Square Wave Generator Using Op amp:

The Square Wave Generator Using Op amp means the **astable multivibrator circuit** using op-amp, which generates the square wave of required frequency. The Fig. 2.83 shows the square wave generator using op amp.

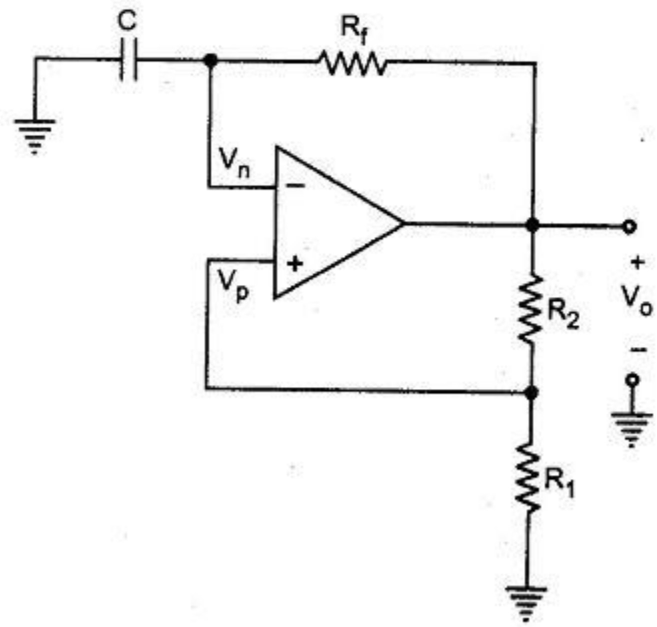

Fig. 2.83 Square wave generator

It looks like a comparator with hysteresis (schmitt trigger), except that the input voltage is replaced by a capacitor. The circuit has a time dependent elements such as resistance and capacitor to set the frequency of oscillation.

As shown in the Fig. 2.83 the comparator and positive feedback resistors R_1 and R_2 form an inverting schmitt trigger.

When V_o is at $+V_{sat}$, the feedback voltage is called the upper threshold voltage V_{UT} and is given as

$$V_{UT} = \frac{R_1 \cdot +V_{sat}}{R_1 + R_2} \quad \ldots (1)$$

When V_o is at $-V_{sat}$, the feedback voltage is called the lower-threshold voltage V_{LT} and is given as

$$V_{LT} = \frac{R_1 \cdot -V_{sat}}{R_1 + R_2} \quad \ldots (2)$$

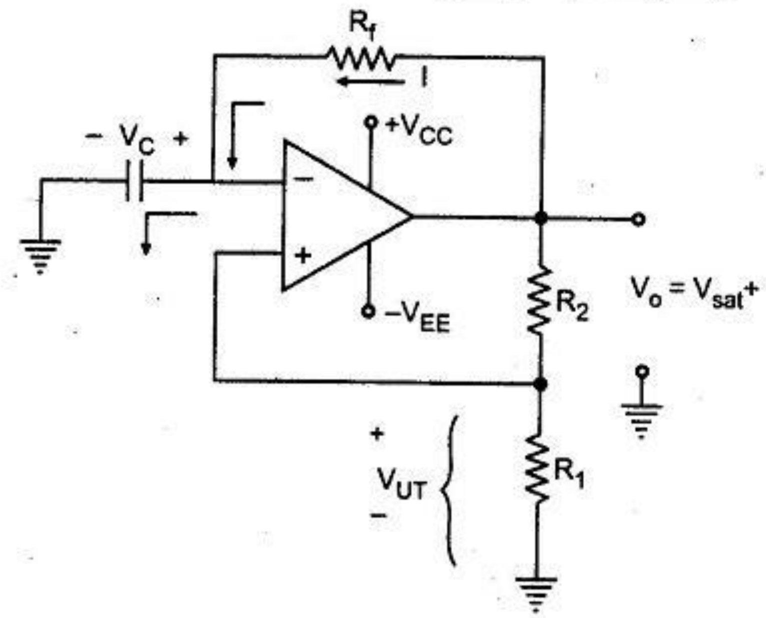

Fig. 2.84 (a) When $V_o = +V_{sat}$, capacitor charges towards V_{UT}

When power is turn ON, V_o automatically swings either to $+V_{sat}$ or to $-V_{sat}$ since these are the only stable states allowed by the schmitt trigger. Assume it swings to $+V_{sat}$. With $V_o = +V_{sat}$ we have – $V_p = V_{UT}$ and capacitor starts charging towards $+V_{sat}$ through the feedback path provided by the resistor R_f to the inverting (-) input. This is illustrated in Fig. 2.84 (a). As long as the capacitor voltage V_C is less than V_{UT}, the output voltage remains at $+V_{sat}$.

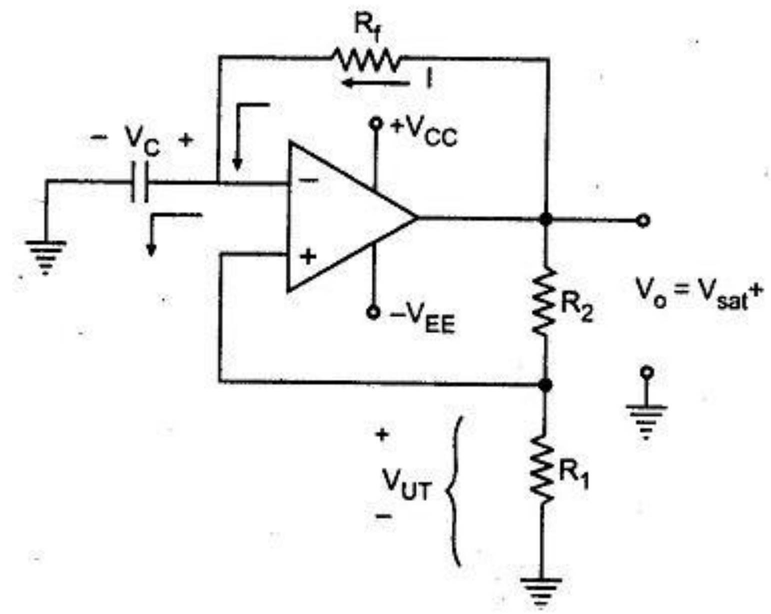

Fig. 2.84 (a) When $V_o = +V_{sat}$, capacitor charges towards V_{UT}

As soon as V_C charges to a value slightly greater than V_{UT}, the (-) input goes positive with respect to the (+) input. This switches the output voltage from $+V_{sat}$ to $-V_{sat}$ and we have $V_p = V_{LT}$, which is negative with respect to ground. As V_o switches to $-V_{sat}$, capacitor starts discharging via R_f, as shown in the Fig. 2.84 (b).

The current I – discharges capacitor to 0 V and recharges capacitor to V_{LT}. When V_C becomes slightly more negative than the feedback voltage V_{LT}, output voltage V_o switches back to $+V_{sat}$. As a result, the condition in Fig. 2.84(a) is reestablished except that capacitor now has a initial charge equal to V_{LT}. The capacitor will discharge from V_{LT} to 0V and then recharge to V_{UT}, and the process is repeating. Once the, initial cycle is completed, the waveform become periodic, as shown in the Fig. 2.84(c).

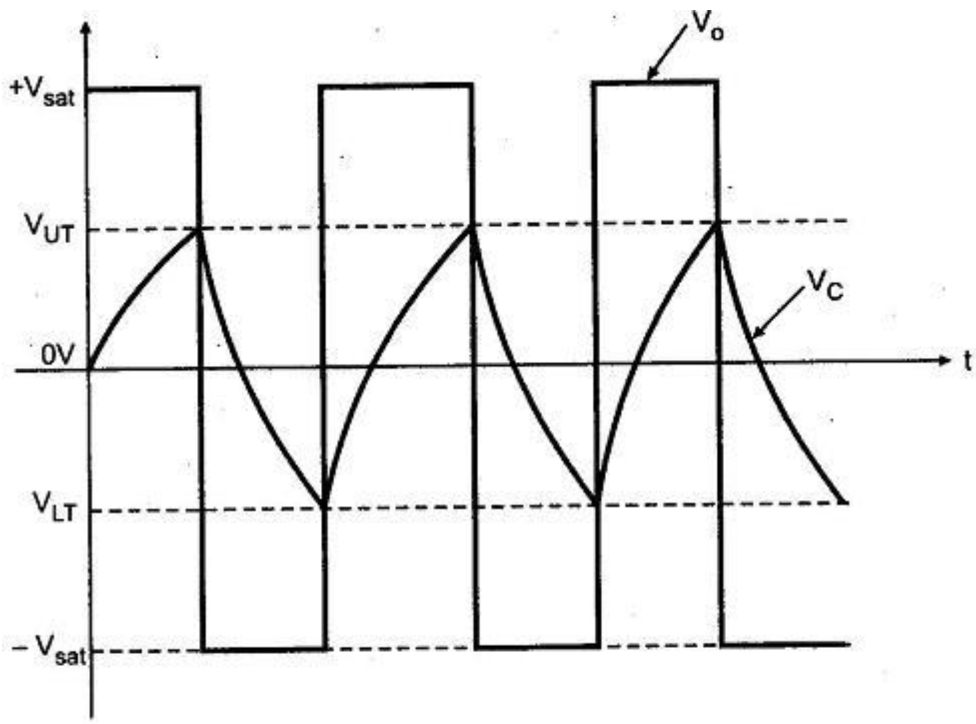

Fig. 2.84 (c) Waveforms

Frequency of Oscillation:

The frequency of oscillation of Square Wave Generator Using Op amp is determined by the time it takes the capacitor to charge from V_{UT} to V_{LT} and vice versa. The voltage across the capacitor as a function of time is given as

$$V_C(t) = V_{max} + (V_{initial} - V_{max})e^{(-t/T)} \quad \dots (3)$$

where

$V_c(t)$ is the instantaneous voltage across the capacitor.

$V_{initial}$ is the initial voltage

V_{max} is the voltage toward which the capacitor is charging.

Let us consider the charging of capacitor from V_{LT} to V_{UT}, where V_{LT} is the initial voltage, V_{UT} is the instantaneous voltage and $+V_{sat}$ is the maximum voltage. At t = T_1, voltage across capacitor reaches V_{UT} and therefore equation (3) becomes

$$V_{UT} = +V_{sat} + (V_{LT} - +V_{sat})\, e^{(-T_1/R_f C)} \qquad \ldots (4)$$

$$\therefore -(V_{LT} - +V_{sat})\, e^{(-T_1/R_f C)} = +V_{sat} - V_{UT}$$

$$\therefore \qquad e^{(-T_1/R_f C)} = \frac{(+V_{sat} - V_{UT})}{(+V_{sat} - V_{LT})}$$

$$\frac{-T_1}{R_f C} = ln\left(\frac{+V_{sat} - V_{UT}}{+V_{sat} - V_{LT}}\right)$$

$$T_1 = -R_f C\, ln\left(\frac{+V_{sat} - V_{UT}}{+V_{sat} - V_{LT}}\right)$$

$$= R_f C\, ln\left(\frac{+V_{sat} - V_{LT}}{+V_{sat} - V_{UT}}\right) \qquad \ldots (5)$$

The time taken by capacitor to charge from V_{UT} to V_{LT} is same as time required for charging capacitor from V_{LT} to V_{UT} . Therefore, total time required for one oscillation is given as

$$T = 2T_1 \qquad \ldots (6)$$

$$= 2R_f C\, ln\left(\frac{+V_{sat} - V_{LT}}{+V_{sat} - V_{UT}}\right) \qquad \ldots (7)$$

The frequency of oscillation can be determined as $f_o = 1/T$, where T represents the time required for one oscillation.

Substituting the value of T we get,

$$f_o = \frac{1}{2 R_f C\, ln\left(\frac{+V_{sat} - V_{LT}}{+V_{sat} - V_{UT}}\right)} \qquad \ldots (8)$$

Triangular Wave Generator Using Op amp:

We have seen that, the output of integrator is a Triangular Wave Generator Using Op amp if its input is a square wave. This means that a Triangular Wave Generator Using Op amp can be formed by simply connecting an integrator to the square wave generator as shown in the Fig. 2.85.

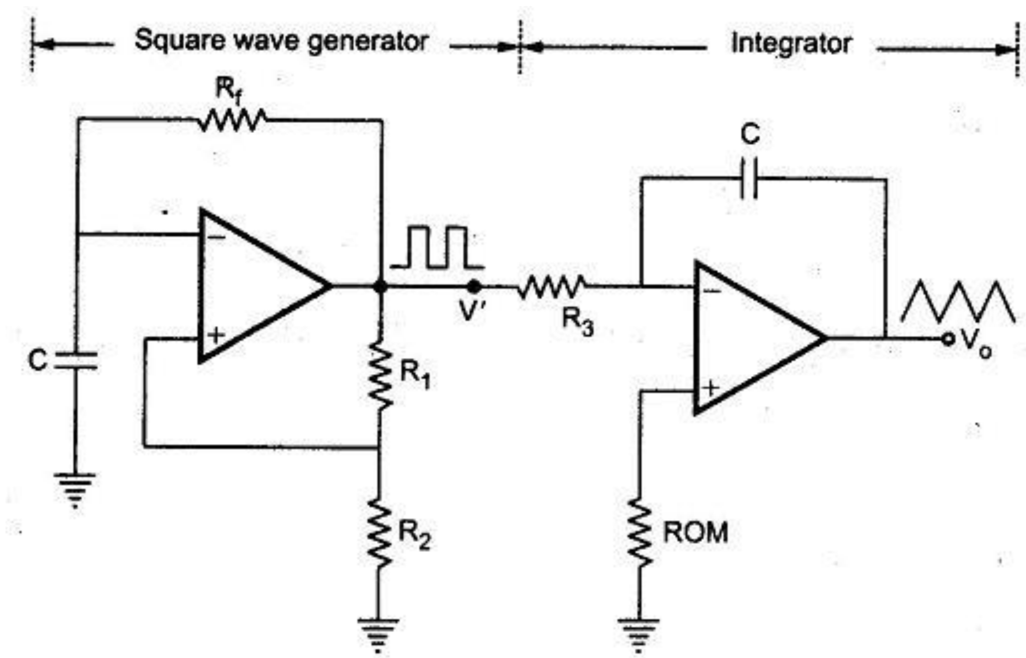

Fig. 2.85 Triangular wave generator

Basically, triangular wave is generated by alternatively charging and discharging a capacitor with a constant current. This is achieved by connecting integrator circuit at the output of square wave generator. Assume that V' is high at $+V_{sat}$. This forces a constant current ($+V_{sat} / R_3$) through C (left to right) to drive V_o negative linearly. When V' is low at $-V_{sat}$, it forces a constant current ($-V_{sat} / R_3$) through C (right to left) to drive V_o positive, linearly. The frequency of the triangular wave is same as that of square wave. This is illustrated in Fig. 2.86. Although the amplitude of the square wave is constant ($\pm V_{sat}$), the amplitude of the triangular wave decreases with an increase in its frequency, and vice versa. This is because the reactance of capacitor decreases at high frequencies and increases at low frequencies.

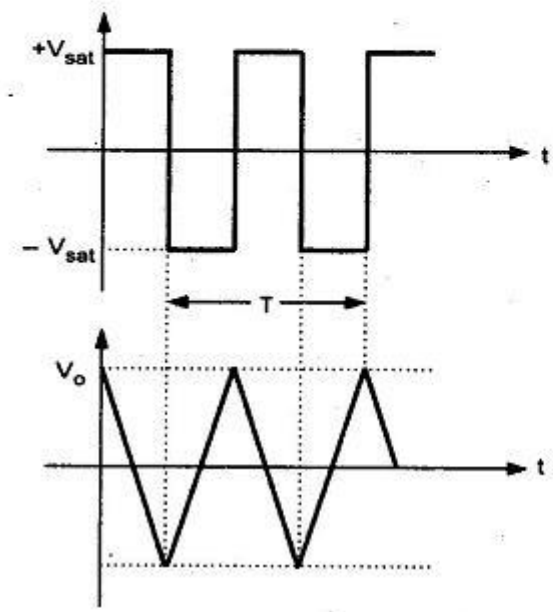

Fig. 2.86 Waveforms of triangular wave generator

In practical circuits, resistance R_4 is connected across C to avoid the saturation problem at low frequencies as in the case of practical integrator as shown in the Fig. 2.87.

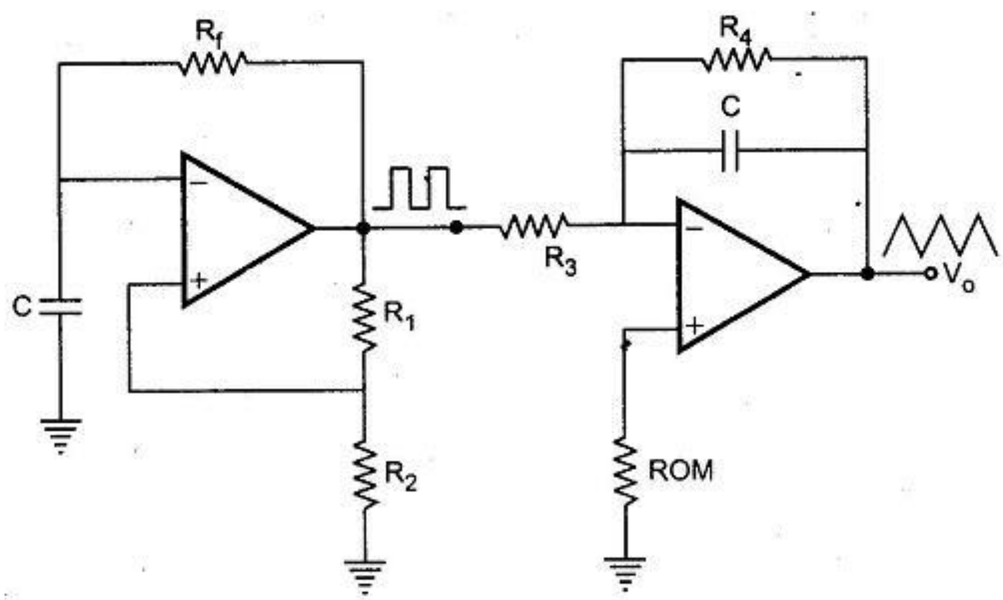

Fig. 2.87 Waveforms for practical triangular wave generator

To obtain stable triangular wave at the output, it is necessary to have $5R_3 C_2 > T/2$, where T is the period of the square wave input.

Another triangular wave generator, which requires fewer components, is shown in the Fig. 2.88.

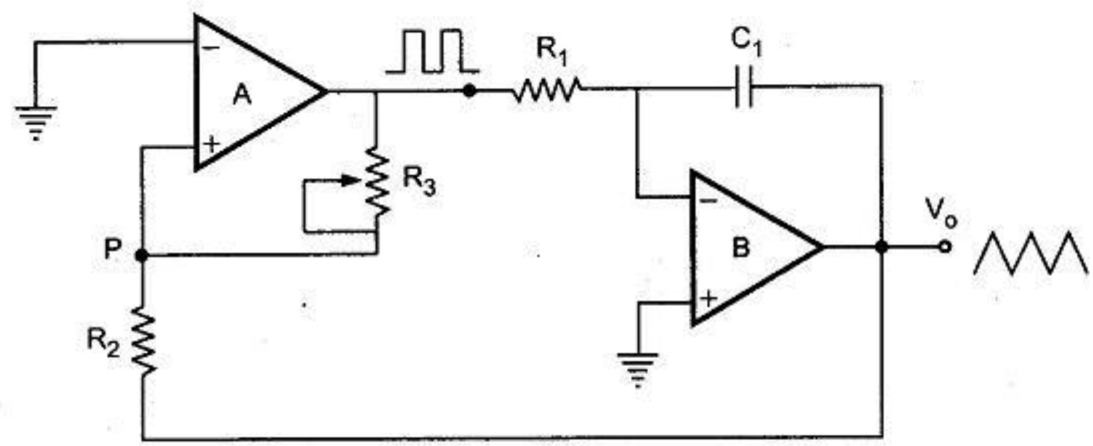

Fig. 2.88 Triangular wave generator

It consists of a comparator (A) and an integrator (B). The output of comparator A is a square wave of amplitude ± V_{sat} and is applied to the inverting (-) input terminal of the integrator B. The output of integrator is a triangular wave and it is feedback as input to the comparator A through a voltage divider R_2 R_3.

To understand circuit operation, assume that the output of comparator A is at + V_{sat} . This forces a constant current (+ V_{sat} / R_1) through C to give a negative going ramp at the output of the integrator, as shown in the Fig. 2.88. Therefore, one end of voltage divider is at a voltage +V_{sat} and the other at the negative going ramp. When the negative going ramp reaches a certain value -V_{ramp}, the effective voltage at point p becomes slightly below 0V.

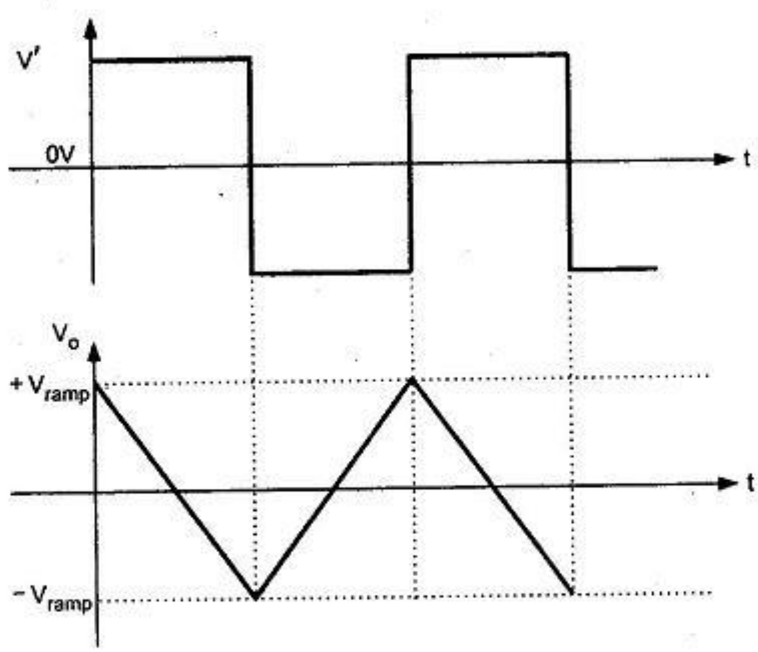

Fig. 2.89 Waveforms of triangular wave generator

As a result, the output of comparator A switches from positive saturation to negative saturation ($-V_{sat}$). This forces a reverse constant current (right to left) through C to give a positive going ramp at the output of the integrator, as shown in the Fig. 2.89. When positive going ramp reaches + V_{ramp}, the effective voltage at point p becomes slightly above 0V. As a result, the output of comparator A switches from negative saturation to positive saturation ($+V_{sat}$). The sequence then repeats to give triangular wave at the output of integrator B.

Amplitude and Frequency Calculations:

The frequency and amplitude of the Triangular Wave Generator Using Op amp wave can be determined as follows :

When comparator output is at $+V_{sat}$, the effective voltage at point P is given by

$$-V_{ramp} + \frac{R_2}{R_2 + R_3}\left[+V_{sat} - (-V_{ramp})\right] \qquad \ldots (1)$$

When effective voltage at P becomes equal to zero, we can write above equation

$$-V_{ramp} + \frac{R_2}{R_2+R_3}[+V_{sat} - (-V_{ramp})] = 0$$

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

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

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

Similarly, when comparator output is at $-V_{sat}$, we can write,

$$V_{ramp} = \frac{-R_2}{R_3}(-V_{sat}) \quad \text{... (3)}$$

The peak to peak amplitude of the triangular wave can be given as

$$V_{o(pp)} = +V_{ramp} - (-V_{ramp}) \quad \text{... (4)}$$

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

If $|+V_{sat}| = |-V_{sat}|$ then, we can write

$$V_{o(pp)} = \frac{R_2}{R_3}V_{sat} + \frac{R_2}{R_3}V_{sat} = \frac{2R_2}{R_3}V_{sat} \quad \text{... (5)}$$

The time taken by the output to swing from $-V_{ramp}$ to $+V_{ramp}$ (or from $+V_{ramp}$ to $-V_{ramp}$) is equal to half the time period T/2. Refer Fig. 2.89. This time can be calculated from the integrator output equation as follows :

$$V_{o(pp)} = -\frac{1}{R_1C_1}\int_0^{T/2}(-V_{sat})\,dt = \left(\frac{V_{sat}}{R_1C_1}\right)\frac{T}{2} \quad \text{... (6)}$$

$$T = \frac{2R_1C_1V_{o(pp)}}{V_{sat}} \quad \text{.... (7)}$$

Substituting value of $V_{o(pp)}$ we get,

$$T = \frac{2R_1 C_1 \left(\frac{2R_2}{R_3} V_{sat}\right)}{V_{sat}} = \frac{4R_1 C_1 R_2}{R_3} \qquad \dots (8)$$

Therefore, the frequency of oscillation can be given as,

$$f_o = \frac{1}{T} = \frac{R_3}{4R_1 C_1 R_2} \qquad \dots (9)$$