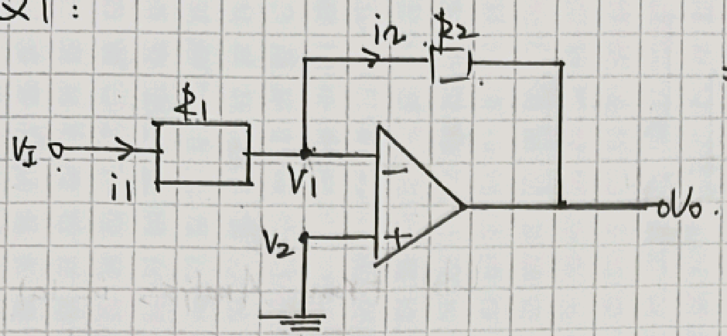
EEE 211 – Assn 3.

Q1:



~~(a)~~

(a) 1° From the virtual short principle, we have:

$V_1 = V_2 \approx 0\ V$.

2° Since the current flowing into the op-amp is assumed to be zero, we have:

$i_1 = i_2$

where by ohm's law.

$i_1 = \frac{V_I - V_1}{R_1}$ and $i_2 = \frac{V_1 - V_o}{R_2}$.

Then, we have:

$\frac{V_o}{V_I} = -\frac{R_2}{R_1}$

That is:

$V_o = \left(-\frac{R_2}{R_1}\right) \cdot V_I = +8.8V$

(b). For an actual Op-Amp. with finite open-loop gain (that means no virtual short)

→ we have

$\frac{V_I - V_1}{R_1} = \frac{V_1 - V_o}{R_2}$.

Since $V_2 = 0$,

→ then $V_d = V_2 - V_1 = -V_1$

→ $V_o = -A_{od} \cdot V_1$

We find.

→ $\frac{V_I}{R_1} = V_1\left(\frac{1}{R_1} + \frac{1}{R_2}\right) - \frac{V_o}{R_2}$

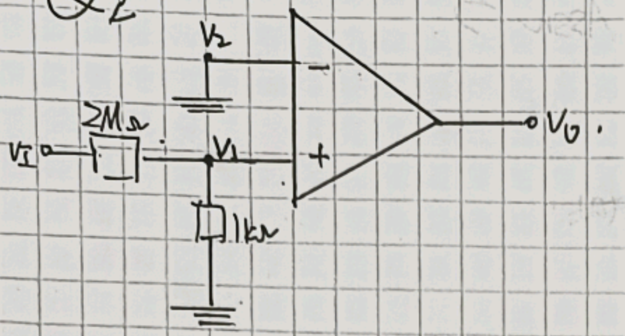
The close-loop gain is then.

→ $A_{cl} = \frac{V_o}{V_I} = \frac{-\frac{R_2}{R_1}}{\frac{1}{A_{od}}\left(1 + \frac{R_2}{R_1}\right) + 1}$

→ $A_{cl} = \frac{-\frac{22k}{1k}}{\frac{1}{5k}\left(1 + \frac{22k}{1k}\right) + 1} = -21.8993$.

→ Finally, $V_o = A_{CL} \cdot V_I = 8.7597\ V$

Q2



(a)

From an op amp with finite loop-gain,

we have: $V_O = A_{od} \cdot V_d$

Since $V_O = -2V$; $A_{od} = 10^4$

then $V_d = \frac{V_O}{A_{od}} = (-2) \times 10^{-4}\ V$ ①

According to the label in schematic.

$\Rightarrow \quad V_d = V_1 - V_2 = V_1$ ②

Apply Ohm's Law

$\Rightarrow \quad V_1 = \frac{1k\Omega}{1k\Omega + 2M\Omega} \cdot V_I$ ③

Combine Equation ①, ②, ③

we have: $V_I = (-2) \times 10^{-4} \times \frac{1k\Omega + 2M\Omega}{1k\Omega}$

$\Rightarrow \quad V_I = -0.40\ V$

(b) From Analysis in (a)

we are able to obtain

$$\begin{cases} V_O = A_{od} \cdot V_d \\ V_d = V_1 \\ V_1 = \frac{1k}{1k+2M} \cdot V_I \end{cases}$$

$\Rightarrow$ then:

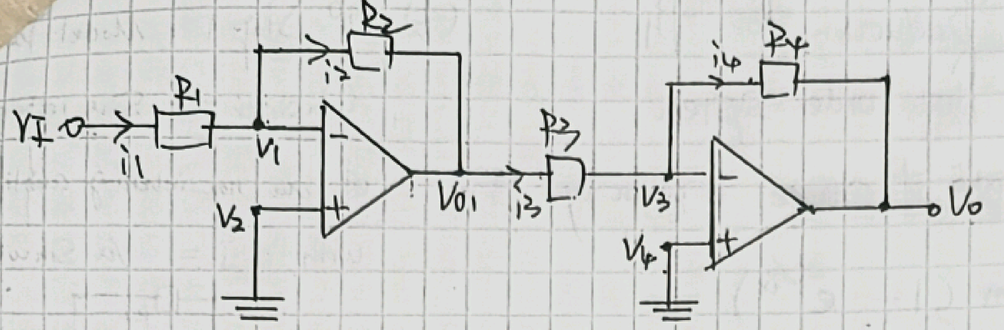
$A_{od} = \frac{V_O}{V_I} \cdot \frac{1k+2M}{1k}$

Since $V_I = 2V$, $V_O = 1V$

$\Rightarrow A_{od} = \frac{1}{2} \cdot \frac{2001}{1}$

$\Rightarrow A_{od} = 1000.5$

Q3



1° Step 1 : Find i_1.

Assume Ideal op-amp (Left)

then we can apply "virtual short".

$\Rightarrow$ that is $V_1 = V_2 = 0$ ①

And virtual open

$\Rightarrow$ we have: $i_1 = i_2$ ②

Apply ohm's law

$\Rightarrow i_1 = \frac{V_I - V_1}{R_1} = \frac{-0.15-0}{10k} = -15\mu A$ ③

2° Step 2 : Find i_2.

Combine ② and ③

$\Rightarrow i_2 = -15\mu A$ ④

3° Step 3 : Find V_{o1}

Apply KVL

$\Rightarrow V_{o1} = V_I - i_1R_1 - i_2R_2$

$\Rightarrow V_{o1} = -0.15 - (-15\mu)\cdot(10k+80k)$

$\Rightarrow V_{o1} = +1.2V$ ⑤

4° Step 4 : Find i_3.

Assume Ideal op-amp (Right)

then we can apply "virtual short"

$\Rightarrow$ that is $V_3 = V_4 = 0$ ⑥

And virtual open

$\Rightarrow$ we have: $i_3 = i_4$ ⑦

Apply ohm's law.

$\Rightarrow i_3 = \frac{V_{o1} - V_3}{R_3} = \frac{1.2-0}{20k} = 60\mu A$ ⑧

5° Step 5 : Find i_4

Combine ⑦ and ⑧

$\Rightarrow i_4 = +60\mu A$ ⑨

6° Step 6 : Find V_o

Apply KVL.

$\Rightarrow V_o = V_3 - i_4R_4$

$\Rightarrow V_o = 0 - 60\mu\cdot 100k$

$\Rightarrow V_o = -6V$ ⑩

7° Summary

$\begin{cases} V_{o1} = 1.2V \\ V_o = -6V \end{cases}$; $\begin{cases} i_1 = -15\mu A \\ i_2 = -15\mu A \end{cases}$; $\begin{cases} i_3 = 60\mu A \\ i_4 = 60\mu A \end{cases}$

Q4

(a) 1° Step 1 : Deduction for f_H

Consider a first order system, its maximum rate of change is given by

$$V_o(t) = V_m(1 - e^{-t/\tau_r}).$$

then its derivative

$$\frac{dV_o(t)}{dt} = \frac{V_m}{\tau_r} e^{-t/\tau_r}$$

$$\Rightarrow \left.\frac{dV_o(t)}{dt}\right|_{max} = SR = \frac{V_m}{\tau_r}.$$

Since $\tau_r = \frac{1}{2\pi f_H}$.

$\Rightarrow$ then $SR = V_m \cdot 2\pi f_H = 5M\ V/s$

$\Rightarrow$ that is $f_H = \frac{SR}{2\pi \cdot V_m} = \frac{5M}{2\pi V_m}$

2° Step 2: Case 1: $V_m = +5V$

$$\Rightarrow f_H = \frac{5M}{2\pi \times 5} = \frac{500}{\pi} kHz = 159.15\ kHz$$

3° Step 3: Case 2: $V_m = +1.5V$

$$\Rightarrow f_H = \frac{5M}{2\pi \times 1.5} = \frac{5000}{3\pi} kHz = 530.52\ kHz.$$

4° Step 4: Case 3: $V_m = +0.4V$

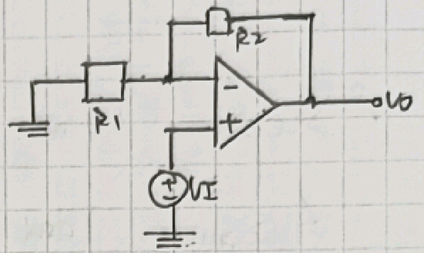
$$\Rightarrow f_H = \frac{5M}{2\pi \times 0.4} = \frac{5}{0.8\pi} MHz = 1.99\ MHz$$

5° Step 5: Summary

$$f_H = \begin{cases} 159.15\ kHz, & \text{when } V_m = +5V \\ 530.52\ kHz, & \text{when } V_m = +1.5V \\ 1.99\ MHz, & \text{when } V_m = +0.4V \end{cases}$$

(b) 1° Step 1 : Model Den[...]

Consider the sine response of an non-inverting amplifier with $v_I = V_a \sin\omega t$



$\Rightarrow$ then $V_o(t) = V_a(1 + \frac{R_2}{R_1})\sin\omega t$

Let $V_m = V_a \cdot (1 + \frac{R_2}{R_1})$

$\Rightarrow V_o(t) = V_m \sin\omega t$.

2° Step 2: Calculations

$$\Rightarrow \frac{dV_o(t)}{dt} = \omega \cdot V_m \cdot \cos\omega t$$

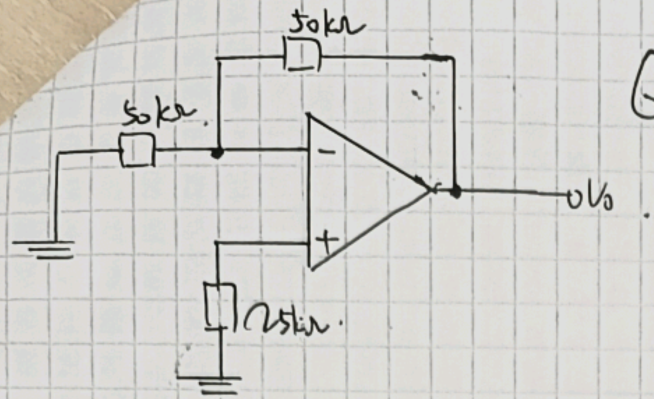
And the slew rate is

$$\Rightarrow SR = \left.\frac{dV_o(t)}{dt}\right|_{max} = \omega \cdot V_m$$

$\Rightarrow$ that is : $V_m = \frac{SR}{\omega}$; $SR = 8V/\mu s$, $\omega = 2\pi f$

$$\Rightarrow V_m = \frac{8M}{2\pi \cdot 250k}$$

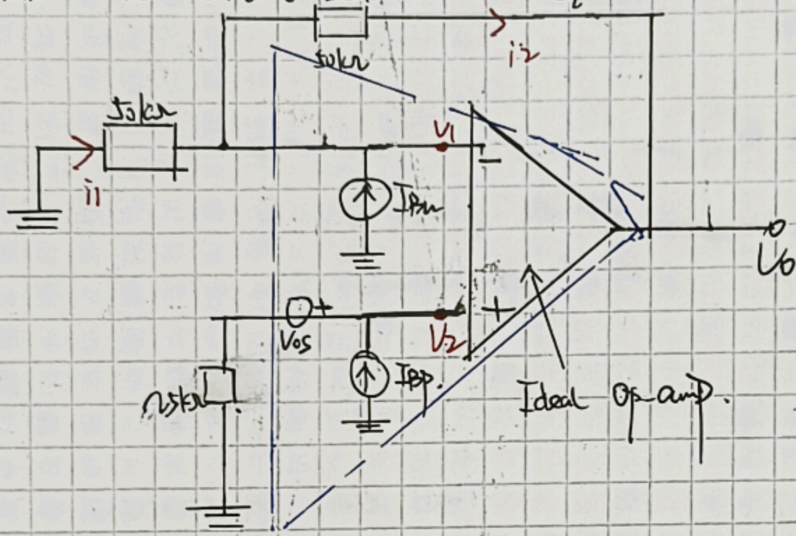
$$\Rightarrow V_m = +5.09\ V$$



Q5.

1° Step 1 : Modelling

Since we have to consider input offset current, then the circuit schematic is equivalent to:



2° Step 2 : I_{Bp} Contribution

Apply Superposition Principle.

⇒ Close / turn off the sources I_{Bn} and V_{os}

and we have: $V_2 = -I_{Bp} \cdot (25k)$.

Since it is an ideal op-amp

⇒ then apply "virtual short principle"

$$\begin{cases} V_1 = V_2 = (-I_{Bp}) \cdot 25k \\ i_1 = i_2 \end{cases}$$

Apply ohm's law

⇒ $V_{oBp} = \frac{50k+50k}{50k} \cdot V_1 = (-I_{Bp}) \cdot 50k$ V. #

2° Step 2 : I_{Bn} Contribution

Assume ideal op-amp and apply similar analysis in Step 1'

⇒ we have: $V_{oBn} = I_{Bn} \cdot 50k$ V.

3° Step 3 : Total Offset Contribution

From the question,

$$\begin{cases} I_B = 0.8\,\mu A \quad ① \\ I_{os} = 0.2\,\mu A \quad ② \end{cases}$$

And we know that

$$\begin{cases} I_B = \frac{I_{Bp}+I_{Bn}}{2} \quad ③ \\ I_{os} = |I_{Bp} - I_{Bn}| \quad ④ \end{cases}$$

then combine ①, ②, ③, ④

$$\Rightarrow \begin{cases} I_{Bp} = 0.9\,\mu A \\ I_{Bn} = 0.7\,\mu A \end{cases} \text{ or } \begin{cases} I_{Bp} = 0.7\,\mu A \\ I_{Bn} = 0.9\,\mu A \end{cases}$$

We also know that

$$\begin{cases} V_{oBp} = (-I_{Bp}) \cdot 50k \\ V_{oBn} = I_{Bn} \cdot 50k \end{cases}$$

$\Rightarrow V_{o\,tot} = V_{oBp} + V_{oBn}$

$\Rightarrow V_{o\text{-}tot} = 50k\,(I_{Bn} - I_{Bp})$

Thus, consider the two solutions,

$\Rightarrow V_{o\text{-}tot} = \pm 0.01$ V