1 FET Capacitances

An NMOS transistor is fabricated with the following physical dimensions and dopant concentrations:

- $t_{ox} = 200\,\text{Å}$
- $W = 10\,\mu\text{m}$
- $L_d = 1.5\,\mu\text{m}$
- $x_d = 0.25\,\mu\text{m}$
- $L_S = 5\,\mu\text{m}$
- $x_j = 0.4\,\mu\text{m}$
- $N_D = 10^{20}\,\text{cm}^{-3}$
- Substrate Doping $N_A = 10^{16}\,\text{cm}^{-3}$
- Channel Stop Implant Doping $N_A^+ = 10^{19}\,\text{cm}^{-3}$

Problem 1.1 Determine the drain diffusion capacitance for $V_{DB} = 5\,\text{V}$ and $2.5\,\text{V}$.

Problem 1.2 Calculate the overlap capacitance between gate and drain.
2 Enhancement Load Inverter

Consider the NMOS inverter circuit shown in Figure 1 which consists of two enhancement-mode NMOS transistors with the following parameters: $V_{T0} = 0.8\,\text{V}$, $W/L$ ratios as shown in the figure, $\gamma = 0.38\,\text{V}^{1/2}$, $\lambda = 0.0\,\text{V}^{-1}$, $\mu C_{ox} = 45\,\mu\text{A}/\text{V}^2$, $-2\Phi_F = 0.6\,\text{V}$, and $V_{DD} = 5\,\text{V}$.

Problem 2.1 Calculate values for $V_{OH}$ and $V_{OL}$. Note that the substrate-bias effect for either or both devices must be taken into consideration.

Problem 2.2 Interpret your results for Problem 2.1 in terms of noise margins and static (DC) power dissipation.

Problem 2.3 Calculate the steady-state current which is drawn from the DC power supply when the input is a logic “1”, i.e. when $V_{in} = V_{OH}$.

3 CMOS Inverter

Consider a CMOS inverter with the following transistor parameters:

- NMOS: $V_{T0} = 0.6\,\text{V}$, $W/L = 8$, $\lambda = 0.0\,\text{V}^{-1}$, $\mu C_{ox} = 60\,\mu\text{A}/\text{V}^2$
- PMOS: $V_{T0} = -0.7\,\text{V}$, $W/L = 12$, $\lambda = 0.0\,\text{V}^{-1}$, $\mu C_{ox} = 25\,\mu\text{A}/\text{V}^2$

Assume $V_{DD} = 3.3\,\text{V}$.

Problem 3.1 Calculate the noise margins and the switching threshold ($V_M$) of this circuit.

Problem 3.2 For this problem and the next, assume the channel length of both transistors is $0.8\,\mu\text{m}$. Determine the $W_P/W_N$ ratio so that the switching threshold of the inverter is $V_M = 1.4\,\text{V}$. 
**Problem 3.3** The CMOS fabrication process used to manufacture this inverter allows a variation in the NMOS threshold voltage $V_{T_0,n}$ of $\pm15\%$ around its nominal value of 0.6V, and a variation in the PMOS threshold voltage $V_{T_0,p}$ of $\pm20\%$ around its nominal value of -0.7V. Assuming that all other device parameters always retain their nominal values, find the upper and lower limits of the switching threshold $V_M$ of the circuit you designed in Problem 3.2.

### 4 CMOS Inverter in Feedback

![CMOS Inverter in Feedback](image)

Figure 2: CMOS inverter in feedback configuration with NMOS device M3.

Consider the CMOS inverter you designed in Problem 3.2, with the circuit configuration shown in Figure 2.

**Problem 4.1** Calculate the output voltage level $V_{out}$.

**Problem 4.2** Determine if the process-related variation of $V_{T_0,n}$ of transistor M3 has any influence on the output voltage $V_{out}$.

**Problem 4.3** Calculate the total current being drawn from the power supply source, and determine its variation due to process-related threshold voltage variations.

### References
