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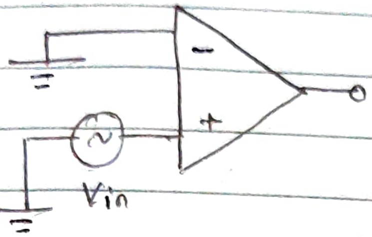
2020522307



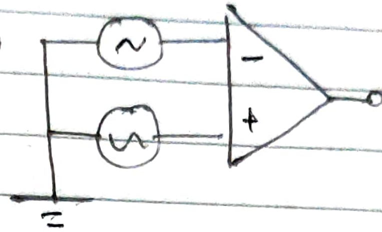
# EC: Assignment 5

Q.1 (Q.2 of Assignment) Identify the type of input mode for each Op-Amp

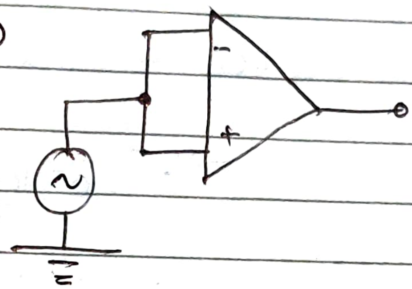
(a)




(b)



(c)



a) Since, one input terminal is grounded and an input signal is applied to other input terminal. The input mode for the Op-Amp is Single-Ended Differential Mode.

b) Since, opposite polarity signals are applied to the inputs. The input mode for the Op-Amp is Double-Ended-Differential Mode.

c) Since, the same input is applied to both the inputs of Op-Amp. The input mode of the Op-Amp is Common Mode.

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Q.2 (Q.4 of Asmnt) The open-loop gain of a certain op-Amp is 175,000. Its common mode gain is 0.18. Determine the CMRR in decibels.

$$\therefore \quad CMRR = \frac{A_{ol}}{A_{cm}}$$

$$\therefore \quad CMRR = \frac{175000}{0.18} = 972222.22$$

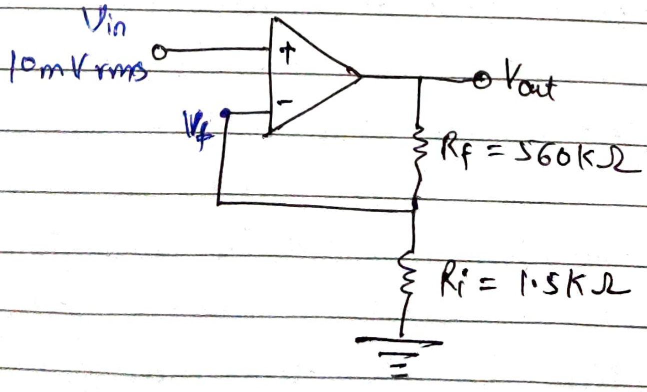
$$\therefore \quad CMRR \text{ in decibels} = 20 \log \left(\frac{A_{ol}}{A_{cm}}\right)$$

$$= 20 \log (972222.22)$$

$$= 119.76 \text{ dB}$$

Q.3 (Q.8 of Asmnt) For the amplifier in the figure, determine the following,

(a) $A_{cl(NI)}$ (b) $V_{out}$ (c) $V_f$




The given circuit is a non-inverting amplifier.

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(a) ∵ closed-loop gain $A_{CL(NI)}$ for non-inverting amplifier is given by,

$$A_{CL(NI)} = \left(1 + \frac{R_f}{R_i}\right)$$

$$\therefore A_{CL(IN)} = \left(1 + \frac{\cancel{560}^{1120}\cancel{K}}{\cancel{1.5}_{3}\cancel{K}}\right)$$

$$A_{CL(IN)} = \frac{1123}{3} = 374.13$$

(b) ∴ $V_{out} = A_{CL(IN)} V_{in}$

$$V_{out} = 374.13 \times 10\,mV$$
$$= 3.7413\,V$$

(c) By Voltage divider Equation,

$$V_f = \frac{R_i}{R_i + R_f} V_{out}$$

$$V_f = \left(\frac{1.5K}{1.5K + 560K}\right) \times V_{out}$$

$$V_f = \frac{1.5}{561.5} \times 3.7413\,V$$

$$V_f = 9.994\,mV$$

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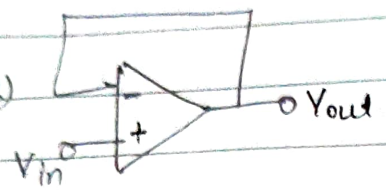
Q.4 (Q.11 of Asgnmnt) Find the gain of each amplifier

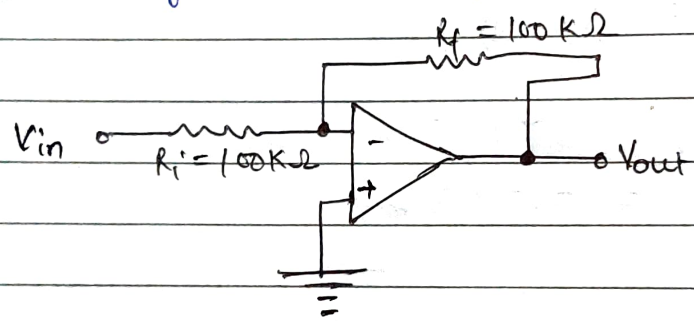
(a)




The given circuit is a voltage follower circuit. Since, it is a non-inverting amplifier with voltage in output equal to voltage at input.

hence, the gain is unity (+1)

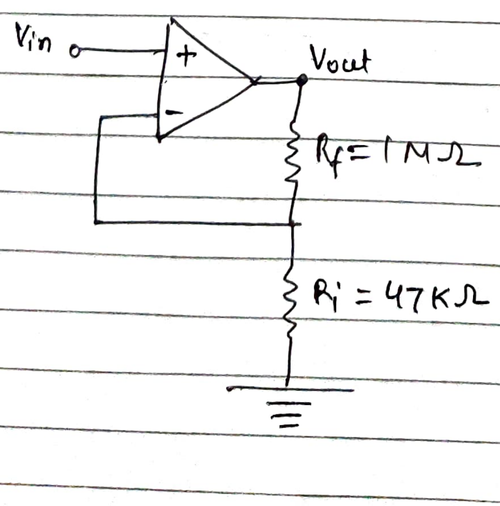
b)




This circuit is an inverting amplifer whose voltage gain is given by

$$\text{voltage gain} = -\frac{R_f}{R_i} = -\frac{100K\Omega}{100K\Omega} = -1$$

c)



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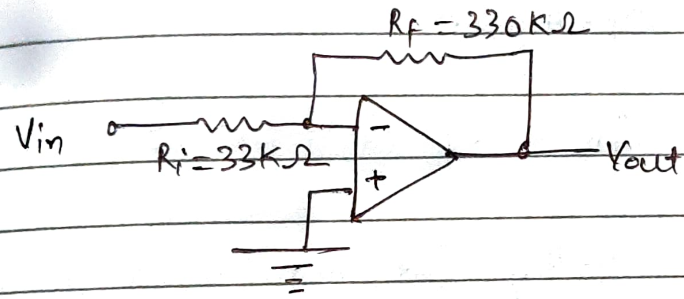
The circuit implies an non-inverting amplifier.
∴ the voltage gain is given by,

$$\text{voltage gain} = \left(1 + \frac{R_f}{R_i}\right)$$

$$= \left(1 + \frac{10^6\,\Omega}{47 \times 10^3\,\Omega}\right)$$

$$= 22.277$$

d)




The circuit implies an inverting amplifier.
∴ the voltage gain is given by

$$\text{voltage gain} = -\frac{R_f}{R_i}$$

$$= -\frac{330\,K\Omega}{33\,K\Omega}$$

$$= -10$$

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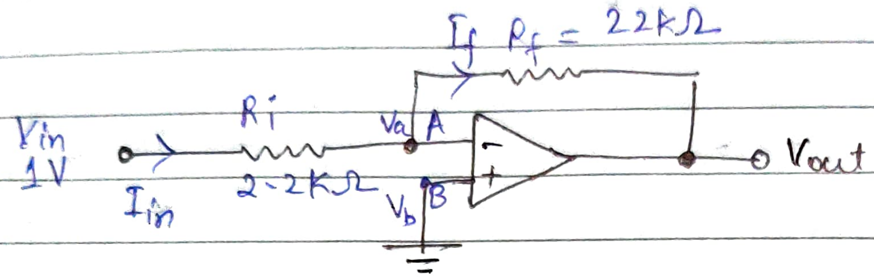
Q.5 (13 of Asgnmnt) Determine the approximate values ~~of~~ for each of the following quantities
(a) $I_{in}$ (b) $I_f$ (c) $V_{out}$ (d) closed loop gain.




Since, no current flows through the input terminals of Op-Amp.

$$\therefore \quad I_{in} = I_f \qquad \text{—(1)}$$

and since, the voltage at both input terminals of Op-Amp is equal (concept of virtual ground)

$$\therefore \quad V_a = V_b = 0 \qquad (\because \text{Node } b \text{ is grounded})$$

(a) $\therefore$ $$I_{in} = \frac{V_{in} - V_a}{R_i} = \frac{1 - 0}{2.2\,K\Omega}$$

$$\therefore \boxed{I_{in} = 0.4545 \text{ mA}}$$

(b) $\because$ $I_f = I_{in}$

$$\therefore \boxed{I_f = 0.4545 \text{ mA}}$$

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(c) Using Nodal Analysis at node A,

$$\frac{V_a - V_{in}}{R_i} + \frac{V_a - V_{out}}{R_f} = 0$$

$$\frac{-1}{(2.2\,k\Omega)} + \frac{(-V_{out})}{(22\,k\Omega)} = 0 \qquad (\because V_a = 0)$$

$$V_{out} = -\frac{\cancel{22\,k\Omega}^{\,10}}{\cancel{2.2\,k\Omega}} \times 1\,V$$

$$\boxed{V_{out} = -10\,V}$$

(d) Closed-loop gain $= \dfrac{V_{out}}{V_{in}} = \dfrac{-10V}{1V}$

$$\therefore \boxed{A_{CL} = -10}$$

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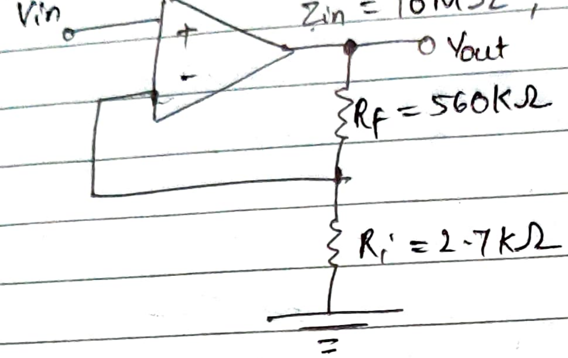
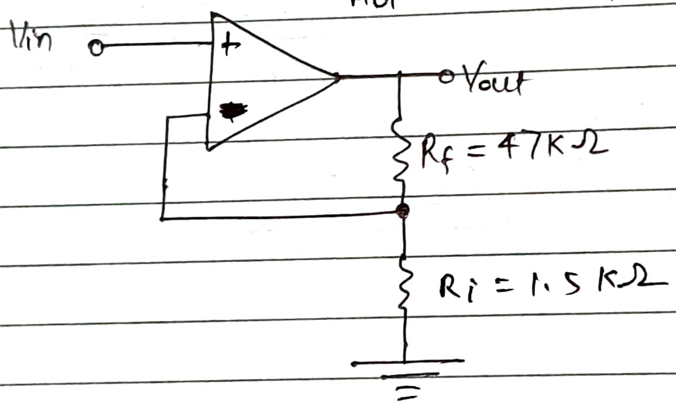
Q.6 (14 of Asnmnt) Determine the input and output impedances for each amplifier configuration.

(a) $A_{ol} = 175000$

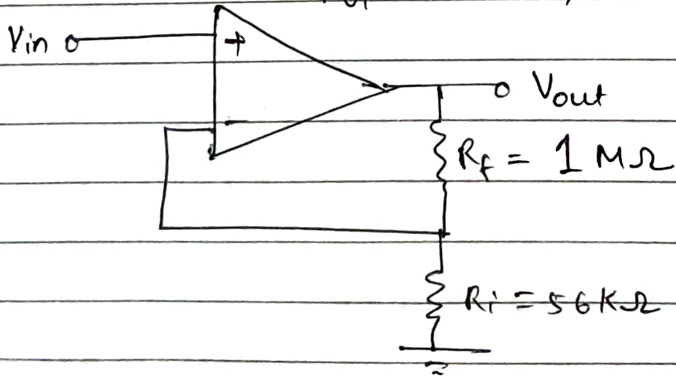
$Z_{in} = 10 M\Omega$, $Z_{out} = 75\Omega$




(b) $A_{ol} = 200000$, $Z_{in} = 1 M\Omega$, $Z_{out} = 25\Omega$




$A_{ol} = 50000$, $Z_{in} = 2 M\Omega$, $Z_{out} = 50\Omega$

(c)



All the three circuits are of non-inverting amplifiers. The input and output impedance for non-inverting amplifier is given by,

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$$Z_{in(NI)} = (1 + A_{ol} B) Z_{in}$$

$$Z_{out(NI)} = \frac{Z_{out}}{1 + A_{ol} B}$$

where B is attenuation factor, $B = \frac{R_i}{R_i + R_f}$

(a) $B = \frac{2.7K}{2.7K + 560K} = 0.0048$

$\therefore Z_{in(NI)} = \{1 + (175000) \times (0.0048)\}(10\,M\Omega)$

$= 8410\,M\Omega = 8.41\,G\Omega$

and $Z_{out(NI)} = \frac{(75\,\Omega)}{\{1 + (175000) \times (0.0048)\}} = 89.1\,m\Omega$

$$\boxed{\begin{aligned} \therefore Z_{in(NI)} &= 8.41\,G\Omega \\ Z_{out(NI)} &= 89.1\,m\Omega \end{aligned}}$$

(b) $B = \frac{1.5K}{1.5K + 47K} = 0.0309$

$\therefore Z_{in(NI)} = \{1 + (200000) \times (0.0309)\}(1\,M\Omega)$

$= 6181\,M\Omega = 6.18\,G\Omega$

and, $Z_{out(NI)} = \frac{(25\,\Omega)}{(6181)} = 4.04\,m\Omega$

$$\boxed{\begin{aligned} \therefore Z_{in(NI)} &= 6.18\,G\Omega \\ Z_{out(NI)} &= 4.04\,m\Omega \end{aligned}}$$

(c) $B = \dfrac{56K}{56K + 1000K} = 0.053$

$\therefore Z_{in(NI)} = \{1 + (50000)(0.053)\}(2M\Omega)$

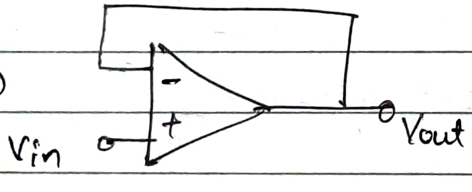
$= 5302\ M\Omega = 5.302\ G\Omega$

and $Z_{out(NI)} = \dfrac{(50\Omega)}{2651} = 18.86\ m\Omega$

$$\boxed{\begin{aligned} \therefore\ Z_{in(NI)} &= 5.302\ G\Omega \\ Z_{out(NI)} &= 18.86\ m\Omega \end{aligned}}$$

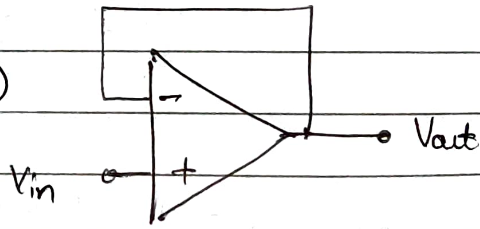
Q.7 (15 of Asgnment) Repeat problem 6 (14 of Asgnmnt) for the circuit shown

(a)



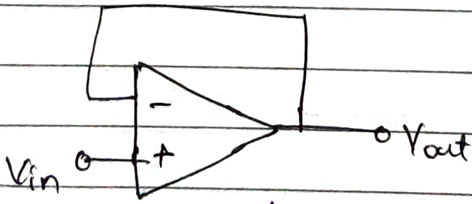

$A_{ol} = 220000$
$Z_{in} = 6\ M\Omega$
$Z_{out} = 100\ \Omega$

(b)




$A_{ol} = 100000$
$Z_{in} = 5\ M\Omega$
$Z_{out} = 60\Omega$

(c)




$A_{ol} = 50000$
$Z_{in} = 800\ k\Omega$
$Z_{out} = 75\ \Omega$

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The circuit in (a), (b) and (c) are voltage followers circuits. The input and output impedance for the voltage follower circuit is given by

$$Z_{in(VF)} = (1 + A_{ol}) Z_{in}$$

and $$Z_{out(VF)} = \frac{Z_{out}}{1 + A_{ol}}$$

(a) $$Z_{in(VF)} = (1 + 220000)(6\,M\Omega)$$

$$= 1320006\,M\Omega = 1320\,G\Omega$$

and $$Z_{out(VF)} = \frac{100\,\Omega}{220001} = 454.5\,\mu\Omega$$

$$\boxed{\therefore\ Z_{in(VF)} = 1320\,G\Omega \quad Z_{out(VF)} = 454.5\,\mu\Omega}$$

(b) $$Z_{in(VF)} = (1 + 100000)(5\,M\Omega) = 500005\,M\Omega$$
$$= 500\,G\Omega$$

$$Z_{out(VF)} = \frac{60\,\Omega}{100001} = 599.9\,\mu\Omega$$

$$\boxed{\therefore\ Z_{in(VF)} = 500\,G\Omega \quad Z_{out(VF)} = 599.9\,\mu\Omega}$$

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(c) $Z_{in(VF)} = (1 + 50000)(800 k\Omega)$
$= 40000800 \ k\Omega$
$= 40 \ G\Omega$

$Z_{out}(VF) = \frac{75 \Omega}{50001} = 1.499 \ m\Omega$

$$\boxed{\begin{aligned} \therefore \ Z_{in}(VF) &= 40 \ G\Omega \\ Z_{out}(VF) &= 1.499 \ m\Omega \end{aligned}}$$

Q.8 (17 of Asgnmnt) A voltage-follower is driven by a voltage source with a source resistance 75 Ω.

(a) What value of compensating resistor is required for bias current, and where should the resistor be placed?

(b) If the two input currents after compensation are 42 μA and 40 μA, what is the output error voltage.

a) The value of compensating resistor should be equal to the source resistor $R_s$ and it should be placed in the feedback path.

b) the two input currents are 42 μA and 40 μA.

$\therefore$ Input offset current $(I_{os}) = |42 \mu A - 40 \mu A|$
$= 2 \mu A$

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(b) $\therefore$ $V_{OUT(error)} = A_v I_{os} R$

$= 1 \times 2\mu A \times 75 \Omega$

$\because A_v = 1$ for voltage follower

$$\boxed{V_{out(error)} = 150 \mu V}$$

Q.9 (21 of Asgnmnt) Determine the attenuation of an RC lag circuit with $f_c = 12 KHz$ for each of the following frequencies

(a) 1KHz (b) 5 KHz (c) 12 KHz (d) 20 KHz
(e) 100 KHz

(a) Attenuation of RC lag circuit $\left(\frac{V_{out}}{V_{in}}\right) = \frac{1}{\sqrt{\left(1+\left(\frac{f}{f_c}\right)^2\right)}}$

$$= \frac{1}{\sqrt{1+\left(\frac{1K}{12K}\right)^2}}$$

$= 0.9966 = 0.997$

(b) $\frac{V_{out}}{V_{in}} = \frac{1}{\sqrt{1+\left(\frac{5K}{12K}\right)^2}} = \frac{1}{\sqrt{\frac{169}{144}}}$

$= \frac{12}{13} = 0.923$

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(c) $\dfrac{V_{out}}{V_{in}} = \dfrac{1}{\sqrt{1+\left(\frac{12K}{12K}\right)^2}} = 0.7071$

(d) $\dfrac{V_{out}}{V_{in}} = \dfrac{1}{\sqrt{1+\left(\frac{20K}{12K}\right)^2}} = \dfrac{1}{\sqrt{\frac{34}{9}}} = 0.5145$

(e) $\dfrac{V_{out}}{V_{in}} = \dfrac{1}{\sqrt{1+\left(\frac{100K}{12K}\right)^2}} = \dfrac{1}{\sqrt{\frac{634}{9}}} = 0.11914$

Q.10 (24 of Assign) An RC lag circuit has a critical frequency of 8.5 KHz. Determine the phase shift for each frequency and plot a graph of its phase angle versus frequency.

(a) 100 Hz (b) 400 Hz (c) 850 Hz
(d) 8.5 KHz (e) 25 KHz (f) 85 KHz

The phase shift is given by $\theta = -\tan^{-1}\left(\dfrac{f}{f_c}\right)$

Here, $f_c = 8.5$ KHz

(a) $f = 100$ Hz

$$\theta = -\tan^{-1}\left(\frac{100}{8500}\right) = -0.674^\circ$$

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(b) $f = 400\,Hz$

$$\theta = -\tan^{-1}\left(\frac{400}{8500}\right) = -2.694^{\circ}$$

(c) $f = 850\,Hz$

$$\theta = -\tan^{-1}\left(\frac{850}{8500}\right) = -5.716^{\circ}$$

(d) $f = 8.5\,KHz$

$$\theta = -\tan^{-1}\left(\frac{8500}{8500}\right) = -45^{\circ}$$

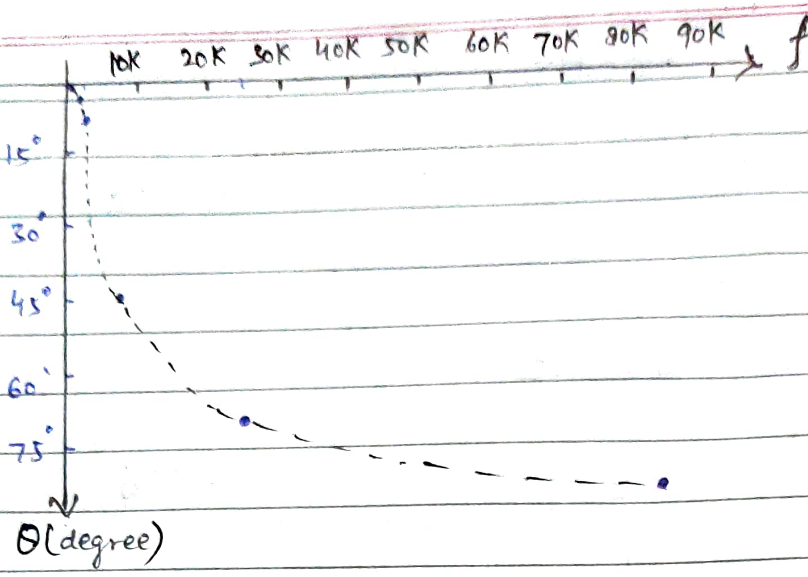
(e) $f = 25\,KHz$

$$\theta = -\tan^{-1}\left(\frac{25000}{8500}\right) = -71.222^{\circ}$$

(f) $f = 85\,KHz$

$$\theta = -\tan^{-1}\left(\frac{85000}{8500}\right) = -84.289^{\circ}$$

The graph of $\theta$ versus $f$ is given on next page




Q.11 (28 of Asgnmnt) A certain amplifier has an open-loop gain in midrange of 180,000 and an open critical frequency of 1500 Hz. If the attenuation of the feedback path is 0.0015, what is closed loop bandwidth?

$$\because \quad BW_{cl} = BW_{ol}\left(1 + BA_{ol(mid)}\right)$$

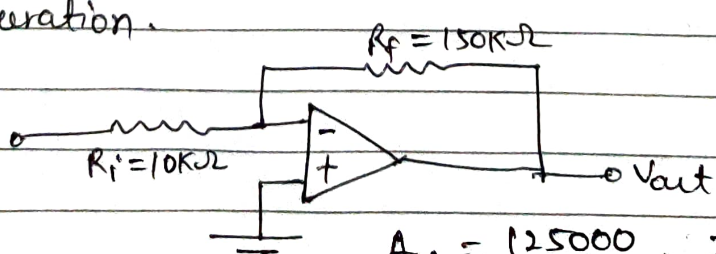
$$\therefore \quad BW_{cl} = 1500\left[1 + (0.015)(180000)\right]$$

$$BW_{cl} = 4.05 \text{ MHz}$$

Hence, close loop bandwidth is 4.05 MHz.

Q.12 (16 of Assign.) Determine the input and output impedances for each amplifier configuration.

(a)




$A_{ol} = 125000$, $Z_{in} = 1.5 M\Omega$,

$Z_{out} = 40 \Omega$

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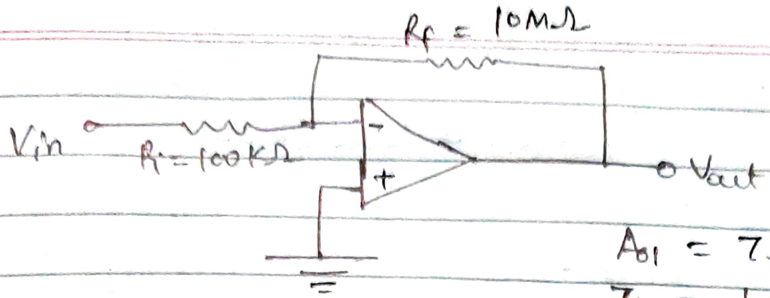
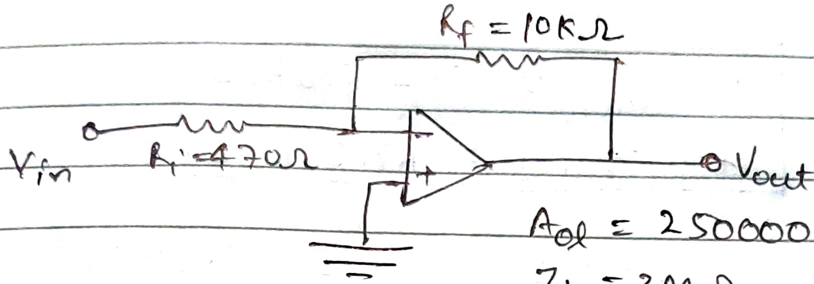
(b)




$A_{ol} = 75000$

$Z_{in} = 1M\Omega$, $Z_{out} = 50\Omega$

(c)




$A_{ol} = 250000$

$Z_{in} = 3M\Omega$, $Z_{out} = 70\Omega$

The amplifier configurations in (a), (b) and (c) are inverting. The input and output impedance for inverting amplifier is given by:

$$Z_{in(I)} \cong R_i$$

$$Z_{out(I)} = \frac{Z_{out}}{1 + A_{ol} B}$$

where $B = \dfrac{R_i}{R_i + R_f}$

(a) $B = \dfrac{10K\Omega}{10K\Omega + 150K\Omega} = 0.0625$

$$\therefore Z_{out(I)} = \frac{40\Omega}{1 + (125000)(0.0625)} = 5.119\ m\Omega$$

$$\boxed{\begin{aligned} \therefore Z_{in(I)} &\cong R_i = 10K\Omega \\ Z_{out(I)} &= 5.119\ m\Omega \end{aligned}}$$

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(b) $$B = \frac{100\,K\Omega}{100\,K\Omega + 10000\,K\Omega} = 0.0099$$

$$\therefore Z_{out(I)} = \frac{50\,\Omega}{1 + (75000)(0.0099)} = 67.25\,m\Omega$$

$$\boxed{\begin{array}{l} \therefore Z_{in(I)} \cong R_i = 100\,K\Omega \\ \text{and } Z_{out(I)} = 67.25\,m\Omega \end{array}}$$

(c) $$B = \frac{470\,\Omega}{470\,\Omega + 10000\,\Omega} = 0.04489$$

$$\therefore Z_{out(I)} = \frac{70\,\Omega}{1 + (250000)(0.04489)} = 6.237\,m\Omega$$

$$\boxed{\begin{array}{l} \therefore Z_{in(I)} \cong R_i = 470\,\Omega \\ Z_{out(I)} = 6.237\,m\Omega \end{array}}$$

Q.13 (6 of Assign) Determine the bias current, $I_{bias}$, given that the input currents to an Op-Amp are 8.4 uA and 7.8 uA. Distinguish between input bias currents and input offset current, and then calculate the input offset current.

Input Bias Current :- The input bias current is the dc current required by the inputs of the amplifier to properly operate the first stage. By definition, the input bias current is average of both

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input currents and is calculated as

$$I_{bias} = \frac{I_1 + I_2}{2}$$

Input Offset Current :- Ideally, the two input bias currents are equal, and thus their difference is zero. In a practical Op-Amp, the bias currents are not exactly equal.
The input offset current, $I_{os}$, is the difference of the input bias currents, expressed as an absolute value.

$$I_{os} = |I_1 - I_2|$$

$\therefore$ bias current, $I_{Bias} = \frac{8.4\,\mu A + 7.8\,\mu A}{2} = 8.1\,\mu A$

and, input offset current, $I_{os} = |8.4\,\mu A - 7.8\,\mu A|$
$= 0.6\,\mu A.$

Q.14 (20 of Assign) What is input offset voltage of an Op-Amp, if a DC ~~current~~ output voltage of 35 mV is measured when the input voltage is zero? The Op-Amp's open loop gain is specified to be 200,000.

given $V_{OUT(error)} = 35\,mV$

$\because A_{ol} V_{os} = V_{OUT(error)}$

$\therefore V_{os} = \frac{V_{OUT(error)}}{A_{ol}} = \frac{35\,mV}{200000} = 175\,nV$

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Hence, the offset voltage of Op-Amp is 175 nV.

Q.15 (22 of Assign) The mid range open loop gain of a certain Op-Amp is 80000. If the open loop critical frequency is 1KHz, what is open loop gain at each of the following frequencies?

(a) 100 Hz (b) 1KHz (c) 10 KHz
(d) 1 MHz.

The open loop gain ($A_{ol}$) is given by

$$A_{ol} = \frac{A_{ol(mid)}}{\sqrt{1+\frac{f^2}{f_c^2}}}$$

given, $f_c = 1KHz$ and $A_{ol(mid)} = 80000$.

(a) ∴ $A_{ol} = \frac{80000}{\sqrt{1+\left(\frac{100}{1000}\right)^2}} = \frac{80000 \times 10}{\sqrt{101}}$

$A_{ol} = 79602.48$

(b) $A_{ol} = \frac{80000}{\sqrt{1+\left(\frac{1000}{1000}\right)^2}} = 56569.085$

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(c) $$A_{oL} = \frac{80000}{\sqrt{1+\left(\frac{10}{1}\right)^2}} = 7960.357$$

(d) $$A_{oL} = \frac{80000}{\sqrt{1+\left(\frac{1000}{1}\right)^2}} = \frac{80000}{316.229} = 252.98$$