COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION

SEMESTER 2 2012 / 2013

PROGRAMME	: **Bachelor of Electrical & Electronics Engineering (Honours)** **Bachelor of Electrical Power Engineering (Honours)**
SUBJECT CODE	: **EEEB273**
SUBJECT	: **ELECTRONIC ANALYSIS AND DESIGN II**
DATE	: **January 2013**
TIME	: **3 hours (0900 – 1200)**

INSTRUCTIONS TO CANDIDATES:

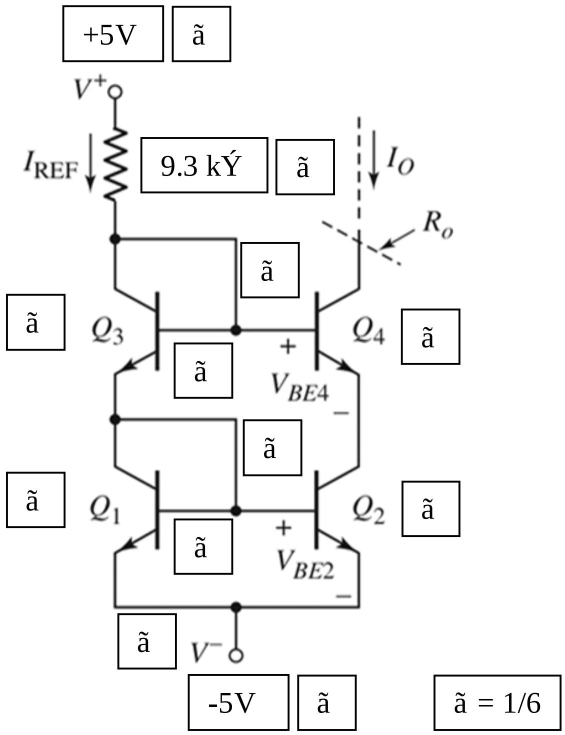
1. This paper contains **Five** (5) questions in **Ten** (10) pages.
2. Answer **ALL** questions.
3. Write **all** answers in the answer booklet provided.
4. Write answer to different question on **a new page**.
5. For all calculations, assume that V_T **= 26 mV**.
6. Use at least **4 significant numbers** in all calculations.

MODEL ANSWERS

THIS QUESTION PAPER CONSISTS OF TEN (10) PRINTED PAGES INCLUDING THIS COVER PAGE.

Answer for Q1(a)

(i)



(ii)

$$I_{E4} = \frac{I_{E3}}{1+2/\beta} \text{ ;From 2T CS}$$ 1

$$I_O = I_{C4} = \frac{\beta}{1+\beta} I_{E4} \rightarrow I_{E4} = \frac{1+\beta}{\beta} I_O$$ 0.5

$$I_{E3} = (1+2/\beta) I_{E4} = (1+2/\beta)\frac{1+\beta}{\beta} I_O = \frac{2+\beta}{\beta}\frac{1+\beta}{\beta} I_O$$ 0.5

$$I_{B4} = \frac{I_{E4}}{1+\beta} = \frac{1}{1+\beta}\frac{1+\beta}{\beta} I_O = \frac{I_O}{\beta}$$ 0.5

$$I_{C3} + I_{B3} = I_{E3} = \frac{2+\beta}{\beta}\frac{1+\beta}{\beta} I_O = \frac{\beta^2+3\beta+2}{\beta^2} I_O$$ 0.5

$$I_{REF} = I_{C3} + I_{B3} + I_{B4} = \frac{\beta^2+3\beta+2}{\beta^2} I_O + \frac{I_O}{\beta}$$ 0.5

$$I_{REF} = \frac{\beta^2+4\beta+2}{\beta^2} I_O = (1+4/\beta+2/\beta^2) I_O$$ 0.5

$$I_O = \frac{I_{REF}}{1+4/\beta+2/\beta^2} \cong \frac{I_{REF}}{1+4/\beta} \text{ when } \beta^2 >> 2$$ 1

Answer for Q1(b)

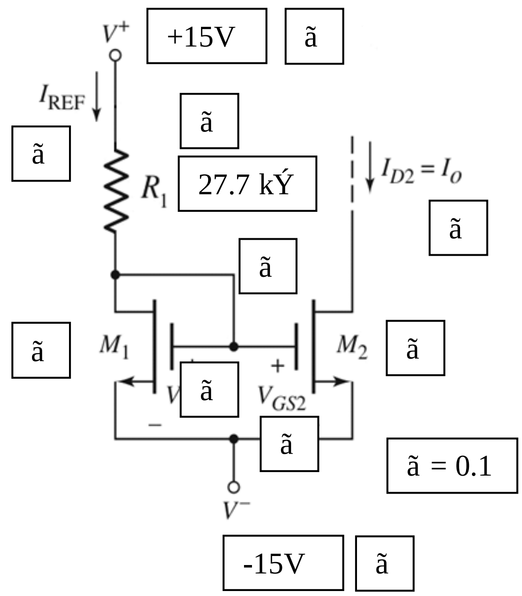
(i)

$$V_{GS1} = V_{DS1}(sat) + V_{TN} = 1.5 + 0.8 = 2.3\,\text{V}$$

$$I_{REF} = I_O$$

$$R_1 = \frac{V^+ - V_{GS1} - V^-}{I_{REF}} = \frac{15 - 2.3 - (-15)}{1\text{m}} = 27.7\,\text{k}\Omega$$

1



(ii)

$$I_{D1} = I_{D2} = I_O = 1\,\text{mA}$$ 0.5

$$I_{D2} = \frac{k_n'}{2}\left(\frac{W}{L}\right)_2 (V_{GS2} - V_T)^2$$ 0.5

$$\left(\frac{W}{L}\right)_2 = \frac{I_{D2}}{\frac{k_n'}{2}(V_{GS2} - V_T)^2} = \frac{1x10^{-3}}{\frac{50x10^{-6}}{2}(2.3 - 1.5)^2} = 62.5$$ 0.5

$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 62.5$$ 0.5

(iii)

$$R_O = dV_O / dI_O = 1/(\lambda I_O) = 1/(0xI_O) = \infty$$ 1

$$dI_O = dV_O / \infty = 0$$ 1

(iv)

Since MOSFETs can be configured to act like a resistor. The reference current in MOSFET current mirrors can be established using additional transistors.

2

Question 2 [20 marks]

Answer for Q2(a)

(i)

$CMRR_{dB} = 20 \log(A_d / A_{cm}) = 55$ dB [1]

$562.34 = A_d / A_{cm} = A_d / 0.2$

$A_d = 112.46$ [1]

$A_d = (g_{m1} R_D) / 2$ [0.5]

$112.46 = (g_{m1} \times 18k) / 2$

$g_{m1} = (2 \times 112.46) / (18k) = 12.496$ mA/V [1]

$g_{m1} = 2\ \mathrm{SQRT}(K_{n1} \times I_{D1})$ [0.5]

$I_{D1} = (g_{m1} / 2)^2 / K_{n1} = (12.496m / 2)^2 / (125\ \mu) = 0.3123$ A [1]

$I_Q = 2\ I_{D1} = 2 \times 0.3123 = 0.6246$ A [1]

(ii)

- **To achieve larger A_d and maintaining A_{cm}, active load such as cascode may be used to replace R_D.** [1.5]
- **To maintain A_d, A_{cm} may be decreased if the current source design is used using an improved implementation, e.g. cascode, to increase its output resistance (R_O).** [1.5]

Answer for Q2(b)

(i)

$$I_{B5} = \frac{I_{E5}}{(1+\beta)} = \frac{I_{B3}+I_{B4}}{(1+\beta)} = \frac{I_{C3}+I_{C4}}{\beta(1+\beta)} \qquad [3]$$

The current $$I_{C3}+I_{C4} \cong I_Q \qquad [2]$$

$$\left.\begin{aligned} I_{C1} &= I_{C3}+I_{B5} \\ I_{C2} &= I_{C4}+I_O \end{aligned}\right\} \qquad [2]$$

Hence, to keep the current balanced:

$$I_O = I_{B5} = \frac{I_Q}{\beta(1+\beta)} \qquad [2]$$

(ii)

Given, I_Q = 0.2 mA, hence:

$$I_O = \frac{I_Q}{\beta(1+\beta)} = \frac{0.2\text{m}}{120(1+120)} = 13.774\ \text{nA} \qquad [2]$$

Question 3 [25 marks]

Answer for Q3(a)

(i)

I_1	$= (V^+ - V_{BE7} - V^-) / (R_1)$		[0.5]
	$= (10 - 0.7 - (-10)) / (19.3k)$	$= 1$ mA	[0.5]
I_Q	$= I_1 / (1 + 2/\beta)$	$= 0.9836$ mA	[1]
I_{C2}	$= I_Q / 2$	$= 0.4918$ mA	[1]
v_{O2}	$= V^+ - I_{C2} R_C = 10 - (0.4918m)(10k) = 5.082$ V		[1]
I_{R4}	$= (v_{O2} - 2 V_{BE}(on)) / (R_4)$		
	$= (5.082 - 1.4) / (11.5k)$	$= 0.320$ mA	
I_{R5}	$\approx I_{R4}$ (neglecting base currents) $= 0.320$ mA		[0.5]
v_{O3}	$= V^+ - I_{R5} R_5 = 10 - (0.320m)(5k) = 8.399$ V		[0.5]

(ii)

Using $I_{C2} = 0.4918$ mA, $I_{R4} = 0.320$ mA:

A_{d1}	$= (g_m / 2)(R_C \parallel R_{i2})$		[1]
g_m	$= I_{C2} / V_T = (0.4918mA)/(26mV) = 18.9153$ mA/V		[1]
$r_{\pi 4}$	$= \beta V_T / I_{R4} = (120x26m)/(0.320m)$	$= 9.750$ kΩ	[1]
$r_{\pi 3}$	$\approx \beta\, r_{\pi 4} = 120x\ 9.750k$	$= 1170$ kΩ	[1]
R_{i2}	$= r_{\pi 3} + (1 + \beta)\, r_{\pi 4}$		
	$= 1170k + (121)(9.750k)$	$= 2349.75$ kΩ	[1]
A_{d1}	$= (18.9153m/2)(10k \parallel 2349.75k) = 94.176$		[1]
A_2	$\approx (I_{R4} / 2V_T)\, R_5 = (0.320m/(2x26m))(5k) = 30.76$		[2]
A_3	≈ 1		[1]
A_d	$= A_{d1} A_2 A_3 = 94.176$ x 30.76 x 1	$= 2896.85$	[1]

OR (i)

I_1	$= (V^+ - V_{BE7} - V^-) / (R_1)$		[0.5]
	$= (10 - 0.7 - (-10)) / (19.3k)$	$= 1$ mA	[0.5]
I_Q	$\approx I_1$ [Since $\beta >> 1$]	$= 1$ mA	[1]
I_{C2}	$= I_Q / 2$	$= 0.5$ mA	[1]
v_{O2}	$= V^+ - I_{C2} R_C = 10 - (0.5m)(10k) = 5$ V		[1]
I_{R4}	$= (v_{O2} - 2 V_{BE}(on)) / (R_4)$		
	$= (5 - 1.4) / (11.5k)$	$= 0.313$ mA	
I_{R5}	$\approx I_{R4}$ (neglecting base currents) $= 0.313$ mA		[0.5]
v_{O3}	$= V^+ - I_{R5} R_5 = 10 - (0.313m)(5k) = 8.44$ V		[0.5]

(ii)

Using $I_{C2} = 0.5$ mA, $I_{R4} = 0.313$ mA:

A_{d1}	$= (g_m / 2)(R_C \parallel R_{i2})$		[1]
g_m	$= I_{C2} / V_T = (0.5mA)/(26mV) = 19.23$ mA/V		[1]
$r_{\pi 4}$	$= \beta V_T / I_{R4} = (120x26m)/(0.313m)$	$= 9.968$ kΩ	[1]
$r_{\pi 3}$	$\approx \beta\, r_{\pi 4} = 120x\ 9.968k$	$= 1196.16$ kΩ	[1]
R_{i2}	$= r_{\pi 3} + (1 + \beta)\, r_{\pi 4}$		
	$= 1196.16k + (121)(9.968k)$	$= 2402.29$ kΩ	[1]
A_{d1}	$= (19.23m/2)(10k \parallel 2402.29k) = 95.75$		[1]
A_2	$\approx (I_{R4} / 2V_T)\, R_5 = (0.313m/(2x26m))(5k) = 30.09$		[2]
A_3	≈ 1		[1]
A_d	$= A_{d1} A_2 A_3 = 95.75$ x 30.09 x 1	$= 2872.54$	[1]

Answer for Q3(b)

(i)

$$I_Q = I_{D6} = I_{D5}$$ 1

$$I_{D5} = K_p\left(V_{SG5} + V_{TP}\right)^2 = (100\varepsilon\,\mathrm{A/V}^2)x(1.5 - 0.5)^2 = 100\varepsilon\,\mathrm{A}$$ 1

$$\Rightarrow I_Q = I_{D5} = 100\varepsilon\,\mathrm{A} = 0.1\mathrm{mA}$$ 1

(ii)

$$A_v = A_d A_{v2}$$ 0.5

$$A_d = g_m\left(r_{o2} \parallel r_{o4}\right)$$ 0.5

$$g_m = \sqrt{2K_p I_Q} = \sqrt{2(100\varepsilon)(100\varepsilon)} = 141.42\varepsilon\,\mathrm{A/V}$$ 1

$$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02x50\varepsilon} = 1\mathrm{Mq}$$ 0.5

$$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01x50\varepsilon} = 2\mathrm{Mq}$$ 0.5

$$A_d = (141.42\varepsilon)\left(1\mathrm{M} \parallel 2\mathrm{M}\right) = 94.286$$ 0.5

$$A_{v2} = g_{m7}\left(r_{o7} \parallel r_{o8}\right)$$ 0.5

$$g_{m7} = 2\sqrt{K_{n7} I_{D7}} = 2\sqrt{(125\varepsilon)(100\varepsilon)} = 223.6\varepsilon\,\mathrm{A/V}$$ 1

$$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01x100\varepsilon} = 1\mathrm{Mq}$$ 0.5

$$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02x100\varepsilon} = 0.5\mathrm{Mq}$$ 0.5

$$A_{v2} = (223.6\varepsilon)\left(1\mathrm{M} \parallel 0.5\mathrm{M}\right) = 74.53$$ 0.5

$$A_v = A_d A_{v2} = 94.286x74.53 = 7027.45$$ 0.5

<u>Question 4 [15 marks]</u>

Answer for Q4

(a) Cross-over distortion is a condition where the output voltage v_O of an actual class-B output stage circuit is zero when its input voltage is in a certain voltage range **[1]**.
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}:

$v_O = -3.5\text{ V} = i_L R_L$ [0.5]
➔ $i_L = v_O / R_L = (-3.5\text{V}) / (1\text{k}\Omega) = -3.5\text{ mA}$ [1]
Therefore, Q_p is conducting and Q_n is OFF.
Approximate value $|i_L| \approx i_{Cp} = I_S \exp(V_{EBP}/V_T) = 3.5\text{ mA}$ [0.5]
$V_{EBP} = V_T \ln(i_{Cp} / I_S) = (26\text{m}) \ln(3.5\text{m} / 2\text{x}10^{-15}) = 0.7329\text{ V}$ [0.5]

$V_{BEN} = V_{BB} - V_{EBP} = 1.4 - 0.7329 = 0.6671\text{ V}$ [0.5]
➔ $i_{Cn} = I_S \exp(V_{BEN}/V_T) = (2\text{x}10^{-15}) \exp(0.6671 / 0.026) = 0.2779\text{ mA}$ [1]

$i_{Cn} = i_{Cp} + i_L$ [0.5]
Actual value of $i_{Cp} = i_{Cn} - i_L = 0.2779\text{m} - (-3.5\text{m})$ [1]
➔ $i_{Cp} = 3.7779\text{ mA}$ [0.5]

<u>2nd iteration</u>

$V_{EBP} = 0.73494\text{ V}$
$V_{BEN} = 0.66506\text{ V}$
$i_{Cn} = 0.2570\text{ mA}$
$i_{Cp} = 3.757\text{ mA}$

(d) Calculation of power dissipation:

$P_{Qn} = i_{Cn} V_{CEn}$ [1]
$V_{CEn} = +V_{CC} - v_O = +6 - (-3.5) = 9.5\text{ V}$ [0.5]
➔ $P_{Qn} = (0.2779\text{ mA})(9.5\text{ V}) = 2.640\text{ mW}$ [0.5]
Or $P_{Qn} = (0.2570\text{ mA})(9.5\text{ V}) = 2.441\text{ mW}$

$P_{Qp} = i_{Cp} V_{ECp}$ [1]
$V_{ECp} = v_O - (-V_{CC}) = -3.5 - (-6) = 2.5\text{ V}$ [0.5]
➔ $P_{Qp} = (3.7779\text{ mA})(2.5\text{ V}) = 9.44475\text{ mW}$ [0.5]
Or $P_{Qp} = (3.757\text{ mA})(2.5\text{ V}) = 9.3925\text{ mW}$

<u>Question 5 [25 marks]</u>

Answer for Q5

(a) Any two (2) of the following answers, [1] for each answer.

1) Internal differential gain (open loop gain), A_{od}, is considered to be Ð.
2) Differential input voltage, (v_2 ï v_1), is assumed to be 0. If A_{od} Ÿ Ð and v_O is finite, then v_2 å v_1.
3) Effective input resistance, R_i, is assumed to be Ð, so input currents i_1 and i_2 are essentially 0.
4) Effective output resistance, R_o, is assumed to be 0, so output voltage is independent of any load connected to the output.
5) Bandwidth Ÿ Ð.
6) Common mode rejection ratio, *CMRR*, is Ð.

(b) Any three (3) of the following answers, [1] for each answer.

1) Current-to-voltage converter
2) Voltage-to-current converter
3) Difference amplifier
4) Instrumentation amplifier
5) Integrator
6) Differentiator

(c)

$v_{I2} = 0$: $v_{O1}(v_{I1}) = (-R_F/R_1)\, v_{I1} = (-100k/100k)\, v_{I1} = -v_{I1}$

[0.5] **[0.5]** **[0.5]** **[0.5]**

$v_{I1} = 0$: $v_{O1}(v_{I2}) = (-R_F/R_2)\, v_{I2} = (-100k/100k)\, v_{I2} = -v_{I2}$

[0.5] **[0.5]** **[0.5]** **[0.5]**

$v_{O1} = v_{O1}(v_{I1}) + v_{O1}(v_{I2}) = (-v_{I1}) + (-v_{I2}) = -(v_{I1} + v_{I2})$

[0.5] **[0.5]** **[0.5]**

$v_O = (-R_F/R_1)v_{O1} = (-100k/100k)[-(v_{I1} + v_{I2})] = v_{I1} + v_{I2}$

[0.5] **[0.5]** **[0.5]**

(d)

v_2	$= [R_4/(R_3 + R_4)]\ v_I$		**[1]**
	$= [(50k)/(50k+25k)]\ v_I$	$= [2/3]\ v_I$	**[0.5]**
v_1	$= v_2$	$= [2/3]\ v_I$	**[1]**
v_O	$= [(1 + R_2/R_1)]\ v_1$		**[1]**
	$= [(1 + 200k/25k)]\ [2/3]\ v_I$	$= 6\ v_I$	**[0.5]**
A_v	$= v_O / v_I$	$= 6$	**[1]**

(e)

$R_F / R_1 = 5 \rightarrow R_F = 5\ R_1$ **[0.5]**

and $R_F / R_2 = 10 \rightarrow R_F = 10\ R_2$ **[0.5]**

So, resistor R_2 will be the **smallest** value. Set $R_2 = 15$ **kΩ**. **[1]**

$\rightarrow$ $R_F = 10\ R_2 = 10 \times 15$ kq **= 150 kΩ** **[0.5]**

and $R_1 = R_F / 4 = 150$kq $/ 5$ **= 30 kΩ** **[0.5]**

$R_N = R_1 \parallel R_2 = 30$ kq $\parallel$ 15 kq = 10 kq

$1 + R_F / R_N = 1 + 150k / (10k) = 16$

$(1 + R_F / R_N)(R_P / R_A) = (16)\ (R_P / R_A) = 5$ **[0.5]**

and $(1 + R_F / R_N)(R_P / R_B) = (16)\ (R_P / R_B) = 2$ **[0.5]**

So, $(R_A / R_B) = 2/5.$ **[0.5]**

Choose $R_A = 80$ **kΩ,** **[1]**

then $R_B = 200$ **kΩ** **[1]**

$R_P = (2\ R_B) / 16 = (5\ R_A) / 16$

$\rightarrow$ $R_P = 25$ **kΩ** **[0.5]**

$R_P = R_A \parallel R_B \parallel R_C$

$\rightarrow$ $R_C = 44.45$ **kΩ** **[1]**