COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION – MODEL ANSWER

SEMESTER 3   2018 / 2019

PROGRAMME	**: Bachelor of Electrical & Electronics Engineering (Honours)** **Bachelor of Electrical Power Engineering (Honours)**
SUBJECT CODE	**: EEEB273/EEEB2014**
SUBJECT	**: ELECTRONIC ANALYSIS AND DESIGN II**
DATE	**: April/May 2019**
DURATION	**: 3 hours**

INSTRUCTIONS TO CANDIDATES:

1. This paper contains **FIVE** (5) questions in **EIGHT** (8) pages.
2. Answer **ALL** questions.
3. Write **all** answers in the answer booklet provided. **Use pen** to write your answer.
4. Write answer to different question on **a new page**.

THIS QUESTION PAPER CONSISTS OF EIGHT* (8) *PRINTED PAGES INCLUDING THIS COVER PAGE.

Question 1 [20 marks]

Answers:

Q1(a) [10 marks]

M_1: $I_{REF} = \left(\frac{k'_p}{2}\right)\left(\frac{W}{L}\right)_1 (V_{SG1} + V_{TP})^2$ **[0.5]**

M_3: $I_{REF} = \left(\frac{k'_p}{2}\right)\left(\frac{W}{L}\right)_3 (V_{SG3} + V_{TP})^2$ **[0.5]**

$M_1 = M_3$:

$\left(\frac{60\mu}{2}\right)(25)_1(V_{SG1} - 0.4)^2 = \left(\frac{60\mu}{2}\right)(5)_3(V_{SG3} - 0.4)^2$ **[1]**

KVL: $V_{SG1} + V_{SG3} = V+ - V- = 3$, $V_{SG3} = 3 - V_{SG1}$ **[1]**

$\sqrt{\frac{25}{5}}(V_{SG1} - 0.4) = (3 - V_{SG1}) - 0.4$ **[1]**

$3.26\ V_{SG1} = 3.499$ ➔ $V_{SG1} = 1.08$ and $V_{SG3} = 1.92$ V **[2]**

$I_{REF} = \left(\frac{60m}{2}\right)(25)_1(1.08 - 0.4)^2 = 0.347$ mA **[2]**

$I_Q = \left(\frac{60m}{2}\right)(15)_2(1.08 - 0.4)^2 = 0.208$ mA **[2]**

Q1(b)(i) [6 marks]

$\boldsymbol{R_O = r_{O4} + r_{O6}(1+g_{m4} r_{O4})}$ **OR** $\boldsymbol{R_O \approx g_{m4} r_{O4} r_{O6}}$ **[1]**

$I_{DQ} = I_Q / 2 = 0.2m/2 = 0.1$ mA **[1]**

$\boldsymbol{r_{O4} = r_{O6}} = 1/(\lambda_p I_{DQ}) = 1/[(0.02)(0.1m)]$ = **500 kΩ** **[1.5]**

$g_{m4} = 2\sqrt{(K_p I_{DQ})} = 2\sqrt{[(0.5)(k'_p (W/L)_p)(I_{DQ})]}$

$g_{m4} = 2\sqrt{[(0.5)(40\mu)(20)(0.1m)]}$ = **0.4 mA/V** **[1.5]**

$\boldsymbol{R_O = r_{O4} + r_{O6}(1+g_{m4} r_{O4})}$ = 500k + 500k(1+0.4m x 500k) = 101 **MΩ**

OR $\boldsymbol{R_O \approx g_{m4} r_{O4} r_{O6}}$ = 0.4m x 500k x 500k = 100 **MΩ** **[1]**

Q1(b)(ii) [4 marks]

$\boldsymbol{A_d = g_{m2}(r_{O2} \| R_O)}$ **[1]**

$\boldsymbol{r_{O2}} = 1/(\lambda_n I_{DQ}) = 1/[(0.02)(0.1m)]$ = **500 kΩ** **[1]**

$g_{m2} = 2\sqrt{(K_n I_{DQ})} = 2\sqrt{[(0.5)(k'_n (W/L)_2)(I_{DQ})]}$

$g_{m2} = 2\sqrt{[(0.5)(80\mu)(10)(0.1m)]}$ = **0.4 mA/V** **[1.5]**

$\boldsymbol{A_d}$ **= (0.4m)(500k || 101M)** = 199 V/V **[0.5]**

Question 2 [20 marks]

Model Answers

Q2(a) **[10 marks]**

I_{REF} $= I_O\,[1 + 2/\beta(\beta+1)]$ **[2]**

$= [(0.8m)(1 + 2/(50 \times 51))]$ **[0.5]**

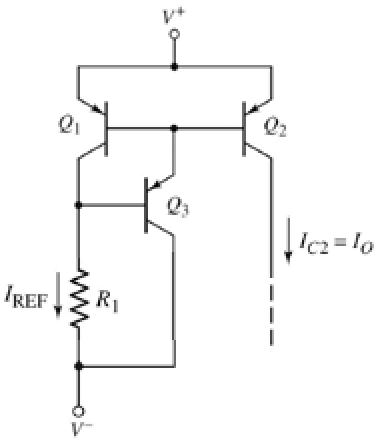
$= (0.8m)(1.00078) = 0.80006$ mA **[0.5]**

R_1 $= (V^+ - V_{EB3} - V_{EB2} - V^-) / I_{REF}$ **[2]**

$= (7.5 - 0.6 - 0.6 - (-7.5)) / (0.80006m)$ **[0.5]**

$= 17.25$ kΩ **[0.5]**

Each parameter is 0.25 marks



[4]

Q2(b)(i) **[2 marks]**

$A_d = (g_{m2} R_C) / 2$ **[0.5]**

$g_{m2} = I_{C2} / V_T = I_Q / 2V_T = (2m) / (2 \times 26m) = 38.46$ mA/V **[1]**

$A_d = (38.46m \times 5k) / 2 = 96.15$ V/V **[0.5]**

Q2(b)(ii) **[2 marks]**

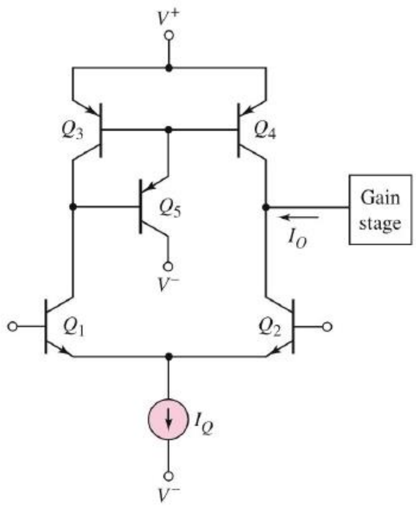
Ro of 2TCS = r_{O2} in Bias circuit = $V_A / I_Q = 100/2m = 50$ kΩ **[1]**

$r_{\pi 2} = \beta V_T / I_{C2} = (100 \times 26m)/1m = 2.6$ kΩ **[0.5]**

$$A_{cm} = \frac{-g_m R_C}{1 + \dfrac{2(1+\beta)R_O}{r_\pi + R_B}}$$

, substitute values, $A_{cm} = -49.5 \times 10^{-3}$ **[0.5]**

Q2(b)(iii) **[6 marks]**



Draw PNP 3TCS active load correctly **[2]**
connected to diff amp **[1]**

$\boldsymbol{A_d = g_{m2} (r_{O2} \parallel R_{OActiveLoad})}$ **[0.5]**

g_{m2} = 38.46 mA/V

$r_{O2} = 2\ V_A / I_Q$ = (2 x 100)/2m = 100 kΩ **[0.5]**

$R_{OActiveLoad}$ = Ro of 3TCS = r_{O4} in Active Load = $2\ V_A / I_Q$

➔ $R_{OActiveLoad}$ = (2 x 100)/2m = 100 kΩ **[0.5]**

➔ A_d = **38.46m(100k || 100k)** = 1923 V/V **[0.5]**

Thus, A_d **had increased** = 1923 – 96.15 = 1826.85 V/V **[1]**

Question 3 [20 marks]

Answers:

Q3(a) [10 marks]

I_Q	$= 1.2$ mA		
I_{C2}	$= I_Q / 2$	$= 0.6$ mA	[0.5]
v_{O2}	$= V^+ - I_{C2} R_C = 12 - (0.6m)(10k)$	$= 6$ V	[0.5]
I_{R4}	$= (v_{O2} - 2 V_{BE}(on)) / (R_4)$		
	$= (6 - 1.4) / (11.5k)$	$= 0.4$ mA	[0.5]

Using $I_{C2} = 0.6$ mA, $I_{R4} = 0.4$ mA:

A_{d1}	$= (g_{m2} / 2)(R_C \parallel R_{i2})$		
g_{m2}	$= I_{C2} / V_T = (0.6mA)/(26mV) = 23.077$ mA/V		[1]
$r_{\pi 4}$	$= \beta V_T / I_{R4} = (200x26m)/(0.4m)$	$= 13$ kΩ	[1]
$r_{\pi 3}$	$\approx \beta r_{\pi 4} = 200x13k$	$= 2600$ kΩ	[1]
R_{i2}	$= r_{\pi 3} + (1 + \beta) r_{\pi 4}$		[1]
	$= 2600k + (201)(13k)$	$= 5213$ kΩ	[0.5]
A_{d1}	$= (23.077m/2)(10k \parallel 5213k)$	$= 115.16$	[0.5]
A_{v2}	$\approx (I_{R4} / 2V_T) R_5 = (0.4m/(2x26m))(5k) = 38.46$		[1]
A_3	≈ 1 (Output stage assume gain = 1)		[1]
A_d	$= A_{d1} A_{v2} A_3$		[1]
	$= 115.16 \times 38.46 \times 1$	$= 4429$ V/V	[0.5]

Q3(b) [10 marks]

$V_P = 0.8\, V_{CC} = (0.8)(24) = 19.2$ V **[1]**

$P_L(ave) = 10 = (1/2)(V_p^2/R_L)$ **[1]**

$R_L = (1/2)[V_p^2/P_L(ave)] = (19.2)^2 / [(2)(10)] = 18.43\ \Omega$ **[1, 1]**

$I(ave) = V_p/(\pi R_L) = 19.2/[(\pi)(18.43)] = 0.3316$ A **[1, 1]**

$P_S(ave) = 2\, V_{CC}\, I(ave) = 2(24)(0.3316) = 15.92$ Watts **[1, 1]**

$\eta = P_L(\text{ave}) / P_S(\text{ave}) = 10/15.92 = 0.628$ or 62.8% **[1, 1]**

Question 4 [20 marks]

Answer to Question 4(a) [10 marks]

To calculate I_{C16}, need to determine I_{C13B}

I_{C13B} = 0.75 I_{C12} = (0.75)(**0.4m**) = **0.3** mA **[1]**

I_{C17} = I_{C13B} = **0.3** mA **[1]**

$I_{C16} \cong I_{E16} = I_{B17} + I_{R9} = I_{C17} / \beta + ([I_{C17} R_8 + V_{BE17}] / R_9)$ **[1]**

I_{C16} = (**0.3**m/200) + ([**0.3**m x 100 + 0.7] /50k)

I_{C16} = **1.5**μ + **14.6**μ = **16.1** μA **[1]**

$R_{b16} = r\pi 16 + (1+\beta n) [R_9 \| R_{b17}]$ **[1]**

$R_{b17} = r\pi 17 + (1+\beta n) R_8$ **[1]**

$r\pi 17 = \beta n\, V_T / I_{C17}$ = (200x26m)/**0.**3m = **17.333 kΩ** **[1]**

$r\pi 16 = \beta n\, V_T / I_{C16}$ = (200x26m)/**16.1**u = **322.981 kΩ** **[1]**

So R_{b17} = **17.333k** + (201)100 = **37.433 kΩ** **[1]**

50k || **37.433**k = **21.4 kΩ**

So R_{b16} = **322.981k** + (201)(50k || **37.433**k] = **4.624 MΩ** **[1]**

Answer to Question 4(b) [10 marks]

Q4b(i) [4 marks]

$I_{D5} = K_{p5}(V_{SG5} + V_{TP})^2 = 125\mu(1.5 - 0.5)^2 = 125\ \mu A$ [2]

$I_Q = I_{D6} = I_{D7} = I_{D8} = I_{D5} = 125\ \mu A$ [1]

$I_{D1} = I_{D2} = I_{D3} = I_{D4} = I_Q/2 = 62.5\ \mu A$ [1]

Q4b(ii) [6 marks]

$A_d = g_{m2}(r_{o2}||r_{o4})$ [1]

$g_{m2} = 2\sqrt{K_{p2}I_{D2}} = 2\sqrt{(125\mu)(62.5\mu)} = 176.77\ \mu A/V$ [0.5]

$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02(62.5\mu)} = 0.8\ M\Omega$ [0.5]

$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01(62.5\mu)} = 1.6\ M\Omega$ [0.5]

$A_d = (176.77\mu)(0.8M||1.6M) = 94.277\ V/V$ [0.5]

$A_{v2} = -g_{m7}(r_{o7}||r_{o8})$

$g_{m7} = 2\sqrt{K_{n7}I_{D7}} = 2\sqrt{(100\mu)(125\mu)} = 223.6\ \mu A/V$ [0.5]

$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01(125\mu)} = 0.8\ M\Omega$ [0.5]

$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02(125\mu)} = 0.4\ M\Omega$ [0.5]

$A_{v2} = -(223.6\mu)(0.8M||0.4M) = -59.63\ V/V$ [0.5]

$A_v = A_d A_{v2} = (94.277)(-59.63) = -5621\ V/V$ [1]

Question 5 [20 marks]

Answers:

Q5(a) [2 marks]

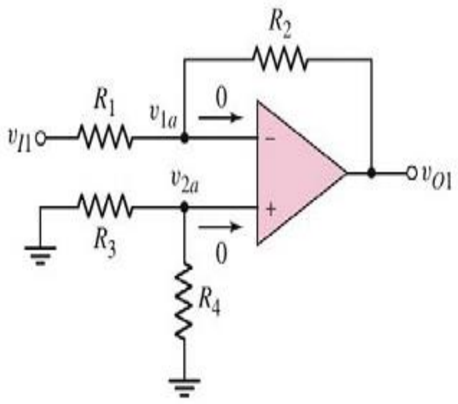
Select 2 of the following:

- A_{od}: Internal differential gain (open loop gain) is considered to be ∞.
- $(v_2 - v_1)$: Differential input voltage is assumed to be 0. If $A_{od} \to \infty$ and v_O is finite, then $v_2 \approx v_1$.
- R_i: Effective input resistance is assumed to be ∞, so input currents i_1 and i_2 are essentially 0.
- R_o: Effective output resistance is assumed to be 0, so output voltage is independent of any load connected to the output.
- Bandwidth → ∞.
- *CMRR*: Common mode rejection ratio = ∞.

⇨ **Each answer above give [1] mark, 2 marks total**

Q5(b) [10 marks]

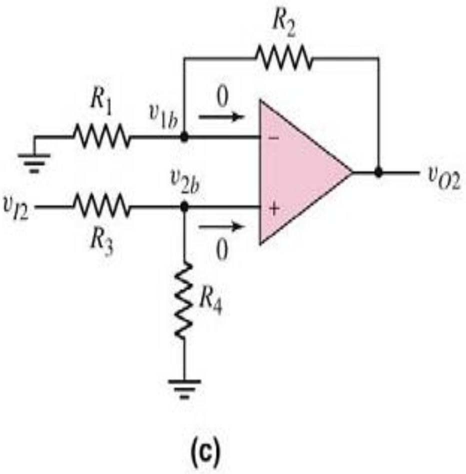
Using superposition theorem



(b)

Let $v_{I2} = 0$, **[1]**

$$\rightarrow v_{O1} = -\frac{R_2}{R_1}(v_{I1})$$ **[2]**



(c)

$$v_{2b} = \left(\frac{R_4}{R_3 + R_4}\right) v_{I2}$$ 1

$$v_{O2} = \left(1 + \frac{R_2}{R_1}\right) v_{1b}$$ 1

$$\rightarrow v_{O2} = \left(1 + \frac{R_2}{R_1}\right) v_{2b}$$ 1

Let $v_{I1} = 0$, 1

$$v_{O2} = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3 + R_4}\right) v_{I2}$$

$$v_{O2} = \left(1 + \frac{R_2}{R_1}\right)\left(\frac{R_4 / R_3}{1 + R_4 / R_3}\right) v_{I2}$$ 1

$v_O = v_{O1} + v_{O2}$ 1

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

Q5(c) **[8 marks]**

R_2 / R_1 = 120k/12k = 10 and **R_4 / R_3 = 440k/40k = 11** **[1]**

v_O = (1+10)[(11)/(1+11)] v_{I2} – 10 v_{I1}

→ **v_O = 10.083 v_{I2} – 10 v_{I1}** **[1]**

From **$v_d = v_{I2} - v_{I1}$** **and** **$v_{cm} = (v_{I2} + v_{I1})/2$**

→ **$v_{I1} = v_{cm} - v_d / 2$** **and** **$v_{I2} = v_{cm} + v_d / 2$** **[1]**

Thus, **v_O = 10.083 ($v_{cm} + v_d$ / 2) – 10 ($v_{cm} - v_d$ / 2)**

→ **v_O = 10.042 v_d + 0.083 v_{cm}** **[1]**

In general form

$v_O = A_d v_d + A_{cm} v_{cm}$ **[1]**

Then **A_d = 10.042** **and A_{cm} = 0.083** **[1]**

Thus,

$CMRR$(dB) = 20 $\log_{10}(A_d / A_{cm})$ **[1]**

$CMRR$(dB) = 20 $\log_{10}$(10.042 / 0.083) = 41.6 dB **[1]**