

ESE 2025

Main Examination

UPSC ENGINEERING SERVICES EXAMINATION

Topicwise
**Conventional
Practice Questions**

Electrical Engineering

PAPER-II





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ESE Main Examination • Conventional Practice Questions : Electrical Engineering PAPER-II

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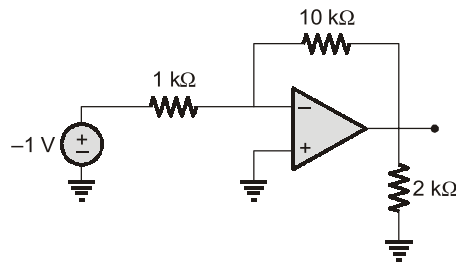
1

Analog Electronics

1. Operational Amplifiers

Level-1

- 1.1 (a) For the circuit shown, find the currents through all branches and the voltages at all nodes.
 (b) Since the current supplied by the OP-AMP is greater than the current drawn from the input signal source, where does the additional current come from. (10 Marks)



Solution:

For an inverting amplifier as we know,

$$\frac{V_0}{V_i} = \frac{-R_2}{R_1}$$

$$\Rightarrow V_0 = \frac{-R_2}{R_1} \times V_i$$

$$V_0 = \left(\frac{-10}{1}\right)(-1) = 10 \text{ volts}$$

i_2 can be calculated as

$$i_2 = \frac{V_0}{2K} = 5 \text{ mA}$$

also, $i_1 = i_3 = \frac{V_0}{10K} = 1 \text{ mA}$

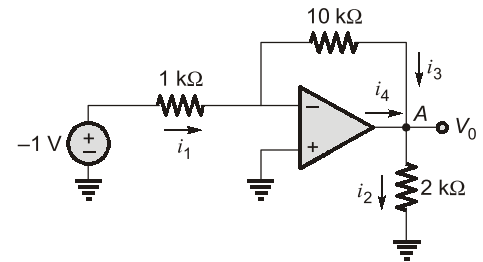
by KCL at point A,

$$i_4 + i_3 = i_2$$

Hence, $i_4 = i_2 - i_3$

$$i_4 = (5 - 1) \text{ mA} = 4 \text{ mA}$$

Hence the additional current comes from the output of the OP-AMP.



- 1.2 An inverting OP-AMP circuit for which the required gain is -50 V/V uses an OP-AMP whose open loop gain is only 200 V/V . If the larger resistor used is $100 \text{ k}\Omega$, to what must the smaller be adjusted? With what resistor must a $2 \text{ k}\Omega$ resistor connected to the input be shunted to achieved this goal?

(Note: A resistor R_a is said is to be shunted by resistor R_b when R_b is placed in parallel with R_a)

(10 Marks)

Solution:

By drawing the figure according to the question

Let the gain of OP-AMP is $A = 200 \text{ V/V}$

$$\therefore V_1 = \frac{-V_0}{A} = \frac{-V_0}{200}$$

and overall close loop gain,

$$\frac{V_0}{V_i} = -50 \text{ V/V}$$

by using KCL at point P :

$$\frac{V_i - \left(\frac{-V_0}{A}\right)}{R_1} = \frac{\left(\frac{-V_0}{A} - V_0\right)}{100K}$$

$$\Rightarrow R_1 = \frac{100K \left[V_i + \frac{V_0}{A} \right]}{- \left[V_0 + \frac{V_0}{A} \right]} = \frac{100K \left[\frac{-V_0}{50} + \frac{V_0}{200} \right]}{- \left[V_0 + \frac{V_0}{200} \right]}$$

$$R_1 = 100K \times \frac{3}{201} = 1.49 \text{ k}\Omega$$

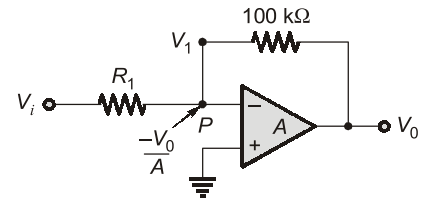
as given in question shunt resistor is R_a ,

and $R_a \parallel 2 \text{ k}\Omega = 1.49 \text{ K}$

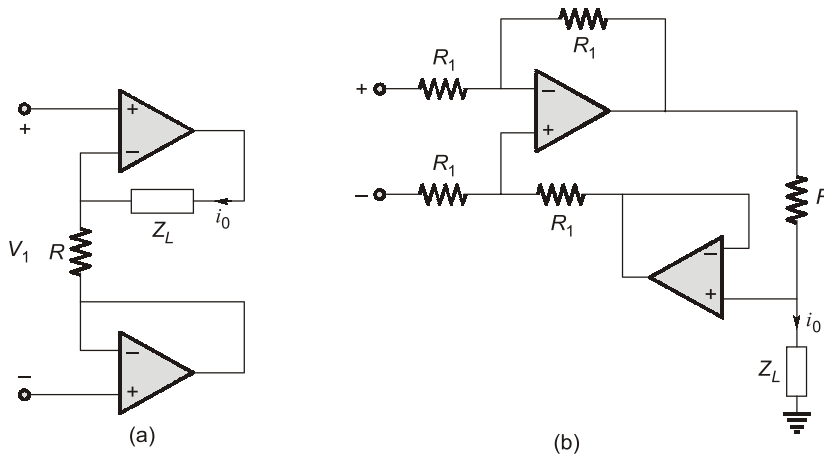
So, $\frac{R_a \times 2K}{R_a + 2K} = 1.49 \text{ K}$

by solving above equation we will get

$$R_a = 5.84 \text{ k}\Omega$$



1.3 The two circuits in figures are intended to function as voltage to current converters, that is, they supply the load impedance Z_L with a current proportional to V_1 and independent of the value of Z_L . Show that this is indeed the case, and find for each circuit i_0 as a function of V_1 . Comment on the differences between the two circuits.



(12 Marks)

Solution:

From figure (a):

Since input current for the Op-amp is zero hence V_i appears across the resistance R .

So,
$$i_0 \approx \frac{V_i}{R}$$

From figure (b):

as

$$V_P = Z_L i_0$$

Using superposition,

$$V_I = V_1 - V_2$$

Considering V_1 only

$$V_B = \frac{V_D}{2} = \frac{Z_L i_{01}}{2}$$

KCL at point,

$$\frac{V_1 - \frac{Z_L i_{01}}{2}}{R_1} = \frac{\frac{Z_L i_{01}}{2} - i_{01}(Z_L + R)}{R_1}$$

So,
$$V_1 = i_{01} R \Rightarrow i_{01} = \frac{V_1}{R}$$

Considering $(-V_2)$ only

$$V_B = \frac{-V_2 + Z_L i_{02}}{2} \tag{by super position}$$

$$V_A = \frac{i_{02} \times (R + Z_L)}{2}$$

as

$$V_A = V_B \text{ hence}$$

$$-V_2 + Z_L i_{02} = i_{02} R + i_{02} Z_L$$

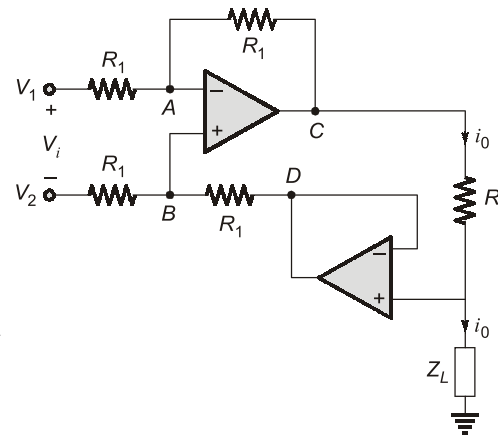
$$-V_2 = i_{02} R$$

$$\Rightarrow i_{02} = \frac{-V_2}{R}$$

Total current is :

$$i_0 = i_{01} + i_{02} = \frac{V_1}{R} - \frac{V_2}{R} = \frac{V_I}{R}$$

Circuit in figure (a) has infinite input while the circuit (b) has finite input resistance with one side of Z_L is grounded.



1.4 A differentiator utilizes an ideal op-amp, a 10 kΩ resistor and a 0.01 μF capacitor.

- (a) What is the frequency f_0 (in Hz) at which its input and output sine-wave signals have equal magnitude?
- (b) What is the output signals for a 1 volt peak to peak sine wave input with frequency equal to $10f_0$? (10 Marks)

Solution:

(a) We know that for a differentiator

$$\frac{V_0}{V_i}(s) = -SRC = -S \times 0.01 \times 10^{-6} \times 10 \times 10^3 = -10^{-4} S$$

$$\frac{V_0}{V_i}(j\omega) = -j\omega(10^{-4})$$

$$\left| \frac{V_0}{V_i} \right| = -10^{-4} \omega$$

When $\omega = 10^4$ rad/s

then $\left| \frac{V_0}{V_i} \right| = 1$

So, $2\pi f = 10^4$

So $f = 1.59$ kHz

- (b) When frequency will be 10 times then the output will be 10 times as large as the input 10 volt peak to peak.
 (-j) means the output lags the input by 90°
 So $V_0(t) = -5 \sin(10^5 t + 90^\circ)$ Volts

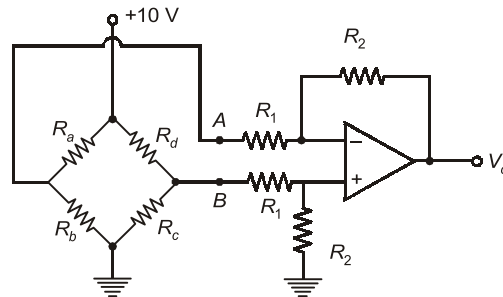
1.5 Consider the circuit shown in figure. The circuit uses an ideal operational amplifier. Assuming that the impedances at nodes A and B do not load the preceding bridge circuit, calculate the output voltage V_o .

(a) when $R_a = R_b = R_c = R_d = 10$ ohms.

(b) when $R_a = R_b = R_c = 10$ ohms and $R_d = 120$ ohms.

$$R_2 = 12 \text{ k}\Omega$$

$$R_1 = 10 \text{ k}\Omega$$



(5 Marks)

Solution:

(a)
$$V_A = 10 \times \frac{R_b}{R_a + R_b} = 10 \times \frac{100}{100 + 100} = 5 \text{ V}$$

$$V_B = \frac{10 R_C}{R_C + R_D} = 10 \times \frac{100}{100 + 100} = 5 \text{ V}$$

Given op-amp is a differential amplifier

$$\text{So, } V_o = \frac{R_2}{R_1} (V_B - V_A) = \frac{12\text{k}}{10\text{k}} (5 - 5) = 0 \text{ V}$$

(b)
$$V_A = 10 \times \frac{R_b}{R_d + R_b} = 10 \times \frac{100}{100 + 100} = 5 \text{ V}$$

$$V_B = 10 \times \frac{R_c}{R_c + R_d} = 10 \times \frac{100}{100 + 120} = 4.55 \text{ V}$$

$$V_o = \frac{R_2}{R_1} (V_B - V_A) = \frac{12\text{k}}{10\text{k}} (4.55 - 5) = -0.55 \text{ V}$$

Level-2

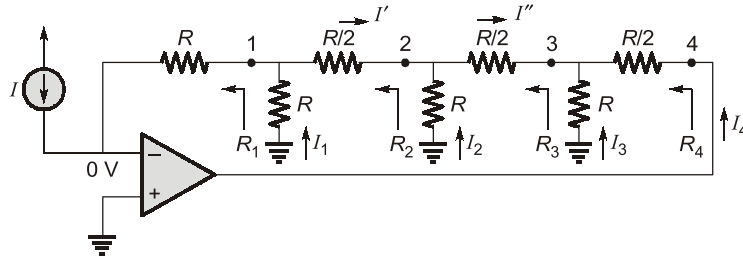
1.6 In the circuit given in the figure,

(a) Find the resistances looking into node 1, R_1 ; node 2, R_2 ; node 3, R_3 ; and node 4, R_4 :

(b) Find the current I_1 , I_2 , I_3 and I_4 in terms of the input current I .

(c) Find the voltages at nodes 1, 2, 3, 4 that is V_1 , V_2 , V_3 and V_4 in terms of (IR)

(15 Marks)



Solution:

(a) From the figure:

$$R_1 = R$$

R_2 can be calculated as:

$$R_2 = (R \parallel R) + \frac{R}{2} = R$$

$$R_3 = (R_2 \parallel R) + \frac{R}{2} = R$$

$$R_4 = (R_3 \parallel R) + \frac{R}{2} = (R \parallel R) + \frac{R}{2} = R$$

(b) As,

$$V = IR$$

So,

$$V_1 = I_1 R$$

and

$$I_1 = I$$

$$I' = I + I = 2I$$

By KVL at node-1

$$V_1 + 2I \left(\frac{R}{2} \right) = RI_2$$

$$I_R + I_R = RI_2$$

So,

$$I_2 = 2I$$

$$I'' = I_2 + I' = 4I$$

By KVL at node-2

$$V_2 + 4I \times \frac{R}{2} = RI_3$$

$$R \times 2I + 4I \times \frac{R}{2} = RI_3$$

hence,

$$I_3 = 4I$$

and

$$I_4 = -[4I + 4I] = -8I$$

(c)

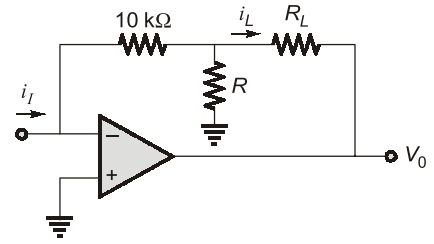
$$V_1 = -I_1 R = -IR$$

$$V_2 = -I_2 R = -2IR$$

$$V_3 = -I_3 R = -4IR$$

$$V_4 = -I_3 R + I_4 \frac{R}{2} = -4IR - \frac{8IR}{2} = -8IR$$

- 1.7 Assuming the Op-amp to be ideal, it is required to design the circuit shown in figure, to implement a current amplifier with gain $i_L/i_I = 20$ A/A



- Find the required value of R .
- If $R_L = 1 \text{ k}\Omega$ and the op-amp operates in an ideal manner so long as V_0 is in the range $\pm 12 \text{ V}$. What range of i_I is possible?
- What is the input resistance of the current amplifier? If the amplifier is fed with a current source having a current of 1 mA and a source resistance of $10 \text{ k}\Omega$ find i_L .

(15 Marks)

Solution:

- (a) Given that:

$$\frac{i_L}{i_I} = 20$$

$$\Rightarrow i_L = 20i_I$$

by KVL :

$$\begin{aligned} -10 \text{ k}\Omega \times i_I &= R(i_I - i_L) \\ R &= \frac{10\text{K} \times i_I}{20i_I - i_I} = 0.53 \text{ k}\Omega \end{aligned}$$

- (b) Given
- $R_L = 1 \text{ k}\Omega$
- and range of
- V_0
- is
- $-12 \leq V_0 \leq 12 \text{ V}$

by KVL:

$$\begin{aligned} V_0 &= R_L i_L + (10\text{K})i_I \\ &= i_I \left[R_L \frac{i_L}{i_I} + 10\text{K} \right] \end{aligned}$$

$$V_0 = i_I [1\text{k} \times 20 + 10\text{k}]$$

$$V_0 = (30 i_I) \text{K}$$

$$i_I = \frac{V_0}{30}$$

$$\text{So, } \frac{-12}{30} \leq i_I \leq \frac{12}{30}$$

$$\Rightarrow -0.4 \text{ mA} \leq i_I \leq 0.4 \text{ mA}$$

- (c) Input resistance of given current amplifier

$$R_I = \frac{V_I}{i_I} = \frac{0}{i_I} = 0$$

as by diagram,

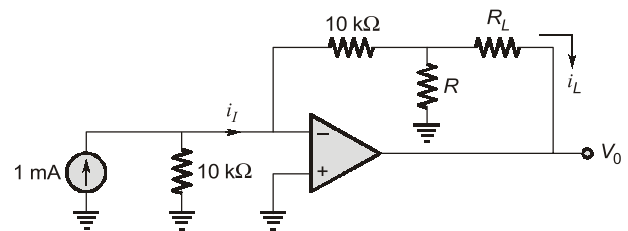
$$i_I = 1 \text{ mA}$$

and

$$i_L = 20 i_I$$

So,

$$i_L = 20 \text{ mA}$$



- 1.8 A designer wanting to achieve a stable gain of 100 V/V at 5 MHz , considers her choice of amplifier topologies. What unity-gain frequency would a single operational amplifier require to satisfy her need? Unfortunately, the best available amplifier has an f_T of 40 MHz .

- How many such amplifiers connected in a cascade of identical non inverting stages would she need to achieve her goal?
- What is the 3-dB frequency of each step she can use?
- What is the overall 3-dB frequency?

(15 Marks)

Solution:

As we know that, $f_T = 100 \times 5 = 500 \text{ MHz}$

If we use single Op-amp

But given in question that best Op-amp has $f_T = 40 \text{ MHz}$, so the possible closed loop gain at 5 MHz is

$$(A) = \frac{40}{5} = 8 \text{ V/V}$$

as we need overall gain as 100 V/V, so at least three such amplifiers are cascaded,

Now if each of 3-stages has closed loop gain K , then its 3-dB frequency will be $\frac{40}{K} \text{ MHz}$.

So for each stage the closed loop gain is

$$A = \frac{K}{\sqrt{1 + \left(\frac{f}{f_{3dB}}\right)^2}}$$

overall gain is 100 so,

$$100 = \left| \frac{K}{\sqrt{1 + \left(\frac{K}{8}\right)^2}} \right|^3$$

by solving $K = 5.7$

So for each cascading stage,

$$f_{3dB} = \frac{40}{5.7}$$

$$f_{3dB} = 7 \text{ MHz}$$

So for overall amplifier total f_T is

$$\left| \frac{5.7}{\sqrt{1 + \left(\frac{f_T}{7}\right)^2}} \right|^3 = \frac{(5.7)^3}{\sqrt{2}}$$

$$f_T = 3.6 \text{ MHz}$$

1.9 A particular inverting amplifier with nominal gain of -100 V/V uses an imperfect Op-amp in conjunction with $100 \text{ k}\Omega$ and $10 \text{ M}\Omega$ resistors. The output voltage is found to be $+9.31 \text{ V}$ when measured with the input open and 9.09 V with the input grounded.

- (a) What is the bias current of this amplifier? In what direction does it flow?
- (b) Estimate the value of the input offset voltage.
- (c) A $10 \text{ M}\Omega$ resistor is connected between the positive input terminal and ground with the input left floating (disconnected), the output dc voltage is measured to be -0.8 V , estimate the input offset current. (15 Marks)

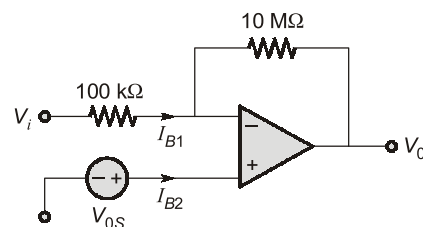
Solution:

(a) ∴
$$I_B = \frac{(I_{B1} + I_{B2})}{2}$$

When input is open :

$$V_0 = V_{0s} + 100KI_{B1}$$

$$9.31 = V_{0s} + 10000I_{B1}$$



...(i)

When input connected to ground:

$$V_0 = V_{0s} + R_2 \left(I_{B1} + \frac{V_{0s}}{R_1} \right)$$

$$V_0 = V_{0s} \left(1 + \frac{R_2}{R_1} \right) + R_2 I_{B1}$$

$$9.09 = V_{0s}(101) + 10000 I_{B1} \quad \dots(ii)$$

From (i) and (ii), [(1) - (2)]

$$100 V_{0s} = -0.22$$

$$V_{0s} = -2.2 \text{ mV}$$

and

$$I_{B1} = 930 \text{ nA}$$

So,

$$I_B \approx I_{B1} = 930 \text{ nA}$$

(b) input offset voltage, $V_{0s} = -2.2 \text{ mV}$

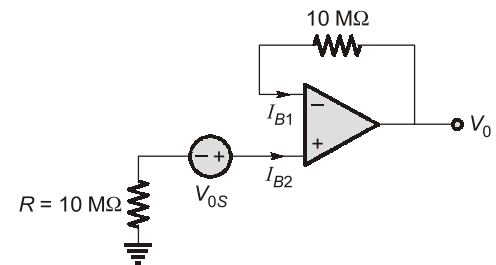
(c) Here V_{0s} can be neglected as magnitude of R is very large

$$\therefore V_{0s} \ll R I_B$$

$$V_0 = I_{0s} \times R_2$$

$$Z_{0s} = \frac{-0.8}{10M}$$

$$I_{0s} = -80 \text{ nA}$$



2. Diodes

Level-1

2.1 The circuit in the figure utilizes three identical diodes having $\eta = 1$ and $I_S = 10^{-14} \text{ A}$. Find the value of the current I required to obtain an output voltage $V_0 = 2 \text{ V}$. If a current of 1 mA is drawn away from the output terminals by a load, what is the change in output voltage? (8 Marks)

Solution:

As each diode is identical. So the voltage across each diode is $\frac{V_0}{3}$.

and diode current,

$$I = I_S e^{\frac{V_0/3}{4V_T}} = 10^{-14} e^{\frac{2/3}{0.025}}$$

$$= 3.81 \text{ mA}$$
