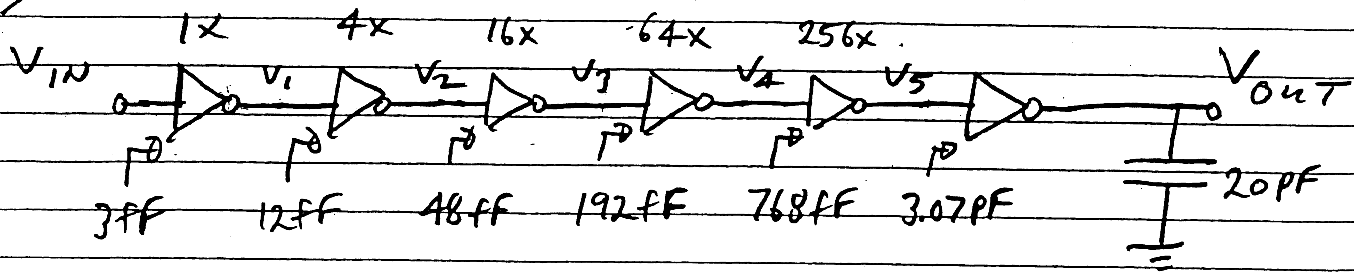
~~Q3~~ 1



DELAY FROM V_{IN} TO V_5 IS GIVEN BY

$$t_{I(1\to5)} = (5)(15\,ps)(\cancel{f}\ f) \quad \text{WHERE } f = 4$$

$$= 300\ ps$$

DELAY FROM V_5 TO V_{OUT} IS

$$t_{I6} = (15\,ps)\left(\frac{20\,pF}{3.07\,pF}\right) = 97.7\ ps$$

TOTAL DELAY $= 300 + 97.7 \cong$ 3[illegible] ps

400

2/

tive to variations in parasitics from one process to another.

4.23 The adder delay is 6.6 FO4 inverter delays, or about 133 ps in the 70 nm process.

4.24 F = (10 pF / 20 fF) = 500. $N = \log_4 F = 4.5$. Use a chain of four inverters with a stage (5 would also wor, but would produce the opposite polarity). $D = 4F^{1/4} + 4 = 22.9\ \tau$ = 4.58 FO4 delays.

4.25 If the first upper inverter has size x and the lower 100-x and the second upper inverter has the same stage effort as the first (to achieve least delay), the least delays are: $D = 2(300/x)^{1/2} + 2 = 300/(100-x) + 1$. Hence x = 49.4, $D = 6.9\ \tau$, and the sizes are 49.4 and 121.7 for the upper inverters and 50.6 for the lower inverter. Such circuits are called *forks* and are discussed in depth in [Sutherland99].

4.26 The clock buffer from Exercise 4.25 is an example of a 1-2 fork. In general, if a 1–2 fork has a maximum input capacitance of C_1 and each of the two legs drives a load of C_2, what should the capacitance of each inverter be and how fast will the circuit operate? Express your answer in terms of p_{inv}.

Let the sizes be x and y in the 2-stage path and $C_1 - x$ in the 1-stage path.

$$D = 2\sqrt{\tfrac{C_2}{x}} + 2p_{\text{inv}} = \frac{C_2}{C_1 - x} + p_{\text{inv}}$$

*** doesn't seem to have any closed-form solution

4.27 $P = aCV^2f$ = 0.1 * (150e^{-12} * 70) * (0.9)^2 * 450e^6 = 0.38 W.

4.28 Dynamic power consumption will go down because it is quadratically dependent on V_{DD}. Static power will go up because subthreshold leakage is exponentially dependent on V_t.

4.29 Simplify using $V_{DD} >> v_T$:

(a)

$$I_1 = I_{ds0} e^{\frac{-V_t}{v_T}}\left[1 - e^{\frac{-V_{DD}}{v_T}}\right] \approx I_{ds0} e^{\frac{-V_t}{v_T}}$$

$$I_2 = I_{ds0} e^{\frac{-V_t}{v_T}}\left[1 - e^{\frac{-x}{v_T}}\right] = I_{ds0} e^{\frac{-V_t - x}{v_T}}\left[1 - e^{\frac{-V_{DD}+x}{v_T}}\right]$$

$$I_2 \approx I_1\left[1 - e^{\frac{-x}{v_T}}\right] = I_1 e^{\frac{-x}{v_T}}$$

$$1 - e^{\frac{-x}{v_T}} = e^{\frac{-x}{v_T}} \Rightarrow e^{\frac{-x}{v_T}} = \tfrac{1}{2} \Rightarrow I_2 / I_1 = 1/2$$

(b) Increasing η increases I_1 because the threshold is effectively reduced. The

PROBLEMS 4 SOLUTIONS

Q~~1~~3)

STATIC

OUTPUT HIGH $\quad P_{OH} = (2V)\left(\frac{1.8V}{20k}\right) = 180\,\mu W$

OUTPUT LOW $\quad P_{OL} = (2V)(0) = 0\,W$

$$P_{STATIC} = P_{(V_0=1)}\,P_{OH} + P_{(V_0=0)}\,P_{OL}$$

$$= (0.3)(180\,\mu W) = \underline{\underline{54\,\mu W}}$$

DYNAMIC

$$P_{DYN} \approx P_{1\to 0}\, f\, C_L (V_{OH} - V_{OL})^2$$

$$P_{1\to 0} = P_{V_0=1}\, P_{V_0=0} = (0.3)(0.7) = 0.21$$

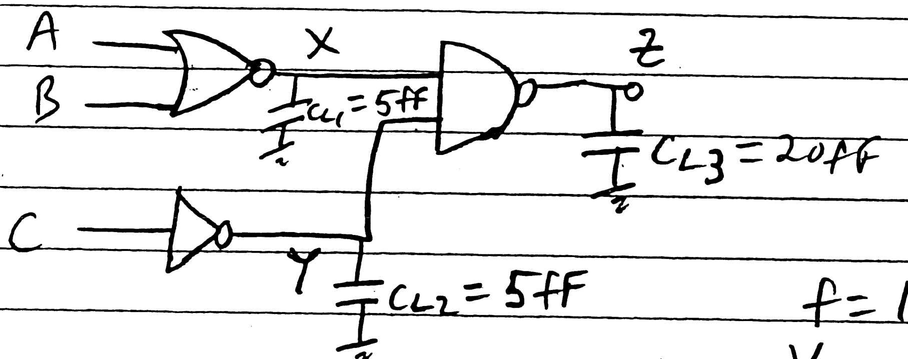
$$f = 1/10ns = 100e6$$

$$P_{DYN} = (0.21)(100e6)(100e{-15})(1.8-0)^2$$

$$= \underline{\underline{6.8\,\mu W}}$$

PROBLEMS 4 SOLUTIONS

Q4)



$f = 1e9$

$V_{DD} = 2V$

$$P_{Y(1\to 0)} = (0.5)(0.5) = 0.25$$

$$P_{X=1} = P_{A=0} P_{B=0} = (0.6)(0.8) = 0.48$$

$$P_{X=0} = 1 - P_{X=1} = 0.52$$

$$P_{X(1\to 0)} = P_{X=1} \, P_{X=0} = (0.48)(0.52) = 0.2496$$

$$P_{Z=0} = P_{X=1} \, P_{Y=1} = (0.48)(0.5) = 0.24$$

$$P_{Z=1} = 1 - P_{Z=0} = 0.76$$

$$P_{Z(1\to 0)} = (0.76)(0.24) = 0.1824$$

$$P_{DYN} = P_{X(1\to 0)} f C_{L1} V_{DD}^2 + P_{Y(1\to 0)} f C_{L2} V_{DD}^2 + P_{Z(1\to 0)} f C_{L3} V_{DD}^2$$

$$= (1e9)(2^2)[(0.2496)(5f) + (0.25)(5f) + (0.1824)(20f)]$$

$$= 24.6\ \mu W$$