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|---|---|
| Name: | **Dr JBO** |
| Student ID Number: | **Model Answer** |
| Section: | 01/02 A/B |
| Lecturer: | Dr. Jamaludin Bin Omar |

EEEB273 - Quiz 6
SEMESTER 2, ACADEMIC YEAR 2016/2017
Date: 10 January 2017 Time: 15 minutes .

**Question:**

Consider the **MC14573** op-amp in **Figure 1.** Assume transistor parameters of $\boldsymbol{V_{TN} = 0.5}$ **V**, $\boldsymbol{K_n =}$ **125 µA/V²** and $\boldsymbol{\lambda_n = 0.01}$ **V⁻¹** for **N-MOSFET**; and $\boldsymbol{V_{TP} = -0.5}$ **V**, $\boldsymbol{K_p = 100}$ **µA/V²,** and $\boldsymbol{\lambda_p = 0.02}$ **V⁻¹** for **P-MOSFET**. Given that $\boldsymbol{V_{SG5} = 1.5}$ **V:**

(a) **Find** the **quiescent bias currents** for all transistors in the **Figure 1**. [4 marks]

(b) **Determine** the **overall small signal differential-mode voltage gain** for the **MC14573** op-amp in the **Figure 1**. Gain for the output stage consists of transistor $\boldsymbol{M_7}$ and $\boldsymbol{M_8}$ is given by equation: $A_{v2} = -g_{m7}\left(r_{o7} \parallel r_{o8}\right)$. [6 marks]

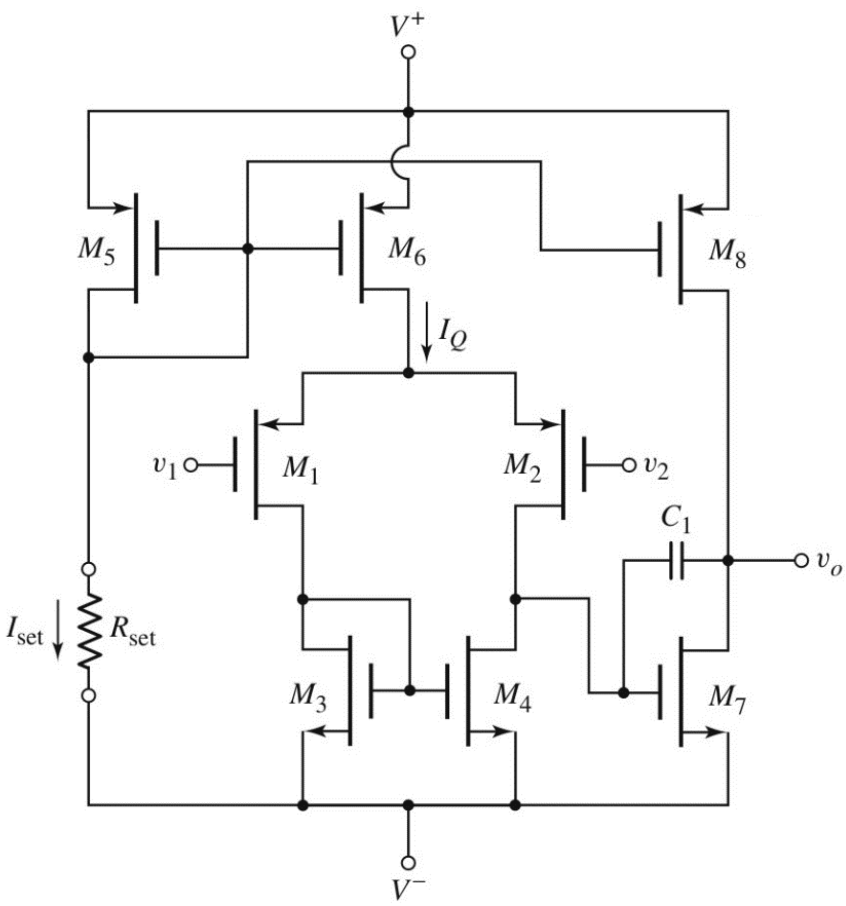


**Figure 1**

; N – MOSFET

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

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

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

; P – MOSFET

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

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

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

; Small signal

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

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

**Answer:**

**Q(a)**

$$I_{D5} = K_{p5}\left(V_{SG5} + V_{TP}\right)^2 = (100\varepsilon) \times (1.5 - 0.5)^2 = 100\,\varepsilon\text{A} \quad [2]$$

$$I_Q = I_{D6} = I_{D7} = I_{D8} = I_{D5} = 100\,\varepsilon\text{A} \quad [1]$$

$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = I_Q / 2 = 50\varepsilon\text{A} \quad [1]$$

**Q(b)**

$$A_d = g_{m2}\left(r_{o2} \parallel r_{o4}\right) \qquad [1]$$

$$g_{m2} = \sqrt{2K_p I_Q} = \sqrt{2(100\varepsilon)(100\varepsilon)} = 141.42\,\varepsilon\text{A/V} \quad [0.5]$$

$$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02 \times 50\varepsilon} = 1\,\text{Mq} \quad [0.5]$$

$$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01 \times 50\varepsilon} = 2\,\text{Mq} \quad [0.5]$$

$$A_d = (141.42\varepsilon)\left(1\text{M} \parallel 2\text{M}\right) = 94.286 \quad [0.5]$$

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

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

$$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01 \times 100\varepsilon} = 1\,\text{Mq} \quad [0.5]$$

$$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02 \times 100\varepsilon} = 0.5\,\text{Mq} \quad [0.5]$$

$$A_{v2} = -(223.6\varepsilon)\left(1\text{M} \parallel 0.5\text{M}\right) = -74.53 \quad [0.5]$$

$$A_v = A_d A_{v2} = 94.286 \times (-74.53) = -7027.45 \quad [1]$$

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EEEB273 - Quiz 6
SEMESTER 2, ACADEMIC YEAR 2016/2017
Date: 10 January 2017 Time: 15 minutes

**Question:**

Consider the **MC14573** op-amp in **Figure 1.** Assume transistor parameters of $V_{TN}$ **= 0.5 V**, $K_n$ **= 125 µA/V$^2$** and $\lambda_n$ **= 0.01 V$^{-1}$** for **N-MOSFET**; and $V_{TP}$ **= -0.5 V**, $K_p$ **= 125 µA/V$^2$,** and $\lambda_p$ **= 0.02 V$^{-1}$** for **P-MOSFET**. Given that $V_{SG5}$ **= 1.5 V:**

(a) **Find** the **quiescent bias currents** for all transistors in the **Figure 1**. [4 marks]

(b) **Determine** the **overall small signal differential-mode voltage gain** for the **MC14573** op-amp in the **Figure 1**. Gain for the output stage consists of transistor $M_7$ and $M_8$ is given by equation: $A_{v2} = -g_{m7}\left(r_{o7} \parallel r_{o8}\right)$. [6 marks]

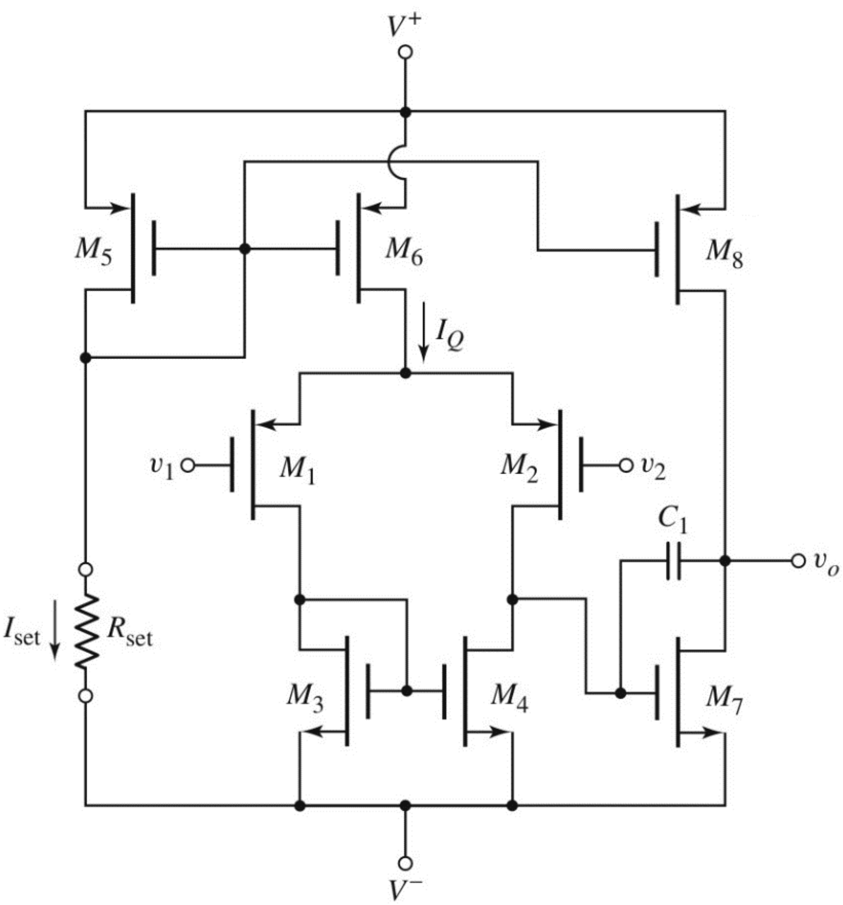


**Figure 1**

;N – MOSFET

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

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

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

;P – MOSFET

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

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

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

;Small signal

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

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

**Answer:**

**Q(a)**

$$I_{D5} = K_{p5}\left(V_{SG5} + V_{TP}\right)^2 = (125\varepsilon)\times(1.5-0.5)^2 = 125\,\varepsilon\text{A} \quad [2]$$
$$I_Q = I_{D6} = I_{D7} = I_{D8} = I_{D5} = 125\,\varepsilon\text{A} \quad [1]$$
$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = I_Q / 2 = 62.5\varepsilon\text{A} \quad [1]$$

**Q(b)**

$$A_d = g_{m2}\left(r_{o2} \parallel r_{o4}\right) \qquad [1]$$
$$g_{m2} = \sqrt{2K_p I_Q} = \sqrt{2(125\varepsilon)(125\varepsilon)} = 176.77\,\varepsilon\text{A/V} \quad [0.5]$$
$$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02\times 62.5\varepsilon} = 0.8\,\text{Mq} \quad [0.5]$$
$$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01\times 62.5\varepsilon} = 1.6\,\text{Mq} \quad [0.5]$$
$$A_d = (176.77\varepsilon)\left(0.8\text{M} \parallel 1.6\text{M}\right) = 94.277 \quad [0.5]$$

$$A_{v2} = -g_{m7}\left(r_{o7} \parallel r_{o8}\right)$$
$$g_{m7} = 2\sqrt{K_{n7} I_{D7}} = 2\sqrt{(125\varepsilon)(125\varepsilon)} = 250\,\varepsilon\text{A/V} \quad [0.5]$$
$$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01\times 125\varepsilon} = 0.8\,\text{Mq} \quad [0.5]$$
$$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02\times 125\varepsilon} = 0.4\,\text{Mq} \quad [0.5]$$
$$A_{v2} = -(250\varepsilon)\left(0.8\text{M} \parallel 0.4\text{M}\right) = -66.67 \quad [0.5]$$

$$A_v = A_d A_{v2} = 94.277\times(-66.67) = -6285.13 \quad [1]$$

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EEEB273 - Quiz 6
SEMESTER 2, ACADEMIC YEAR 2016/2017
Date: 10 January 2017 Time: 15 minutes ;

**Question:**

Consider the **MC14573** op-amp in **Figure 1.** Assume transistor parameters of $V_{TN}$ **= 0.5 V**, $K_n$ **= 100 µA/V$^2$** and $\lambda_n$ **= 0.01 V$^{-1}$** for **N-MOSFET**; and $V_{TP}$ **= -0.5 V**, $K_p$ **= 100 µA/V$^2$,** and $\lambda_p$ **= 0.02 V$^{-1}$** for **P-MOSFET**. Given that $V_{SG5}$ **= 1.5 V:**

(a) **Find** the **quiescent bias currents** for all transistors in the **Figure 1**. [4 marks]

(b) **Determine** the **overall small signal differential-mode voltage gain** for the **MC14573** op-amp in the **Figure 1**. Gain for the output stage consists of transistor $M_7$ and $M_8$ is given by equation: $A_{v2} = -g_{m7}\left(r_{o7} \parallel r_{o8}\right)$. [6 marks]

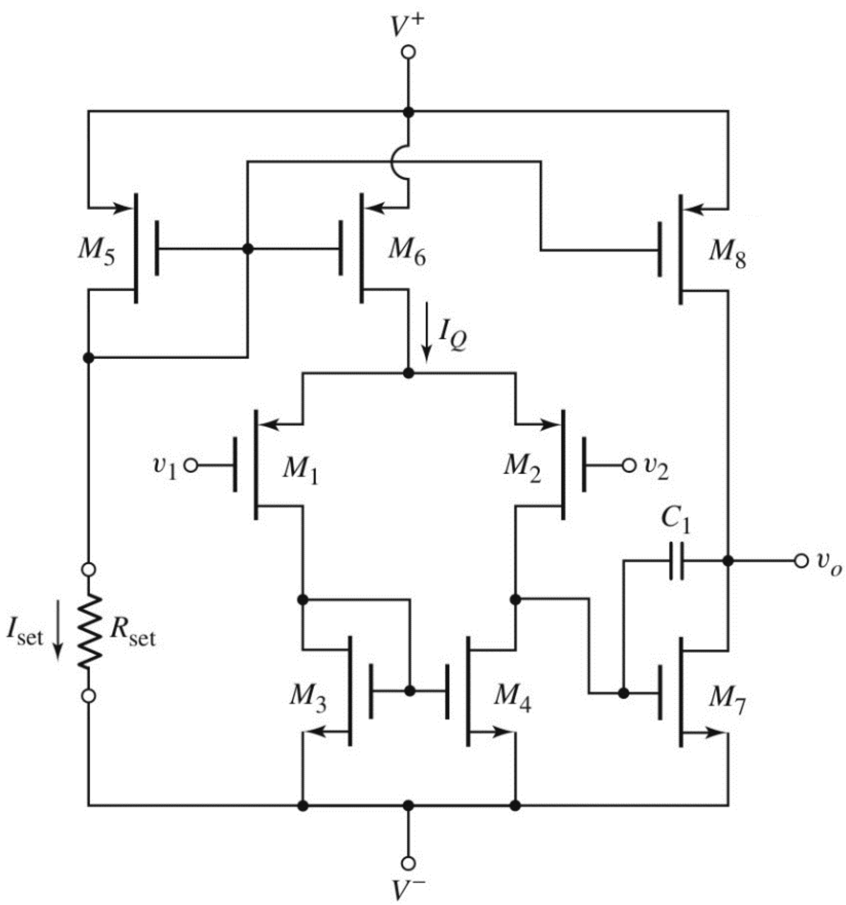


Figure 1

; N – MOSFET

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

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

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

; P – MOSFET

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

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

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

; Small signal

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

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

**Answer:**

**Q(a)**

$$I_{D5} = K_{p5}\left(V_{SG5} + V_{TP}\right)^2 = (100\varepsilon) \times (1.5 - 0.5)^2 = 100\,\varepsilon\text{A} \quad [2]$$

$$I_Q = I_{D6} = I_{D7} = I_{D8} = I_{D5} = 100\,\varepsilon\text{A} = 0.1\,\text{mA} \quad [1]$$

$$I_{D1} = I_{D2} = I_{D3} = I_{D4} = I_Q / 2 = 50\varepsilon\text{A} = 0.5\,\text{mA} \quad [1]$$

**Q(b)**

$$A_d = g_{m2}\left(r_{o2} \parallel r_{o4}\right) \qquad [1]$$

$$g_{m2} = \sqrt{2K_p I_Q} = \sqrt{2(100\varepsilon)(100\varepsilon)} = 141.42\,\varepsilon\text{A/V} \quad [0.5]$$

$$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02 \times 50\varepsilon} = 1\,\text{Mq} \quad [0.5]$$

$$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01 \times 50\varepsilon} = 2\,\text{Mq} \quad [0.5]$$

$$A_d = (141.42\varepsilon)\left(1\text{M} \parallel 2\text{M}\right) = 94.286 \quad [0.5]$$

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

$$g_{m7} = 2\sqrt{K_{n7} I_{D7}} = 2\sqrt{(100\varepsilon)(100\varepsilon)} = 200\,\varepsilon\text{A/V} \quad [0.5]$$

$$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01 \times 100\varepsilon} = 1\,\text{Mq} \quad [0.5]$$

$$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02 \times 100\varepsilon} = 0.5\,\text{Mq} \quad [0.5]$$

$$A_{v2} = -(200\varepsilon)\left(1\text{M} \parallel 0.5\text{M}\right) = -66.67 \quad [0.5]$$

$$A_v = A_d A_{v2} = 94.286 \times (-66.67) = -6285.73 \quad [1]$$

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Section: 01/02 A/B

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EEEB273 - Quiz 6

SEMESTER 2, ACADEMIC YEAR 2016/2017

Date: 10 January 2017 Time: 15 minutes :

**<u>Question:</u>**

Consider the **MC14573** op-amp in **Figure 1.** Assume transistor parameters of $\boldsymbol{V_{TN} = 0.5}$ **V**, $\boldsymbol{K_n =}$ **100 μA/V²** and $\boldsymbol{\lambda_n = 0.01}$ **V⁻¹** for **N-MOSFET**; and $\boldsymbol{V_{TP} = -0.5}$ **V**, $\boldsymbol{K_p = 125}$ **μA/V²,** and $\boldsymbol{\lambda_p = 0.02}$ **V⁻¹** for **P-MOSFET**. Given that $\boldsymbol{V_{SG5} = 1.5}$ **V:**

(a) **Find** the **quiescent bias currents** for all transistors in the **Figure 1**. [4 marks]

(b) **Determine** the **overall small signal differential-mode voltage gain** for the **MC14573** op-amp in the **Figure 1**. Gain for the output stage consists of transistor $\boldsymbol{M_7}$ and $\boldsymbol{M_8}$ is given by equation: $A_{v2} = -g_{m7}\left(r_{o7} \parallel r_{o8}\right)$. [6 marks]

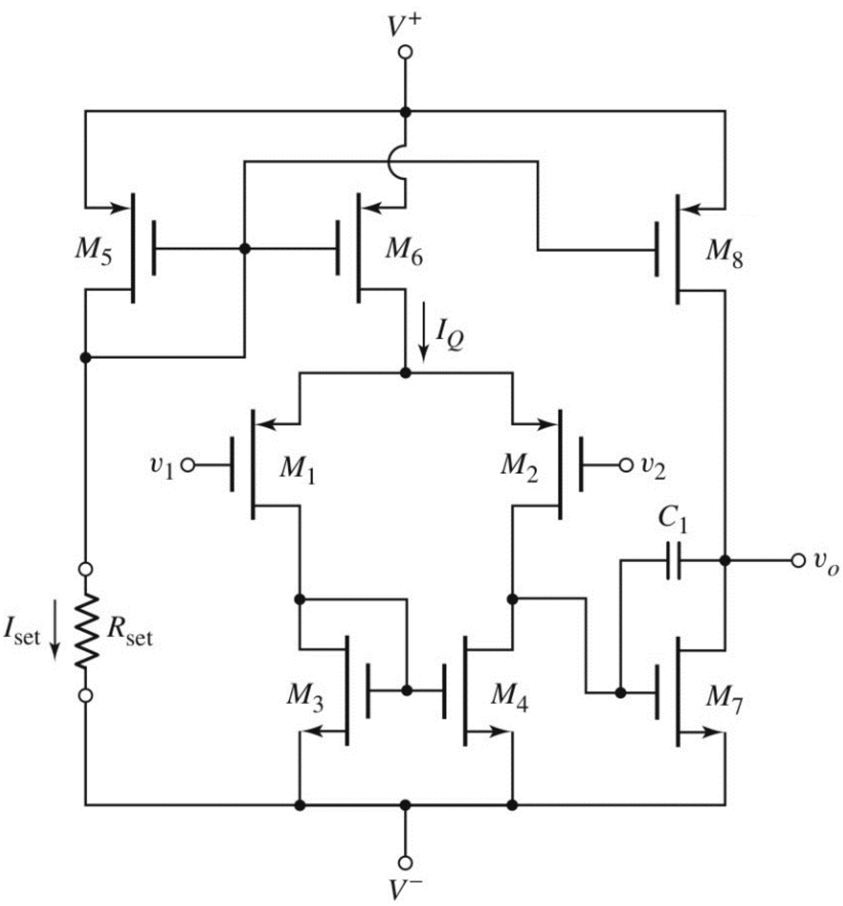


**Figure 1**

;N – MOSFET

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

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

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

;P – MOSFET

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

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

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

;Small signal

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

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

**<u>Answer:</u>**

**Q(a)**

$$I_{D5} = K_{p5}\left(V_{SG5} + V_{TP}\right)^2 = (125\varepsilon) \times (1.5 - 0.5)^2 = 125\,\varepsilon\text{A} \quad [2]$$

$$I_Q = I_{D6} = I_{D7} = I_{D8} = I_{D5} = 125\,\varepsilon\text{A} \quad [1]$$

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

**Q(b)**

$$A_d = g_{m2}\left(r_{o2} \parallel r_{o4}\right) \qquad [1]$$

$$g_{m2} = \sqrt{2K_p I_Q} = \sqrt{2(125\varepsilon)(125\varepsilon)} = 176.77\,\varepsilon\text{A/V} \quad [0.5]$$

$$r_{o2} = \frac{1}{\lambda_p I_{D2}} = \frac{1}{0.02 \times 62.5\varepsilon} = 0.8\,\text{Mq} \quad [0.5]$$

$$r_{o4} = \frac{1}{\lambda_n I_{D4}} = \frac{1}{0.01 \times 62.5\varepsilon} = 1.6\,\text{Mq} \quad [0.5]$$

$$A_d = (176.77\varepsilon)\left(0.8\text{M} \parallel 1.6\text{M}\right) = 94.277 \quad [0.5]$$

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

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

$$r_{o7} = \frac{1}{\lambda_n I_{D7}} = \frac{1}{0.01 \times 125\varepsilon} = 0.8\,\text{Mq} \quad [0.5]$$

$$r_{o8} = \frac{1}{\lambda_p I_{D8}} = \frac{1}{0.02 \times 125\varepsilon} = 0.4\,\text{Mq} \quad [0.5]$$

$$A_{v2} = -(223.6\varepsilon)\left(0.8\text{M} \parallel 0.4\text{M}\right) = -59.63 \quad [0.5]$$

$$A_v = A_d A_{v2} = 94.277 \times (-59.63) = -5618.61 \quad [1]$$