Name:

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Table Number:

UNIVERSITI TENAGA NASIONAL

The National Energy University

College of Engineering

Department of Electrical Engineering

Midterm Test – Model Answer

SEMESTER 3, ACADEMIC YEAR 2018/2019

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**5 April 2019**
Duration	:	**2 hours**

Instructions to the candidates:

1. Write your **Name** and **Student ID Number**.
2. **Write all your answers using pen**. **DO NOT USE PENCIL** except for the diagram.
3. **ANSWER ALL QUESTIONS. Show clearly** all your calculations. Every value **must** be written with its correct Unit.
4. **WRITE YOUR ANSWER ON THIS QUESTION PAPER.**

NOTE: DO NOT OPEN THE QUESTION PAPER UNTIL INSTRUCTED TO DO SO.

☺ GOOD LUCK! ☺

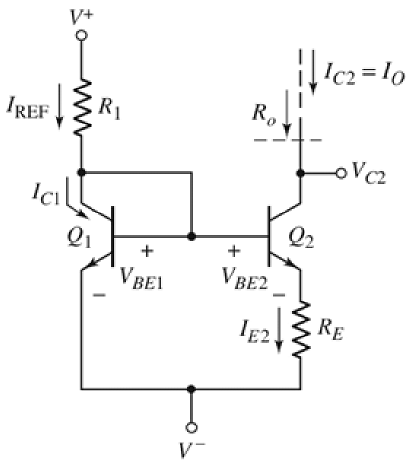
Question Number	Q1 (a)	Q1 (bcd)	Q2 (abc)	Q3 (ab)	Q4 (ab)	Total
Marks						
CO	9	1	3	1	2	

QUESTION 1 [25 marks]

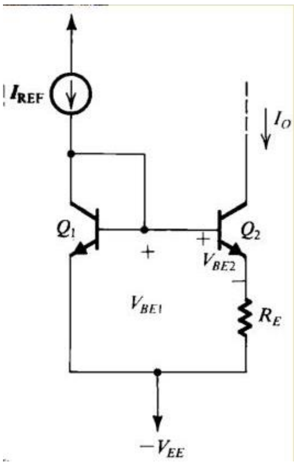
Answers for Question 1

Q1(a) **[4 marks]**

Each component, V_{BE}, I_{REF}, I_O, and power supplies will be given 0.25 marks.
Total = 4 marks.



Q1(b) **[6 marks]**



- $V_{BE1} = V_T \ln (I_{REF}/I_S)$ **[1]**
- $V_{BE2} = V_T \ln (I_0/I_S)$, **[1]**
- $V_{BE1} - V_{BE2} = V_T \ln (I_{REF}/I_0)$ **[1]**
- From the circuit,
- $V_{BE1} = V_{BE2} + I_0R_E$ **[1]**
- and so, $I_0R_E = V_T \ln (I_{REF}/I_O)$ **[2]**

<u>**Answers for Question 1 (Continued)**</u>

Q1(c) **[10 marks]**

Basic formula: $I_C = I_S \exp(V_{BE} / V_T)$

$V_{BE} = V_T \ln(I_{REF} / I_S)$

From the given information $V_{BE} = 0.7$ **V at 1 mA,**

$I_S = I_C / \{\exp(V_{BE} / V_T)\}$ **[1]**

$= (1m) / \{\exp(0.7 / 0.026)\} = 2.03 \times 10^{-15}$ A **[1.5]**

For $I_{REF} = I_{C1} = 2$ **mA,**

$V_{BE1} = V_T \ln(I_{REF} / I_S)$ **[1]**

$= (0.026) \ln(2m / 2.03 \times 10^{-15}) = 0.718$ V **[1.5]**

$I_{REF} = (V^+ - V_{BE1} - 0) / R_1$

$R_1 = (V^+ - V_{BE1} - 0) / I_{REF}$ **[1]**

$= (15 – 0.718) / (2m) = 7.14$ kΩ **[1.5]**

$I_O R_E = V_T \ln(I_{REF} / I_O)$

$R_E = (V_T / I_O) \ln(I_{REF} / I_O)$ **[1]**

$= (26m / 50\mu) \ln(2m / 50\mu) = 1.92$ kΩ **[1.5]**

Q1(d) **[5 marks]**

$$R_O = r_{O2}[1 + g_m(R_E // r_{\pi 2})]$$ **[1]**

$r_{\pi 2} = \beta V_T / I_O$ = [50(26m)]/50µ = **26 kΩ** **[1]**

$r_{O2} = V_A / I_O$ = 100/50µ = **2 MΩ** **[1]**

$g_m = I_O / V_T$ = 50µ/26m = **1.923 mA/V** **[1]**

R_O = 2M [1 + 1.923m (1.92k || 26k)] = **8.88 MΩ** **[1]**

<u>QUESTION 2 [25 marks]</u>

<u>Answers for Question 2 (Continued)</u>

Q2(a) **Calculate** I_O such that the **DC currents** in the diff-amp **are balanced**. **[6 marks]**

Derive formula $I_O = I_Q / \beta$ and use it

$I_{B3} + I_{B4} = I_{C3} / \beta + I_{C4} / \beta = (I_{C3} + I_{C4}) / \beta$ **[1]**

Assuming base currents for transistors in the diff-amp and I_O are small, then

$I_{C3} + I_{C4} \approx I_{C1} + I_{C2} \approx I_{E1} + I_{E2} = I_Q$

Then $I_{B3} + I_{B4} = I_Q / \beta$ **[1]**

For the DC currents in the diff-amp to be **balanced**

$I_O = I_{B3} + I_{B4} = I_Q / \beta$ **[2]**

$I_O = I_Q / \beta = 0.2\text{ mA} / 100 = 0.002\text{ mA}$ $= \mathbf{2\ \mu A}$ **[2]**

Q2(b) **Determine** the open-circuit differential-mode voltage gain, A_d. **[12 marks]**

$r_{O2} = V_A / I_{CQ2} = V_A / (I_Q/2) = 100/(2\mu/2)$ $= 1\text{ M}\Omega$ **[2]**

$r_{O4} = V_A / I_{CQ4} = V_A / (I_Q/2) = 100/(2\mu/2)$ $= 1\text{ M}\Omega$ **[2]**

$g_{m2} = I_{CQ2}/V_T = I_Q / 2V_T = 2\ \mu/[2(26\text{m})]$ $= 3.846\text{ mA/V}$ **[4]**

$A_d = g_{m2}\,(r_{O2} \parallel r_{O4}) = (3.846\text{m})\,(1\text{M} \parallel 1\text{M})$ $= 1923\text{ V/V}$ **[4]**

Q2(c) **Find** the differential-mode voltage gain if load resistance $R_L = 250\text{ k}\Omega$ **[7 marks]**

$A_d = g_{m2}\,(r_{O2} \parallel r_{O4} \parallel R_L)$ **[3]**

$A_d = (3.846\text{m})\,(1\text{M} \parallel 1\text{M} \parallel 250\text{k})$ $= 641\text{ V/V}$ **[4]**

QUESTION 3 [25 marks]

Answers for Question 3 (Continued)

Q3(a) [15 marks]

M_1: $I_{REF} = I_{D1} = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_1 (V_{GS1} - V_{TN})^2$ **[1]**

M_3: $I_{REF} = I_{D3} = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_3 (V_{GS3} - V_{TN})^2$ **[1]**

KVL: $V_{GS1} + V_{GS3} = V+ - V- = 5 - (-5)$

→ $V_{GS3} = 10 - V_{GS1}$ **[1]**

$M_1 = M_3$:

$$\left(\frac{70\mu}{2}\right)(20)_1(V_{SG1} - 0.7)^2 = \left(\frac{70\mu}{2}\right)(3)_3(V_{SG3} - 0.7)^2$$ **[1]**

$$\sqrt{\frac{20}{3}}(V_{GS1} - 0.7) = (10 - V_{GS1}) - 0.7$$

Solve the equation clearly to find $V_{GS1} = 3.1$ V **[1]**

→ $V_{GS3} = 10 - V_{GS1} = 10 – 3.1 = 6.9$ V **[2]**

$I_{REF} = I_{D1} = \left(\frac{70\mu}{2}\right)(20)_1(3.1 - 0.7)^2 = 4.032\ mA$ **[2]**

$V_{GS2} = V_{GS1} = 3.1$ V **[1]**

M_2: $I_O = I_{D2} = \left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TN})^2$ **[1]**

$I_O = I_{D2} = \left(\frac{70\mu}{2}\right)(12.5)_2(3.1 - 0.7)^2 = 2.520\ mA$ **[2]**

$V_{DS2} = V_{DS1} = V_{GS1} = 3.1$ V **[2]**

Q3(b) [10 marks]

Ro is calculated at $V_{DS2} = V_{DS1} = V_{GS1} = 3.1$ V where Io = 2.520 mA

$$R_O = \frac{1}{\lambda I_O} = \frac{1}{\mathbf{0.015 \times 2.52m}} = 26.455\ k\Omega$$ **[2]**

Io at $V_{DS2} = 2.5$ V is given by Io at $V_{DS2} = 3.1$ V plus change in Io (i.e. *dIo*) when V_{DS2} changes from 3.1 V to 2.5 V. **[2]**

$$dI_O = \frac{dV_{DS2}}{R_O} = \frac{2.5 - 3.1}{26.455k} = -0.02268\ mA$$ **[3]**

➔ Io at $V_{DS2} = 2.5$ V = 2.520 mA + $(-0.02268\ mA)$ = 2.4973 mA **[3]**

QUESTION 4 [25 marks]

Answers for Question 4 (Continued)

Q4(a) [15 marks]

$$I_1 = \frac{V^+ - V^- - V_{GS4}}{R_1} = \frac{20 - V_{GS4}}{R_1}$$ **1**

$$I_1 = K_{n3}(V_{GS4} - V_{TN})^2$$ **1**

$$9V_{GS4}^2 - 17V_{GS4} - 11 = 0$$

$$V_{GS4} = 2.40 \text{ V}$$ **2**

$$I_1 = 0.587 \text{ mA}$$ **2**

$I_Q = I_1 = 0.587$ mA **[2]**

The **quiescent drain currents** in M_1 and M_2:

$I_{D1} = I_{D2} = I_Q / 2 \approx$ **0.293 mA** **[2]**

The gate-to-source voltages are then

$$V_{GS1} = V_{GS2} = \sqrt{\frac{I_{D1}}{K_{n1}}} + V_{TN} = \sqrt{\frac{0.293}{0.1}} + 1 = 2.71\text{V}$$ **[2]**

The quiescent values of v_{O1} and v_{O2} are

$v_{O1} = v_{O2}$ $= V^+ - I_{D1} R_D$ **[2]**

$= 10 - (0.293\text{m})(16\text{k}) =$ **5.31 V** **[1]**

Q4(b) [10 marks]

The maximum common-mode input voltage, v_{CM} **(max)**, is the value **at** v_1 when M_1 **and** M_2 **reach the saturation point,**

v_{CM} **(max)** $= V_{S1}$**(max)** $+ V_{GS1} = (v_{O1} - V_{DS1}(\text{sat})) + V_{GS1}$ **[2]**

V_{DS1}**(sat)** $= V_{GS1} - V_{TN} = 2.71 - 1 =$ **1.71 V** **[1]**

Therefore,

v_{CM} **(max)** $= 5.31 - 1.71 + 2.71 =$ **6.31 V** **[2]**

The minimum common-mode input voltage, v_{CM} **(min)**, is the value **at** v_1 when M_4 **reaches the saturation point,**

v_{CM} **(min)** $= V_{S1}$**(min)** $+ V_{GS1} = (V^- + V_{DS4}(\text{sat})) + V_{GS1}$ **[2]**

V_{DS4}**(sat)** $= V_{GS4} - V_{TN} = 2.4 - 1 =$ **1.4 V** **[1]**

Therefore,

v_{CM} **(min)** $= (-10) + 1.4 + 2.71 =$ **-5.89 V** **[2]**