CSE 350
Digital Electronics and Pulse Techniques

Signal Generator:
Square Wave and Triangular Wave

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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

We know for capacitor,

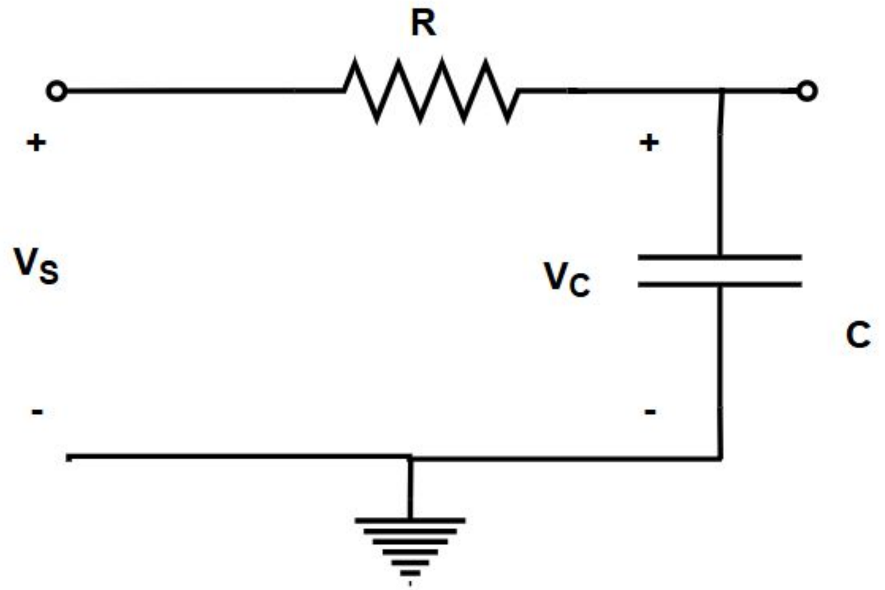
$$I_C = C\frac{dV_C}{dt}$$

From the circuit,

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

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

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



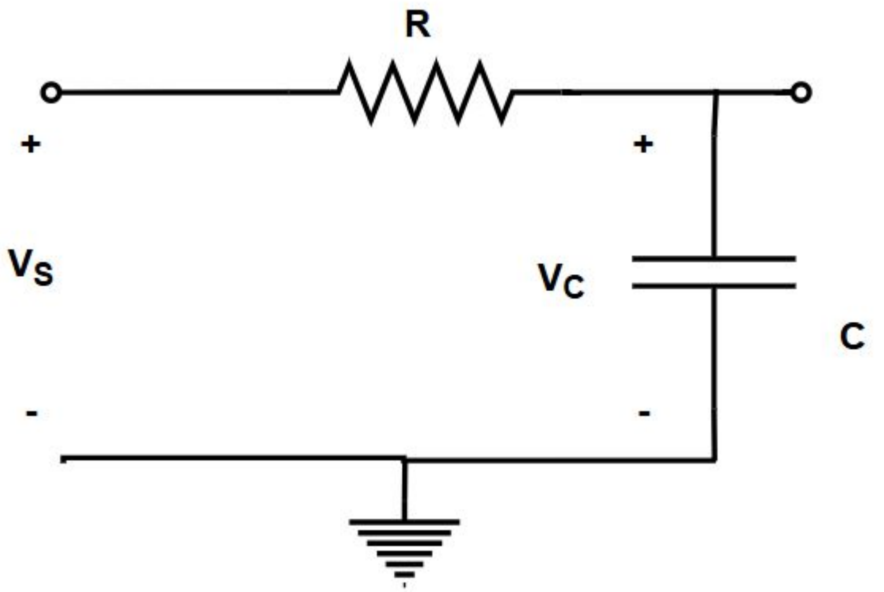
Basic RC circuit

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,

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

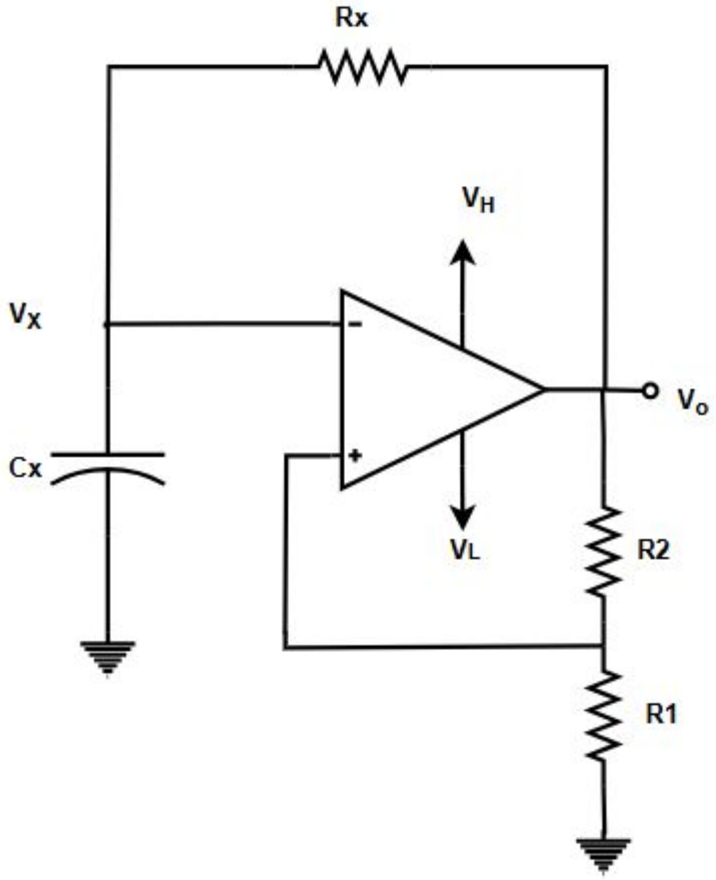


Square wave generator

- Here is the square wave generator,

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

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



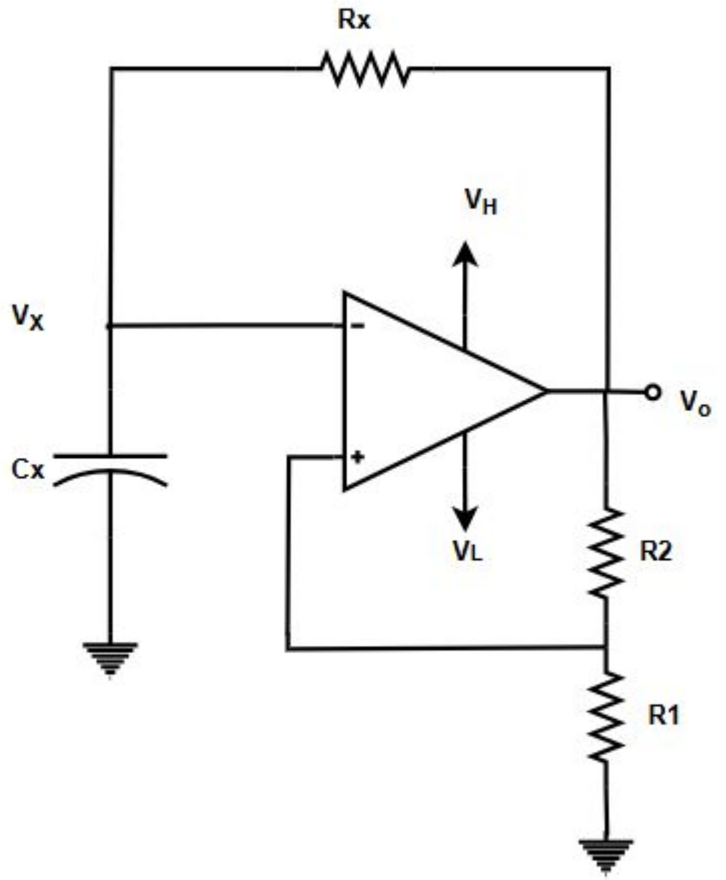
Square wave generator

- 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: $0 < t < T_1$

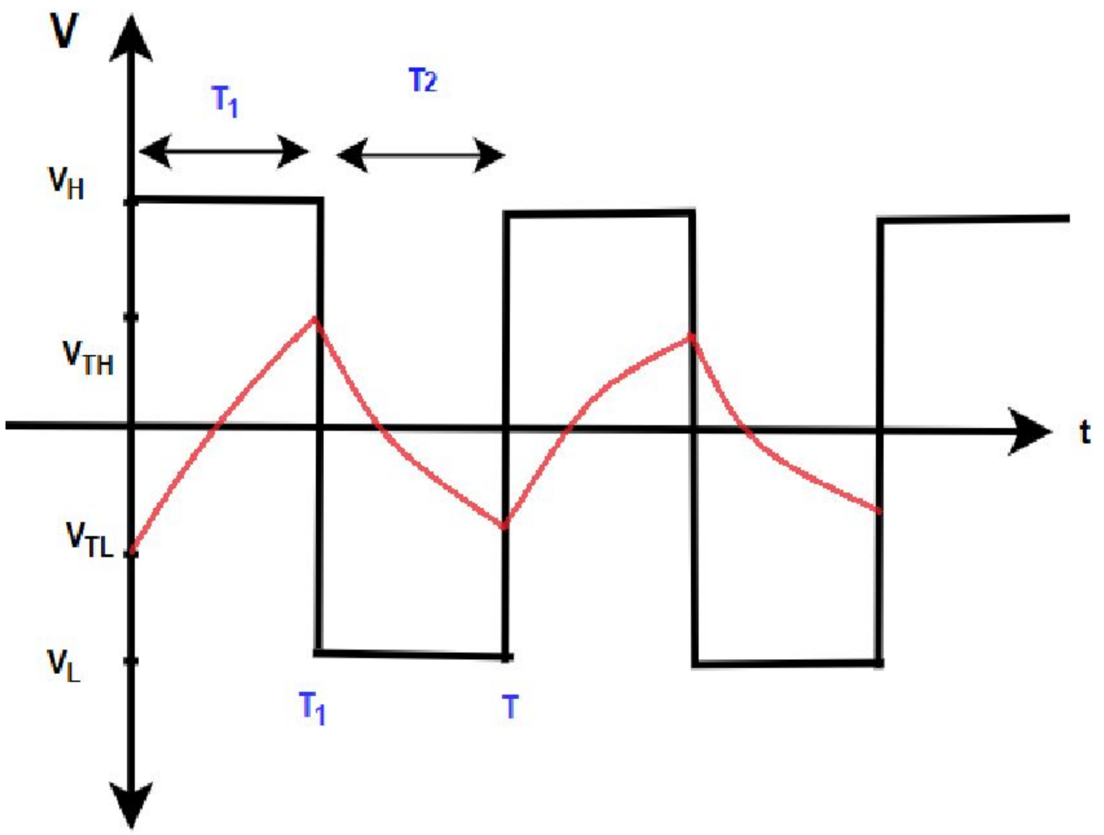
Initially,

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

$$Untill\ , V_x < V_{TH},$$

$$the\ output\ will\ remain\ at\ V_H$$

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



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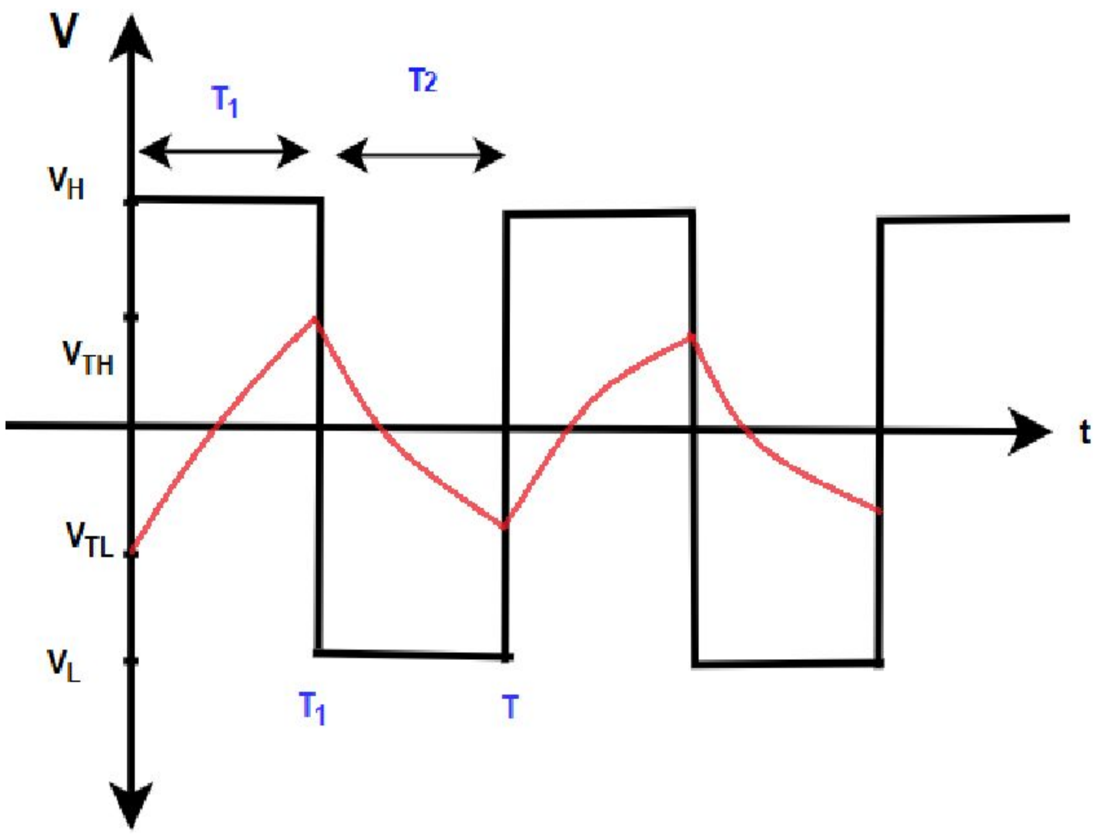
Square wave generator

We can use eq (i), $t_2 = T_1, and\ t_1 = 0$

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

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



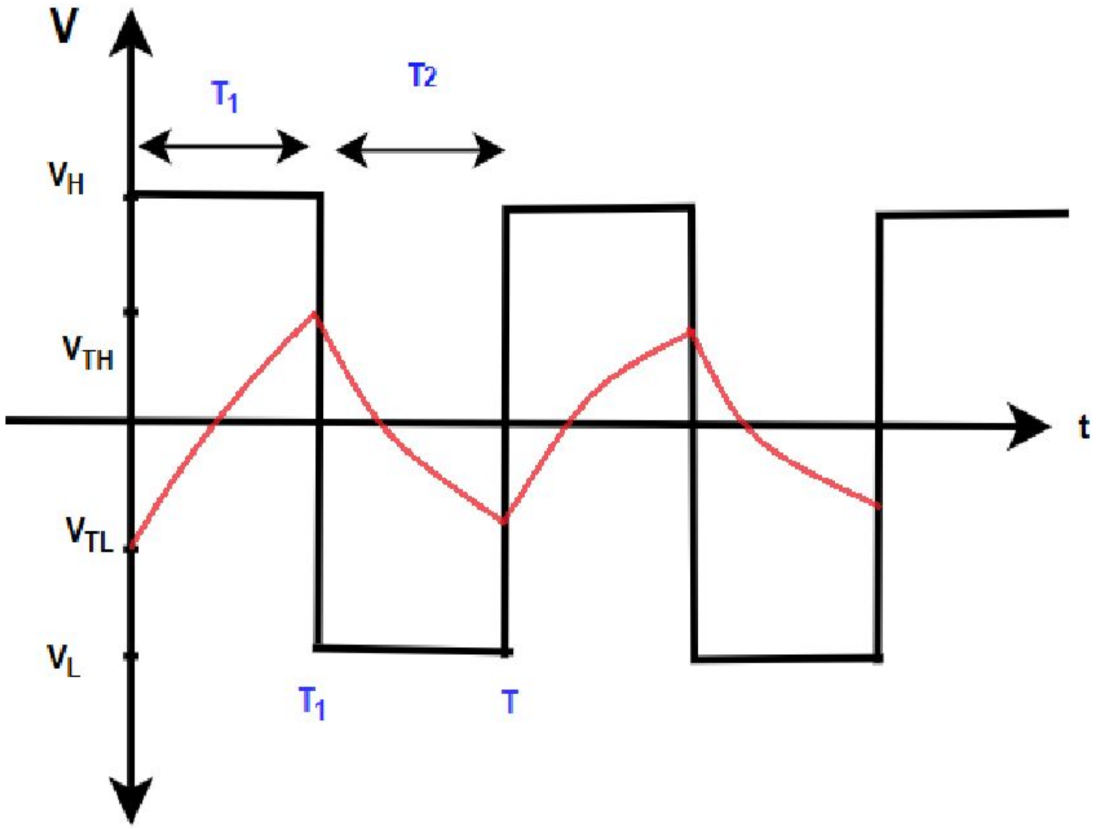
Square wave generator

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.

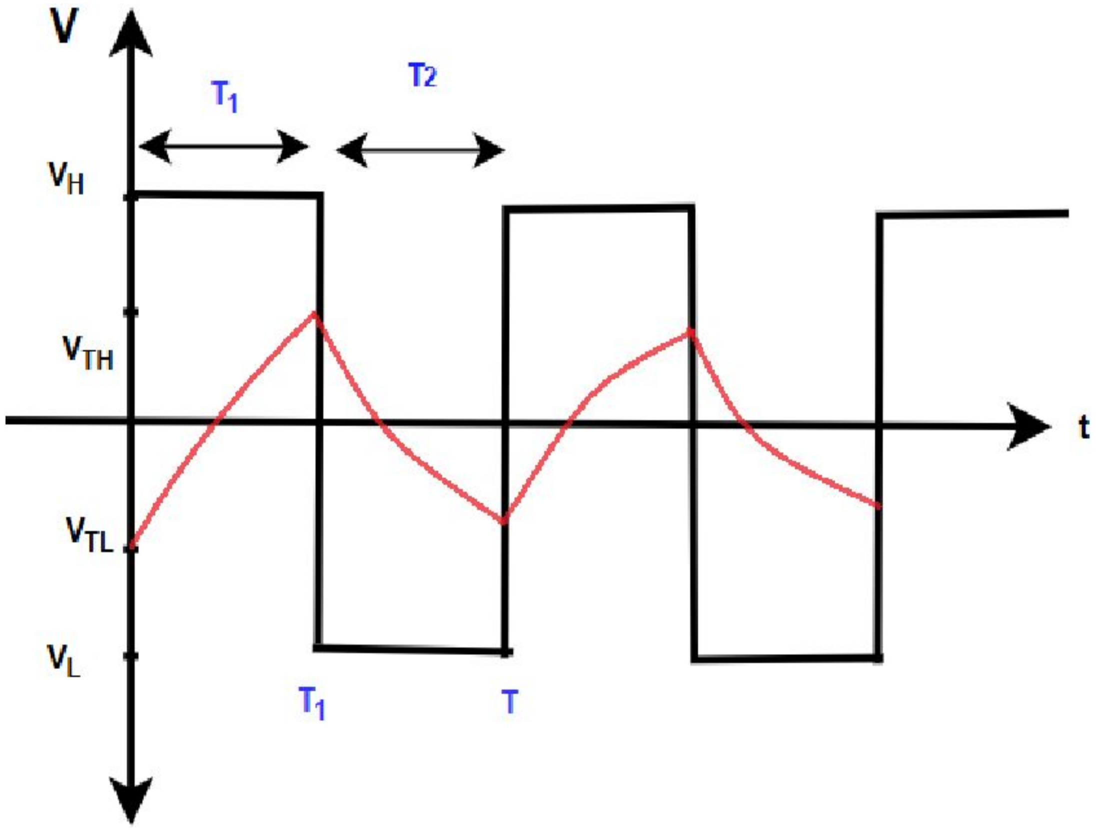


Square wave generator

- We can use eq (i), $t_2 = T, and\ t_1 = T_1$

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

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



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Square wave generator Formulas

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

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

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

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

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

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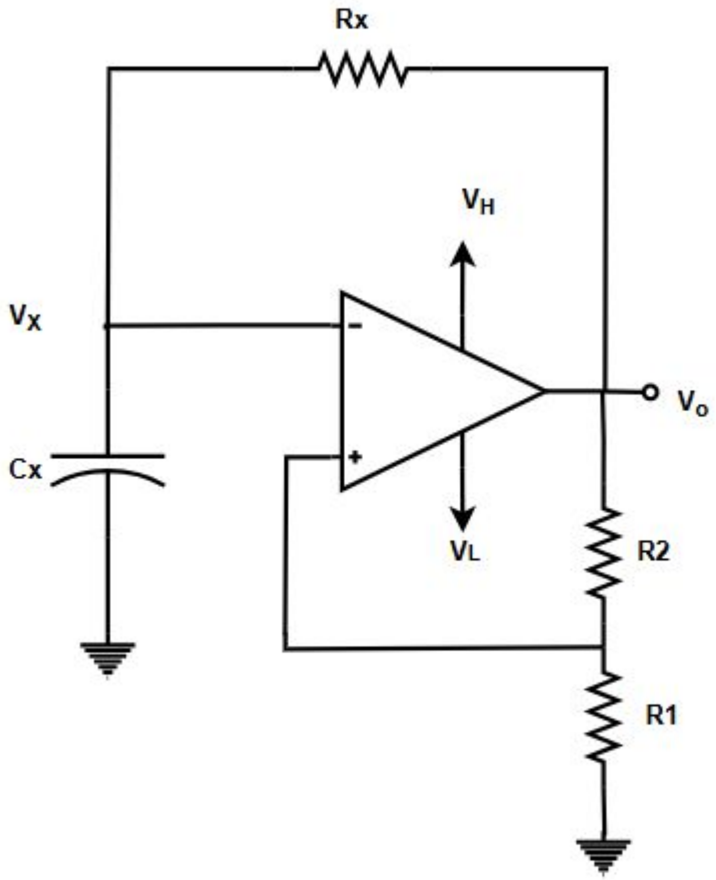
Exercise:

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.

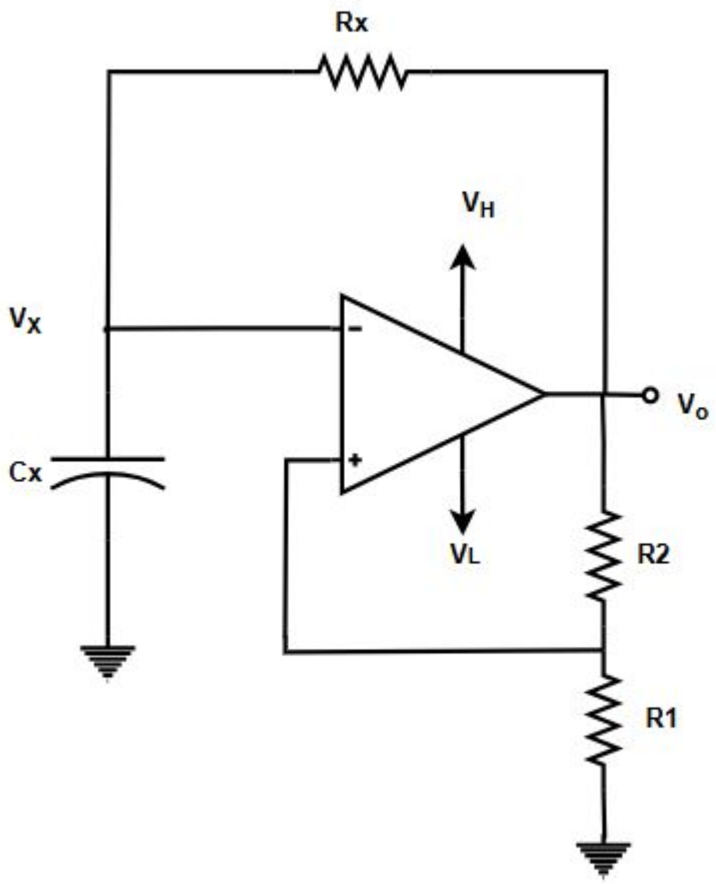


Exercise:

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

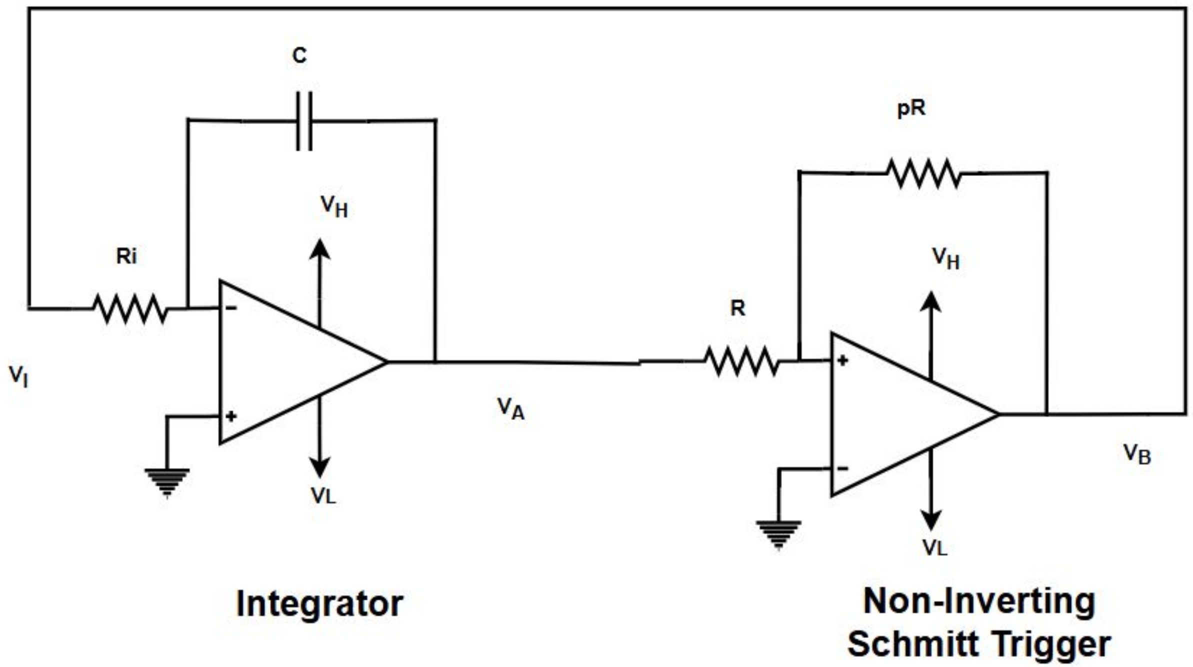
[Hints: Symmetrical power supply

$V_H = +V_{sat}$ *and* $V_L = -V_{sat}$]



Triangular wave generator

Here is the circuit of the triangular wave generator.



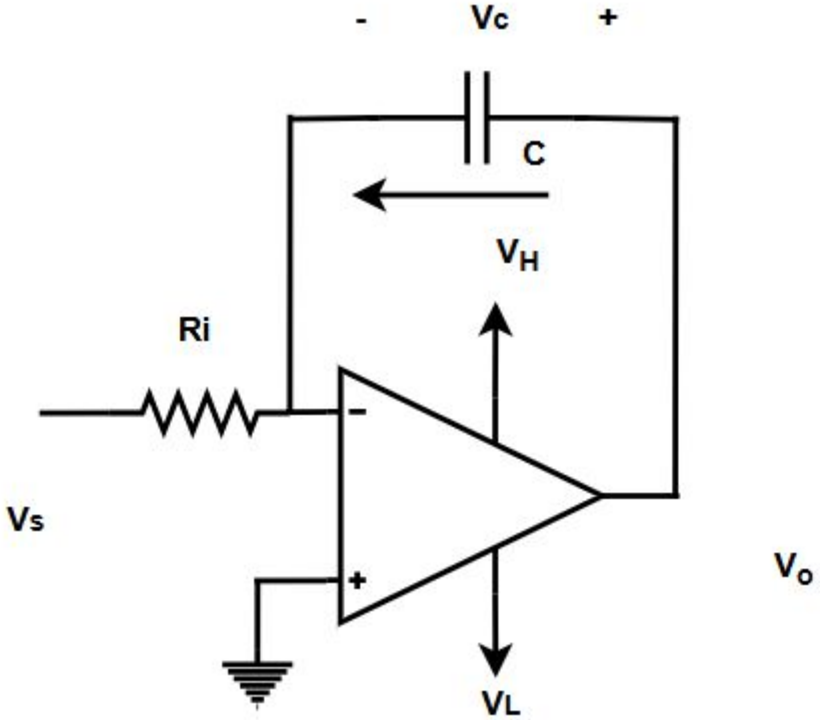
Integrator

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

V_s is a constant voltage.

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

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

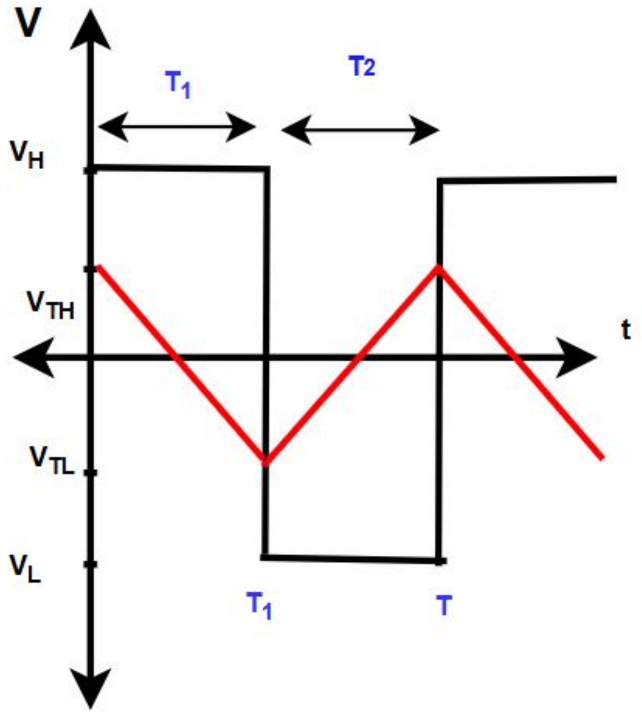


Integrator

Triangular

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

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



Triangular

Case 01: $0 < t < T_1$

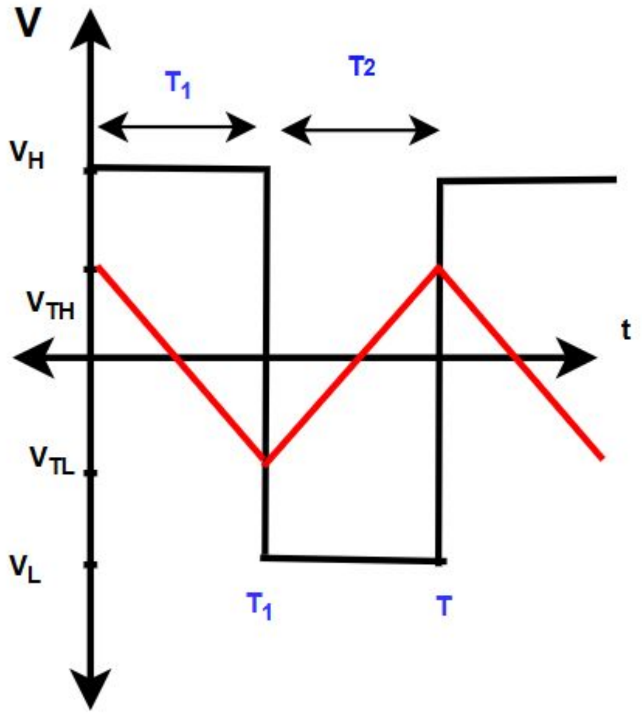
$$V_C(t) = V_{initial} - \frac{V_S}{R_i C}(t - 0)$$

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

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

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

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



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Formula of Triangular Wave

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

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

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

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

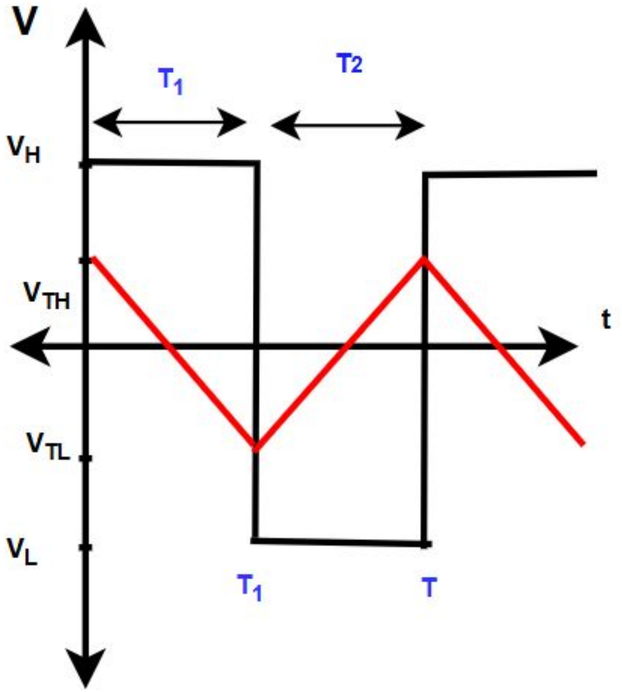
$$Duty\ Cycle(\ Square\ ) = \frac{T_1}{T_1 + T_2} * 100\%$$

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

Special Case: When $V_L = -V_H$

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

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



Exercise:

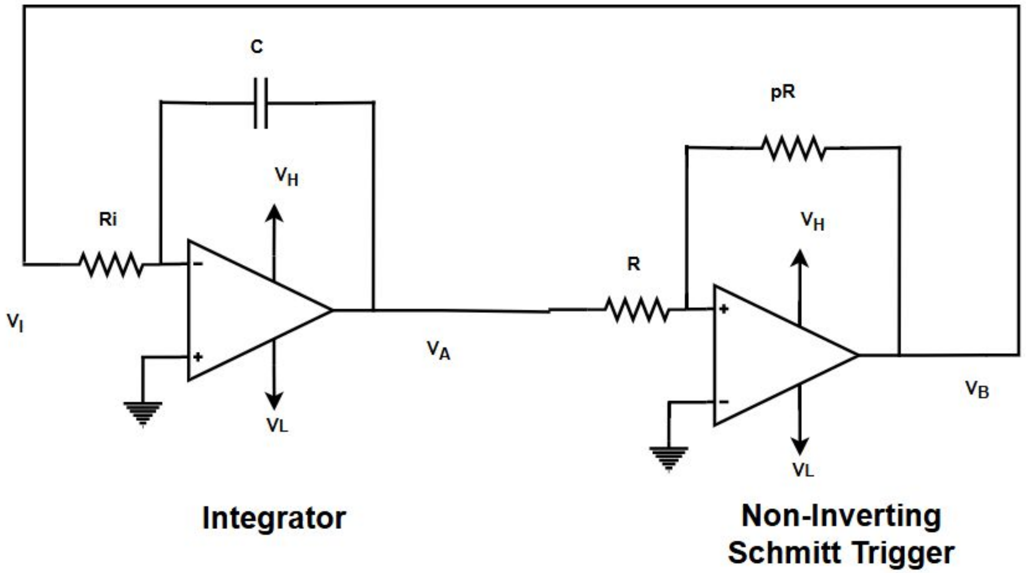
Answer the following question for the Triangular wave generator.

Given, $R_i = 10k, C = 10\ \mu F\ , R_2 = pR = 20k,\ \ R1 = R = 10k, \mathrm{V_L} = -\mathrm{V_H}$ or $\mathrm{V_H} = 15\ \mathrm{V}, \mathrm{V_L} = -15\ \mathrm{V}$

a). Draw the voltage $V_A\ and\ V_B\ vs\ t$ 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, $R_i = 10k, C = 10\ \mu F\ , R_2 = pR = 20k,\ \ R1 = R = 10k, \mathrm{V_H} = 10\ \mathrm{V}, \mathrm{V_L} = -12\ \mathrm{V}$

a). Draw the voltage $V_A\ and\ V_B\ vs\ t$ 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.