Assignment 1

ELE-350: Digital Electronics

Department of Electronics, Carleton University

Maitham Shams

Name: ______________ ID: ___________________

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1. Given the data in the following table for an NMOS transistor with $k' = 20\frac{\mu A}{V^2}$, calculate $V_{TO}$, $\lambda$, $\Upsilon$, $2|\phi_f|$, and W/L. Use long-channel transistor models.[1]

| | $V_{GS}$ (V) | $V_{DS}$ (V) | $V_{BS}$ (V) | $I_D$ (uA) |
|---|---|---|---|---|
| 1 | 3 | 5 | 0 | 1210 |
| 2 | 5 | 5 | 0 | 4410 |
| 3 | 5 | 10 | 0 | 5292 |
| 4 | 5 | 5 | -2 | 3265 |
| 5 | 5 | 5 | -5 | 2381 |

--In all five cases the device is in saturation, i.e. $V_{DS} > V_{GS} - V_T$

--From cases 1 and 2 : $\frac{I_{D2}}{I_{D1}} = \frac{(V_{GS2} - V_{T0})^2}{(V_{GS1} - V_{T0})^2}$ , $V_{DS1} = V_{DS2}$ & $V_{BS} = 0$

$$\therefore V_{T0} = \frac{V_{GS2} \cdot \sqrt{\frac{I_{D1}}{I_{D2}}} - V_{GS1}}{\sqrt{\frac{I_{D1}}{I_{D2}}} - 1} = 0.8V$$

--From cases 2 and 3: $\frac{I_{D3}}{I_{D2}} = \frac{(1 + \lambda \cdot V_{DS3})}{(1 + \lambda \cdot V_{DS2})}$, $V_{GS2} = V_{GS3}$

$$\therefore \lambda = \frac{\frac{I_{D2}}{I_{D3}} - 1}{V_{DS2} - \left(V_{DS3} \cdot \frac{I_{D2}}{I_{D3}}\right)} = 0.05 V^{-1}$$

--From $\frac{W}{L} = \frac{2 \cdot I_{D1}}{k'(V_{GS1} - V_{T0})^2 (1 + \lambda \cdot V_{DS1})}$, we get $\frac{W}{L} = 20$

--Solve for $V_T$:

$$V_T = V_{GS} - \sqrt{\frac{2 I_D}{K(1 + \lambda \cdot V_{DS}) I_{D2}}} \quad \text{where } k = k'\frac{W}{L} = 400\frac{uA}{V^2}$$

$$V_{T4} = 5 - \sqrt{\frac{2 \cdot 3265}{400(1 + 0.05 \cdot 5)}} = 1.386 V \text{ for case 4.}$$

$V_{T5} = 1.914 V$ like wise for case 5.

On the other hand we can write

$$V_{T4} = V_{T0} - \Upsilon(\sqrt{|-2\phi_F + V_{SB4}|} - \sqrt{|-2\phi_F|})$$

$$V_{T5} = V_{T0} - \Upsilon(\sqrt{|-2\phi_F + V_{SB5}|} - \sqrt{|-2\phi_F|})$$

Now you have two equations and two unknowns.
Solve to get $\Upsilon = 0.7 V^{0.5}$ and $2|\phi_F| = 0.6 V$

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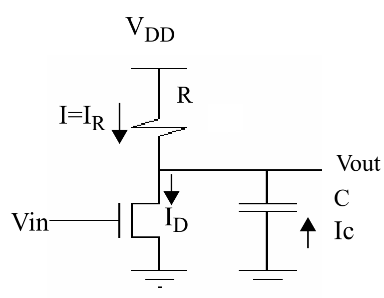
[1] Answer: $V_{T0} = 0.8 V$, $\lambda = 0.05 V^{-1}$, $\Upsilon = 0.7 V^{0.5}$, $2|\phi_F| = 0.6 V$ and W/L=20.

2. For the following NMOS inverter circuit, assume $V_{DD} = 5V$, $R = 75k\Omega$, W/L=3.6/1.2, and C=3pF. Use the following data for an NMOS transistor : $k' = 19\times10^{-6}\frac{\mu A}{V^2}$, $V_{TO} = 0.743V$, and $\lambda = 0.06V^{-1}$, see the answer. [2 3 4 5]

a) Discuss qualitatively why this circuit behaves as an inverter.
b) Find $V_{OH}$ and $V_{OL}$.
c) Calculate $t_{plh}$ (falling delay $D_f$), $t_{phl}$ (rising delay $D_r$), and $t_p$ (average delay D).
d) Are the rising and falling delays equal? Why?
e) Calculate the static power dissipation for: (i) Vin=0 V and (ii) Vin=5 V.
f) Calculate the dynamic power dissipation assuming that the gate in clocked as fast as possible.




a) It works as an inverter because
   if $V_{in} < V_T$ (i.e. low), NMOS is off, I=0 ===> Vout=5 V i.e. High.
   if $V_{in}$ is high (i.e. 5 V), NMOS is on, $I \neq 0$ ===> Vout=5-IR i.e. Low.

b) For $V_{in} < V_T$ ===> $V_{OH} = 5V$.

   For $V_{in} = V_{OH} = 5V$, NMOS is in linear (or triode) mode.

$$I = K_n V_{OL}\left(5 - V_T - \frac{V_{OL}}{2}\right) = \frac{5 - V_{OL}}{R} = I_R = I_D \Longrightarrow V_{OL} = 0.26V$$

c)

-- $t_{plh} = 0.64RC = 155ns$

-- For $t_{phl}$ we should calculate $I_{ave}$

$I_C = I_D - I_R$

$V_{out} = 5V, I_{D,sat} = 923uA, \ I_R = 0, ===> I_C = 923uA$

$V_{out} = 2.5V, I_{D,lin} = 589uA, \ I_R = 33uA, ===> I_C = 556uA$

$===> \quad I_{ave} = I_{c,ave} = 740uA$ ; C=3PF

Since C is large, we ignore parasitics.

$$t_{phl} = \frac{2.5 \times C}{I_{ave}} = 10.1ns \quad \text{and} \quad t_p = 82.5ns$$

d) $t_{plh} >> t_{phl}$ because $R = 75K\Omega$ is much larger than the effective on-resistance of NMOS.

e) If $V_{in} = V_{OL} \quad ===> V_{out} = V_{OH} = 5V, \ I_{VDD} = 0 ===> P_s = 0$

If $V_{in} = V_{OH} \quad ===> V_{out} = V_{OL}, \ I_{VDD} = 63.2uA \quad ===> P_s = 0.316mW$

f) $f_{max} = \frac{1}{t_p} = \frac{12.1}{2}MHz, \quad V_{swing} = V_{OH} - V_{OL} = (5 - 0.26)V$

$$P_d = C \cdot V_{swing} \cdot V_{DD} \cdot f_{max} = (3PF) \cdot (5 - 0.26) \cdot 5 \cdot \left(\frac{12.1}{2}M\right)$$

$$P_d = 0.43mW$$

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[2] Answer (b): $V_{OH}$=5V and $V_{OL}$=0.26V.

[3] Answer (c): $t_{plh}$=155ns, $t_{phl}$=10.1ns and $t_p$=82.5ns.

[4] Answer (e): 0 and 0.316mW.

[5] Answer (f): $P_d$=0.43mW.