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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CONTENTS

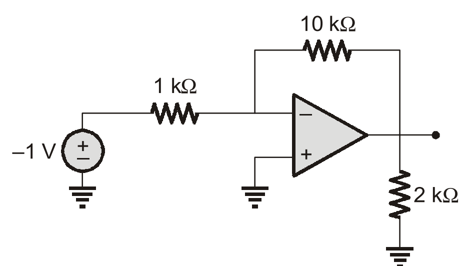
1 Analog Electronics

1. Operational Amplifiers

Level-1

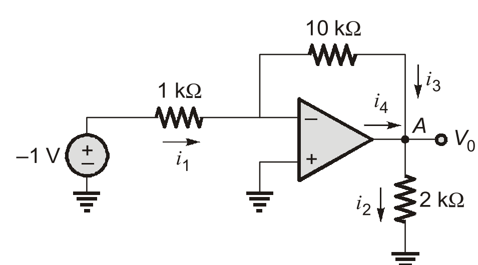
1.1 (a) For the circuit shown, find the currents through all branches and the voltages at all nodes.

(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,



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

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

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

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,

$$i_4 + i_3 = i_2$$

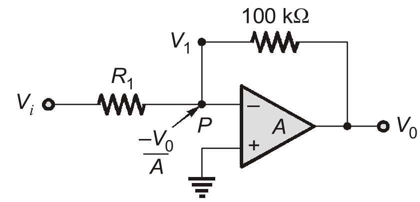
Hence, $$i_4 = i_2 - i_3$$

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

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 kΩ, to what must the smaller be adjusted? With what resistor must a 2 kΩ 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 $A = 200$ V/V

$$\because \qquad V_1 = \frac{-V_0}{A} = \frac{-V_0}{200}$$

and overall close loop gain,

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

by using KCL at point P:

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

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

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

as given in question shunt resistor is R_a ,

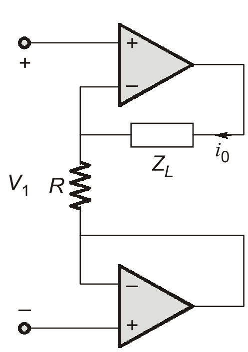
and $\qquad R_a \parallel 2\text{ k}\Omega = 1.49$ K

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

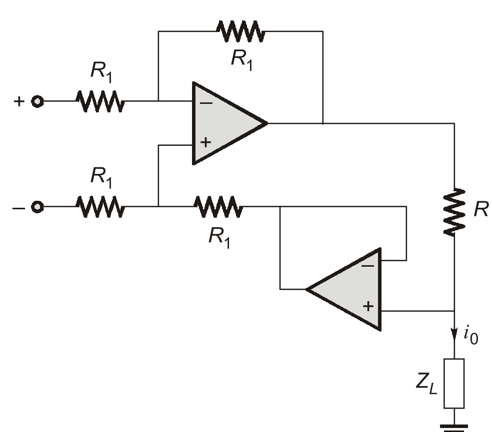
by solving above equation we will get

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

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.



(a)



(b)

(12 Marks)

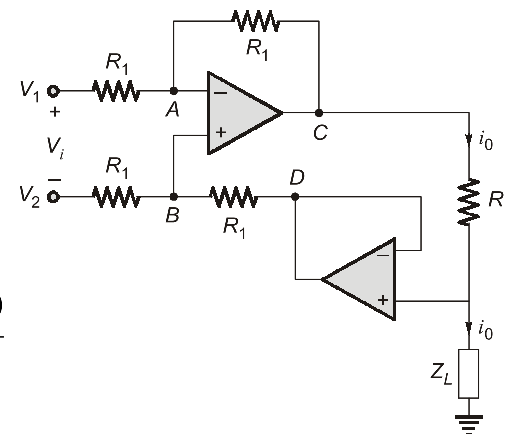
Solution:

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

$$V_B = \frac{-V_2 + Z_L i_{02}}{2} \quad \text{(by super position)}$$

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

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

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

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

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

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 differentiater 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

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

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

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

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 $V_0(t) = -5\sin(10^5 t + 90°)$ Volts

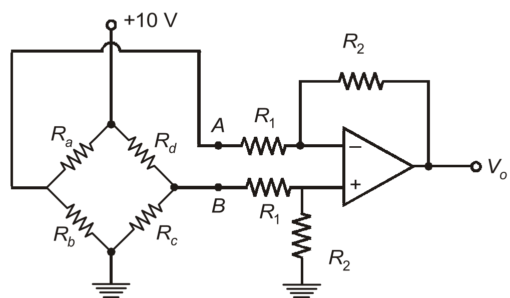
1.5 Consider the circuit shown in figure. The circuit uses an ideal operational amplifier. Assuming that the impedances at nodes A and B do not load the preceding bridge circuit, calculate the output voltage V_o.

(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)

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

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

Given op-amp is a differential amplifier

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

(b)

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

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

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

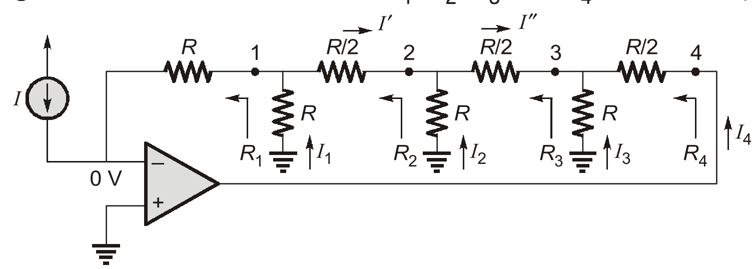
Level-2

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, $V_1 = I_1R$

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)

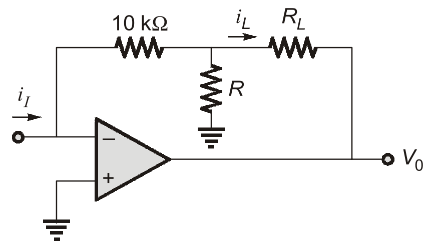
$$V_1 = -I_1R = -IR$$

$$V_2 = -I_2R = -2IR$$

$$V_3 = -I_3R = -4IR$$

$$V_4 = -I_3R + I_4\frac{R}{2} = -4IR - \frac{8IR}{2} = -8IR$$

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



(a) Find the required value of R.

(b) If R_L = 1 kΩ and the op-amp operates in an ideal manner so long as V_0 is in the range ±12 V. What range of i_I is possible?

(c) 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 kΩ find i_L.

(15 Marks)

Solution:

(a) Given that:

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

⇒ $$i_L = 20 i_I$$

by KVL :

$$-10\text{ k}\Omega \times i_I = R(i_I - i_L)$$

$$R = \frac{10K \times i_I}{20 i_I - i_I} = 0.53\text{ k}\Omega$$

(b) Given R_L = 1 kΩ and range of V_0 is $-12 \leq V_0 \leq 12$ V

by KVL:

$$V_0 = R_L i_L + (10\text{K}) i_I$$

$$= i_z \left[R_L \frac{i_L}{i_Z} + 10K \right]$$

$$V_0 = i_Z [1k \times 20 + 10k]$$

$$V_0 = (30\, i_I)K$$

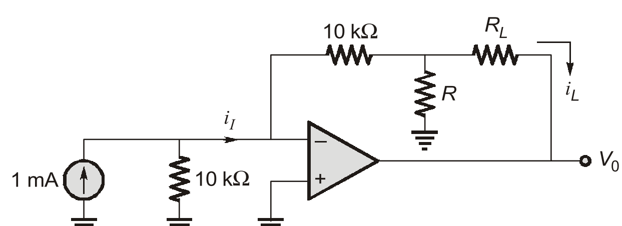
$$i_I = \frac{V_0}{30}$$

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

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

(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 mA

and $i_L = 20\, i_I$

So, i_L = 20 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.

(a) How many such amplifiers connected in a cascade of identical non inverting stages would she need to achieve her goal?

(b) What is the 3-dB frequency of each step she can use?

(c) What is the overall 3-dB frequency?

(15 Marks)

Solution:

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

If we use single Op-amp

But given in question that best Op-amp has $f_T = 40$ 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 $\frac{40}{K}$MHz .

So for each stage the closed loop gain is

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

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,

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

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

So for overall amplifier total f_T is

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

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

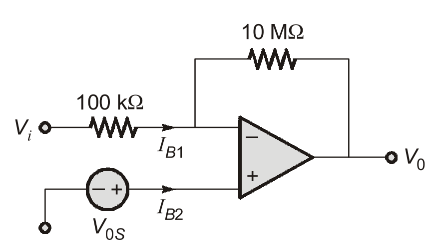
1.9 A particular inverting amplifier with nominal gain of –100 V/V uses an imperfect Op-amp in conjunction with 100 kΩ and 10 MΩ resistors. The output voltage is found to be +9.31 V when measured with the input open and 9.09 V with the input grounded.

(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 MΩ 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) ∵ $$I_B = \frac{(I_{B_1} + I_{B_2})}{2}$$

When input is open :

$$V_0 = V_{0S} + 100K I_{B_1}$$

$$9.31 = V_{0S} + 10000 I_{B_1} \quad \text{...(i)}$$

When input connected to ground:

$$V_0 = V_{0s} + R_2\left(I_{B_1} + \frac{V_{0s}}{R_1}\right)$$

$$V_0 = V_{0s}\left(1 + \frac{R_2}{R_1}\right) + R_2 I_{B_1}$$

$$9.09 = V_{0s}(101) + 10000 I_{B_1} \quad \text{...(ii)}$$

From (i) and (ii), [(1) – (2)]

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

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

and $I_{B_1} = 930$ nA

So, $I_B \approx I_{B_1} = 930$ nA

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

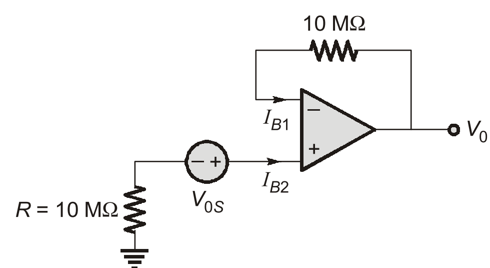
(c) Here V_{0s} can be neglected as magnitude of R is very large

$\because V_{0s} << RI_B$

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

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

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



2. Diodes

Level-1

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

Solution:

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

and diode current, $I = I_S e^{\frac{V_0/3}{4V_T}} = 10^{-4} e^{\frac{2/3}{0.025}}$

$= 3.81$ mA