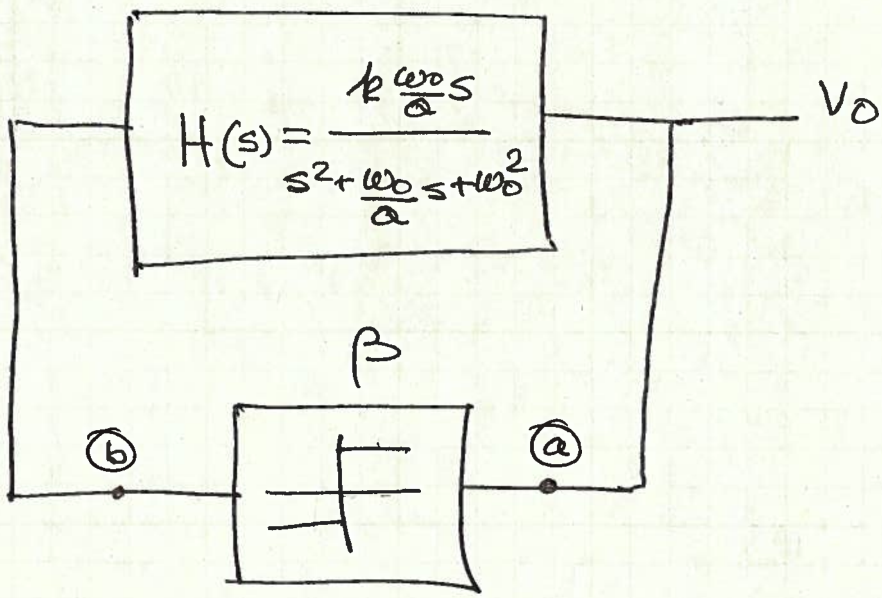
SIGNAL GENERATORS

- SINUSOIDAL
  - BP (TWO INTEGRATOR) BASED
  - ONE OP AMP (WIEN-BRIDGE)
- TRIANGULAR AND SQUARE WAVE
- SAWTOOTH
- V-F AND F-V CONVERTERS

HOW TO MAKE A SINUSOIDAL OSCILLATOR BASED ON FILTERS?

BAND PASS BASED OSCILLATOR



ASSUMINING SMALL SIGNAL CONDITIONS, WE CAN WRITE THE LOOP FILTER

$$1-\beta H(s)=0 \quad ; \quad K = k\frac{\omega_0}{Q}$$

$$1-\frac{Ks}{s^2+\frac{\omega_0}{Q}s+\omega_0^2}=0 \quad \text{or} \quad \beta H(s)=1$$

THUS THE CHARACTERISTIC EQUATION YIELDS:

$$s^2-\left(K-\frac{\omega_0}{Q}\right)s+\omega_0^2=0$$

IN ORDER TO HAVE THE POLES IN THE RHP, IT IS IMPOSED THAT

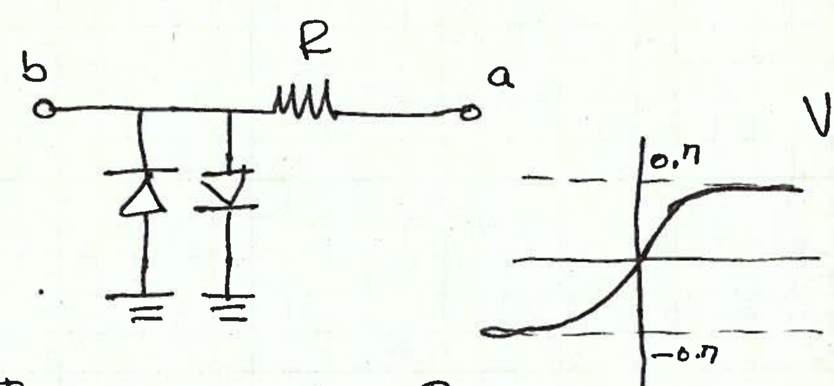
$$K - \frac{\omega_0}{Q} > 0$$

OR

$$K \geq \frac{\omega_0}{Q}$$

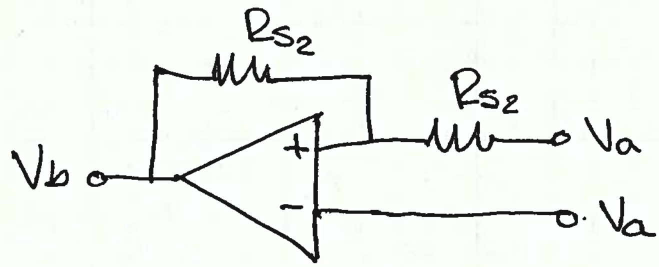
HOWEVER TO MOVE THE POLES ON THE $j\omega$ AXIS WE REQUIRE A NON-LINEAR BLOCK IMPLEMENTATION OF β. THERE A NUMBER OF BLOCKS TO ACCOMPLISH THIS.

IMPLEMENTATION 1



$V_b \cong \pm 0.7V$

IMPLEMENTATION 2

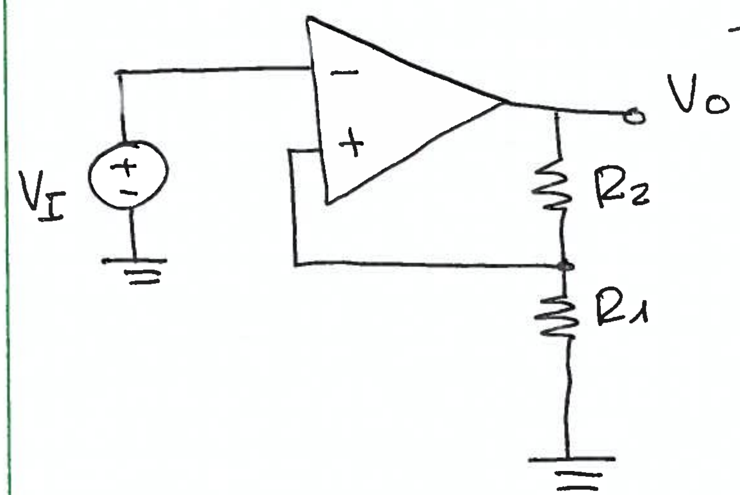


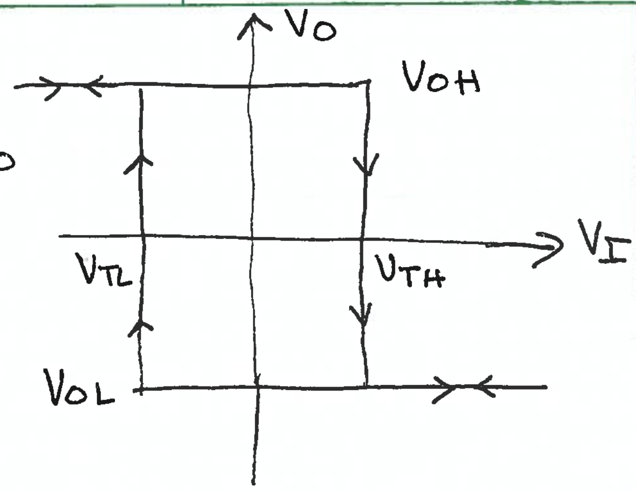
FOR $-H_{BP}(s)$

FOR $+H_{BP}(s)$

INVERTING SCHMITT TRIGGER

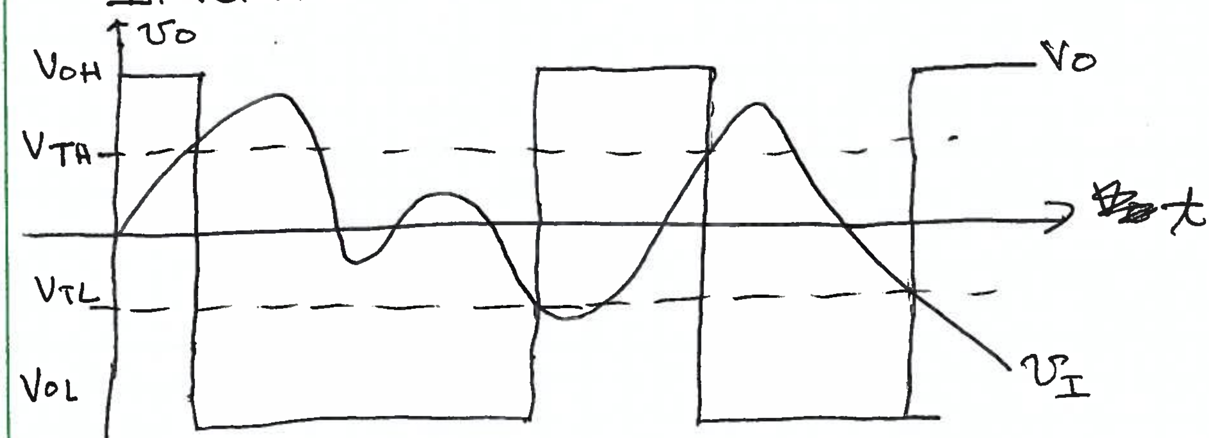
$$V_{TH} = \frac{R_{S1}}{\quad}$$





(See Section 9.3)

INVERTING SCHMITT TRIGGER



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

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

HYSTERISIS 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

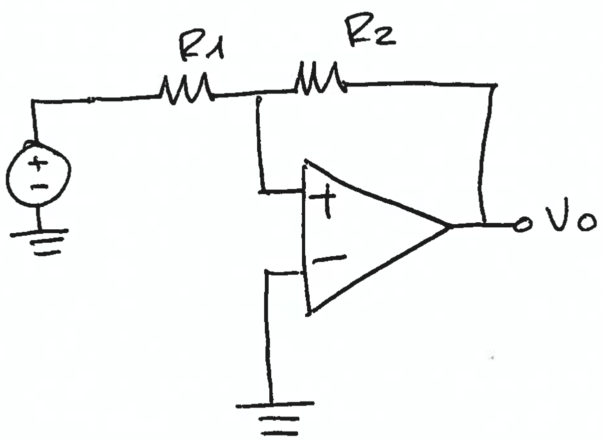
$V_{OH} = 13V \quad ; \quad V_{OL} = -13V$

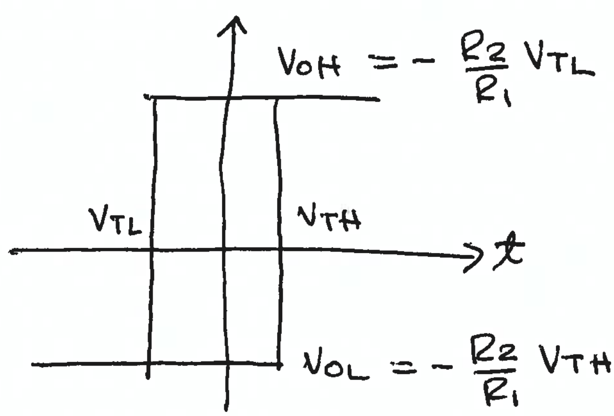
FOR $R_2 = 16k\Omega$ AND $R_1 = 10k\Omega$

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

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

LET US CONSIDER THE NON-INVERTING SCHMITT TRIGGER



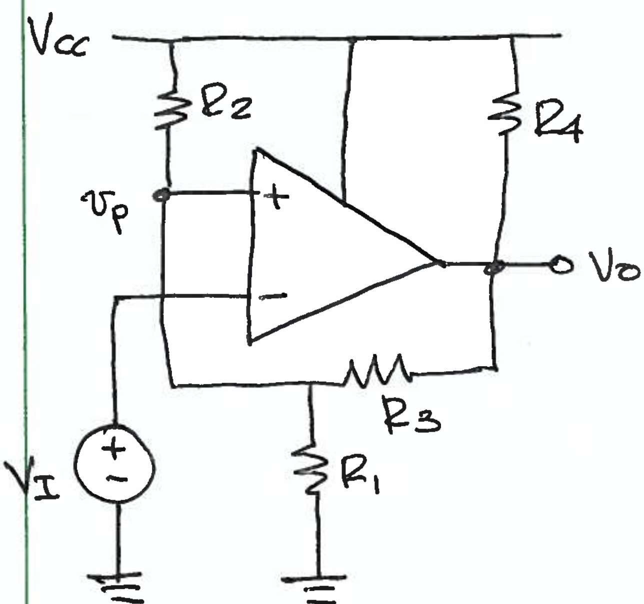


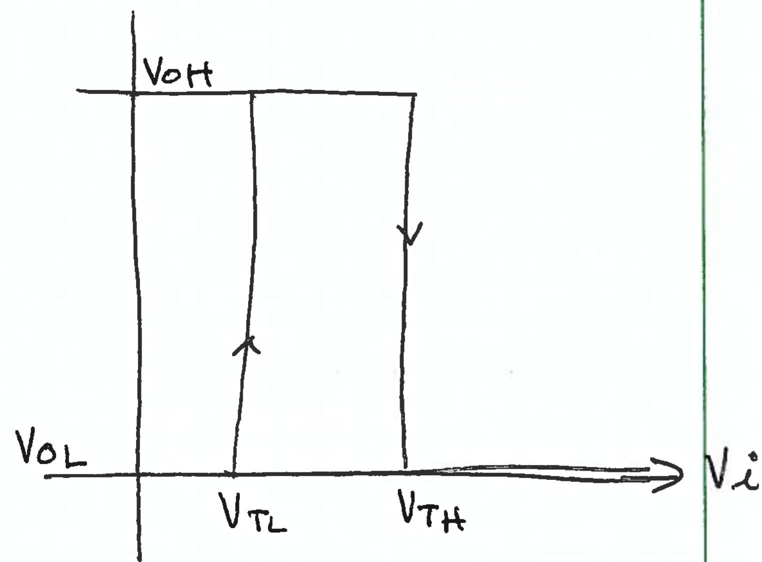
$$V_{TH} = -\frac{R_1}{R_2} V_{OL} \Longleftarrow \frac{V_{TH} - 0}{R_1} = \frac{0 - V_{OL}}{R_2}$$

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

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

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

IF $V_{OH} \cong V_{CC}$ AND $V_{OL} = 0$

THEN $R_4 \ll R_3 + R_{1,2}$

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

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

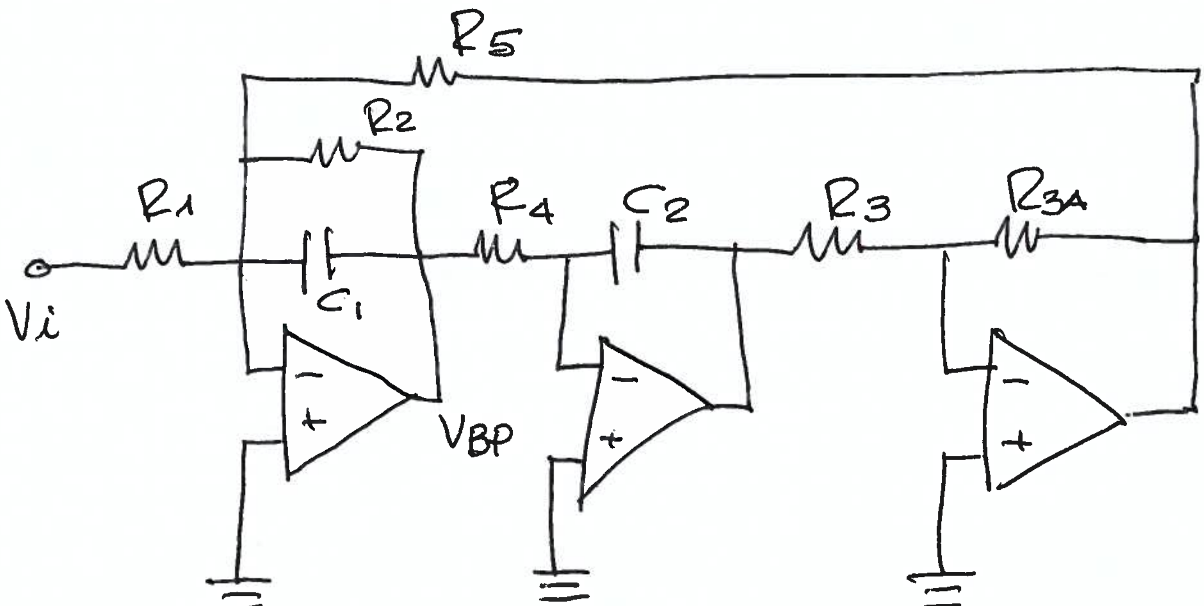
REARRANGING TERMS AND FIX R_4 AND $R_3 >> R_4$

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

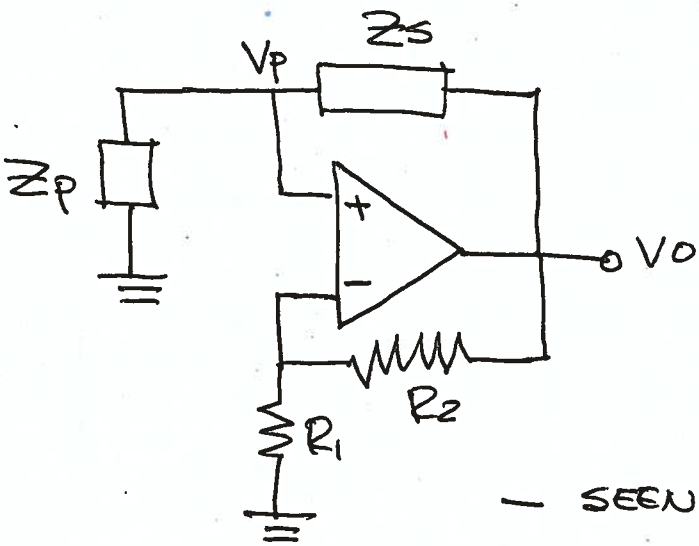
$$\frac{1}{R_1} = \frac{V_{CC} - V_{TH}}{V_{TH}} \left(\frac{1}{R_2} + \frac{1}{R_3} \right)$$

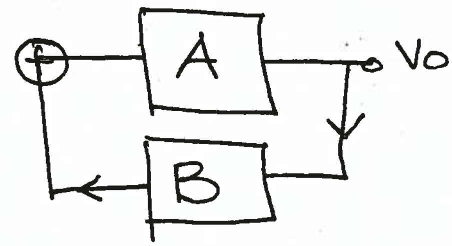
THUS THE TWO ABOVE EQUATIONS CAN BE SOLVED.

THE BP CAN BE IMPLEMENTED USING THE TOW-THOMAS



WIEN - BRIDGE



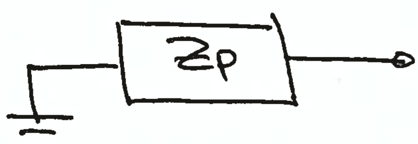


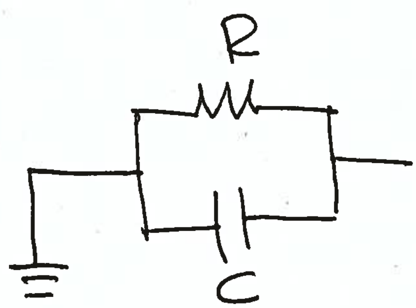
— SEEN AS INON-INVERTER

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

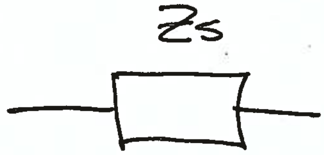
FURTHERMORE WE CAN SEE AS A VOLTAGE DIVIDER

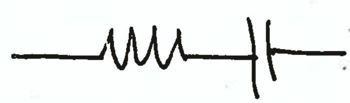
$$\frac{Z_p}{Z_p + Z_s} V_o = V_p$$





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





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

THUS

$$\frac{V_o}{V_p} = \frac{Z_p + Z_s}{Z_p}$$

$$B = \frac{V_p}{V_o} = \frac{Z_p}{Z_p + Z_s} = \frac{1}{1 + \frac{Z_s}{Z_p}} = \cancel{\frac{1}{1 + \frac{R}{1+sRC} \frac{SC}{1+sRC}}}$$

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

$$B = \frac{sRC}{(sRC)^2 + 3sRC + 1} \Rightarrow \text{BAND PASS FILTER}$$

CHARACTERISTIC EQUATION

$$1 - AB = 1 - T$$

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

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

IF $RC = \frac{1}{\omega_0}$

$$T(j\omega) = \frac{1+\frac{R_2}{R_1}}{j\omega/\omega_0 - \frac{j}{\omega/\omega_0} + 3} = \frac{1+\frac{R_2}{R_1}}{3 + j\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right)}$$

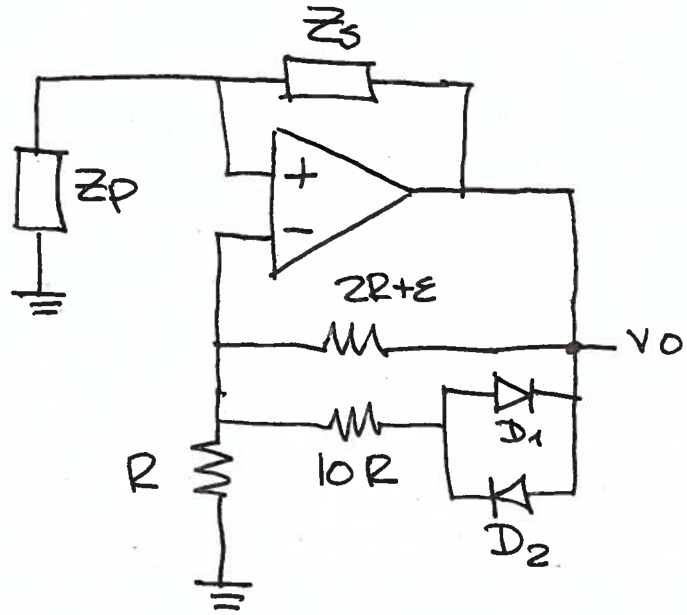
$$T(j\omega_0) = \frac{1+R_2/R_1}{3}$$

TO ~~[illegible]~~ FORCE OSCILLATION

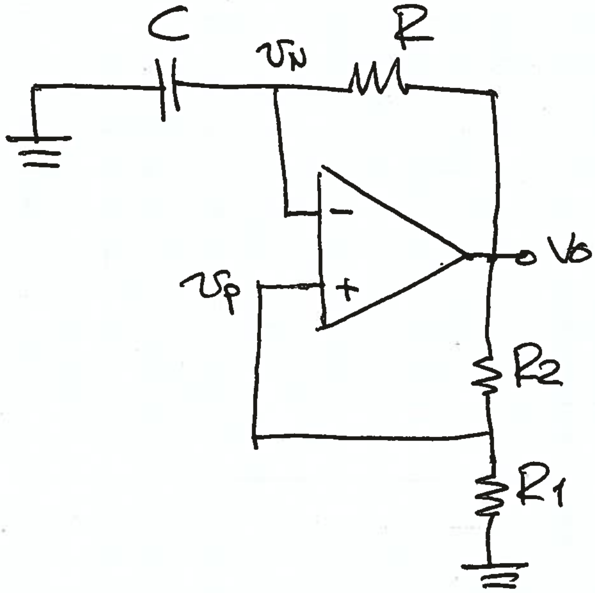
$$T(j\omega_0) > 3 \quad \text{i.e.} \quad \frac{R_2}{R_1} > 2$$

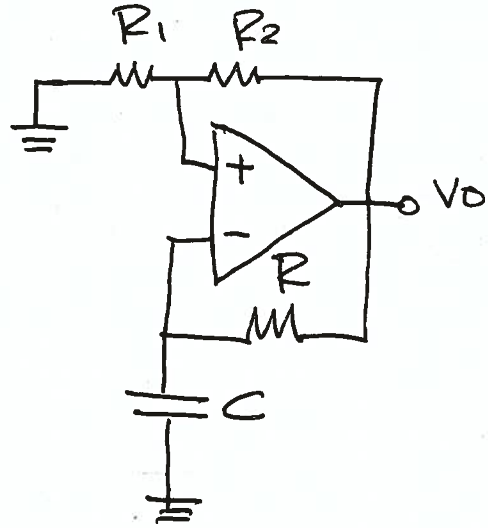
$$\frac{R_2}{R_1} = 2 + \varepsilon$$

THE NON-LINEAR PART OF THE OSCILLATOR MUST BE ADDED



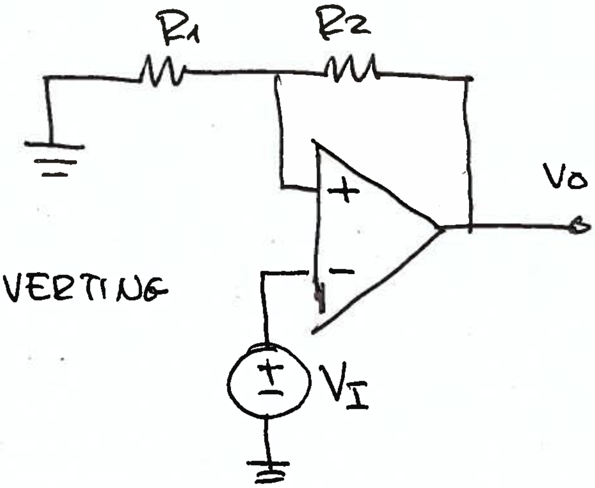
SQUARE WAVE OSCILLATOR

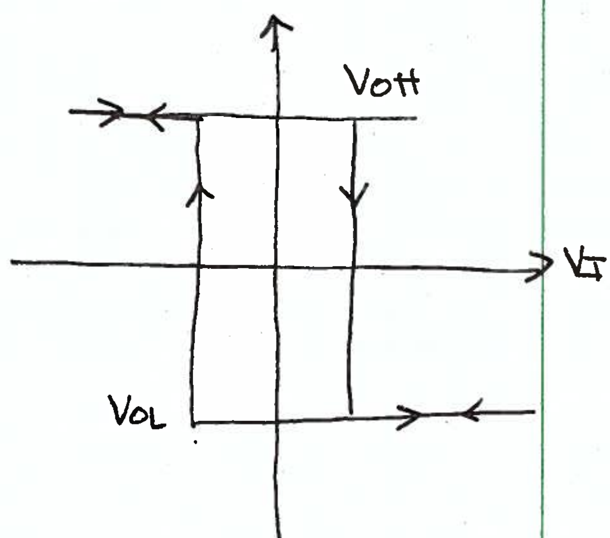




LET US LOOK CLOSER TO THE SCHMITT TRIGGER

INVERTING



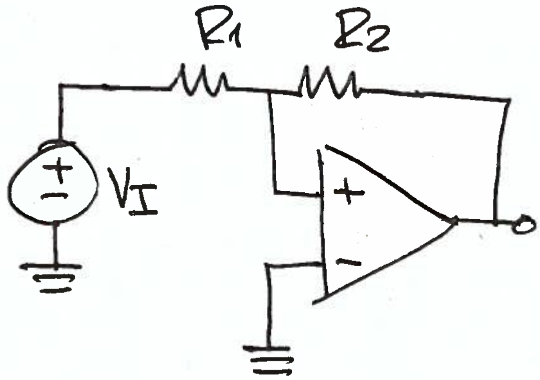


$$V_{TH} = \frac{R_1}{R_1+R_2} V_{OH}$$

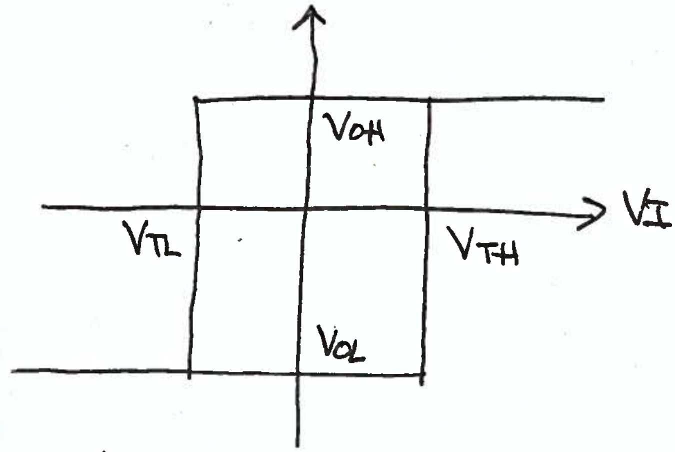
$$V_{TL} = \frac{R_1}{R_1+R_2} V_{OL}$$

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

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



NON-INVERTING SCHMITT TRIGGER



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

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

TRIPPING VOLTAGE V_{TL} BECOMES

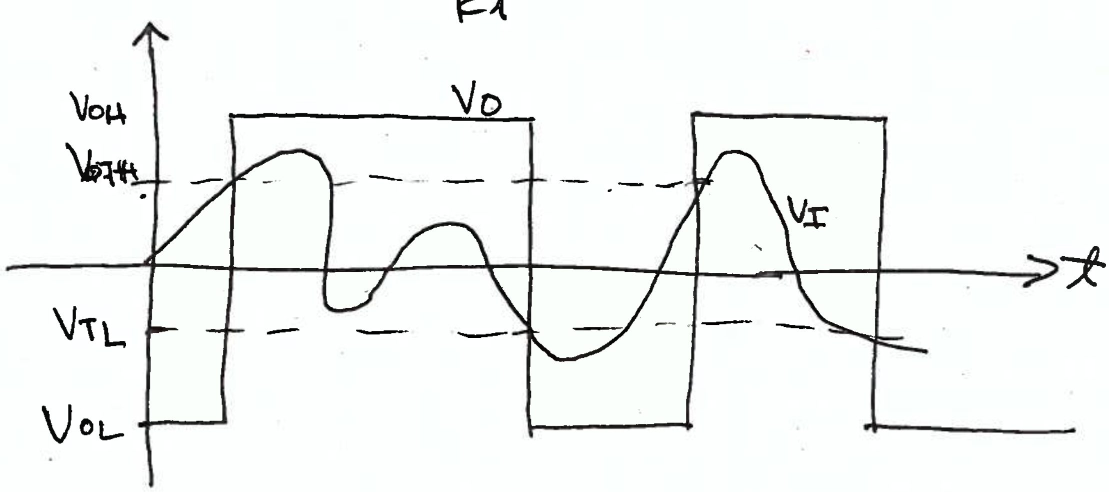
$$\frac{V_{OH} - 0}{R_2} = \frac{0 - V_{TL}}{R_1}$$

OR

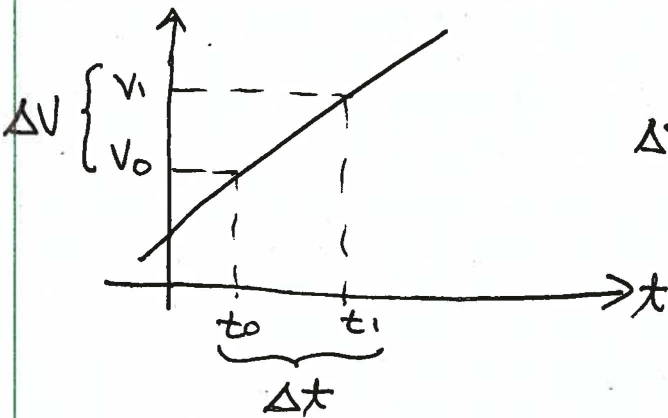
$$V_{TL} = -\frac{R_1}{R_2} V_{OH}$$

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

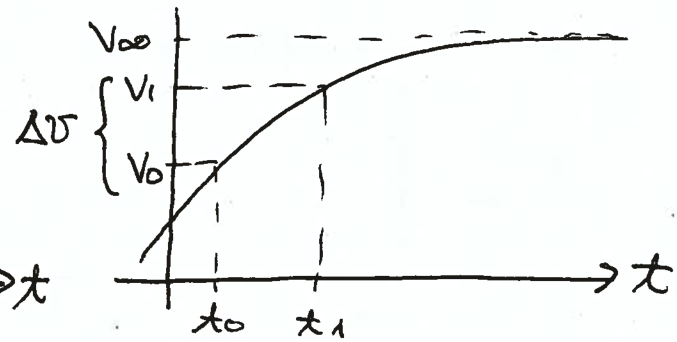
$$\Delta V_T = \frac{1}{\frac{R_2}{R_1}}\left(V_{OH} - V_{OL}\right)$$



NOTES ON RELAXATION OSCILLATORS



LINEAR



EXPONENTIAL

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

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

$$v(t) = V_\infty + (V_0 - V_\infty)\, e^{-\frac{t-t_0}{\tau}}$$

$$\tau = RC$$

$$V_1 = V_\infty + (V_0 - V_\infty)\, e^{-\frac{t_1-t_0}{\tau}}$$

$$\Delta t = t_1 - t_0 = \tau \ln \frac{V_\infty - V_0}{V_\infty - V_1}$$

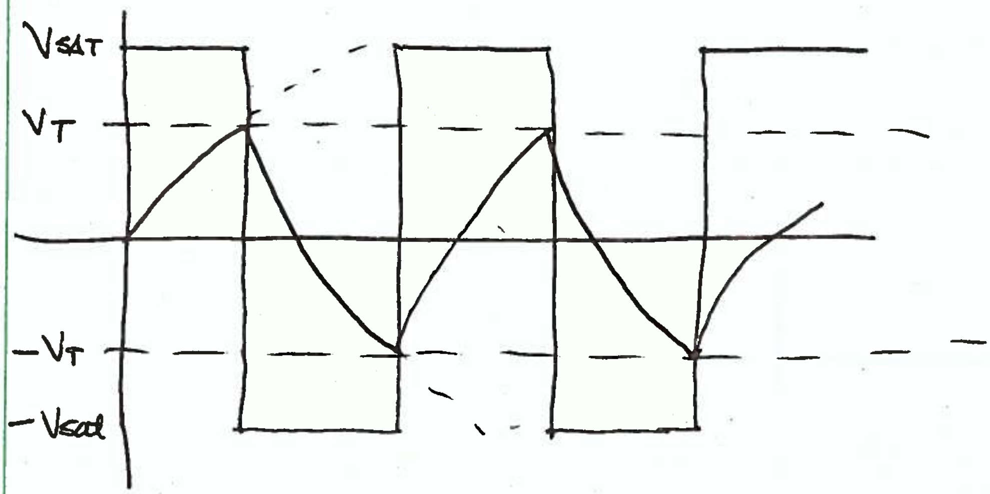
THUS FOR THE BASIC-FREE-RUNNING OSCILLATOR

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

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

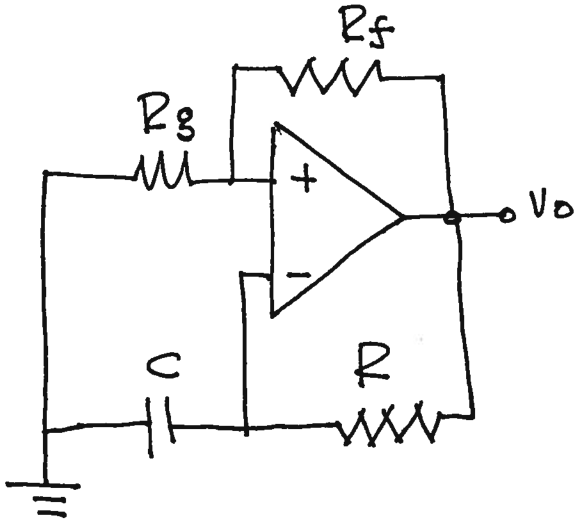
THEN

$$f_0 = \frac{1}{T} = \frac{1}{2RC \ln (1 + 2R_1/R_2)}$$



$$f_0 \neq f(V_T, V_{SAT})$$

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 FROM ITS INITIAL VALUE V_{TL}^- TOWARD V_{OH}. THUS

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

OR EQUIVALENT

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

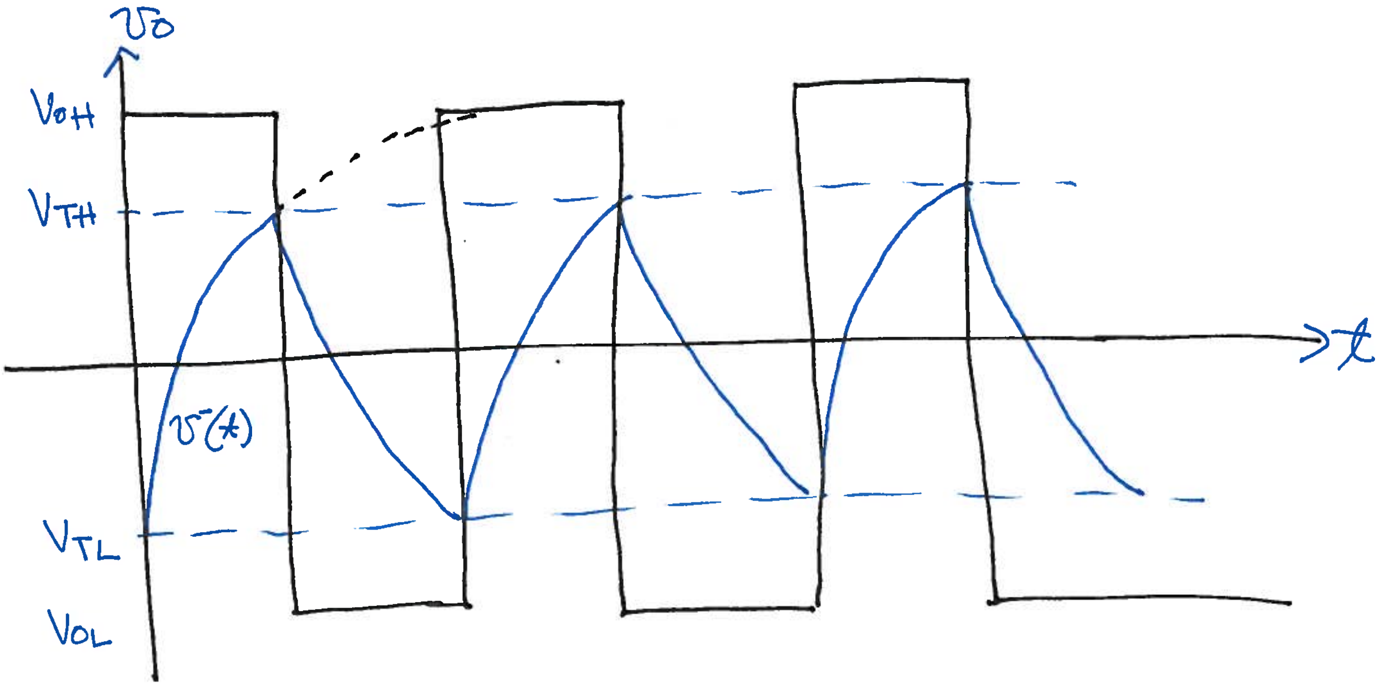
THE TOTAL EXPONENTIAL TRANSITION TIME IS THE SOLUTION TO THE EQUALITY

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

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

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

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

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

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

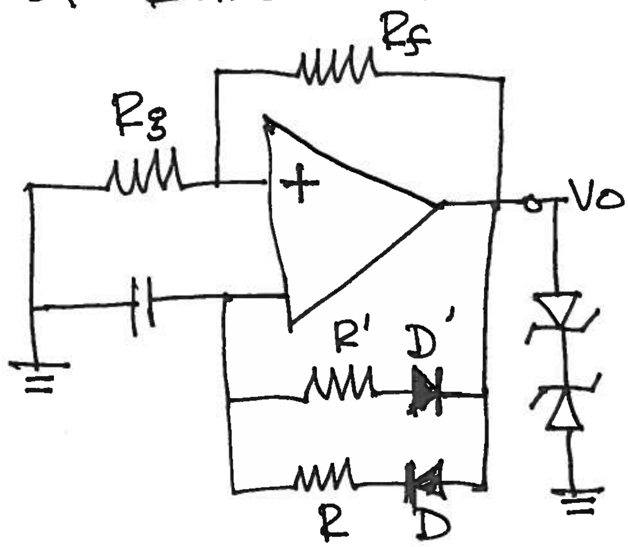
$$T = 2t_{HL} = 2RC\ln\left(1+2\frac{R_g}{R_f}\right)$$

T WILL BE AFFECTED BY THE SR OF THE COMPARATOR. ALSO THE PARASITIC CAPACITANCE ASSOCIATED TO THE "+" TERMINAL OF THE COMPARATOR.

NOTE THAT V_{OL} AND V_{OH} CAN NOT BE EXACTLY PREDICTED THUS A CLAMPING CIRCUIT IS PLACED USUALLY AT THE OUTPUT.

ASTABLE, 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.



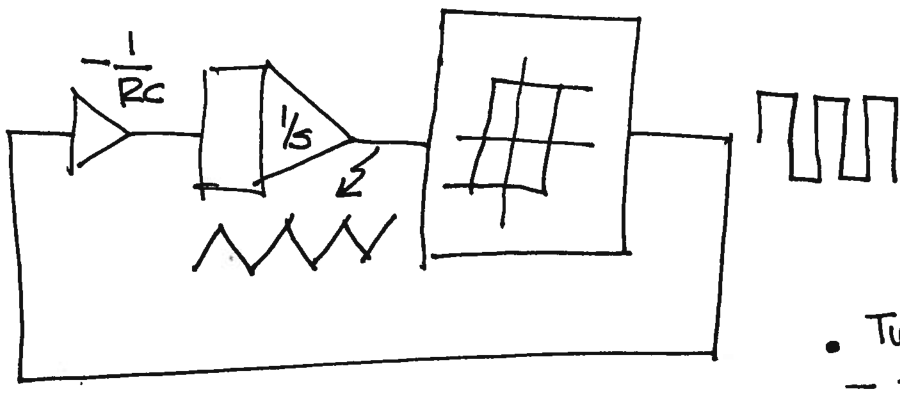
THEN ONE CAN SHOW THAT

$$T = t_H + t_L$$

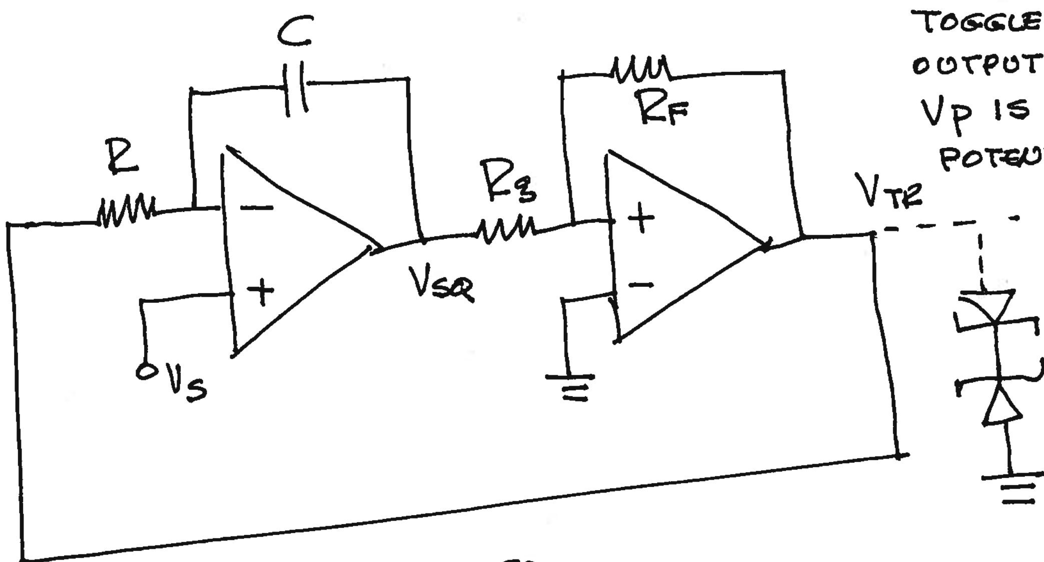
$$T = RC \ln\left(1 + \frac{2R_g}{R_f}\right) + R'C \ln\left(1 + \frac{2R_g}{R_f}\right)$$

$$\text{DUTY CYCLE} \triangleq \frac{t_H}{T} = \frac{R}{R+R'}$$

BASIC TRIANGULAR/SQUARE WAVE GENERATOR



- TWO QUASI-STATIC STATE: — FOR V_{OH} AND V_{OL}
- THE SCHMITT TRIGGER TOGGLES BETWEEN OUTPUT STATES WHEN V_p IS AT GROUND POTENTIAL.



TRANSITION OCCURS

$$V_{TR(trans)} = -\frac{R_s}{R_f} V_{sq} = \mp \frac{R_s}{R_f} V_{OH}$$

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

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 TRANSISTION.

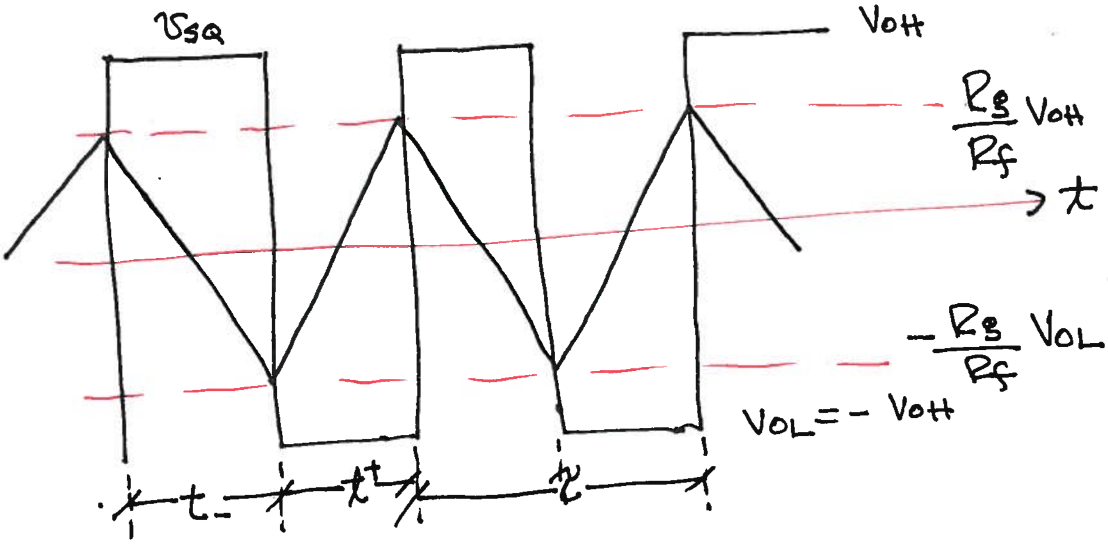
$$2\frac{R_g}{R_f}V_{OH} = \frac{V_{OH}-V_S}{RC}t_-$$

THEREFORE

$$t_- = \frac{2R_g V_{OH}\cdot RC}{R_f\,(V_{OH}-V_S)}$$

NOW WHEN THE POSITIVE TRANSITION OCCURS

FOR $V_S>0$



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

$$2\frac{R_g}{R_f}V_{OH} = \frac{V_{OH}+V_S}{RC}t_+ \Rightarrow t_+ = \frac{2R_g\,RC\,V_{OH}}{R_f\,(V_{OH}+V_S)}$$

THUS THE PERIOD BECOMES:

$$\tau = t_- + t_+ = 4R_g RC\,\frac{V_{OH}^2}{R_f(V_{OH}^2 - V_S^2)}$$

$$\text{DUTY CYCLE}^+ = \frac{t_+}{\tau} = \frac{1}{2}\left(1-\frac{V_S}{V_{OH}}\right)$$