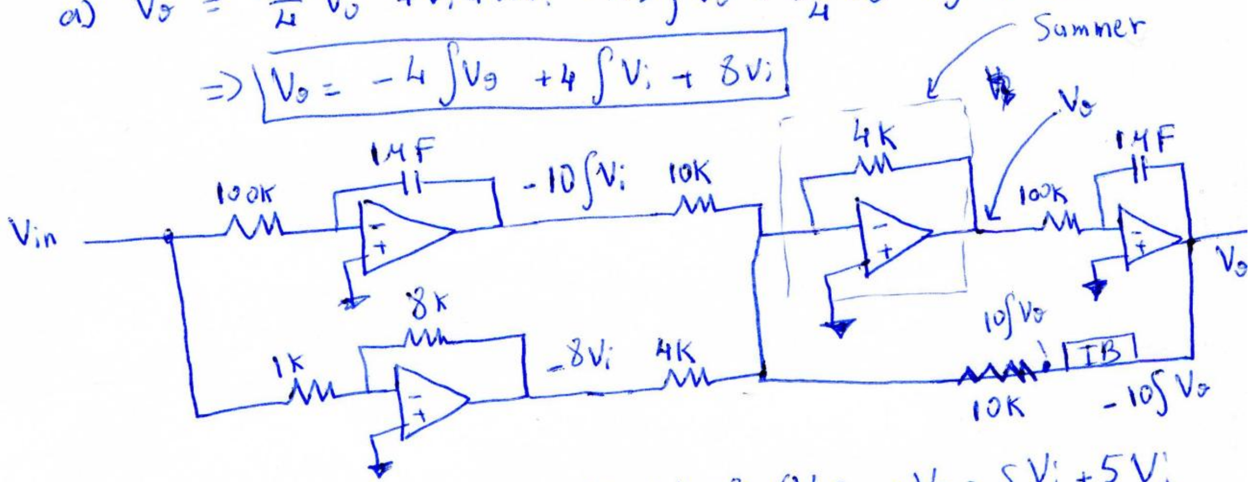
Problem 1

a) $V_o = -\frac{1}{4}V_o' + V_i + 2V_i' \Rightarrow \int V_o = -\frac{1}{4}V_o + \int V_i + 2V_i$

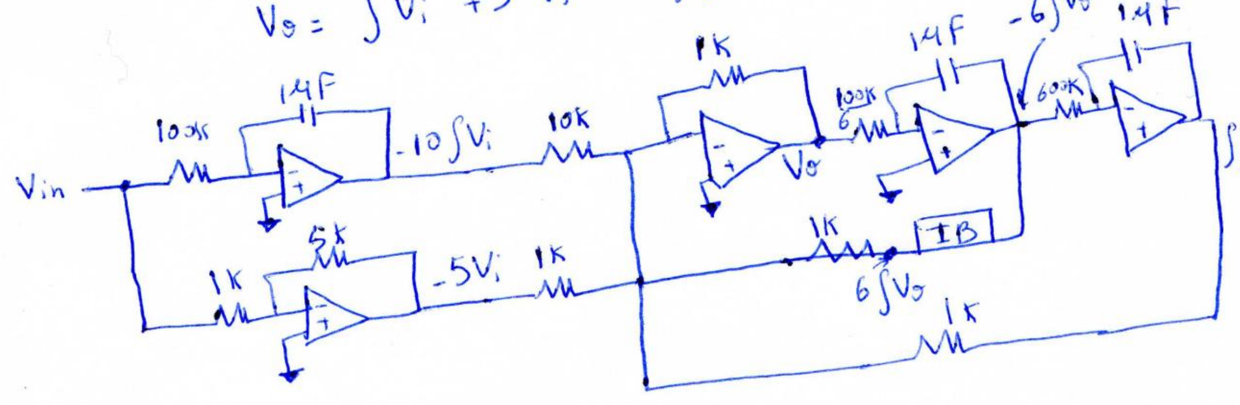
$$\Rightarrow \boxed{V_o = -4\int V_o + 4\int V_i + 8V_i}$$



b) $T(s) = \frac{s+5}{s^2+6s+1} \Rightarrow V_o(s)s^2 + 6V_o s + V_o = sV_i + 5V_i$

$$\iint V_o + 6\int V_o + V_o = \int V_i + 5V_i$$

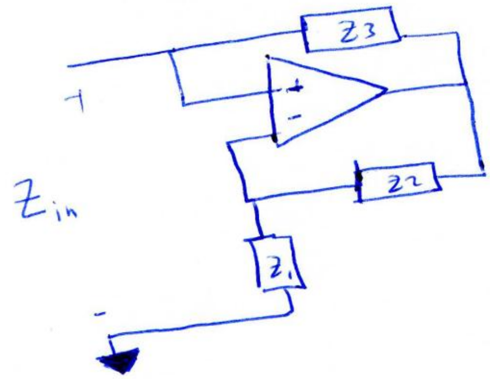
$$V_o = \int V_i + 5V_i - \iint V_o - 6\int V_o$$



IB is an inverting Buffer

Problem 2

$C = 1\mu F \Rightarrow Z = \frac{1}{sC} = \frac{1}{s \times 10^{-6}} = \frac{10^6}{s}$

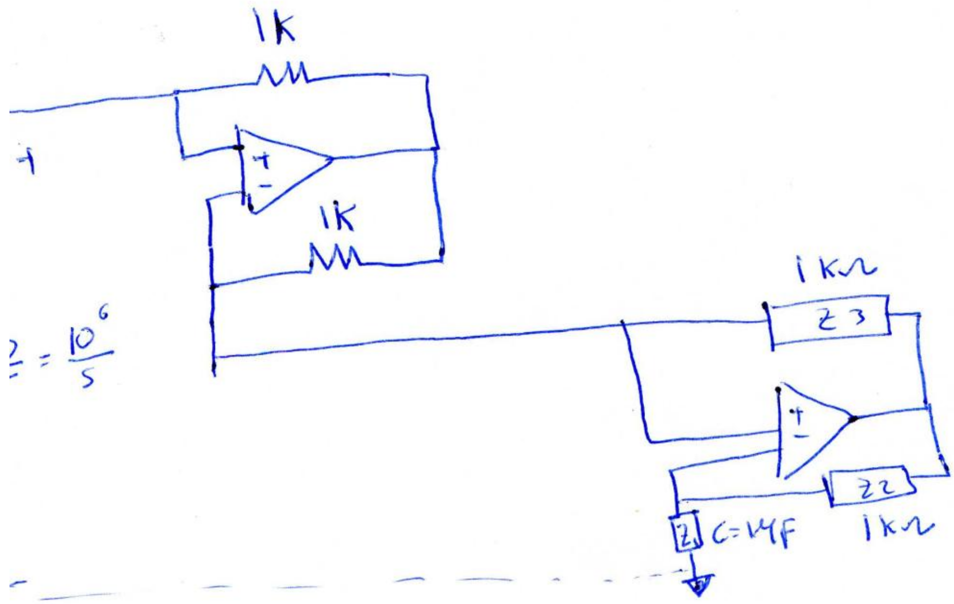


$$Z_{in} = -\frac{Z_1 Z_3}{Z_2}$$

Choose $Z_2 = R_2 \quad Z_1 = \frac{1}{sC} \quad Z_3 = R_3 \Rightarrow Z_{in} = -\frac{R_3}{sCR_2}$

choose $C = 1\mu F \quad R_2 = 1k\Omega \quad R_3 = 1k\Omega \Rightarrow Z_{in} = -\frac{10^6}{s}$

We need to invert that to obtain $Z = \frac{10^6}{s}$



Problem 3

$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in} = 12 \sin(2\pi f t$$

$$V_{in} = 2 \sin(2\pi f t)$$

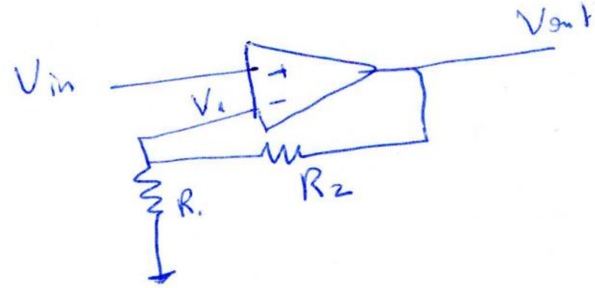
$$\frac{dV_{out}}{dt} = 24\pi f \cos(2\pi f t)$$

$$24\pi f \le SR = 5 V/\mu s = 5 \times 10^6 V/s$$

$$f \le \frac{5 \times 10^6}{24\pi}$$

$$f \le 66.3 \text{ KHz}$$

Problem 4



$$(V_{in} - V_1)\frac{GB}{S} = V_{out}$$

$$V_1 = V_{out}\frac{R_1}{R_1+R_2} = \frac{V_{out}}{K_o}$$

$$\Rightarrow V_{out} = \frac{GB}{s}\left(V_{in} - \frac{V_{out}}{K_2}\right)$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = T(s) = \frac{K_o}{1 + s\frac{K_o}{GB}}$$

$$|T(s)| = \frac{K_o}{\sqrt{1 + \frac{\omega^2 K^2}{GB^2}}} \qquad \angle T(s) = \theta$$

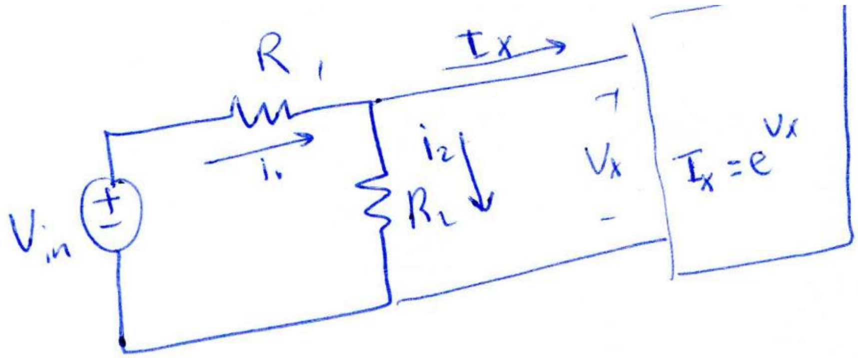
$$\& \quad V_{out}(t) = \frac{K_o}{\sqrt{1+\frac{\omega^2 K^2}{GB^2}}} V_m \sin(\omega t + \theta)$$

$$\frac{d V_{out}(t)}{dt} = \frac{K_o \omega V_m}{\sqrt{1 + \left(\frac{\omega K_o}{GB}\right)^2}} \cos(\omega t + \theta) \leq SR$$

$$\Rightarrow V_m \leq \frac{SR\sqrt{1 + \left(\frac{\omega K_o}{GB}\right)^2}}{K_o \omega}$$

$$\boxed{V_m \leq SR\sqrt{\left(\frac{1}{K_o \omega}\right)^2 + \frac{1}{GB^2}}}$$

Problem 5



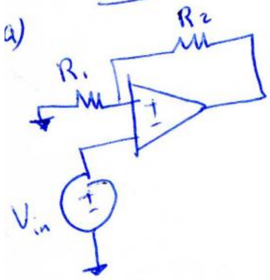
$$I_x = i_1 - i_2$$

$$e^{V_x} = \frac{(V_{in} - V_x)}{R_1} - \frac{V_x}{R_2}$$

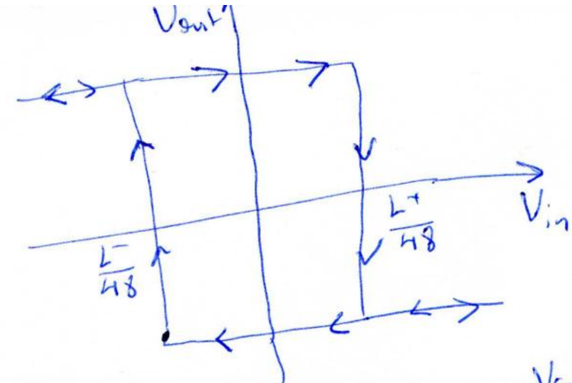
$$\boxed{V_{in} = R_1 e^{V_x} + V_x\left(\frac{R_1}{R_2} + 1\right)}$$

Problem 6

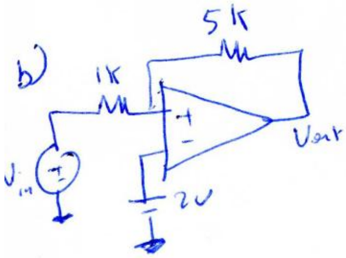
a)



$$\beta = \frac{R_1}{R_1 + R_2} = \frac{1}{48}$$



b)



Assume $V_{out} = V_{sat-H}$ $\xrightarrow{\text{Valid if}}$ $V^+ - V^- > \frac{V_{sat-H}}{A_0}$

$$V^+ = V_{out}\frac{1}{1+5} + V_{in}\frac{5}{1+5} = \frac{V_{out}}{6} + V_{in}\frac{5}{6}$$

$$V^+ = \frac{V_{sat-H}}{6} + \frac{5}{6}V_{HYH} \quad ; \quad V^- = 2V$$

$$V^+ - V^- > \frac{V_{sat-H}}{A_0} \approx 0 \Rightarrow \frac{V_{sat-H}}{6} + \frac{5}{6}V_{HYH} - 2 > 0$$

$$\Rightarrow \boxed{V_{HYH} = \left(2 - \frac{V_{sat-H}}{6}\right)\frac{6}{5} = 2.4 - \frac{V_{sat-H}}{6}}$$

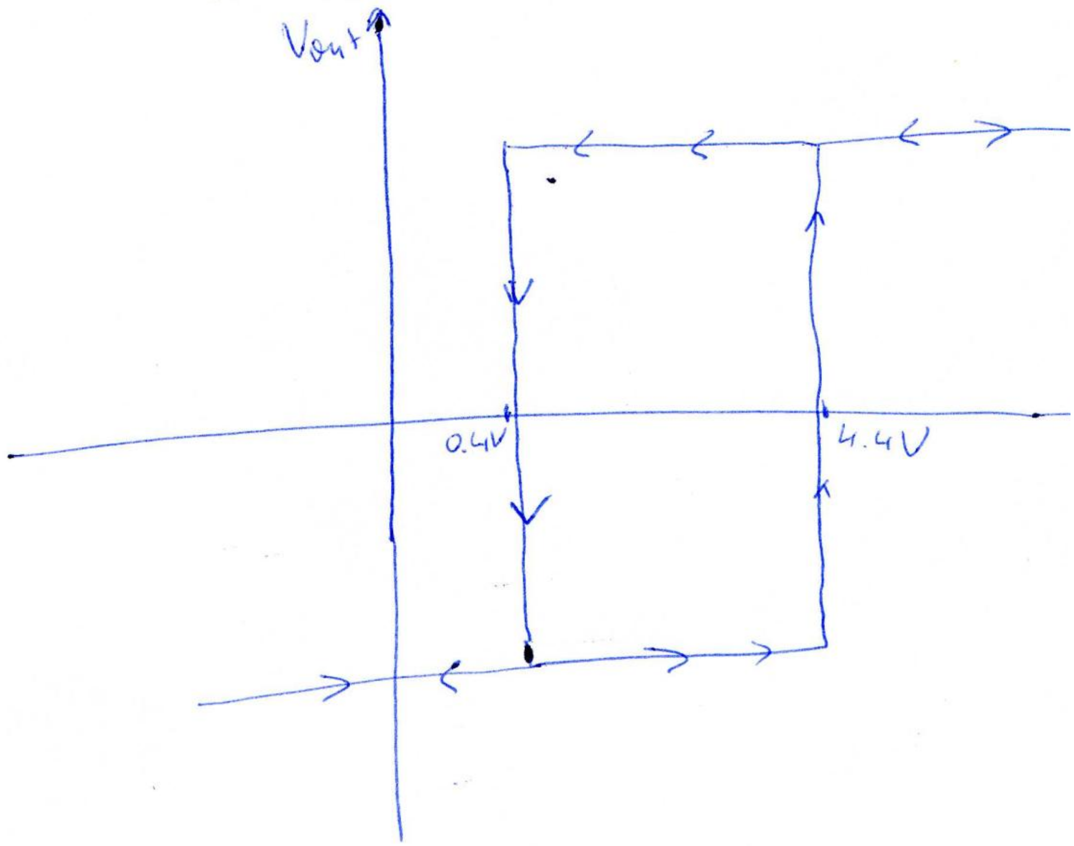
Now Assume $V_{out} = V_{sat-L}$ $\xrightarrow{\text{Valid if}}$ $V^+ - V^- < \frac{V_{sat-L}}{A_0} \approx 0$

$$\frac{V_{sat-L}}{6} + \frac{5}{6}V_{HYL} - 2 < 0$$

$$\boxed{V_{HYL} = \left(2 - \frac{V_{sat-L}}{6}\right)\frac{6}{5} = 2.4 - \frac{V_{sat-L}}{6}}$$

Assume $V_{satH} = -V_{sat-L} = 12\,V$

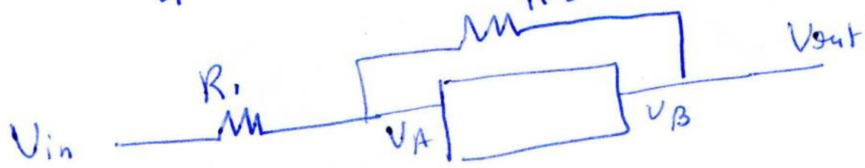
$V_{HYH} = 0.4\,V$ $V_{HYL} = 4.4\,V$



Problem 1

a) $V_B = \begin{cases} -2V & V_A \leq -2V \\ V_A & -2V \leq V_A \leq 2V \\ \frac{V_A+6}{4} & V_A \geq 2V \end{cases}$

b)



Assume Operation in Region 1 $\Rightarrow$ $V_B = -2V = V_{out}$

$$V_A\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = V_B\left(\frac{1}{R_2}\right) + V_{in}\left(\frac{1}{R_1}\right)$$

$$V_A\left(\frac{1}{4}+1\right) = -2\left(\frac{1}{4}\right) + 1 = \frac{1}{2}$$

$$\Rightarrow V_A = \frac{2}{5} > -2$$

Based on this result, our assumption is wrong

No Assume operation in Region 2 $\Rightarrow V_A = V_B = V_{out}$

$$V_A\left(\frac{1}{4}+1\right) = \frac{V_A}{4} + 1$$

$$-1V \leq V_A = 1V \leq 2V$$

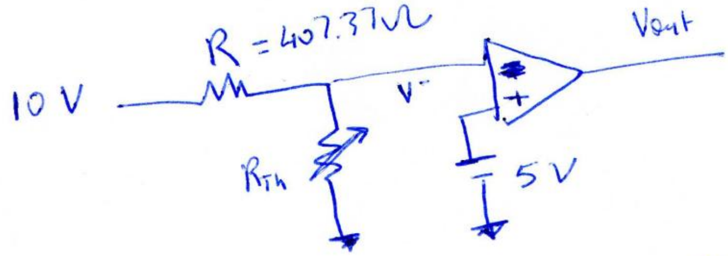
Our assumption is correct $\Rightarrow$ $V_{out} = 1V$

Problem 8

a) $B_{25/85} = 3528\,K$

b) $$R(T) = \begin{cases} 1000\, e^{\left(-12.0596 + \frac{3687.667}{T} - \frac{7617.15}{T^2} - \frac{5.9141\times10^{6}}{T^3}\right)} & T < 25 \\ 1000\, e^{\left(-21.07 + \frac{11903.95}{T} - \frac{2504694}{T^2} + \frac{2.4703\times10^{8}}{T^3}\right)} & T \geq 25^\circ C \end{cases}$$

c) At $T = 50^\circ$ $R = 407.37\,\Omega$

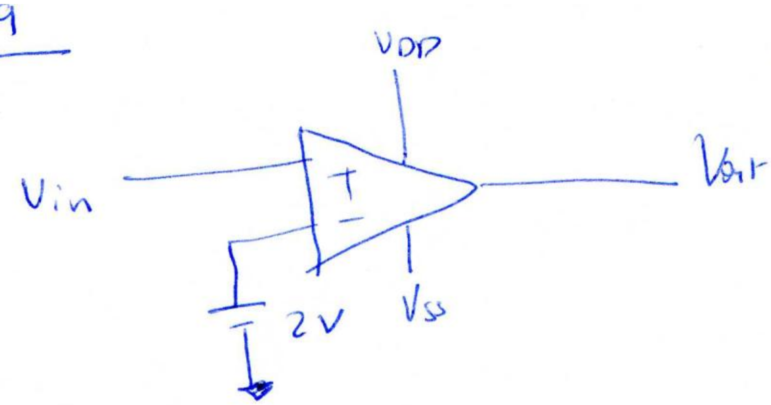


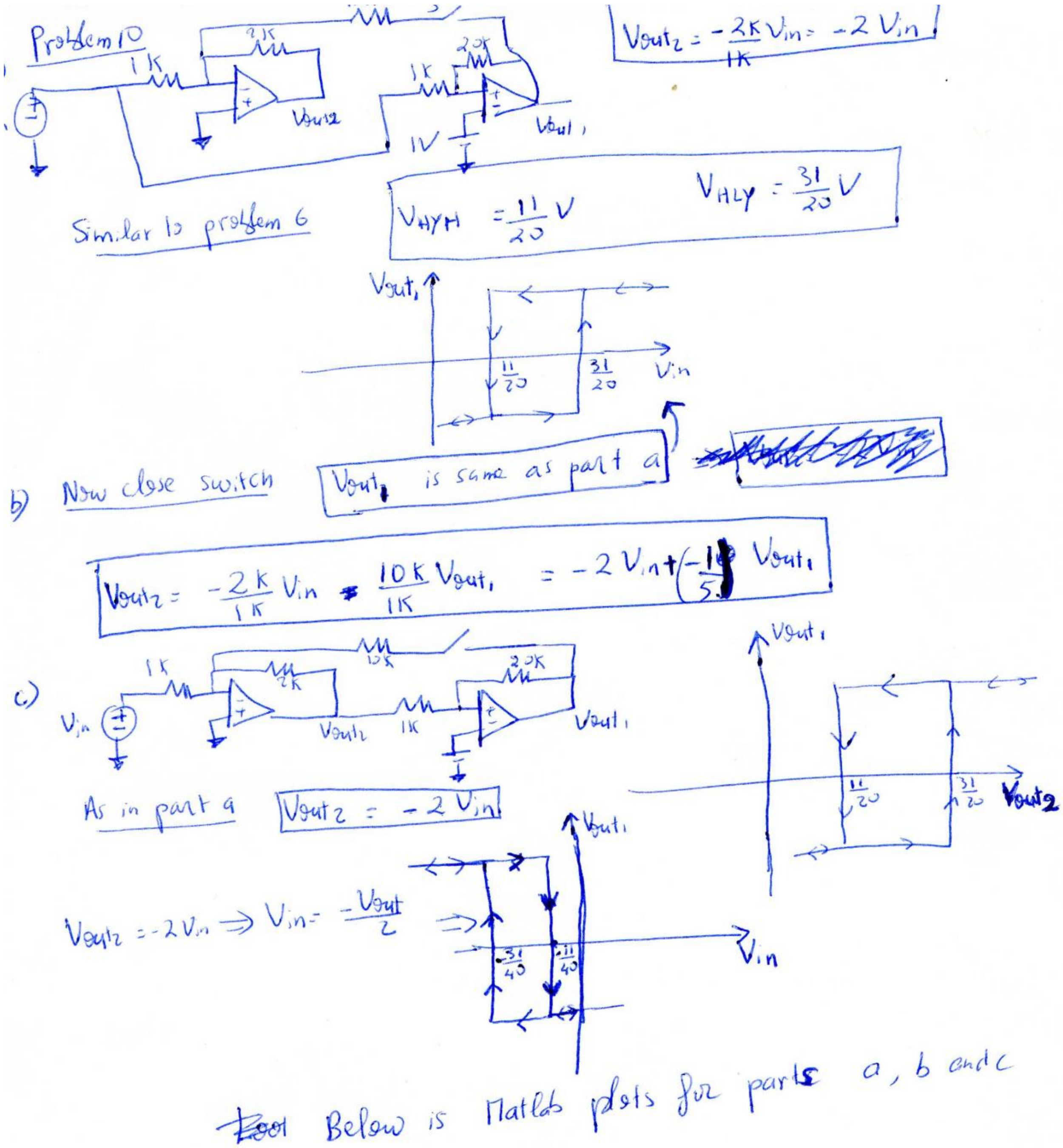
At low temperatures $R_{Th} > R \Rightarrow V^- > 5V$
$\Downarrow$ $\Downarrow$
$T < 50^\circ$ Vout is Low

At temperatures $T > 50^\circ C$ $R_{Th} < R \Rightarrow V^- < 5V$
$\Downarrow$
Vout is high

At $T = 50^\circ$ $R_{Th} = R = 407.37\,\Omega$

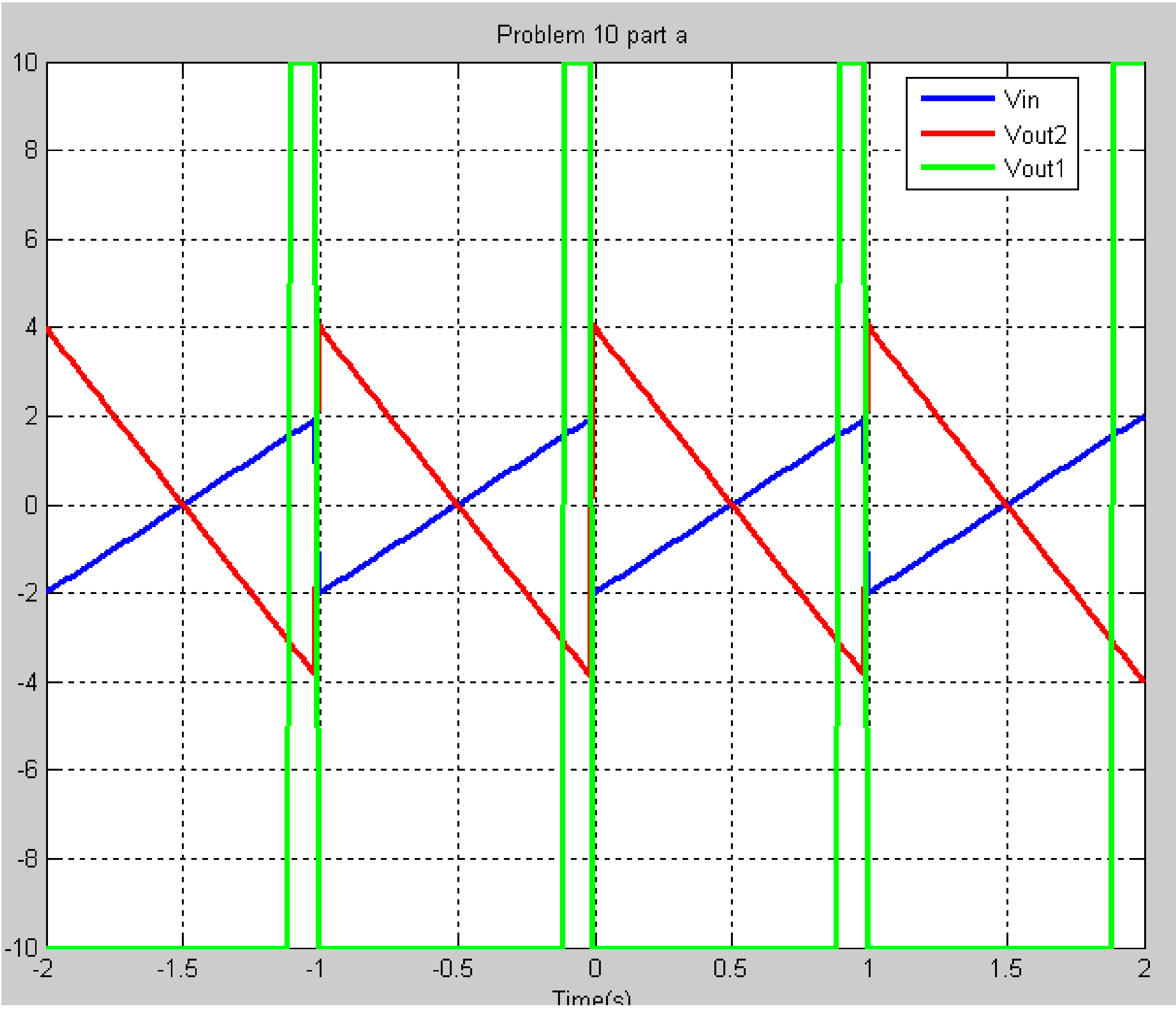
Problem 9

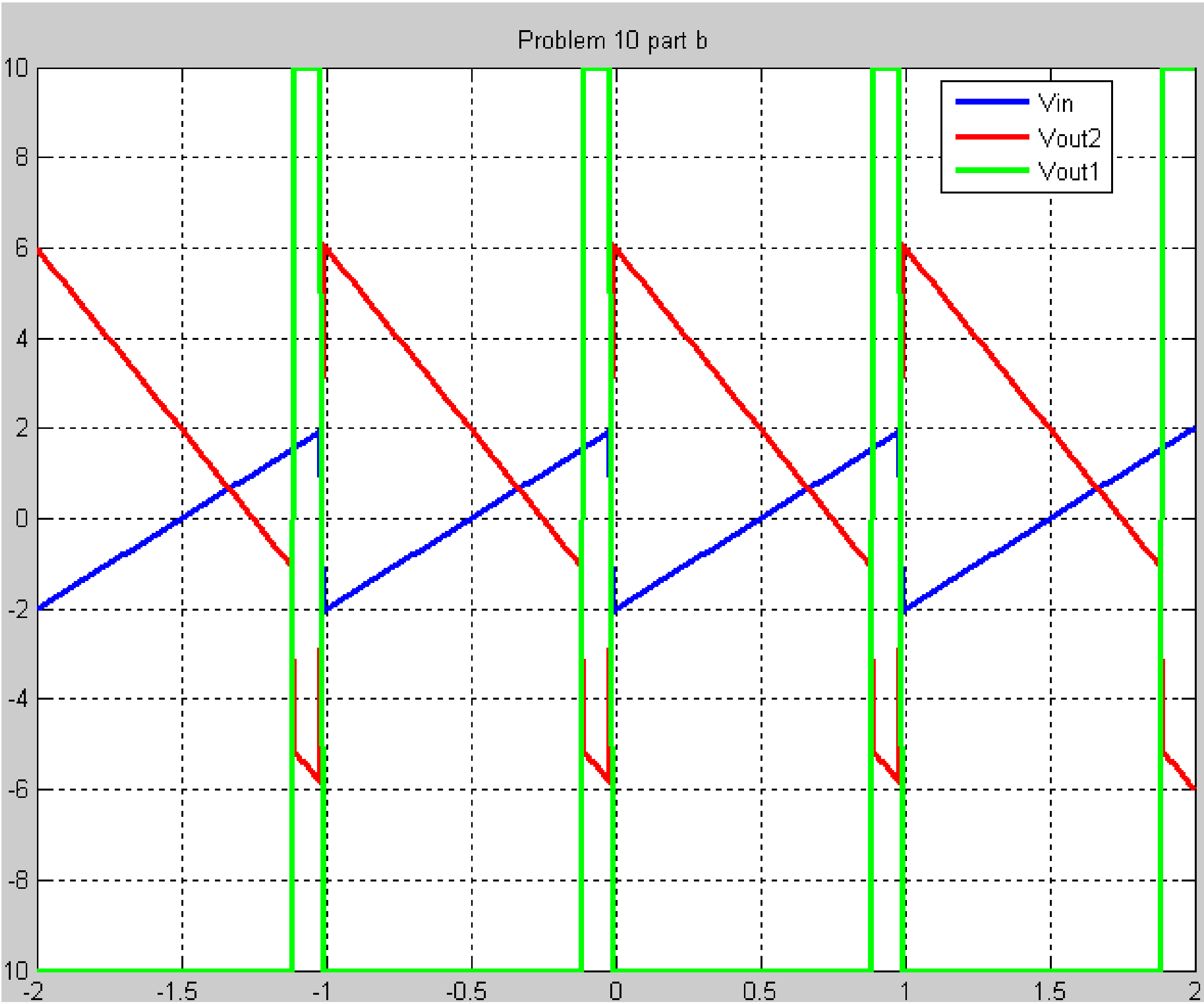


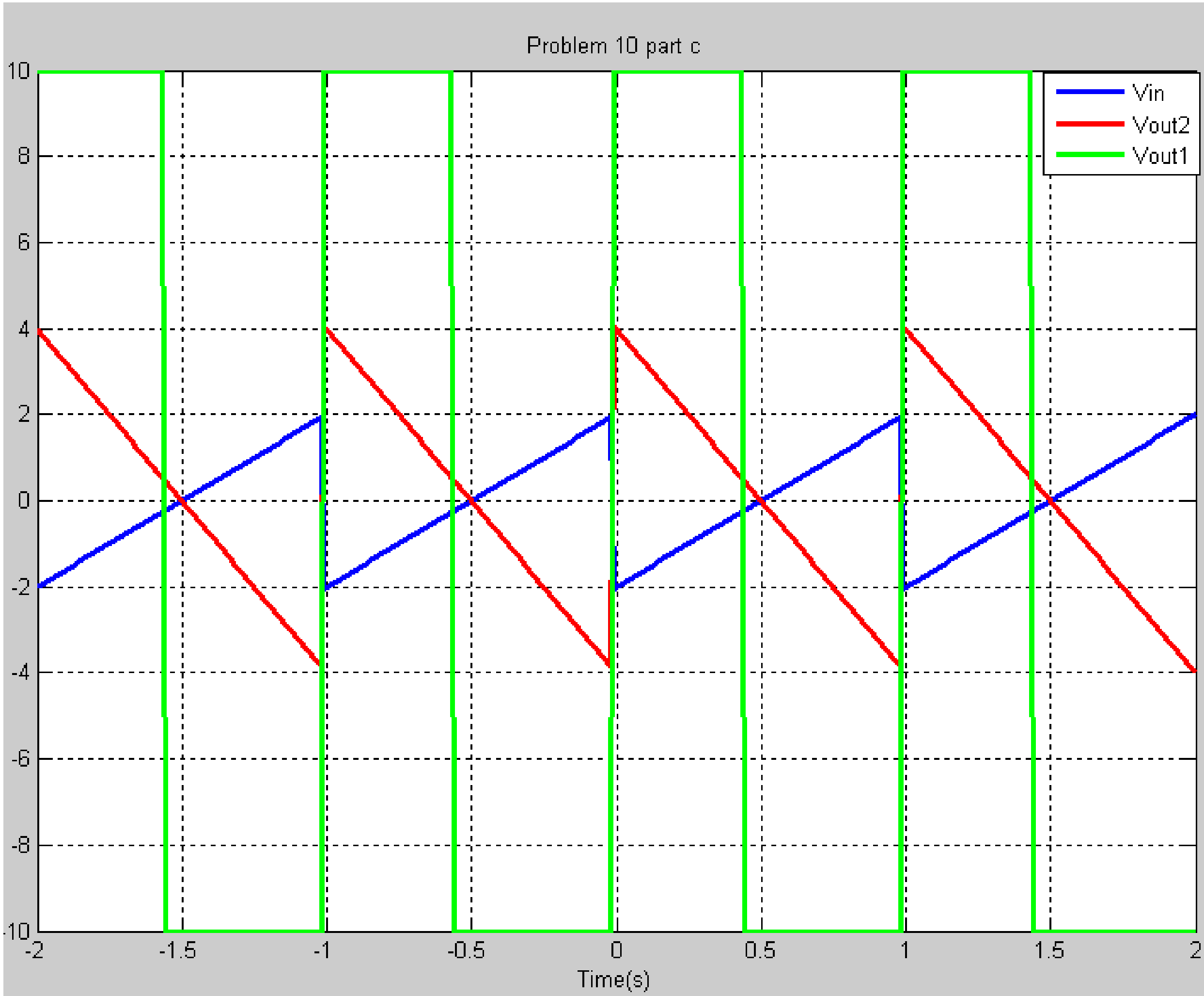



```
clear all
close all

time = -2:0.01:2;   % 8 seconds gives us 8 cycles
Vin = [(4*time(1:99)+6),(4*time(100:199)+2),(4*time(200:299)-
2),(4*time(300:401)-6)];

%%%%%%%%%%%%%%%%%%% part a %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Vout2 = -2*Vin;
Vout1 = 10*(Vin>31/20)-10*(Vin<31/20);
```

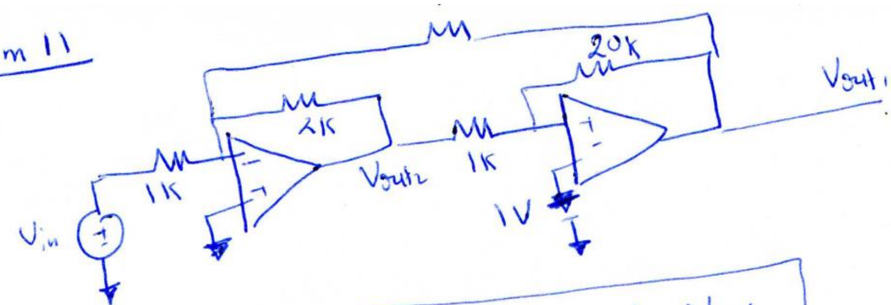
```
figure(1)
plot(time,Vin,'b','linewidth',2.5)
hold on
plot(time,Vout2,'r','linewidth',2.5)
hold on
plot(time,Vout1,'g','linewidth',2.5)
xlabel('Time(s)')
grid on
legend('Vin','Vout2','Vout1')
title('Problem 10 part a')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%% part b %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Vout2 = -2*Vin -(1/5)*Vout1;
Vout2(Vout2>=10)=10;
Vout2(Vout2<=-10)=-10;
figure(2)
plot(time,Vin,'b','linewidth',2.5)
hold on
plot(time,Vout2,'r','linewidth',2.5)
hold on
plot(time,Vout1,'g','linewidth',2.5)
xlabel('Time(s)')
grid on
legend('Vin','Vout2','Vout1')
title('Problem 10 part b')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%% part c %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
Vout2 = -2*Vin;
Vout1 = 10*(Vin<-11/40)-10*(Vin>-11/40);
figure(3)
plot(time,Vin,'b','linewidth',2.5)
hold on
plot(time,Vout2,'r','linewidth',2.5)
hold on
plot(time,Vout1,'g','linewidth',2.5)
xlabel('Time(s)')
grid on
legend('Vin','Vout2','Vout1')
title('Problem 10 part c')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```


Problem 10 part a
Vin
Vout2
Vout1
10
8
6
4
2
0
-2
-4
-6
-8
-10
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Time(s)

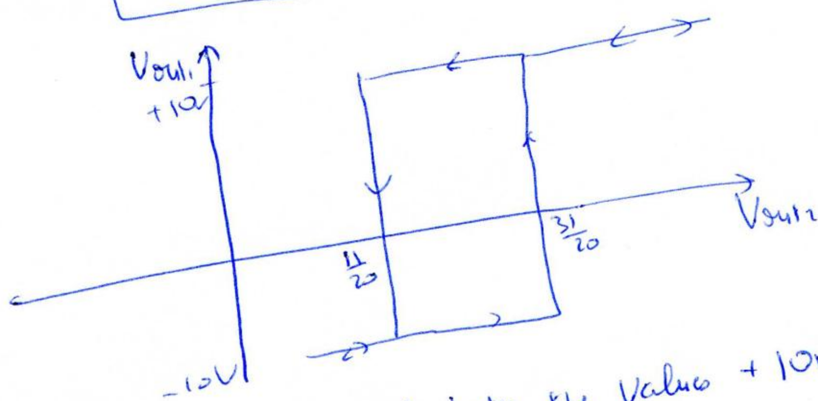

Problem 10 part b
Vin
Vout2
Vout1
10
8
6
4
2
0
-2
-4
-6
-8
10
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2


Problem 10 part c
Vin
Vout2
Vout1
10
8
6
4
2
0
-2
-4
-6
-8
-10
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Time(s)

Problem 11



$$V_{out_2} = -2V_{in} - \frac{1}{5} V_{out_1}$$



Based on the plot V_{out_1} can only take the values +10V and -10V

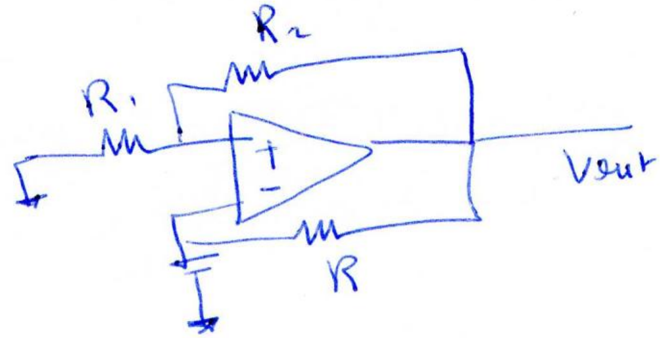
~~Assume [illegible]~~ ⟹ ~~$\frac{11}{20} < V_{out_2} < \frac{31}{20}$~~
$V_{out_2} = -2V_{in} - 2$ $\quad V_{out_1} = 10$
$V_{out_2} = -2V_{in} + 2$ $\quad V_{out_1} = -10$

Assume $V_{out_1} = 10V$ ⟹
$\frac{11}{20} < V_{out_2} < \frac{31}{20}$ $\quad -\frac{71}{40} < V_{in} < -\frac{51}{40}$ case 1
$V_{out_2} < \frac{11}{20}$ $\quad V_{in} > -\frac{51}{40}$ case 2
$V_{out_3} > \frac{31}{20}$ $\quad V_{in} < -\frac{71}{40}$ case 3

Only case 2 is valid because $-2 < V_{in} ? 2$, however if $V_{out_2} < \frac{11}{20}$
$V_{out_1} = -10V$ ⟹ V_{out_1} can never be 10V

Therefore $V_{out_1} = -10V$ always

Problem 12



$$f = \frac{1}{2RC} \frac{1}{\ln\left(\frac{1+\vartheta}{1-\vartheta}\right)} = 4\text{ KHz} \qquad \vartheta = \frac{R_1}{R_1+R_2}$$

$$R_1 = R_2 = 1k \Rightarrow \vartheta = \frac{1}{2}$$

$$4000 = \frac{1}{2RC}\left(\frac{1}{\ln\left(\frac{1.5}{0.5}\right)}\right)$$

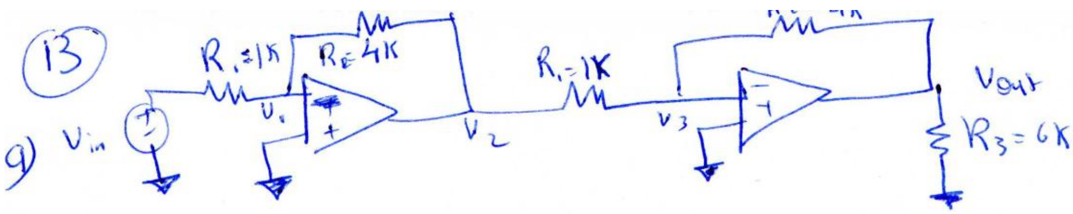
$$RC = 1.1378 \times 10^{-4}$$

Choose $C = 10nF$ $R = 11.38 k\Omega$

Bias op amps at ±10V

(13)

a)



The first stage is an inverting amp $\Rightarrow \frac{V_2}{V_{in}}(s) = \frac{-4}{1+(1+4)\frac{s}{GB}} = \frac{-\frac{4}{5}GB}{\frac{GB}{5}+s}$

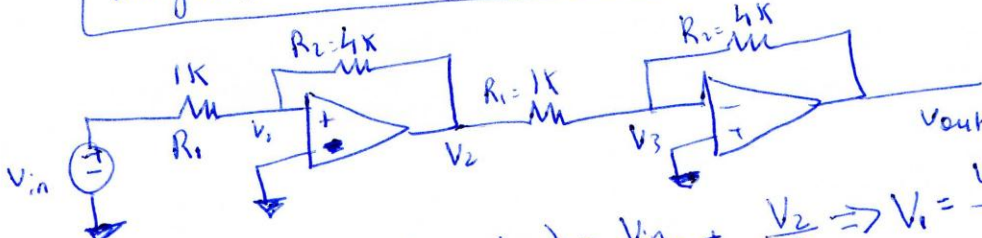
pole at $\left(-\frac{GB}{5}\right) = -200KHz \Rightarrow$ **stable** 1st stage

The second stage is also an inverting amp $\Rightarrow \frac{V_{out}}{V_2}(s) = \frac{-\frac{4}{5}GB}{\frac{GB}{5}+s}$ (1)

$$\Rightarrow \frac{V_{out}}{V_{in}}(s) = \frac{\frac{16}{25}GB^2}{\left(\frac{GB}{5}+s\right)^2} \Rightarrow \text{double pole at } -200KHz$$

Therefore, we have a stable system

b)



$V_2 = V_1 \frac{GB}{s}$ and $V_1\left(\frac{1}{R_1}+\frac{1}{R_2}\right) = \frac{V_{in}}{R_1} + \frac{V_2}{R_2} \Rightarrow V_1 = \frac{V_{in}R_2 + V_2R_1}{R_1+R_2}$

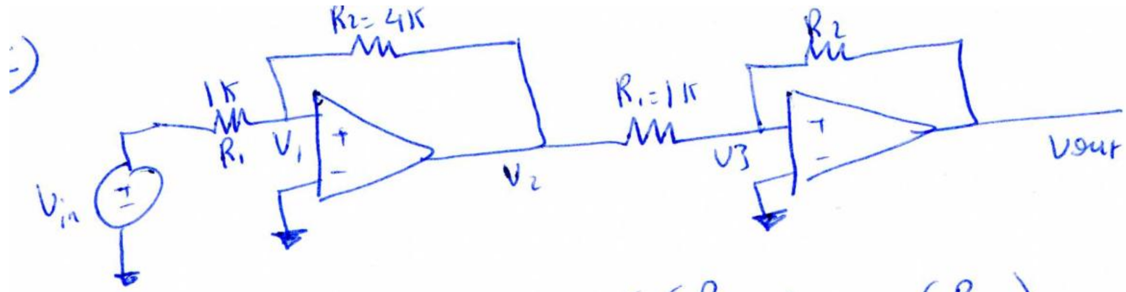
$V_2 = \frac{V_{in}R_2 + V_2R_1}{R_1+R_2}\left(\frac{GB}{s}\right) \Rightarrow \frac{V_2}{V_{in}} = \frac{K_0}{\frac{K_0 s}{GB} - 1}$ $\left(K_0 = 1 + \frac{R_2}{R_1} = \frac{R_2+R_1}{R_1}\right)$

$$\frac{V_2}{V_{in}} = \frac{5}{\frac{5}{GB}s - 1} = \frac{GB}{\left(s - \frac{GB}{5}\right)}$$

using (1) $\Rightarrow$

$$\frac{V_{out}}{V_{in}} = \frac{-\frac{4}{5}GB^2}{\left(s - \frac{GB}{5}\right)\left(s + \frac{GB}{5}\right)}$$

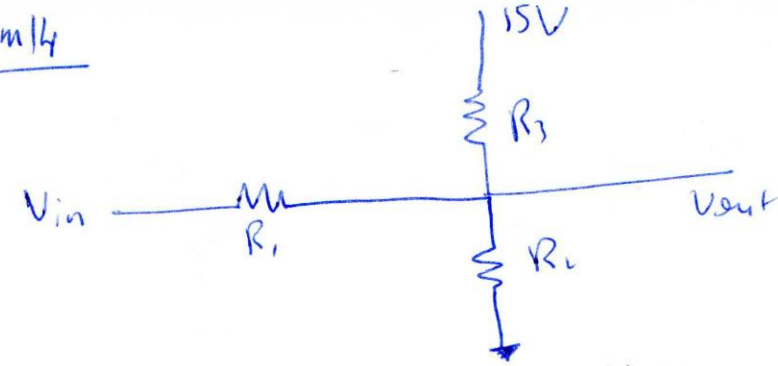
1 pole at $-200KHz$ and 1 pole at $200KHz \Rightarrow$ **unstable**



from part B $\dfrac{V_{out}}{V_{in}} = \left(\dfrac{GB}{s - \frac{GB}{s}}\right)\left(\dfrac{GB}{s - \frac{GB}{s}}\right)$

2 poles at $\dfrac{GB}{s} = 200\text{kHz}$ $\Longrightarrow$ **not stable**

problem 4



$$\frac{V_{out} - 15}{R_3} + \frac{V_{out} - V_{in}}{R_1} + \frac{V_{out}}{R_2} = 0 \quad (\text{KCL})$$

$V_{out} = 5V$ $V_{in} = 15$

$V_{out} = 0V$ $V_{in} =$

$$(1) \begin{cases} \dfrac{-10}{R_3} + \dfrac{-10}{R_1} + \dfrac{5}{R_2} = 0 \\ -\dfrac{15}{R_3} + \dfrac{15}{R_1} = 0 \end{cases}$$

let $R_1 = R_3$

solve (1) $\Longrightarrow$ $R_2 = 1k\Omega$ $R_1 = 4k\Omega$ $R_3 = 4k\Omega$