CSE350: Digital Electronics & Pulse Techniques

Lecture 04: Signal Generator - Square and Triangular Wave

Course Instructor:

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Signal Generator

We will study two types of signal generator

i. Square wave generator

ii. Triangular wave generator

Basic RC Circuit Overview

We know for capacitor, $I_C = C\frac{dV_C}{dt}$

From the circuit,

$$\frac{V_c - V_s}{R} + C\frac{dV_C}{dt} = 0$$

$$\Rightarrow \int_{V_c(t_1)}^{V_c(t_2)} \frac{dV_C}{V_C - V_S} = -\frac{1}{RC}\int_{t_1}^{t_2} dt$$

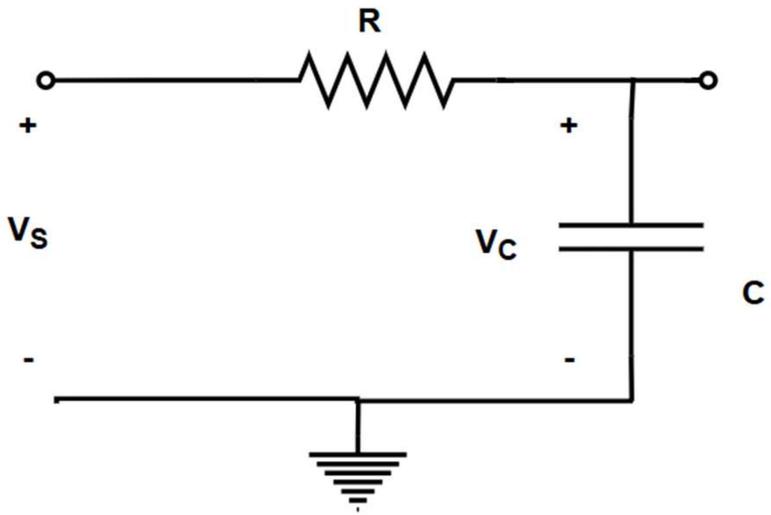
$$\Rightarrow \boxed{V_C\ (t_2) = V_s + (V_C(t_1) - V_S)\ e^{-(\frac{t_2-t_1}{\tau})}}$$

We can see if $t_2 \rightarrow \infty, then, V_C(\infty) = V_S$

If $t_1 = 0, t_2 = t, \tau = RC$

we can simply use this form,

$$V_C(t) = V_c(\infty) + (V_C(0) - V(\infty))\ e^{-\frac{t}{\tau}}$$



Square Wave Generator

$$\Rightarrow \boxed{V_C\ (t_2) = V_s + (V_C(t_1)\ - V_S)\ e^{-(\frac{t_2-t_1}{\tau})}}$$

Here is the square wave generator, for it -

$$\Rightarrow V_x\ (t_2) = V_o + (V_x(t_1)\ - V_o)\ e^{-(\frac{t_2-t_1}{\tau})}$$

$$\Rightarrow V_x\ (t_2) - V_o = (V_x(t_1)\ - V_o)\ e^{-(\frac{t_2-t_1}{\tau})}$$

$$\Rightarrow \frac{V_x(t_1)-V_o}{V_x(t_2)-V_o} = e^{(\frac{t_2-t_1}{\tau})}$$

$$\Rightarrow t_2 - t_1 = \tau \ln \frac{V_o - V_x(t_1)}{V_o - V_x(t_2)} \quad \text{-----(i)}$$

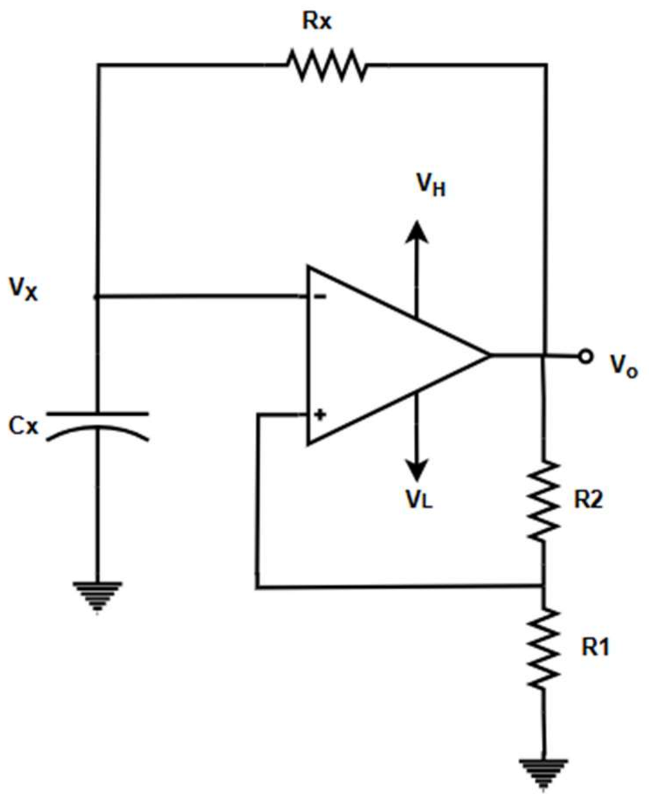
We already know from Inv. Schmitt Trigger

Higher threshold voltage,

$$V_{TH} = V_H \frac{R_1}{R_1 + R_2}$$

Lower threshold voltage,

$$V_{TL} = V_L \frac{R_1}{R_1 + R_2}$$



Square Wave Generator

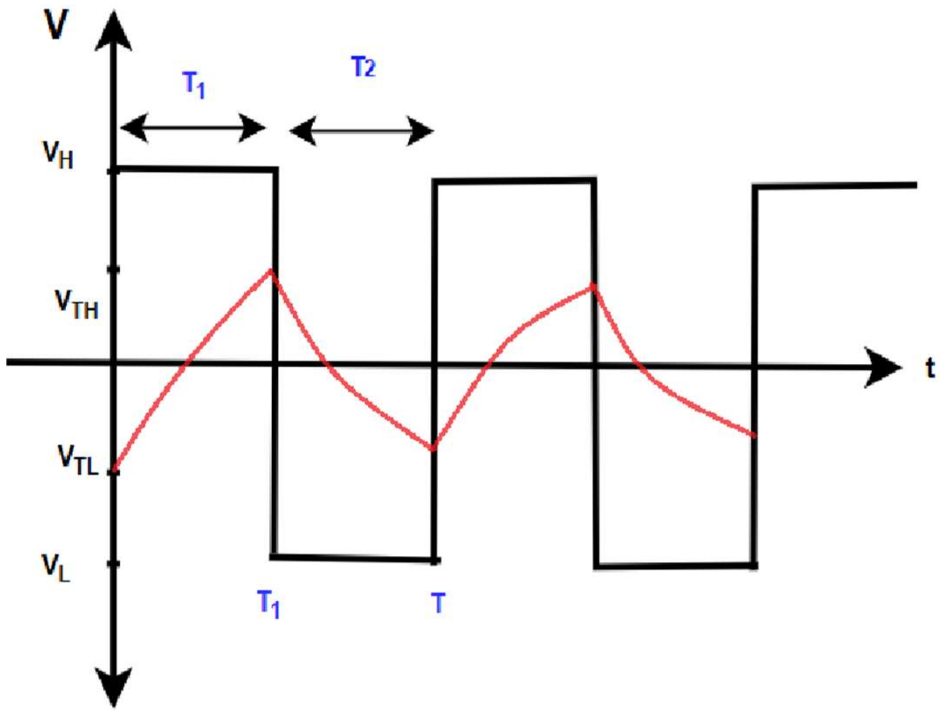
Case 01: $0 < t < T_1$

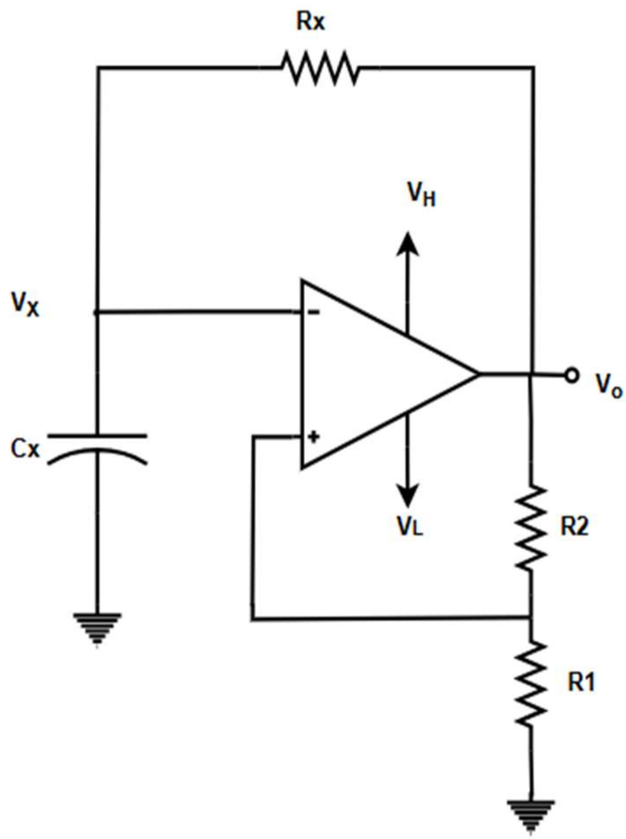
Initially,

$$V_x(t=0) = V_{TL} \; and,$$
$$V_o = V_H$$

$$Untill\ , V_x < V_{TH},$$
$$the\ output\ will\ remain\ at\ V_H$$

But when $V_x > V_{TH}$ output will change.





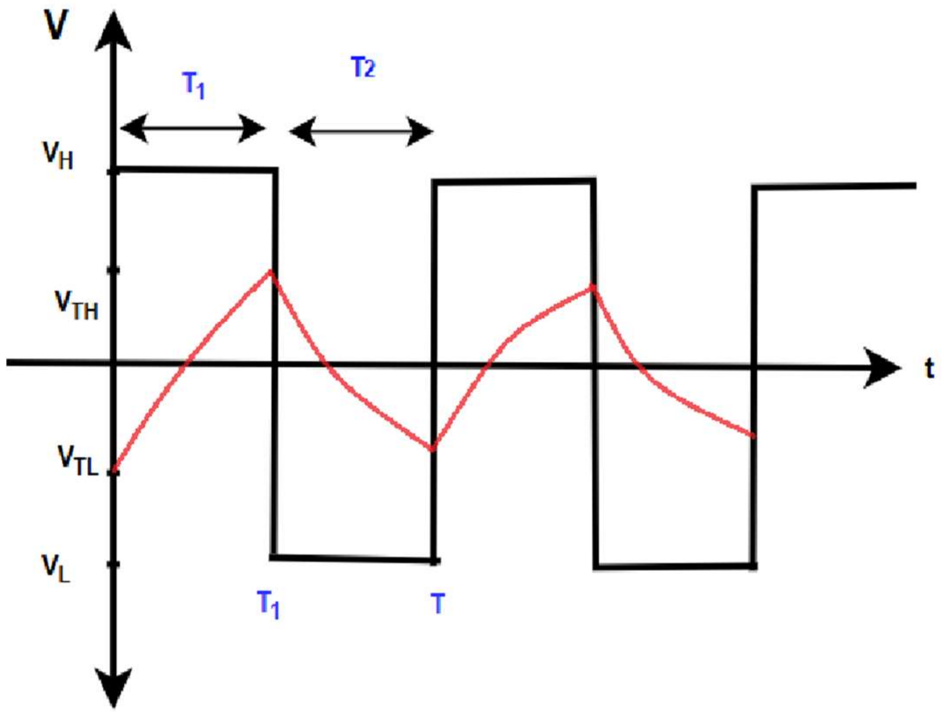
Square Wave Generator

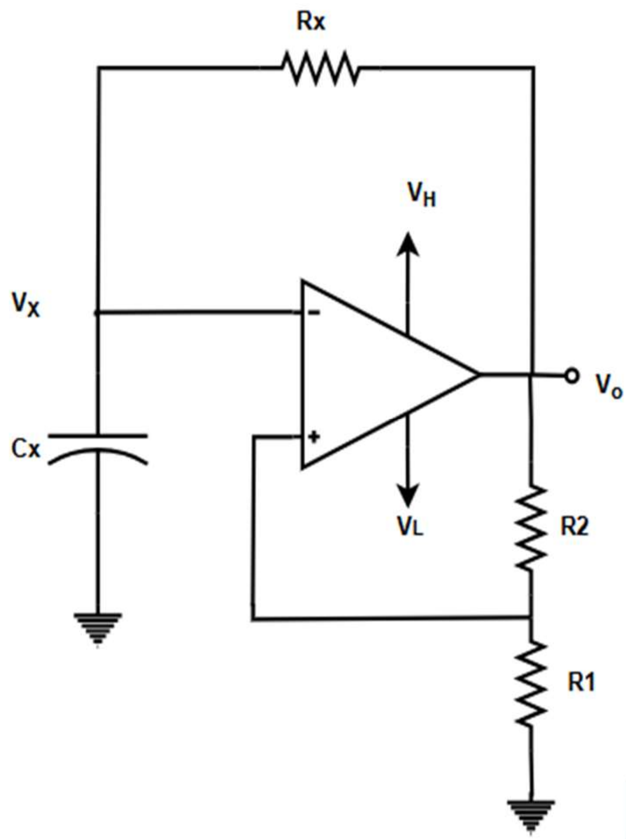
We can use eq (i),

$t_2 = T_1, and\ t_1 = 0$

$$T_1 - 0 \ = \tau \ln \frac{V_o - V(0)}{V_o \ - V(T_1)}$$

$$T_1 \ = R_x \ C_x \ln \frac{V_H \ - V_{TL}}{V_H \ - V_{TH}}$$





Square Wave Generator

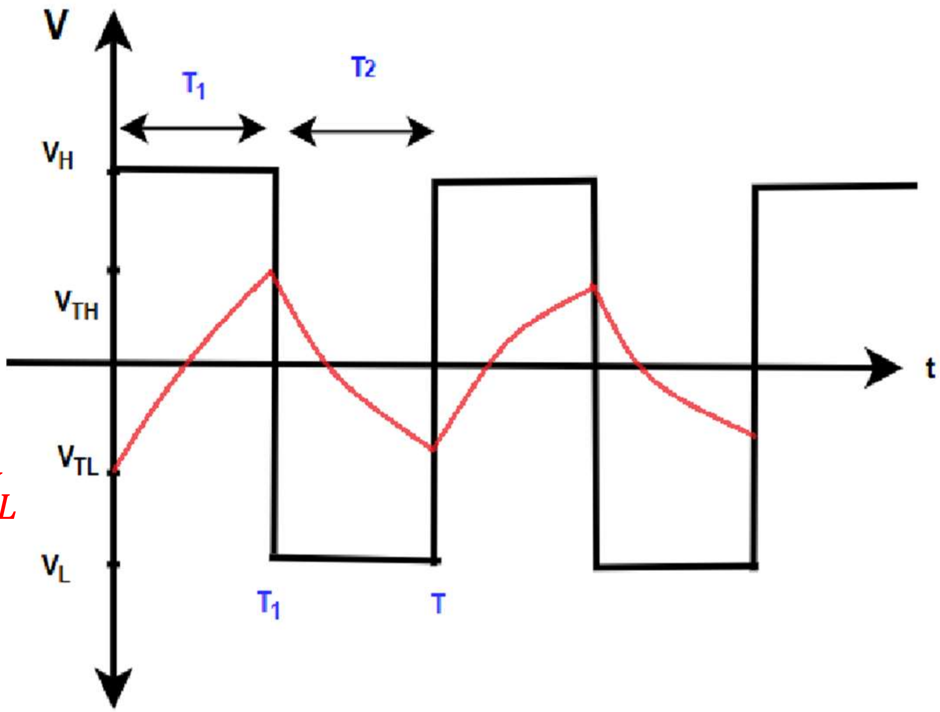
Case 02: $T_1 < t < T$

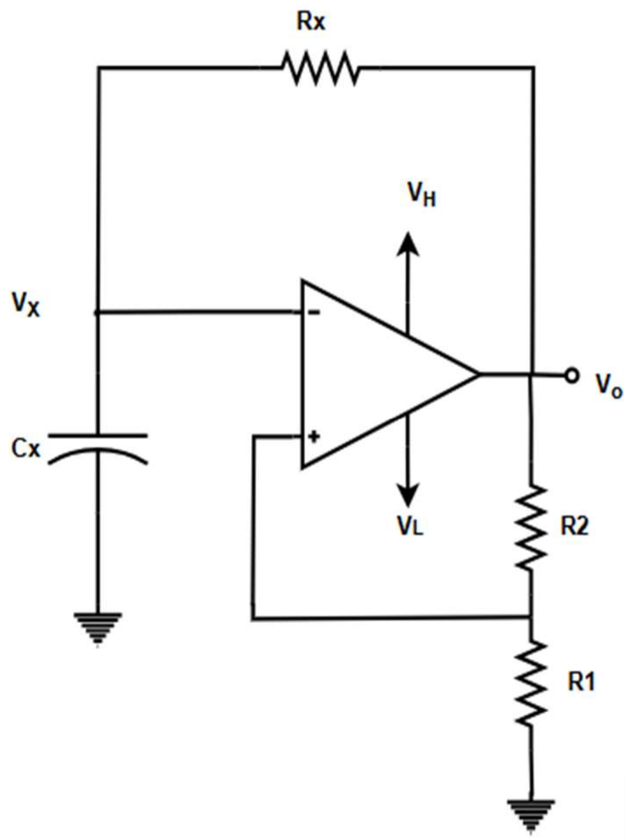
Initially,

$$V_x(t = T_1) = V_{TH}$$
$$and, V_o = V_L$$

Untill , $V_x > V_{TL}$, the output will remain at V_L

But when $V_x < V_{TL}$ output will change.





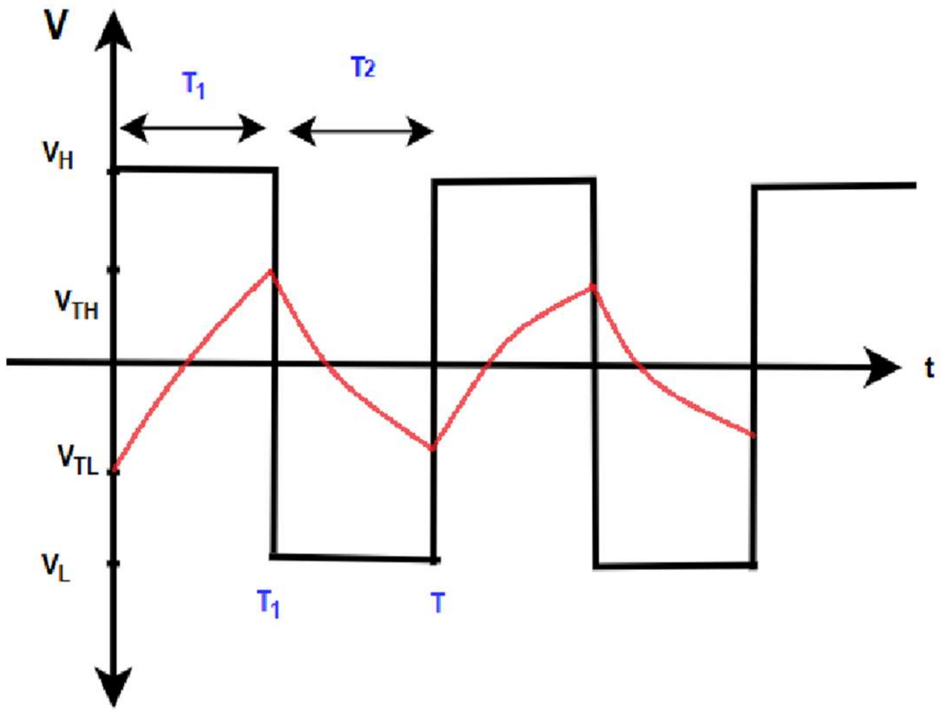
Square Wave Generator

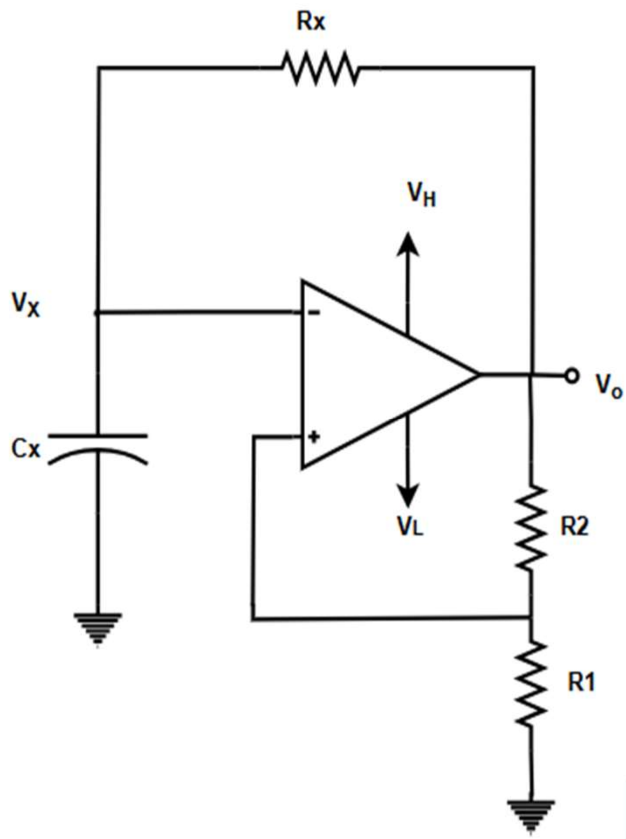
We can use eq (i),

$t_2 = T, and\ t_1 = T_1$

$$T - T_1 = \tau \ln \frac{V_o - V(T_1)}{V_o \ - V(T)}$$

$$T_2 \ = R_x\ C_x \ln \frac{V_L \ - V_{TH}}{V_L \ - V_{TL}}$$





Square Wave Generator Formulas

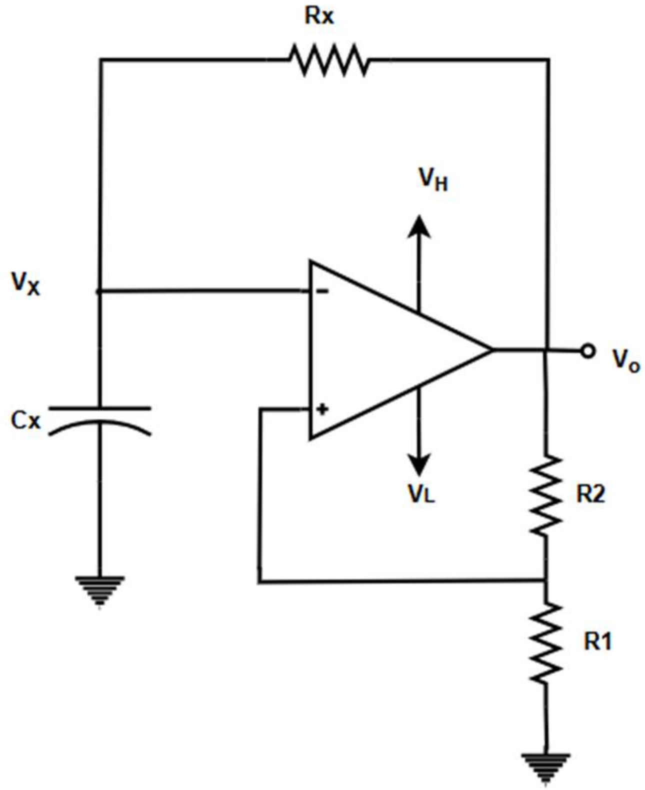
$$V_{TL} = V_L \frac{R_1}{R_1 + R_2}$$

$$V_{TH} = V_H \frac{R_1}{R_1 + R_2}$$

$$T_2 = R_x C_x \ln \frac{V_L - V_{TH}}{V_L - V_{TL}}$$

$$T_1 = R_x C_x \ln \frac{V_H - V_{TL}}{V_H - V_{TH}}$$

$$Duty\ cycle = \frac{T_1}{T_1+T_2} * 100\% \ \ or \ \ \frac{T_1}{T} * 100\%$$

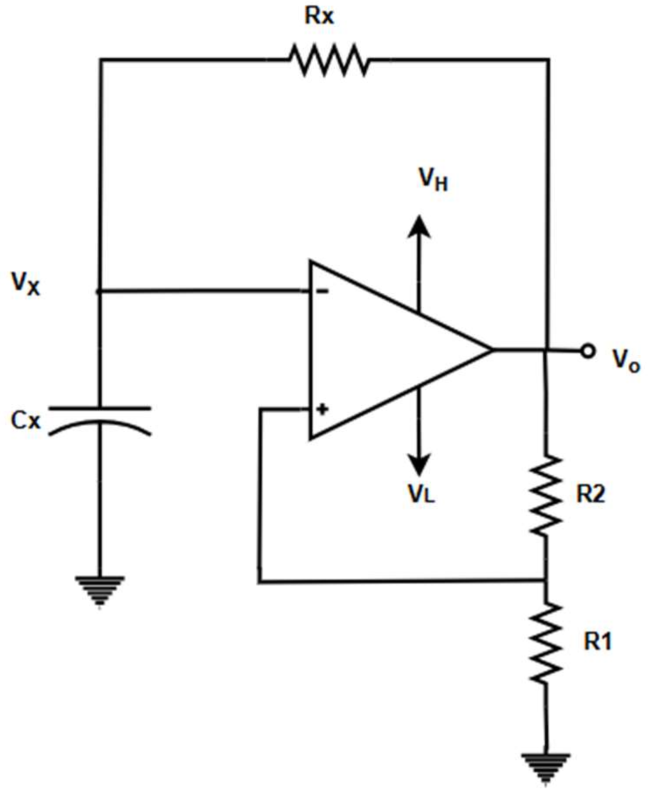


Exercise

For the Schmitt-trigger oscillator the saturation output voltages are +10V and -5V.

$R_1 = R_2 = 20\ k\Omega$ and $C_x = 0.01\ \mu F$ and $R_x = 10\ k\Omega$.

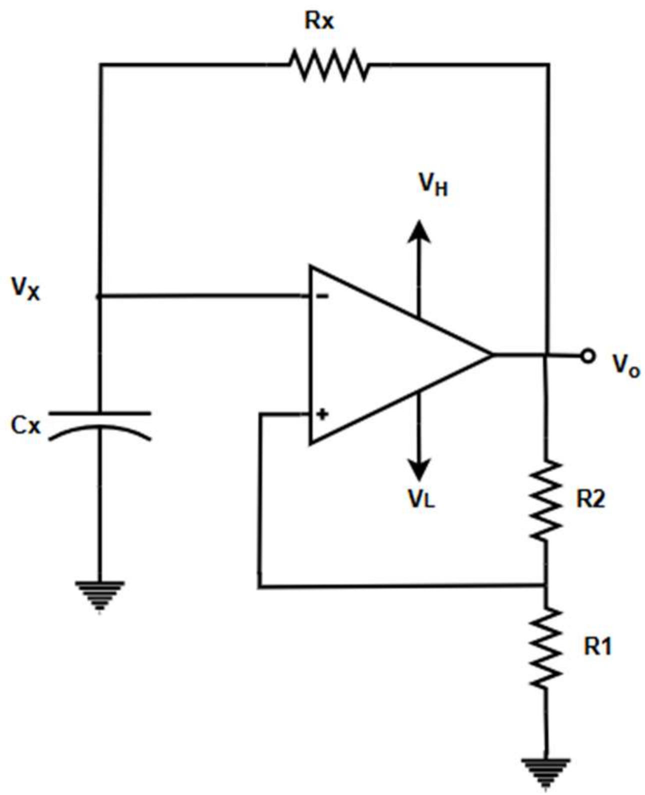
Determine the frequency of oscillation and duty cycle.



Exercise

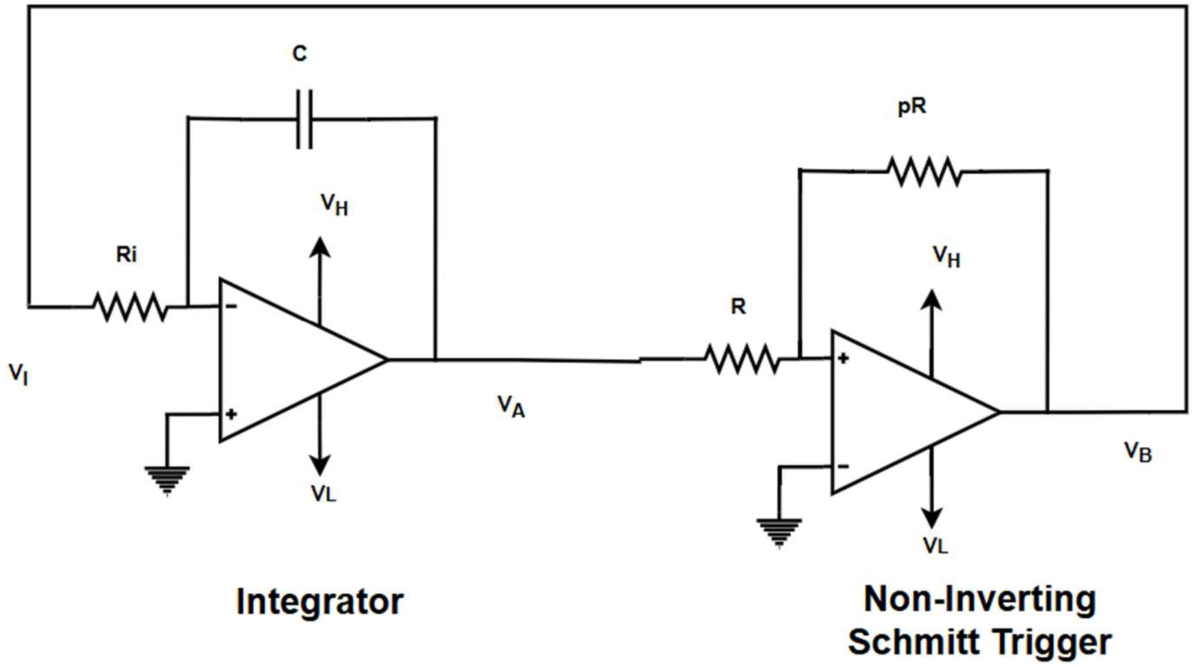
Find the duty cycle of the oscillator if the power supply of the OP-AMP is symmetrical.

[Hints: Symmetrical power supply V_{H} = $+V_{\mathrm{sat}}$ $and\ V_L$= $-V_{\mathrm{sat}}$]



Triangular Wave Generator

Here is the circuit of the triangular wave generator.



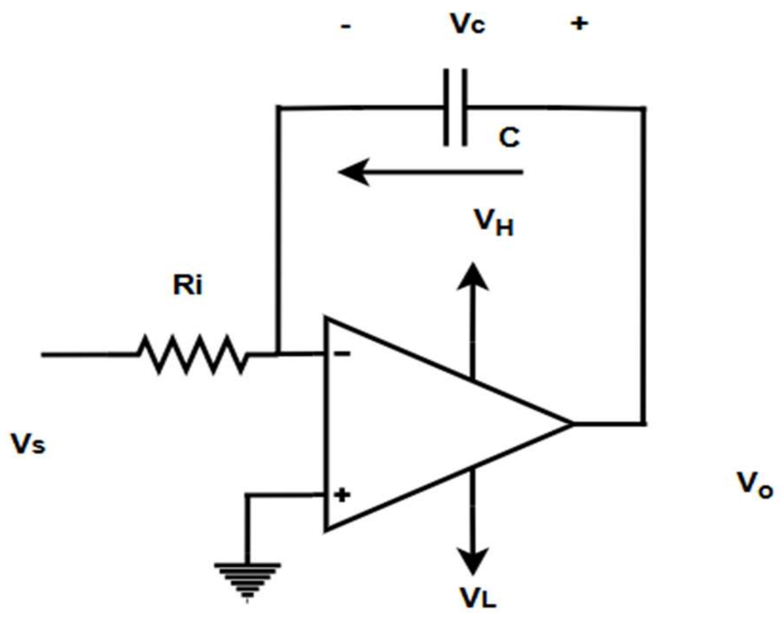
Integrator

Here, $I_C = C\frac{dV_c}{dt} = \frac{0-V_S}{R_i}$

V_s is a constant voltage.

$$\Rightarrow \int_{V_{innital}}^{V_C} \frac{dV_c}{V_s} = -\frac{1}{R_i C}\int_{t_1}^{t} dt$$

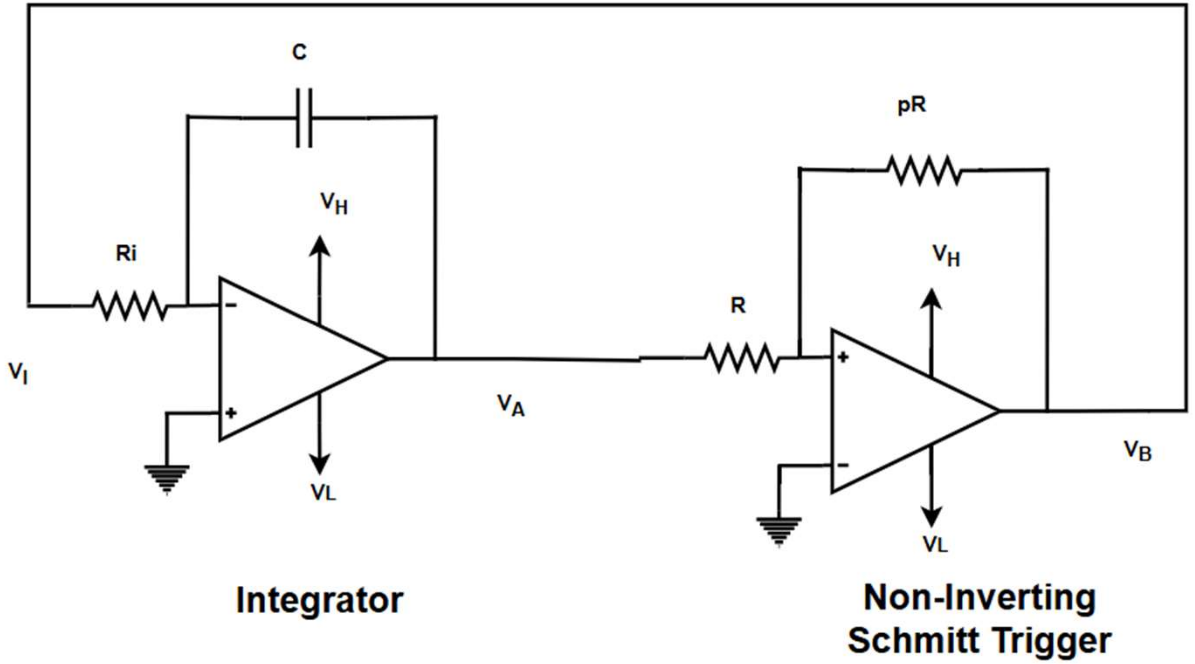
$$\boxed{V_C(t) = V_{initial} - \frac{V_S}{R_i C}(t - t_i)}$$



Integrator

Triangular Wave Generator

Here is the circuit of the triangular wave generator.



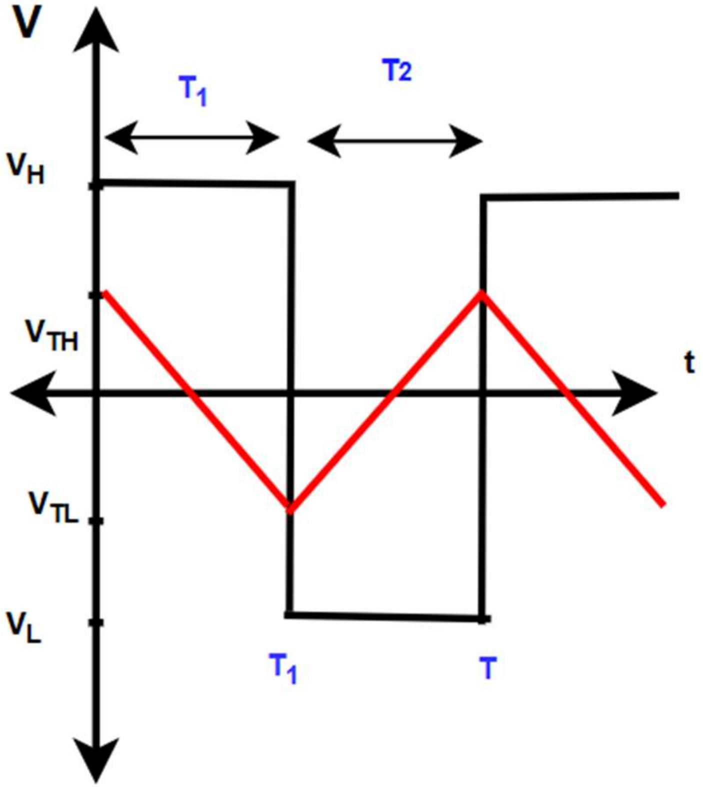
Triangular Wave Generator

$$V_{TH} = -\frac{R_1}{R_2} V_L$$

$$= -\frac{R}{pR} V_L \; = -\frac{V_L}{p}$$

Likewise,

$$V_{TL} = -\frac{V_H}{p}$$



Triangular Wave Generator

Case 01: $0 < t < T_1$

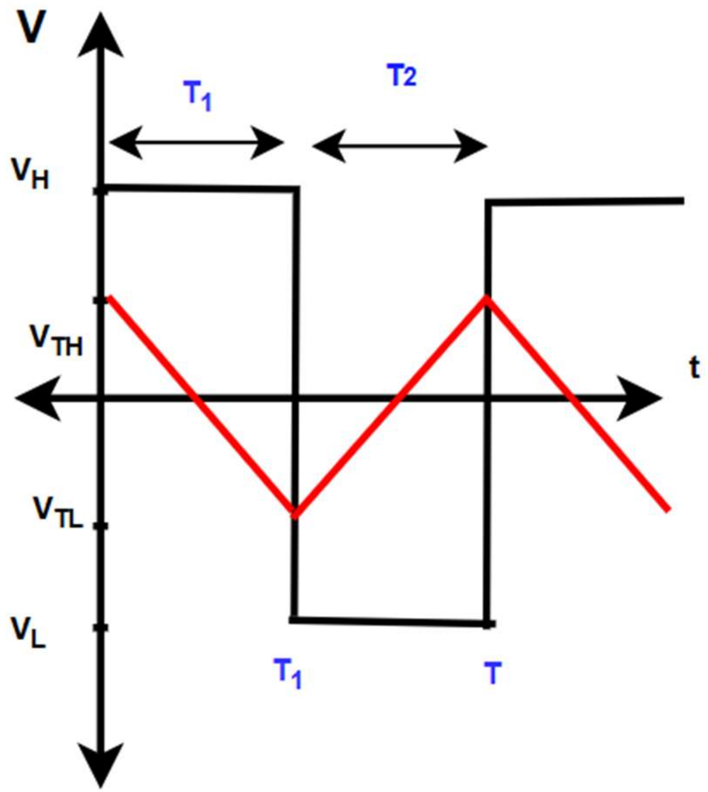
$$V_C(t) = V_{initial} - \frac{V_S}{R_i C}(t-0)$$

$$V_C(T_1) = V_{TL} \ and \ V_C(0) = V_{TH}$$

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

Case 02: $\mathrm{T}_1 < t < T$

Similarly, $T_2 = R_i C \left(\frac{V_{TL} - V_{TH}}{V_L}\right)$



Triangular Wave Generator

$$P = \frac{R_2}{R_1}, \qquad V_{TH} = -\frac{V_L}{p}$$

$$, \qquad V_{TL} = -\frac{V_H}{p}$$

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

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

$$T = T1 + T2, \qquad f = \frac{1}{T},$$

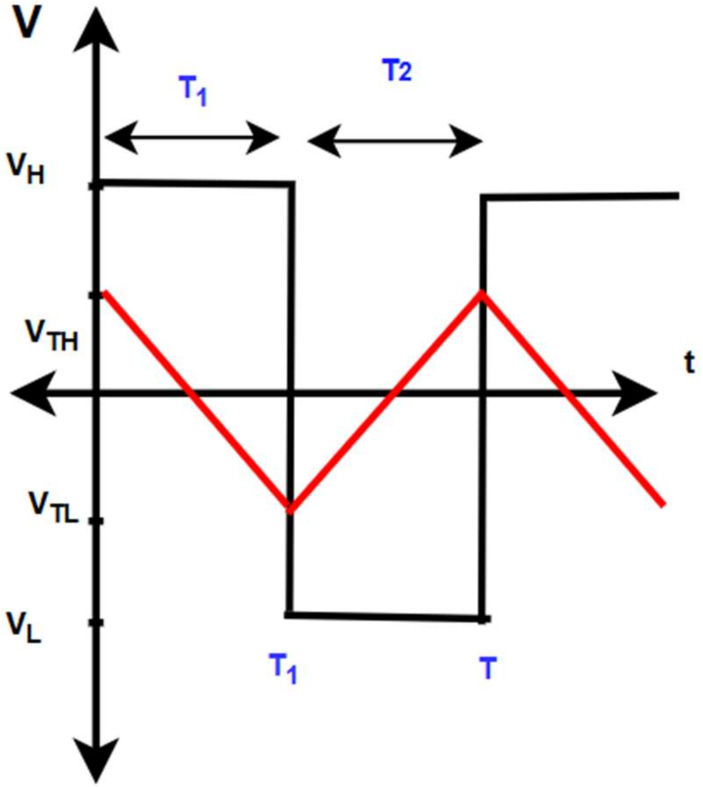
$$Duty\ Cycle(\ Square\ ) = \frac{T_1}{T_1 + T_2} * 100\%$$

$$Duty\ Cycle(\ Triangular\ ) = \frac{T_2}{T_1 + T_2} * 100\%$$

Special Case: When $V_L = -V_H$

$$T = T1 + T2 = \frac{4R_iC}{P}$$

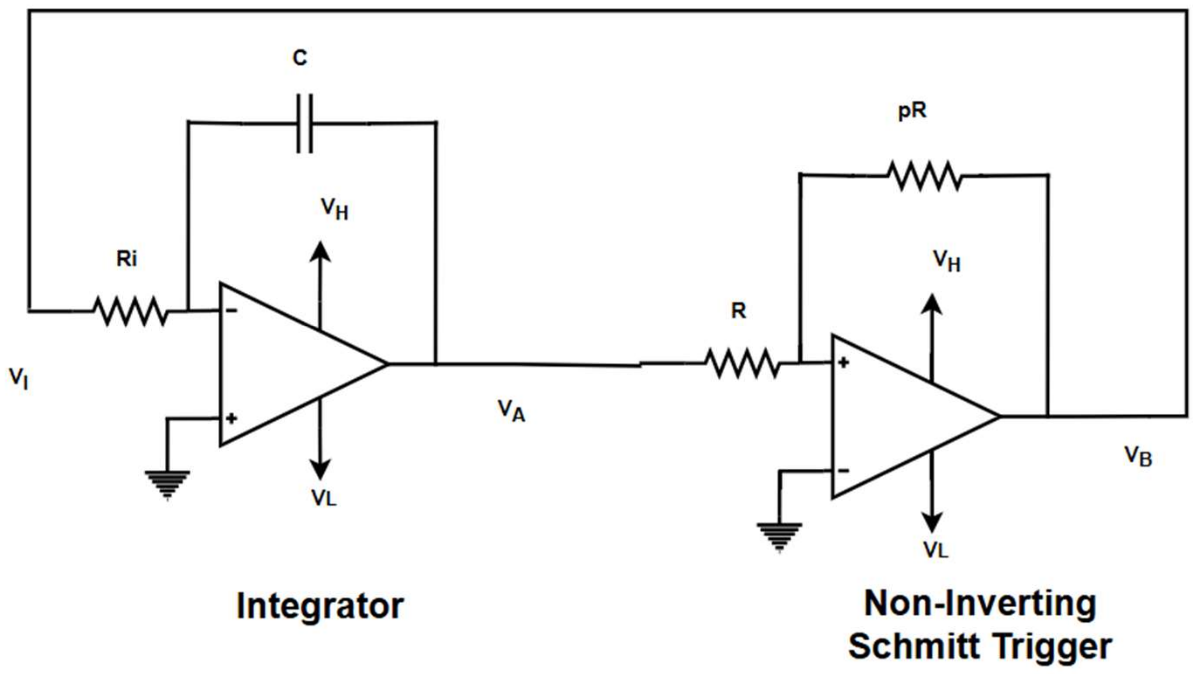
$$f = \frac{1}{T} = \frac{P}{4R_iC}$$



Exercise

Answer the following question for the Triangular wave generator.
Given, R_i = 10k, C = 10 μF , R_2= pR = 20k,
R_1=R=10k,
$V_L = -V_H$ or V_H = 15 V, V_L = −15 V

a). Draw the voltage $\boldsymbol{V_A}$ $\boldsymbol{and}$ $\boldsymbol{V_B}$ $vs\ t$ plot with proper labeling.
b.) Draw the VTC of the Schmitt trigger.
c.) Find the frequency, Time period, Duty cycle of the Triangular wave, Duty cycle of the Square wave.



Exercise

Answer the following question for the Triangular wave generator.
Given, $R_i = 10k$, $C = 10\ \mu F$, $R_2 = pR = 20k$,
$R_1 = R = 10k$,
And, $V_H = 10$ V, $V_L = -12$ V

a). Draw the voltage $\boldsymbol{V_A}$ $\boldsymbol{and}$ $\boldsymbol{V_B}$ $vs\ t$ plot with proper labeling.
b.) Draw the VTC of the Schmitt trigger.
c.) Find the frequency, Time period, Duty cycle of the Triangular wave, Duty cycle of the Square wave.