COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION

SEMESTER 2 2016 / 2017

MODEL ANSWER

PROGRAMME	**: Bachelor of Electrical & Electronics Engineering (Honours)** **Bachelor of Electrical Power Engineering (Honours)**
SUBJECT CODE	**: EEEB273**
SUBJECT	**: ELECTRONIC ANALYSIS AND DESIGN II**
DATE	**: January/February 2017**
TIME	**: 3 hours**

INSTRUCTIONS TO CANDIDATES:

1. This paper contains **FIVE** (5) questions in **NINE** (9) 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**.
5. **Show clearly all calculations, complete with proper Unit for every parameter.**

THIS QUESTION PAPER CONSISTS OF NINE (9) PRINTED PAGES INCLUDING THIS COVER PAGE.

Answers to QUESTION 1 [20 marks]

a) R_o (output resistance of Widlar CS) [Total = 8]

$R_2 = (V_T \ln[I_1/I_{C4}])/I_{C4} = (0.026\ln[0.5m/200\mu]/200\mu = 119\Omega$ [2]

$g_{m4} = I_{C4}/V_T = I_Q/(V_T) = (200\mu)/0.026 = 7.692$ mA/V [1]

$r_{\pi 4} = \beta V_T / I_{C4} = 100(0.026)/200\mu = 13k\Omega$ [1]

$r_{\pi 4} \| R_2 = 118\Omega$ [1]

$r_{o4} = V_A/I_{C4} = 100/200\mu = 0.5M\Omega$ [1]

$R_o = r_{o4}[1+ g_{m4} (r_{\pi 4} \| R_2)] = 0.5M[1+7.692m(118)] = 954k\Omega$ [2]

b) Value of $\boldsymbol{R_C}$ [Total = 4]

$v_{o2} = V^+ - I_{C2}R_C$ [1]

$R_C = (V^+ - v_{o2}) / I_{C2} = (10\text{-}8)/(0.5 * I_{C4}) = 2/100\mu = 20k\Omega$ [3]

c) Differential-mode input resistance, $\boldsymbol{R_{id}}$ [Total = 4]

$r_{\pi 2} = \beta V_T / I_{C2} = 100(0.026)/100\mu = 26k\Omega$ [2]

$R_{id} = 2 r_{\pi 2} = 2(26k) = 52k\Omega$ [2]

d) Common-mode input resistance, $\boldsymbol{R_{icm}}$ [Total = 4]

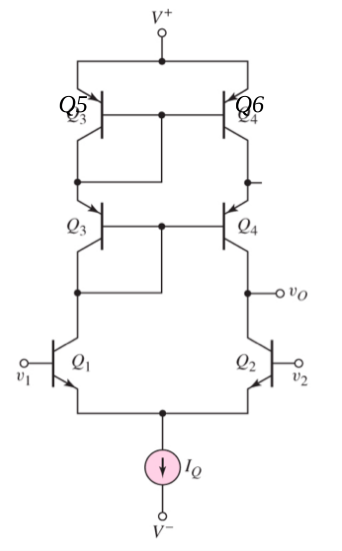
Assume $r_\mu = \infty$. $r_O = V_{A1}/I_{CQ1} = \infty/ I_{CQ1} = \infty$. [1]

Thus, $R_{icm} \cong (1+\beta)R_o = (101)(954k) = 96.4M\Omega$ [2, 1]

Answers to QUESTION 2 [20 marks]

(a) Cascode current source labeled for *pnp* transistors [2 marks]

Labelled the R_{OAL} [1 mark]



(b) Calculate R_{OAL}:

$I_O = I_{CQ}/2 = 0.2\text{m}/2 = 0.1$ mA [1 mark]

$r_{O4} = V_{AP}/I_O = 120/0.1\text{m} = 1.200$ MΩ [1 mark]

$R_{OAL} = \beta r_{O4} = (80)(1.200\text{M}) = 96.00$ MΩ [2 marks]

With two-transistor current source,

$R_{OAL} = r_{O4} = V_{AP}/I_O = 120/0.1\text{m} = 1.200$ MΩ [1 mark]

Thus, the output resistance is smaller than the former [2 marks]

(c) $v_O = g_m v_d R_O$ [1 mark]

$R_O = R_{OAL} \,||\, r_{O2}$ [1 mark]

$r_{o2} = V_{AN}/I_O = 100/0.1\text{m} = 1.000$ MΩ [1 mark]

$R_O = 96\text{M} \,||\, 1\text{ M} = 0.9897$ MΩ [1 mark]

$g_{m2} = I_O/V_T = 0.1\text{m}/0.026 = 3.846$ mA/V [1 mark]

$A_d = g_{m2}R_O = (3.846\text{m})(0.9897\text{M}) = 3806$ [1 mark]

(d) $v_O = A_d v_d = (3806)(10 \sin \omega t)\text{ m} = 38.06 \sin \omega t$ V [2, 2 marks]

Answers to QUESTION 3(a) [10 marks]

(i) **Calculation of i_L, i_{Cp}, i_{Cn}, and v_I.** **[6 marks]**

$v_O = -4\text{ V} = i_L R_L$

➔ $i_L = v_O/R_L = (-4\text{V})/(1\text{k}\Omega) = -4\text{ mA}$ **[0.5]**

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]**

$V_{EBP} = V_T \ln(i_{Cp}/I_S) = (26\text{m}) \ln(4\text{m}/2\text{x}10^{-15}) = 0.7364\text{ V}$ **[0.5]**

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

➔ $i_{Cn} = I_S \exp(V_{BEN}/V_T) = (2\text{x}10^{-15}) \exp(0.6636/0.026) = 0.2429\text{ mA}$ **[0.5]**

$i_{Cn} = i_{Cp} + i_L$ **[0.5]**

Actual value of $i_{Cp} = i_{Cn} - i_L = 0.2429\text{m} - (-4\text{m}) = 4.2429\text{ mA}$ **[0.5]**

$V_{EBP} = V_T \ln(i_{Cp}/I_S) = (26\text{m}) \ln(\mathbf{4.2429}\text{ m}/2\text{x}10^{-15}) = \mathbf{0.73796}\text{ V}$ **[0.5]**

$V_{BEN} = V_{BB} - V_{EBP} = \mathbf{1.4 - 0.73796 = 0.66204}\text{ V}$ **[0.5]**

➔ $i_{Cn} = I_S \exp(V_{BEN}/V_T) = (2\text{x}10^{-15}) \exp(\mathbf{0.66204}/0.026) = \mathbf{0.2288}\text{ mA}$ **[0.5]**

$v_I = v_O + V_{BEN} - V_{BB}/2 = -4 + \mathbf{0.66204} - 0.7 = \mathbf{-4.03796}\text{ V}$

OR $v_I = v_O - V_{EBP} + V_{BB}/2 = -4 - 0.73796 + 0.7 = \mathbf{-4.03796}\text{ V}$ **[1]**

(ii) Calculation of power dissipation in transistor Q_n and Q_p: **[4 marks]**

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

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

➔ $P_{Qn} = (0.2288\text{ mA})(10\text{ V}) = 2.288\text{ mW}$ **[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]**

Answers to QUESTION 3(b) [10 marks]

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

$r_{\pi 2} = \beta v_T/I_Q = (120)(0.026)/1\text{m} = 3.120\text{ k}\Omega$ [1 mark]

$I_{C1} = \frac{\beta}{1+\beta} I_{B2} = I_Q/(1+\beta) = 1\text{m}/(1+120) = 8.26\ \mu\text{A}$ [1 mark]

$r_{\pi 1} = \beta v_T/I_{C1} = (120)(0.026)/(1\text{m}/(1+120)) = 377.52\text{ k}\Omega$ [1 mark]

Thus, $R_i = 377.52\text{k} + (1+120)(3.12\text{k}) = \underline{\mathbf{755.04\text{ k}\Omega}}$ [1 mark]

$R_O = 5\text{k} \parallel (r_{\pi 3} + 10\text{k})/(1+\beta)$ [2 marks]

$R_{\pi 3} = \beta vT/I_{C3} = (120)(0.026)/2\text{m} = 1.56\text{ k}\Omega$ [1 mark]

Thus, $R_O = 5\text{k} \parallel (1.56\text{k} + 10\text{k})/(121)$

$= 5\text{k} \parallel 0.095537\text{k} = \underline{\mathbf{0.09375\text{ k}\Omega}}$ [2 marks]

Answers to QUESTION 4(a) [10 marks]

Q4(a)(i) [5 marks]

$$I_{C10} = I_{C9} = 10x10^{-6}\,\text{A}, I_{REF} = 1x10^{-3}\,\text{A} \quad [1]$$

$$R_4 = \frac{V_T}{I_{C10}} \ln \frac{I_{REF}}{I_{C10}} \quad [1]$$

$$R_4 = \frac{0.026}{10x10^{-6}} \ln \frac{1x10^{-3}}{10x10^{-6}} = 11.97\text{k}\Omega \quad [0.5]$$

$$R_5 = \frac{V^+ - V_{EB12} - V_{BE11} - V^-}{I_{REF}} \quad [1]$$

$$V_{EB12} = V_{BE11} = V_T \ln \frac{I_{REF}}{I_S} = 0.026 \ln \frac{1x10^{-3}}{10^{-14}} = 0.658\text{V} \quad [1]$$

$$R_5 = \frac{15 - 0.658 - 0.658 - (-15)}{1\text{m}} = 28.68\text{k}\Omega \quad [0.5]$$

Q4(a)(ii) [3 marks]

$$I_{C1} = \frac{I_{C8}}{2} = \frac{I_{C9}}{2} = \frac{10\mu\text{A}}{2} = 5\mu\text{A} \quad [1]$$

$$I_{C6} = I_{C1} = 5\mu\text{A} \quad [0.5]$$

$$r_{\pi 6} = \frac{\beta V_T}{I_{C6}} = \frac{200x0.026}{5\mu} = 1.04\text{M}\Omega \quad [1.5]$$

Q4(a)(iii) [2 marks]

Apply balanced concept, vc6 = vc5

Vc6 = Vc5 **[0.5]**

$$V_{C6} = V_{C5} = V^- + I_{C6}R_2 + V_{BE6} + V_{BE7} \quad [1]$$

$$V_{C6} = (-15) + (5\mu\text{A})(1\text{k}\Omega) + 0.6 + 0.6 = -13.795\,\text{V} \quad [0.5]$$

Answers to QUESTION 4(b) [10 marks]

Q4(b)(i) [4 marks]

$$I_Q = I_{D6} = I_{D5} \quad \boxed{1}$$

$$I_{D5} = K_p(V_{SG5} + V_{TP})^2 = (100\mu\text{A/V}^2)x(1.5 - 0.5)^2 = 100\mu\text{A} \quad \boxed{2}$$

$$\Rightarrow I_Q = I_{D5} = 100\mu\text{A} = 0.1\text{mA} \quad \boxed{1}$$

Q4(b)(ii) [6 marks]

$$A_d = g_{m2}(r_{o2} \parallel r_{o4}) \quad \boxed{1}$$

$$g_{m2} = \sqrt{2K_p I_Q} = \sqrt{2(100\mu)(100\mu)} = 141.42\mu\text{A/V} \quad \boxed{0.5}$$

$$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02x50\mu} = 1\text{M}\Omega \quad \boxed{0.5}$$

$$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01x50\mu} = 2\text{M}\Omega \quad \boxed{0.5}$$

$$A_d = (141.42\mu)(1\text{M} \parallel 2\text{M}) = 94.286 \quad \boxed{0.5}$$

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

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

$$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01x100\mu} = 1\text{M}\Omega \quad \boxed{0.5}$$

$$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02x100\mu} = 0.5\text{M}\Omega \quad \boxed{0.5}$$

$$A_{v2} = (223.6\mu)(1\text{M} \parallel 0.5\text{M}) = 74.53 \quad \boxed{0.5}$$

$$A_v = A_d A_{v2} = 94.286x74.53 = 7027.45 \quad \boxed{1}$$

Answers to QUESTION 5(a) [6 marks]

Calculation:

A_v = $1 + R_2/(R_{1F} + R_{1V})$ [1]

R_2 = 250 kΩ.

R_{1F} is a fixed-value resistor.

R_{1V} is a potentiometer.

Gain is maximum, i.e. A_v(max) = 51, when R_{1V} = **0** Ω.

A_v(max) = 51 = $1 + R_2/(R_{1F} + R_{1V})$ = $1 + 250\text{k}/(R_{1F} + \mathbf{0})$ [1]

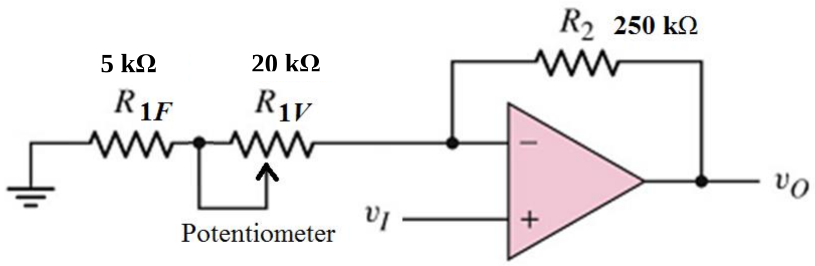
R_{1F} = 5 kΩ [0.5]

Gain is minimum, i.e. A_v(min) = 11, when R_{1V} is maximum.

A_v(min) = 11 = $1 + R_2/(R_{1F} + R_{1V})$ = $1 + 250\text{k}/(5\text{k} + R_{1V})$ [1]

R_{1V} = 20 kΩ [0.5]

Circuit: [2]



Answers to QUESTION 5(b) [4 marks]

$\boldsymbol{R_1}$ **= 75 kΩ**, $\boldsymbol{R_2}$ **= 100 kΩ**, $\boldsymbol{R_3}$ **= 80 kΩ**, and $\boldsymbol{R_4}$ **= 200 kΩ**.

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

v_{O1} / v_I = -(100k/75k) = -1.333 V/V [1]

v_O = $(-R_4/R_3)v_{O1}$ = $(-R_4/R_3)(-R_2/R_1)v_I$ [1]

v_O / v_I = $(R_4/R_3)(R_2/R_1)$

= [(200k/80k)(100k/75k)] = 3.333 V/V [1]

Answers to QUESTION 5(c) [10 marks]

Q5(c)(i) **$R_3 = R_4 = 100\ k\Omega$**

$$A_v = \frac{R_4}{R_3}\left(1+\frac{2R_2}{R_1+R_{1POT}}\right) = \frac{100k}{100k}\left(1+\frac{2R_2}{R_1+R_{1POT}}\right) = \left(1+\frac{2R_2}{R_1+R_{1POT}}\right)$$

[1]

A_v is maximum (i.e. $A_v = 100$) when $R_{1POT} = 0$, i.e.

$$100 = \left(1+\frac{2R_2}{R_1+0}\right) \qquad \textbf{[1]}$$

$99\ R_1 = 2\ R_2$ **{Eqn 1}** **[0.5]**

A_v is minimum (i.e. $A_v = 10$) when $R_{1POT} = 100\ k\Omega$, i.e.

$$10 = \left(1+\frac{2R_2}{R_1+100k}\right) \qquad \textbf{[1]}$$

$9(\ R_1 + 100k) = 2\ R_2$ **{Eqn 2}** **[0.5]**

{Eqn 1} = {Eqn 2}

$99\ R_1 = 9\ R_1 + 900k$ **[1]**

➔ **$R_1 = 10\ k\Omega$** **[1]**

➔ **$R_2 = (\ 99\ R_1\ ) / 2 = 495\ k\Omega$** **[1]**

Q5(c)(ii) **$v_{I1} = 1.45$ V, $v_{I2} = 1.13$ V, $R_4 = 2\ R_3$, $R_{1POT} = 40\ k\Omega$**

$$A_v = \frac{R_4}{R_3}\left(1+\frac{2R_2}{R_1+R_{1POT}}\right) = \frac{2R_3}{R_3}\left(1+\frac{2(495k)}{10k+40k}\right) = 41.6 \qquad \textbf{[1.5]}$$

$$v_O = A_v(v_{I2}-v_{I1}) = (41.6)(1.13-1.45) = -13.312\,V \qquad \textbf{[1.5]}$$