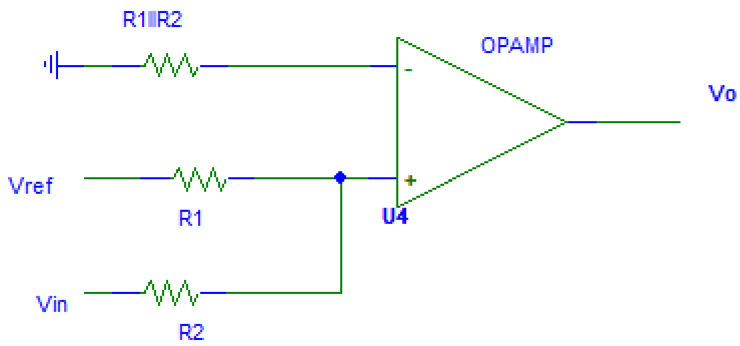
Comparator and Schmitt Trigger

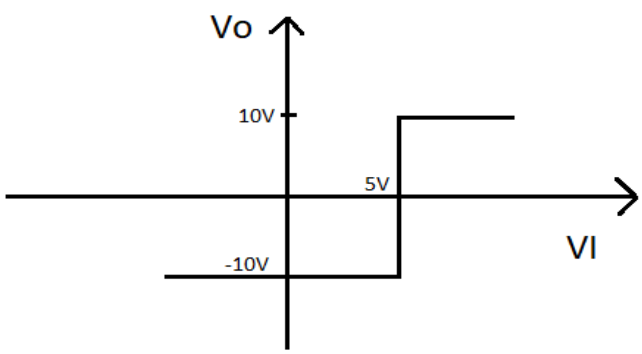
1.



Here R1 = 5k, R2 = 10k, Vref = 2V, VH=+10V and VL = -10V

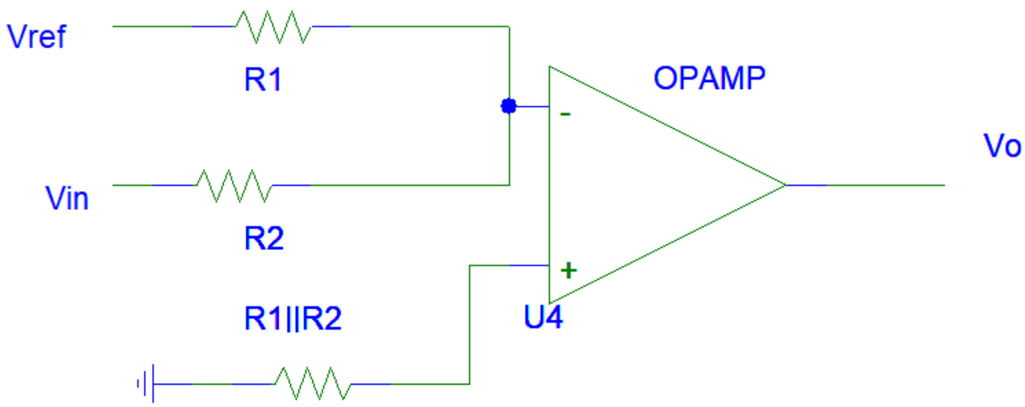
a. Draw the input and output characteristics plot for this circuit with proper labeling.
b. What is the type of this comparator? Explain your answer.

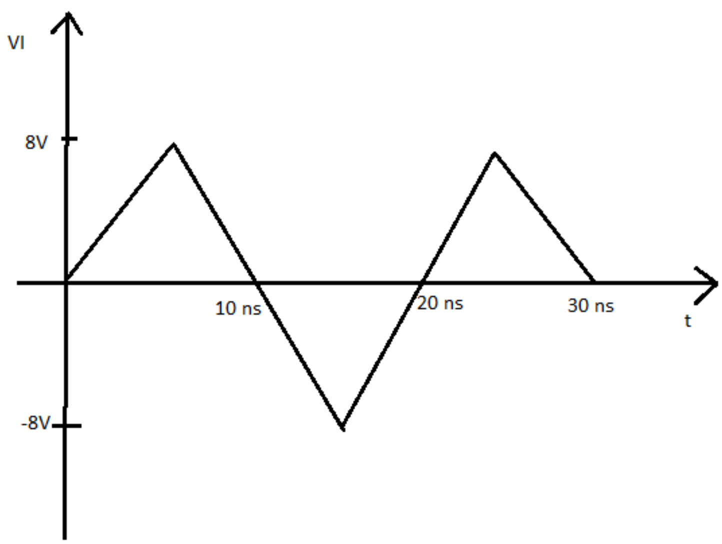
2.



Design a comparator circuit that can implement the above transfer characteristics.

3.

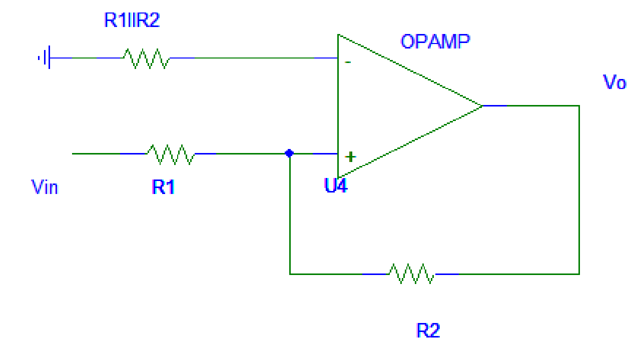


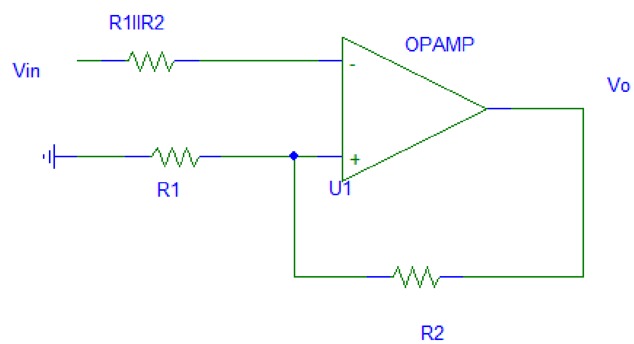


Here, R1 = 5k, R2 = 10k, Vref = 2V, VH=+10V and VL = -10V

a. Identify the type of comparator.
b. Suppose the above signal is applied to the circuit as input , what will be the output waveform? Draw the output waveform.

4.

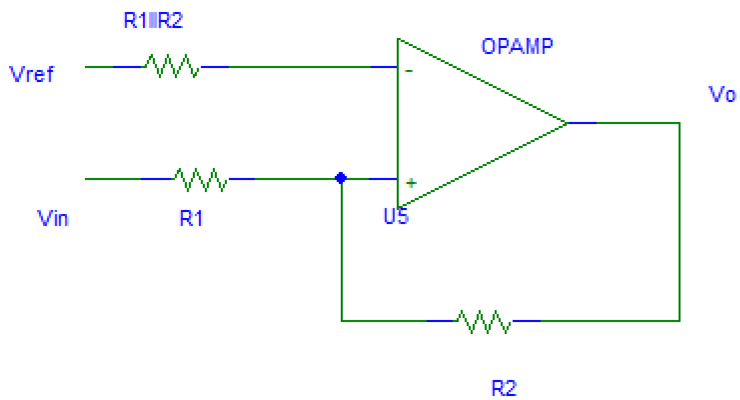


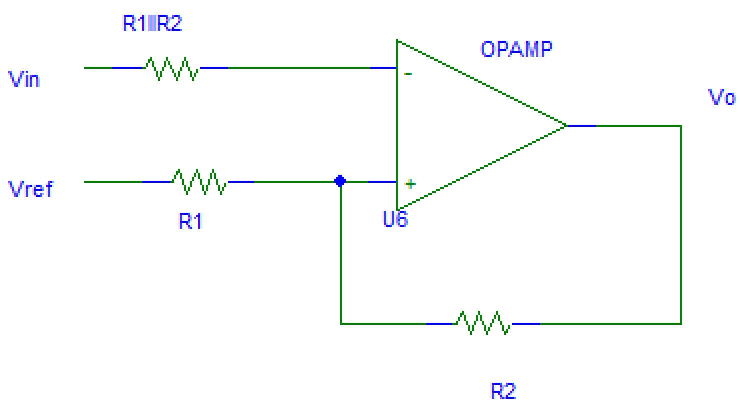


Here, R1 = 5k, R2 = 10k, Vref = 2V, VH=+10V and VL = -5V

a. Identify the type of the above schmitt trigger circuits and compare their input output characteristics.
b. What will be their higher threshold voltage, lower threshold voltage and hysteresis width?
c. Draw their transfer characteristics.
d. Is it possible to shift their center voltage from the origin with little modification of the circuits? Draw new circuits with this modification.

5.





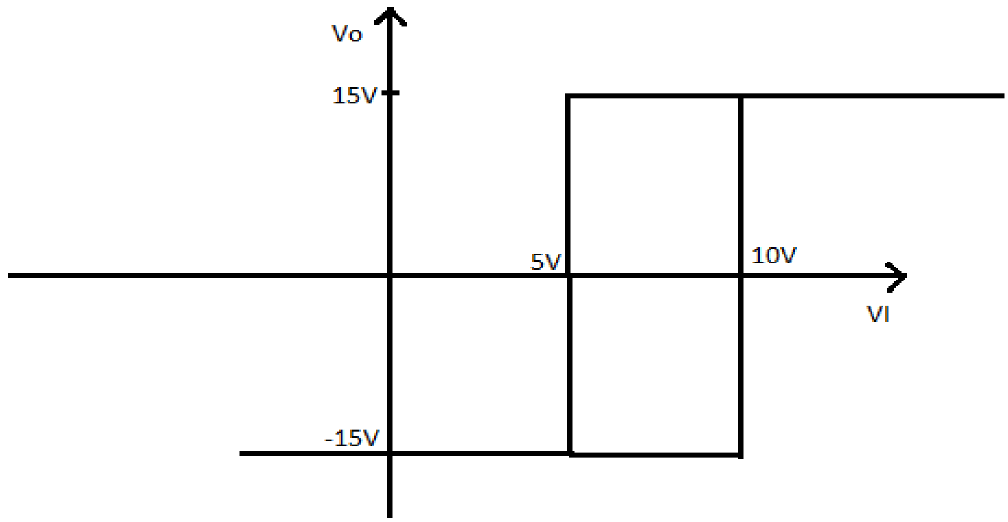
Here, R1 = 5k, R2 = 10k, Vref = 2V, VH=+10V and VL = -10V

a. Identify the type of the above schmitt trigger circuits and compare their input output characteristics.

b. What will be their higher threshold voltage, lower threshold voltage, shift voltage and hysteresis width?

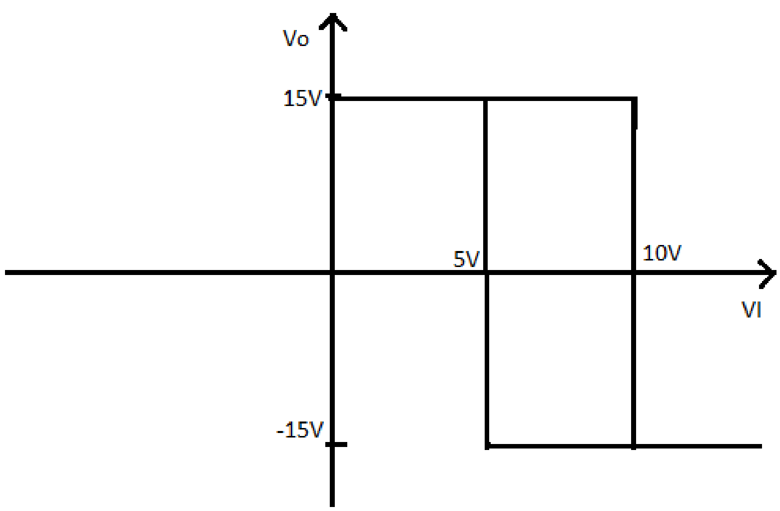
c. Draw the voltage transfer characteristics curve (V_{in} vs V_{out} plot). Clearly label the plot.

6.



a. Identify the schmitt circuit from the VTC.
b. What is the hysteresis width, Shift voltage, VH, VL , VTH and VTL from this VTC.
c. Design a schmitt trigger that will produce the same VTC.

7.



a. Identify the schmitt circuit from the VTC.
b. What is the hysteresis width, Shift voltage, VH, VL , VTH and VTL from this VTC.
c. Design a schmitt trigger that will produce the same VTC.

*8. Suppose you want to design a street light controller. You have a sensor that gives output as voltage as proportional to the light intensity. You need to switch off the light when the output of the sensor is above 5V. You need to switch on the light when the sensor output is below the 5V. (You can assume the VH and VL value)

a. **Draw** the voltage transfer characteristics curve (**V_{in} vs V_{out} plot**). Clearly **label** the plot.

b. Draw the circuit diagram that can be perfect for this specification.

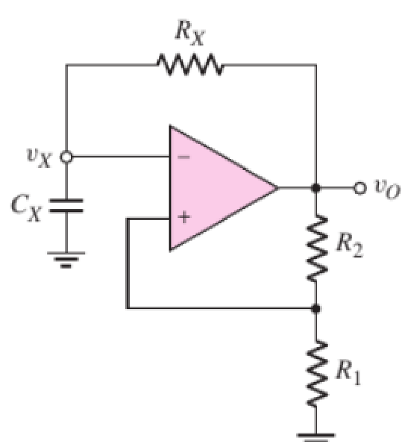
c. **Find out the parameter value of the circuit.**

9. Suppose you want to design a street light controller. You have a sensor that gives output as voltage as proportional to the light intensity. You need to switch off the light when the output of the sensor is above 5V. You need to switch on the light when the sensor output is below the 5V. There is a noise source of 1V peak-peak. Your instructor has told you to use a schmitt trigger circuit to improve performance. (You can assume the VH and VL value)

a. What VTH and VTL value can be used for this design to solve the problem of noise?
b. **Draw** the voltage transfer characteristics curve (**V_{in} vs V_{out} plot**) and clearly **label** the plot.
c. Draw the circuit diagram that can be perfect for this specification
d. Find out the parameter value of the circuit.

Square Wave Generator

1.

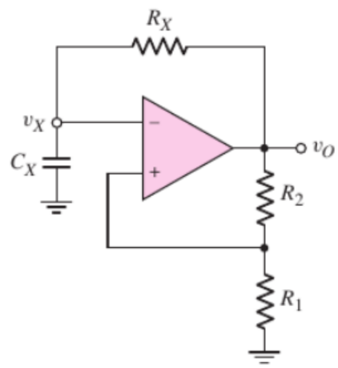


Here suppose R1 = 10k, R2 = 20k, Rx = 1k, Cx = 1 mF, VH= 10V and VL = -10 V

a. Find the period and frequency of the square wave?

b. What will be the value of the duty cycle of the square wave?
c. Draw the output waveform with proper labeling.

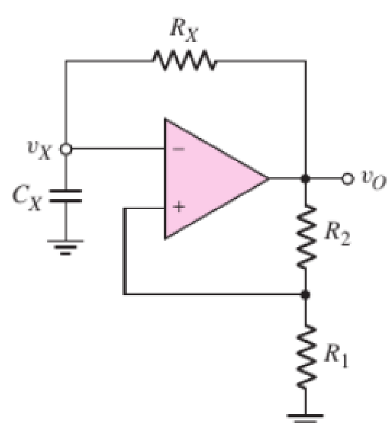
2.



Here VH = 10 V and VL = -10 V

Design the circuit so that it can generate a square wave with 1 kHz frequency and 50% duty cycle.

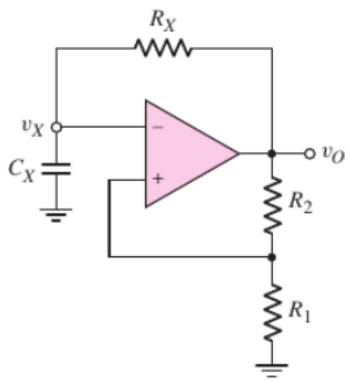
3.



suppose R1 = 10k, R2 = 20k, Rx = 1k, Cx = 1 mF

Design the circuit so that it can generate square wave with a 30% duty cycle. Find the frequency of your designed circuit.

4.

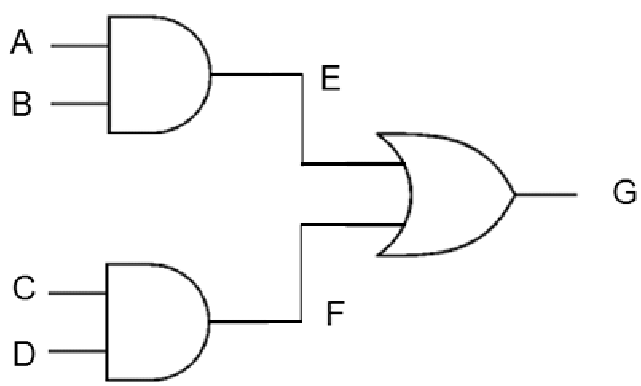


Here suppose R1 = 10k, R2 = 20k, Rx = 1k, Cx = 1 mF, VH = 10V and VL = -5V

Find out the duty cycle of inverted output signal of the above circuit.

CMOS logic design

1. Design a CMOS logic circuit to implement the given compound gate in Figure below. First derive the logical expression of output Y and then design the CMOS network.



2. a) Design a static CMOS logic circuit that implements the logic function Y= AB
   b) Design a static CMOS logic circuit that implements the logic function Y= (A+B)
3. Design a static CMOS logic circuit that will implement the following logic
   a. NAND gate ($Y = \overline{AB}$)
   b. XOR gate ($Y = A\overline{B} + \overline{A}B$)
3. Design a static CMOS logic circuit that will implement the following logic
   a. NOR gate ($Y = \overline{A + B}$)
   b. XNOR gate ($Y = AB + \overline{AB}$)
4. Design static CMOS circuit for the following expression,
   a. Y = AB + CD

b. Y = AB +C
c. Y = (A+B)C
d. Y = (A+B)(C+D)
e. Y = $\overline{AB + CD}$
f. Y = $\overline{AB + C}$
g. Y = $\overline{(A + B)C}$
h. Y = $\overline{(A + B)(C + D)}$
i. $Y = \bar{A} + \bar{B} + \bar{C}$

5.

Truth Table

Input A	Input B	Output
0	0	1
0	1	0
1	0	0
1	1	1

Design a static CMOS logic circuit that will implement the above truth table.

Comparator and Schmitt Trigger

1. a) Here, $V_- = 0$

$$V_+ = V_{REF} \times \frac{R2}{R1+R2} + V_I \times \frac{R1}{R1+R2}$$

$$= 2 \times \frac{10}{10+5} + V_I \times \frac{5}{5+10}$$

$$V_+ = \frac{4}{3} + \frac{V_I}{3}$$

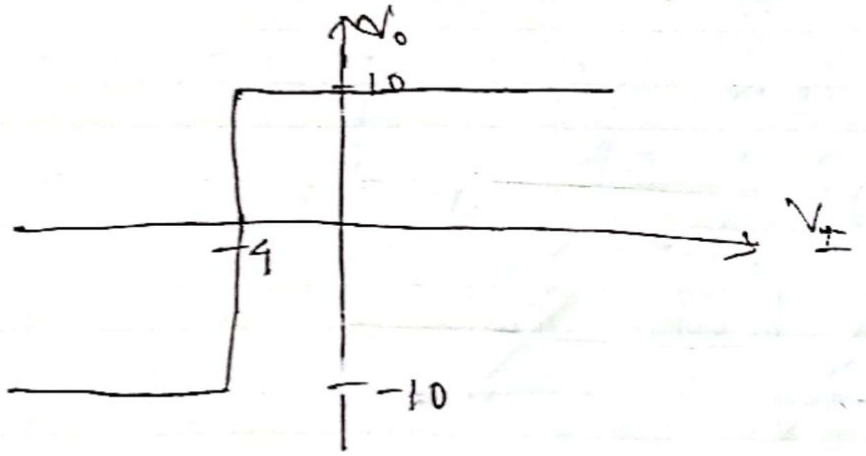
We know, $V_0 = V_H = 10V$

if, $V_I > -\frac{R2}{R1} V_{REF}$

$\Rightarrow V_I > -\frac{10}{5} \times 2$

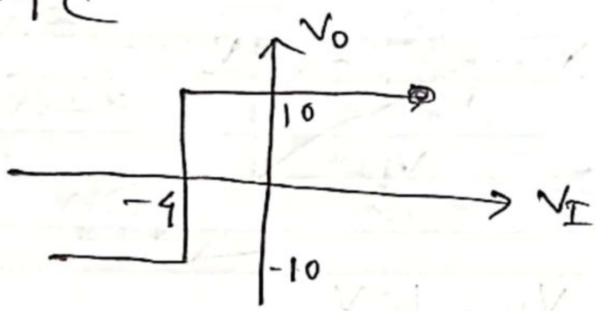
$\Rightarrow V_I > -4 \longrightarrow V_0 = 10V$

So, $V_I < -4 \longrightarrow V_0 = -10V$



1.b) This is a non-inverting comparator as the input is applied to the positive terminal.

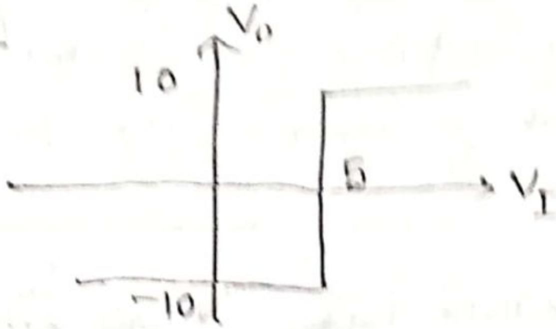
VTC



From the graph if V_I is high V_o is also high
if V_I is low V_o is low

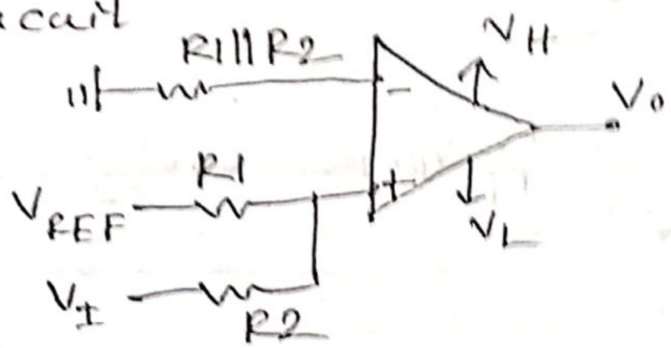
This is the characteristics of non-inverting comparator

2. (a)



This is a non-inverting comparator with Vref

Circuit



Now, From the VTC, $V_H = +10V$

$V_L = -10V$

$$V_{Threshold} = 5 = -\frac{R2}{R1} V_{REF}$$

Suppose, $R1 = R2 = 10k\Omega$

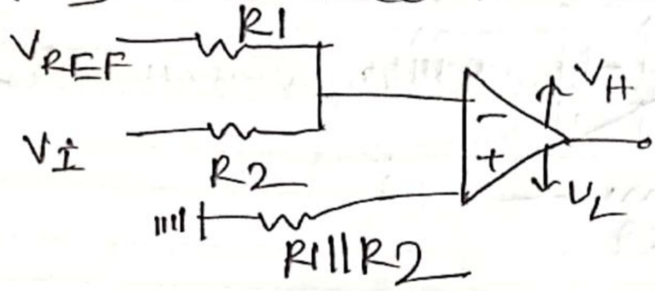
$$\therefore \quad 5 = -\frac{10}{10} V_{REF}$$

$$\therefore V_{REF} = -5V$$

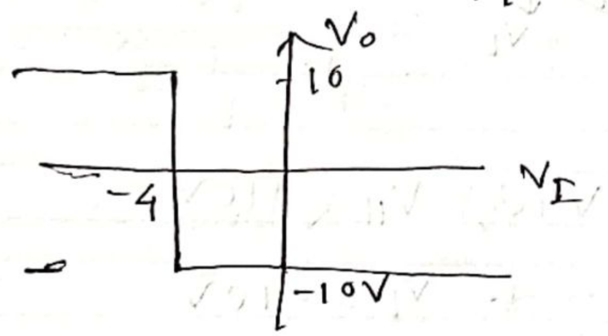
$\therefore V_H = +10V, \quad V_L = -10V, \quad R1 = R2 = 10k\Omega, V_{REF} = -5V$

3. a) This is a inverting comparator with V_{REF} as input is connected to negative terminal.

3. b) We need to know the VTC first,

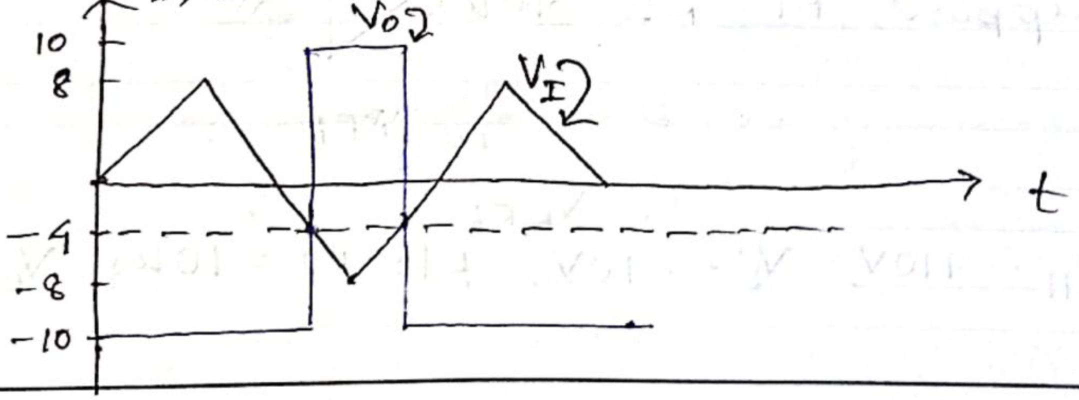


$$V_{threshold} = -\frac{R_2}{R_1} V_{REF} = -\frac{10}{5} \times 2 = -4V$$



if, $V_I > -4V$, $V_o = -10V$

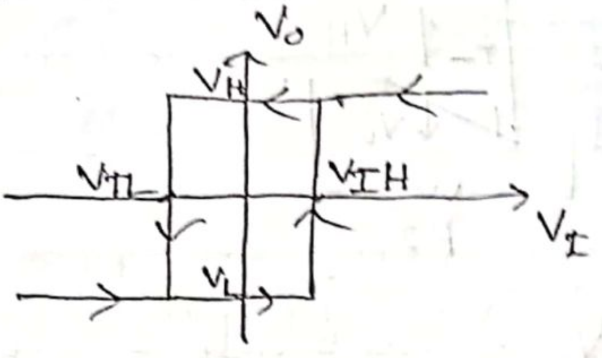
$V_I < -4V$, $V_o = +10V$



Output will be a square wave.

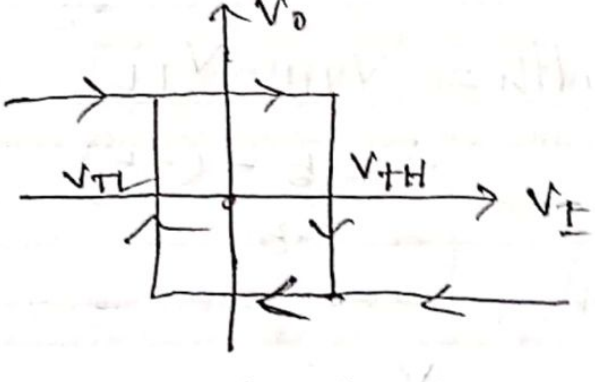
4.a) First circuit is non-inverting Schmitt triger.

VTC,



b) 2nd circuit is inverting schmitt triger,

VTC

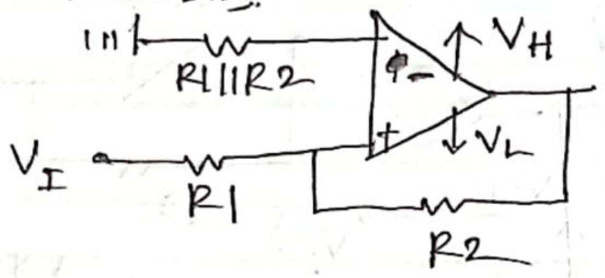


Their input output characteristics is inverse.

b) Given, $R1 = 5k$, $R2 = 10k$, $V_{REF} = 2V$

$V_H = 10V$, $V_L = -5V$

For circuit 1,



$$V_{TH} = -\frac{R1}{R2} V_L = -\frac{5}{10} \times -5 = 2.5V$$

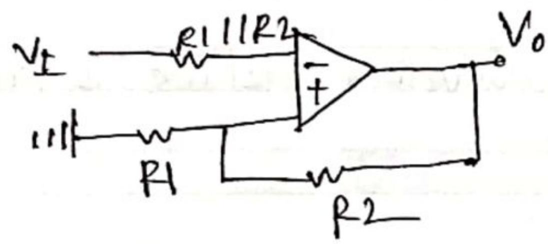
$$V_{TL} = -\frac{R1}{R2} V_H = -\frac{5}{10} \times 10 = -5V$$

Hysteresis width $= V_{TH} - V_{TL}$

$= 2.5 - (-5)$

$= 7.5$

For circuit 2,

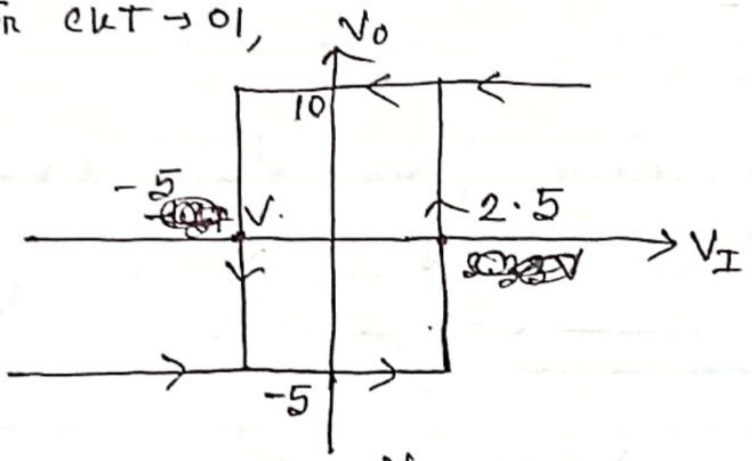


$$V_{TH} = V_H \times \frac{R1}{R1+R2}$$
$$= 10 \times \frac{5}{5+10}$$
$$= 3.33\,V$$

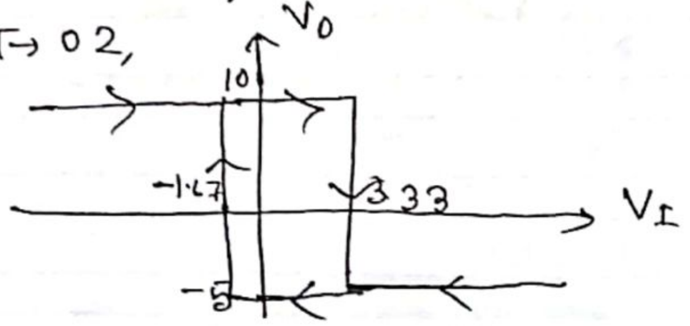
$$V_{TL} = V_L \times \frac{R1}{R1+R2}$$
$$= -\cancel{15}\,5 \times \frac{5}{5+10}$$
$$= -1.67\,V$$

$$\text{Hysteresis width} = V_{TH} - V_{TL}$$
$$= 3.33 - (-1.67) = 5\,V$$

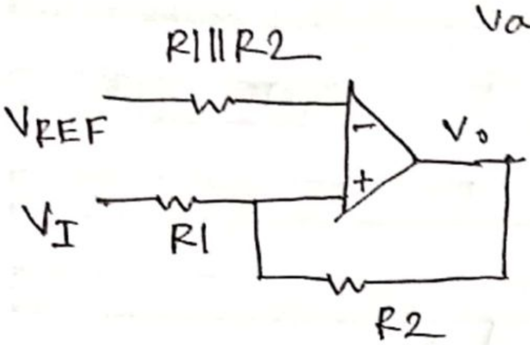
c) For ckt → 01,

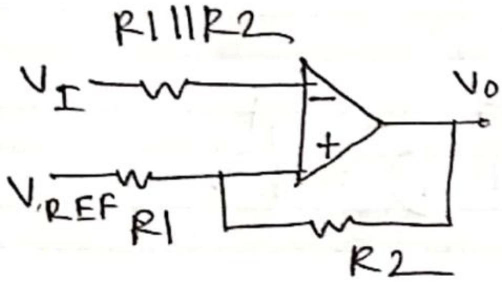


For ckt → 02,



d) If we can add V_{ref}, center voltage will shift. In another way we can use different value V_H and V_L.

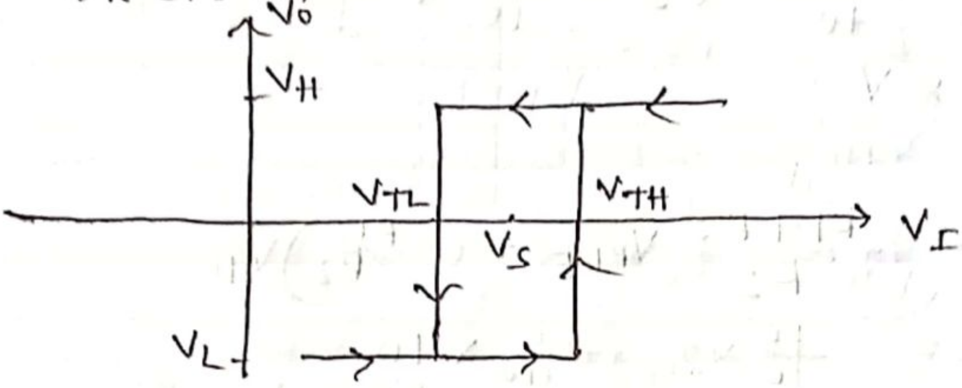




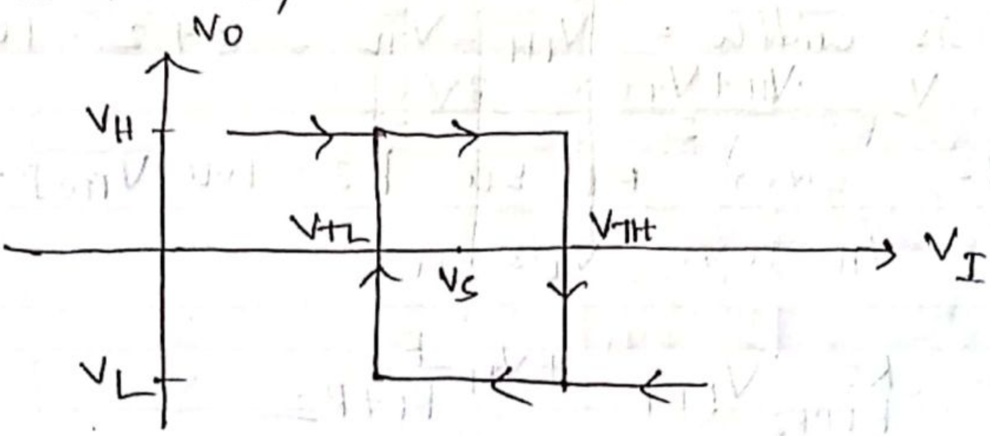
5. a) Circuit 1, is the non-inverting schmitt trigger circuit with reference voltage

Circuit 2, is the inverting schmitt trigger circuit with reference voltage.

For CKT→01,



For CKT→02,



5.b)

For CKT 1, given, $R1 = 5k$, $R2 = 10k$, $V_{REF} = 2V$

$V_H = 10V$, $V_L = -10V$

$$V_{TH} = \frac{R1+R2}{R2} V_{REF} + \left(-\frac{R1}{R2}\right) V_L$$

$$= \frac{15}{10} \times 2 - \frac{5}{10} \times -10$$

$$= 8V$$

$$V_{TL} = \frac{R1+R2}{R2} V_{REF} + \left(-\frac{R1}{R2}\right) V_H$$

$$= \frac{15}{10} \times 2 - \frac{5}{10} \times 10$$

$$= -2V$$

Hysteresis width $= V_{TH} - V_{TL} = 8+2 = 10V$

$$V_S = \frac{V_{TH} + V_{TL}}{2} = 3V$$

For CKT 2, given, $R1 = 5k$, $R2 = 10k$, $V_{REF} = 2V$

$V_H = 10V$, $V_L = -10V$

$$V_{TH} = \frac{R2}{R1+R2} V_{REF} + V_H \frac{R1}{R1+R2}$$

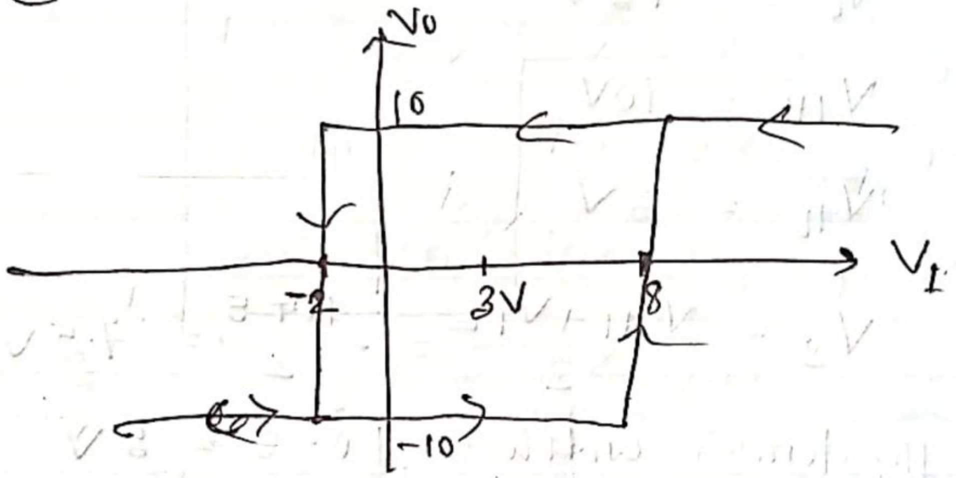
$$= \frac{10}{15} \times 2 + 10 \times \frac{5}{10}$$

$$= 6.33V$$

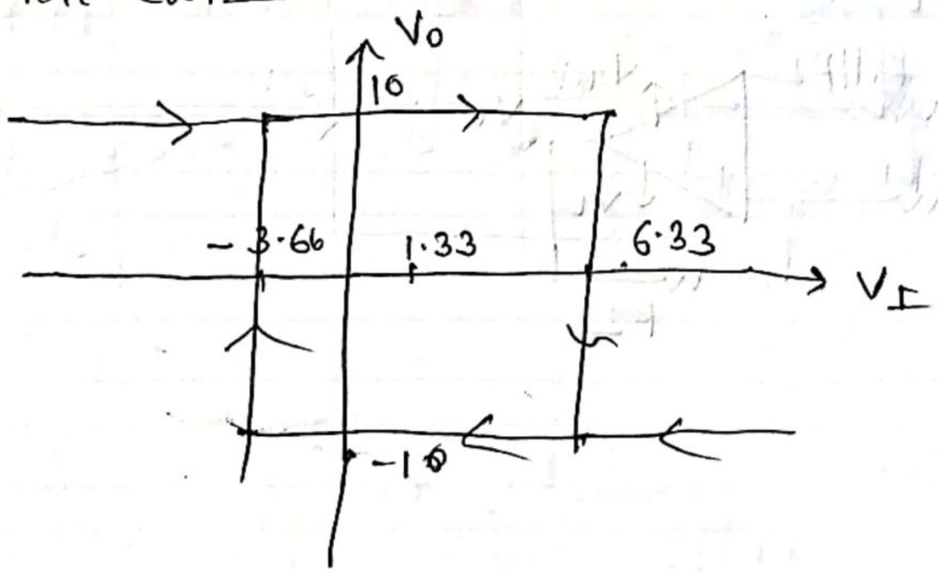
$$V_{TL} = \frac{R2}{R1+R2} V_{REF} + V_L \frac{R1}{R1+R2} = -3.66V$$

$$\text{Hysteresis width} = 6.33 + 3.66$$
$$= 10V$$
$$V_S = \frac{6.33 + (-3.66)}{2} = 1.33V$$

5. (a) For CKT1,



For CKT2



6. a) This is a non-inverting schmitt trigger circuit

6. b) From the graph,

$$V_H = +15V$$

$$V_L = -15V$$

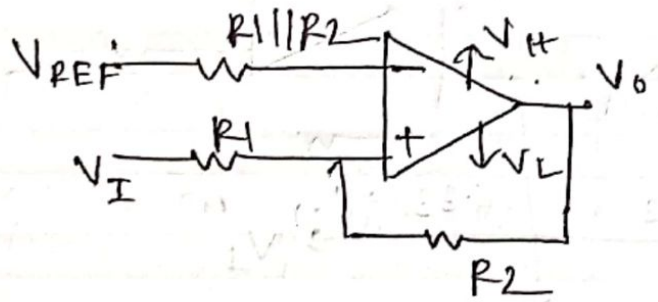
$$V_{TH} = 10V$$

$$V_{TL} = 5V$$

$$V_S = \frac{V_{TH} + V_{TL}}{2} = \frac{10+5}{2} = 7.5V$$

Hysteresis width $= 10 - 5 = 5V$

6. c) Circuit



$V_H = +15V$ and $V_L = -15V$, These two are from graph.

$$V_{TH} = \frac{R1+R2}{R2} V_{REF} + \left(-\frac{R1}{R2}\right) V_L$$

$$V_{TL} = \frac{R1+R2}{R2} V_{REF} + \left(-\frac{R1}{R2}\right) V_H$$

$$V_S = \frac{V_{TH} + V_{TL}}{2}$$

$$\therefore V_S = \frac{R1+R2}{R2} V_{REF} \longrightarrow (1)$$

$$V_{Hysteresis} = V_{TH} - V_{TL} = \frac{R1}{R2}(V_H - V_L) \rightarrow (II)$$

From graph, $V_S = \frac{5+10}{2} = 7.5$

$V_{Hysteresis} = 10 - 5 = 5$

Suppose, $R1 = 10k\Omega$,

From, (1), $5 = \frac{10k}{R_2}(15+15)$

$R2 = \cancel{40k}\ 60k$

From, (2), $\cancel{V_{REF}}$ $7.5 = \frac{\cancel{50}\ 70}{40} \times V_{REF}$

$\therefore V_{REF} = \cancel{6}\ 4.29V$

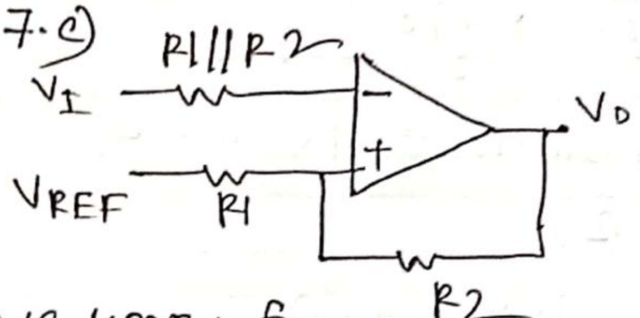
7 a) This is inverting schmitt trigger with V_{REF}.

7.b

$$V_H = 15V,$$
$$V_L = -15V$$

$$V_{TH} = +10V$$
$$V_{TL} = +5V$$
$$V_{Hysteresis} = V_{TH} - V_{TL} = 5V$$
$$V_S = \frac{V_{TH} + V_{TL}}{2} = \frac{10+5}{2} = 7.5$$

7.c)



$$V_S = V_{REF} \times \frac{R2}{R1+R2} \rightarrow (i)$$

$$V_{Hysteres} = (V_H - V_L)\frac{R1}{R1+R2} \rightarrow (ii)$$

we know, from graph

$V_S = 7.5V$

$V_{Hyster} = 5V$

From, (ii), $5 = (15+15)\dfrac{R1}{R1+R2}$

$$\frac{R1}{R1+R2} = \frac{1}{6} \Rightarrow \frac{R1}{R2} = \frac{1}{5}$$

Now suppose, $R1 = 1k\Omega$,

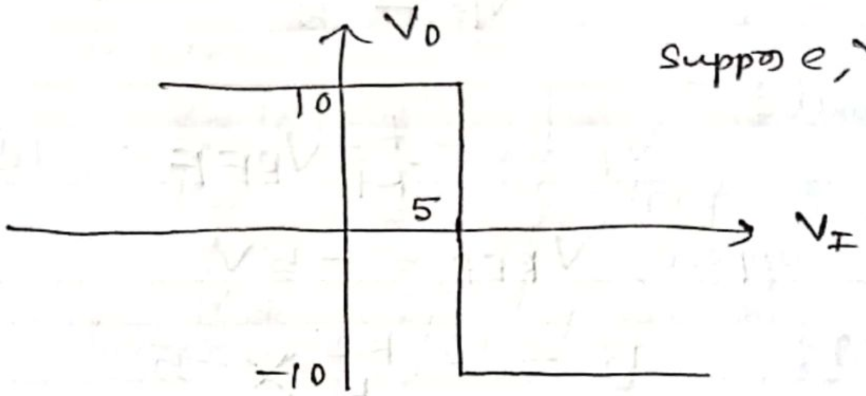
then, $\frac{1k}{R_2} = \frac{1}{5}$

$R2 = 5k\Omega$

From ①, $7.5 = V_{REF} \times \frac{5}{1+5}$

$\Rightarrow V_{REF} = +6V$

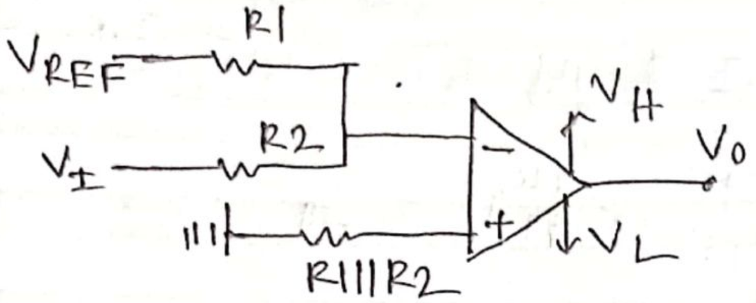
8. a)



suppose, $V_H = 10V$,
$V_L = -10V$

8.b) There ~~are~~ is single transition point, and input output is inverse.

Inverting comparator with V_{REF} can be used



8.c) From 8(a), $V_H = +10V$

$V_L = -10V$

$V_T = 5$

Formula,

$$V_T = -\frac{R2}{R1} V_{REF} \longrightarrow (1)$$

Suppose, $V_{REF} = -5V$,

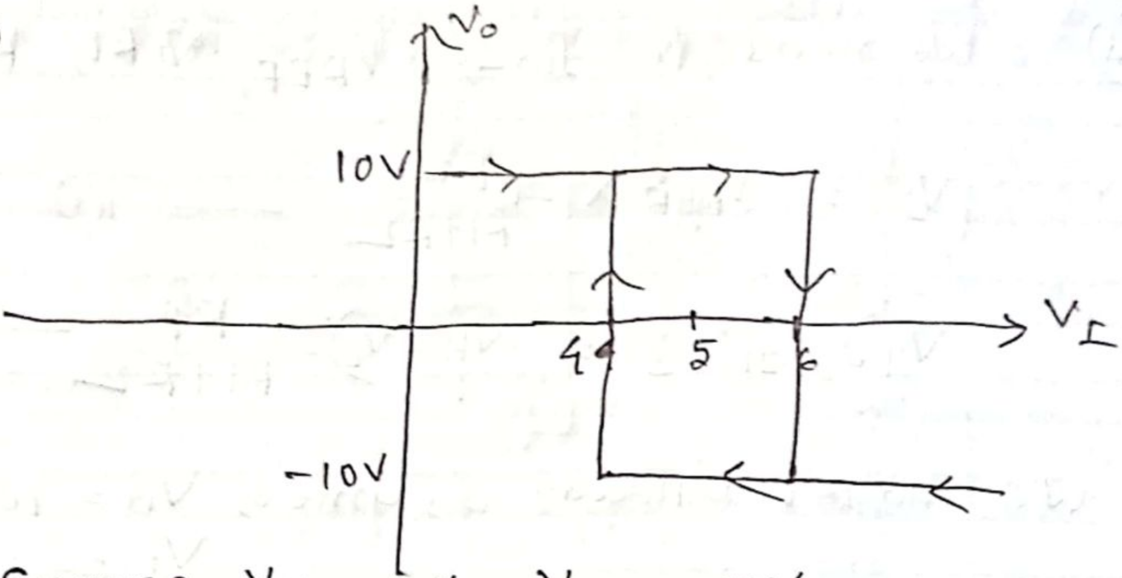
From (1), $5 = -\frac{R2}{R1} \times -5$

$$\frac{R2}{R1} = 1.$$

If, $R1 = 10K$,

$R2 = 10K$

9. a)

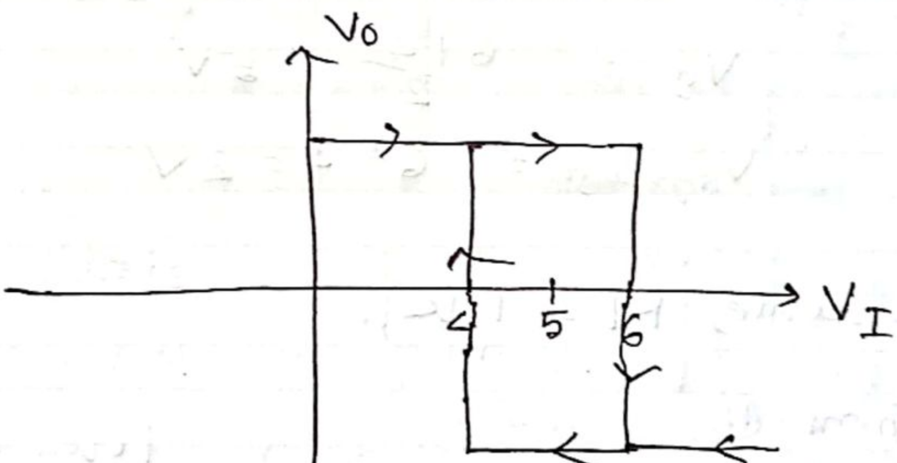


Suppose, $V_H = +10V$, $V_L = -10V$,

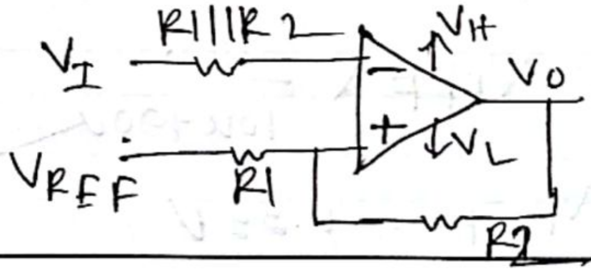
$V_{TL} = 5 - 1 = 4V$,

$V_{TH} = 5 + 1 = 6V$

9. b)



9. c) Inverting schmitt trigger with V_{REF} can be used,



9.d) We need to find, V_{REF}, R1, R2

$$V_S = V_{REF} \times \frac{R2}{R1+R2} \quad \text{——— (i)}$$

$$V_{Hysteresis} = (V_H - V_L)\frac{R1}{R1+R2} \quad \text{——— (ii)}$$

We have already assumed, $V_H = 10V$,
$V_L = -10V$

From Specification,

$$V_{TH} = 5+1 = 6V$$

$$V_{TL} = 5-1 = 4V$$

$$V_S = \frac{6+4}{2} = 5V$$

$$V_{Hyster} = 6-4 = 2V$$

Now assume, $R1 = 10k$,

From (ii),

$$2 = (10+10)\frac{10k}{10k+R2}$$

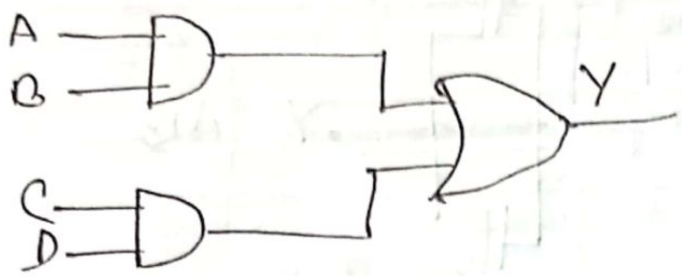
$$R2 = 90k$$

From (i), $5 = V_{REF} \times \frac{90k}{10k+90k}$

$$V_{REF} = 5.55V$$

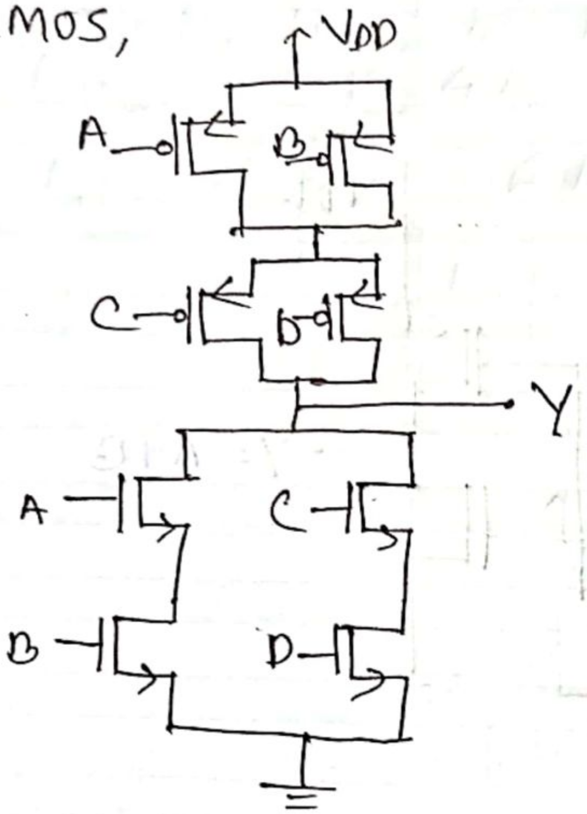
CMOS logic design

1.

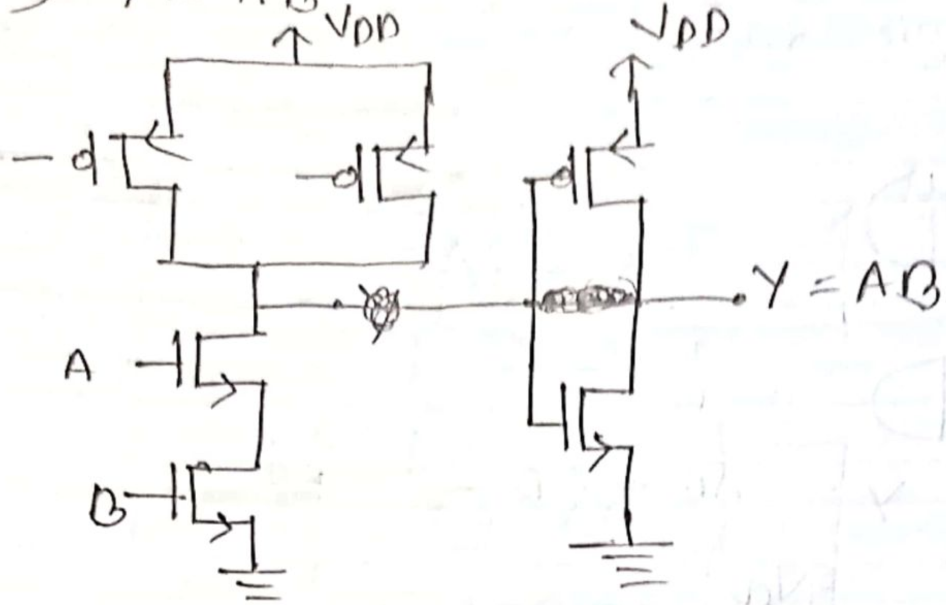


$Y = AB + CD$

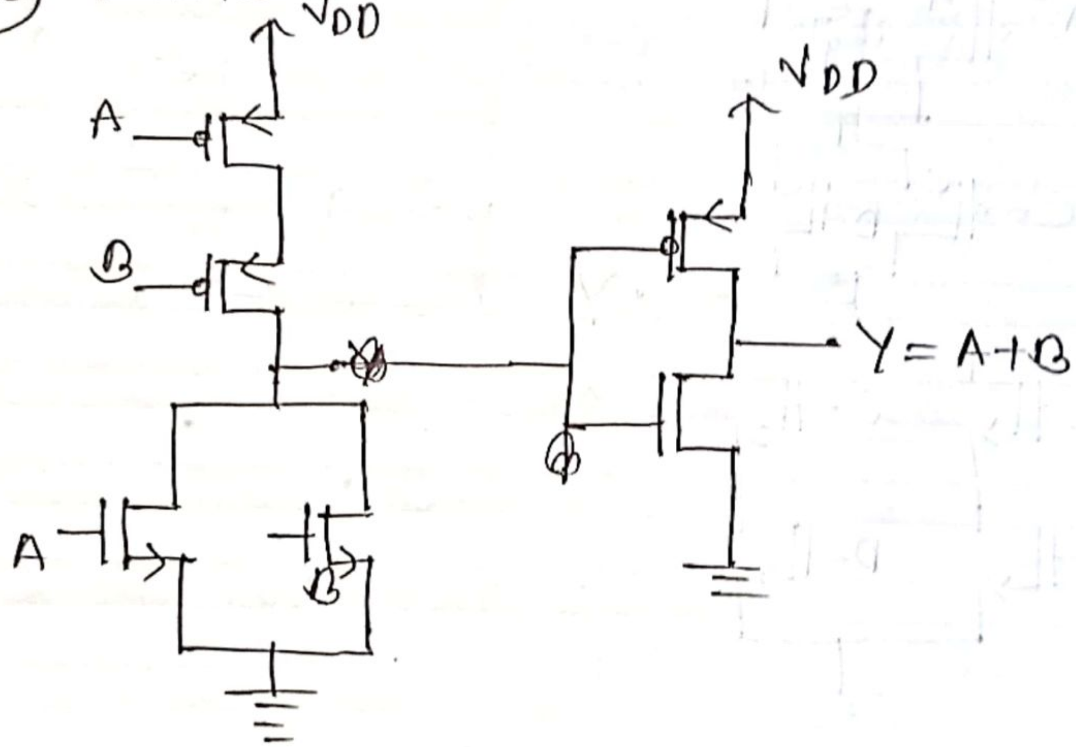
CMOS,



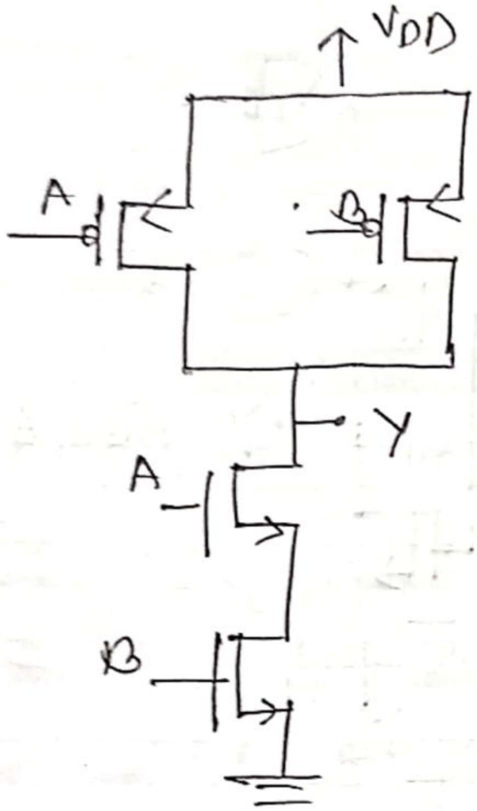
2. a) $Y = AB$



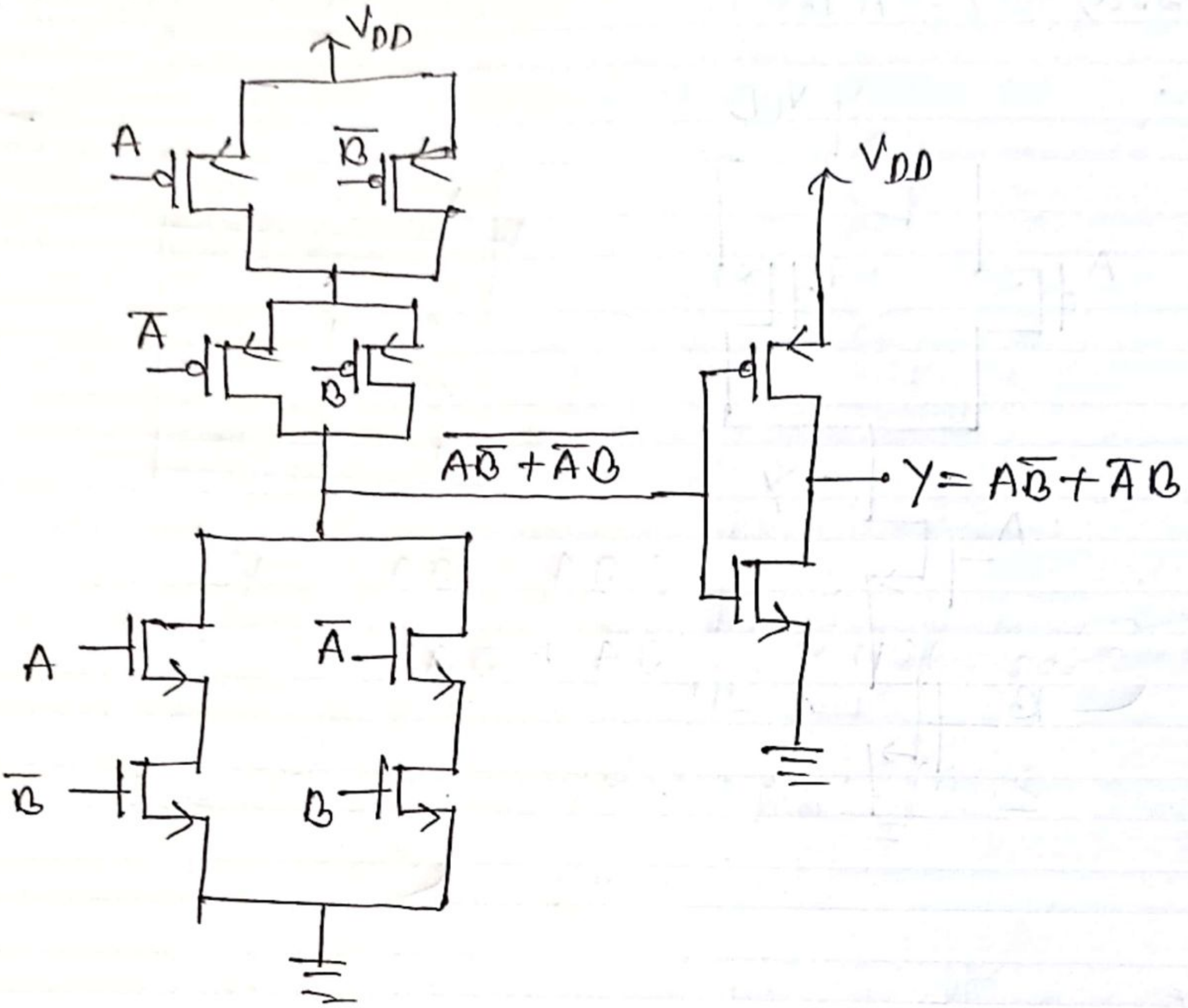
2. b) $Y = A+B$



3. a) $Y = \overline{AB}$



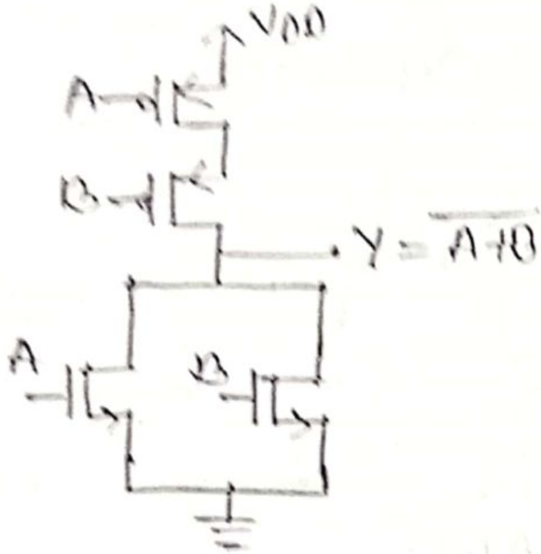
8. b) $Y = A\overline{B} + \overline{A}B$



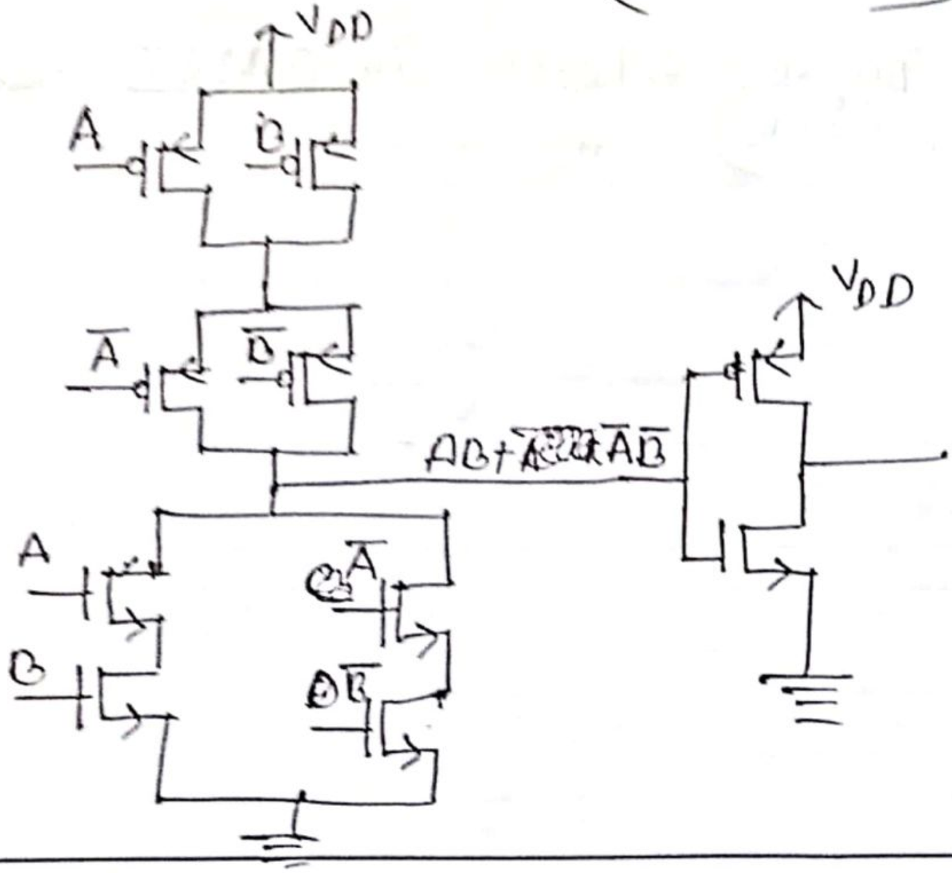
web: www.ulkasemi.com
e-mail: info@ulkasemi.com

[2 number is term]

3. a) $Y = \overline{A+B}$



3 $Y = AB + \overline{A}\,\overline{B}$ (connection)



4. Try Yourself

5.

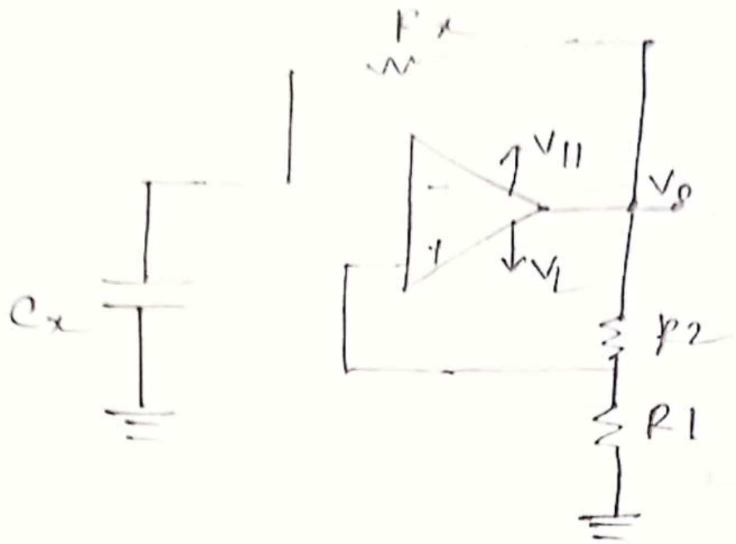
A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

$$Y = \overline{A}\overline{B} + AB$$

$$= AB + \overline{A}\overline{B} \quad (\text{XNOR Gate})$$

See previous solution for CMOS (3(b))

Square Wave Generation



$$V_{TH} = V_H \frac{R1}{R1+R2}, \quad V_{TL} = V_L \frac{R1}{R1+R2}$$

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

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

1. a) $R1 = 10k$, $R2 = 20k$, $R_x = 1k$, $C_x = 1mF$,

$$V_H = +10V, \quad V_L = -10V$$

$$V_{TH} = V_H \times \frac{R1}{R1+R2}$$

$$= 10 \times \frac{10}{10+20} = 3.33$$

$$V_{TL} = V_L \times \frac{R1}{R1+R_2} = -3.33$$

$$\tau = R_x C_x = 1k \times 1m = 1s$$

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

$$= 1 \times \ln \frac{10-(-3.33)}{10-3.33}$$

$$= 0.69 s$$

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

$$= 1 \times \ln \frac{-10-3.33}{-10-(-3.33)}$$

$$= 0.69 s.$$

$$T = T_1 + T_2 = 0.69 + 0.69 = 1.38 s$$

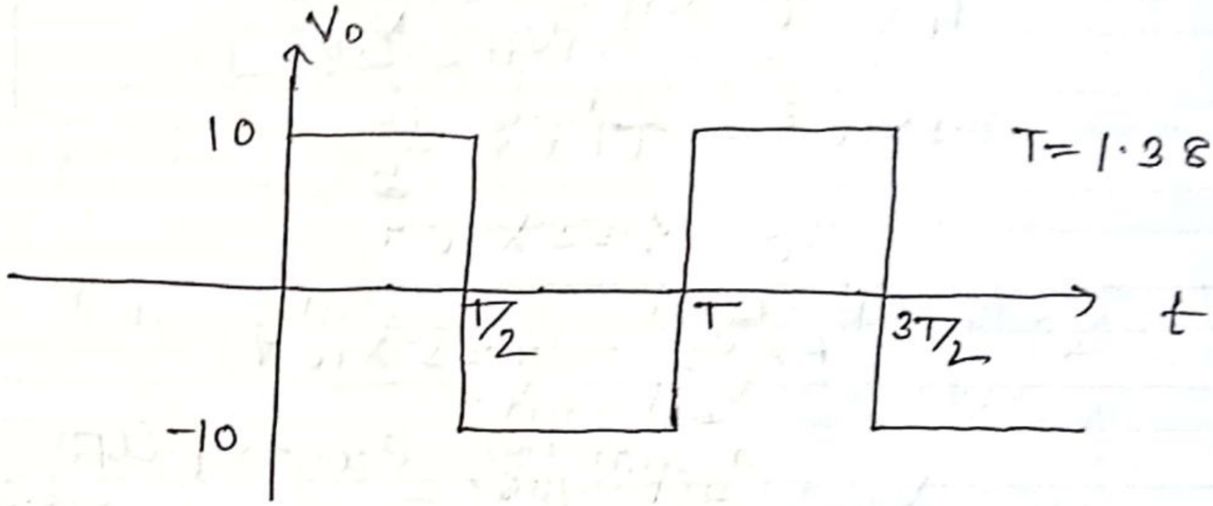
$$f = \frac{1}{T} = 0.72 \text{ Hz}$$

1. b) Duty cycle $= \frac{T_1}{T_1+T_2} \times 100\%$

$= \frac{0.69}{0.69+0.69} \times 100\%$

$= 50\%$

1. c)



T = 1.38 sec

2. $V_H = 10V$, $V_L = -10V$

Assuming, $R_1 = R_2 = 10k\Omega$

$V_{TH} = V_H \times \frac{R_1}{R_1+R_2} = 5V$

$V_{TL} = V_L \times \frac{R_1}{R_1+R_2} = -5V$

given, $f = 1kHz$, $T = \frac{1}{f} = 1ms$

Duty cycle = 50% and, $T = T_1 + T_2$

$$\therefore \frac{T_1}{T_1+T_2} = 0.5, \Rightarrow T_1 = T_2 = T/2$$

$$= 0.5\times10^{-3}$$

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

$$0.5\times10^{-3} = \tau \ln \frac{15}{5}$$

$$\tau = 4.55\times10^{-4}$$

$$R_x C_x = 4.55\times10^{-4}$$

assuming, $C_x = 1\mu F$

$$R_x = \frac{4.55\times10^{-4}}{C_x}$$

$$= 455\Omega$$

3. $\tau = R_x C_x = 1k \times 1mF = 1s$

$$\frac{t_1}{t_1+t_2} = 0.3 = \frac{3}{10}$$

$$\frac{t_1}{t_2} = \frac{3}{7}$$

$$t_1 = \tau \ln \frac{V_H - V_{TL}}{V_H - V_{TH}}$$

Assuming $R1 = R2 = 10$

$$t_1 = \tau \ln \frac{V_H - V_L \frac{R_1}{R_1+R_2}}{V_H - V_H \frac{R_1}{R_1+R_2}}$$

$$t_1 = \tau \ln \frac{V_H - V_L/2}{V_H - V_H/2}$$

$$t_1 = \tau \ln \frac{2V_H - V_L}{V_H}$$

$$t_2 = \tau \ln \frac{V_L - V_{TH}}{V_L - V_{TL}}$$

$$= \tau \ln \frac{V_L - V_H/2}{V_L/2}$$

$$t_2 = \tau \ln \frac{2V_L - V_H}{V_L}$$

Now, $7T_1 = 3T_2$

$$\Rightarrow 7 \ln \frac{2V_H - V_L}{V_H} = 3 \ln \frac{2V_L - V_H}{V_L}$$

suppose, $V_H = 10V$,

Find $V_L = ?$ -2.24 (use calculator solve eqn)

4. $\tau = R_x C_x = 1s$

$V_H = +10V$, $V_L = -5V$

$$V_{TH} = V_H \frac{R1}{R1+R2} = 10 \times \frac{10}{10+20} = 3.33$$

$$V_{TL} = V_L \frac{R1}{R1+R2} = -5 \times \frac{10}{10+20} = -1.67$$

$$T_1 = \tau \times \ln \frac{V_H - V_{TL}}{V_H - V_{TH}}$$

$$= 1 \times \ln \frac{10 - (-1.67)}{10 - 3.33} = 0.559,$$

$$T_2 = \tau \ln \frac{V_L - V_{TH}}{V_L - V_{TL}} = 1 \times \ln \frac{-5 - 3.33}{-5 - (-1.67)}$$

$= 0.91$ sec

$$\text{Duty cycle} = \frac{T_1}{T_1 + T_2} \times 100\% = 37.9\%$$