COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION

SEMESTER 3   2011 / 2012

MODEL ANSWERS

PROGRAMME	: **Bachelor of Electrical & Electronics Engineering (Honours)** **Bachelor of Electrical Power Engineering (Honours)**
SUBJECT CODE	: **EEEB273**
SUBJECT	: **ELECTRONIC ANALYSIS AND DESIGN II**
DATE	: **May 2012**
TIME	: **3 hours**

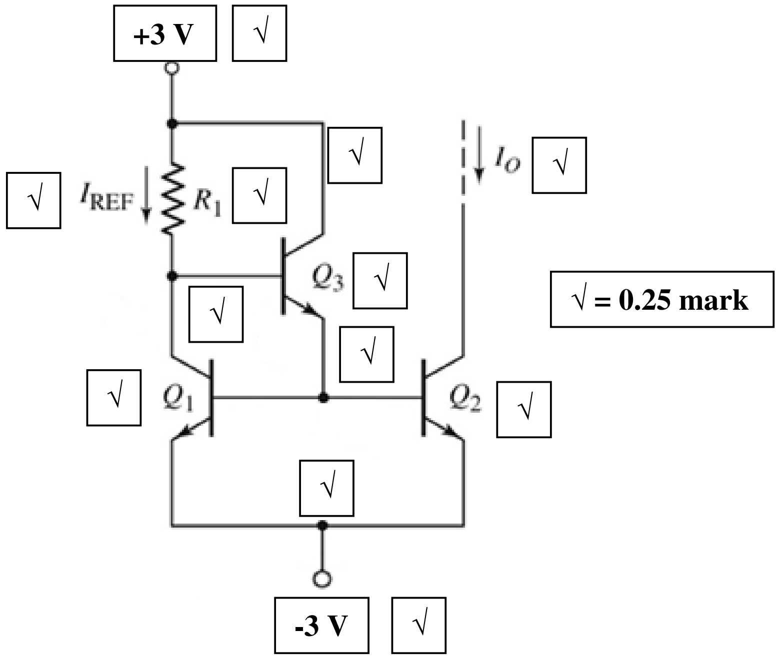
INSTRUCTIONS TO CANDIDATES:

1. This question paper contains **SIX (6)** questions in **THIRTEEN (13)** pages.
2. Answer **ALL** questions.
3. Write **all** answers in the answer booklet provided.
4. Write answer to each question on **a new page**.
5. For all calculations, assume that V_T **= 26 mV**.
6. Use at least **4 significant numbers** in all calculations.

THIS QUESTION PAPER CONSISTS OF THIRTEEN (13) PRINTED PAGES INCLUDING THIS COVER PAGE AND APPENDIX.

<u>Question 1(a)</u>

(i)



(ii)

I_{REF}	$= I_O\,[1 + 2/\beta(1+\beta)]$	**[1]**
	$= (0.25\text{m})[1 + 2/(50\text{x}51)] = 0.250196\text{ mA}$	**[1]**
R_1	$= (V^+ - V_{BE3} - V_{BE1} - V^-)\,/\,I_{REF}$	**[1]**
	$= (3 - 0.7 - 0.7 - (-3))\,/\,(0.250196\text{m}) = 18.385\text{ k}\Omega$	**[1]**

(iii)

I_O of a BJT three-transistor current source is closer to its I_{REF} at lower value of β compared to the two-transistor current source, thus it has more stable I_O. This is due to a better approximation of the relationship between I_O and I_{REF} due to addition of transistor Q_3 in the circuit. **[2]**

Question 1(b)

(i)

V_{DS2} (sat) = $V_{GS2} - V_{TN}$ [0.5]

$0.4 = V_{GS2} - 0.4 \rightarrow V_{GS2} = 0.8$ V [0.5]

$V_{GS1} = V_{GS2} = 0.8$ V [0.5]

$(W/L)_1 = I_{REF} / [(k'_n/2)(V_{GS1} - V_{TN})^2]$ [0.5]

$= (100\mu) / [(100\mu/2)(0.8 - 0.4)^2] = 12.5$ [0.5]

$(W/L)_2 = I_O / [(k'_n/2)(V_{GS2} - V_{TN})^2]$ [0.5]

$= (60\mu) / [(100\mu/2)(0.8 - 0.4)^2] = 7.5$ [0.5]

$V_{GS3} = V^+ - V_{GS1} - V^+ = 2.5 - 0.8 - (-2.5) = 4.2$ V [0.5]

$(W/L)_3 = I_{REF} / [(k'_n/2)(V_{GS3} - V_{TN})^2]$ [0.5]

$= (100\mu) / [(100\mu/2)(4.2 - 0.4)^2] = 0.138$ [0.5]

(ii)

$R_O = r_{O2} = 1 / (\lambda I_O)$ [0.5]

$= 1 / (0.01 \times 60\mu) = 1.6667$ MΩ [0.5]

$R_O = \Delta V_{D2} / \Delta I_O$ [0.5]

$\Delta I_O = \Delta V_{D2} / R_O = 3/(1.6667\text{M}) = 1.8$ µA [0.5]

Question 2(a)

(i)

$A_d = v_o / v_d = (g_{m2} R_C)/2$ **[2]**

$A_d = v_o / v_d = 7.5/0.05 = 150$ **[0.5]**

$g_{m2} = I_{CQ2}/V_T = I_Q/(2V_T) = (1m)/(2 \times 26m) = 19.231$ mA/V **[0.5]**

$A_d = (g_{m2} R_C)/2 = (19.231m \times R_C)/2 = 150$ **[0.5]**

$R_C = 300/19.231m = 15.599$ kΩ **[0.5]**

(ii)

$R_{id} = 2\, r_\pi = (2\, \beta\, V_T) / I_{CQ}$ **[0.5, 0.5]**

$= (4\, \beta\, V_T) / I_Q = (4 \times 100 \times 0.026)/(1m) = 10.4$ kΩ **[0.5, 0.5]**

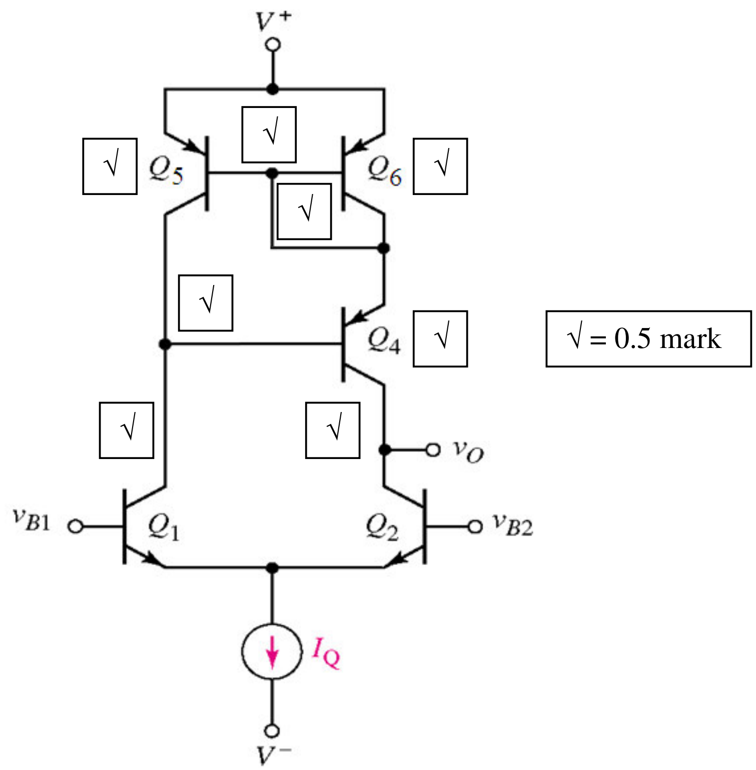
(iii)

$CMRR = | A_d / A_{cm} | = | 150 / -0.2 | = 750$ **[0.5, 0.5]**

$CMRR_{dB} = 20\text{Log}_{10}\,(750) = 57.5$ **[0.5, 0.5]**

Question 2(b)

(i)



(ii)

$R_{OAL} \approx (\beta r_{O4}) / 2$ **[1]**

$= (\beta V_{A4}) / (2 I_{C4}) = (\beta V_{AP}) / (I_Q)$ **[0.5]**

$= (150 \times 100) / (0.18\text{m}) = 83.333\ \text{M}\Omega$ **[0.5]**

(iii)

$v_O = v_{C2} = g_{m2}\, v_d\, (r_{O2} \parallel R_{OAL})$

$A_d = v_O / v_d = g_{m2}\, (r_{O2} \parallel R_{OAL})$ **[0.5]**

$g_{m2} = I_{CQ2} / V_T = I_Q / 2V_T$

$= (0.18\text{m})/(2\text{x}26\text{m}) = 3.461\ \text{mA/V}$ **[0.5]**

$r_{O2} = V_{A2} / I_{C2} = (V_{AN}) / (I_Q / 2)$

$= (120) / (0.18\text{m} / 2) = 1.333\ \text{M}\Omega$ **[0.5]**

$r_{O2} \parallel R_{OAL} = 1.333\text{M} \parallel 83.333\text{M} = 1.312\ \text{M}\Omega \approx r_{O2}$

$A_d = (3.461\text{m})(1.312\text{M})$

$= 4540.832$ **[0.5]**

Question 3(a)

(i)

R_O	$= (r_{o2} \parallel r_{o4})$	**[0.5]**
I_{D2}	$= I_{D4} = I_Q / 2 = (0.4\text{m})/2 = 0.2$ mA	**[0.5, 0.5]**
r_{o2}	$= 1 / (\lambda_p I_{D2}) = 1 / (0.01\text{x}0.2\text{m}) = 500$ kΩ	**[0.5]**
r_{o4}	$= 1 / (\lambda_n I_{D4}) = 1 / (0.02\text{x}0.2\text{m}) = 250$ kΩ	**[0.5]**
R_O	$= (500\text{k} \parallel 250\text{k}) = 166.67$ kΩ	**[0.5]**

(ii)

A_d	$= g_{m2}(r_{o2} \parallel r_{o4}) = g_{m2}(R_O)$	**[1]**
g_{m2}	$= 2\ \text{SQRT}[K_p I_{D2}] = 2\ \text{SQRT}[(60\mu)(0.2\text{m})] = 0.219$ mA/V	**[1]**
A_d	$= (0.219\text{m})(166.67\text{k}) = 36.515$ V/V	**[1]**

(iii)

$v_O = A_d v_d = [36.515\text{ V/V}] \text{ x } [(20 \sin \omega t)\ \mu\text{V}] = (0.730 \sin \omega t)$ mV **[1]**

Question 3(b)

(i)

$I_{CQ2} = I_Q / 2 = 0.5\text{m} / 2 = 0.25 \text{ mA}$

$v_{O2} = V^+ - I_{CQ2} R = 5 - (0.25\text{m})\text{x}(12\text{k}) = 2 \text{ V}$ [1]

$v_{O3} = V^+ - I_{CQ3} R_C = 5 - (0.5\text{m})\text{x}(4\text{k}) = 3 \text{ V}$ [1]

$v_O = v_{O3} - V_{BE4} = 3 - 0.7 = 2.3 \text{ V}$ [1]

or $v_O \approx V^- + I_{CQ4} R_{E2} = -5 + (3\text{m})\text{x}(2.43\text{k}) = 2.29 \text{ V}$

(ii)

$A_v = v_O/v_d = (v_{O2}/v_d)(v_{O3}/v_{O2})(v_O/v_{O3}) = A_d A_{v2} A_{v3}$

$A_d = (g_{m2}/2)(R \parallel R_{in3})$

$g_{m2} = I_{CQ2}/V_T = I_Q/(2V_T) = (0.5\text{m})/(2 \text{ x } 26\text{m}) = 9.615 \text{ mA/V}$ [0.5]

$r_{\pi3} = \beta V_T / I_{CQ3} = (100 \text{ x } 26\text{m}) / (0.5\text{m}) = 5.2 \text{ k}\Omega$ [0.5]

$R_{in3} = r_{\pi3} + (1 + \beta) R_{E1} = 5.2\text{k} + (1+100)(2.6\text{k}) = 267.8 \text{ k}\Omega$ [1]

$A_d = (g_{m2}/2)(R \parallel R_{in3}) = (9.615\text{m}/2)(12\text{k} \parallel 267.8\text{k}) = 55.218 \text{ V/V}$ [1, 0.5]

$A_{v2} = v_{O3}/v_{O2} = -1.47 \text{ V/V}$ [0.5]

$A_{v3} \approx 1$ [0.5]

$A_v = A_d A_{v2} A_{v3} = 55.218 \text{ x } (-1.47) \text{ x } 1 = -81.17 \text{ V/V}$ [1, 0.5]

Question 4(a)

I_{REF}	$= (V^{+} - V_{EB12} - V_{BE11} - V^{-}) / R_5$		[1]
	= (12 – 0.6 – 0.6 – (-12)) / (40k) = 0.57 mA		[1]
I_{C17}	$= I_{C13B} = 0.70\ I_{REF}$		[1]
	= (0.70)(0.57m)	= 0.399 mA	[0.5]
I_{C16}	$\approx I_{E16}$	(With β = 200)	[1]
	$= I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$		[1]
	$= I_{C17}/\beta + (I_{C17} R_8 + V_{BE17})/R_9$		[1]
	= (0.399m/200) + [(0.399m)(100) + 0.6]/(50k)		[1]
	= 14.793 µA		[0.5]

Question 4(b)

(i)

I_{D3}	$= (k'_p/2)(W/L)_3(V_{SG3} + V_{TP})^2$		[0.5]
150µ	$= (40\mu/2)(50)(V_{SG3} - 0.4)^2$		
V_{SG3}	= 0.7873 V		[0.5]
R_{D1}	$= V_{SG3} / I_{D1} \quad = V_{SG3} / (I_Q/2)$		[0.5]
	= 0.7873 / (200µ/2)	= 7.87 kΩ	[0.5]
I_{D4}	$= (k'_n/2)(W/L)_4(V_{GS4} - V_{TN})^2$		[0.5]
200µ	$= (100\mu/2)(40)(V_{GS4} - 0.4)^2$		
V_{GS4}	= 0.7162 V		[0.5]
V_{G4}	$= V_O + V_{GS4}$ = 0 + 0.7162	= 0.7162 V	
R_{D2}	$= (V_{G4} - (V^{-})) / I_{D3}$		[0.5]
	= (0.7162 – (-3))/(150µ)	= 24.8 kΩ	[0.5]
R_S	$= (V_O - (V^{-})) / I_{D4}$		[1]
	= (0 – (-3))/(200µ)	= 15 kΩ	[1]

(ii)

A_{d1}	$= (g_{m1}/2)(R_{D1})$		[0.5]
g_{m1}	$= 2\ \text{SQRT}[(k'_n/2)(W/L)_1(I_Q/2)]$		[0.5]
	= 2 SQRT[(100µ/2)(20)(200µ/2)]	= 0.6325 mA/V	[0.5]
A_{d1}	= (0.6325m / 2)(7.87k)	= 2.49	[0.5]

Question 5

(a) Cross-over distortion is a condition where the output voltage v_O of an actual class-B output stage circuit is zero **[1]** when its input voltage is in a certain voltage range. In this condition, both transistors in the circuit are cut-off because the input voltage is within V_{EBP} to V_{BEN} **[1]**, thus producing v_O **= zero** and causing distortion at the output of the actual class-B output stage **[1]**.

(b) Its advantage over class-A is less power dissipation and increased power conversion efficiency **[1]**, while its advantage over class-B is no cross-over distortion **[1]**.

(c) **Calculation of i_L, i_{Cp},** and i_{Cn}:

$v_O = -4\text{ V} = i_L R_L$ **[1]**

➔ $i_L = v_O/R_L = (-4\text{V})/(1\text{k}\Omega) = -4\text{ mA}$ **[1]**

Therefore, Q_p is conducting and Q_n is OFF.

Approximate value $i_L \approx i_{Cp} = I_S \exp(V_{EBP}/V_T) = 4\text{ mA}$ **[0.5]**

$V_{EBP} = V_T \ln(i_{Cp}/I_S) = (26\text{m}) \ln(4\text{m}/2\text{x}10^{-15})$

$V_{EBP} = 0.7364\text{ V}$ **[0.5]**

$V_{BEN} = V_{BB} - V_{EBP} = 1.4 - 0.7364 = 0.6636\text{ V}$ **[0.5]**

➔ $i_{Cn} = I_S \exp(V_{BEN}/V_T) = (2\text{x}10^{-15}) \exp(0.6636/0.026) = 0.2429\text{ mA}$ **[1]**

$i_{Cn} = i_{Cp} + i_L$ **[1]**

Actual value of $i_{Cp} = i_{Cn} - i_L = 0.2429\text{m} - (-4\text{m})$ **[0.5]**

➔ $i_{Cp} = 4.2429\text{ mA}$ **[1]**

(d) Calculation of power dissipation:

$P_{Qn} = i_{Cn} V_{CEn}$ **[1]**

$V_{CEn} = +V_{CC} - v_O = +6 - (-4) = 10\text{ V}$ **[0.5]**

➔ $P_{Qn} = (0.2429\text{ mA})(10\text{ V}) = 2.429\text{ mW}$ **[0.5]**

$P_{Qp} = i_{Cp} V_{ECp}$ **[1]**

$V_{ECp} = v_O - (-V_{CC}) = -4 - (-6) = 2\text{ V}$ **[0.5]**

➔ $P_{Qp} = (4.2429\text{ mA})(2\text{ V}) = 8.4858\text{ mW}$ **[0.5]**

<u>Question 6</u>

(a) Any 4 applications from the following list. Give 1 mark for each answer. [4]

1. **Current-to-voltage converter**
2. **Voltage-to-current converter**
3. **Difference Amplifier**
4. **Instrumentation Amplifier**
5. **Integrator**
6. **Differentiator**

(b) Answer for finding v_O/v_I:

$R_1 = 20$ kΩ, $R_2 = 100$ kΩ, $R_3 = 80$ kΩ, and $R_4 = 40$ kΩ

$v_O/v_I = (v_O/v_{O1}) \text{x} (v_{O1}/v_I)$ **[2]**

$v_O/v_{O1} = -(R_4/R_3)$ **[1]**

$v_{O1}/v_I = -(R_2/R_1)$ **[1]**

$v_O/v_I = [-(R_4/R_3)] \text{x} [-(R_2/R_1)] = (R_4R_2)/(R_3R_1)$ **[1]**

$= (40\text{k x } 100\text{k})/(80\text{k x } 20\text{k}) = 2.5$ **[1]**

(c) Answer for finding A_d, A_{cm}, and calculate the *CMRR* in dB:

$R_1 = R_3 = 10$ kΩ, $R_2 = 100$ kΩ, and $R_4 = 110$ kΩ

$$v_O = \left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4/R_3}{1+R_4/R_3}\right)v_{I2} - \left(\frac{R_2}{R_1}\right)v_{I1}$$

$$v_O = \left(1+\frac{100\text{k}}{10\text{k}}\right)\left(\frac{110\text{k}/10\text{k}}{1+110\text{k}/10\text{k}}\right)v_{I2} - \left(\frac{100\text{k}}{10\text{k}}\right)v_{I1}$$

$$v_O = (1+10)\left(\frac{11}{12}\right)v_{I2} - 10v_{I1}$$ [2]

$$v_O = 10.083v_{I2} - 10v_{I1} = 10.083(v_{cm} + \frac{v_d}{2}) - 10(v_{cm} - \frac{v_d}{2})$$

$$v_O = 10.0415v_d + 0.083v_{cm}$$ [2]

$A_d = 10.0415$, $A_{cm} = 0.083$ [2, 2]

***CMRR* = 20 $\log_{10}$[10.0415/0.083] = 41.65 dB** [2]