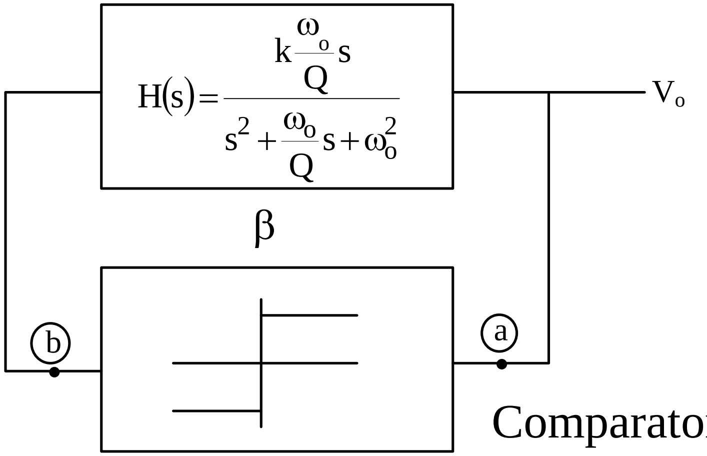
SIGNAL GENERATORS

- SINUSOIDAL
  - BP (Two integrator) Based
  - One Op Amp (Wien-Bridge)
- EXPONENTIAL,TRIANGULAR AND SQUARE WAVE

How to make a sinusoidal oscillator based on filters?

Band Pass Based Oscillator



Comparator

Assuming small signal conditions, we can write the loop filter

$$1-\beta H(s)=0 \quad ; \quad K=k\frac{\omega_o}{Q}$$

$$1-\frac{sK'}{s^2+\frac{\omega_o}{Q}s+\omega_o^2}=0 \text{ or } \beta H(s)=1$$

Thus the characteristic equation-yields:

$$s^2-\left(K'-\frac{\omega_o}{Q}\right)s+\omega_o^2=0$$

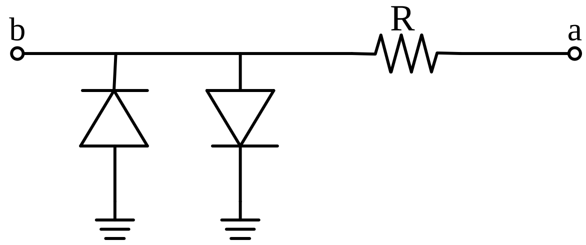
In order to have the poles in the RHP, it is imposed that

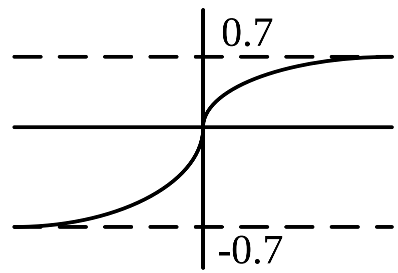
$$K' - \frac{\omega_o}{Q} > 0 \quad \text{or} \quad K' \geq \frac{\omega_o}{Q}$$

where $K' = K_C K$ and $K_C = V_{sat} / \Delta V_{TH}$

However to move the poles on the jω axis we require a non-linear block implementation of β. There are a number of blocks to accomplish this.

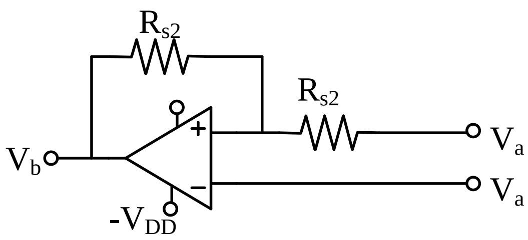
Implementation 1





$V_b \cong \pm 0.7V$

Implementation 2



For – $H_{BP}(s)$

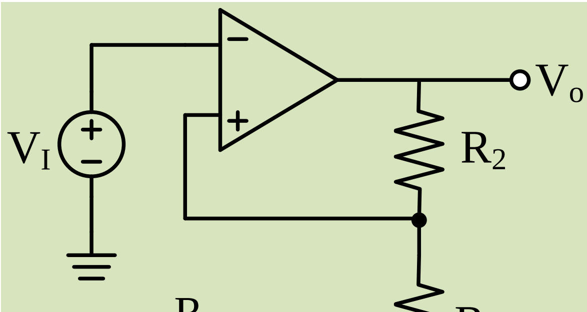
For + $H_{BP}(s)$

$$K_C = \frac{V_{DD}}{\Delta V_{TH}} \cong \frac{V_{DD}}{\frac{R_1}{R_2}\left(V_{DD} - \left(-V_{DD}\right)\right)}$$

Inverting Schmitt Trigger

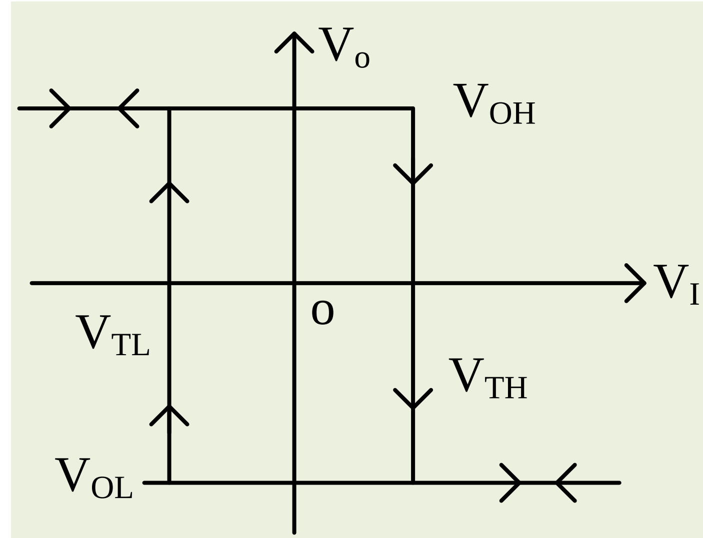
$$K_C \cong \frac{R_{s2}}{2R_{s1}}$$

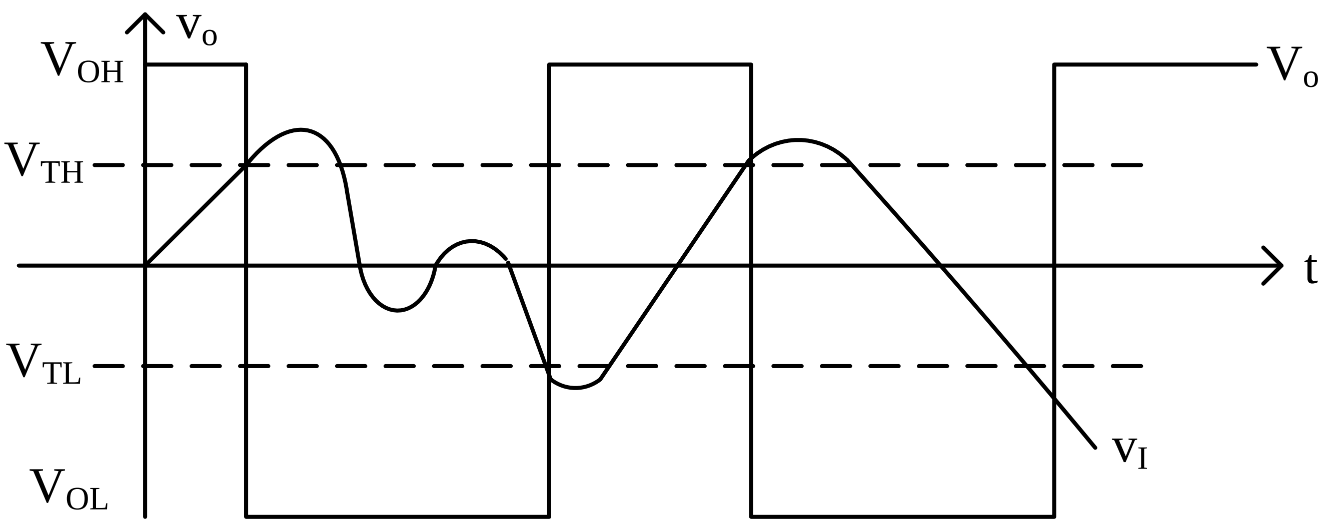
Inverting Schmitt Trigger



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

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





$$V_{TH} = \frac{R_1}{R_1 + R_2} V_{OH} \quad \text{or} \quad V_{OH} = \left(1 + \frac{R_2}{R_1}\right) V_{TH}$$

$$V_{TL} = \frac{R_1}{R_1 + R_2} V_{OL} \quad \text{or} \quad V_{OL} = \left(1 + \frac{R_2}{R_1}\right) V_{TL}$$

Hysteresis (window) Width:

$$\Delta V_T = V_{TH} - V_{TL} = \frac{R_1}{R_1 + R_2} \left(V_{OH} - V_{OL}\right)$$

or

$$V_{OH} - V_{OL} = \left(1 + \frac{R_2}{R_1}\right) \Delta V_T$$

Numerical Example

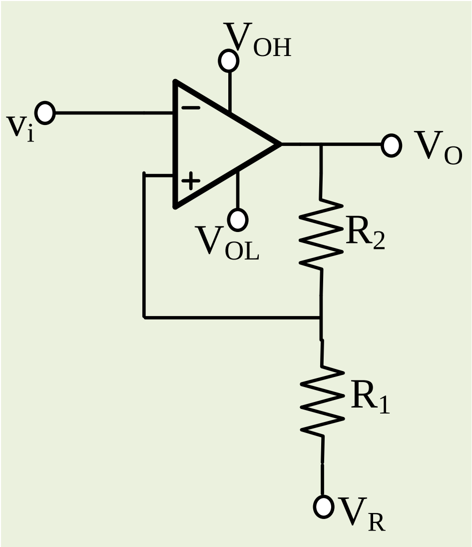
$V_{OH} = 13V \quad ; \quad V_{OL} = -13V$

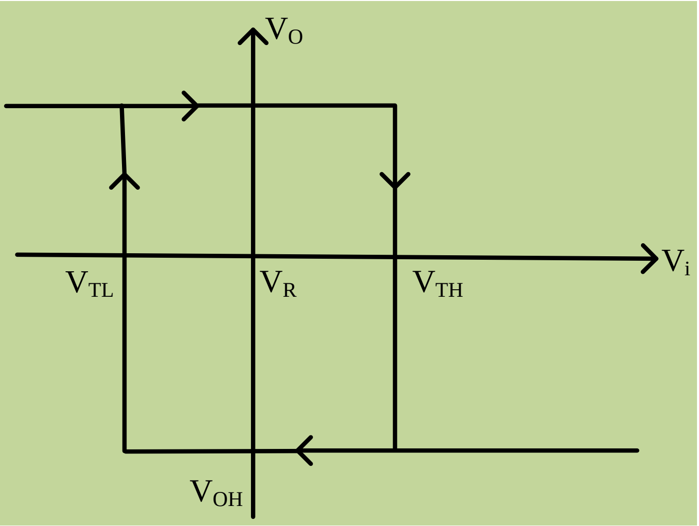
for $R_2 = 16K\Omega$ and $R_1 = 10K\Omega$

$$V_{TH} = \frac{13}{26} \times 10 = 5V$$

$$V_{TL} = \frac{-13}{26} \times 10 = -5V$$

INVERTING SCHMITT TRIGGER WITH REFERNCE VOLTAGE





$$V_{TH} = \frac{V_{OH}R_1 + V_R R_2}{R_1 + R_2} = \frac{V_R + \frac{R_1}{R_2}V_{OH}}{1 + \frac{R_1}{R_2}}$$

$$V_{TL} = \frac{V_{OL}R_1 + V_R R_2}{R_1 + R_2} = \frac{V_R + \frac{R_1}{R_2}V_{OL}}{1 + \frac{R_1}{R_2}}$$

$$\Delta V_T = \frac{\frac{R_1}{R_2}}{1 + \frac{R_1}{R_2}}\left(V_{OH} - V_{OL}\right) = \frac{R_1}{R_1 + R_2}\left(V_{OH} - V_{OL}\right)$$

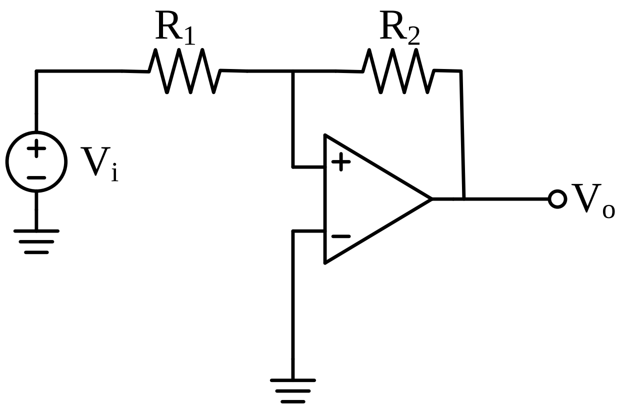
Reader. Exchange input and reference terminals in the figure of Previous page and prove that for the non-inverting comparator

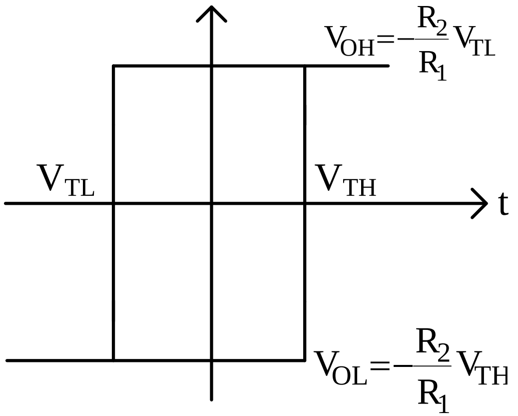
$$V_{TH} = \frac{R_1}{R_2} V_{OH} + V_R \left(1 + \frac{R_1}{R_2} \right)$$

$$V_{LH} = \frac{R_1}{R_2} V_{OL} + V_R \left(1 + \frac{R_1}{R_2} \right)$$

$$\Delta V_T = \frac{R_1}{R_2} \left(V_{OH} - V_{OL} \right)$$

Non-Inverting Schmitt Trigger



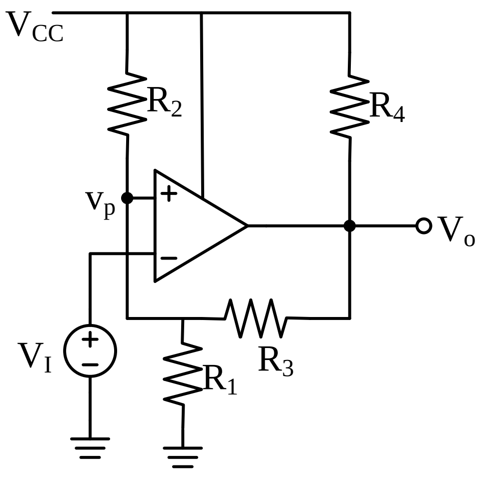


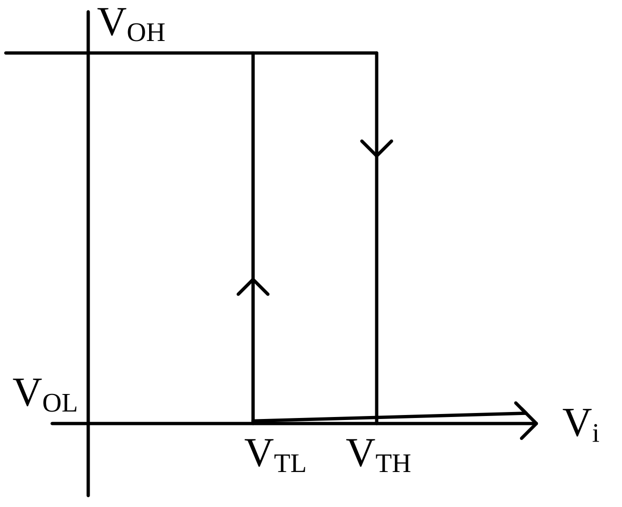
$$V_{TH} = -\frac{R_1}{R_2} V_{OL} \Leftarrow \frac{V_{TH} - 0}{R_1} = \frac{0 - V_{OL}}{R_2}$$

$$V_{TL} = -\frac{R_1}{R_2} V_{OH}$$

$$\Delta V_T = \frac{R_1}{R_2}\left(V_{OH} - V_{OL}\right) \quad \text{Hysteresis Window}$$

Schmitt Trigger in I/O in first quadrant and having a single supply.





Using Superposition

$$V_p = \frac{R_{1,3}}{R_{1,3} + R_2} V_{CC} + \frac{R_{1,2}}{R_{1,2} + R_3} V_o$$

where $R_{1,3} = R_1 // R_3$ and $R_{1,2} = R_1 // R_2$

If $V_{OH} \cong V_{CC}$ and $V_{OL} = 0$

then $R_4 << R_3 + R_{1,2}$

thus, imposing $V_p = V_{TL}$ for $V_o = V_{OL} = 0$

and $v_p = V_{TH}$ for $V_o = V_{OH} = V_{CC}$, we get

$$V_{TL} = \frac{R_{1,3}}{R_{1,3} + R_2} V_{CC} \; ; \; V_{TH} = \frac{R_1}{R_1 + R_{2,3}} V_{CC}$$

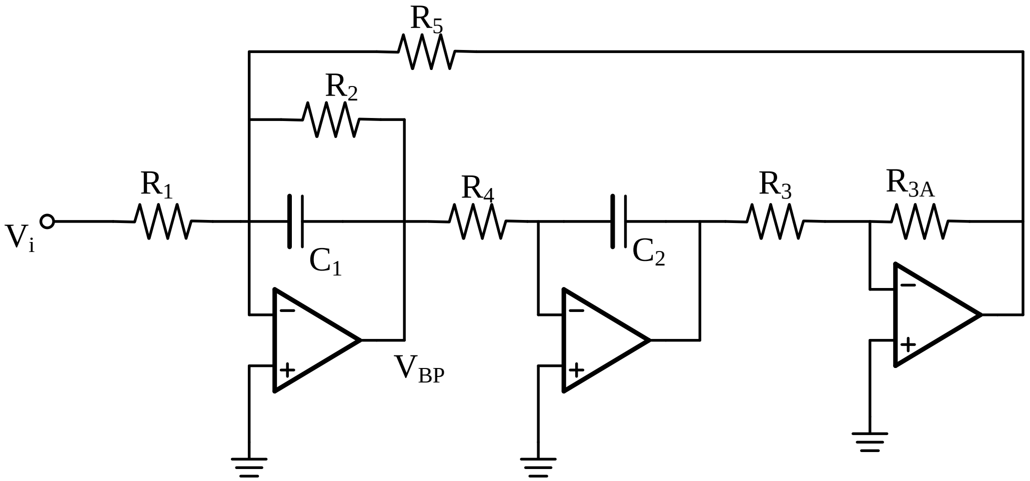
Rearranging terms and fix R_4 and $R_3 << R_4$

$$\frac{1}{R_2} = \frac{V_{TL}}{V_{CC} - V_{TL}}\left(\frac{1}{R_1} + \frac{1}{R_3}\right)$$

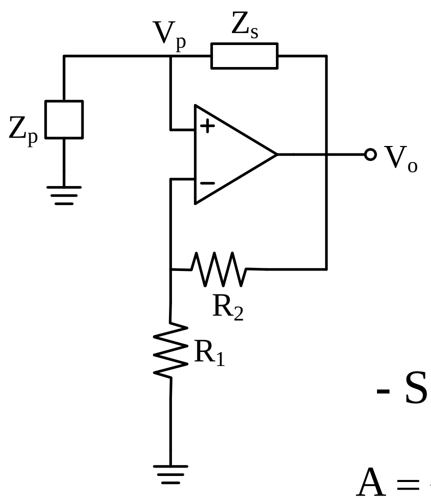
$$\frac{1}{R_1} = \frac{V_{CC} - V_{TH}}{V_{TH}}\left(\frac{1}{R_2} + \frac{1}{R_3}\right)$$

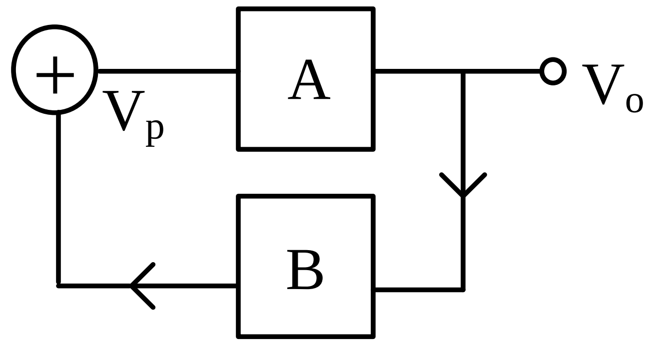
Thus the two above equations can be solved.

The BP in page1 can be implemented using the Tow-Thomas



WIEN-BRIDGE OSCILLATOR

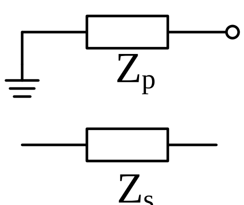


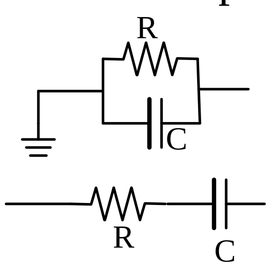


- Seen as non-inverter

$$A = \frac{V_o}{V_p} = 1 + \frac{R_2}{R_1}$$

Furthermore we can see V_p a voltage divider $\frac{Z_p}{Z_p + Z_s} V_o = V_p$





$$Z_p = \frac{R}{1 + sRC}$$

$$Z_s = \frac{1 + sRC}{sC}$$

Thus

$$\frac{V_o}{V_p} = \frac{Z_p + Z_S}{Z_P} = 1 + \frac{Z_s}{Z_p}$$

$$B = \frac{V_P}{V_O} = \frac{Z_p}{Z_p + Z_s} = \frac{1}{1 + \frac{Z_s}{Z_p}}$$

$$B = \frac{1}{1 + \frac{Z_s}{Z_p}} = \frac{1}{1 + \frac{(1 + sRC)^2}{sRC}}$$

$$B = \frac{sRC}{(sRC)^2 + 3sRC + 1} \Rightarrow \text{Band Pass Filter}$$

Characteristic Equation

$$1 - AB = 1 - T$$

$$T = AB = \frac{\left(1 + \frac{R_2}{R_1}\right)sRC}{(sRC)^2 + 3sRC + 1}$$

$$T = \frac{1 + \frac{R_2}{R_1}}{sRC + 3 + \frac{1}{sRC^2}} 2$$

$$\text{If} \quad RC = \frac{1}{\omega_o}$$

$$T(j\omega) = \frac{1 + \frac{R_2}{R_1}}{j\frac{\omega}{\omega_o} - \frac{j}{\omega / \omega_o} + 3} = \frac{1 + \frac{R_2}{R_1}}{3 + j\left(\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega}\right)}$$

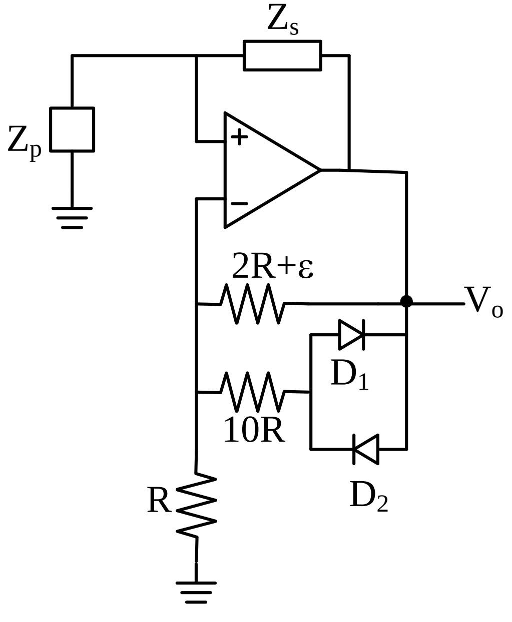
$$T(j\omega_o) = \frac{1 + R_2 / R_1}{3}$$

To force oscillation

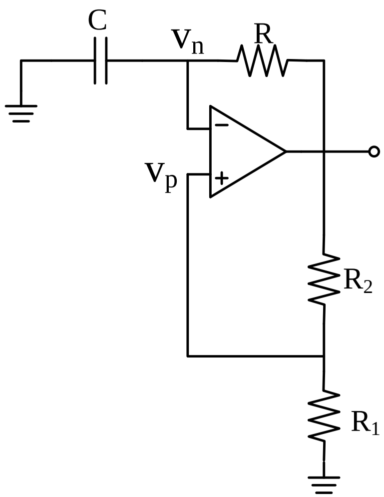
$$T(j\omega_o) > 1 \qquad \text{i.e. } \frac{R_2}{R_1} > 2$$

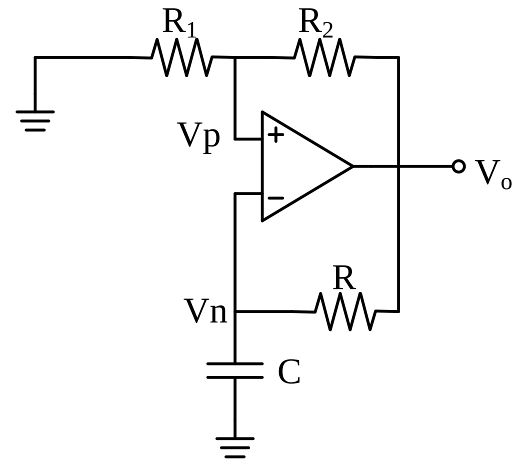
$$\frac{R_2}{R_1} = 2 + \varepsilon$$

The non-linear part of the oscillator must be added if we want the comparator not to do the non-linear operation.

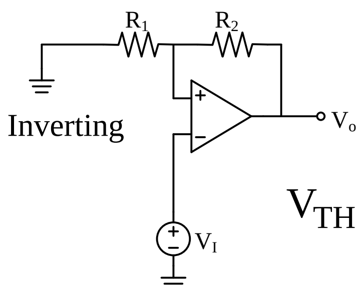


SQUARE WAVE OSCILLATOR





Let us look closer to the Schmitt Trigger

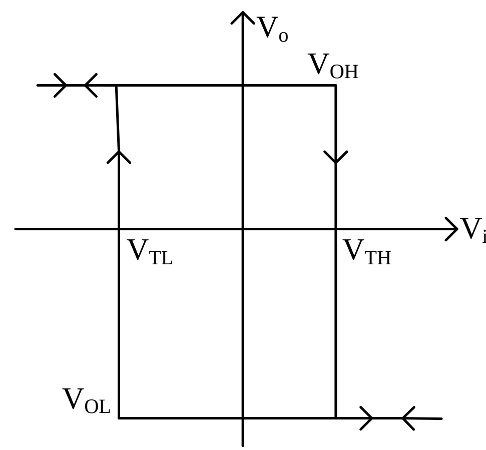


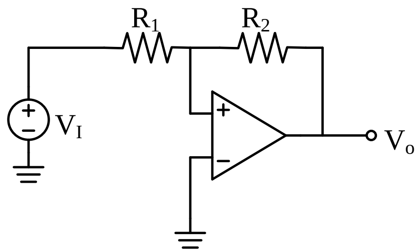
$$V_{TH} = \frac{R_1}{R_1 + R_2} V_{OH}$$

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

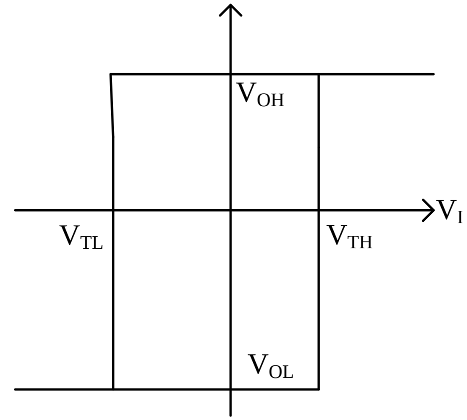
$$\Delta V_T = V_{TH} - V_{TL} = \frac{R_1}{R_1 + R_2} (V_{OH} - V_{OL})$$

$$\Delta V_T = \frac{1}{1 + \frac{R_2}{R_1}} (V_{OH} - V_{OL})$$





Non-Inverting
Schmitt Trigger



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

$$\frac{V_{TH} - 0}{R_1} = \frac{0 - V_{OL}}{R_2}$$

Tripping voltage V_{TL} becomes

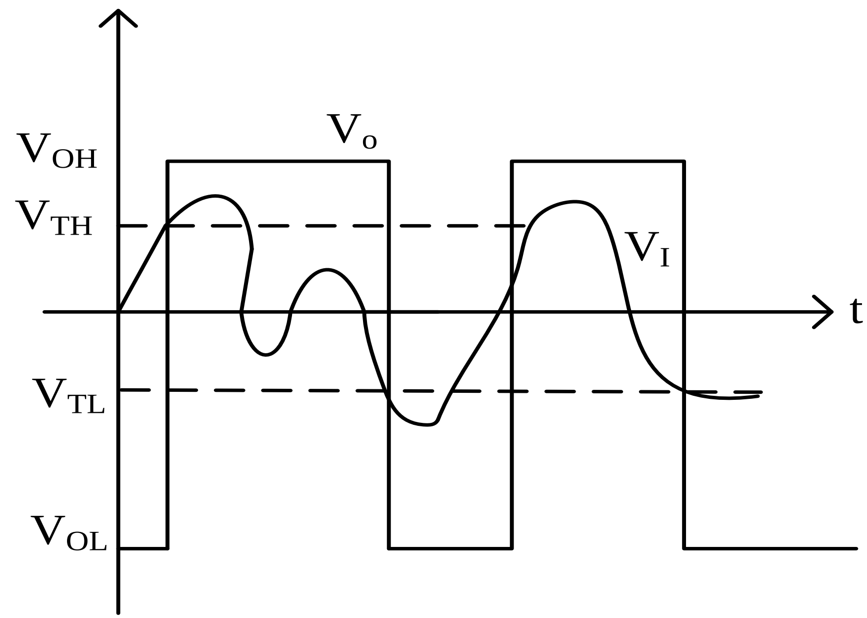
$$\frac{V_{OH} - 0}{R_2} = \frac{0 - V_{TL}}{R_1}$$

or

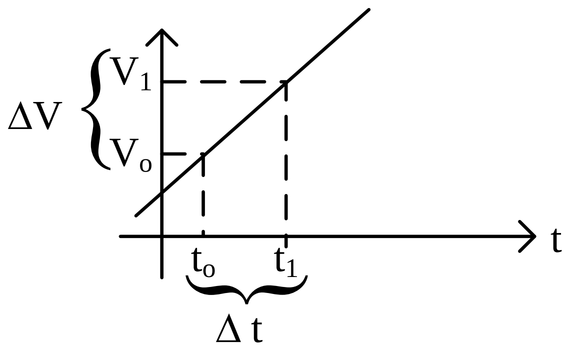
$$V_{TL} = -\frac{R_1}{R_2} V_{OH}$$

$$\Delta V_T = \frac{R_1}{R_2}\left(V_{OH} - V_{OL}\right)$$

$$\Delta V_T = \frac{1}{\frac{R_2}{R_1}}\left(V_{OH} - V_{OL}\right)$$



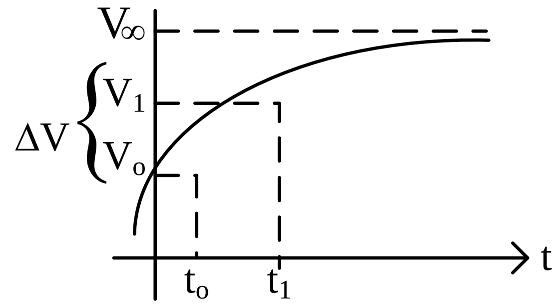
Notes on Relaxation Oscillators



Linear

$$C\Delta V = I\Delta t$$

$$\Delta t = \frac{C}{I}\Delta v$$



Exponential

$$v(t) = V_\infty + (V_o - V_\infty)e^{\frac{t-t_o}{\tau}}$$

$$\tau = RC$$

$$V_1 = V_\infty + (V_o - V_\infty)e^{\frac{t_1-t_o}{\tau}}$$

$$\Delta t = t_1 - t_o = \tau \ln\frac{V_\infty - V_o}{V_\infty - V_1}$$

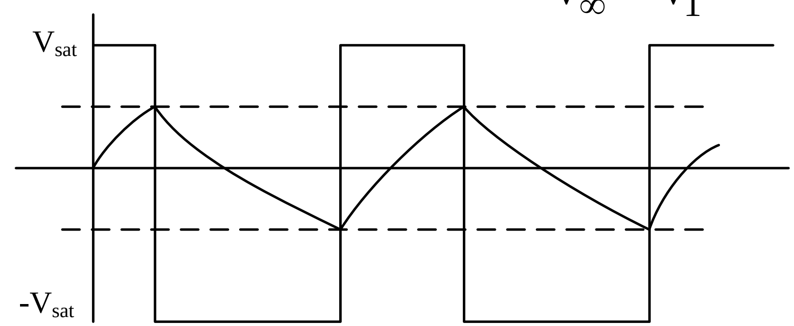
Thus for the basic-free-running exponential oscillator

$$\frac{T}{2} = RC\ln\frac{V_{sat} + V_T}{V_{sat} - V_T}$$

$$V_T = \frac{V_{sat}}{1 + \frac{R_2}{R_1}}$$

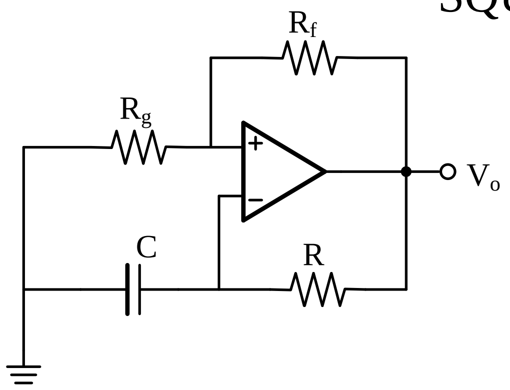
then

$$f_o = \frac{1}{T} = \frac{1}{2RC\ln(1 + 2R_1/R_2)}$$



$$f_o \neq f(V_T, V_{sat})$$

SQUARE WAVE GENERATOR



$$V_{TH} = \frac{R_g}{R_g + R_f} V_{OH}$$

or

$$V_{TL} = \frac{R_g}{R_g + R_f} V_{OL}$$

High to Low. -

Assume the output voltage is at V_{OH} , then the non-inverting input is at V_{TH} , and the Inverting is in exponential transition form its initial value V_{TL}^{-} toward V_{OH}. Thus

$$v^{-}(t) = V_{OH} - \left(V_{OH} - V_{TL}^{-}\right)e^{-t/RC}$$

or equivalent in the s-domain

$$V^{-}(s) = \frac{V_{OH}}{s} - \frac{\left(V_{OH} - V_{TL}^{-}\right)}{1 + s/RC}$$

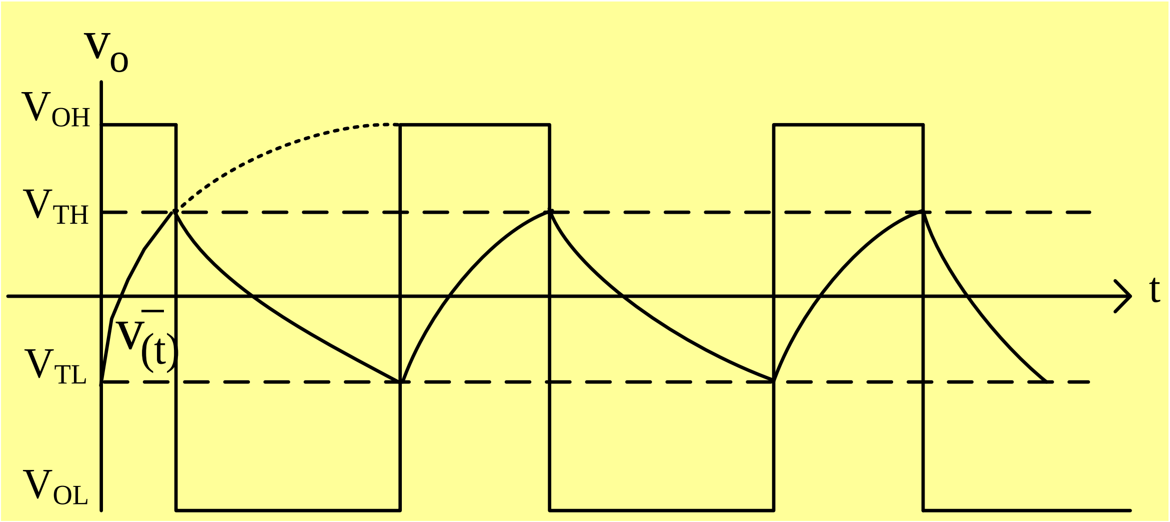
The total exponential transition time is the solution to the equality

$$v^{-}(t) = v_{TH}^{+}$$

or

$$V_{OH} - \left(V_{OH} - \frac{R_g}{R_g + R_f} V_{OL}\right)e^{-t/RC} = \frac{R_g}{R_g + R_f} V_{OH}$$

Note.- See Section 10.2 Text



Then

$$V_{OH}\left(1-\frac{R_g}{R_g+R_f}\right)=\left(V_{OH}-\frac{R_g}{R_g+R_f}V_{OL}\right)e^{-t/RC}$$

The transition time is given by

$$t_{HL}=RC\ln\left[\frac{(R_g+R_f)V_{OH}-R_gV_{OL}}{R_fV_{OH}}\right]$$

$$t_{HL}=RC\ln\left(1+\frac{R_g(V_{OH}-V_{OL})}{R_fV_{OH}}\right)$$

$$t_{HL}=RC\ln\left(1+\frac{\Delta V_T}{V_{OH}}\right)$$

Low to High

Same as before by interchanging V_{OH} and V_{OL} . Then the duty cycle is determined by The sum of the transition times:

$$\tau = RC\left[\ln\left(1+\frac{R_g(V_{OH}-V_{OL})}{R_f V_{OH}}\right)+\ln\left(1+\frac{R_g(V_{OL}-V_{OH})}{R_f V_{OL}}\right)\right]$$

$$\tau = RC\left[\ln\left(1+\frac{\Delta V_T}{V_{OH}}\right)+\ln\left(1-\frac{\Delta V_T}{V_{OL}}\right)\right]$$

For 50% duty cycle V_{OL} =-V_{OH} yields

$$t_{HL} = t_{LH} = RC\ln\left(1+\frac{2R_g}{R_f}\right)$$

Then the period is given by

$$T = 2t_{HL} = 2RC\ln\left(1+2\frac{R_g}{R_f}\right)$$

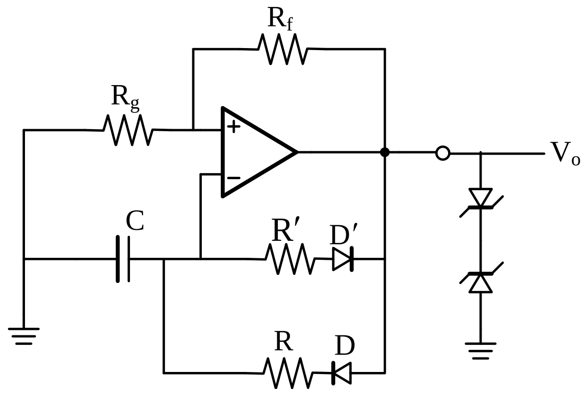
T will be affected by the SR of the comparator. Also the parasitic capacitance associated to the “+” terminal of this comparator.

Note that $V_{OL}$and V_{OH} cannot be exactly predicted thus often a clamping circuit is placed usually at the output.

A Stable, Nonsymmetric Square-Wave Generator

— One option is by making $-V_{OL} \neq V_{OH}$

— Another option is by changing the equality of rising and decaying times.



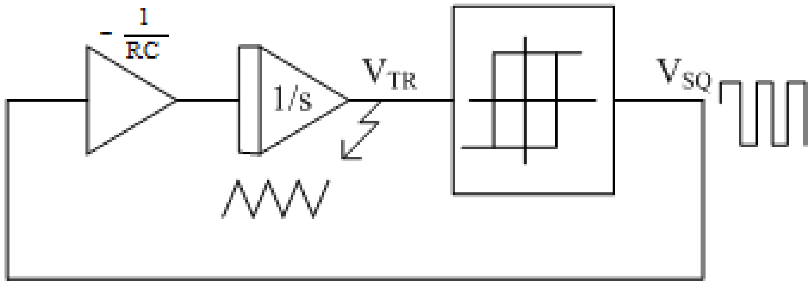
Then one can show that

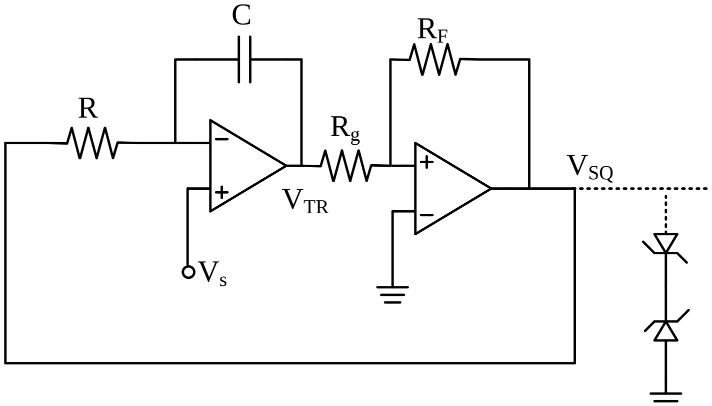
$$T = t_H + t_L$$

$$T = RC \ln\left(1 + \frac{2R_g}{R_f}\right) + R'C \ln\left(1 + \frac{2R_g}{R_f}\right)$$

$$\text{Duty cycle} \triangleq \frac{t_H}{T} = \frac{R}{R + R'}$$

Basic Triangular/Square Wave Generator





- Two Quasi-static state.
  – For outputs V_{OH} and V_{OL}
- The Schmitt Trigger Toggles between output states.

Transition occurs

$$V_{TR(trans)} = -\frac{R_g}{R_f} V_{SQ} = \mp \frac{R_g}{R_f} V_{OH}$$

$$V_{TR} = -\frac{1}{RC} \int \left[V_{SQ}(t) - V_s \right] dt$$

When, v_{SQ} is in the high state, V_{TR} is linearly decreasing between its toggle values.

$$v_{TR} = -\frac{1}{RC} \int (V_{OH} - V_s) dt = \frac{V_s - V_{OH}}{RC} t + v_{TR}(0^+)$$

Initial condition

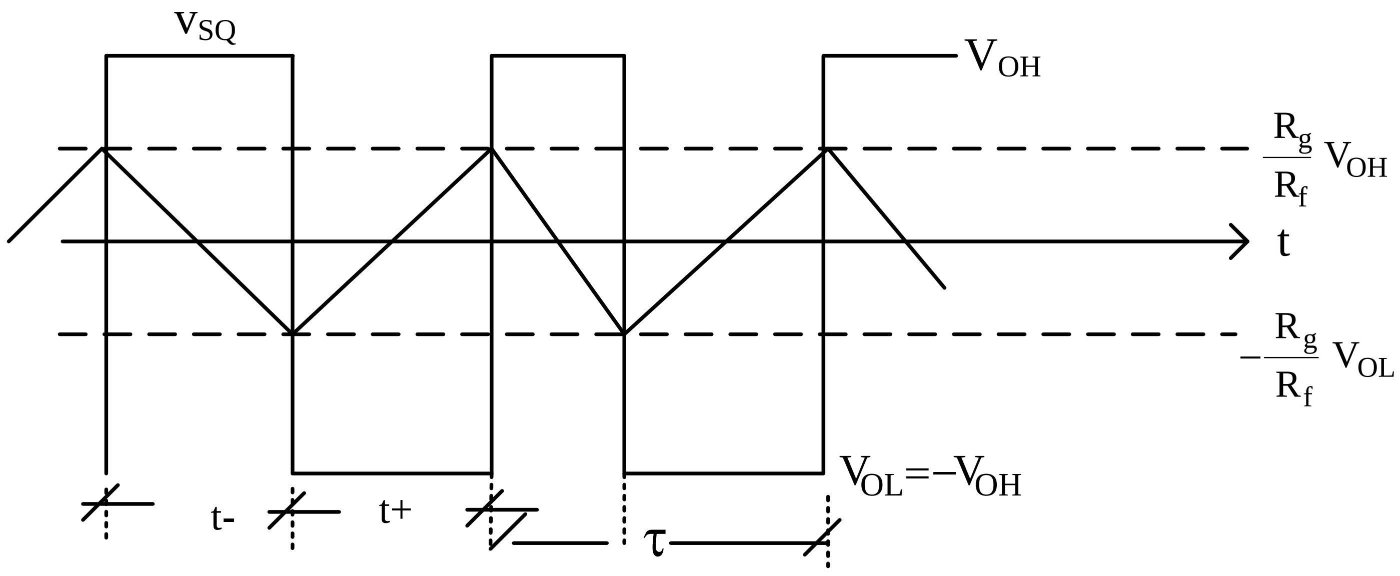
Thus, the voltage transition is the differences in toggle values divided by the slope of the linear transition.

$$2\frac{R_g}{R_f}V_{OH} = \frac{V_{OH} - V_s}{RC} t_-$$

Therefore

$$t_- = \frac{2R_g V_{OH} \cdot RC}{R_f \left(V_{OH} - V_s\right)}$$

Now when the positive transition occurs for $V_{s>o}$



$$v_{TR} = -\frac{1}{RC}\int -\left(V_{OH} + V_s\right)dt = \frac{V_{OH} + V_s}{RC}t + v_{ti}\left(o^-\right)$$

$$2\frac{R_g}{R_f}V_{OH} = \frac{V_{OH} + V_s}{RC}t_+ \Rightarrow t_+ = \frac{2R_gRCV_{OH}}{R_f\left(V_{OH} + V_s\right)}$$

Thus the period becomes:

$$T = t_- + t_+ = 4R_gRC\frac{V_{OH}^2}{R_f\left(V_{OH}^2 - V_s^2\right)}\Bigg|_{\text{for } V_s = 0} \cong \frac{4RC}{R_g/R_f} \quad \text{or } f_o = \frac{\frac{R_g}{R_f}}{4RC}$$

$$D = \text{Duty cycle} + = \frac{t_+}{T} = \frac{1}{2}\left(1 - \frac{V_s}{V_{OH}}\right)$$

for $V_s = 0$, $D = 0.5$

for $V_s = \frac{1}{4}V_{OH}$, then $D = \frac{1}{2}\left(1 - 0.25\right) = \frac{3}{8}$