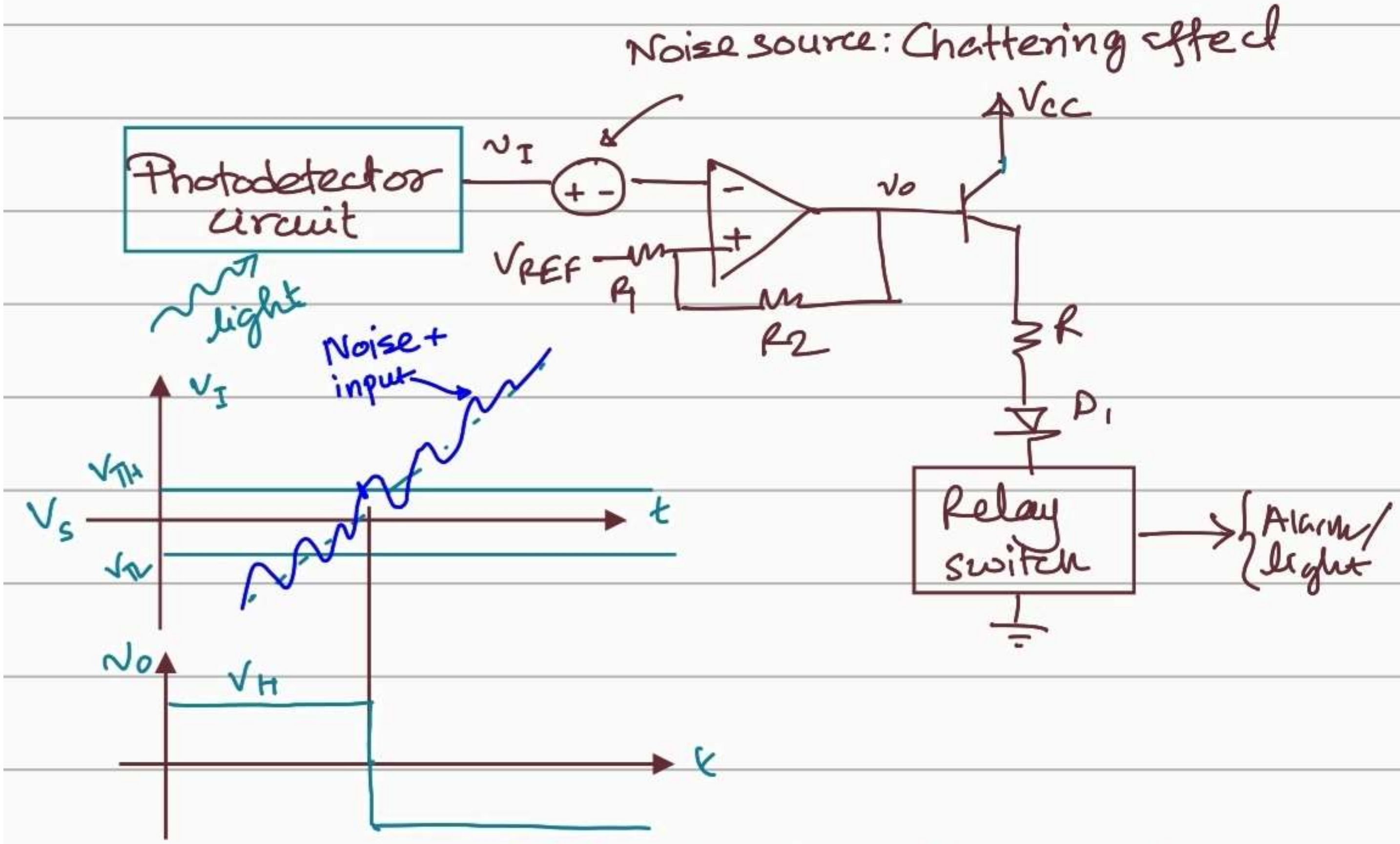
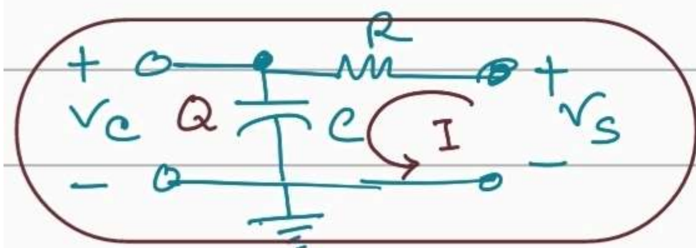


Design problem 15.7 (Practice | Final Exam)

Lecture 19: Signal Generators.

Basic R-C circuit:



Suppose, at initial time t_1 the capacitor has a voltage $v_c(t_1) = v_{initial}$.

If $v_S > v_c(t_1)$. $Q \uparrow$ and if $v_S < v_c(t_1)$. $Q \downarrow$.

From the definition of current flow, we know that, $I = \frac{dQ}{dt}$

Using the definition of capacitance ($C = \frac{Q}{V}$)

$$I = \frac{dQ}{dt} = \frac{d}{dt}(CV_c) = \boxed{C\frac{dV_c}{dt} = \frac{V_S - V_c}{R}}$$

We want to determine the voltage across capacitor for the time $t_1 < t < \infty$.

$$C\frac{dV_c}{dt} = \frac{V_s - V_c}{R} \Rightarrow \int_{V_c(t_1)}^{V_c(t)} \frac{dV_c}{V_s - V_c} = \int_{t_1}^{t} \frac{dt}{RC}$$

$$\Rightarrow -\ln|V_s - V_c|\Big|_{V_c(t_1)}^{V_c(t)} = \frac{t-t_1}{RC} \Rightarrow t - t_1 = RC\ln\left|\frac{V_s - V_c(t_1)}{V_s - V_c(t)}\right|$$

$$\Rightarrow \boxed{V_c(t) = V_s + (V_c(t_1) - V_s)\exp\left(-\frac{t-t_1}{RC}\right)}$$

$t \to \infty$, $V_c(\infty) = V_s$ because $\exp(-\infty) \to 0$.

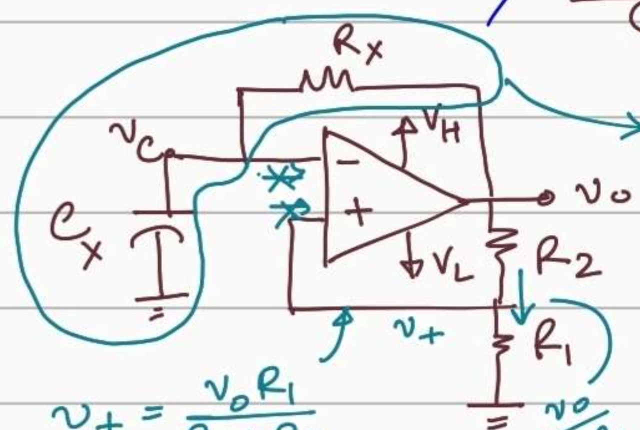
$V_c(\infty) = V_s = V_{final}$ and $V_c(t_1) = V_{initial}$.

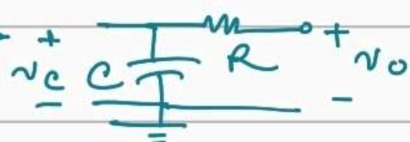
$\tau = RC$ = time constant.

$$\boxed{V_c(t) = V_{final} + (V_{initial} - V_{final})\exp\left(-\frac{t-t_1}{\tau}\right)}$$

Schmitt Oscillator / Astable Multivibrator:

↳ There is no stable state.





$$v_c(t) = v_o + (v_{initial} - v_o)\exp\left(-\frac{t-t_1}{R_x C_x}\right)$$

$$v_+ = \frac{v_o R_1}{R_1 + R_2}$$

$$\frac{v_o}{R_1+R_2}$$

$$t - t_1 = \tau\ln\left|\frac{v_{final} - v_c(t_1)}{v_{final} - v_c(t_2)}\right|$$

$v_{final} \to v_o$

\# We already know the threshold voltages.

$$V_{TH} = V_H\frac{R_1}{R_1+R_2} \quad \text{and} \quad V_{TL} = V_L\frac{R_1}{R_1+R_2}$$

\# Coughline. Chapter 6.

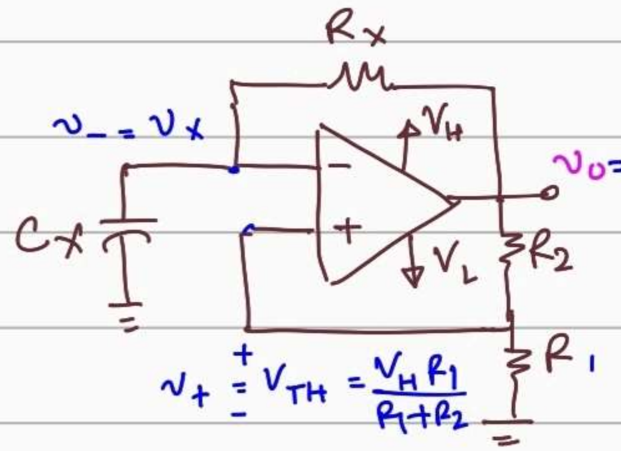
$V_{TH} \to V_{UT}$ = upper threshold voltage

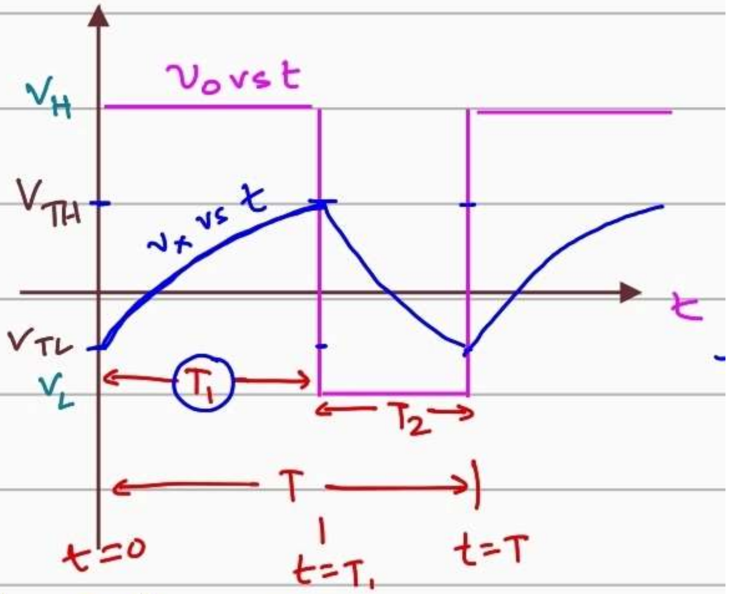
$V_{TL} \to V_{LT}$ = lower threshold voltage

$V_H \to V_{sat}$, $V_L \to -V_{sat}$, $|V_{sat}| \neq |-V_{sat}|$

Square Wave Generator: (Steady state analysis)

① **Case 1**: $0 < t < T_1$





Initial condition: $v_x = V_{TL}$ and $v_o = V_H$

The output v_o will remain at same value until $v_- = v_x$ crosses the voltage V_{TH}. $[v_+ > v_-,\ v_o = V_H]$

$$\boxed{v_c = v_x(t) = V_H + (V_{TL} - V_H)\exp\left(-\frac{t-0}{R_x C_x}\right)}$$

At $t = T_1$, $v_x(T_1) = V_{TH}$. Using this condition we can determine the value of T_1

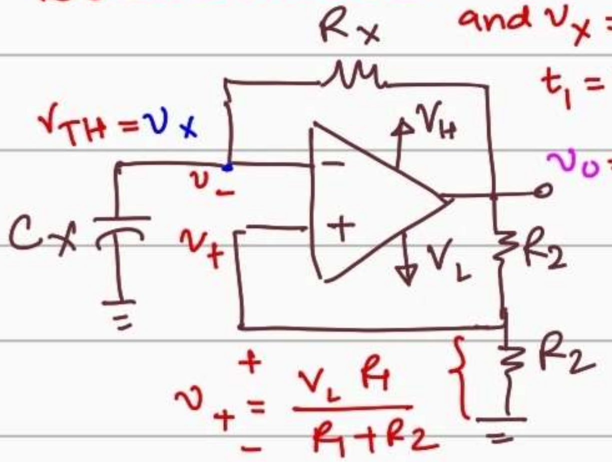
$$v_x(T_1) = V_{TH} = V_H + (V_{TL} - V_H)\exp\left(-\frac{T_1}{R_x C_x}\right)$$

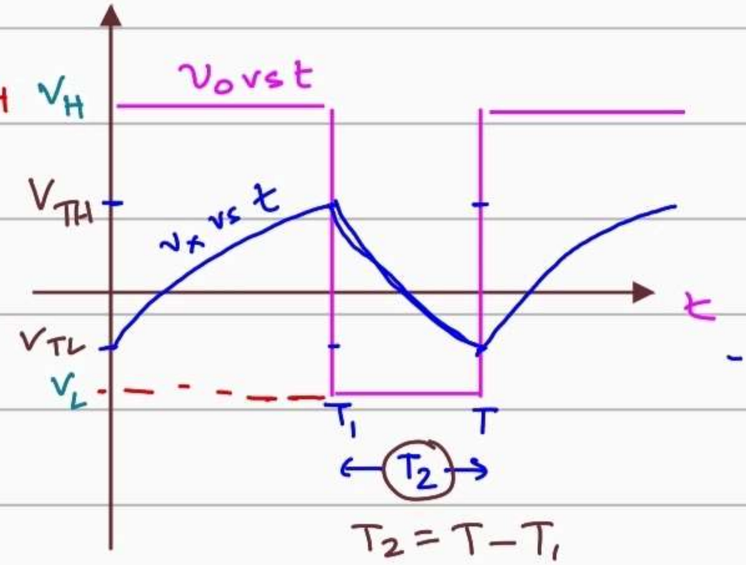
$$\Rightarrow \boxed{T_1 = R_x C_x \ln\left|\frac{V_H - V_{TL}}{V_H - V_{TH}}\right|}$$

② **Case 2**: $T_1 < t < T$

Initial condition: $v_o = V_L$ and $v_x = V_{TH}$

$t_1 = T_1$





$(v_+ < v_-)$ Now output will remain at $v_o = V_L$ until v_x crosses V_{TL}.

$$\boxed{v_c = v_x(t) = V_L + (V_{TH} - V_L)\exp\left(-\frac{t - T_1}{R_x C_x}\right)}$$

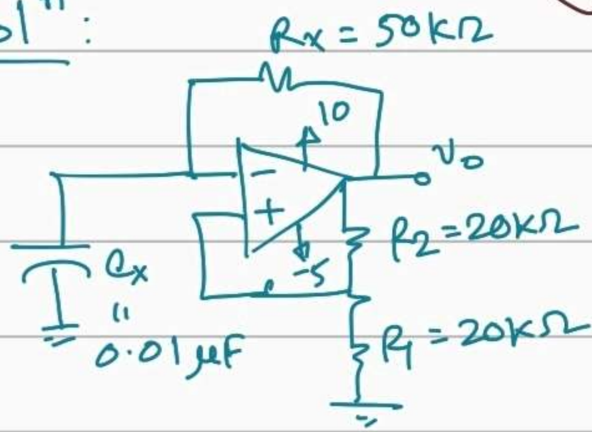
At $t = T$ time $v_x(T) = V_{TL}$. So using this we find.

$$V_x(T) = V_{TL} = V_L + (V_{TH} - V_L)\exp\left(-\frac{\overset{T_2}{\cancel{(T - T_1)}}}{R_x C_x}\right)$$

$$\Rightarrow \boxed{T_2 = R_x C_x \ln\left|\frac{V_L - V_{TH}}{V_L - V_{TL}}\right|}$$ ← Just swap $H \leftrightarrow L$ to get T_1.

Neamann's Exercise 15.8. For the Schmitt trigger Oscillator, the saturation output voltages are +10V and −5V. $R_1 = R_2 = 20\,K\Omega$, $R_x = 50\,K\Omega$ and $C_x = 0.01\,\mu F$. Determine the frequency and duty cycle.

Sol^n:



$$V_{TH} = \frac{V_H R_1}{R_1 + R_2} = \frac{10 \times 20}{20 + 20} = 5\,V$$

$$V_{TL} = \frac{V_L R_1}{R_1 + R_2} = \frac{-5 \times 20}{20 + 20} = -2.5\,V$$

$$\tau = R_x C_x = 50 \times 10^3 \times 0.01 \times 10^{-6}\ \Omega F$$
$$= 0.5 \times 10^{-3}\,s$$
$$= 0.5\,ms$$

Time duration of high output. $T_1 = \tau \ln\left|\frac{V_H - V_{TL}}{V_H - V_{TH}}\right|$

$$T_1 = 0.5\,ms \times \ln\left|\frac{10 - (-2.5)}{10 - 5}\right| = 0.5 \ln(2.5)\ ms$$

Time duration of low output. $T_2 = \tau \ln\left|\frac{V_L - V_{TH}}{V_L - V_{TL}}\right|$

$$T_2 = 0.5\,ms \times \ln\left|\frac{-5 - 5}{-5 - (-2.5)}\right| = 0.5 \ln(4)\ ms$$

Total time period. $T = T_1 + T_2 = 0.5 \ln(2.5 \times 4)$

$$= 0.5 \ln(10)$$

frequency. $f = \frac{1}{T} = \frac{1}{0.5\ln(10)\,mS} = 0.868\,KHz$

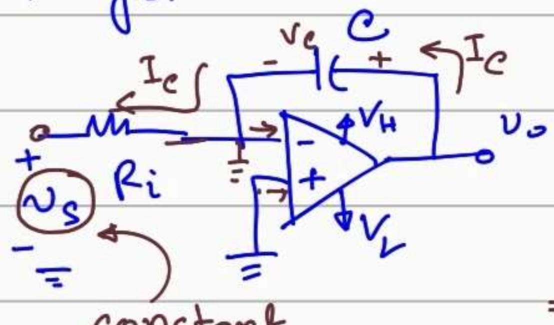
$$= \boxed{868\,Hz}$$

Duty cycle = % of time output voltage is high with a time period

$$= \frac{T_1}{T} \times 100\% = \frac{\ln(2.5)}{\ln(10)} \times 100\% = \boxed{39.1\%}$$

Triangular Wave Generator:

Integrator :



We are assuming virtual ground is present here.

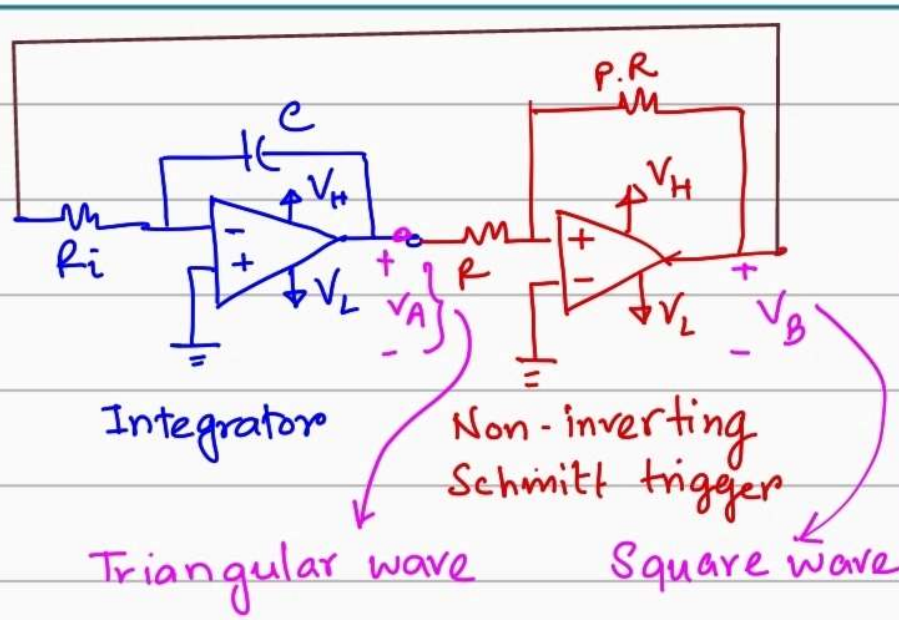
$$I_c = C\frac{dV_c}{dt} = \frac{0 - v_s}{R_i}$$

$$\Rightarrow \int_{V_c(t_1)}^{V_c(t)} dV_c = -\frac{V_s}{R_i C}\int_{t_1}^{t} dt$$

$$\Rightarrow V_c(t) - V_c(t_1) = -\frac{v_s}{R_i C}(t - t_1)$$

$$\Rightarrow \boxed{V_c(t) = V_c(t_1) - \frac{v_s}{R_i C}(t - t_1)}$$

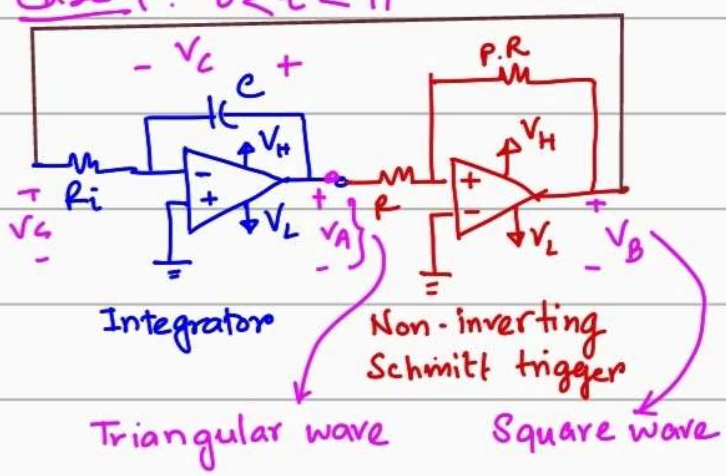
$V_c(t_1) = V_{initial}$

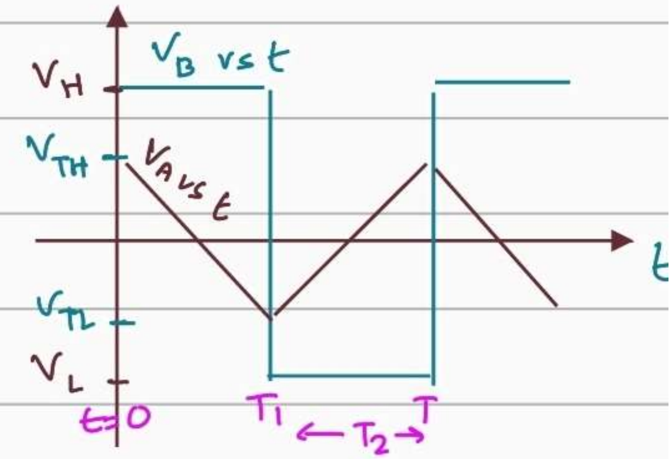


$$V_{TL} = V_H\left(-\frac{R}{pR}\right)$$

$$\boxed{\begin{aligned} V_{TL} &= -\frac{V_H}{p} \\ V_{TH} &= -\frac{V_L}{p} \end{aligned}}$$

Case: 1 : $0<t<T_1$





Initial condition: $v_B = V_H$ and $V_A = V_{TH}$, $t_{initial} = 0$

$$v_c(t) = v_A(t) = v_{initial} - \frac{v_s}{R_i C}(t - t_{initial}) \quad [V_s = V_B = V_H]$$

$$\Rightarrow V_A(t) = V_{TH} - \frac{V_H}{R_i C}(t-0)$$

Because $V_A(T_1) = V_{TL}$. we can find.

$$\boxed{T_1 = R_i C\left(\frac{V_{TH} - V_{TL}}{V_H}\right)}$$

Case 2: $T_1 < t < T$. Using similar analysis like square wave we can desire,

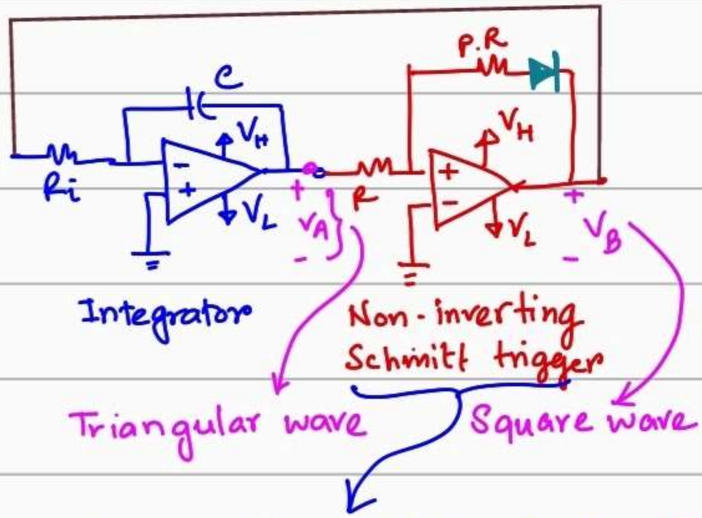
$$\boxed{T_2 = R_i C\left(\frac{V_{TL} - V_{TH}}{V_L}\right)}$$ $H \leftrightarrow L$

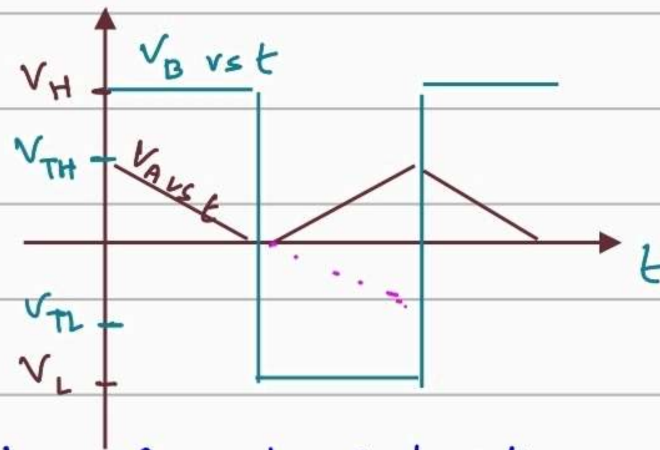
Total time period, $T = T_1 + T_2$. frequency, $f = \frac{1}{T}$

Special case: $\boxed{V_L = -V_H}$ $V_{TH} = -\frac{V_L}{P}$, $V_{TL} = -\frac{V_H}{P}$

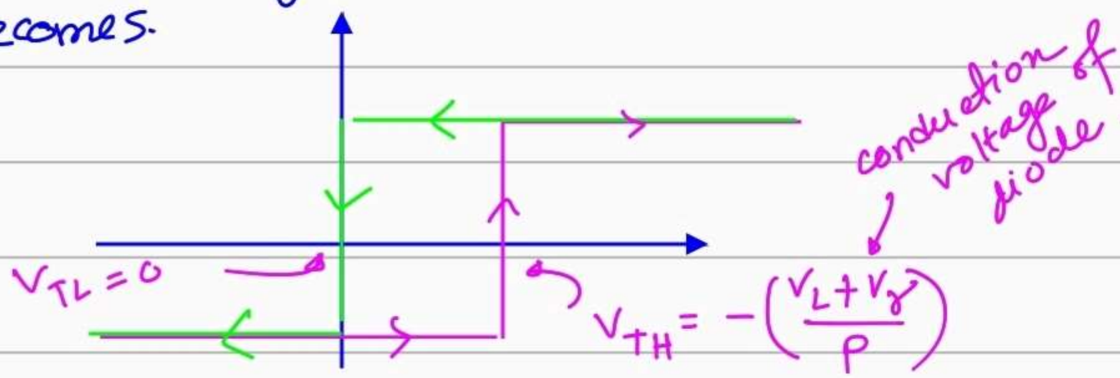
$$\boxed{f = \frac{P}{4R_i C}}$$

Unipolar Triangular Wave Generator





After putting this diode the transfer characteristics becomes.



Assuming $V_H = -V_L$, we will get

$$\boxed{f = \frac{P}{2RC}}$$