Seat Number:

Name:
Student ID Number:
Section: **01/02/03/04/05/06 A/B**
Lecturer: **Dr Fazrena / Dr Jamaludin / Dr Azni Wati / Dr Jehana / Ms Zarrin**

UNIVERSITI TENAGA NASIONAL

College of Engineering

Department of Electronics and Communication Engineering

Test 1 SOLUTION

SEMESTER 1, ACADEMIC YEAR 2016/2017

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**15 July 2016**
Time Allowed	:	**1½ hour**

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.** Use both sides of the question paper to write your answers.
5. For all calculations, assume that V_T = **26 mV**.

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

☺ **GOOD LUCK!** ☺

Question No.	1	2	3	Total
Marks				

<u>Question 1</u> **[40 marks]**

(a) The Widlar current source is shown in **Figure 1**. It is given that V^+ **= 12V** , V^- **= -12V**, R_1 **= 50kΩ** and V_{BE1} **= 0.68V at 1mA.**

i) **By clearly stating any assumptions, <u>derive</u>** the relationship between I_o and I_{REF} for a Widlar current source to achieve the equation below:

[8 marks]

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

ii) **Design** the current source to provide output current of **3μA** by determining I_{REF}, I_{C1}, I_{C2}, V_{BE2} and R_E. [12 marks]

<u>Answers for Question 1(a)i)</u>

Neglecting base currents, $I_B = 0$, $I_C = I_E$ [1mark]
$I_{C1} = I_{REF} = I_{E1}$, $I_{C2} = I_O = I_{E2}$ [1mark]
$I_{C1} = I_S \exp(V_{BE1}/V_T) = I_{REF}$ [1mark]
$I_{C2} = I_S \exp(V_{BE2}/V_T) = I_O$ [1mark]
$V_{BE1} = V_T \ln(I_{REF}/I_S)$ and $V_{BE2} = V_T \ln(I_O/I_S)$ [1mark]

KVL in B-E Loop:
$V_{BE1} = V_{BE2} + I_{E2}R_E$ [1mark]
$V_{BE1} = V_{BE2} + I_O R_E$
$I_O R_E = V_{BE1} - V_{BE2}$ [1mark]
$= V_T \ln(I_{REF}/I_S) - V_T \ln(I_O/I_S)$
$= V_T \ln(I_{REF}/I_O)$ [1mark]

<u>Answers for Question 1(a)ii)</u>

IREF = [V^+ - VBE1 – V^-] / R1 = [12 – 0.68 – (-12)]/50k
= 0.4664 mA [2marks]

Calculate IS:
IC= 1mA when VBE1 = 0.68 V
1m = IS exp [0.68/26m]
IS = 4.308×10^{-15} A [2marks]

Recalculate VBE1:
VBE1 = VT ln (IREF/IS) = 26m ln (0.4664m/4.308×10^{-15})
= 0.6602V [2marks]

Recalculate IREF:
IREF = [12 – 0.6602 – (-12)]/50k = 0.4668 mA [1mark]
Therefore, IC1 = IREF = 0.4668 mA [1mark]
IC2 = IO = 3 uA [1mark]
VBE2 = VT ln (IO/IS) = 26m ln (3 uA /4.308×10^{-15}) = 0.5289 V [1mark]

Calculating RE:
$R_E = (V_T/I_O)\ln(I_{REF}/I_O)$ = (26m/3 u) ln (0.4668 mA /3 uA)
= 43.74 kΩ [2marks]

(b) Design a **pnp version of the Wilson current source** using a resistor, R_1, to establish the current, I_{REF}. The circuit parameters are V^+ **= 10 V**, V^- **= −10 V**, and the transistor parameters are: $V_{EB}(on)$ **= 0.6 V**, β **= 80**, and $V_A = \infty$.

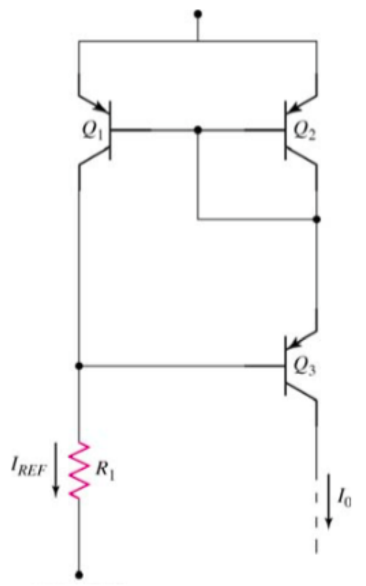
i) **Sketch** the circuit of the design. [8 marks]

ii) What is I_{REF}, if the load current, I_O **is 0.8 mA**? [8 marks]

iii) **Compare and contrast** the **stability** of the **Wilson current source** to a **three-transistor current source**. [4 marks]

Answers for Question 1(b)

(i) V^+ = 10 V



V^- = 10 V

Q1, Q2 and Q3 placement: **[4 marks]**
Insertion of R_1 **[2 marks]**
Labels of I_{REF} and I_O **[2 marks]**

(ii) $I_O = I_{REF}\left[\frac{1}{\left(1+\frac{2}{\beta(\beta+2)}\right)}\right]$ **…[2 marks]**

For I_O = 0.8 mA, substitute into eqn.,

$$I_{REF} = I_O\left[1+\frac{2}{\beta(\beta+2)}\right]$$

$$I_{REF} = (0.8m)\left[1+\frac{2}{(80)(82)}\right]$$

I_{REF} = **0.8002 mA [2 marks]**

For R1;

$R_1 = \frac{V^+ - V_{BE1} - V_{BE3} - V^-}{I_{REF}}$ **…[2 marks]**

$$R_1 = \frac{10-0.6-0.6-(-10)}{0.8002m}$$

= **23.49 kΩ [2 marks]**

(iii) The stability of the circuits:

Wilson: $R_O = \frac{\beta}{2} r_{O3}$, and …**[1 mark]**

3TCS: $R_O = r_{O2}$ …**[1 mark]**

Therefore, Wilson current source has more stability than 3TCS by a factor of $\beta/2$.

[2 marks]

Question 2 [30 marks]

(a) Consider the basic two-transistor NMOS current source in **Figure 2**. The circuit parameters are V^+ **= 2.5V**, V^- **= -2.5V**, and I_{REF} **= 120μA**. The transistor parameters are V_{TN} **= 0.8 V**, k'_n **= 80 μA/V²**, $(W/L)_1$ **= 3**, $(W/L)_2$ **= 4.5**, and λ **= 0.01 V⁻¹**. Calculate I_{D2} at V_{DS2} **= 3 V**.

[15 marks]

(b) **Redesign** the NMOS current source circuit in **Figure 2** such that the **minimum voltage at V_{D2} = -2.0 V**, I_{REF} **= 60 μA**, and the load current I_O **= 100 μA**. [15 marks]

Answers for Question 2(a)

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

$$V_{GS1} = \sqrt{\frac{2I_{REF}}{k_n^{'}(W/L)_1}} + V_{TN} = \sqrt{\frac{2(120\mu)}{(80\mu)(3)}} + 0.8 = 2V$$ (3)

$$V_{GS1} = V_{GS2}$$

$$I_{D2} = \frac{k_n^{'}}{2}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TN})^2 = \frac{80\mu}{2}(4.5)(2-1)^2 = 180\mu A$$ (3)

$$I_{D2} = 180\mu A \text{ at } V_{DS2} = 2V$$

$$\text{At } V_{DS2} = 3V$$

$$I_{D2(new)} = I_{D2} + \Delta I_{D2} = 180\mu A + \frac{\Delta V_{DS2}}{R_o}$$ (3)

$$\text{where } R_o = \frac{1}{\lambda I_{DQ}} = \frac{1}{(0.01)(180\mu)} = 555.6k\Omega$$ (2)

$$\Delta V_{DS2} = 3 - 2 = 1V$$ (1)

$$I_{D2(new)} = 180\mu A + \frac{1}{555.6k} = 181.8\mu A$$ (2)

Answers for Question 2 (b)

$VD2 = VDS2 + VS2 = VDS2 + V-$
$VD2min = VDS2(sat) + V-$
$VDS2(sat) = VD2min – V-$
$= -2 - (-2.5) = 0.5V$ [3marks]

Also, $VDS2(sat) = VGS2 – VTN$
$VGS2 = VDS2(sat) + VTN$
$= 0.5 + 0.8 = 1.3V = VGS1$ [3marks]

$ID1 = IREF = 60\ uA$
$ID1 = (kn'/2)(W/L)_1(VGS1-VTN)^2$
$60u = (80u/2)\ (W/L)_1(1.3-0.8)^2$
$(W/L)_1 = 6$ [3marks]

$ID2 = IO = 100\ uA$
$ID2 = (kn'/2)(W/L)_2(VGS2-VTN)^2$
$100u = (80u/2)\ (W/L)_2(1.3-0.8)^2$
$(W/L)_2 = 10$ [3marks]

$R = [V^+ - VGS1 – V^-] / IREF$
$= [2.5 – 1.3 – (-12)]/60u$
$= 61.67k\Omega$ [3marks]

Question 3 **[30 marks]**

The basic BJT differential pair is shown in **Figure 3**. The circuit parameter values are: V^+ **= +12 V**, V^- **= -12 V,** I_Q **= 1.2 mA,** and R_C = **12 kΩ**. The transistor parameters in the differential pair are β = ∞ (neglect base currents), V_A = ∞, and V_{BE} (on) = **0.7 V**. The constant current source in **Figure 3** that is providing the current I_Q is implemented using the **cascode current source**.

(a) **Sketch the full differential pair circuit** that includes the circuit for the **cascode current source**. [10 marks]

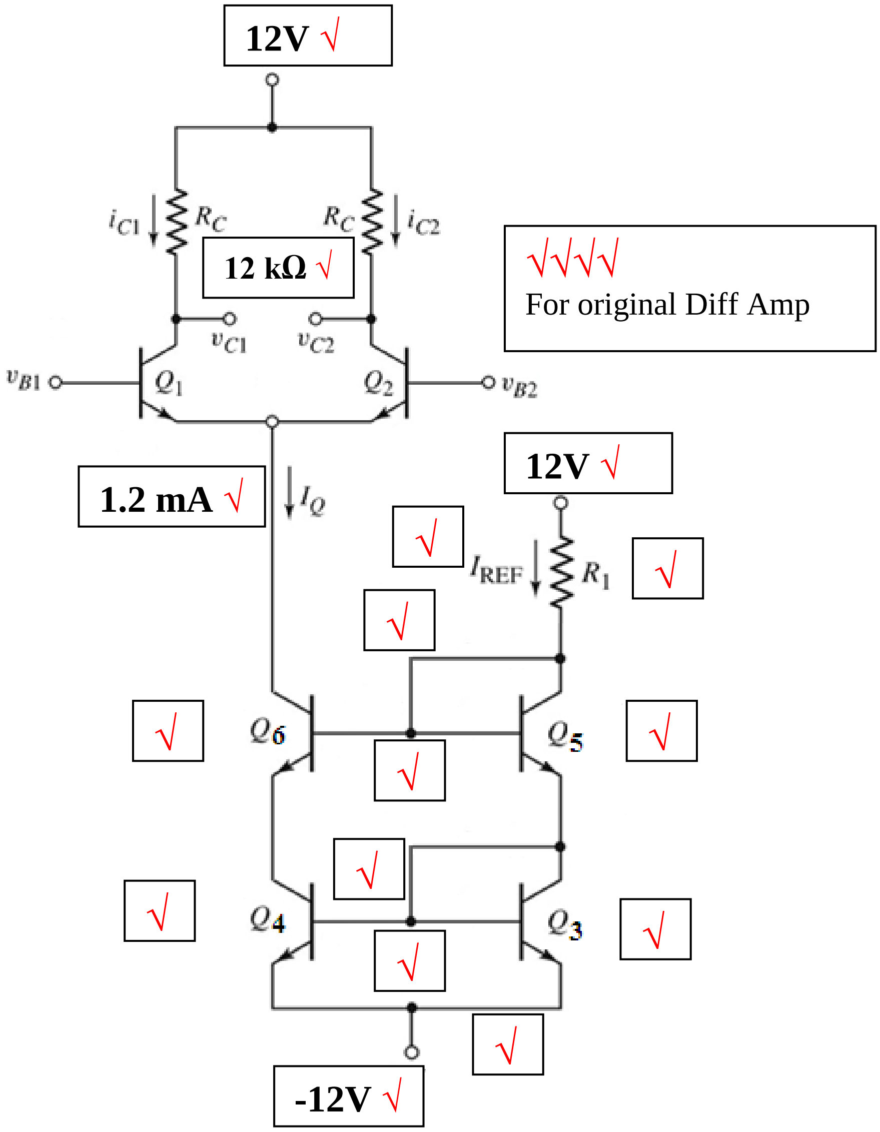
(b) **Determine** i_{C1} and v_{CE2} for common-mode voltages v_{B1} = v_{B2} = v_{CM} = **-3.5 V**. [10 marks]

(c) It is given that the input voltages for the differential amplifier are v_{B1} **= 210 x 10**$^{-6}$ **sin ωt** V and v_{B2} **= 180 x 10**$^{-6}$ **sin ωt** V. **Calculate** the differential-mode input voltage **(**v_d**)** and common-mode input voltage **(**v_{cm}**)** of the differential amplifier. Then, find the **maximum and minimum values of** v_d and v_{cm}.

[10 marks]

Answers for Question 3

(a)



√ = 0.5 mark

(b)

$\beta = \infty$

$i_{C1} = i_{E1} = I_Q / 2 = 1.2m/2 = 0.6$ mA [1, 1]

$v_{B1} = v_{B2} = v_{CM}$

$i_{C2} = i_{C1} = 0.6$ mA [1]

$v_{C2} = V^+ - i_{C2} R_C$ [1]

$= 12 - (0.6m)(12k) = 4.8$ V [1]

For $v_{CM} = -3.5$ V

$v_E = v_{CM} - V_{BE}(on)$ [1]

$= -3.5 - 0.7 = -4.2$ V [1]

$v_{CE2} = v_{C2} - v_E$ [2]

$= 4.8 - (-3.5) = 8.3$ V [1]

(c)

$v_d = v_{B1} - v_{B2}$ [1]

$= 210\text{x}10^{-6} \sin \omega t - 180\text{x}10^{-6} \sin \omega t$ [1]

$= 30\text{x}10^{-6} \sin \omega t$ V [1]

$v_d(\text{max}) = 30\text{x}10^{-6}(1) = 30\ \mu\text{V}$ $\{\sin \omega t = 1\}$ [1]

$v_d(\text{min}) = 30\text{x}10^{-6}(-1) = -30\ \mu\text{V}$ $\{\sin \omega t = -1\}$ [1]

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

$= (210\text{x}10^{-6} \sin \omega t + 180\text{x}10^{-6} \sin \omega t)/2$ [1]

$= 195\text{x}10^{-6} \sin \omega t$ [1]

$v_{cm}(\text{max}) = 195\text{x}10^{-6}(1) = 195\ \mu\text{V}$ $\{\sin \omega t = 1\}$ [1]

$v_{cm}(\text{min}) = 195\text{x}10^{-6}(-1) = -195\ \mu\text{V}$ $\{\sin \omega t = -1\}$ [1]