

[5] Question 1:

- a) When a NMOS transistor is in the “velocity saturation” region, what exactly is saturated?

The electrons velocity is saturated

- b) Why is velocity saturation much more common in transistors with short channel lengths than transistors with long channel lengths?

Larger electric fields in short channel transistors

- c) In a reverse biased pn junction, the depletion capacitance decreases as the reverse bias voltage is made larger. Does the stored charge in the depletion region **increase** or **decrease** as the reverse bias voltage is made larger?

The charge increases

- d) When creating metal wiring on a microchip, which of the following 2 statements is true?

1) First, silicon dioxide is grown and photoresist is used to etch where wires should exist. Next, aluminum is sprayed on using silicon dioxide as a mask.

2) First, Aluminum is sprayed on the entire microchip, then photoresist and silicon oxide is used to mask where wires should exist and the rest is etched off.

#2

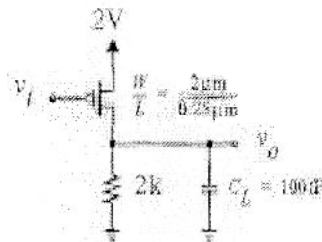
- e) What is the processing step called when the wafer is heated to around 1000 degrees C and then slowly cooled?

Annealing

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[5] Question 2: For the inverter shown below, find t_{pHL} and t_{pLH} . Assume the input is a step change with low and high values of 0 and 2V. Also, assume the only capacitance in the circuit is the shown C_L .



$$t_{pHL} = 138 \text{ ps}$$

$$t_{pLH} = 97 \text{ ps}$$

$$t_{pHL} = 0.69 R_{eq} C_L = 0.69 (2^k) (100^f) = 138 \text{ ps} \quad (2 \text{ marks})$$

$$t_{pLH} = 0.69 (R_{PMOS} \parallel 2^k) C_L = 0.69 (R_{PMOS} \parallel 2^k) (100^f)$$

$$R_{PMOS} = \frac{3}{4} \left(\frac{V_{DD}}{|I_{D,SAT}|} \right) \left(1 - \frac{5}{6} \left| \frac{V_{GS}}{V_{DD}} \right| \right)$$

$$I_{D,SAT} = k_p' \left(\frac{W}{L} \right) \left[(|V_{GS}| - V_{TH}) |V_{DSAT}| - \frac{1}{2} |V_{DSAT}|^2 \right]$$

$$= -30 \frac{\text{A}}{\text{m}^2} \left[(|10-2| - 1 \cdot 0.4) |1-1| - \frac{1}{2} |1-1|^2 \right]$$

$$= -264 \mu\text{A} = -0.264 \text{ mA}$$

$$R_{PMOS} = \frac{3}{4} \frac{2}{|-264 \times 10^{-3}|} \left(1 - \frac{5}{6} \left| \frac{10-2}{10} \right| \right) = 4.7^k$$

$$t_{pLH} = (0.69) (4.7 \parallel 2^k) (100^f) = 97 \text{ ps} \quad (3 \text{ marks})$$

[5] **Question 3:** Assuming velocity saturation does NOT occur, find the switching threshold, V_M , for an inverter where the NMOS has $W/L = 10$ and the PMOS has $W/L = 5$ and the power supply is 2V.

$$V_M = 0.74$$

From Equation Sheet:

$$V_M = (V_{Tn} + r(V_{DD} + V_{Tp})) / (1 + r) \quad (\text{sat})$$

$$r = \sqrt{-k_p / k_n} \quad (\text{sat})$$

Given (in equation sheet and question):

$$V_{DD} = 2V$$

$$V_{Tp} = -0.4V$$

$$V_{Tn} = 0.43V$$

$$k'_p = -30 \mu A / V^2$$

$$k'_n = 115 \mu A / V^2$$

$$(W/L)_p = 5$$

$$(W/L)_n = 10$$

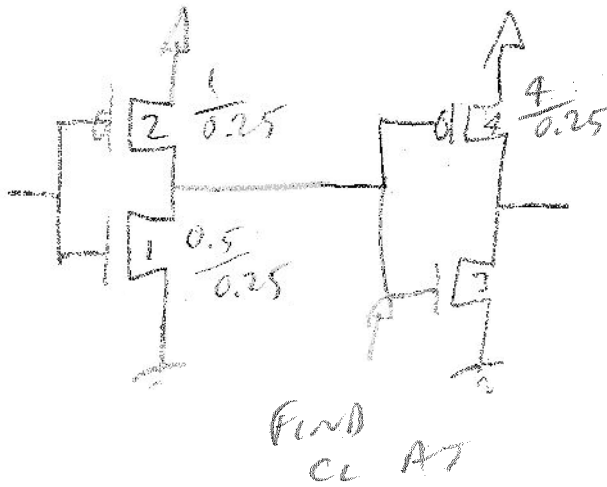
Solution:

$$r = \sqrt{\frac{-(W/L)_p k_p}{(W/L)_n k_n}} = \sqrt{\frac{5 * 30}{10 * 115}} = 0.361$$

$$V_M = (V_{Tn} + r(V_{DD} + V_{Tp})) / (1 + r) = (0.43 + 0.361(2 - 0.4)) / (1 + 0.361) = \underline{0.74V}$$

[5] **Question 4:** A size 1 inverter has the NMOS size of $W/L = 0.5\mu\text{m}/0.25\mu\text{m}$ while the PMOS size is $W/L = 1\mu\text{m}/0.25\mu\text{m}$. Given that this size 1 inverter is driving a size 4 inverter (a fanout of 4), find the total effective load capacitance, C_L , at the output of the size 1 inverter IGNORING all drain-to-bulk capacitances and any wiring capacitance.

$C_L = 11.55 \text{ fF}$



$$C_L = 2C_{gd1} + 2C_{gd2} + C_{gd3} + 4C_{g3} + C_{g4}$$

$$C_{gd1} = (C_o) \times (W_1) = (0.31)(0.5) = 0.155 \text{ fF}$$

$$C_{gd2} = (0.27) = 0.27 \text{ fF}$$

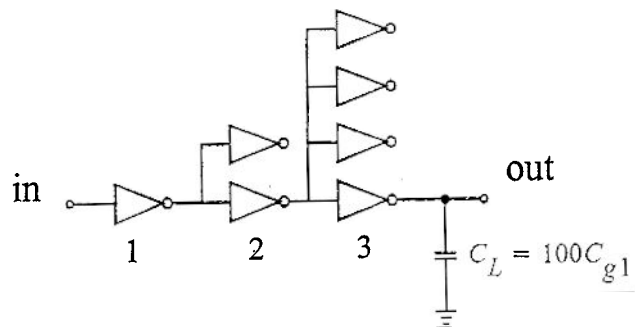
$$C_{gd3} = 4C_{gd1} = 0.62 \text{ fF}$$

$$C_{gd4} = 4C_{gd2} = 1.08 \text{ fF}$$

$$C_{g3} = (W_3)(L_3)(C_{ox}) = (2)(0.25)(6) = 3 \text{ fF}$$

$$C_{g4} = (W_4)(L_4)(C_{ox}) = (4)(0.25)(6) = 6 \text{ fF}$$

$$C_L = 11.55 \text{ fF}$$



$$\frac{\text{size 2}}{\text{size 1}} = 4.64$$

$$\frac{\text{size 3}}{\text{size 1}} = 10.77$$

$$\frac{2C_{g2}}{C_{g1}} = \frac{4C_{g3}}{C_{g2}} = \frac{C_L}{C_{g3}} = \frac{100C_{g1}}{C_{g3}}$$

$$A = \frac{C_{g2}}{C_{g1}} = \frac{\text{SIZE2}}{\text{SIZE1}}$$

$$B = \frac{C_{g3}}{C_{g1}} = \frac{\text{SIZE3}}{\text{SIZE1}}$$

$$\frac{2C_{g2}}{C_{g1}} = \frac{4C_{g3}}{C_{g2}} \Rightarrow 2A = 4\left(\frac{B}{A}\right) \Rightarrow A^2 = 2B$$

$$\frac{2C_{g2}}{C_{g1}} = \frac{100C_{g1}}{C_{g3}} \Rightarrow 2A = \frac{100}{B} \Rightarrow 2A = \frac{100}{A^2/2} \Rightarrow A^3 = 100$$

$$A = \sqrt[3]{100} = 4.64$$

$$B = A^2/2 = 10.77$$