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UNIVERSITI TENAGA NASIONAL

College of Engineering

Department of Electronics and Communication Engineering

Test 1

SEMESTER 2, ACADEMIC YEAR 2014/2015

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**6 December 2014**
Time Allowed	:	**1½ hours**

Instructions to the candidates:

1. Write your Name, Student ID number, and Section number. Indicate your Lecturer.
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 all calculations, use V_T = **26 mV** when necessary.

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

☺ **GOOD LUCK!** ☺

Question No.	1	2	3	Total
Marks				

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

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

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

Question 1 **[30 marks]**

The circuit parameters of a **Widlar** current source shown in **Figure 1** are V^+ **= +5 V**, and V^- **= -5 V**. The transistor parameters are β **= 120** and V_A **= 80 V**. The reference current is **10 times** the bias current and is established by a resistance R_1. The forward-active operation for transistor Q_1 is V_{BE1} **= 0.7 V at 1 mA.** Let the bias current I_O **= 50 µA**.

(a) **Determine** V_{BE1}, V_{BE2}, and R_1. [12 marks]

(b) **Neglect** base currents and **calculate** the value for emitter resistance R_E. [5 marks]

(c) **Determine** the **Widlar** current source output resistance, R_O. [8 marks]

(d) **Determine** the percent change in I_O if V_{C2} changes by **5 V**. [5 marks]

Answer for Question 1

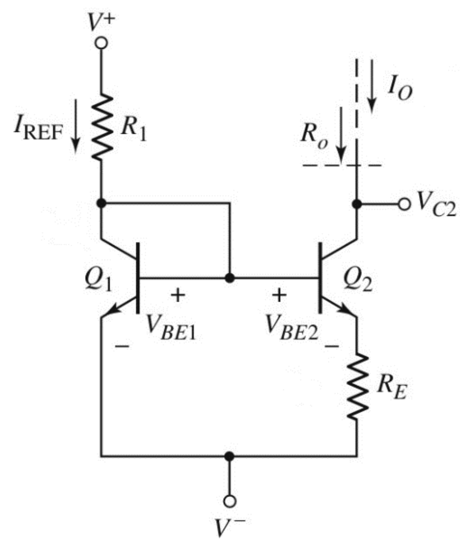


Figure 1

(a)

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

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

$= (1m) / \{\exp(0.7 / 0.026)\}$ [1]

$= 2.03 \times 10^{-15}$ A [0.5]

I_O = 50 µA

$I_{REF} = 10 \times I_O = 10 \times 50$ µA = 0.5 mA [2]

At I_{REF} = 0.5 mA,

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

$= (0.026) \ln(0.5m / 2.03 \times 10^{-15})$ [1]

$= 0.682$ V [0.5]

$V_{BE2} = V_T \ln(I_O / I_S)$ [1]

$= (0.026) \ln(50\mu / 2.03 \times 10^{-15})$ [1]

$= 0.6221$ V [0.5]

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

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

$= (5 - 0.682 + 5) / (0.5m)$ [1]

$= 18.636$ kΩ [0.5]

(b)

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

$R_E = (V_T / I_O) \ln(I_{REF} / I_O)$ [2]

$= (26m / 50\mu) \ln(0.5m / 50\mu)$ [2]

$= 1.198$ kΩ [1]

Answer for Question 1

(c)

$$r_{o2} = \frac{V_A}{I_O} = \frac{80}{50\mu} = 1.6\ \text{M}\Omega$$ **[1.5]**

$$g_{m2} = \frac{I_O}{V_T} = \frac{50\mu}{0.026} = 1.923\ \text{mA/V}$$ **[1.5]**

$$r_{\pi 2} = \frac{\beta V_T}{I_O} = \frac{(120)(0.026)}{50\mu} = 62.4\ \text{k}\Omega$$ **[1.5]**

$$R_E^{'} = R_E \parallel r_{\pi 2} = 1.177\ \text{k}\Omega$$ **[1]**

$$R_O = r_{o2}\left[1 + g_{m2}\left(R_E \| r_{\pi 2}\right)\right]$$ **[1]**

$$R_O = (1.6\text{M})\left[1 + (1.923\text{m})\left(1.198\text{k}\|62.4\text{k}\right)\right] = 5.221\ \text{M}\Omega$$ **[1.5]**

(d)

$$\Delta I_O = \frac{1}{R_O}\Delta V_{C2} = \frac{1}{(5.221\text{M})}(5) = 0.958\ \varepsilon\text{A}$$ **[3]**

$$\Delta I_O / I_O = 0.958\varepsilon / 50\varepsilon = 0.01916 \Rightarrow 1.916\%$$ **[2]**

<u>Question 2</u> **[30 marks]**

The transistors in the circuit shown in **Figure 2** have parameters $\boldsymbol{V_{TN} = 0.4}$ **V**, $\boldsymbol{V_{TP} = -0.4}$ **V**, $\boldsymbol{k'_n = 80\ \mu A/V^2}$, $\boldsymbol{k'_p = 60\ \mu A/V^2}$, and $\boldsymbol{\lambda_n = \lambda_p = 0}$. The transistor width-to-length ratios are $\boldsymbol{(W/L)_{1,2} = 15}$, $\boldsymbol{(W/L)_3 = 10}$, and $\boldsymbol{(W/L)_4 = 5}$.

(a) **Determine** the I_O, I_{REF}, and V_{DS2}**(sat).** [20 marks]

(b) **Calculate** the values of V_{GS1}, V_{GS3}, and V_{SG4}. [10 marks]

<u>Answer for Question 2</u>

$V^+ = 5$ V

Q2(b)

Using the equation $I_D = K'_n(V_{GS} - V_{TN})^2$; **[1]**

Equation for I_{REF} **with respect to** M_3 **and** M_4:

$$I_{REF} = \frac{k'_n}{2}\left(\frac{W}{L}\right)_3 (V_{GS3} - V_{TN})^2 = \frac{k'_n}{2}\left(\frac{W}{L}\right)_4 (V_{SG4} + V_{TP})^2 \quad [2]$$

$$I_{REF} = \frac{80\mu}{2}(10)_3(V_{GS3} - 0.4)^2 = \frac{60\mu}{2}(5)_4(V_{SG4} - 0.4)^2 \quad [2]$$

Solving the equations in V_{GS3} **and** V_{SG4} **terms:**

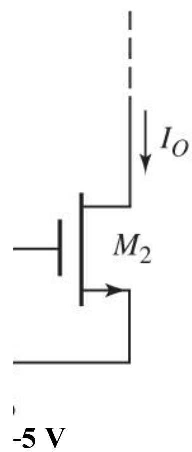
$V_{SG4} = 1.63299V_{GS3} - 0.25319$ **…(1)** **[2]**

Equation for I_{REF} **with respect to** M_3 **and** M_1:

$$I_{REF} = \frac{k'_n}{2}\left(\frac{W}{L}\right)_1 (V_{GS1} - V_{TN})^2 = \frac{k'_n}{2}\left(\frac{W}{L}\right)_3 (V_{GS3} - V_{TN})^2 \quad [2]$$

$$I_{REF} = \frac{80\mu}{2}(15)_3(V_{GS3} - 0.4)^2 = \frac{80\mu}{2}(10)_3(V_{GS3} - 0.4)^2 \quad [2]$$

$V_{GS3} = 1.22474V_{GS1} - 0.08989$ **…(2)** **[2]**



ıre 2

Using nodal analysis for LHS:

$V^+ - V_{SG4} - V_{GS3} - V_{GS1} - V^- = 0$; **[2]**

So, $V_{SG4} + V_{GS3} + V_{GS1} = 10$ **…(3)**

Substitute (1) into (3),

$V_{GS3} = 3.89412 - 0.37979V_{GS1}$ **…(4)** **[2]**

Substitute (4) into (2);

$V_{GS1} =$ <u>2.483 V</u> **[1]**

$V_{GS3} =$ <u>2.951 V</u> **[1]**

$V_{SG4} =$ <u>4.566 V</u> **[1]**

Answer for Question 2

Q2(a)

Based on the calculations above,

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

$I_{REF} = \frac{80\mu}{2}(15)(2.483 - 0.4)^2$ **[2]**

$= \underline{2.603\ mA}$ **[1]**

$I_O = \underline{2.603\ mA}$ **[2]**

and

$V_{DS}(sat) = V_{GS2} - V_{TN}$ **[2]**

$= 2.483 - 0.4 = \underline{2.083\ \text{V}}$ **[1]**

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: $\beta = \infty$ (neglect base current), $V_A = \infty$, and $V_{BE}(\text{on}) = 0.7$ V. For the circuit also, voltages measured at v_{C1} and v_{C2} are **4.5 V**. **Calculate** the value of I_Q and v_{CE2}.

[10 marks]

Answer for Question 3(a)

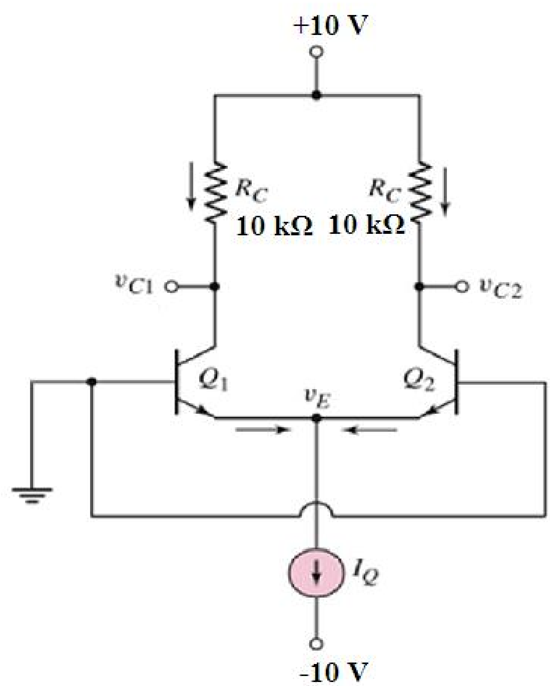


Figure 3a

Q3(a)

Given: $v_{C1} = v_{C2} = 4.5$ V

$10 - I_{C1} R_C = v_{C1} = 4.5$ V **[2]**

→ $I_{C1} = 0.55$ mA $= I_{C2}$ **[1]**

→ $I_Q = I_{C1} + I_{C2} = 1.1$ mA **[2]**

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]**

→ $v_{CE2} = v_{C2} - v_E = 4.5 - (-0.7) = 5.2$ V **[1]**

(b) For a basic BJT differential amplifier shown in **Figure 3b**, the circuit parameter values are: V^+ **= +10 V**, V^- **= -10 V,** I_Q **= 1 mA,** and R_C **= 12 kΩ**. The transistor parameters in the differential pair are $\beta = \infty$ (neglect base currents), $V_A = \infty$, and V_{BE} (on) = **0.7 V**. The constant current source in the **Figure 3b** (that is providing the current I_Q) is implemented using a **cascode current source**.

(i) For all transistors in the **cascode current source**, V_A = **120 V** and β **= 100**. **What** is the value of the **output resistance (**R_O**)** looking into the constant current source? [5 marks]

(ii) **Calculate** the differential-mode voltage gain **(**A_d**)** taken as **one-sided output voltage** at v_{C2}. [5 marks]

(iii) **Calculate** the common-mode voltage gain **(**A_{cm}**)** using the following formula when all transistors in the **cascode current source** have $V_A = \infty$ **(**or that the **cascode current source is an ideal current source)**:

$$A_{cm} = \frac{-\beta R_C}{r_\pi + 2(1+\beta)R_o}$$ [5 marks]

(iv) It is given that the input voltages for the differential amplifier are v_{B1} **= 210 x 10**$^{-6}$ **sin ωt V** and v_{B2} **= 190 x 10**$^{-6}$ **sin ωt V**. **Calculate** differential-mode input voltage **(**v_d**)**, common-mode input voltage **(**v_{cm}**)**, and the output voltage **(**v_o**)** of the differential amplifier using values of A_d and A_{cm} from (ii) and (iii) above. [15 marks]

Answer for Question 3(b)

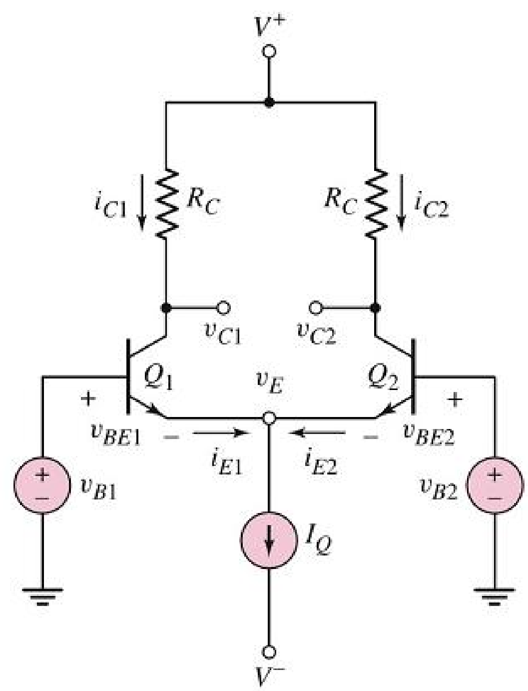


Figure 3b

Answer for Question 3 (Cont.)

Q3(b)

(i)

β = 100, I_Q = 1 mA

For cascode current source

R_O	$= (\beta\, r_{O\text{Casc}})$	[2]
$r_{O\text{Casc}}$	$= V_A / I_Q$	[1]
	= (120)/(1m) = 120 kΩ	[1]
R_O	$= (\beta\, r_{O\text{Casc}})$ = 100 x 120k	
	= 12 MΩ	[1]

(ii)

A_d	$= g_{m2} R_C / 2$	[2]
g_{m2}	$= (I_Q / 2) / V_T$	[1]
	= 0.5 mA / 26 mV = 19.23 mA/V	[1]
A_d	= (19.23 m x 12k) / 2	
	= 115.38 V/V	[1]

(iii)

For cascode current source that has transistors with $V_A = \infty$,

R_O $= (\beta V_A / I_Q)$ = (100 x ∞)/(1m) = ∞ [2]

$$A_{cm} = \frac{-\beta R_C}{r_\pi + 2(1+\beta)R_o} = \frac{-(\infty)(12k)}{r_\pi + 2(1+\infty)(\infty)} = 0$$

→ A_{cm} = {use formula} = Value / ∞ = 0 [3]

(iv)

v_d	$= v_{B1} - v_{B2}$	[2]
	$= 210\text{x}10^{-6}$ sin ωt - $190\text{x}10^{-6}$sin ωt	[2]
	= 20 x 10^{-6} sin ωt (V)	[1]
v_{cm}	$= (v_{B1} + v_{B2}) / 2$	[2]
	= ($210\text{x}10^{-6}$ sin ωt + $190\text{x}10^{-6}$sin ωt)/2	[2]
	= 200 x 10^{-6} sin ωt (V)	[1]
v_o	$= A_d$ x v_d + A_{cm} x v_{cm}	[2]
	= (115.38)(20 x 10^{-6} sin ωt) + (0)(200 x 10^{-6} sin ωt)	[2]
	= 2307.6 x 10^{-6} sin ωt V	[1]