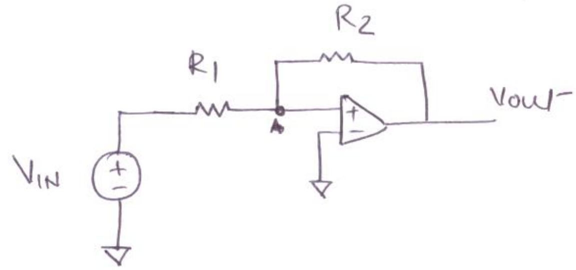
1.



$R_2 = 10k \quad R_1 = 100\,\Omega$

$$V_+ = V_{IN}\frac{R_2}{R_1+R_2} + V_{out}\frac{R_1}{R_1+R_2} \quad \text{-- (1)}$$

If circuit is in positive stable state ($V_{out} = L_+$), V_{in} must be made negative to trigger it to ($V_{out} = L_-$) state. For such value of V_{in} ; $V_+ = 0$. Thus putting $V_{out} = L_+ = 15$ in equn (1)

$$0 = V_{in}\frac{10000}{10100} + 15\cdot\frac{100}{10100}$$

$$\Rightarrow V_{in} = -\frac{1500}{10000} = -0.15\ V = V_{TL} \quad \text{-- (2)}$$

similarily for getting V_{TH}, we put $V_{out} = L_- = -15$ V in equn (1)

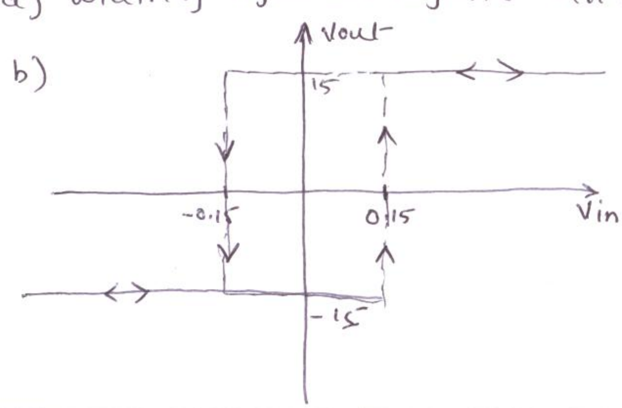
$$0 = V_{in}\cdot\frac{10000}{10100} - 15\cdot\frac{100}{10100}$$

$$\Rightarrow V_{in} = +0.15\ V = V_{TH} \quad \text{--- (3)}$$

Hence

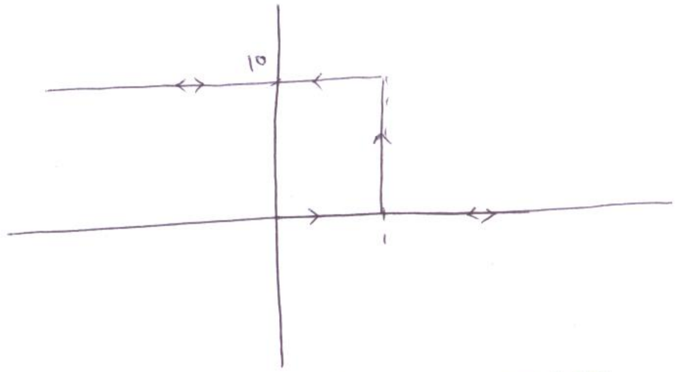
a) width of hysteresis region = $V_{TH} + V_{TL}$ = 0.3 V

b)

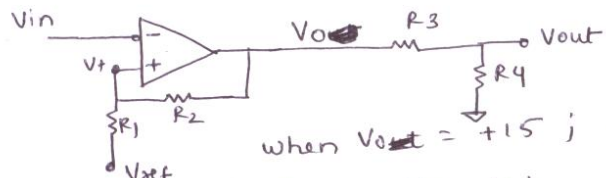


Transfer charecteristics,

2.



It is an inverting comparator



when $V_o = +15$; $V_{in} = V_{TH}$ will flip it to -15

Given $V_{TH} = 1$

$$\Rightarrow \quad \frac{V_o - V_+}{R_2} = \frac{V_+ - V_{ref}}{R_1}$$

$$\Rightarrow \quad \frac{15 - 1}{R_2} = \frac{1 - V_{ref}}{R_1} \quad \Rightarrow \quad \frac{14}{1 - V_{ref}} = \frac{R_2}{R_1} \quad \text{-- 1)}$$

when $V_o = -15$; $V_{in} = V_{TL}$ will flip it to $+15$

Given $V_{TL} = 0$

$$\frac{-15 - 0}{R_2} = \frac{0 - V_{ref}}{R_1} \quad \Rightarrow \quad \frac{15}{R_2} = \frac{V_{ref}}{R_1}$$

$$\Rightarrow \frac{R_2}{R_1} = \frac{15}{V_{ref}} \quad \text{-- 2)}$$

from 1) and 2)

$$\frac{14}{1 - V_{ref}} = \frac{15}{V_{ref}} \quad \Rightarrow \quad 14 V_{ref} = 15 - 15 V_{ref}$$

$$V_{ref} = \frac{15}{29} \text{ volts.}$$

2 cont'd

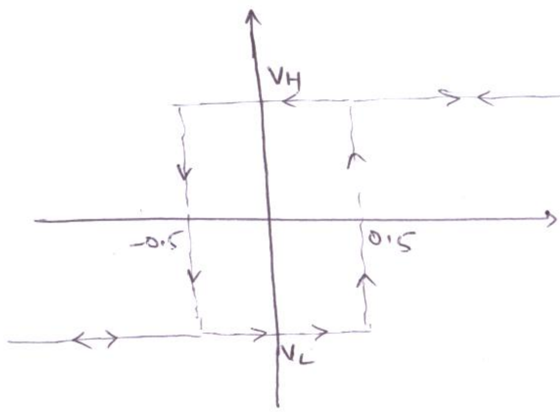
2) $\frac{R_2}{R_1} = 29$

$\Rightarrow R_2 = 29K$ and $R_1 = 1K$ should work.

Now final output is 10V which can be obtained by a voltage divider with

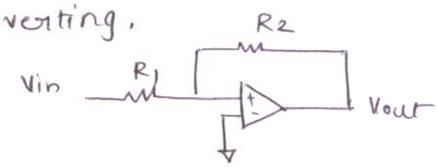
$$\frac{R_4}{R_3 + R_4} = \frac{10}{15}$$

3.



Given :- $V_{TH} = 0.5\ V$ $\quad V_{TL} = -0.5\ V$

The comparator is non-inverting.



Assume $V_H = 15\ V$
$V_L = -15\ V$

$$V_{TL} = -V_H \cdot \frac{R_1}{R_2}$$

$$\Rightarrow -0.5 = -15 \cdot \frac{R_1}{R_2} \Rightarrow \frac{R_1}{R_2} = \frac{0.5}{15} = \frac{1}{30}$$

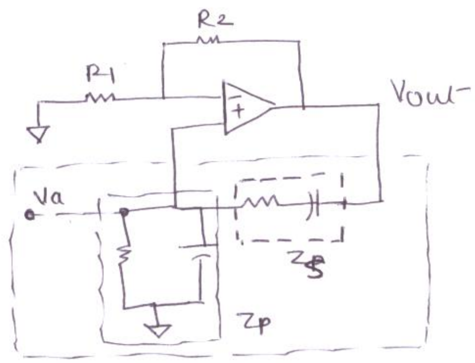
Hence $R_1 = 100\,\Omega$ $\quad R_2 = 3000\,\Omega$ is a solution.

Let us check if this value works for $V_{TH} = 0.5$

$$V_{TH} = -V_L\left(\frac{R_1}{R_2}\right)$$

$$0.5 = 15 \cdot \frac{100}{3000} = 0.5$$ (Thus verified)

4.



The loop gain for the above circuit can be obtained by multiplying $\frac{V_a(s)}{V_o(s)}$ by amplifier gain which is $1+\frac{R_2}{R_1}$

$$L(s) = \left[1+\frac{R_2}{R_1}\right]\frac{Z_p}{Z_p+Z_s}$$

On simplifying

$$L(s) = \frac{1+R_2/R_1}{3+sCR+1/sCR} = \frac{(1+R_2/R_1)\,sCR}{s^2R^2C^2+3sCR+1}$$

characteristic eqn : $s^2R^2C^2+3sCR+1 = \left(1+\frac{R_2}{R_1}\right)sC$

~~poles~~;

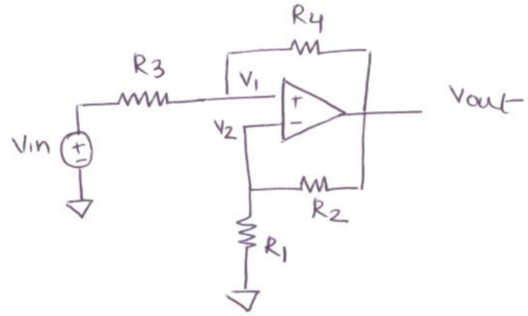
$$\Rightarrow s^2R^2C^2 + sRC\left[3-\left(1+\frac{R_2}{R_1}\right)\right]+1 = 0$$

but $\frac{R_2}{R_1} = 2$ (Given)

$\Rightarrow$ $s^2R^2C^2+1 = 0$ } characteristic equation

$$s = \pm\frac{1}{RC} \quad \text{(poles)}$$

5.



$$V_1\left(\frac{1}{R_3}+\frac{1}{R_4}\right)=\frac{V_{in}}{R_3}+\frac{V_{out}}{R_4} \qquad \text{-- 1)}$$

$$V_2=\frac{R_1}{R_1+R_2}\cdot V_{out} \qquad \text{-- 2)}$$

$$V_{out}=\frac{GB}{s}\left(V_1-V_2\right) \qquad \text{-- 3)}$$

from 2 and 3

$$V_{out}\left(1+\frac{GB}{s}\frac{R_1}{R_1+R_2}\right)=\frac{GB}{s}V_1$$

from 1)

$$V_{out}\left(1+\frac{GB}{s}\frac{R_1}{R_1+R_2}\right)=\frac{GB}{s}\left(\frac{\frac{V_{in}}{R_3}+\frac{V_{out}}{R_4}}{\frac{1}{R_3}+\frac{1}{R_4}}\right)$$

$$\Rightarrow \quad V_{out}\left[\frac{s}{GB}+\frac{R_1}{R_1+R_2}\right]=\frac{R_4V_{in}+R_3V_{out}}{R_3+R_4}$$

putting given values for R_1, R_2, R_3

$$V_{out}\left[\frac{s}{GB}+\frac{1}{6}\right]=\frac{R_4V_{in}}{1+R_4}+\frac{V_{out}}{1+R_4}$$

$$V_{out}=\left[\frac{R_4/(1+R_4)}{\frac{s}{GB}+\frac{1}{6}-\frac{1}{1+R_4}}\right]V_{in}$$

-- ans a)

For stability pole < 0

$$\Rightarrow \quad \frac{1}{6} - \frac{1}{1+R_4} > 0$$

$$\Rightarrow \quad 1 + R_4 > 6$$

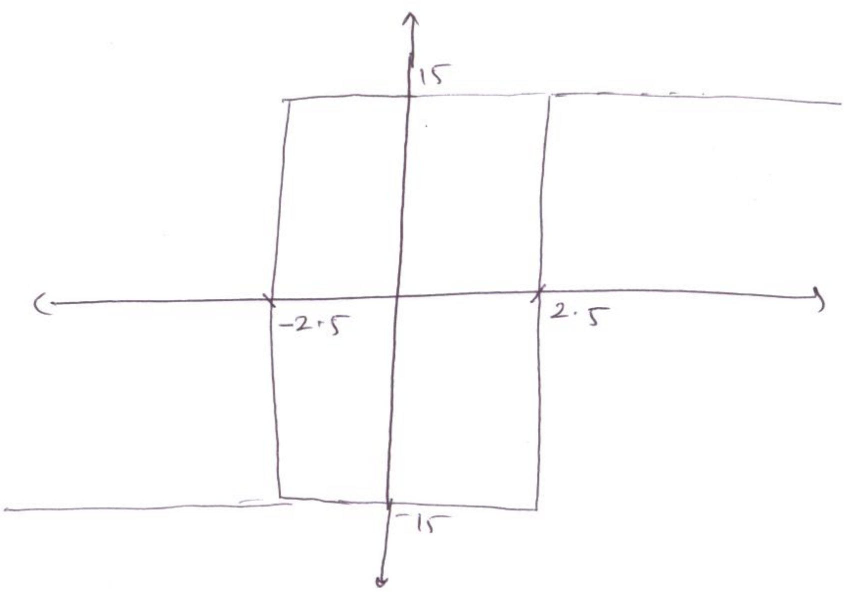
$R_4 > 5\,K$. -- ans b)

if $R_4 = 0.5\,R_{4\,min}$

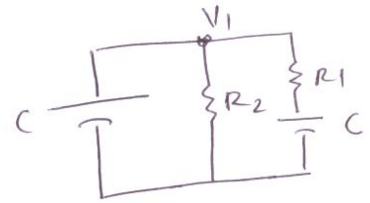
$R_4 = 2.5\,K$

$$\Rightarrow \cancel{V_{out} = \frac{2.5/3.5}{\frac{s}{GB} + \frac{1}{6} - \frac{1}{3.5}}} \cdot V_{in}$$

Transfer characteristics.



6. a)



Applying KCL

$$V_1\left(sC + \frac{1}{R_2} + \frac{1}{R_1 + \frac{1}{sC}}\right) = 0$$

$$\Rightarrow \quad sCR_2\left(R_1 + \frac{1}{sC}\right) + R_1 + \frac{1}{sC} + R_2 = 0$$

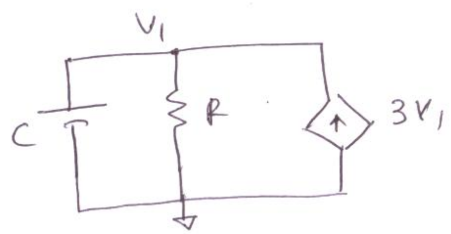
$$\Rightarrow \quad sCR_1R_2 + R_2 + R_1 + \frac{1}{sC} + R_2 = 0$$

$$\Rightarrow \quad s^2C^2 R_1R_2 + (R_1 + 2R_2)Cs + 1 = 0$$

$$s = \frac{-C(R_1 + 2R_2) \pm C\sqrt{R_1^2 + 4R_2^2}}{2C^2R_1R_2}$$

both poles in LHP, hence stable.

b)



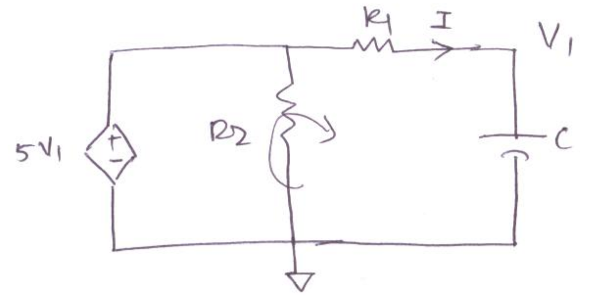
Applying KCL.

$$3V_1 = V_1\left(\frac{1}{R} + sC\right)$$

$$3 = sC + \frac{1}{R} \Rightarrow \quad s = \frac{1}{C}\left(3 - \frac{1}{R}\right)$$

Can be stable or unstable depending on R.

(c)



Applying KVL in outer loop

$$5V_1 - IR_1 - \frac{I}{sC} = 0$$

$$I = \frac{5V_1}{R_1 + 1/sC}$$

$$V_1 = 0 + \frac{I_1}{sC} = \frac{5V_1}{sC\left(R_1 + \frac{1}{sC}\right)} = \frac{5}{sR_1C + 1} V_1$$

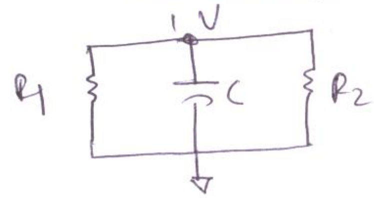
$$\Rightarrow \quad sR_1C + 1 = 5$$

$$s = \frac{4}{R_1C}$$

Pole in RHP => unstable.

d)

Dead Network



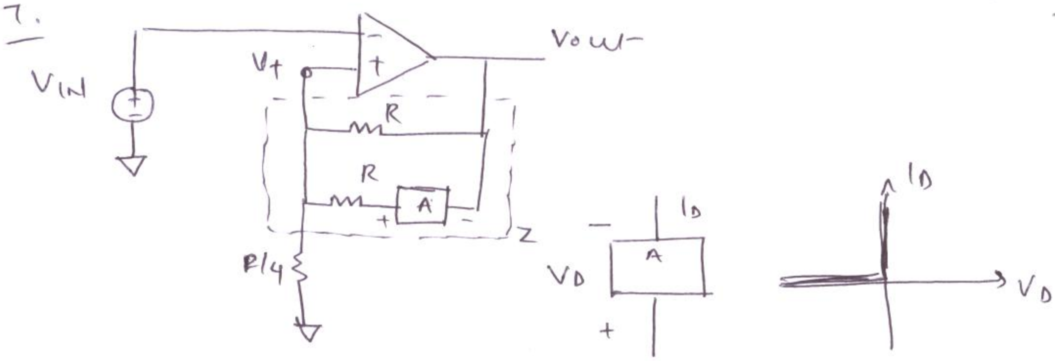
KCL at Node 1

$$\frac{V}{R_1} + \frac{V}{R_2} + VsC = 0$$

$$V\left[sC + \frac{1}{R_1} + \frac{1}{R_2} \right] = 0$$

– stable.

7.



The component is open-ckt for $V_D < 0$ while it is short ckt for $V_D \geq 0$.

clearly, above circuit is inverting comparator

for $V_{out} = V_{SATH}$

$$V_+ = \frac{R/4}{R/4 + Z} V_{out} < V_{out} \quad (V_{out} > 0)$$

$\Rightarrow$ V_D across component A is negative

$\Rightarrow$ $Z = R$

$$V_+ = \frac{R/4}{R/4+R} V_{out} = \frac{R}{5R} V_{out} = \frac{V_{out}}{5} = \frac{V_{SATH}}{5}$$

$\Rightarrow$ $V_{in} > \frac{V_{SATH}}{5}$ will flip V_{out} to V_{SATL}

$\Rightarrow$ $V_{TH} = \frac{V_{SATH}}{5}$

for $V_{out} = V_{SATL}$

$$V_+ = \frac{R/4}{R/4 + Z} \cdot V_{out} > V_{out} \quad (V_{out} < 0)$$

$\Rightarrow$ V_D across component A is +ve

2) $Z = R \| R = R/2$

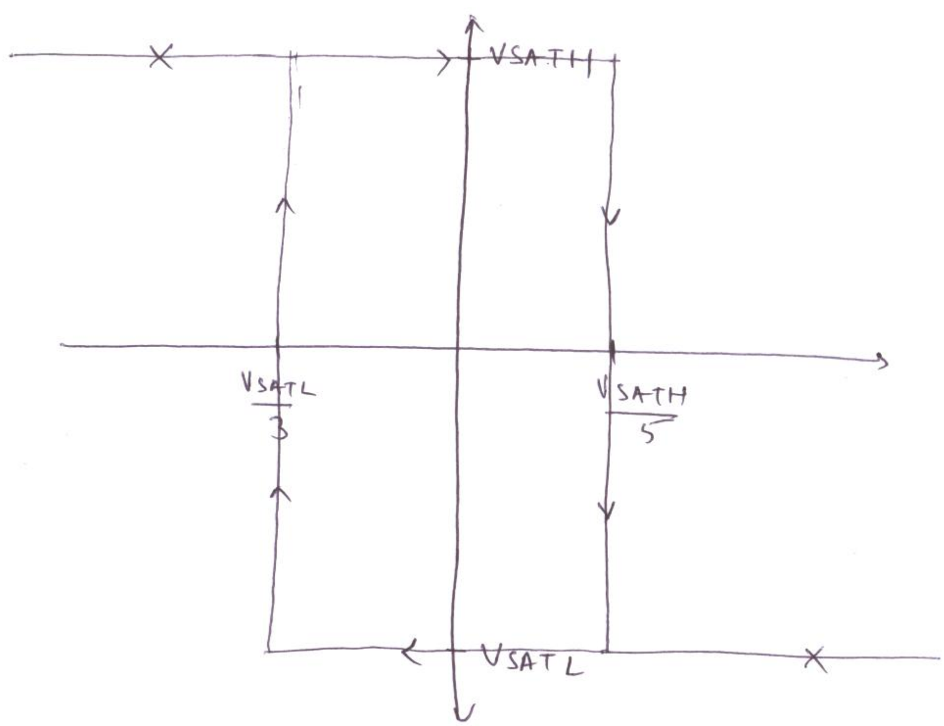
$$\Rightarrow V_+ = \frac{R/4 \, V_{out}}{R/4 + R/2} = \frac{R}{3R} \cdot V_{out}$$

$$V_+ = \frac{V_{out}}{3} = \frac{V_{SATL}}{3}$$

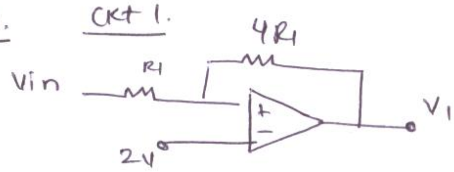
2) for $V_{in} < \frac{V_{SATL}}{3}$, output will flip to V_{SATH}

$$\Rightarrow V_{TL} = \frac{V_{SATL}}{3}$$

Hence Transfer characteristics



8. CKt 1.



It is a non inverting comparator.

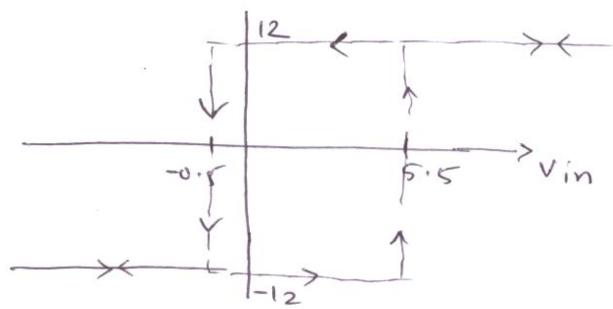
$$V_{TH} = \frac{-V_{SATL} + V_{ref}}{R_2} + V_{ref}$$

$$= 5.5 \text{ V}$$

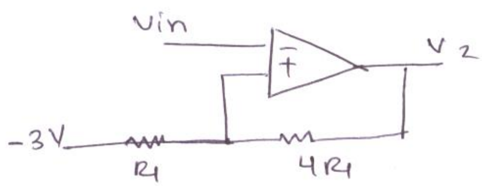
$$V_{TL} = -\left(\frac{V_{SATH} - V_{ref}}{R_2}\right) + V_{ref}$$

$$= -0.5 \text{ V}$$

characteristic



CKt 2. (Inverting Comparator)



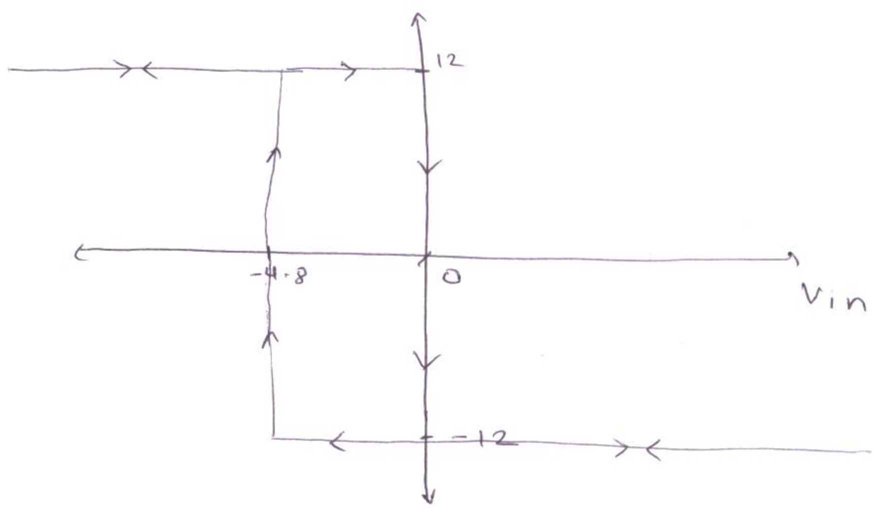
$$V_+ = \frac{R_1}{5R_1}(V_2+3) - 3$$

$$= \frac{V_2+3}{5} - 3$$

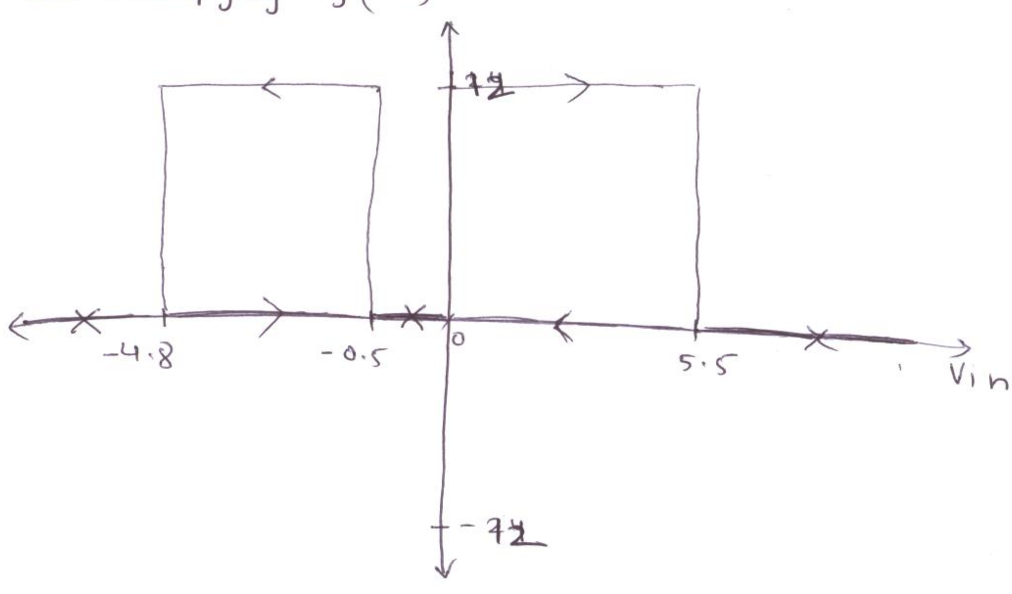
$$V_+ = \frac{V_2 - 12}{5}$$

$\Rightarrow V_{TH} = 0$; $V_{TL} = -\frac{24}{5} = -4.8$ V

⇒ Transfer charecteristics for ckt 2



Third opamp is just a inverting summer. Thus overall Transfer characteristics can be obtained by adding 2 curves. and multiplying by (−1)

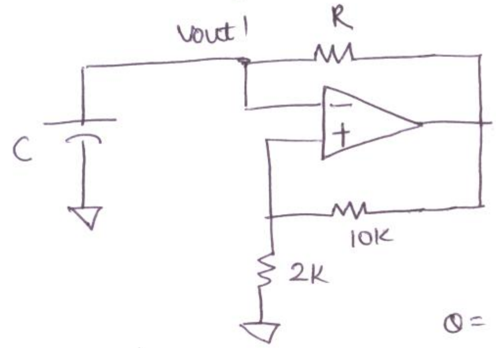


9.

Errata:

~~[illegible]~~.

Required p-p value of Vout1 = 4V.



$$\theta = \frac{2}{12} = \frac{1}{6}$$

$$f = \frac{1}{2RC} \cdot \frac{1}{\ln\left(\frac{1+\theta}{1-\theta}\right)}$$

$$2000 = \frac{1}{2RC} \cdot \frac{1}{\ln\left(\frac{7}{5}\right)}$$

$$RC = 7.43 \times 10^{-4}$$

take $C = 1\mu f$

$R = 7.43 \times 10^{2}\ \Omega$