Name:
Student ID Number:
Section:
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Table Number:

UNIVERSITI TENAGA NASIONAL

College of Engineering

Department of Electronics and Communication Engineering

Test 2

SEMESTER 2, ACADEMIC YEAR 2016/2017

Subject Code	:	**EEEB273**
Course Title	:	**Electronics Analysis & Design II**
Date	:	**31 December 2016**
Time Allowed	:	**2 hours**

Instructions to the candidates:

1. Write your Name and Student ID number. Indicate Lecturer for your section. Write your Table Number.
2. Write all your answers using pen. **DO NOT USE PENCIL** except for the diagram.
3. **ANSWER ALL QUESTIONS.**
4. **WRITE YOUR ANSWER ON THIS QUESTION PAPER.**

NOTE: DO NOT OPEN THE QUESTION PAPER UNTIL INSTRUCTED TO DO SO.

☺ **GOOD LUCK!** ☺

Question Number	Q1	Q2	Q3	Total
Marks				

Question 1 **[30 marks]**

For a **MOSFET** differential amplifier **with cascode active load** shown in **Figure 1** the circuit parameters are: $V^+ = 5$ **V,** $V^- = -5$ **V,** and $I_Q = 1.2$ **mA**. Transistor parameters for **N-MOSFET** are: $V_{TN} = 0.7$ **V**, $k'_n = 130\ \mu A/V^2$, $(W/L)_n = 100$ and $\lambda_n = 0.1\ V^{-1}$; and the transistor parameters for **P-MOSFET** are: $V_{TP} = -0.8$ **V**, $k'_p = 35\ \mu A/V^2$, $(W/L)_p = 200$ and $\lambda_p = 0.2\ V^{-1}$.

(a) **Find** the differential-mode voltage gain (A_d) of the differential amplifier with **cascode** active load. [14 marks]

(b) Given that the common-mode voltage gain (A_{cm}) for the circuit is **-0.0025**. **Calculate** the Common-Mode Rejection Ratio (***CMRR***) **in dB**. [4 marks]

(c) **Calculate** the **maximum and minimum output voltage at** v_o, i.e. v_o**(max)** and v_o**(min)**. State any assumption used in the calculation. [12 marks]

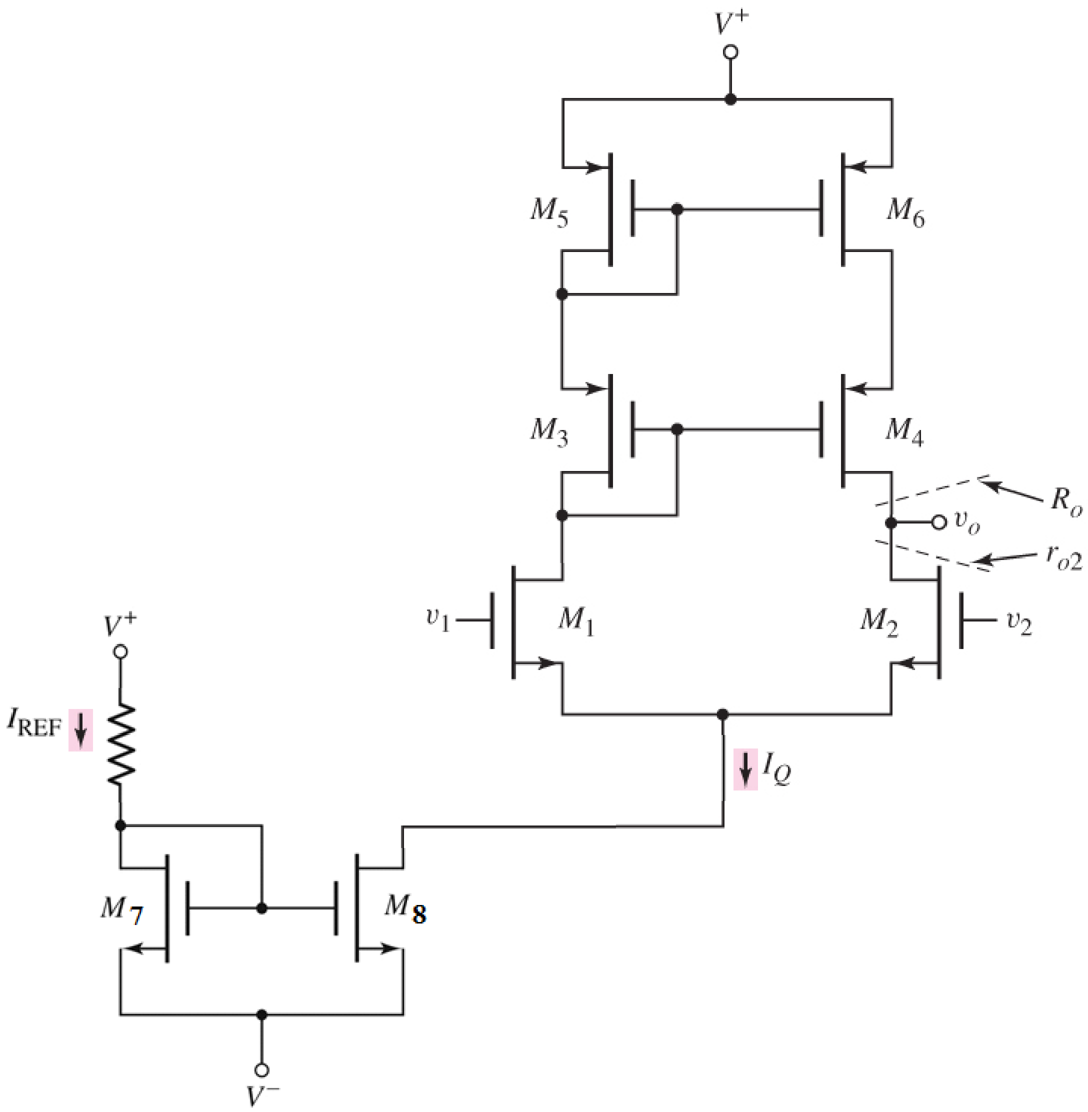

Figure 1

Answer for Question 1

Q1(a)

$$I_{D1} = I_Q / 2 = I_{D2} = I_{D3} = I_{D4} = I_{D5} = I_{D6} = 1.2mA/2 = 0.6mA \text{ [2]}$$

$$A_d = g_{m2}\left(r_{o2} \| R_o\right) \text{ [1]}$$

$$g_{m2} = 2\sqrt{K_n I_{D2}} = 2\sqrt{\left(\frac{k_n^{'}}{2}\right)\left(\frac{W}{L}\right)_2 I_{D2}}$$

$$g_{m2} = 2\sqrt{\left(\frac{130\mu}{2}\right)(100)(0.6m)} = 3.949mA/V \quad \text{[2]}$$

$$r_{o2} = \frac{1}{\lambda_n I_{D2}} = \frac{1}{(0.1)(0.6m)} = 16.667k\Omega \quad \text{[2]}$$

$$r_{o4} = \frac{1}{\lambda_p I_{D4}} = \frac{1}{(0.2)(0.6m)} = 8.333k\Omega = r_{o6} \quad \text{[2]}$$

$$g_{m4} = 2\sqrt{K_P I_{D4}} = 2\sqrt{\left(\frac{k_p^{'}}{2}\right)\left(\frac{W}{L}\right)_4 I_{D4}}$$

$$g_{m4} = 2\sqrt{\left(\frac{35\mu}{2}\right)(200)(0.5m)} = 2.645mA/V \quad \text{[2]}$$

$$R_o = g_{m4} r_{o4} r_{o6} = (2.65m)(8.333k)(8.333k) = 183.7k\Omega \quad \text{[2]}$$

$$A_d = (3.949m)(16.667k \| 183.7k) = 60.35V/V \quad \text{[1]}$$

Q1(b)

$$CMRR = \left|\frac{A_d}{A_{cm}}\right| = \left|\frac{60.35}{-0.0025}\right| = 24140 \quad \text{[2]}$$

$$CMRR_{dB} = 20\log\left|CMRR\right| = 20\log(24140) = 87.65dB \quad \text{[2]}$$

Q1(c)

$$V_o(\text{max}) = V^+ - V_{SD6}(sat) - V_{SD4}(sat) \quad [1]$$

$$V_{SG4} = V_{SG6} \Rightarrow I_{D4} = \left(\frac{k_p^{'}}{2}\right)\left(\frac{W}{L}\right)_4 (V_{SG4} + V_{TP})^2 \quad [1]$$

$$0.6m = \left(\frac{35\mu}{2}\right)(200)(V_{SG4} + (-0.8))^2 \Rightarrow V_{SG4} = 1.214\text{ V} \quad [0.5]$$

$$V_{SD4}(sat) = V_{SG4} + V_{TP} = 1.214 + (-0.8) = 0.414V = V_{SD6}(sat) \quad [1.5]$$

$$\Rightarrow V_o(\text{max}) = 5 - 2(0.414) = 4.172\text{ V} \quad [1]$$

$$V_o(\text{min}) = V^- + V_{DS8}(sat) + V_{DS2}(sat) \quad [1]$$

$$V_{GS8} \Rightarrow I_{D8} = I_Q = \left(\frac{k_n^{'}}{2}\right)\left(\frac{W}{L}\right)_8 (V_{GS8} - V_{TN})^2 \quad [1]$$

$$1.2m = \left(\frac{130\mu}{2}\right)(100)(V_{GS2} - 0.7)^2 \Rightarrow V_{GS8} = 1.13\text{ V} \quad [0.5]$$

$$V_{DS8}(sat) = V_{GS8} - V_{TN} = 1.13 - 0.7 = 0.43\text{ V} \quad [1]$$

$$V_{GS2} \Rightarrow I_{D2} = \left(\frac{k_n^{'}}{2}\right)\left(\frac{W}{L}\right)_2 (V_{GS2} - V_{TN})^2 \quad [1]$$

$$0.6m = \left(\frac{130\mu}{2}\right)(100)(V_{GS2} - 0.7)^2 \Rightarrow V_{GS2} = 1.004\text{ V} \quad [0.5]$$

$$V_{DS2}(sat) = V_{GS2} - V_{TN} = 1.004 - 0.7 = 0.304\text{ V} \quad [1]$$

$$\Rightarrow V_o(\text{min}) = (-5) + 0.43 + 0.304 = -4.266\text{ V} \quad [1]$$

<u>Question 2</u> **[30 marks]**

The circuit in **Figure 2** shows a simple multi-stage BJT op-amp, **consisting of 3 different stages**. It is given that V_{BE}**(on) = 0.6 V,** V_A **= 120 V,** and β **= 120 for all transistors**.
Assume the op-amp is ideal and $I_{C7} = I_Q$ **= 40 μA. Neglect base currents when calculating quiescent values.**

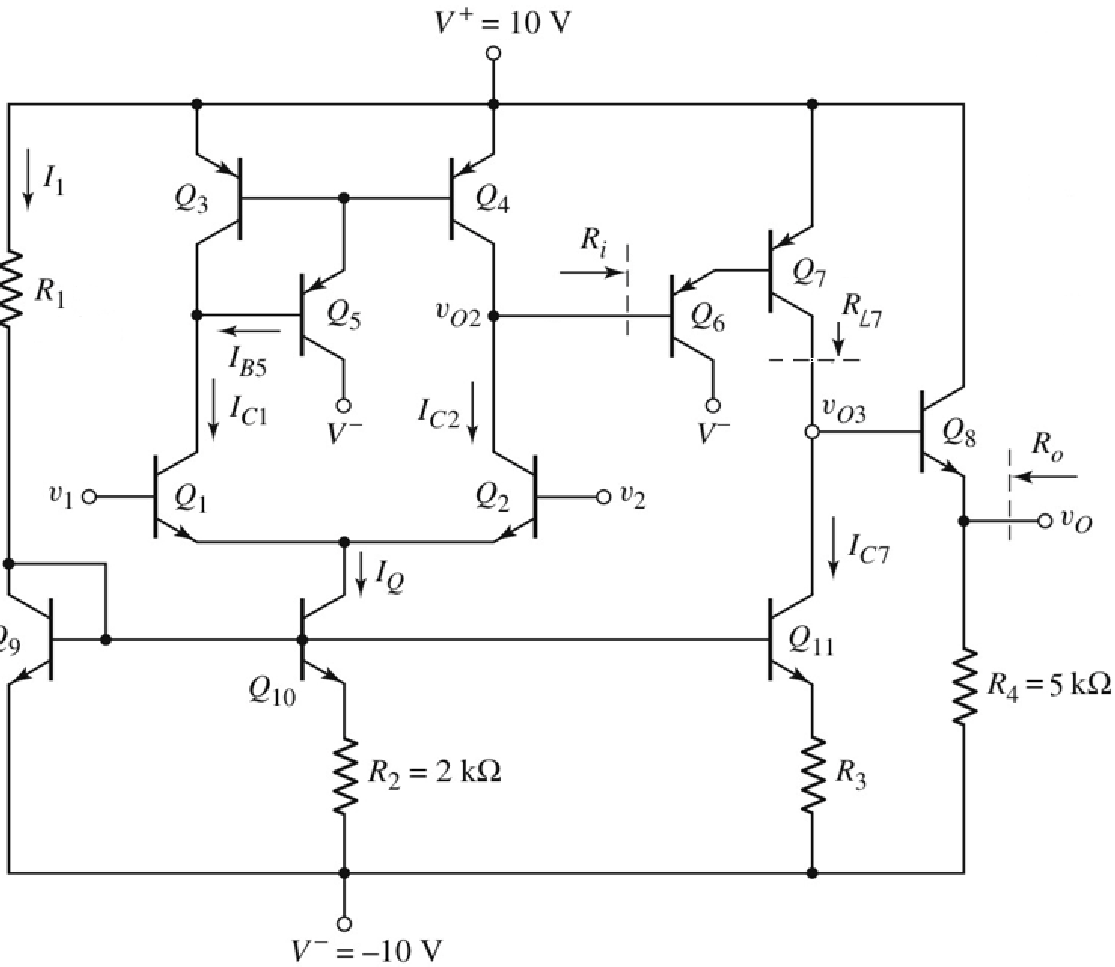

Figure 2

(a) **Calculate the input resistance (**R_i**) and the load resistance (**R_{L7}**) for the Darlington Pair** as indicated in the **Figure 2.** [17 marks]

(b) **Calculate** the **<u>overall</u> differential-mode voltage gain of the op-amp,** $A_d = v_O/v_d$. Consider the voltage gain of the gain stage, $A_2 = v_{O3}/v_{O2}$ is derived from the following relationships:

$$v_{O3} = I_{c7}\,(r_{o7} \,\|\, R_{L7})$$

$$v_{O2} = I_{b6}\,R_i$$

[13 marks]

<u>Answer for Question 2</u>

Q2(a)

$$I_{C7} = I_Q = 40\mu A$$

$$I_{C6} = (\beta I_{E6})/(1+\beta) = (\beta I_{B7})/(1+\beta) = (\beta I_{C7}/\beta)/(1+\beta) \quad [1]$$
$$I_{C6} = I_{C7}/(1+\beta) = 40\mu/121 = 0.3305\mu A \quad [1]$$

$$r_{\pi 6} = \beta V_T / I_{C6} = (120x0.026)/0.3305\mu = 9.44M\Omega \quad [1]$$
$$r_{\pi 7} = \beta V_T / I_{C7} = (120x0.026)/40\mu = 78k\Omega \quad [1]$$
$$R_i = r_{\pi 6} + r_{\pi 7}(1+\beta) = 9.44M + 78k(121) = 18.878M\Omega \quad [2]$$

$$R_i = \frac{2(1+\beta)\beta V_T}{I_Q} = \frac{2x121x120x0.026}{40\mu} = 18.876M\Omega \quad [\text{Option} = 6 \text{ marks}]$$

$$R_{c11} = r_{o11}[1 + g_{m11}(r_{\pi 11} \| R_3)] \quad [1]$$
$$R_3 = R_2 = 2k\Omega \quad [1]$$
$$r_{o11} = V_A / I_{C7} = 120/40\mu = 3M\Omega \quad [0.5]$$
$$r_{\pi 11} = \beta V_T / I_{C7} = 120x0.026/40\mu = 78k\Omega \quad [05]$$
$$g_{m11} = I_{C7}/V_T = 40\mu/0.026 = 1.538mA/V \quad [1]$$
$$R_{c11} = 3M[1 + (1.538m)(78k \| 2k)] = 1.99M\Omega \quad [1]$$

[Total for R_{c11} = 5 marks]

$$I_{C8} = (v_O - V^-)/R_4 = (0-(-10))/5k = 2mA \quad [1]$$
$$R_{b8} = r_{\pi 8} + (1+\beta)R_4 \quad [1]$$
$$R_4 = 5k\Omega$$
$$r_{\pi 8} = \beta V_T / I_{C8} = 120x0.026/2m = 1.56k\Omega \quad [1]$$
$$\rightarrow R_{b8} = 606.56k\Omega \quad [1]$$

[Total for R_{b8} = 4 marks]

$$R_{L7} = R_{c11} \| R_{b8} \quad [1]$$
$$\rightarrow R_{L7} = 1.99M \| 606.6k = 577.35k\Omega \quad [1]$$

[Total for R_{L7} = 2 marks]

Q2(b)

From previous calculations :
$I_{C7} = I_Q = 40\mu A$
$R_i = 18.876M\Omega$
$R_{L7} = 577.35k\Omega$

$I_{C2} = I_{C4} = I_Q / 2 = 20\mu A$ [1]
$g_{m2} = I_{C2} / V_T = 20\mu / 0.026 = 0.769mA / V$ [1]
$r_{o2} = V_A / I_{C2} = 120 / 20\mu = 6M\Omega$ [0.5]
$r_{o4} = V_A / I_{C4} = 120 / 20\mu = 6M\Omega$ [0.5]
$A_{d1} = g_{m2}(r_{o2} \parallel r_{o4} \parallel R_i)$ [1]
$\rightarrow A_{d1} = 0.769m(2.588M) = 1990$ [1]

$v_{o3} = I_{c7}(r_{o7} \parallel R_{L7}) = (\beta I_{b7})(r_{o7} \parallel R_{L7}) = \beta(1+\beta)I_{b6}(r_{o7} \parallel R_{L7})$ [1]
$v_{o2} = I_{b6}R_i$
$A_2 = \dfrac{v_{o3}}{v_{o2}} = \dfrac{\beta(1+\beta)(r_{o7} \parallel R_{L7})}{R_i}$ [1]
$r_{o7} = V_A / I_{C7} = 120 / 40\mu = 3M\Omega$ [1]
$(r_{o7} \parallel R_{L7}) = 3M \parallel 577.35k = 402.5k\Omega$
$\rightarrow A_2 = \dfrac{120x121x402.5k}{18.876M} = 309.6$ [1]

$A_3 = 1$ [1]

Overall Gain, $Ad = A_{d1}xA_2xA_1$ [2]
$\rightarrow A_d == 1990x309.6x1 = 616134$ [1]

<u>Question 3</u> **[40 marks]**

(a) **Compare** the performance of both **Class A** and **Class B** output stage in terms of **power conversion efficiency, η**. [5 marks]

(b) **Describe** the **crossover distortion** experienced in **Class B** output stage and **explain** how the **crossover distortion** can be **eliminated**. [5 marks]

(c) Consider the **Class A emitter-follower** circuit shown in **Figure 3**. Assume all transistors are matched with $V_{BE}(on) = 0.6$ **V**, $V_{CE}(sat) = 0.2$ **V**, and $V_A = \infty$**. Neglect** base currents.

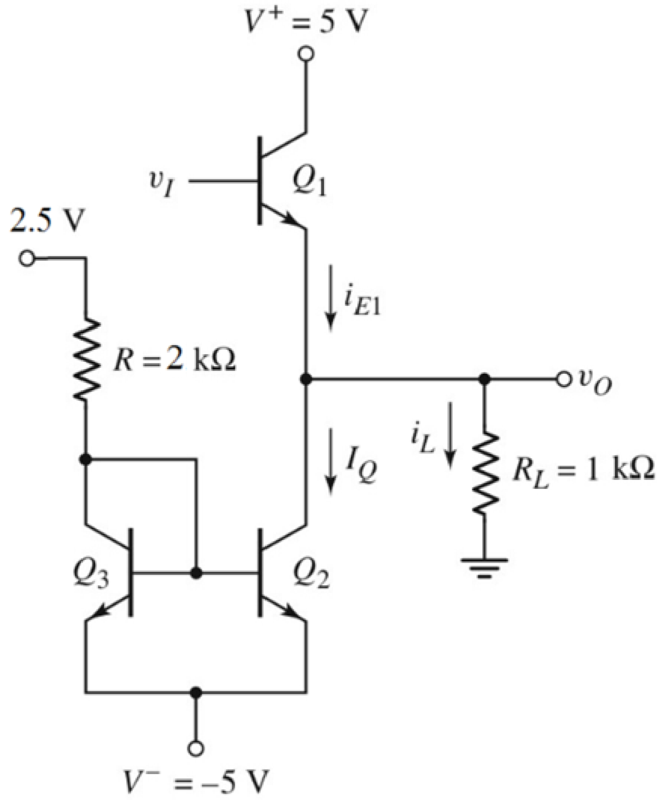

Figure 3

(i) **Find** the value of I_Q. [5 marks]

(ii) **Determine** the maximum and minimum values of **input voltage** for the circuit to operate in the linear region. [10 marks]

(iii) For $v_O = 0$ **V**, **calculate** the power dissipated in the transistor Q_1 and the power dissipated in the current source (Q_2, Q_3, and R). [8 marks]

(iv) **Determine** the power conversion efficiency (η) for a symmetrical sine-wave output voltage (v_O) with peak value of **4 V**. [7 marks]

Answer for Question 3

(a) Class A has low power conversion efficiency where its maximum efficiency is 25% [2.5] while Class B can reach up to 78.5% although suffering from cross-over distortion [2.5].

(b) For a complementary push-pull output stage in Class B, both transistors are cut off [1] and v_O is 0 in the dead band portion [0.5]. A not perfect sinusoidal signal means that crossover distortion is produced by the dead band region [1.5]. Crossover distortion in Class B can be virtually eliminated by applying a small quiescent bias on each output transistor for a zero input signal. This creates a class-AB output stage. [2]

(c) **Class A emitter-follower** circuit

(i) $I_Q = (V^+ - v_{BE}(on) - V^-)/ R$ [2]

$= (2.5 – 0.6 + 5) / 2k$ [2]

$=$ **3.450 mA** [1]

(ii) $v_I(max) = v_O(max) + v_{BE}(on)$ [2]

$v_O(max) = V^+ - v_{CE1}(sat) = 5 – 0.2 = 4.8$ V [2]

So, $v_I(max) = 4.8 + 0.6 =$ **5.4 V** [1]

$v_I(min) = v_O(min) + v_{BE}(on)$ [2]

$= [i_L(min)R_L + v_{BE}(on)$ [1]

$i_L(min) = -I_Q = -3.450$ mA [1]

$v_I(min) = (-3.450m)(1k) + 0.6 =$ **−2.850 V** [1]

(iii) $P_{Q1} = I_{C1}.v_{CE1}$ [1]

$= I_Q.v_{CE1} = (3.450m)(5) =$ **17.25 mW** [1]

$P_{Q2} = I_{C2}.v_{CE2}$ [1]

$= I_Q.v_{CE2} = (3.450m)(0 – (– 5)) =$ **17.25 mW** [1]

$P_{Q3} = I_{C3}.v_{CE3}$ [1]

$= I_Q.v_{BE}(on) = (3.450m)(0.6) =$ **2.070 mW** [1]

$P_R = I^2R$ [1]

$= (3.450m)^2(2k) =$ **0.0238 mW** [1]

(iv) With peak value of 4 V.

Power conversion efficiency, $\eta = P_L / P_S \times 100\%$ [2]

$P_L = 0.5(V_p)^2 / R_L = 0.5 (4)^2 / 1k =$ **8 mW** [2]

$P_S = (V^+ - V^-)2I_Q = (5 -(-5))(3.45m) +(2.5-(-5))(3.45m) =$ **60.375 mW** [2]

$\eta = 8m/60.375m \times 100\% =$ **13.25%** [1]

BASIC FORMULA FOR TRANSISTOR

BJT

$$i_C = I_S e^{v_{BE}/V_T} \text{; npn}$$

$$i_C = I_S e^{v_{EB}/V_T} \text{; pnp}$$

$$i_C = \alpha i_E = \beta i_B$$

$$i_E = i_B + i_C$$

$$\alpha = \frac{\beta}{\beta + 1}$$

;Small signal

$$\beta = g_m r_\pi$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}}$$

$$r_o = \frac{V_A}{I_{CQ}}$$

$$V_T = 26\,\text{mV}$$

MOSFET

;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

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

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