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Student ID Number:
Section:
Lecturer: Dr Azni Wati/ Dr Fazrena Azlee/ Dr Jehana Ermy/ Dr Jamaludin
Table Number:

UNIVERSITI TENAGA NASIONAL

College of Engineering
Department of Electronics and Communication Engineering

Test 1 – MODEL ANSWERS

SEMESTER 1, ACADEMIC YEAR 2015/2016

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**5 July 2015**
Time Allowed	:	**1½ hours**

Instructions to the candidates:

1. Write your Name and Student ID number. Circle Lecturer for your section.
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.**

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

☺ **GOOD LUCK!** ☺

Question Number	Q1	Q2	Q3	Total
Marks	40	30	30	100

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

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

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

Question 1 **[40 marks]**

For all **BJT current sources** in **this question**, all transistors are matched and have same parameters. The transistor parameters are: β **= 50**, V_{BE}**(on) = 0.6 V**, and V_A **= 150 V**. The circuit parameters for the current sources are: V^+ **= 10 V**, V^- **= -10 V,** and R_1 **= 24 kΩ**.

(a) **Calculate** reference current (I_{REF}), output current (I_O), and output resistance (R_O) for **Three-transistor** current source, **Wilson** current source, and **Cascode** current source. **Show all calculations clearly** and **do not forget** to put proper **Units** for I_{REF}, I_O, and R_O.
[36 marks]

(b) Based on I_O and I_{REF} relationships and R_O, **which current source** has the most stable I_O, **which current source** has the medium stable I_O, and **which current source** has the least stable I_O from the three current sources given in **part (a)**? **Explain** why you had said that.
[4 marks]

Answer for Question 1

Question 1(a) [36 marks]

Three-transistor current source	**Wilson current source**	**Cascode current source**
$I_{REF} = (V^+ - 2\ V_{BE} - V^-)/R_1$ **= (10 – 2x0.6 – (-10))/(24k)** **= 0.783 mA**	$I_{REF} = (V^+ - 2\ V_{BE} - V^-)/R_1$ **= (10 – 2x0.6 – (-10))/(24k)** **= 0.783 mA**	$I_{REF} = (V^+ - 2\ V_{BE} - V^-)/R_1$ **= (10 – 2x0.6 – (-10))/(24k)** **= 0.783 mA**
$I_O = I_{REF}/(1 + 2/(\beta(1+\beta)))$ **= (0.783m)/(1+2/(50x51))** **= 0.783 mA**	$I_O = I_{REF}/(1 + 2/(\beta(2+\beta)))$ **= (0.783m)/(1+2/(50x52))** **= 0.783 mA**	$I_O = I_{REF}/(1 + 4/\beta)$ **= (0.783m)/(1+4/(50))** **= 0.725 mA**
$r_{O2} = V_A / I_O$ **= 150/(0.783m)** **= 191.57 kΩ** $R_O = r_{O2}$ **= 191.57 kΩ**	$r_{O3} = V_A / I_O$ **= 150/(0.783m)** **= 191.57 kΩ** $R_O = (\beta\ r_{O3})/2$ **= (50 x 191.57k)/2** **= 4.789 MΩ**	$r_{O4} = V_A / I_O$ **= 150/(0.725m)** **= 206.89 kΩ** $R_O = \beta\ r_{O4}$ **= 50x206.89k** **= 10.3445 MΩ**

[4 marks each box, Total 36 marks]

Question 1(b) [4 marks]

Most stable: Wilson, medium: Cascode, least: 3-transistor.
Io for Wilson is approximately equal to Iref although Ro is the middle.
Although Io for Cascode is less than Iref, its Ro is highest.
3-transistor has smallest Ro although its Io is similar to Wilson.
Any explanation that makes sense may be accepted!
[4 marks]

Question 2 **[30 marks]**

The circuit shown in **Figure 2** is a **PMOS** version of a two-transistor current source. Assume that the transistor parameters are V_{TP} **= -0.4 V,** k'_p **= 80 µA/V²**, and λ **= 0**. The transistor width-to-length ratios are $(W/L)_1$ **= 30,** $(W/L)_2$ **= 15,** and $(W/L)_3$ **= 10**.

(a) **Determine** I_O, I_{REF}, V_{SG1}, and V_{SG3} [18 marks]

(b) **Calculate** the maximum value of V_{D2} such that M_2 remains biased in the saturation region. [6 marks]

(c) **Find** the largest value of R such that M_2 remains biased in the saturation region . [6 marks]

Answer for Question 2

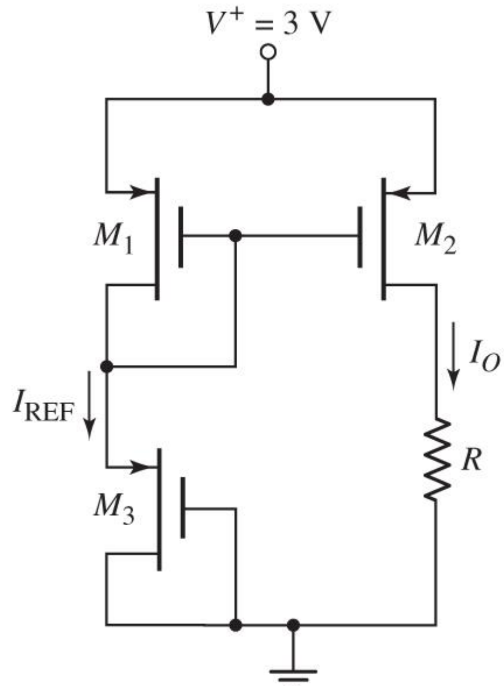

Figure 2

<u>Answer for Question 2</u>

Question 2(a) [18 marks]

ID1 = ID3 = IREF [2 marks]
I_{D1} = (1/2) kôp(W/L)$_1$(V_{SG1}+V_{TP})^2 = (1/2)(80u)(30)(VSG1-0.4)^2 é é eqn 1 [2 marks]
I_{D3} = (1/2) kôp(W/L)$_3$(V_{SG3}+V_{TP})^2 = (1/2)(80u)(10)(VSG3-0.4)^2 é é eqn 2 [2 marks]
V^+ - V_{SG1} ï V_{SG3} = 0 , so VSG3 = V+ - VSG1 é .. eqn 3 [2 marks]

Solve simultaneous equations: ID1 = ID3 = IREF
(1/2)(80u)(30)(VSG1-0.4)^2= (1/2)(80u)(10)(VSG3-0.4)^2 , replace VSG3 into eqn 2
~~(1/2)(80u)~~ (30)(VSG1-0.4)^2= ~~(1/2)(80u)~~ (10)(3 - VSG1 - 0.4)^2
(30)(VSG1-0.4)^2= (10)(2.6 - VSG1)^2 [2 marks]
VSG1 = -2.605V or 1.205V, choose VSG1 = 1.205V since VSG > |VTP| [2 marks]
IREF = I_{D1} = (1/2) kôp(W/L)$_1$(V_{SG1}+V_{TP})^2 = (1/2)(80u)(30)(1.205-0.4)^2 = 0.78mA [2 marks]

IO = I_{D2} = (1/2) kôp(W/L)$_2$(V_{SG2}+V_{TP})^2 = (1/2)(80u)(15)(1.205-0.4)^2 = 0.39mA ,
or, IO = (W/L)$_2$/(W/L)$_1$ x IREF = 15/30 x 0.78m = 0.39 mA [2 marks]

VSG3 = 3 ï VSG1 = 3 ï 1.205 = 1.795V [2 marks]

Question 2(b) [6 marks]

VD2 = V+ - VSD2 [1 mark]
VD2(max) = V+ - VSD2(min) = V+ - VSD2(sat) [2 marks]

VSD2(sat) = VSG2 + VTP = 1.205 + (-0.4) = 0.805 V [2 marks]

So VD2(max) = 3- 0.805 = 2.195 V [1 marks]

Question 2(c) [6 marks]

VR = VD2 = V+ - VSD2 = Io x R [2 marks]
VR(max) = VD2(max) = 2.195 = Io x R [2 marks]
R = 2.195 / Io = 2.195 / 0.39m = 5.63 kOhm [2 marks]

Question 3 **[30 marks]**

Figure 3 shows a circuit diagram for a **BJT** differential amplifier (diff-amp). The circuit parameter values are: V^+ **= +10 V**, V^- **= −10 V,** and R_C = **10 kΩ**. The transistor parameters are: $\beta = \infty$ (neglect base current), $V_A = \infty$, and V_{BE}**(on) = 0.7 V**.

(a) Assume that Q_1 and Q_2 are **matched pair** and operating at the same temperature.

By defining $$v_d = v_{B1} - v_{B2}$$

Show that $$i_{C1} = \frac{I_Q}{1 + e^{-v_d/V_T}} \quad \text{and} \quad i_{C2} = \frac{I_Q}{1 + e^{+v_d/V_T}}$$

[10 marks]

(b) The circuit has voltages measured at $v_{C1} = v_{C2}$ **= 4.0 V**, for $v_{B1} = v_{B2}$ **= 0 V**. **Find** I_Q.
[6 marks]

(c) If v_{B1} **= 1.2 mV** and v_{B2} **= -2.0 mV**

(i) **Calculate** v_d and v_{cm}. [4 marks]

(ii) **Calculate** i_{C1} and i_{C2}. [5 marks]

(iii) **Find** v_o if the diff-amp gain A_d **= 40 and** A_{cm} **= -0.05**. [5 marks]

Answer for Question 3

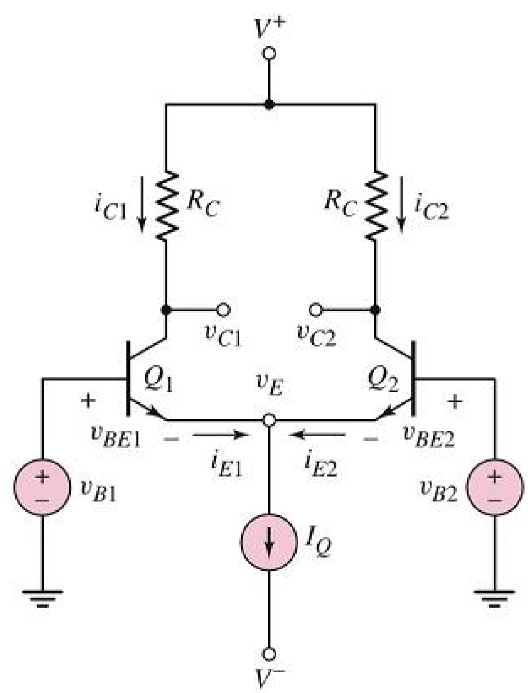

Figure 3

Answer for Question 3(a)

$$i_{C1} = I_S e^{v_{BE1}/V_T}$$ [1]

$$i_{C2} = I_S e^{v_{BE2}/V_T}$$ [1]

$$I_Q = i_{C1} + i_{C2} = I_S \left[e^{v_{BE1}/V_T} + e^{v_{BE2}/V_T} \right]$$ [3]

$$v_{BE2} - v_{BE1} = (v_{B2} - v_E) - (v_{B1} - v_E) = v_{B2} - v_{B1} = -v_d$$ [1]

$$\frac{i_{C1}}{I_Q} = \frac{1}{1 + e^{(v_{BE2} - v_{BE1})/V_T}} = \frac{1}{1 + e^{-v_d/V_T}}$$ [2]

$$\frac{i_{C2}}{I_Q} = \frac{1}{1 + e^{-(v_{BE2} - v_{BE1})/V_T}} = \frac{1}{1 + e^{+v_d/V_T}}$$ [2]

Answer for Question 3(b)

v_{C1} = V^+ ï $i_{C1} R_C$ [1]
4.0 V = 10 ï (i_{C1})(10k) [1]
i_{C1} = 0.6 mA [1]

β = Ð
i_{C1} = i_{E1} = I_Q / 2 [1]
I_Q = 2xi_{C1} = 2x0.6 mA [1]
= 1.2 mA [1]

Answer for Question 3(c)
$\boldsymbol{v_{B1}}$ **= 1.2 mV** and $\boldsymbol{v_{B2}}$ **= -2.0 mV**

(i) v_d = v_{B1} - v_{B2}

= 1.2m ï (-2m) = 3.2 mV [2]

v_{cm} = (v_{B1} + v_{B2}) / 2

= (1.2m + (-2m))/2 = - 0.4 mV [2]

(ii) i_{C1} = I_Q / [1+exp(-v_d/V_T)]

= 1.2m/ [1+exp (-3.2m/0.026)]

= 0.6369 mA [2.5]

i_{C2} = I_Q / [1+exp(+v_d/V_T)]

= 1.2m/ [1+exp (+3.2m/0.026)]

= 0.5631 mA [2.5]

(iii) v_o = A_d x v_d + A_{cm} x v_{cm} [2]

= (40)(3.2m) + (-0.05)(-0.4m) [2]

=128.02 mV [1]