VE311 Electronic Circuit Homework 3

Due: **May 25th**

费彦卓

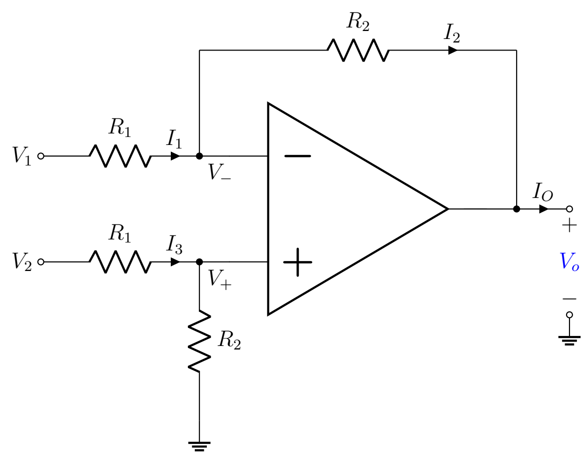
520370910021

Note:

1) *Please use A4 size paper or page.*
2) *Please clearly state out your final result for each question.*
3) *Please attach the screenshot of Pspice simulation result if necessary.*

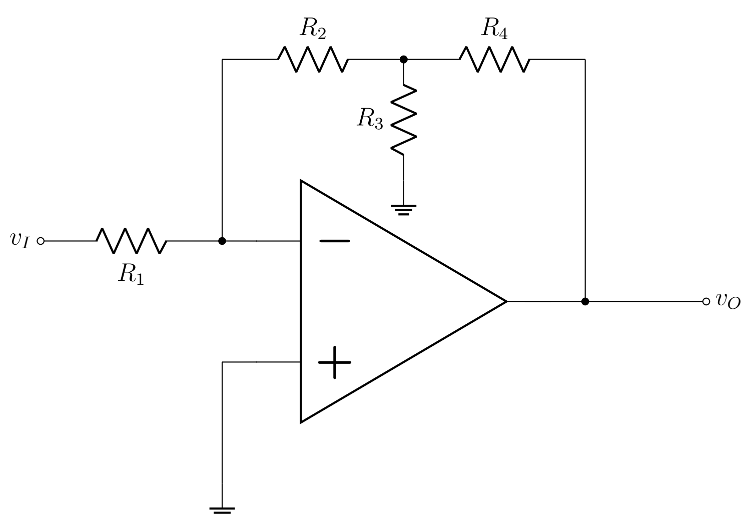
Question 1. Difference Amplifier

Find the values of V_O, V_+, V_-, I_1, I_2, I_3, and I_O for the difference amplifier shown below with $V_1 = 5V$, $V_2 = 3V$, $R_1 = 10k\Omega$, and $R_2 = 100k\Omega$.



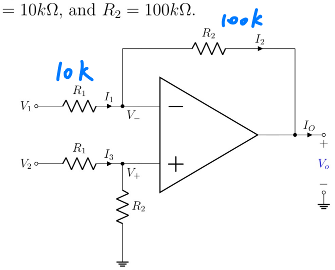
Question 2. Input and Output Resistance

Assuming the op amp to be ideal, derive an expression for the closed-loop gain v_O/v_I of the circuit shown below.



Question 1. Difference Amplifier

Find the values of V_O, V_+, V_-, I_1, I_2, I_3, and I_O for the difference amplifier shown below with $V_1 = 5V$, $V_2 = 3V$, $R_1 = 10k\Omega$, and $R_2 = 100k\Omega$.



$$I_3 = \frac{V_2}{R_1+R_2} = \frac{3}{110\times 10^3} = 2.73\times 10^{-5}\ A$$

$$V_+ = \frac{R_2}{R_1+R_2}V_2 = \frac{10}{11}V_2 = 2.73\ V$$

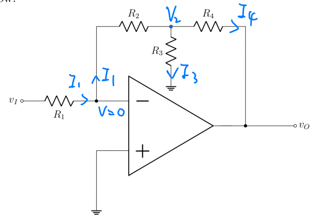
$$\Rightarrow V_- = V_+ = \frac{10}{11}V_2 = 2.73V$$

since $I_1 = \dfrac{V_1 - V_-}{10^4} = I_2 = \dfrac{V_- - V_o}{10^5} = 2.73\times 10^{-4}\ A$

$$\Rightarrow 10(V_1 - V_-) = V_- - V_o$$

$$\Rightarrow V_o = 11V_- - 10V_1 = -20V$$

Question 2. Input and Output Resistance
Assuming the op amp to be ideal, derive an expression for the closed-loop gain v_O/v_I of the circuit shown below.



$$I_1 = \frac{V_1}{R_1} \Rightarrow V_2 = -I_1 \cdot R_2 = \frac{-R_2}{R_1} V_1 \quad ①$$

$$I_3 = \frac{V_2}{R_3}, \quad I_4 = \frac{V_2 - V_0}{R_4} \Rightarrow \frac{V_2}{R_3} + \frac{V_2 - V_0}{R_4} = I_1 \quad ②$$

Plug ① into ②:

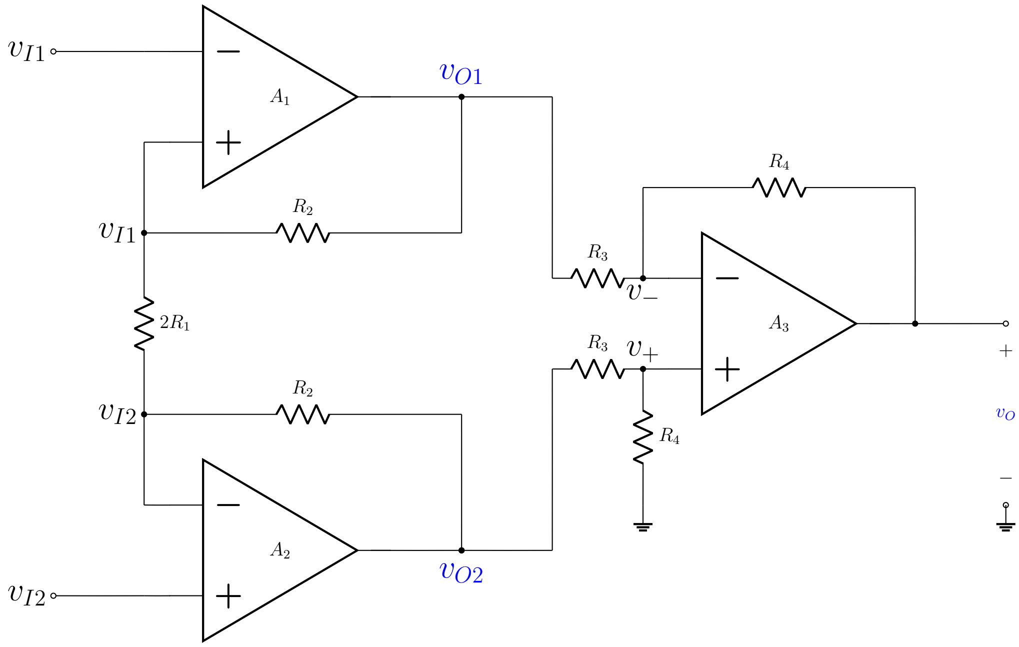
$$\frac{-R_2}{R_1 R_3} V_1 + \frac{-R_2}{R_1 R_4} V_1 - \frac{V_0}{R_4} = \frac{V_1}{R_1}$$

$$\Rightarrow -R_2^2 R_4 V_1 - R_2^2 R_3 V_1 - R_1 R_2 R_3 V_0 = R_2 R_3 R_4 V_1$$

$$\Rightarrow G = \frac{V_0}{V_1} = -\frac{R_2 R_3 R_4 + R_2^2 R_3 + R_2^2 R_4}{R_1 R_2 R_3}$$

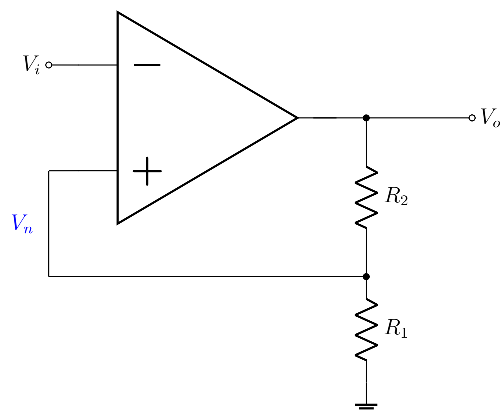
Question 3. Instrumentation Amplifier

Consider the instrumentation amplifier shown below with a common-mode input voltage of $+5V$ (dc) and a differential input signal of $10-mV$-peak sine wave. Let $(2R_1) = 1k\Omega$, $R_2 = 0.5M\Omega$, and $R_3 = R_4 = 10k\Omega$. Find the voltage at every node (total 9 nodes) in the circuit. Also find the differential voltage gain A_d.



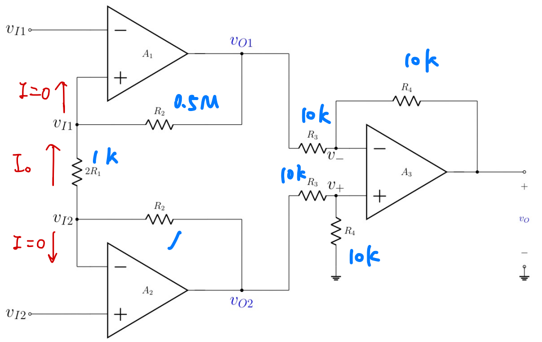
Question 4. Nonideal Amplifier Analysis

A noninverting amplifier is constructed with $R_1 = 1k\Omega$ and $R_2 = 39k\Omega$ using an operational amplifier with an open-loop gain of $80dB$ and an output resistance of 50Ω. Find the output resistance of the noninverting amplifier.



Question 3. Instrumentation Amplifier

Consider the instrumentation amplifier shown below with a common-mode input voltage of $+5V$ (dc) and a differential input signal of $10 - mV$-peak sine wave. Let $(2R_1) = 1k\Omega$, $R_2 = 0.5M\Omega$, and $R_3 = R_4 = 10k\Omega$. Find the voltage at every node (total 9 nodes) in the circuit. Also find the differential voltage gain A_d.



Assume $V_{Id} = 20\times 10^{-3}\,k$

where $k = \sin(wt+\varphi)$

$V_{I_2} = 5 + 0.01k$

$V_{I_1} = 5 - 0.01k$

$\Rightarrow V_{O_2} = V_{I_2} + \frac{V_{Id}}{2R_1}\cdot R_2 = 5 + 0.01k + \frac{0.02k}{10^3}\cdot 0.5\times 10^6 = 5 + 10.01k$

$V_{O_1} = V_{I_1} - \frac{V_{Id}}{2R_1}\cdot R_2 = 5 - 0.01k - \frac{0.02k}{10^3}\cdot 0.5\times 10^6 = 5 - 10.01k$

since $V_- = V_+ \ (= V)$

$\Rightarrow \frac{V_{O_1} - V_-}{R_3} = \frac{V_- - V_o}{R_4} \Leftrightarrow \frac{(5 - 10.01k) - V}{10\times 10^3} = \frac{V - V_o}{10\times 10^3}$

$\frac{0 - V_+}{R_4} = \frac{V_+ - V_{O_2}}{R_3} \Leftrightarrow \frac{0 - V}{10\times 10^3} = \frac{V - (5 + 10.01k)}{10\times 10^3}$

$\Rightarrow V_+ = V_- = V = 2.5 + 5.005k$,

$V_o = 2V - (5 - 10.01k) = 20.02k$

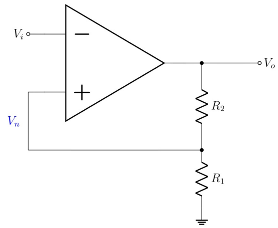
$\Rightarrow A_d = \frac{V_o}{V_{id}} = \frac{20.02k}{20\times 10^{-3}k} = 1.001\times 10^3 \approx 1\times 10^3$

According to the slide, $A_d = \frac{R_4}{R_3}\cdot\frac{R_2}{R_1} = 1\cdot\frac{0.5\times 10^6}{0.5\times 10^3} = 1\times 10^3$

$\Rightarrow$ My answer is correct

Question 4. Nonideal Amplifier Analysis

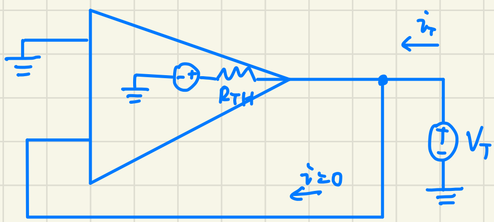
A noninverting amplifier is constructed with $R_1 = 1k\Omega$ and $R_2 = 39k\Omega$ using an operational amplifier with an open-loop gain of $80dB$ and an output resistance of 50Ω. Find the output resistance of the noninverting amplifier.



open-loop $G = \dfrac{A}{1+\beta A}$ and $\beta = \dfrac{R_1}{R_1+R_2} = \dfrac{1}{40}$

$$\Rightarrow 80 = \frac{A}{1+\frac{1}{40}A} \Rightarrow A = -80$$

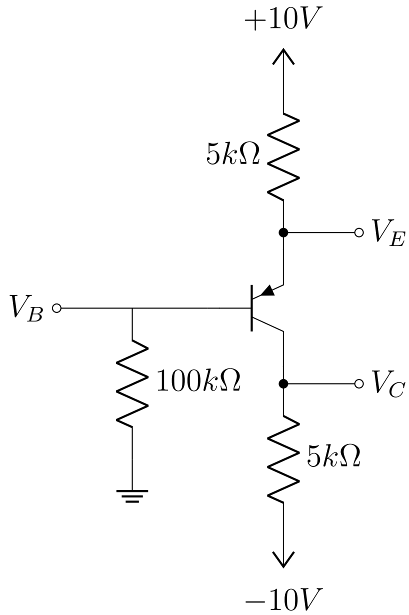
To calculate R_{TH}:



$$R_{TH} = \frac{R_{out}}{1+A} = \frac{50}{-79} = -0.633$$

Question 5. BJT

In the circuit shown below, measurement indicates V_B to be $+1.0V$ and V_E to be $+1.7V$. What are α and β for this transistor? What voltage V_C do you expect at the collector?

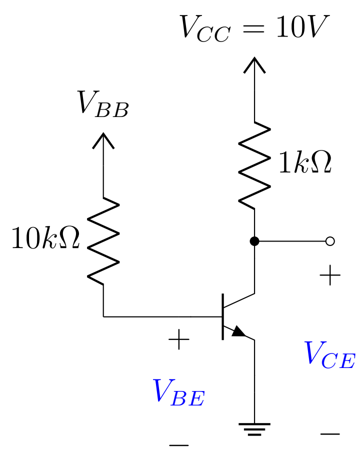


Question 6. Saturation

For the circuit shown below, it is required to determine the value of the voltage V_{BB} that results in the transistor operating

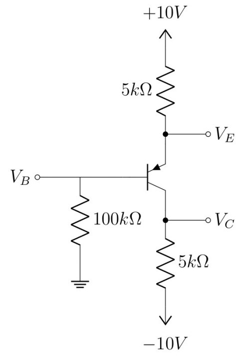
1) in the active mode with $V_{CE} = 5V$
2) at the edge of saturation
3) deep in saturation with $\beta_{forced} = 10$

For simplicity, assume that V_{BE} remains constant at 0.7 V. The transistor β is specified to be 50.



Question 5. BJT

In the circuit shown below, measurement indicates V_B to be $+1.0V$ and V_E to be $+1.7V$. What are α and β for this transistor? What voltage V_C do you expect at the collector?



From $V_b = 1V$:

$-1 + 100 \cdot 10^3 I_b = 0$, so $I_b = 0.01\,mA$

Also, From $V_e = 1.7V$

$-10 + 5 \cdot 10^3 I_e + 1.7 = 0$

And as $I_b + I_c = I_e$

$\Rightarrow I_c = 1.65\,mA$

Therefore, $\alpha = I_c\, I_e = 0.99$

$\beta = I_c\, I_b = 165$

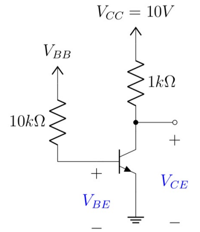
$V_c = I_c \cdot 5 \times 10^3 - 10 = -1.75\,V$

Question 6. Saturation

For the circuit shown below, it is required to determine the value of the voltage V_{BB} that results in the transistor operating

1) in the active mode with $V_{CE} = 5V$
2) at the edge of saturation
3) deep in saturation with $\beta_{forced} = 10$

For simplicity, assume that V_{BE} remains constant at 0.7 V. The transistor β is specified to be 50.



(a)

$$\begin{cases} V_{BB} - I_B R_B - 0.7 = 0 \\ V_{CC} - I_C R_C - V_{CE} = 0 \\ \beta = \dfrac{I_C}{I_B} \text{ (in active region)} \end{cases} \Rightarrow \begin{cases} I_C = 5mA \\ I_B = 0.1mA \\ V_{BB} = 1.7V \end{cases}$$

(b)

We have known that:

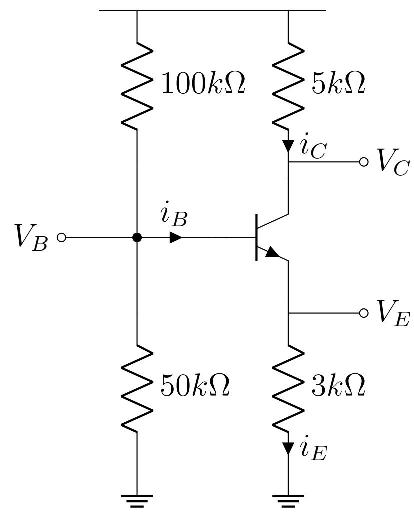
$$\begin{cases} V_{CE} = 0.2 \\ V_{BE} = 0.7 \\ V_{BB} - I_B R_B - 0.7 = 0 \\ V_{CC} - I_C R_C - V_{CE} = 0 \\ I_B = \dfrac{I_C}{\beta} = \dfrac{I_C}{50} \end{cases} \Rightarrow \begin{cases} I_C = 9.8mA \\ I_B = 0.196mA \\ V_{BB} = 2.66V \end{cases}$$

(c)

$$\begin{cases} V_{BB} - I_B R_B - 0.7 = 0 \\ V_{CC} - I_C R_C - 0.2 = 0 \\ I_B = \dfrac{I_C}{\beta_f} = \dfrac{I_C}{10} \end{cases} \Rightarrow \begin{cases} I_C = 9.8mA \\ I_B = 0.98mA \\ V_{BB} = 10.5V \end{cases}$$

Question 7. BJT at DC

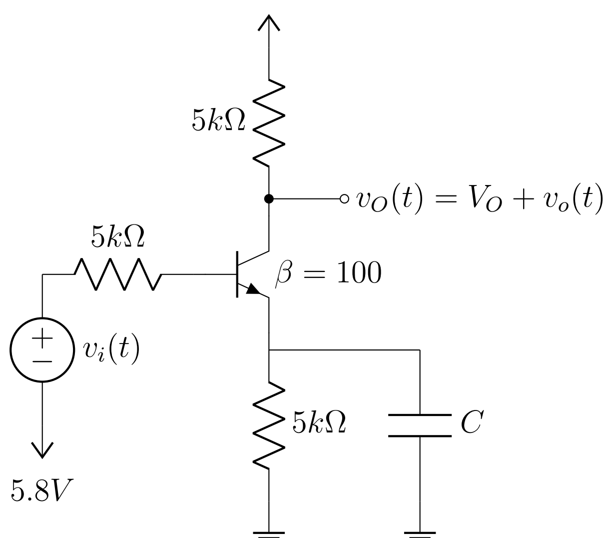
We want to analyze the circuit shown below to determine the voltages at all nodes and the currents through all branches. Assume $\beta = 100$.



Question 8. Small Signal Analysis

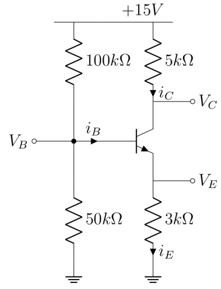
Consider the following BJT amplifier, determine its small-signal, open-circuit voltage gain $A_v = \frac{v_o(t)}{v_i(t)}$. Hint: Try to follow the steps to solve this question

1) Complete a D.C. Analysis.
2) Calculate the small-signal circuit parameters for each BJT.
3) Carefully replace all BJTs with their small-signal circuit model.
4) Set all D.C. sources to zero.
5) Analyze small-signal circuit.



Question 7. BJT at DC

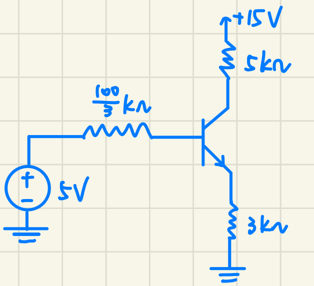
We want to analyze the circuit shown below to determine the voltages at all nodes and the currents through all branches. Assume $\beta = 100$.



$V_{TH} = 15 \cdot \frac{50}{150} = 5V$

$R_{TH} = \frac{100 \times 50}{100+50} = \frac{100}{3}\, k\Omega$

⇒ The circuit is as below



$\Rightarrow -5 + 33.33k \cdot I_B + 0.7 + 3k\, I_E = 0$

and $I_E = (1+\beta) \cdot I_B$

$\Rightarrow I_B = 0.0127\, mA$, $I_E = 1.291\, mA$

So $I_C = \beta I_B = 1.27\, mA$

$\Rightarrow V_E = 3k \cdot I_E = 3.873\, V$

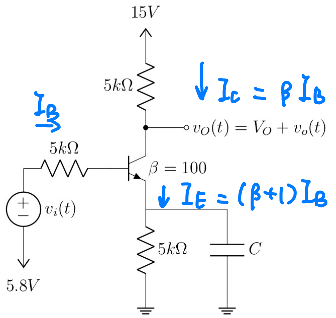
So $V_B = V_E + 0.7 = 4.573\, V$

Since $15 - 5k I_C - V_C = 0$

$\Rightarrow V_C = 8.65\, V$

Question 8. Small Signal Analysis
Consider the following BJT amplifier, determine its small-signal, open-circuit voltage gain $A_v = \frac{v_o(t)}{v_i(t)}$. Hint: Try to follow the steps to solve this question

1) Complete a D.C. Analysis.
2) Calculate the small-signal circuit parameters for each BJT.
3) Carefully replace all BJTs with their small-signal circuit model.
4) Set all D.C. sources to zero.
5) Analyze small-signal circuit.



DC Analysis :

By KVL :

$$5.8 = 5k\, I_B + V_{BE} + (\beta+1)\, 5k\, I_B$$

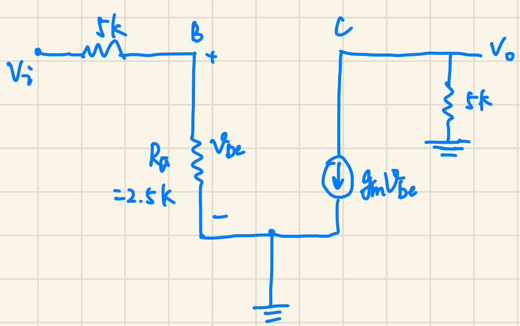
$$\Rightarrow I_B = \frac{5.8 - 0.7}{5k + 101 \cdot 5k} = 10\,\mu A$$

$$\Rightarrow I_C = \beta I_B = 1mA$$

$$g_m = \frac{I_C}{V_T} = \frac{1m}{25m} = 40\,mA/V$$

$$R_\pi = \frac{\beta}{g_m} = \frac{100}{40m} = 2.5k\Omega$$

Small Signal Analysis :



by voltage division rule:

$$V_{be} = \frac{2.5k}{2.5k + 5k} \cdot V_i$$

$$= \frac{1}{3} V_i$$

by ohm's law:

$$V_o = -g_m V_{be} \cdot 5k$$

$$\frac{V_o(t)}{V_i(t)} = \frac{-g_m 5k}{3} = \frac{-200}{3} = -66.67$$