Name:

Student ID Number:

Section: **01A / 01B / 02A /02B**

Lecturer: **Dr Jamaludin / Dr Azni Wati**

UNIVERSITI TENAGA NASIONAL

# College of Engineering

Department of Electronics and Communication Engineering

# Midterm Test – Model Answer

**SEMESTER 3, ACADEMIC YEAR 2011/2012**

| | | |
|---|---|---|
| Subject Code | : | **EEEB273** |
| Course Title | : | **Electronics Analysis & Design II** |
| Date | : | **10 March 2012** |
| Time Allowed | : | **2 hours** |

## Instructions to the candidates:

1. Write your Name and Student ID number. Circle your section number.
2. Write all your answers using pen. **DO NOT USE PENCIL** except for the diagram.
3. **ANSWER ALL QUESTIONS.**
4. **WRITE YOUR ANSWER ON THIS QUESTION PAPER.**
5. For BJT, use $V_T$ **= 26 mV** where appropriate.

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

☺ **GOOD LUCK!** ☺

## Question 1 [30 marks]

The circuit in **Figure 1** is a BJT current source with $\boldsymbol{R_1 = 8.6\ k\Omega}$. The transistor parameters are: $\boldsymbol{V_{BE1} = 0.65\ V}$, $\boldsymbol{V_A = 100\ V}$ and $\boldsymbol{\beta = 80}$. The quiescent load current, $\boldsymbol{I_O}$, is **12.5 µA**. Answer the following questions:

(a) Calculate $\boldsymbol{R_E}$. [7 marks]

(b) Find $\boldsymbol{V_{BE2}}$. [5 marks]

(c) **Draw** the small-signal equivalent circuit for the current source. [5 marks]

(d) **Determine** the output resistance, $\boldsymbol{R_O}$, of the current source. [8 marks]

(e) Find the new load current if $\boldsymbol{V_{C2}}$ changes by **4 V**. [5 marks]

## Answers for Question 1

**(a)**

$$I_{REF} = \frac{V^+ - V_{BE(on)} - V^-}{R_1} = \frac{5 - 0.65 + 5}{8.6k} = 1.0872mA$$ [1, 1, 1]

$$I_O R_E = V_T ln\left[\frac{I_{REF}}{I_O}\right]$$ [1]

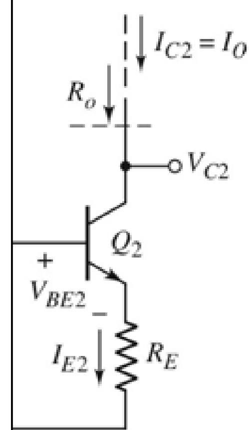
$$R_E = \frac{V_T}{I_O} ln\left[\frac{I_{REF}}{I_O}\right] = \frac{(0.026)}{(12.5\mu)} ln\left[\frac{1.0872x10^{-3}}{12.5x10^{-6}}\right] = 9.2885k\Omega$$ [1, 1, 1]

**(b)**

$$I_E = \frac{(1+\beta)}{\beta} I_C = \frac{(1+80)}{80} x12.5\mu = 12.6562\mu A$$ [1, 1, 0.5]

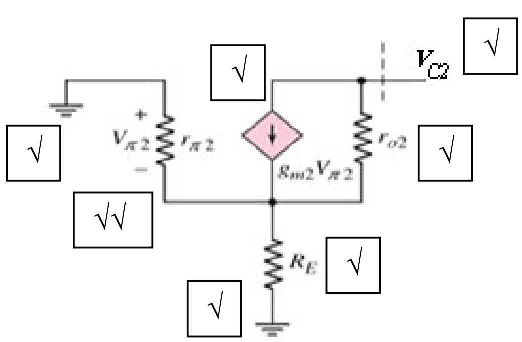
$$V_{BE2} - V_{BE1} - I_E R_E$$ [1]

$$V_{BE2} = 0.65 - (12.6562\mu)(9.2885k) = 0.5324V$$ [1, 0.5]




re 1

**(c)**

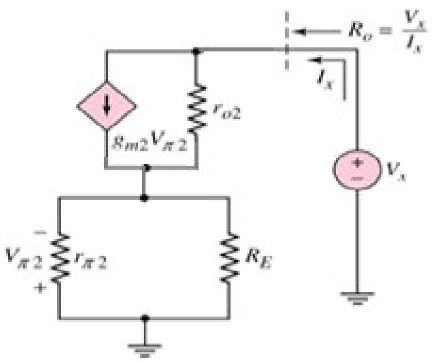



√√ - Correct connections

√ = 0.5 mark

**Answers for Question 1 (Cont.)**

**(d)**




$R'_E = R_E \parallel r_{\pi 2}$ [0.5]

$V_{\pi 2} = -I_x R'_E$ [0.5]

$V_x = r_{o2}(I_x - g_{m2}V_{\pi 2}) - V_{\pi 2}$

$V_x = I_x r_{o2} - I_x g_{m2} V_{\pi 2} - V_{\pi 2}$ [0.5]

$V_x = r_{o2} I_x + g_{m2} r_{o2} R'_E I_x + R'_E I_x$ [0.5]

$\frac{V_x}{I_x} = r_{o2} + g_{m2} r_{o2} R'_E + R'_E \cong r_{o2}(1 + g_{m2} R'_E)$ [1]

$R_O = r_{o2}(1 + g_{m2} R'_E)$

$r_{\pi 2} = \frac{\beta V_T}{I_O} = \frac{(80)(0.026)}{12.5\mu} = 166.4k\Omega$ [1]

$R'_E - (9.2885k) \parallel 166.4k = 8.797k\Omega$ [1]

$r_{o2} = \frac{V_A}{I_{C2}} = \frac{V_A}{I_O} = \frac{100}{12.5\mu} = 8M\Omega$ [1]

$g_{m2} = \frac{I_O}{V_T} = \frac{12.5\mu}{0.026} = 4.8077x10^{-4}$ [1]

$R_O = (8M)[1 + (4.8077x10^{-4})(8.797k)] = 41.83M\Omega$ [1]

**(e)**

$\frac{\Delta I_O}{\Delta V_{C2}} = \frac{1}{R_O}$ [2]

$\Delta I_O = \frac{\Delta V_{C2}}{R_O} = \frac{4}{41.83M} = 0.09563\mu A$ [1, 0.5]

$I_{O(new)} = 12.5\mu A + 0.09569\mu A = 12.59563\mu A$ [1, 0.5]

**Question 2** **[30 marks]**

Refer to **Figure 2**. The circuit parameters are: $V^+ = 5$ **V**, $V^- = -5$ **V**, and $I_{REF} = 20$ **μA**. Let $K_n = 80$ **μA/V²**, $V_{TN} = 1$ **V,** and $\lambda = 0.002$ **V⁻¹** for **all transistors**.

(a) **Find** the bias current, $I_O$. [2 marks]

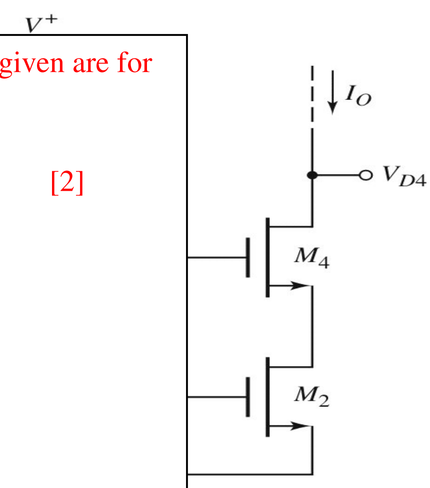
(b) **Determine** the gate-to-source voltage, $V_{GS}$, for each transistor. [5 marks]

(c) **Calculate** the lowest possible value of $V_{D4}$. [5 marks]

(d) **Draw** the ac equivalent circuit of the current source. [5 marks]

(e) **Determine** the output resistance $R_O$ looking into the drain of $M_4$. [13 marks]

**Answers for Question 2**




re 2

(a) Assume all transistors are identical because parameters given are for **all transistors**.

$I_O = I_{REF} = 20$ μA [2]

(b) $I_{REF} = K_n(V_{GS3} - V_{TN})^2 = K_n(V_{GS1} - V_{TN})^2$

$I_O = I_{REF} = K_n(V_{GS2} - V_{TN})^2 = K_n(V_{GS4} - V_{TN})^2$

Since $V_{GS1} = V_{GS2}$ and $V_{GS1} = V_{GS3}$,

then $V_{GS1} = V_{GS2} = V_{GS3} = V_{GS4} = \sqrt{\frac{I_{REF}}{K_n}} + V_{TN} = \sqrt{\frac{20\mu}{30\mu}} + 1 = 1.5V$

[5]

(c) $V_{D4}$ **(min)** $= V^- + V_{GS1} + V_{GS3} - V_{GS4} + V_{DS4}$ **(sat)** **[2]**

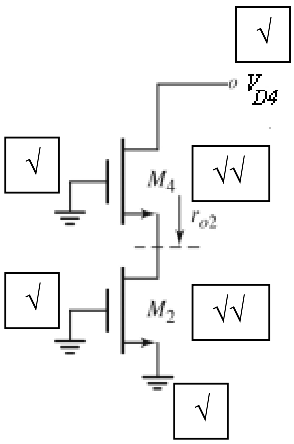
$V_{D4}$ **(min)** $= V^- + V_{GS1} + V_{GS3} - V_{GS4} + (V_{GS4} - V_{TN})$ **[1]**

$V_{D4}$ **(min)** $= V^- + 2V_{GS} - V_{TN}$ **[1]**

**= (-5) + 2(1.5) – 1 = -3 V** **[1]**

**Answers for Question 2 (Cont.)**

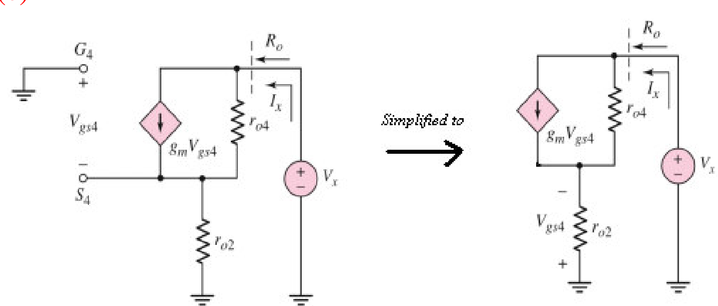
(d)




√√ - Correct connections

√ = 0.5 mark

(e)




**[1] for drawing**

$V_{gs4} = -I_x r_{o2}$ **[1]**

$V_x = (I_x - g_{m4} V_{gs4}) r_{o4} - V_{gs4}$ **[1]**

$V_x = I_x r_{o4} - g_{m4} V_{gs4} r_{o4} - V_{gs4}$ **[1]**

$V_x = I_x r_{o4} + g_{m4} I_x r_{o2} r_{o4} + I_x r_{o2}$ **[1]**

$R_O = \frac{V_x}{I_x} = r_{o4} + r_{o2}(1 + g_{m4} r_{o4}) \simeq g_m r_{o4} r_{o2}$ **[1, 1, 1]**

$r_{o4} = r_{o2} = 1/(\lambda I_O) = 1/(0.002 \text{ x } 20\mu) = 25 \text{ M}\Omega$ **[1, 1, 0.5]**

$g_{m4} = 2\sqrt{K_n I_O} = 2\sqrt{(80\mu)(20\mu)} = 80\mu\text{A/V}^2$ **[1, 0.5]**

$R_O = (80\mu)(25\text{M})(25\text{M}) = 50000 \text{ M}\Omega$ **[0.5, 0.5]**

**Question 3** [40 marks]

(a) **Figure 3a** shows a circuit diagram for a BJT differential amplifier (**diff-amp**). Study the circuit diagram carefully. Transistor parameters are: $\boldsymbol{\beta} = \infty$ (neglect base current), $\boldsymbol{V_A} = \infty$, and $\boldsymbol{V_{BE}}$**(on) = 0.7 V**. For the circuit also, voltages measured at $\boldsymbol{v_{C1}}$ and $\boldsymbol{v_{C2}}$ are **+3.5 V**.

(i) **What** are the values for $\boldsymbol{v_{cm}}$ and $\boldsymbol{v_d}$? Show clearly your calculations. [5 marks]

(ii) Find $\boldsymbol{I_Q}$. [5 marks]

(iii) Find $\boldsymbol{v_{CE1}}$. [5 marks]

(iv) **Determine** the differential mode voltage gain ($\boldsymbol{A_d}$) for a one-sided output taken at $\boldsymbol{v_{C2}}$. [5 marks]

**Answers for Question 3a**

**(i)**

$v_{B1} = v_{B2} = 0.3$ V [1, 1]

$v_{cm} = (v_{B1} + v_{B2}) / 2 = (0.3 + 0.3) / 2 = 0.3$ V [1, 0.5]

$v_d = (v_{B1} - v_{B2}) = (0.3 - 0.3) = 0$ V [1, 0.5]

**(ii)**

$I_{RC} = [(+10) - v_{C1}] / R_C = [(+10) - v_{C2}] / R_C$ [1]

$= [(+10) - 3.5] / (10k) = 0.65$ mA [0.5, 0.5]

$I_Q = 2\, I_{RC} = 2\,(0.65m) = 1.3$ mA [2, 1]

**(iii)**

$v_{CE1} = v_{C1} - v_{E1}$ [1.5]

$= v_{C1} - (v_{B1} - v_{BE1})$ [1.5]

$= 3.5 - (0.3 - 0.7) = 3.9$ V [2]

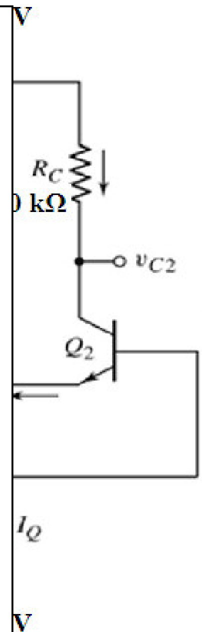
**(iv)**

$A_d = (g_{m2}\, R_C) / 2 = (I_Q\, R_C) / (4\, V_T)$ [2]

$g_{m2} = I_{C2} / V_T = I_Q / 2V_T$ [1]

$= (1.3m) / (2 \times 26m) = 0.025$ A/V [1]

$A_d = (0.025 \times 10k) / 2 = 125$ [1]




re 3a

(b) The BJT differential amplifier shown in **Figure 3b** is biased by a **0.20 mA** constant current source (i.e. $\boldsymbol{I_Q}$ **= 0.20 mA**). It is to be redesigned to use an active load in order to increase its differential-mode voltage gain ($A_d$). The active load to be used is a **BJT cascode current source** using **pnp transistors** to replace the collector resistors ($\boldsymbol{R_C}$) in the differential amplifier, as graphically shown in **Figure 3b**.

The transistor parameters are $\boldsymbol{\beta = 150}$, $\boldsymbol{V_{BE}(on) = V_{EB}(on) = 0.7\ V}$, $\boldsymbol{V_{AN} = 120\ V}$, and $\boldsymbol{V_{AP} = 100\ V}$. **The one-sided output** voltage taken at $v_{C2}$ can be calculated using **Equation (1)**:

$$v_O = v_{C2} = g_{m2}\, v_d\, (r_{O2} \parallel R_{OAL}) \qquad \textbf{(1)}$$

where $\boldsymbol{R_{OAL}}$ is the output resistance of the **BJT cascode current source**.

(i) **Draw the new circuit** incorporating the **active load's full circuit diagram**. Label the circuit correctly and clearly with appropriate symbols and numbering for transistors used in circuit. Leave $\boldsymbol{I_Q}$ symbol as it is in **Figure 3b**. [10 marks]

(ii) **Find** the output resistance of the **BJT cascode current source** ($\boldsymbol{R_{OAL}}$). [5 marks]

(iii) **Determine** the differential-mode voltage gain ($\boldsymbol{A_d}$) of **the new circuit**. [5 marks]

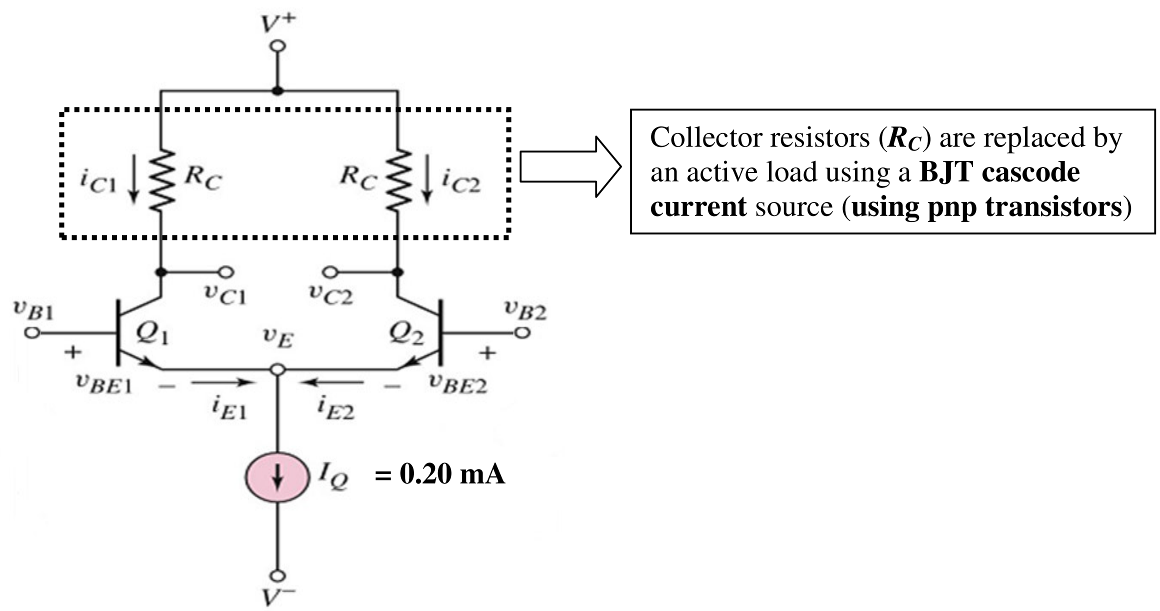
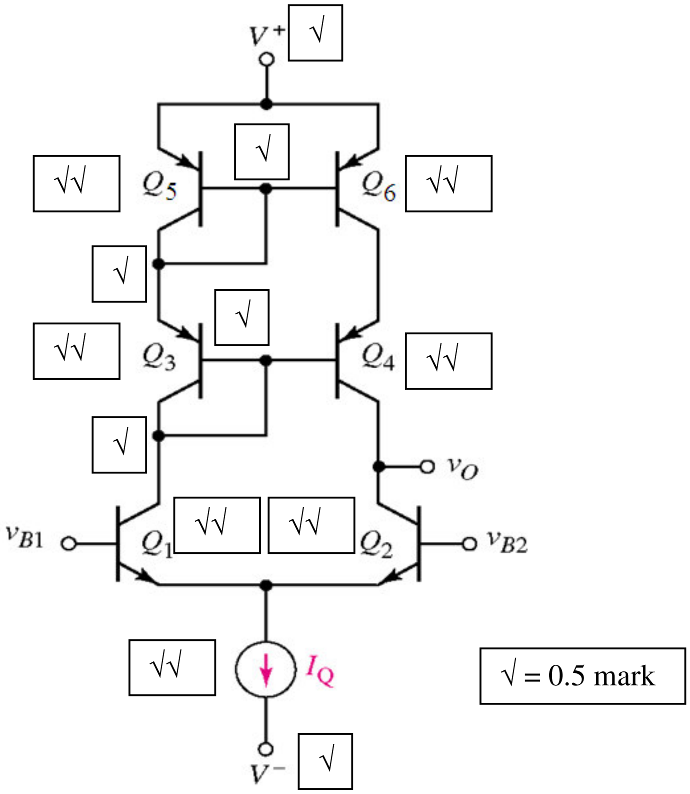



**Figure 3b**

**<u>Answers for Question 3b</u>**

**Answers for Question 3b (Cont.)**

**(i)**




**(ii)**

| | | |
|---|---|---|
| $R_{OAL}$ | $\approx \beta r_{O4}$ | [2] |
| | $= \beta (V_{A4} / I_{C4}) = (\beta V_{AP}) / (I_Q / 2)$ | [2] |
| | $= (150 \times 100) / (0.20m / 2) = 150\ M\Omega$ | [1] |

**(iii)**

$v_O = v_{C2} = g_{m2} v_d (r_{O2} \parallel R_{OAL})$

$A_d = v_O / v_d = g_{m2} (r_{O2} \parallel R_{OAL})$ [1]

$g_{m2} = I_{CQ2} / V_T = I_Q / 2V_T$ [1]

$= (0.20m)/(2 \times 26m) = 3.846\ mA/V$ [0.5]

$r_{O2} = V_{A2} / I_{C2} = (V_{AN}) / (I_Q / 2)$ [1]

$= (120) / (0.20m / 2) = 1.2\ M\Omega$ [0.5]

$r_{O2} \parallel R_{OAL} = 1.2M \parallel 150M = 1.19\ M\Omega \approx r_{O2}$

$A_d = (3.846m)(1.2M \parallel 150M)$

$= 4578.57$ [1]

# Appendix: BASIC FORMULA

## BJT

$$i_C = I_S e^{v_{BE}/V_T} \text{ ; npn}$$

$$i_C = I_S e^{v_{EB}/V_T} \text{ ; pnp}$$

$$i_C = \alpha i_E = \beta i_B$$

$$i_E = i_B + i_C$$

$$\alpha = \frac{\beta}{\beta + 1}$$

;Small signal

$$\beta = g_m r_\pi$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_o = \frac{V_A}{I_{CQ}}$$

## MOSFET

;N – MOSFET

$$v_{DS}(\text{sat}) = v_{GS} - V_{TN}$$

$$i_D = K_n[v_{GS} - V_{TN}]^2$$

$$K_n = \frac{k_n'}{2} \cdot \frac{W}{L}$$

;P – MOSFET

$$v_{SD}(\text{sat}) = v_{SG} + V_{TP}$$

$$i_D = K_p[v_{SG} + V_{TP}]^2$$

$$K_p = \frac{k_p'}{2} \cdot \frac{W}{L}$$

;Small signal

$$g_m = 2K_n\left(V_{GSQ} - V_{TN}\right) = 2\sqrt{K_n I_{DQ}}$$

$$r_o \cong \frac{1}{\lambda I_{DQ}}$$