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UNIVERSITI TENAGA NASIONAL

College of Engineering

Department of Electronics and Communication Engineering

Test 2 – Model Answers

SEMESTER 2, ACADEMIC YEAR 2012/2013

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**30 November 2012**
Time Allowed	:	**1½ 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.**
5. For BJT, use V_T **= 26 mV** where appropriate.
6. Use at least **4 significant numbers** in all calculations.

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

☺ **GOOD LUCK!** ☺

Question No.	1	2	3	Total
Marks				

Question 1 **[30 marks]**

The bias voltages in the differential amplifier shown in **Figure 1** are $V^+ = 3$ **V** and $V^- = -3$ **V**. The transistor parameters are $K_{n1} = K_{n2} = 100$ **μA/V²**, $K_{n3} = K_{n4} = 200$ **μA/V²**, $\lambda_1 = \lambda_2 = 0$, $\lambda_3 = \lambda_4 = 0.01$ **V⁻¹** and $V_{TN} = 0.3$ **V** for all transistors.

a) **Design** the circuit such that $V_{DS1} = V_{DS2} = 3.8$ **V** and $I_{D1} = I_{D2} = 60$ **μA** when $v_1 = v_2 = -1.2$ **V.** [20 marks]

b) Calculate the change in I_Q if $v_1 = v_2 = +0.8$ **V**. [10 marks]

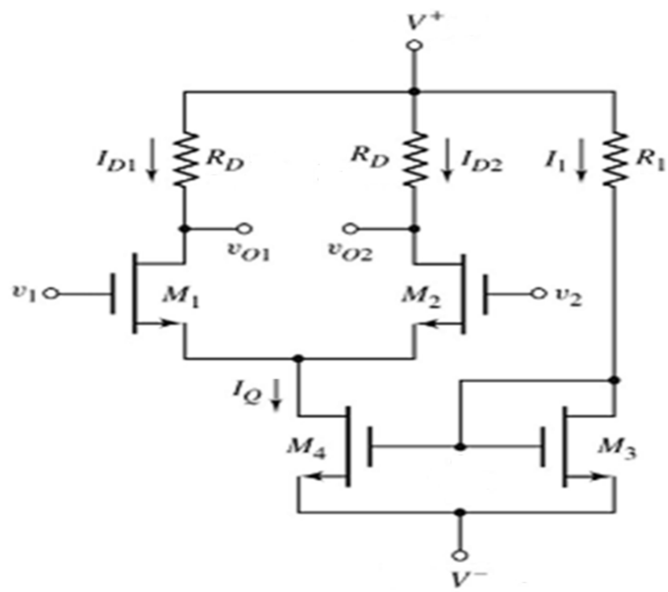


Figure 1

Answers for Question 1

(a)

R_D	$= (V^+ - V_{O1}) / I_{D1}$	[2]
I_{D1}	$= K_{n1} (V_{GS1} - V_{TN})^2$	[2]
60μ	$= (100\mu)(V_{GS1} - 0.3)^2$	[1]
V_{GS1}	$= 1.075$ V	[1]
V_{O1}	$= V_1 - V_{GS1} + V_{DS1}$	[2]
	$= (-1.2) - 1.075 + 3.8 = 1.525$ V	[1]
R_D	$= (3 - 1.525) / 60\mu = 24.583$ kΩ	[1]

R_1	$= (V^+ - V_{GS3} - V^-) / I_1$	[2]
I_1	$= I_Q$	[1]
	$= I_{D1} + I_{D2} = 60\mu + 60\mu = 120$ µA	[2]
I_1	$= K_{n3} (V_{GS3} - V_{TN})^2$	[2]
120μ	$= (200\mu)(V_{GS1} - 0.3)^2$	[1]
V_{GS3}	$= 1.075$ V	[1]
R_1	$= (3 - 1.075 - (-3)) / 120\mu = 41.041$ kΩ	[1]

(b)

Output resistance of the current source,

R_O	$= r_{O4} = 1 / (\lambda_4 I_Q)$	[2]
	$= 1 / (0.01 \times 120\ \mu) = 833.333$ kΩ	[1]

R_O	$= \Delta V_{DS4} / \Delta I_Q$	[2]
ΔV_{DS4}	$= \Delta V_{S1} = \Delta v_1 = 0.8 - (-1.2) = 2$ V	[3]
ΔI_Q	$= \Delta V_{DS4} / R_O$	[1]
	$= 2 / [1 / (0.01 \times 120\ \mu)]$	
	$= 2 \times (0.01 \times 120\ \mu) = 2.4$ µA	[1]

Question 2 **[30 marks]**

The circuit parameters for differential amplifier with active load shown in **Figure 2** are $V^+ = 5$ V, $V^- = -5$ V, $A_{cm} = -0.28$, and $I_Q = 250\ \mu A$. The **NMOS** transistor parameters are $V_{TN} = 0.4$ V, $k'_n = 100\ \mu A/V^2$, $(W/L)_n = 8$, and $\lambda_n = 0.018\ V^{-1}$. The **PMOS** transistor parameters are $V_{TP} = -0.4$ V, $k'_p = 40\ \mu A/V^2$, $(W/L)_p = 10$, and $\lambda_p = 0.02\ V^{-1}$.

a) **Determine** the output resistance R_o of the differential amplifier. [5 marks]

b) **Calculate** the small-signal differential-mode voltage gain $A_d = v_o/v_d$ and ***CMRR*** of the differential amplifier. [8 marks]

c) **Suggest** one way **to increase** the differential-mode voltage gain and **show** your new circuit and **justify** the change(s). [5 marks]

d) **Find** the **one-sided output voltage** (v_O) taken at v_{D2} of the differential amplifier when $v_1 = (0.10 + 0.05 \sin \omega t)$ **mV** and $v_2 = (-0.15 + 0.05 \sin \omega t)$ **mV.** [12 marks]

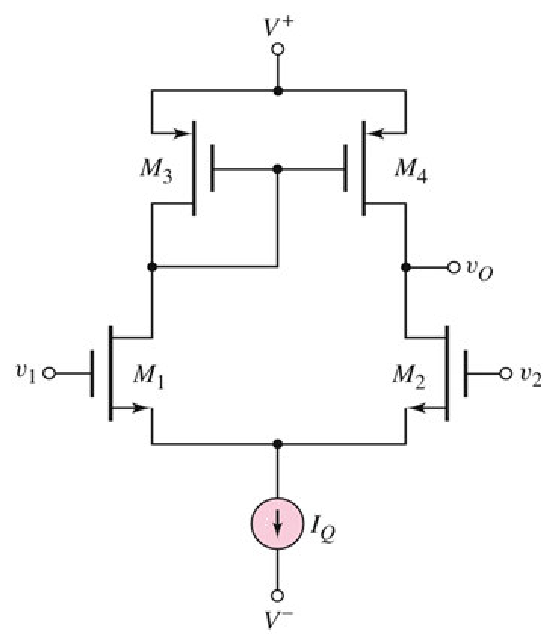


Figure 2

Answers for Question 2

(a)

I_D	$= I_Q / 2 = 250\mu / 2$		$= 125\ \mu A$	[1]
r_{o2}	$= 1 / (\lambda_n I_D)$	$= 1 / [(0.018)(125\mu)]$	$= 444.44\ k\Omega$	[1]
r_{o4}	$= 1 / (\lambda_p I_D)$	$= 1 / [(0.02)(125\mu)]$	$= 400.00\ k\Omega$	[1]
R_o	$= r_{o2} \parallel r_{o4}$	$= 444.44k \parallel 400.00\ k$	$= 210.52\ k\Omega$	[2]

(b)

R_o	$= r_{o2} \parallel r_{o4}$		$= 210.52\ k\Omega$	[0.5]
g_m	$= 2\sqrt{[K_n I_D]}$	$= 2\sqrt{[(k'_n/2)(W/L)_n(I_Q/2)]}$		[2]
	$= 2\sqrt{[(100\mu/2)(8)(125\mu)]}$		$= 0.4472\ mA/V^2$	[1]
A_d	$= g_m R_o = (0.4472m)(210.52k)$		$= 94.144$	[2.5]

CMRR $= |A_d / A_{cm}|$ $= 94.144 / 0.28$ $= 336.228$ [2]

(c)

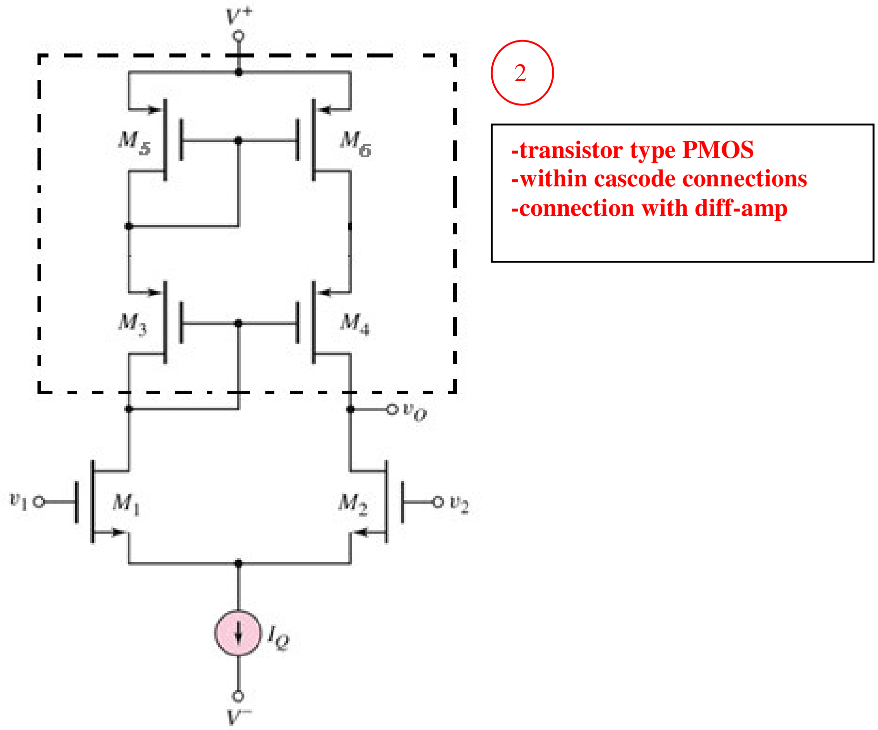
Increase voltage gain by using cascode active load. [1]

$A_d = g_m R_o$

Previous $R_o = r_{o2} \parallel r_{o4}$ [1]

New circuit $R_o = r_{o2} \parallel R_o(\text{active load}) = r_{o2} \parallel g_m r_{o4} r_{o6} \cong r_{o2}$

The new R_o is larger than the previous one. [1]



Answers for Question 2 (Cont.)

(d)

v_d	$= v_1 - v_2$	[1]
	= (0.10 +0.05 sin ωt) - (–0.15 +0.05 sin ωt)	[2]
	= 0.25 mV	[1]
v_{cm}	$= (v_1 + v_2)/2$	[1]
	= [(0.10 +0.05 sin ωt) + (–0.15 +0.05 sin ωt)]/2	[2]
	= (-0.025 + 0.05 sin ωt) mV	[1]
v_O	$= A_d v_d + A_{cm} v_{cm}$	[1]
	= (94.144)(0.25mV) + (-0.28)(-0.025 + 0.05 sin ωt mV)	[2]
	= (23.543 – 0.014 sin ωt) mV	[1]

Question 3 **[40 marks]**

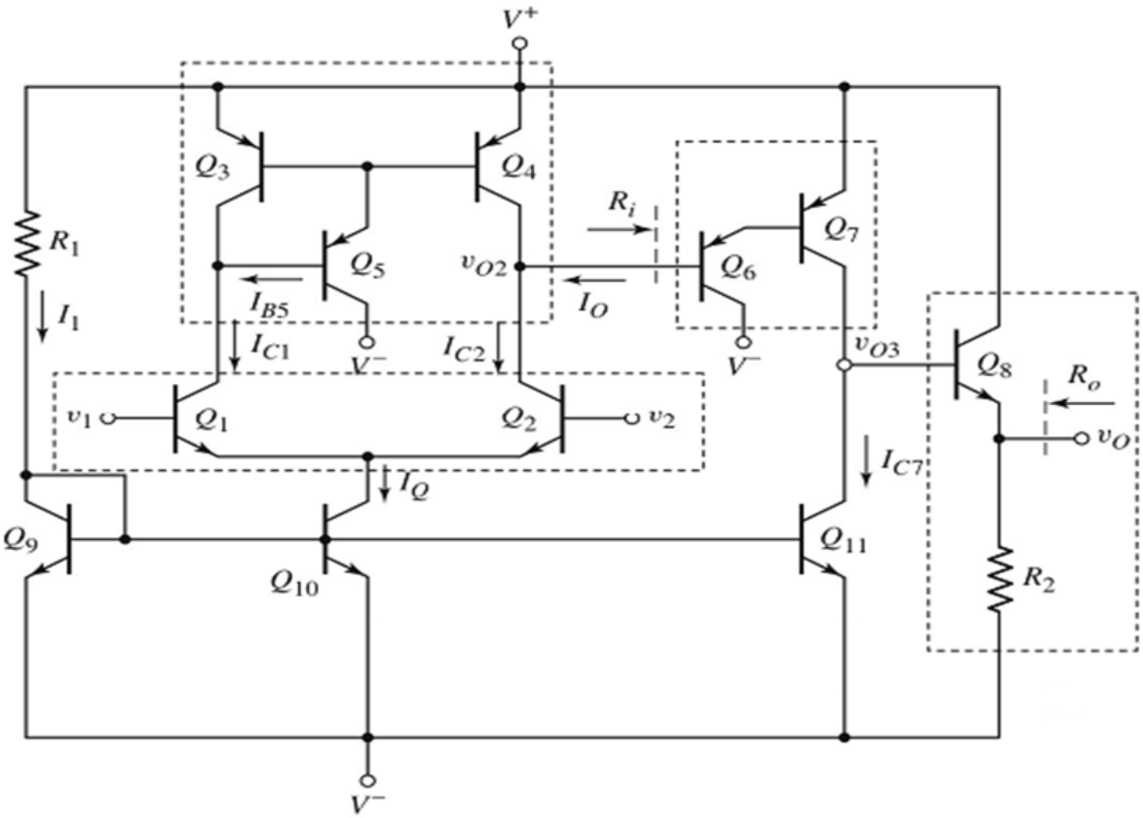


Figure 3

Consider the circuit shown in **Figure 3**, with parameters $I_{C7} = I_Q = 0.2$ **mA**, $I_{C8} = 1$ **mA,** and $R_2 = 12$ **kΩ**. Study the figure carefully. _Note that biasing for amplifiers in the circuit is provided by **two-transistor current mirrors**_. Assume that $\beta = 100$ for all transistors, and the **Early voltage** for Q_7 and Q_{11} is **100 V**.

(a) With small-signal analysis, input resistance (R_i) of the **Darlington pair** can be given by:

$$R_i = r_{\pi 6} + r_{\pi 7}\,(1+\beta) \quad \{\text{Equation 3.1}\}$$

Show that R_i can also be calculated using the following equation: [10 marks]

$$R_i = \frac{2(1+\beta)\beta V_T}{I_Q} \quad \{\text{Equation 3.2}\}$$

(b) **Calculate** the input resistance (R_i) of the **Darlington pair**. [6 marks]

(c) With the small-signal analysis also, **voltage gain** (***A_v***) of the **Darlington pair** can be found using:

$$A_v = \frac{\beta(1+\beta)R_{L7}}{R_i} \qquad \text{\{Equation 3.3\}}$$

where ***R_{L7}*** is the parallel combination of the resistance looking into collector of ***Q_{11}*** (denoted as ***R_{c11}***) and the resistance looking into base of ***Q_8*** (denoted as ***R_{b8}***). Show that the voltage gain ***A_v*** <u>can also be calculated</u> using the following equation:

[4 marks]

$$A_v = \left(\frac{I_Q}{2V_T}\right)R_{L7} \qquad \text{\{Equation 3.4\}}$$

(d) **Calculate** the voltage gain (***A_v***) of the **Darlington pair**. [10 marks]

(e) Output resistance (***R_O***) of the **Emitter follower** in the Figure 3 can be calculated using:

$$R_o = R_2 \left\| \left(\frac{r_{\pi 8} + Z}{1+\beta}\right)\right. \qquad \text{\{Equation 3.5\}}$$

where $Z = R_{c7} \| R_{c11}$

Calculate the output resistance (***R_O***) of the **Emitter follower**. [10 marks]

Answers for Question 3

a)

$$R_i = r_{\pi 6} + r_{\pi 7}(1+\beta)$$ **[2]**

$$r_{\pi 6} = \frac{\beta V_T}{I_{C6}} = \frac{\beta V_T(1+\beta)}{\beta I_{E6}} = \frac{V_T(1+\beta)}{I_{B7}} = \frac{V_T(1+\beta)}{I_{C7}}\frac{\beta}{\,} = \frac{(1+\beta)\beta V_T}{I_Q}$$ **[4]**

$$r_{\pi 7} = \frac{\beta V_T}{I_{C7}} = \frac{\beta V_T}{I_Q}$$ **[2]**

$$R_i = \frac{(1+\beta)\beta V_T}{I_Q} + \frac{\beta V_T}{I_Q}(1+\beta) = \frac{2(1+\beta)\beta V_T}{I_Q}$$ **[2]**

b)

$$R_i = \frac{2(1+\beta)\beta V_T}{I_Q}$$ **[2]**

$$R_i = \frac{2(1+100)(100)(26\text{m})}{0.2\text{m}} = 2.626\ \text{M}\Omega$$ **[4]**

c)

$$A_v = \frac{\beta(1+\beta)R_{L7}}{R_i} = \frac{\beta(1+\beta)R_{L7}}{\frac{2(1+\beta)\beta V_T}{I_Q}} = \frac{I_Q}{2V_T}R_{L7}$$ **[2, 2]**

d)

$$A_v = \frac{I_Q}{2V_T}R_{L7}$$ **[1]**

$$R_{L7} = R_{c11} \parallel R_{b8}$$ **[2]**

$$R_{c11} = r_{o11} = \frac{V_{A11}}{I_{C7}} = \frac{V_{A11}}{I_Q} = \frac{100}{0.2\text{m}} = 500\ \text{k}\Omega$$ **[2]**

$$R_{b8} = r_{\pi 8} + (1+\beta)R_2 = \frac{\beta V_T}{I_{C8}} + (1+\beta)R_2$$ **[2]**

$$R_{b8} = \frac{100(26\text{m})}{1\text{m}} + (1+100)(12\text{k}) = 1.2146\ \text{M}\Omega$$ **[1]**

$$R_{L7} = 500\ \text{k}\Omega \parallel 1.2146\ \text{M}\Omega = 354.19\ \text{k}\Omega$$ **[1]**

$$A_v = \frac{0.2\text{m}}{2(26\text{m})}(354.19\text{k}) = 1362.28$$ **[1]**

e)

R_O = $R_2 \parallel \{[r_{\pi 8} + (R_{c7} \parallel R_{c11})]/[(1+\beta)]\}$ **[2]**

$r_{\pi 8}$ = $\beta\, V_T / I_{C8}$ = (100)(0.026)/(1m) = 2.6 kΩ **[2]**

R_{c7} = r_{o7} = V_{A7} / I_{c7} = V_{A7} / I_Q = 100/0.2m = 500 kΩ **[2]**

R_{c11} = r_{o11} = V_{A11} / I_{c7} = V_{A11} / I_Q = 100/0.2m = 500 kΩ **[2]**

→ R_O = (12k) || {[2.6k + (500k || 500k)]/[(1+100)]}
= (12k) || (2.50k) = 2.069 kΩ **[2]**

Appendix: 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

$$g_m = 2K_n\left(V_{GSQ} - V_{TN}\right) = 2\sqrt{K_n I_{DQ}}$$

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