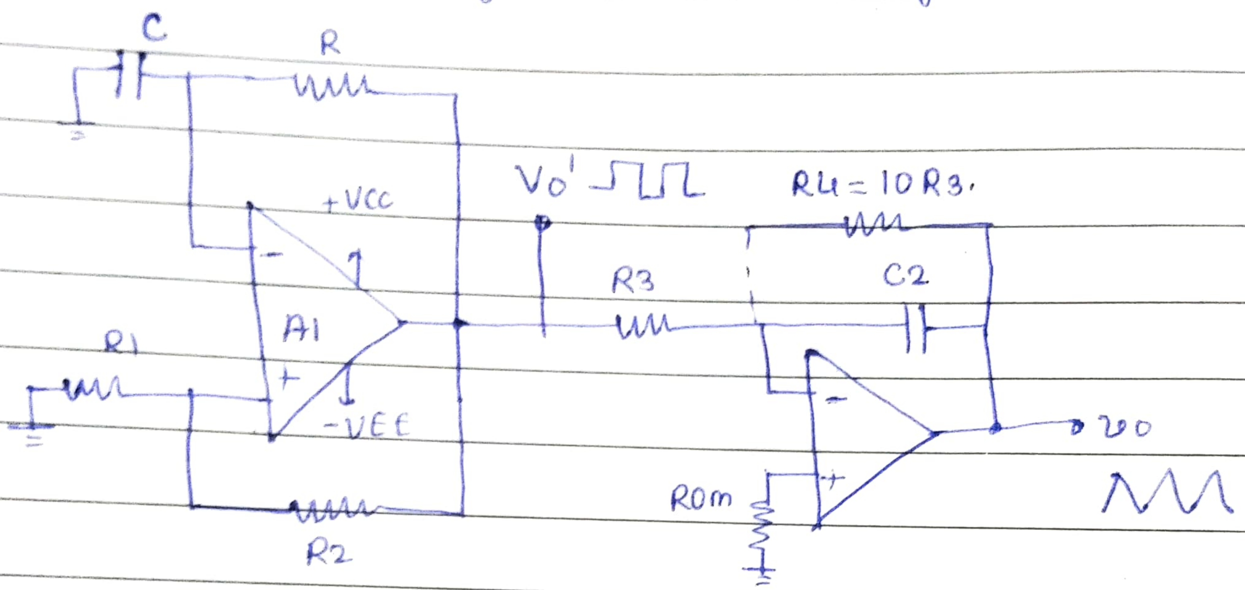
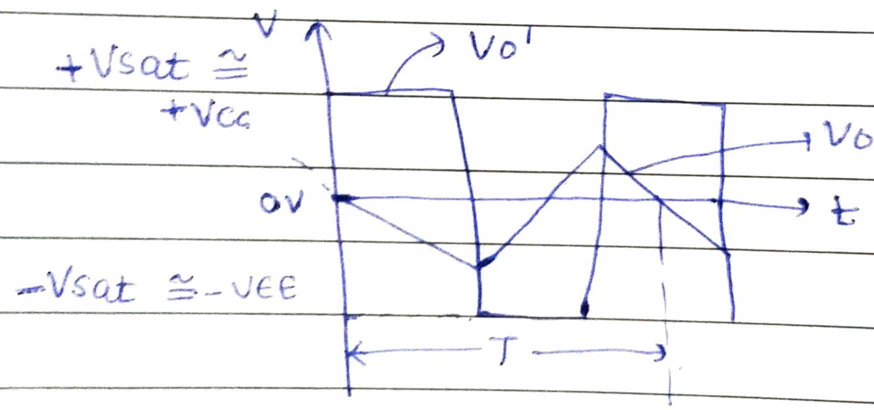
* Triangular Wave Generator :-

- we know that, if I/P of integrator is sq. wave, O/P will be triangular wave.
- i.e we can design triangular wave gen. as

sq. wave generator $\longrightarrow$ Integrator.





- freq^n of sq. wave & triangular wave are same.

fo of both waves depends on R.

$R \propto \frac{1}{fo}$

- amplitude of sq wave is constant at $\pm V_{sat}$.
- amplitude of triangular wave will ↓ or ↑ with ↑ or ↓ in frequency.
- O/P of A1 is sq. wave, i.e input to A2.
- To be the O/P of triangular wave A2,

$5 R_3 C_2 > T/2$

where $T \rightarrow$ period of sq. wave.

$R_8 C_2 \simeq T$

- freq^n of triangular wave is limited by slew rate of op-amp.

$\therefore$ op-amp with high slew rate is used.

II Triangular wave generator with fewer components :-

- Requires less no. of components

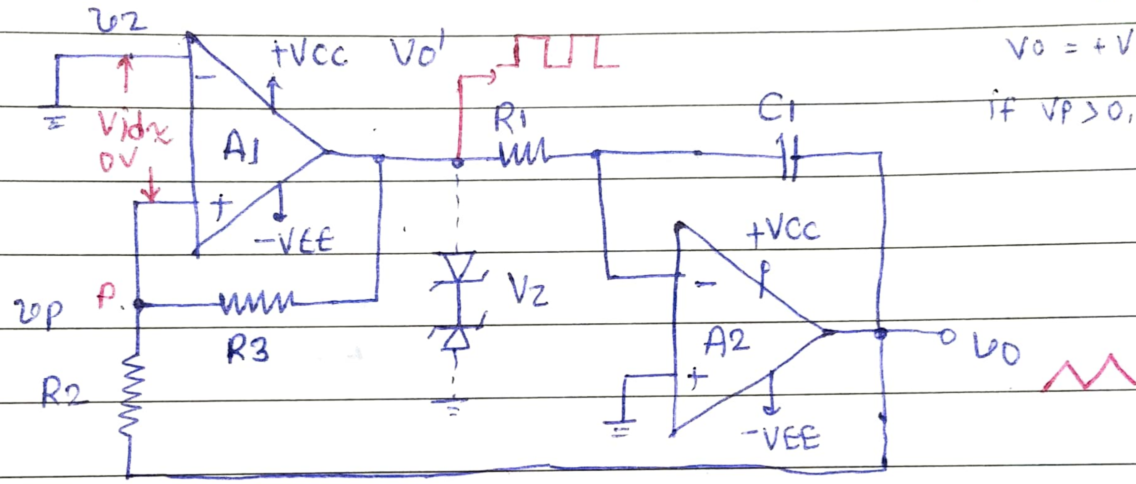
- comparator + Integrator.

$V_0' = +V_{sat}$, $V_o = -V_{ramp}$.

if $V_p < 0$, $V_o' = -V_{sat}$,

$V_o = +V_{ramp}$.

if $V_p > 0$, $V_o = +V_{sat}$.

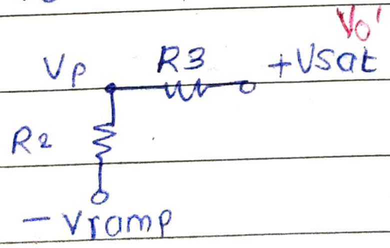


- A1 compares vtg at pt. P continuously with inverting input i.e $v_2 = 0V$. when $v_p < 0$, $V_o' = -V_{sat}$ & if $v_p > 0$, $V_o' = +V_{sat}$.

- This sq. wave is I/P to integrator.

- If $V_o' = +V_{sat}$, v_o will be -ve going ramp.

i e



If $V_o = -V_{ramp}$, $v_p < 0$.

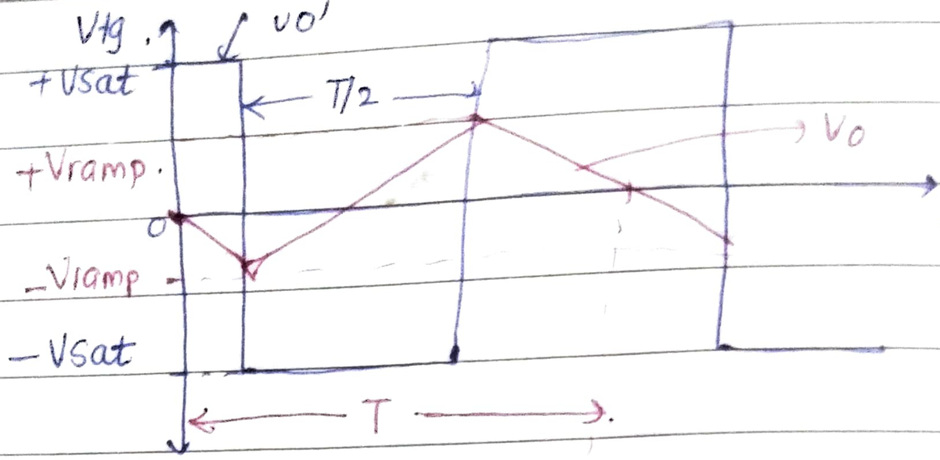
$\therefore$ $v_o' = -V_{sat}$

$\therefore$ $v_o \uparrow$ to $+V_{ramp}$

If $V_o = +V_{ramp}$, $V_p > 0$

$\therefore$ $V_o' = +V_{sat}$

- sequence is repeated.



- freq^n of triangular & square wave are same.
- amplitude of sq. wave is func of DC supply. we can obtain desired O/P by using diodes at O/P.
- from dia, $-V_{ramp}$ developed a/c R_2 & $+V_{sat}$ a/c R_3

$$\frac{-V_{ramp}}{R_2} = -\frac{+V_{sat}}{R_3}$$

or. $$-V_{ramp} = -\frac{R_2}{R_3}(+V_{sat})$$

Similarly,

$$+V_{ramp} = -\frac{R_2}{R_3}(-V_{sat})$$

$$\therefore V_{opp} = +V_{ramp} - (-V_{ramp})$$
$$= \frac{2R_2}{R_3}(V_{sat})$$

where $V_{sat} = |+V_{sat}| = |-V_{sat}|$

i.e. $V_{opp} \downarrow$ with $\uparrow R_3$.

- Time taken by o/p to swing from $-V_{ramp}$ to $+V_{ramp}$ is equal to $T/2$

$\therefore$ substitute $v_i = -V_{sat}$, $v_o = V_{opp}$ & $c = 0$

$$v_{O(PP)} = -\frac{1}{R_1C_1}\int_0^{T/2} (-V_{sat})\cdot dt$$

$$= \left(\frac{V_{sat}}{R_1C_1}\right)\left(\frac{T}{2}\right).$$

$$\therefore \frac{T}{2} = \frac{V_{OPP}}{V_{sat}}\left(R_1 \cdot C_1\right).$$

$$\therefore T = \frac{2R_1C_1(v_{OPP})}{V_{sat}}.$$

$$V_{sat} = |+V_{sat}| = |-V_{sat}|.$$

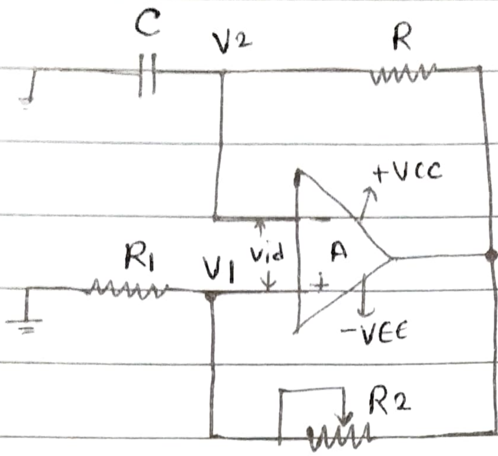
substitute value of V_{OPP}.

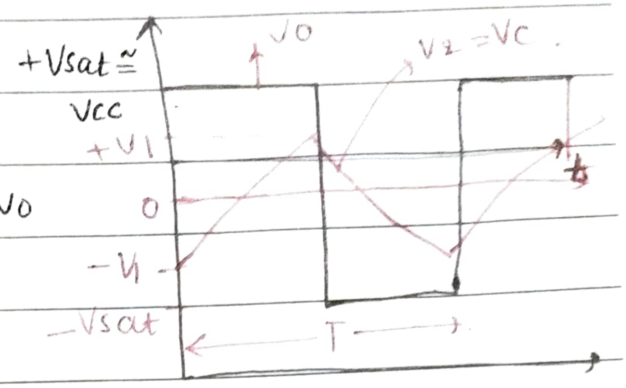
$$\therefore T = \frac{4R_1C_1R_2}{R_3}.$$

$$\therefore f_o = \frac{R_3}{4R_1C_1R_2}$$

Square wave Generator :-

- op-amp is forced to operate in saturation region, sq. wave generated.
- Also called as free-running or astable multivibrator.





$$|V_1| = \frac{R_1}{R_1+R_2} \cdot |V_{sat}|.$$

$$f_0 = \frac{1}{T} = \frac{1}{2RC} \quad \text{if } R_2 = 1.16 R_1.$$

- Assume that V_c (vtg a/c C) is 0 when Vcc & VEE are applied.

i.e. $V_2 = 0$ initially.

But V_1 = very small value due to VOOT & R_1-R_2 n/w.

$\therefore$ $V_{id} = v_1 \rightarrow$ starts driving op-amp into saturation.

As C acts as short ckt, the gain of the op-amp is very large.

e.g. Let VOOT is +ve

$\therefore$ v_1 is +ve.

& V_1 drives op-amp into saturation (+Vsat).

with v_o = +Vsat, C starts charging towards +Vsat thr' R.

As soon as, $V_2 = V_c > V_1$, the

V_{id} = -ve $\Rightarrow$ $V_o = -V_{sat}$.

with $V_o = -V_{sat}$ - v_1 a/c R_1 is also -ve.

as. $V_1 = \frac{R_1}{R_1+R_2}(-V_{sat})$.

Thus the net diffn vtg, $V_{id} = V_1 - V_2$ = -ve $\therefore$ $V_o = -V_{sat}$

until C discharges & then recharges to a -ve voltage slightly higher than $-v_1$.

- Now, when $-v_C = v_2 > -v_1$, $v_{id} = +ve \Rightarrow V_o = +V_{sat}$
- This completes one cycle.
- with o/p at $+V_{sat}$, v_1

$$v_1 = \frac{R_1}{R_1 + R_2}(+V_{sat}).$$

The time period T of the o/p waveform is given by

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

or

$$f_o = \frac{1}{2RC \ln[(2R_1 + R_2)/R_2]}$$

i.e f_o depends on RC, R_1, R_2.

if $R_2 = 1.16 R_1$

$$f_o = \frac{1}{2RC}.$$

RC ↓ f_o ↑ & vice versa.

fmax → depends on slew rate of op-amp.

⇓ f_o ↑, V_o → triangular.

practically Rs at inv & non-inv terminal is required to prevent excessive differential current flow. (due to vid).

$R_s \geq 100 k\Omega$

Que: Design the square-wave osc. so that $f_o = 1\,kHz$. The supply vtg is $\pm 15V$.

Sol^n: Use $R_2 = 1.16 R_1$ so that,

1)
$$f_o = \frac{1}{RC}.$$

Let $R_1 = 10\,k\Omega$. Then

$$R_2 = (1.16)(10 \times 10^3) = 11.6\,k\Omega$$

Use $R_2 = 20\,k\Omega$ pot.

2) Let $C = 0.05\,\mu F$

$$\therefore R = \frac{1}{10 \times 10^{-8}\, 10^3} = 10\,k\Omega$$

Thus,

$R_1 = 10\,k\Omega$

$R_2 = 11.6\,k\Omega$

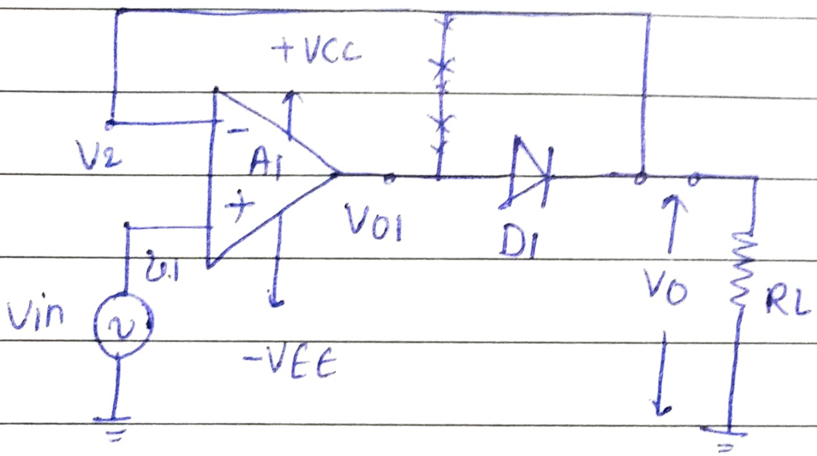
$R = 10\,k\Omega$

$C = 0.05\,\mu F$

* Precision Rectifier :-

- Disadv ⟶ Conventional / diode rectifier ⟶ can not rectify vtgs below $V_{D(ON)} = 0.7V$, the cut-in vtg. of the diode.
- To overcome this use op-amp with diodes → precision rectifiers.
- can rectify vtg. less than 0.7V. Hence called small signal precision rectifiers.

a) +ve Precision Half wave Rectifier :



- D1 is connected in f/b loop.

1) During +ve half cycle :

→ D1 → ON → f/b path is completed.

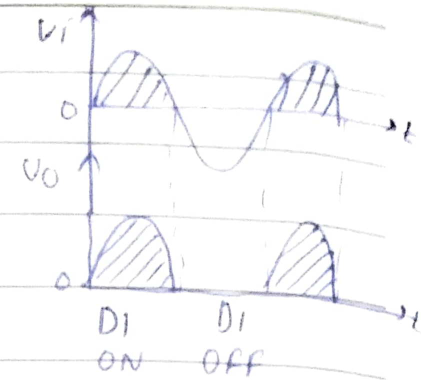
∴ Vo = Vin.

$1 + \frac{RF}{R1} \rightarrow$ D1 ON → RF = 0, R1 = ∞.

$1 + \frac{0}{\infty} = 1$

→ Due to very high gain D1 turns ON immediately.

Hence +ve half cycle appears a/c load.

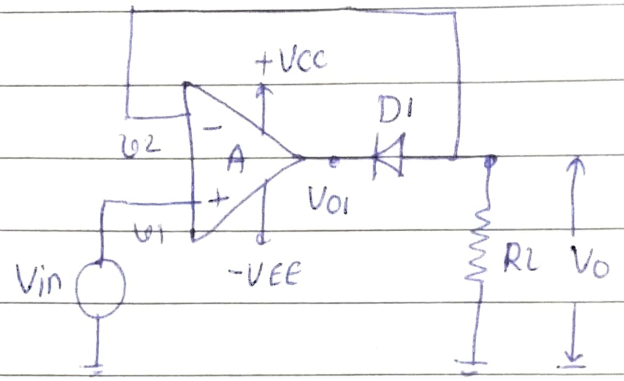


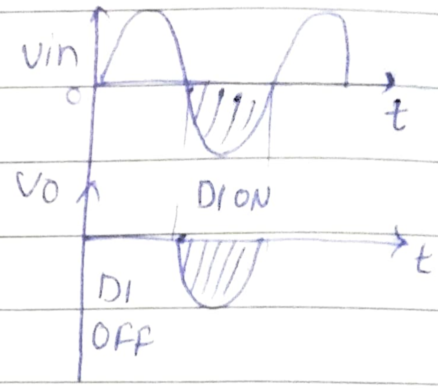
2) During -ve half cycle:

D1 → R.B., ∴ no f/b is present ∴ $V_o = 0$

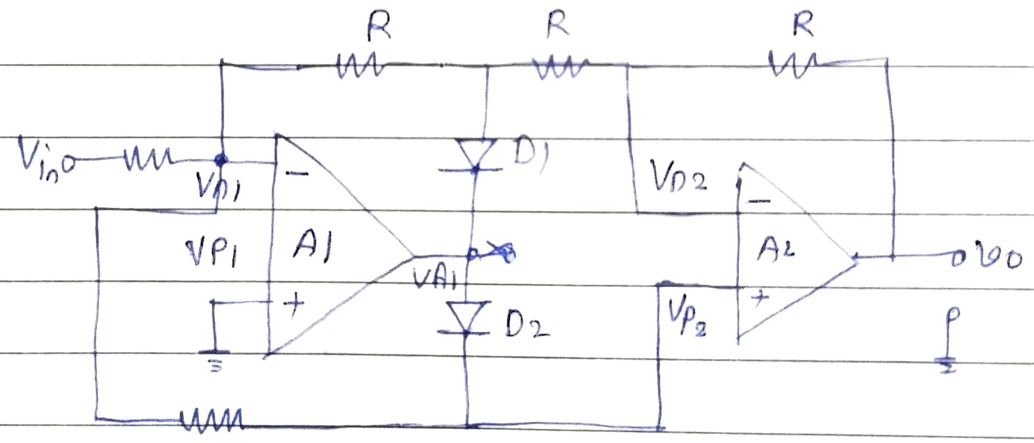
- can rectify very small vtgs (in mVs).

2) -ve Precision Half wave Rectifier :-





* Precision Full wave Rectifiers :-

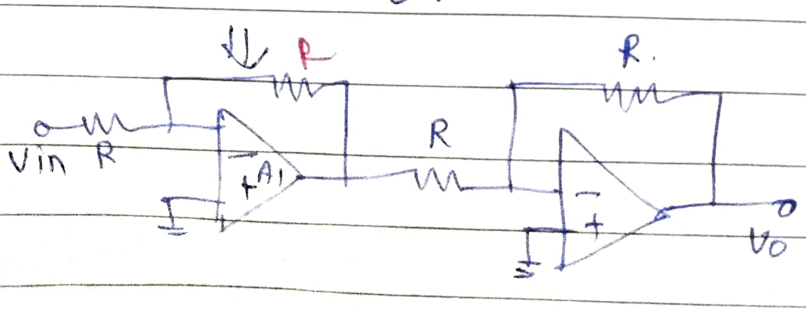


R → no current (vin > 0).

Case 1 :- $V_{in} > 0$, $V_{A1} = -ve$, D1 → F.B, D2 → R.B

no current thr' R betn V_{n1} & V_{P2}.

∴ $V_{n1} = V_{P2} = 0\,V$.

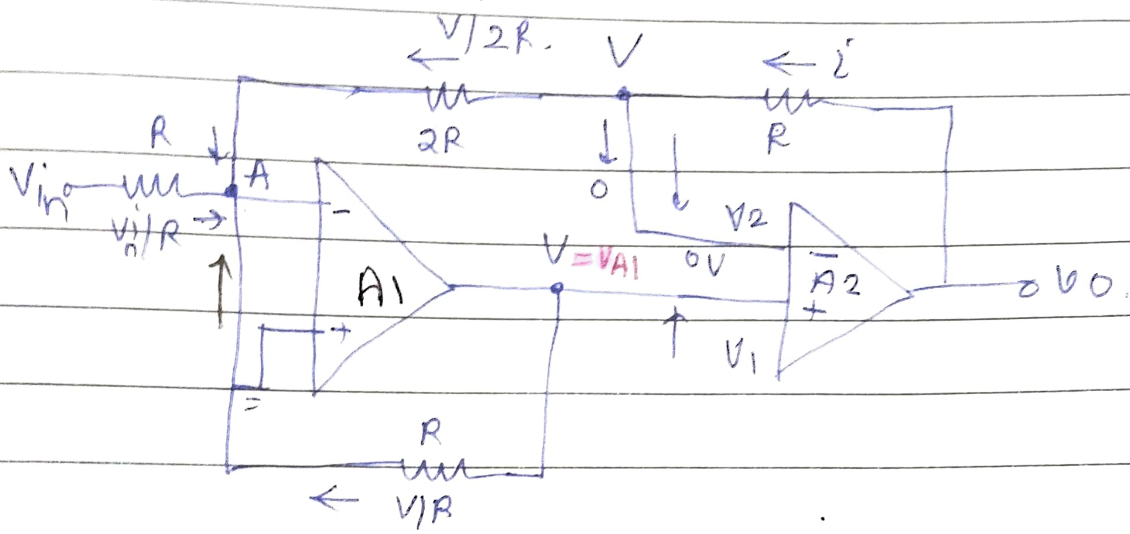


$\therefore V_o = \left(\frac{-R}{R}\right) \times \left(\frac{-R}{R}\right) \cdot v_i = v_i$

$\therefore \boxed{v_o = v_i}$ → +ve half cycles will be present in the o/p.

Case 2 : If $V_{in} < 0$, $V_{A1} \rightarrow +ve$, $D_1 \rightarrow R/B$ & $D_2 \rightarrow F/B$.

now ckt will be,



$\therefore$ As $v_{id2} = 0V$, $\therefore V_A = 0$.

$\therefore$ Apply KCL at node A

$$\frac{V_{in}}{R} + \frac{V}{2R} + \frac{V}{R} = 0.$$

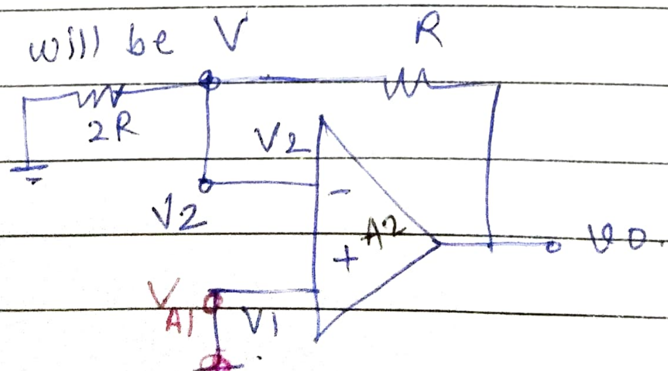
$$\frac{V_{in}}{R} + \frac{R \cdot V + 2 \cdot R \cdot V}{2R^2} = 0$$

$$\frac{V_{in}}{R} + \frac{\cancel{R}[3V]}{2R^{\cancel{2}}} = \frac{3V}{2R}$$

i.e $\frac{3V}{2R} = \frac{-V_{in}}{R}$.

$$\therefore \boxed{V = \frac{-2 V_{in}}{3}}$$

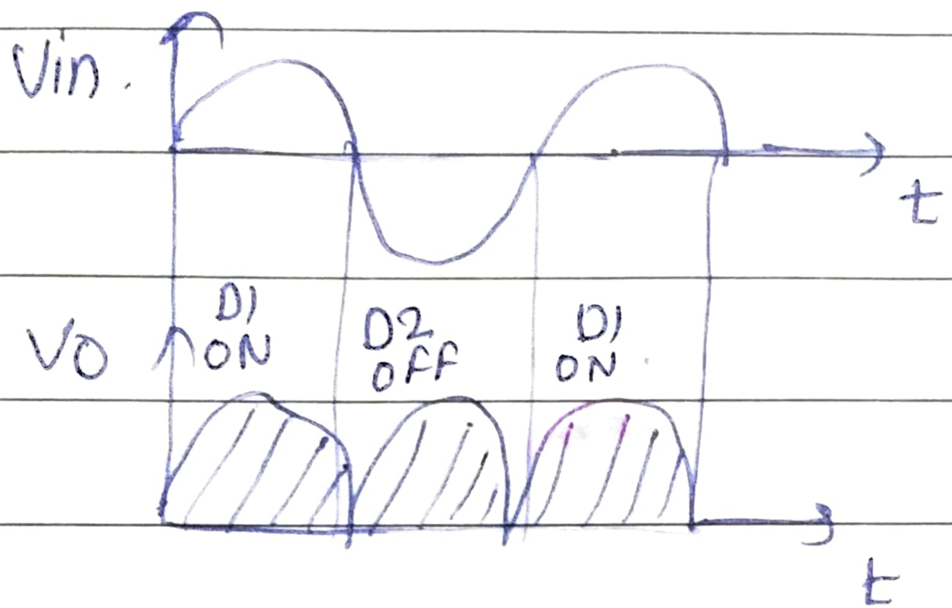
$\therefore$ A2 will be



$$\therefore V_o = \left(1 + \frac{R}{2R}\right) V_{A1} = \left(\frac{2R + R}{2R}\right) V_{A1} = \frac{3}{2} V.$$

$$\therefore V_o = \frac{3}{2}\left[-\frac{2}{3} V_{in}\right] = -V_{in}$$

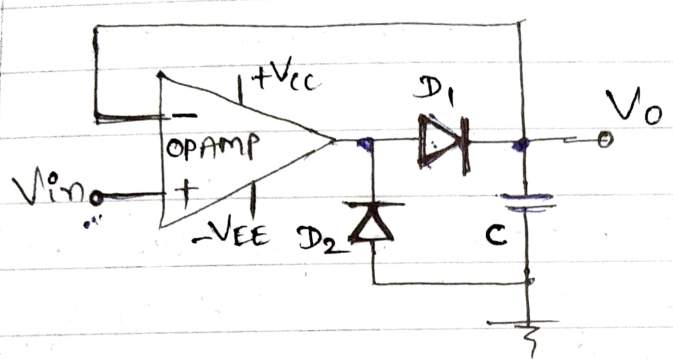
$\boxed{\therefore V_o = -V_{in}}$ ---- -ve half cycle

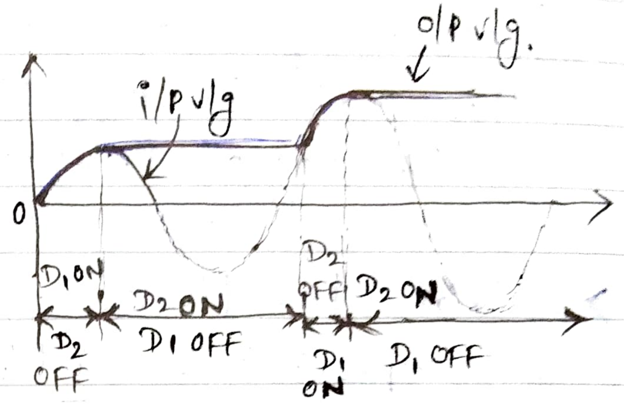


→ **Peak Detector Using OPAMP**

It is used to detect & hold the peak value of i/p sig. o/p of this ckt will follow the peak value of i/p sig. & store the maximum value infinitely.

→ **Positive Peak detector**





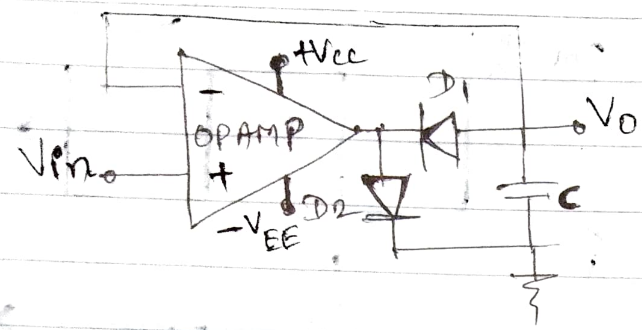
➤ The OPAMP is used as a v/g follower. ∴ the gain of this ckt is '1'. The diode D_1 will be forward biased only in +ve half cycle of i/p, hence ckt is sensitive only to +ve i/p v/gs. D_2 will not allow -ve v/g to go ahead.

➤ The diode D_1 & D_2 are assumed to be ideal & o/p v/g Vo is nothing but v/g across capacitor i.e. $V_o = V_c$.

➤ Track mode → Assuming initial v/g on the capacitor is 0V. Hence in the first +ve half cycle of i/p, the diode D_1 is forward biased, D_2 is reverse biased & capacitor charges to positive peak of i/p.

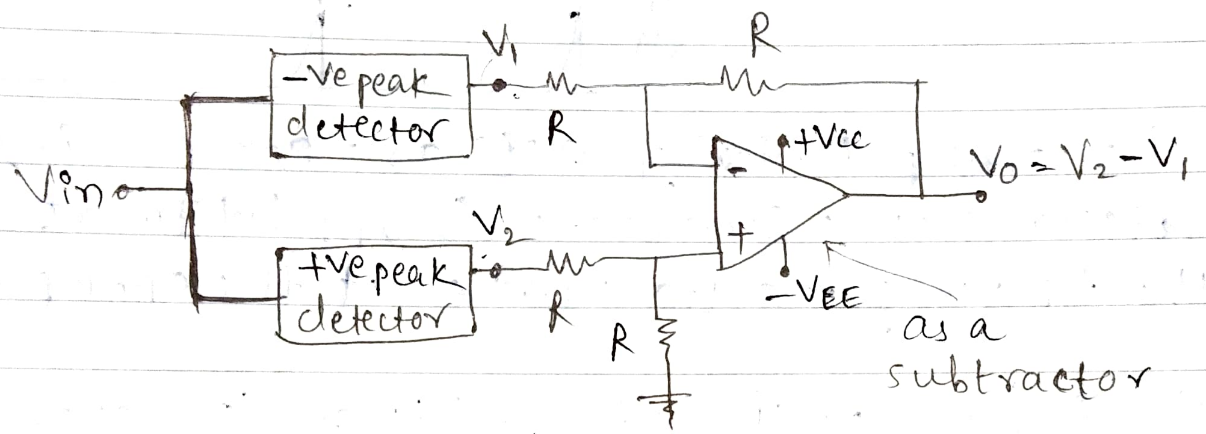
➤ Hold mode → Now as i/p v/g ↓ses, the diode D_1 is reverse biased & stop conducting. The capacitor then maintains constant o/p v/g which is equal to peak value of i/p. It will hold till next +ve half cycle.

→ -ve peak detector



By reversing the direction of diode 'D1' the same circuit will be used as -ve peak detector.

→ Peak to peak detector



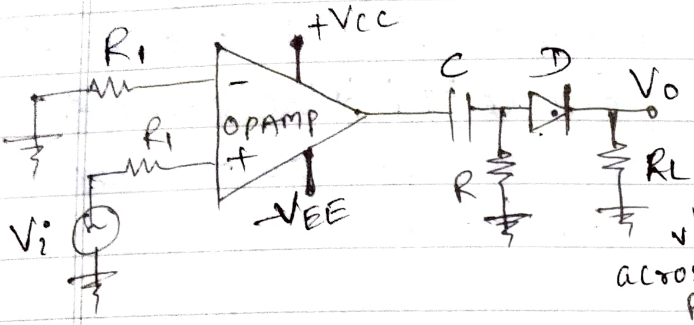
It consist of +ve peak detector, -ve peak detector, & subtractor.

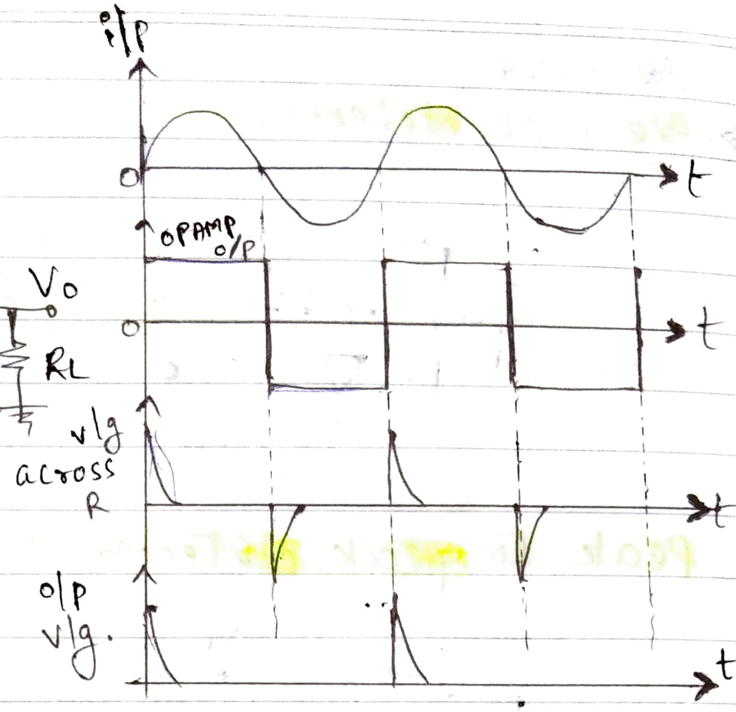
- The +ve peak detector responds only to +ve half cycles of i/p v/g Vin, Thus v/g 'V_2' at its o/p corresponds to peak positive voltage.
- The -ve peak detector will responds only to -ve half cycles of i/p v/g Vin, Thus 'V_1' at its o/p corresponds to peak -ve v/g.
- The o/p of these peak detector are applied to subtractor & thus the o/p v/g is given by,

$$V_o = V_2 - V_1 = \text{'+ve' peak v/g} - \text{'-ve' peak v/g}.$$

ie V_o = peak to peak v/g.

→ phase detector





→ The OPAMP Basically acts as zero crossing detector hence sine wave is applied to at the i/p we get square wave at the OPAMP o/p.

→ C & R form passive differentiator, so across 'R' we get +ve & -ve pulses.

→ The diode will allow only positive pulses to pass through the load & blocks -ve pulses. Thus at the o/p we get the +ve spikes. because during +ve spike diode will be forward bias & in -ve spike diode will be reverse bias.

> we can use pulse generator ckt to measure phase angle. The v/gs under the phase measurement are applied to two different pulse generator.

> These v/gs are then converted in to +ve trigger pulses. These pulses are applied to two channels of CRO. The time duration of between the pulses corresponding to two v/gs represents phase shift between them.