Santa Clara University

Department of Electrical and Computer Engineering

No. _____ DAREN LIU Submitted on: 10/1/20

Name *(please print)*

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ELEN 153 **Problem Set #1** **Due: 10-01-2020, Thursday, 12:00 pm**
Fall 2020

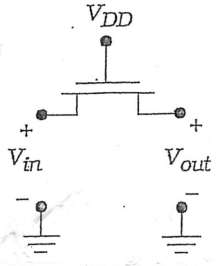
1. A silicon nFET is fabricated with the following specification:
Threshold voltage = 0.7 V; Process transconductance = 154 μA/V^2 ; Width = 20 μm; Channel length = 47 nm.

(10) i) Calculate the Device transconductance of the nFET.

(42) ii) Indicate Threshold voltage, V_{Tn}, Saturation voltage, V_{sat} , Gate-Source voltages, V_{GSn}, and Drain-Source voltages, V_{DSn} in the I_{Dn} - V_{GSn} and I_{Dn} – V_{DSn} Figs. (see back) to verify if Channel is ON/OFF, mode of operation (saturation/non-saturation), and then calculate and indicate the magnitude of Drain current, I_{Dn} for the operating Gate-Source V_{GSn} and Drain-Source V_{DSn} voltages in the Table below. Show all calculations for each case separately.

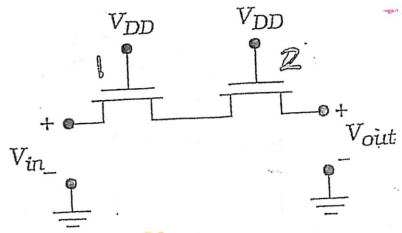
Operation Point	V_{GSn} (V)	V_{DSn} (V)	If $V_{GSn} \geq V_{Tn}$ → Channel ON If $V_{GSn} < V_{Tn}$ → Channel OFF	V_{sat} = $V_{GSn} - V_{Tn}$ (V) (V)	If $V_{DSn} \geq V_{sat}$ → Saturation If $V_{DSn} < V_{sat}$ → Non-Saturation	Drain Current (mA)
a	1.25	0.51				
b	0.65	2.13				
c	1.94	1.87				
d	0.76	0.82				

(8) 2. The nFET in Figure has power supply voltage = 3.3 V and Threshold voltage = 0.65 V. Find the output voltage, V_{out} for input voltages, V_{in} = 2.58 V; 2.71 V ; 2.10 V ; 1.20 V. If nFET is OFF, find V_{out} for minimum ON $V_{GSn} = V_{Tn}$.
Hint: Use Table below.



Let $V_{Gn} = V_{DD}$ (V)	Let $V_{in} = V_{Dn}$ (V)	Assume Channel ON $V_{Sn} = V_{Dn}$ (V)	V_{GSn} = $V_{Gn} - V_{Sn}$ (V)	If $V_{GSn} \geq V_{Tn}$ → Channel ON $V_{out} = V_{Sn}$ (V)	If $V_{GSn} < V_{Tn}$ (V) → Channel OFF Assume $V_{Gn} - V_{Sn} = V_{GSn} = V_{Tn}$ $V_{Sn} = V_{Gn} - V_{Tn} = V_{out}$

(16) 3. Consider the two-nFET chain in Figure. The power supply voltage = 5.0 V and Threshold voltage is 0.5V. Find the output voltage V_{out} for V_{in1} = 4.55 V; 3.18 V; 4.69 V; 2.90 V. If nFETs are OFF, find V_{Sn1} or V_{out} for minimum ON V_{GSn1} and $V_{GSn2} = V_{Tn}$.
Hint: Use Table in Problem 2 above to find V_{Sn1}, then use a second Table with $V_{Sn1} = V_{Dn2}$ to find V_{out}.



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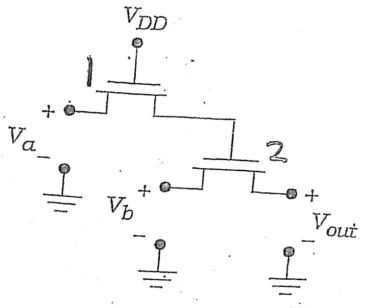
4. The output of nFET1 is used to drive the gate of another nFET2 as shown in Figure. Assume power supply voltage = 4.0 V and Threshold voltage = 0.75 V.

(16) Find V_{out} for input voltages V_a= 2.5 V, V_b= 1.65 V; V_a = 3.6 V, V_b = 0.1 V; V_a = 1.9 V, V_b = 0.7 V; and V_a = 3.1V, V_b = 0.3 V. If nFETs are OFF, find V_{Sn1} and V_{out} for minimum ON V_{GSn1} and $V_{GSn2} = V_{Tn}$.

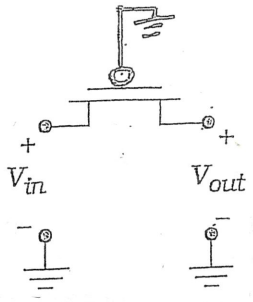
Hint: Repeat processes in Problem 2 with $V_{Gn2} = V_{Sn1}$.



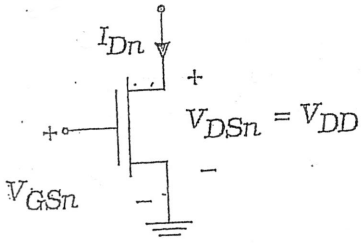
5. The pFET in Figure has gate voltage = 0 V and Threshold voltage = - 0.8 V. Find V_{out} for the input Voltages, V_{in} = 1.6 V; 0.7 V ; 2.1 V ; 0.3 V.

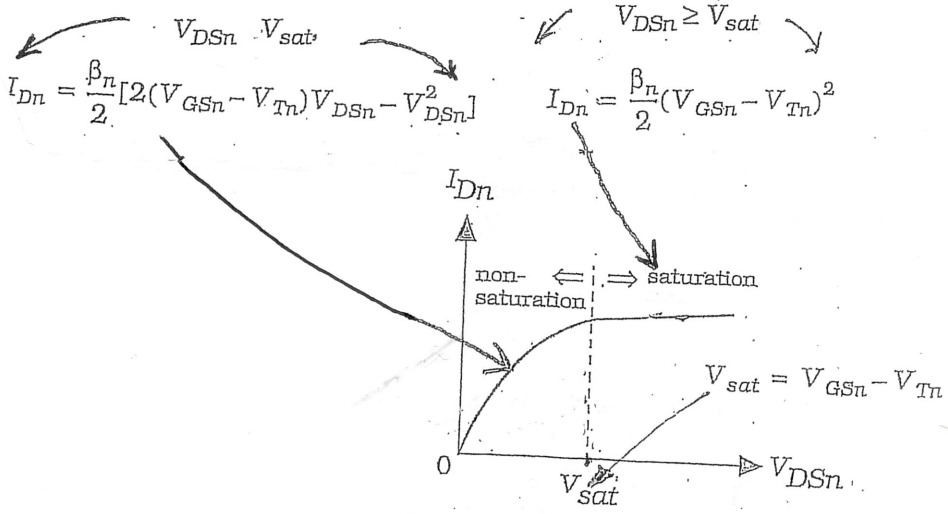
(8) If pFET is OFF, find V_{out} for minimum ON $V_{SGp} = |V_{Tp}|$

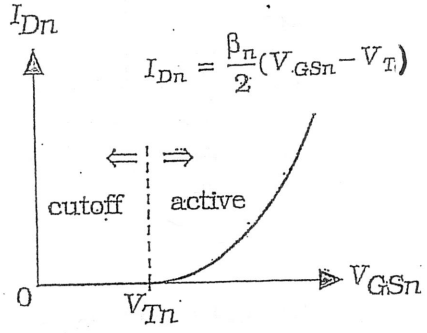
Hint.: Use Table below.



$V_{Gp} = 0$	Let $V_{in} = V_{Dp}$	Assume Channel ON $V_{Sp} = V_{Dp}$	$V_{SGp} = V_{Sp} - V_{Gp}$	If $V_{SGp} \geq \|V_{Tp}\|$ → Channel ON $V_{out} = V_{Sp}$	If $V_{SGp} < \|V_{Tp}\|$ → Channel OFF Assume $V_{Sp} - V_{Gp} = V_{SGp} = \|V_{Tp}\|$ $V_{Sp} = V_{Gp} + \|V_{Tp}\| = V_{out}$







M. Rahman Office hours Tuesdays: 5:00 - 6:30 pm ; Wednesdays: 4:00 - 5:30 pm ; mrahman@scu.edu

1) i) $V_{Tn} = 0.7\,V$ $K_n' = 154\,\mu A/V^2$ $W = 20\,\mu m$ $L = 47\,nm$ Daren Lin ①

$$\beta_n = K_n'\left(\frac{W}{L}\right)_n$$

$$= (154)\left(\frac{20\cdot10^{-6}}{47\cdot10^{-9}}\right) = 65531.91\ \mu A/V^2 = 6.55\cdot10^{-2}\ A/V^2$$

ii)

a) $V_{GSn} = 1.25$ $V_{DSn} = 0.51$ $V_{Tn} = 0.7$

$V_{GSn} \geq V_{Tn}$: $1.25 \geq 0.7$, Channel ON

$$V_{sat} = V_{GSn} - V_{Tn} = 1.25 - 0.7 = 0.55\,V$$

$V_{DSn} < V_{sat}$: $0.51 < 0.55$, Non-saturation

$$I_{Dn} = \frac{\beta_n}{2}\left(2(V_{GSn} - V_{Tn})V_{DSn} - V_{DSn}^2\right)$$

$$= \frac{6.55\cdot10^{-2}}{2}\left(2(0.55)(0.51) - (0.51)^2\right) = 9.86\cdot10^{-3}\ A$$

b) $V_{GSn} = 0.65$, $V_{DSn} = 2.13$

$V_{GSn} < V_{Tn}$: $0.65 < 0.7$, Channel OFF

$V_{sat} = V_{GSn} - V_{Tn} = 0.65 - 0.7 = -0.5\,V$

$V_{DSn} \geq V_{sat}$: $2.13 \geq -0.5$, Saturation

$I_{Dn} =$ 0 A

c) $V_{GSn} = 1.94$ $V_{DSn} = 1.87$

$V_{GSn} \geq V_{Tn}$: $1.94 \geq 0.7$, Channel ON

$V_{sat} = V_{GSn} - V_{Tn} = 1.94 - 0.7 = 1.24\,V$

$V_{DSn} \geq V_{sat}$: $1.87 \geq 1.24$, Saturation

$$I_{Dn} = \frac{6.55\cdot10^{-2}}{2}(1.94 - 0.7)^2 = 5.04\cdot10^{-2}\,A$$

d) $V_{GSn} = 0.76$, $V_{DSn} = 0.82$

$V_{GSn} \geq V_{Tn}$: $0.76 \geq 0.7$, Channel ON

$V_{sat} = V_{Gsn} - V_{Tn} = 0.76 - 0.7 = 0.7\ V$

$V_{DSn} \geq V_{sat}$: $0.82 \geq 0.7$, Saturation

$I_{Dn} = \frac{\beta_n}{2}(V_{Gsn} - V_{Tn})^2 = \frac{6.55 \cdot 10^{-2}}{2}(0.76 - 0.7)^2 = 1.18 \cdot 10^{-4}\ A$

2) $V_{DD} = 3.3V$ $V_{Tn} = 0.65$

$V_{in} = 2.58$) $V_{Gn} = 3.3$ $V_{Dn} = 2.58$ Assume ON: $V_{sn} = 2.58$

$V_{Gsn} = V_{Gn} - V_{sn} = 3.3 - 2.58 = 0.72$

$V_{Gn} \geq V_{Tn}$: $0.72 \geq 0.65$, Channel ON

$V_{out} = V_{sn} = 2.58V$

$V_{in} = 2.7$) $V_{Gn} = 3.3$ $V_{Dn} = 2.7$ Assume ON: $V_{sn} = 2.7$

$V_{Gsn} = V_{Gn} - V_{sn} = 3.3 - 2.7 = 0.6$

$0.6 < 0.65$, Channel OFF

$V_{Gn} - V_{sn} = V_{Gsn} = 0.65$

$3.3 - V_{sn} = 0.65$ $V_{sn} = 2.65$

$V_{out} = V_{sn} = 2.65V$

$V_{in} = 2.10$) $V_{Gn} = 3.3$ $V_{Dn} = 2.10$ Assume ON: $V_{sn} = 2.10$

$V_{Gsn} = 3.3 - 2.10 = 1.2$

$V_{Gsn} \geq V_{Tn}$: $1.2 \geq 0.65$, Channel ON

$V_{out} = 2.10\ V$

$V_{in} = 1.20$) $V_{Gn} = 3.3$ $V_{Dn} = 1.20$ Assume OFF: $V_{sn} = 1.2$

$V_{Gsn} = 3.3 - 1.2 = 2.1$

$V_{Gsn} \geq V_{Tn}$: $2.1 \geq 0.65$, Channel ON

$V_{out} = 1.2V$

3) $V_{DD} = 5$ $V_{Tn} = 0.5$

$V_{in_1} = 4.55$) 1) $V_{Gn1} = 5$ $V_{Dn_1} = 4.55$ $V_{Sn1} = 4.55$

$V_{GSn1} = 5 - 4.55 = 0.45$

$V_{GSn1} < V_{Tn}$: $0.45 < 0.5$, $nFET_1$ is OFF

$V_{Sn1} = V_{Gn1} - V_{Tn} = 4.50V$

2) $V_{Sn1} = V_{Dn2} = 4.5$

$V_{Sn2} = V_{Dn2} = 4.5$

$V_{GSn2} = 5 - 4.5 = 0.5$

$V_{GSn2} \geq V_{Tn}$: $0.5 \geq 0.5$

$V_{out} = V_{Sn2} = 4.5\ V$

$V_{in} = 3.18$) $V_{Gn1} = 5$ $V_{Dn1} = 3.18$ $V_{Sn1} = 3.18$

$V_{GSn_1} = 5 - 3.18 = 1.82$

$V_{GSn_1} \geq V_{Tn}$: $1.82 \geq 0.5$, $nFET_1$ is ON

$V_{Dn2} = V_{Sn_1} = 3.18$

$V_{Sn2} = 3.18$

$V_{GSn_2} = 5 - 3.18 = 1.82$

$V_{out} = 3.18V$ $nFET_2$ is ON

$V_{in} = 4.69$) $V_{Gn1} = 5$ $V_{Dn1} = 4.69$ $V_{Sn1} = 4.69$

$V_{GSn_1} = 5 - 4.69 = 0.31$

$V_{GSn1} < V_{Tn}$: $0.31 < 0.5$, $nFET_1$ is OFF

$V_{Sn1} = 5 - 0.5 = 4.5$

$V_{Dn2} = V_{sn1} = 4.5$

$V_{sn2} = V_{Dn2} = 4.5$

$V_{GSn2} = 5 - 4.5 = 0.5$

$V_{GSn2} \geq V_{Tn}$: $0.5 \geq 0.5$

$V_{out} = 4.5\ V$

$V_{in} = 2.9$) $V_{Gn} = 5$ $V_{sn} = 2.1$ $V_{Dn} = 2.9$

$V_{GSn} = 5 - 2.9 = 2.1$

$V_{GSn} \geq V_{Tn}$: $2.1 \geq 0.5$ $nFET_1$ is ON

$V_{out} = 2.9\ V$ $nFET_2$ is ON

4) $V_{DD} = 4$ $V_{Tn} = 0.75$

$V_a = 2.5$, $V_b = 1.65$) $V_{Gn1} = V_{DD} = 4$ $V_{in} = V_a = 2.5$

$V_{Dn_1} = 2.5$ $V_{sn} = 2.5$

$V_{GSn1} = 4 - 2.5 = 1.5$ $V_{GSn_1} \geq V_{Tn}$: $1.5 \geq 0.75$ $nFET_1$ is ON

$V_{out_1} = V_{DD_2} = 2.5$

$V_{Gn2} = V_{DD_2} = 2.5$ $V_{in2} = V_b = 1.65$

$V_{Dn2} = 1.65$ $V_{sn2} = 1.65$

$V_{GSn2} = 2.5 - 1.65 = 0.85$

$V_{GSn2} \geq V_{Tn}$: $0.85 \geq 0.75$, $nFET_2$ is ON

$V_{out_2} = 1.65\ V$

$V_a = 3.6$, $V_b = 0.1$) $V_{Gn1} = 4$ $V_{sn_1} = V_a = 3.6$ $V_{Dn1} = 3.6$

$V_{GSn1} = 4 - 3.6 = 0.4$

$V_{GSn1} < V_{Tn}$: $0.4 < 0.75$ $nFET_1$ is OFF

$V_{out_1} = V_{Gn1} - V_{Tn} = 4 - 0.75 = 3.25$

$V_{Gn2} = V_{out_1} = 3.25$

$V_{Sn2} = 0.1 \quad V_{Dn2} = 0.1$

$V_{GSn2} = 3.25 - 0.1 = 3.15$

$V_{GSn2} \geq V_{Tn}: \; 3.15 \geq 0.75$

$V_{out_2} =$ **0.1 V**

$V_a = 1.9, \; V_b = 0.7$) $\quad V_{Gn1} = 4 \quad V_{Sn1} = V_n = 1.9$

$V_{Dn} = 1.9$

$V_{GSn1} = 4 - 1.9 = 2.1$

$V_{GSn1} \geq V_{Tn}: \; 2.1 \geq 0.75$ $\quad nFET_1$ is ON

$V_{out_1} = V_{Sn1} = 1.9$

$V_{Gn2} = V_{out_1} = 1.9 \quad V_{Sn2} = 0.7 \quad V_{Dn2} = 0.7$

$V_{GSn2} = 1.9 - 0.7 = 1.2$

$V_{GSn2} \geq V_{Tn}: \; 1.2 \geq 0.75$ $nFET_2$ is ON

$V_{out_2} =$ **0.7 V**

$V_a = 3.1, \; V_b = 0.3$) $\quad V_{Gn} = 4 \quad V_{Dn1} = V_n = 3.1 \quad V_{Sn1} = 3.1$

$V_{GSn1} = 4 - 3.1 = 0.9$

$V_{GSn1} \geq V_{Tn}: \; 0.9 \geq 0.75$, $nFET_1$ is ON

$V_{out} = V_{Sn1} = 3.1$

$V_{Gn2} = 3.1 \quad V_{Dn2} = 0.3 \quad V_{Sn2} = 0.3$

$V_{GSn2} = 3.1 - 0.3 = 2.8$

$V_{GSn2} \geq V_{Tn}: \; 2.8 \geq 0.75$, nFET2 is ON

$V_{out_2} =$ **0.3 V**

5) $V_{GP} = 0$ $V_{TP} = -0.8$

$V_{in} = 1.6$) $V_{DP} = V_{in} = 1.6\,V$ $V_{SP} = V_{DP} = 1.6$

$V_{SG_P} = 1.6 - 0 = 1.6\,V$

$V_{SG_P} \geq |V_{TP}|$: $1.6 \geq 0.8$, Channel ON

$V_{out} = 1.6\,V$

$V_{in} = 0.7$) $V_{DP} = 0.7\,V$ $V_{SP} = V_{DP} = 0.7$

$V_{SG_P} = 0.7 - 0 = 0.7$

$V_{SG_P} < |V_{TP}|$: $0.7 < 0.8$ Channel OFF

$V_{out} = V_{SP} = V_{GP} + |V_{TP}| = 0 + 0.8 = 0.8\,V$

$V_{in} = 2.1$) $V_{DP} = 2.1\,V$ $V_{SP} = 2.1$

$V_{SG_P} = 2.1$ $V_{SG_P} \geq |V_{TP}|$: $2.1 \geq 0.8$ Channel ON

$V_{out} = V_{SP} = 2.1\,V$

$V_{in} = 0.3$) $V_{DP} = 0.3\,V$ $V_{SP} = 0.3$

$V_{SG_P} = 0.3$ $V_{SG_P} < |V_{TP}|$: $0.3 < 0.8$ Channel OFF

$V_{out} = V_{SP} = |V_{TP}| = 0.8\,V$