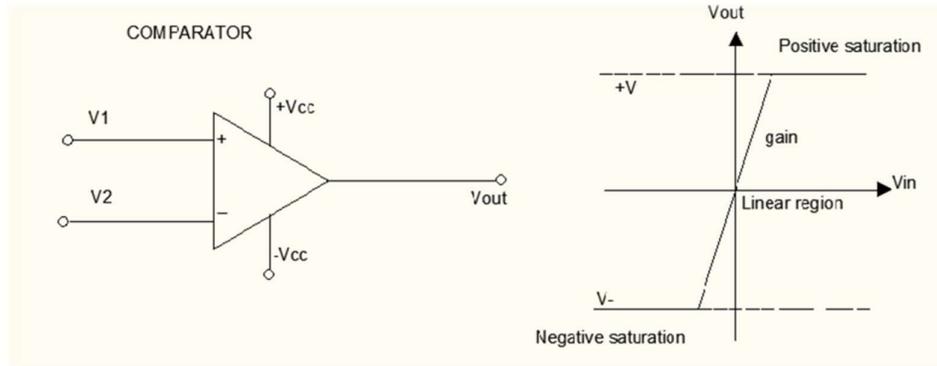# Unit IV
Comparators and Signal Generators

COMPARATOR:

The circuit diagram and response characteristics of comparator are shown in given figure. It contains two input terminals and only one output terminal. The voltage applied to the inverting input is V**1** and the non-inverting input is V**2**.


When V_1 is greater than V_2, the input differential voltage $V_2 - V_1$ is negative then the output reaches maximum negative, typically equal or less than the negative supply voltage (negative saturation). Similarly, when V_2 is greater than V_1 the input differential voltage $V_2 - V_1$ is positive and the output reaches maximum positive, typically equal to or less than the positive supply voltage (positive saturation). When V_1 is equal to V_2, output goes to zero.

It is summarized as follows
(i) **When V₁ (-) > V₂ (+); V0 = - V$_{sat}$**
(ii) **When V₂ (+) > V₁ (-); V0 = +V$_{sat}$**
(iii) **When V₁ (-) = V₂ (+); V0 = 0 volt**

One application of comparator for converting a sine wave signal into a square wave signal is shown in the given figure.
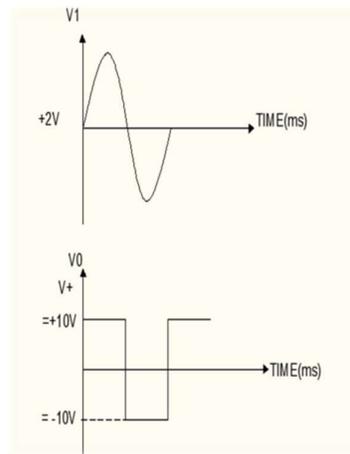
During positive half cycles of input, the non-inverting input voltage is higher than the inverting input voltage. So, the output goes to +ve saturation level(+V_{sat})

➢ During negative half cycles of input, the non-inverting input voltage is lesser than the inverting input voltage. So, the output goes to -ve saturation level(-V_{sat})
➢ Saturation ⟶ equal to +ve (or) –ve supply voltage.

Level Detector

Inverting
Comparator
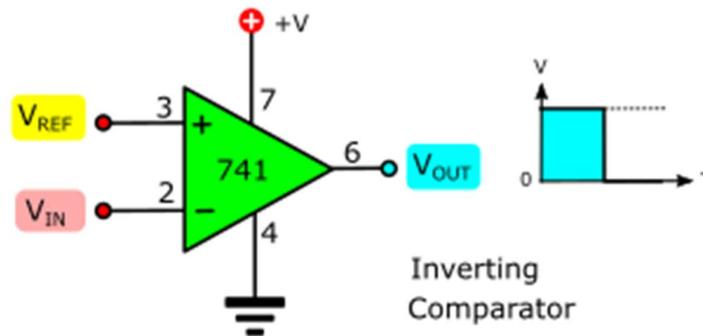
An op-amp level detector uses the high gain of an operational amplifier as a comparator, comparing an input voltage to a fixed reference voltage, producing a digital-like output that switches between positive and negative saturation levels (near supply rails) when the input crosses the set threshold, effectively indicating if the input is above or below a specific voltage level, often used in zero-crossing, positive, or negative detectors.

Working
➢ Comparator Action: An op-amp in open-loop (no negative feedback) acts as a high-gain comparator.
➢ Reference Voltage: A stable reference voltage (V_{ref}) is applied to one input (e.g., inverting), and the input signal (V_{in}) is applied to the other (e.g., non-inverting).
Output **Switching**:

➢ If $V_{in} > V_{ref}$, the output swings to the positive saturation voltage (+V_{sat})
➢ If $< V_{ref}$, the output swings to the negative saturation voltage($-V_{sat}$).

Applications:

➢ **Zero-Crossing Detector**: When V_{ref} is 0V, it detects when a signal crosses zero.
➢ **Positive Level Detector**: Sets V_{ref} to a positive voltage to detect when input goes above that level.
➢ **Negative Level Detector**: Sets V_{ref} to a negative voltage.

Schmitt Trigger

When positive feedback is added to the comparator circuit, gain can be increased greatly. Consequently, the transfer curve of comparator becomes more close to ideal curve. Theoretically, if the loop gain $-\beta A_{oL}$ is adjusted to unity, then the gain with feedback, A_v, becomes infinite. This results in an abrupt (zero rise time) transition between the extreme

values of output voltage. In practical circuits, however, it may not be possible to maintain loop-gain exactly equal to unity for a long time because of supply voltage and temperature variations. So a value greater than unity is chosen. This also gives an output wave-form virtually discontinuous at the comparison voltage. This circuit, however, now exhibits a phenomenon called hysteresis or backlash.
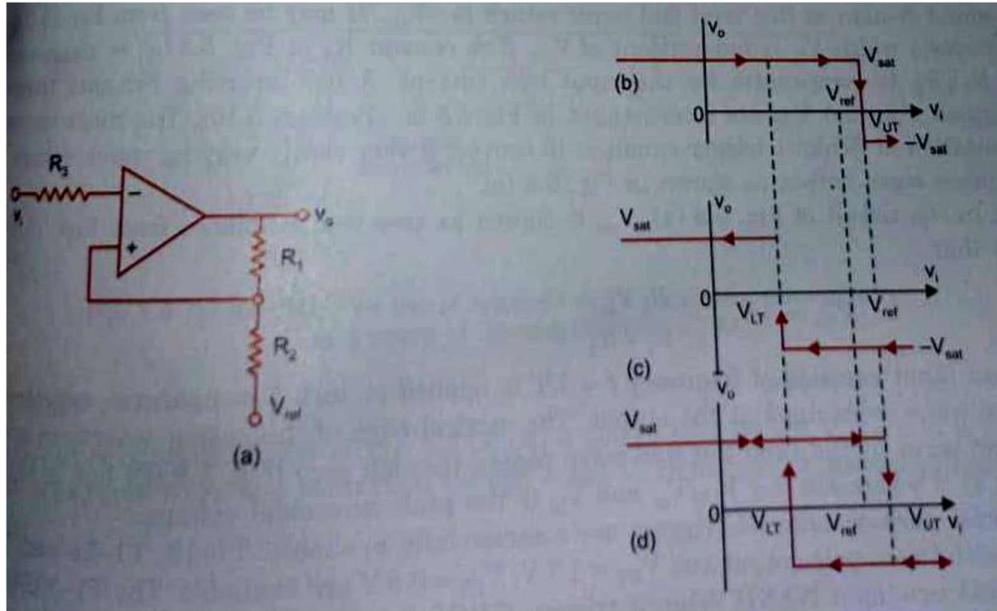

Figure (a) shows such a regenerative comparator. The circuit is also known as Schmitt Trigger. The input voltage is applied to the (-) input terminal and feedback voltage to the (+) input terminal. The input voltage v triggers the output v, every time it exceeds certain voltage levels. These voltage levels are called upper threshold voltage (V_{UT}) and lower threshold voltage (V_{LT}). The hysteresis width is the difference between these two threshold voltages. These threshold voltages are calculated as follows.

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

This voltage is called upper threshold voltage V_{UT}. As long as vi is less than, V_{UT} the output V_o , remains constant at + V_{sat}. When v_i is just greater than V_{UT} shown in Fig (b). For v_o = -V_{sat} the voltage at the (+) input terminal is,

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

This voltage is referred to as lower threshold voltage V_{LT}. The input voltage v_i must become lesser than in order to cause v_o, to switch from -V_{sat} to +V_{sat}. A regenerative transition takes place as shown in Fig (c) and the output v_o returns from -V_{sat} to +V_{sat} almost instantaneously. The complete transfer characteristics are shown in Fig. (d).

Note that the difference between these two voltages is the hysteresis width V_H and can be written as

$$V_H = V_{UT} - V_{LT}$$
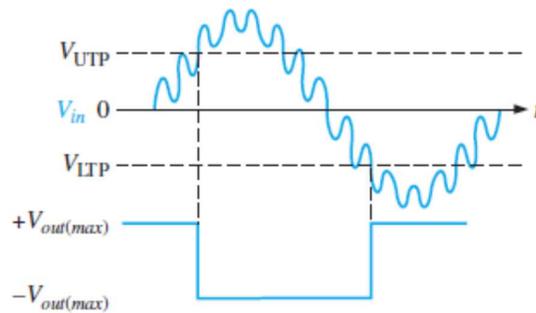
Concept of Sinusoidal and Relaxation Type

Sinusoidal and relaxation oscillators are two main types of electronic circuits that generate periodic signals, primarily distinguished by the waveform they produce and their underlying operating principle.

Sinusoidal Oscillators

Sinusoidal (or harmonic) oscillators generate a smooth, continuous waveform that follows a mathematical sine or cosine function.

Output Waveform: Pure sine waves, ideally with constant amplitude and a single frequency (minimal harmonic distortion).

Operating Principle: They use an amplifier and a frequency-selective feedback network (often involving inductors (L) and capacitors (C), or resistors (R) and capacitors (C)) to provide positive feedback at a specific frequency, satisfying the Barkhausen criterion. The energy flow is generally smooth and continuous.

Frequency Control: The frequency is highly stable and precisely determined by the components in the resonant circuit (e.g., LC tank circuits or quartz crystals).

Applications: Used as reference or carrier signals in communication systems, audio systems, and highly stable clock sources in computers and watches, where a clean, pure tone is essential.

Examples: Hartley, Colpitts, Clapp, Wien-bridge, and crystal oscillators.

Relaxation Oscillators

Relaxation oscillators generate non-sinusoidal, repetitive signals that have sharp transitions and distinct shapes.

Output Waveform: Square, triangular, rectangular, or saw tooth waves.

Operating Principle: They operate on the principle of repeatedly charging and discharging an energy-storage element, typically a capacitor, through a resistive path. A non-linear switching device (like a UJT, Op-Amp, or 555 timer IC) triggers the rapid discharge when a certain voltage threshold is reached, causing abrupt changes in the waveform.

Frequency Control: The frequency depends on the time constant (RC values) of the charging/discharging cycle and is generally less stable than sinusoidal oscillators. They are easier to tune over a wide range, however.

Applications: Used in digital circuits for clock signals (though less stable than crystal oscillators), blinking lights, electronic beepers, function generators, and time-base circuits for displays.

Examples: Multivibrators, UJT relaxation oscillators, and circuits based on the 555 timer IC.

RC Phase Shift Oscillator

        The circuit diagram of RC phase shift oscillator using op-amp for producing sinusoidal signal is shown in given figure.
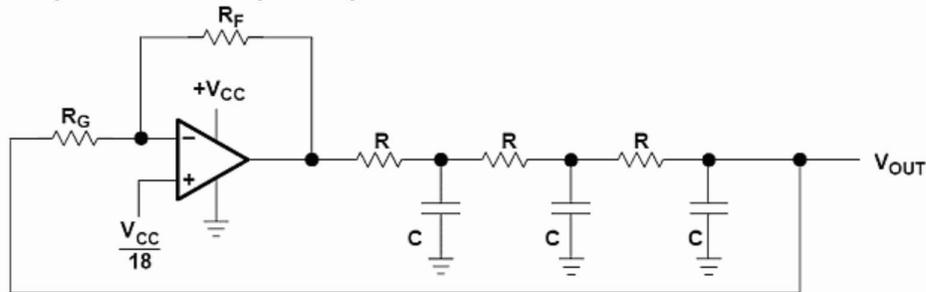
RC phase shift oscillator using op-amp uses op-amp in inverting amplifier mode.

- ➢ Thus it introduces the phase shift of 1800 between the input and output.
- ➢ The feedback network produces another 1800. So the total phase shift is 3600.
- ➢ In the feedback loop three RC networks are used. So each RC network produces 600phase shift.
- ➢ This satisfies the required conditions for positive feedback and circuit works as an oscillator.

        The frequency of the signal produced by this oscillator, $f = \dfrac{1}{2\pi RC \sqrt{6}}$

Advantages:
- ➢ The circuit is easy to design.
- ➢ It produces output over audio frequency range.
- ➢ It is a fixed frequency oscillator.

Disadvantage:
- ➢ It cannot be used for tuned oscillator.

WIEN BRIDGE OSCILLATOR

     ➢ It uses a non-inverting amplifier (does not provide any phase shift during amplifier stage).

     ➢ As total phase shift required is 00 or 2nπ radians, in wien bridge type no phase shift is necessary through feedback.

     ➢ Thus the total phase shift around a loop is 00.

     ➢ A Wien-Bridge Oscillator is a type of phase-shift oscillator which is based upon a Wien-Bridge network comprising of four arms connected in a bridge fashion.

     ➢ Here two arms are purely resistive while the other two arms are a combination of resistors and capacitors.

     ➢ In particular, one arm has resistor and capacitor connected in series (R1 and C1) while the other has them in parallel (R2 and C2).

   ➢ Two arms of the bridge R1 , C1 in series and R2 , C2 in parallel are frequency sensitive.

     ➢ In this circuit, at high frequencies, the reactance of the capacitors C1 and C2 will be much less due to which the voltage V0 will become zero as R2 will be shorted.

     ➢ At low frequencies, the reactance of the capacitors C1 and C2 will become very high. However even in this case, the output voltage V0 will remain at zero only, as the capacitor C1 would be acting as an open circuit.

➢ This kind of behavior exhibited by the Wien-Bridge network makes it a lead-lag circuit in the case of low and high frequencies, respectively

$$f = \frac{1}{2\pi RC}$$
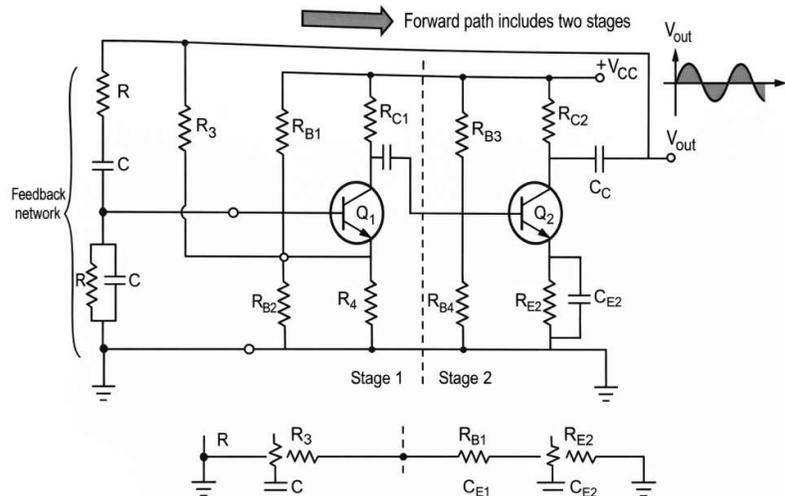
Advantages
The advantages of Wien bridge oscillator are as follows −

➢ The circuit provides good frequency stability.

➢ It provides constant output.

➢ The operation of circuit is quite easy.

➢ The overall gain is high because of two transistors.

➢ The frequency of oscillations can be changed easily.

➢ The amplitude stability of the output voltage can be maintained more accurately, by replacing R2 with a thermistor.

Disadvantages
The disadvantages of Wien bridge oscillator are as follows −

➢ The circuit cannot generate very high frequencies.

➢ Two transistors and number of components are required for the circuit construction.

Square Wave Generator:
A simple square wave generator by using op-amp is shown in given figure. It is otherwise called astable multivibrator or a free running oscillator.
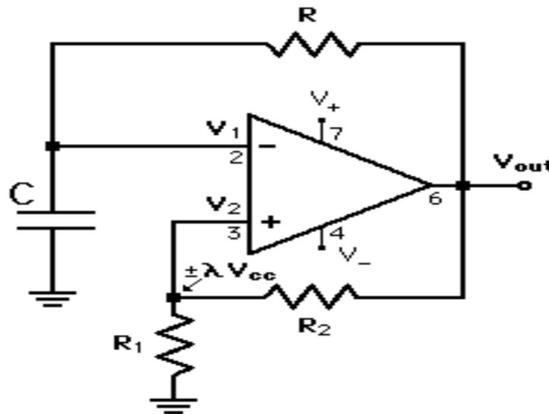
A capacitor is connected at is inverting input terminal .It is basically a comparator circuit. So the output goes to either $+V_{sat}$ or $-V_{sat}$, depending upon its differential input voltage. By connecting the portion divider across the output terminal, a portion of output voltage ($\beta Vsat$) is applied to the non-inverting input of op-amp. From the figure, now we are going to calculate the output voltage starting from ground.

From the figure, now we are going to calculate the output voltage starting from ground.

$$\frac{0 - V_2}{R_2} = \frac{V_2 - V_0}{R_1}$$

$$\frac{-V_2}{R_2} = \frac{V_2 - V_0}{R_1}$$

$$\frac{-V_2}{R_2} = \frac{V_2}{R_1} - \frac{V_0}{R_1}$$

$$\frac{V_0}{R_1} = \frac{V_2}{R_1} + \frac{V_2}{R_2}$$

$$\frac{V_0}{R_1} = V_2 \left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

Now take LCM,

$$\frac{V_0}{R_1} = V_2 \frac{R_1 + R_2}{R_1 R_2}$$

$$\frac{1}{\not{R_1}} \left(\frac{\not{R_1} R_2}{R_1 + R_2}\right) = \frac{V_2}{V_0}$$

$$\frac{R_2}{R_1 + R_2} = \frac{V_2}{V_0}$$

$$V_2 = V_0 \left(\frac{R_2}{R_1 + R_2}\right)$$

Assume,

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

$$V_2 = \beta V_0$$

That is β amount of output voltage is fed back to non-inverting input terminal.
Due to the mismatch between the inverting and non-inverting terminals of the op-amp, the output goes to either $+V_{sat}$ or $-V_{sat}$.

➢ When the supply voltage is switched ON, assume that the output goes to $+V_{sat}$. Due to this, $+\beta V_{sat}$ is applied to the non-inverting input of op-amp.

➢ Then the capacitor C starts charging with a polarity of upper plate positive and lower plate negative towards $+V_{sat}$ through resistor R.

➢ When the capacitor reaches $+\beta V_{sat}$, the output goes to $-V^{sat}$.
➢ Now $-\beta V_{sat}$ voltage is applied to the non-inverting input of op-amp.
➢ Then the capacitor starts charging in opposite direction, with lower plate positive and upper plates negative towards $-V_{sat}$ through the resistor R.
➢ Similarly when the capacitor attains $-\beta V_{sat}$ the output of op-amp goes to $+V_{sat}$, and $+\beta V_{sat}$ is applied to its non-inverting terminal. And the process repeated.

The signal waveform of square wave generator is shown in figure.

A continuous square wave signal is generated at the output with respect to the charging and discharging effect of capacitor. The total time period for one oscillation is given as
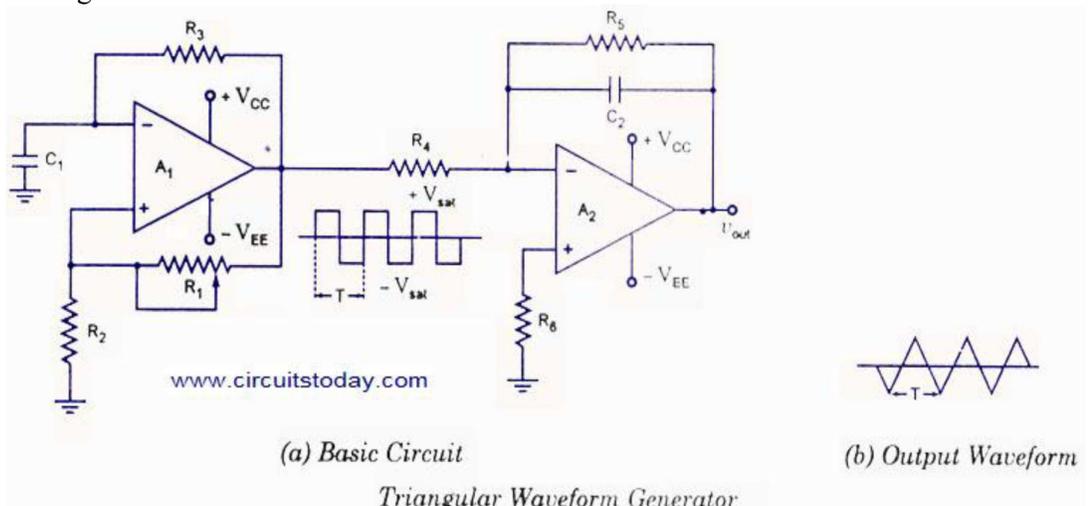
$$T = 2RC \ln \left(\frac{2R_1 + R_2}{R_2} \right) \text{ sec}$$
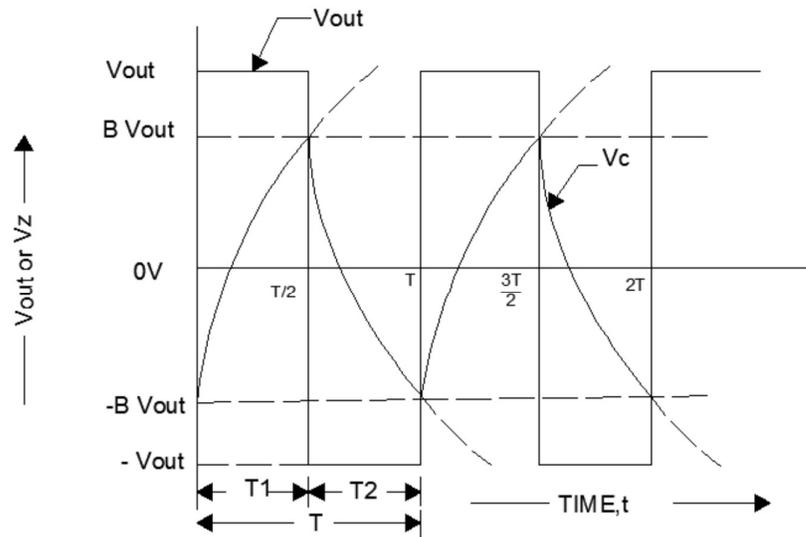

OUTPUT AND CAPACITOR VOLTAGE WAVEFORM

Triangle Wave Generator

By connecting an integrator circuit at the output of square wave generator, triangular wave will be generated.

(a) Basic Circuit   (b) Output Waveform

Triangular Waveform Generator

The amplitude of square wave generator is constant at $\pm V_{sat}$. But in triangular wave, amplitude will decrease as the frequency increases. This is due to the reactance of capacitor

C$_2$ in the feedback circuit. A resistance R$_4$ is connected across C$_2$ to avoid saturation problem at low frequencies. But the frequency of the triangular wave is same as that of square wave.
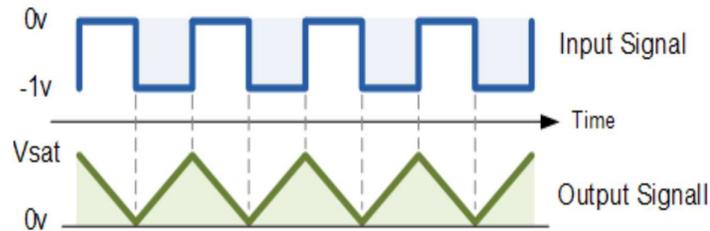

The square wave at the output of square wave generator is converted into triangular wave signal with respect to the charging and discharging effect of capacitor.

➢ When V' is low at –V$_{sat}$, it forces a constant current $\left(-\frac{V_{sat}}{V_3}\right)$ through C$_2$ (right to left) to drive V$_0$ positive linearly.

➢ Because, the output of square wave generator is applied to the inverting input of integrator.

➢ Similarly, when V' is high at +V$_{sat}$, forces constant current $\left(+\frac{V_{sat}}{V_3}\right)$ through C$_2$ (left to right) to drive V$_0$ negative linearly.

The frequency of oscillation can be given as,

$$\mathbf{f_0} = \frac{1}{T} = \frac{R_3}{4R_1C_1R_2}$$

Saw Tooth Generator
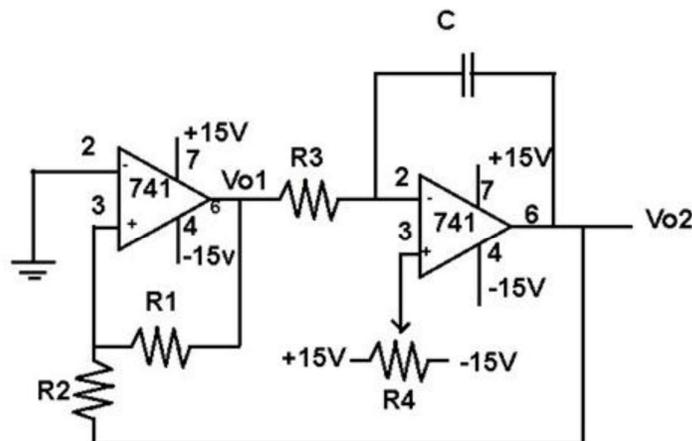
Triangular wave has equal rise and fall times but a saw tooth wave rises positively than it falls or it falls many times faster than it rises. Therefore, a triangular wave generator can be converted into a saw tooth wave generator by connecting a variable dc voltage into the non-inverting terminal of integrator, as shown in above figure.

Here, the non-inverting terminal (+input) of the integrator is driven by the voltage set between +V$_{CC}$ to –V$_{EE}$ by the potentiometer R$_4$. Depending on the R$_4$ setting, a certain dc level is added in the output of integrator.

As output of the integrator decides the effective voltage at point P, added dc level in the output of the integrator will affect the duty cycle of the comparator output. When the voltage at the non-inverting input of the integrator is negative, the duty cycle is less than 50%, resulting longer rise time than the fall time.

On the other hand, when voltage at the non-inverting input of the integrator is positive, the duty cycle is greater than 50% and rise time is less than the fall time. The frequency of the saw tooth generator decreases, when the voltage at the non-inverting input of the integrator B is adjusted towards $+V_{CC}$ or $-V_{EE}$. The amplitude of saw tooth wave is independent of the voltage setting at the non-inverting input of the integrator.