UNIVERSITI TENAGA NASIONAL

COLLEGE OF ENGINEERING
PUTRAJAYA CAMPUS
FINAL EXAMINATION

SEMESTER I 2010 / 2011

PROGRAMME	: Bachelor of Electrical Engineering (Honours)
SUBJECT CODE	: EEEB273
SUBJECT	: ELECTRONIC ANALYSIS AND DESIGN II
DATE	:
TIME	: 9.00 am – 12.00 pm (3 hours)

Final Exam Answer

Question 1 [16 marks]

Question 1.a

(i)

$I_{REF} = (V^+ - V_{EB}(\text{on}) - V^-) / R_1$ [1]

$(1.5\text{m}) = (5 - 0.7 - (-5)) / R_1$ [1]

$R_1 = 6.2\ \text{k}\Omega$ [1]

(ii)

$I_O = 3\, I_{REF}$ [1]

$= 3\,(1.5\text{m})$ [1]

$= 4.5\ \text{mA}$ [1]

(iii)

$R_O = r_{O2}$ [1]

$= V_A/I_O = (450)/(4.5\text{m}) = 100\ \text{k}\Omega$ [1]

Question 1.b

$V_{DS2}\ (\text{sat}) = V_{GS2} - V_{TN}$ [1]

$0.4 = V_{GS2} - 0.4$ $\quad V_{GS2} = 0.8\ \text{V}$ [1/2]

$V_{GS1} = V_{GS2} = 0.8\ \text{V}$ [1]

$(W/L)_1 = I_{REF} / [(k'_n/2)\,(V_{GS1} - V_{TN})^2]$ [1]

$= (100\mu) / [(100\mu/2)(0.8 - 0.4)^2$ $\quad = \mathbf{12.5}$ [1/2]

$(W/L)_2 = I_O / [(k'_n/2)\,(V_{GS2} - V_{TN})^2]$ [1]

$= (60\mu) / [(100\mu/2)(0.8 - 0.4)^2$ $\quad = \mathbf{7.5}$ [1/2]

$V_{GS3} = V^+ - V_{GS1} - V^+ = 3 - 0.8 - 0$ $\quad = \mathbf{2.2\ V}$ [1]

$(W/L)_3 = I_{REF} / [(k'_n/2)\,(V_{GS3} - V_{TN})^2]$ [1]

$= (100\mu) / [(100\mu/2)(2.2 - 0.4)^2$ $\quad = \mathbf{0.617}$ [1/2]

Question 2 [18 marks]

(a) Consider the BJT differential amplifier in **Figure 2a**. The circuit and transistor parameters are $\mathbf{V^+=10\ V}$, $\mathbf{V^-=-10\ V}$, $\boldsymbol{\beta}$**=100**, $\mathbf{V_T=26\ mV}$, $\mathbf{I_Q=1mA}$, and early voltage $\mathbf{V_A=\infty}$.

(i) **Redesign** the circuit such that the differential-mode output voltage of $\boldsymbol{v_{c2}}$**=8V** when a differential-mode input voltage of $\boldsymbol{v_d}$**=0.05V** is applied.
[4 marks]

(ii) Determine the differential-mode input resistance.
[2 marks]

(iii) Determine the **CMRR** when the common-mode voltage gain ($\boldsymbol{A_{cm}}$)= **-0.2**
[2 marks]

(iv) Suggest a practical method to increase the differential-mode voltage gain, draw the circuit diagram.
[2 marks]

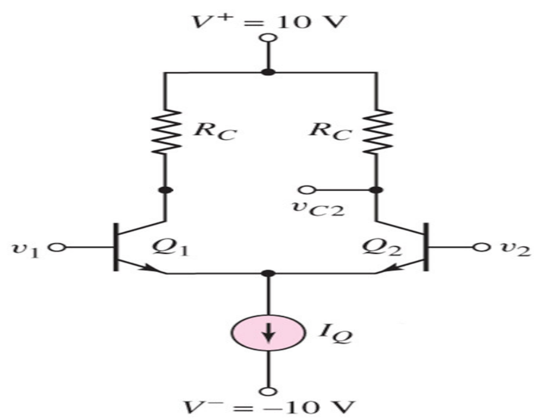


Figure 2a

Answer:

(i) The differential-mode voltage gain is given by

$$A_d = \frac{v_o}{v_d} = \frac{g_m R_C}{2} \quad \boxed{1}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.5mA}{26mV} = 19.231mA/V \quad \boxed{0.5}$$

$$A_d = \frac{8}{0.05} = 160 = \frac{g_m R_C}{2} = \frac{19.231\times10^{-3} R_C}{2} \quad \boxed{1}$$

$$\Rightarrow R_C = \frac{320}{19.231\times10^{-3}} \quad \boxed{1}$$

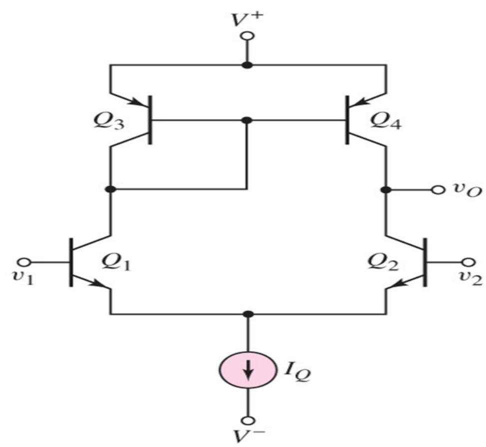
$$R_C = 16.64k\Omega \quad \boxed{0.5}$$

(ii) $$Rid = 2r_\pi = \frac{2\beta V_T}{I_{CQ}} = \frac{2\times100\times0.026}{0.5mA} = 10.4k\Omega \quad \boxed{2}$$

(iii) $$CMRR = \left|\frac{Ad}{Acm}\right| = \frac{160}{0.2} = 800$$ 2

$$CMRR_{dB} = 20Log800 = 58.06dB$$

(iv) Since the differential-mode voltage gain is proportional to the output resistance. The differential-mode voltage gain can be increased if the output resistance can be increased. The output resistance can be increased by replacing the resistive load with active load as shown below in **Figure 2(a)**



2

Figure 2(a)

(b) The MOSFET differential amplifier with cascode active load shown in **Figure 2b** is to be designed to achieve the desired differential-mode voltage gain. The circuits parameters are to be $\mathbf{V^+=10\ V}$, $\mathbf{V^-=-10\ V}$, and $\mathbf{I_Q=0.4mA}$. The **NMOS** transistors parameters are $\boldsymbol{\lambda_n}$**=0.02V**$^{-1}$, $\boldsymbol{k_n'}$**=100µA/V**^{2}, $\boldsymbol{V_{TN}}$**=1V** and the transconductance $\boldsymbol{g_m}$**=0.5mA/V**. The **PMOS** transistors parameters are $\boldsymbol{\lambda_p}$**=0.01V**$^{-1}$, $\boldsymbol{k_p'}$**=200µA/V**^{2}, $\boldsymbol{V_{TP}}$**=-1 V** and the transconductance $\boldsymbol{g_m}$**=0.5mA/V**.

(i) Design the differential amplifier pair (i.e. calculate the aspect ratios (***W/L***) for M_1 & M_2).

[3 marks]

(ii) Determine the output resistance of the amplifier.

[3 marks]

(iii) Determine the differential-mode voltage gain.

[2 marks]

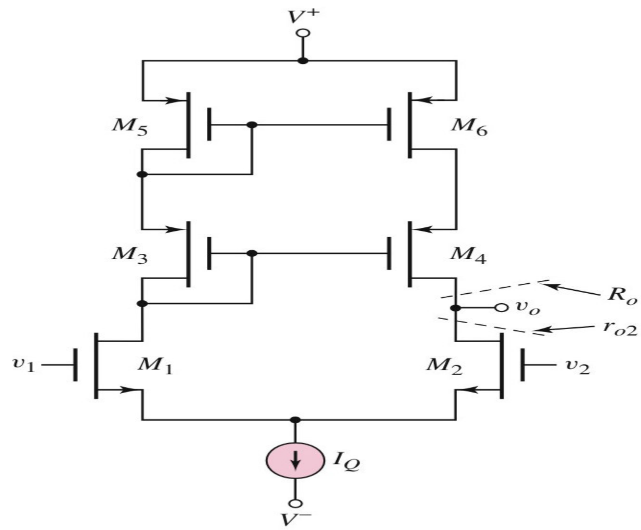


Figure 2b

Answer:

(i)

$$I_{DQ} = \frac{I_Q}{2} = \frac{0.4mA}{2} = 0.2mA \quad \boxed{0.5}$$

$$g_m = 0.5\times10^{-3} = 2\sqrt{\frac{k_n'}{2}\frac{W}{L}I_{DQ}} = 2\times\sqrt{\frac{100\times10^{-6}}{2}\left(\frac{W}{L}\right)0.2\times10^{-3}} \quad \boxed{1}$$

$$\left(\frac{W}{L}\right) = \frac{\left(0.5\times10^{-3}/2\right)^2}{\frac{100\times10^{-6}}{2}\times0.2\times10^{-3}} = 6.25 \quad \boxed{1}$$

$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 6.25 \quad \boxed{0.5}$$

(ii)

$$R_o = r_{o2} \,//\, R_{oac} \quad \boxed{0.5}$$

$$R_{oac} \cong g_m r_{o4} r_{o6} \ , \quad \boxed{0.5}$$

$$r_{o4} = r_{o6} = \frac{1}{\lambda_p I_{DQ}} = \frac{1}{0.01\times0.2\times10^{-3}} = 500\text{k}\Omega \quad \boxed{0.5}$$

$$R_{oac} \cong 0.5\times10^{-3}\times500\times10^3\times500\times10^3 = 125M\Omega \quad \boxed{0.5}$$

$$r_{o2} = \frac{1}{\lambda_n I_{DQ}} = \frac{1}{0.02\times0.2\times10^{-3}} = 250\text{k}\Omega \quad \boxed{0.5}$$

$$R_o = r_{o2} \,//\, R_{oac} = 250\text{k}\Omega \,//\, 125M\Omega = 249.501\text{k}\Omega \quad \boxed{0.5}$$

(iii)

$$A_d = g_m (r_{o2} \,//\, R_{oac}) \quad \boxed{1}$$

$$A_d = (0.5\times10^{-3})\left(249.501\times10^3\right) = 124.75 \quad \boxed{1}$$

Question 3 [16 marks]

Consider the circuit shown in **Figure 3**. The circuit and transistor parameters are $\mathbf{V^+=12\ V}$, $\mathbf{V^-=-12\ V}$, $\mathbf{V_{GS4}=3.37V}$, $\lambda=\infty$, $\mathbf{K_n=0.2mA/V^2}$, and $\mathbf{V_{TN}=1V}$.

(i) Calculate the output voltage v_{O2} and v_{O3}

[6 marks]

(ii) Calculate the overall voltage gain (v_{O3}/v_d)

[6 marks]

(iii) Determine V_{GS2} and the maximum common-mode input voltage ($\boldsymbol{v_{CM}}$(max)) of $\boldsymbol{M_2}$.

[4 marks]

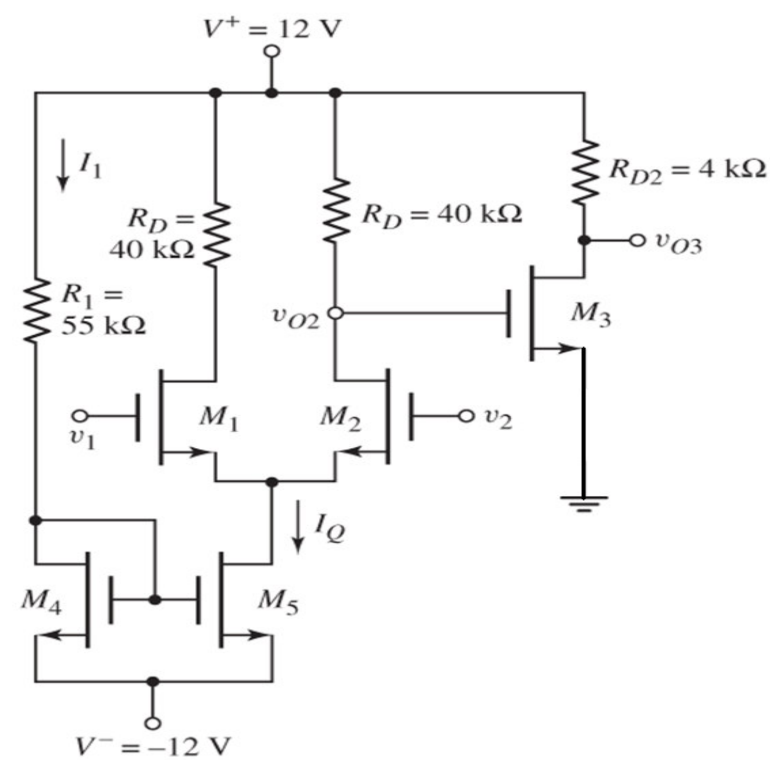


Figure 3

(*i*)

$V_{o2} = V^{+} - I_{D2}R_D$ [0.5]

$I_{D2} = \frac{I_Q}{2}$

$I_Q = \frac{V^{+} - V_{GS4} - V^{-}}{R_1}$ [0.5]

$I_Q = \frac{12 - 3.37 + 12}{55k\Omega} = 375.091\mu A$ [0.5]

$I_{D2} = \frac{I_Q}{2} = \frac{375.091\mu A}{2} = 187.545\mu A$ [0.5]

$V_{o2} = V^{+} - I_{D2}R_D = 12 - (187.545\times10^{-6}\times40\times10^{3}) = 4.498V$ [1]

$V_{o3} = V^{+} - I_{D3}R_{D2}$ [0.5]

$I_{D3} = K_n(V_{GS3} - V_{TN})^2$ [0.5]

$V_{GS3} = V_{o2} = 4.498V$ [0.5]

$I_{D3} = 0.2\times10^{-3}(4.498-1)^2 = 2.447mA$ [0.5]

$V_{o3} = 12 - (2.447\times10^{-3}\times4\times10^{3}) = 2.212V$ [1]

(*ii*)

$A_v = \frac{v_{o3}}{v_d} = A_d A_{v1}$ [1]

$A_v = \frac{g_m R_D}{2} g_{m3} R_{D2}$ [2]

$= 2\sqrt{0.2\times10^{-3}\times187.545\times10^{-6}} \times \frac{40\times10^{3}}{2} \times 2\sqrt{0.2\times10^{-3}\times2.447\times10^{-3}} \times 4\times10^{3}$ [2]

$Av = 43.356$ [1]

(iii)

$I_{D2} = K_n(V_{GS2} - V_{TN})^2$ [0.5]

$V_{GS2} = V_{TN} + \sqrt{\frac{I_{D2}}{K_n}} = 1 + \sqrt{\frac{187.545\times10^{-6}}{0.2\times10^{-3}}}$ [0.5]

$V_{GS2} = 1.968V$ [0.5]

$V_{CM2}(\max) = V_{GS2} + V_{S2}$ 0.5

$V_{S2} = V_{o2} - V_{DS2}(Sat),$ 0.5

$V_{DS2}(Sat) = V_{GS2} - V_{TN} = 1.968 - 1 = 0.968$ 0.5

$V_{S2} = 4.498V - 0.968 = 3.53V$ 0.5

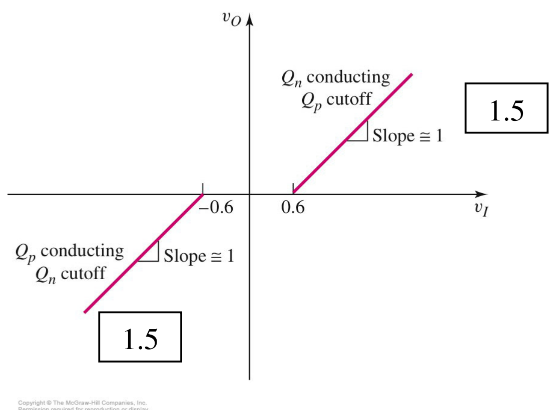
$V_{CM2}(\max) = V_{GS2} + V_{S2} = 1.968V + 3.53V = 5.498V$ 0.5

Question 4 [17 marks]

(a) **Figure 4.1** shows a basic complimentary push-pull output stage circuit. Assume the B-E cut-in voltage of 0.6V such that v_O remains zero for the interval -0.6V $\leq v_I \leq$ 0.6V.

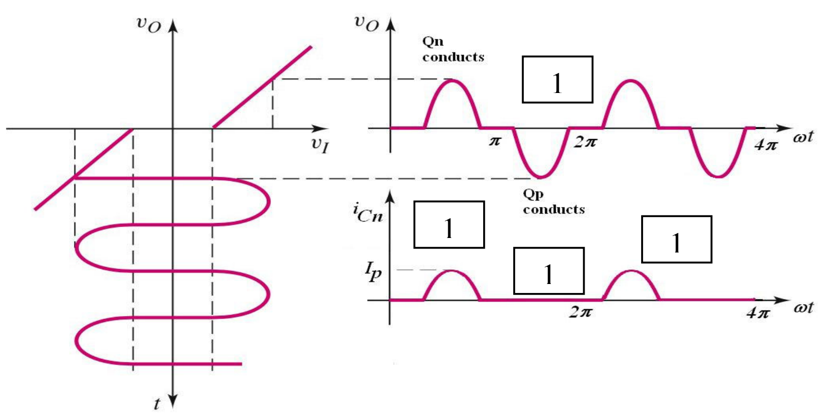
(i) Sketch the voltage transfer characteristic of the circuit. Indicate when Q_n is conducting and when it is not conducting.

[3 marks]



(ii) Sketch the current i_{Cn} for two input cycles corresponds to a sinusoidal input voltage $v_I = V_p \sin \omega t$ V.

[4 marks]



(b) Consider the circuit in **Figure 4.2**. The circuit parameters are V_{CC}=12V, R_L=100Ω, and Q_n and Q_p are matched with $I_S = 4x10^{-13}$ A. Let V_{BB} = 1.2 V, and β>>1.

(i) For the case of the input voltage $v_I = 0$, calculate the quiescent collector currents, i_{Cn} and i_{Cp}, and the power dissipated in transistors Q_p and Q_n.

[3 marks]

$$i_{Cn} = i_{Cp} = I_S e^{\frac{V_{BB}}{2V_T}}$$ [0.5]

$$i_{Cn} = (4x10^{-13})(e^{\left[\frac{1.2}{(2)(0.026)}\right]}) = 4.210\, mA$$ [1]

$$P_{Qn} = P_{Qp} = v_{CE} i_C$$ [0.5]

$$v_{CE} = 12V$$

$$P_Q = (12)(4.210\, m) = 50.52\, mW$$ [1]

(ii) What is the maximum amplitude of the output voltage, v_O, and the corresponding maximum power that can be delivered to the load?

[2 marks]

$$v_{O(\max)} = 12V$$ [1]

$$P_{L(\max)} = \frac{1}{2}\frac{V_p^2}{R_L} = (0.5)\left(\frac{12^2}{100}\right) = 0.72W$$ [1]

(iii) For the case of v_O =-4 sin ωt V, **determine i_L, i_{Cn}, i_{Cp}, and v_I.**

At v_O =-4 V peak, the load current flows into Q_p,

thus $i_{Cp} \cong i_L = \frac{v_O}{R_L} = \frac{-4\sin\omega t}{100} = -40\sin\omega t$ mA [1]

i_{Cn},=0 [1]

$$v_I = v_O - v_{EBp} + \frac{V_{BB}}{2}$$ [1]

$$v_{EBp} = V_T \ln\left[\frac{i_{Cp}}{Is}\right] = (0.026)\ln\left[\frac{40m}{4x10^{-13}}\right] = 0.6585V$$ [1]

$$v_I = -4 - 0.6585 + \frac{1.2}{2} = -4.0585$$

v_I = -4.0585 sin ωt V [1]

Question 5 [17 marks]

Question 5.a

$I_{C17} = I_{C13B}$ [1]

$= 0.70\, I_{REF}$ [1]

$= (0.70)(0.72\text{m}) \quad = 0.504$ mA [1]

$I_{C16} \approx I_{E16}$ $\quad (\beta = 200)$ [1]

$= I_{B17} + (I_{E17} R_8 + V_{BE17})/R_9$ [1]

$= I_{C17}/\beta + (I_{C17} R_8 + V_{BE17})/R_9$ [1]

$= (0.504\text{m}/200) + [(0.504\text{m})(100) + 0.6]/(50\text{k})$ [1/2]

$= \mathbf{15.028\ \mu A}$ [1/2]

Question 5.b

(i)

$I_{D3} = (k'_p/2)(W/L)_3(V_{SG3} + V_{TP})^2$ [1/2]

$150\mu = (40\mu/2)(50)(V_{SG3} - 0.4)^2$

$V_{SG3} = 0.7873$ V [1/2]

$R_{D1} = V_{SG3} / I_{D1} \quad = V_{SG3} / (I_Q/2)$ [1/2]

$= 0.7873 / (200\mu/2) \quad = \mathbf{7.87\ k\Omega}$ [1/2]

$I_{D4} = (k'_n/2)(W/L)_4(V_{GS4} - V_{TN})^2$ [1/2]

$200\mu = (100\mu/2)(40)(V_{GS4} - 0.4)^2$

$V_{GS4} = 0.7162$ V [1/2]

$V_{G4} = V_O + V_{GS4} = 0 + 0.7162 \quad = \mathbf{0.7162\ V}$

$R_{D2} = (V_{G4} - (V^-)) / I_{D3}$ [1/2]

$= (0.7162 - (-3))/(150\mu) \quad = \mathbf{24.8\ k\Omega}$ [1/2]

$R_S = (V_O - (V^-)) / I_{D4}$ [1]

$= (0 - (-3))/(200\mu) \quad = \mathbf{15\ k\Omega}$ [1]

(ii)

$A_{d1} = (g_{m1}/2)(R_{D1})$ [1/2]

$g_{m1} = 2\ \text{SQRT}[(k'_n/2)(W/L)_1(I_Q/2)]$ [1/2]

$= 2\ \text{SQRT}[(100\mu/2)(20)(200\mu/2)] \quad = 0.6325$ mA/V [1/2]

$A_{d1} = (0.6325\text{m} / 2)(7.87\text{k}) \quad = \mathbf{2.49}$ [1/2]

$A_2 = -19.21$ [1/2]

$A_3 = 1$ [1/2]

$A = A_{d1} \times A_2 \times A_3$ [1/2]

$= (2.49) \times (-19.21) \times (1) \quad = \mathbf{-47.83}$ [1/2]

Question 6 [16 marks]

(a) State four (4) applications of an ideal operational amplifiers.

Any four of the following:

Current-to-voltage converter

Voltage-to-current converter

Difference Amplifier

Instrumentation Amplifier

Integrator

Differentiator

[1+1+1+1=4 marks]

(b) A general output equation for difference amplifier is $v_O = A_d v_d + A_{cm} v_{cm}$. For the difference amplifier in **Figure 6.1**, the circuit parameters are $R_1 = R_3 =$ 10kΩ, $R_2 =$ 100kΩ, and $R_4 =$ 110kΩ and the output voltage equation is as follows;

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

where; $v_{I1} = v_{cm} - \frac{v_d}{2}$, and $v_{I2} = v_{cm} + \frac{v_d}{2}$. **Find A_d, A_{cm}, and calculate the *CMRR* in dB.**

[5 marks]

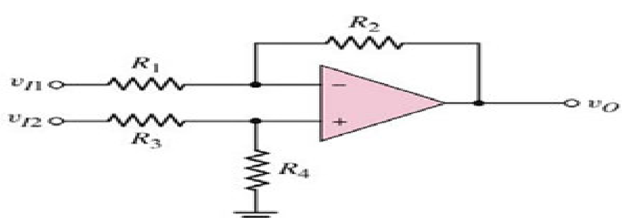


Figure 6a

$$v_O = \left(1+\frac{100}{10}\right)\left(\frac{110/10}{1+110/10}\right)v_{I2} - \left(\frac{100}{10}\right)v_{I1} = (1+10)\left[\frac{11}{12}\right]v_{I2} - 10v_{I1} \quad \boxed{1}$$

$$v_O = 10.083v_{I2} - 10v_{I1} = 10.083(v_{cm} + \frac{v_d}{2}) - 10(v_{cm} - \frac{v_d}{2}) \quad \boxed{1}$$

$$= 10.0415v_d + 0.083v_{cm} \quad \boxed{1}$$

A_d=10.0415; A_{cm}=0.083 $\boxed{1}$

CMRR = 20 log[10.0415/0.083] = 41.65dB $\boxed{1}$

(c) Consider the two inverting op-amp circuit connected in cascade as in **Figure 6b**. Let $\boldsymbol{R_1=20\text{k}\Omega}$, $\boldsymbol{R_2=160\text{k}\Omega}$, $\boldsymbol{R_3=10\text{k}\Omega}$, and $\boldsymbol{R_4=80\text{k}\Omega}$. Find $\boldsymbol{v_O/v_I}$ for the circuit.

[7 marks]

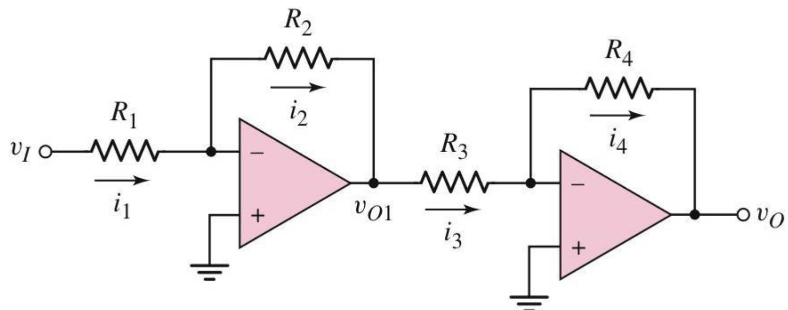


Figure 6b

$$\frac{v_O}{v_I} = \left(\frac{v_O}{v_{O1}}\right) \times \left(\frac{v_{O1}}{v_I}\right) \quad \boxed{2}$$

$$\frac{v_O}{v_{O1}} = \frac{-R_4}{R_3} \quad \boxed{1.5}$$

$$\frac{v_{O1}}{v_I} = \frac{-R_2}{R_1} \quad \boxed{1.5}$$

$$\frac{v_O}{v_I} = \frac{R_4 R_2}{R_3 R_1} = \frac{(80)(160)}{(10)(20)} = 64 \quad \boxed{2}$$