Name:

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Section:

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UNIVERSITI TENAGA NASIONAL

College of Engineering

Department of Electronics and Communication Engineering

Midterm Test – Model Answer

SEMESTER 2, ACADEMIC YEAR 2010/2011

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**21 January 2011**
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.**

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

☺ **GOOD LUCK!** ☺

<u>Question 1</u> **[30 marks]**

For a BJT cascode current source:

(a) Draw its circuit diagram. [5 marks]

(b) From the circuit diagram, draw its AC equivalent circuit. [4 marks]

(c) Draw its small-signal equivalent circuit using hybrid-$\boldsymbol{\pi}$ equivalent circuit for the BJT. [4 marks]

(d) Derive a formula for its output resistance, $\boldsymbol{R_O}$. [5 marks]

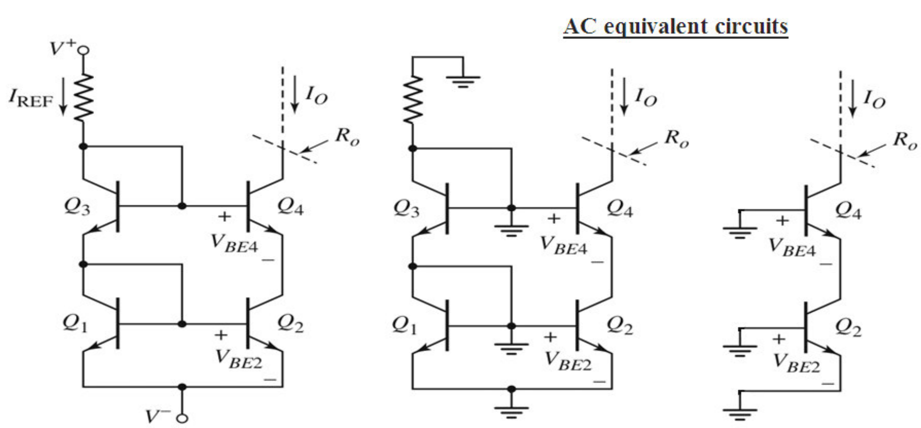
(e) Given that $\boldsymbol{V+}$ = 5 V, $\boldsymbol{V-}$ = -5 V, and for all transistors $\boldsymbol{V_{BE}}$(on) = 0.7 V, $\boldsymbol{V_A}$ = 200 V, and $\boldsymbol{\beta}$ = 200:

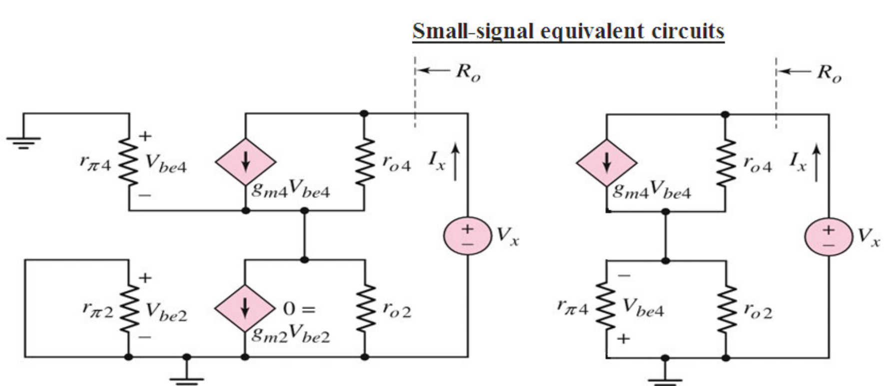
  (i) Design a BJT cascode current source with $\boldsymbol{I_O}$ = 0.5 mA [8 marks]

  (ii) Find the output resistance, $\boldsymbol{R_O}$ [4 marks]

<u>Answer for Question 1</u>

Answer (a) to (c): Give marks appropriately!





Answer for Question 1

(d)

$\boldsymbol{V_{be4} = - I_x (r_{o2} \parallel r_{\pi 4})}$ **[1/2]**

Summing currents at output node yields

$$I_x = g_{m4}V_{be4} + \left(\frac{V_x - (-V_{be4})}{r_{o4}}\right)$$
$$I_x = -g_{m4}I_x(r_{o2} \parallel r_{\pi 4}) + \left(\frac{V_x - I_x(r_{o2} \parallel r_{\pi 4})}{r_{o4}}\right)$$
$$\frac{V_x}{r_{o4}} = I_x + g_{m4}I_x(r_{o2} \parallel r_{\pi 4}) + \frac{I_x(r_{o2} \parallel r_{\pi 4})}{r_{o4}}$$
$$V_x = I_x(r_{o4} + r_{o4}g_{m4}(r_{o2} \parallel r_{\pi 4}) + (r_{o2} \parallel r_{\pi 4}))$$
$$V_x = I_x(r_{o4} + r_{o4}g_{m4}(r_{\pi 4}) + (r_{\pi 4}))$$

[3]

Where $\boldsymbol{\beta = g_{m4}r_{\pi 4}}$ and assuming $\boldsymbol{r_{\pi 4} << r_{o2}}$

$$R_O = \frac{V_x}{I_x} = r_{o4}(1+\beta) + r_{\pi 4}$$

[1/2]

$\boldsymbol{R_O \simeq \beta r_{o4}}$ **[1]**

(e)

(i) $\boldsymbol{I_O \approx I_{REF} / (1 + 4/\beta)}$

$\boldsymbol{I_{REF} = I_O (1 + 4/\beta) = (0.5m)(1 + 4/200) =}$ **0.51 mA**

[2] **[1]** **[1]**

$\boldsymbol{R_1}$ **= (**$\boldsymbol{V+}$ **-** $\boldsymbol{V-}$ **- 2**$\boldsymbol{V_{BE}}$(on)**) /** $\boldsymbol{I_{REF}}$ **= (10 – 1.4)/(0.51m) = 16.86 kΩ**

[2] **[1]** **[1]**

(ii) $\boldsymbol{R_O \simeq \beta r_{o4} = \beta V_A / I_O}$ **= (200 x 200) / (0.5m)** = 80000 **kΩ** = 80 M**Ω**

[1] **[1]** **[1]** **[1]**

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

For a MOSFET current source circuit shown in **Figure 2**, the transistor parameters are $\boldsymbol{V_{TN}}$ = 0.7 V, $\boldsymbol{k'_n}$ = 60 μA/V^2, and $\boldsymbol{\lambda}$ = 0.015 V^{-1}. The transistor aspect ratios are $\boldsymbol{(W/L)_1}$ = 20, $\boldsymbol{(W/L)_2}$ = 12, and $\boldsymbol{(W/L)_3}$ = 3.

(a) Determine $\boldsymbol{V_{GS1}}$, $\boldsymbol{I_{REF}}$, $\boldsymbol{I_O}$, and $\boldsymbol{V_{DS2}}$ [20 marks]

(b) Find $\boldsymbol{V_{GS3}}$ [5 marks]

(c) Find $\boldsymbol{I_O}$ at $\boldsymbol{V_{DS2}}$ = 3.0 V [5 marks]

<u>Answer for Question 2</u>

(a)

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

$$I_{REF} = \frac{k_n'}{2}\left(\frac{W}{L}\right)_3 (V_{GS3} - V_{TN})^2$$

$$V_{GS1} + V_{GS3} = 10$$

$$I_O = \frac{k_n'}{2}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TN})^2$$

[2] for every equation = [8]

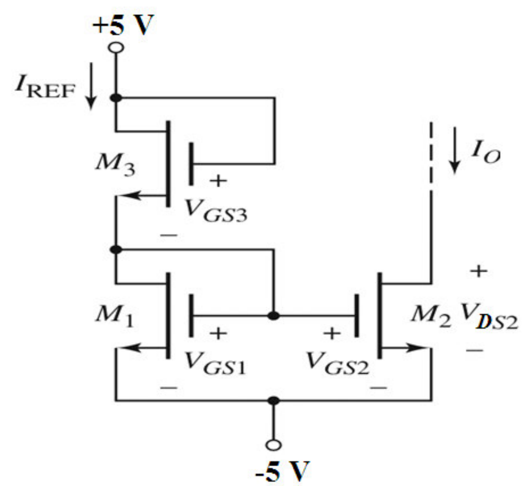


Figure 2

→ $\boldsymbol{V_{GS1} = 3.1}$ **V** **[2]**
→ $\boldsymbol{I_{REF} = 3.456}$ **mA** **[2]**

→ $\boldsymbol{V_{GS2} = V_{GS1} = 3.1}$ **V** **[3]**
$\boldsymbol{I_O = 2.073}$ **mA** **[3]**

→ $\boldsymbol{V_{DS2} = V_{DS1} = V_{GS1} = 3.1}$ **V** **[2]**
$\boldsymbol{I_O = 2.073}$ **mA** at $\boldsymbol{V_{DS2} = 3.1}$ **V**

(b) $\boldsymbol{V_{GS3} = 10 - V_{GS1} = 6.9}$ **V** **[5]**

(c) $\boldsymbol{I_O = 2.073}$ **mA** at $\boldsymbol{V_{DS2} = 3.1}$ **V** **[1]**
$\boldsymbol{R_O = 1/(\lambda I_O) = 32.159}$ **kΩ** **[1]**

At $\boldsymbol{V_{DS2} = 3.0}$ **V,**
$\boldsymbol{\Delta I_O = (3.0 - 3.1)/R_O = -0.003}$ **mA** **[2]**
→ $\boldsymbol{I_O = 2.073m + (-0.003m) = 2.070}$ **mA** **[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}(on) = 0.7 V. For the circuit also, voltages measured at v_{C1} and v_{C2} are 4 V.

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

(ii) Find I_Q [10 marks]

(iii) Find v_{CE1} [5 marks]

Answer for Question 3a

(b)

(i)

From Figure 3a:

$v_{B1} = v_{B2} = 0$ V **[1]**

→ $v_{cm} = (v_{B1} + v_{B2})/2 = 0$ V **[2]**

→ $v_d = v_{B1} - v_{B2} = 0$ V **[2]**

(ii)

Given: $v_{C1} = v_{C2} = 4$ V

$10 - I_{C1}R_C = v_{C1} = 4$ V **[4]**

→ $I_{C1} = 0.6$ mA $= I_{C2}$ **[3]**

$I_Q = I_{C1} + I_{C2} = 1.2$ mA **[3]**

(iii)

Given: $v_{C1} = 4$ V

$v_{CE1} = v_{C1} - v_E$ **[2]**

$v_E = v_{B1} - V_{BE}(\text{on}) = 0 - 0.7 = -0.7$ V **[2]**

→ $v_{CE1} = v_{C1} - v_E = 4 - (-0.7) = 4.7$ V **[1]**

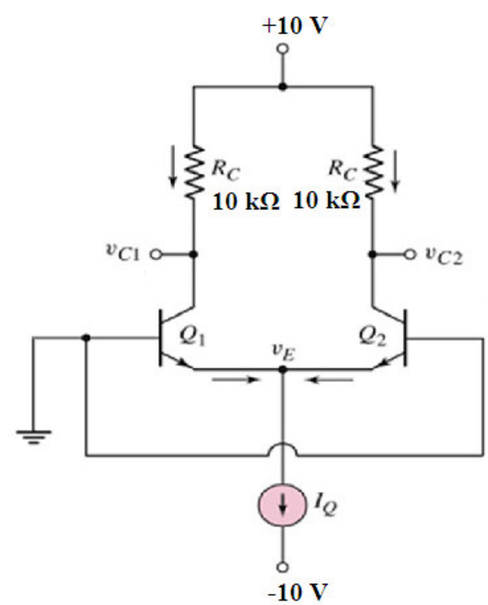


Figure 3a

(b) The differential amplifier in **Figure 3b** has a pair of pnp transistors connected as an active load. A two-transistor current source is also incorporated to establish the bias current, $\boldsymbol{I_Q}$ = **250µA**. The transistor parameters are $\boldsymbol{\beta}$ **= 150**, V_{BE}(on) = V_{EB}(on) = **0.7** V, V_{AN} **= 120** V, and V_{AP} **= 100** V. The output voltage can be calculated from Equation (1):

$$v_0 = g_m v_d (r_{o2} \parallel r_{o4} \parallel R_L) \quad (1)$$

(i) Draw the complete circuit incorporating the bias circuit. [5 marks]

(ii) What is the open-circuit differential-mode voltage gain? [10 marks]

(iii) Determine the differential-mode voltage gain if the load resistance is **100 kΩ**. [5 marks]

Answer for Question 3b

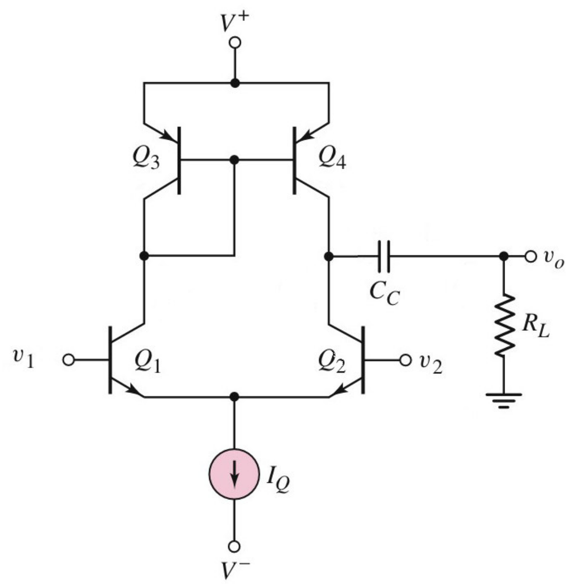
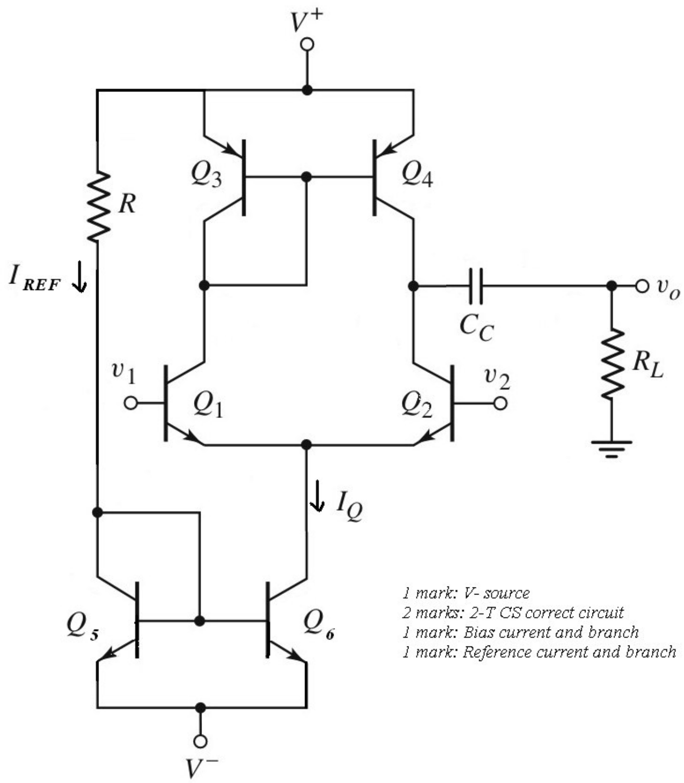


Figure 3b

(i)



(ii)

$$v_0 = g_m v_d (r_{o2} \parallel r_{o4})$$ **[1.5]**

$$A_d = \frac{v_o}{v_d} = g_m (r_{o2} \parallel r_{o4})$$ **[1]**

$$g_m = \frac{I_Q/_2}{V_T} = \frac{250\mu/_2}{0.026} = 4.808mA/V$$ **[1.5]**

$$r_{o2} = \frac{V_{AN}}{I_Q/_2} = \frac{120}{125\mu} = 960k\Omega$$ **[2]**

$$r_{o4} = \frac{V_{AP}}{I_Q/_2} = \frac{100}{125\mu} = 800k\Omega$$ **[2]**

$$r_{o2} \parallel r_{o4} - \frac{(960k)(800)k}{(960+800)k} - 436.4k\Omega$$ **[1]**

$$A_d = (4.808m)(436.4k) = 2098$$ **[1]**

(iii)

$$v_0 = g_m v_d(r_{o2} \parallel r_{o4} \parallel R_L)$$ **[1]**

$$A_d = \frac{v_c}{v_d} = g_m(r_{o2} \parallel r_{o4} \parallel R_L)$$ **[1]**

$$r_{o2} \parallel r_{o4} \parallel R_L = \frac{(436.4k)(100)k}{(436.4+100)k} = 81.36k\Omega$$ **[2]**

$$A_d = (4.808\text{m})(81.36\text{k}) = 391.2$$ **[1]**