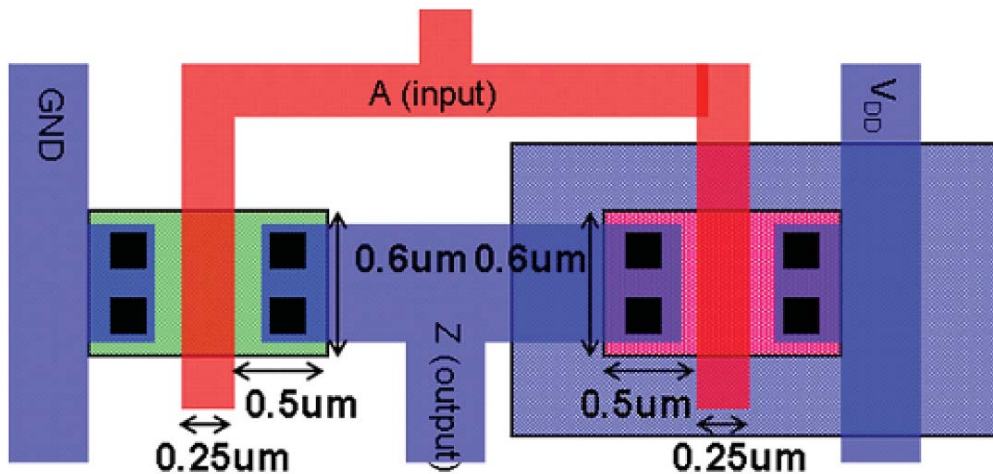


1. The following is the layout of an inverter with dimensions. Assume that $V_{DD}=2.5V$, $K'_n=100\mu A/V^2$, $V_{tn}=0.4V$, $K'_p=60\mu A/V^2$, $V_{tp}=-0.5V$, $t_{ox}=12nm$, $\epsilon_{ox}=3.9$, $X_d=42nm$ (overlap distance under the gate), $C_j=0.74fF/\mu m^2$, $C_{jsw}=0.43fF/\mu m$ for both NMOS and PMOS devices at zero bias.
- Estimate the effective input capacitance of the inverter, C_{in} .
 - Estimate the effective output capacitance of the inverter, C_{out} . For simplicity find effective C_{out} at zero bias.
 - If the output of this inverter is connected to a similar inverter, estimate the t_{pHL} and t_{pLH} . Ignore the wire parasitic capacitance.



$$\begin{aligned}
 (a) C_{input} &= (C_{asov_n} + C_{ox} W_N L_{eff} + C_{adov_n}) + (C_{asov_p} + C_{ox} W_P L_{eff} + C_{adov_p}) \\
 &= 4 C_{G_{ov}} + 2 C_{ox} W \cdot L_{eff}. \quad [\because W_p = W_n; L_p = L_n] \\
 &= 4 \frac{\epsilon_{ox}}{t_{ox}} \cdot W \cdot X_d + 2 \cdot \frac{\epsilon_{ox}}{t_{ox}} \cdot W \cdot (L - 2X_d) \\
 &= \frac{2\epsilon_{ox}}{t_{ox}} (2W X_d + WL - 2W X_d) = 2 \frac{\epsilon_{ox}}{t_{ox}} \cdot W_0 L \\
 &= \frac{2 * 3.9 * 8.854 * 10^{-12}}{12 * 10^{-9}} * 0.6 * 10^{-6} * 0.25 * 10^{-6} \\
 &= 8.63 * 10^{-16} F = \underline{\underline{0.86 fF}}
 \end{aligned}$$

$$\begin{aligned}
 (b) C_{output} &= (C_{jn} + 2 C_{adov_n}) + (C_{jp} + 2 C_{adov_p}) \\
 &= 4 C_{adov} + 2 (C_{jsw} (W + 2L_d) + C_j (W \cdot L_d))
 \end{aligned}$$

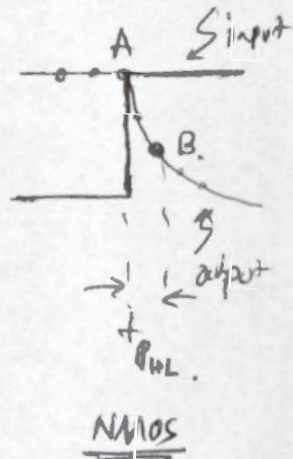
$$= \frac{4 \times 39 \times 8.854 \times 10^{-12}}{12 \times 10^{-9}} * 0.6 \times 10^6 * 42 \times 10^{-9} + 2 \left[0.43 \times 10^{-15} * 1.6 + 0.74 \times 10^{-15} * 0.6 \right]$$

$$= 2.11 \times 10^{-15} = \underline{\underline{2.11 \text{ fF}}}$$

(c) $C_L = C_{\text{input}} + C_{\text{output}} = 2.97 \text{ fF.}$

$$t_{p_{HL}} = \frac{Q \cdot V_{DD}/2}{I_{\text{avg}}}$$

$$I_{A, \text{Sat}} = \frac{K_n'}{2} \left(\frac{W}{L}\right)_n (V_{DD} - V_{tn})^2$$



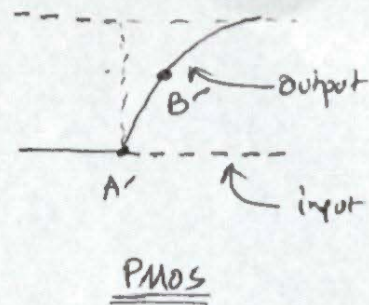
$$I_{B, \text{Linear}} = \frac{K_n'}{2} \left(\frac{W}{L}\right)_n \left[(V_{DD} - V_{tn}) V_{DS} - \frac{V_{DS}^2}{2} \right] = 0.53 \text{ mA.}$$

$$\equiv 0.4425 \text{ mA.}$$

$$\therefore I_{\text{avg}} = \frac{I_A + I_B}{2} = 0.48 \text{ mA.}$$

$$\therefore t_{p_{HL}} = \frac{2.97 \times 10^{-15} \times 1.25}{0.48 \times 10^{-3}} = 7.73 \times 10^{-12} \text{ sec} = \underline{\underline{7.73 \text{ psec}}}$$

$$t_{p, LH} = \frac{C_L \cdot V_{DD}/2}{I_{avg}}$$



$$I_{A', SAT} = \frac{k_p'}{2} \left(\frac{W}{L}\right)_p (V_{DD} - |V_{th}|)^2$$

$$= 0.288 \text{ mA}$$

$$I_{B', LN} = k_p' \left(\frac{W}{L}\right)_p \left(2 * \frac{2.5}{2} - \frac{2.5^2}{8}\right) \approx 0.2475 \text{ mA}$$

$$\therefore I_{avg} = 0.267 \text{ mA}$$

$$\therefore t_{p, LH} = \frac{2.97 \times 10^{-15} * \frac{2.5}{2}}{0.267 \times 10^{-3}} = \underline{\underline{13.9 \text{ pSec}}}$$