KVL in o/p loop -

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E = 0$$

$$15 - 2R_C - 4 - 2I_E = 0$$

$$R_C = ?$$

01/10/19

FIELD EFFECT TRANSISTOR (FET)

unipolar device - current flows due to majority charge carriers.

advantages

FET	BJT
① FET → unipolar	BJT → Bipolar.
② I/p impedence of FET is very high (100 MΩ)	
③ FET → voltage controlled device. (o/p current changes due to change in I/p voltage.	BJT → current controlled device. (o/p current changes due to change in I/p current)

④ FET is less noisy as compare to BJT

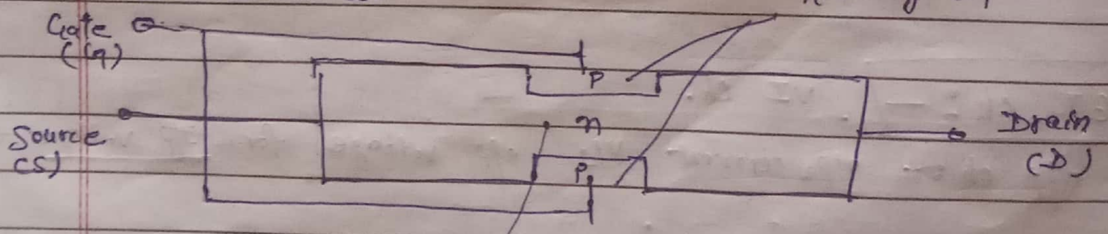
⑤ Thermal stability is better.

⑥ It occupies less space (during IC fabrication)

S	D	G		
Source	Drain	Gate	n-channel FET	p-channel FET
E Emitter	C Collector	B Base	npn	pnp.

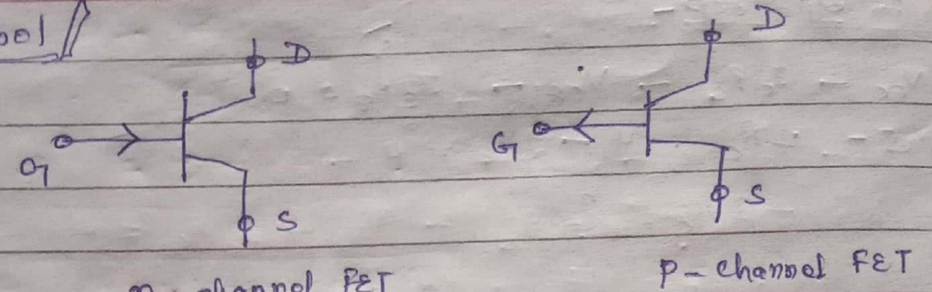
* Constructional Diagram of FET

⇒ n- channel FET —



channel → (space b/w 2 pn. junction through which majority charge carrier passes).

* **Symbol**

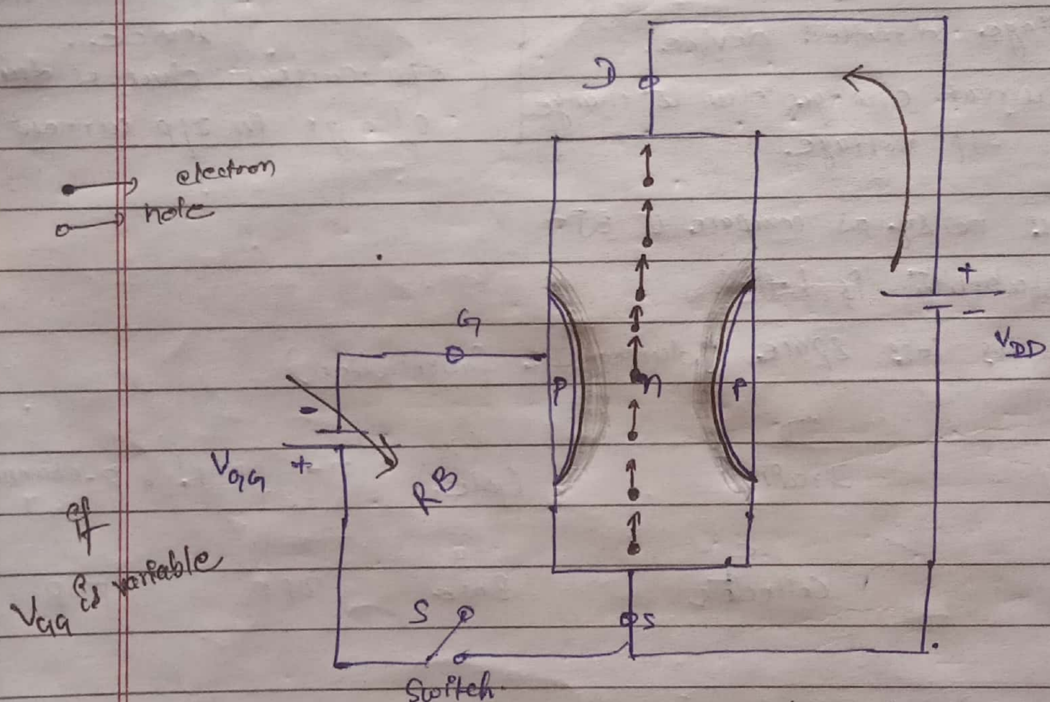


on gate
Arrow show dirⁿ of current when GS junction is forward Bias.

→ configurations:-

→ * **operating Principle of FETs:-**

n-channel FET:-



then depletion layer will inc. less majority charge carrier will enter through cannel, less conduction will occurs.

⟹ external field effect..

* **FET ch:-** . VI ch.

o/p ch:- o/p current v/s o/p voltage for I/P voltage → constant

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$V_{GS} = 0 \rightarrow$ switch open.

COMMON SOURCE

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[1] * **Common Source :-** for n-channel FET

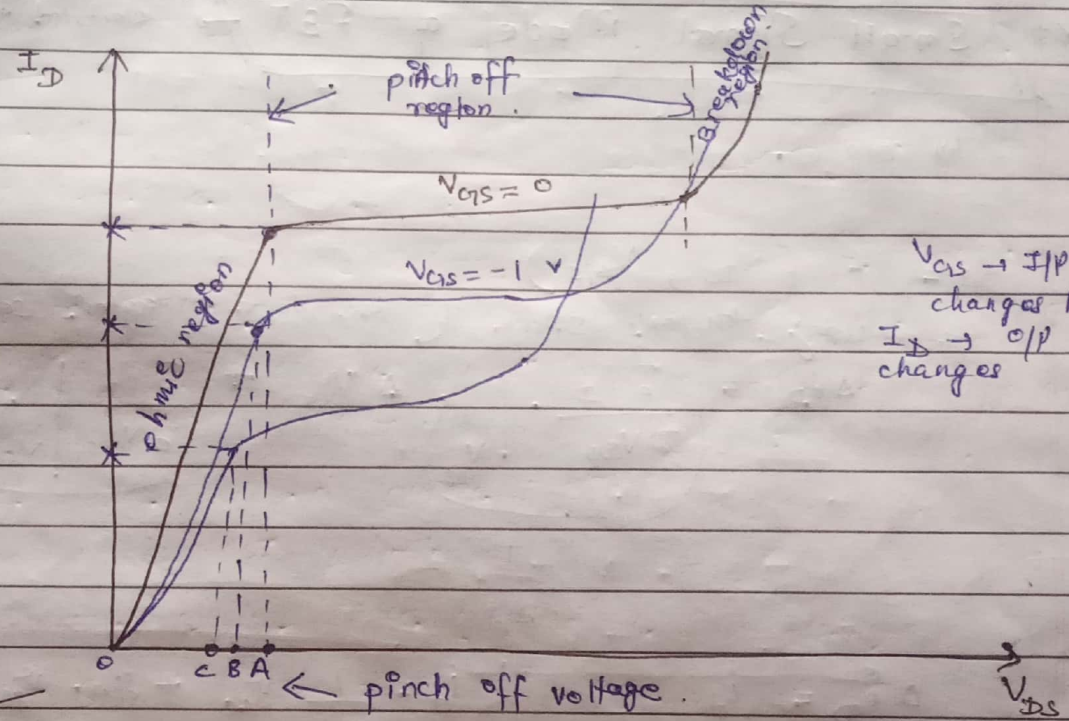
I/p → Gate o/p → Drain Common → Source.

o/p current → Drain current. (I_D)

o/p voltage → Drain to source voltage (V_{DS})

I/p " → Gate to source " (V_{GS})

o/p ch :- I_D v/s V_{DS} for $V_{GS} \rightarrow$ constant.



$V_{GS} \rightarrow$ I/p voltage changes hences $I_D \rightarrow$ o/p current changes

10/10/19

* FET parameters :-

⟹ Common Source amplifier :-

(1) ac drain resistance (r_d) ✓

$$r_d = \frac{\Delta V_{DS}}{\Delta I_D} \Bigg|_{V_{GS} = \text{constant}}$$

$\Delta V_{GS} =$ zero.

(2) Trans conductance (g_m)

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} \Bigg|_{V_{DS} = \text{const}}$$

I → o/p
V → I/p.

(3) Amplification factor (μ)

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}} \Bigg|_{I_D = \text{const.}}$$

GOOD WRITE

common source amplifier. $\longrightarrow$ $\boxed{V_{DS} \quad I_D \quad V_{GS}}$

$$\mu = \frac{\Delta V_{DS}}{\Delta V_{GS}}$$

$$= \frac{\Delta V_{DS}}{\Delta I_D} \cdot \frac{\Delta I_D}{\Delta V_{GS}}$$

$$\boxed{\mu = r_d \cdot g_m}$$

* **Small Signal Model of FET** $\rightarrow$ electrical eq. ckt of FET

by o/p ch.

$i_D = f(V_{DS}, V_{GS})$

by using taylor's series (two term of taylor's series)

$$\Delta i_D = \underbrace{\frac{\partial i_D}{\partial V_{DS}}\Big|_{V_{GS}}}_{\frac{1}{r_d}} \cdot \Delta V_{DS} + \underbrace{\frac{\partial i_D}{\partial V_{GS}}\Big|_{V_{DS}}}_{g_m} \Delta V_{GS}$$

$\Delta i_D = i_d$

$\Delta V_{DS} = v_{ds}$

$\Delta V_{GS} = v_{gs}$

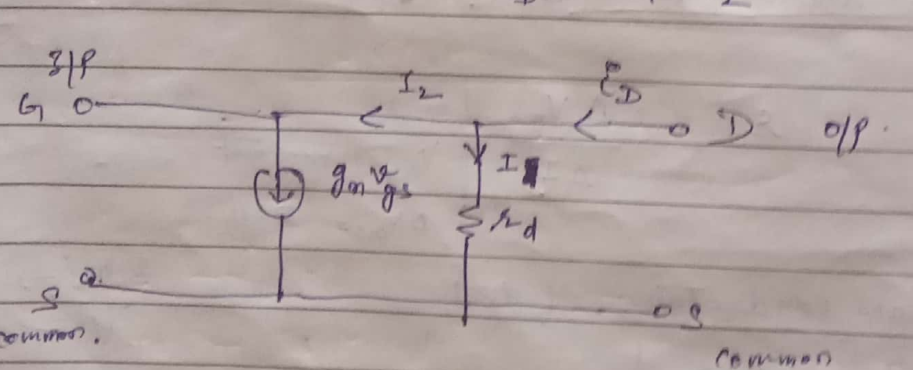
$$\boxed{i_d = \underbrace{\frac{1}{r_d} v_{ds}}_{\text{current}} + \underbrace{g_m \cdot v_{gs}}_{\text{current}}}$$ * 1

current — current current —

KCL.

$i_D = I_1 + I_2$

1



Common Source Amplifier —

I/P $\rightarrow$ Gate, o/P $\rightarrow$ Drain common $\rightarrow$ source.

 P-channel = $-V_{DD}$, n-channel = $+V_{DD}$.

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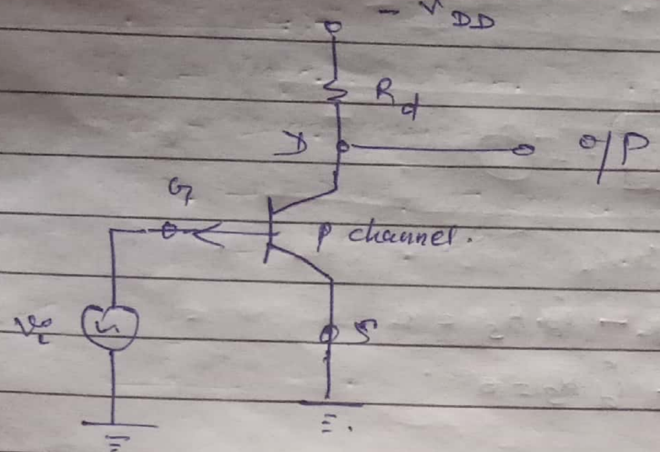
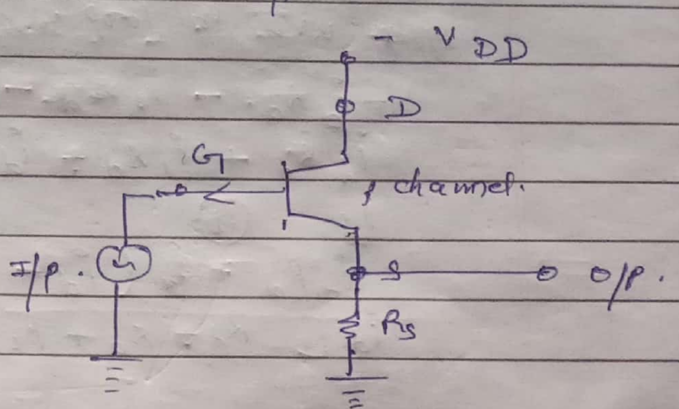


Common Drain Amplifier.

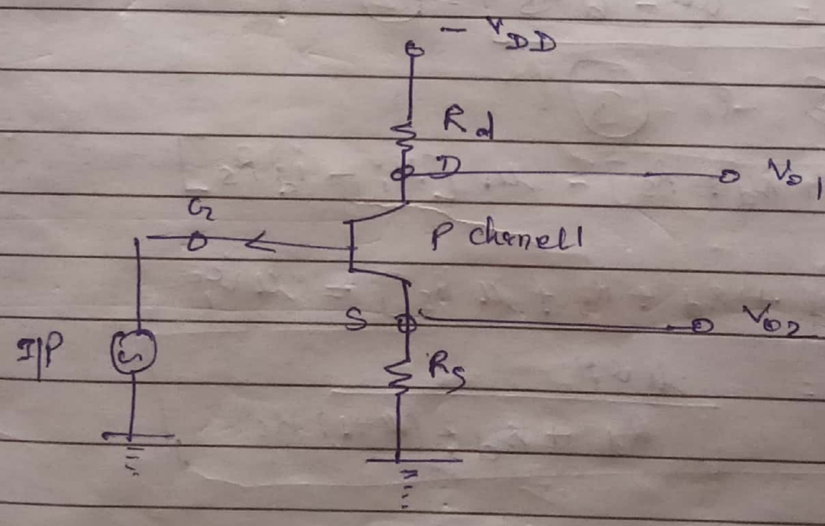
I/p → Gate
o/p → source, common → Drain



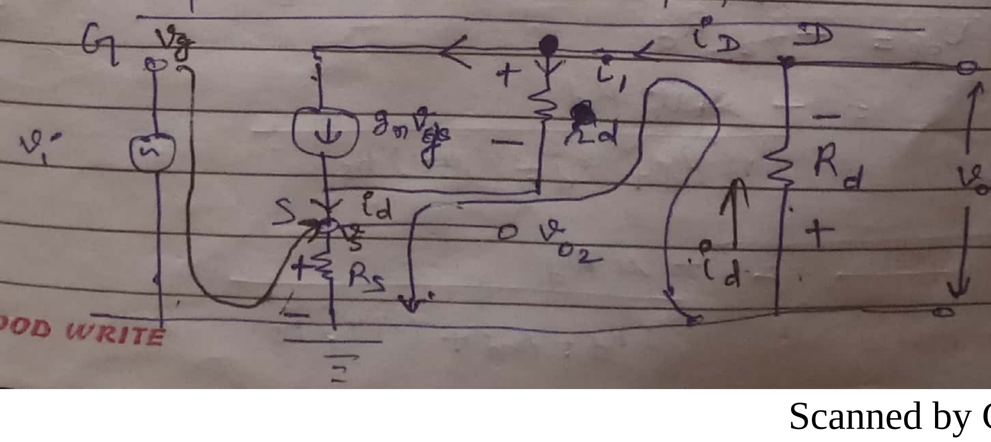
⟹ General ckt for amplifier. ⟶ FET

If o/p → v_{o1} (Drain) and $R_s = 0$
then ckt → common source amplifier.

If o/p → v_{o2} (source) and $R_d = 0$
then ckt → common drain amplifier.



Generalised FET amplifier ckt.



14/10/19

Apply KCL at node

$$i_d = i_1 + g_m v_{gs}$$

$$\boxed{i_1 = i_d - g_m v_{gs}} \quad \text{--- (1)}$$

Apply KVL in loop

$$-i_d R_d - i_1 r_d - i_d R_s = 0$$

$$i_d R_d + i_1 r_d + i_d R_s = 0$$

Put (1)

$$i_d R_d + (i_d - g_m v_{gs}) r_d + i_d R_s = 0$$

$$i_d [R_d + r_d + R_s] = \underbrace{g_m \cdot r_d}_{\mu} \cdot v_{gs}$$

$$i_d [R_d + r_d + R_s] = \mu \cdot v_{gs} \quad \text{--- (3)}$$

→ Apply KVL

$$v_g - v_i^o + i_d R_s - v_s = 0$$

$$v_g - v_s = v_i^o - i_d R_s$$

$$\boxed{v_{gs} = v_i^o - i_d R_s} \quad \text{--- (2)}$$

Put (2) in (3)

$$i_d [R_d + r_d + R_s] = \mu \cdot [v_i^o - i_d R_s]$$

$$i_d [R_d + r_d + R_s + \mu R_s] = \mu v_i^o$$

$$\boxed{i_d = \frac{\mu v_i^o}{R_d + r_d + (\mu+1) R_s}}$$

$$v_{o1} = -i_d R_d$$

$$= -\frac{\mu v_i^o R_d}{R_d + r_d + (\mu+1) R_s}$$

$$\frac{v_{o1}}{v_i^o} = \frac{-\mu R_d}{R_d + r_d + (\mu+1) R_s}$$

DATE: / /
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for common source amplifier.

$o/p \rightarrow v_{o1}$, $R_s = 0$

$$\boxed{A_v = \frac{v_{o1}}{v_i} = \frac{-\mu R_d}{R_d + r_d}}$$

voltage gain for common source amplifier.

$$v_{o2} = i_d R_s$$

$$v_{o2} = \frac{\mu v_i}{R_d + r_d + (\mu+1) R_s} \cdot R_s$$

for common drain amplifier $\rightarrow$ Source follower.

$o/p \rightarrow v_{o2}$ and $R_d = 0$

$$v_{o2} = \frac{\mu v_i R_s}{r_d + (\mu+1) R_s}$$

$$\frac{v_{o2}}{v_i} = \frac{\mu R_s}{r_d + (\mu+1) R_s}$$

if $(\mu+1) R_s >> r_d$

$$\frac{v_{o2}}{v_i} \simeq \frac{\mu R_s}{(\mu+1) R_s}$$

$$\frac{v_{o2}}{v_i} \simeq \frac{\mu}{\mu+1}$$

if $\mu >> 1$

$$A_v = \frac{v_{o2}}{v_i} \simeq 1$$

$o/p \rightarrow$ follows $\rightarrow$ I/p.

o/p is at source

so it is Source follower.

$$\boxed{v_{o2} = v_i}$$

$$\boxed{A_v = \frac{v_{o2}}{v_i}}$$

voltage gain for common drain amplifier.

I/I ch of common source amplifier :-

In pinch off region

$$\boxed{I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2}$$

where I_{DSS} = Drain current when gate is shorted to source.

$V_{GS} \longrightarrow$ Voltage b/w gate & source

V_P = pinch off voltage.

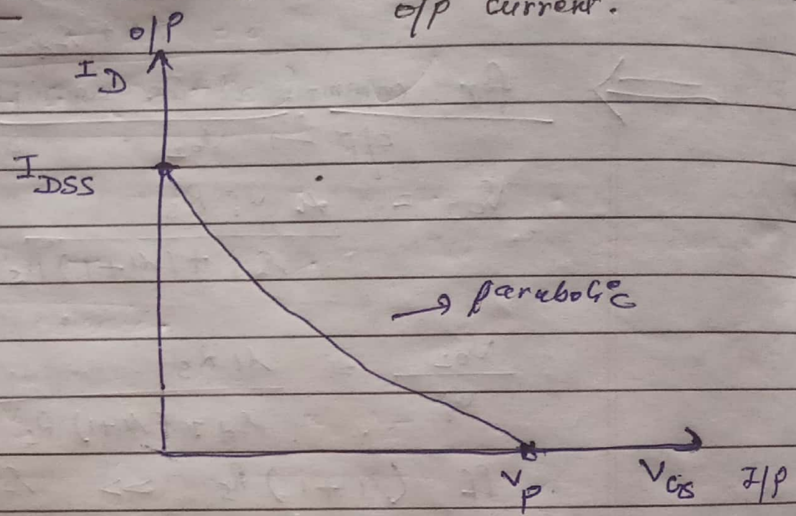
⇒ TRANSFER CH. → graph b/w I/P voltage & O/P current.

x-axis, $I_D = 0$

$V_{GS} = V_P$

y axis

$I_D = I_{DSS}$

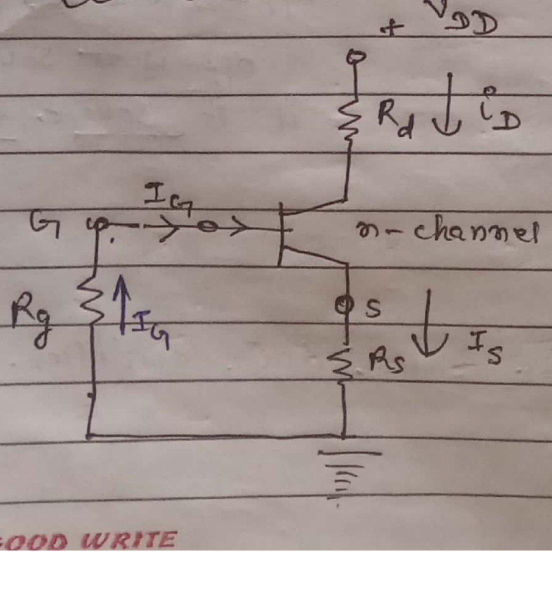


* BIASING OF FET

operating point (I_D, V_{DS})

$Q = ((I_C)_Q, (V_{CE})_Q)$

1 ⇒ Self Bias ⇒



Since gate junction is Reverse biased.

Therefore $I_G \simeq 0$, $V_G = I_G R_S = 0$

$$V_{GS} = V_G - V_S$$
$$= 0 - V_S$$
$$= 0 - I_S R_S$$

$$\boxed{I_S \simeq I_D}$$

$$V_{GS} = 0 - I_D R_S$$

$$\boxed{I_D = -\frac{V_{GS}}{R_S}}$$

Apply KVL in o/p loop

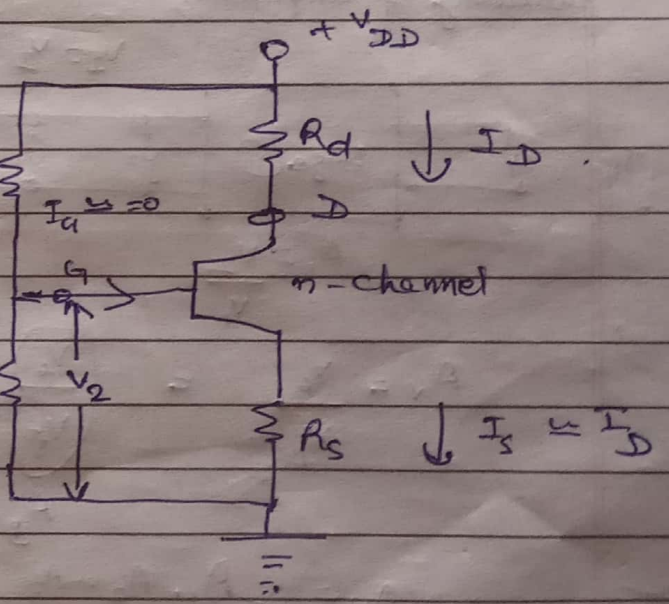
$$V_{DD} - I_D R_d - V_{DS} - I_D R_S = 0$$

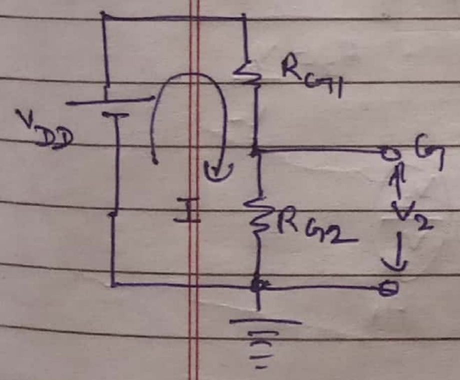
$$\boxed{V_{DS} = V_{DD} - I_d (R_d + R_S)}$$

(2) Potential Divider Biasing :-

Since gate junction is Reverse bias

$I_G = 0$





$$V_{DD} = I (R_{G1} + R_{G2})$$

$$I = \frac{V_{DD}}{R_{G1} + R_{G2}}$$

$$V_2 = I R_{G2}$$

$$V_2 = \frac{V_{DD} \cdot R_{G2}}{R_{G1} + R_{G2}} \checkmark$$

$$V_{GS} = V_G - V_S$$

$$V_{GS} = V_G - I_d R_S$$

$$I_d = \frac{V_2 - V_{GS}}{R_S}$$

$$I_d = \frac{\frac{V_{DD} R_{G2}}{R_{G1} + R_{G2}} - V_{GS}}{R_S}$$

Apply KVL in o/p loop –

$$V_{DD} - I_d R_d - V_{DS} - I_d R_S = 0$$

$$\boxed{V_{DS} = V_{DD} - I_D (R_d + R_S)}$$

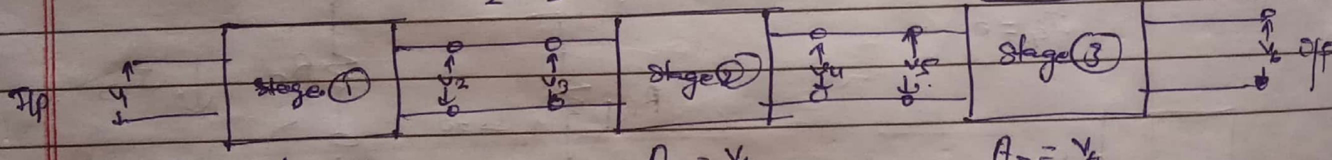
15/10/17

* Multi Stage Amplifier – many amplifiers are connected.

high voltage gain is obtained.

cascading of amplifiers: -

$V_2 = V_3$ $\quad$ $V_4 = V_5$



$A_1 = \frac{V_2}{V_1}$ $\quad$ $A_2 = \frac{V_4}{V_3}$ $\quad$ $A_3 = \frac{V_6}{V_5}$

$$A_v = \frac{V_6}{V_1} = \underbrace{\frac{V_6}{V_5}}_{A_3} \cdot \frac{V_5}{V_4} \cdot \underbrace{\frac{V_4}{V_3}}_{A_2} \cdot \frac{V_3}{V_2} \cdot \underbrace{\frac{V_2}{V_1}}_{A_1}$$

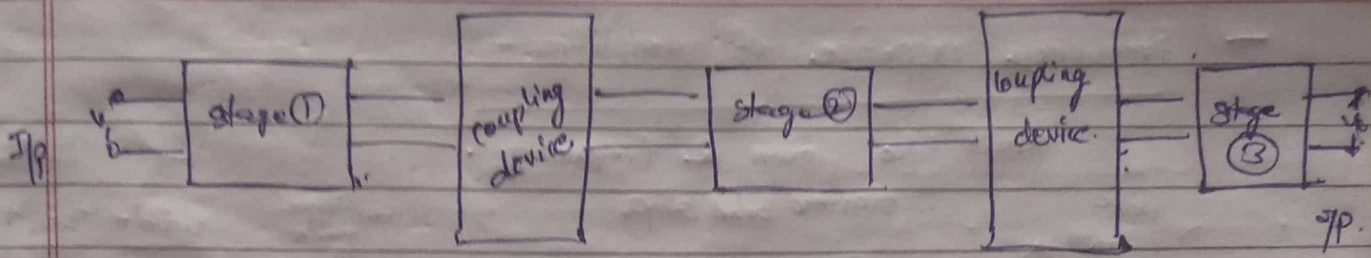
$$A_v = A_1 \cdot A_2 \cdot A_3 \; \cdots \; A_n .$$

only for voltage gain.

Coupling device → blocks dc , allows AC component to one stage to another.

Aim to block dc is to stabilize the operating points.

bcz dc will disturb Q pt. and stability.



Device		Multistage amplifier
1. capacitor	—	R-c coupled amplifier.
2. Transformer	—	T/F " "
3 Direct	—	Direct " " .

only for known amount of dc output,

The dc o/p is given at the designing time at the I/P of stage (another)

→ Power

$$1\,bal = \log_{10} \frac{P_{out}}{P_{in}}$$

decimal (dB)

$$\text{Power gain (1 dB)} = 10 \log_{10}\left(\frac{P_{out}}{P_{in}}\right) \to \text{Power gain.}$$

~~1 bal = 10 decibal~~ 1 decibal = 10 bal

$$\text{Voltage gain (dB)} = 20 \log_{10} \frac{V_{out}}{V_{in}}$$

$P \propto V^2$

$P \propto I^2$

$$\text{current gain (dB)} = 20 \log_{10}\left(\frac{I_{out}}{I_{in}}\right)$$

If Power gain = 100, then $\underline{dB} = 10 \log_{10} 10^2 = 2\times10 = 20.$

$A_v(dB) = 20 \log_{10} A_1$

$A_2\ (dB) = 20 \log_{10}(A_2)$

$A_3\ (dB) = 20 \log_{10}(A_3)$

$A_v = A_1 \cdot A_2 \cdot A_3$

$\log_{10} A_v = \log_{10} A_1 + \log_{10} A_2 + \log_{10} A_3$

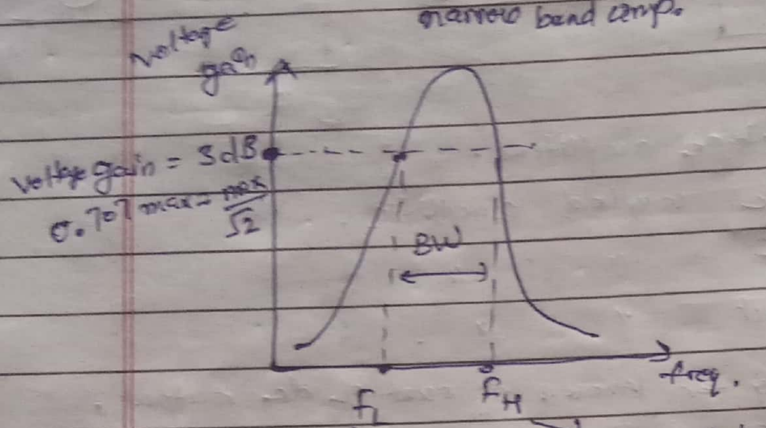
$20 \log_{10} A_v = 20 \log_{10} A_1 + 20 \log_{10} A_2 + 20 \log_{10} A_3$

$(A_v)(dB) = A_1(dB) + A_2(dB) + A_3(dB)$

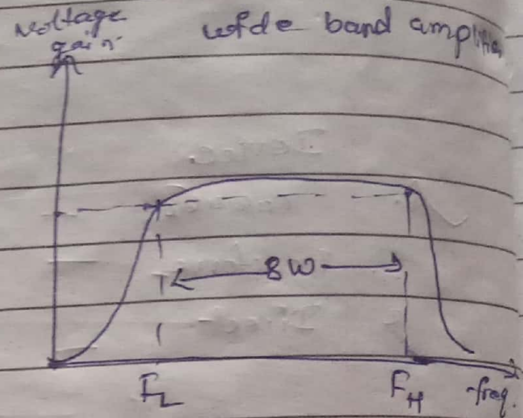
— frequency response of amplifier -

graph b/co gain & frequency.

narrow band amp.



wide band amplifier



lower cut off freq.
lower 3 dB freq.

upper cut off.
upper 3 dB freq.

cut off frequency → 3dB freq → half power freq.

power gain $\propto V^2$

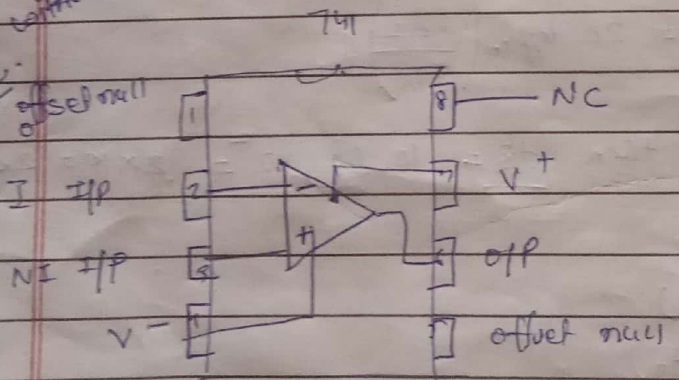
$\propto \left(\frac{1}{\sqrt{2}}\right)^2$

$\propto \frac{1}{2}$.

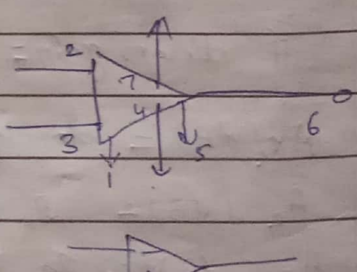
22/10/17 operational Amplifier (opamp)

± 12 V to ± 15 V

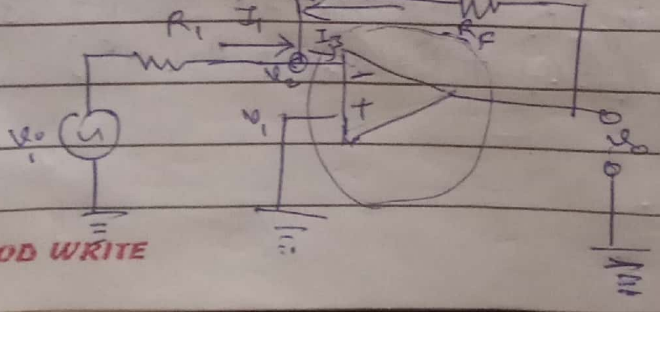
don't works critical dc.



Symbol



Inverting Amplifier :—



PAGE

$A_{vol} = \infty$ $\qquad A = \frac{V_o}{V_1 - V_2} = \infty$

Since $V_1 = 0$

$V_2 = 0$ $\qquad \boxed{V_1 = V_2}$.

virtual ground.

Apply KCL at node pt. (2).

$I_1 + I_2 = I_3 = 0$ $\qquad$ bcz $I = \infty$

$$\frac{V_{in} - V_2}{R_1} + \frac{V_o - V_2}{R_F} = 0$$

Since $V_1 = V_2 = 0$

$$\frac{V_{in}}{R_1} + \frac{V_o}{R_F} = 0$$

$$\boxed{V_o = -\frac{R_F}{R_1} V_{in}}$$ —ve due to 180° ϕ.

$$\Rightarrow \boxed{\text{gain} = A_V = \frac{V_o}{V_{in}} = -\frac{R_F}{R_1}}.$$

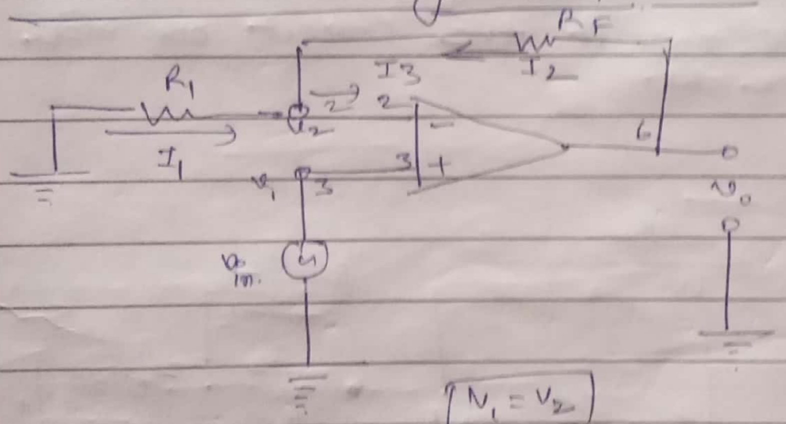
If $R_1 = R_F$

$\boxed{V_o = -V_{in}}$ same magnitude ϕ.

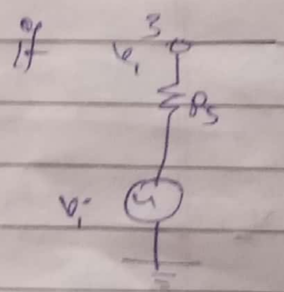
inverter.

NON Inverting Amplifier.

more gain is obtained.



$\boxed{V_1 = V_2}$



$V_1 \neq V_i$

Apply KCL at pt. (2).

$I_1 + I_2 = I_3 = 0$

0 —.

$\boxed{V_o = V_{in}}$

$0 = \frac{0}{\infty}$

$$A_V = \frac{V_o}{V_{in}} = 1 + \frac{R_F}{R_1} \rightarrow \text{if } R_F = SC, \; R_1 = OC, \; \frac{V_o}{V_{in}} = 1$$

if R_S $\qquad V_o = \left(1 + \frac{R_F}{R_1}\right) \times$ voltage of NI

GOOD WRITE

⇒ ADDER —

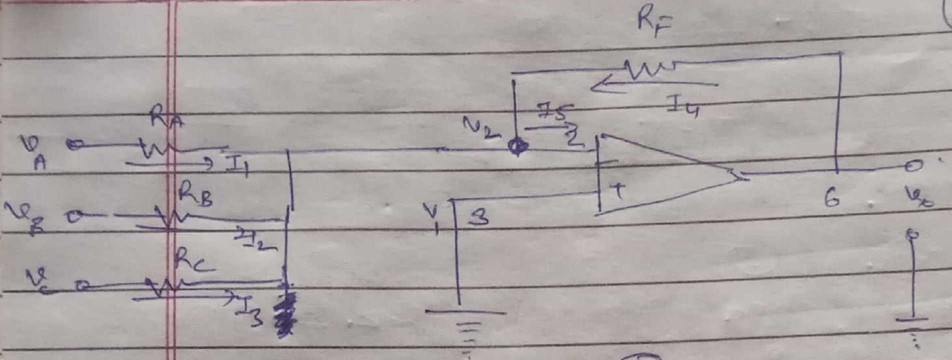
(1) Inverting Adder

max o/p is less than DC voltage

$V_1+V_2+V_3 \le V_{DC}$

other opamp goes into saturation if

$V_1+V_2+V_3 > V_{DC}$



Apply KCL at pt (2)

$$I_1 + I_2 + I_3 + I_4 = I_5 = 0$$

$$\frac{V_A - V_2}{R_A} + \frac{V_B - V_2}{R_B} + \frac{V_C - V_2}{R_C} + \frac{V_o - V_2}{R_F} = 0$$

since $V_1 = V_2 = 0$

$$\frac{V_A}{R_A} + \frac{V_B}{R_B} + \frac{V_C}{R_C} + \frac{V_o}{R_F} = 0$$

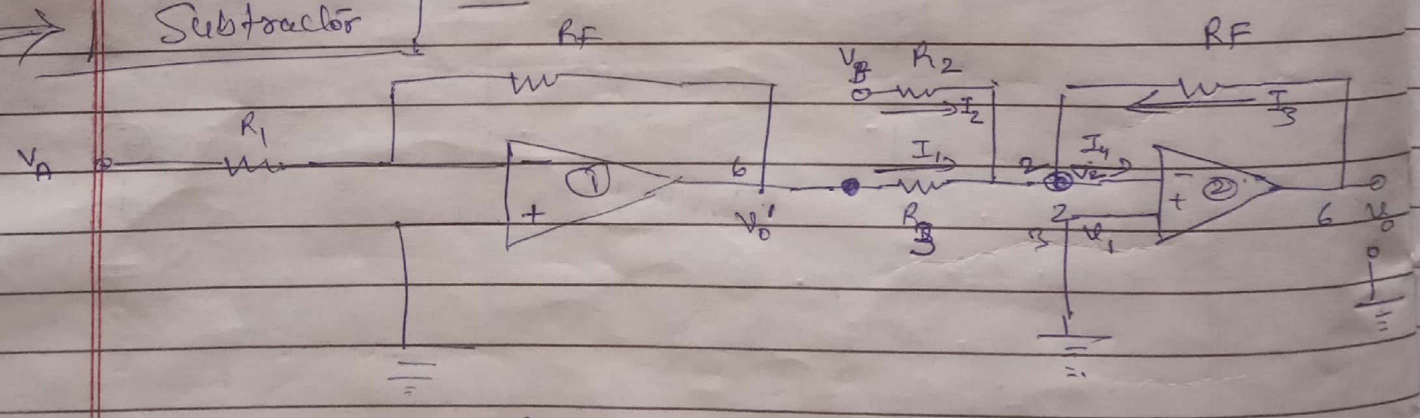
$$V_o = -\frac{R_F}{R_A}V_A - \frac{R_F}{R_B}V_B - \frac{R_F}{R_C}V_C$$

if $R_A = R_B = R_C = R_F$

$$V_o = -(V_A + V_B + V_C)$$

to make it +ve connect one more inverter in the ckt.

⇒ Subtractor —



$$V_o' = -\frac{R_F}{R_1}V_A$$

Apply KCL at pin (2) of opamp (2).

$$I_1 + I_2 + I_3 = I_4 = 0$$

$$\frac{V_o' - V_2}{R_3} + \frac{V_B - V_2}{R_2} + \frac{V_o - V_2}{R_F} = 0$$

GOOD WRITE

since $v_1 = v_2 = 0$

$$\frac{v_o'}{R_3} + \frac{v_B}{R_2} + \frac{v_o}{R_F} = 0$$

$$\frac{v_o}{R_F} = -\frac{v_o'}{R_3} - \frac{v_B}{R_2}$$

$$v_o = -\frac{R_F}{R_3}\left(-\frac{R_F}{R_1} v_A\right) - \frac{v_B}{R_2} \cdot R_F$$

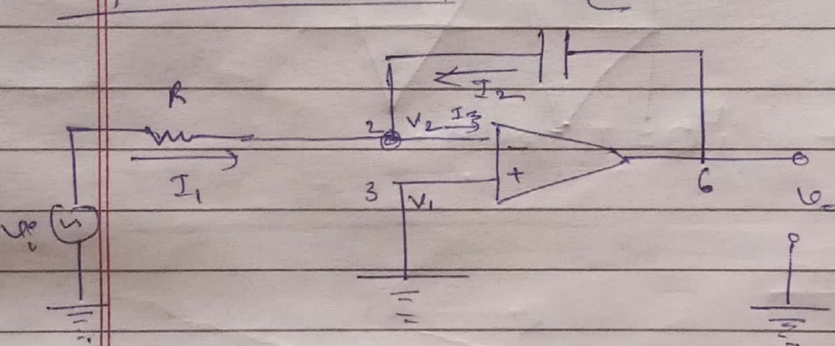
$$v_o = \frac{R_F^2 \, v_A}{R_1 R_3} - \frac{v_B}{R_2} \cdot R_F$$

If $R_1 = R_2 = R_3 = R_F$

$$\boxed{v_o = v_A - v_B}$$

d/f must be less than 12 V.

⇒ **Integrator** → adds I/P.



$Q = CV$

$Q = C(v_o - v_2)$

$Q = C v_o$

$I = \frac{dq}{dt} = C \cdot \frac{dv_o}{dt}$

$I_2 = C \cdot \frac{dv_o}{dt}$

$$\boxed{V_1 = V_2 = 0}$$

Apply KCL at pt. 2

$I_1 + I_2 = I_3 = 0$

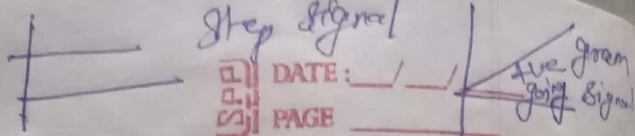
$$\frac{v_{in} - 0}{R} + I_2 = 0$$

$$\frac{v_{in}}{R} + C \cdot \frac{dv_o}{dt} = 0$$

$$\frac{dv_o}{dt} = -\frac{1}{RC} \cdot v_{in}$$

$$\boxed{v_o = -\frac{1}{RC} \int v_{in} \cdot dt}$$

$-\frac{1}{1}\int_0^4$



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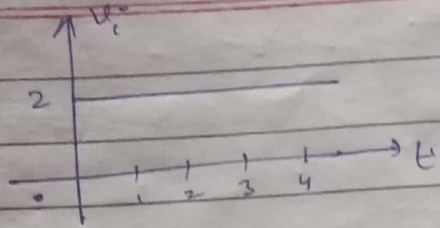
RC = 1 sec.



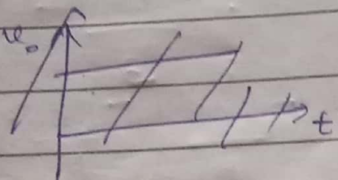
$$v_o = \frac{-1}{RC} \int v_i\,dt.$$

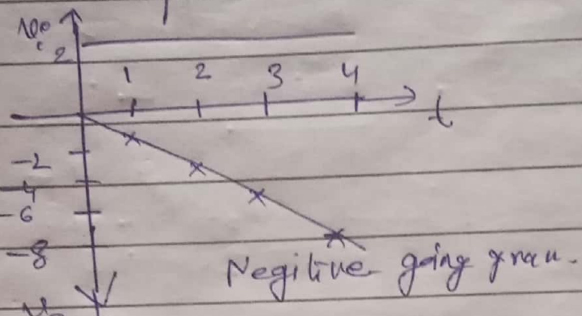
$$-1 . \int_0^{\infty} 2 \cdot dt$$

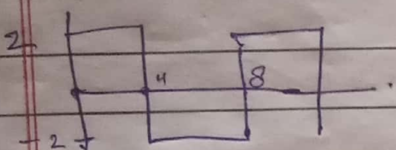
$$= 2[t]_0^{\infty}$$

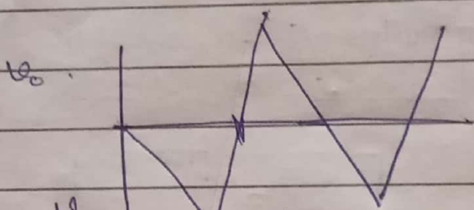
$$= -2[\infty - 0]$$

$$v_o = -\infty$$



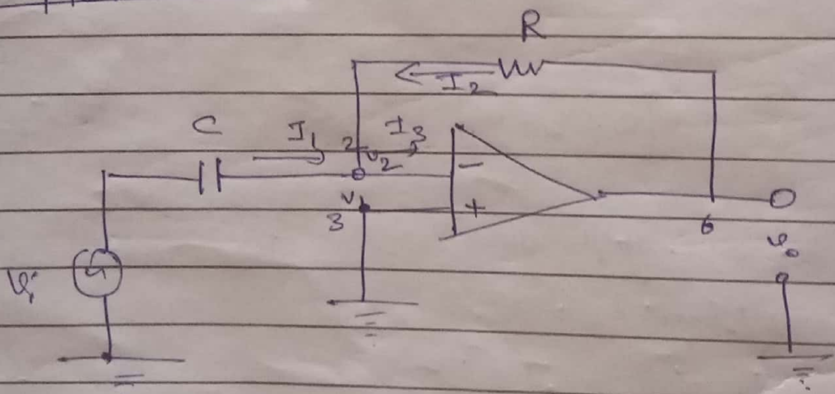






I/p = Square $\quad$ v_o = Triangular.

✱ Differentiator



Apply KCL at (2)

$$I_1 + I_2 = I_3 = 0$$

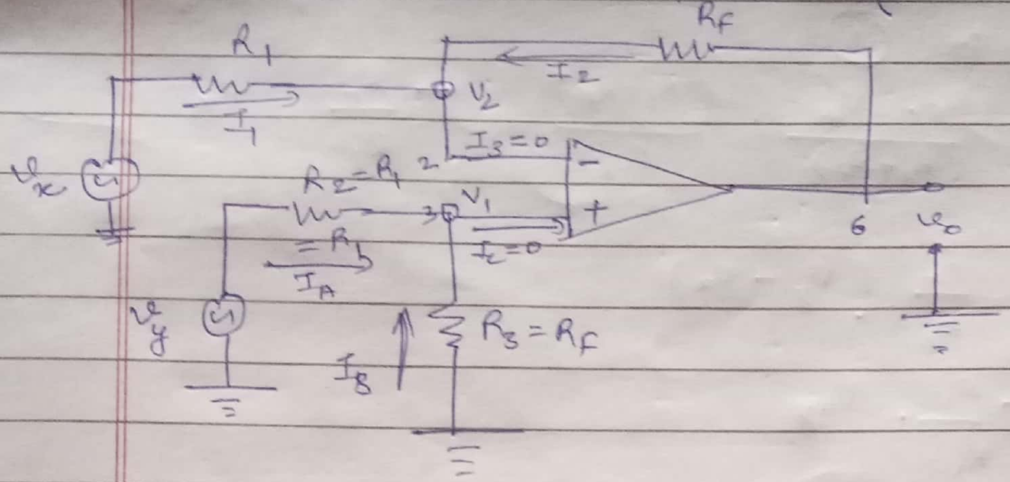
$$V_1 = 0, \quad V_2 = 0.$$

$$\frac{C\,d(v_i - V_2)}{dt} + \frac{V_o - V_2}{R} = 0$$

$$C \cdot \frac{dv_i}{dt} + \frac{V_o}{R} = 0$$

$$\boxed{v_o = -RC \cdot \frac{dv_i}{dt}}$$

⟹ Differential Amplifier (using opamp) → one opamp - I/P is at 2 & 3 pin both.



Since $\boxed{V_1 = V_2}$.

— Apply KCL at pin (2).

$$I_1 + I_2 = 0$$

$$\frac{v_x - V_2}{R_1} + \frac{V_o - V_2}{R_F} = 0$$

Since $V_2 = V_1$

$$\frac{v_x - V_1}{R_1} + \frac{V_o - V_1}{R_F} = 0$$

$$\frac{v_x}{R_1} + \frac{v_o}{R_F} = V_1\left(\frac{1}{R_1} + \frac{1}{R_F}\right)$$

$$\frac{v_x}{R_1} + \frac{v_o}{R_F} = V_1\left(\frac{R_1 + R_F}{R_1 R_F}\right)$$

$$v_o = V_1\left(\frac{R_1 + R_F}{R_1}\right) - \frac{R_F}{R_1} v_x \quad (1)$$

— Apply KCL at pin (3)

$$I_A + I_B = 0$$

$$\frac{v_y - V_1}{R_1} + \frac{0 - V_1}{R_F} = 0$$

$$\frac{v_y}{R_1} = \frac{V_1}{R_1} + \frac{V_1}{R_F}$$

$$\frac{v_y}{R_1} = v_1\left(\frac{R_1+R_F}{R_1 R_F}\right)$$

$$\boxed{V_1 = \frac{R_F}{R_1+R_F} \cdot v_y}$$

put in (1)

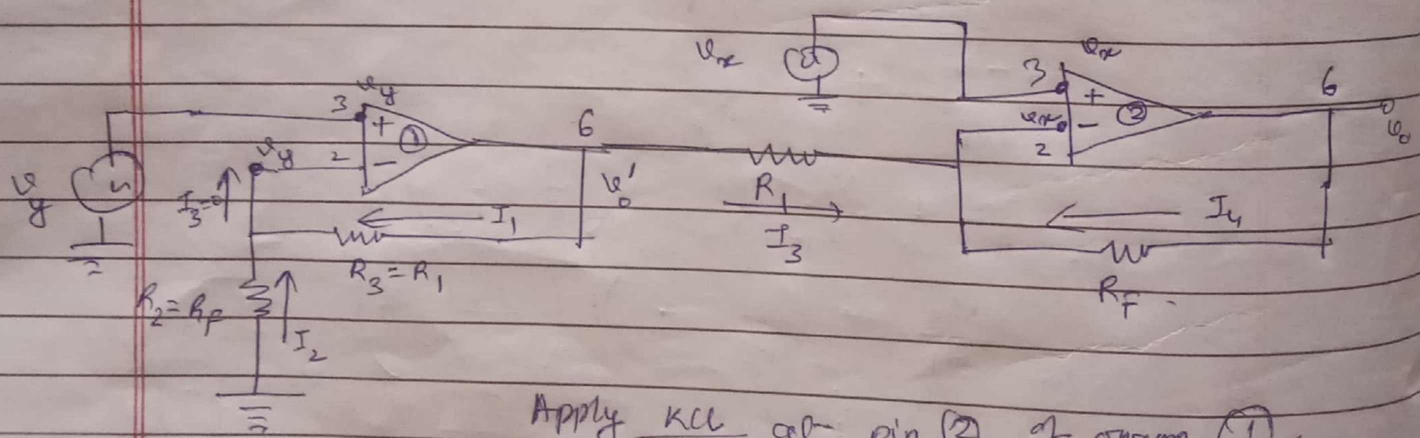
$$v_o = \frac{R_F \cdot v_y}{(R_1+R_F)} \cdot \frac{(R_1+R_F)}{R_1} - \frac{R_F}{R_1} \cdot v_x$$

$$v_o = \frac{R_F}{R_1}(v_y - v_x)$$

$$v_o = -\frac{R_F}{R_1} \cdot v_{xy}$$

$$\text{gain} = \frac{v_o}{v_{xy}} = \frac{-R_F}{R_1}$$

→ Differential Amplifier using two opamps.



Apply KCL at pin (2) of opamp (1).

$$I_1 + I_2 = I_3 = 0$$

$$\frac{v_o' - v_y}{R_1} + \frac{0 - v_y}{R_F} = 0$$

$$\frac{v_o'}{R_1} = \frac{v_y}{R_1} + \frac{v_y}{R_F}$$

$$v_o' = v_y\left(\frac{R_1+R_F}{R_F}\right), \quad \boxed{v_o' = v_y\left(1 + \frac{R_1}{R_F}\right)}$$

Apply KCL at pin ② of opamp ②

$$I_3 + I_4 = 0$$

$$\frac{V_o' - V_x}{R_1} + \frac{V_o - V_x}{R_F} = 0$$

$$\frac{V_o'}{R_1} + \frac{V_o}{R_F} = V_x \left(\frac{R_1 + R_F}{R_1 R_F} \right)$$

$$\frac{V_o}{R_F} = V_x \left(\frac{R_1 + R_F}{R_1 R_F} \right) - \frac{V_o'}{R_1}$$

$$V_o = V_x \left(\frac{R_1 + R_F}{R_1} \right) - \frac{R_F}{R_1} V_o'$$

$$V_o = \frac{V_x (R_1 + R_F)}{R_1} - \frac{R_F}{R_1} \cdot V_y \left(\frac{R_F + R_1}{R_F} \right)$$

$$V_o = \frac{R_1 + R_F}{R_1} \left[V_x - V_y \right]$$

$$V_o = \left(1 + \frac{R_F}{R_1} \right) (V_{xy})$$

$$\text{gain} = \frac{V_o}{V_{xy}} = 1 + \frac{R_F}{R_1}$$

Apply KCL at pin ② of opamp ②

$$I_3 + I_4 = 0$$

$$\frac{V_o' - V_x}{R_1} + \frac{V_o - V_x}{R_F} = 0$$

$$\frac{V_o'}{R_1} + \frac{V_o}{R_F} = V_x\left(\frac{R_1+R_F}{R_1 R_F}\right)$$

$$\frac{V_o}{R_F} = V_x\left(\frac{R_1+R_F}{R_1 R_F}\right) - \frac{V_o'}{R_1}$$

$$V_o = V_x\left(\frac{R_1+R_F}{R_1}\right) - \frac{R_F}{R_1} V_o'$$

$$V_o = \frac{V_x(R_1+R_F)}{R_1} - \frac{R_F}{R_1} \cdot V_y\left(\frac{R_F+R_1}{R_F}\right)$$

$$V_o = \frac{R_1+R_F}{R_1}\left[V_x - V_y\right]$$

$$V_o = \left(1+\frac{R_F}{R_1}\right)(V_{xy})$$

$$\text{gain} = \frac{V_o}{V_{xy}} = 1+\frac{R_F}{R_1}$$

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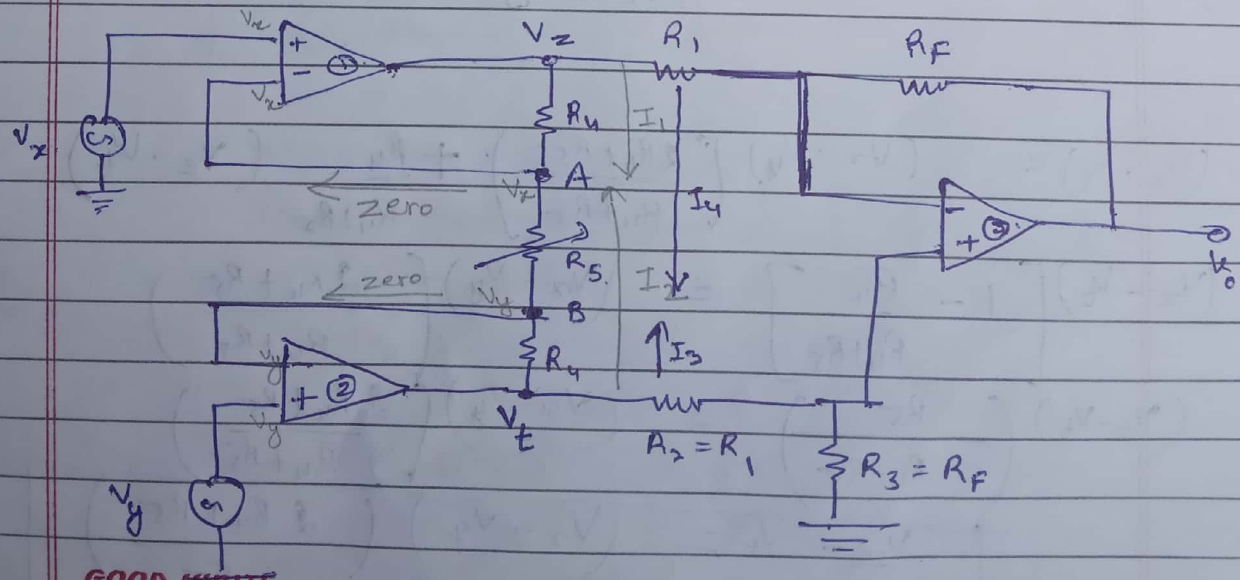
* Differential Amplifier using three opamps.



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Apply KCL at A

$I_1 + I_2 = 0$

$$\frac{V_z - V_x}{R_4} + \frac{V_t - V_x}{R_4 + R_5} = 0$$

$$\frac{V_z}{R_4} = \frac{V_x}{R_4} - \frac{V_t}{R_4+R_5} + \frac{V_x}{R_4+R_5}$$

$$\frac{V_z}{R_4} = V_x\left[\frac{2R_4+R_5}{R_4(R_4+R_5)}\right] - \frac{V_t}{R_4+R_5}$$

$$\boxed{V_z = V_x\left[\frac{2R_4+R_5}{R_4+R_5}\right] - \frac{R_4 V_t}{R_4+R_5}}$$

Apply KCL at B

$I_3 + I_4 = 0$

$$\frac{V_t - V_y}{R_4} + \frac{V_z - V_y}{R_4+R_5} = 0$$

$$\frac{V_t}{R_4} = \frac{V_y}{R_4} - \frac{V_z}{R_4+R_5} + \frac{V_y}{R_4+R_5}$$

$$\frac{V_t}{R_4} = V_y\left[\frac{2R_4+R_5}{R_4(R_4+R_5)}\right] - \frac{V_z}{R_4+R_5}$$

$$\boxed{V_t = V_y\left[\frac{2R_4+R_5}{R_4+R_5}\right] - \frac{R_4 V_z}{R_4+R_5}}$$

$$(V_z - V_t) = (V_x - V_y)\left(\frac{2R_4+R_5}{R_4+R_5}\right) + \frac{R_4}{R_4+R_5}(V_z - V_t)$$

$$(V_z - V_t)\left[1 - \frac{R_4}{R_4+R_5}\right] = (V_x - V_y)\left(\frac{2R_4+R_5}{R_4+R_5}\right)$$

$$(V_z - V_t)\left(\frac{R_5}{R_4+R_5}\right) = (V_x - V_y)\left(\frac{2R_4+R_5}{R_4+R_5}\right)$$

$$V_z - V_t = (V_x - V_y)\left(\frac{2R_4+R_5}{R_5}\right)$$

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using po

input of
(V_i

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$$\boxed{V_{zt} = \frac{2R_4 + R_5}{R_5} \cdot V_{xy}}$$

using opamp,

$$V_o = -\frac{R_F}{R_1}(V_z - V_t)$$

$$V_o = -\frac{R_F}{R_1}\left(\frac{2R_4 + R_5}{R_5}\right) V_{xy}.$$

gain $\frac{V_o}{V_{xy}} = -\frac{R_F}{R_1}\left(\frac{2R_4+R_5}{R_5}\right) = -\frac{R_f}{R_1}\left(1 + \frac{2R_4}{R_5}\right)$

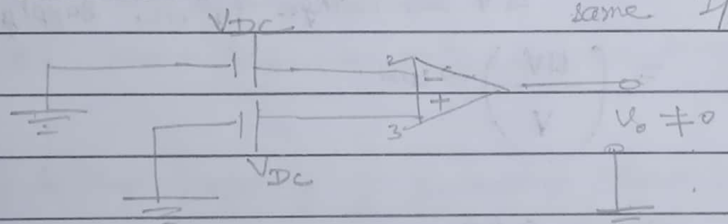
⇒ offset Error voltage and current. →

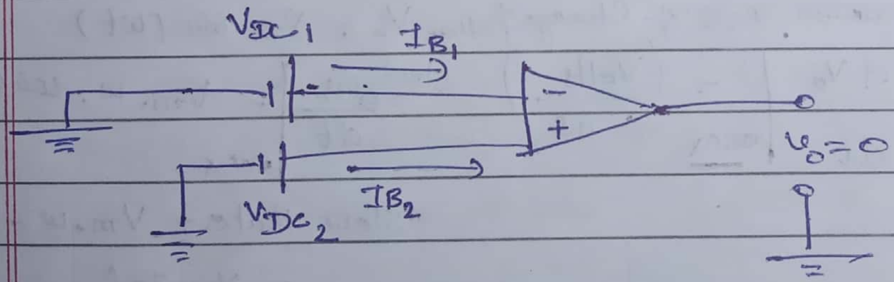
due to internal mis-matching of transistors inside the IC

[1] Input offset Voltage (V_{io}).

input offset voltage (V_{io})

same I/P dc, the o/P should be zero but is not due to error





$$V_{io} = V_{DC_1} - V_{DC_2}$$

↑ input offset voltage

[2] input offset current (I_{io})

$$I_{io} = |I_{B_1} - I_{B_2}|_{V_o = 0}$$

[3] Input Bias current –

$$I_B = \frac{I_{B_1} + I_{B_2}}{2} \Bigg|_{V_o = 0}$$

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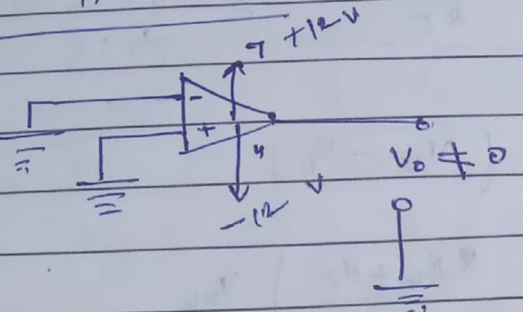
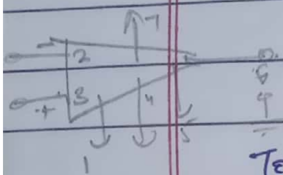
[4] o/p offset voltage (V_o)

Dc is not zero.



input voltages are zero but o/p is not zero.



To make o/p offset voltage Null Zero, we uses pin no. 1 and 5. Rehostat is placed b/w 1 & 5.

[5] Supply Voltage Rejection Ratio (SVRR)

Power supply Rejection Ratio (PSRR).

$$SVRR = \frac{\Delta V_{io}}{\Delta V}$$

ΔV_{io} → change in input offset voltage

ΔV → change in dc supply voltage

$$SVRR = \left(\frac{\mu V}{V}\right) \rightarrow \text{unit.}$$

max $\cos\omega t = 1$

[6] Slew Ratio (SR)

maximum Rate of Change of voltage $V_o = V_m \sin(\omega t)$

$$SR = \frac{dV_o}{dt}\bigg|_{max} = \left(\frac{\text{Volts}}{\mu s}\right)$$

$$\text{slew} = \frac{dV_o}{dt}\bigg|_{max} = V_m \cdot \omega \cdot \cos\omega t\bigg|_{max}$$

$$\text{Slew Rate} = V_m \cdot \omega = V_m\, 2\pi f \quad \text{Volts/sec}$$

$$= \frac{V_m\, 2\pi f}{10^6} = \text{Volts}/\mu s.$$

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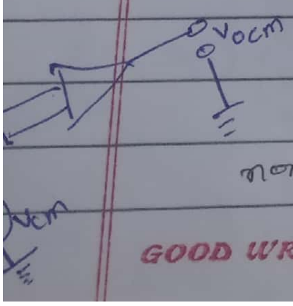
[7] Common Mode Rejection Ratio (CMRR)

It is a ratio of differential gain of an opamp to the common mode gain.

$$CMRR = \frac{\text{differential Gain } (A_d)}{\text{common Mode gain } (A_c)} = \frac{A_d}{A_c}$$



common Mode gain: gain when same I/p signal is applied at both Inverting & non-inverting terminal (V_{cm})

SI unit.

$$A_c = \frac{V_{ocm}}{V_{cm}} = \boxed{dB}$$

for an ideal opam $V_{ocm} = 0$,

$\Rightarrow A_c = 0$

ideally, CMRR = ∞

practically . CMRR → very large → very good opamp.

⇒ $\boxed{\text{OSCILLATORS}}$ — converts DC into AC.

is a ckt that generated a repetitive waveform of fixed amplitude & freq without giving any external ~~I/P~~ signal source. ~~by~~ but dc is given. (means AC is not given)

eg → CRO .

⇒ Classification of oscillator —

1. According to wave shape of generated signal :→

oscillator ← (a) Sinusoidal oscillator . → sine wave is generated

waveform generator ← (b) Non - Sinusoidal oscillators. → square wave, triangular wave

2 According to the frequency of generated signal :→

(a) Audio freq ~~generator~~ oscillator. (few Hz - 20 KHz)

(b) Radio freq. oscillator (20 KHz - 30 MHz)

(c) very high freq " (30 MHz - 300 MHz)

(d) ultra high freq. oscill. (UHF) (300 MHz - 3 GHz)

(e) Micro wave oscillator (3 GHz - several GHz)

3 According to the type of components used in ckt. →

Radio freq osci. [a] LC oscillator. → eg - Hartley oscillator, Collpitt's oscillator

Audio freq osci [b] 180 180° RC " → eg → RC phase shift oscillator, Wein Bridge oscillator. °°°

[c] Craystal oscillator. → wrist watch , cars.

used for stabilisation.

Sinusodial oscillator.

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+ve feedback's appⁿ → oscillator.

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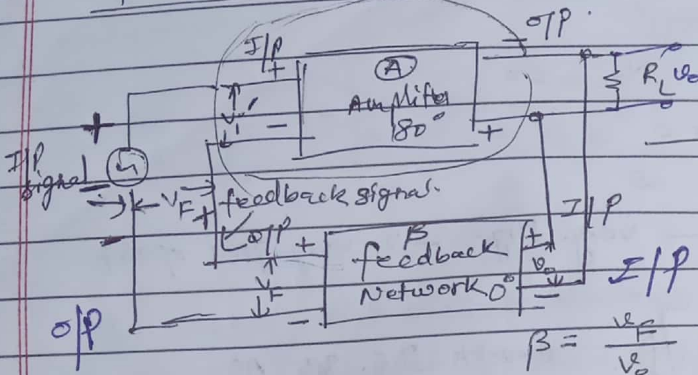
— feedback —

(A) gain without feedback



→ Negative feedback

$$\beta = \frac{v_F}{v_o}$$

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

$$v_i' = v_i - v_f$$

$$v_i' = v_i - \beta v_o$$

$$A = \frac{v_o}{v_i - \beta v_o}$$

$$A v_i - A\beta v_o = v_o$$

$$A v_i = (1 + A\beta)\, v_o$$

–ve feedback ←
$$A_F = \frac{v_o}{v_i} = \frac{A}{1 + A\beta}$$

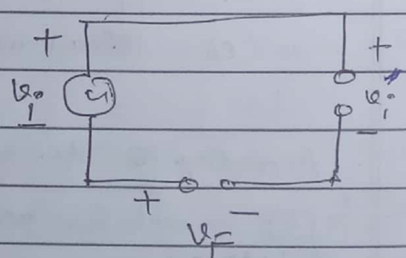
→ +ve feedback → behave as oscillator when $A\beta = 1$

Amp → 0°
feedback Network → 0°

$$v_i' = v_i + v_F$$

$$v_i' = v_i + \beta v_o$$

$$A = \frac{v_o}{v_i + \beta v_o}$$



$$A_F = \frac{v_o}{v_i} = \frac{A}{1 - A\beta}$$

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$A\beta$ = loop gain.

$$A_F = \frac{v_o}{v_i} = \frac{A}{1 - A\beta}$$

if $A\beta = 1$

$$\frac{v_o}{v_i} = \frac{A}{0} = \infty$$

when $\boxed{v_i = 0}$, $A_F = \infty$ — defⁿ of oscillator.

polar form $A\beta = 1 \angle 0°$ or $360°$
← magnitude

This is called Barkhausein Criteria of oscillator.

two requirements for oscillations —

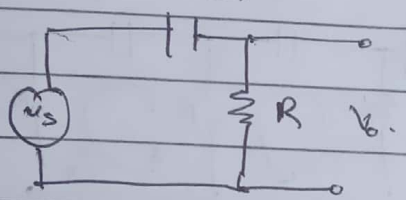
(1) The magnitude of loop gain ($A\beta$) must be at least 1

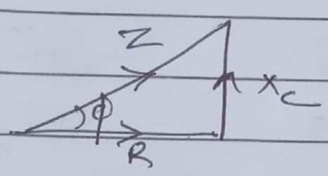
(2) The total phase shift of loop gain " " equal to 0° or 360

* RC phase Shift Oscillator —

⇒ Phase shift Network (using RC) →

feedback Networks





$\phi = \tan^{-1}\left(\frac{X_C}{R}\right)$

$X_C = \frac{1}{2\pi f C}$

$|Z| = \sqrt{R^2 + X_C^2}$

$\phi = \tan^{-1}\left(\frac{1}{2\pi f C R}\right)$

180 ϕ.

$\phi = 180°$

~~$\tan(180)$~~ $= \underbrace{\frac{1}{2\pi f R C}}_{\text{very large}} = 0$

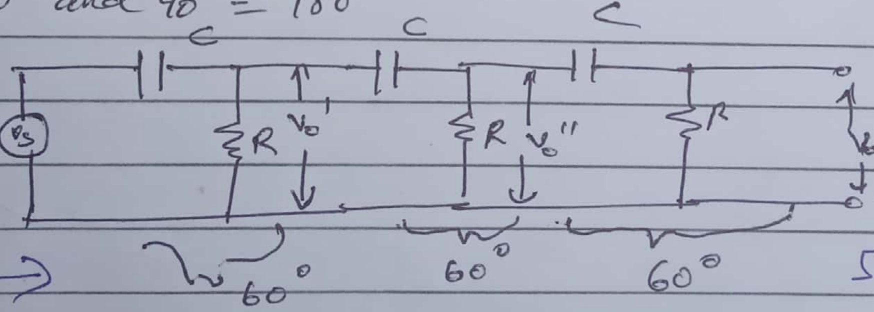
practically not possible.

$\frac{1}{2\pi f c} = \infty \rightarrow$ same

2 if each 90° and 90° = 180 →

using 60°, 60°, 60°,

feedback N/W



I/P

possible o/p.

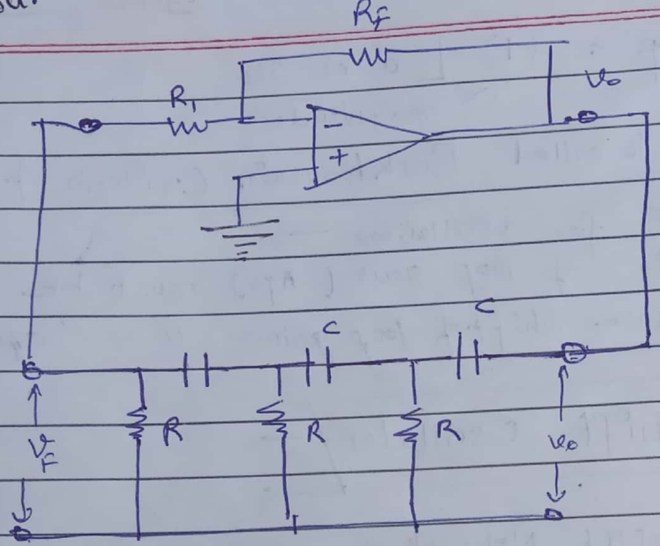
$\sqrt{3} = \frac{1}{2\pi f c}$

input is at capacitor.

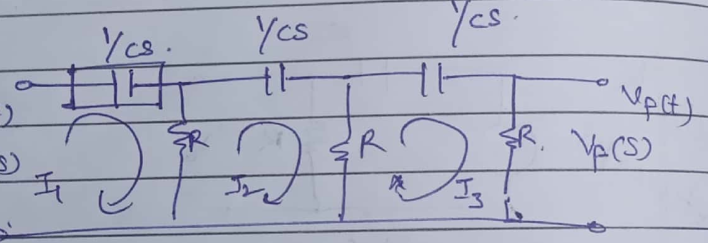
R → output

RC phase shift oscillator using opamp: —

No ac source



components.	laplace
C	$\frac{1}{CS}$
L	LS
R	R.



voltage $= I_i \cdot 1/cs$

find $\frac{V_f(S)}{V_o(S)} =$

converter !!

→ works in saturation region.

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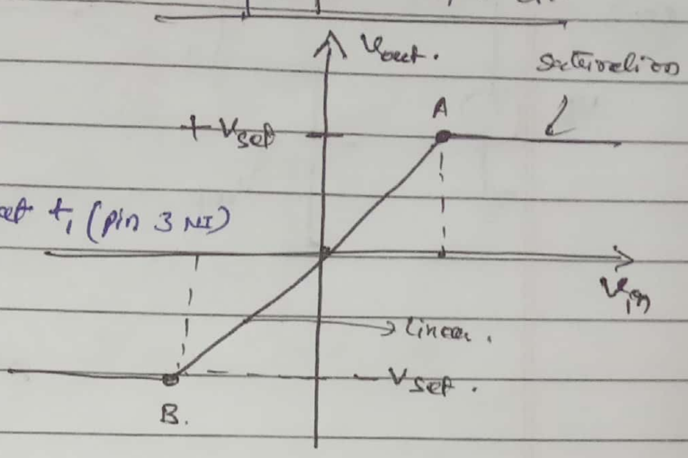
Inverting → I
NI → Non Inverting

COMPARATOR :- using opamp.

if NI > I
o/p → $+V_{sat}$
if NI < I o/p → $-V_{sat}$

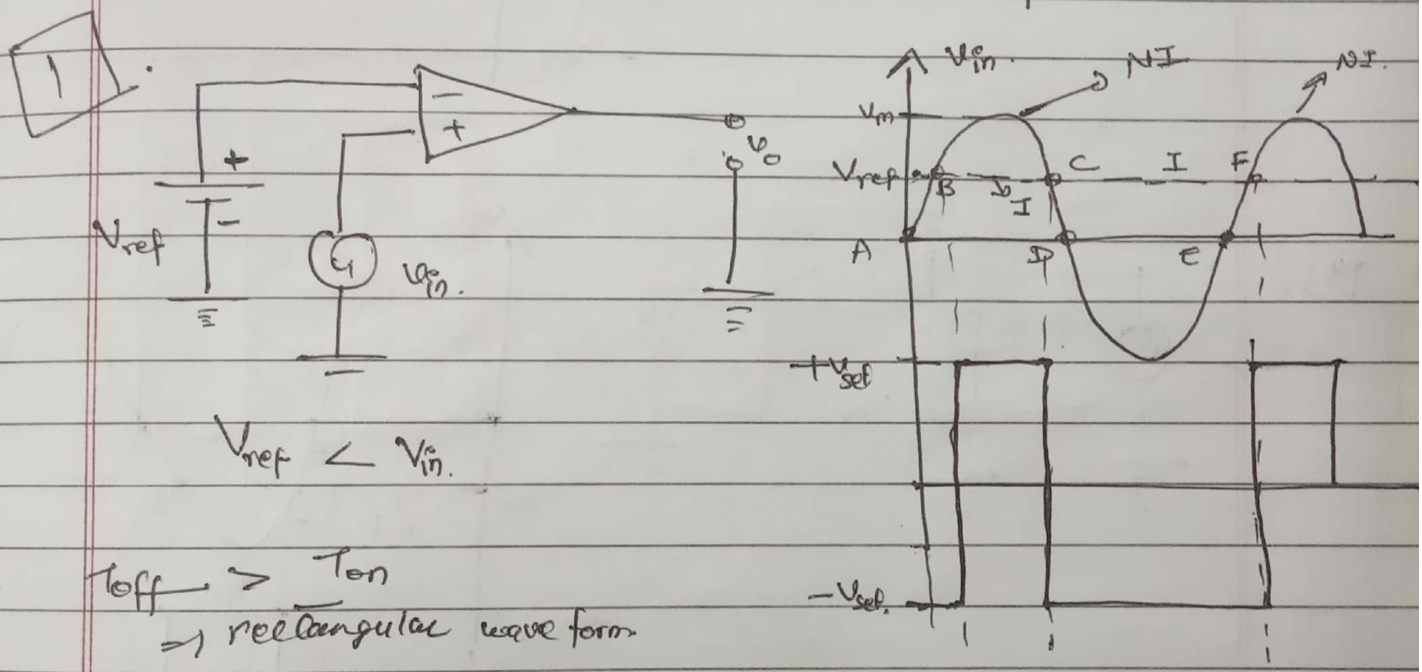
opamp. Transfer ch.



Non-inverting comparator — if V_{in} is at $+_1$ (pin 3 NI)

$V_{ref} < V_{in}$

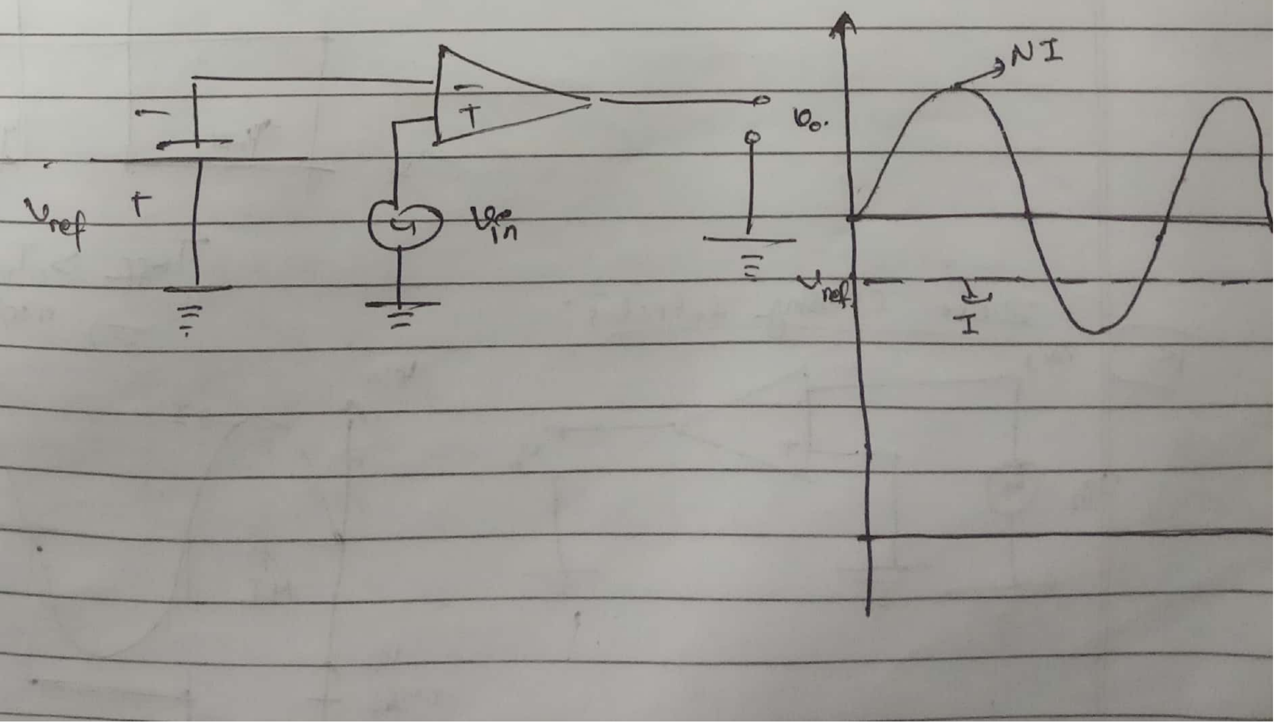
1.



$V_{ref} < V_{in}$

Toff > Ton
→ rectangular wave form

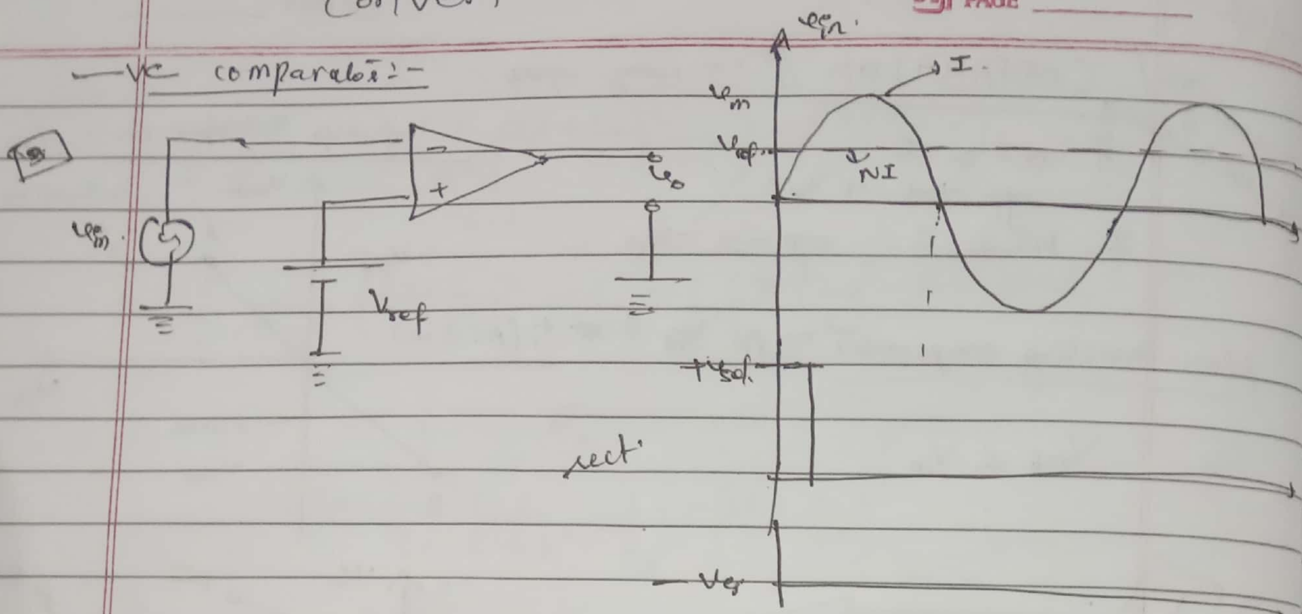
2



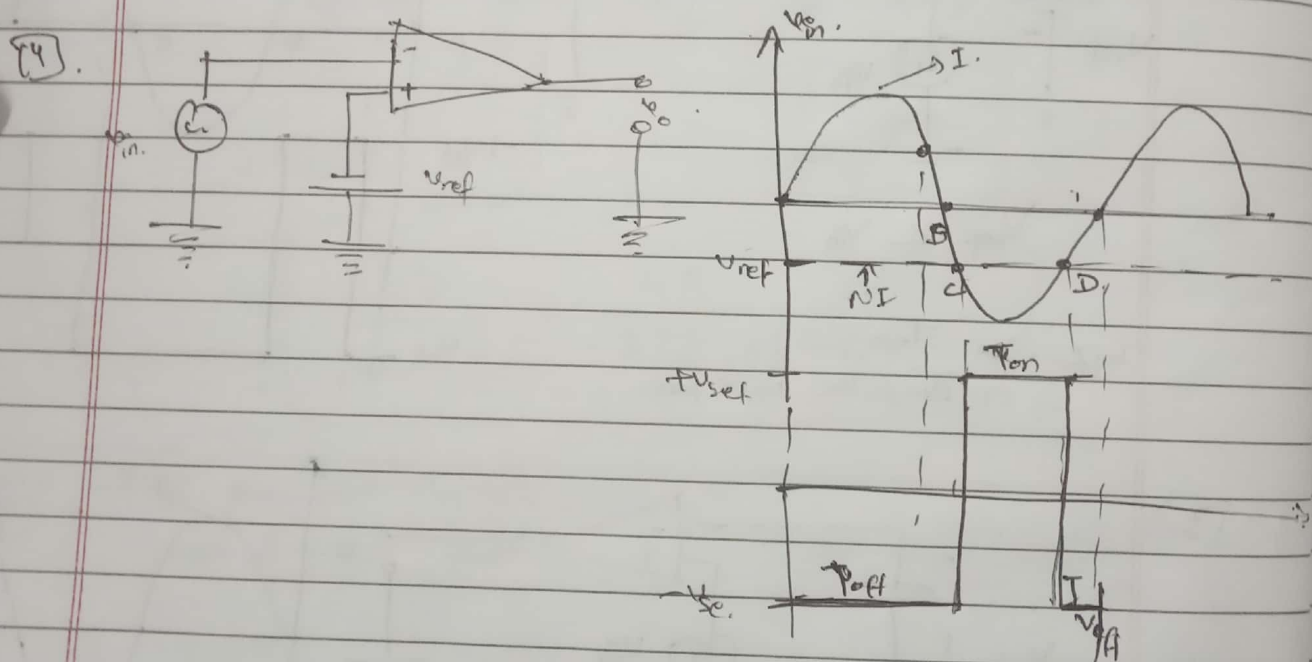
Converter.

Rect generator.

-ve comparator :-



[4].

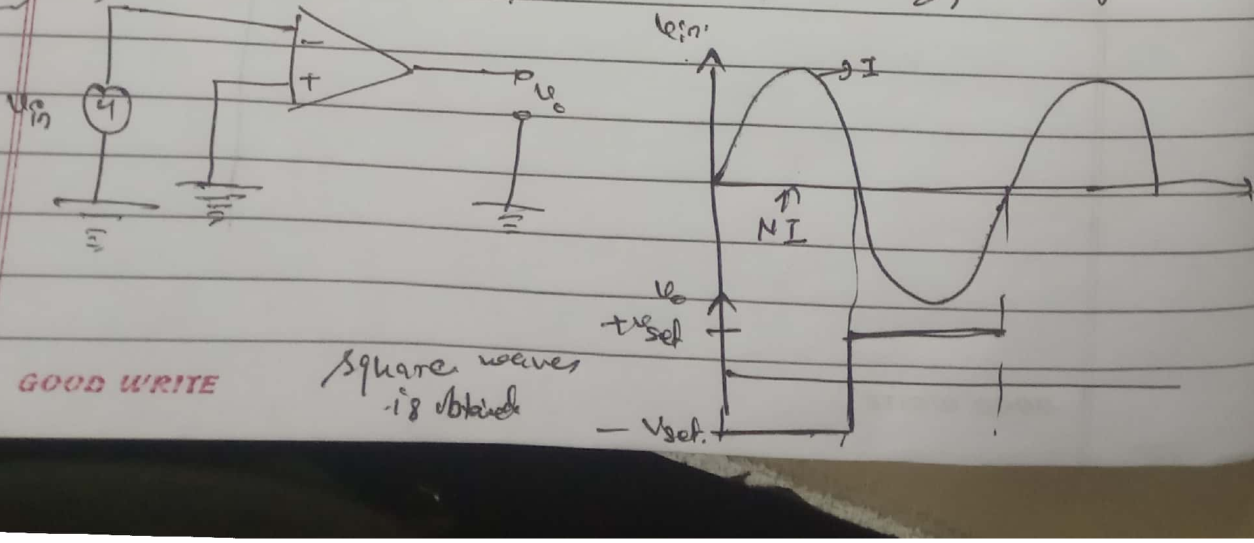


$T_{off} > T_{on}$.

=> rectangular.

[5] Zero crossing detector:

(a)



Square waves is obtained

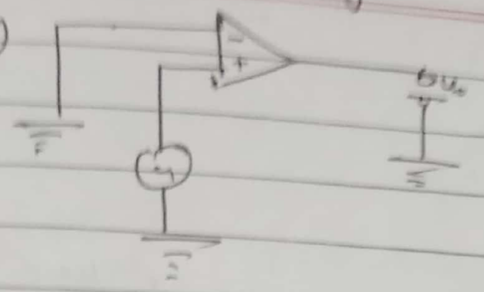
V_o is crossing the zero at the zero of the I/p.

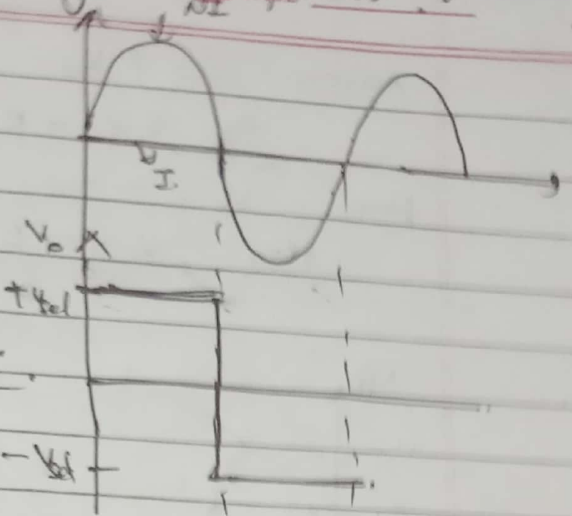
Converter

↓ zero crossing detector using +ve comparator

Not Generator

(ii)

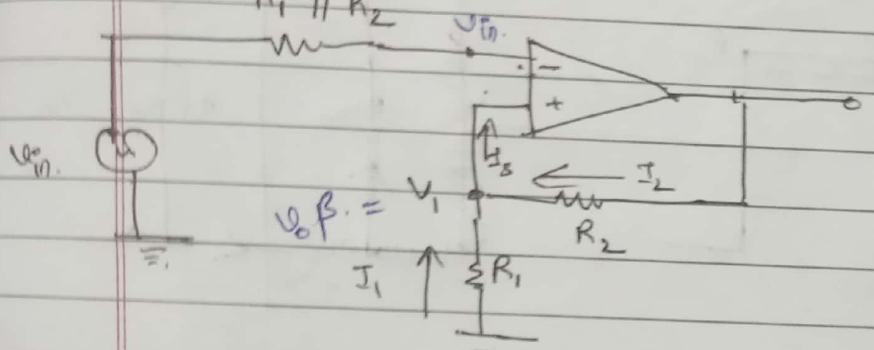




$T_{on} = T_{off}$, square wave.

Hysteretic comparator.

Schmitt trigger :—



$+\beta V_{sat} < V_{m(max)}$

Apply KCL at pin (3).

$$I_1 + I_2 = I_3 = 0$$

$$\frac{0 - v_1}{R_1} + \frac{v_o - v_1}{R_2} = 0$$

$$\frac{v_o}{R_2} = v_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$v_o = v_1\left(\frac{R_1 + R_2}{R_1}\right)$$

$$v_1 = \underbrace{\left(\frac{R_1}{R_1 + R_2}\right)}_{\beta} v_o$$

$+V_{sat} = UTV \rightarrow$ upper threshold voltage

$-V_{sat} = LTV \rightarrow$ lower

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Assume $V_o = +V_{sat}$.

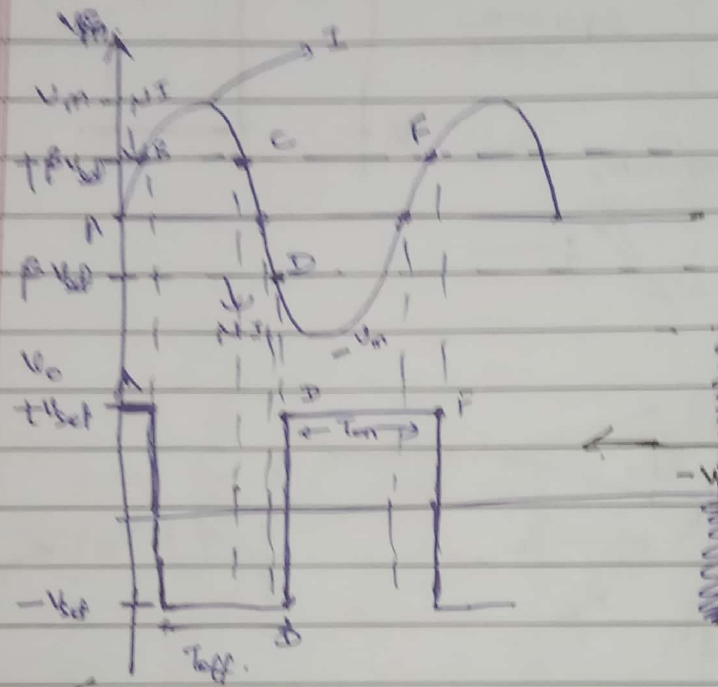
then $V_1 = +\beta V_{sat}$.

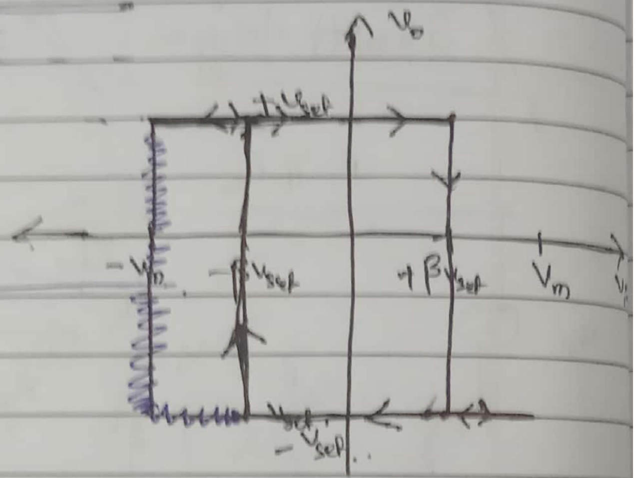
Now $V_o = -V_{sat}$.

then $V_1 = -\beta V_{sat}$.

Square wave converter.

Transfer ch.





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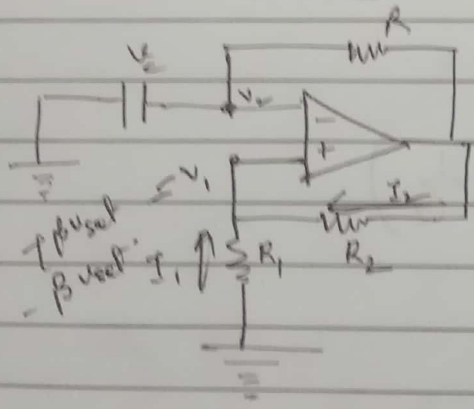
Square wave Generator - (non-sinusoidal oscillator).

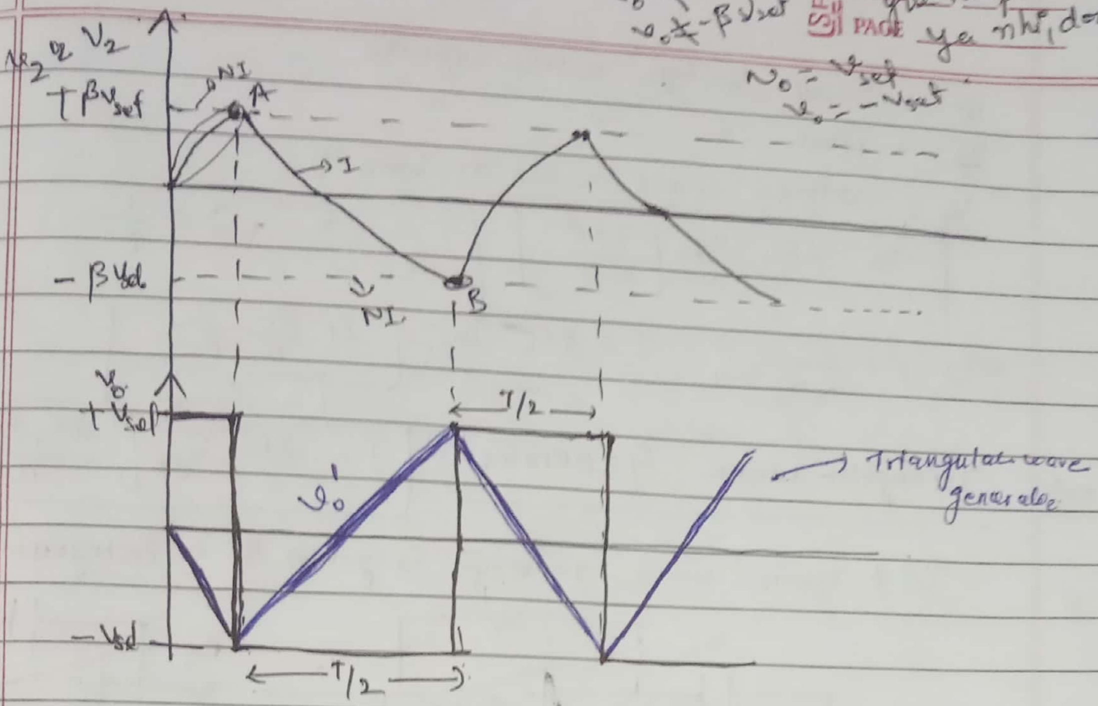


$V_o = +V_{sat}$

$-V_{sat}$

* opamp is forced to operate in saturation region.
* Initially capacitor is fully discharge.

$v_o = +\beta V_{sat}$ (ifs ckt condition
$v_o = -\beta V_{sat}$ give the phochlā h
ya nhi, don't case)
$v_o = V_{sat}$
$v_o = -V_{sat}$



square wave.

Apply KCL at pin (3)

$I_1 + I_2 = 0$

$$\frac{0 - v_1}{R_1} + \frac{v_o - v_1}{R_2} = 0$$

$$\frac{v_o}{R_2} = \frac{v_1}{R_1} + \frac{v_1}{R_2}$$

$$\frac{v_o}{R_2} = v_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

$$v_o = v_1\left(\frac{R_1 + R_2}{R_1}\right)$$

$$v_1 = v_o\left(\frac{R_1}{R_1 + R_2}\right) \rightarrow \beta$$

$$v_1 = \beta v_o$$

$$\boxed{v_1 = \beta v_o}.$$

If $v_o = +V_{sat}$
then $v_1 = +\beta V_{sat}$.

If $v_o = -V_{sat}$
then $v_1 = -\beta V_{sat}$.

charging and discharging eqⁿ :-

for single time constant RC ckt :-

$$v_t = V_f + (v_i - V_f)\, e^{-t/RC}. \quad (1)$$

During Discharging :- AB.

$v_i = +\beta V_{sat}$

$V_f = -V_{sat}$

at $t = T/2$

$v_t = -\beta V_{sat}$.

Put in (1)

$$-\beta V_{sat} = -V_{sat} + (\beta V_{sat} + V_{sat})\, e^{-T/2RC}$$

$$\cancel{V_{sat}}(1-\beta) = \cancel{V_{sat}}(1+\beta)\, e^{-T/2RC}$$

$$\frac{1-\beta}{1+\beta} = e^{-T/2RC}$$

frequency-

$$e^{T/2RC} = \frac{1+\beta}{1-\beta}$$

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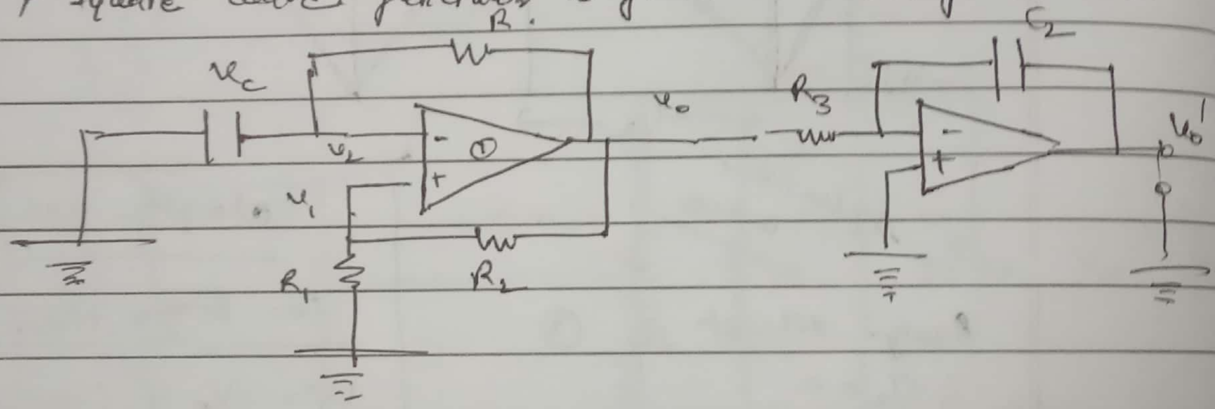
$v_i \rightarrow$ initial voltage across capacitor.
$v_f \rightarrow$ final " " "
V_t = voltage across across at time t.

$$\boxed{T = 2RC \log_e\left[\frac{1+\beta}{1-\beta}\right]} \qquad \nu = \frac{1}{T}.$$

also, $\beta = \frac{R_1}{R_1+R_2}$, $T = 2RC \log_e\left[\frac{1+\frac{R_1}{R_1+R_2}}{1-\frac{R_1}{R_1+R_2}}\right]$

$\Rightarrow$ Triangular wave Generator $\boxed{T = 2RC \log_e\left[\frac{2R_1+R_2}{R_2}\right]}$ *.

O/P of square wave generator is given to a integrator ckt.



$V_i \rightarrow$ initial voltage across capacitor.

$V_f \rightarrow$ final " " "

V_t = Voltage across across at time t.

$$\boxed{T = 2RC \log_e\left[\frac{1+\beta}{1-\beta}\right]}$$

$$\nu = \frac{1}{T}.$$

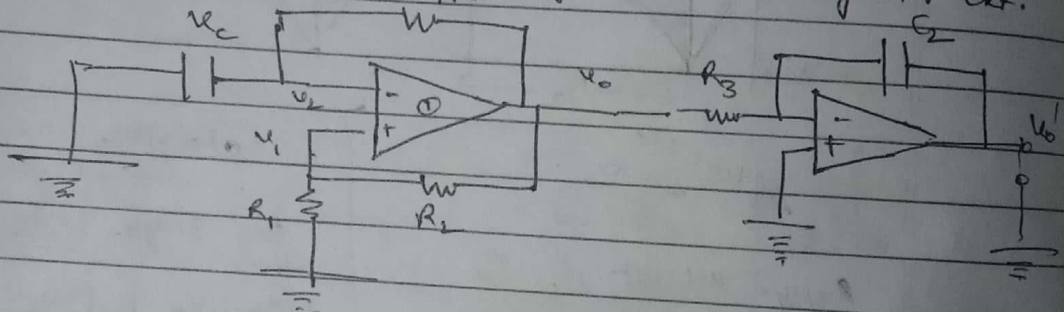
also, $\beta = \frac{R_1}{R_1+R_2}$,

$$T = 2RC \log_e\left[\frac{1+\frac{R_1}{R_1+R_2}}{1-\frac{R_1}{R_1+R_2}}\right]$$

$$\boxed{T = 2RC \log_e\left[\frac{2R_1+R_2}{R_2}\right]}$$

⇒ Triangular wave Generator

O/P of square wave generator is given to a integrator ckt.



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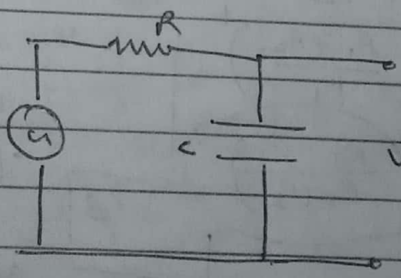
Active Filter :–

[1] low pass filter (low pass ckt) — allows low ν signal & blocks high ν

↑ o/p is obtained

↓ low o/p.



→. No gain is obtained

Not active
passive don't containing active component
Qs

at low freq

$X_c = \frac{1}{2\pi fc}$.

$f \longrightarrow$ low

$f = 0$

$X_c = \infty \rightarrow$ open ckt.

$V_o = V_i$.

at high freq.

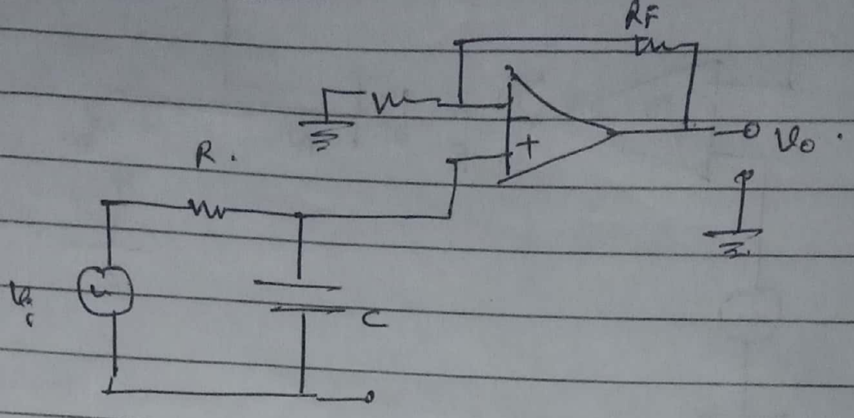
$f \rightarrow$ high

$F = \infty$

$X_c = 0 \rightarrow$ short ckt

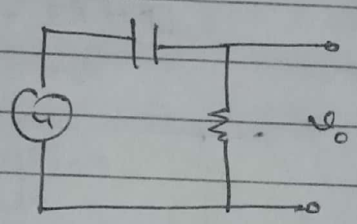
$V_o = 0$

1st order low pass active low pass filter –



high pass filter :-

passive

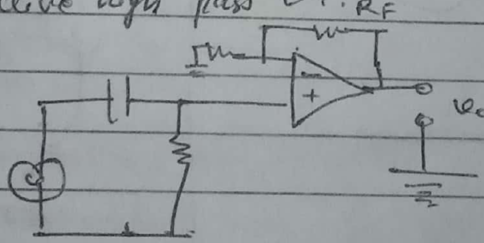


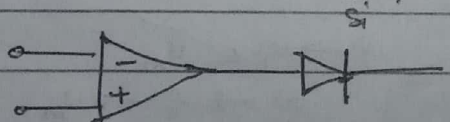
$X_c = \frac{1}{2\pi f c}$

at low freq.
f → low
f → 0
$X_c = \infty$
c → oc
$V_o = 0$

at high f
f → high
f → ∞
$X_c = 0$
c → sc
$V_o = V_i$

1st order active high pass ckt:





Precision diode.

for low voltage I/P signal.
↓
half wave rectifier can't rectify low voltage signal like mV or nV bcz $V_\gamma = 0.6V$ for Si the Diode will never conduct & no o/p will be obtained.

let A_V → very high (10^4)

$A_V = \frac{o/p}{I/p} = 10^4$

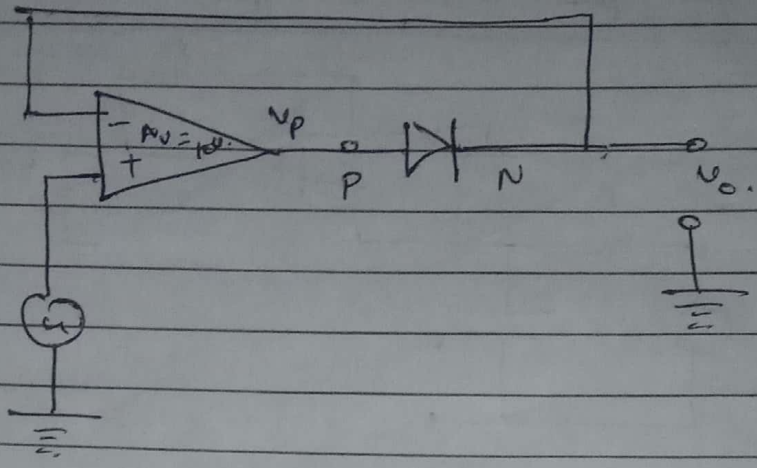
$\frac{0.6}{I/p} = 10^4$

$I/p = 0.6 \times 10^{-4} V$
$= 60\ \mu V$ → minimum voltage (at least)

→ I/P signal should be greater than 60 µV.

Precision rectifier diode

Using Buffer



If $v_i > 60\ \mu V$

$v_p > 0.6\ V$

$D \to FB \to SC$

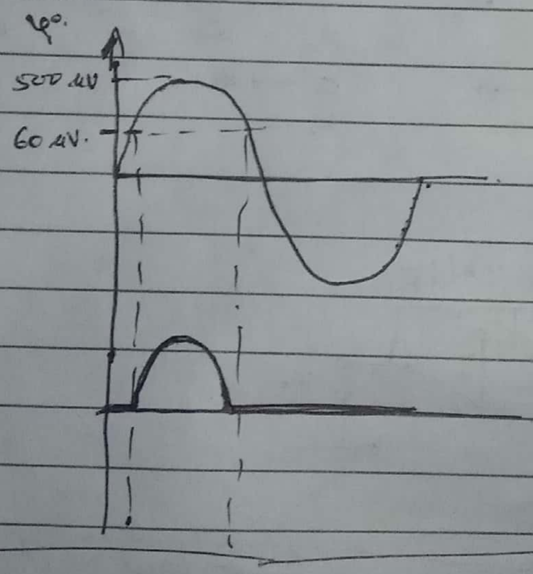
$v_o = v_i$

If $v_i < 60\ \mu V$

$v_p < 0.6\ V$

$D \to RB \to OC$

$v_o = 0$.



Multimeter → only measures sine wave

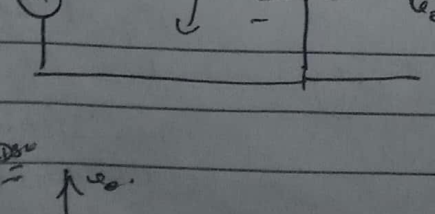
can't use for measuring other ~~signals peak value.~~

Peak Detector:-

sin, cos, ~~square, triangle~~

~~non-sinusoidal signal~~

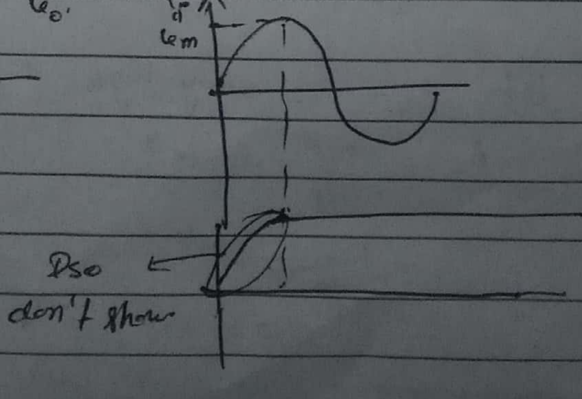
for high I/P signal.



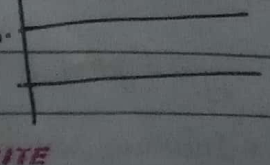
$P \to v_i < v_m$

$N \to v_c \to v_m$

$D \to RB \to OC$.

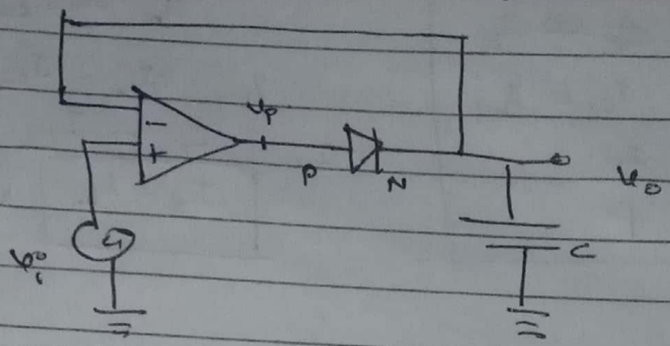


O/p on Dso =

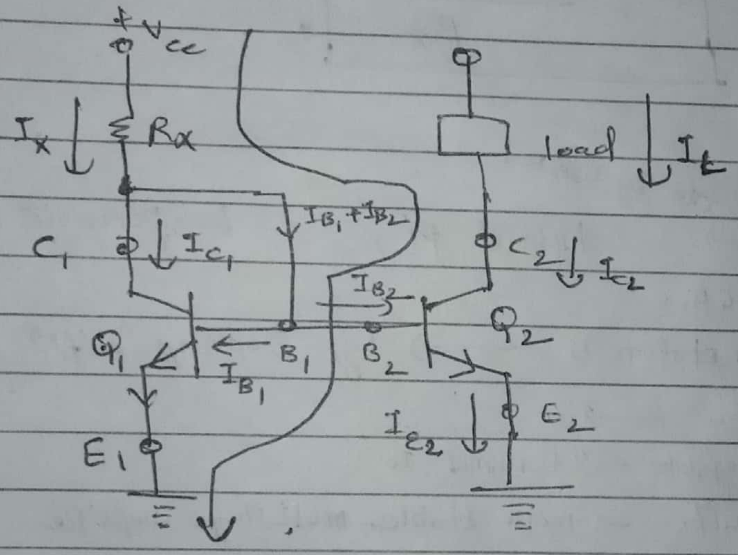


DATE (Full wave rectifier).
PAGE

Peak Detector → for low signal → Precision diode



* Current Mirror :—



$I_E = I_C + I_B$

$I_C = \beta I_B$

$I_E = \beta I_B + I_B$

$I_E = (1+\beta) I_B$

since $\beta >> 1$.

$\boxed{I_E \simeq \beta I_B \simeq I_C}$

① • Both transistors are identical.

② • Both transistors are in active region.

$$I_L = I_{C2}$$

since both transistors are identical.

$$V_{BE1} = V_{BE2}$$

$$I_{B_1} = I_{B2} = I_B$$

$$I_{E_1} = I_{E_2} = I_E$$

→ $I_X = I_{C_1} + I_{B_1} + I_{B_2}$

$= I_{C1} + 2 I_B = I_{E_1} + 2 I_B = I_E + 2 I_B$

$I_X = I_E + 2\dfrac{I_E}{\beta} = I_E \left(1 + \dfrac{2}{\beta}\right)$ since $\beta \to$ large

$I_X \simeq I_E \Rightarrow \boxed{I_X \simeq I_C}$

since, $I_C \simeq I_E$

$I_{C1} = I_{E1}$

$I_E \simeq \beta I_B$, $\Rightarrow I_B = \frac{I_E}{\beta}$

$I_X \simeq I_C$.

$I_{C_1} = I_{C_2} = I_C$.

$I_X = I_{C_2} = I_L$

$\boxed{I_X = I_L}$ *

Apply KVL in I/p.

$V_{CC} - I_X R_X - V_{BE} = 0$

$$\boxed{I_X = \frac{V_{CC} - V_{BE}}{R_X}}$$ *

do by ussel.

high ν → hybrid π, h→parameter → low ν.

power amplifier

instrumetation " → by 3 opamp diff^n ampli

PIV rectifier →

Voltage regulator → 3 terminal IC.

monosulf. → mono stable multistage amplifier.