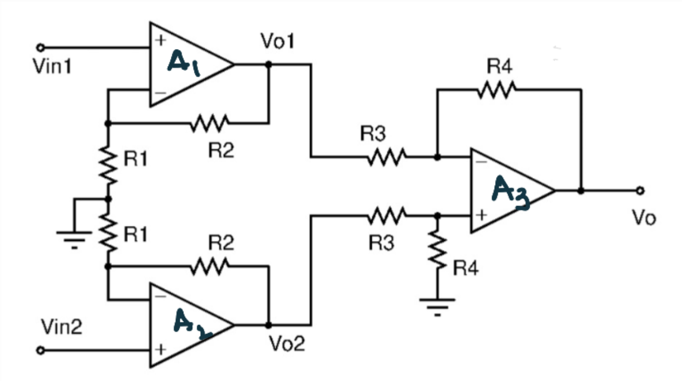
Q1.



$R_4 = R_2 = 10K\Omega$; $R_3 = R_1 = 5K\Omega$

a. A_1, A_2 are connected in non-inverting configuration

So, $V_{o1} = \left(1 + \frac{R_2}{R_1}\right) \cdot Vin1$

$= \left(1 + \frac{R_2}{R_1}\right) \cdot (V_{cm} - V_{id}\sin(\omega t))$

$= \left(1 + \frac{10K}{5K}\right) \cdot (V_{cm} - V_{id}\sin(\omega t))$

$= 3 \cdot (V_{cm} - V_{id}\sin(\omega t))\,V$ — (0.5 marks)

Similarly,

$V_{o2} = \left(1 + \frac{10K}{5K}\right)(V_{cm} + V_{id}\sin\omega t)$

$= 3 \cdot (V_{cm} + V_{id}\sin(\omega t))\,V$ — (0.5 marks)

Now, V_{o1}, V_{o2} are inputs to a differential Amp. stage

$V_o = \frac{R4}{R3}(V_{o2} - V_{o1})$

$= 3 \cdot 2\left[(V_{cm} + V_{id}\sin(\omega t)) - (V_{cm} - V_{id}\sin(\omega t))\right]$

$= 6\left[2 \cdot V_{id}\sin(\omega t)\right]$

$= 12 \cdot V_{id} \sin(\omega t)$ V — (0.5 marks)

b. Given $V_{cm} = 1.8V$, $V_{id} = 0.3V$

If the Op-Amps were completely ideal & didn't saturate the ouputs would be :

using solutions from part a -

$V_{O1} = 5.4 - 0.9 \sin(\omega t)$ V

$V_{O2} = 5.4 + 0.9 \sin(\omega t)$ V

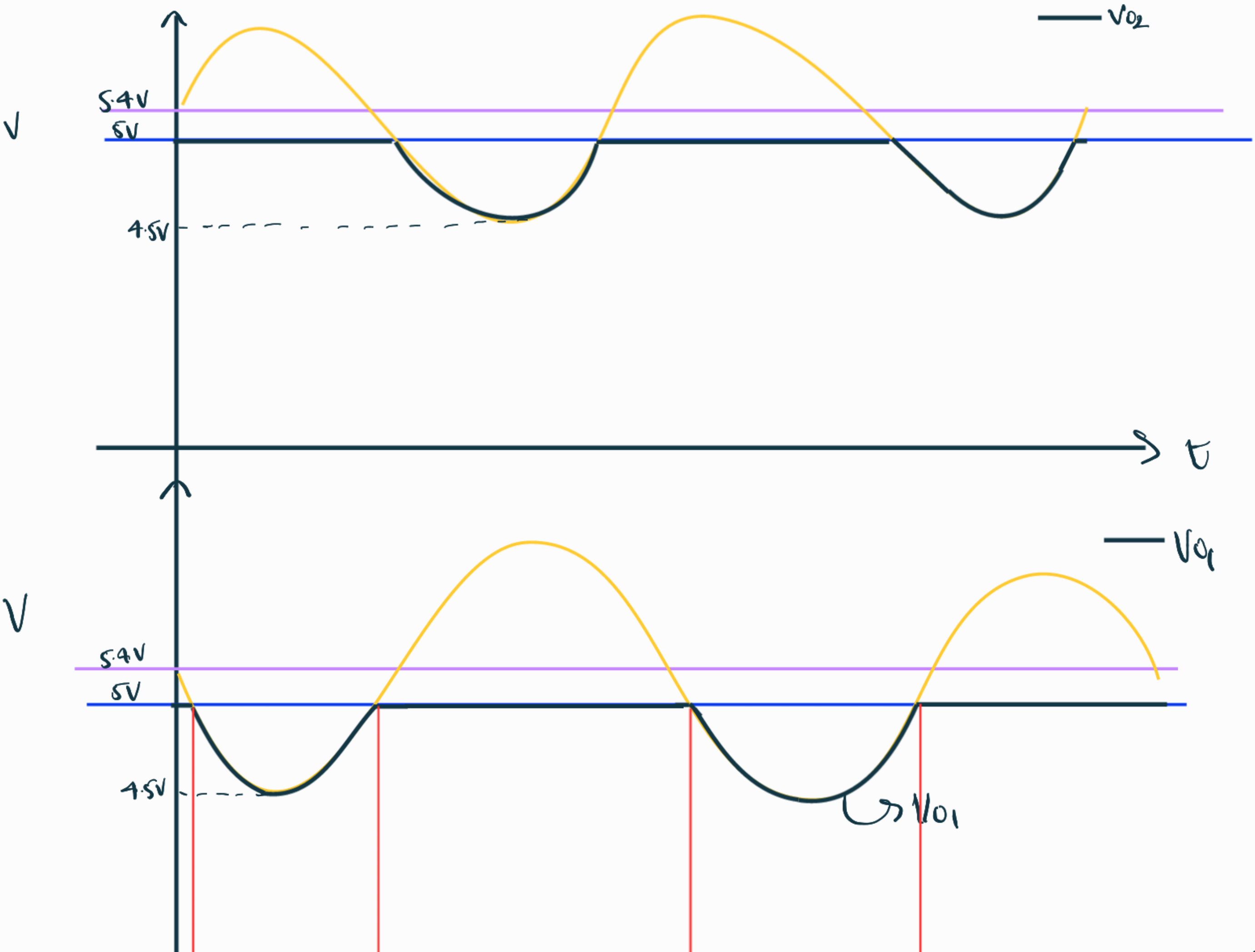
$V_O = 3.6 \sin(\omega t)$ V

(and $V_{omin} = 0V$)

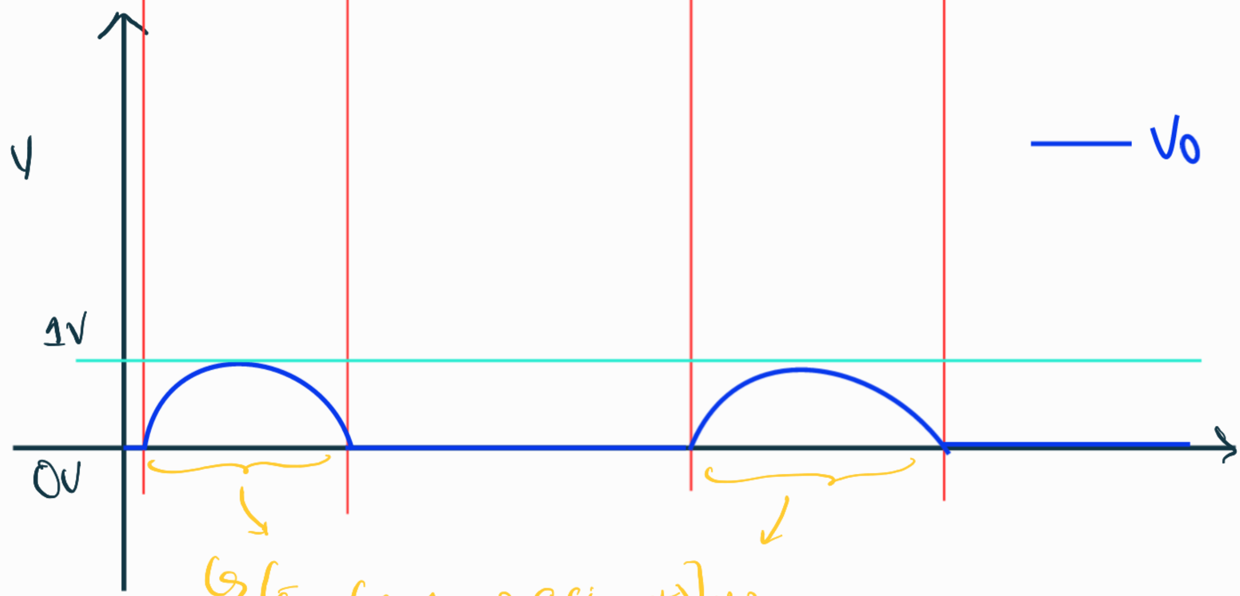
But, outputs all op-amps saturate at 5V. (given)

So, the outputs, when drawn would be -

$0V \leq V_o \leq 5V$



Now, $V_o = V_{o_2} - V_{o_1}$



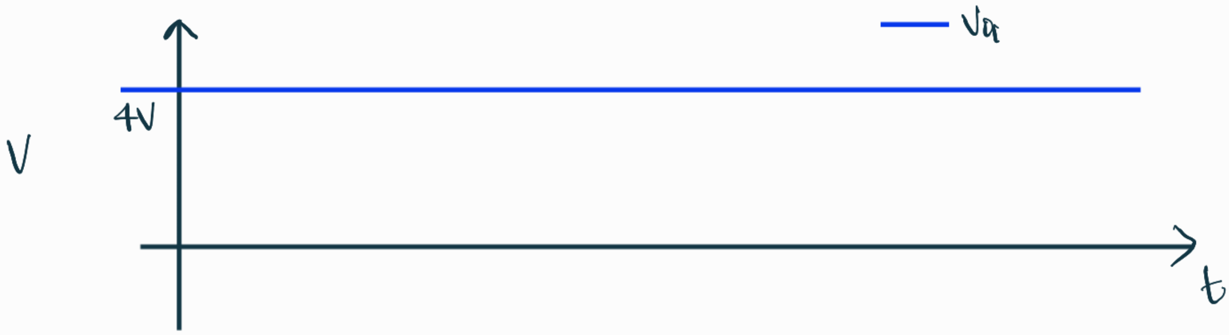
$\left[5 - (5.4 - 0.9\sin\omega t)\right] \times 2$

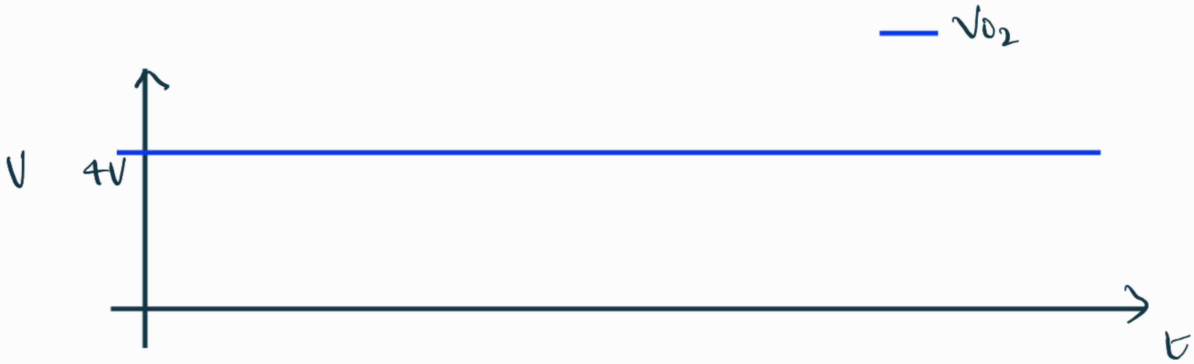
$\Rightarrow 1.8\sin\omega t - 0.8\ V$

$-\ (0.5 \times 3 = 1.5\ \text{marks})$

c. It is now given that, the outputs saturate at 4V but from previous parts V_{o_1}, V_{o_2} are always > 4V

Hence,





— (0·5 x 3 = 1·5 marks)

Q2. $V_b = 0.8V$ $V_{dd} = 1.8V$, $W/L = 9/0.36$, $\mu_n C_{ox} = 260\mu A/V^2$

$V_{TH} = 0.4V$.

Assuming M1 is in Saturation

a. $$I_D = \frac{\mu_n C_{ox}}{2} \cdot \frac{W}{L} \cdot (V_{GS} - V_{TH})^2$$

$$I_D = \frac{260 \times 10^{-6}}{2} \times \frac{9}{0.36} (0.8 - 0.4)^2$$

$$= 0.52\ mA\ (or)\ 520\mu A$$ — 0.25 marks

$$V_o = V_{dd} - I_D \cdot R_D$$
$$= 1.8 - 0.52 \times 0.8 = 1.384\ V$$ — 0.25 marks

To check for saturation:

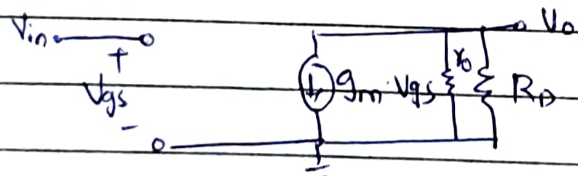
$$V_{DS} \geq V_{GS} - V_{TH}$$

$V_{DS} = 1.384$, $V_{GS} - V_{TH} = 0.8 - 0.4 = 0.4V$

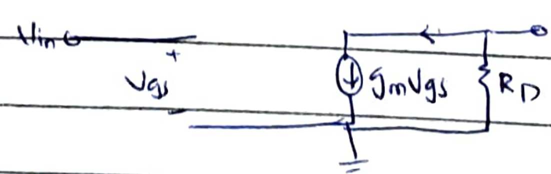
$V_{DS} \geq V_{GS} - V_{TH}$ is true.

Our assumption is valid & M_1 is indeed in saturation

b.



Small signal model with $r_o \to \infty$



— (0.5 marks)

$$g_m = \frac{\partial I_D}{\partial V_{gs}} = \mu_n C_{ox} \cdot \frac{W}{L} (V_{GS} - V_T) = 2.6m\ \text{Siemens}$$

Small Signal gain $A_v = -g_m \cdot R_D = -2.08$ — (0.5 marks)

(c) $V_{GS} = V_D = 0.8V$

Say, $V_{GS_1} = 0.8 + 0.1 = 0.81V$

$V_{GS_2} = 0.8 - 0.1 = 0.79V$

for $V_{GS_1} \rightarrow I_{D_1} = \frac{1}{2} \cdot \mu_n C_{ox} \cdot \frac{W}{L} \cdot (V_{GS_1} - V_{TH})^2$

$= 0.546325 mA$

$V_{O_1} = V_{dd} - I_{D_1} \cdot R_D = 1.36294 V$

for $V_{GS_2} \rightarrow I_{D_2} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS_2} - V_{TH})^2$

$= 0.494325 mA$

$V_{O_2} = V_{dd} - I_{D_2} \cdot R_D = 1.40454$

pk-pk output-input gain $= \frac{V_{O_2} - V_{O_1}}{V_{GS_2} - V_{GS_1}} = -2.08$

Absolute value of gain is 2.08 & the gain is inverting

- (2 marks)

(or) using Small signal analysis

$|\Delta V_o| = g_m \cdot |\Delta I_D| \cdot R_D$

$= g_m R_D |\Delta V_{in}|$

$\left|\frac{\Delta V_o}{\Delta V_{in}}\right| = g_m R_D = 2.08$ ← Absolute value of gain

Also, as $V_{in} \uparrow \rightarrow I_D \uparrow$ and $V_o \downarrow$

the gain is inverting.

- (2 marks)

(d) for $R_D = 2 \times 0.8 k\Omega = 1.6 k\Omega$

$V_d = V_D = V_{dd} - I_D \cdot R_D = 0.968 V$

$V_{GS} - V_{TH} = 0.4V$, $V_{DS} \geq V_{GS} - V_{TH}$, Hence M1 is still in Sat.

(d) for same V_{GS1}, V_{GS2} as in the above part

$I_{D1} = 0.546325\,mA,\ I_{D2} = 0.494325\,mA$ (same as above)

$V_{O1} = V_{dd} - I_{D1} \cdot R_D = 0.92588\ V$

$V_{O2} = V_{dd} - I_{D2} \cdot R_D = 1.00908$

pk-pk output input gain $= \dfrac{V_{O2} - V_{O1}}{V_{GS2} - V_{GS1}} = -4.16$

(or)

using small signal analysis

$A_V = -g_m \cdot R_D = -g_m \cdot (2 \times 0.8\,k\Omega)$

$= -2.6 \times 2 \times 0.8 = -4.16$

If it is assumed that ~~no~~ small signal is not present: – (1 mark)

for M_1 to be in saturation $V_{DS} \geq V_{GS} - V_{TH}$ — ①

$V_{DS} = 1.8 - I_D \cdot R_D - 0$

$= 1.8 - (0.52 \times 10^{-3}) \cdot R_D\ V$

$V_{GS} - V_{TH} = 0.4\ V$

from ① $1.8 - 0.52 \times 10^{-3} \times R_D \geq 0.4$

$0.52 \times 10^{-3} \times R_D \leq 1.4$

$R_D \leq \dfrac{1.4 \times 10^{3}}{0.52}$

$R_D \leq 2.692\ k\Omega$

$\therefore R_{D,max} = 2.692\ k\Omega$

– (1 mark)

(or)

If it is assumed that small signal is still present

$V_{DS\,min} = V_{O1} = V_{dd} - I_{D1} \cdot R_D = 1.8 - 0.546325 \times 10^{-3} \times R_D$

Now, $0.546325 \times 10^{-3} \times R_D \leq 1.4$

$R_D \leq 2.5625\ k\Omega$

$\therefore R_{D,max} = 2.5625\ k\Omega$