Signal Generators

LECTURE 16

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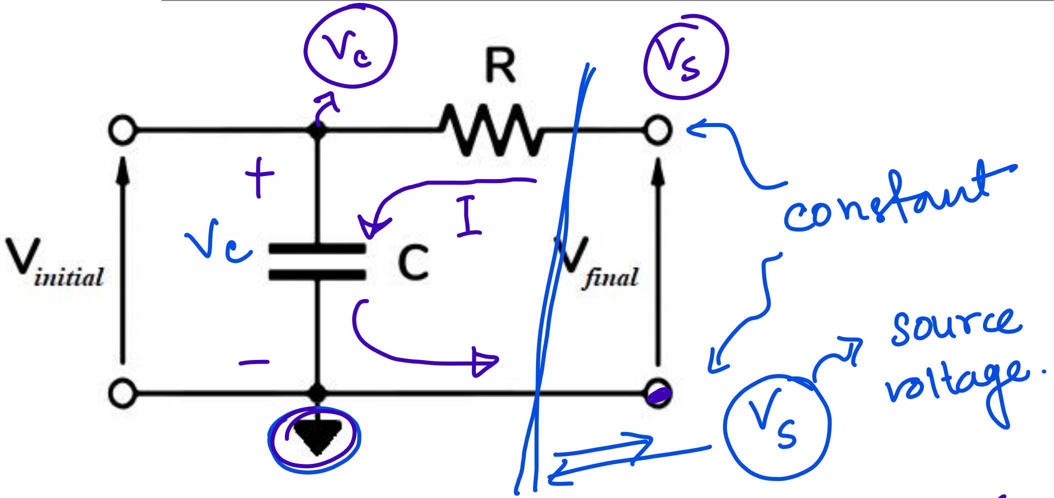
Basic RC circuit



$t = t_1$, rest of the circuit is connected to RC circuit, $V_c(t = t_1) = V_{initial}$

$V_c < V_s$, $Q \uparrow$, $V_s < V_c$, $Q \downarrow$.

$C = \frac{Q}{V_c}$

$$I = \frac{dQ}{dt} = \frac{d(CV)}{dt} = C\frac{dV_c}{dt}$$

$$I = \frac{V_s - V_c}{R} \quad \therefore \boxed{C\frac{dV_c}{dt} = \frac{V_s - V_c}{R}} \Rightarrow \frac{dV_c}{V_s - V_c} = \frac{dt}{RC}$$

$\tau = RC$ = time constant

$\boxed{t_1 < t_2 < \infty}$

$$\int_{V_c(t_1)}^{V_c(t_2)} \frac{dV_c}{\underbrace{V_s - V_c}_{x}} = \frac{1}{RC}\int_{t_1}^{t_2} dt \Rightarrow -\ln|V_s - V_c|\Big|_{V_c(t_1)}^{V_c(t_2)} = \frac{1}{RC}(t_2 - t_1)$$

$$\Rightarrow \boxed{(t_2 - t_1) = RC \ln\left|\frac{V_s - V_c(t_1)}{V_s - V_c(t_2)}\right|}$$

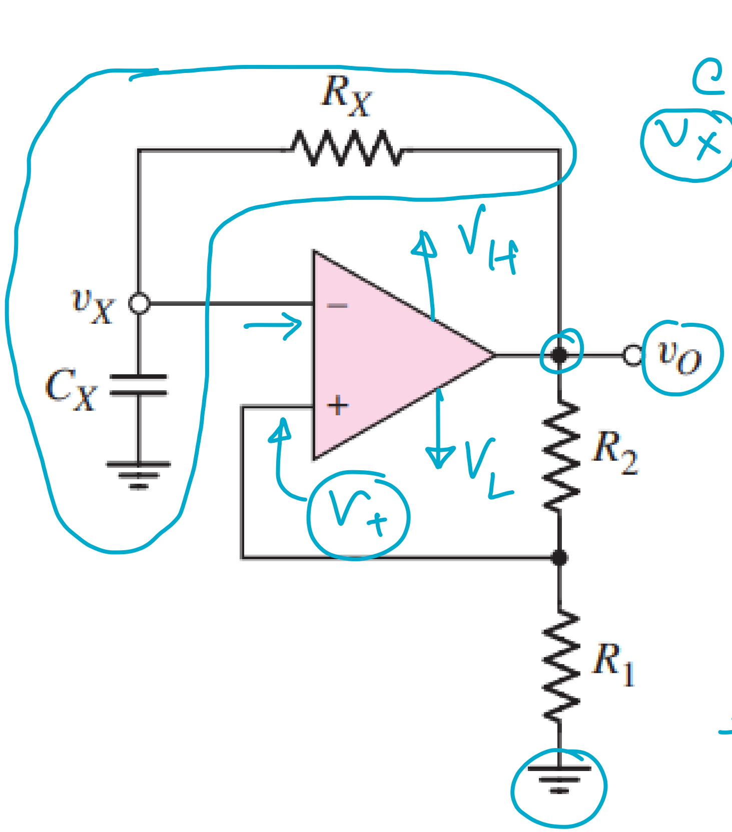
$$\Rightarrow \boxed{V_c(t_2) = V_s + (V_c(t_1) - V_s)\, e^{-\frac{(t_2 - t_1)}{\tau}}}$$

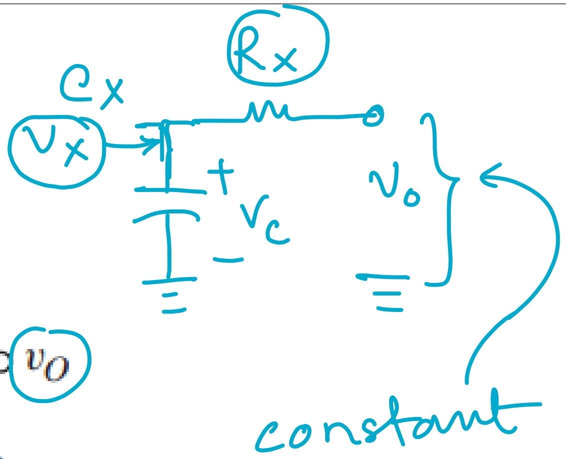
Astable Multivibrator

$v_c(t_1)$ = initial voltage.

$t_2 \to \infty, \quad e^{-(t_2-t_1)/\tau} = e^{-\infty} \to 0$

$v_c(t_2 \to \infty) = V_s$.





$$v_X = \underbrace{v_o}_{v_s = v_{final}} + \left(v_{initial} - \underbrace{v_o}_{v_{final}}\right) e^{-\frac{(t_2 - t_1)}{\tau}}$$

$$\tau = R_X C_X$$

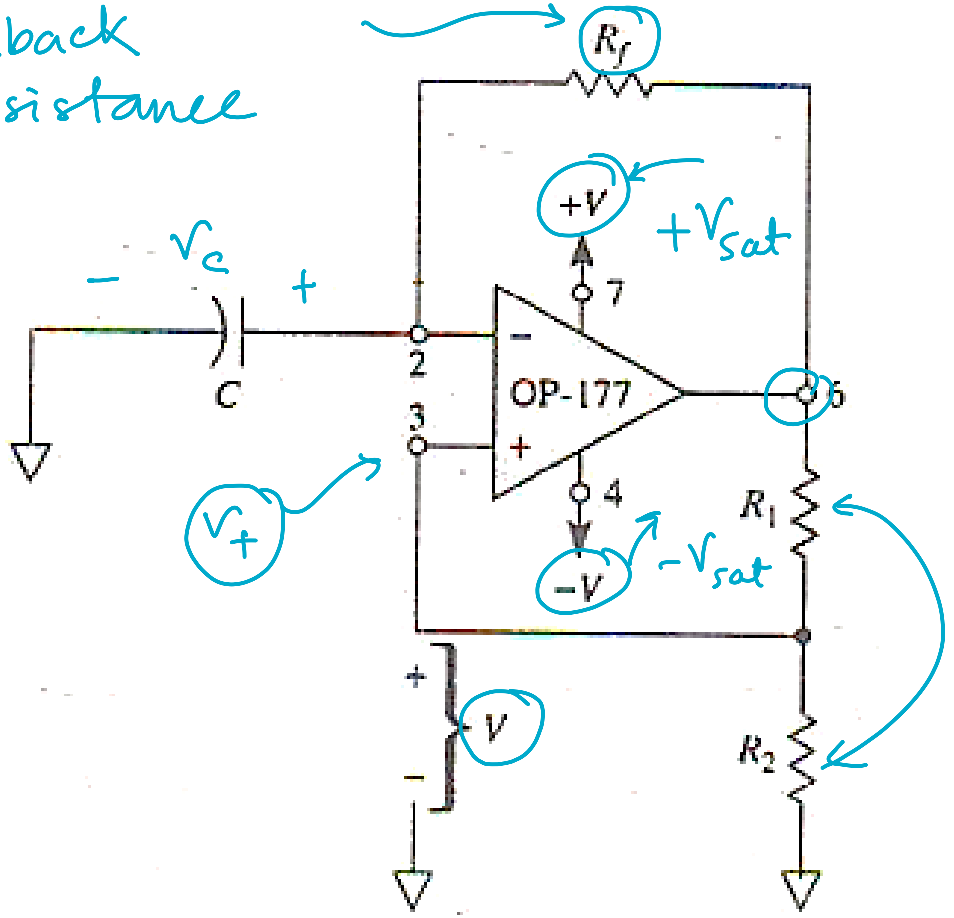
$$t_2 - t_1 = \tau \ln \left| \frac{V_{final} - V_c(t_1)}{V_{final} - V_c(t_2)} \right|$$

Neamen → $V_{TH} = V_H\left(\frac{R_1}{R_1+R_2}\right)$, $V_{TL} = V_L\left(\frac{R_1}{R_1+R_2}\right)$

Coughline chapter 6

Square Wave Generator

feedback resistance



- V_{UT} is given in equation

$$V_{UT} = \frac{R_2}{R_1 + R_2}\left(\overbrace{+V_{sat}}^{V_H}\right)$$

upper threshold

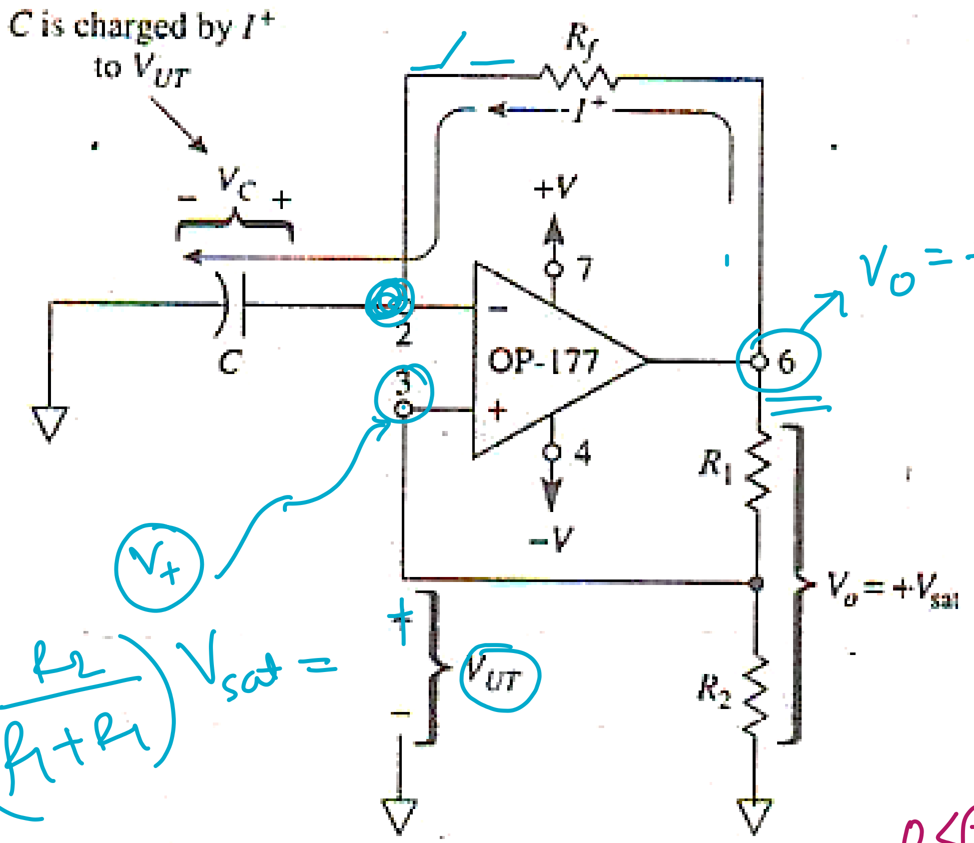
- V_{LT} is given in equation

$$V_{LT} = \frac{R_2}{R_1 + R_2}\left(\overbrace{-V_{sat}}^{V_L}\right)$$

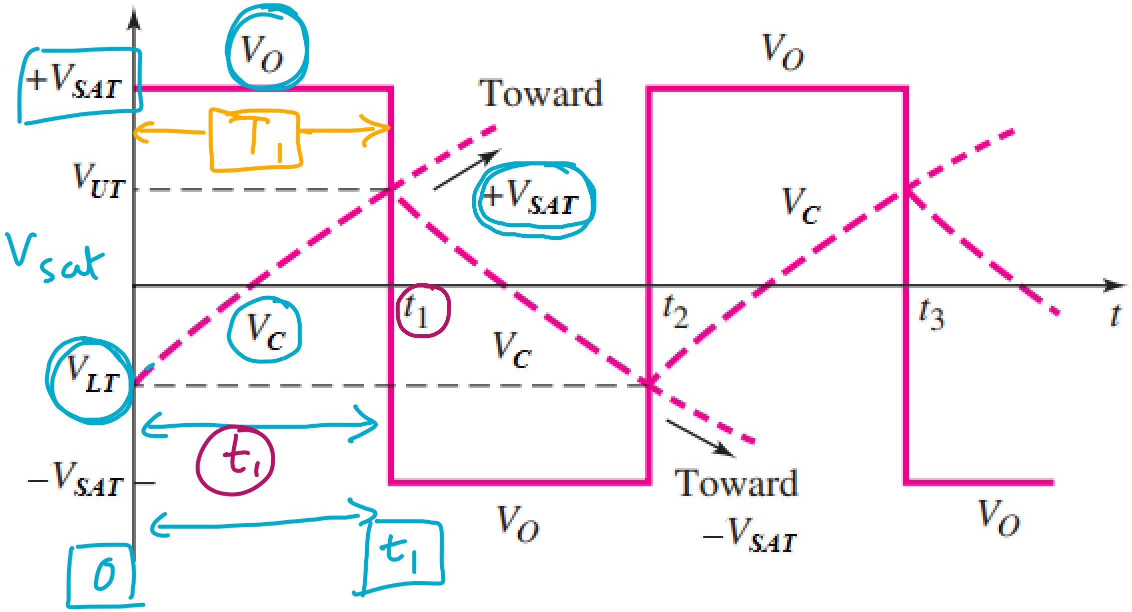
lower threshold

Square Wave Generator

Steady State Behavior



$$\left(\frac{R_2}{R_1+R_2}\right) V_{sat} = V_{UT}$$

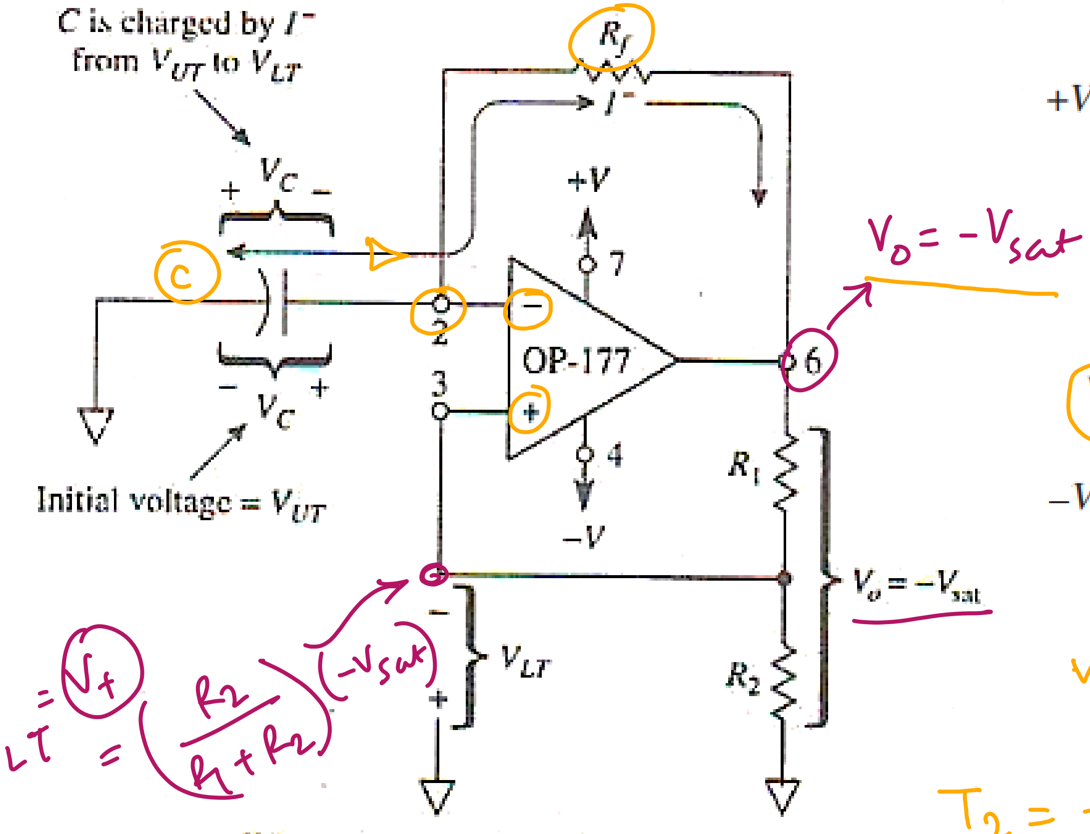


$$V_{LT} = \left(\frac{R_2}{R_1+R_2}\right)(-V_{sat})$$

$$0 < t < t_1, \quad V_c(t) = V_{sat} + (V_{Lt} - V_{sat})\, e^{-\left(\frac{t-0}{R_f C}\right)}$$

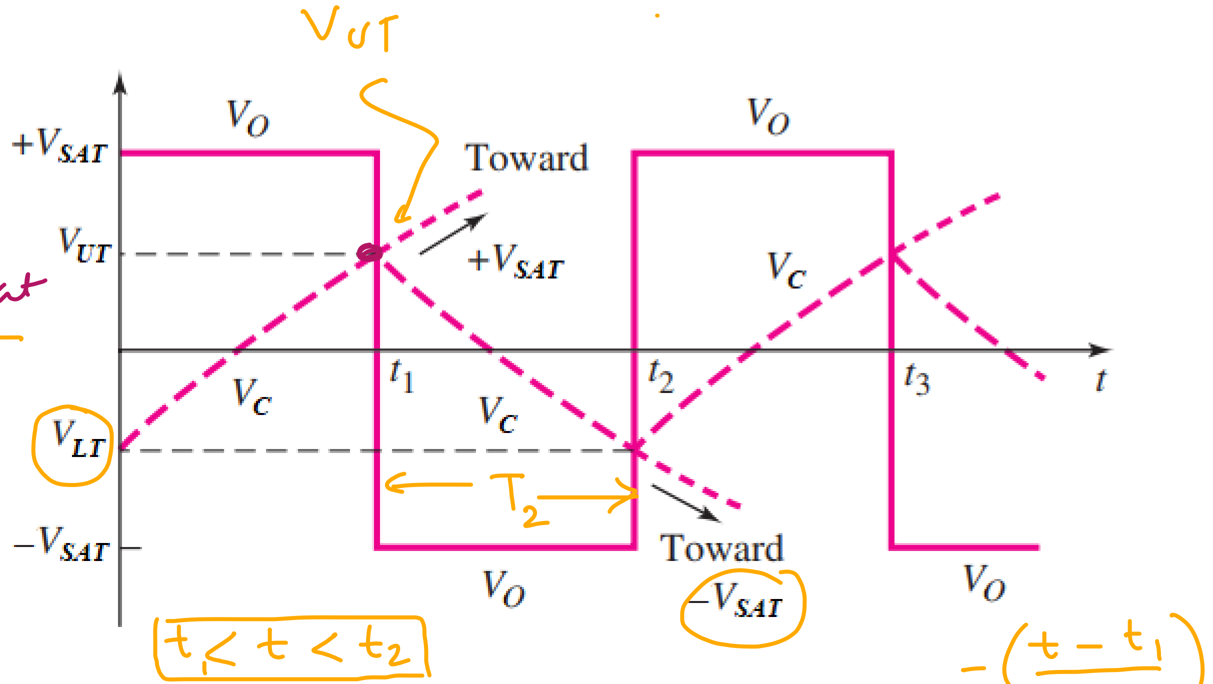
$$V_c(t_1) = V_{UT} \qquad T_1 = t_1 = R_f C \ln\left(\frac{V_{sat} - V_{LT}}{V_{sat} - V_{UT}}\right)$$

Square Wave Generator



(a) When $V_o = -V_{sat}$, V_C charges toward V_{LT}.

$$V_{LT} = V_f = \left(\frac{R_2}{R_1+R_2}\right)(-V_{sat})$$



$t_1 < t < t_2$

$$v_c(t) = -V_{SAT} + \left(V_{UT} - (-V_{SAT})\right) e^{-\left(\frac{t-t_1}{R_f C}\right)}$$

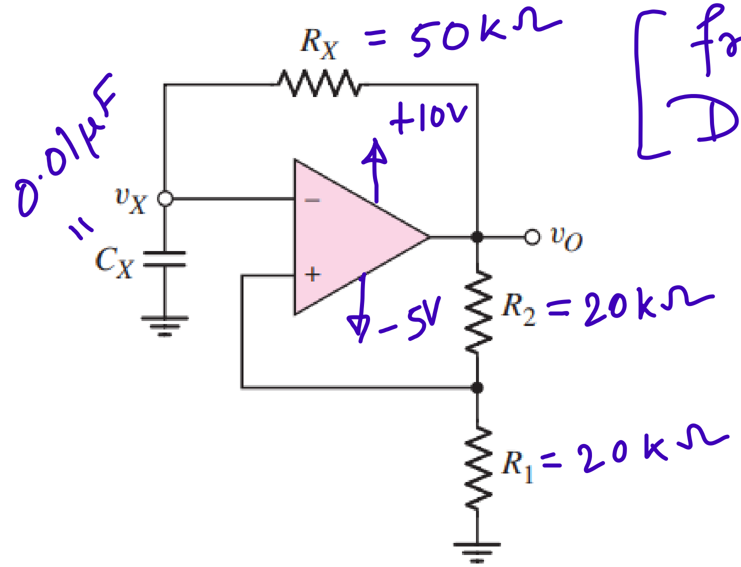
$T_2 = t_2 - t_1,$

$$T_2 = (t_2 - t_1) = R_f C \ln\left(\frac{(-V_{SAT}) - V_{UT}}{(-V_{SAT}) - V_{LT}}\right)$$

Square Wave Generator

EXERCISE PROBLEM

***Ex 15.8:** For the Schmitt trigger oscillator in Figure 15.35, the saturation output voltages are +10 V and −5 V. $R_1 = R_2 = 20\,\text{k}\Omega$, $R_X = 50\,\text{k}\Omega$, and $C_X = 0.01\,\mu\text{F}$. Determine the frequency of oscillation and the duty cycle. Sketch



[frequency
Duty cycle]

T_1 = Voltage high time duration

T_2 = " low " "

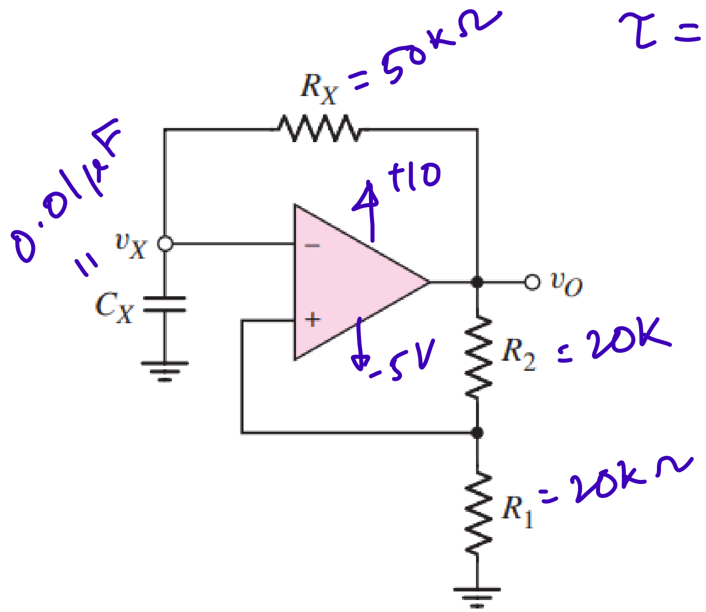
$T = T_1 + T_2$ = total time period

f = frequency $= \frac{1}{T}$. Duty cycle $= \frac{T_1}{T}$

$$V_{UT} = (+V_{sat}) \times \frac{R_1}{R_1+R_2} = 10 \times \frac{20}{20+20} = 5V$$

$$V_{LT} = (-V'_{sat}) \times \frac{R_1}{R_1+R_2} = (-5) \times \frac{20}{20+20} = -2.5V$$

Square Wave Generator



$$\tau = R_X C_X = 50\times10^{3}\,\Omega \times 0.01\times10^{-6}\,F = 0.5\,ms$$

$$T_1 = \tau \ln\left(\frac{+V_{sat} - V_{LT}}{V_{sat} - V_{UT}}\right) = 0.5\,ms \ln\left[\frac{10-(-2.5)}{10-5}\right] = 0.5\,ms \ln(2.5)$$

$$T_2 = \tau \ln\left(\frac{-V_{sat} - V_{UT}}{-V_{sat} - V_{LT}}\right) = 0.5\,ms \ln\left[\frac{-5-5}{-5-(-2.5)}\right] = 0.5\,ms \ln(4)$$

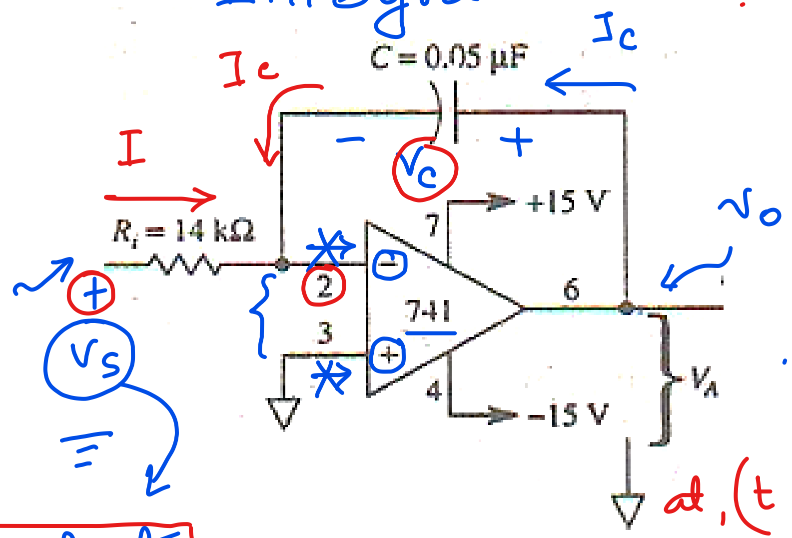
$$T = T_1 + T_2 = 0.5 \ln(2.5\times4) = 0.5 \ln(10)$$

$$f = \frac{1}{0.5\ln(10)} = 0.868\,KHz = 868\,Hz$$

$$\text{Duty Cycle} = \frac{T_1}{T} = \frac{\ln(2.5)}{\ln(10)} \approx 39.1\%$$

Triangular Wave Generator

Integrator



constant

$$v^- = 0\,V \qquad I = \frac{V_s}{R_i}, \quad I + I_c = 0$$

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

$$\Rightarrow \int dV_c = -\int \frac{V_s}{R_i C}\,dt$$

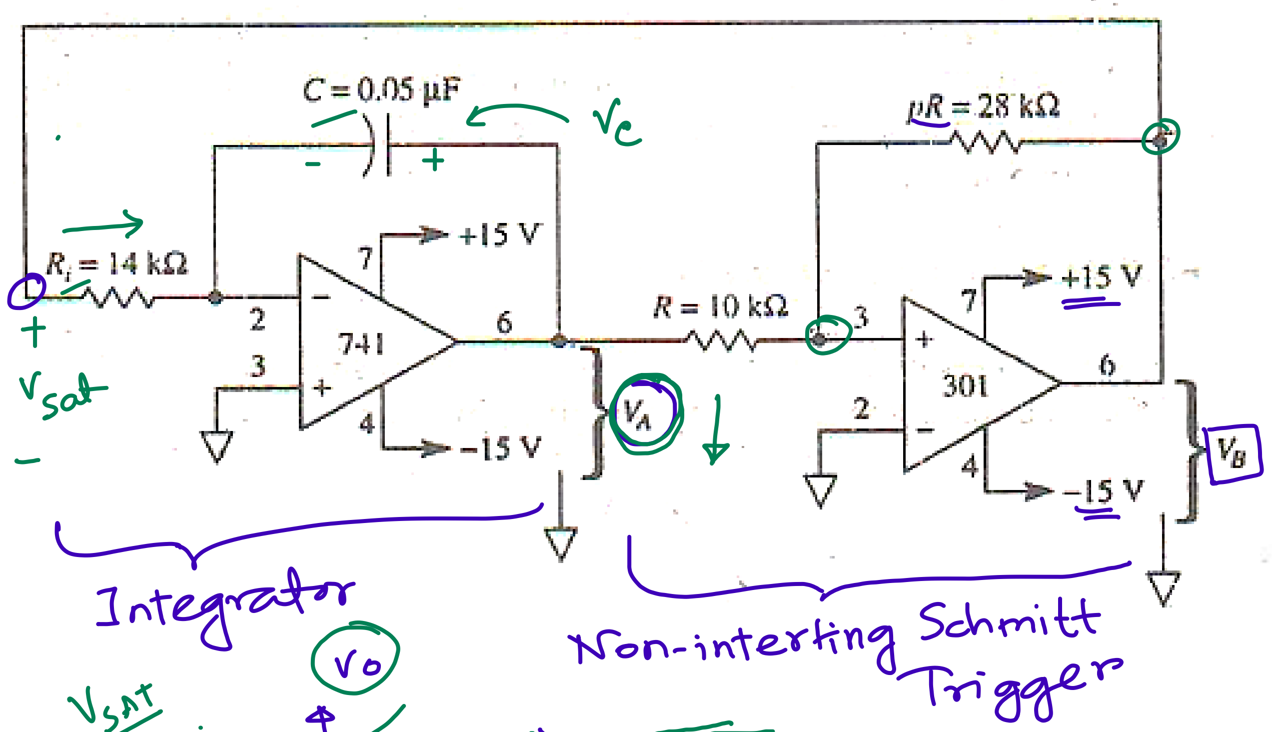
at, $(t = t_1)$, $V_c = V_{initial}$, $\quad V_c(t) = \,?$ where $t > t_1$

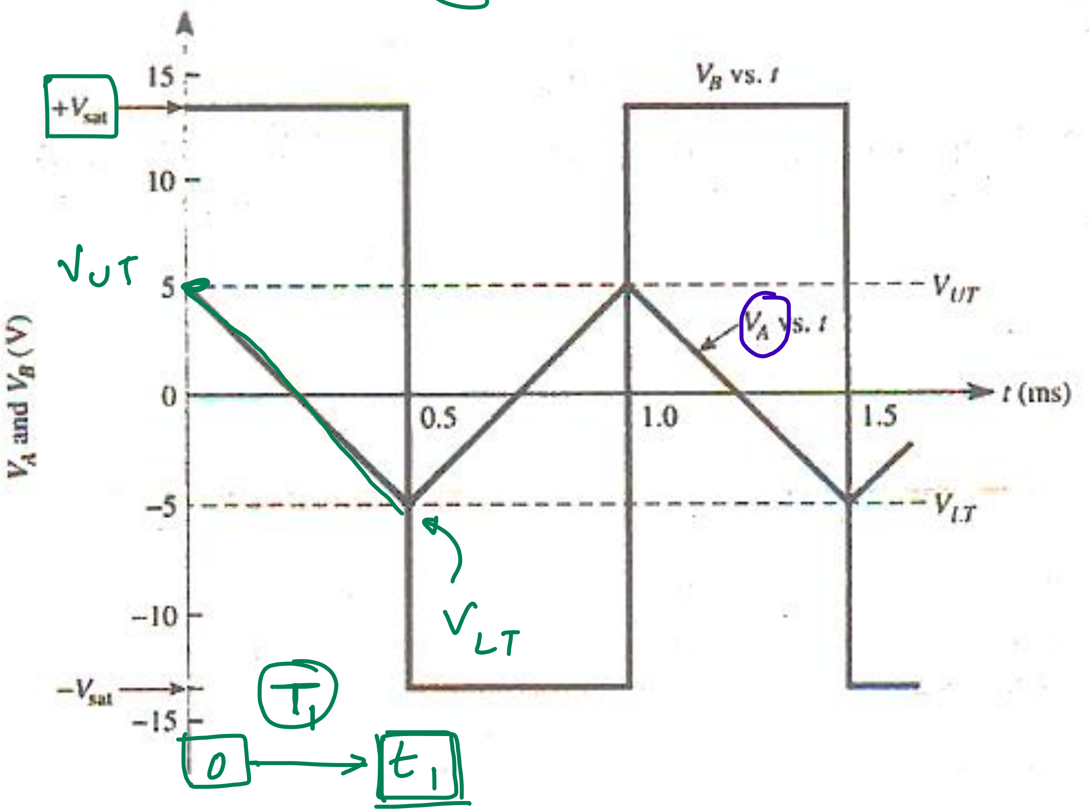
$$\Rightarrow \int_{V_{initial}}^{V_c(t)} dV_c = -\int_{t_1}^{t} \frac{V_s}{R_i C}\,dt \Rightarrow V_c(t) - V_{initial} = -\frac{V_s}{R_i C}(t - t_1)$$

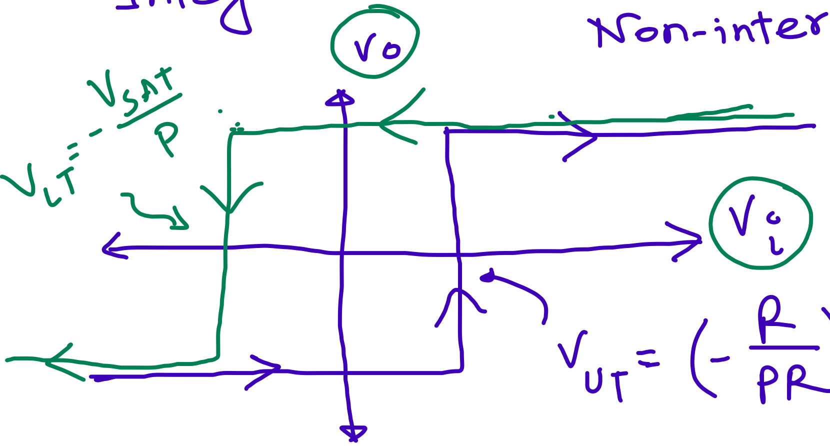
$$\Rightarrow \boxed{V_c(t) = V_{initial} - \frac{V_s}{R_i C}(t - t_1)}$$

Triangular Wave Generator

Steady state condition







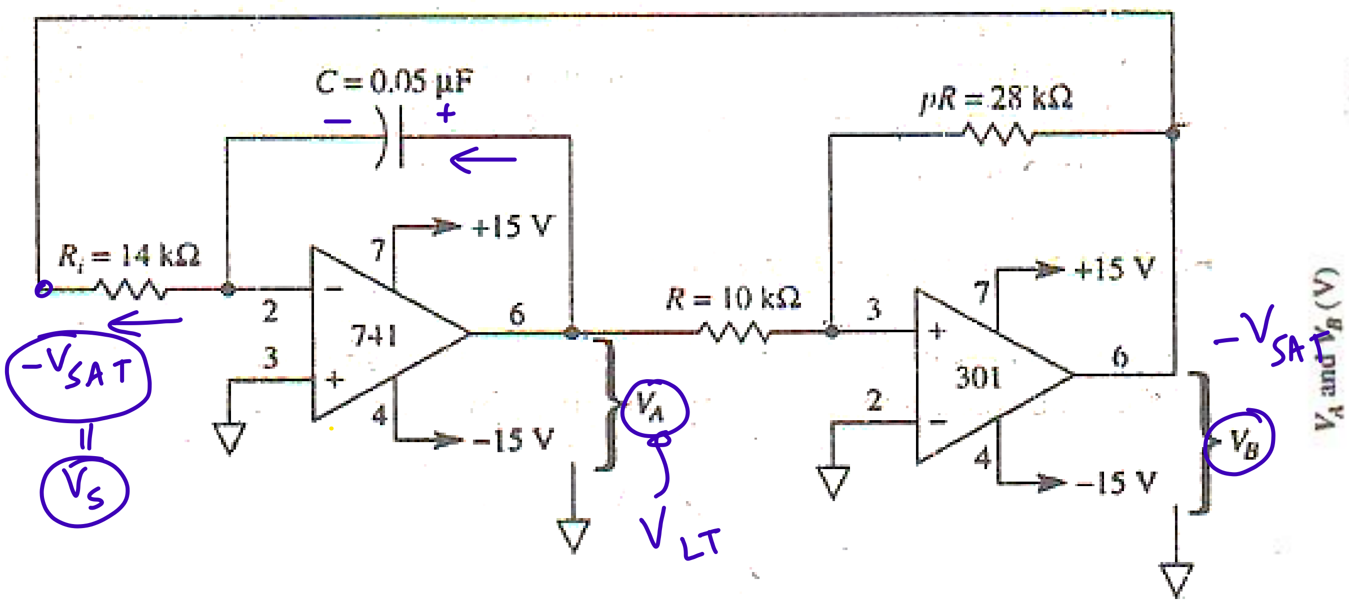
$$V_{UT} = \left(-\frac{R}{pR}\right)(-V_{SAT}) = \frac{\overbrace{-(-V_{SAT})}^{V_L}}{p}$$

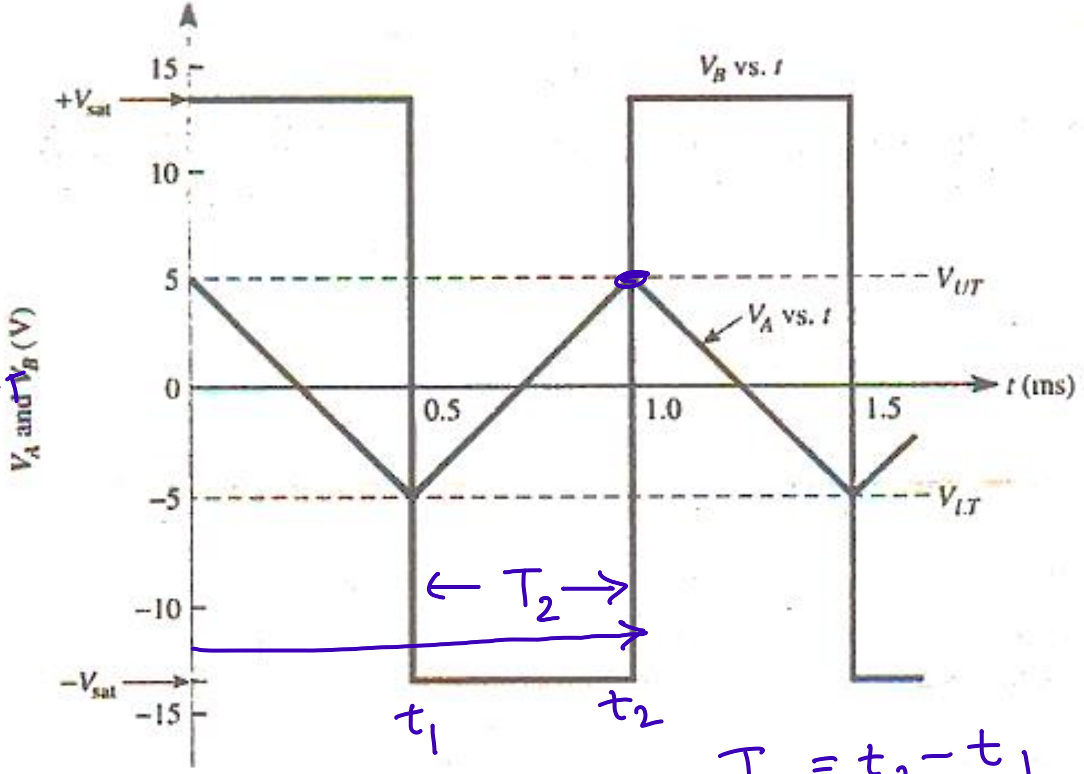
$$v_c(t) = v_{initial} - \frac{V_S}{R_i C}(t - t_{initial})$$

$$\Rightarrow v_{LT} = V_{UT} - \frac{V_{SAT}}{R_i C}(T_1) \Rightarrow \boxed{T_1 = R_i C\left(\frac{V_{UT}-V_{LT}}{V_{SAT}}\right)}$$

higher saturation voltage

Triangular Wave Generator





$T_2 = t_2 - t_1$

$$V_c(t) = v_{initial} - \frac{V_S}{R_i C}(t - t_{initial})$$

$$\Rightarrow \underbrace{V_c(t_2)}_{V_{UT}} = V_{LT} - \frac{(-V_{SAT})}{R_i C}\underbrace{(t_2 - t_1)}_{T_2} \Rightarrow T_2 = \frac{(V_{LT} - V_{UT})}{\underbrace{(-V_{SAT})}_{\text{lower saturation voltage}}} R_i C$$

Triangular Wave Generator

Total time period, $T = T_1 + T_2$

$$= \left(\frac{V_{UT} - V_{LT}}{+V_{SAT}} + \frac{V_{LT} - V_{UT}}{-V_{SAT}} \right) \times R_i C$$

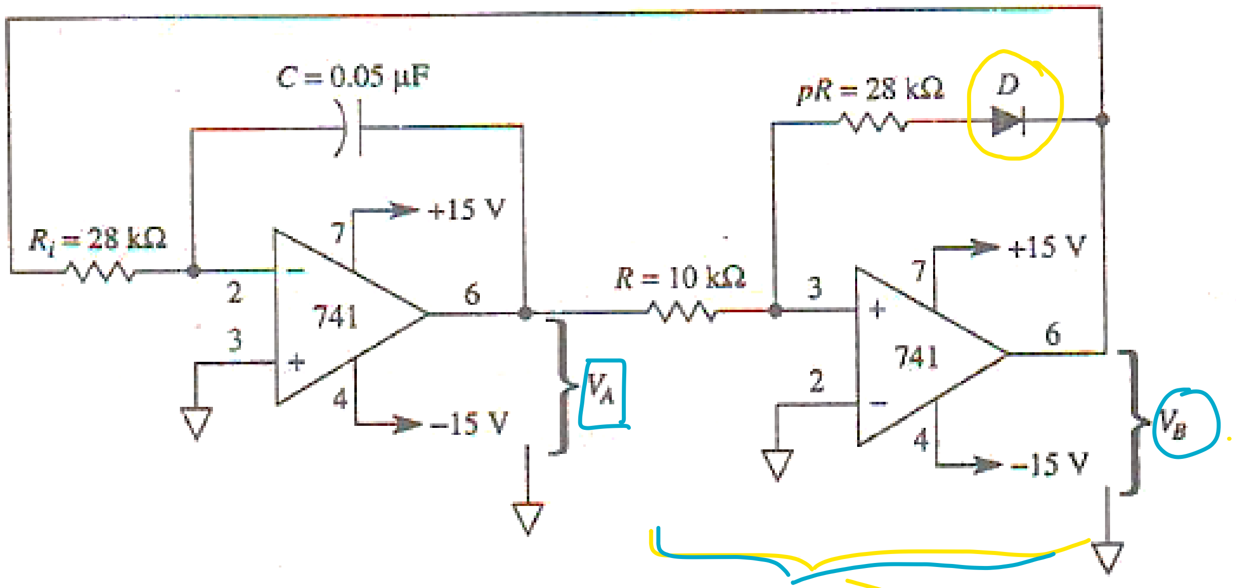
frequency, $f = \frac{1}{T}$, $\pm V_{SAT} = 15$, $P = \frac{pR}{R} = \frac{28}{10} = 2.8$

$$\left[V_{UT} = \frac{-(-V_{SAT})}{P} \right] = -\frac{(-15)}{2.8} = 5.357V, \quad V_{LT} = -5.357V$$

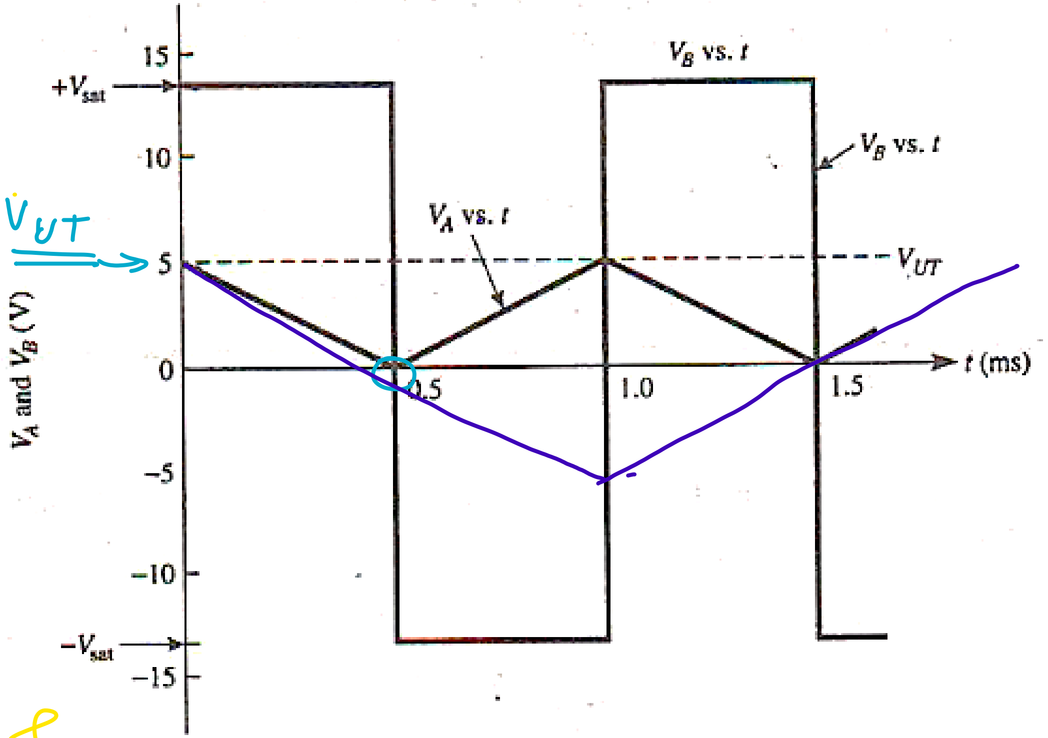
$$T = \left(\frac{4 \times 5.357}{15} \right) \times 0.05\mu \times 14K = 1ms. \quad \boxed{f = 1KHz}$$

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

Unipolar Triangular Wave Generator

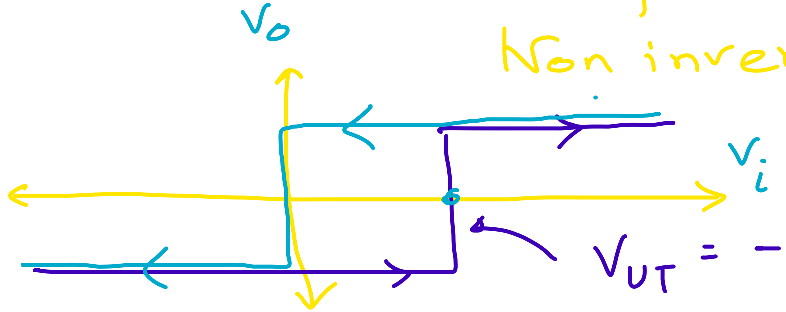


(a) Unipolar triangle-wave generator.



(b) Waveshapes.

Transfer characteristics of Non inverting Schmitt Trigger



$$V_{UT} = -\frac{(-V_{SAT} + V_\gamma)}{P}$$

Unipolar Triangular Wave Generator

Example 6-7 → Coughlin's

Find the approximate peak voltage and frequency for the unipolar triangle-wave generator in Fig.

Solution Calculate

$$p = \frac{pR}{R} = \frac{28\ \text{k}\Omega}{10\ \text{k}\Omega} = 2.8$$

Find the peak value of V_A from Eq.

$15 \rightarrow 13.8\ \text{V}$

Conduction voltage of a diode

$$V_{UT} = -\left(\frac{-V_{sat} + 0.6\ \text{V}}{p}\right) = -\left(\frac{-13.8\ \text{V} + 0.6\ \text{V}}{2.8}\right) \simeq 4.7\ \text{V}$$

$$2 \times \left(\frac{p}{4R_iC}\right)$$

$$f = \frac{p}{2R_iC} = \frac{2.8}{2(28\ \text{k}\Omega)(0.05\ \mu\text{F})} = 1000\ \text{Hz}$$

Reference

- ❑ Chapter 6 of Operational Amplifiers and Linear Integrated Circuits by Coughlin & Driscoll
- ❑ Chapter 15 of Microelectronics Circuit Analysis by Donald Neamen