Unit 04-

Op - Amp

(Operational Amplifiers)

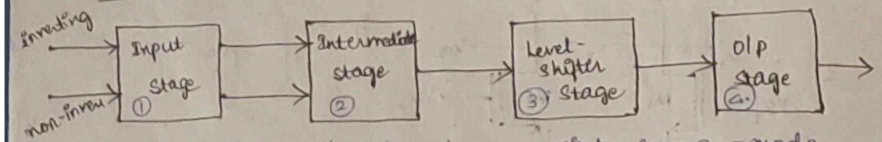
High gain, direct coupled, differential amplifier and can perform multiple operations [mathematical].

Coupling / blocking capacitor - blocks DC and couples AC

disadvantages - * No DC o/p is possible, amplification of DC is not possible as it is blocked.

Differential amplifier:-
Considers the difference b/w I/p signals and blocks all common-mode signals like noise etc.

Block diagram [provides (cascading) overall high gain]



① → Input stage should always reject common-mode signal. High input impedance. CMRR should be present. → dual i/p, balanced output, diff amplifier. Introduces high gain.

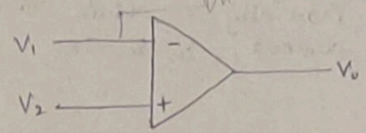
② → Cascaded stage. Dual i/p, unbalanced o/p. Also introduces high V gain as it is differential amplifier.

③ → Accumulation of DC leads to operating point shift. And due to which signal might be lost to clipping. [There might be offset]

[Pin no. 1 and 5 of op-amp IC → for offset adjustment & null the DC]

④ Power Amplifier / o/p stage: Class B power amplifier is used. [Current is also amplified and small resistance is used] → transistors are more prefered due to device stability. → low o/p impedance [CC is used] [Com. Collector gives low o/p resistance]

Symbol of op-amp:



V_0 - o/p V_1 - inverting i/p V_2 - non-inverting i/p

$V_0 = A_{OL}(V_2 - V_1)$ [non-inverting - inverting]

V_0 → o/p, A_{OL} → gain, $(V_2 - V_1)$ → differential voltage

Parameters:- / characteristics of op-amp

	Ideal	
R_{in}	∞	
R_{out}	0	[o/p impedance low for voltage amplification]
BW	∞	
A_v	∞	
CMRR	∞	
Slew rate	∞	

SR = $\left.\frac{dV_0}{dt}\right|_{max}$ ↳ how fast the op-amp responds [o/p] with change in i/p. If slew rate is high, we can use it for high frequency applications.

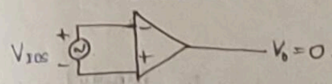
Applications:-

used as
* open loop :- no feedback resistance
closed loop :- feedback resistance is present → +ve f.B / -ve f.B

Other op-amp parameters:

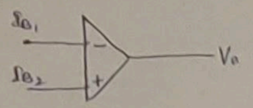
i) i/p offset voltage: When i/p = 0 [not applied] o/p should be zero. Ideal = 0

The voltage applied in order to make o/p zero.



ii) o/p offset voltage:- The small voltage obtained when i/p voltage is zero [mostly due to level shifter]. Ideal = 0

iii) I/p bias current :- Ideally, input current is zero. Practically, we obtain a small bias current $I_B = \frac{I_{B_1} + I_{B_2}}{2}$



Output offset voltage is due to i/p offset voltage and bias current.

iv) Power supply Rejecⁿ Ratio :- [ideal = 0]

$\frac{\Delta V_{os}}{\Delta V_{cc}}$ → change in output offset voltage due to change in supply - the ratio is PSRR.

Drift: The change in values of parameters with time and change in temperature.

→ +ve feedback :- when feedback is in phase with the i/p & aiding it.

→ -ve feedback :- when feedback is out of phase with the i/p & not supporting it.

Open loop application :-

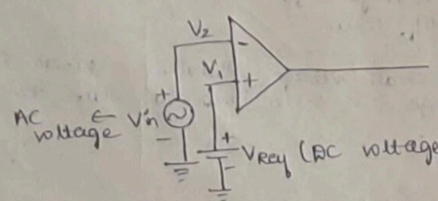
i) Comparator
- Inverting
  - +ve ref
  - -ve ref
- Non-Inverting
  - +ve ref
  - -ve ref

→ Inverting comparator :-

ii) Zero-crossing detector :-

iii) Schmitt trigger

(1) Inverting comparator :- [case i: with +ve reference]
Input is given at the inverting terminal

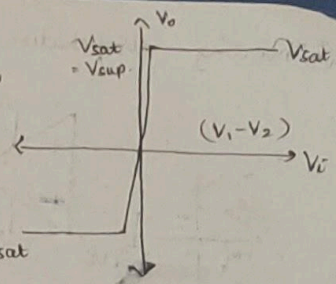


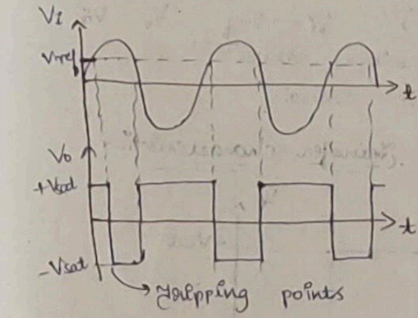
Let $A_{OL} = \infty$ (Ideally)

$V_o = A_{OL}(V_1 - V_2)$ [non-inverting - inverting]

$V_1 = V_{ref}$ (+ve) $V_2 = V_{in}$

When $V_{ref} > V_{in}$, gain is positive and o/p will go to saturaⁿ [+ve sat]
→ Usually it is (V_{sat}) is supply voltage, but difference is due to device.



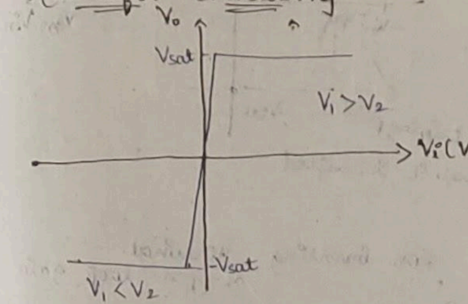


Applicatⁿ: Any wave can be converted into square wave.

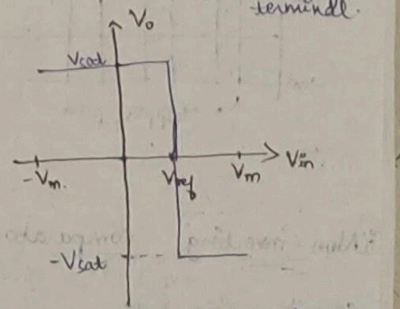
and :- Tripping point is, V_{ref}

Duty cycle (DC) = $\frac{T_{ON}}{T}$

Transfer characteristics:

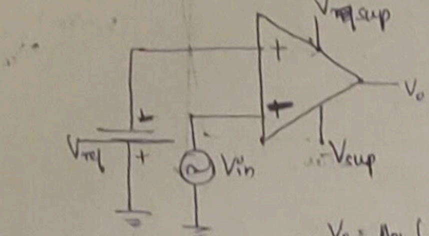


V_{in} - inverting terminal.

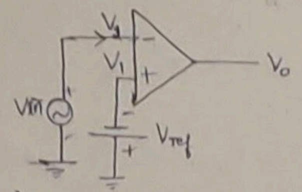


Vsat because gain is added which has a cap of Vsat, hence o/p is $\pm V_{sat}$ irrespective of i/p. [Ideally assuming gain is ∞)

(b) Inverting comparator (-ve ref)

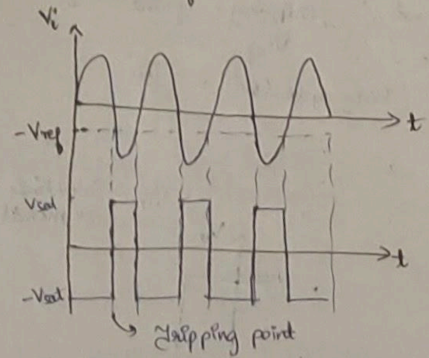


or

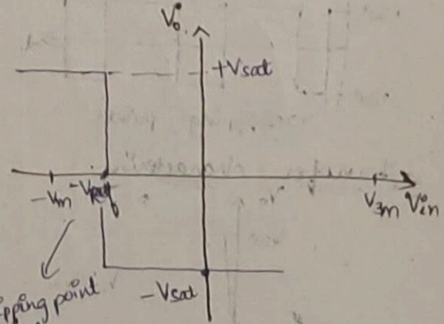


$V_o = A_{OL}(V_1 - V_2)$ $V_1 = -V_{ref}$ $V_2 = V_{in}$

$V_{in} < V_{ref}$, then o/p is positive saturaⁿ.
$V_{in} > V_{ref}$, then o/p is -ve saturaⁿ.



Transfer characteristics

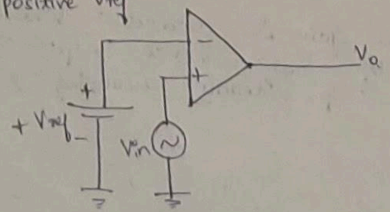


tripping point
w.r.t it is shifted.

(ii) Non-inverting comparator:-

Input is given to non-inverting terminal.
or-open loop gain.

Case i):- positive V_{ref}

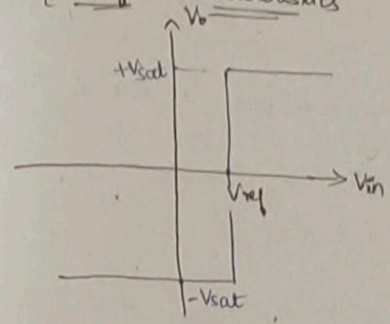


$V_o = A_{OL}(V_1 - V_2)$

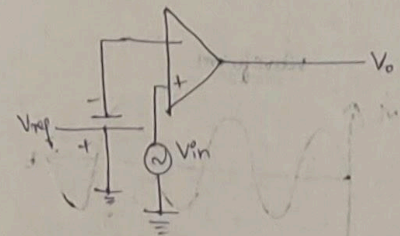
$V_1 = V_{in}$ $V_2 = V_{ref}$

i) $V_{in} > V_{ref}$, +ve saturaⁿ
ii) $V_{in} < V_{ref}$, -ve saturaⁿ

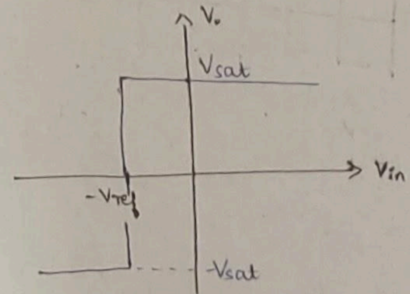
Transfer characteristics



Case ii) negative V_{ref}



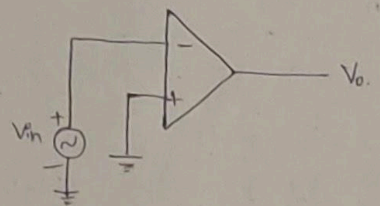
Transfer characteristics!



(iii) Zero crossing Detector

a) Inverting ZCD

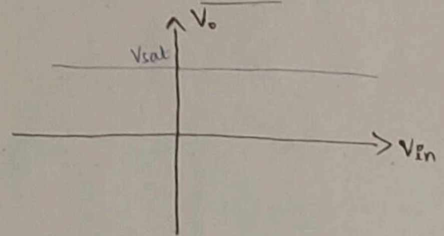
Reference voltage [+ve non-inverting terminal] is zero & i/p is given to inverting terminal.



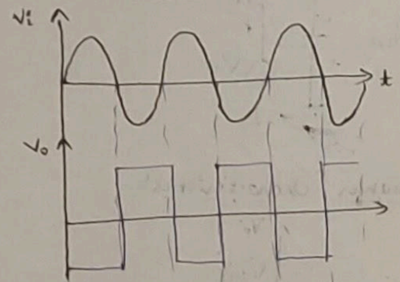
$V_{ref} - V_{in}$

$\rightarrow -V_{in}$

Transfer characteristics

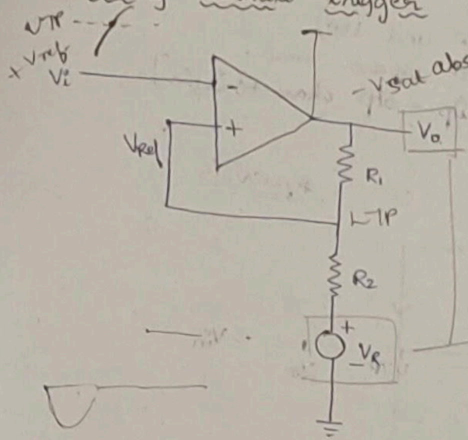


Waveform



(iv) Schmitt trigger [based on inverting comparator]

Inverting Schmitt trigger



absence of feedback

If there is no negative feedback, gain is very large.

output can either be positive satura^n.

Theory:- superposition multiple potentials are present, ground one.

If $V_o = +V_{sat}$

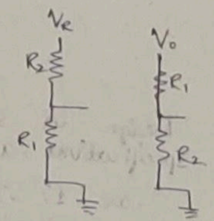
$V_{ref} = UTP$ [Upper trip point]

$V_{ref} = UTP_1 = \frac{+V_{sat} \cdot R_2}{R_1+R_2}$ [$V_R \rightarrow$ grounded]

$UTP_2 = \frac{V_R R_1}{R_1+R_2}$ [V_o is grounded]

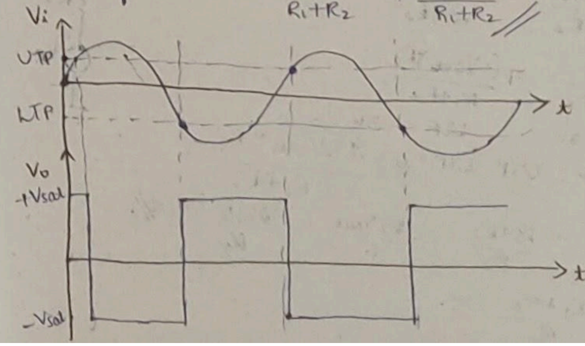
$\therefore UTP = \frac{+V_{sat} R_2}{R_1+R_2} + \frac{V_R R_1}{R_1+R_2}$

Biasing circuit



If $V_o = -V_{sat}$

$V_{ref} = LTP = \frac{-V_{sat} R_2}{R_1+R_2} + \frac{V_R R_1}{R_1+R_2}$



If UTP = LTP duty cycle is same.

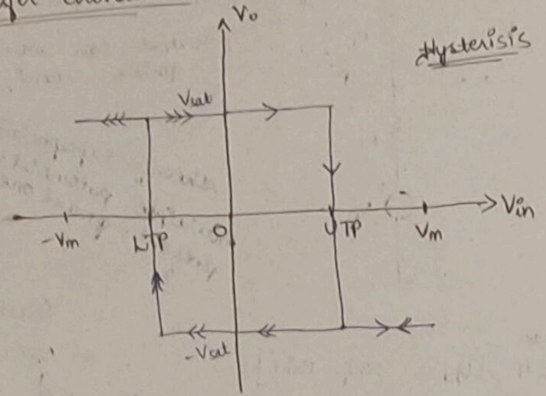
$T_{off} = T_{on}$

Application!

* Window / two level detector (UTP and LTP).
* Any signal is converted into square wave.

Transfer characteristics [i/p - o/p characteristics]

Hysterisis



Design a Schmitt trigger for the following specifications, assume $\pm V_{sat} = \pm 15V$.

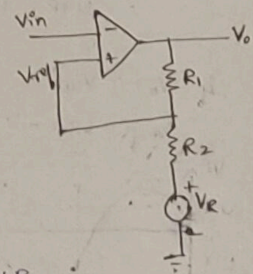
case 1: UTP = +3V, LTP = -3V

case 2: UTP = +4V, LTP = -2V

case 3: UTP = +2V, LTP = -4V

case 4: UTP = +7V, LTP = +1V

case 5: UTP = -1V, LTP = -7V



Sol^n: $UTP = \frac{+V_{sat}R_2}{R_1+R_2} + \frac{V_R R_1}{R_1+R_2}$

$LTP = \frac{V_R R_1}{R_1+R_2} + \frac{(-V_{sat})R_2}{R_1+R_2}$

case 1: UTP = 3V, LTP = -3V

step 1: $UTP - LTP = 6 = \frac{2 \times V_{sat} \times R_2}{R_1+R_2}$

$\frac{R_1+R_2}{R_2} = \frac{2 \times V_{sat}}{6} = \frac{2 \times 15}{6} = 5$

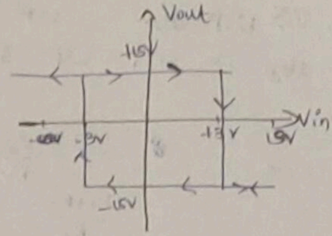
$\frac{R_1+R_2}{R_2} = 5$

$\frac{R_1}{R_2} + 1 = 5$

$\frac{R_1}{R_2} = 4\,\Omega$

Let $R_2 = 10K\Omega$

$\therefore R_1 = 40K\Omega$



step 2) UTP + LTP (for V_R)

$0 = \frac{2V_R R_1}{R_1+R_2}$ As R_1 & R_2 cannot be zero

$\boxed{V_R = 0}$

case 2: UTP = 4V, LTP = -2V

step 1: $UTP - LTP = 6 = \frac{2V_{sat}R_2}{R_1+R_2}$

$\frac{R_1+R_2}{R_2} = \frac{2V_{sat}}{6} = \frac{2 \times 15}{6} = 5$

$\frac{R_1}{R_2} + 1 = 5\,\Omega$ Assume $R_2 = 10K\Omega$, $R_1 = 40K\Omega$

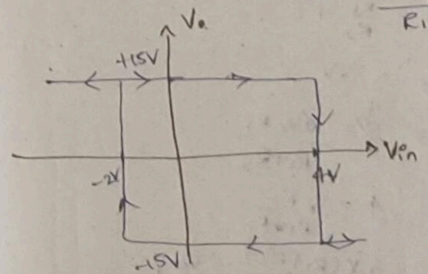
$\frac{R_1}{R_2} = 4\,\Omega$

Till window size is same, resistance ratio is same (interdependent)

Step 2: $UTP + LTP = 2 = \frac{2V_R R_1}{R_1+R_2}$

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

$V_R = \frac{R_1+R_2}{R_1} = \frac{50K\Omega}{40K\Omega} = \frac{5}{4} = 1.25V$



case iii> UTP = 2V LTP = -4V

step i> UTP - LTP = 6V = $\frac{2V_{sat} R_2}{R_1+R_2}$

$3 = \frac{V_{sat} R_2}{R_1+R_2}$

$\frac{R_1+R_2}{R_2} = \frac{V_{sat}}{3} = \cancel{15}/\cancel{3} = 5V$//.

$\frac{R_1}{R_2} + 1 = 5$ Assume $R_2 = 10k\Omega$

$R_1 = 40k\Omega$

$\frac{R_1}{R_2} = 4V$

Step (ii) $UTP + LTP = -\cancel{2}V = \frac{\cancel{2}V_R R_1}{R_1+R_2}$

$-1 = \frac{V_R R_1}{R_1+R_2}$

$V_R = \frac{-(R_1+R_2)}{R_1} = -\frac{50k\Omega}{40k\Omega} = -1.25V$

case iv> UTP = 7V LTP = 1V

step i> $UTP - LTP = \overset{3}{\cancel{6}}V = \frac{\cancel{2}V_{sat} R_2}{R_1+R_2}$

$3 = \frac{V_{sat} R_2}{R_1+R_2}$ $R_2 = 10k\Omega$

$R_1 = 40k\Omega$

$\frac{V_{sat}}{3} = \frac{R_1+R_2}{R_2}$

$\frac{\cancel{15}^{5}}{\cancel{3}} = \frac{R_1}{R_2} + 1$

$R_1/R_2 = 4V$

step ii> $UTP + LTP = \overset{4}{\cancel{8}} = \frac{\cancel{2}V_R R_1}{R_1+R_2}$

$4 = \frac{V_R R_1}{R_1+R_2}$

$\frac{4 \times (R_1+R_2)}{R_1} = V_R$

$V_R = \frac{4 \times (\cancel{50}k)}{\cancel{40}k}$ $V_R = +5V$

case v> UTP = -1V LTP = -7V

step i> $UTP - LTP = \overset{3}{\cancel{6}}V = \frac{\cancel{2}V_{sat} R_2}{R_1+R_2}$

$3 = \frac{V_{sat} R_2}{R_1+R_2}$

$\frac{V_{sat}}{3} = \frac{R_1+R_2}{R_2} \Rightarrow \frac{\cancel{15}^{5}}{\cancel{3}} = \frac{R_1}{R_2} + 1$

$\frac{R_1}{R_2} = 4\Omega$ Assume $R_2 = 10k\Omega$

$R_1 = 40k\Omega$

Step ii> $UTP + LTP = -\overset{4}{\cancel{8}}V = \frac{\cancel{2}V_R R_1}{R_1+R_2}$

$-4 = \frac{V_R R_1}{R_1+R_2} \Rightarrow -4 = \frac{V_R (40k)}{50k}$

$\rightarrow \frac{-\cancel{4} \times 5\cancel{0}k}{\cancel{4}\cancel{0}k} = V_R$

$V_R = -5V$

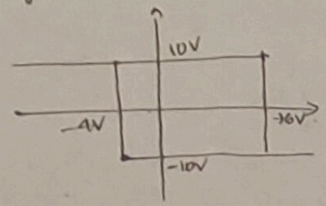
$\frac{V_{sat} R_2}{R_1+R_2}$

$\frac{R_1+R_2}{R_2} = \frac{10}{3}$

$\frac{R_1}{R_2} = 3.3333 - 1$

$= 2.3$

Design



UTP = 6 V LTP = -4V $\pm V_{sat} = \pm 10$

Step 1:- UTP − LTP = $\cancel{10}^{5}V = \cancel{2}^{1}V_{sat}\dfrac{R_2}{R_1+R_2}$

$5 = V_{sat}\dfrac{R_2}{R_1+R_2}$

$\dfrac{R_1+R_2}{R_2} = \dfrac{\cancel{10}^{2}}{\cancel{5}}$

$\dfrac{R_1}{R_2} + 1 = 2$

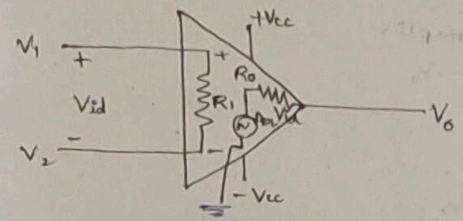
$\dfrac{R_1}{R_2} = 1$ $\underline{R_1 = R_2}$

Step 2:- UTP + LTP = $\cancel{2}V = \dfrac{\cancel{2}V_R R_1}{R_1+R_2}$ As $R_1 = R_2$

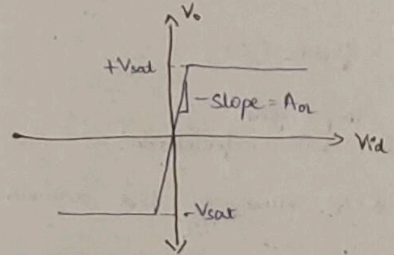
$1 = \dfrac{V_R \cancel{R_1}}{2\cancel{R_1}}$

$\boxed{V_R = 2V}$

Equivalent circuit of op-Amp [closed loop]



Transfer characteristics



Open loop gain is extremely high.

$V_o = +V_{sat} = \pm 15V$

$A_{OL} = 10^5$

$V_{id} = ?$

$V_o = (A_{OL})V_{id}$

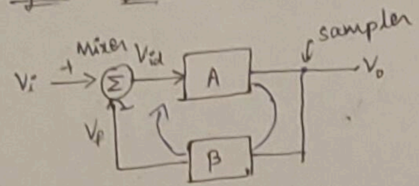
$V_{id(max)} = \dfrac{V_{o\,max}}{A_{OL}} = \dfrac{15}{10^5} = \underline{150\mu V} / \underline{0.15mV}$

At any voltage greater than 0.15mV, the o/p saturates and gain is not observed according to eq^n - $V_o = A_{OL}(V_{id})$

Negative feedback

A part of o/p is fed back as i/p which is out of phase, hence termed as -ve feedback.

Negative feedback



A - open loop gain - A_{OL}
where $A_{OL} = A = \frac{V_o}{V_{id}}$ where $V_{id} = V_i - V_f$

& $V_f = \beta V_o$.

where β = feedback factor (<1)

$A_F = \frac{V_o}{V_i}$ ⇝ closed loop gain
(Gain with feedback)

$A_f = \frac{V_o}{V_i} = \frac{V_o}{V_{id} + V_f}$ divide numerator and denominator by V_{id}.

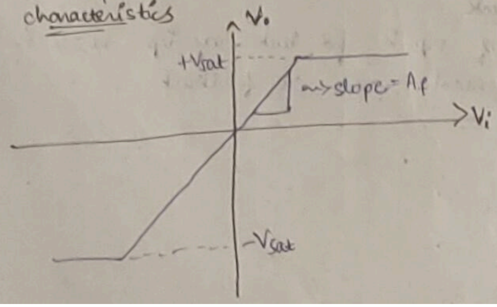
$= \frac{\frac{V_o}{V_{id}}}{1 + \frac{V_f}{V_{id}}}$

$A_f = \frac{V_o/V_{id}}{1 + \frac{V_f}{V_{id}} \times \frac{V_o}{V_o}} = \frac{A_{OL}}{1 + A_{OL}\beta} = \frac{A}{1+A\beta}$

$1 + A\beta$ ⇝ Amount of feedback.
[Gain is reduced]

$A\beta$ ⇝ loop gain

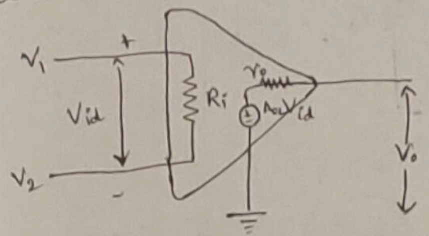
Transfer characteristics



Closed loop application

⇝ non-inverting amplifier ⇝ inverting amplifier ⇝ voltage follower
⇝ summer ⇝ difference amplifier ⇝ integrator
⇝ differentiator

Virtual ground



Imp: $V_1 = V_2$ due to virtual ground.

$V_o = A_{OL}V_{id} = A_{OL}(V_1 - V_2)$ ⇝ $A_{OL} = \frac{V_o}{V_1 - V_2}$

if $A_{OL} = \infty$ (Ideal op. Amp)

$V_1 - V_2 = 0$

∴ $V_1 = V_2$ ⇝ this condiⁿ holds good when

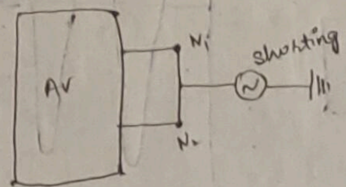
One terminal is physically grounded and other terminal becomes virtually grounded.

∴ Since, $R_i = \infty$ [Input current $I_1 = I_2 = 0$]
through the resistor R_i; current is zero.

∴ when two nodes N_1 and N_2 are shorted, voltage is zero, and current may or may not exist and in open circuit current is zero and voltage and may or may not exists.

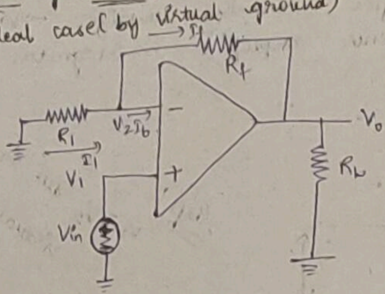
⇝ loaded circuit, voltage and current are non-zero.

⇝ virtual ground, voltage and current are zero.



Non-inverting amplifier

(I) Ideal case [by virtual ground)



KCL at node 2

$I_1 = I_f + I_b$ $\quad \Rightarrow I_b = 0$ [by virtual ground $-R_i = \infty$]

$V_1 = V_2 = V_{in}$ [by virtual ground]

$I_1 = I_f$

$V_{AB} = I_{AB} R.$

$\frac{0 - V_2}{R_1} = \frac{V_2 - V_0}{R_f}$ $\quad V_{AB} = V_A - V_B$

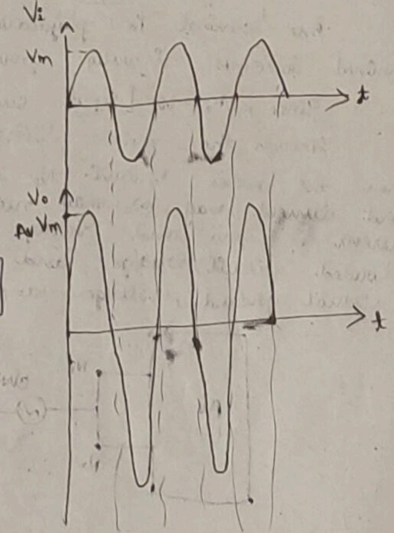
$\frac{-V_{in}}{R_1} = \frac{V_{in}}{R_f} - \frac{V_0}{R_f}$

$\frac{V_0}{R_f} = \frac{V_{in}}{R_f} + \frac{V_{in}}{R_1}$

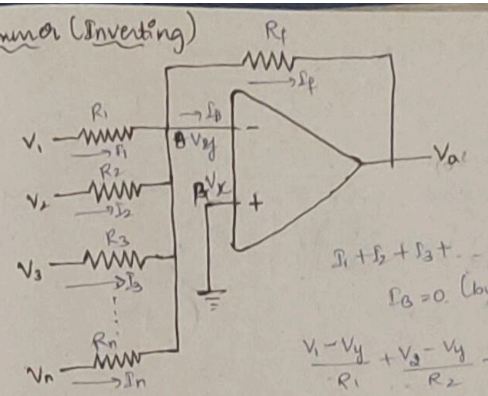
$\frac{V_0}{R_f} = V_{in}\left[\frac{1}{R_f} + \frac{1}{R_1}\right]$

$\frac{V_0}{V_{in}} = R_f\left[\frac{1}{R_f} + \frac{1}{R_1}\right]$

$$\boxed{A_v = 1 + \frac{R_f}{R_1}}$$



Summer (Inverting)



KCL at node 2

$I_1 + I_2 + I_3 + \ldots + I_N = I_f + I_B$

$I_B = 0$ (by virtual group $[R_i = \infty]$)

$\frac{V_1 - V_y}{R_1} + \frac{V_2 - V_y}{R_2} + \ldots + \frac{V_n - V_y}{R_n} = \frac{V_y - V_0}{R_f}$

But $V_y = V_x = 0$ [Virtual ground]

$\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \ldots + \frac{V_n}{R_n} = \frac{-V_0}{R_f}$

$$\boxed{V_0 = -\left(\frac{R_f}{R_1}V_1 + \frac{R_f}{R_2}V_2 + \frac{R_f}{R_3}V_3 + \ldots + \frac{R_f}{R_n}V_n\right) = -(aV_1 + bV_2 + cV_3 + \ldots + kV_n)} \rightarrow ①$$ scaling amplifiers.

* summer (Inverting) & a scaling amplifiers.

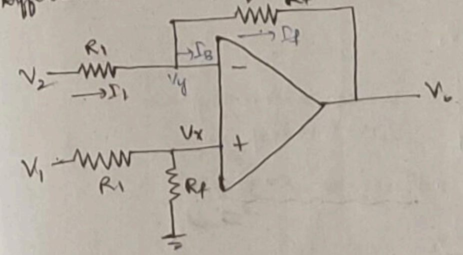
(i) In eqⁿ ①, if we consider $R_1 = R_2 = \ldots = R_n = R$

then eqⁿ ⇒ $\boxed{V_0 = -\frac{R_f}{R}(V_1 + V_2 + V_3 + \ldots + V_n)}$ ⇝ summer

(ii) If in eqⁿ ①, if we consider $R_f = R_1 = R_2 = \ldots = R_n = R$

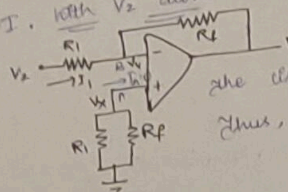
then eqⁿ ⇒ $\boxed{V_0 = -(V_1 + V_2 + V_3 + \ldots + V_n)}$ ⇝ Adder

Differential amplifier / subtractor:-



V_o can be obtained by applying superposition theorem.

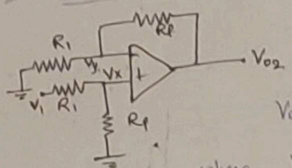
I. With V_2 alone



The circuit looks like an inverting amplifier

Thus, $\boxed{V_{o1} = \frac{-R_f}{R_1} V_2}$ → ①

II. With V_1 alone



The circuit looks like a non-inverting amplifier.

$V_{o2} = \left(1 + \frac{R_f}{R_1}\right) V_x$ → ②

where $V_x = \frac{R_f}{R_1 + R_f} V_1$ [voltage division rule]

② ⇒ $\left(1 + \frac{R_f}{R_1}\right)\left(\frac{R_f}{R_1+R_f}\right) V_1$

$= \left(\frac{R_1+R_f}{R_1}\right)\left(\frac{R_f}{R_1+R_f}\right) V_1$

$\boxed{V_{o2} = \frac{R_f}{R_1} V_1}$ → ②

Using super-position theorem

$V_o = V_{o1} + V_{o2}$

$= \frac{-R_f}{R_1} V_2 + \frac{R_f}{R_1} V_1$

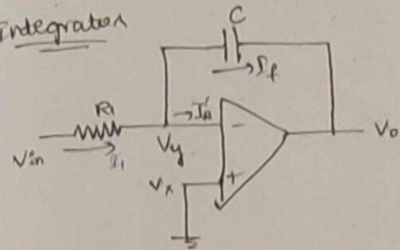
$\boxed{V_o = \frac{R_f}{R_1}(V_1 - V_2)}$ V_1 → non-inverting, V_2 → inverting

→ difference amplifier

if $R_f = R_1 = R$

$\boxed{V_o = V_1 - V_2}$ → subtractor

Integrator



KCL at node Y

$I_1 = I_B + I_f$

$I_B = 0$ [by common ground]

$I_1 = I_f$

$\frac{V_i - V_y}{R_1} = \frac{C d(V_y - V_o)}{dt}$

$V_y = V_x = 0$ [virtual ground].

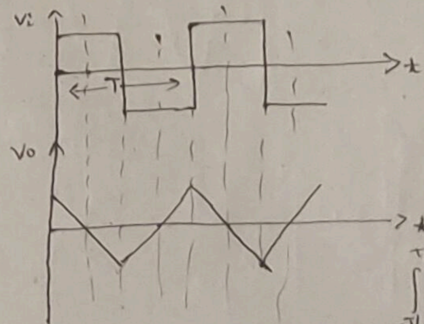
$\frac{V_i}{R_1} = \frac{C d(-V_o)}{dt}$ → $\frac{V_i}{R_1} = -C \frac{dV_o}{dt}$

$dV_o = \frac{-1}{RC} V_i dt$

Integrate the eqⁿ w.r.t. t

$\boxed{V_o(t) = -\frac{1}{RC} \int V_i dt}$ $\boxed{V_o = -\frac{1}{RC} \int V_i dt}$

Note: $RC >> T$ → if circuit acts as an integraⁿ.



$\int x(t).dt$

$= \int_0^{T/2} 1\, dt + \int_{T/2}^{T} -1\, dt$

$x(t) = T/2 - [T - T/2]$

$T/2 + T/2 - T$

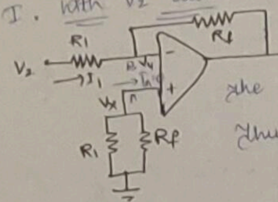
$T - T = 0$

$\int_{-T/2}^{T/2} x(t)\, dt$

$\int_{-T/2}^{0} x(t) - \int_0^{T/2} dt = 0 + T/2 + (T/2) = 0$

V_o can be obtained by applying superposition theorem

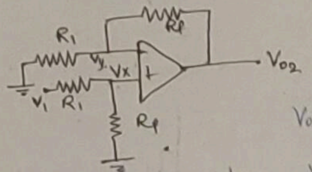
I. With V_2 alone



The circuit looks like an inverting amplifier

Thus, $\boxed{V_{o1} = \frac{-R_f}{R_1} V_2}$ → ①

II. With V_1 alone



The circuit look like a non-inverting amplifier

$$V_{o2} = \left(1 + \frac{R_f}{R_1}\right) V_x \rightarrow ②$$

where $V_x = \frac{R_f}{R_1 + R_f} V_1$ [voltage division rule]

② ⇒ $\left(1 + \frac{R_f}{R_1}\right)\left(\frac{R_f}{R_1 + R_f}\right) V_1$

$$= \left(\frac{R_1 + R_f}{R_1}\right)\left(\frac{R_f}{R_1 + R_f}\right) V_1$$

$\boxed{V_{o2} = \frac{R_f}{R_1} V_1}$ → ②

Using super-position theorem

$$V_o = V_{o1} + V_{o2}$$

$$= \frac{-R_f}{R_1} V_2 + \frac{R_f}{R_1} V_1$$

$\boxed{V_o = \frac{R_f}{R_1}(V_1 - V_2)}$ → difference amplifier

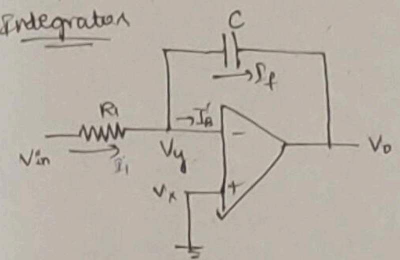
V_1 → non-inverting

V_2 → inverting

if $R_f = R_1 = R$

$\boxed{V_o = V_1 - V_2}$ → subtractor

Integrator



KCL at node Y

$$I_1 = I_B + I_f$$

$I_B = 0$ [by common ground]

$$I_1 = I_f$$

$$\frac{V_i - V_y}{R_1} = \frac{C\,d(V_y - V_o)}{dt}$$

$V_y = V_x = 0$ [virtual ground]

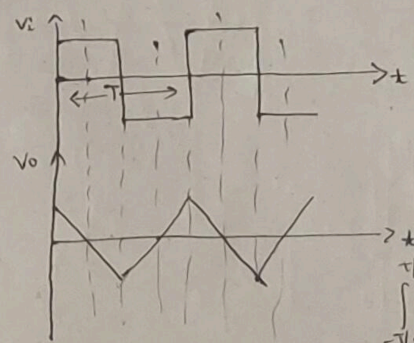
$$\frac{V_i}{R_1} = \frac{C\,d(V_o)}{dt} \Rightarrow \frac{V_i}{R_1} = -C\frac{dV_o}{dt}$$

$$dV_o = \frac{-1}{RC} V_i dt$$

integrate the eq^n w.r.to t

$\boxed{V_o(t) = -\frac{1}{RC}\int V_i\,dt}$ $\boxed{V_o = -\frac{1}{RC}\int V_i\,dt}$

Note: $RC >> T$ → if circuit acts as an integra^n



$$\int x(t)\,dt$$

$$= \int_0^{T/2} 1\,dt + \int_{T/2}^{T} -1\,dt$$

$$x(t) = T/2 - [T - T/2]$$

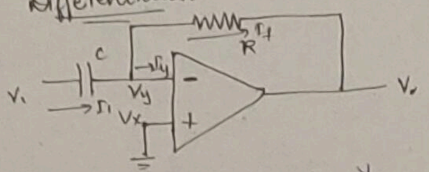
$$T/2 + T/2 - T$$

$$T - T = 0$$

$$\int_{-T/2}^{T/2} x(t)\,dt$$

$$\int_{-T/2}^{0} x(t) - \int_0^{T/2} dt = 0 + T/2 + (T/2) = 0$$

Differentiator



Apply KCL at node Y

$I_1 = I_y + I_f$ [$I_y = 0$, by virtual ground]

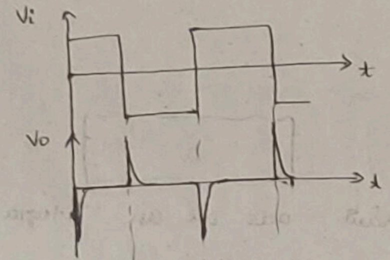
$I_1 = I_f$

$C\frac{d(V_1 - V_y)}{dt} = \frac{V_y - V_o}{R}$ $V_x = V_y = 0$ [by virtual ground]

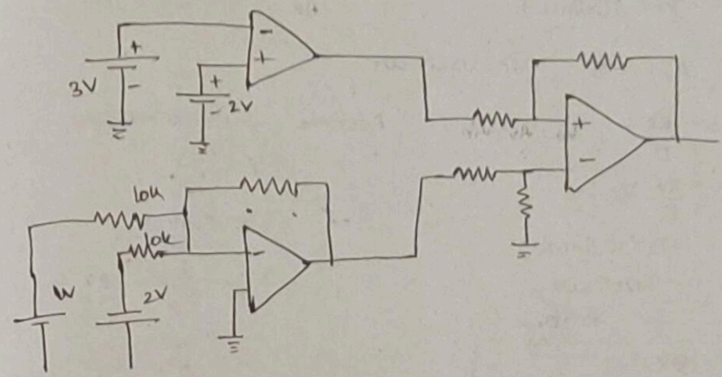
$C\frac{dV_1}{dt} = \frac{-V_o}{R}$

$V_o = -RC\left[\frac{dV_1}{dt}\right]$

Note RC<<T



Problems:-



1. Design inverting amplifier for $A_v = -5$, & sketch i/p & o/p waveform for $V_i = 10\sin\omega t$.

2. Desing non-inverting amplifier for $A_v = 11$ & sketch i/p and o/p waveform for $V_i = 10\sin\omega t$

3. For a differentiator. $RC = 10\mu sec$ sketch i/p o/p waveform for $V_i = 10\sin\omega t$ $\omega = 314$

4. For an integrator $RC = 100 msec$, sketch i/p & o/p for $V_i = 10\sin\omega t$

5. Design a circuit using op-amp to get o/p express^n:-

i) $V_o = -(2V_1 + 3V_2 + 4V_3)$ ii) $V_o = +(2V_1 + 3V_2 + 4V_3)$

iii) $V_o = -(2V_1 + 3V_2 + 4V_3)$ iv) $V_o = +(2V_1 - 3V_2 + 4V_3)$

v) $V_o = +(2V_1 - 3V_2)$ vi) $V_o = -2(2V_1 + 3V_2 + 4V_3)$.

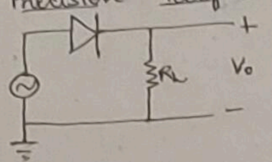
vii) $V_o = 2(V_1 - V_2)$

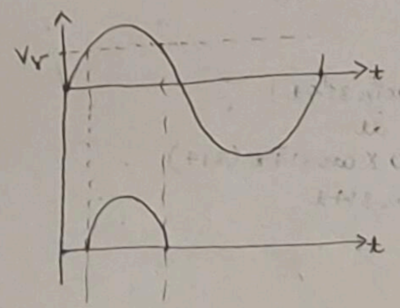
Precision rectifier

Instrumentation amplifier

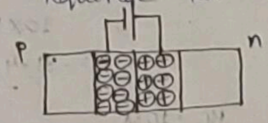
Square wave or triangular wave generator:-

Precision rectifier:





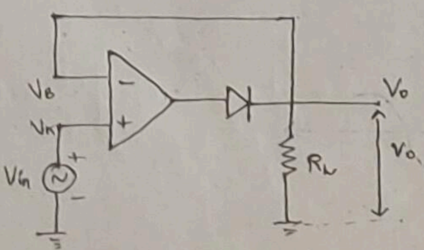
Note) Cut-in voltage is minimum voltage required for the diode to start conducting and overcome the barrier potential, hence regular rectifier do not rectify a voltage equivalent to or less than V_γ because it is the min. potential required for diode to be a.



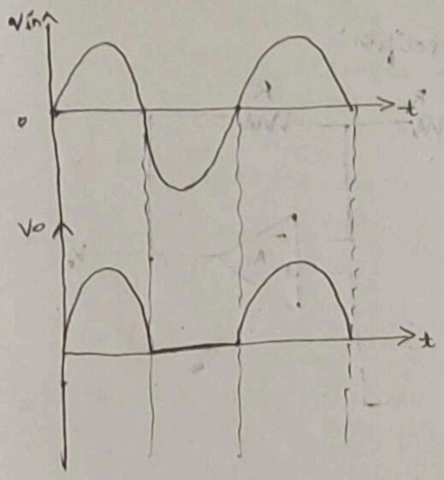
Precis^n rectifier is a rectifier whose i/p is rectified even if it is less than V_γ. Very small signals is rectified.

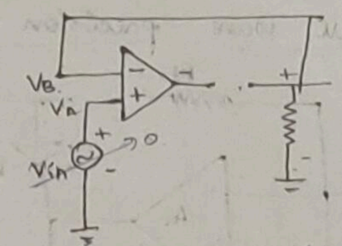
Precision rectifier — Half wave &
— Full wave

Half wave Rectifier (Precision):-

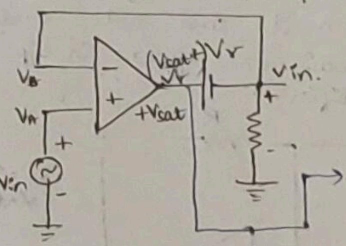


$V_A = V_B$ (virtual ground)





When no potential is applied, diode is reverse biased, conduc^n does not take place, as there is no current in the circuit thus o/p voltage would be zero.



When a positive potential is applied, diode is forward biased and conducting, and we obtain a o/p voltage equivalent to V_{in}.

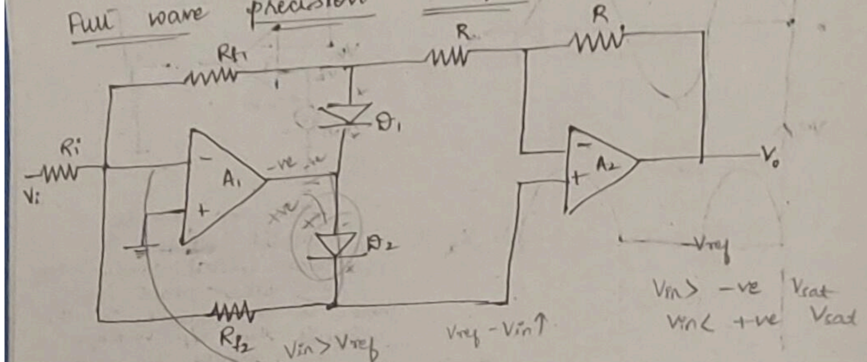
→ At the point, potential is $V_\gamma + V_{sat}$ (V_{in}). V_γ is used to drive the diode thus, obtaining V_{in} at o/p.

During -ve half cycle, diode is reverse biased, hence it does not conduct and hence, o/p voltage is zero.

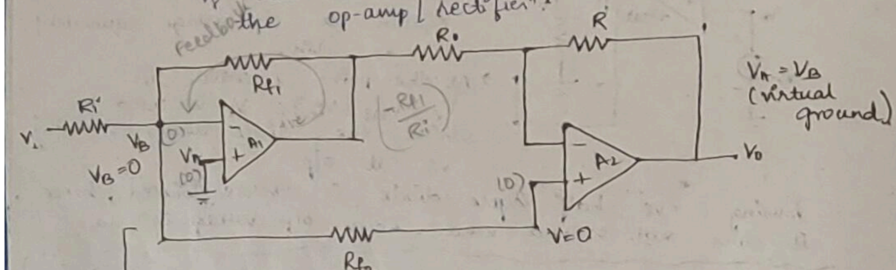
"V_γ has no contribution to o/p of the rectifier".

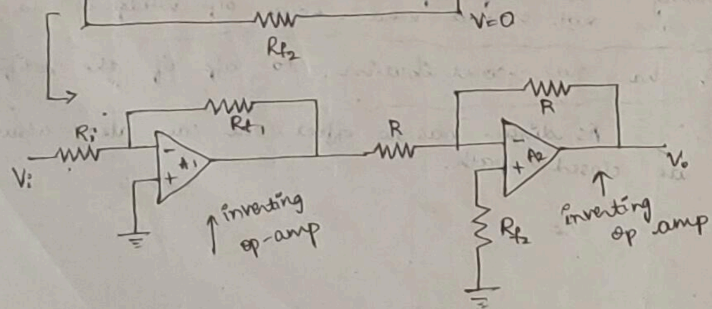
As diode has no effect, one can also assumed it as closed path.

Full wave precision rectifier:



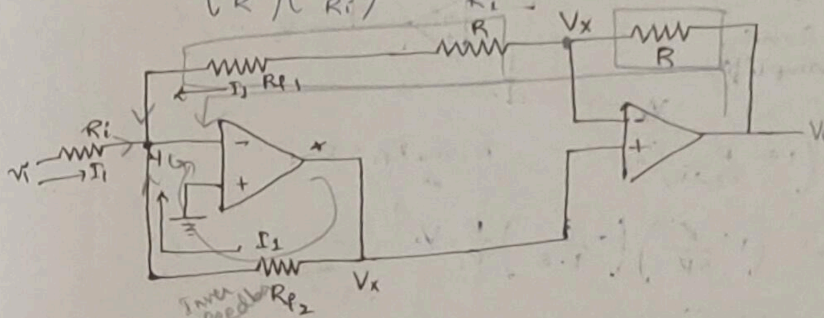
1. During the have cycle
As i/p is applied to inverting terminal, the o/p at terminal is $-V_{sat}$, due to which D_1 is f-biased and conducting and D_2 is r-biased and not conducting.
" V_r has no contribuⁿ or effect in o/p of the op-amp / rectifier".





$V_o = A_{V_1} \cdot A_{V_2} \cdot V_i$

$V_o = \left(\frac{-R}{R}\right)\left(-\frac{R_{f_1}}{R_i}\right)V_i = \frac{R_{f_1}}{R_i} V_i$



Apply KCL at Node Y

$I_1 + I_2 + I_3 = 0$

$\frac{V_i}{R_i} + \frac{V_x}{R+R_{f_1}} + \frac{V_x}{R_{f_2}} = 0$

Assume $R_{f_1} = R_{f_2} = R$

then $\frac{V_i}{R_i} + \frac{3V_x}{2R} = 0$

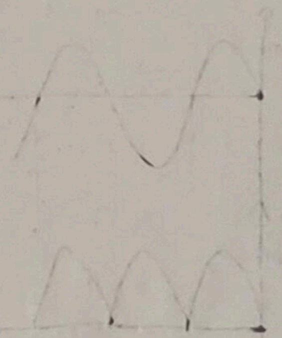
$\frac{V_i}{R_i} + \frac{1.5V_x}{R} = 0$

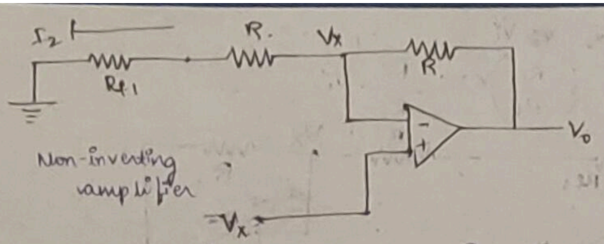
$\frac{V_i}{R_i} = -\frac{1.5V_x}{R}$

$\frac{-1.5V_x}{R} = \frac{V_i}{R_i}$

$V_x = -\frac{V_i R}{R_i(1.5)}$

$$\boxed{\therefore V_x = -\left(\frac{1}{1.5}\right)\left(\frac{R}{R_i}\right)V_i}$$





Non-inverting amplifier

$= V_x$

$$V_o = \left(1 + \frac{R}{R_{f1}+R}\right) V_x$$

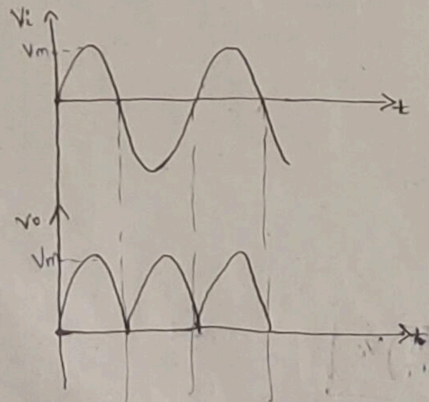
Assume $R_{f1} = R$

$$V_o = \left(1 + \frac{R}{2R}\right)\left(-\frac{1}{1.5}\right)\frac{R}{R_i} V_i$$

$$= -\left(\frac{\cancel{1.5}}{\cancel{1.5}}\right)\frac{R}{R_i} V_i$$

$$\boxed{V_o = \frac{-R}{R_i} V_i}$$

This proves that the o/p is rectified which may or may not be amplified depending on R_{f1}, R and R_i.



Design a full-w. precis. rectifier for a gain of 10.

For a positive half-cycle $V_o = \frac{R_{f1}}{R_i} V_i \rightarrow ①$ & for -ve half cycle $V_o = -\frac{R}{R_i} V_i \rightarrow ②$

Now, let $R_{f1} = R_{f2} = R = 10K$

then $|A_V| = 10$

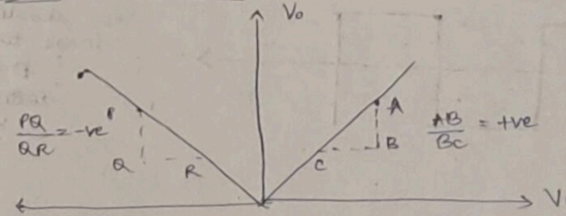
① $V_o = \frac{R}{R_i} V_i$ ② $\Rightarrow V_o = \frac{-R}{R_i} V_i \rightarrow$

Now $|A| = R/R_i$

$10 = R/R_i$ As $R = 10K$

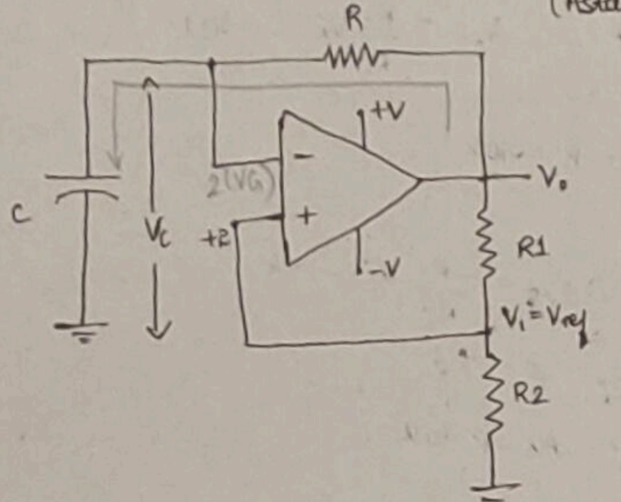
$\boxed{R_i = 1K}$

Transfer characteristics



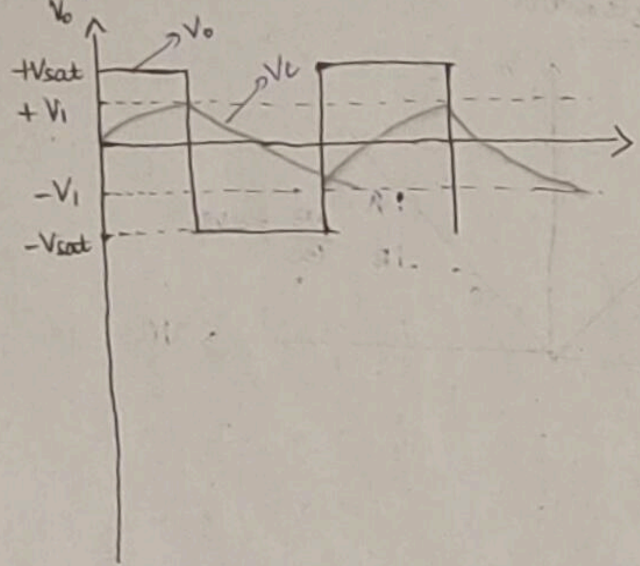
Square or triangular wave generator

(Astable multivibrator)



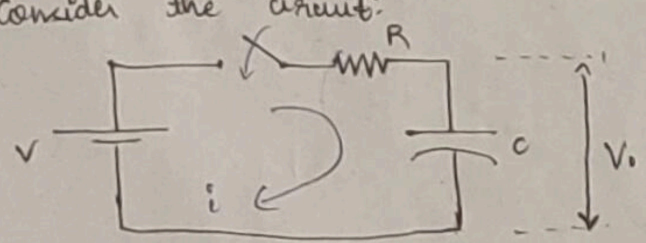
$$V_1 = \frac{\pm V_{sat} R_2}{\underbrace{R_1 + R_2}_{V_{ref}}}$$

Assuming, O/p at the saturation and capacitor is not charged.



RC should be large to obtain a proper triangular wave

Consider the circuit:



$I = C \frac{dV}{dt}$

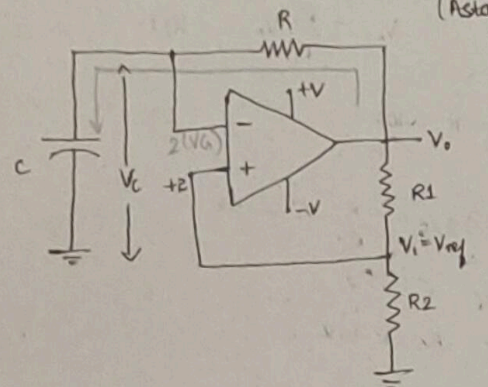
$V = \frac{1}{C} \int I \, dt$

$+V - i(t)R - \frac{1}{C} \int i(t)\, dt$

differentiate w.r.to 't'

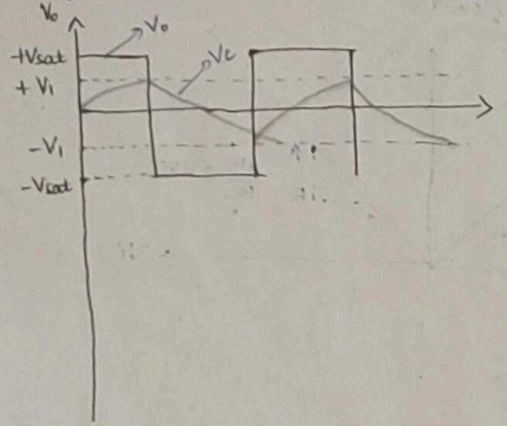
$-\frac{di(t)}{dt} R - \frac{1}{C} I(t) . dt = 0$

Square or triangular wave generator
(Astable multivibrator)



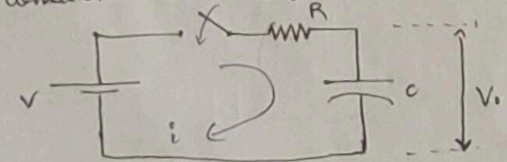
$V_1 = \frac{+V_{sat} R_2}{\underbrace{R_1+R_2}_{V_{ref}}}$

Assuming, O/p at the saturation and capacitor is not charged.



RC should be large to obtain a proper triangular wave

Consider the circuit:



$I = C \frac{dV}{dt}$

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

$+V - i(t)R - \frac{1}{C} \int i(t)\,dt$

differentiate w.r.to 't'

$\frac{-di(t)}{dt} R - \frac{1}{C} i(t) \cdot dt = 0$

$\frac{d\,i(t)}{dt} + \frac{1}{RC} i(t) = 0$

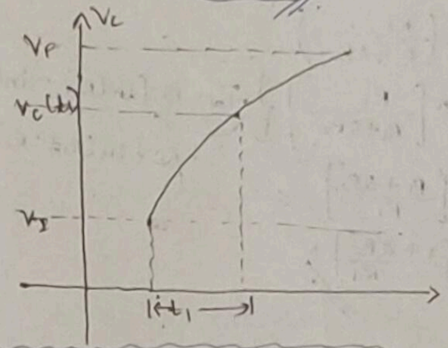
$dy/dx + Py = Q$

$y(I.F) = \int Q(I.F)\,dx$

$I.F = e^{-\int P dx} = e^{-\int 1/RC \, dt}$

Solving for $i(t)$

$\boxed{V_o = V_c(t) = \frac{1}{C} \int i(t)\,dt}$



$\boxed{V_c(t_1) = V_f - (V_f - V_I)e^{-t_1/RC}}$

Expression for T_{ON}

During T_{ON} $\quad V_I = -V_1 = -\frac{V_{sat} R_2}{R_1+R_2}$

$V_f = +V_{sat} \qquad t_1 = T_{ON}$

$V_c(t_1) = +V_1$

$V_1 = +V_{sat} - \left(V_{sat} + \frac{V_{sat} R_2}{R_1+R_2}\right) e^{-\frac{T_{ON}}{RC}}$, $\quad V_{sat} - V_{sat}\left[\frac{R_1+R_2}{R_1+R_2}\right] e^{-T_{ON}/RC}$

$\frac{V_{sat} R_2}{R_1+R_2} = V_{sat} - \left[\frac{V_{sat}(R_1+R_2) + V_{sat} R_2}{R_1+R_2}\right] e^{-T_{ON}/RC}$

$= V_{sat} - V_{sat}\left[1 + \frac{R_2}{R_1+R_2}\right] e^{-T_{ON}/RC}$

$\frac{\cancel{V_{sat}} R_2}{R_1+R_2} = \cancel{V_{sat}}\left[1 - \left(1 + \frac{R_2}{R_1+R_2}\right) e^{-T_{ON}/RC}\right]$

$\frac{R_2}{R_1+R_2} - 1 = -\left[\frac{R_1+R_2+R_2}{R_1+R_2}\right] e^{-T_{ON}/RC}$

$\frac{\cancel{-} R_1}{R_1+R_2} = \cancel{-}\left[\frac{R_1 + 2R_2}{R_1+R_2}\right] e^{-T_{ON}/RC}$

$$e^{-T_{ON}/RC} = \frac{R_1}{R_1+2R_2}$$

Take 'ln' on both sides

$$-\frac{T_{ON}}{RC} = \ln\left(\frac{R_1}{R_1+2R_2}\right)$$

$$-T_{ON} = RC\ln\left[\frac{R_1}{R_1+2R_2}\right] \quad \left\{ -T_{ON} = RC\left[\ln(R_1) - \ln(R_1+2R_2)\right]\right\}$$

$$= RC\{\ln(R_1+2R_2) - \ln(R_1)\}$$

$$T_{ON} = RC\ln\left[\frac{R_1+2R_2}{R_1}\right]$$

$$T_{ON} = RC\ln\left[1+\frac{2R_2}{R_1}\right]$$

T_{OFF}

$$V_f = V_1 = \frac{+V_{sat}R_2}{R_1+R_2}, \quad V_f = -V_{sat}; \quad t_1 = T_{OFF},$$

$$V_c(t_1) = -V_1 = \frac{-V_{sat}R_2}{R_1+R_2}$$

$$V_c(t_1) = V_f - (V_f - V_i)e^{-t_1/RC}$$

$$-V_1 = -V_{sat} - \left(-V_{sat} + \frac{V_{sat}R_2}{R_1+R_2}\right)e^{-T_{OFF}/RC}$$

$$\frac{-V_{sat}R_2}{R_1+R_2} = -V_{sat} - V_{sat}\left[-1+\frac{R_2}{R_1+R_2}\right]e^{-T_{OFF}/RC}$$

$$\frac{\cancel{-V_{sat}}R_2}{R_1+R_2} = \cancel{-V_{sat}}\left[1 + \left[\frac{+R_1 - \cancel{R_2} + \cancel{R_2}}{R_1+R_2}\right]e^{-T_{OFF}/RC}\right]$$

$$\frac{R_2}{R_1} + \cancel{1} = \cancel{1} + \left[\left(\frac{-R_1}{R_1+R_2}\right)e^{-T_{OFF}/RC}\right]$$

$$\frac{R_2}{R_1} = \frac{-R_1}{R_1+R_2}e^{(-T_{OFF}/RC)}; \quad \frac{\cancel{R_1}\,\cancel{R_1}}{R_2} \quad R_1R_2 + R_2^2 = R_1^2$$

$$\frac{R_2}{R_1} = \left(-1-\frac{R_1}{R_2}\right)e^{-T_{OFF}/RC}$$

@

$$\frac{R_2}{\cancel{R_1+R_2}} = \frac{R_1+R_2 - R_1C}{R_1+R_2}$$

$$T_{OFF} = RC\ln\left(1+\frac{2R_2}{R_1}\right)$$

$$\boxed{\begin{aligned} T &= T_{ON} + T_{OFF} \\ &= 2RC\ln\left[1+\frac{2R_2}{R_1}\right] \end{aligned}}$$

$$\boxed{f = \frac{1}{T} = \frac{1}{2RC\ln\left[1+\frac{2R_2}{R_1}\right]}}$$

$$\text{Duty cycle} = \frac{T_{ON}}{T} = \frac{\cancel{RC\ln\left[1+\frac{2R_2}{R_1}\right]}}{2\cancel{RC\ln\left[1+\frac{2R_2}{R_1}\right]}} = \frac{1}{2} = 0.5\% = 50\%$$

Design a sq. wave generator using op.amp to generate a frequency of 1KHz.

$$f = 1\,kHz \qquad T = 1/f = \frac{1}{10^3} = 10^{-3} = \underline{1m\ sec}$$

$$T = 2RC\ln\left(1+\frac{2R_2}{R_1}\right)$$

Let $C = 0.1\mu F$ and $R = 1K\Omega$

$$1m = 2(10^3)(0.1)10^{-6}\ln\left[1+\frac{2R_2}{R_1}\right]$$

$$\cancel{10^{-3}} = \cancel{10^{-3}}[0.2]\ln\left[1+\frac{2R_2}{R_1}\right]$$

$$\frac{1}{0.2} = \ln\left[1+\frac{2R_2}{R_1}\right]$$

$$\ln\left[1+\frac{2R_2}{R_1}\right] = 5$$

exponential on b.s

$$1+\frac{2R_2}{R_1} = e^5$$

$$\frac{2R_2}{R_1} = \frac{e^5-1}{2} \Rightarrow \frac{R_2}{R_1} = 73.706$$

Let $R_1 = 1K\Omega$

$$R_2 = 73.706K\Omega$$

We have square/triangular wave generator

if $\left(1+\frac{2R_2}{R_1}\right) = e = 2.7183$

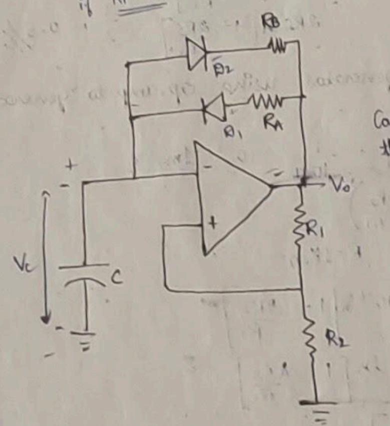
$T_{ON} = T_{OFF} = RC\ln(e) = RC$

$T = 2RC$

$f = 1/T = \frac{1}{2RC}$

$\frac{R_2}{R_1} = \frac{2.7183-1}{2} = 0.8591$

if $R_1 = 10K$ $R_2 = 8.591K$



Capacitor charging takes place through C by R_A.

Capacitor discharges through R_B.

$R_A \neq R_B$ [may or may not be]

$T_{ON} = R_AC\ln\left(1+\frac{2R_2}{R_1}\right)$ $T_{OFF} = R_BC\ln\left(1+\frac{2R_2}{R_1}\right)$

$T = T_{ON} + T_{OFF}$

$T = (R_A+R_B)\left[C\ln\left(1+\frac{2R_2}{R_1}\right)\right]$

$f = \frac{1}{T} = \frac{1}{(R_A+R_B)C\ln\left(1+\frac{2R_2}{R_1}\right)}$

Depending on ratio of R_A & R_B, Duty cycle may be more than, equal to or less than 50%

$\text{Duty cycle} = \frac{T_{ON}}{T} = \frac{R_A}{R_A+R_B}$ //

if $R_2/R_1 = 0.8591$ or $\left(1+\frac{2R_2}{R_1}\right) = e$

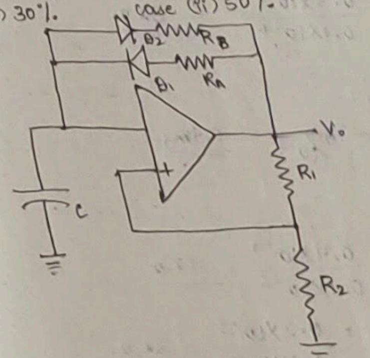
$T_{ON} = R_AC$ $T_{OFF} = R_BC$

$T = (R_A+R_B)C$

$f = 1/T = 1/(R_A+R_B)C$

$D = \frac{R_A}{R_A+R_B}$

Design a free running oscillator which generates a frequency of 1kHz and D = case (i) 30%. case (ii) 50%. case (iii) 70%.



$f = 1kHz$

$C = 0.1\,\mu F$

We have $T = 1/f = \frac{1}{10^3} = 10^{-3} = 1ms$

$T = T_{ON} + T_{OFF}$

$T_{ON} = R_AC\ln\left(1+\frac{R_2(2)}{R_1}\right)$ $T_{OFF} = R_BC\ln\left(1+\frac{R_2(2)}{R_1}\right)$

Let $\left(1+\frac{R_2(2)}{R_1}\right) = e$. $\therefore \frac{R_2}{R_1} = 0.8591$.

$\therefore T_{ON} = R_AC$ $T_{OFF} = R_BC$

Given if $D = 30\% = 0.3$

$D = \frac{T_{ON}}{T}$ $\Rightarrow 0.3 = \frac{T_{ON}}{10^{-3}}$, $T_{ON} = 0.3ms$

$T_{OFF} = T - T_{ON} = (1-0.3)m = 0.7ms$

$0.3\times10^{-3} = R_A(0.1\times10^{-6})$ $0.7\times10^{-3} = R_B(0.1\times10^{-6})$

$R_A = 3K\Omega$ $R_B = 7K\Omega$

case (i) 50% = D D = 0.5

$D = \frac{T_{ON}}{T} \Rightarrow 0.5 = \frac{T_{ON}}{10^{-3}}$

$T_{ON} = \underline{0.5ms}$

$T_{OFF} = T - T_{ON} = \underline{0.5ms}$

$T_{ON} = R_A C \quad R_A = \frac{T_{ON}}{C} = \frac{0.5 \times 10^{-3}}{0.1 \times 10^{-6}}$

$R_A = 5k\Omega$

$R_B = T_{OFF}/C = \frac{0.5 \times 10^{-3}}{0.1 \times 10^{-6}} = \underline{5k\Omega}$

case (ii) 70% = D D = 0.7

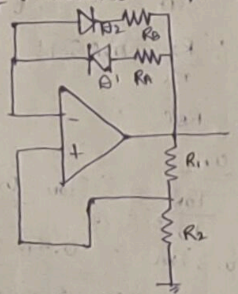
$D = T_{ON}/T \Rightarrow 0.7 = T_{ON}/10^{-3} = \underline{0.7ms}$

$T_{OFF} = T - T_{ON} = \underline{0.3ms}$

$T_{ON} = R_A C \quad R_A = T_{ON}/C = \frac{0.7 \times 10^{-3}}{0.1 \times 10^{-6}} = \underline{7k\Omega}$

$T_{OFF} = R_B C \quad R_B = T_{OFF}/C = \frac{0.3 \times 10^{-3}}{0.1 \times 10^{-6}} = \underline{3k\Omega}$

Design a sq. wave generator using op-amp. and generate a frequency of 5kHz with on time twice that of T_{OFF}. Assume $R_1 = R_2 = 10k\Omega$, $C = 0.1\mu F$



T_{ON}

f = 5kHz

$T = \frac{1}{5 \times 10^3} = \underline{0.2ms}$

$T = T_{ON} + T_{OFF}$ $T_{ON} = 2T_{OFF}$

$T = 3T_{OFF}$

$T_{OFF} = \frac{0.2 \times 10^{-3}}{3} = \underline{66.664 \mu s}$

$T_{ON} = 2T_{OFF} = \underline{133.333 \mu s}$

$D = \frac{T_{ON}}{T} = 0.6666 = \underline{66.66\%}$

$T_{ON} = R_A C \ln\left(1 + \frac{2R_2}{R_1}\right)$

$133.33 \times 10^{-6} = R_A (0.1 \times 10^{-6}) \ln\left[1 + 2\frac{(10k)}{10k}\right]$

$R_A = \frac{133.33 \times 10^{-6}}{0.1 \times 10^{-6} \ln(3)}$

$= \frac{133.33}{0.1 \times 1.0986} = \underline{1.2136k\Omega}$

$T_{OFF} = R_B C \ln\left(1 + \frac{2R_2}{R_1}\right)$

$66.664 \times 10^{-6} = R_B (0.1 \times 10^{-6}) \ln\left(1 + 2\frac{(10k)}{10k}\right)$

$R_B = \frac{66.664 \times 10^{-6}}{0.1 \times 10^{-6} \ln(3)}$

$= \frac{66.664 \times 10^{-6}}{0.1 \times 10^{-6} (1.0986)}$

$R_B = \underline{0.6068k\Omega}$

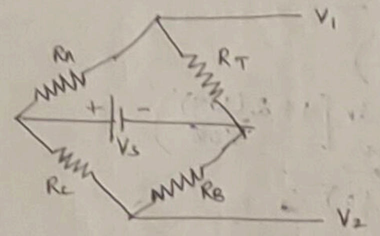
Instrumentation amplifier

Instrumentation system

Sensor and transducer → Instrumentation amplifier → o/p measuring Instrument

I.A should have i/p impedance and high CMRR due to persisting noise from the environment.

Example (transducer)

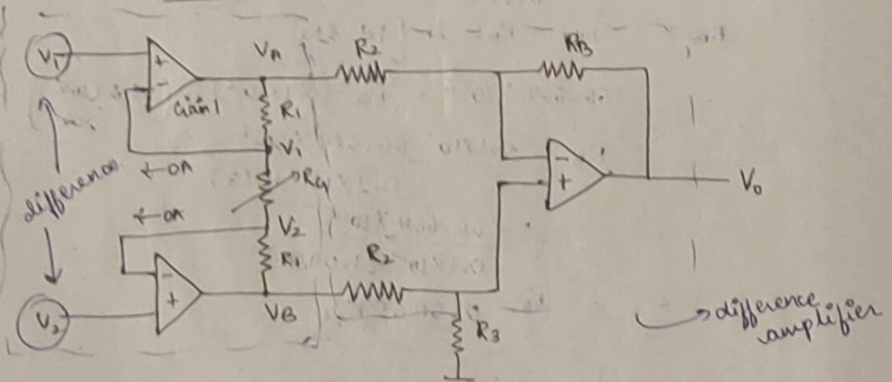


When bridge is balanced (i.e, $R_A R_B = R_C R_T$)

$V_1 - V_2 = 0$

@ $V_1 = V_2$

Instrumentation amplifier



The amplifiers where i/p is connected should have high CMRR to avoid noise.

$V_A - V_B = A_V(V_1 - V_2)$

current across resistors in series is constant

$I = \frac{V_A - V_1}{R_1} = \frac{V_1 - V_2}{R_g} = \frac{V_2 - V_B}{R_1}$

case i) $\frac{V_A - V_1}{R_1} = \frac{V_1 - V_2}{R_g}$

$V_A - V_1 = \frac{R_1}{R_g}(V_1 - V_2)$

$\therefore V_A = V_1 + \frac{R_1}{R_g}V_1 - \frac{R_1}{R_g}V_2 \Rightarrow V_A = -\frac{R_1}{R_g}V_2 + V_1\left(1 + \frac{R_1}{R_g}\right) \rightarrow ①$

case (ii) $\frac{V_1 - V_2}{R_g} = \frac{V_2 - V_B}{R_1}$

$V_2 - V_B = \frac{R_1}{R_g}(V_1 - V_2)$

$V_2 - \frac{R_1}{R_g}(V_1 - V_2) = V_B \Rightarrow V_B = V_2 + V_2\frac{R_1}{R_g} - \frac{R_1}{R_g}V_1$

$V_B = V_2\left[1 + \frac{R_1}{R_g}\right] - \frac{R_1}{R_g}V_1 \rightarrow ②$

$V_0 = \frac{R_3}{R_2}(V_B - V_A)$

$= \frac{R_3}{R_2}\left\{\left[V_2\left(1 + \frac{R_1}{R_g}\right) - \frac{R_1}{R_g}V_1\right] - \left[-\frac{R_1}{R_g}V_2 + V_1\left(1 + \frac{R_1}{R_g}\right)\right]\right\}$

$= \frac{R_3}{R_2}\left\{V_2\left[1 + \frac{R_1}{R_g}\right] - \frac{R_1}{R_g}V_1 + \frac{R_1}{R_g}V_2 - V_1\left(1 + \frac{R_1}{R_g}\right)\right\}$

$= \frac{R_3}{R_2}\left\{\left(1 + \frac{R_1}{R_g}\right)(V_2 - V_1) + \frac{R_1}{R_g}(V_2 - V_1)\right\}$

$= \frac{R_3}{R_2}(V_2 - V_1)\left[1 + \frac{2R_1}{R_g}\right]$

$V_0 = \frac{R_3}{R_2}(V_2 - V_1)\left[1 + \frac{2R_1}{R_g}\right]$

$A_V = \frac{V_0}{V_2 - V_1} = \frac{R_3}{R_2}\left(1 + \frac{2R_1}{R_g}\right)$

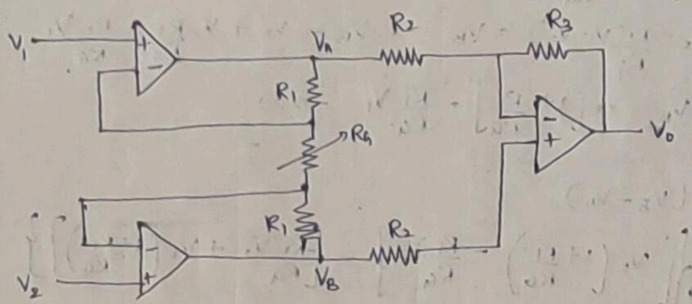
$A_V = \frac{V_0}{V_1 - V_2} = -\frac{R_3}{R_2}\left(1 + \frac{2R_1}{R_g}\right)$

∴ R_3 and R_2, suitable resistors would be enough to control the required gain.
Reducing value of R_G, gain can be adjusted.
∴ Usually R_1, R_2, R_3 are fixed. R_G is variable.

Design an Instrumentation amplifier for a gain 11.

$A_v = 11 \qquad A_v = \frac{V_o}{V_2 - V_1} = \frac{R_3}{R_2}\left[1 + \frac{2R_1}{R_G}\right]$

Let $R_1 = R_2 = R_3 = R = 10K\Omega$ (Assume).



$$11 = \frac{\cancel{10K}}{\cancel{10K}}\left[1 + \frac{2(10K)}{R_G}\right]$$

$$10 = \frac{2(10K)}{R_G}$$

$$R_G = \frac{2(10K)}{10} = \underline{\underline{2K\Omega}}$$

or:

Let $R_3/R_2 = 1$ & $R_3 = R_2 = 10K\Omega \qquad R_G = 10K\Omega$

$$\therefore 1 + \frac{2R_1}{R_2} = 11 \qquad \therefore 1 + \frac{2R_1}{R_G} = 11$$

$$1 + \frac{2R_1}{10K} = 11$$

$$R_1 = \frac{\overset{5}{\cancel{10}} \times 10K}{\cancel{2}} = \underline{\underline{50K\Omega}}$$

$\therefore R_3$ and R_2, suitable resistors would be enough to control the required gain.

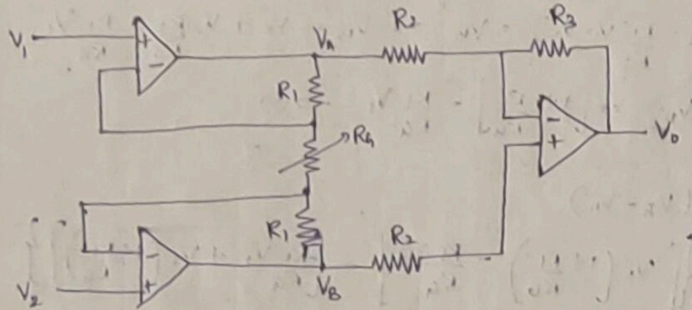
Reducing value of R_G, gain can be adjusted.

$\therefore$ Usually R_1, R_2, R_3 are fixed. R_G is variable.

Design an Instrumentation amplifier for a gain 11.

$A_V = 11$ $\quad A_V = \frac{V_0}{V_2 - V_1} = \frac{R_3}{R_2}\left[1 + \frac{2R_1}{R_G}\right]$

Let $R_1 = R_2 = R_3 = R = 10K\Omega$ (Assume)



$11 = \frac{\cancel{10K}}{\cancel{10K}}\left[1 + \frac{2(10K)}{R_G}\right]$

$10 = \frac{2(10K)}{R_G}$

$R_G = \frac{2(10K)}{10} = \underline{\underline{2K\Omega}}$

or:

Let $R_3/R_2 = 1$ & $R_3 = R_2 = 10K\Omega$ $\quad R_G = 10K\Omega$

$\therefore 1 + \frac{2R_1}{R_2} = 11$ $\quad \therefore 1 + \frac{2R_1}{R_G} = 11$

$1 + \frac{2R_1}{10K} = 11$

$R_1 = \frac{\cancel{10}^{5} \times 10K}{\cancel{2}} = \underline{\underline{50K\Omega}}$

555 timer:

Multivibrator

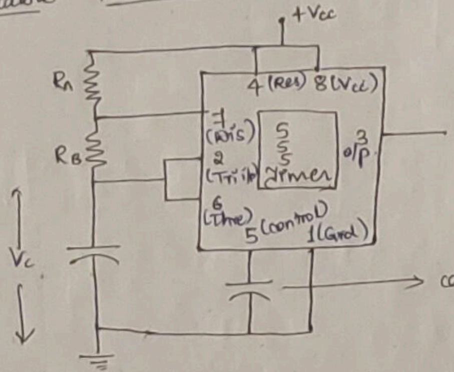
It can be stable state or quasi-stable state, thus the o/p is existant in two states.

Based on number of stable state, we have

- Astable (zero ~~stable~~ stable) multivibrator
- Monostable (one stable ~~stable~~ state) multivibrator
- Bistable (two stable state) multivibrator

Astable is also called free running oscillator.

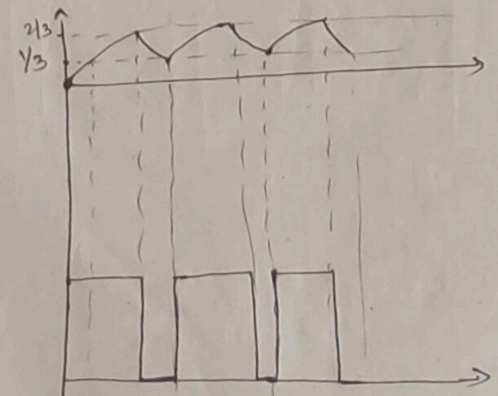
Astable Multivibrator



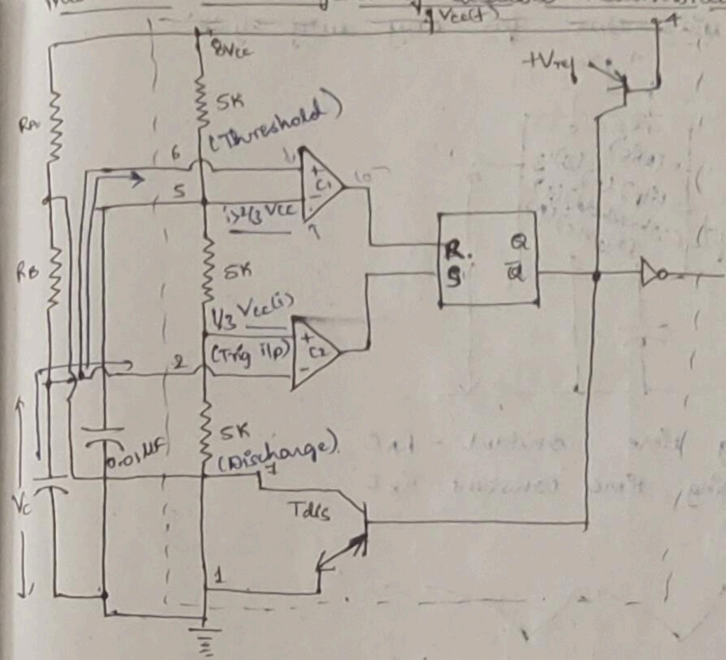
[digital]
5 - control input
8 - Vcc
1 - Gnd
4 - Reset
7 - Discharge
2 - Trigger i/p
6 - Threshold.
3 - o/p

capacitor is to cancel the noise ($2/3$ of Vcc)

5 - Control i/p = $2/3^{rd}$ of VCC



Internal block diagram of astable multivibrator:-



Changing time constant = $(R_A+R_B)C$

Discharging time constant = $(R_B)C$

Discharge transistor (npn) depends on $\bar{Q}$ acting as switch.

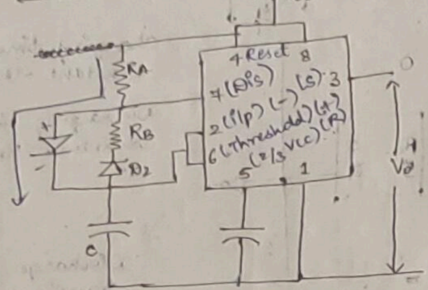
Charging time constant = T = $(R_A+R_B)C$

stage (i) Capacitor voltage = $1/3^{rd}$ of VCC or greater (less than $2/3$)
then, Trigger i/p > Vcc
Threshold < 5 (control i/p)
$\therefore$ C1 = 0, C2 = 0, no change than previous state
as S=0, R=0

[Previous state:- When capacitor had no charge, its voltage is zero.
Then, 2 and 6 depends on it (Trigger i/p, Threshold)
$\therefore$ R = 0 as $C_1 = 0$, S = 1 as $C_2 = 1$, $\therefore$ Q = 1, $\bar{Q} = 0$
o/p = 1, Transistor (discharge is off)]

stage (ii) capacitor voltage $\therefore$ $2/3^{rd}$ of Vcc
The (2) i/p > $1/3$Vcc, then $C_2 = 0$, $G_1 = 0$, $\bar{Q} = 0$.
6 (Threshold) > 5 ($2/3^{rd}$ Vcc), then C1 = 1, R = 1, $\bar{Q}$ = 1.
Transistor (discharge) is on - 1, capacitor sta

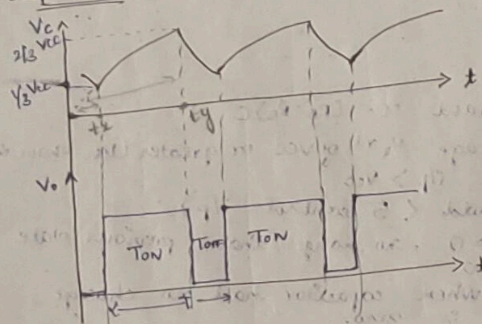
Astable multivibrator for any duty cycle:-



Charging time constant - $R_A C$

Discharging time constant - $R_B C$

Output express^n



(Without diode $T_{ON} = T_{OFF}$)

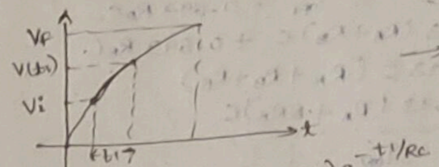
Charging time constant $= T_{ON} = (R_A+R_B)C$

Discharging time constant $= T_{OFF} = R_B C$

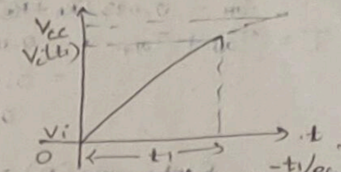
$T = T_{ON} + T_{OFF}$

$= 0.693(R_A+R_B)C + 0.693(R_B)C$

$T = 0.693(R_A+2R_B)C$



$V_c(t_1) = V_f - (V_f - V_i)e^{-t_1/RC}$



$V_c(t_1) = V_{cc}(1 - e^{-t_1/RC})$

To find t_x:-

$V_c(t_x) = V_{cc}(1 - e^{-t_x/(R_A+R_B)C})$

$\frac{1}{3}\cancel{V_{cc}} = \cancel{V_{cc}}\left(1 - e^{\frac{-t_x}{(R_A+R_B)C}}\right)$

$e^{-t_x/(R_A+R_B)C} = 1 - 1/3 = 2/3$

'ln' on b.s.

$\frac{-t_x}{(R_A+R_B)C} = \ln(2/3) = -0.40546$

$t_x = 0.40546\,(R_A+R_B)C$

To find t_y:

$V_c(t_y) = V_{cc}(1 - e^{-t_y/(R_A+R_B)C}) = V_{cc}(1 - e^{-t_y/(R_A+R_B)C})$

$\frac{2}{3}\cancel{V_{cc}} = \cancel{V_{cc}}(1 - e^{-t_y/(R_A+R_B)C})$

$e^{-t_y/(R_A+R_B)C} = 1 - 2/3 = 1/3$

'ln' on b.s

$\frac{-t_y}{(R_A+R_B)C} = \ln(1/3) = -1.0986$

$t_y = 1.0986\,(R_A+R_B)C$

$t_1 = T_{ON} = t_y - t_x = (1.0986 - 0.40546)(R_A+R_B)C$

$= 0.6932\,(R_A+R_B)C$

Similarly $T_{OFF} = 0.693 R_B C$

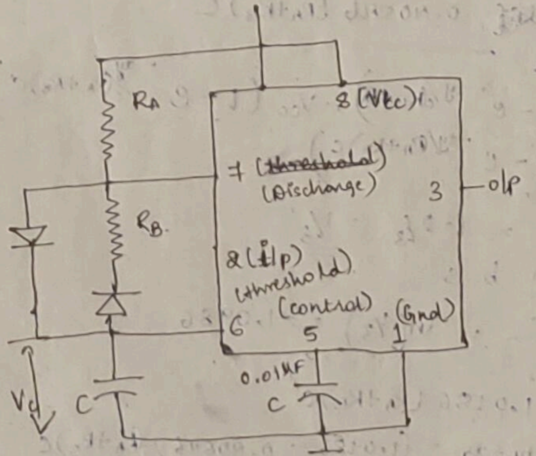
$T_{ON} = 0.693\,(R_A + R_B)\,C \qquad T_{OFF} = 0.693\,R_B C$

$$T = T_{ON} + T_{OFF} = 0.693\,(R_A + R_B)\,C + 0.693\,R_B C$$
$$= 0.693\,C\,(R_A + R_B + R_B)$$
$$= 0.693\,(R_A + 2R_B)\,C$$

$$\text{Duty cycle } (D) = \frac{T_{ON}}{T}$$
$$= \frac{0.693\,(R_A + R_B)\cancel{C}}{0.693\,(R_A + 2R_B)\cancel{C}}$$
$$D = \frac{R_A + R_B}{R_A + 2R_B}$$

$$f = \frac{1}{T} = \frac{1}{0.693\,(R_A + 2R_B)\,C}$$

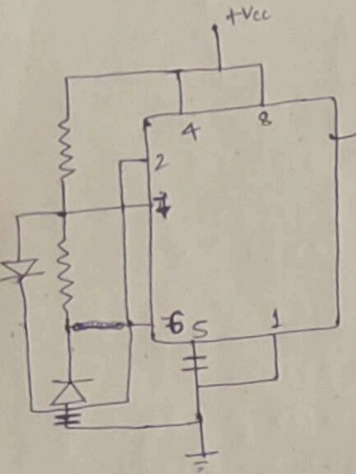
Astable multivibrator for any duty cycle:



Design astable multivibrator using 555 timer for following specifica^n

i) $f = 1KHz$, $D = 50\%$.   ii) $f = 1KHz$, $D = 75\%$.

iii) $f = 1KHz$, $D = 25\%$.



i) $f = 1KHz$

$T = 1/f = \frac{1}{10^3} = 10^{-3} = \underline{1ms}$

$D = 50\% = 0.5$

$D = \frac{T_{ON}}{T} \Rightarrow 0.5 \times T = T_{ON}$

$T_{ON} = 0.5 \times 10^{-3} = \underline{0.5ms}$

$T_{OFF} = T - T_{ON}$

$= \underline{0.5ms}$

$T_{ON} = 0.693(R_A)C$ Assume $C = 0.1\mu F$

$\frac{0.5ms}{0.693 \times C} = R_A$

$R_A = \frac{0.5 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}} =$

$R_A = \underline{7.215 K\Omega}$

$T_{ON} = T_{OFF} = R_A = R_B = \underline{7.215K\Omega}$

$= \underline{7.2K\Omega}$

ii) $T = 1/f = \frac{1}{10^3} = 10^{-3} = \underline{1ms}$

$D = 75\% = 0.75$

$0.75 = \frac{T_{ON}}{T} \Rightarrow 0.75 \times T = T_{ON}$

$T_{ON} = \underline{0.75ms}$

$T_{OFF} = T - T_{ON} = (1 - 0.75)ms = \underline{0.25ms}$

$T_{ON} = 0.693\, R_A\, C$

$T_{OFF} = 0.693 R_B C$

Assume $C = 0.1\mu F$

$T_{ON} = 0.693 R_A C$

$R_A = \frac{T_{ON}}{0.693 C} = \frac{0.75 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}} = \underline{10.8225K\Omega}$

$T_{OFF} = 0.693 R_B C$

$R_B = \frac{T_{OFF}}{0.693 C} = \frac{0.25 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}} = \underline{3.6075K\Omega}$

iii) $f = 1KHz$, $D = 25\%$

$T = 1/f = \frac{1}{10^3} = 10^{-3} = 1ms$

$D = 25\% = 0.25$

$D = \frac{T_{ON}}{T} \Rightarrow 0.25 = \frac{T_{ON}}{10^{-3}}$

$T_{ON} = 0.25 \times 10^{-3} = \underline{0.25ms}$

$T = T_{ON} + T_{OFF}$

$T_{OFF} = T - T_{ON} = (1 - 0.25)m = \underline{0.75ms}$

Assume $C = 0.1\mu F$

$T_{ON} = 0.693 R_A C =$

$R_A = \frac{T_{ON}}{0.693C} = \frac{0.25 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}}$

$R_A = \underline{3.6075K\Omega}$

$T_{OFF} = 0.693 R_B C$

$R_B = \frac{T_{OFF}}{0.693C} = \frac{0.75 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}}$

$R_B = \underline{10.8225K\Omega}$

Design astable multivibrator for 555 timer without diode for following specificatⁿ.

i) $f = 1KHz$, $D = 70\%$.

$f = \frac{1}{T} \Rightarrow T = 1/f = \frac{1}{10^3} = 10^{-3} = \underline{1ms}$

$D = \frac{T_{ON}}{T}$ $\quad D = 70\% = 0.7$

$T_{ON} = D \times T = 0.7 \times 10^{-3} = \underline{0.7ms}$

$T_{OFF} = T - T_{ON} = (1-0.7)m = \underline{0.3ms}$

$T_{ON} = 0.693(R_A + R_B)C$

$T_{OFF} = 0.693 R_B C$ $\quad$ (Assume $C = 0.1\,\mu F$

$0.8ms = 0.693 R_B (0.1 \times 10^{-6})$

$R_B = \frac{0.3 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}}$

$R_B = \underline{4.329 K\Omega}$

$T_{ON} = 0.693 R_A C + \underbrace{0.693 R_B C}_{T_{OFF}}$

$0.7ms = 0.693 R_A C + 0.3ms$

$0.693 R_A C = (0.7 - 0.3) \times 10^{-3}$

$R_A = \frac{0.4 \times 10^{-3}}{0.693 \times 0.1 \times 10^{-6}} = \underline{5.772 K\Omega}$