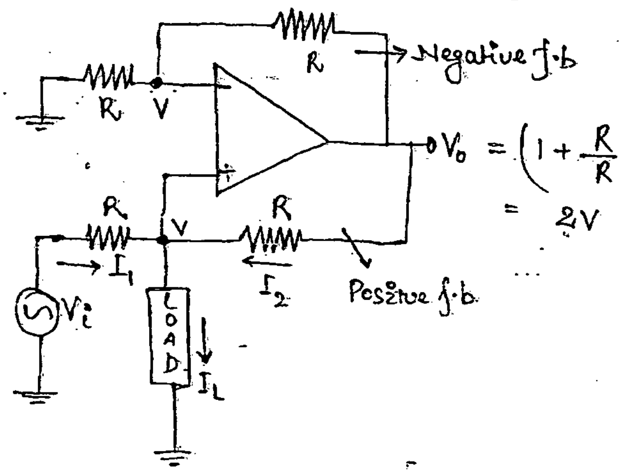


$$\phi = +2\tan^{-1} 2\pi f RC$$

0° to 180° → 1^{st} order

0 to 360° → 2^{nd} order.

☐ NEGATIVE AND POSITIVE FEEDBACK.



$$V_o = \left(1 + \frac{R}{R}\right)V = 2V$$

$$I_1 + I_2 = I_L$$

$$\frac{V_i - V}{R} + \frac{V_o - V}{R} = I_L$$

$$V_i + \underbrace{V_o - 2V}_{2V} = I_L R$$

$$\Rightarrow \boxed{I_L = V_i/R}$$