Module:5 Comparators and Waveform Generators

Course: BECE206L – Analog Circuits

Module 5

Module:5 Comparators and Waveform Generators

- **Comparator** and its applications - **Schmitt trigger** - Free-running, One-shot Multivibrators - Barkhausen Criterion - Sinewave generators - Phase-shift and Wein-bridge oscillators - Square, Triangular and Saw-tooth wave function generators.

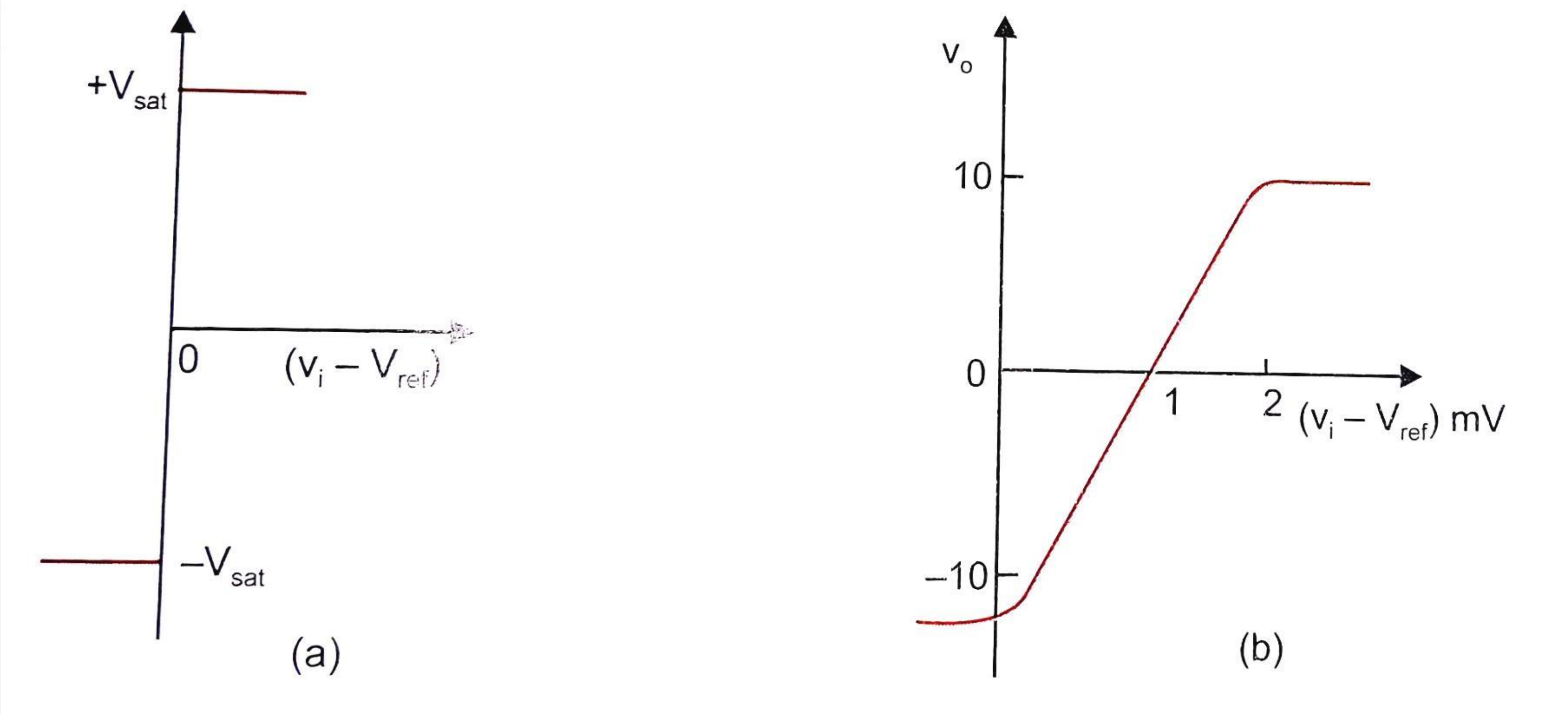
1. Applications of Op-amp in Open loop configuration

- Open-loop: Non linear behavior of Op-amp

- Comparators
- Detectors
- Limiters
- Digital interfacing devices (converters)

2. Comparators

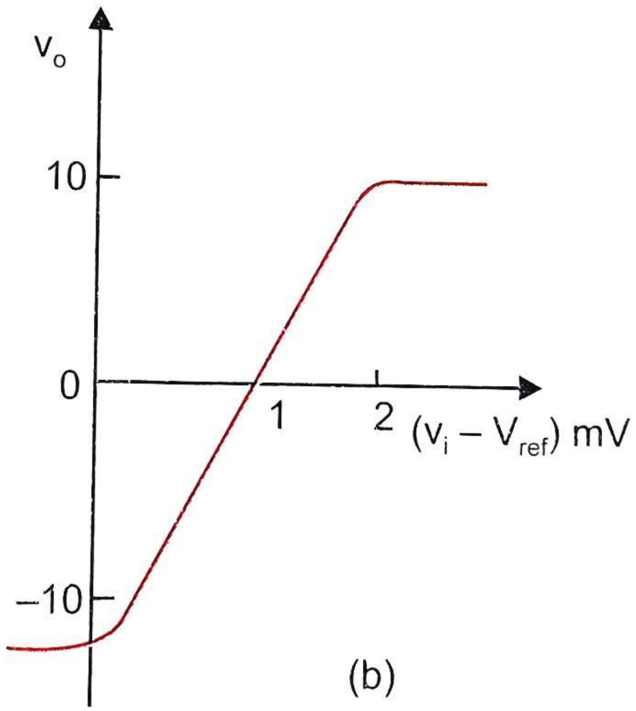
- Circuit which compares **signal voltage** applied at one input of op-amp with a **known reference voltage** at other input
- Open loop op-amp with output = $\pm V_{sat} (= V_{cc})$
- Commercial op-amps have transfer functions (practical)
- X-axis is input
  Y-axis is output



. 5.1 The transfer characteristics (a) Ideal comparator (b) Practical comparator

2. Comparators

- Commercial op-amps have transfer functions (practical)
- X-axis is input;   Y-axis is output
- Complete change of output only after $v_i = 2\ mV$ (Uncertain region) where output cannot be defined
- This is due to input offset voltage
  Use offset null compensating techniques to eliminate uncertain region



comparator (b) Practical comparator

3. Types of comparators

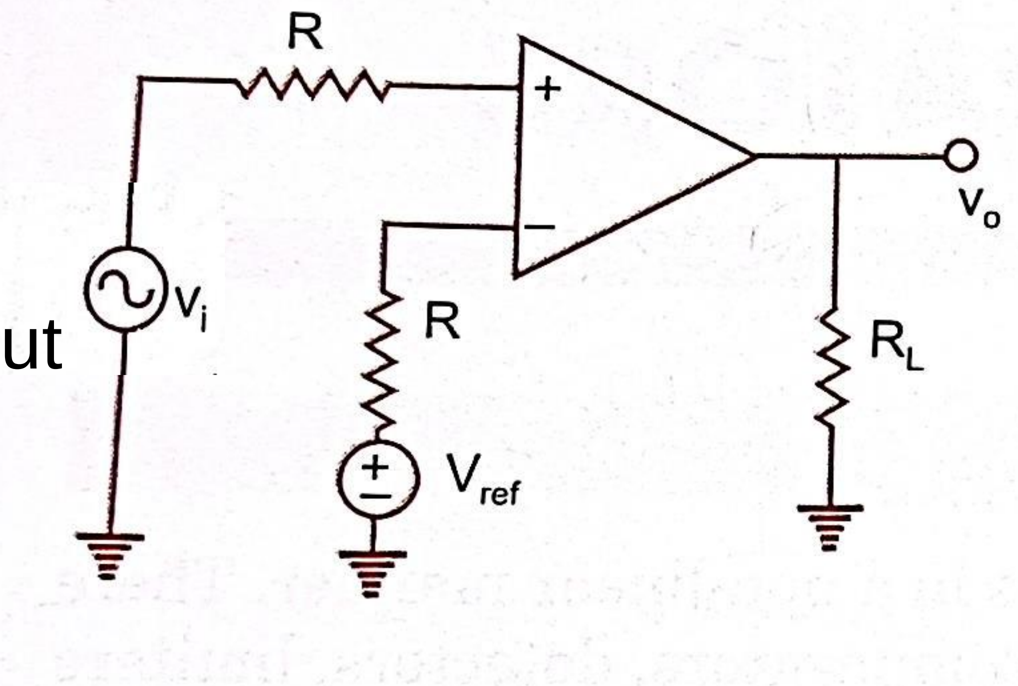
- Non-inverting comparator
- Inverting comparator

3.1 Non inverting comparator

Ideal:

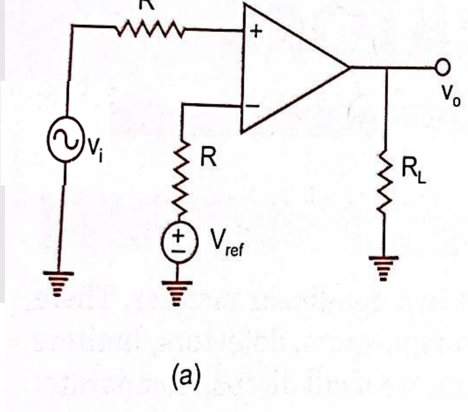
- Fixed reference V_{ref} applied to (-) input
- Time varying signal v_i applied to (+) input
- For $v_i < V_{ref}$: output $v_o = -V_{sat}$

  $v_i > V_{ref}$: output $v_o = +V_{sat}$



(a)

3.1 Non inverting comparator



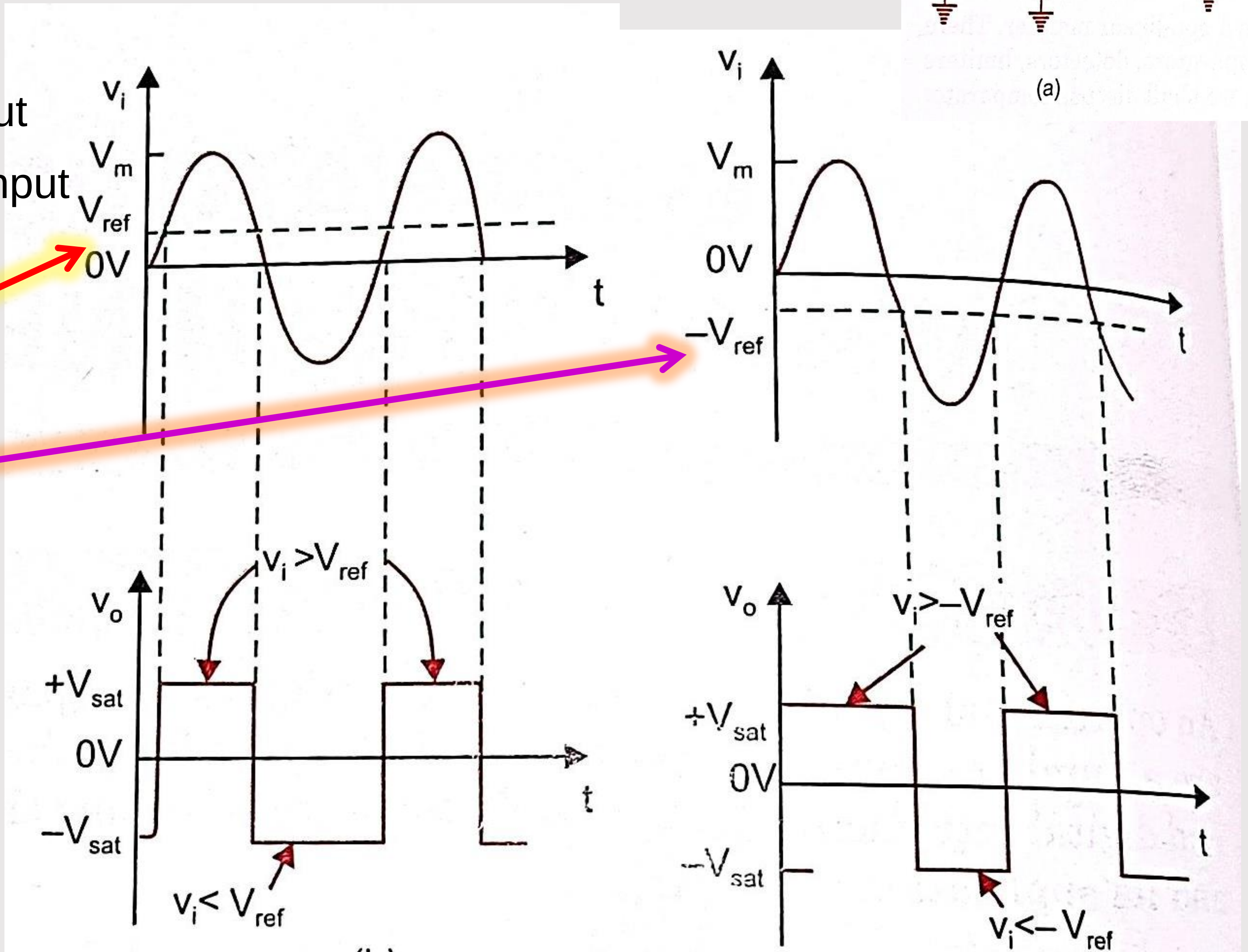
Ideal:

- Fixed reference V_{ref} applied to (-) input
- Time varying signal v_i applied to (+) input
- For $v_i < V_{ref}$: output $v_o = -V_{sat}$

  $v_i > V_{ref}$: output $v_o = +V_{sat}$

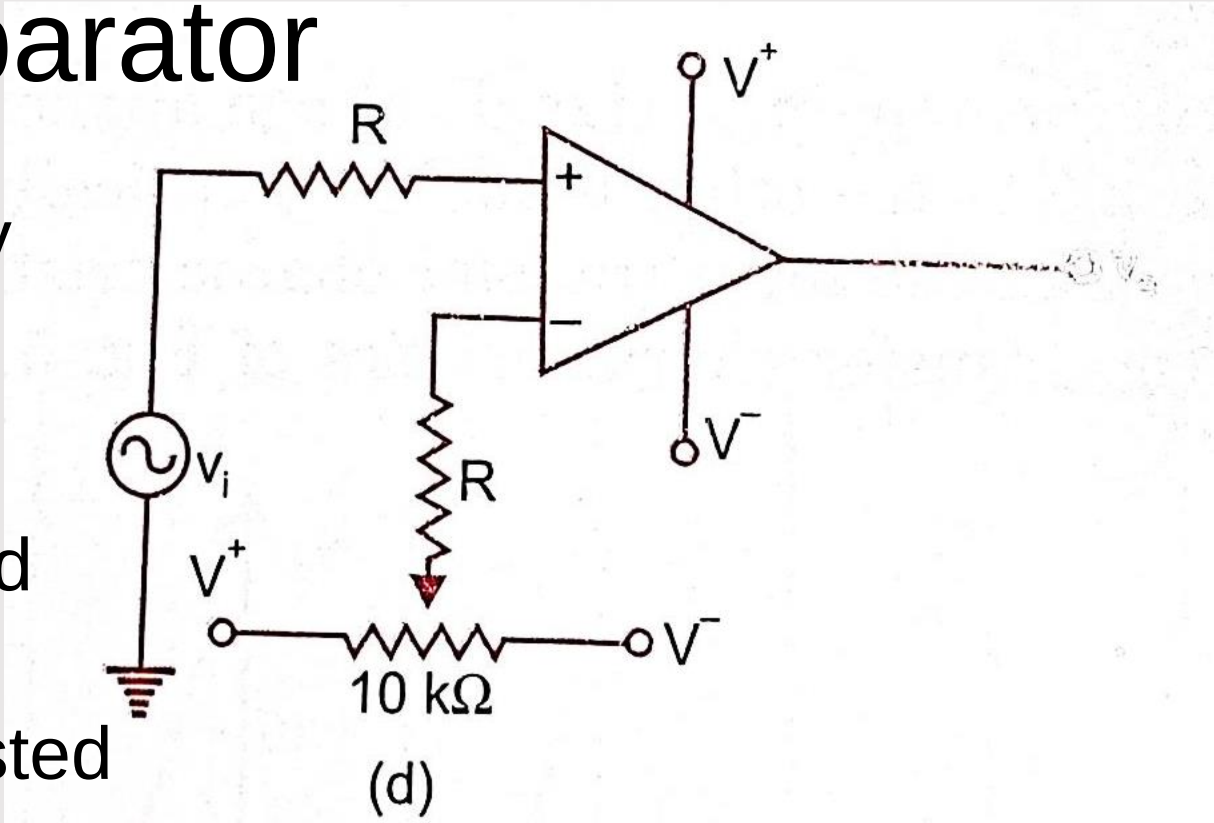
If V_{ref} is positive

If V_{ref} is negative



3.1 Non inverting comparator

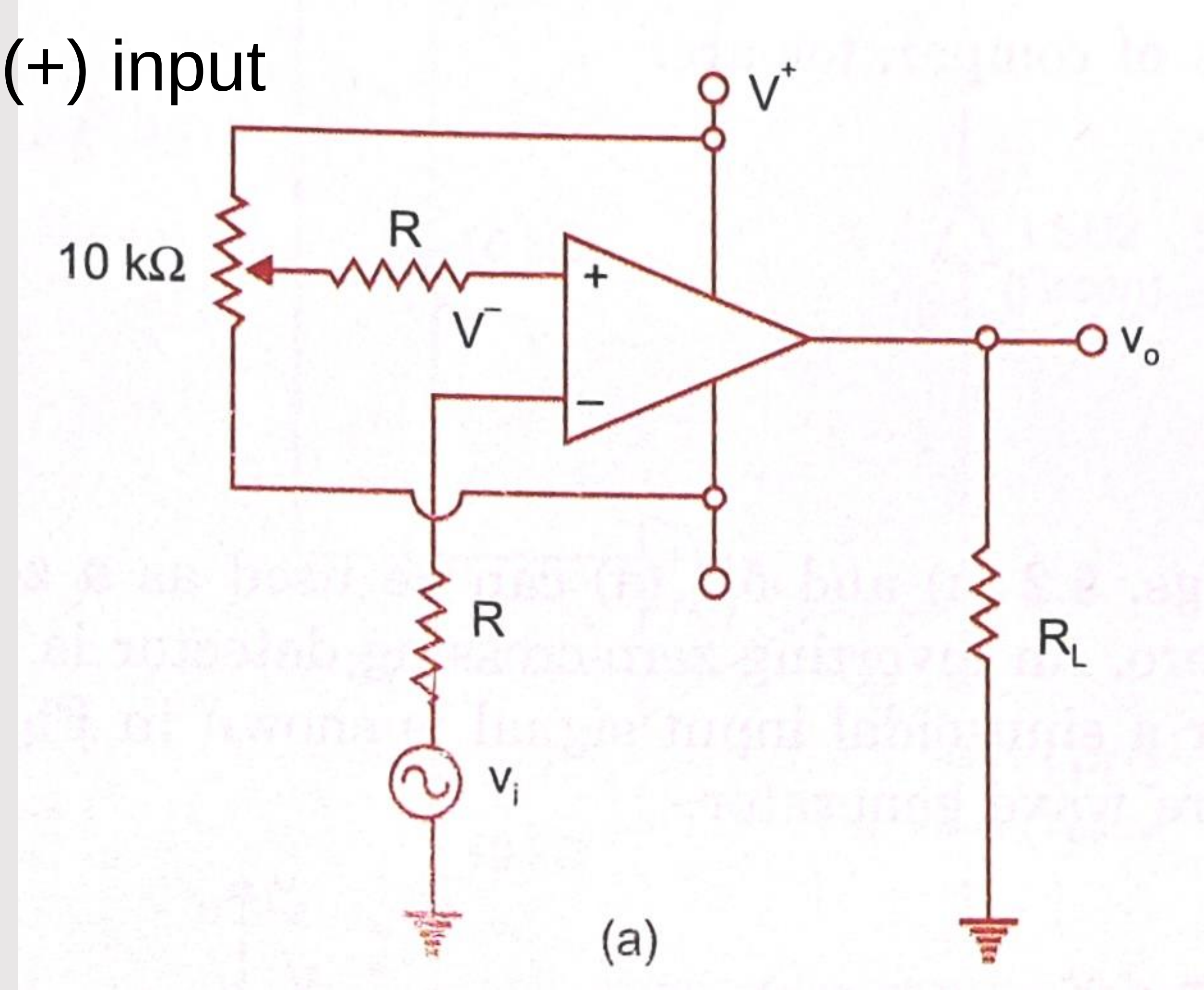
- Practical circuit: V_{ref} is obtained by using voltage divider with 10 $k\Omega$ potentiometer connected between V^+ and V^-
  wiper of potentiometer is connected to (-) input terminal
- V_{ref} of required value can be adjusted for amplitude and polarity



(d)

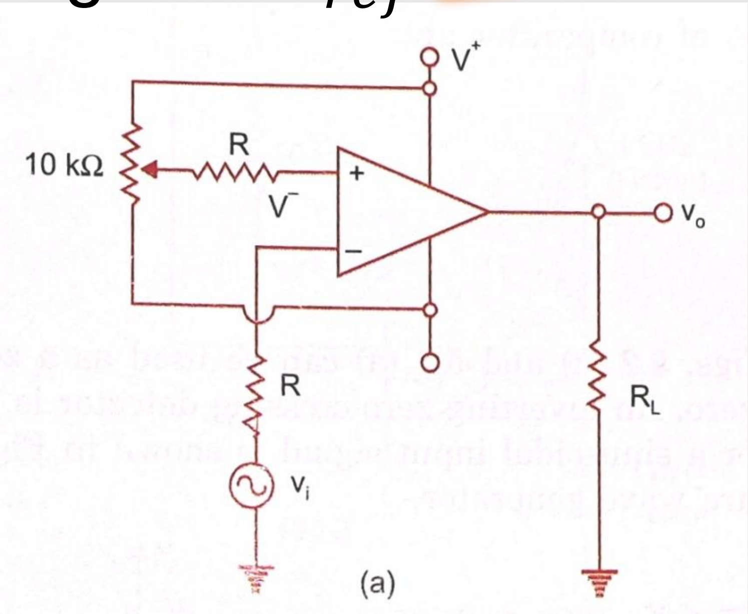
3.2 **Inverting comparator**

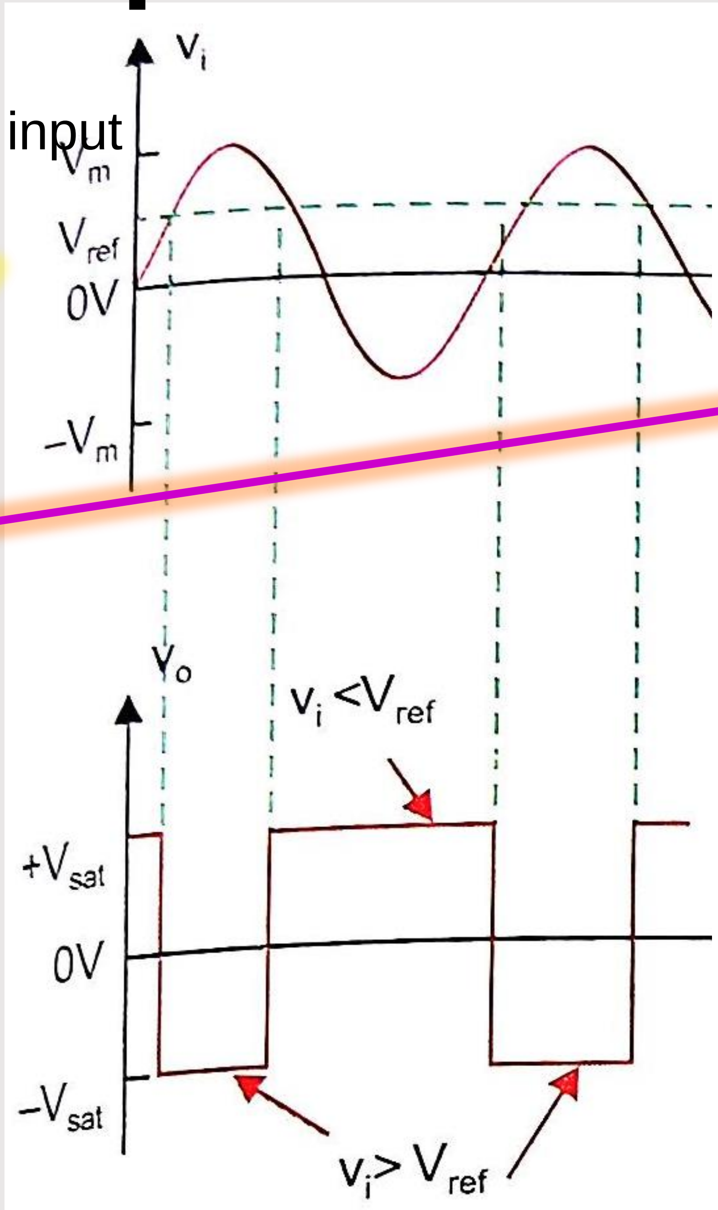
- Practical inverting comparator
- Reference voltage V_{ref} applied to (+) input
- v_i is applied to (-) input

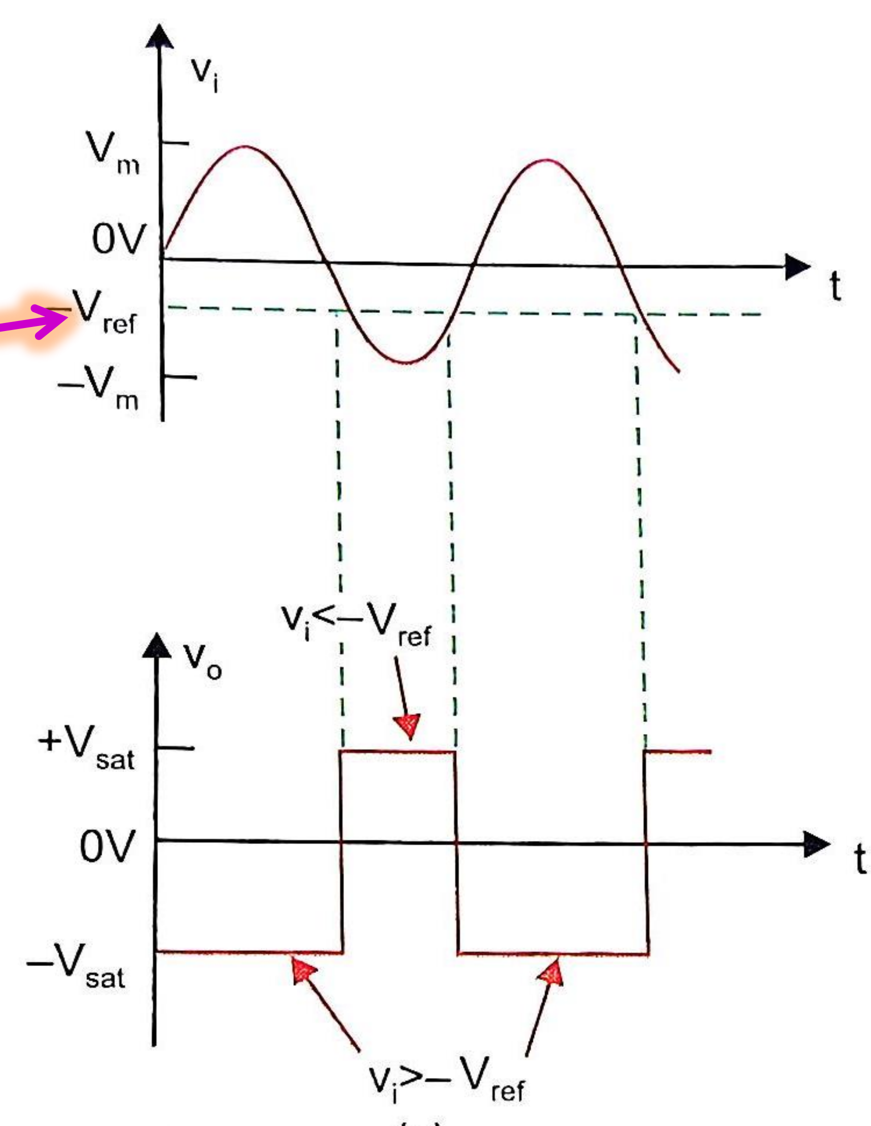


3.2 **Inverting comparator**

- Practical inverting comparator
- Reference voltage V_{ref} applied to (+) input
- v_i is applied to (-) input
- For sinusoidal input signal output waveform
  Positive V_{ref}
  Negative V_{ref}

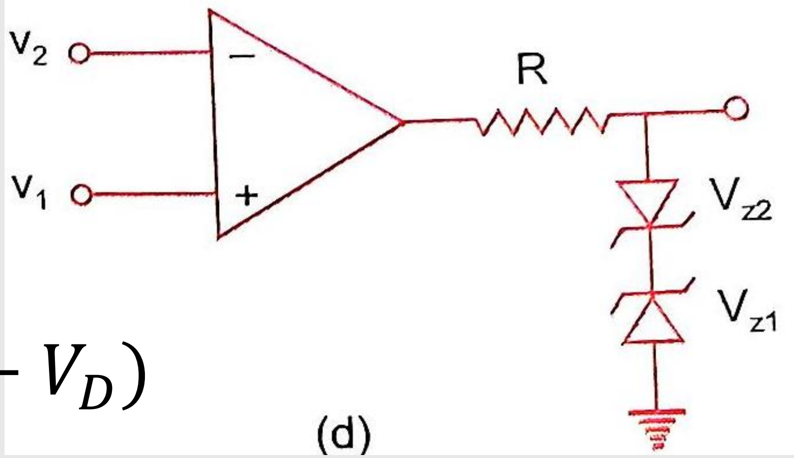






3.3 Comparator independent of Power supply

- By using resistor R and two back-to-back zener diodes at output of Op-amp
- Value of resistor chosen so that zener diodes operate at recommended current
- Limiting voltages of v_0 are $(V_{Z1} + V_D)$ and $-(V_{Z2} + V_D)$
- V_D is diode forward voltage
  V_Z is zener voltages



(d)

3.4 Practical case of uncertain region

- For increased speeds, monolithic voltage comparators are available (Fairchild μA710 and 760, National LM111, 160, 311)
- Response times : 311 has 200ns
  760 has 50ns
- CMOS comparators:
  Texas instruments: TLC 320 dual, TLC 374 quad,
  Motorola: MC14574 quad

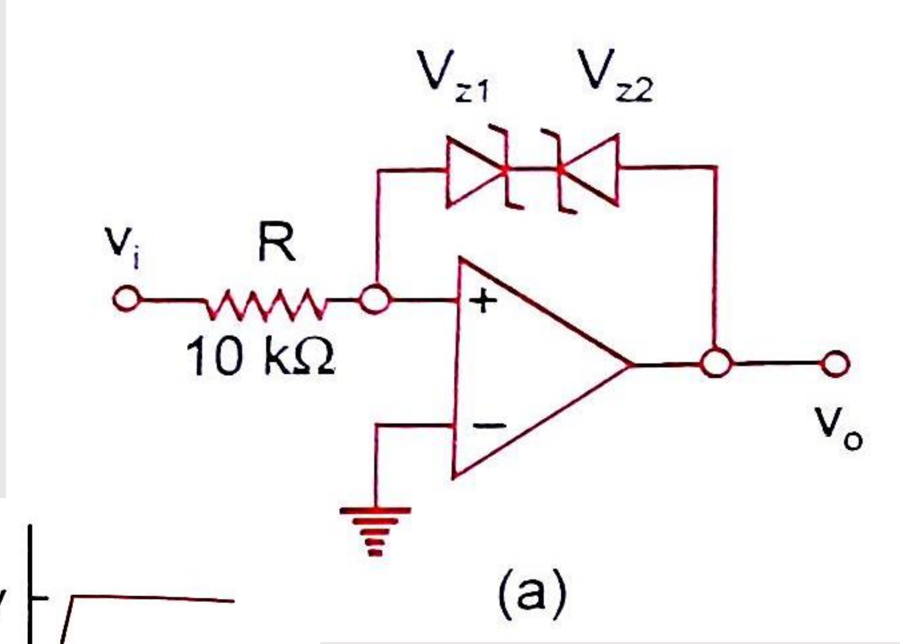
3.5 Applications of comparator

- Zero crossing detector
- Window detector
- Time marker generator
- Phase meter

Problem: For comparator,

a) plot transfer curve if op-amp is ideal and $V_{Z1} = V_{Z2} = 9V$ and $V_D = 0.7V$.

B) Repeat same if open loop gain of op-amp is 50000

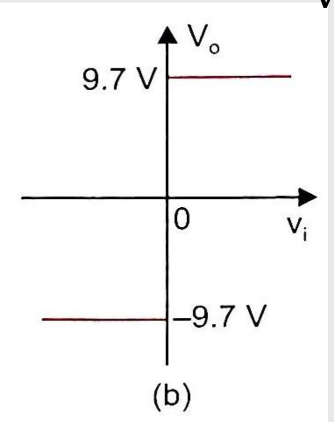


A) Open loop gain $A_{OL} = \infty$, small positive voltage at input will drive output to $\pm V_{sat}$

Accordingly V_{Z1} or V_{Z2} will be in breakdown

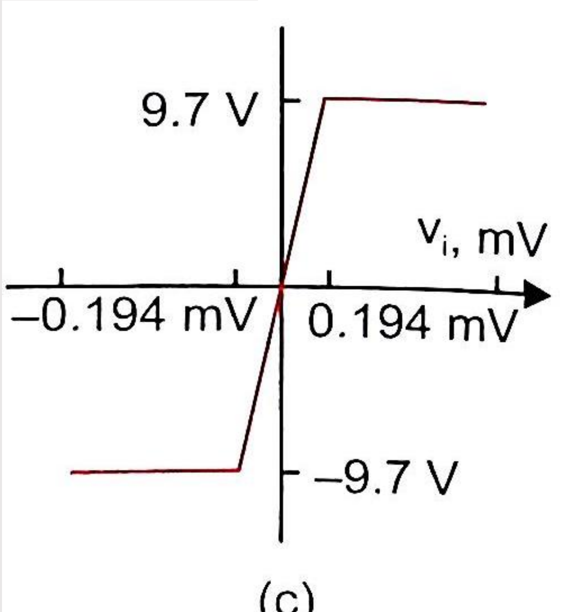
$$v_o = \pm(V_Z + V_D) = \pm 9.7V$$

Transfer curve of ideal:



B) $A_{OL} = 50000$, $\Delta v_i = \frac{9.7}{A_{OL}} = 0.194\, mV$

The zener breaks down after $\pm 0.194\, mV$



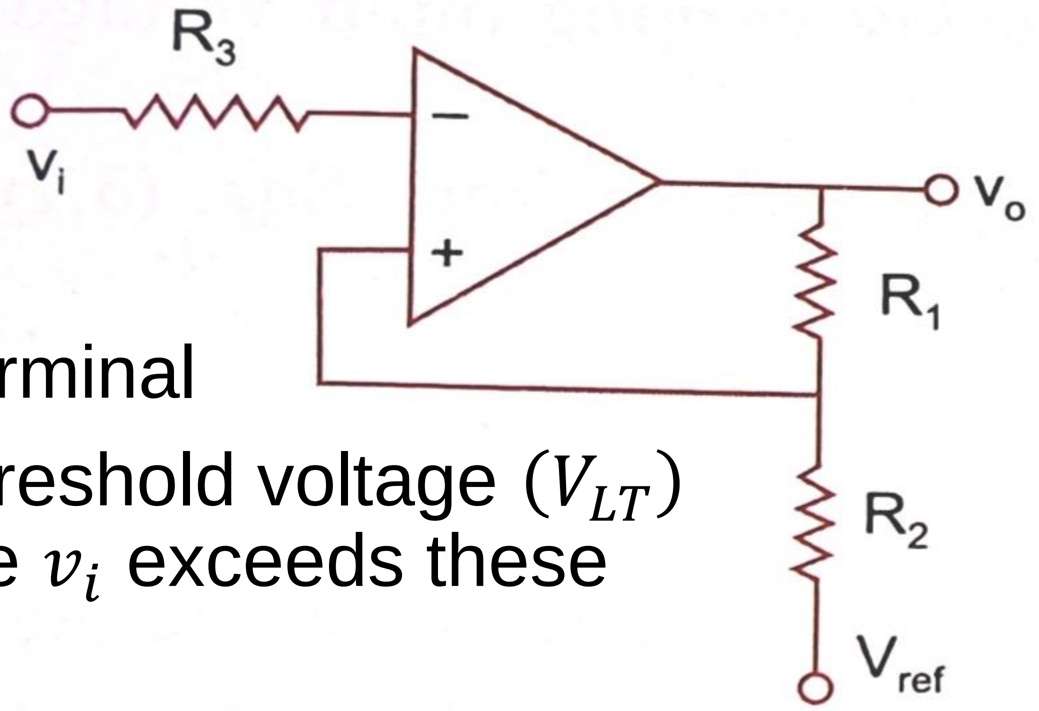
4. Regenerative comparator **(SCHMITT Trigger)**

- When Positive feedback is added to comparator circuit, gain can be increased greatly
- Transfer curve of comparator becomes close to ideal curve
- Theoretically, loop gain: $-\beta A_{OL}$ is adjusted to unity,
  then gain with feedback A_{Vf} becomes infinite
  Ideal: Zero rise time in transitions between extreme values of output voltage
- Practical: Cannot maintain gain as unity due to supply voltage or temperature variations
  So, value of gain is chosen greater than unity

4. Regenerative comparator **(SCHMITT Trigger)**

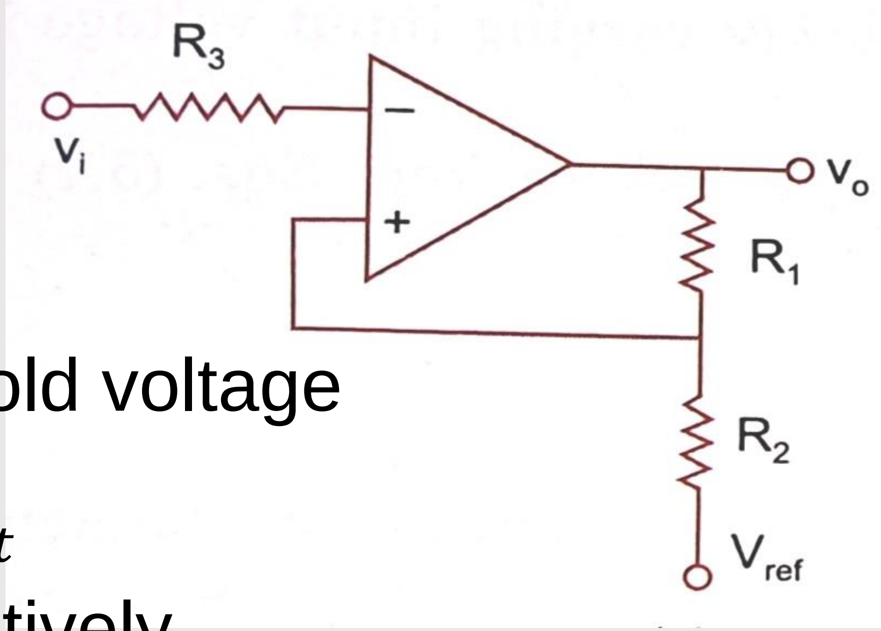
- Practical: Cannot maintain gain as unity due to supply voltage or temperature variations
  So, value of gain is chosen greater than unity
- Output waveform is discontinuous at comparison voltage (for comparator to work)
- Hysterisis (or backlash)

4. 1 Schmitt Trigger



- Regenerative comparator (Schmitt trigger)
- v_i to (-) terminal; Feedback voltage to (+) terminal
- Upper threshold voltage (V_{UT}) and Lower threshold voltage (V_{LT}) Input voltage v_i triggers output v_0 every time v_i exceeds these voltage levels
- Hysteresis width is $V_{UT} - V_{LT}$ (difference between these two threshold voltages)

4. 1 Schmitt Trigger

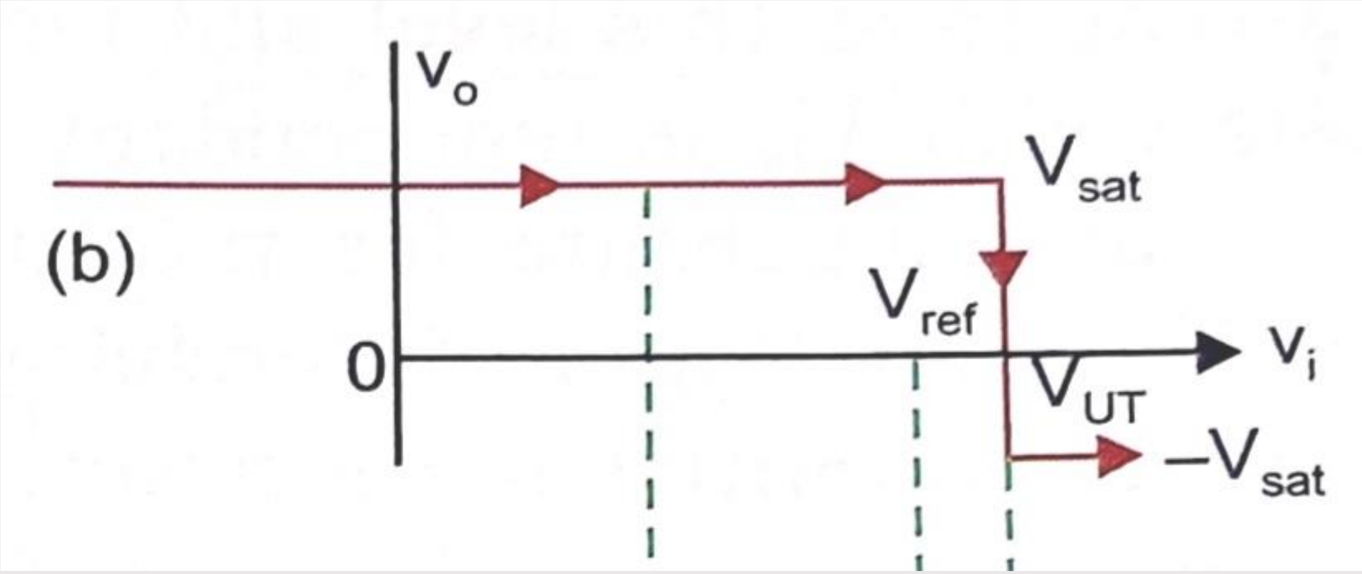


- When $v_o = +V_{sat}$, voltage at (+) terminal

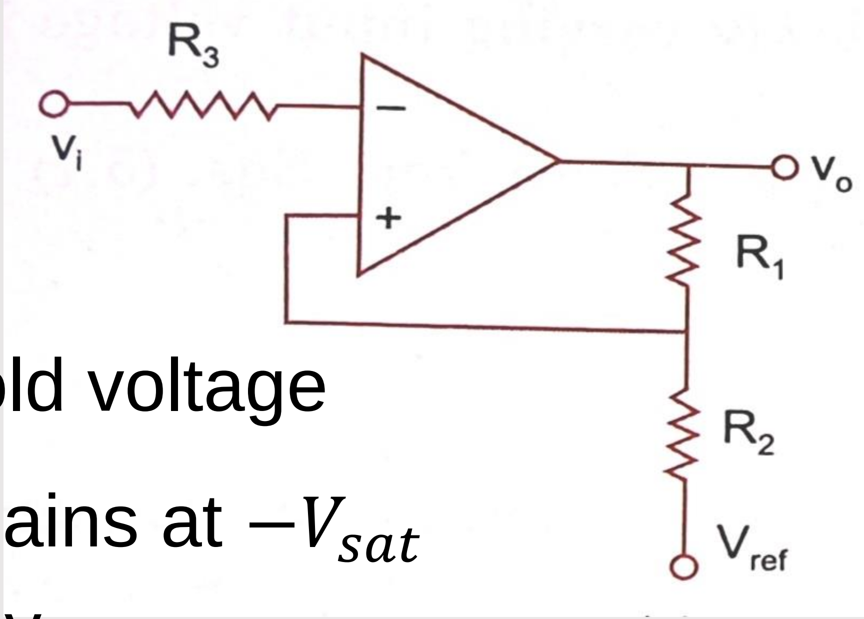
  $V_{UT} = V_{ref}\frac{R_1}{R_1+R_2} + V_{sat}\frac{R_2}{R_1+R_2}$ This is upper threshold voltage

- When v_i is less than V_{UT}, output remains at $+V_{sat}$

  When v_i is just greater than V_{UT}, output regeneratively switches to $-V_{sat}$ and remains as long as $v_i > V_{UT}$



4. 1 Schmitt Trigger

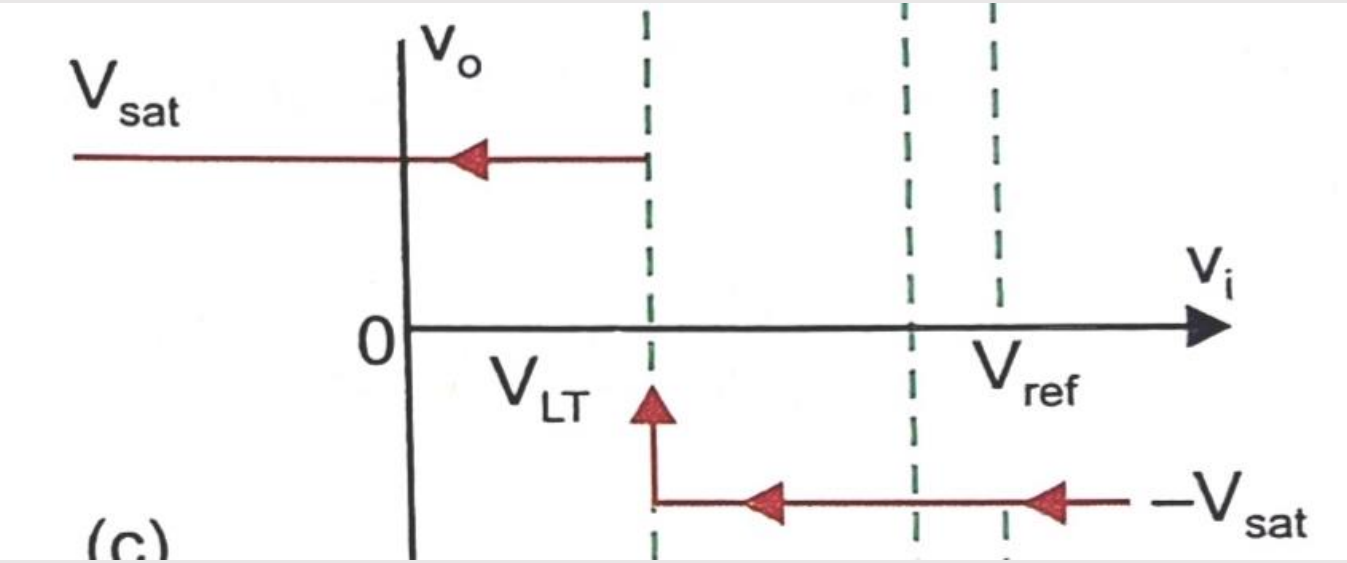


- When $v_o = -V_{sat}$, voltage at (+) terminal

  $V_{LT} = V_{ref}\frac{R_1}{R_1+R_2} - V_{sat}\frac{R_2}{R_1+R_2}$ This is Lower threshold voltage

- Now, as long as v_i is greater than V_{LT}, output remains at $-V_{sat}$

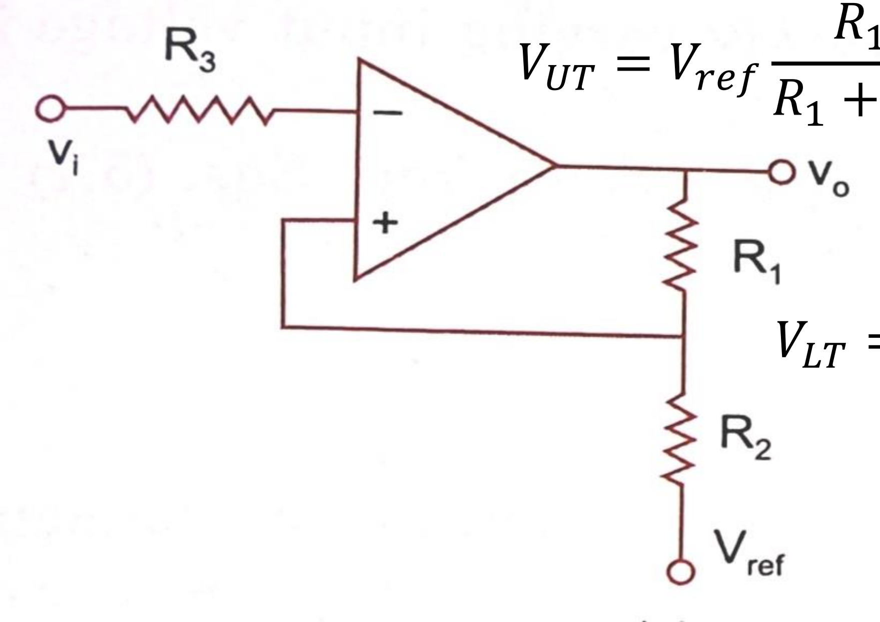
  When v_i is just less than V_{LT}, output regeneratively switches from $-V_{sat}$ to $+V_{sat}$ almost instantly



4. 1 Schmitt Trigger

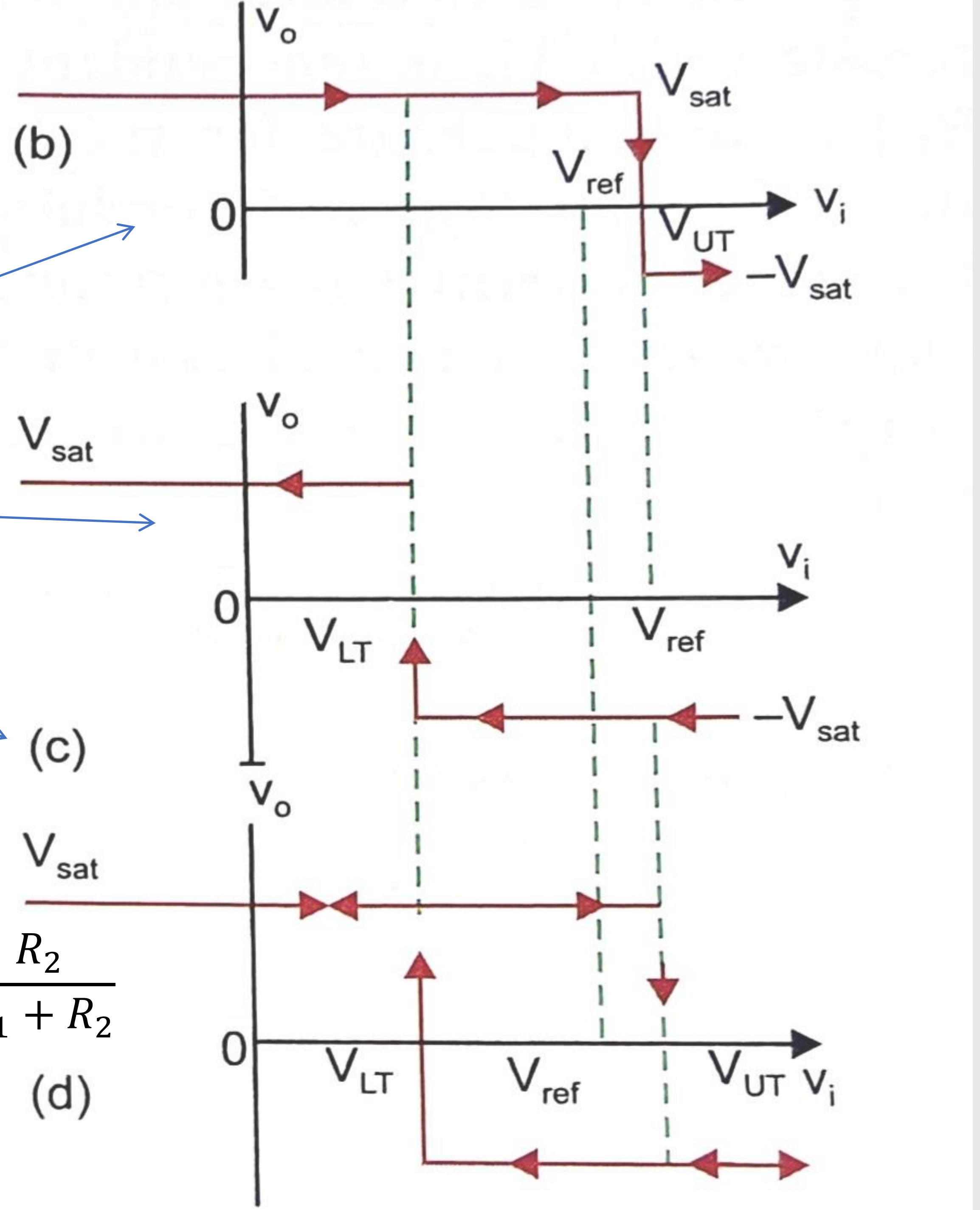
Transfer characteristics:

- increasing v_i : ($v_i > V_{UT}$)
- decreasing v_i : ($v_i < V_{LT}$)
- Complete transfer characteristics



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

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



4. 1 Schmitt Trigger

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

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

- Note: $V_{LT} < V_{UT}$ and the difference between these two voltages is hysteresis width $V_H = V_{UT} - V_{LT} = 2V_{sat}\frac{R_2}{R_1+R_2}$

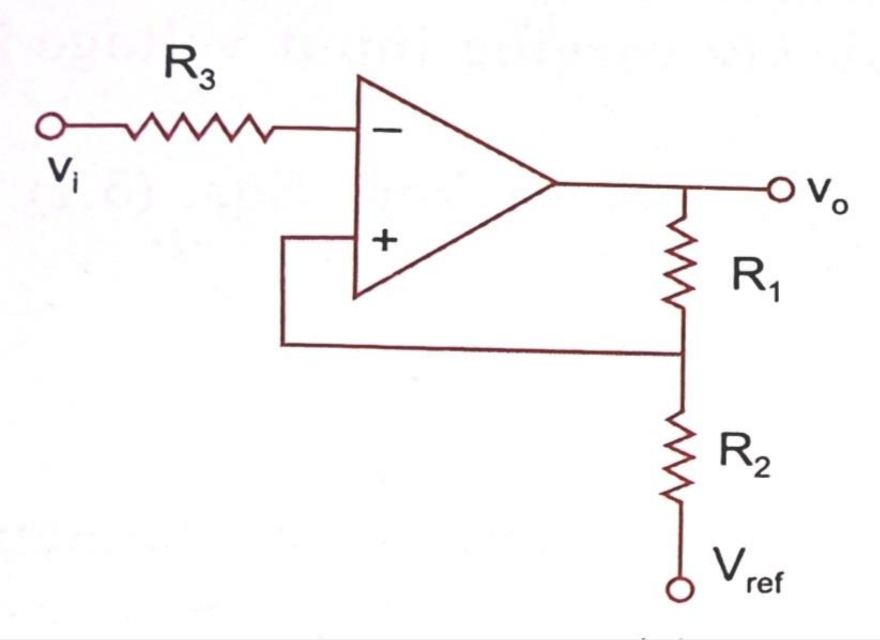
4.2 Application of Schmitt Trigger

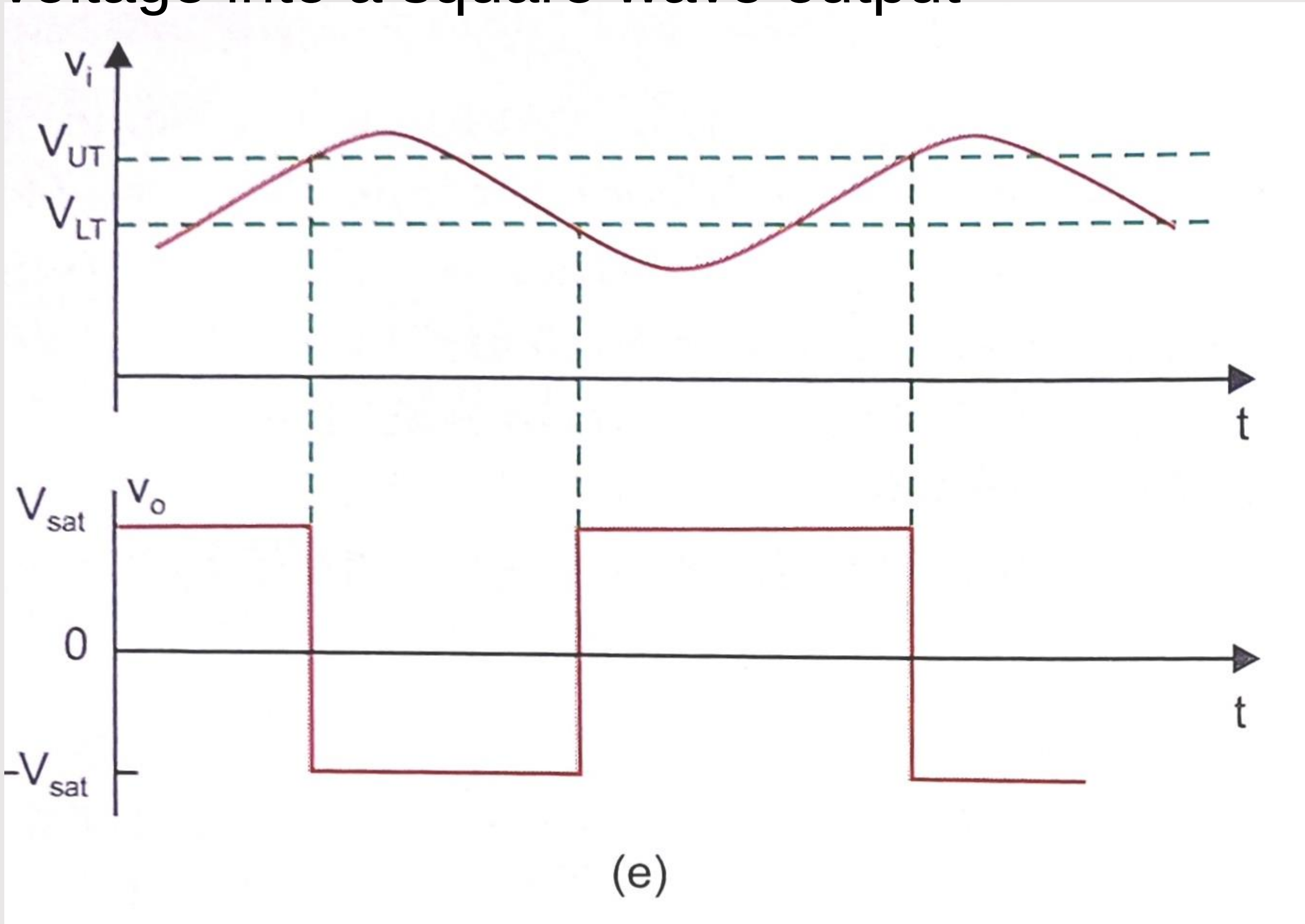
$$V_{UT} = V_{ref}\frac{R_1}{R_1+R_2} + V_{sat}\frac{R_2}{R_1+R_2}$$
$$V_{LT} = V_{ref}\frac{R_1}{R_1+R_2} - V_{sat}\frac{R_2}{R_1+R_2}$$

- Convert slow varying input voltage into a square wave output
- If $V_{ref} = 0$, then

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

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



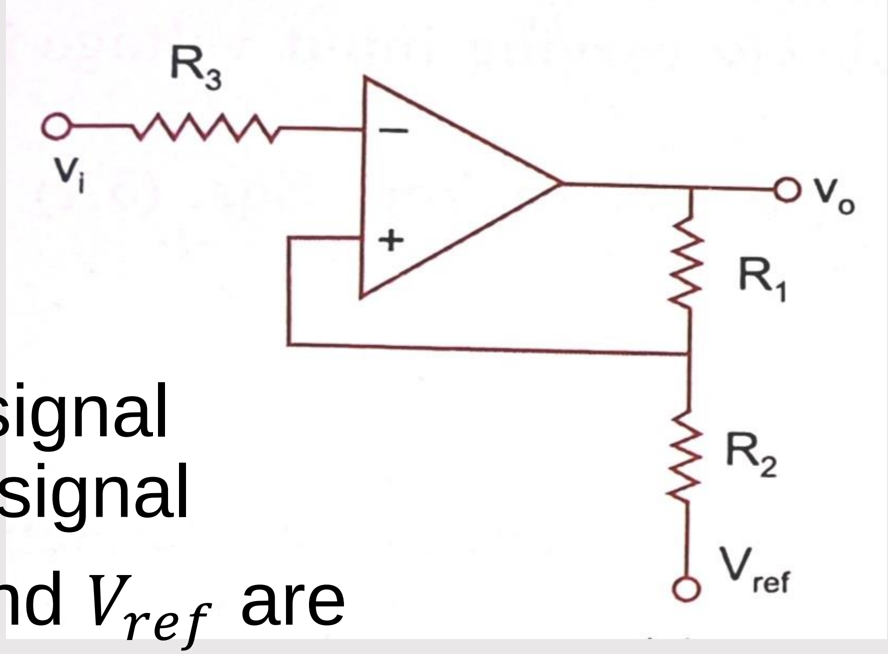


4. 1 Schmitt Trigger

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

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

- Note: $V_{LT} < V_{UT}$ and the difference between these two voltages is hysteresis width $V_H = V_{UT} - V_{LT} = 2V_{sat}\frac{R_2}{R_1+R_2}$
- Hysteresis is independent of V_{ref}
- R_3 is chosen to $R_1 \parallel R_2$
- Because of hysteresis,
  circuit triggers at higher voltage for increasing signal
  circuit triggers at Lower voltage for decreasing signal
- Non-inverting Schmitt trigger is obtained if v_i and V_{ref} are interchanged



4.2 Application of Schmitt Trigger

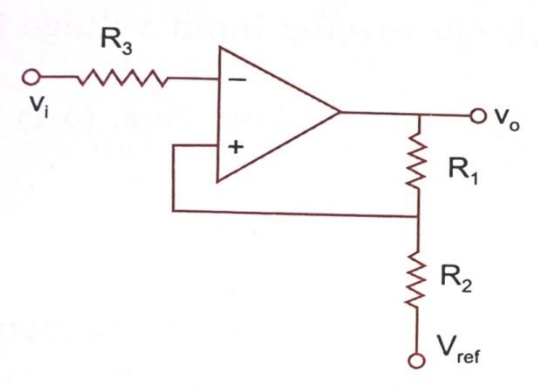
$$V_{UT} = V_{ref}\frac{R_1}{R_1+R_2} + V_{sat}\frac{R_2}{R_1+R_2}$$

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

- Convert slow varying input voltage into a square wave output
- If $V_{ref} = 0$, then

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

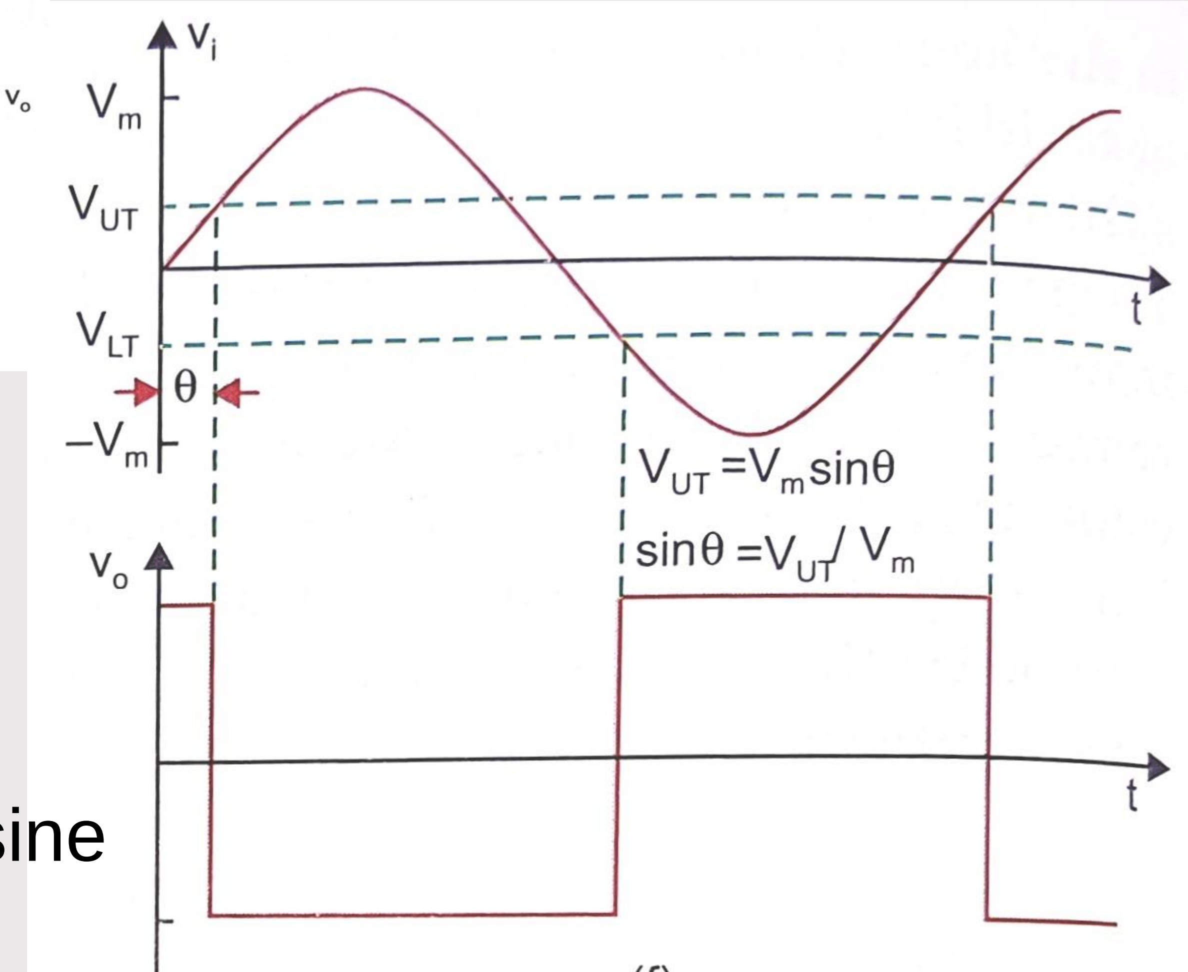
$$V_{LT} = -V_{sat}\frac{R_2}{R_1+R_2}$$



In such case, when $f = 1/T$ for sine wave. Symmetric square wave output is obtained

The zero crossing of sine wave and square wave differ by θ phase shift

$\sin\theta = V_{UT}/V_m$ where V_m is peak of sine



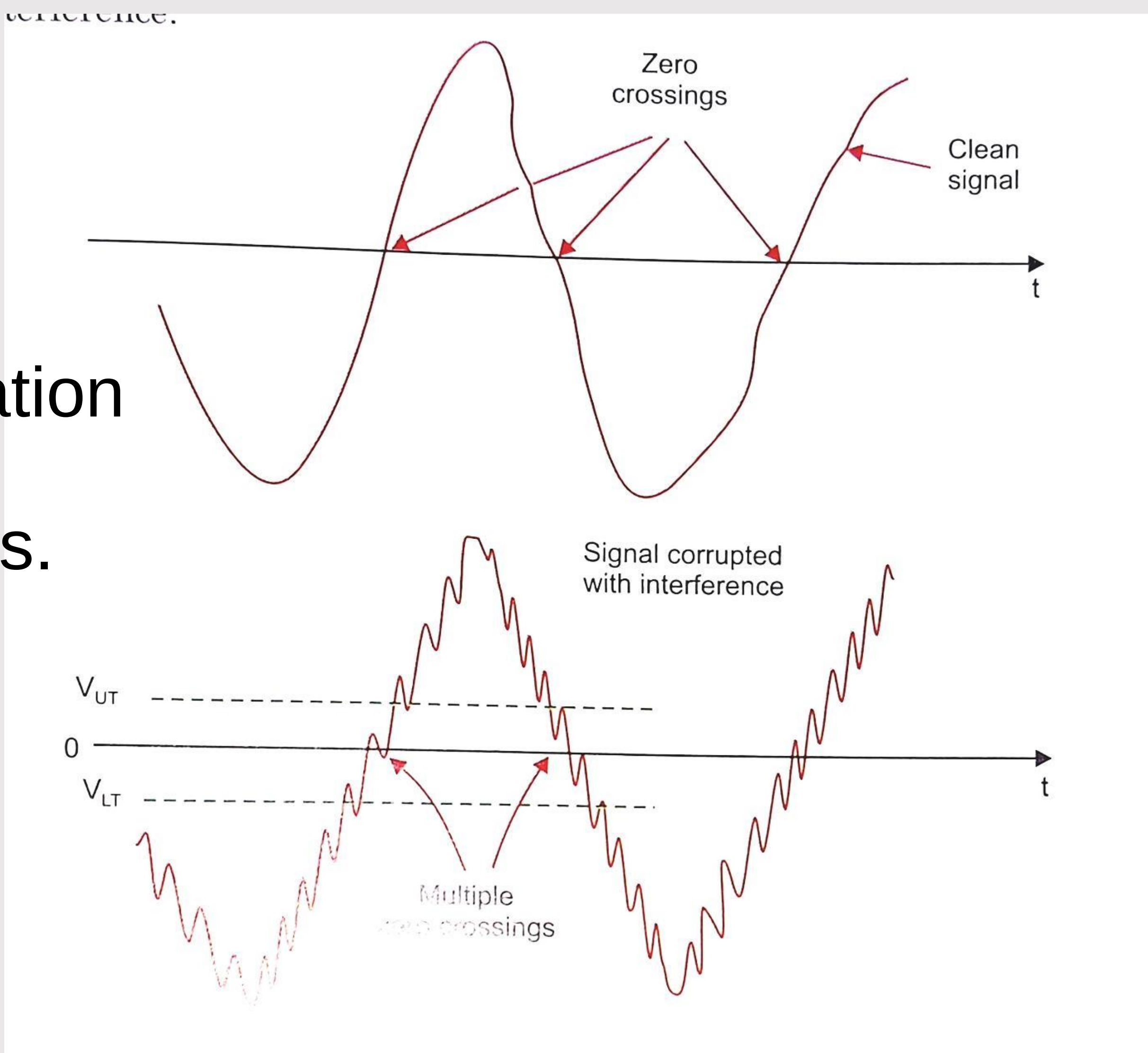
(f)

4.3 Interesting Application of Schmitt Trigger

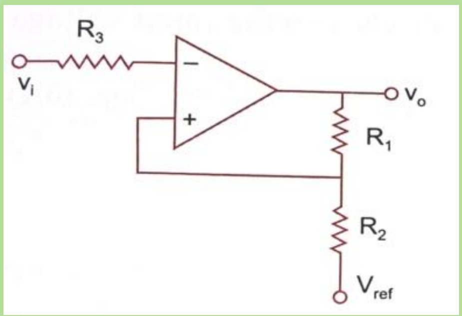
$$V_{UT} = V_{ref}\frac{R_1}{R_1+R_2} + V_{sat}\frac{R_2}{R_1+R_2}$$

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

- Detection and counting of zero crossings of arbitrary waveform if it is superimposed with interference (of higher frequency)
- Clean signal (three zero crossings)
- For interference superimposed signal. Hysteresis will help in proper identification of zero crossings of intended signal And rejects interference zero crossings.



Numerical



In the circuit of Schmitt trigger of fig ,R_2 =100Ω ,R_1=50kΩ,V_{ref} =0V,v_i=1V_{pp} sine wave and saturation voltage =±14V.Determine threshold voltage V_{UT} and $V_{UT.}$

Solutions

$$V_{UT} = \frac{100}{50k + 100} \times 14 = 28mV$$

$$V_{LT} = \frac{100}{50k + 100} \times -(14) = 28mV$$

Numerical:2

A schmitt trigger with the upper threshold level V_{UT} =0V and hysteresis width V_H =0.2V converts a 1KHz sine wave of amplitude 4 V_{PP} in to a square wave. Calculate the time duration of negative and positive portion of the output waveform

$Solution:$

$V_{UT} = 0$

$V_H = V_{UT} - V_{LT} = 0.2V$

$V_{LT} = -0.2V$

The angle θ can be calculated as

$-0.2 = V_m \sin(\pi + \theta) = -V_m \sin\theta = -2\sin\theta$

$\theta = arc$ sin 0.1=0.1 radian

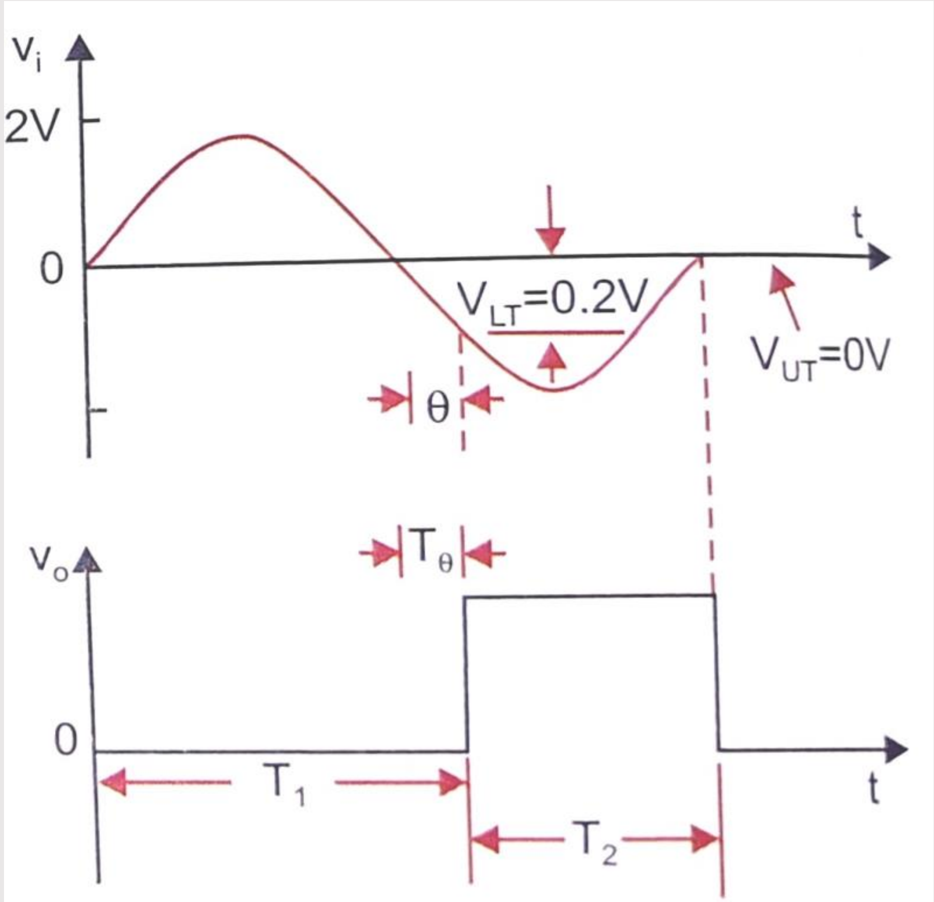
The period T=1/f=1/1000=1ms

$\omega \mathrm{T}_\theta = 2\pi(1000)\mathrm{T}_\theta = 0.1$

$\mathrm{T}_\theta = (0.1/2\pi)ms = 0.016ms$

$\mathrm{T}_1 = T/2 + (0.1/2\pi)ms = 0.516ms$

$\mathrm{T}_2 = T/2 - (0.1/2\pi)ms = 0.484ms$



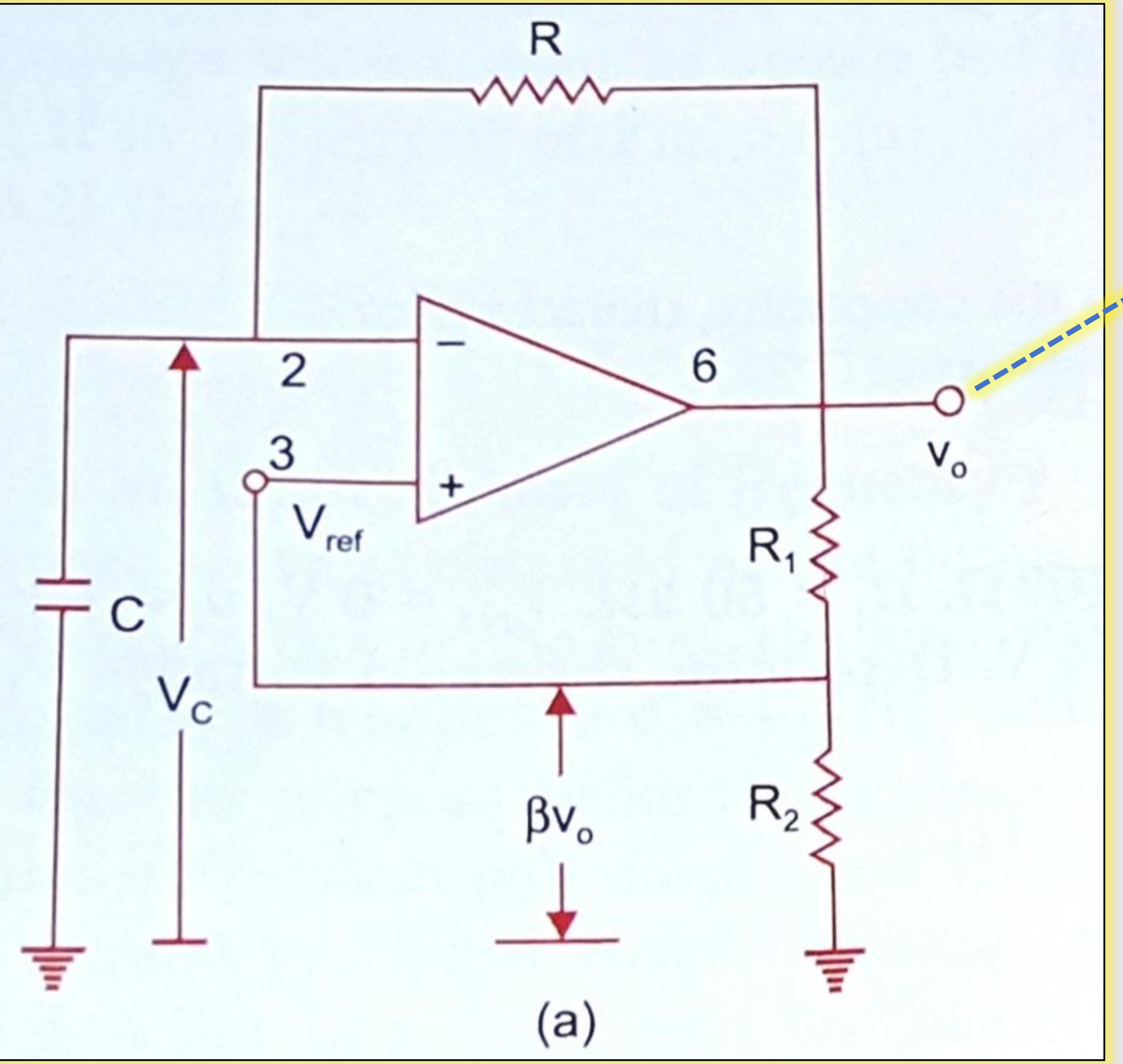
Astable Multivibrator

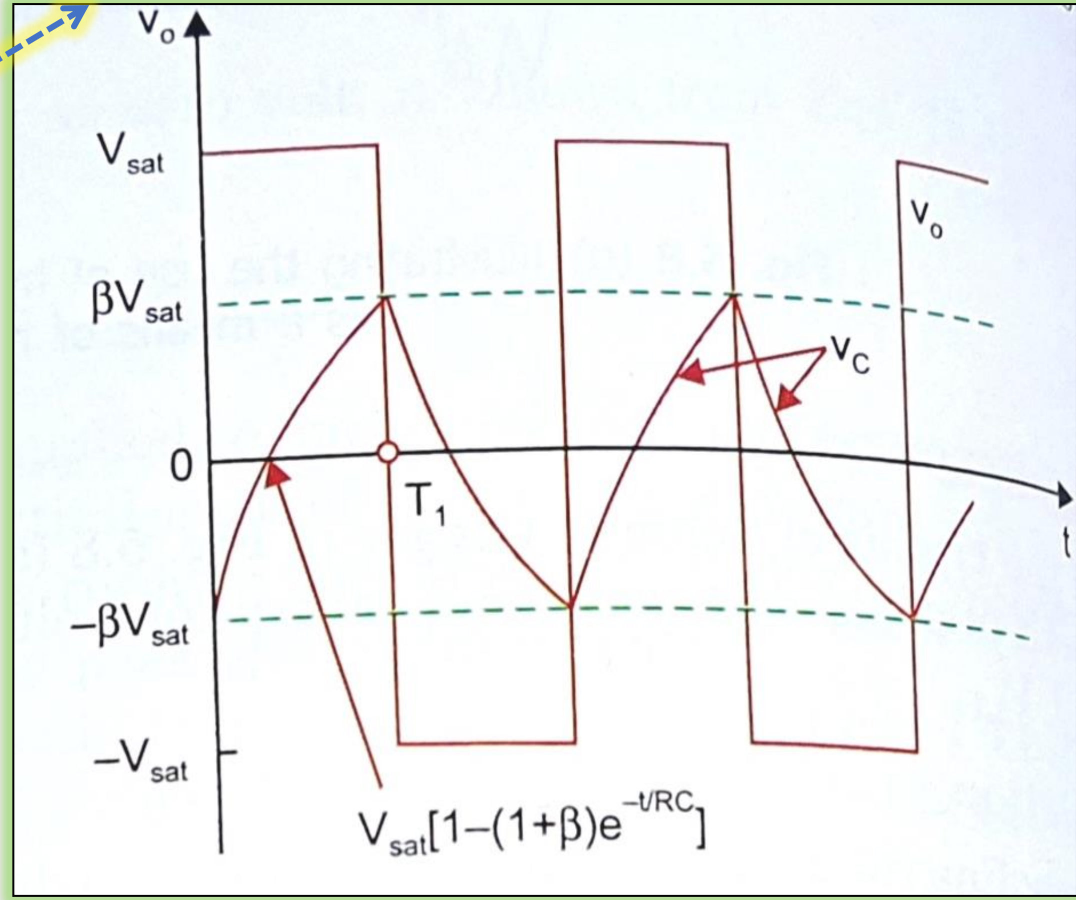
Also called **Square wave generator**

Free running oscillator: **A free-running multi-vibrator that has NO stable states but switches continuously between "HIGH" and a "LOW" states this action produces a train of square wave pulses at a fixed frequency.**

Not required any additional input to generate the oscillations

One power supply, no additional input.





Principal: Forcing an op-amp to operate in the saturation region

Output is either $+V_{sat}$ or $-V_{sat}$

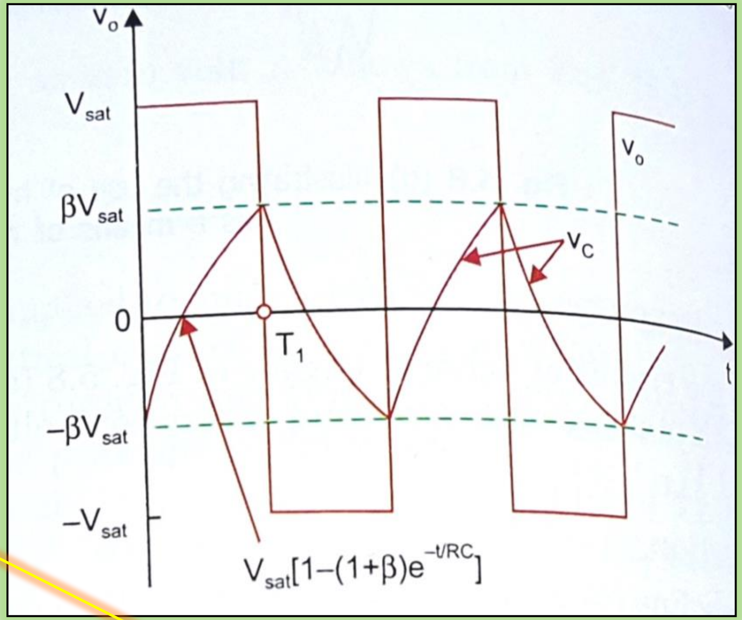
$$\boxed{\beta = \frac{R_2}{R_1 + R_2}}$$ of the output – fed back-

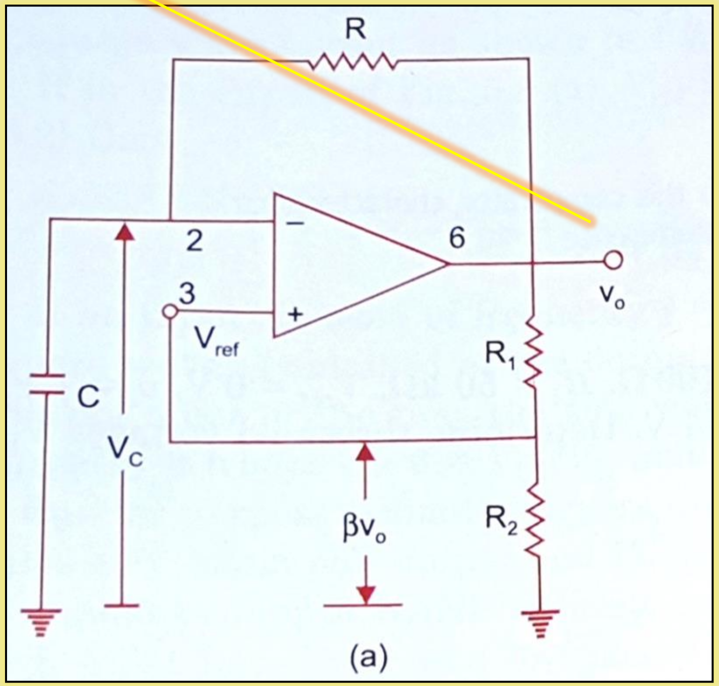
to the **input terminal**

Reference voltage V_{ref} is βV_o $+\beta V_{sat}$ or $-\beta V_{sat}$

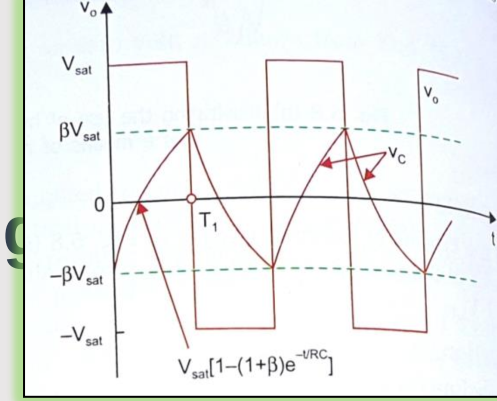
Input at the (-) input terminal just exceeds V_{ref} switching take place resulting in the **square wave input**

Both the states are quasi stable





How its working



Consider the output is at **+V_{sat} .The capacitor now start charging towards +V_{sat} through resistance R.**

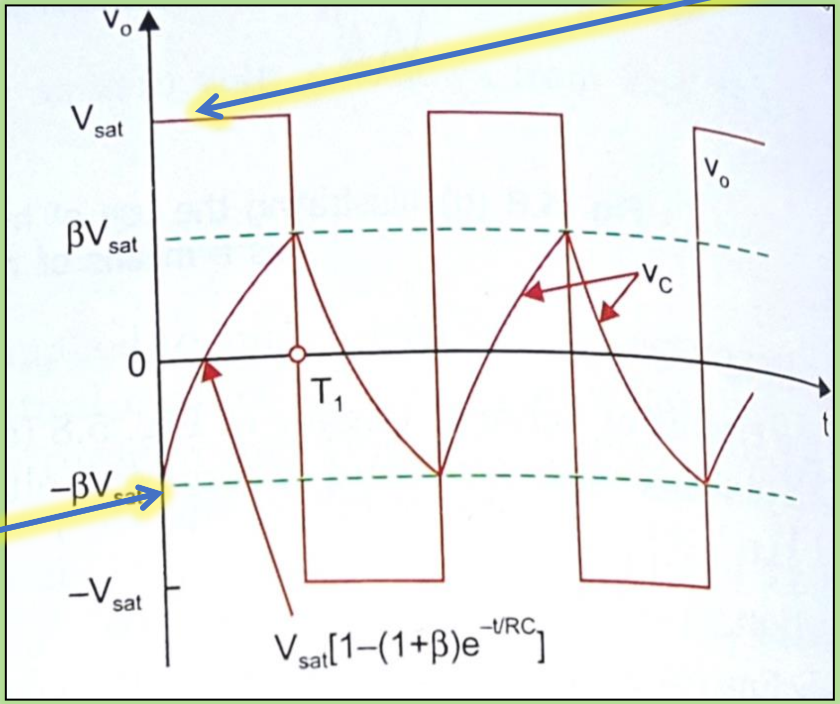
The Voltage at the (+) input terminal is held at +βV_{sat} by R_1 and R_2 combinations

This condition continues as the charge on C rises,unitl it has just exceeded +βV_{sat} the reference voltage.

The voltage at the (-) input terminal becomes greater than this reference voltage.The output is driven to -V_{sat} .At the instant the voltage on the capacitor is +βV_{sat} .

- **It begins to discharge through R, charges toward $-V_{sat}$ .The output .When the output voltage switches to $-V_{sat}$.**
- **The capacitor charges more and more negatively until its output voltage switches to $-\beta V_{sat}$**
- **The output switches back to $+V_{sat}$**
- This cycle repeats

V_f



final value of the capacitor

V_i

Initial value of the capacitor

The voltage across the capacitor as a function of time is given by

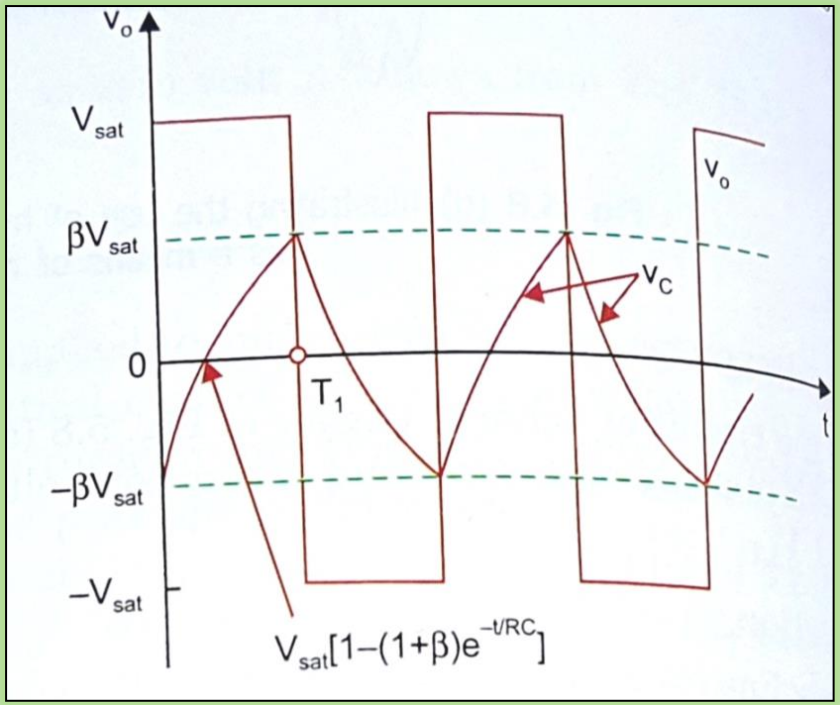
$$v_c(t) = V_f + (V_i - V_f)e^{-t/RC}$$

$$V_i = -\beta V_{sat}$$

$$V_f = +V_{sat}$$

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

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



at t=T$_1$ voltage across the capcitor reaches $\beta V_{sat} and$ switching take place

$$v_c(t) = \beta V_{sat}$$

$$v_c(\mathrm{T}_1) = \beta V_{sat} = +V_{sat}(1-(1+\beta)e^{-\mathrm{T}_1/RC})$$

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

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

Taking ln on both sides

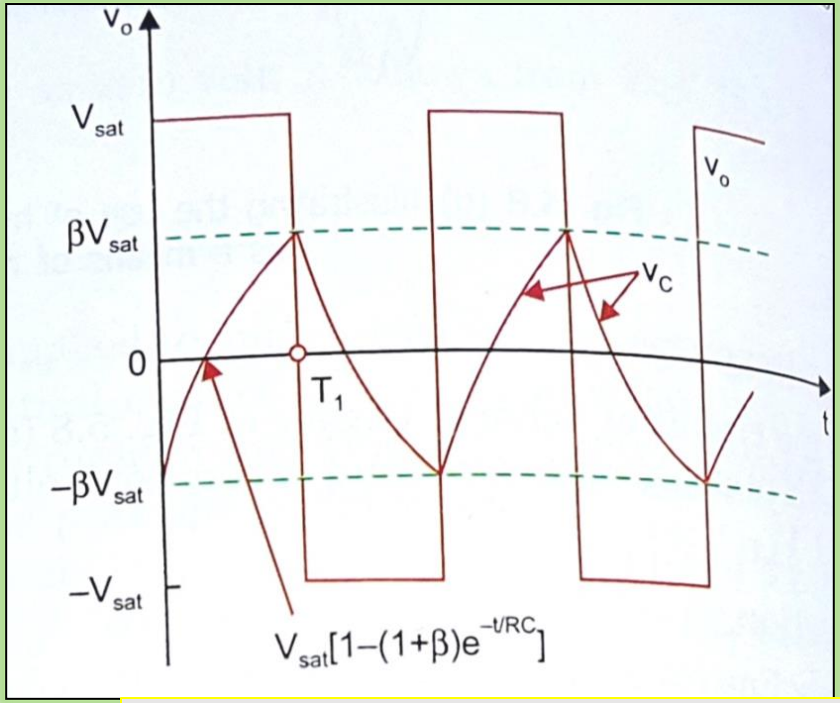
$$(1+\beta) - T_1 / RC = 1-\beta$$

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

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

Total time period for full cycle

$$T = 2T_1 = 2RC\ln\frac{1+\beta}{1-\beta}$$



Output swings from **+V$_{sat}$** **to -V$_{sat}$**

$V_{o(p-p)} = 2V_{sat}$

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

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

If $R_1 = R_2$

$$\beta = \frac{R_2}{R_1+R_2} = \frac{R_2}{2R_2} = \frac{1}{2} = 0.5$$

$$T = 2T_1 = 2RC\ln\frac{1+\beta}{1-\beta} = 2RC\ln\frac{1+0.5}{1-0.5} = 2RC\ \ln\ 3$$

If $R_1 = 1.16R_2$

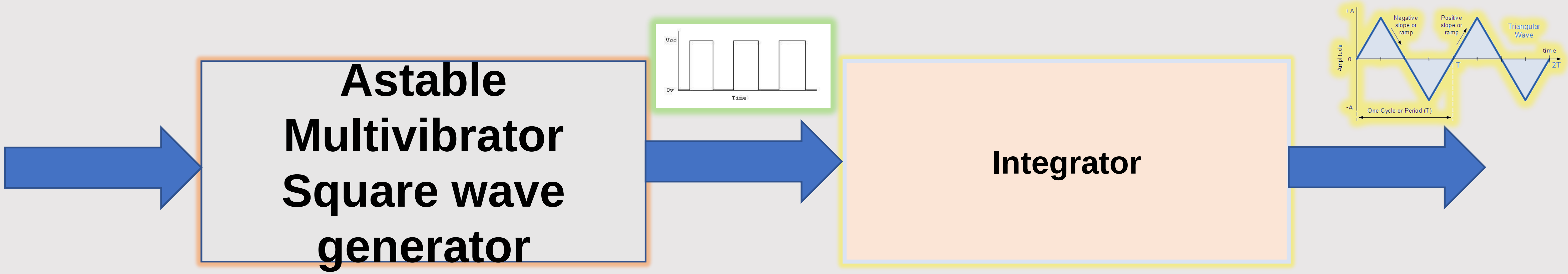
T= $2RC$

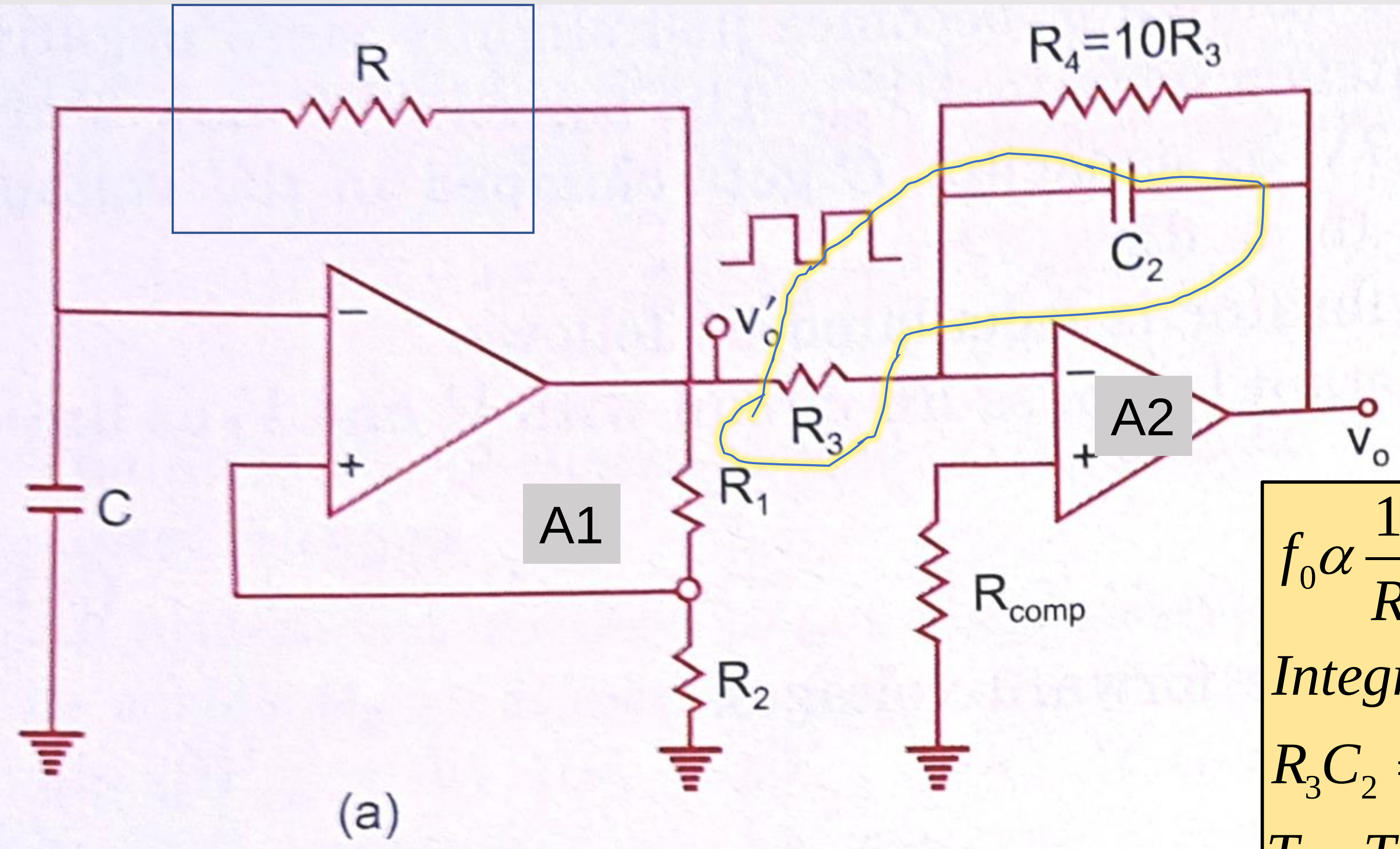
Triangular wave Generator

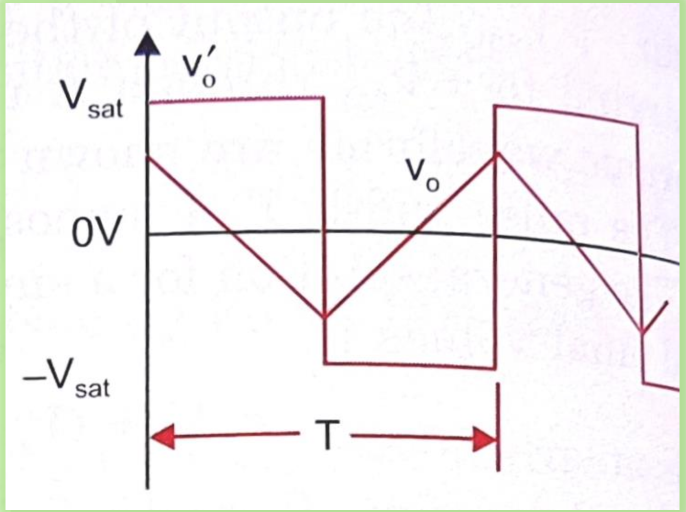
Non sinusoidal wave generator

Combination of Square wave generator +Integrator

Square wave-Integrating –Triangular wave generator







$$f_0 \alpha \frac{1}{R}$$

Integral Time components

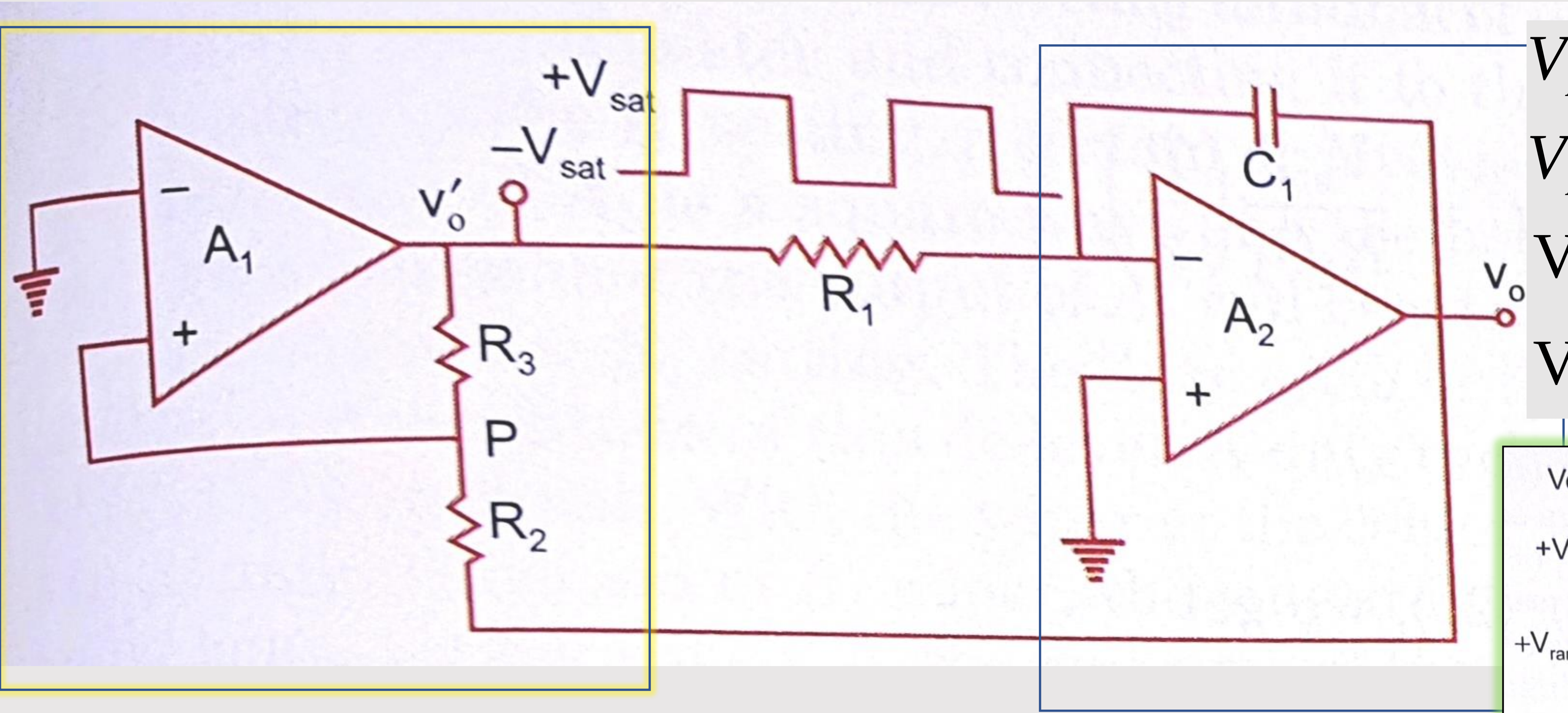
$$R_3 C_2 = T$$

$T = $ *Time* period of square wave

Frequency of square and Triangular wave is the same

Required more no of components (2 capacitors, 5 resistors)

Triangular wave Generator (Lesser Components)

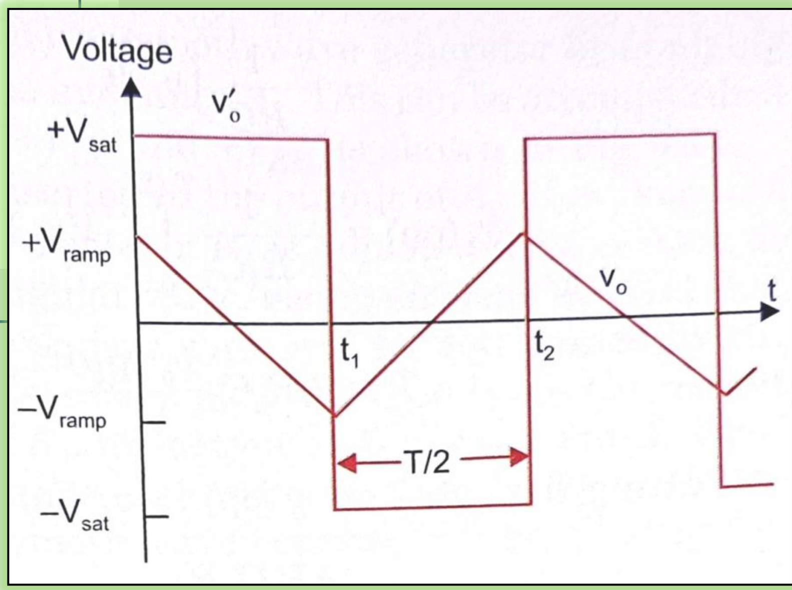


$$V_A > V_B \quad V_{o1} = +V_{sat}$$

$$V_A < V_B \quad V_{o1} = -V_{sat}$$

$$V_{o1} = +V_{sat} \qquad V_{o2} = -V_{ramp}$$

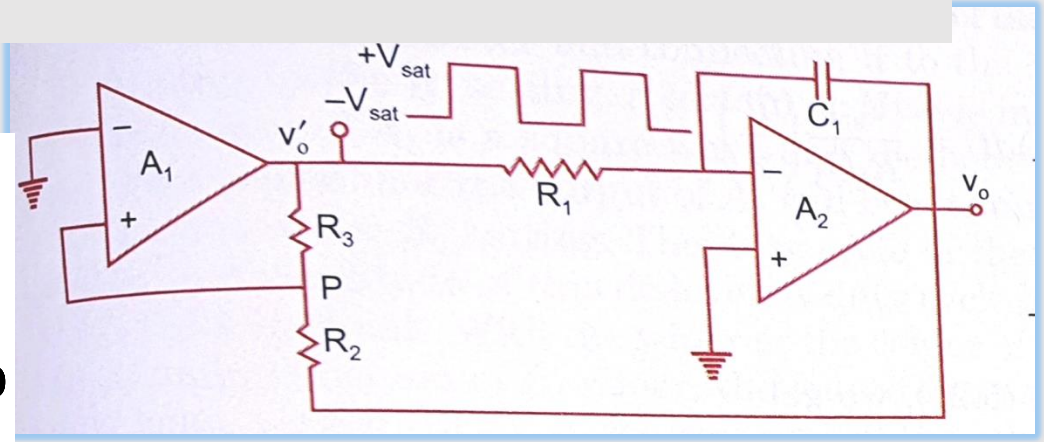
$$V_{o1} = -V_{sat} \qquad V_{02} = +V_{ramp}$$



Comparator or Schmitt trigger

Integrator

The effective voltage at point P during the time When the output of A_1 is at $+V_{sat}$ level



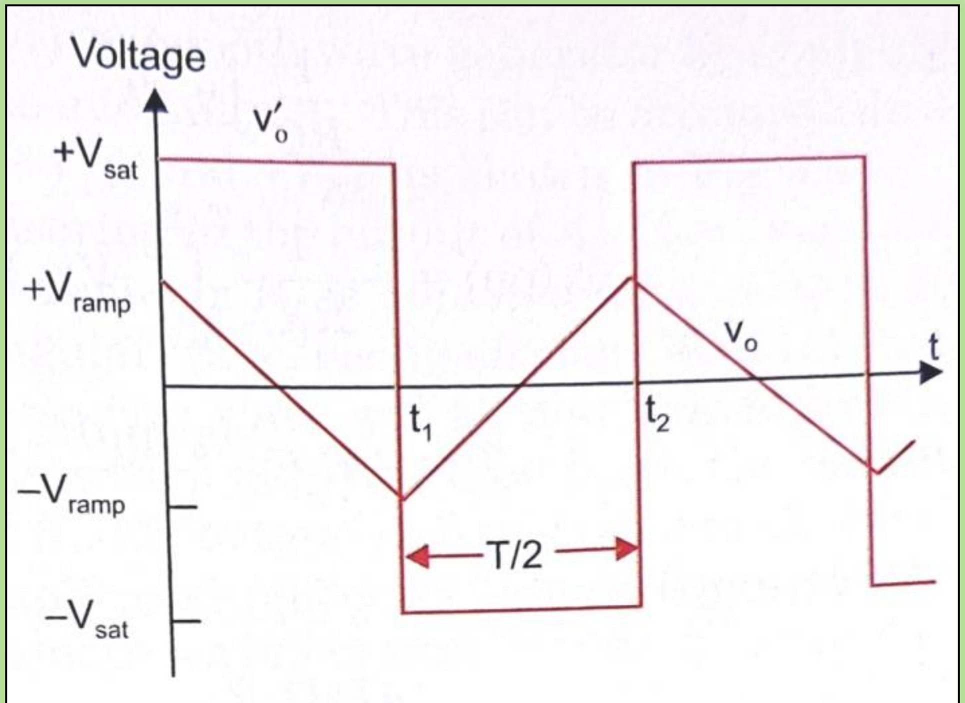
$$V_o = -V_{ramp} + \frac{R_2}{R_2 + R_3}[V_{sat} - (-V_{ramp})]$$

At t=t$_1$; The voltage at point P becomes equal to zero

$$= -V_{ramp} + \frac{R_2}{R_2 + R_3}V_{sat} + \frac{R_2}{R_2 + R_3}V_{ramp} = 0$$

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

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



Similarly at t=t_2, *when* the output A_1 switch from $-V_{sat}$ *to* $+V_{sat}$

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

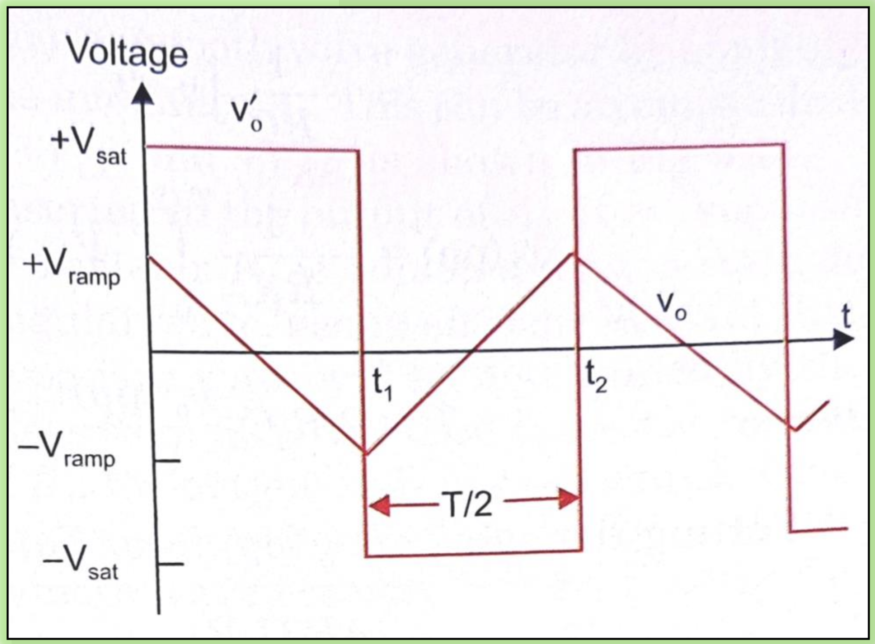
$$V_{ramp} = -\frac{R_2}{R_3} V_{sat}$$

Peak to peak of the traingular wave

$$v_o(pp) = V_{ramp} - (-V_{ramp})$$

$|+V_{sat}| = |-V_{sat}|$ we can write us

$$v_o(pp) = 2\frac{R_2}{R_3} V_{sat}$$



The output switches from –V_{ramp} to +V_{ramp} in half the time period T/2

The output switches from $-V_{ramp}$ to $+V_{ramp}$ in half the time period T/2

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

$$v_o = -\frac{1}{R_1C_1}\int_0^{T/2}(-V_{sat})dt = \frac{V_{sat}}{R_1C_1}\left(\frac{T}{2}\right)$$

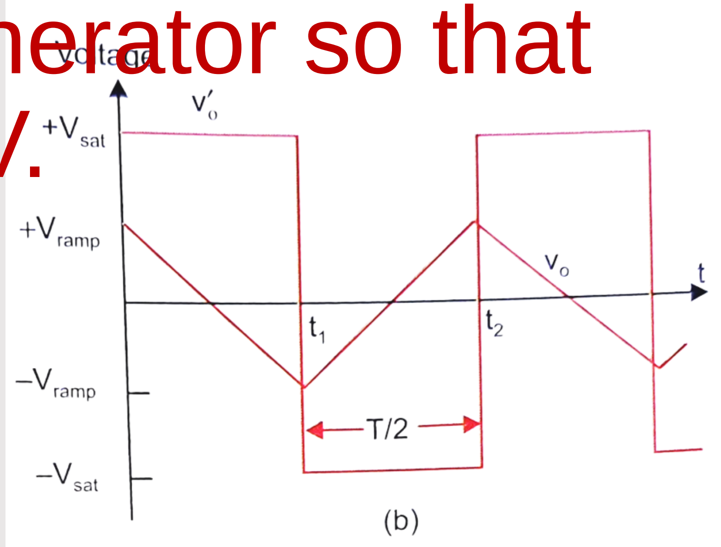
$$T = 2R_1C_1\frac{v_o(pp)}{V_{sat}}$$

$$\mathrm{v_o}(pp) = 2\frac{R_2}{R_3}V_{sat}$$

$T = 2R_1C_1\frac{v_o(pp)}{V_{sat}} = \frac{4R_1C_1R_2}{R_3}$ and

frequency of Oscillation: $f_0 = \frac{1}{T} = \frac{R_3}{4R_1C_1R_2}$

Problem: Design the triangular wave generator so that f_o=1 kHz and v_o (pp)=6 V with V_{sat}=±15 V.



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

$6 = 2\frac{R_2}{R_3}\,15 \qquad \frac{R_2}{R_3} = \frac{6}{30} = \frac{1}{5}$

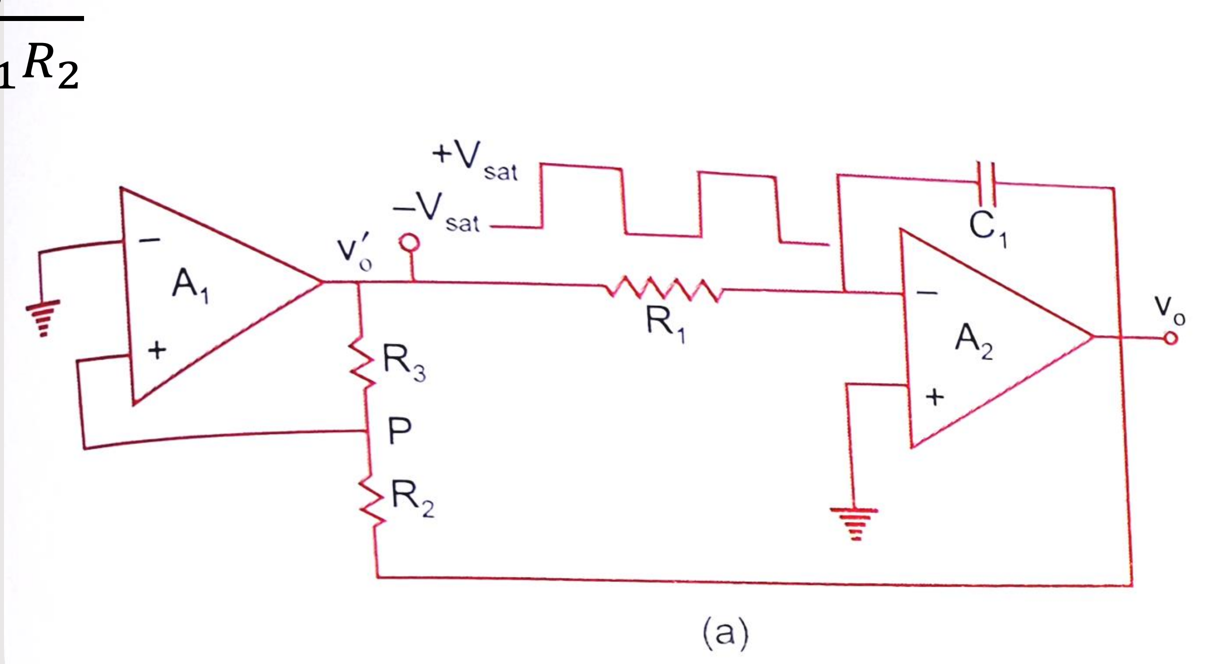
Take $R_2 = 10k\Omega$; $R_3 = 50k\Omega$

- frequency of Oscillation: $f_0 = \frac{1}{T} = \frac{R_3}{4R_1C_1R_2}$

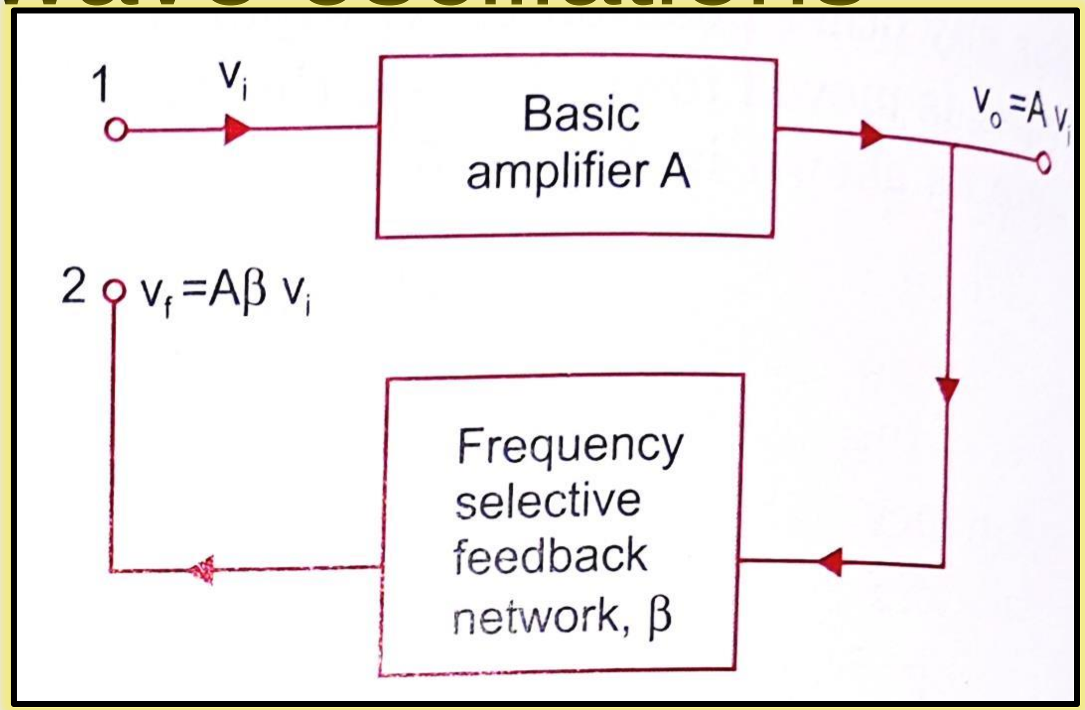
$1k = \frac{1}{4R_1C_1}.\left(\frac{R_3}{R_2}\right) = \frac{1}{4R_1C_1}.\left(\frac{5}{1}\right)$

$\frac{4k}{5} = \frac{1}{R_1C_1} \qquad R_1C_1 = 1.25 \times 10^{-3}$

Take $R_1 = 10k\Omega$; $C_1 = \frac{1.25m}{10k} = 0.125\mu F$

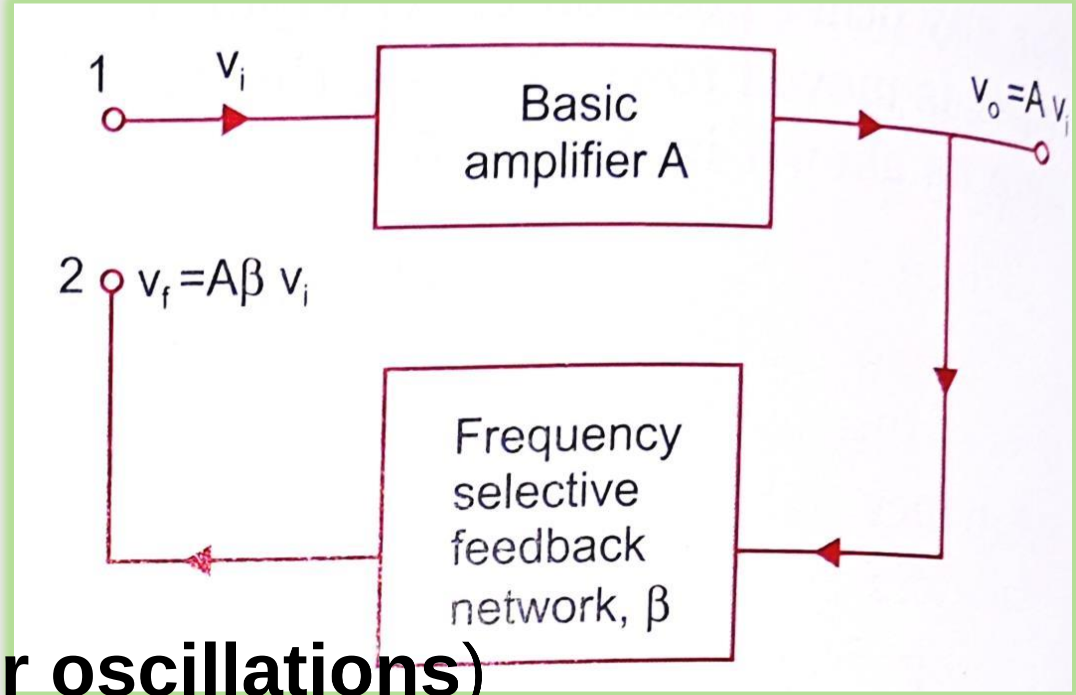


3. Basic principle of Sine wave oscillations



- Basic structure of sine wave oscillators based on use of feedback in amplifiers
- Amplifier with gain A
- Frequency selective feedback network (inductor or capacitor components) with transfer ration β
- Note: Loop is incomplete as terminal 2 is not connected to terminal 1
- Oscillators don't need input ac. Just for understanding, v_i input is given at 1 Feedback signal at 2: $v_f = A\beta v_i$
- $A\beta$ is loop-gain of the system and are adjusted such that $A\beta = 1$

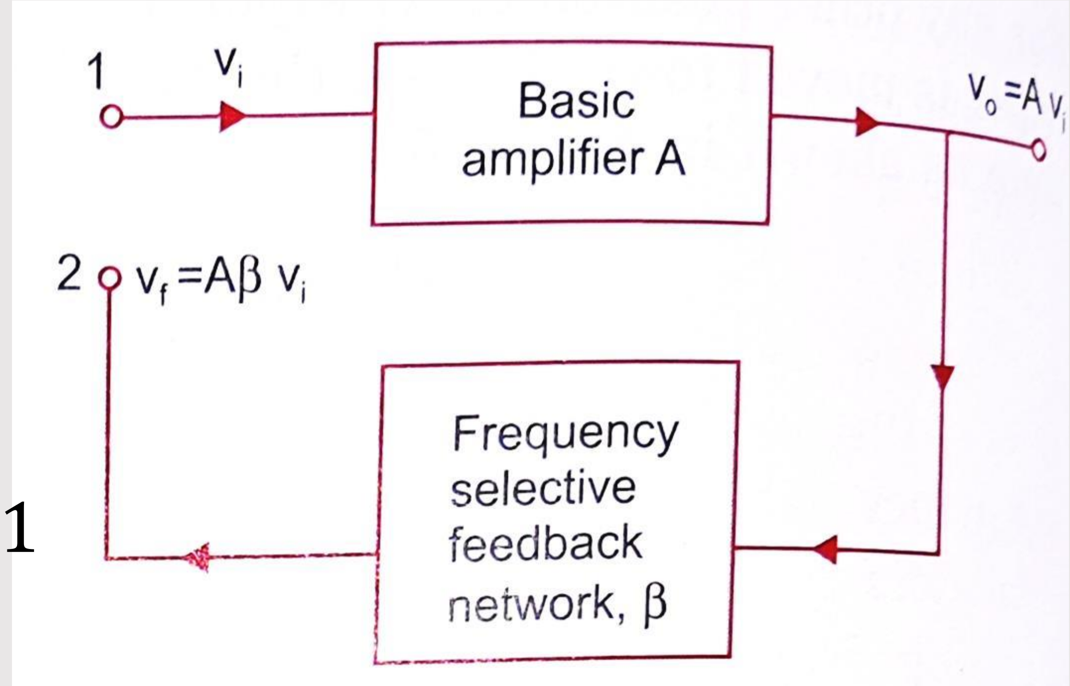
3. Basic principle of Sine wave oscillations

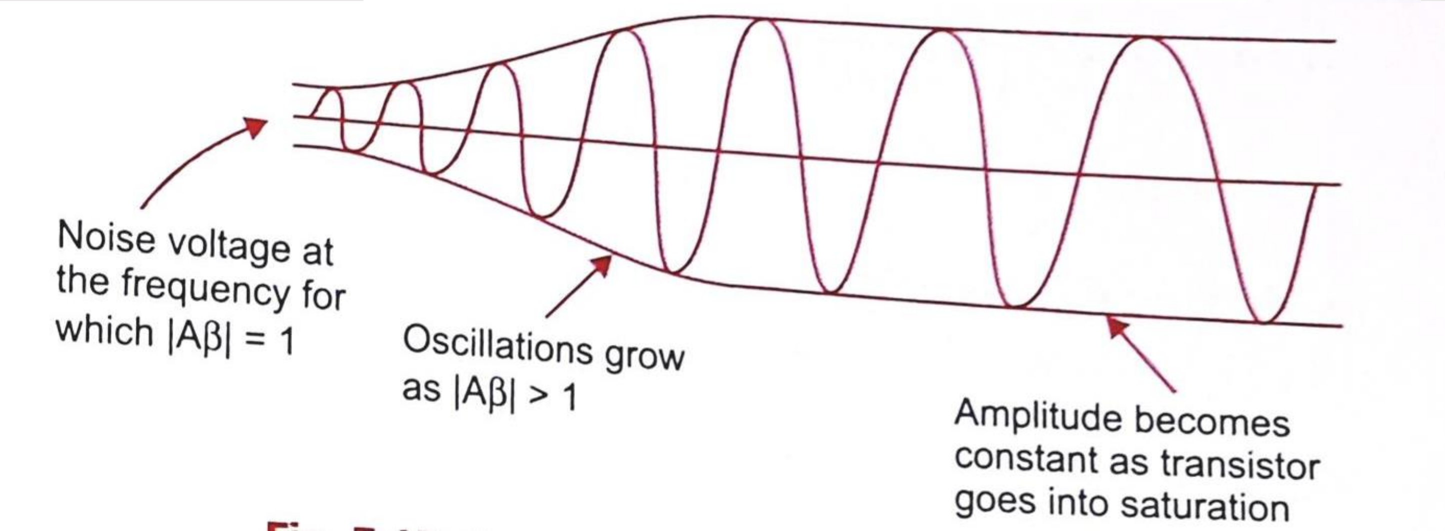


- $v_f = A\beta v_i$ and with $\boldsymbol{A\beta = 1}$, when 2 is connected to 1 and $v_i\ (external)$ is removed, output will be continuously provided.
- Output signal can be obtained continuously without any input signal if the condition of loop gain is satisfied, $A\beta = 1$ (This is **Barkhausen criterion for oscillations**)
- This condition can be satisfied only at specific frequency f_0 for given component values. $A(j\omega_0)\beta(j\omega_0) = 1\angle 0°$
- **Magnitude of loop gain : $|\boldsymbol{A\beta}| = 1$**
  Phase shift of loop gain: $\angle \boldsymbol{A\beta} = 0°\ \boldsymbol{or}$ multiples of 2π

3. Basic principle of Sine wave oscillations

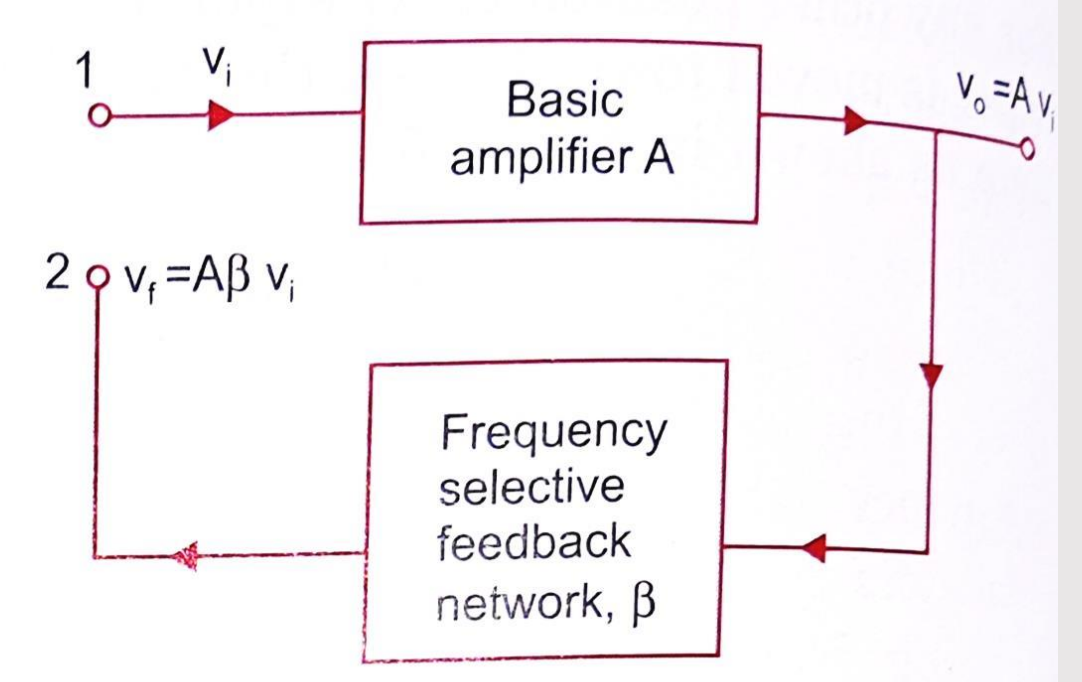
- $|A\beta| = 1$ $\quad\quad \angle A\beta = 0° \; or$ multiples of 2π
- At different temperatures Loop gain can go below 1, and when loop gain goes below 1, the amplitude drops to zero.
- Hence, Loop gain magnitude is generally maintained above unity $|A\beta| > 1$

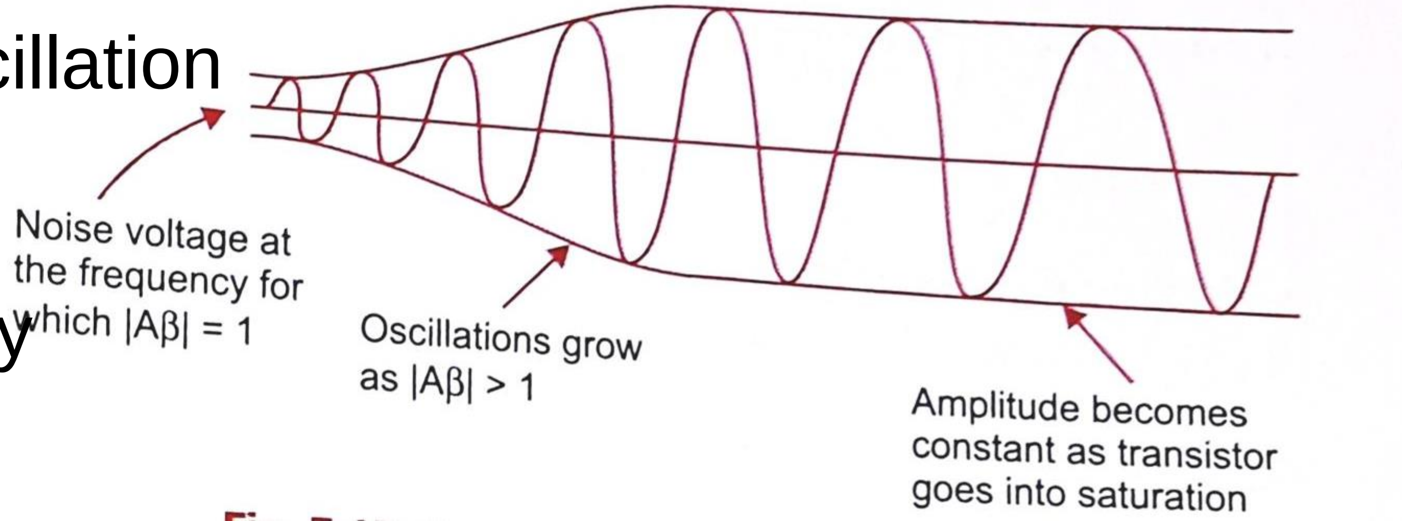




3. Basic principle of Sine wave oscillations

- Practically, no input is given,
  Noise is always present in transistor (Johnson's noise) or in carrier concentration variation (Schottky noise)
- With $|A\beta| > 1$
  This would generally increase amplitude until saturation and then amplitude becomes stable.
- Different types of sine-wave oscillation available according to range of frequency.
- RC phase shift for low frequency
  LC for high frequencies





RC Phase shift oscillator

- Op-amp: Inverting mode – Provides 180° phase shift
- Additional phase of 180° is provided by RC feedback network
- Conventional feedback network: 3 identical RC stages for single frequency
- Non-identical 3RC stages may be used for generating 180° phase shifts for more than one frequency, but can cause undesirable frequencies .

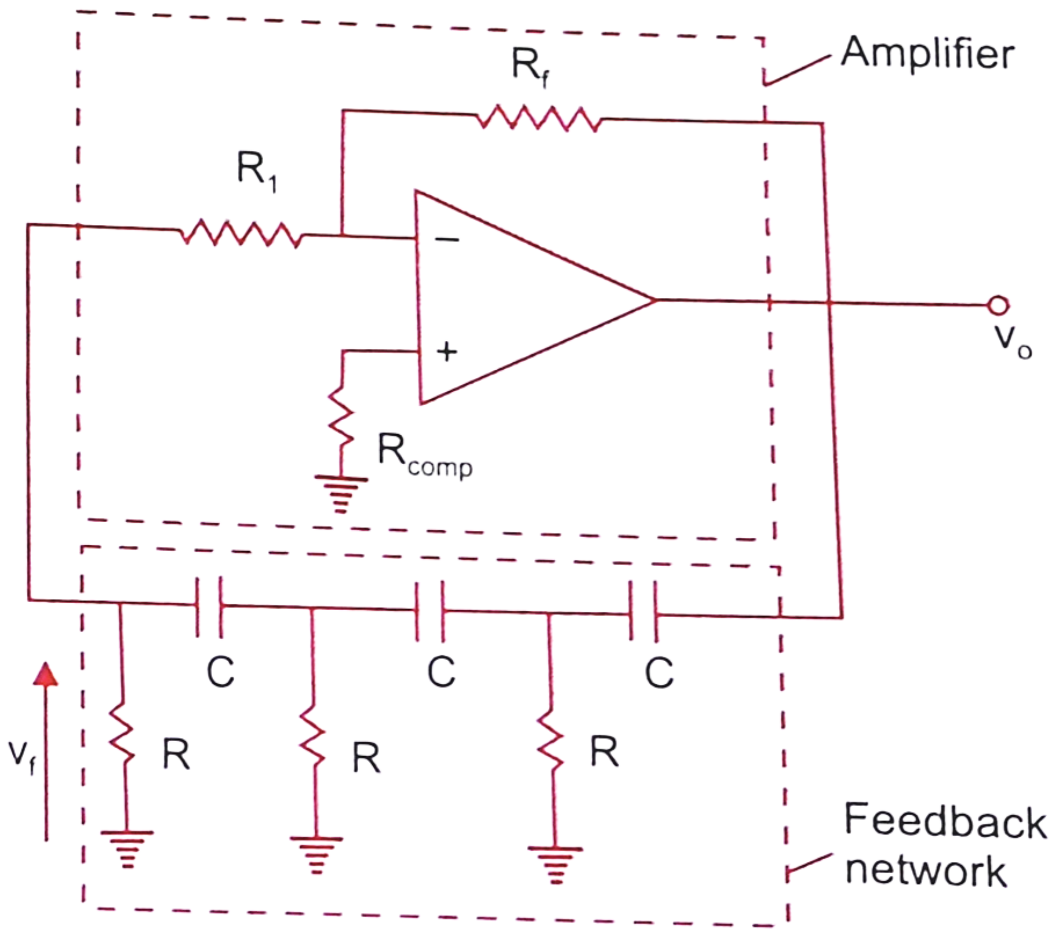


Fig. 5.18 (a) Phase shift oscillator

RC Phase shift oscillator

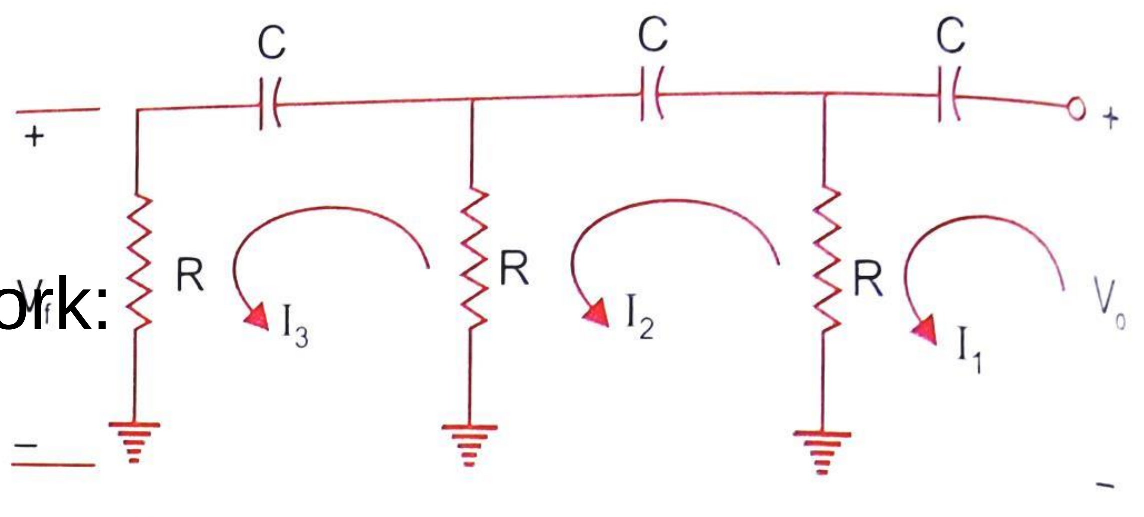


Fig. 5.18 (b) (

- Feedback factor $\beta = V_f/V_0$: KVL in network:

$$\boldsymbol{I_1\left(R+\frac{1}{sC}\right)-I_2R=V_0}$$

$$\boldsymbol{-I_1R+I_2\left(2R+\frac{1}{sC}\right)-I_3R=0}$$

$$\boldsymbol{0-I_2R+I_3\left(2R+\frac{1}{sC}\right)=0}$$

On solving $\boldsymbol{I_3=\frac{V_0R^2s^3C^3}{1+5sRC+6s^2C^2R\&2-s^3C^3R^3}}$ and

$$V_f=I_3R=\frac{V_0R^2s^3C^3}{1+5sRC+6s^2C^2R\&2-s^3C^3R^3}=\frac{V_0}{1+\frac{6}{sRC}+\frac{5}{s^2R^2C^2}-\frac{1}{s^3R^3C^3}}$$

Replacing $s=j\omega$, $s^2=-\omega^2, s^3=-j\omega^2$ and $\alpha = 1/\omega RC$

$$\beta=\frac{V_f}{V_0}=\frac{1}{1+\frac{6}{sRC}+\frac{5}{s^2R^2C^2}-\frac{1}{s^3R^3C^3}}=\frac{1}{1-\frac{6}{j\omega RC}-\frac{5}{(\omega RC)^2}+\frac{6}{j(\omega RC)^3}}=\frac{1}{(1-5\alpha^2)+j\alpha(6-\alpha^2)}$$

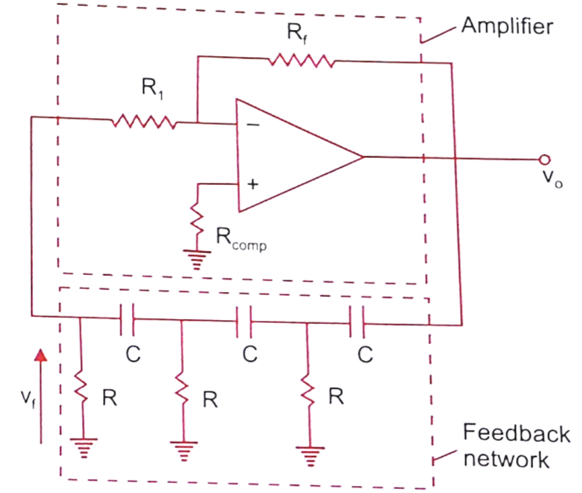


Fig. 5.18 (a) Phase shift oscillator

RC Phase shift oscillator

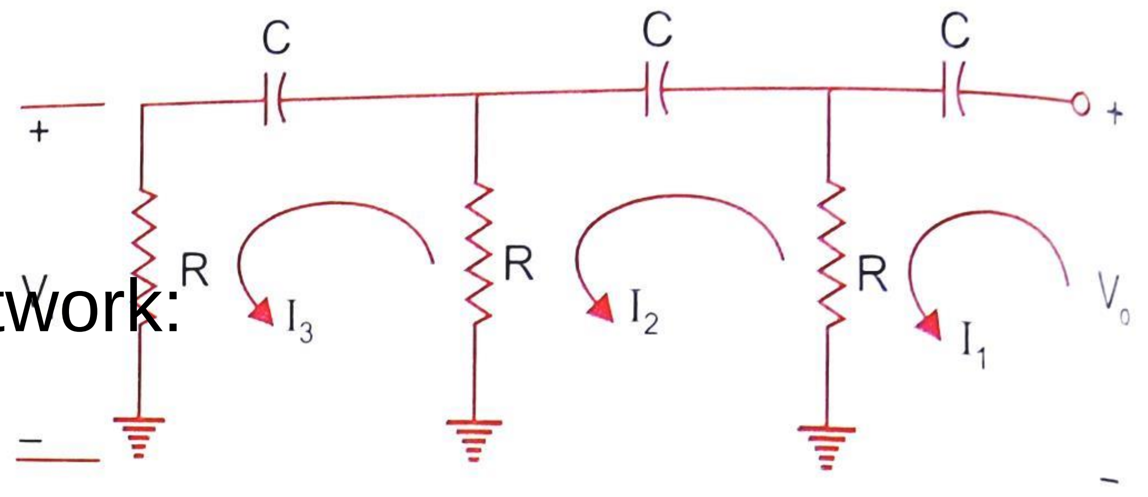


Fig. 5.18 (b) Cal... shi...

- **Feedback factor $\boldsymbol{\beta = V_f/V_0}$** : KVL in network:

  $\alpha = 1/\omega RC \qquad \beta = \dfrac{1}{(1-5\alpha^2)+j\alpha(6-\alpha^2)}$

- For $A\beta = 1$, β should be real, and imaginary term of β should be zero
- $\alpha(6-\alpha^2) = 0 \qquad \alpha = \sqrt{6} \qquad \dfrac{1}{\omega RC} = \sqrt{6} \qquad \omega = \dfrac{1}{RC\sqrt{6}}$
- The frequency of oscillation is therefore $\quad \boldsymbol{f_0 = \dfrac{1}{2\pi RC\sqrt{6}}}$
- With $\alpha = \sqrt{6}$, $\beta = \dfrac{1}{(1-5(6))+j\sqrt{6}(0)} = -\dfrac{1}{29}$ or $|\beta| = 1/29$
- **For sustained oscillations: $\boldsymbol{|A\beta| \geq 1}$ or $\boldsymbol{|A| \geq \left|\dfrac{1}{\beta}\right|}$ or $\boldsymbol{|A| \geq 29}$**

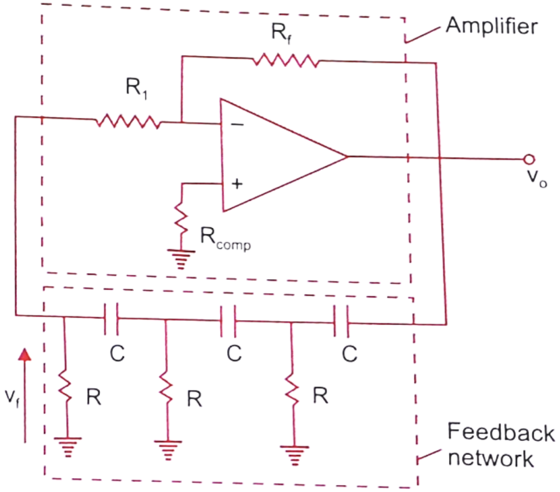
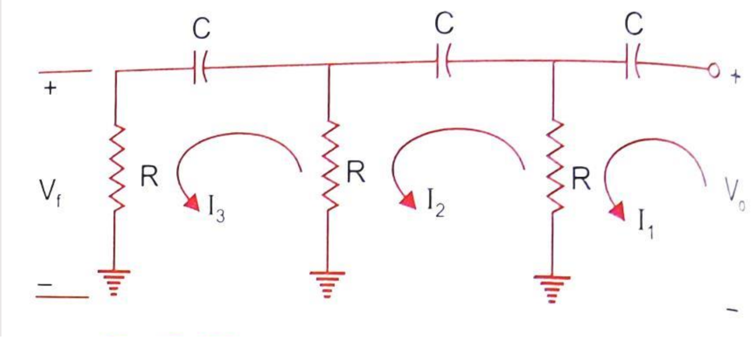


Fig. 5.18 (a) Phase shift oscillator

RC Phase shift oscillator

- For sustained oscillations: $|A\beta| \geq 1$
  with $|\beta| = 1/29$ $|A| \geq 29$ $f_0 = \frac{1}{2\pi RC\sqrt{6}}$
- The gain of inverting amplifier should be atleast 29
- $|A| = \left|-\frac{R_f}{R_1}\right| \geq 29$ $R_f \geq 29R_1$
- For low frequencies(<1kHz), Opamp 741 may be used
- For higher frequencies. $LM318$, LF351



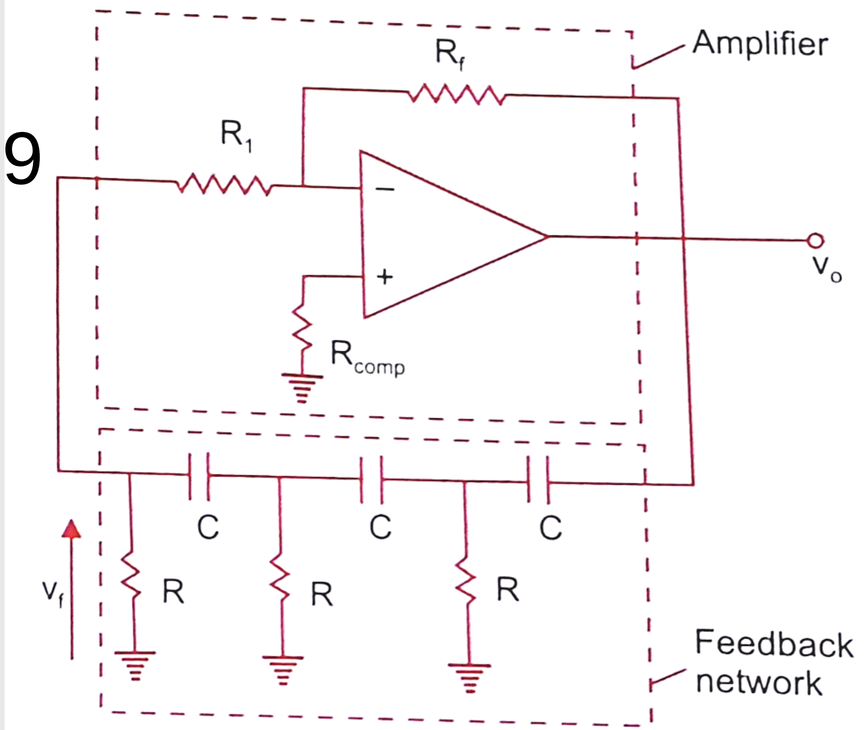
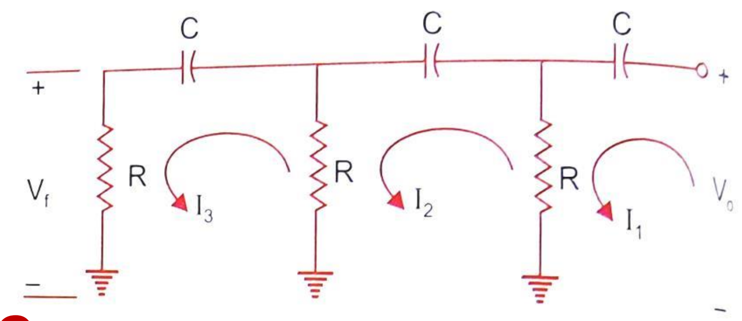


Fig. 5.18 (a) Phase shift oscillator

2. RC Phase shift oscillator



Problem: Design a phase shift oscillator to oscillate at 100Hz

- Let $C = 0.1\mu F$, then from $f_0 = \dfrac{1}{2\pi RC\sqrt{6}}$

$$R = \frac{1}{2\pi C\sqrt{6}\ (f_0)} = \frac{1}{2\pi(0.1\mu)\sqrt{6}(100)} = 6.49k\Omega$$

Use $R = 6.5k\Omega$

To prevent loading of the amplifier by RC network, $R_1 \geq 10R$

Therefore $R_1 = 10R = 65k\Omega$

We know $|A| = \left|-\dfrac{R_f}{R_1}\right| \geq 29$ $\quad R_f \geq 29R_1 \quad R_f = 29R_1 = 1885k\Omega$

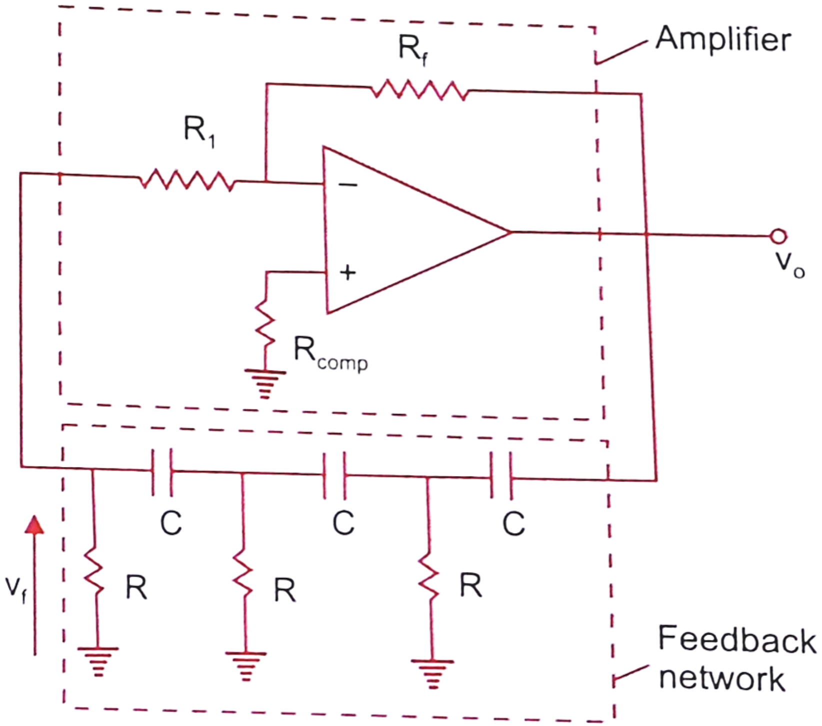


Fig. 5.18 (a) Phase shift oscillator

3. Wien Bridge oscillator

- Feedback is connected to non-inverting terminal (No phase shift from feedback)
- Zero phase shift is achieved by balancing network – bridge
- Frequency of oscillations: $f_0 = \frac{1}{2\pi\sqrt{R_1 R_1 C_1 C_2}}$ $\beta = \frac{V_f}{V_0} = \frac{R_2 C_1}{R_1 C_1 + R_2 C_2 + R_2 C_1}$
- When $R_1 = R_2 = R_3$ and $C_1 = C_2 = C_3$

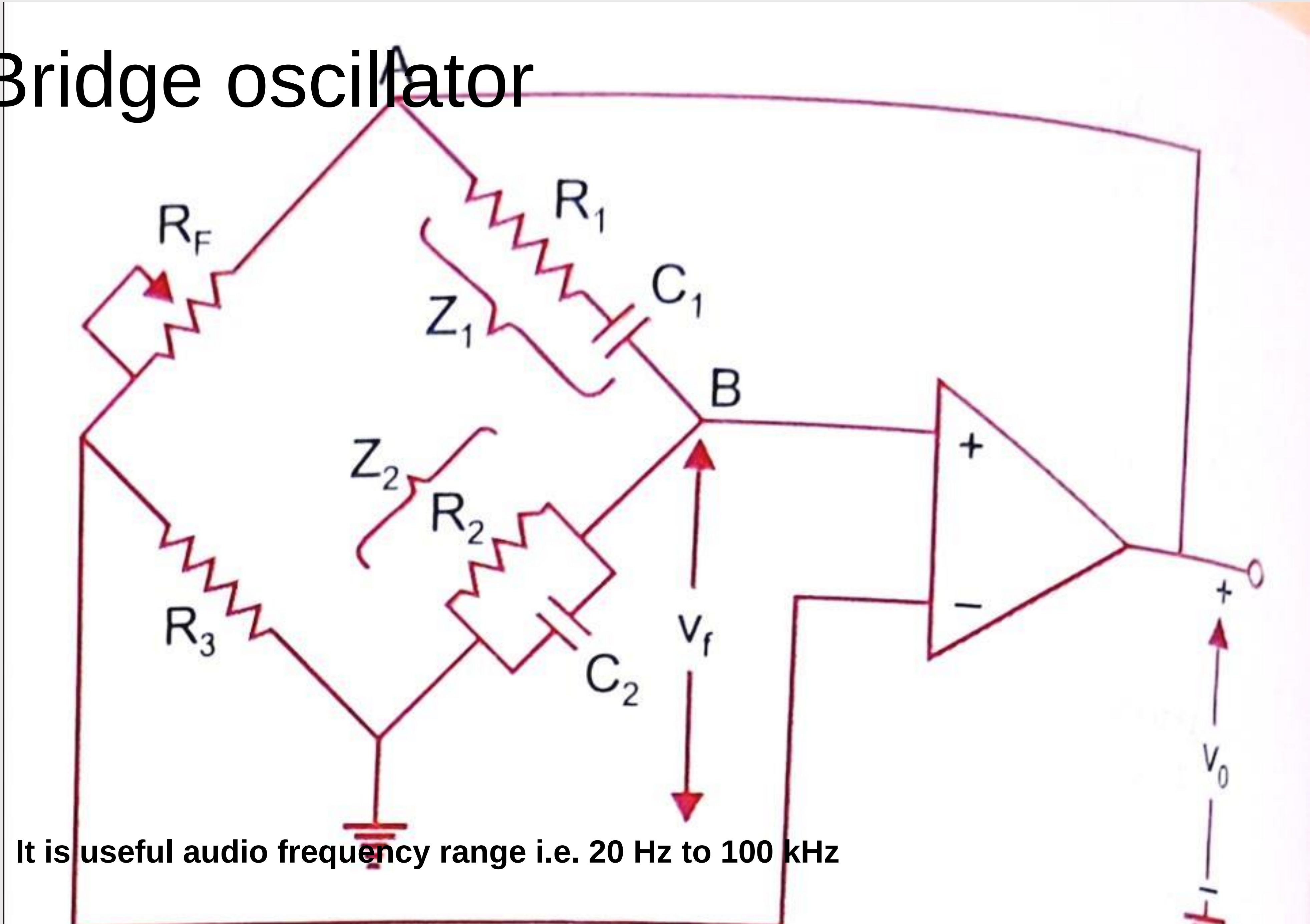
$f_0 = \frac{1}{2\pi RC}$ and $\beta = \frac{1}{3}$

For sustained oscillations $|A\beta| \geq 1$ $|A| \geq 3$ and $1 + \frac{R_F}{R_1} \geq 3$

$R_F = 2R_1$

It is useful audio frequency range i.e. 20 Hz to 100 kHz

3. Wien Bridge oscillator



It is useful audio frequency range i.e. 20 Hz to 100 kHz