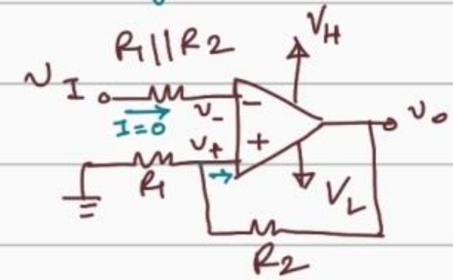
| otherwise, $v_o = V_L$

Schmitt Trigger

Inverting S.T.



$$\boxed{\begin{aligned} v_- &= v_I \\ v_+ &= v_o \frac{R_1}{R_1 + R_2} \end{aligned}}$$

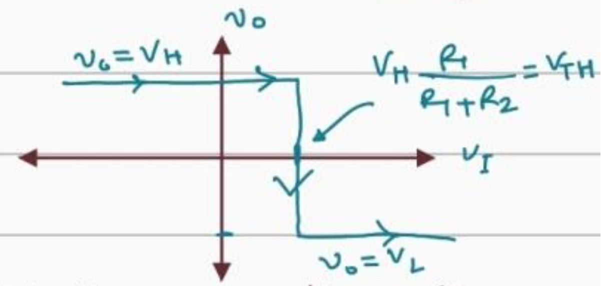
[use node eq^n at "+" terminal]

Output depends on the initial condition of the input.

Case 1: $|v_I| \gg 0$ but v_I is negative

We can expect, $v_+ > v_-$

$\Rightarrow v_o = V_H$ and $v_+ = V_H \frac{R_1}{R_1 + R_2}$

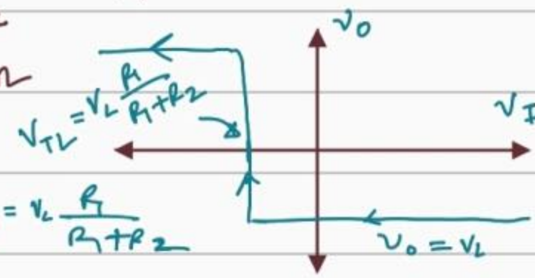


we can increase $v_I = v_-$ until it crosses the voltage of $v_+ = \frac{R_1 V_{REF}}{R_1 + R_2}$. After that output changes to V_L.

So $V_{REF} \cdot \frac{R_1}{R_1 + R_2}$ is denoted as higher threshold voltage, V_{TH}

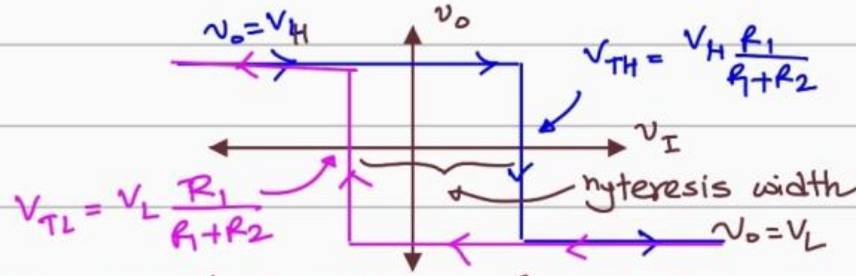
Case 2: $|v_I| \gg 0$ but v_I is positive. we can expect that $v_- > v_+$ and $v_o = V_L \Rightarrow v_+ = V_L \frac{R_1}{R_1 + R_2}$.

When v_I decreases below the $v_+ = V_L \frac{R_1}{R_1 + R_2}$, v_o changes from V_L to V_H.



Lower threshold voltage. $V_{TL} = V_L \frac{R_1}{R_1 + R_2}$

Combined transfer characteristics.



Bistable multivibrator = Schmitt trigger

It has two stable output states. $v_o = V_H / V_L$

Example 15.6 Neamann

Determine the hysteresis width of a particular Schmitt trigger.

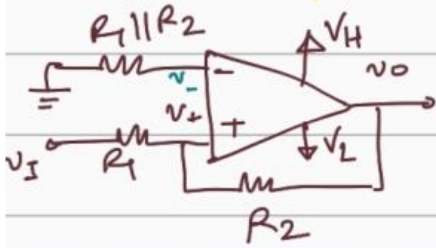
$R_1 = 10k\Omega$, $R_2 = 90k\Omega$, $V_H = 10V$ and $V_L = -10V$.

Sol^n:

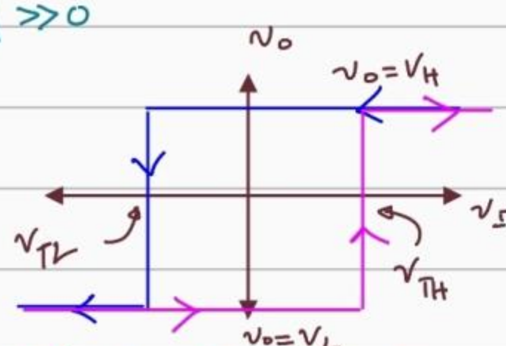
Hysteresis width $= V_{TH} - V_{TL}$

$$\Rightarrow V_{TH} - V_{TL} = V_H \frac{R_1}{R_1+R_2} - V_L \frac{R_1}{R_1+R_2} = (V_H - V_L)\frac{R_1}{R_1+R_2} = 20 \times \frac{10}{100} = 2V$$

Non-inverting Schmitt Trigger Circuit:



Consider the two cases just like before and use $|v_I| \gg 0$



$$\boxed{\begin{aligned} v_- &= 0 \\ v_+ &= v_o \frac{R_1}{R_1+R_2} + v_I \frac{R_2}{R_1+R_2} \end{aligned}}$$

At transition point $v_+ = v_-$ and for V_{TH} we can say from transfer characteristics that $v_O = V_L$

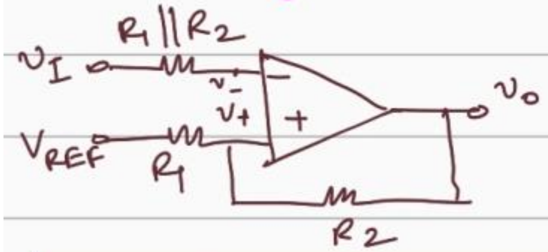
$$0 = V_L \frac{R_1}{R_1+R_2} + V_{TH} \frac{R_2}{R_1+R_2} \Rightarrow V_{TH} = \left(-\frac{R_1}{R_2}\right) V_L$$

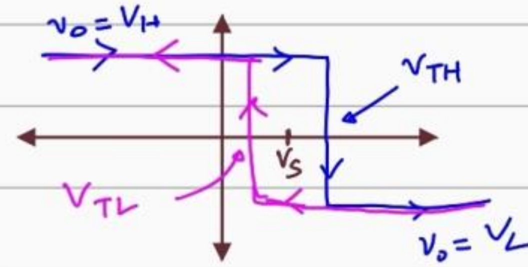
Similarly, we can get. $V_{TL} = \left(-\frac{R_1}{R_2}\right) V_H$

$v_I \uparrow \downarrow$, $v_O \uparrow \downarrow$ when $|v_I| >> 0$

Schmitt Trigger with Applied Voltage:

Inverting S.T.





V_S = shift voltage.

$$\boxed{\begin{aligned} v_- &= v_I \\ v_+ &= V_{REF}\frac{R_2}{R_1+R_2} + v_o\frac{R_1}{R_1+R_2} \end{aligned}}$$

Now. $v_- = v_+ \ (v_o = V_H, V_I = V_{TH})$

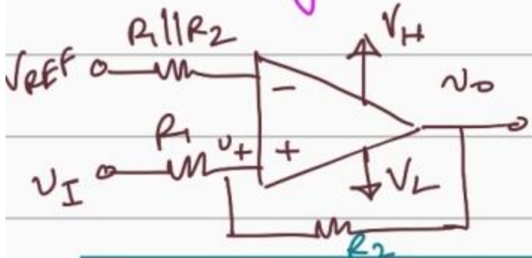
$$\Rightarrow V_{TH} = \underbrace{V_{REF}\left(\frac{R_2}{R_1+R_2}\right)}_{V_S} + \underline{V_H\left(\frac{R_1}{R_1+R_2}\right)}$$

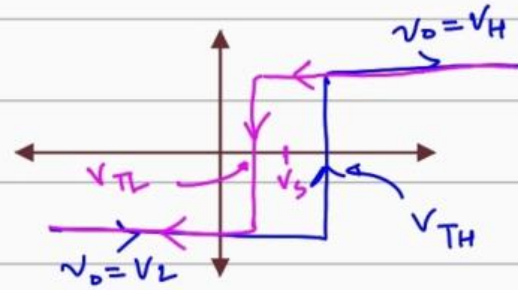
Similarly. $v_- = v_+ \ (v_o = V_L, v_I = V_{TL})$

$$\Rightarrow V_{TL} = \underline{V_{REF}\left(\frac{R_2}{R_1+R_2}\right)} + \underline{V_L\left(\frac{R_1}{R_1+R_2}\right)}$$

So shift/ switching voltage. $\boxed{V_S = V_{REF}\frac{R_2}{R_1+R_2}}$

NonInverting S.T.





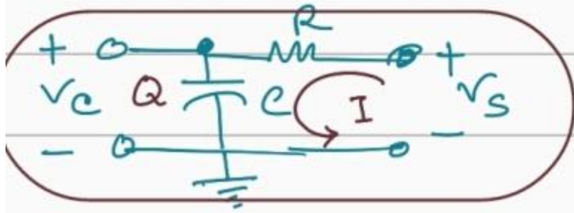
$$\boxed{\begin{aligned} v_- &= V_{REF} \\ v_+ &= v_I\frac{R_2}{R_1+R_2} + v_o\frac{R_1}{R_1+R_2} \end{aligned}}$$

$$V_{TH} = \left(\frac{R_1+R_2}{R_2}\right)V_{REF} + \left(-\frac{R_1}{R_2}\right)V_L$$

$$V_{TL} = \left(\frac{R_1+R_2}{R_2}\right)V_{REF} + \left(-\frac{R_1}{R_2}\right)V_H$$

Shift/ switching voltage. $V_S = \left(\frac{R_1+R_2}{R_2}\right)V_{REF}$

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 $\left(C = \frac{Q}{V}\right)$

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

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 $v_c(t_1) = v_{initial}$.

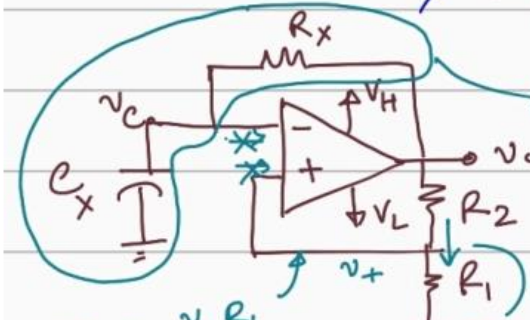
$\tau = RC$ = time constant.

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

Signal generators

Schmitt Oscillator / Astable Multivibrator:

→ There is no stable state.



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

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

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

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.

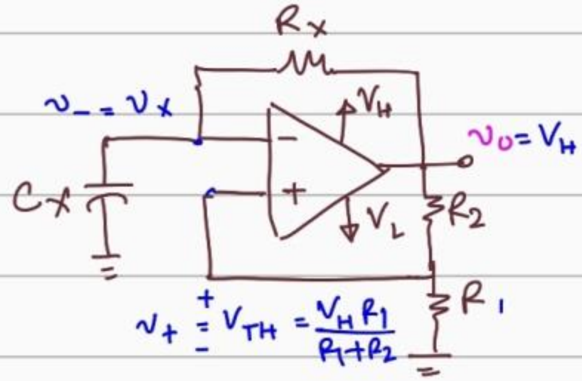
$V_{TH} \rightarrow V_{UT}$ = upper threshold voltage

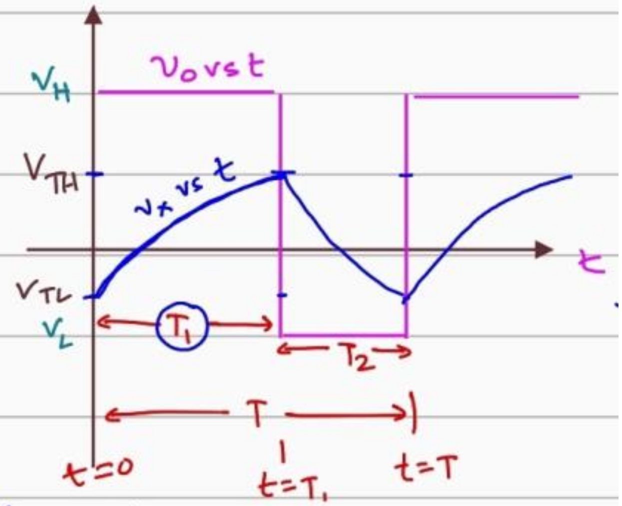
$V_{TL} \rightarrow V_{LT}$ = lower threshold voltage

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

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 $v_o = v_x$ 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

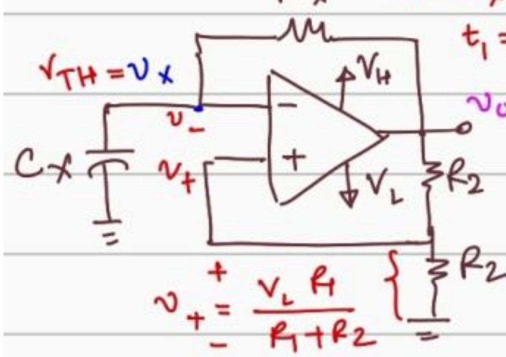
$$v_x(T_1) = V_{TH} = V_H + (V_{TL} - V_H)\exp\left(-\frac{T_1}{R_x C_x}\right)$$

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

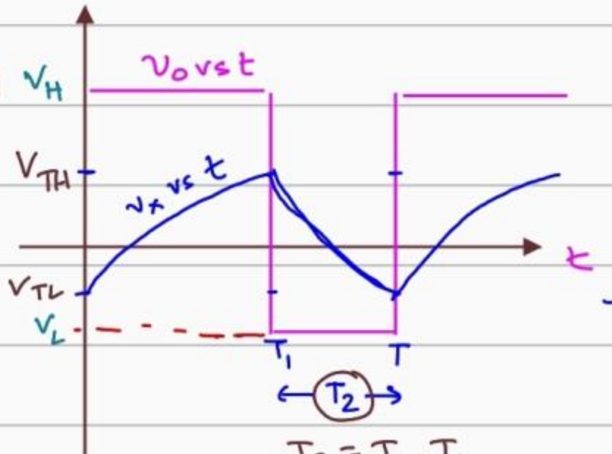
② Case 2: $T_1 < t < T$

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

$t_1 = T_1$



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



$T_2 = T - T_1$

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

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

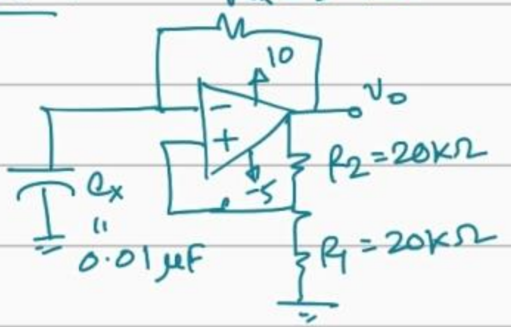
At $t = T$ time $v_x(T) = V_{TL}$. So using this we find.

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

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

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

Sol^n:



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

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

$$\tau = R_X C_X = 50\times 10^3 \times 0.01\times 10^{-6}\ \Omega F$$
$$= 0.5\times 10^{-3} s$$
$$= 0.5 ms$$

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

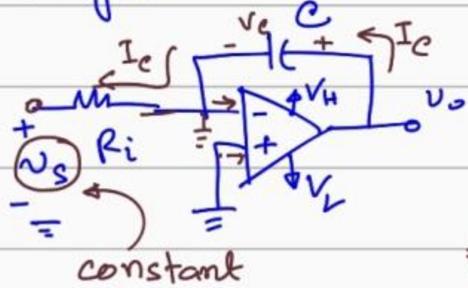
$$= \boxed{868 Hz}$$

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.

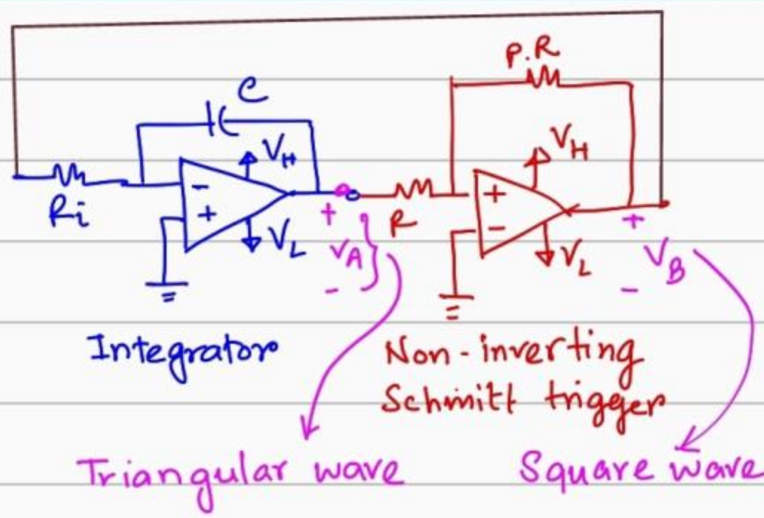
$$I_c = C\frac{dv_c}{dt} = \frac{0 - v_s}{R_i}$$

$$\Rightarrow \int_{v_c(t_1)}^{v_c(t)} dv_c = -\frac{v_s}{R_i C}\int_{t_1}^{t} dt$$

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

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

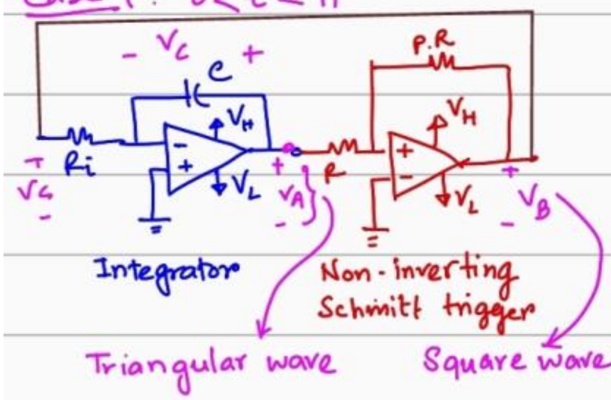
$v_c(t_1) = V_{initial}$

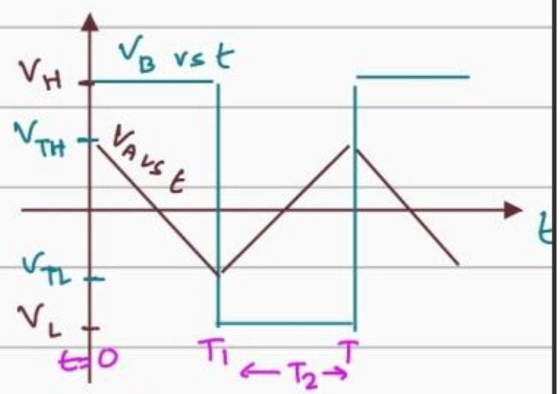


$$V_{TL} = V_H\left(-\frac{R}{pR}\right)$$

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

Case 1: $0<t<T_1$





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

$$V_C(t) = V_A(t) = V_{initial} - \frac{V_s}{R_iC}(t - t_{initial}) \quad [V_s = V_B = V_H]$$

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

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

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

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

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

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

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

$$\boxed{f = \frac{P}{4R_iC}}$$