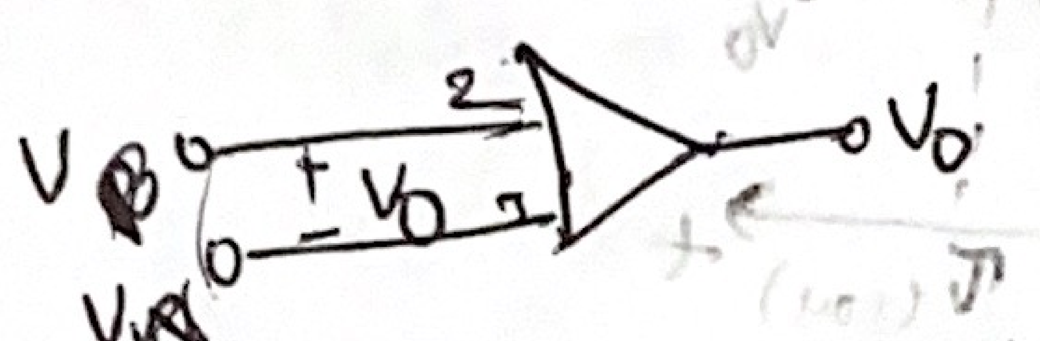
Non-Linear circuits

Voltage comparators

$V_i \Rightarrow V_0 = V_{OL}$ for $V_i < V_N$

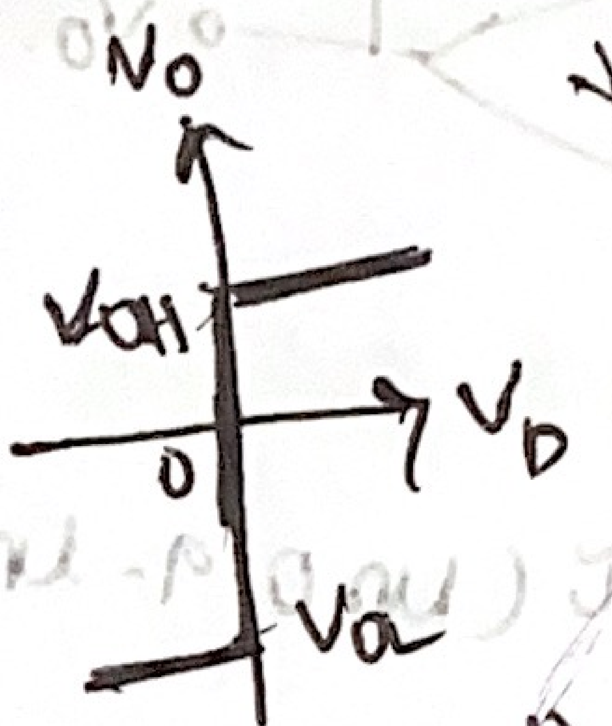
$V_0 = V_{OH}$ for $V_P > V_N$



$V_D = V_P - V_N$

$V_O = V_{OL}$ if $V_D < 0V$

$V_O = V_{OH}$ if $V_D > 0V$

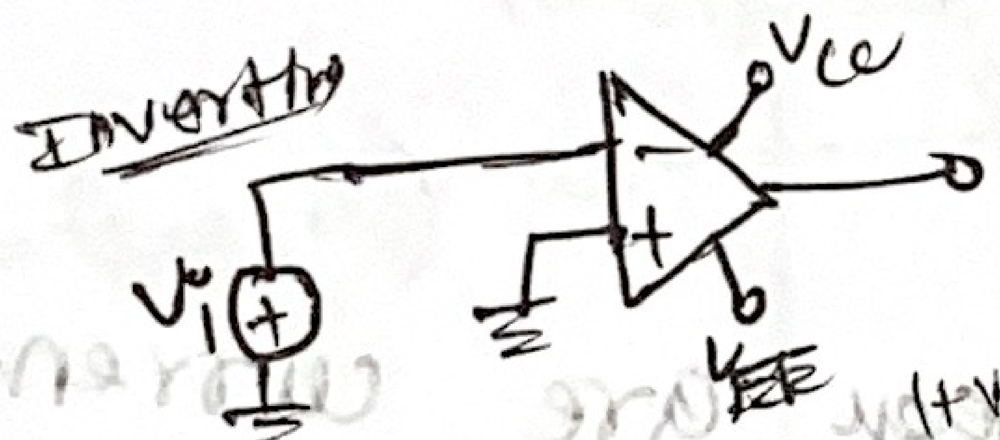


$V_O = V_{OL} \rightarrow V_P < V_N$

$V_O = V_{OH} \rightarrow V_P > V_N$

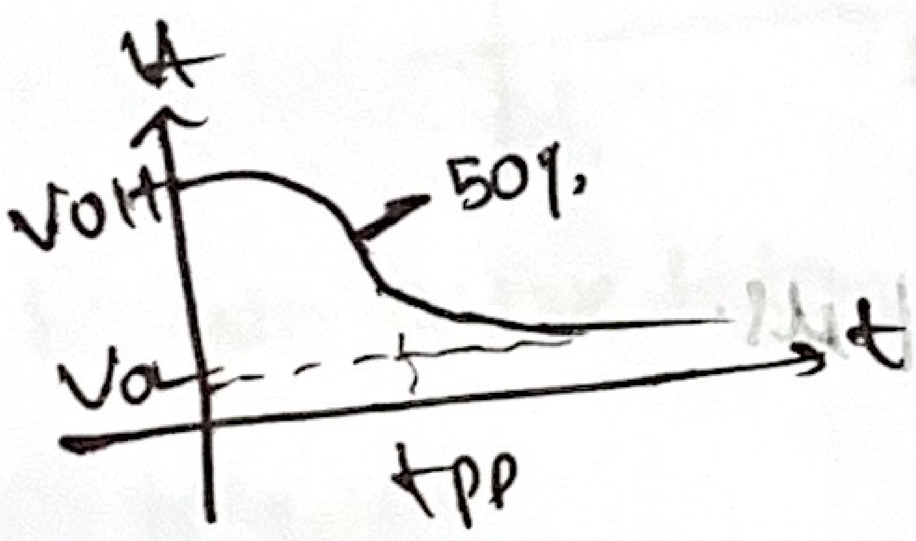
$V_N = 0$, zero-crossing detector.

opamp as a comparator:



$+V_{sat} < V_O < -V_{sat}$

Open loop circuit, open loop mean gain '∞' so it will be operate in non-linear range.



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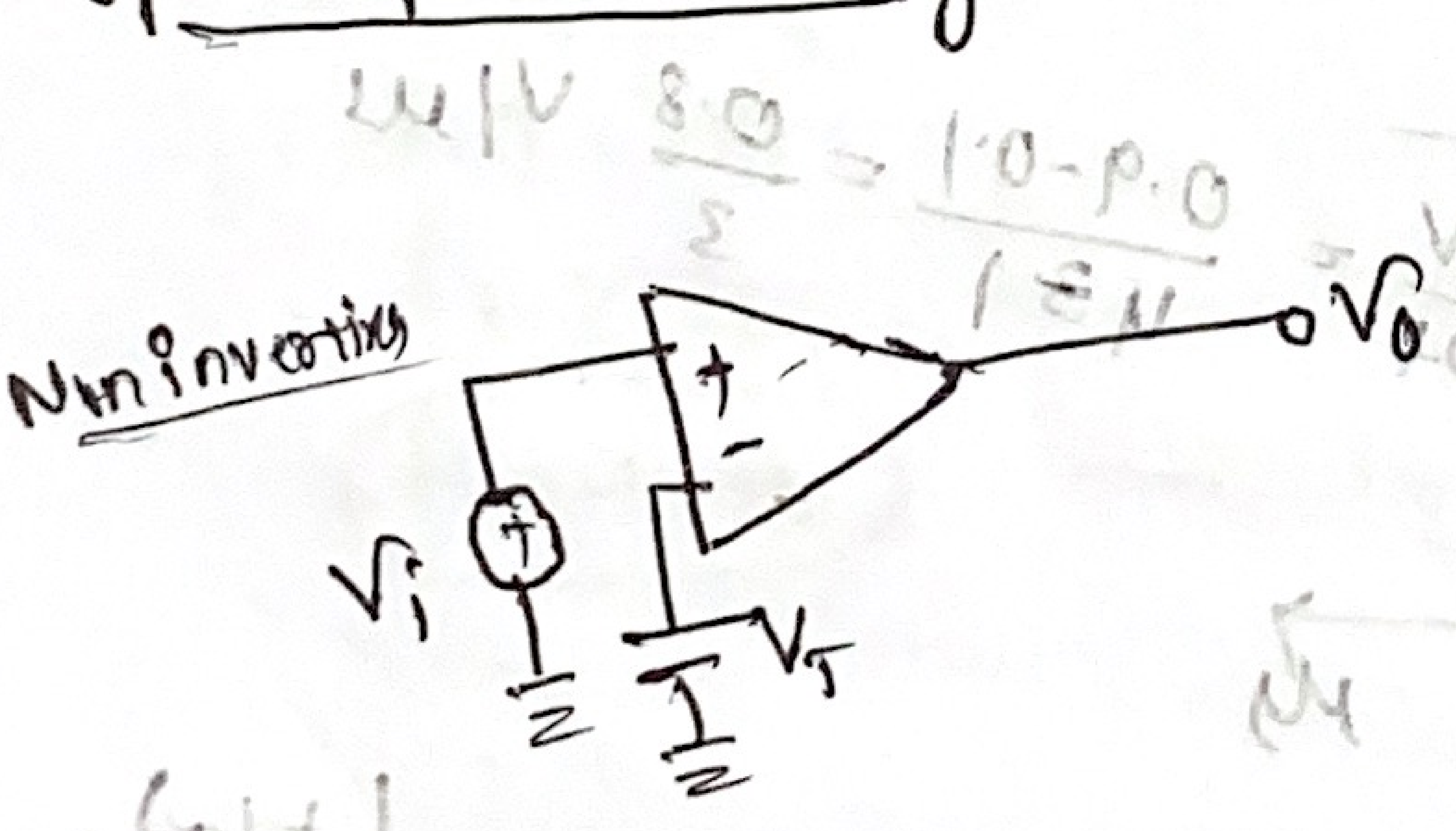
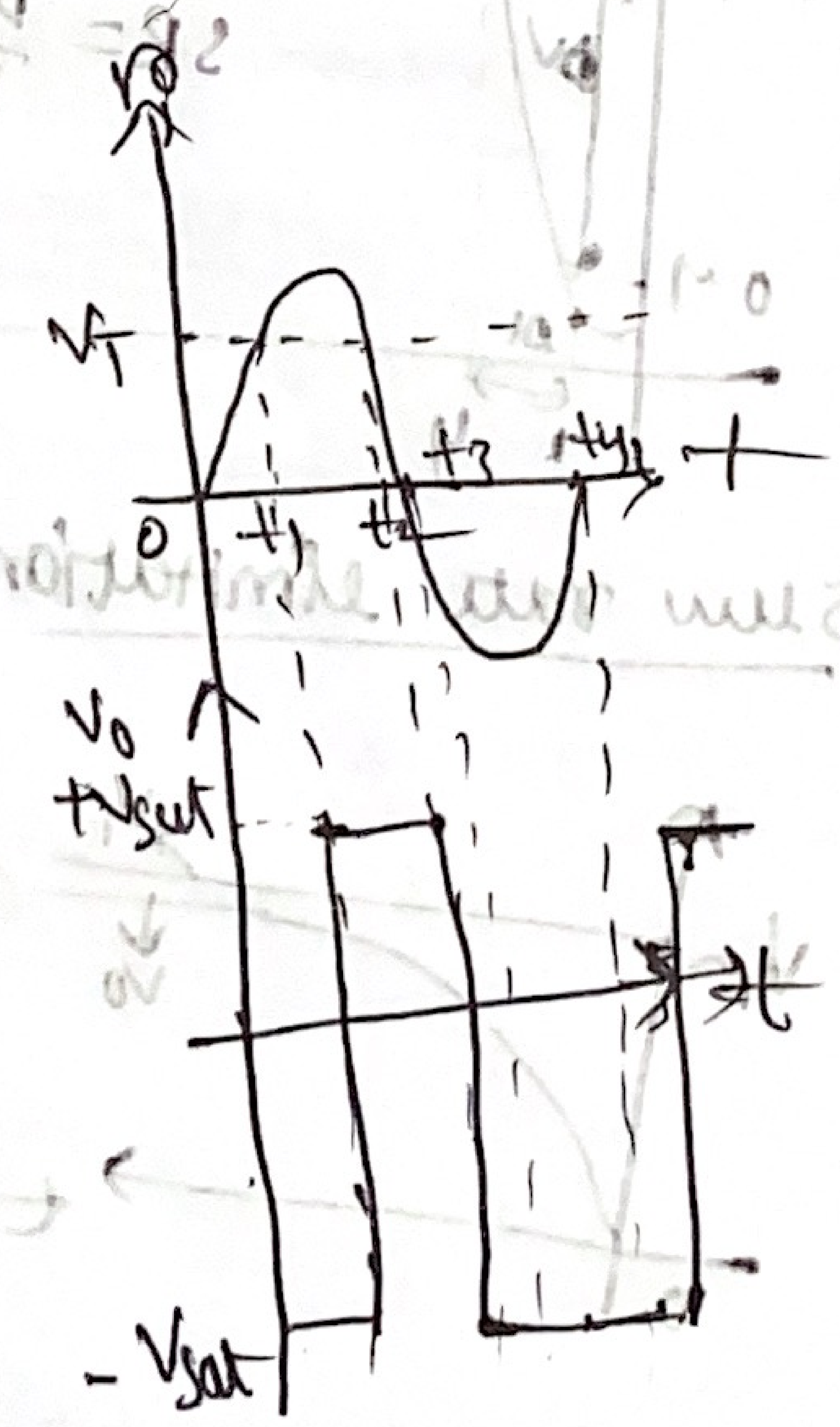
opamp as voltage comparator:



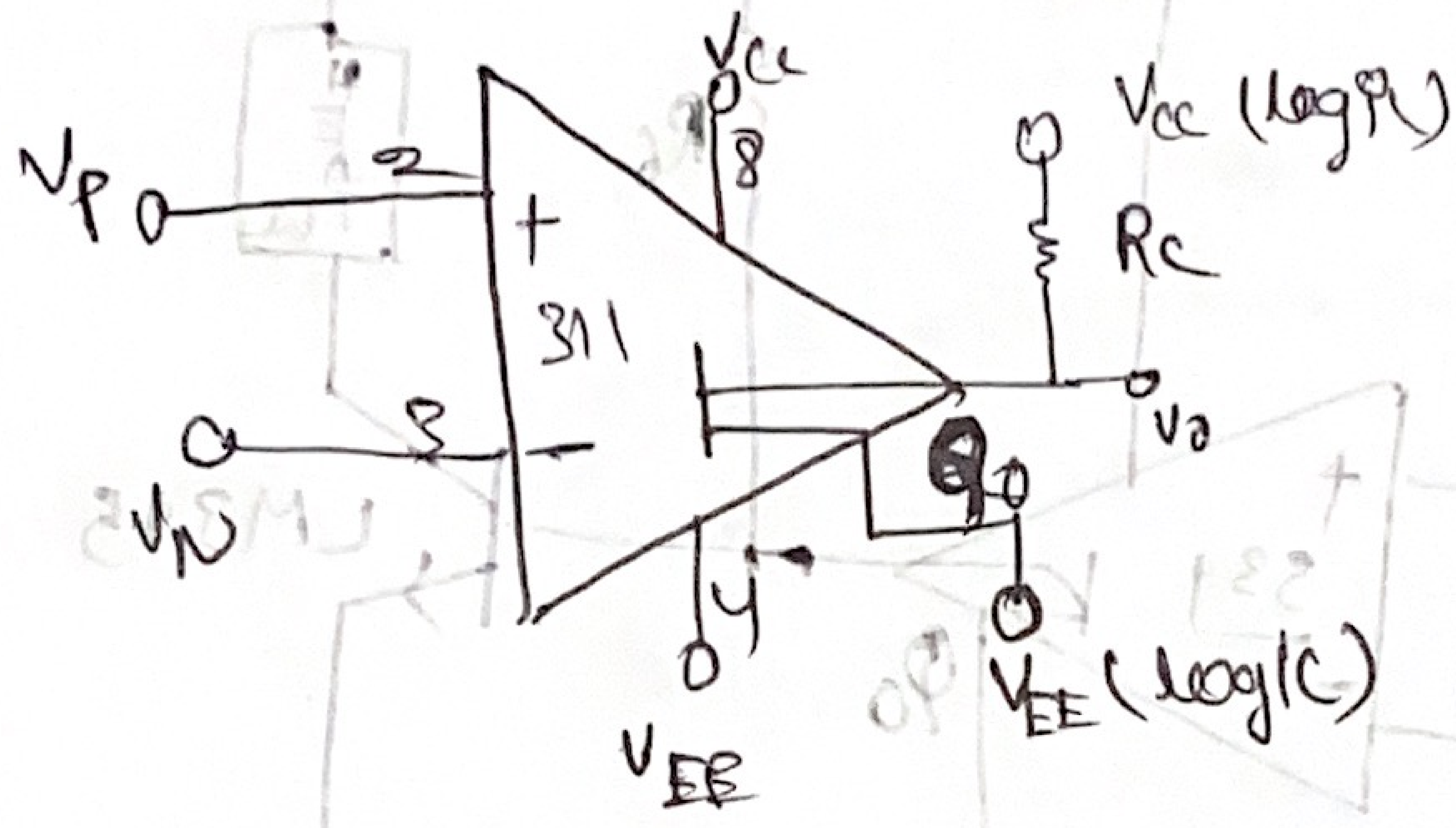


$V_i > V_T \Rightarrow V_o = +V_{sat}$

$V_i < V_T \Rightarrow V_o = -V_{sat}$

→ $V_T = 0$, then it is called zero crossing detector.

General Response IC Configuration:



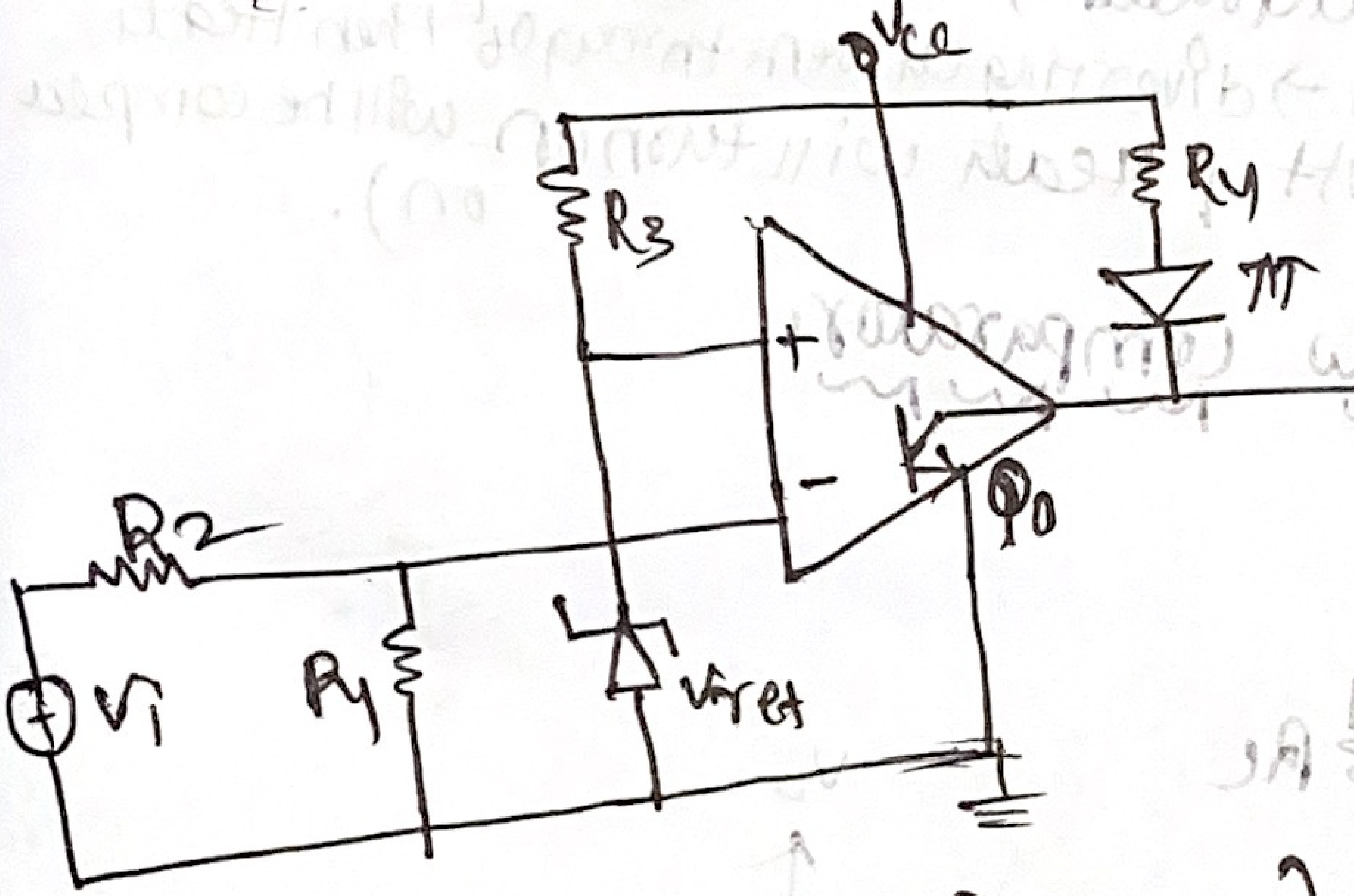
LM 311

$V_P < V_N$,
$V_0 = V_{CE(sat)} + V_{EE}(logic)$
$V_0 = V_{OL} \simeq V_{EE}(logic)$.
$V_P > V_N$,
$V_0 = V_{cc}(logic) = V_{OH}$.

V_{OL} (output Low)
V_{OH} (output High).

Comparator Applications:

① Level Detector / Threshould Detector:



$V_{ref} = V_i \left(\frac{R_1}{R_1 + R_2} \right)$

o/p trips.

If suppose to be '0' but not zero (comparator o/p reaches '0')

Voltage wrt V_i) $\left(V_T = \frac{R_1 + R_2}{R_1} \times V_{ref} \right)$

$V_i < V_T \Rightarrow Q_0 = $ Off , LED is off.

$V_i > V_T \Rightarrow Q_0 = $ saturated , LED glows.

If terminals are reversed the o/p is reversed

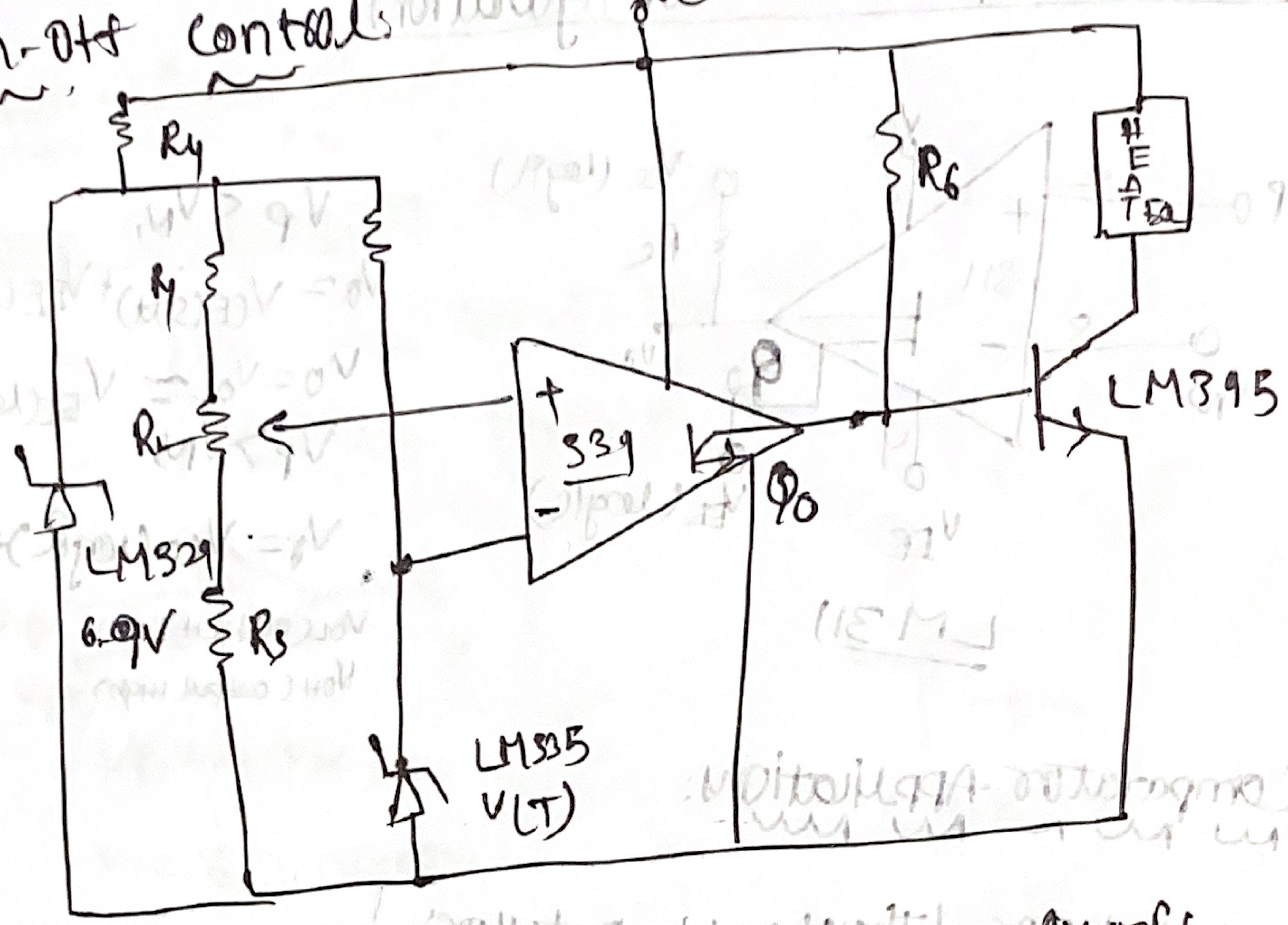
then.

$V_i < V_T$ Q_0 = saturated , LED glow,

$V_i > V_T$ Q_0 = Off , LED is Off.

inverting and non inverting reversed

② On-Off control



$V_p < V_N$, Q_0 = Saturated, Heater will off
(cutoff → diverting current through Q_0 to base of LM391 then Heater will be completely on).
$V_p > V_N$, Q_0 = Off, Heater will turn on.

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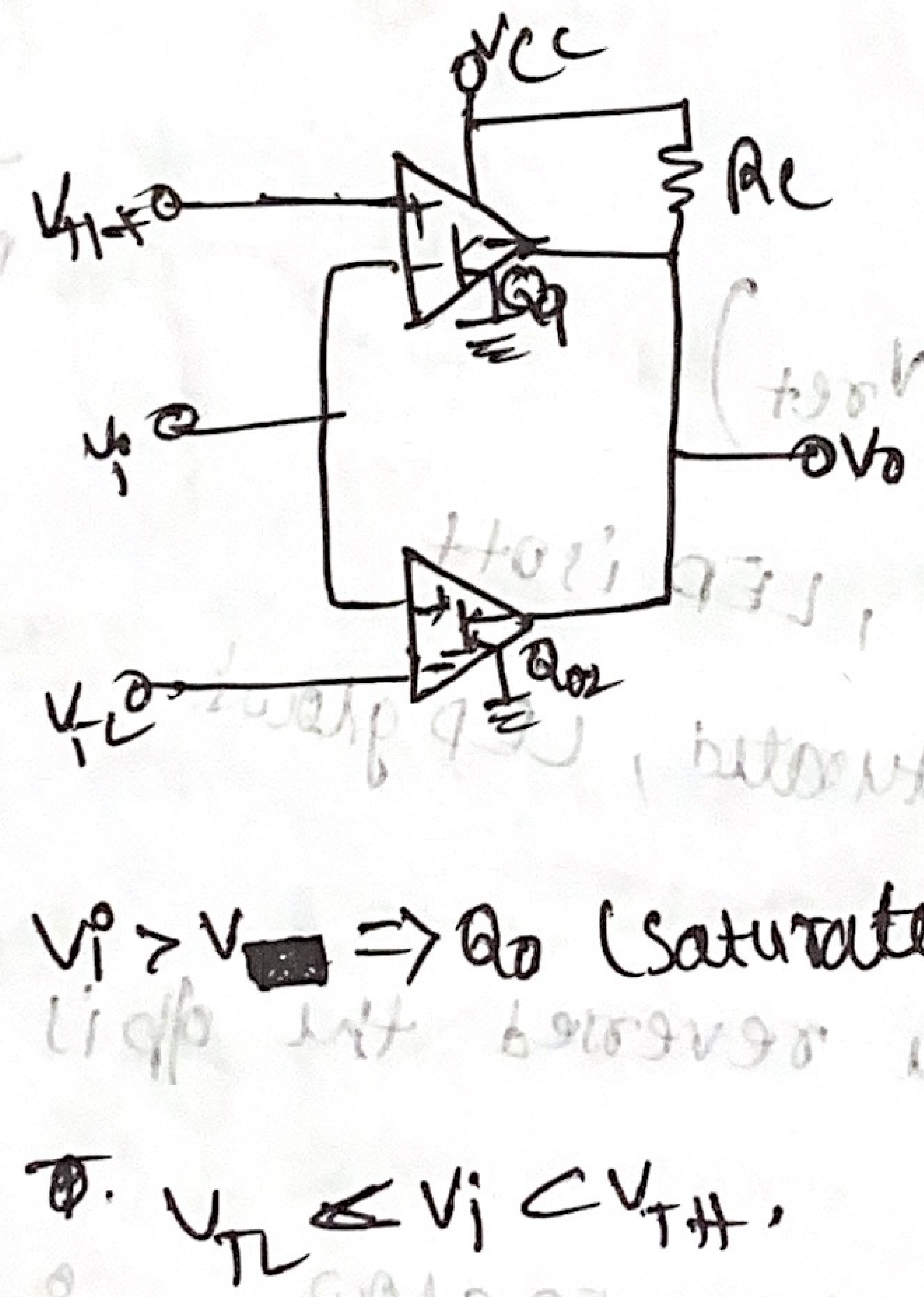
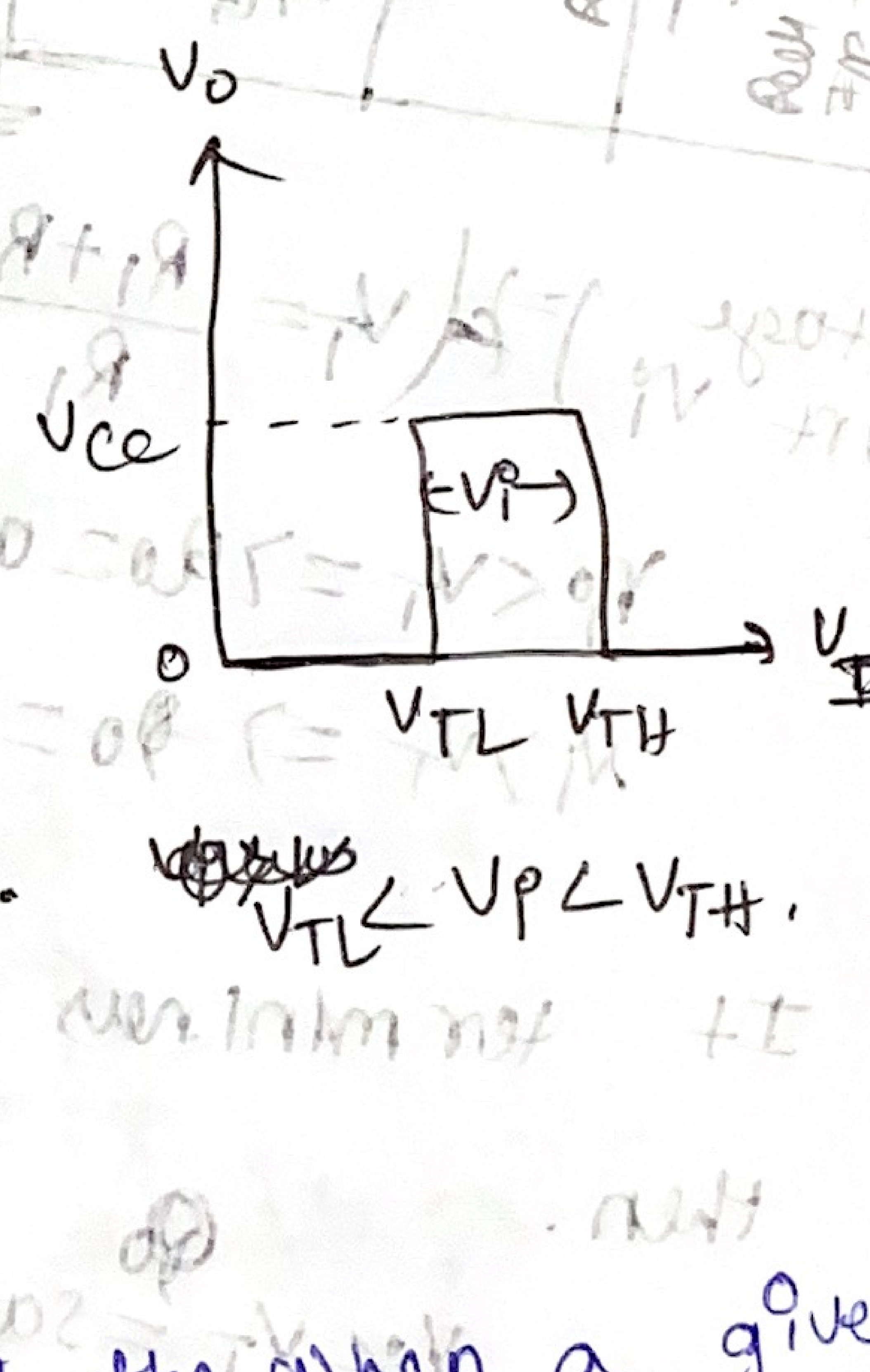
Window detector / window comparator:



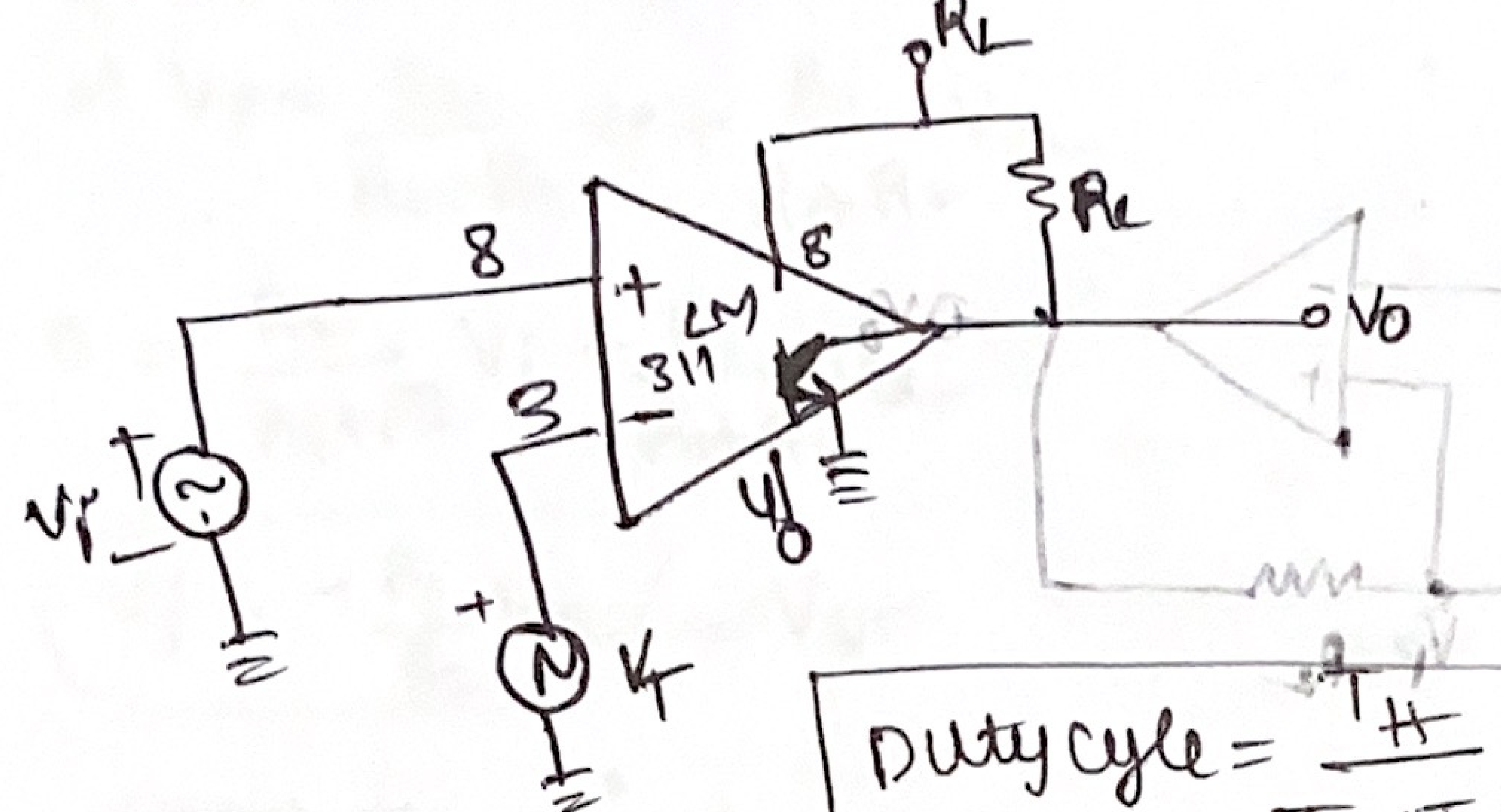


$V_i > V$[redacted] $\Rightarrow Q_0$ (saturated). $V_{TL} < V_P < V_{TH}$.

$V_{TL} < V_i < V_{TH}$.

→ Window comparator is to indicate the when a given voltage falls within a specific band or window

Pulse width Modulation



Duty cycle (%) $= \frac{T_H}{T_H+T_L} \times 100$

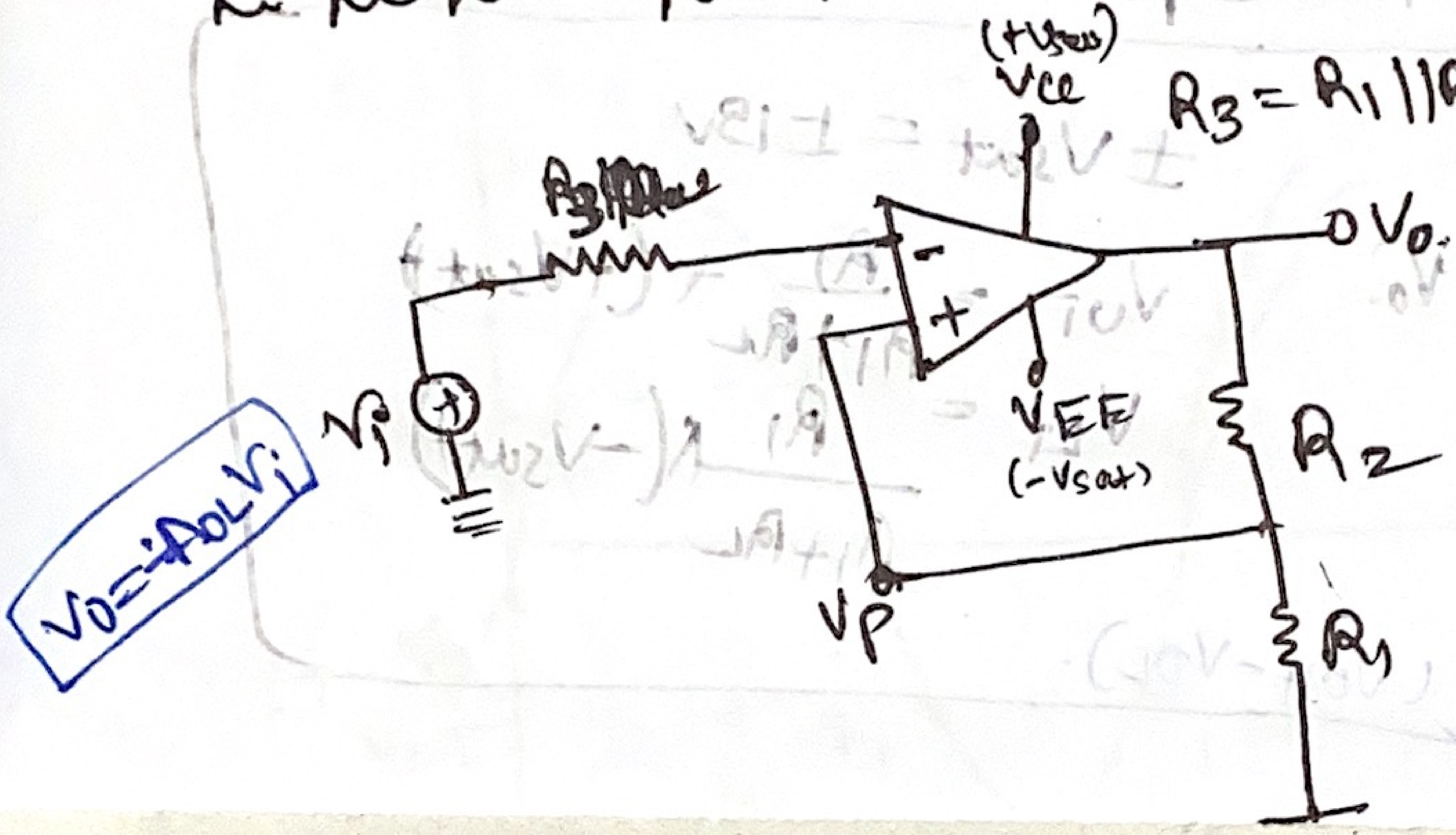
$V_i < V_T \Rightarrow Q_0$

$V_i \geq V_T \Rightarrow Q_0$.

$\boxed{\text{Duty cycle} = \frac{T_H}{T_H+T_L}}$

Schmitt Trigger:

Inverting Schmitt Trigger:



$R_3 = R_1 || R_2$

[R_3 is used to minimize the other in circuit].

Assume,

$V_0 = +V_{sat} \Rightarrow V_d = +ve$

$V_f = V_{UT}$

As soon as $V_i > V_{UT}$, $V_d = -ve$

$V_0 = -V_{sat}$

$V_f = V_{LT}$

As long as $V_i > V_{LT}$ | $V_d = -ve$

$V_0 = -V_{sat}$

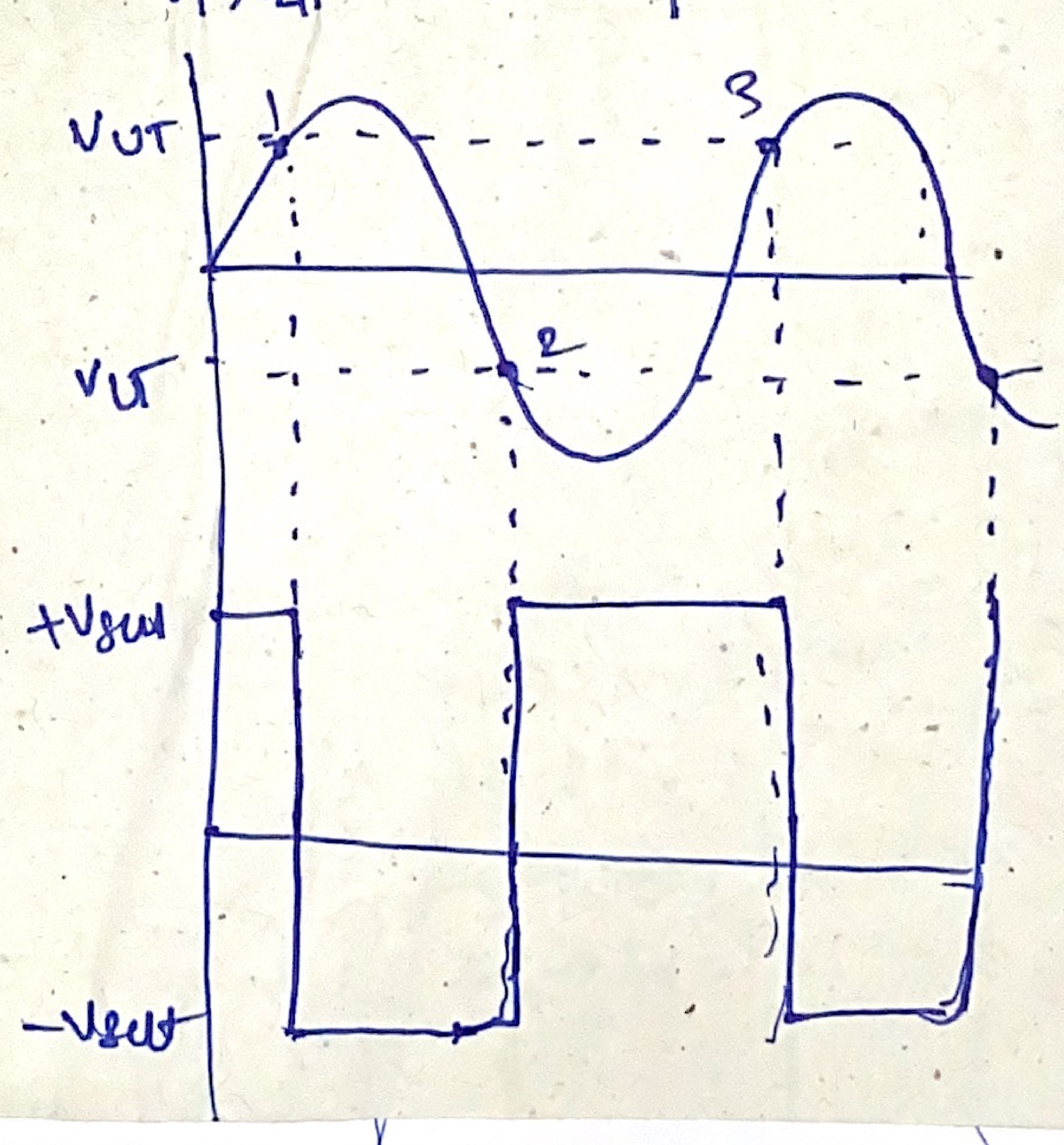
$V_f = V_{LT}$

As soon as $|V_i < V_{LT} \Rightarrow V_d = +ve$

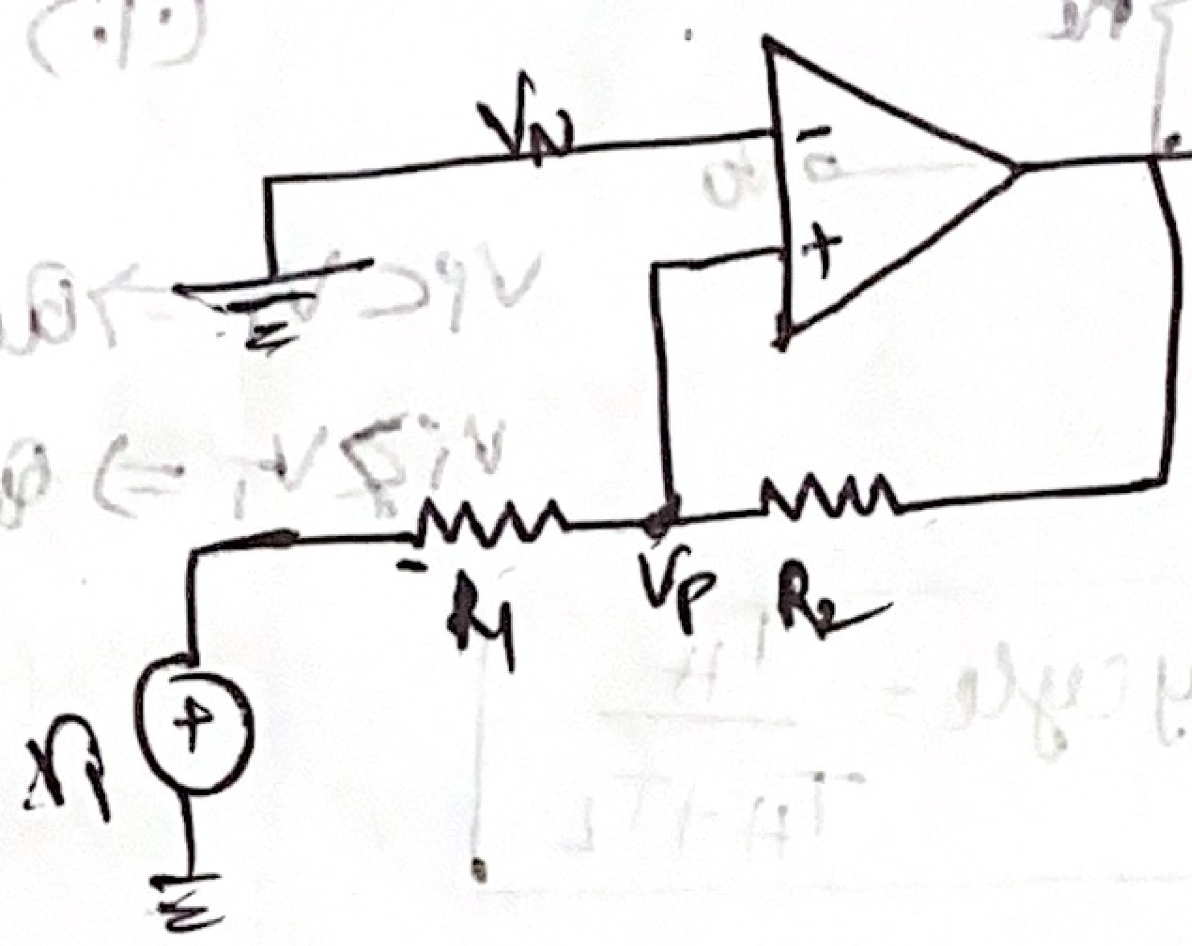
$V_0 = +V_{sat}$

$V_f = V_{UT}$

Condition	i/p V	o/p V
$V_i < V_{UT}$	$V_d = +Ve$	$V_0 = +V_{sat}$
$V_i > V_{UT}$	$V_d = -Ve$	$V_0 = -V_{sat}$
$V_i < V_{LT}$	$V_d = -Ve$	$V_0 = -V_{sat}$
$V_i > V_{LT}$	$V_d = +Ve$	$V_0 = +V_{sat}$



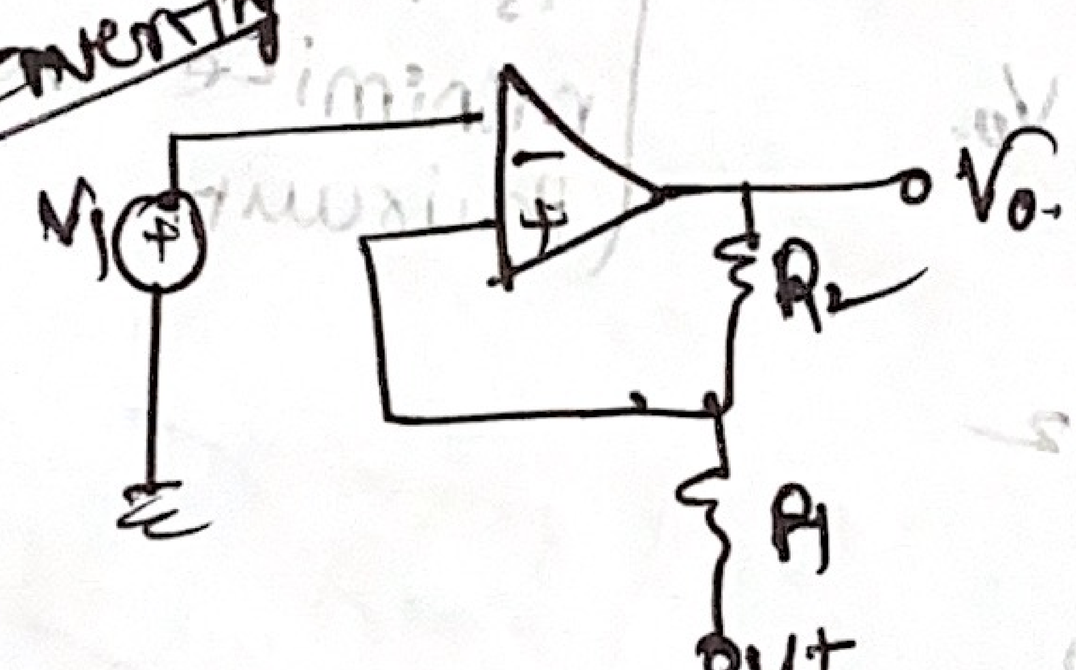
Non-Inverting Schmitt Trigger:



Assume, $V_i < V_P \Rightarrow V_o = V_{OH}$,

Apply KCL to find V_P.

Inverting



$\pm V_{sat} = \pm 15V$

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

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

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

HW

$$\begin{cases} V_i > 0, & V_o = V_{OH} \\ V_i < 0, & V_o = V_{OL} \end{cases}$$

$$\frac{V_i - V_P}{R_1} + \frac{V_O - V_P}{R_2} = 0$$

$$V_i R_2 - V_P R_2 + V_O R_1 - V_P R_1 = 0$$

$$V_P(-R_2 - R_1) + V_O R_1 + V_i R_2 = 0$$

$$V_P = \frac{V_O R_1 + V_i R_2}{R_1 + R_2}$$

$$V_P = \frac{R_2}{R_1+R_2}V_i + \frac{R_1}{R_1+R_2}V_o.$$

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$V_i < 0 \Rightarrow V_O = V_{OL}$

$\Rightarrow V_P = \frac{R_2}{R_1+R_2} V_P + \frac{R_1}{R_1+R_2} V_{OL}$

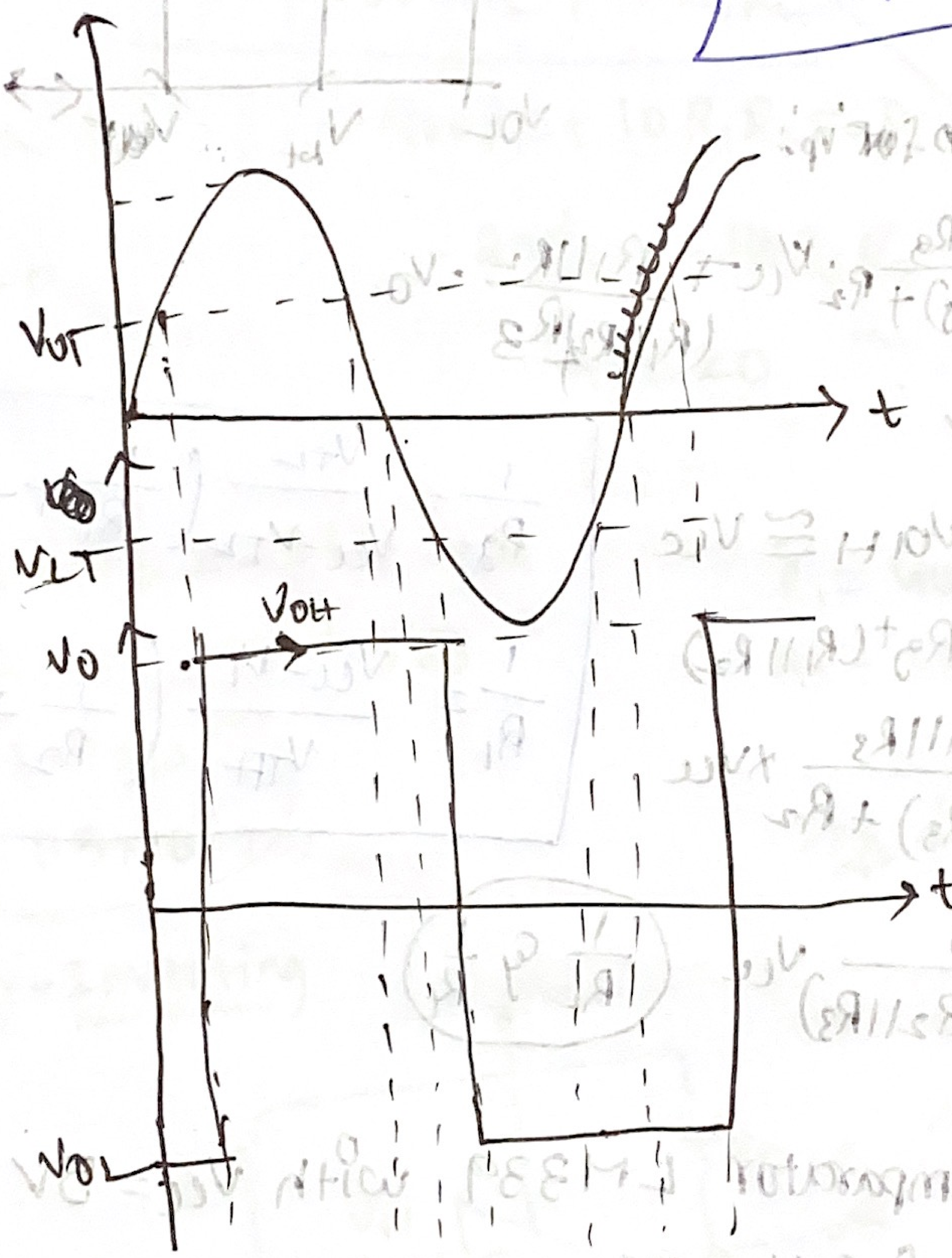
$0 = \frac{R_2}{R_1+R_2} V_i + \frac{R_1}{R_1+R_L} V_{OL}$

$\boxed{V_i = -\frac{R_1}{R_2} V_{OL}} = V_{UT}$

$V_i > 0 \Rightarrow V_O = V_{OH}$

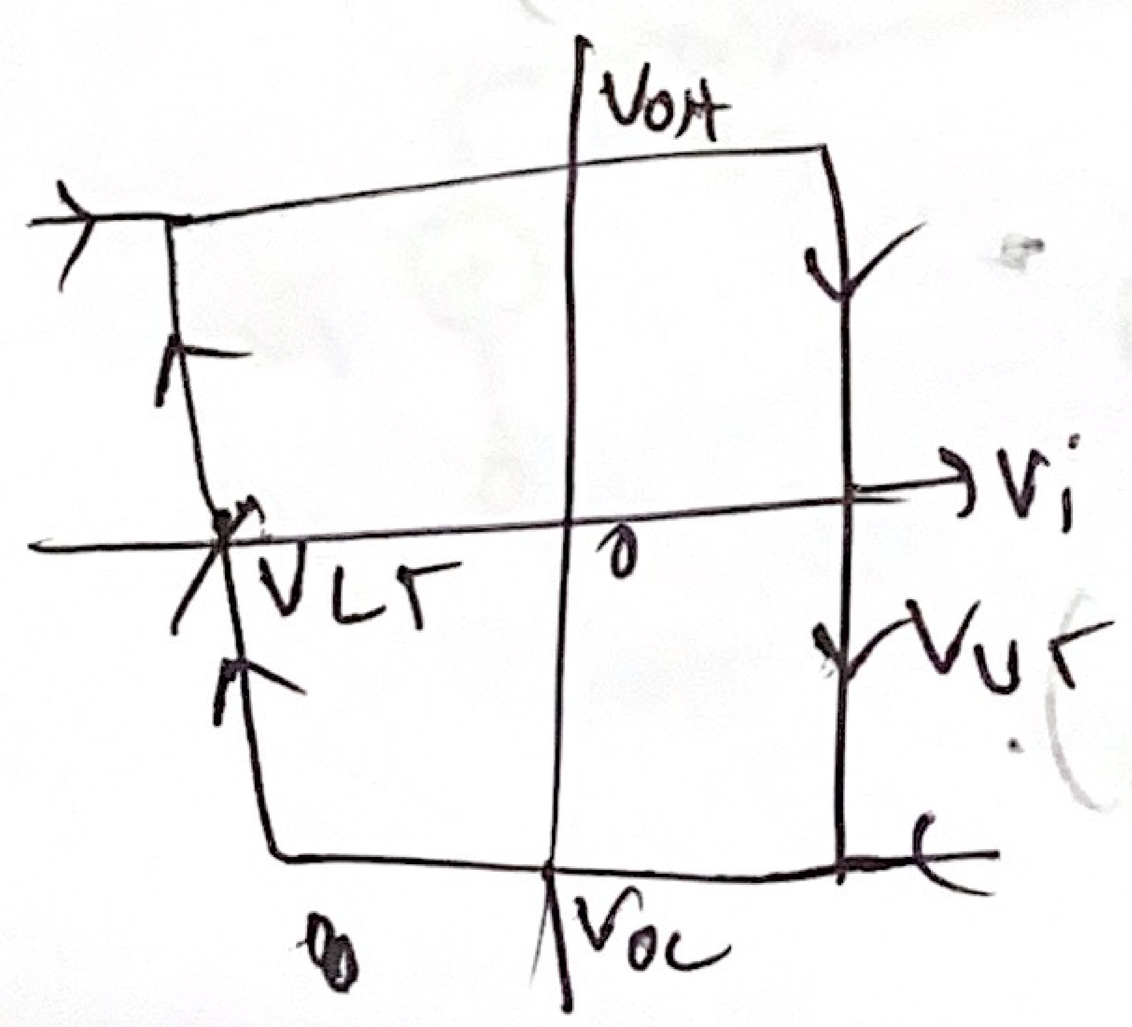
$\boxed{V_i = -\frac{R_1}{R_2} V_{OH}} = V_{LT}$

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

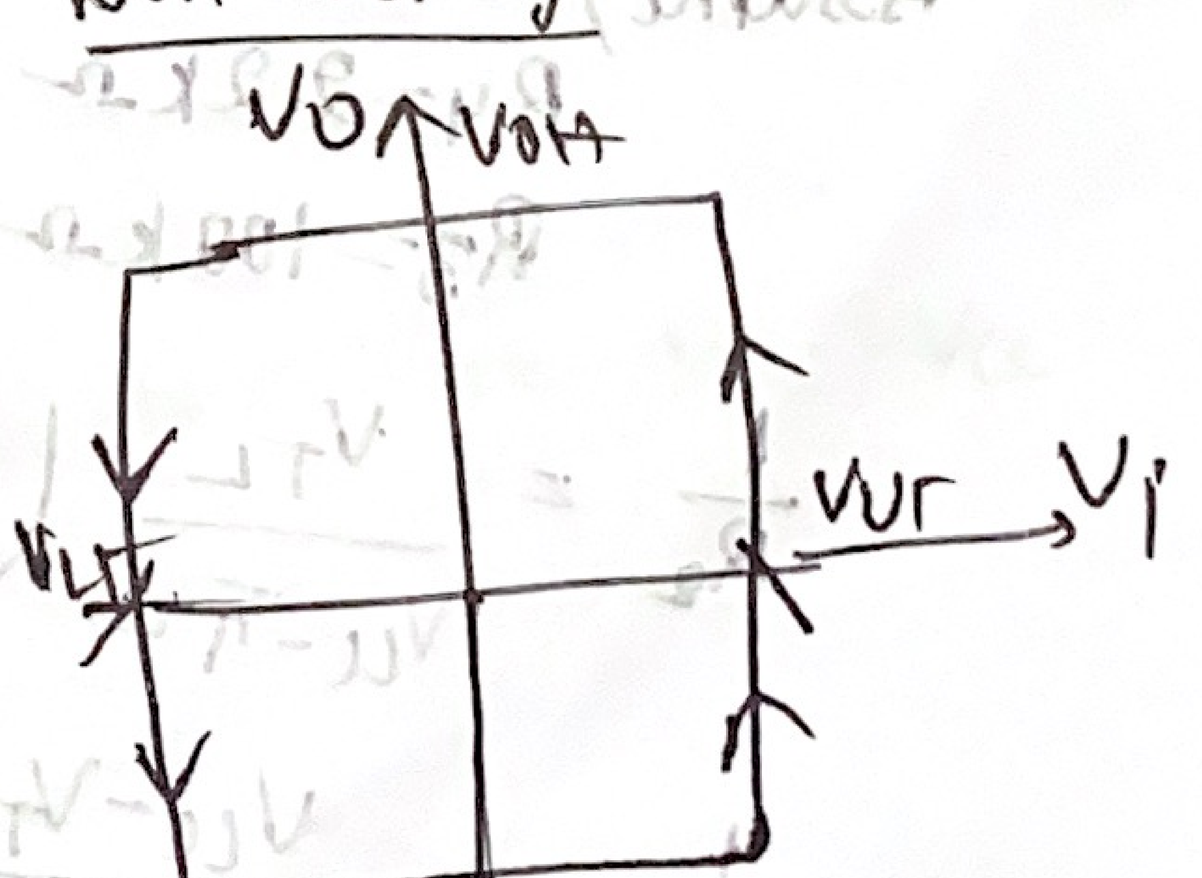


Hysteris graph

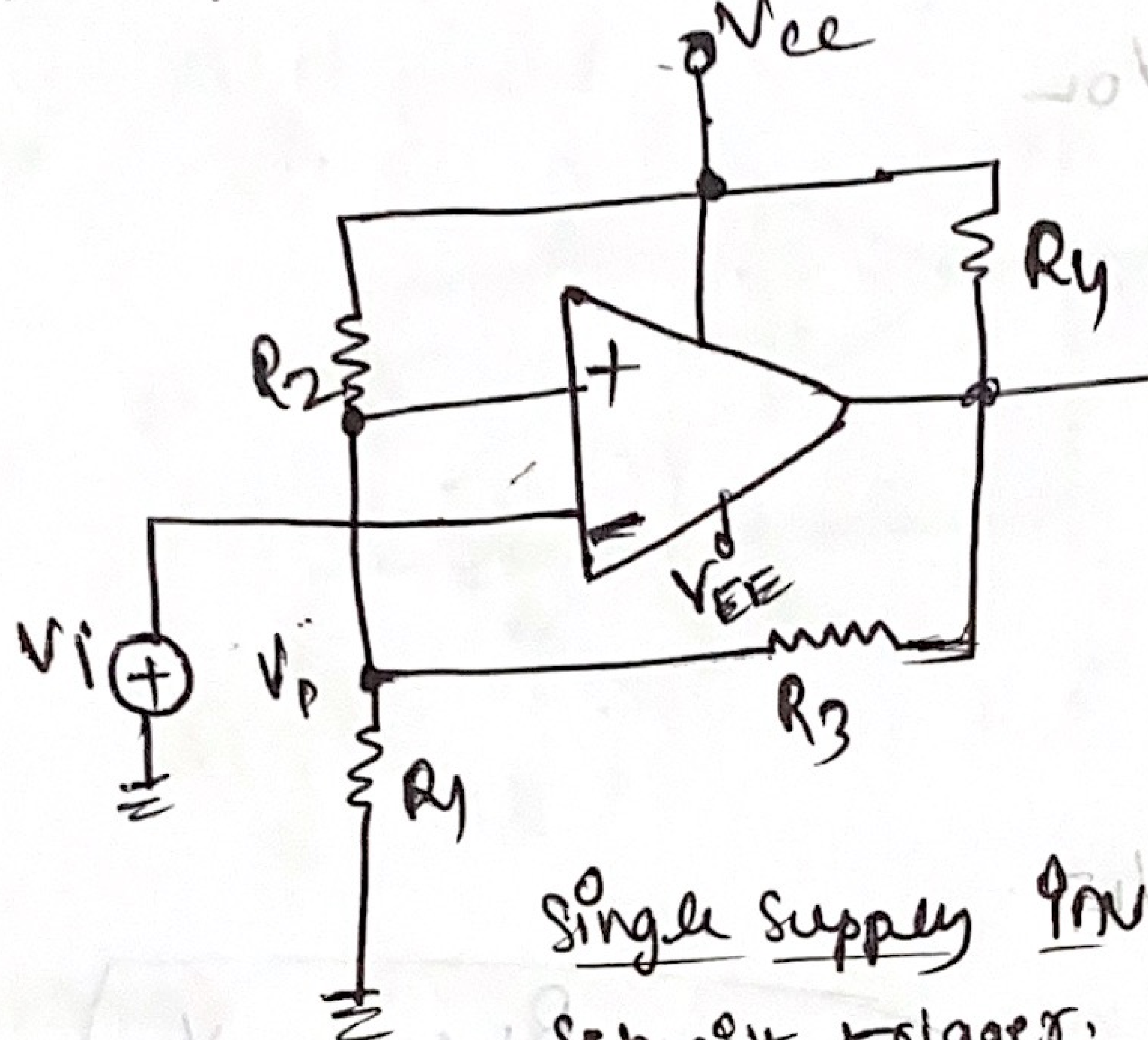
Inverting



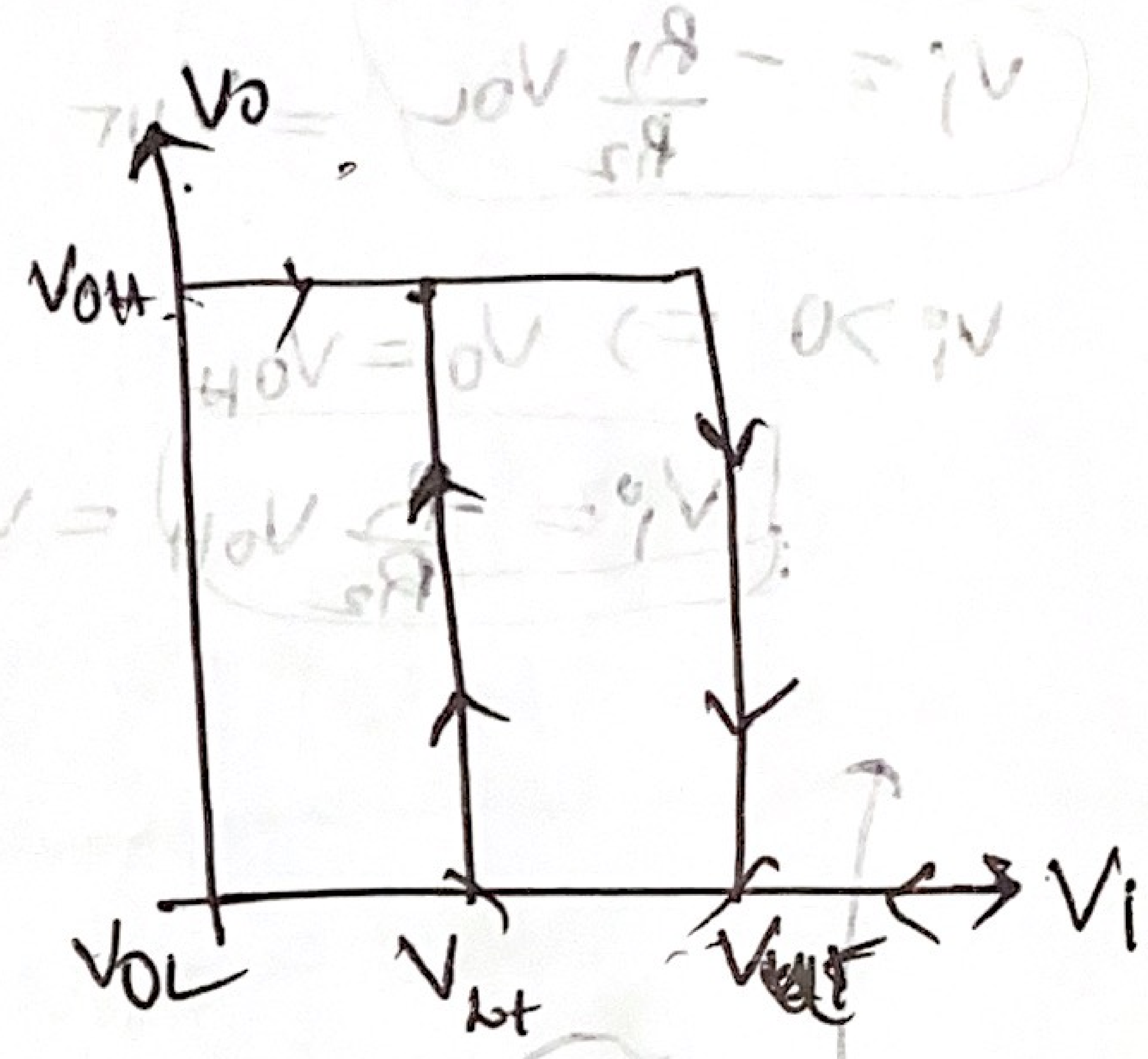
NonInverting



VTC offsetting (voltage transfer curve)



Single supply inv Schmitt trigger:



- Apply superposition for v_p:

$$V_p = \frac{R_1 \| R_3}{(R_1 \| R_3) + R_2} \cdot V_{cc} + \frac{R_1 \| R_2}{(R_1 \| R_2) + R_3} \cdot V_0.$$

$V_{OL} \simeq 0V$

To achieve $V_{OH} \cong V_{cc}$

$R_4 << R_3 + (R_1 \| R_2)$

$V_0 = V_{OL} = 0.$

$$\Leftarrow V_{LT} = \frac{R_1 \| R_3}{(R_1 \| R_3) + R_2} \times V_{cc}$$

$V_0 = V_{OH} = V_{cc}$

$$\Leftarrow V_{UT} = \frac{R_1}{R_1 + (R_2 \| R_3)} V_{cc} \qquad \frac{1}{R_2} \;\&\; \frac{1}{R_1}.$$

$$\boxed{\begin{aligned} \frac{1}{R_2} &= \frac{V_{TL}}{V_{cc} - V_{TL}} \left(\frac{1}{R_1} + \frac{1}{R_3}\right) \\ \frac{1}{R_1} &= \frac{V_{cc} - V_{TH}}{V_{TH}} \left(\frac{1}{R_2} + \frac{1}{R_3}\right) \end{aligned}}$$

3/3/22

Q1) Consider a comparator LM339 with $V_{cc} = 5V$. Calculate the resistances for $V_{OL} = 0V$, $V_{OH} = 5V$, $V_{TL} = 1.5V$, $V_{TH} = 2.5V$

Ans) Assume,

$$\left.\begin{aligned} R_4 &= 2.2\,k\Omega \\ R_3 &= 100\,k\Omega \end{aligned}\right\} \text{coz } R_4 << R_3 (R_1 \| R_2)$$

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

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

$$\frac{1}{R_2} = \frac{1.5}{5-1.5}\left(\frac{1}{R_1}+\frac{1}{100}\right). \qquad \frac{1}{R_1} = \frac{5-2.5}{2.5}\left(\frac{1}{R_2}+\frac{1}{100}\right)$$

$$\frac{1}{R_2} = \frac{1.5}{3.5}\left(\frac{100+R_1}{100R_1}\right) \qquad \frac{1}{R_1} = \frac{3.5}{2.5}\left(\frac{100+R_2}{100R_2}\right) = \frac{7}{5}\left(\frac{100+R_2}{100R_2}\right)$$

$$R_2 = \frac{7}{3}\left(\frac{100R_1}{100+R_1}\right) \qquad R_1 = \frac{500R_2}{700+7R_2}$$

$$300R_2 + 3R_1R_2 = 700R_1 \rightarrow ① \qquad 700R_1 + 7R_1R_2 = 500R_2 \rightarrow ②$$

$$-700R_1 + 300R_2 + 3R_1R_2 = 0$$

$$700R_1 - 500R_2 + 7R_1R_2 = 0$$

$$-200R_2 + 10R_1R_2 = 0 \qquad -200\times 20 + 200R_1 = 0$$

$$200R_1 = 4000$$

$$-20R_2 = -10R_1\cancel{R_2} \qquad R_2 = 20$$

$$R_1 = 20$$

$$R_2 =$$

Let $\frac{1}{R_1} = a$

$\frac{1}{R_2} = b$

$$3a - 7b = -3\times10^{-5} \rightarrow ①$$

$$a - b = 10^{-5} \rightarrow ②$$

$$a = 2.5\times10^{-5}$$

$$b = 1.5\times10^{-5}$$

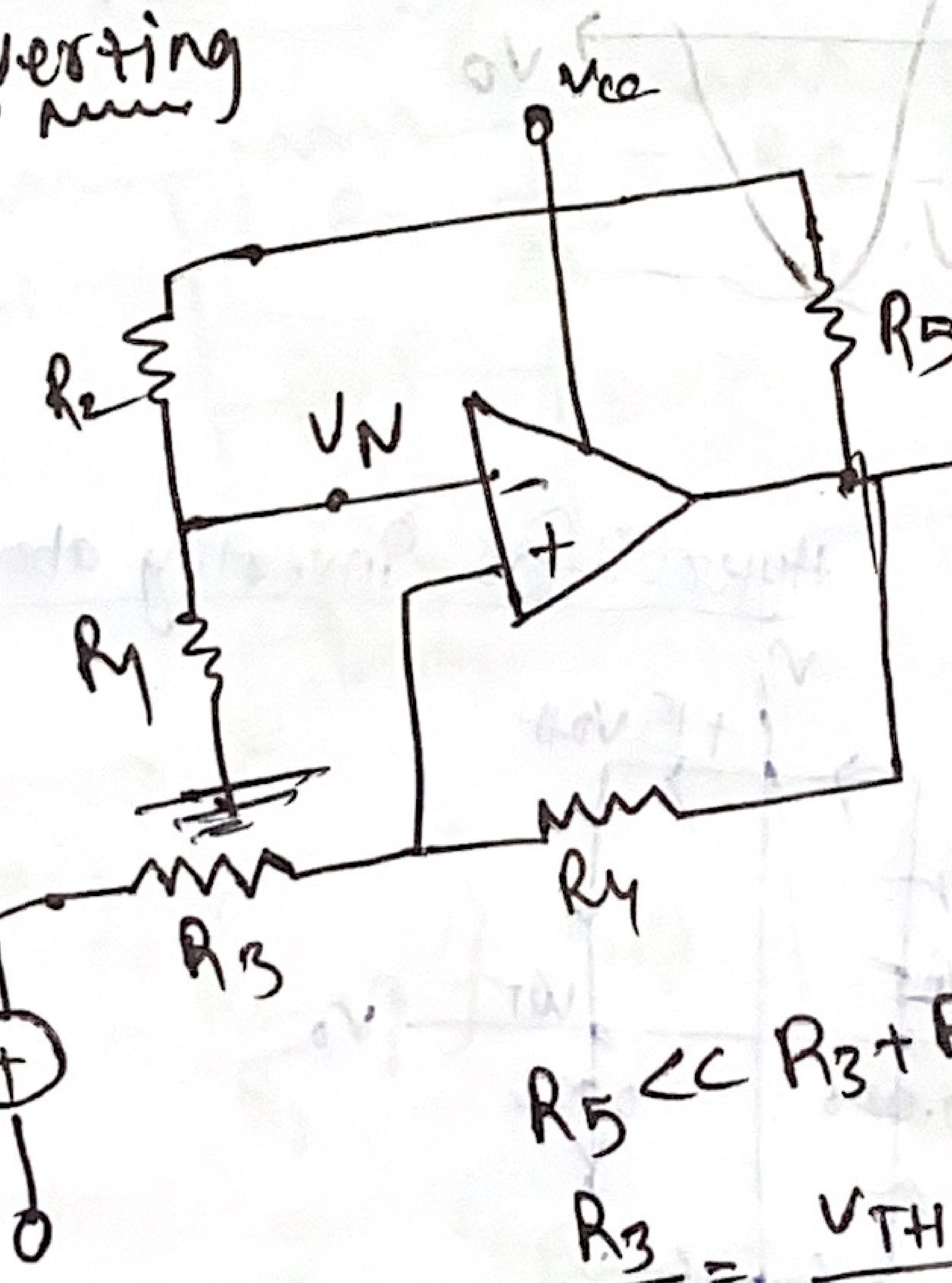
$R_1 = 40k\Omega$

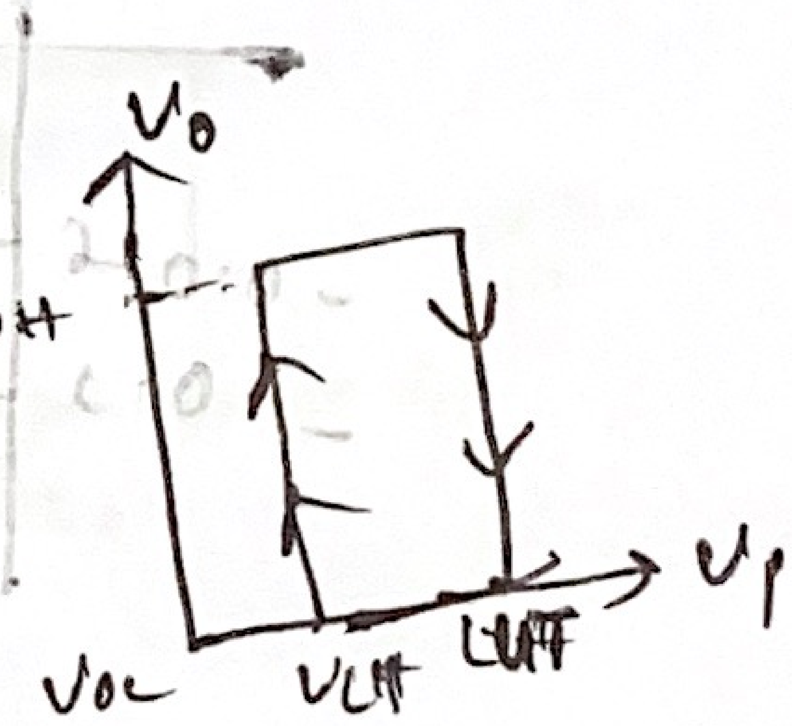
$R_2 = 66.66k\Omega$

$V_{TH} = LUT$ → upper threshold

$T_{TL} = LLT$ → lower threshold

Non-Inverting





$R_5 << R_3 + R_4$, to ensure $V_{OH} \cong V_{CC}$

$$\frac{R_3}{R_4} = \frac{V_{TH} - V_{TL}}{V_{CC}}$$

$$\frac{R_2}{R_1} = \frac{V_{CC} - V_{TL}}{V_{TH}}$$

Q2) consider a inverting schmitt trigger circuit with $R_1 = 100\,\Omega$, $R_2 = 56\,k\Omega = 56 \times 10^3\,\Omega$, $V_{in} = 1V$ p-p sine wave, $\pm V_{cc} = \pm 15V$ and determine threshold voltages V_{LT} and V_{UT} and draw the hysteresis graph. o/p waveform

Ans)

$$\cancel{V_{UT} = \frac{R_1 \| R_3}{(R_1 \| R_3) + R_2} \times V_{cc}} \qquad \cancel{V_{LT} = -\frac{R_1}{R_1 + (R_2 \| R_3)} \times V_{cc}}$$

$$\cancel{= \frac{R_1 R_3}{R_1 R_3 + R_2 (R_1 + R_3)} \times V_{cc}}$$

Assume $R_3 = 100\,k\Omega$, $R_4 = 1\,k\Omega$

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

$\pm V_{CC} = \pm 15$

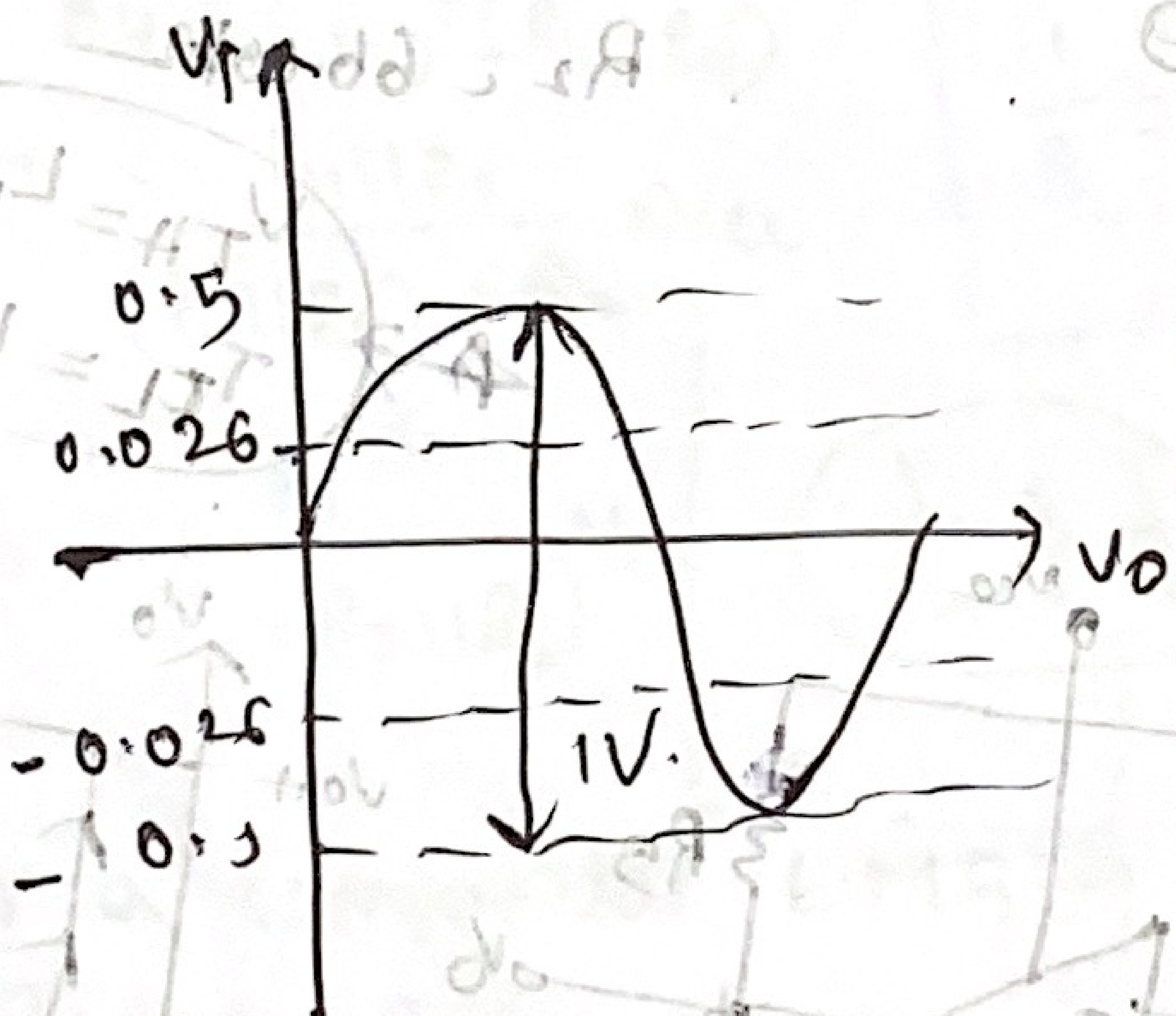
$+V_{CC} = V_{OH}$

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

$-V_{CC} = V_{OL}$

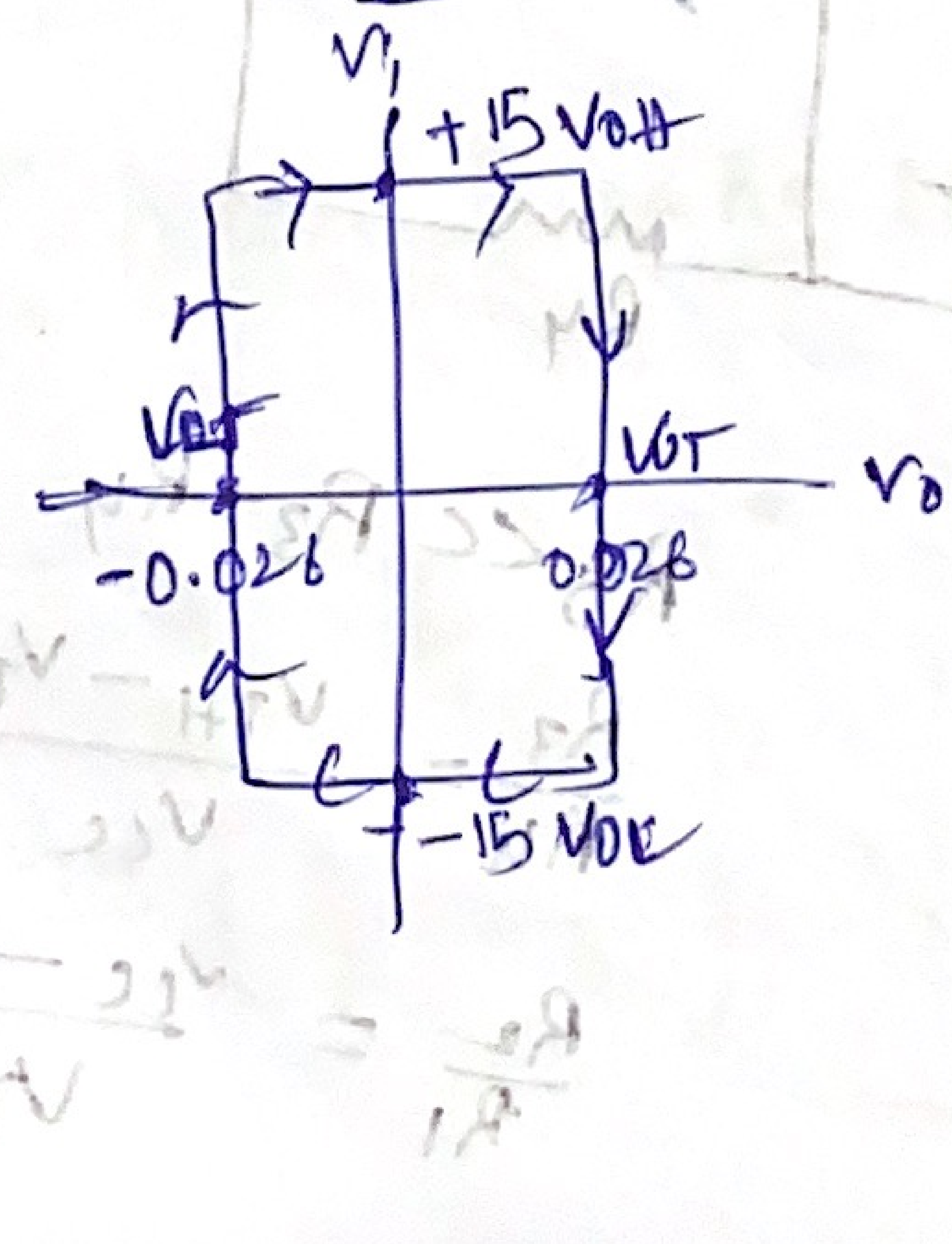
$$V_{UT} = \frac{100}{100 + 56 \times 10^3} \times 15 = \frac{100}{56100} \times 15 = 0.026$$

$$V_{LT} = \frac{100}{56100} \times -15 = -0.026$$



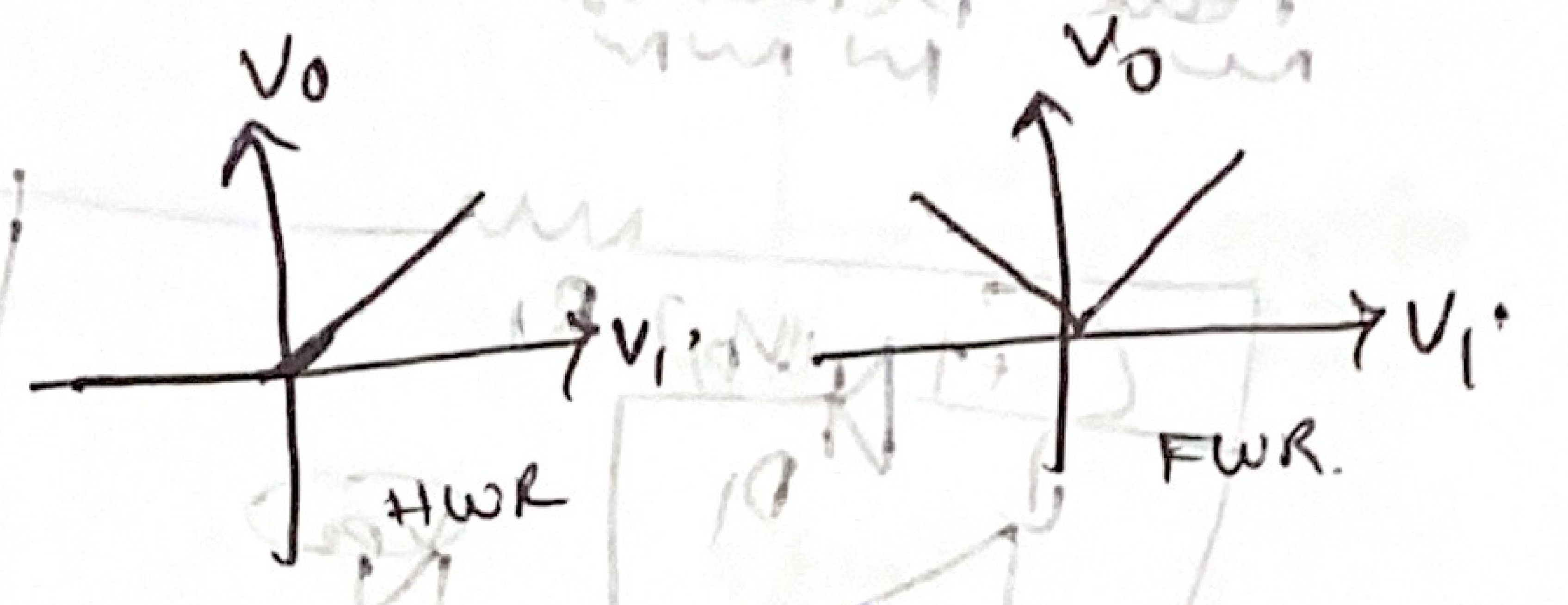
Peak to peak is 1
so, 0.5 = peak

Hysteresis for inverting above problem.



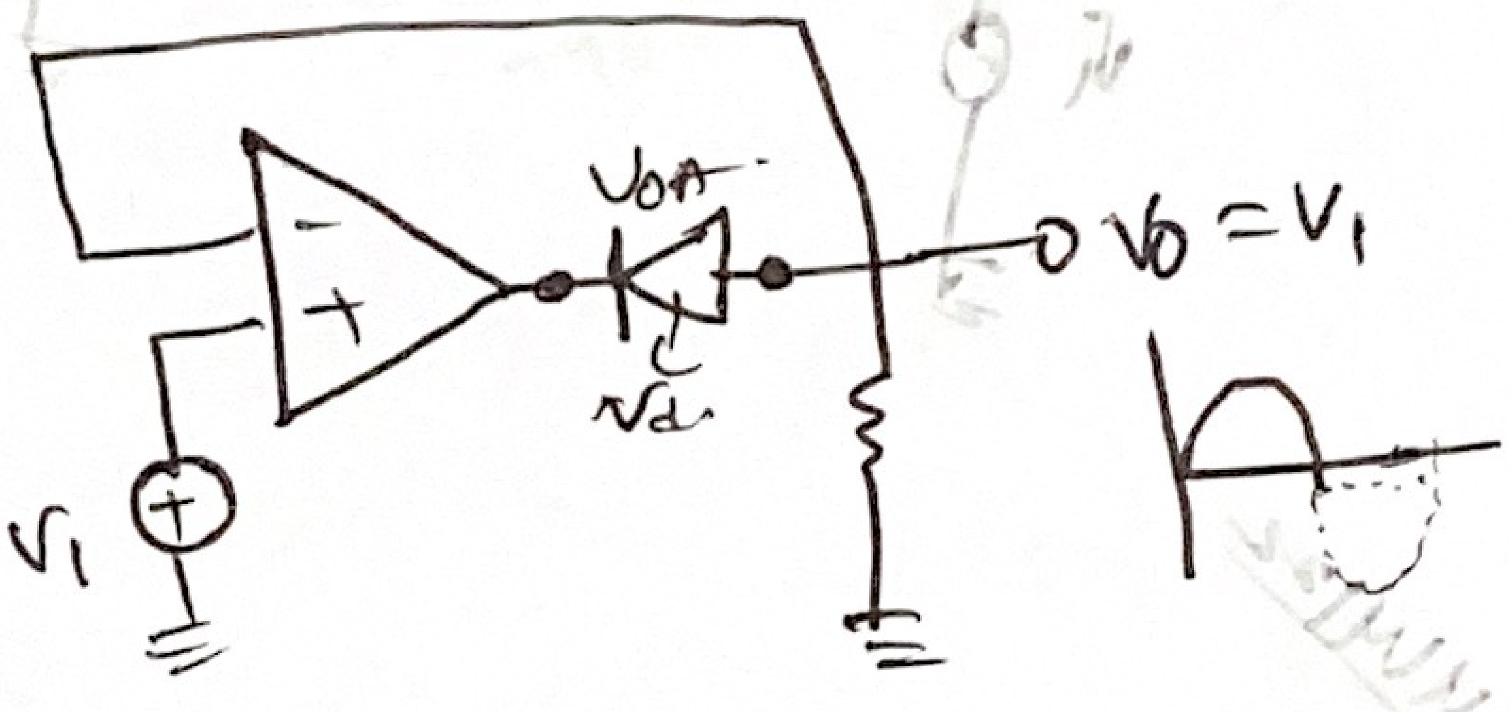
Precision Rectifiers

1. Half wave Rectifier.
2. full wave Rectifier.



1. Half wave Rectifier:

$V_o = V_i$ for $V_i > 0$
$V_o = 0$ for $V_i < 0$ $\boxed{V_o = -V_i}$



$V_{OA} = V_o + V_{D(ON)}$

$V_i < 0 \quad V_o \approx V_o + 0.7V$

$V_i > 0 \Rightarrow$ +ve i/p $\Rightarrow V_o = V_i$

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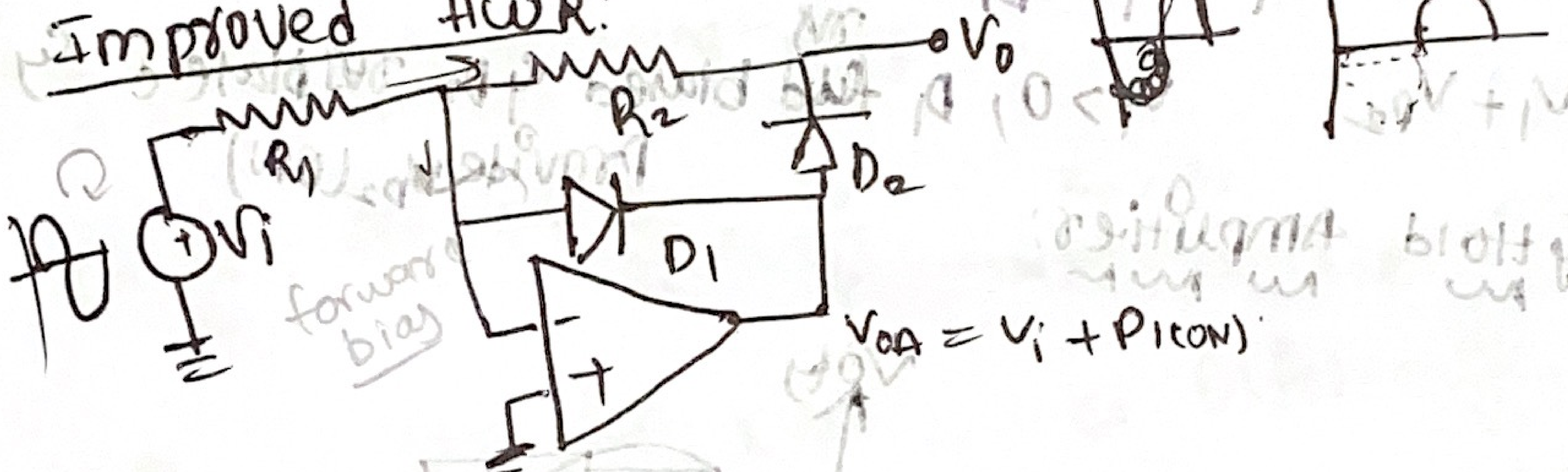
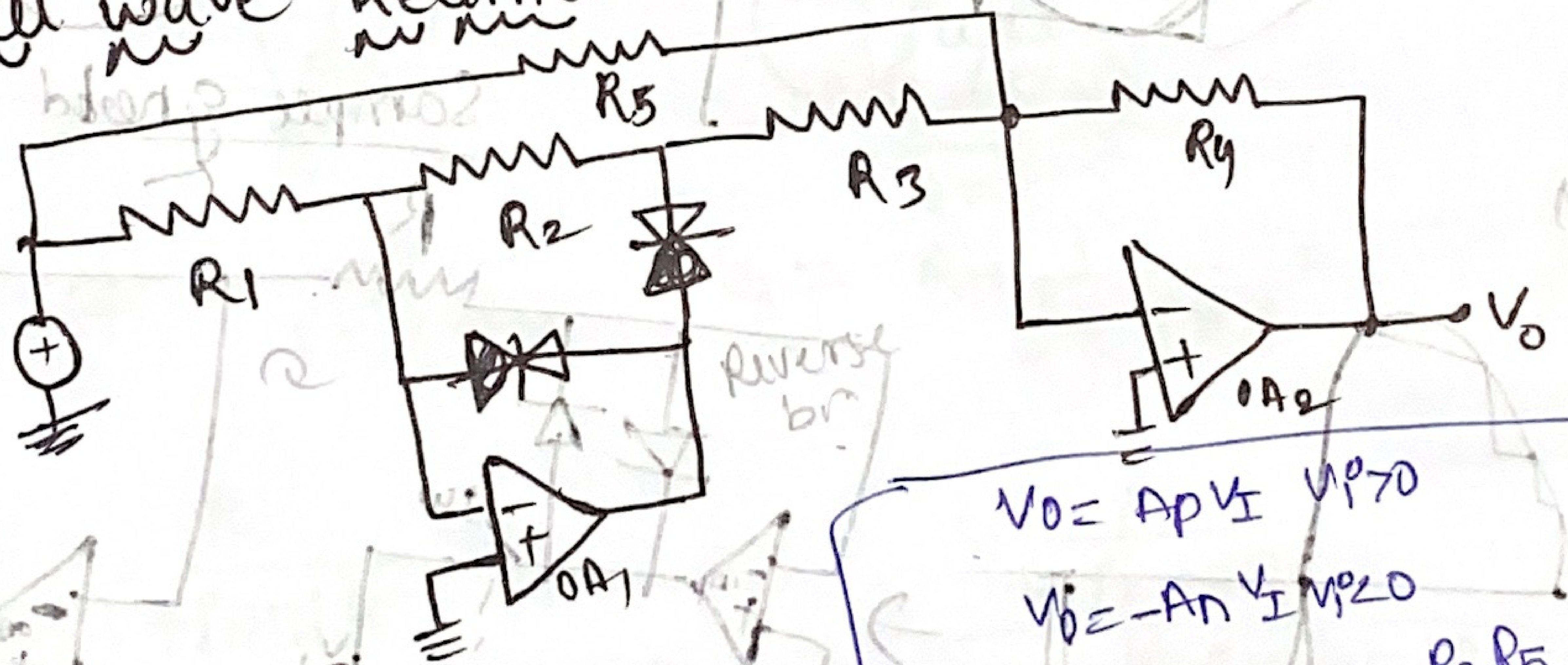
Improved HWR:



$V_i > 0 \quad V_{OA} = V_o + V_{D(ON)}$

$V_i < 0 \rightarrow V_o = -\frac{R_2}{R_1} V_i$

2. Full wave Rectifier:



$V_o = A_p V_I \quad V_i > 0$

$V_o = -A_n V_I \quad V_i < 0$

$A_n = \frac{R_5}{R_4} \quad A_p = \frac{R_2 R_5}{R_1 R_3} - A_n$

$V_i < 0 \;,\; 0$
$V_i > 0 \;,\; -\frac{R_2}{R_1} V_i$ } V_{HW}

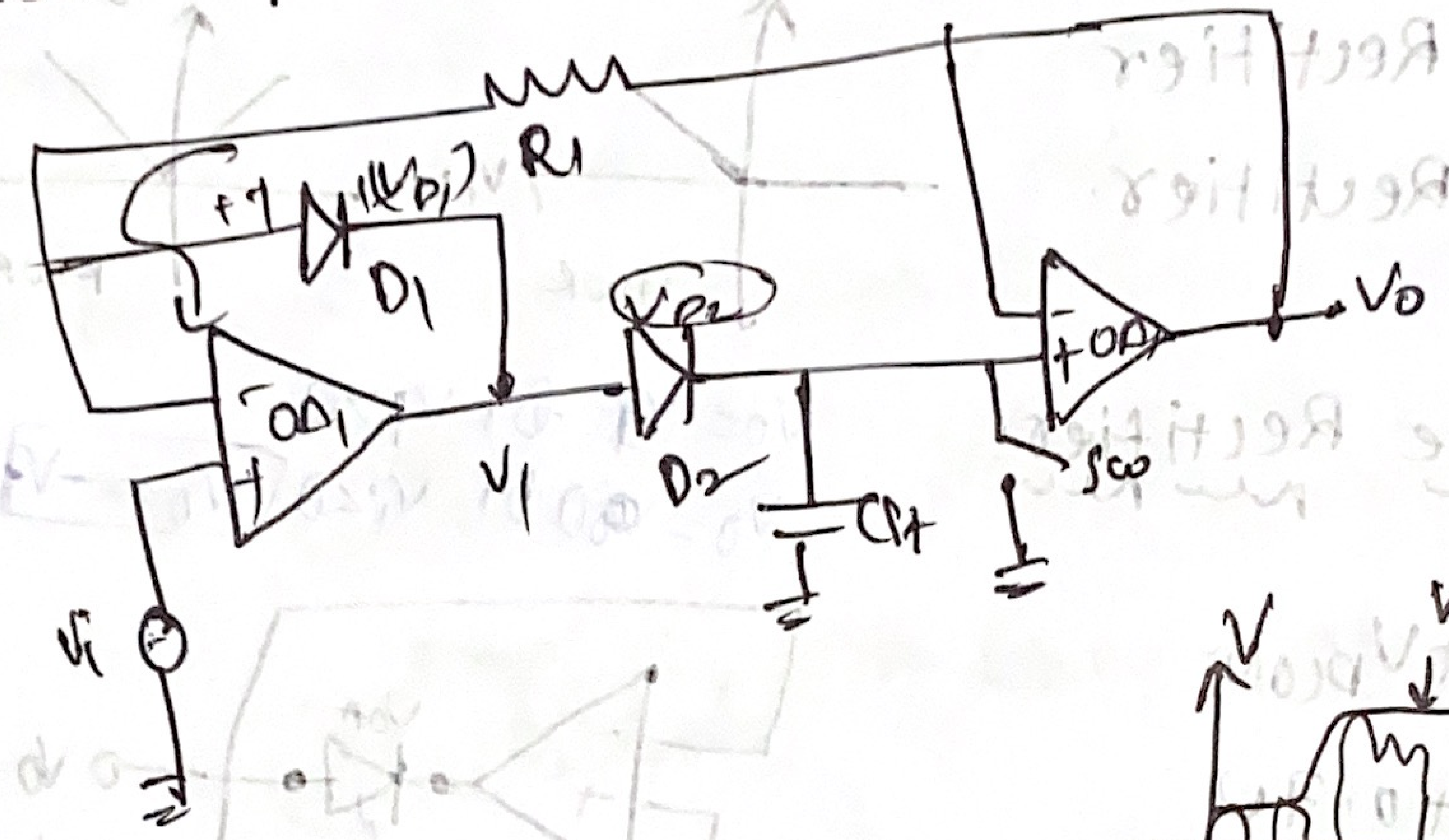
$V_o = -\frac{R_4}{R_5} V_i - \frac{R_4}{R_3} V_{HW}$

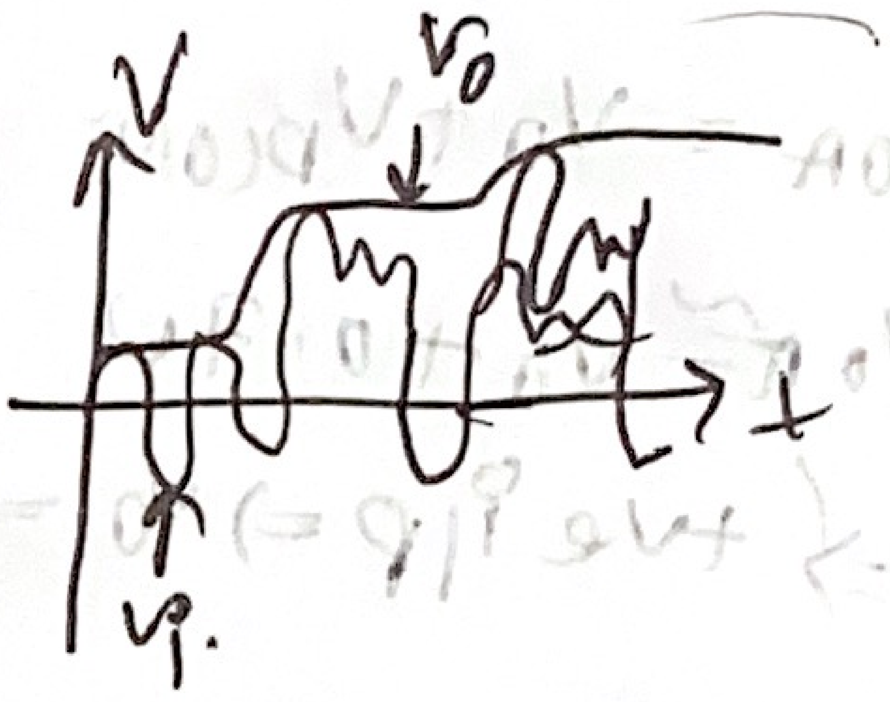
$V_{out} = V_i < 0 \;,\; -\frac{R_4}{R_5} V_i$

$V_i > 0 \;,\; R_4 \left(\frac{R_5 R_2 - R_3 R_1}{R_3 R_1 R_5} \right) V_i$

$\boxed{V_o = V_i |A|}$

Peak Detectors:



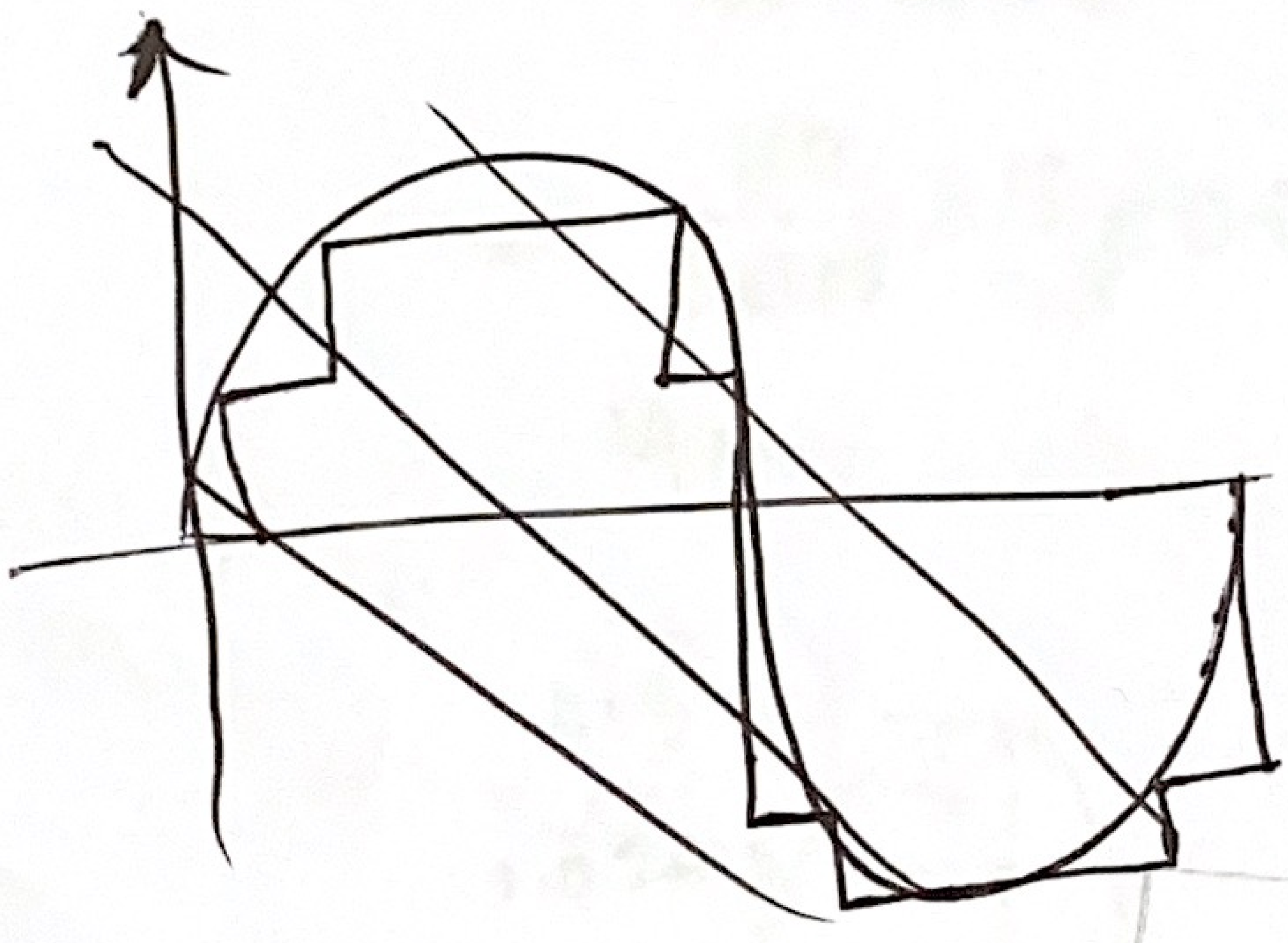


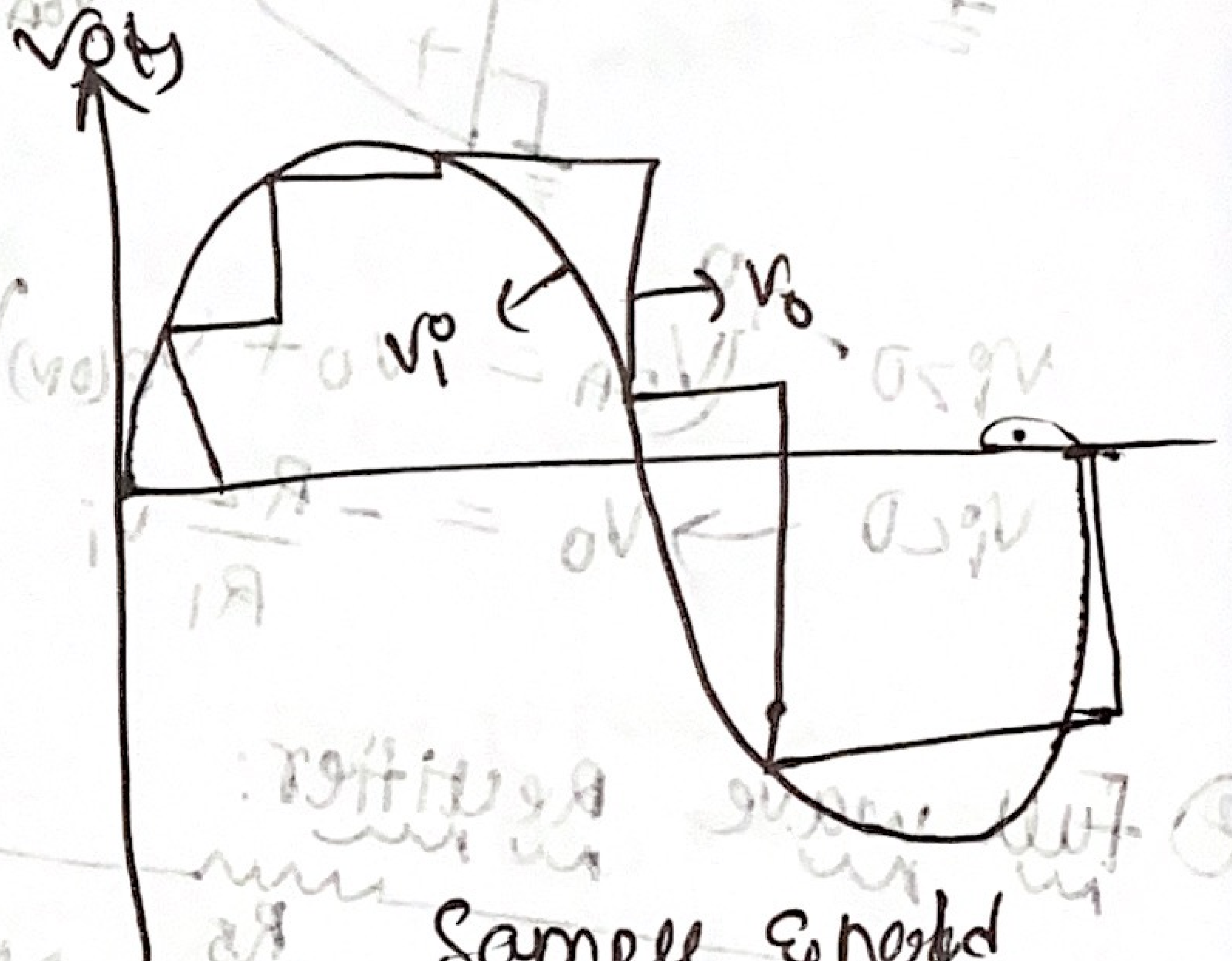
11/4/22

$V_1 < V_{D2}$, then $V_1 = V_i - V_{D1}$.

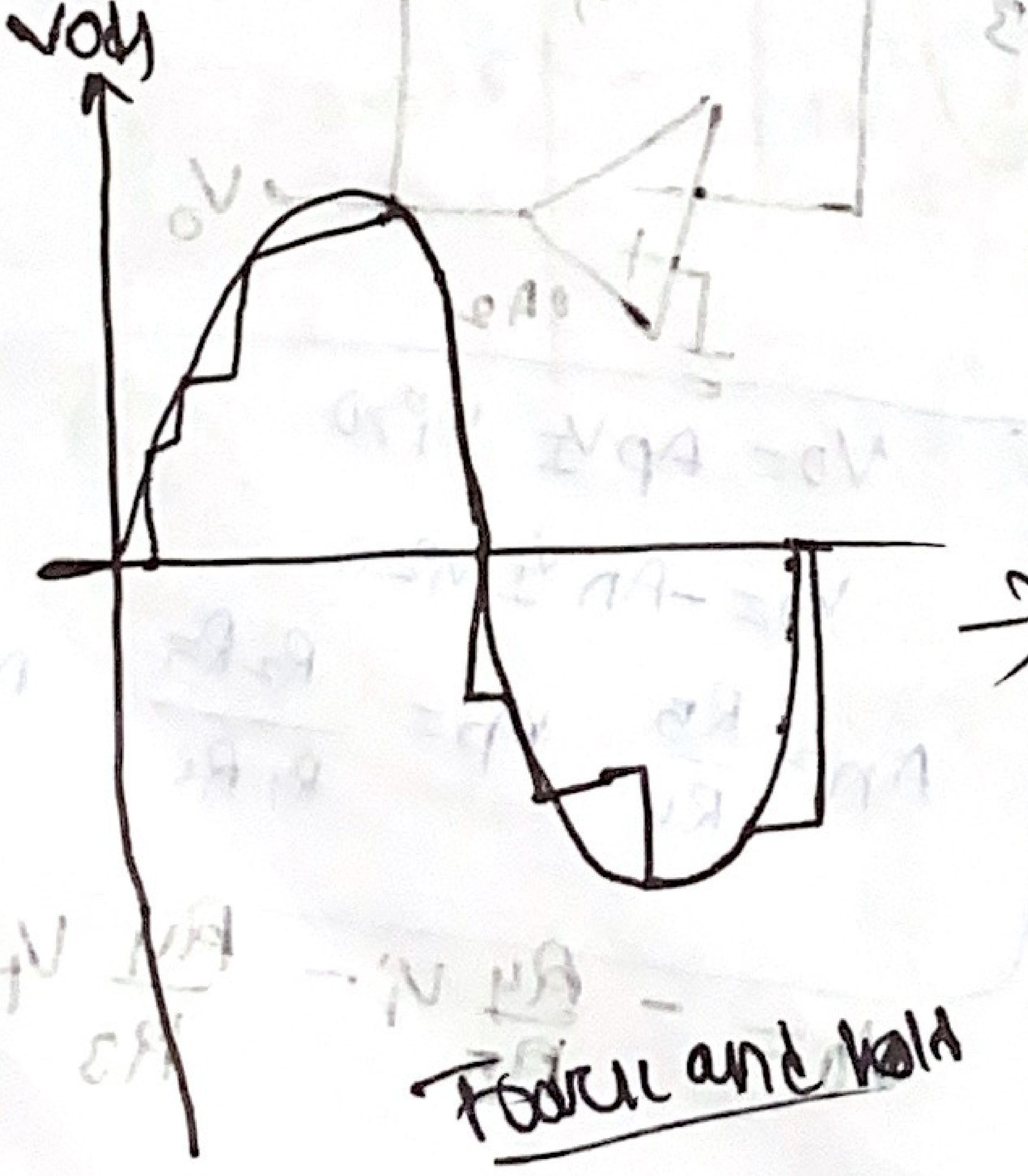
$V_i < 0$, $V_0 = V_1 + V_{D2}$. $V_i > 0$, D_1 fwd biased & D_2 rev biased & provide $V_{D2}(ON)$.

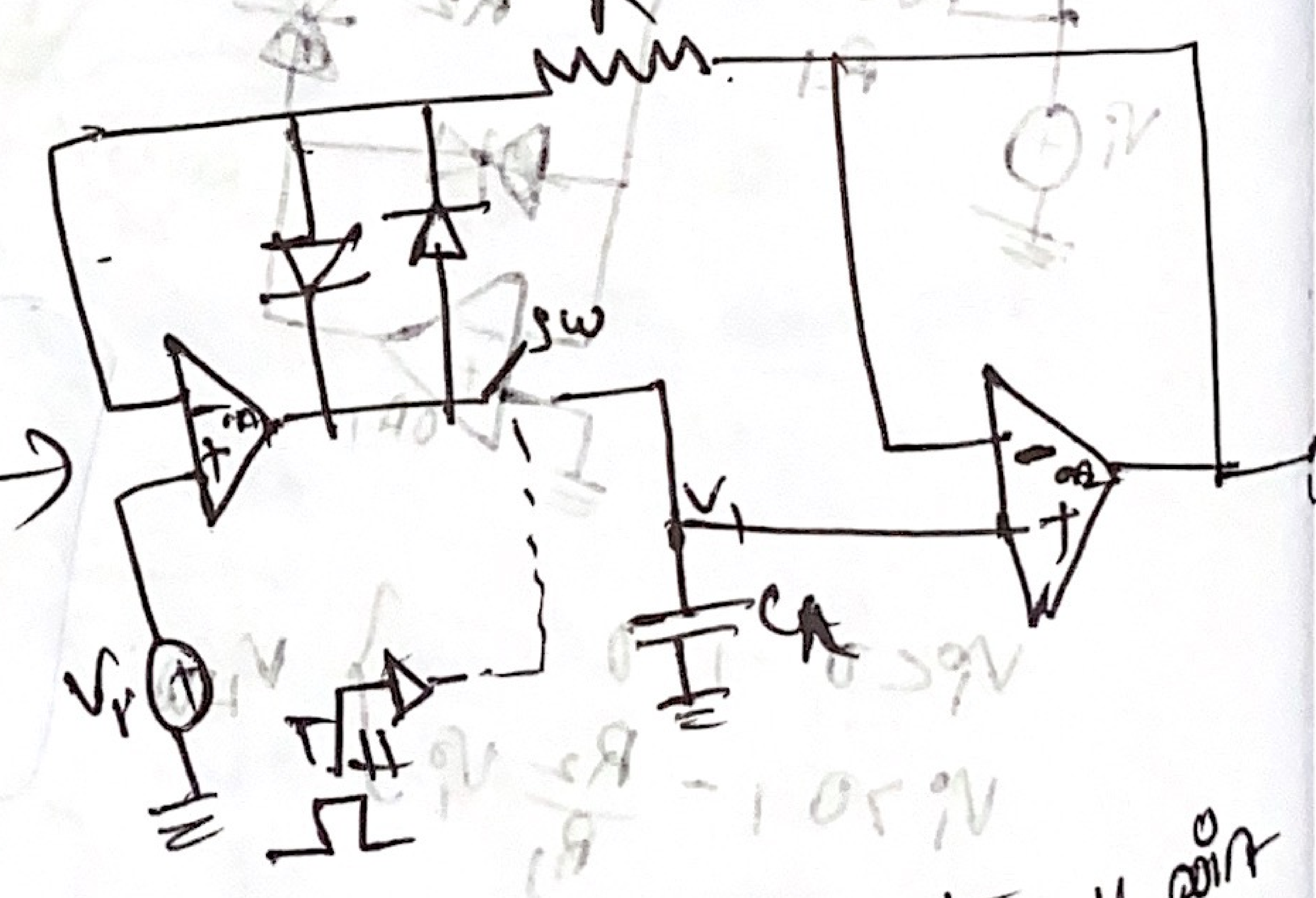
Sample & Hold Amplifiers:





Sample & hold





Track and hold

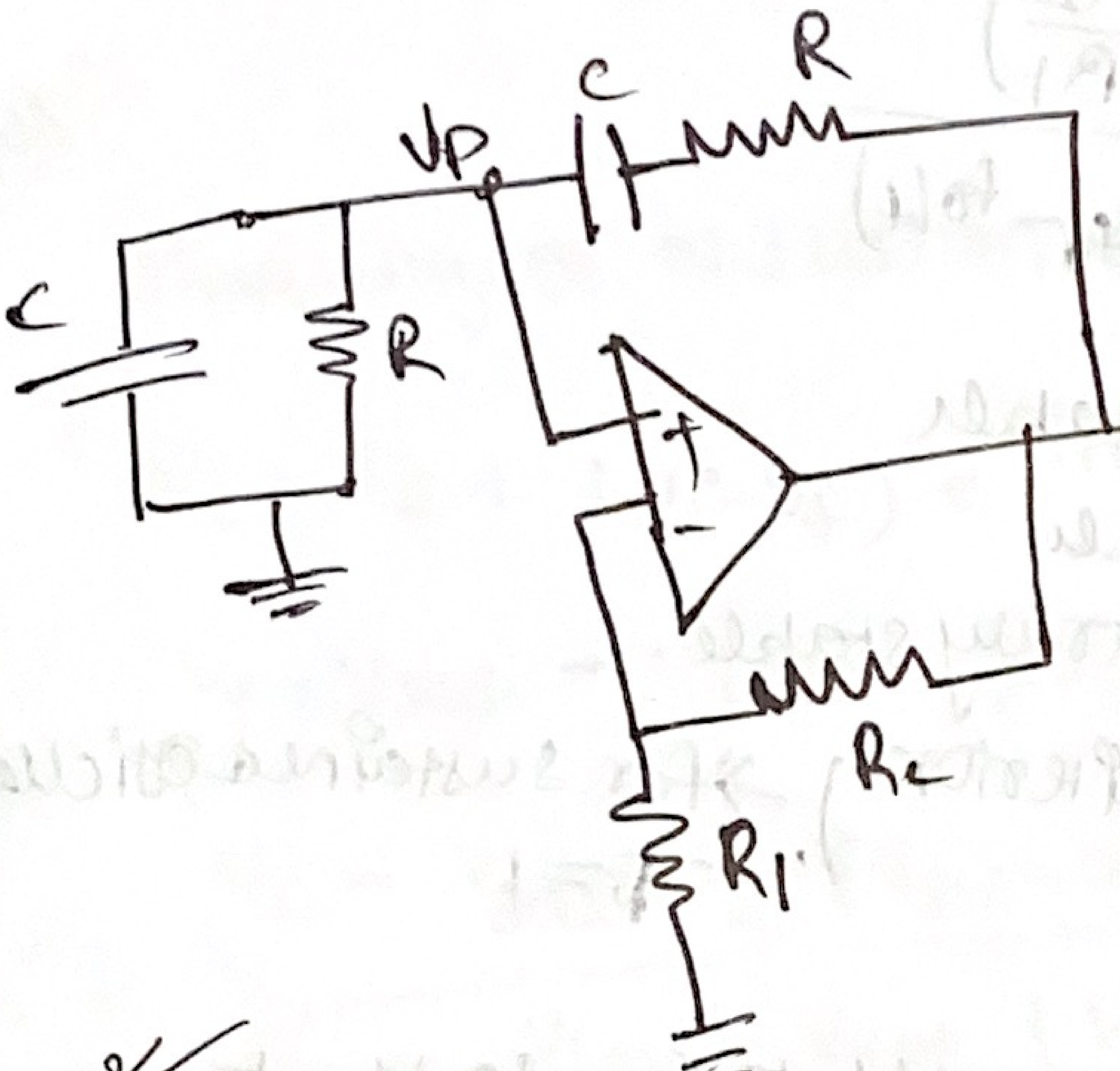
for track switch is closed, then the feedback path switch - OA_2 - R then V_{o2}

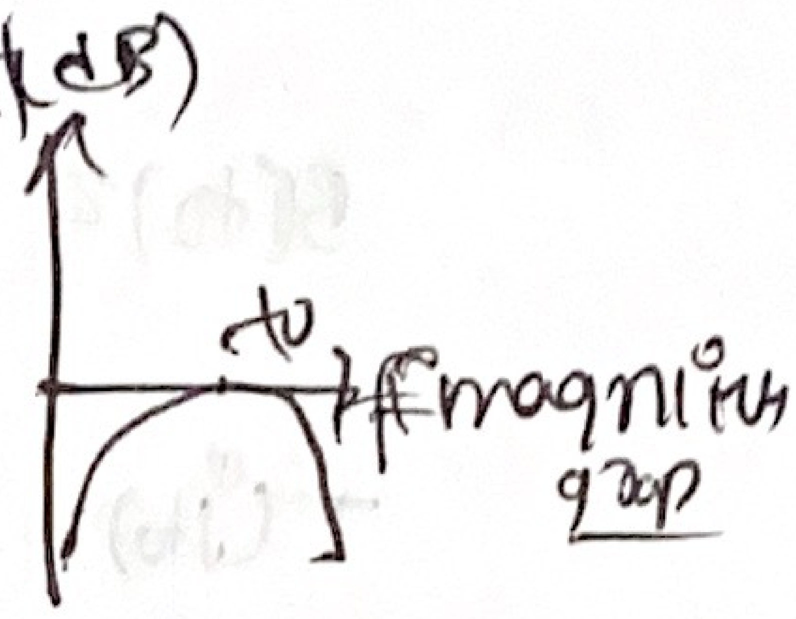
For hold the voltage at y point will be Vo as switch is open.

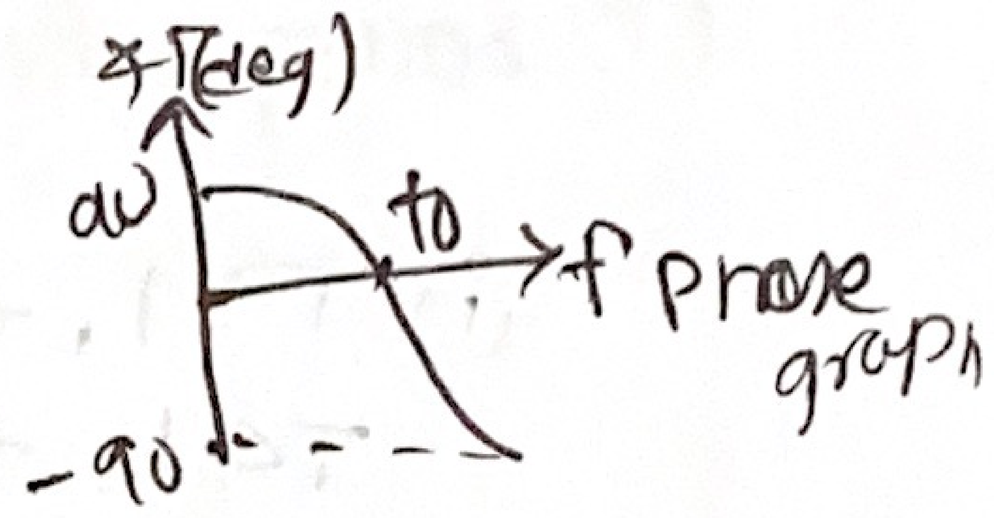
Sine wave Generators

2021

Wien Bridge Oscillator:







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★ consider Non inverting amp:

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

Z_p, Z_s

Total gain $= T(jf) = A \times B$. $\boxed{T = A \times B}$

$$V_p = \frac{Z_p}{Z_p + Z_s} \times V_o \quad \Leftarrow \quad B(jf) = \frac{V_p}{V_o} = \frac{Z_p}{Z_p + Z_s}$$

$Z_p = R \| X_c \qquad Z_s = R + X_c$

$= R \| \frac{1}{j\omega c} \qquad = R + \frac{1}{j\omega c}$

$= R \| \frac{1}{j2\pi fc} \qquad = \frac{Rj\omega c + 1}{j\omega c}$

$= \frac{R}{R} \qquad = \frac{Rj2\pi f c + 1}{j2\pi f} =$

$$Z_p = \frac{R}{1 + j2\pi fRC} \qquad Z_s = R + \frac{1}{j2\pi fC} = \frac{1 + Rj2\pi fC}{j2\pi fC}$$

$$\frac{V_p}{V_o} = \frac{\frac{R}{1+j2\pi fRC}}{\frac{R}{1+j2\pi fRC} + \frac{1+j2\pi fRC}{j2\pi fc}} = \frac{\frac{R}{1+j2\pi fRC}}{\frac{R + (R+1)(1+j2\pi fRC)}{1+j2\pi fRC}}$$

$$\Leftarrow \frac{R}{R + (R+1)(1+j2\pi fRC)}$$

$$\frac{V_p}{V_o} = \frac{2\pi fRC}{1 + (j2\pi fRC)^2 + 2(2\pi fRC) + j2\pi fRC}$$

$$B(jf) = \frac{1}{\frac{1}{2\pi fRC} + j2\pi fRC + 3} \Rightarrow \boxed{f_0 = \frac{1}{2\pi RC}}$$

$$\boxed{R_F = 2R_1}$$

$$B(jf_0) = \frac{1}{3+j(f/f_0 - f_0/f)}$$

$$T(jf_0) = A \times B = \frac{\left(1+\frac{R_2}{R_1}\right)}{3+j(f/f_0 - f_0/f)}$$

(i) $T > 1$, $A > 3$ V/V, unstable
$T < 1$, $A < 3$ V/V, stable
$T = 1$, $A = 3$ V/V, Neutrally stable.

($AB = 1 \Rightarrow$ Barkhausen criterion for oscillation.) → for sustained oscillation $T = 1$

Q) Design a wein-bridge oscillator, so that $f_0 = 965$ Hz, $C = 0.05\mu F$. $\boxed{R_2 = 2R_1}$ assume

A) Assume that sustained oscillator,

So, $T = 1$

$T = AB$

$A = \frac{1}{B}$ [If $T = 1$ then $A = 3$ V/V]

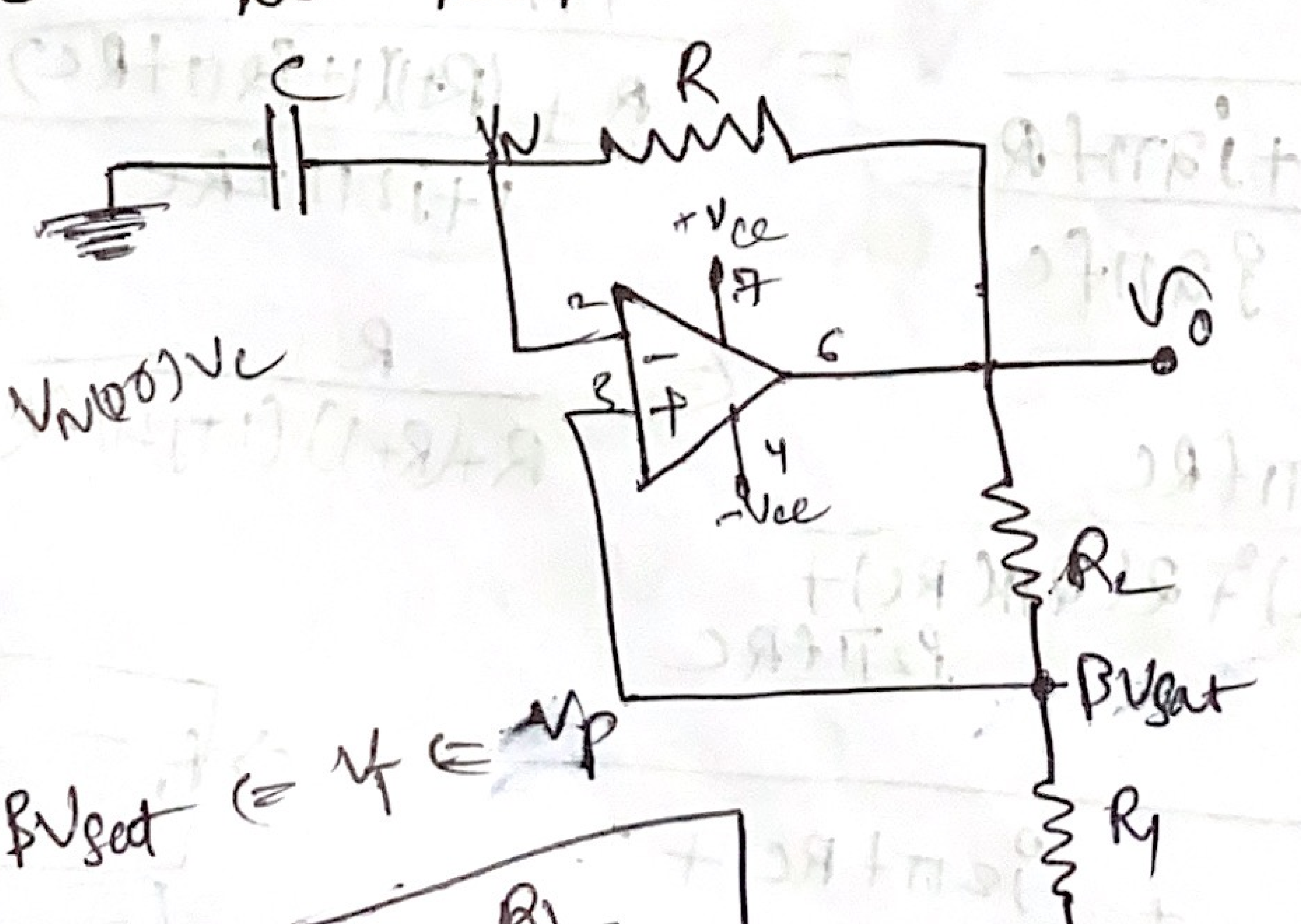
$3 = \frac{1}{B}$.

$\boxed{B = \frac{1}{3}}$ $\boxed{A = 3}$

$\boxed{R_2 = 2R_1}$

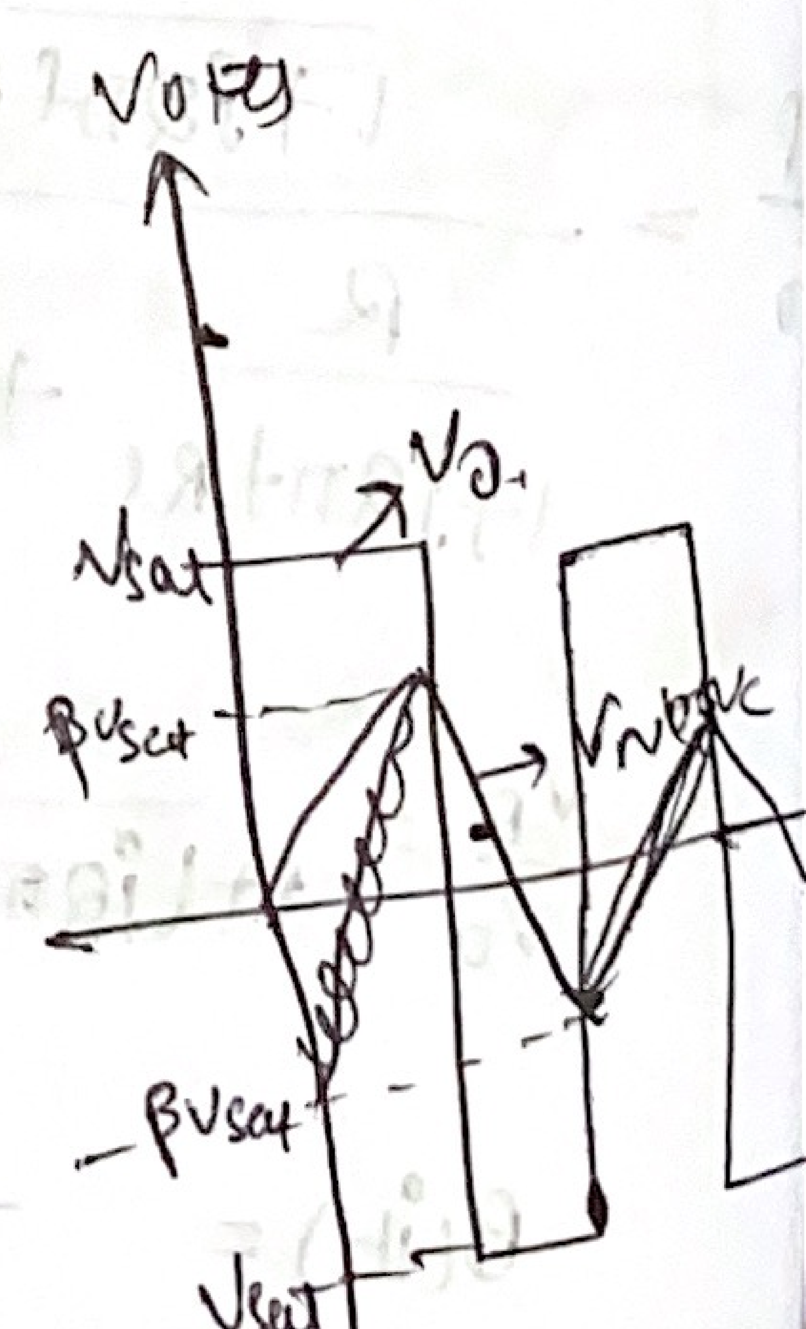
Multivibrators:

① Astable Multivibrator using opamp:



$\beta V_{sat} = V_f = V_p$

$$\boxed{B = \frac{R_1}{R_1+R_2}}$$



Duty cycle (D) = $\frac{T_{ON}}{T_{ON}+T_{OFF}}$

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Frequency of oscillation (f) or total time period (T).

$V_C = V_f + (V_i - V_f)\, e^{-t/RC}$

$V_f = V_{sat}$ $V_i = -\beta V_{sat}$

$V_C = V_{sat} + (-\beta V_{sat} - V_{sat})\, e^{-t/RC}$

$\boxed{V_C = V_{sat} - V_{sat}(1+\beta)\, e^{-t/RC}}$

At $t = T_1$, $V_C = \beta V_{sat}$

$\beta V_{sat} = V_{sat} - V_{sat}(1+\beta) e^{-T_1/RC}$

$\beta = 1 - (1+\beta)\, e^{-T_1/RC}$ $\qquad 1+\beta = (1+\beta) e^{-T_1/RC}$

$\frac{\beta + 1}{1-\beta} = -e^{-T_1/RC}$

$T_1 = +RC \ln\left(\frac{1+\beta}{1-\beta}\right)$

$T = 2T_1$

$\boxed{T = 2RC \ln\left(\frac{1+\beta}{1-\beta}\right)}$ $\qquad \boxed{T = 2RC \ln \frac{V_{sat}+V_T}{V_{sat}-V_T}}$

$f_0 = \frac{1}{T}$

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

If, $R_1 = R_2$

then, $\beta = 0.5$

$T = 2RC \ln\left(\frac{1+0.5}{1-0.5}\right)$

$= 2RC \ln 3$

$R_1 = 1.16 R_2$,

then $\beta = \frac{1.16 \cancel{R_2}}{2.16 \cancel{R_2}}$

$T = 2RC$, $f_0 = \frac{1}{2RC}$

Q1) An op-Amp Astable Multivibrator circuit is constructed using following components $R_2 = 35\,k\Omega$, $R_1 = 30\,k\Omega$, $R = 50\,k\Omega$, $C = 0.01\,\mu F$. Calculate frequency of oscillation.

Ans) $\beta = \frac{R_1}{R_1+R_2} = \frac{30}{30+35}$.

$\beta = 0.461$

$T = 2 \times 50 \times 0.01 \times 10^{-6} \times \ln\left(\frac{1+0.461}{1-0.461}\right)$

$= 100 \times 0.01 \times 10^{-6} \times 0.99 \times 10^{4} = 2 \times 50 \times 10^{4} \times 10^{-6} \times 0.01$

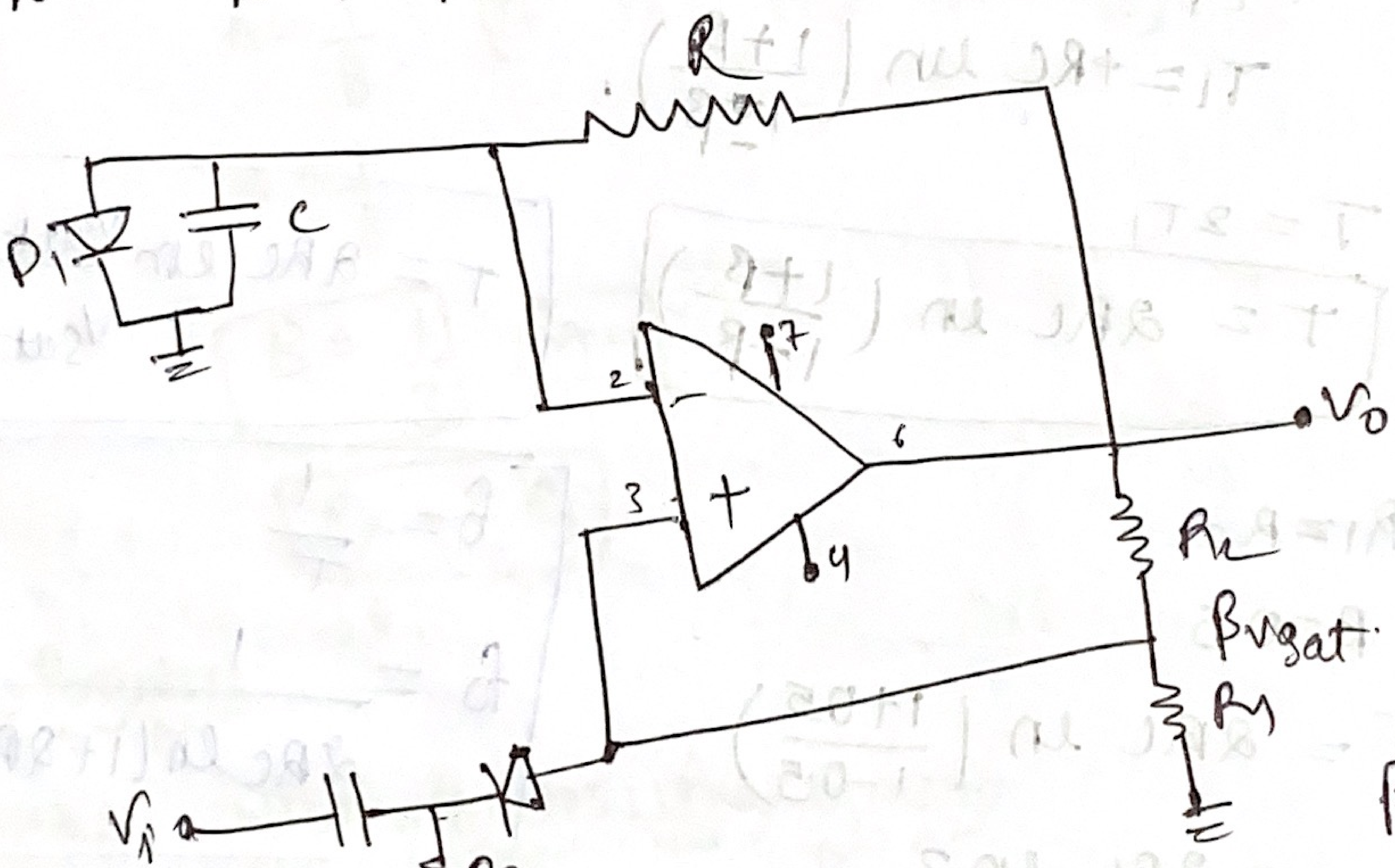
$10^{-2} \times 10^{4}$

$T = 0.99 \times 10^{-6} \times 10^{4}$

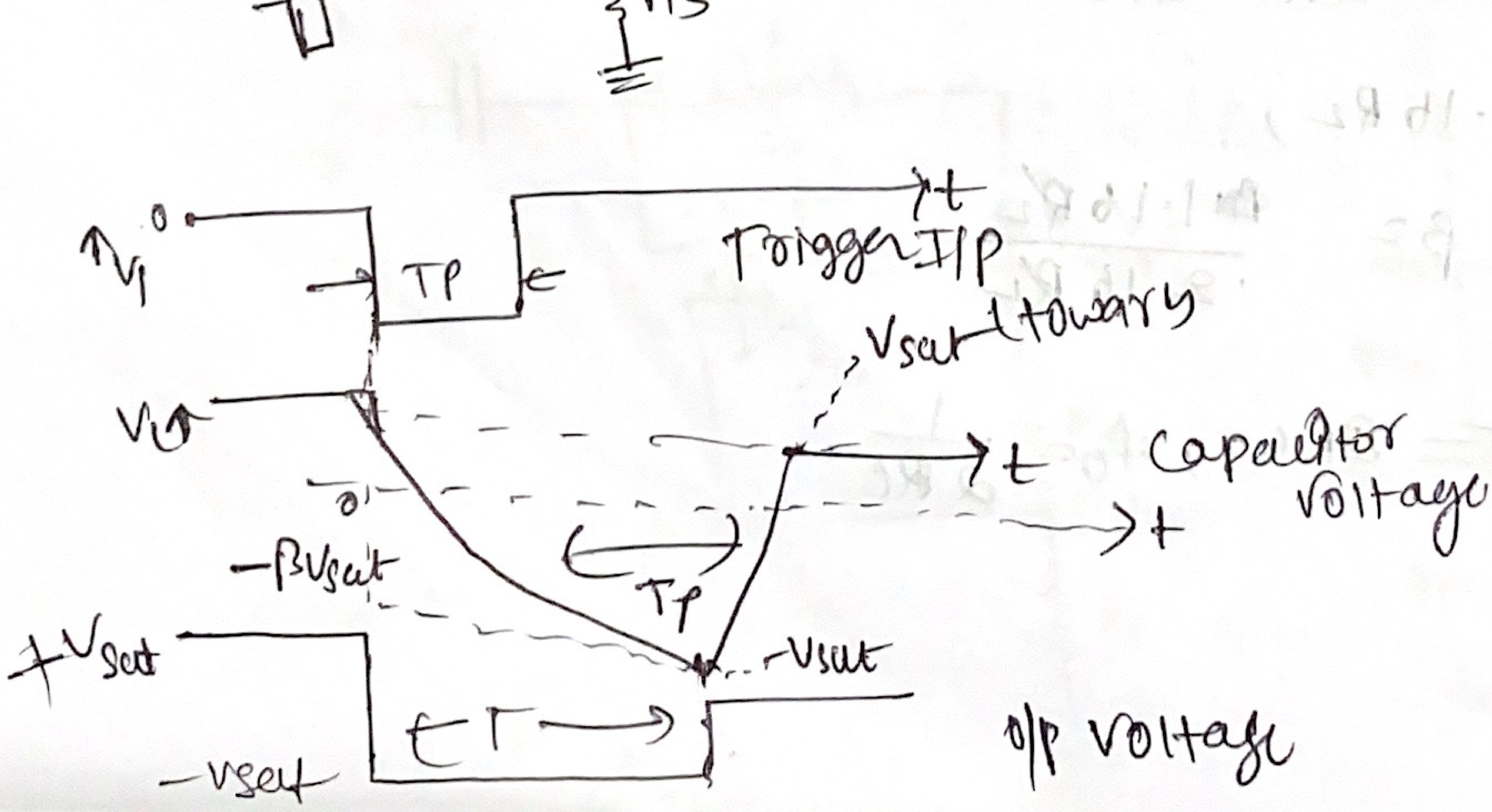
$f = \frac{1}{0.99 \times 10^{-6}}$ $T = 0.99 \times 10^{-3}$

$= \frac{10^{6}}{0.99}$ $\boxed{f = \frac{10^{3}}{0.99}} = 1\,KHz$.

Monostable Multivibrator using op-amp:



$\beta = \frac{R_1}{R_1+R_2}$.



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$V_0 = V_f + (V_i - V_f)\, e^{-t/RC}$

$V_f = -V_{sat}$

$V_i = V_D.$

$V_C \cancel{=} V_0 = -V_{sat}\ (V_D + V_{sat})\, e^{-t/RC}$

$t = T \Rightarrow V_C = -\beta V_{sat}$

$+\beta V_{sat} = \cancel{+}V_{sat}\ (V_D + V_{sat})\, e^{-T/RC}$

$\beta = (V_D + V_{sat})\ e^{-T/RC}$

$$\boxed{T = RC\ \ln\left(\frac{1 + V_D/V_{sat}}{1-\beta}\right)}$$

$V_D << V_{sat}$

$T = +RC\ \ln\left(\frac{1}{1-\beta}\right)$

$T_{discharge} = RC \ln\left(1 + \frac{R_1}{R_2}\right).$

$$\boxed{T = 0.69\ RC}$$

Q1) An op-amp Mono stable circuit is constructed using a following components $R_1 = R_2 = 30\,k\Omega$, $R = 150\,k\Omega$ $C = 1\mu F$. If op amp is supplied $\pm 12V$, and timing pulse ~~[illegible]~~ is initiates 10ms pulse calculate the circuit time period and capacitor recovery time and T b/w Tp & V's.

A) $t_p = 10\,ms$ $C = 1\mu F$ $R = 150\,k\Omega$.

$T = 0.69 \times 150 \times 10^3 \times 1 \times 10^{-6}$

$= 0.1035$

$T = 150 \times 10^3 \times 10^{-6} \ln\left(\frac{1 + \frac{0.7}{12}}{1 - \frac{1}{2}}\right)$

$= 0.15 \ln\left(\frac{1.05}{\frac{1}{2}}\right) = 0.15\ \ln(\cancel{2} 2 \times 1.05) = \cancel{0.0315}$

$= 112\,ms.$

$T_{discharge} = RC \ln\left(1 + \frac{R_1}{R_2}\right) = 103\,ms.$

$T = T_{charge} + T_{disch} = 215\,ms.$