Name:

Student ID Number:

Section Number: 01/02/03/04 A/B

Lecturer: Dr Jamaludin/ Dr Jehana Ermy/ Dr Azni Wati

Table Number:

UNIVERSITI TENAGA NASIONAL

College of Engineering

Department of Electronics and Communication Engineering

Test 1 – With Model Answer

SEMESTER 2, ACADEMIC YEAR 2016/2017

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**19 November 2016**
Time Allowed	:	**2 hours**

Instructions to the candidates:

1. Write your Name and Student ID Number. Indicate your Section Number and Lecturer's Name. Write also your Table 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	Q2	Q3	Total
Marks				

QUESTION 1 [40 marks]

(a) Consider the **three-transistor BJT current source** as in **Figure 1(a)**. All transistors have $\boldsymbol{V_{BE}}$**(on) = 0.6 V** and $\boldsymbol{V_A}$ **= 120 V**. Transistors $\boldsymbol{Q_1}$ and $\boldsymbol{Q_2}$ are identical with $\boldsymbol{\beta = 80}$**,** while $\boldsymbol{Q_3}$ has $\boldsymbol{\beta_3 = 50}$. Given $\boldsymbol{V^+ = 10}$ **V**, $\boldsymbol{V^- = -10}$ **V**, and $\boldsymbol{I_O = 0.70}$ **mA.**

(i) **Calculate** <u>all</u> transistor currents in the circuit, $\boldsymbol{I_{REF}}$, and $\boldsymbol{R_1}$. [12 marks]

(ii) **What** is the minimum voltage at $\boldsymbol{V_{C2}}$? [2 marks]

(iii) **How much** reference current differs from the bias current? [2 marks]

(iv) **Describe** any similarity and difference of this current source with the Wilson current source. [4 marks]

Answers for Question 1(a)

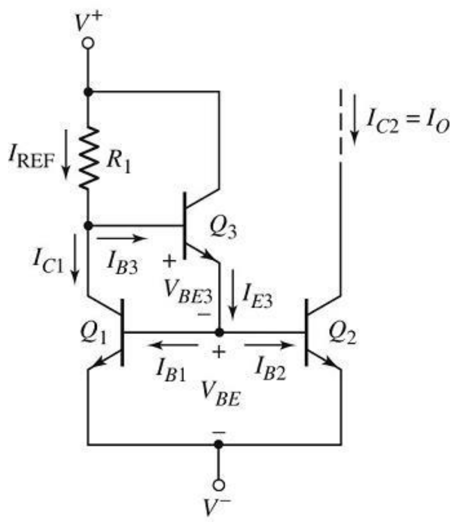


Figure 1(a)

Answers for Question 1(a) (Continued)

Answers for Question 1(a)

(i) **Calculate** all transistor currents in the circuit, $\boldsymbol{I_{REF}}$, and $\boldsymbol{R_1}$. [12 marks]

$I_{B1} = I_{B2}$ [1]

$I_O = \beta I_{B2} \Rightarrow I_{B2} = I_O / \beta$ = 0.7m/80 = 8.75uA [1.5]

$I_{C1} = \beta I_{B2} \Rightarrow I_{C1} = I_O$ = 0.7mA [1]

$I_{E3} = 2 I_{B2}$ = 2(8.75u) =17.5uA [1]

$I_{B3} = I_{E3} / (1 + \beta_3)$ = 17.5u/51 =0.3431uA [1.5]

$I_{REF} = I_{C1} + I_{B3}$ =0.7m+0.3431u = 700.3431uA [2]

$R_1 = (V^+ - 2V_{BE}(on) - V^-) / I_{REF}$ [2]

= (20 - 2(0.6)) / (0.7003431m) [2]

= **26.84** kΩ

(ii) **What** is the minimum voltage at $\boldsymbol{V_{C2}}$? [2 marks]

$V_{C2} = V^- + v_{CE2(min)}$ = -10 +0.6 = -9.4 V [2]

(iii) **How much** reference current differs from the bias current? [2 marks]

I_{REF} is 0.049% higher than I_O OR differs 0.3431uA [2]

(iv) **Describe** any similarity and difference of this current source with the Wilson current source. [4 marks]

1) Very close approximation of I_O to I_{REF} [2]
2) Lower output resistance by a factor of $(\beta / 2)$. [2]

(b) **Study** a **multi-transistor BJT current mirror** shown in **Figure 1(b)** thoroughly and carefully. With circuit analysis, load current for a mirror transistor $\boldsymbol{Q_N}$ can be found using

$$I_{ON} = \frac{I_{REF}}{1 + \frac{(1+N)}{\beta}}$$

where $\boldsymbol{N}$ is the total number of **equivalent** mirror transistors inside $\boldsymbol{Q_1}$ to $\boldsymbol{Q_N}$ in the circuit. Every **equivalent** mirror transistor is matching with the reference transistor $\boldsymbol{Q_R}$.

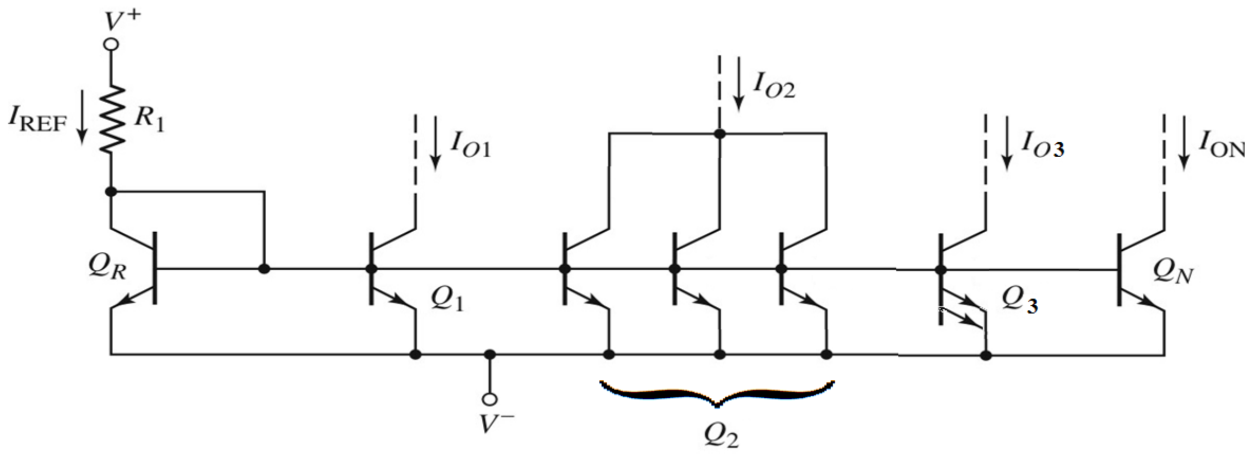


Figure 1(b)

All transistors have $\boldsymbol{V_{BE}}$**(on) = 0.7 V,** $\boldsymbol{\beta}$ **= 40,** and $\boldsymbol{V_A}$ **= 150 V**. Given $\boldsymbol{V^+}$ **= 10 V,** $\boldsymbol{V^-}$ **= -10 V**, and $\boldsymbol{R_1}$ **= 10 kΩ.**

(i) **What** is the total number of **equivalent** mirror transistors ($\boldsymbol{N}$) in the circuit? [4 marks]

(ii) **Calculate** $\boldsymbol{I_{REF}}$, $\boldsymbol{I_{O1}}$, $\boldsymbol{I_{O2}}$, $\boldsymbol{I_{O3}}$, and $\boldsymbol{I_{ON}}$ in the circuit. [12 marks]

(iii) **Find** output resistance of the current mirror at transistor $\boldsymbol{Q_3}$ (i.e. $\boldsymbol{R_{O3}}$). [4 marks]

Answers for Question 1(b)

Answers for Question 1(b) (Continued)

Answers for Question 1(b)

(i) **What** is the total number of **equivalent** mirror transistors (***N***) in the circuit? [4 marks]

N = 1 (for Q1) + **3** (for Q2) + **2** (for Q3) + **1** (for QN) = 7 [4]

(ii) **Calculate** I_{REF}, I_{O1}, I_{O2}, I_{O3}, and I_{ON} in the circuit. [12 marks]

I_{REF} $= (V^+ - V_{BE}(on) - V^-) / R_1$ [2]

= (10 - 0.7 – (-10)) / (10k) = 1.93 mA [2]

I_{ON} $= I_{REF} / (1 + (1 + N) / \beta)$

= (1.93 mA) / (1 + (1 + 7) / 40) = 1.608 mA [2] *Note

I_{O1} $= I_{ON}$ = 1.608 mA [2] *Note

I_{O2} $= 3\, I_{ON}$ = 3x1.608 mA = 4.824 mA [2] *Note

I_{O3} $= 2\, I_{ON}$ = 2x1.608 mA = 3.216 mA [2] *Note

*Note: If answer for 1(b)(i) is not N = 7, may give [1.5 marks] for values of I_{O1}, I_{O2}, I_{O3}, and I_{ON} based value of N given in 1(b)(i) on condition that respective **formula** is correct.

(iii) **Find** output resistance of the current mirror at transistor Q_3 (i.e. R_{O3}). [4 marks]

R_{O3} $= V_A / I_{O3}$ [2]

= 150 / 3.216m = 46.6418 kΩ [2]

QUESTION 2 [30 marks]

Figure 2 shows a **MOSFET** cascode current source with all transistors are regarded as identical. The transistor parameters are: V_{TN} **= 0.5 V,** K_n **= 80** μ**A/V**^{2}, and **λ = 0.02 V**$^{-1}$. The circuit parameters are: V^+ **= +7 V,** V^- **= –7 V,** and I_{REF} **= 120** μ**A**.

(a) **Calculate** the V_{GS} of each transistor and I_O. [10 marks]

(b) If I_{REF} symbol in the **Figure 2** is replaced by another MOSFET transistor M_5 (but M_5 is **NOT identical** to M_1 to M_4) to act like a resistor, what is the value of V_{GS5}? [4 marks]

(c) **Determine** the percent change in I_O as V_{D4} changes from **-3 V** to **+3 V**. [16 marks]

Answers for Question 2

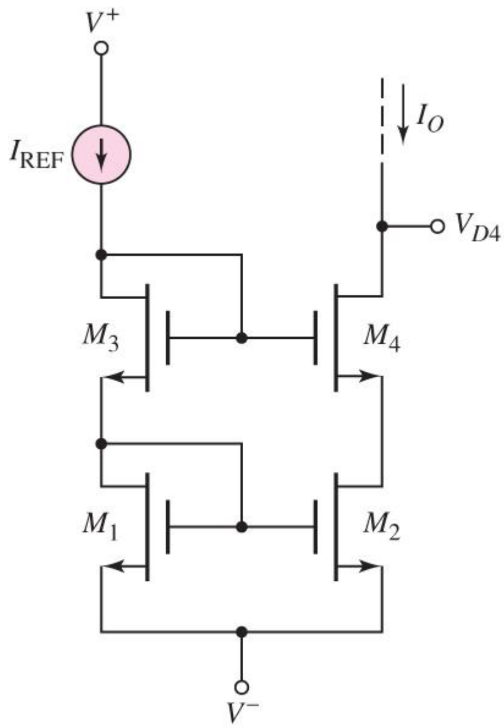


Figure 2

Answers for Question 2 (Continued)

(a) Using the formula of $I_D = K_n (V_{GS} - V_{TN})^2$ [2 marks]

$I_{REF} = K_n (V_{GS1} - V_{TN})^2 \rightarrow 120\mu = 80\mu\,(V_{GS1} - 0.5)^2$ [2 marks]

$\mathbf{V_{GS1} = 1.7247\ V}$ [2 marks]

$\mathbf{V_{GS2} = V_{GS3} = V_{GS4} = V_{GS1} = 1.7247\ V}$ [2 marks]

$I_O = I_{D4} = I_{D2} = K_n (V_{GS} - V_{TN})^2 = \mathbf{120\ \mu A}$ [2 marks]

(b) $V^+ - V_{GS5} - V_{GS3} - V_{GS1} = V^-$ [2 marks]

$V_{GS5} = V^+ - V_{GS3} - V_{GS1} - V^- = 7 - 1.7247(2) - (-7) = 10.5506\ V$ [2 marks]

(c) $R_O = r_{O4} + r_{O2}(1 + g_m r_{04})$ [2 marks]

OR $R_O \approx g_m r_{04} r_{O2}$

[Because approximation was also taught in the lecture]

$g_m = 2\sqrt{K_n I_O} = 2\sqrt{(0.08m)(0.12m)} = 0.19596 \frac{mA}{V}$ [2 marks]

$r_{O2} = r_{O4} = \frac{1}{\lambda I_O} = \frac{1}{(0.02)(0.12m)} = 416.666\ k\Omega$ [2 marks]

$R_O = 416.666k + 416.666k[1+(0.19596m)(416.666k)] = 34.854\ M\Omega$ [2 marks]

OR $R_O = (0.19596m)(416.666k)(416.666k) = 34.02\ M\Omega$

$\Delta I_O = \frac{\Delta V_{D4}}{R_O} = \frac{3-(-3)}{34.854M} = 0.1721\ \mu A$ [2, 2 marks]

OR $\Delta I_O = \frac{\Delta V_{D4}}{R_O} = \frac{3-(-3)}{34.02M} = 0.1764\ \mu A$

$\therefore \frac{\Delta I_O}{I_O} \times 100\% = \frac{0.1721\mu}{120\mu} \times 100\% = \mathbf{0.1434\%}$ [2, 2 marks]

OR $\therefore \frac{\Delta I_O}{I_O} \times 100\% = \frac{0.1764\mu}{120\mu} \times 100\% = \mathbf{0.1469\%}$

QUESTION 3 [30 marks]

Figure 3 shows a circuit diagram for a BJT differential amplifier biased with a current source to provide bias current I_Q. Study the circuit diagram carefully. Transistor parameters are V_{BE}**(on) = 0.7 V**, $\beta = \infty$, and $V_A = \infty$.

For the circuit diagram also, **voltages measured** at v_{C1} and v_{C2} are **4.5 V** respectively.

(a) **Calculate** the values for v_{cm} and v_d. [6 marks]

(b) **Determine** the value of I_Q. [6 marks]

(c) **Find** the value for v_{CE2}. [6 marks]

(d) **Determine** the differential-mode voltage gain (A_d) of the differential amplifier for a **one-sided output** taken at v_{C2}. [6 marks]

(e) **Draw and label clearly** the full circuit diagram if the differential amplifier is biased with a **Widlar** current source. [6 marks]

Show clearly all your calculations. Every parameter must be written with its correct Unit.

Answers for Question 3

(a) From Figure 3:
$v_{B1} = v_{B2} = 0$ V **[2]**
$v_{cm} = (v_{B1} + v_{B2})/2 = 0$ V **[2]**
$v_d = v_{B1} - v_{B2} = 0$ V **[2]**

(b) Given: $v_{C1} = v_{C2} = 4.5$ V
$10 - I_{C1}R_C = v_{C1} = 4.5$ V **[2]**
$I_{C1} = 0.55$ mA $= I_{C2}$ **[2]**
$I_Q = I_{C1} + I_{C2} = 1.1$ mA **[2]**

(c) Given: $v_{C2} = 4.5$ V
$v_{CE2} = v_{C2} - v_E$ **[2]**
$v_E = v_{B2} - V_{BE}(\text{on}) = 0 - 0.7 = -0.7$ V **[2, 1]**
$v_{CE2} = v_{C2} - v_E = 4.5 - (-0.7) = 5.2$ V **[1]**

(d) $A_d = (g_{m2} R_C)/2$ **[2]**
$g_{m2} = I_{C2} / V_T$ **[2]**
$= 0.55\text{m}/26\text{m} = 21.153$ mA/V **[1]**
$A_d = (g_{m2} R_C)/2$
$= (21.153\text{m} \times 10\text{k})/2 = 105.76$ **[1]**

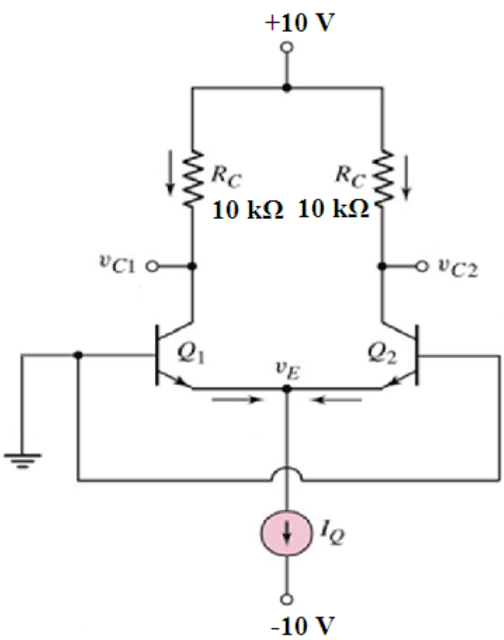
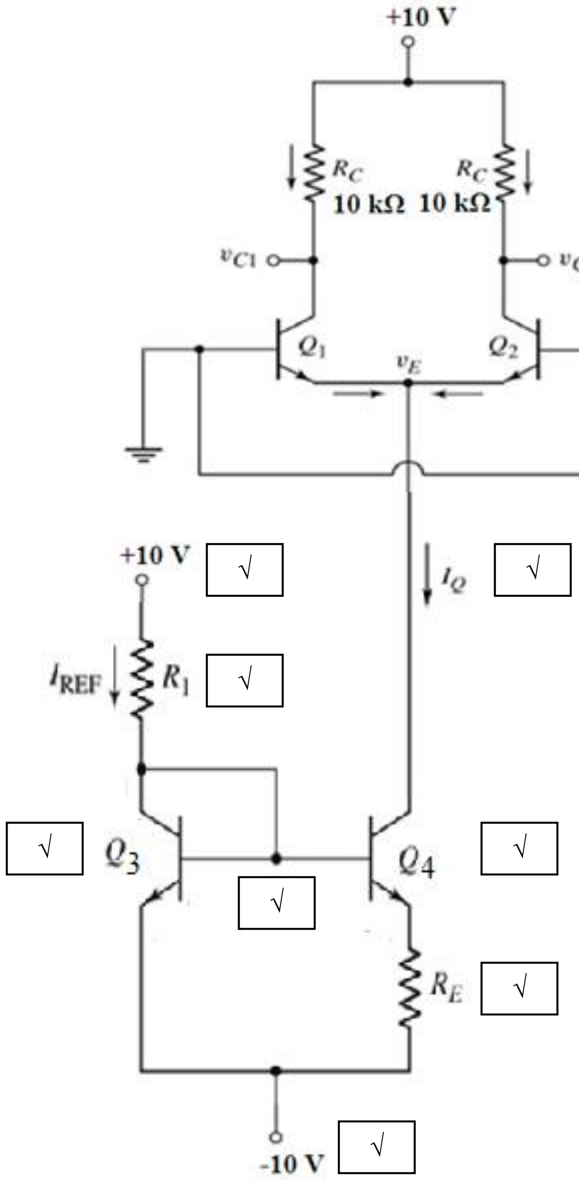


Figure 3

Answers for Question 3 (Continued)

(e)



Diff amp: 2 marks

√ = 0.5 marks

Total: 4 marks

BASIC FORMULA FOR TRANSISTOR

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

$$\beta = g_m r_\pi$$

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

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

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

$$V_T = 26 \text{ mV}$$

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

$$g_m = 2\sqrt{K_? I_{DQ}}$$

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

Quadratic formula :

$$Ax^2 + Bx + C = 0 \rightarrow x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$$