MODULE - 5

SYLLABUS

1) op amp circuits

→ differentiate & integrator ckts

→ practical ckts, design

2) Comparators

→ zero crossing and voltage level detectors

→ schmitt trigger

→ comparator IC LM 311

3) waveform generation using op-amp

→ square, triangular and ramp generator using op amp

→ Effect of slew rate on waveform generation

4) Timer 555 IC

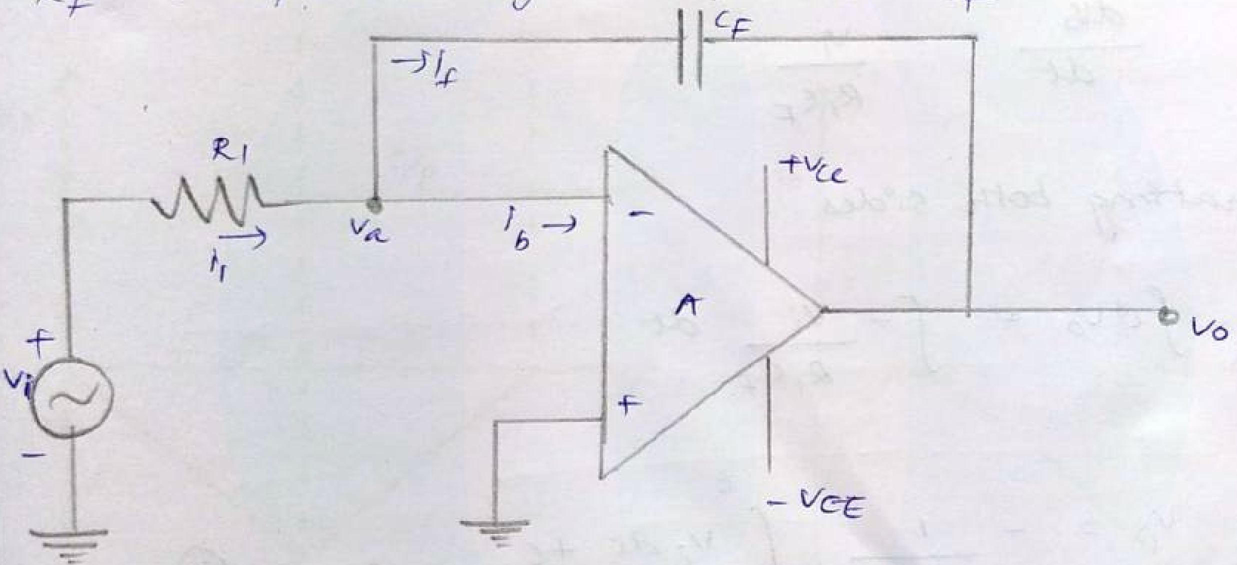
→ Internal diagram of 555 IC

→ Astable and monostable multivibrators using 555 IC.

INTEGRATOR CIRCUIT

a) * A circuit in which output waveform is the integral of the input voltage waveform is the integrator or integration amplifiers.

* Integration is the process of continuous addition. Such a circuit is obtained by using a basic inverting amplifier configuration if the feedback resistor R_F is replaced by a capacitor C_F.



At node a, apply KCL

$$i_1 = i_B + i_f$$

$$\frac{V_i - V_a}{R_1} = i_b + i_f$$

But $V_a = 0$, $i_b = 0$ } virtual ground concept

$$\frac{V_i}{R_i} = i_f \quad \text{---} \quad (1)$$

i_f is the current flowing through the capacitor.

Relationship between current and voltage in a capacitor is given by

$$i_c = C \frac{dv}{dt}$$

$$i_f = C_F \frac{d}{dt}(V_a - V_o) = C_F \frac{d}{dt}(-V_o)$$

$$\therefore ① \Rightarrow \frac{V_i}{R_i} = C_F \frac{d}{dt}(-V_o)$$

$$\frac{dV_o}{dt} = -\frac{V_i}{R_1 C_F}$$

Integrating both sides

$$\int dV_o = \int -\frac{V_i}{R_1 C_F}\, dt$$

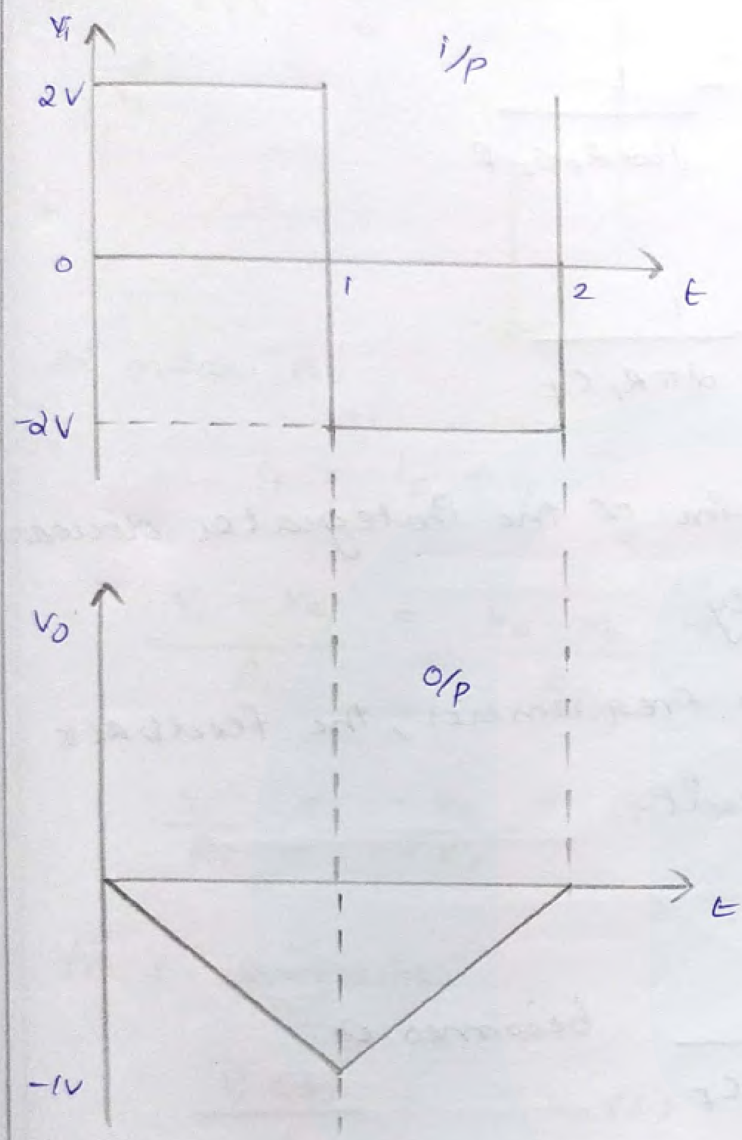
$$V_o = -\frac{1}{R_1 C_F}\int_0^t V_i\, dt + C \quad \text{—— ②}$$

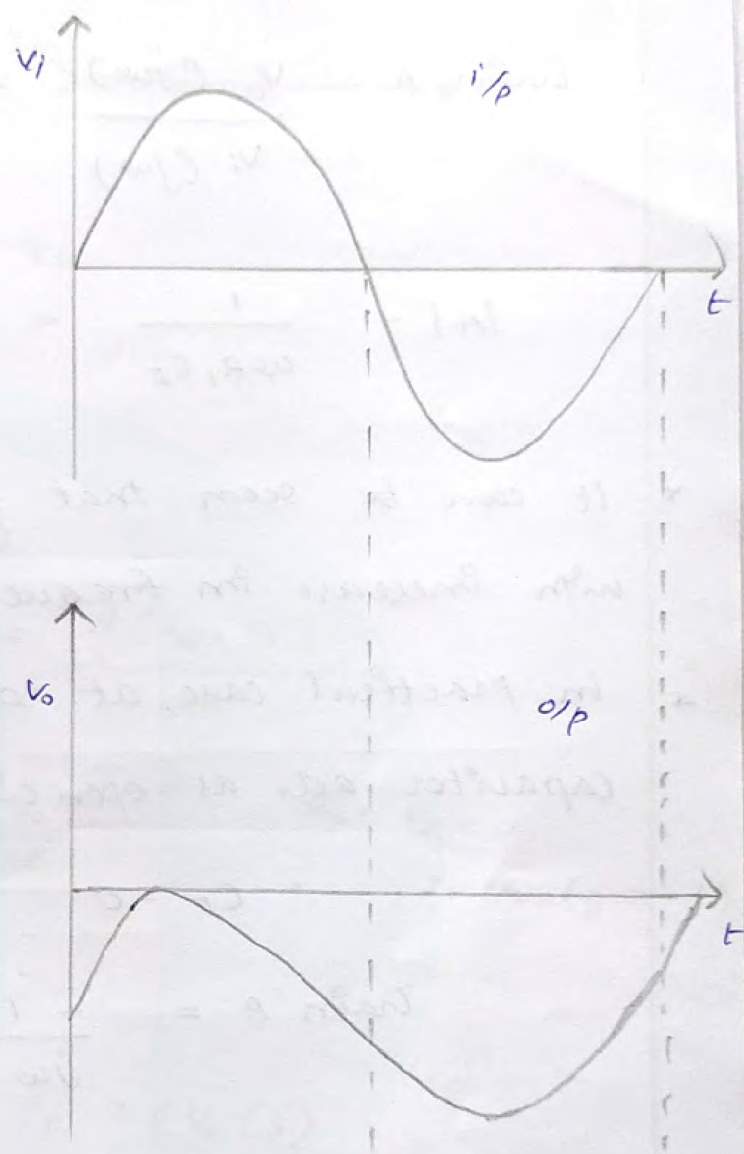
C is the integration constant.

* Equation ② shows that the output voltage is directly proportional to the negative integral of the input voltage and inversely proportional to the time constant $R_1 C_F$.

* If the input is sine wave, o/p will be cosine wave.

* If the i/p is a square wave, the o/p is a ramp signal.





In the s-domain

$$V_o(s) = -\frac{1}{R_1 C_F} \frac{V_i(s)}{s}$$

put $s = j\omega$

$$V_o(j\omega) = -\frac{1}{R_1 C_f} \frac{V_i(j\omega)}{j\omega}$$

$$= \frac{-1}{j\omega R_1 C_F} V_i(j\omega)$$

$$\text{Gain } A = \frac{V_0(j\omega)}{V_i(j\omega)} = -\frac{1}{j\omega R_1 C_F f}$$

$$|A| = \frac{1}{\omega R_1 C_F} = \frac{1}{2\pi R_1 C_F}$$

* It can be seen that gain of the integrator decrease with increase in frequency.

* In practical case, at low frequencies, the feedback capacitor acts as open circuit.

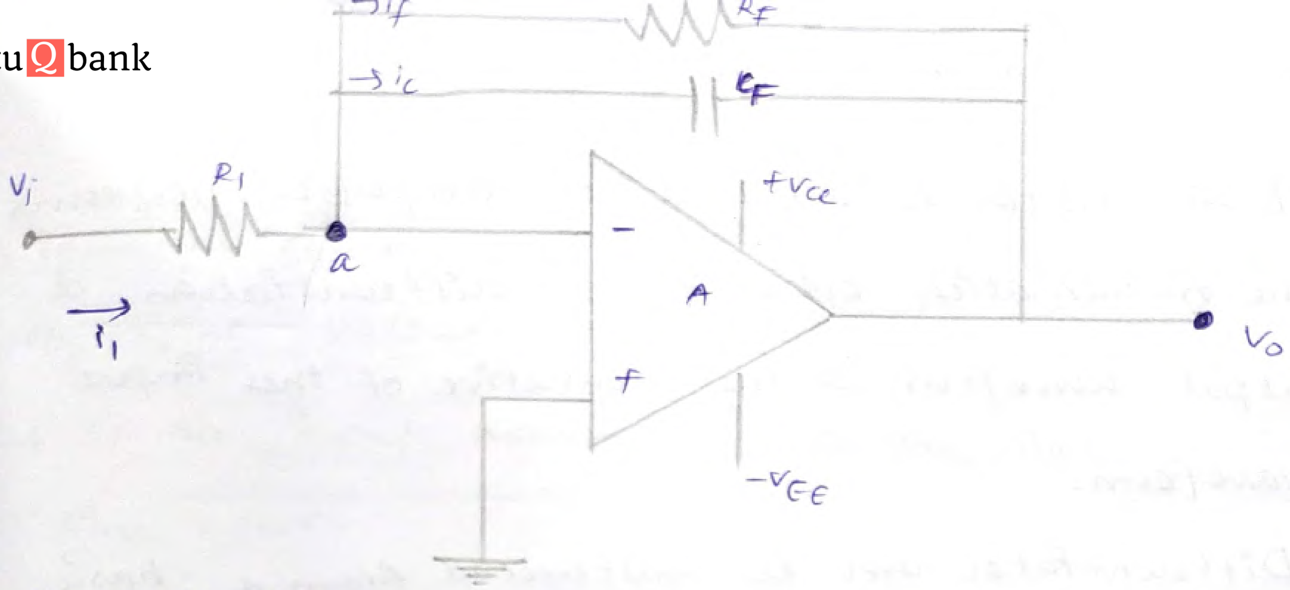
$$\therefore C_F = 0$$

$$\text{Gain } A = \frac{-1}{j\omega R_1 C_F} \text{ becomes } \infty$$

* Thus the output becomes infinity (high). Thus error is produced at the output.

* In order to reduces error in the output we use a resistor R_F in parallel to C_F.

Thus practical integrator circuit is as shown below



At node a,

$$i_1 = i_f + i_c$$

$$\frac{V_i - V_a}{R_1} = \frac{V_a - V_o}{R_f} + C_F \frac{d(V_a - V_o)}{dt}$$

$$\frac{V_i}{R_1} = \frac{-V_o}{R_F} + C_F \frac{-dV_o}{dt}$$ But $V_a = 0$ (virtual ground)

In s-domain

$$\frac{V_i(s)}{R_1} = \frac{-V_o(s)}{R_F} - C_F\, s\, V_o(s)$$

$$= -V_o(s)\left[\frac{1}{R_F} + C_F s\right]$$

$$= -V_o(s)\left(\frac{R_F C_F s + 1}{R_F}\right)$$

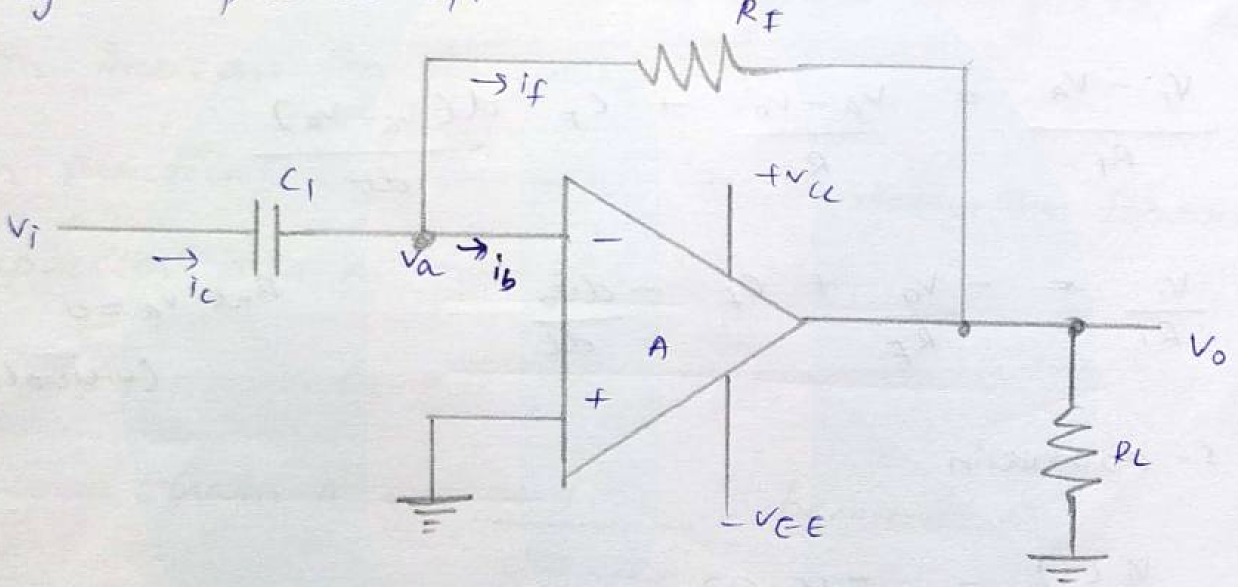
~~Gain $V_o(s)$ (~~

$$\text{Gain } \frac{V_o(s)}{V_i(s)} = \frac{-R_F}{R_1(R_F C_F s + 1)} = \frac{-R_F/R_1}{1 + R_F C_F s}$$

DIFFERENTIATOR

* Differentiator or differentiator amplifier performs the mathematical operation of differentiation ie output waveform is the derivative of the input waveform.

* Differentiator can be constructed from a basic inverting amplifier if the input resistor is replaced by a capacitor C_1.



Apply KCL at node 'a'

$$i_c = i_f + i_b$$

$$C_1 \frac{d(v_i - v_a)}{dt} = -\frac{V_a - V_0}{R_F} + 0$$

$i_b = 0$
$V_a = 0$
virtual gnd concept

$$C_1 \frac{dv_i}{dt} = -\frac{V_0}{R_F}$$

$$C_1 \frac{dv_i}{dt} = \frac{-V_0}{R_F}$$

$$v_0 = -C_1 R_F \frac{dv_i}{dt}$$

Thus the output voltage is $-C_1 R_F$ times the derivative of input voltage.

→ If the input waveform is cosine, the o/p will be sine wave.

→ If the i/p is triangular, the o/p will be square wave.

In s domain,

$$V_0(s) = -R_1 C_F \, s \, V_i(s)$$

$$\frac{V_0(s)}{V_i(s)} = -R_F C_1 s$$

put $s = j\omega$

$$A = \frac{V_0(j\omega)}{V_i(j\omega)} = -R_F C_1 j\omega$$

$$|A| = |-R_F C_1 j\omega|$$

$$= R_F C_1 \omega$$

Put $\omega = 2\pi f$

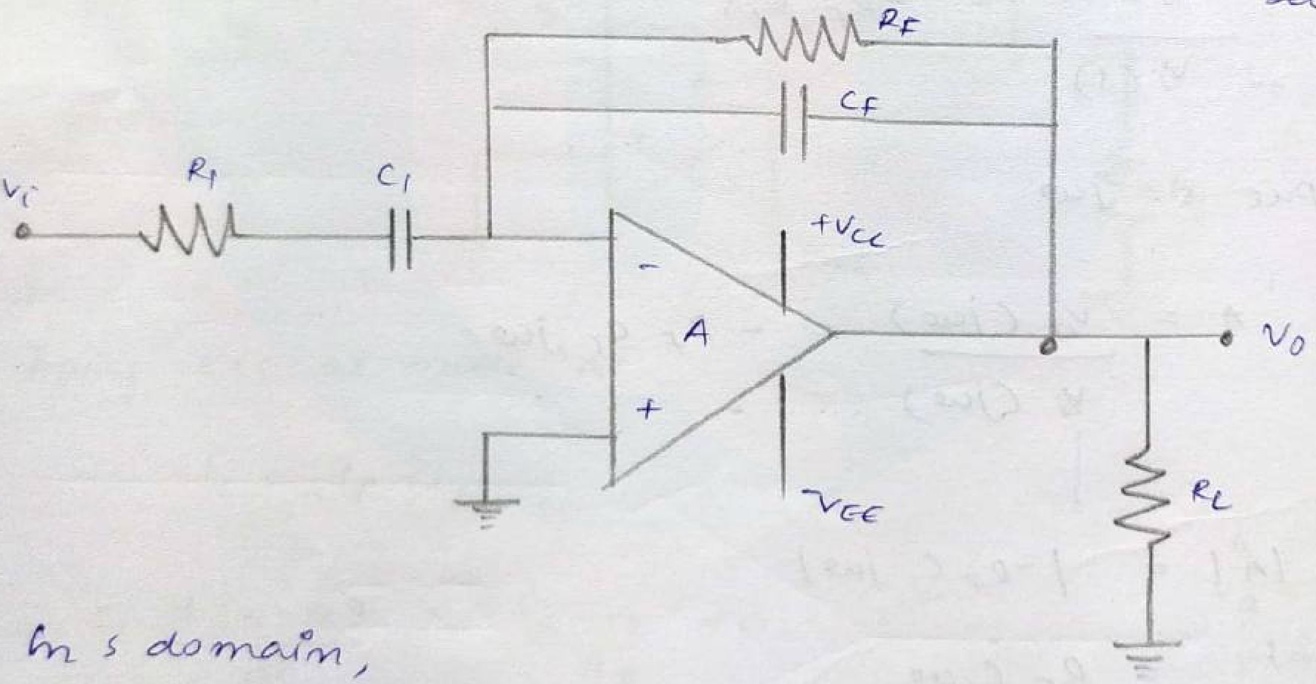
$$|A| = 2\pi f C_1 R_F$$

As frequency increases, gain also increases at a rate of 20 dB/dec. Thus circuit is unstable.

Also when frequency increases, $X_{C_1} = \frac{1}{2\pi f C_1}$, i.e. X_{C_1} decreases which makes the circuit very susceptable to high frequency noise.

Both stability and high frequency noise problems can be corrected by the addition of two components R_1 and C_F.

The practical differentiator circuit is shown below.



In s domain,

$$\frac{V_o(s)}{V_i(s)} = \frac{-sR_FC_1}{[1+sR_1C_1]^2}$$

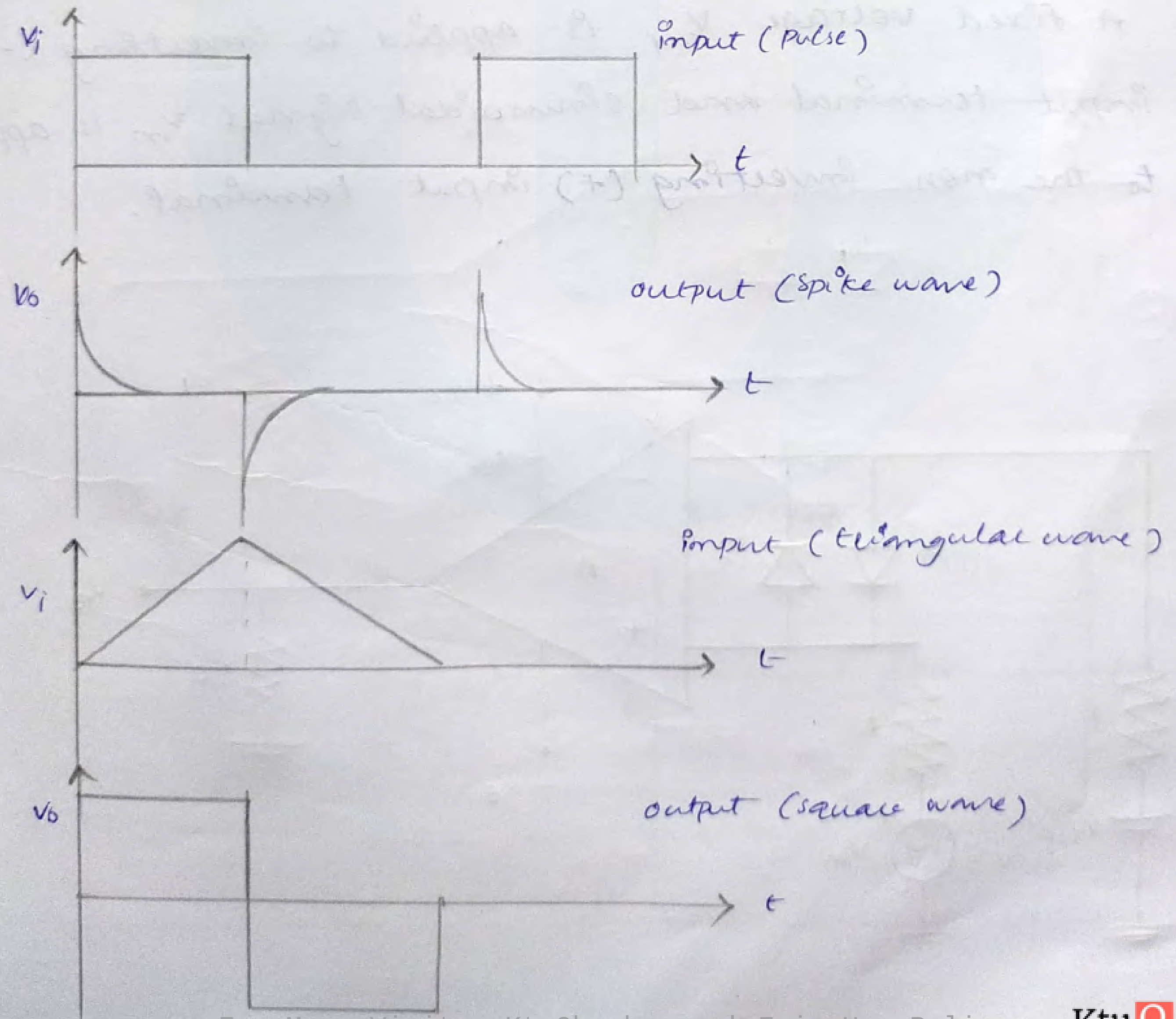
put $s = j\omega$

$$\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{-j\omega R_F C_1}{[1+j\omega R_1 C_1]^2}$$

put $\omega = 2\pi f$

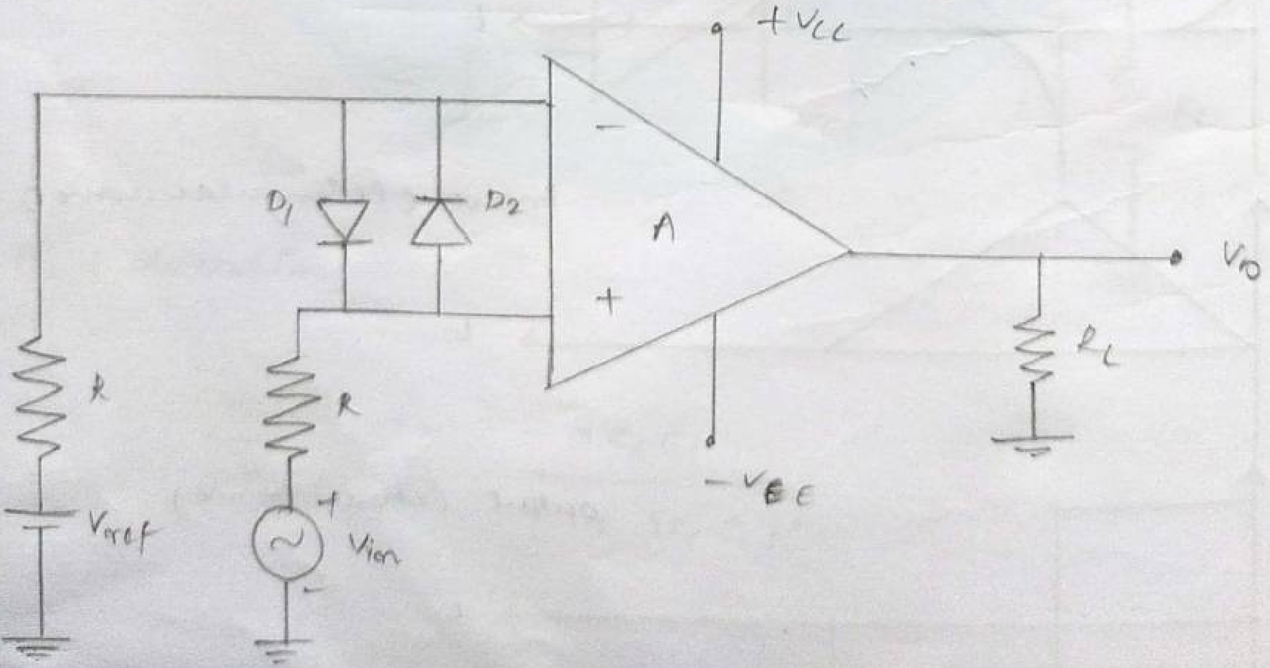
$$\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{-j2\pi f R_F C_1}{[1+j2\pi f R_1 C_1]^2}$$

$$= \frac{-j2\pi f R_F C_1}{[1+j\, f/f_b]^2} \qquad f_b = \frac{1}{2\pi R_1 C_1}$$



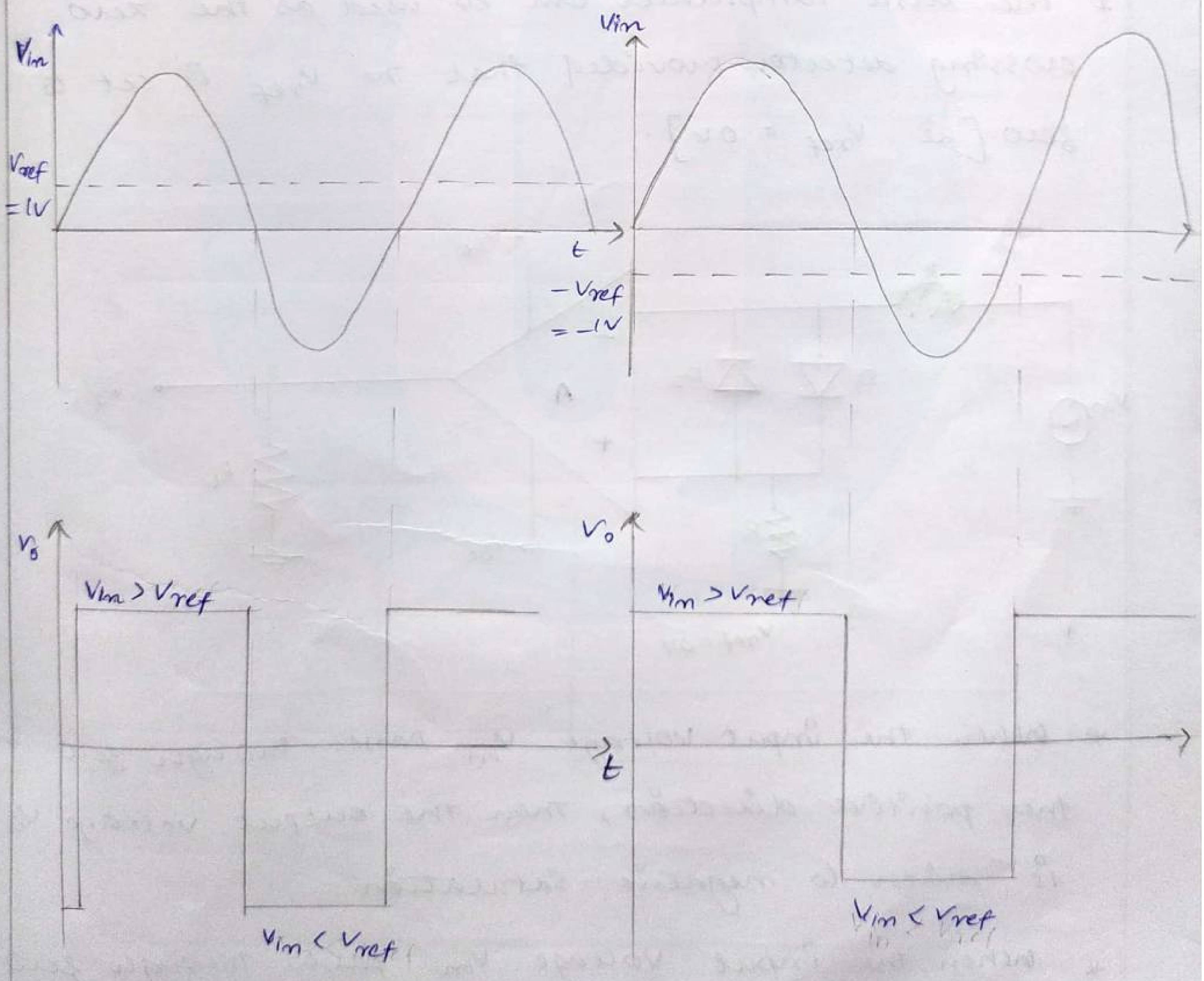
COMPARATORS

* A comparator compares the voltages at the positive and negative inputs.
* A comparator compares a signal voltage on one input of an op amp with a known voltage called reference voltage on the other input.
* Comparators are used to circuits such as digital interfacing, schmitt trigger, discriminators, voltage level detectors and oscillators.
* Figure below shows an op amp comparator circuit.
* A fixed voltage V_{ref} is applied to inverting (-) input terminal and sinusoidal signal v_{in} is applied to the non inverting (+) input terminal.



* When V_{in} exceeds V_{ref}, the output voltage goes to positive saturation. On the other hand, when V_{in} is less than V_{ref}, the output voltage goes to negative saturation. Thus V_o changes from one saturation level to another whenever $V_{in} \cong V_{ref}$.

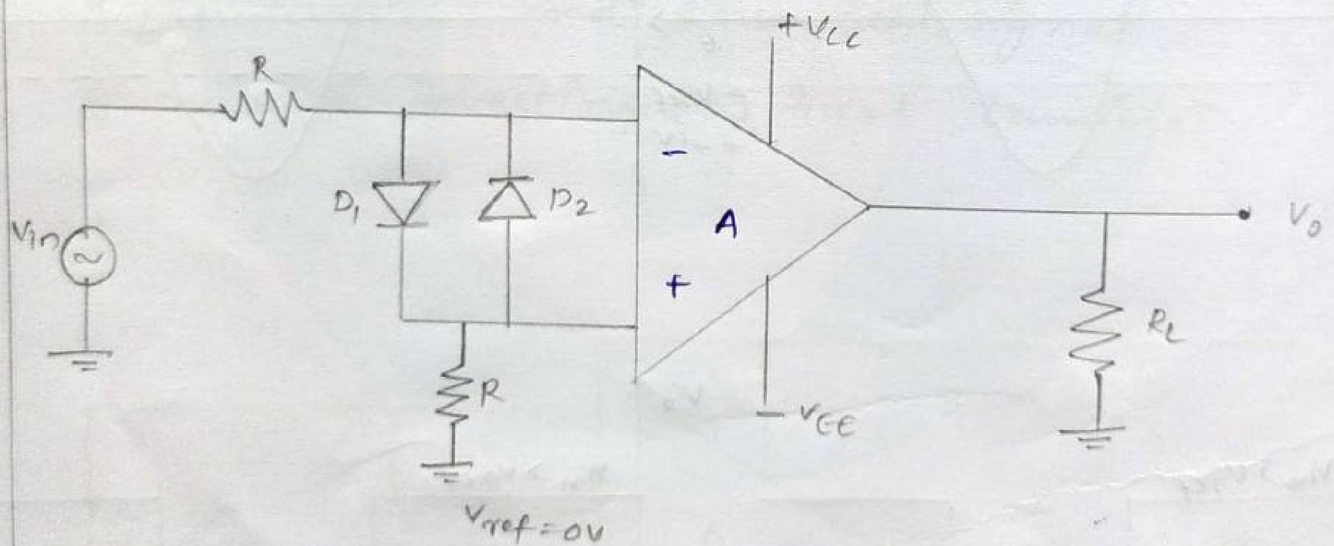
* This comparator is also called a voltage level detector because for a desired value of V_{ref}, the voltage level of the input V_{in} can be detected.



* The diodes D_1 and D_2 protect the op amp from damage due to excessive input voltage V_{in}.
* Due to these diodes, the difference input voltage V_{id} of the op amp is clamped to either 0.7 V or -0.7 V. Hence these diodes are called clamp diodes.

Zero Crossing Detector

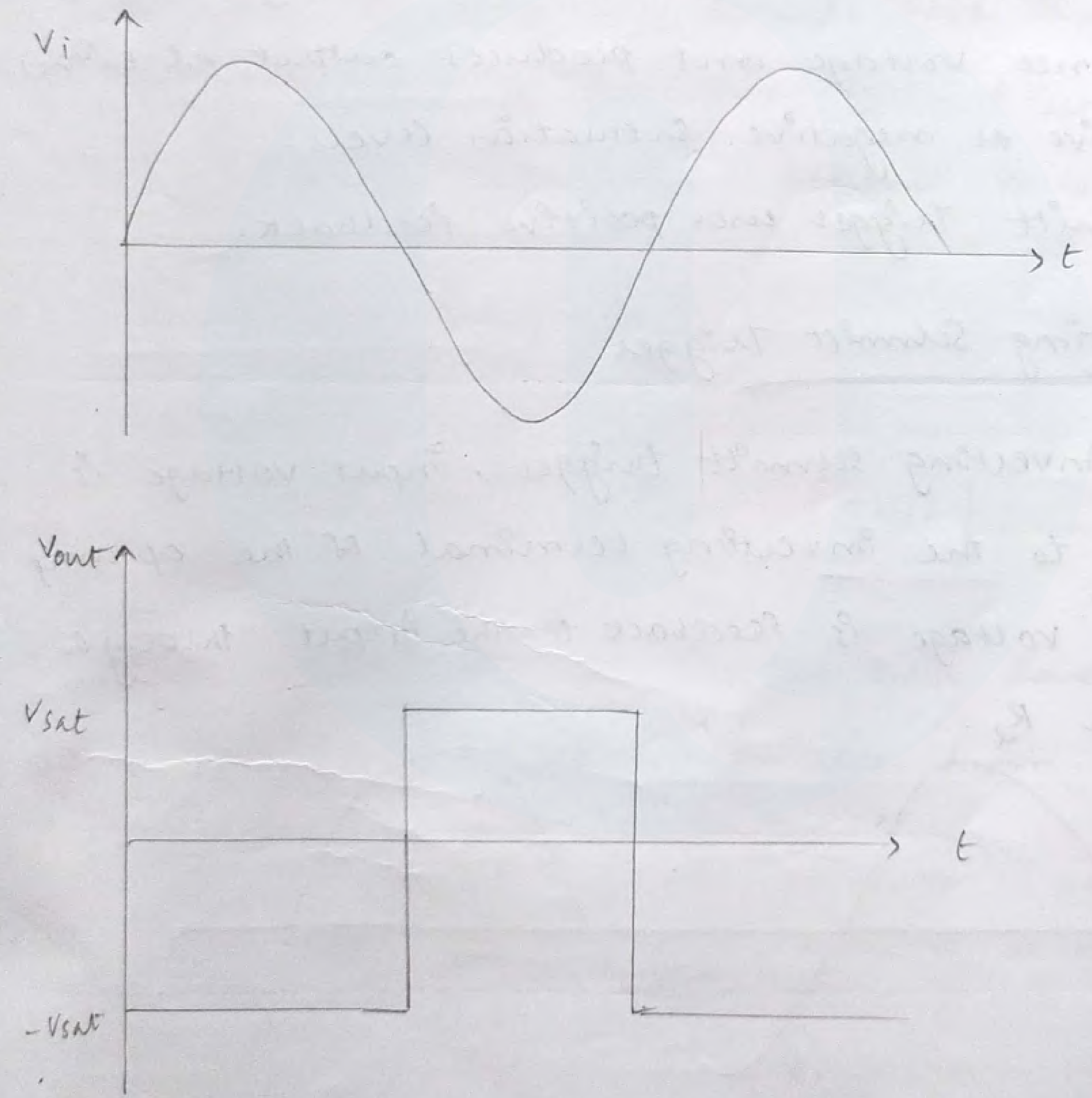
* It is also called sine to square wave converter.
* The basic comparator can be used as the zero crossing detector provided that the V_{ref} is set to zero [ie V_{ref} = 0V].



* When the input voltage V_{in} passes through zero in the positive direction, then the output voltage V_o is driven to negative saturation.
* When the input voltage V_{in} passes through zero

 the negative direction, then the output voltage V_0 is driven to positive saturation.

* Thus we get a square wave at the o/p.
* Diodes D_1 and D_2 are used to protect the op amp from damage due to excessive input voltage V_{in}.
* Resistor R is used to limit the current through the diodes.

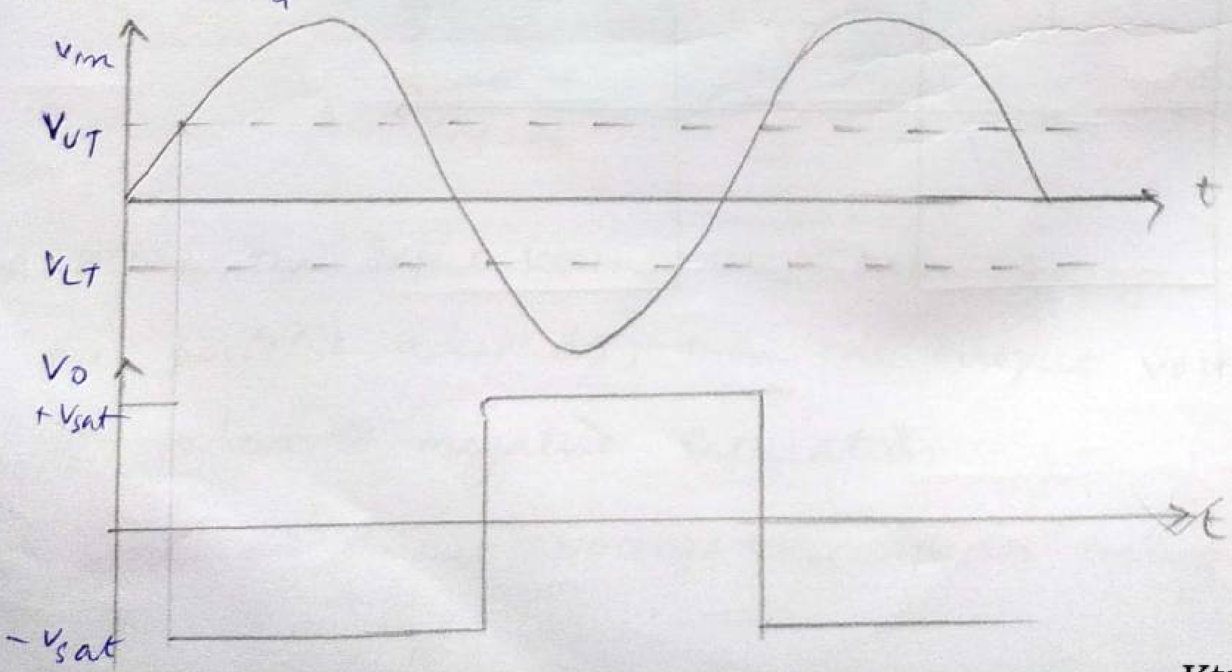


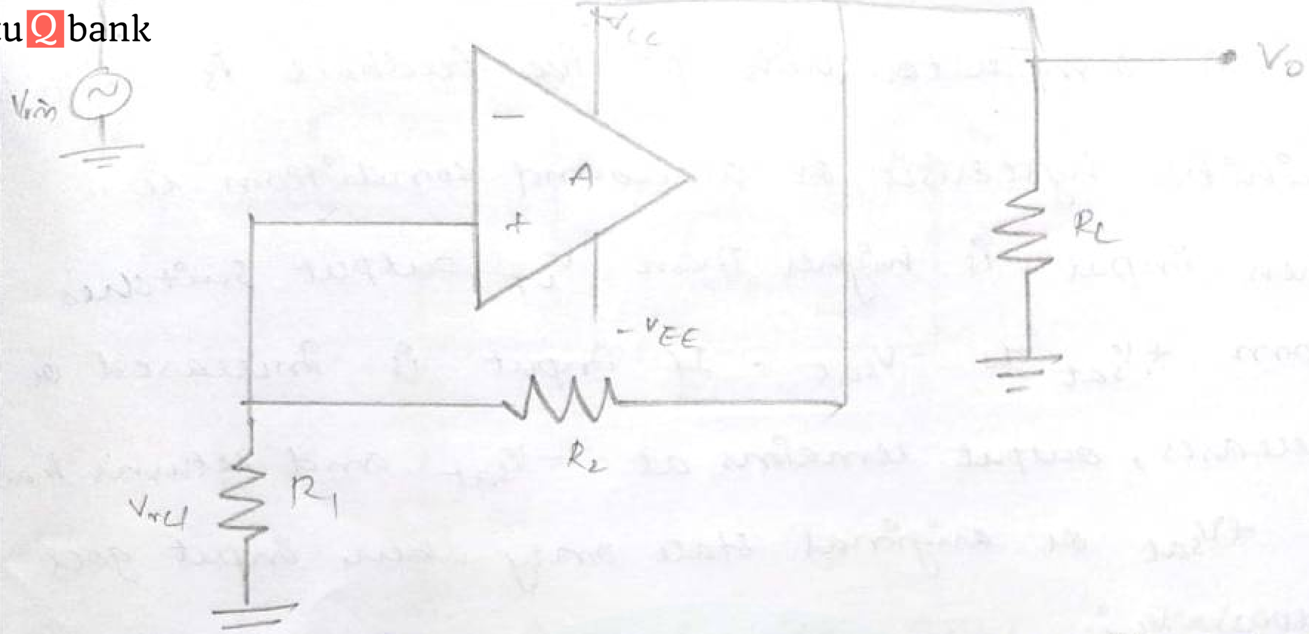
SCHMITT TRIGGER

* Schmitt Trigger is a comparator circuit that converts an irregular waveform to a square wave or pulse.
* Also known as squaring circuit / regenerative comparator.
* Schmitt Trigger circuit is a comparator circuit that compares the applied input voltage with a reference voltage and produces output at either positive or negative saturation levels.
* Schmitt Trigger uses positive feedback.

Inverting Schmitt Trigger

In inverting schmitt trigger, input voltage is applied to the inverting terminal of the op amp. Output voltage is feedback to the input through resistor R_2.





* when the input voltage exceeds upper threshold voltage V_{UT}, output switches from $+V_{sat}$ to $-V_{sat}$.

when output $V_o = +V_{sat}$, reference voltage is V_{UT}.

$$V_{UT} = \frac{V_o R_1}{R_1 + R_2}$$

$$V_{UT} = \frac{R_1}{R_1 + R_2}\left[+V_{sat}\right]; \quad V_o = +V_{sat}$$

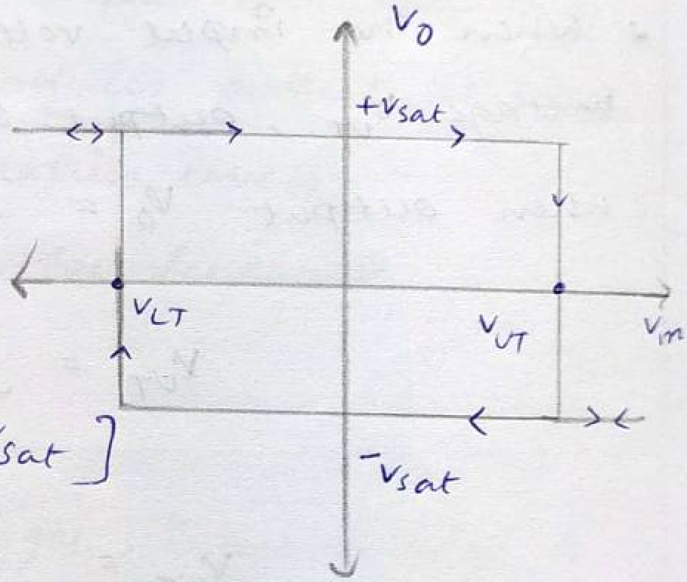
* when input voltage is less than lower threshold voltage V_{LT}, the output switches from $-V_{sat}$ to $+V_{sat}$.

when output $V_o = -V_{sat}$, reference voltage is V_{LT}

$$V_{LT} = V_o \frac{R_1}{R_1 + R_2}$$

$$= \frac{R_1}{R_1 + R_2}\left(-V_{sat}\right)$$

A comparator with positive feedback is said to exhibit hysteresis or deadband condition ie, when input is higher than V_{UT} output switches from $+V_{sat}$ to $-V_{sat}$. If input is increased or decreases, output remains at $-V_{sat}$ and returns back to $+V_{sat}$ or original state only when input goes below V_{LT}



Hysteresis voltage,

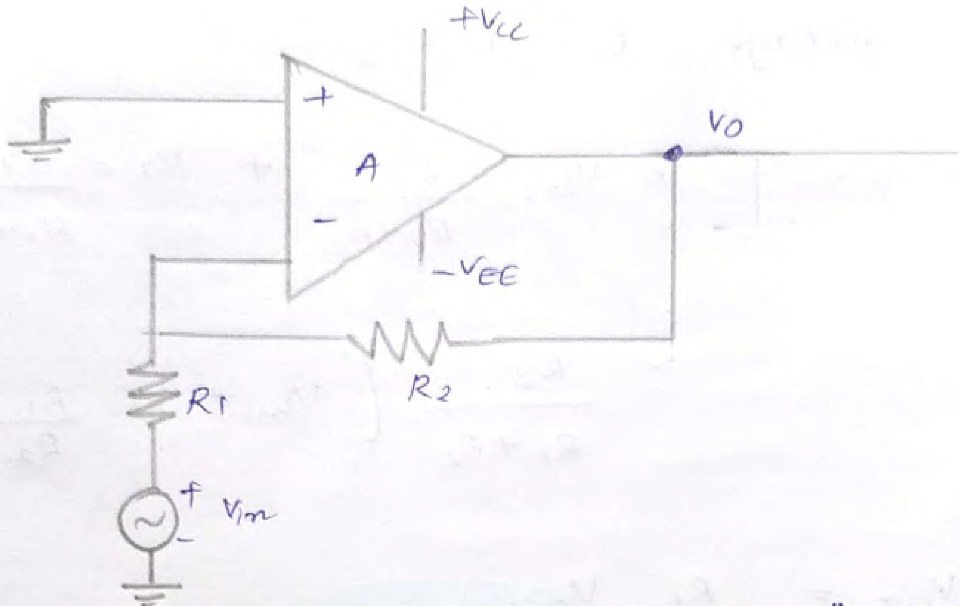
$$V_{hys} = V_{UT} - V_{LT}$$

$$= \frac{R_1}{R_1+R_2}\left[V_{sat} - -V_{sat}\right]$$

$$= \frac{2R_1}{R_1+R_2} V_{sat}$$

Non inverting Schmitt Trigger

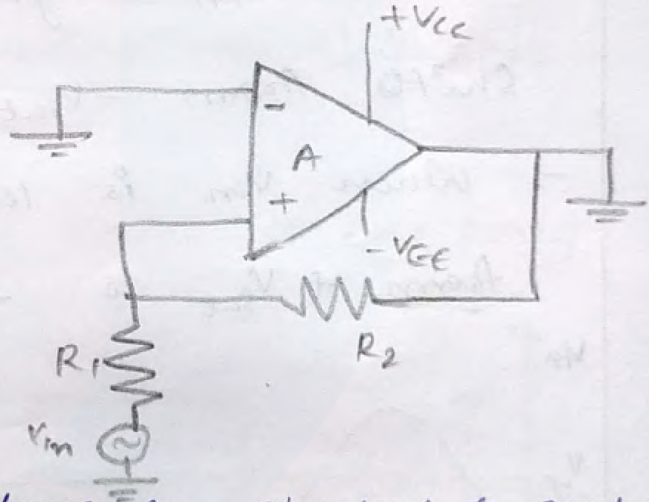
In non inverting schmitt trigger, input is applied to the non-inverting terminal of op amp. Feedback is applied at the non-inverting terminal itself.



* Voltage at non inverting terminal is calculated by superposition theorem.

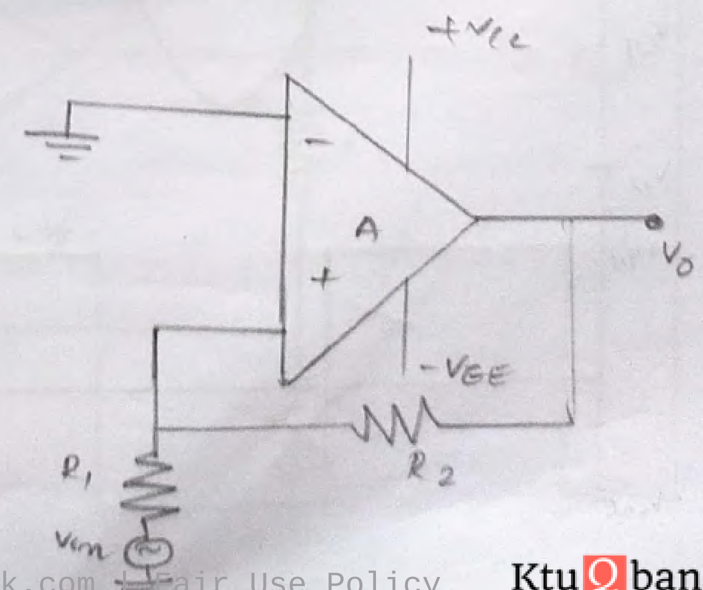
Case 1 : when V_o is shorted to gnd (V_{in} is acting alone)

$$V_1 = V_{in} \frac{R_2}{R_1+R_2}$$



Case 2 : when V_o is acting alone (V_{in} shorted to gnd)

$$V_2 = V_o \frac{R_1}{R_1+R_2}$$



Total voltage $V = V_1 + V_2$

$$= V_{in} \frac{R_2}{R_1+R_2} + V_0 \frac{R_1}{R_1+R_2}$$

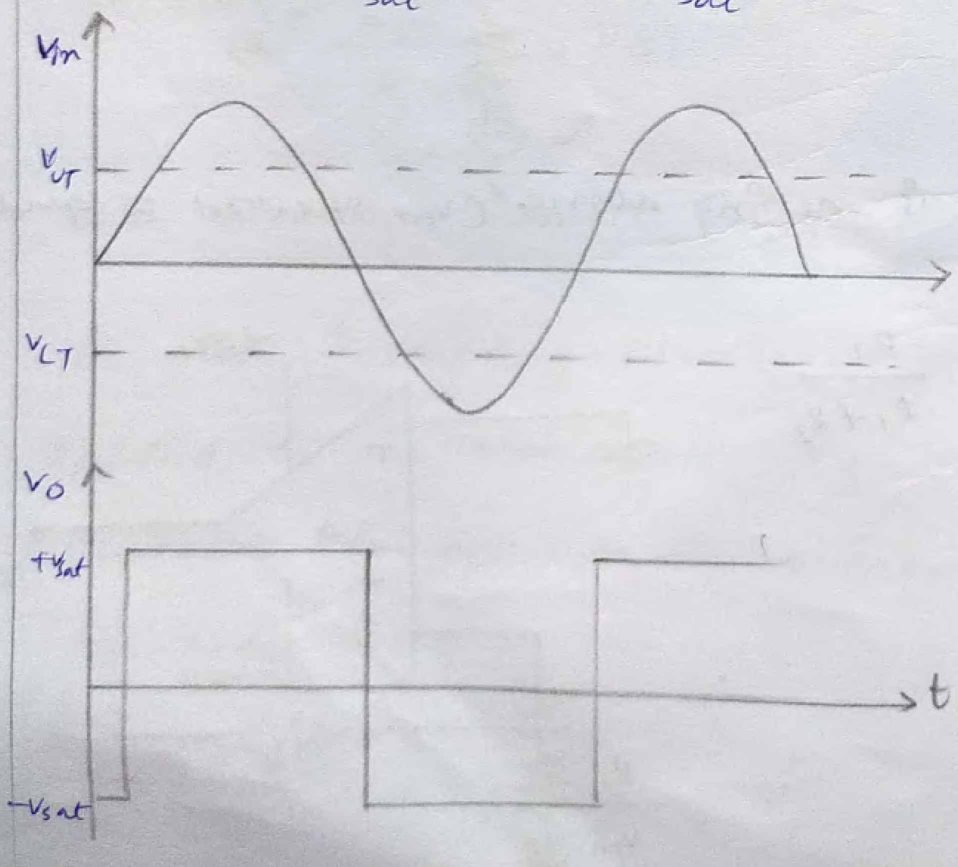
$$= \frac{R_2}{R_1+R_2} \left[V_{in} + V_0 \frac{R_1}{R_2} \right]$$

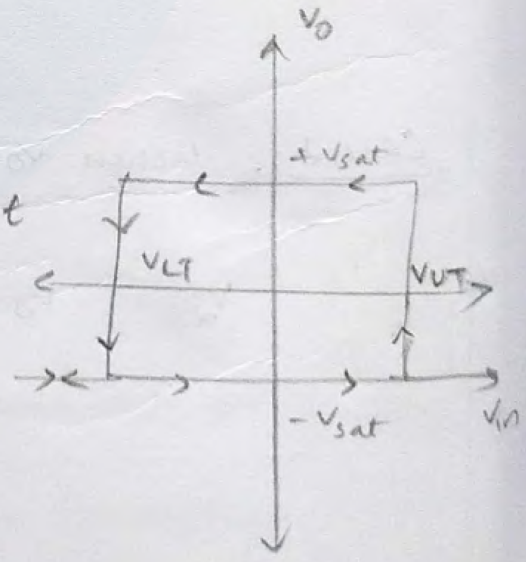
→ $V_{UT} = \frac{R_1}{R_2} V_{sat}$

→ $V_{LT} = -\frac{R_1}{R_2} V_{sat}$

→ when V_{in} is greater than V_{UT}, the output shifts from $-V_{sat}$ to $+V_{sat}$.

→ when V_{in} is less than V_{LT}, the output shifts from $+V_{sat}$ to $-V_{sat}$.





Wave form Generation using op amps

Different waveforms can be generated using op amps some of them are

(1) Square wave generator

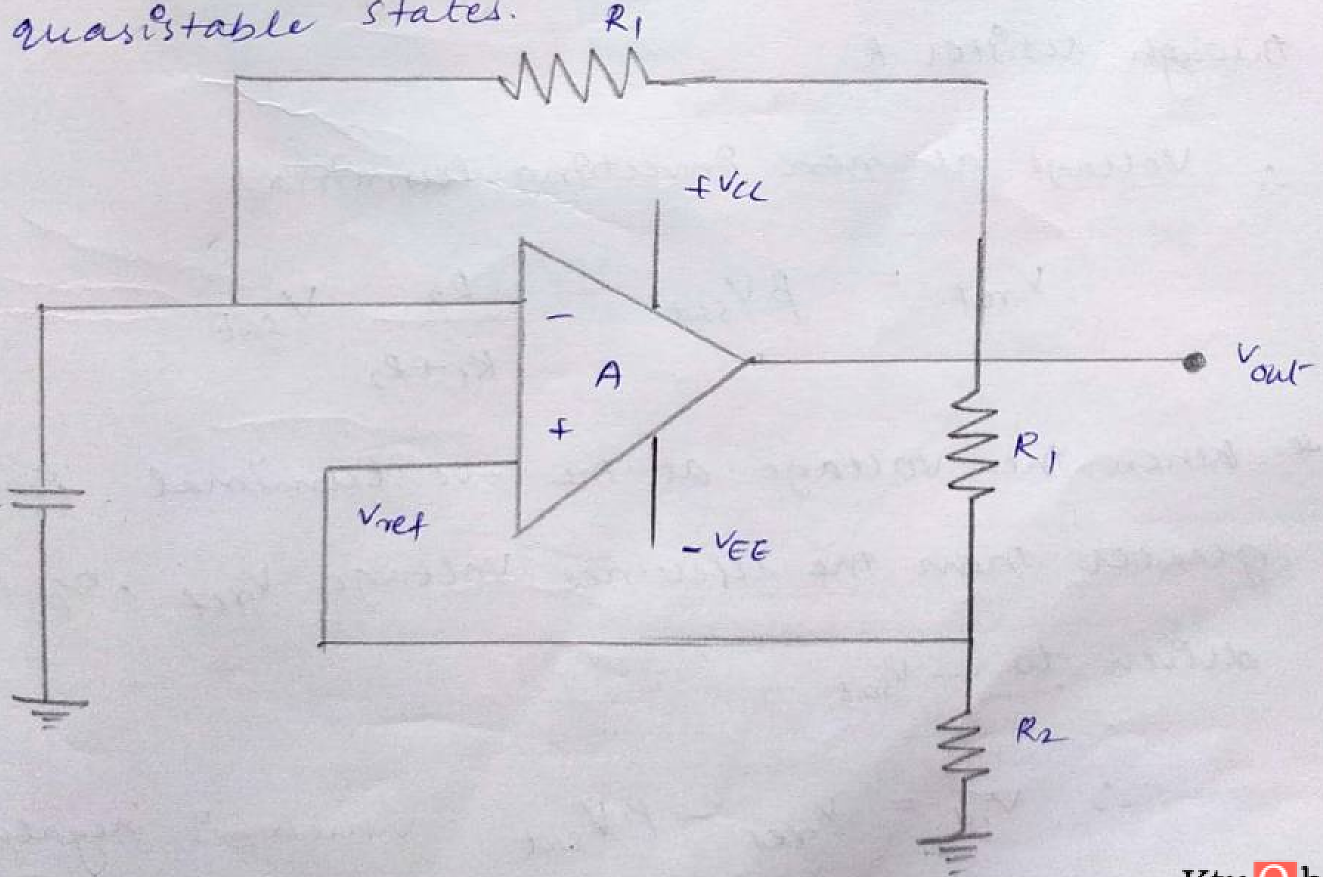
(2) Triangular wave generator

(3) Saw tooth wave generator

Square wave Generator

* The circuit is a stable multivibrator circuit and is also known as free running multivibrator. ie, no external input is used.

* The circuit has no stable states. It has only quasistable states.



* The circuit has no external signal source

* voltage across R_1 is feed back to the input terminal

* when dc supply voltages V_{cc} and $-V_{EE}$ is applied, voltage across capacitor is zero .ie voltage at inverting terminal is zero initially.

* At the same instant voltage across non inverting terminal (V_{ref}) is there.

∴ The differential voltage at the input

$$V_{id} = V_{ref} - 0 = V_{ref}$$

At that time o/p of op amp is $+V_{sat}$.
Now the capacitor starts charging towards $+V_{sat}$ through resistor R.

∴ Voltage at non inverting terminal

$$V_{ref} = \beta V_{sat} = \frac{R_2}{R_1+R_2} V_{sat}$$

* When the voltage at the -ve terminal is greater than the reference voltage V_{ref}, o/p is driven to $-V_{sat}$

∴ $V_{id} = V_{ref} - \beta V_{sat}$ which is negative

$$V_{out} = -V_{sat}$$

Now the capacitor C starts discharging through R.

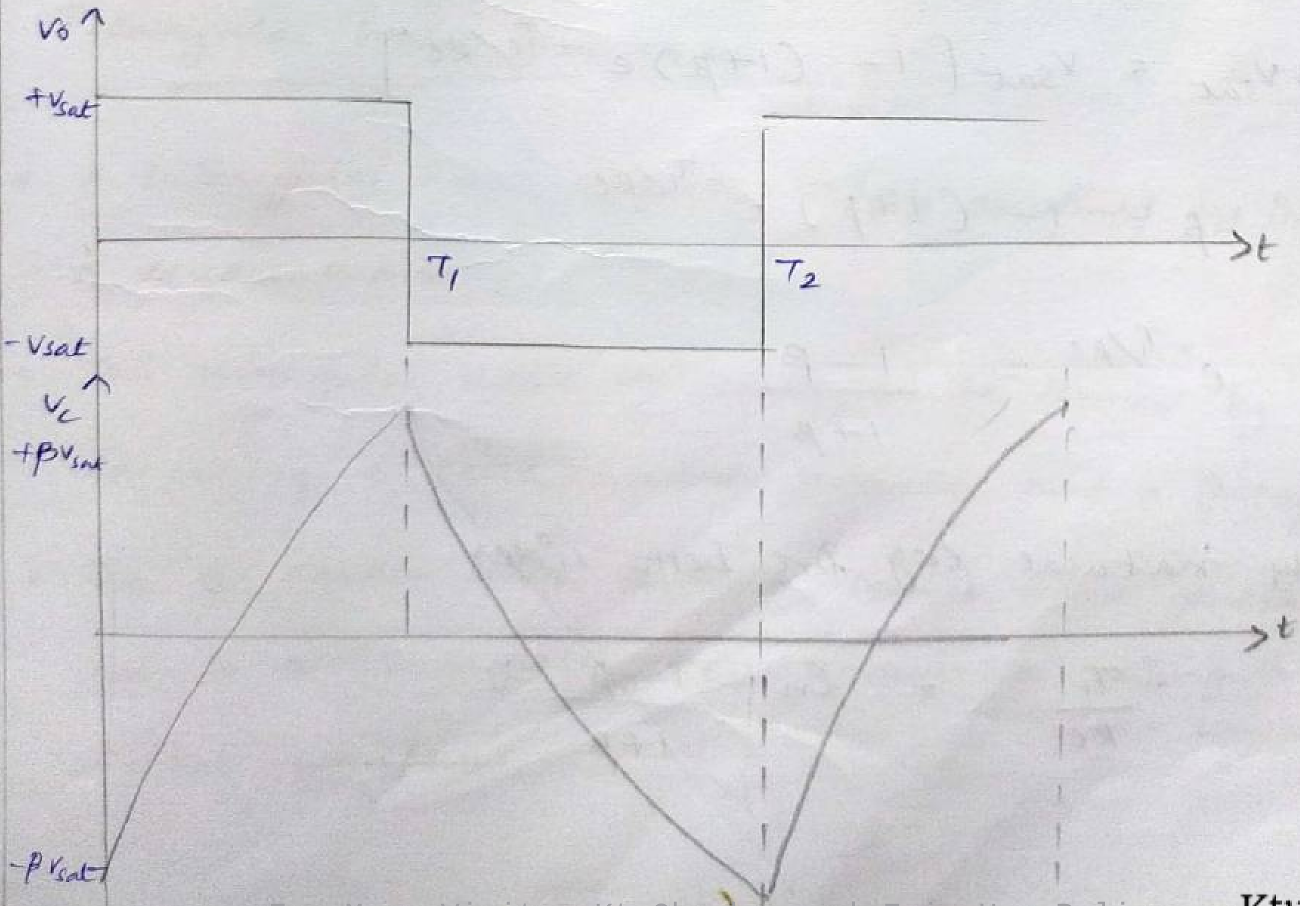
∴ Voltage at non inverting terminal

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

* This condition continues until the charge on capacitor exceeds $-\beta V_{sat}$.

* Thus the o/p is a square wave which swings between $+V_{sat}$ and $-V_{sat}$.

* The period (frequency) of square wave is determined by the time constant RC and the feedback ratio β.



* voltage across capacitor is a function of time

$$V_c(t) = V_f + (V_i - V_f)\, e^{-t/RC}$$

$V_f \rightarrow$ final value $= +V_{sat}$

$V_i \rightarrow$ initial value $= -\beta V_{sat}$

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

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

At $t = T_1$,

$$V_c(T_1) = V_{sat} - V_{sat}(1+\beta)\, e^{-T_1/RC}$$

$$V_c(T_1) = V_{sat} - V_{sat}(1+\beta)\, e^{-T_1/RC}$$

$$\beta V_{sat} = V_{sat}\left[1 - (1+\beta)\, e^{-T_1/RC}\right]$$

$$\beta = 1 - (1+\beta)\, e^{-T_1/RC}$$

$$e^{-T_1/RC} = \frac{1-\beta}{1+\beta}$$

Apply natural log in both sides

$$-\frac{T_1}{RC} = \ln \frac{1-\beta}{1+\beta}$$

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

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

Total time period. $\boxed{T = 2T_1 = 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)}$

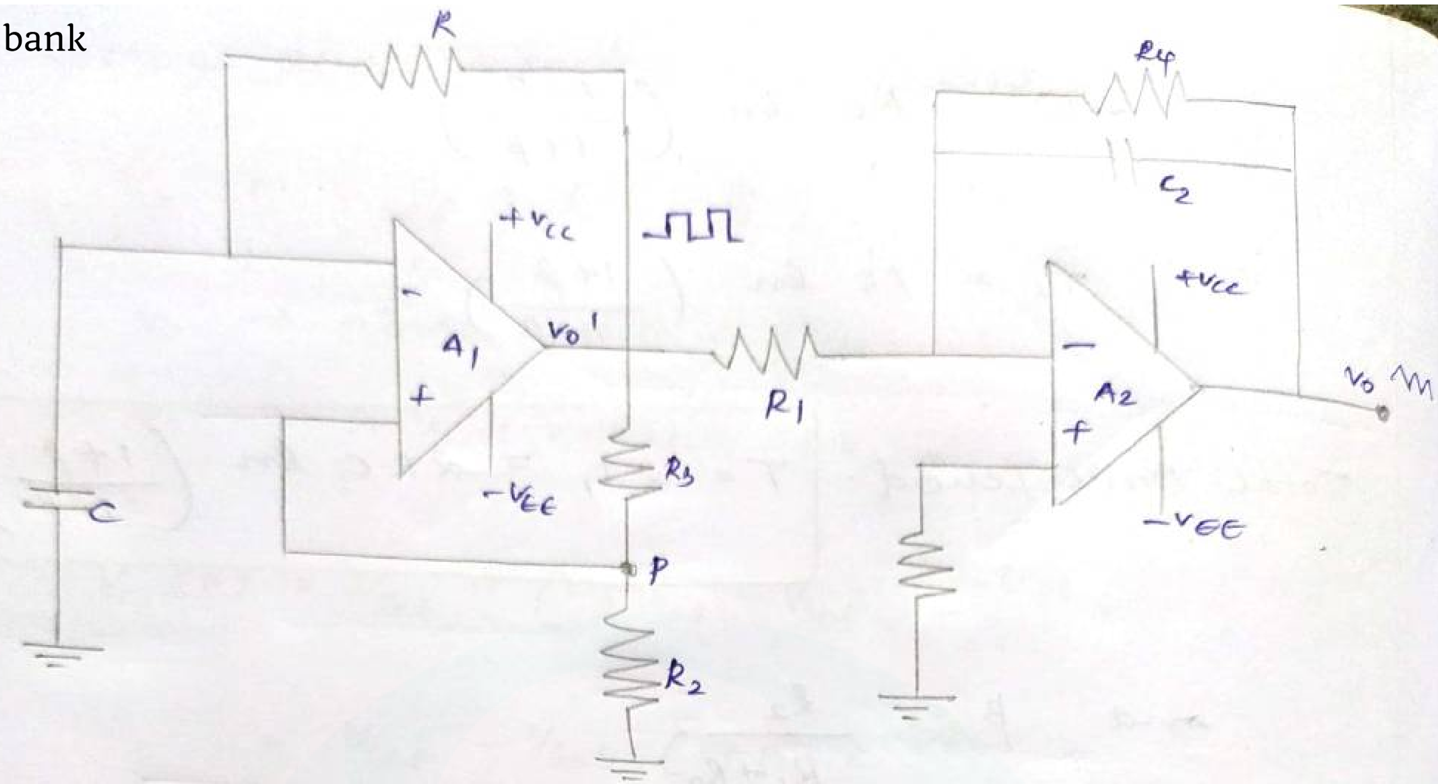
and $\beta = \dfrac{R_2}{R_1+R_2}$

Frequency of oscillation

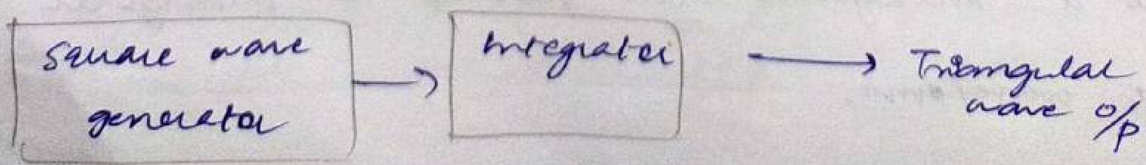
$$f_{osc} = \frac{1}{T} = \frac{1}{2RC \ln\left(\frac{1+\beta}{1-\beta}\right)}$$

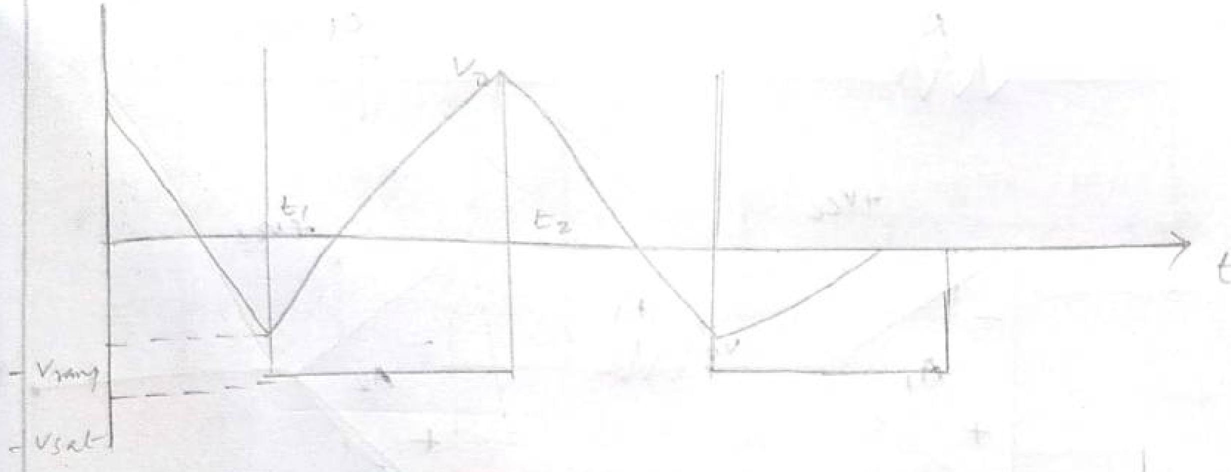
Triangular wave generation

* A triangular wave can be simply obtained by integrating a square wave
* This triangular wave generator can be formed by simply cascading a square wave generator and a integrator
* The o/p square wave form a square wave generator is fed to a integrator and produces a triangular output waveform.



* When the voltage at P goes slightly above 0V, output of A_1 is at $+V_{sat}$. This $+V_{sat}$ is the input to the integrator. The integrator output is a negative going ramp and reaches a value $-V_{ramp}$ at time $t = t_1$
* After $t = t_1$, the voltage at point P will be below 0V, hence the output of A_1 is $-V_{sat}$. $-V_{sat}$ is the input to the integrator and it produces a positive going ramp at the output of the integrator. At $t = t_2$ it reaches a value $+V_{ramp}$
* This cycle repeats and generates a triangular wave form.





Time period $\boxed{T = \frac{4 R_1 R_2 C_1}{R_3}}$

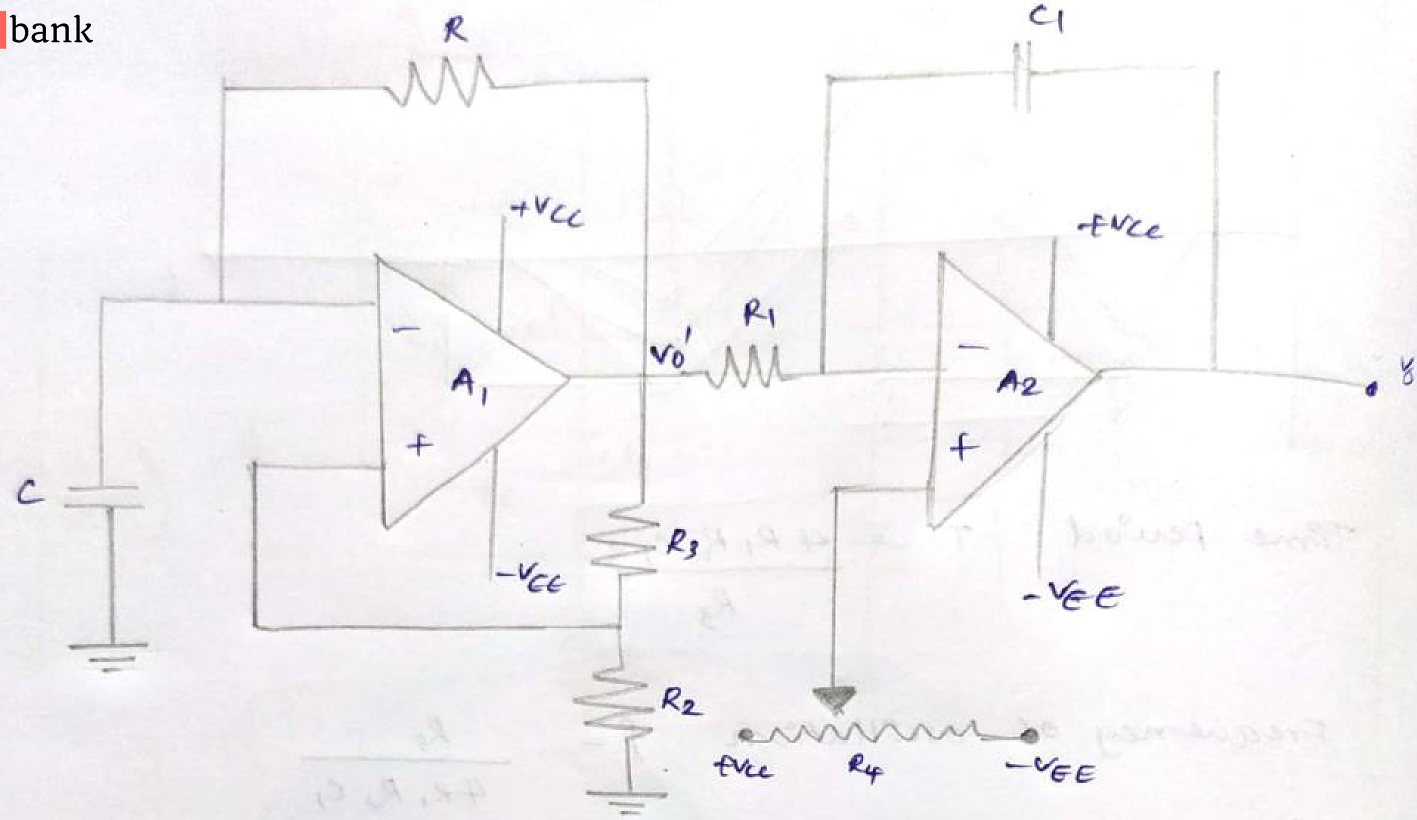
Frequency of oscillation $\boxed{f = \frac{R_3}{4 R_1 R_2 C_1}}$

Sawtooth wave generator / Ramp generator

* In triangular wave form, rise time and fall time is equal. But in sawtooth wave, rise time and fall time are unequal.

* Triangular waveform generator can be converted to sawtooth wave generator by injecting a variable dc voltage into non inverting terminal of integrator.

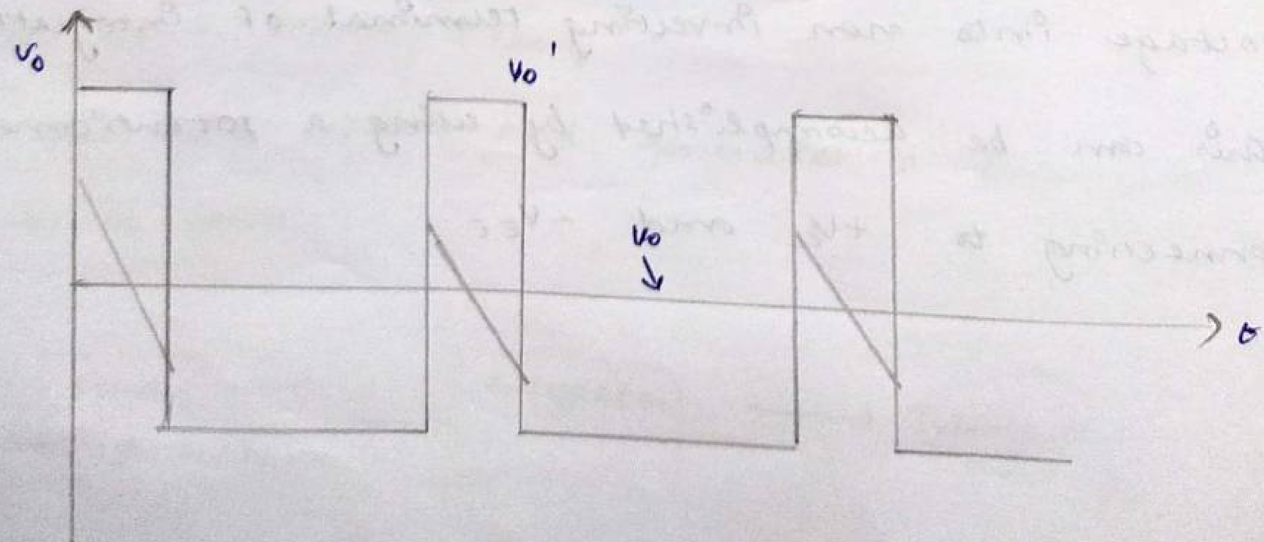
* This can be accomplished by using a potentiometer connecting to $+V_{cc}$ and $-V_{EE}$.



* When wiper is at the centre of R_4, the output of A_2 is a triangular wave.

* For any other position of wiper the output is sawtooth waveform.

* As R_4 is moved towards $-V_{EE}$, the risetime of sawtooth wave is larger than fall time and as R_4 is moved towards $+V_{cc}$ the fall time of sawtooth is larger than rise time.



Effect of Slewrate on wave form generator

* Slew rate is defined as the maximum rate of change of output voltage per unit of time

$$SR = \frac{dV_o}{dt}\Big|_{max} \quad V/\mu s$$

* If an op amp is operated above the slewrate input signals will become distorted.

→ consider a sine wave

$$V(t) = V_m \sin \omega t$$

$$= V_m \sin (2\pi f) t$$

$$\frac{dV(t)}{dt} = \frac{d}{dt} (V_m \sin 2\pi f t)$$

$$= V_m 2\pi f \cos (2\pi f) t$$

This represents the slope of a sine wave.

* Maximum rate of change will occur when the sine wave passes through zero, ie at $t = 0$.

$$\therefore \frac{dV}{dt}\Big|_{max} = V_m 2\pi f \cos 0$$

$$= V_m 2\pi f$$

∴ Rate of change of the signal is directly proportional to the frequency and amplitude.

* So for high frequencies, high amplitude signals and high slewrate op amp is required to prevent slewing.

$$\text{Slew rate required} = V_{max} \cdot 2\pi f_{max}$$

$$f_{max} = \frac{\text{slewrate}}{2\pi V_{max}}$$

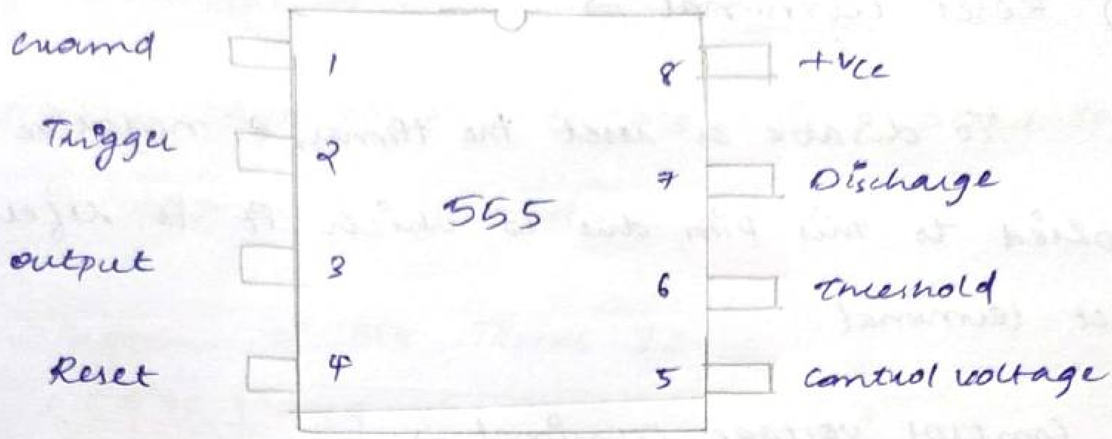
* Thus f_{max} represents the highest frequency sinewave that the op amp can reproduce without produce slewing induced distortion (SID). This frequency is commonly referred to as the power bandwidth or fullpower response.

* If frequency / amplitude of input signal is increased to exceed slewrate of op amp, output will be distorted.

555 TIMER IC

* 555 Timer IC is an integrated circuit used in a variety of timer, pulse generation and oscillator applications.

* 555 timer can produce time delays or oscillations.



1) Ground terminal ⇒

All the voltages are measured with respect to ground terminal.

2) Trigger terminal ⇒

This pin is the inverting input to the comparator 2 of 555 timer, which is responsible for transition of flipflop from set to reset. Output of timer depends on the amplitude of external trigger pulse applied to this pin. If trigger pulse is not applied, it is connected to +Vcc.

3) Output terminal ⇒

Output of timer is available at this pin. The load connected between pin 3 and supply pin is called normally ON load. The load connected between pin 3 and ground pin is called normally off load.

4) Reset terminal ⇒

To disable or reset the timer, a negative pulse is applied to this pin due to which it is referred to as a reset terminal.

5) Control voltage terminal ⇒

The function of this terminal is to control the threshold and trigger levels. When this pin is not used it should be connected to the ground through a 0.01μF capacitor

6) Threshold terminal ⇒

This is the non-inverting input terminal of comparator which compares the voltage applied to this terminal with a reference voltage of 2/3 Vcc. The amplitude of the voltage applied to this terminal is responsible for set state of flipflop.

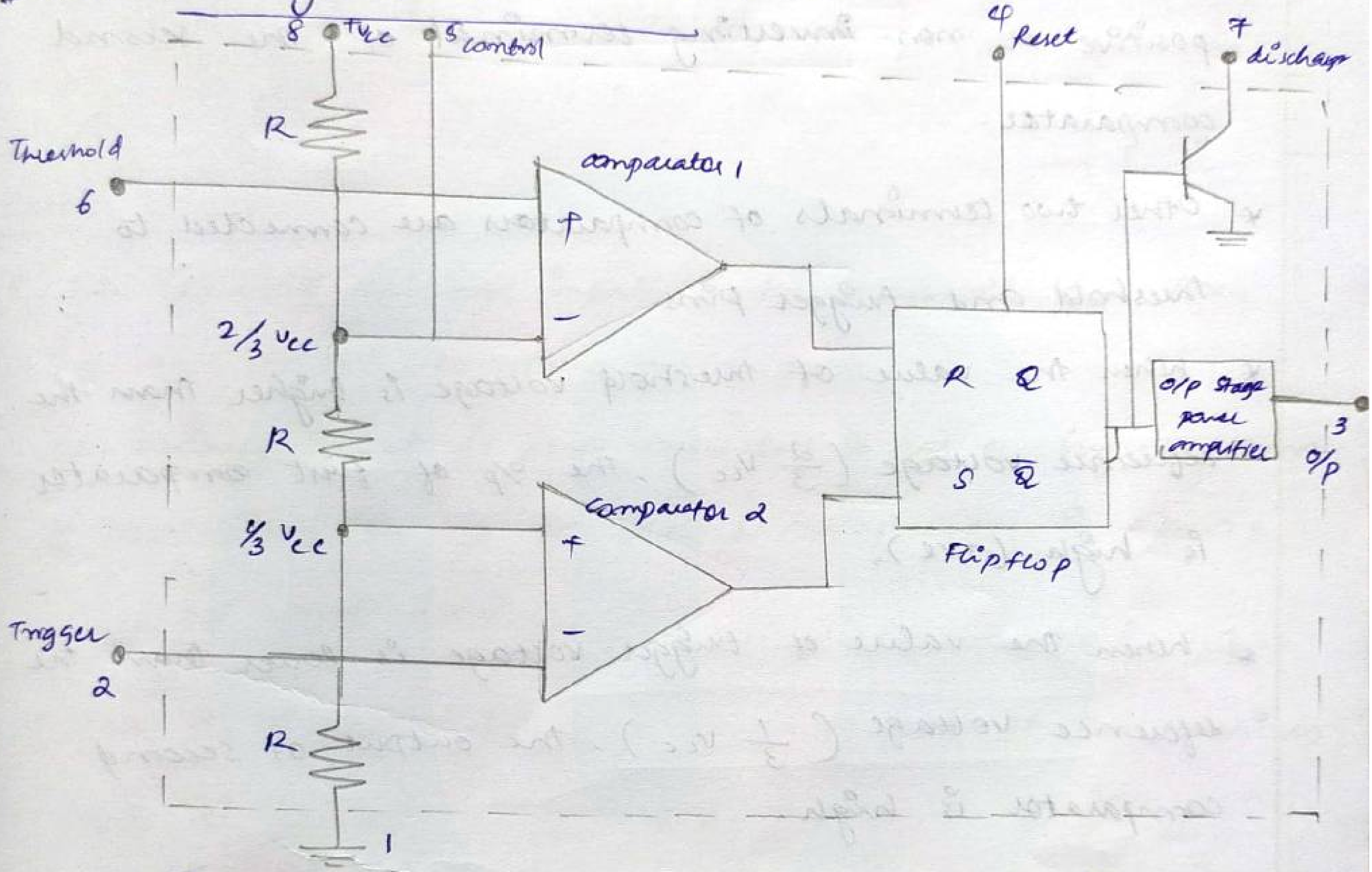
7) Discharge terminal ⇒

This pin is connected internally to the collector of transistor in 555 timer and mostly a capacitor is connected between this terminal and ground.

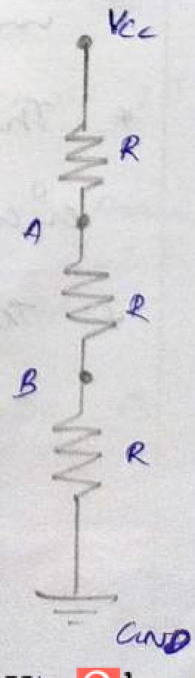
8) Supply terminal ⇒

A supply voltage of +5V to +18V is applied to this terminal with respect to ground.

Internal Diagram of 555 Timer IC



* It consists of resistive network, comparator circuit, SR flipflop, discharge circuit and output circuit



→ Resistive Network

* It acts as a voltage divider circuit
* Three resistors are of equal values.
* voltage at B $= V_{cc} \dfrac{R}{R+2R} = \dfrac{1}{3} V_{cc}$

voltage at A $= V_{cc} \cdot \dfrac{2R}{R+2R} = \dfrac{2}{3} V_{cc}$

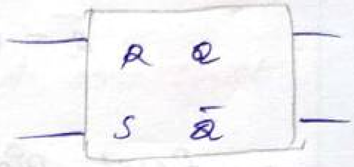
Comparator circuits

* There are two components comparator 1 and 2
* voltage A is applied ~~is~~ to the negative terminal of the first comparator. voltage at B is applied to the positive or non-inverting terminal of the second comparator.
* Other two terminals of comparators are connected to threshold and trigger pins.
* When the value of threshold voltage is higher than the reference voltage ($\frac{2}{3} V_{cc}$), the o/p of first comparator is high (+ve).
* When the value of trigger voltage is lower than the reference voltage ($\frac{1}{3} V_{cc}$), the output of second comparator is high.

⇒ SR FLIP FLOP

* The o/p of the comparators are given to the flipflop circuit SR flipflop is used here.
* Truthtable of SR flipflop

S	R	Q_{n+1}	$\overline{Q_{n+1}}$	
0	0	Q_n	$\overline{Q_n}$	
0	1	0	1	→ Reset state
1	0	1	0	→ Set state
1	1	INVALID		



Case 1

* If threshold voltage input is less than $2/3\ V_{cc}$. Then the o/p of 1^{st} comparator is zero.

If trigger input is ~~zero~~ connected to V_{cc} or higher than $1/3\ V_{cc}$. Then the o/p of second comparator is zero.

$\therefore$ $R = 0$ and $S = 0$

$\therefore$ The o/p of the flipflop is same as that of the previous state ie remains unchanged.

Case 2 :

If threshold voltage is less than $2/3\ V_{cc}$, the o/p of 1^{st} comparator is low (zero). If trigger voltage is less than $1/3\ V_{cc}$, the o/p of second comparator is high (one).

ie $S=1$, $R=0$ $\therefore$ o/p is 1 so the o/p of flipflop is one ($Q=1$, $\bar{Q}=0$)

→ Output circuit

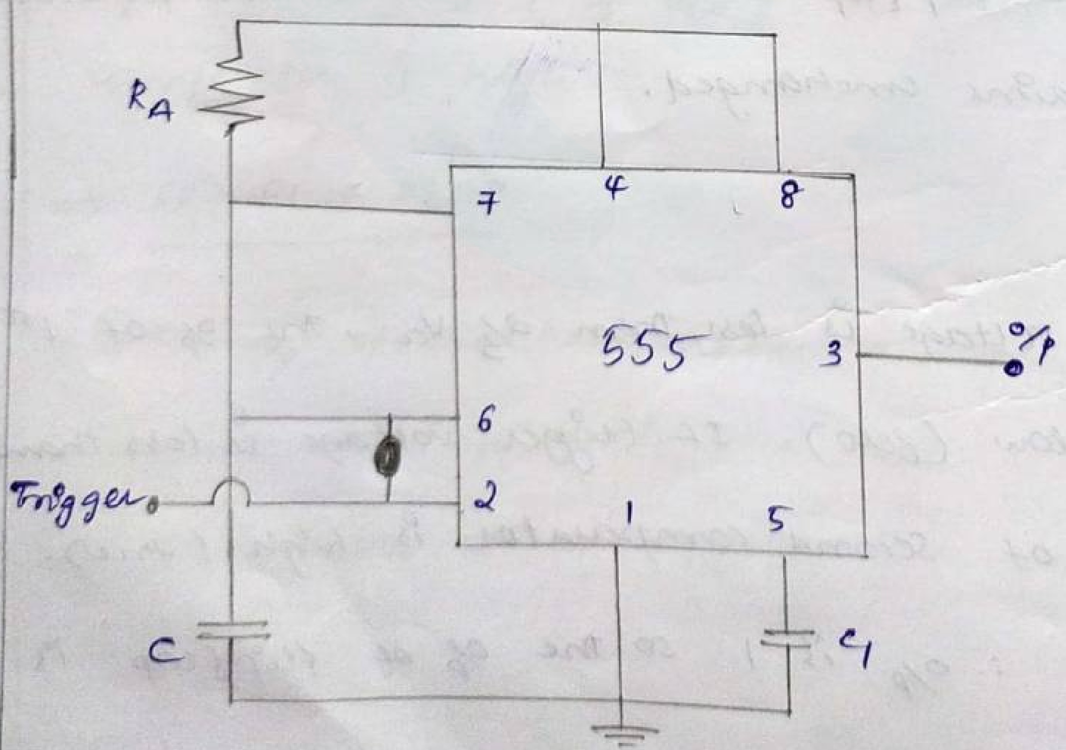
The o/p of flipflop $\bar{Q}$ is connected to the output circuit. Output stage is an inverting power amplifier so if $\bar{Q}=0$, the output is 1.

$\bar{Q}=1$, output is 0.

→ Reset pin

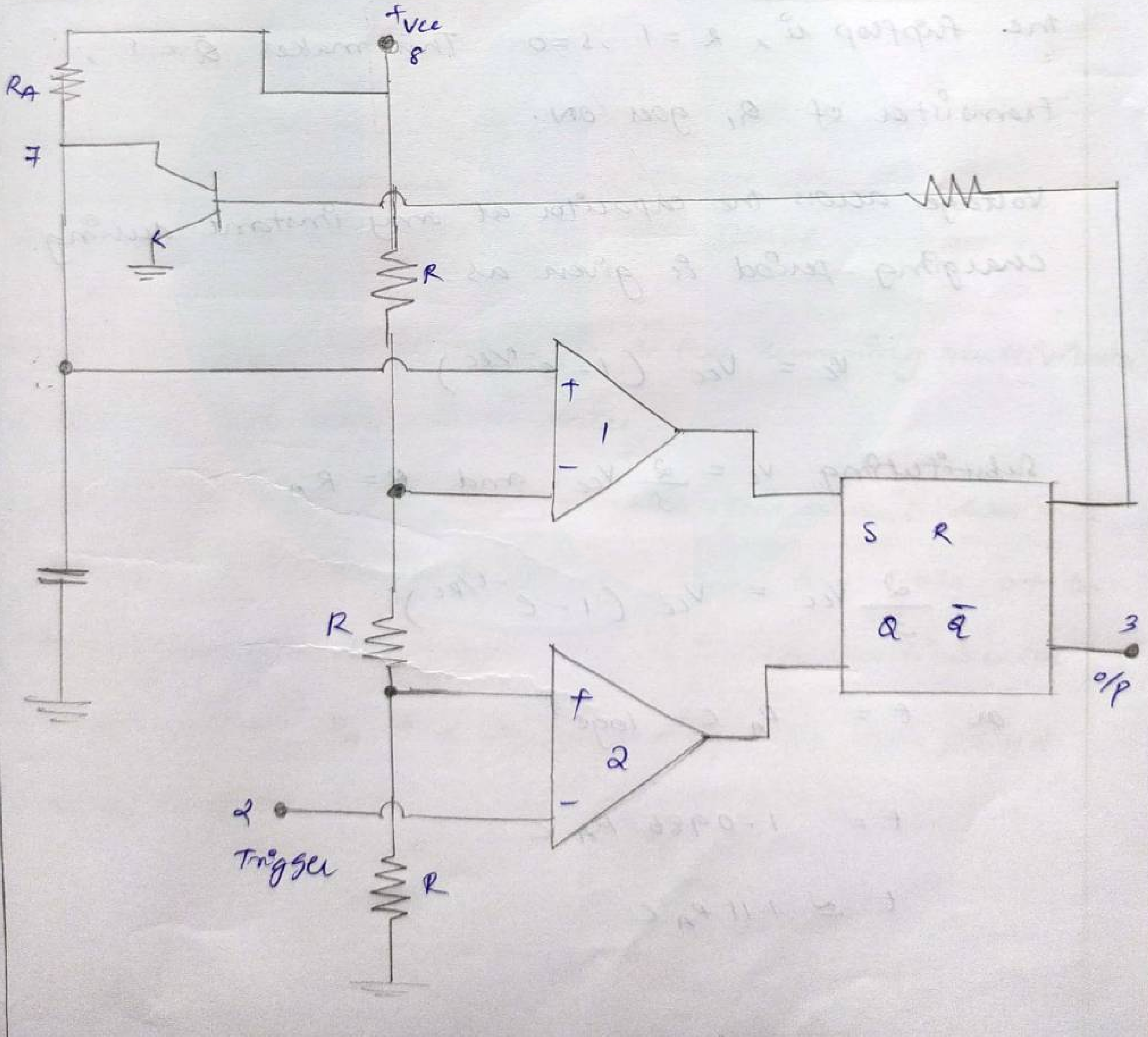
When logic 0 is applied to the reset pin, the flipflop get reset. So output of 555 timer also gets reset. Whenever this pin is not used, it should be connected to V_{cc}.

MONOSTABLE MULTIVIBRATOR USING 555 IC



The monostable multivibrator is having one stable state and one quasi stable state. During working the system triggered to quasi stable state, remain there for some time and return back to the stable state automatically.

Monostable multivibrator is also called one shot multivibrator.



When trigger pulse is applied, it passes through $\frac{1}{3} V_{cc}$, then the FF is set ie $\bar{Q} = 0$. This makes the transistor Q_1 is OFF. As $\bar{Q}$ is low, the output goes high.

The capacitor C gets charged, it exponentially through R towards V_{cc} with a time constant RC.

After a time period T, the capacitor voltage is just greater than ($\frac{2}{3} V_{cc}$) and the upper comparator resets the flipflop ie, R = 1, S = 0. This makes $\bar{Q} = 1$, transistor of Q_1 goes ON.

Voltage across the capacitor at any instant during charging period is given as

$$V_C = V_{cc}\left(1 - e^{-t/RC}\right)$$

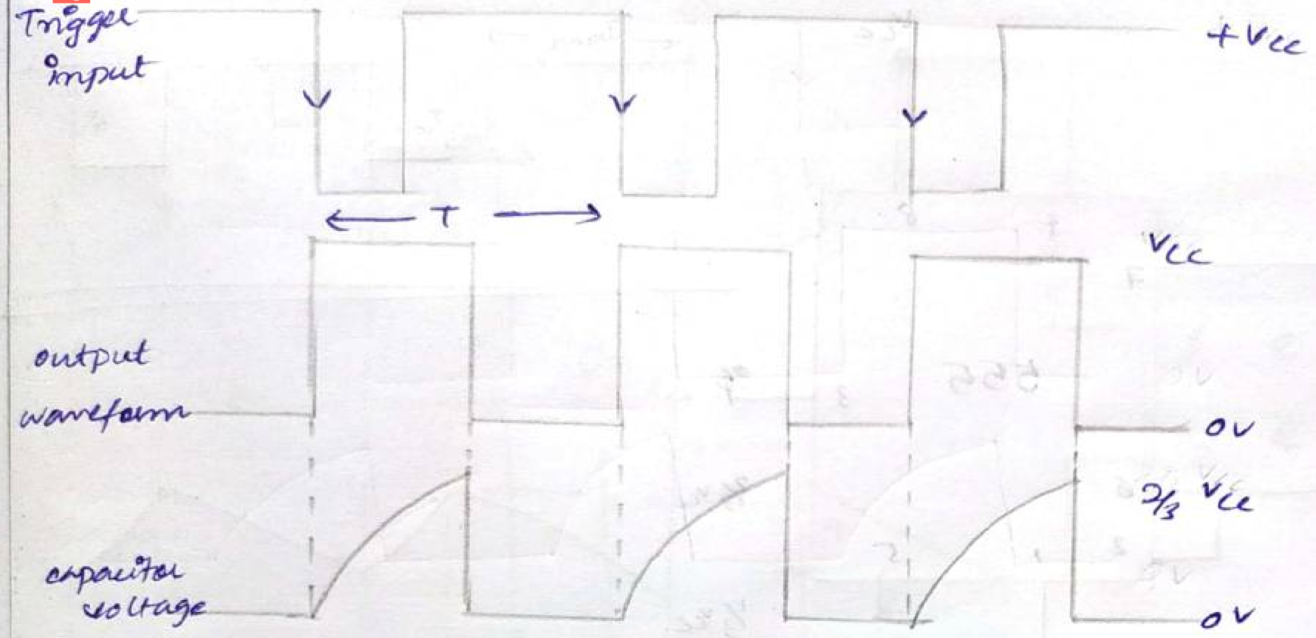
Substituting $V_C = \frac{2}{3} V_{cc}$ and $R = R_A$

$$\frac{2}{3} V_{cc} = V_{cc}\left(1 - e^{-t/RC}\right)$$

or $t = R_A C \log_e 3$

$t = 1.0986 \, R_A C$

$t \simeq 1.11 \, R_A C$



Applications of monostable vibrator =>

(1) Frequency divider

(2) Pulse width Modulation

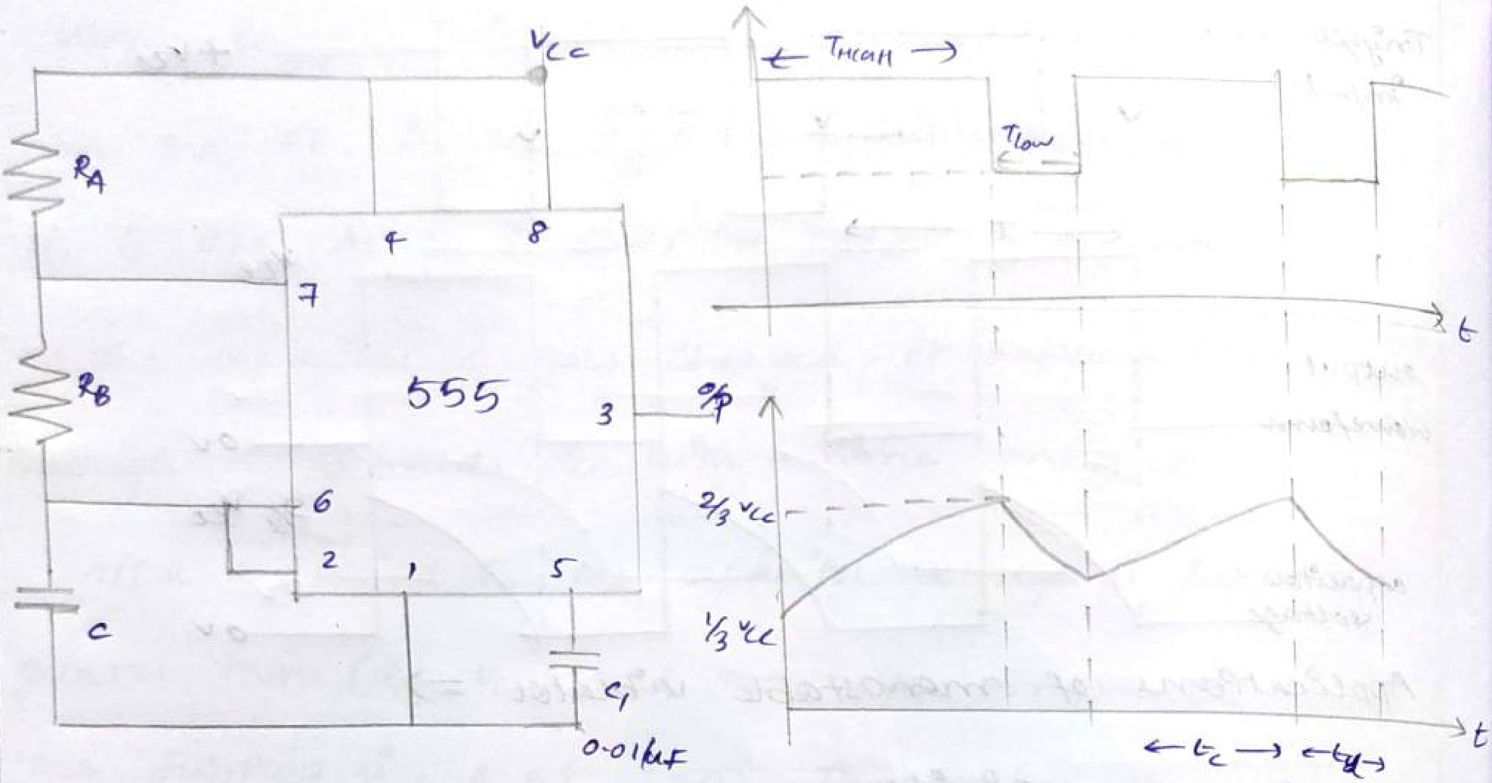
ASTABLE MULTIVIBRATOR USING 555 TIMER

* An astable multivibrator is a free running multivibrator.

* It does not have stable states.

* Unlike monostable multivibrator, this circuit does not require any external trigger to change the state of the output. Hence the name free running multivibrator.

* The resistors R_A and R_B determines the time period of the output.



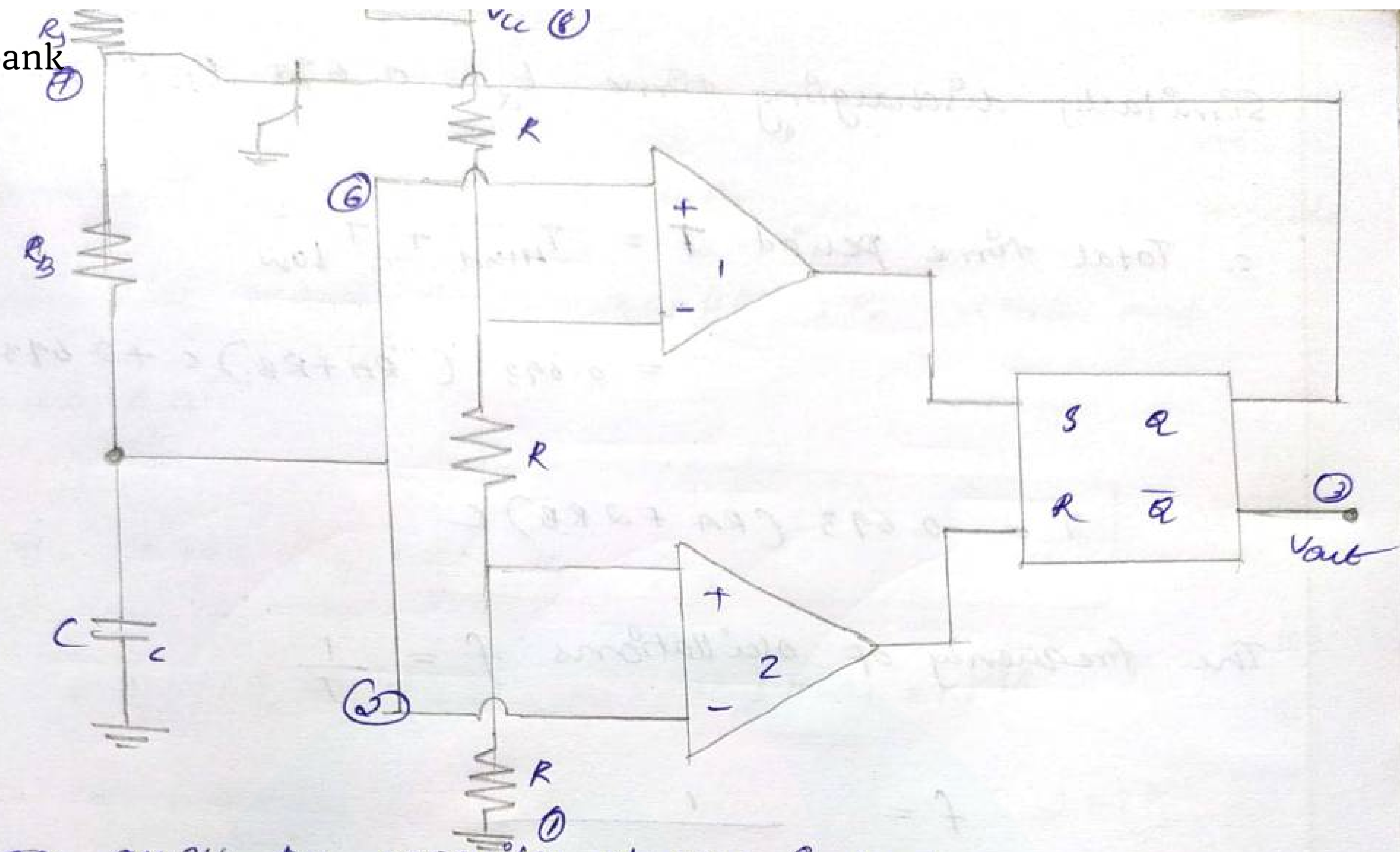
* When Q is low or output Vout is high, the discharging transistor is cutoff and the capacitor C begins charging toward Vcc through resistances RA and RB.

* As the capacitor charges, the threshold voltage increases when it exceeds $\frac{2}{3}$ Vcc, Q is high and timer o/p is low.

* Then the capacitor C discharges through RB.

* When it drops below $\frac{1}{3}$ Vcc, Q is low timer o/p is high

* This cycle repeats



voltage across the capacitor at any instant

$$V_c = V_{cc}\left(1 - e^{-t/RC}\right) \quad \text{--- (1)}$$

At changing time, $V_c = \frac{1}{3} V_{cc}$

$$\therefore (1) \Rightarrow \frac{1}{3} V_{cc} = V_{cc}\left(1 - e^{-t/RC}\right)$$

$$t_1 = 0.405\, RC$$

At changing time when $V_c = \frac{2}{3} V_{cc}$

$$(1) \Rightarrow \frac{2}{3} V_{cc} = V_{cc}\left(1 - e^{-t/RC}\right)$$

$$t_2 = 1.0986\, RC$$

If $R_A = R_A + R_B$

$$T_{HIGH} = t_c = 0.693\,(R_A + R_B)C$$

Similarly discharging time $t_d = 0.693\, R_B C = T_{low}$

$\therefore$ Total time period $T = T_{HIGH} + T_{Low}$

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

$$\boxed{T = 0.693\,(R_A + 2R_B)C}$$

The frequency of oscillations $f = \frac{1}{T}$

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

The duty cycle ~~of~~ is the ratio of charging time to the total time period T.

$$\boxed{\%D = \frac{t_c}{T} \times 100 = \frac{T_{HIGH}}{T_{HIGH} + T_{LOW}} \times 100}$$

Applications of Astable multivibrator

(1) Square wave oscillator

(2) Free running ramp generator

(3) Pulse position modulator

(4) Schmitt Trigger

PROBLEMS

1) Determine the frequency and duty cycle for the 555 astable multivibrator output for $C = 0.01\,\mu F$, $R_A = 2\,k\Omega$ and $R_B = 100\,k\Omega$

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

$= 0.693\,(2\times10^3 + 2\times100\times10^3)\,0.01\times10^{-6}$

$= 1.4\,ms$

Frequency of oscillator $f = \frac{1}{T} = \frac{1}{1.4ms} = 714.3\,Hz$

Duty cycle $= \frac{T_{HIGH}}{T} = \frac{0.693\,(R_A + R_B)C}{T} = \frac{0.707}{1.4} = 0.505$

% Data cyple = 50.5 %

2) Determine the positive pulse width, negative pulse width and free running frequency for an astable multivibrator using 555 timer $R_A = 4.7K$, $R_B = 1K$, $C = 1\mu F$, $C_1 = 0.01\,\mu F$. What is the duty cycle of output waveform

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

$= 0.693 \, (4.7 \times 10^3 + 1 \times 10^3) \, 1 \times 10^{-6}$

$= 3.95 \, ms$

$T_{OFF} = T_{LOW} = 0.693 \, R_B \, C$

$= 0.693 \times 1 \times 10^3 \times 1 \times 10^{-6}$

$= 0.693 \, ms$

Total $T = T_{HIGH} + T_{LOW}$

$= 3.95 \, ms + 0.693 \, ms$

Free running frequency of $f = \frac{1}{T} = 208.9 \, HZ$

Data cycle $D = \frac{T_{HIGH}}{} = 85\%$