Santa Clara University

Department of Electrical and Computer Engineering

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Name *(please print)*

- **Include this page with Homework**
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ELEN 153 **Problem Set #6** **Due: 11-12-2020, Thursday, 12:00 pm**
Fall 2020

1. An nFET with Channel width and length of 6 μm and 45 nm, respectively, is built in a process where $\kappa'_n = 158\ \mu A/V^2$ and $V_{Tn} = 0.75$ V. The voltages are set to a value of $V_{GSn} = V_{DSn} = V_{DD} = 3.3$ V.

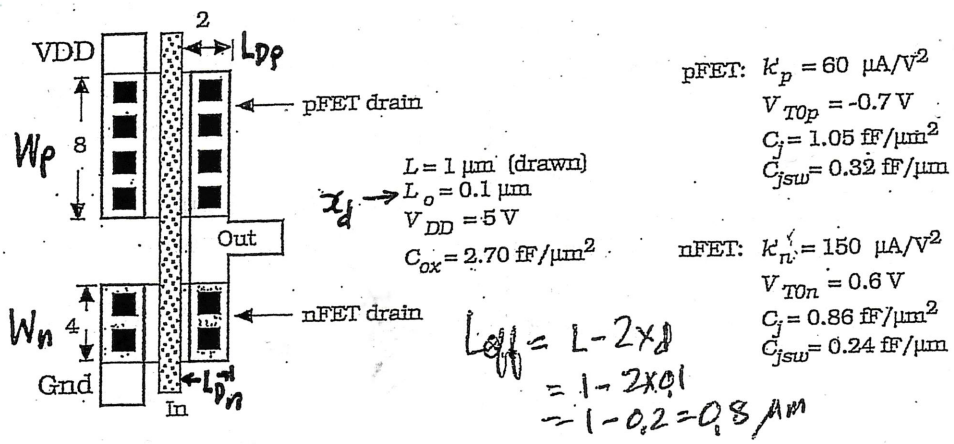
(15)
   a) Is the transistor saturated or non-saturated ?
   b) Calculate the drain-source resistance using the appropriate relationship for the transistor.
   c) Compare your value in b) with that found using relationship (6.71) Page 214, with a value of $\eta = 1$..

2. Consider the NOT gate (see below) when an external load of $C_L = 72$ fF is connected to the output. Note that the electrical channel length is L = 0.8 μm.

(30)
   a) Calculate the input capacitance, $C_{in} = C_{Gp} + C_{Gn}$ of the circuit.
   b) Calculate the FET capacitance, $C_{FET} = C_{Dp} + C_{Dn}$ and the Output capacitance $C_{out} = C_{FET} + C_L$.
   $C_{Dp} = C_{GDp} + C_{DBp} = (C_{gd} + C_{gdo}) + C_{Ddiff}$, where $C_{Ddiff} = C_{jo} W_p L_{Dp} + C_{jswo} (W_p + 2L_{Dp})$

3. An nFET has a gate oxide with a thickness of $t_{ox} = 24$ nm. The p-type bulk region is doped with Boron at a density of $N_a = 4 \times 10^{15}/cm^3$. Channel width = 4 μm; Channel length = 25 nm.

(30)
   a) Calculate the device No body-bias threshold voltage.
   b) Calculate the body bias coefficient γ.
   c) What is the device threshold voltage if a body bias voltage of $V_{SBn} = 1.2$ V is applied.
   d) Calculate the drain current with bias voltages of $V_{GSn} = 2.3$V, $V_{DSn} = 1.9$ V applied to the device in c). Use mobility value from mobility chart.



$L_{eff} = L - 2x_j$
$= 1 - 2 \times 0.1$
$= 1 - 0.2 = 0.8\ \mu m$

1) a) $V_{sat} = V_{GSn} - V_T = 3.3 - 0.75 = 2.55$

$V_{DSn} = 3.3 > 2.55$, saturated

b) $R_n = \frac{2V_{DSn}}{\beta_n (V_{sat})^2} = \frac{2(3.3)}{(158)(\frac{6000}{45})(2.55)^2} = 48.18\ \Omega$

c) $R_n = \frac{n}{\beta_n (V_{DD} - V_{Tn})} = \frac{1}{(158)(\frac{6000}{45})(3.3 - 0.75)} = 18.62\ \Omega$

2) a) $C_{in} = C_{GP} + C_{GN} = C_{ox} L_{eff} (W_p + W_n)$

$= (2.7)(1)(8+4) = 32.44$ fF

b) $C_{DP} = C_{GDP} + C_{DBP} = C_{ox}(W_p)(\frac{1}{2}L_{eff} + x_d) + C_{jo} W_p L_{DP} + C_{jswo}(W_p + 2L_{DP})$

$= (2.7)(8)(\frac{1}{2}(0.8) + 0.1) + (1.05)(8)(2) + (0.32)(8 + 2(2))$

$= 31.44$ fF

$C_{DN} = C_{ox}(W_n)(\frac{1}{2}L_{eff} + x_d) + C_{jon}(W_n)(L_{DN}) + C_{jswon}(W_n + 2L_{DN})$

$= (2.7)(4)(\frac{1}{2}(0.8) + 0.1) + (0.86)(4)(2) + (0.24)(4 + 2(2))$

$= 14.2$ fF

$C_{FGT} = C_{DN} + C_{DP} = 14.2 + 31.44 = 45.64$ fF

$C_{out} = C_{FGT} + C_L = 45.64 + 72 = 117.64$ fF

3) a) $\phi_F = \frac{kT}{q} \ln(\frac{N_A}{n_i}) = \frac{(1.381 \cdot 10^{-23})(300)}{1.602 \cdot 10^{-19}} \ln(\frac{4 \cdot 10^{15}}{1.45 \cdot 10^{10}})$

$= 0.324$ J/C

$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9(8.854 \cdot 10^{-14})}{24(\frac{1\text{cm}}{10^7\text{nm}})} = 1.44 \cdot 10^{-7}$ F/cm^2

$$V_{TO_n} = \frac{1}{C_{ox}}\sqrt{2q\varepsilon_{Si}N_n(2\phi_F)} + 2\phi_F$$

$$= \frac{1}{1.44\cdot10^{-7}}\sqrt{2(1.602\cdot10^{-19})(11.7\cdot8.854\cdot10^{-14})(4\cdot10^{15})(2\cdot0.324)} + 2(0.324)$$

$$= 0.852\ V$$

b) $$\gamma = \frac{\sqrt{2q\varepsilon_{Si}N_n}}{C_{ox}} = \frac{\sqrt{2(1.602\cdot10^{-19})(11.7\cdot8.854\cdot10^{-14})(4\cdot10^{15})}}{1.44\cdot10^{-7}}$$

$$= 0.253\ V^{\frac{1}{2}}$$

c) $$V_{Tn} = V_{TO_n} + \gamma\left(\sqrt{2\phi_F + V_{SBn}} - \sqrt{2\phi_F}\right)$$

$$= 0.852 + (2.53)\left(\sqrt{2(0.324)+1.2} - \sqrt{2(0.324)}\right)$$

$$= 0.992\ V$$

d) $$M_n = 10^{4/33}\cdot 1000 = 1321.94$$

$$\beta_n = M_n C_{ox}\left(\frac{W_n}{L_n}\right) = (1321.94)(1.44\cdot10^{-7})\left(\frac{4000}{25}\right)$$

$$= 0.0305\ A/V^2$$

$$V_{sat} = V_{GSn} - V_{Tn} = 2.3 - 0.992 = 1.308V$$

$V_{DSn} = 1.9 > 1.308$ saturation

$$I_{Dn} = \frac{1}{2}\beta_n(V_{sat})^2 = \frac{1}{2}(0.0305)(1.308)^2$$

$$= 0.026\ A$$