Name:	**Dr JBO**
Student ID Number:	**Model Answer**
Section:	01 A/B
Lecturer:	Dr. Jamaludin Bin Omar

EEEB273 - Quiz 3
SEMESTER 1, ACADEMIC YEAR 2018/2019
Date: 19 July 2018 Time: 15 minutes .

Question:

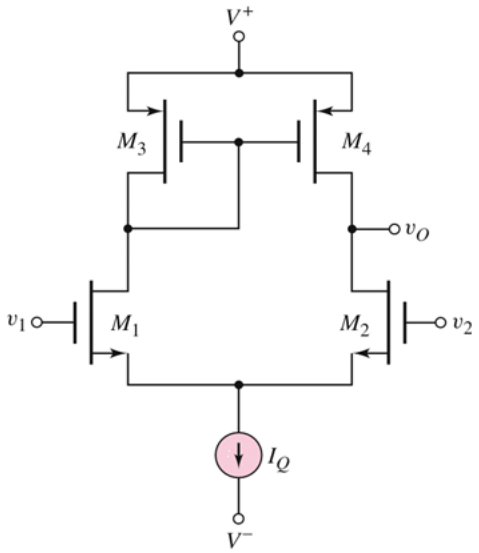
The circuit parameters for differential amplifier with active load shown in **Figure 1** are $V^+ = 5$ **V**, $V^- = -5$ **V**, and $I_Q = 220$ **μA**. The **NMOS** transistor parameters are $V_{TN} = 0.4$ **V**, $k'_n = 100$ **μA/V²**, $(W/L)_n = 8$, and $\lambda_n = 0.018$ **V⁻¹**. The **PMOS** transistor parameters are $V_{TP} = -0.4$ **V**, $k'_p = 40$ **μA/V²**, $(W/L)_p = 10$, and $\lambda_p = 0.02$ **V⁻¹**.

a) **Determine** the output resistance (R_O) of the differential amplifier. [4 marks]

b) **Calculate** the differential-mode voltage gain (A_d) and the common-mode voltage gain (A_{cm}) if ***CMRR*** of the differential amplifier is **55 dB**. [6 marks]

c) **Draw** a differential amplifier with active load that has a higher differential-mode voltage gain compared to the differential amplifier shown in the **Figure 1**. [2 marks]

Answer:



;N – MOSFET

$$v_{DS}(\text{sat}) = v_{GS} - V_{TN}$$

$$i_D = K_n[v_{GS} - V_{TN}]^2$$

$$K_n = \frac{k'_n}{2} \cdot \frac{W}{L}$$

;P – MOSFET

$$v_{SD}(\text{sat}) = v_{SG} + V_{TP}$$

$$i_D = K_p[v_{SG} + V_{TP}]^2$$

$$K_p = \frac{k'_p}{2} \cdot \frac{W}{L}$$

;Small signal

$$g_m = 2\sqrt{K_? I_{DQ}}$$

$$r_o \cong \frac{1}{\lambda I_{DQ}}$$

(a)

I_D	$= I_Q / 2 = 220\mu / 2$		$= 110$ μA	[1]
r_{o2}	$= 1 / (\lambda_n I_D)$	$= 1 / [(0.018)(110\mu)]$	$= 505.05$ kΩ	[1]
r_{o4}	$= 1 / (\lambda_p I_D)$	$= 1 / [(0.02)(110\mu)]$	$= 454.54$ kΩ	[1]
R_o	$= r_{o2} \| r_{o4}$	$= 505.05\text{k} \| 454.54\text{k}$	$= 239.23$ kΩ	[1]

(b)

R_o	$= r_{o2} \| r_{o4}$		$= 239.23$ kΩ	
g_{m2}	$= 2\sqrt{[K_n I_D]}$	$= 2\sqrt{[(k'_n/2)(W/L)_n(I_Q/2)]}$		
	$=2\sqrt{[(100\mu/2)(8)(110\mu)]}$		$= 0.4195$ mA/V²	[1]
A_d	$= g_{m2} R_o = (0.4195\text{m})(239.23\text{k})$		$= 100.35$	[1]

$CMRR_{dB}$	$= 20 \log [A_d / A_{cm}] = 55$ dB	[1]
A_{cm}	$= A_d / [10^{55/20}] = 0.17845$	[1]

(c) **A drawing using cascode or Wilson active load** [2]

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Question:

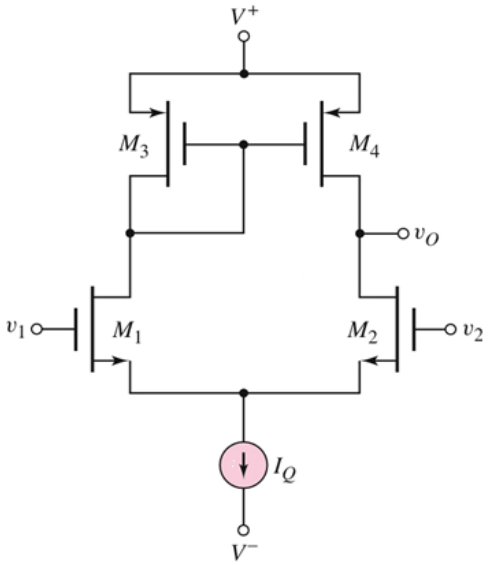
The circuit parameters for differential amplifier with active load shown in **Figure 1** are $V^+ = 5$ **V**, $V^- = -5$ **V**, and $I_Q = 230$ **μA**. The **NMOS** transistor parameters are $V_{TN} = 0.4$ **V**, $k'_n = 100$ **μA/V²**, $(W/L)_n = 8$, and $\lambda_n = 0.02$ **V⁻¹**. The **PMOS** transistor parameters are $V_{TP} = -0.4$ **V**, $k'_p = 40$ **μA/V²**, $(W/L)_p = 10$, and $\lambda_p = 0.018$ **V⁻¹**.

a) **Determine** the output resistance (R_O) of the differential amplifier. [4 marks]

b) **Calculate** the differential-mode voltage gain (A_d) and the common-mode voltage gain (A_{cm}) if ***CMRR*** of the differential amplifier is **45 dB**. [4 marks]

c) **Draw** a differential amplifier with active load that has a higher differential-mode voltage gain compared to the differential amplifier shown in the **Figure 1**. [2 marks]

Answer:



;N – MOSFET

$$v_{DS}(\text{sat}) = v_{GS} - V_{TN}$$

$$i_D = K_n[v_{GS} - V_{TN}]^2$$

$$K_n = \frac{k'_n}{2} \cdot \frac{W}{L}$$

;P – MOSFET

$$v_{SD}(\text{sat}) = v_{SG} + V_{TP}$$

$$i_D = K_p[v_{SG} + V_{TP}]^2$$

$$K_p = \frac{k'_p}{2} \cdot \frac{W}{L}$$

;Small signal

$$g_m = 2\sqrt{K_? I_{DQ}}$$

$$r_o \cong \frac{1}{\lambda I_{DQ}}$$

(a)

I_D	$= I_Q / 2 = 230\mu / 2$		$= 115$ μA	[1]
r_{o2}	$= 1 / (\lambda_n I_D)$	$= 1 / [(0.02)(115\mu)]$	$= 434.78$ kΩ	[1]
r_{o4}	$= 1 / (\lambda_p I_D)$	$= 1 / [(0.018)(115\mu)]$	$= 483.09$ kΩ	[1]
R_o	$= r_{o2} \parallel r_{o4}$	$= 434.78k \parallel 483.09k$	$= 228.83$ kΩ	[1]

(b)

R_o	$= r_{o2} \parallel r_{o4}$		$= 228.83$ kΩ	
g_{m2}	$= 2\sqrt{[K_n I_D]}$	$= 2\sqrt{[(k'_n/2)(W/L)_n(I_Q/2)]}$		
	$=2\sqrt{[(100\mu/2)(8)(115\mu)]}$		$= 0.4289$ mA/V²	[1]
A_d	$= g_{m2} R_o = (0.4289m)(228.83k)$		$= 98.145$	[1]
$CMRR_{dB}$	$= 20 \log [A_d / A_{cm}] = 45$ dB			[1]
A_{cm}	$= A_d / [10^{45/20}] = 0.5519$			[1]

(c) **A drawing using cascode or Wilson active load** [2]

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Question:

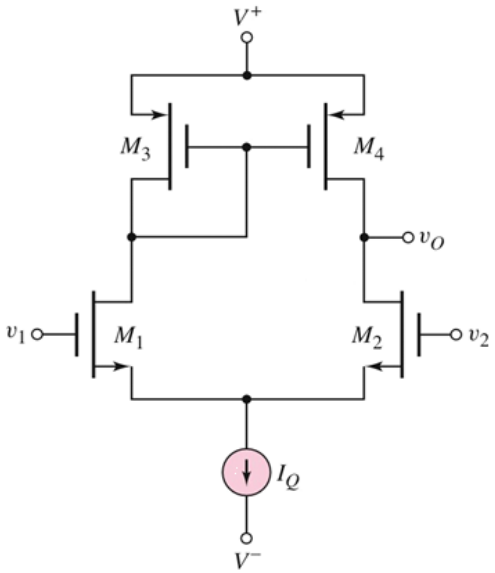
The circuit parameters for differential amplifier with active load shown in **Figure 1** are $V^+ = 5$ V, $V^- = -5$ V, and $I_Q = 240$ μA. The **NMOS** transistor parameters are $V_{TN} = 0.4$ V, $k'_n = 100$ μA/V^2, $(W/L)_n = 5$, and $\lambda_n = 0.018$ V^{-1}. The **PMOS** transistor parameters are $V_{TP} = -0.4$ V, $k'_p = 40$ μA/V^2, $(W/L)_p = 10$, and $\lambda_p = 0.02$ V^{-1}.

a) **Determine** the output resistance (R_O) of the differential amplifier. [4 marks]

b) **Calculate** the differential-mode voltage gain (A_d) and the common-mode voltage gain (A_{cm}) if ***CMRR*** of the differential amplifier is **55 dB**. [4 marks]

c) **Draw** a differential amplifier with active load that has a higher differential-mode voltage gain compared to the differential amplifier shown in the **Figure 1**. [2 marks]

Answer:



;N – MOSFET

$$v_{DS}(\text{sat}) = v_{GS} - V_{TN}$$

$$i_D = K_n[v_{GS} - V_{TN}]^2$$

$$K_n = \frac{k'_n}{2} \cdot \frac{W}{L}$$

;P – MOSFET

$$v_{SD}(\text{sat}) = v_{SG} + V_{TP}$$

$$i_D = K_p[v_{SG} + V_{TP}]^2$$

$$K_p = \frac{k'_p}{2} \cdot \frac{W}{L}$$

;Small signal

$$g_m = 2\sqrt{K_? I_{DQ}}$$

$$r_o \cong \frac{1}{\lambda I_{DQ}}$$

(a)

I_D	$= I_Q / 2 = 240\mu / 2$		$= 120$ μA	[1]
r_{o2}	$= 1 / (\lambda_n I_D)$	$= 1 / [(0.018)(120\mu)]$	$= 462.96$ kΩ	[1]
r_{o4}	$= 1 / (\lambda_p I_D)$	$= 1 / [(0.02)(120\mu)]$	$= 416.67$ kΩ	[1]
R_o	$= r_{o2} \parallel r_{o4}$	$= 462.96k \parallel 416.67k$	$= 219.29$ kΩ	[1]

(b)

R_o	$= r_{o2} \parallel r_{o4}$		$= 219.29$ kΩ	
g_{m2}	$= 2\sqrt{[K_n I_D]}$	$= 2\sqrt{[(k'_n/2)(W/L)_n(I_Q/2)]}$		[1]
	$=2\sqrt{[(100\mu/2)(5)(120\mu)]}$		$= 0.3464$ mA/V^2	[1]
A_d	$= g_{m2} R_o = (0.3464m)(219.29k)$		$= 75.96$	[1]
$CMRR_{dB}$	$= 20 \log [A_d / A_{cm}] = 55$ dB			[1]
A_{cm}	$= A_d / [10^{55/20}] = 0.13507$			[2]

(c) **A drawing using cascode or Wilson active load** [2]

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Question:

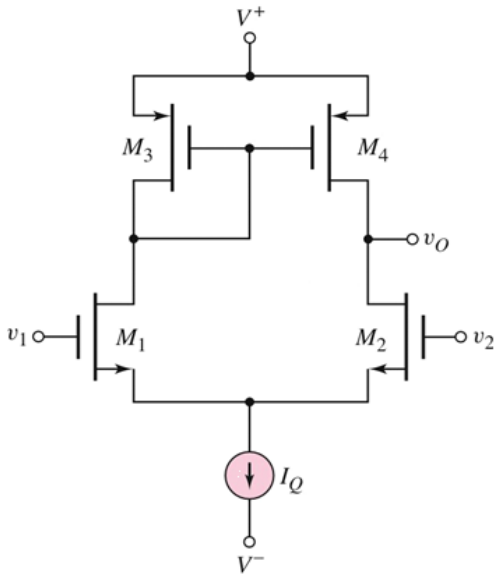
The circuit parameters for differential amplifier with active load shown in **Figure 1** are $V^+ = 5$ **V**, $V^- = -5$ **V**, and $I_Q = 260$ **μA**. The **NMOS** transistor parameters are $V_{TN} = 0.4$ **V**, $k'_n = 100$ **μA/V²**, $(W/L)_n = 5$, and $\lambda_n = 0.02$ **V⁻¹**. The **PMOS** transistor parameters are $V_{TP} = -0.4$ **V**, $k'_p = 40$ **μA/V²**, $(W/L)_p = 10$, and $\lambda_p = 0.018$ **V⁻¹**.

a) **Determine** the output resistance (R_O) of the differential amplifier. [4 marks]

b) **Calculate** the differential-mode voltage gain (A_d) and the common-mode voltage gain (A_{cm}) if ***CMRR*** of the differential amplifier is **65 dB**. [4 marks]

c) **Draw** a differential amplifier with active load that has a higher differential-mode voltage gain compared to the differential amplifier shown in the **Figure 1**. [2 marks]

Answer:



;N – MOSFET

$$v_{DS}(\text{sat}) = v_{GS} - V_{TN}$$

$$i_D = K_n[v_{GS} - V_{TN}]^2$$

$$K_n = \frac{k_n'}{2} \cdot \frac{W}{L}$$

;P – MOSFET

$$v_{SD}(\text{sat}) = v_{SG} + V_{TP}$$

$$i_D = K_p[v_{SG} + V_{TP}]^2$$

$$K_p = \frac{k_p'}{2} \cdot \frac{W}{L}$$

;Small signal

$$g_m = 2\sqrt{K_? I_{DQ}}$$

$$r_o \cong \frac{1}{\lambda I_{DQ}}$$

(a)

I_D	$= I_Q / 2 = 260\mu / 2$		$= 130$ μA	[1]
r_{o2}	$= 1 / (\lambda_n I_D)$	$= 1 / [(0.02)(130\mu)]$	$= 384.61$ kΩ	[1]
r_{o4}	$= 1 / (\lambda_p I_D)$	$= 1 / [(0.018)(130\mu)]$	$= 427.35$ kΩ	[1]
R_o	$= r_{o2} \parallel r_{o4}$	$= 384.61k \parallel 427.35k$	$= 202.43$ kΩ	[1]

(b)

R_o	$= r_{o2} \parallel r_{o4}$		$= 202.43$ kΩ	
g_{m2}	$= 2\sqrt{[K_n I_D]}$	$= 2\sqrt{[(k'_n/2)(W/L)_n(I_Q/2)]}$		
	$=2\sqrt{[(100\mu/2)(5)(130\mu)]}$		$= 0.3605$ mA/V²	[1]
A_d	$= g_{m2} R_o = (0.3605m)(202.43k)$		$= 72.97$	[1]
$CMRR_{dB}$	$= 20 \log [A_d / A_{cm}] = 65$ dB			[1]
A_{cm}	$= A_d / [10^{65/20}] = 0.04103$			[1]

(c) **A drawing using cascode or Wilson active load** [2]