EEE 425/591

HW2 Solutions

Q1

(a) $C_{ox} = \dfrac{\varepsilon_{ox}}{t_{ox}} = \dfrac{3.9 \times 8.85 \times 10^{-12}\ F/m}{9 \times 10^{-9}\ m} = 3.8 \times 10^{-3}\ F/m^2$

(b) $k_n = \mu_n C_{ox} \dfrac{W_n}{L_n} = 0.056 \dfrac{m^2}{VS} \times 3.8 \times 10^{-3} \dfrac{F}{m^2} \times \dfrac{2\mu m}{0.25\mu m}$

$= 1.7\ mA/V^2$

(c) Transistor in linear region

$C_{gd} = C_{ox} \dfrac{WL}{2} + C_o W$

$= 3.8 \times 10^{-15} \dfrac{F}{\mu m^2} \times \dfrac{2\mu m \times 0.25\mu m}{2} + 0.4 \times 10^{-15} \dfrac{F}{\mu m} \times 2\mu m$

$= 1.76\ fF$

$C_{gs} \cong C_{gd} = 1.76\ fF$

$C_{dbj0} = (2\mu m)(0.6\mu m) \times 1.7 \dfrac{fF}{\mu m^2} = 2.04\ fF$

$C_{dbsw0} = (2\mu m + 2 \times 0.6\mu m) \times \dfrac{0.4 fF}{\mu m} = 1.28\ fF$

$C_{db} = \dfrac{2.04\ fF}{(2.25)^{1/2}} + \dfrac{1.28\ fF}{(2.25)^{1/3}} = 2.34\ fF$

Q2 $W_n = 0.36$ $W_p = 0.8$

ⓐ $r = \sqrt{\frac{\mu_p W_p}{\mu_n W_n}} = \sqrt{\frac{220 \times 0.8}{560 \times 0.36}} = 0.93$

$$V_M = \frac{0.6 + 0.93(2.5 - 0.6)}{1 + 0.93} = 1.23V$$

ⓑ $R_n = \frac{1}{k_n \frac{W_n}{L}(V_{DD} - V_T)} = \frac{1}{0.56 \times \frac{0.36}{0.25} \times (2.5 - 0.6)} k\Omega$

$R_n = 0.65 k\Omega$

$R_p = \frac{1}{0.22\left(\frac{0.8}{0.25}\right)(1.9)} k\Omega = 0.75 k\Omega$

ⓒ R_n remains the same $W_n = 0.36$

$W_p = W_n \frac{\mu_n}{\mu_p} = 0.36 \times \frac{56}{22} = 0.92 \mu m$

ⓓ $C_{gdtot} = (W_n + W_p) C_{OV} = (0.36 + 0.8) \times 10^{-6} \times 0.4 \times 10^{-9} F$
$= 0.46 fF$

$C_{dbpjo} = W_p L_s C_{jo} = (0.8\mu \times 0.6\mu) \times \frac{1.7 fF}{\mu m^2} = 0.82 fF$

$C_{dbnjo} = 0.37 fF$

$C_{dbpswo} = (W_p + 2L_s) C_{jswo} = (2\mu m) \times 0.4 fF/\mu m = 0.8 fF$

$C_{dbnswo} = (W_n + 2L_s) C_{jswo} = (1.56 \mu m) \times 0.4 fF/\mu m = 0.6 fF$

$$C_{TOT} = \underbrace{74fF}_{\text{load}} + \underbrace{\frac{0.82f + 0.37f}{\sqrt{1 + \frac{1.25}{1}}}}_{\text{bottom}} + \underbrace{\frac{0.8f + 0.6f}{(1+1.25)^{1/3}}}_{\text{sidewall}} + \underbrace{2 \times 0.46f}_{2C_{gd}}$$

$$(74 + 0.79 + 1.07 + 0.92)fF = 76.8fF$$

$$t_{pHL} = 0.7 \times 0.65k \times 76.8f = 34.9ps$$

$$t_{pLH} = 0.7 \times 0.75k \times 76.8f = 40.3ps$$

e) Delay doubles when $(V_{DD} - V_T)$ reduces to half of its value

$$V_{DDnew} - V_T = \frac{1}{2}(2.5 - 0.6)$$

$$V_{DD} = 1.55V$$

Q3

(a) $V_{in} = V_{DD} \rightarrow$ PMOS leakes

$V_{SG} = 0 \quad V_{SD} = V_{DD}$

$$I_{leakp} = \frac{W_p}{L_p} I_0 \, e^{\frac{-V_{th}}{V_T}} \left(1 - \cancel{e^{\frac{-V_{DD}}{V_T}}}^{\,0}\right)$$

$$= 2{,}5 \times 10^{-7} e^{\frac{-600}{3 \times 25}} = 8{,}4 \times 10^{-11}\ A$$

$P_{leak} = 2.1 \times 10^{-10}\ W$

$V_{in} = 0 \rightarrow$ Nmos leaks

$I_{leakn} = I_{leakp} \times \frac{W_n}{W_p} = 3{,}4 \times 10^{-11}\ A$

$P_{leak_n} = 8{,}4 \times 10^{-11}\ W$

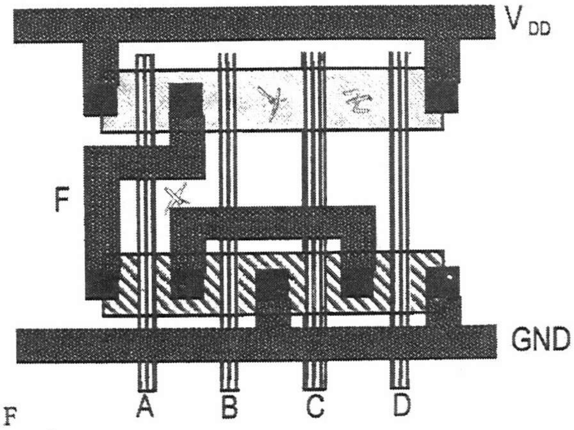
(b) $E = CV_{DD}^2 = 50 \times 10^{-15} \times (2{,}5)^2 = 0{,}3 \times 10^{-12}\ J$

(c) Total leakage energy

$= P_{leakp} \times 100ns + P_{leakn} \times 100ns$

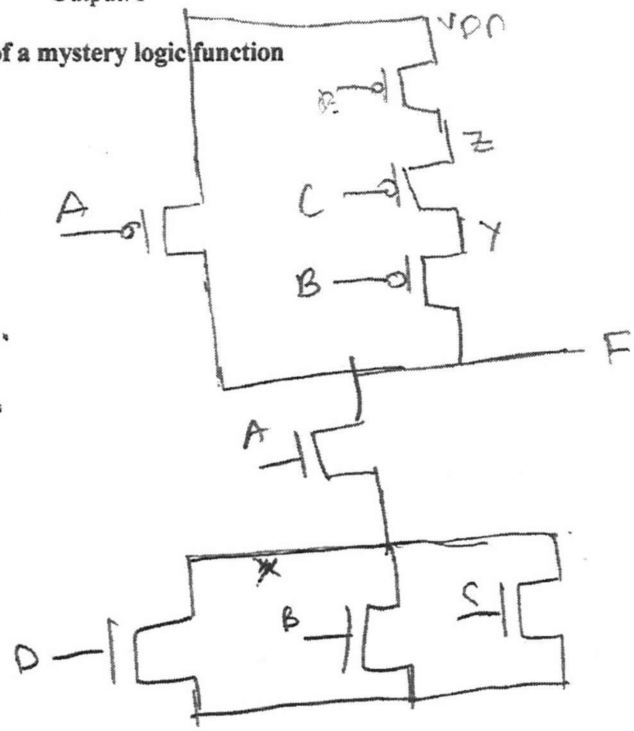
$= 21 \times 10^{-11} \times 10^{-7} + 8{,}4 \times 10^{-11} \times 10^{-7} = 29.4 \times 10^{-18}\ J$

Q4



Inputs: A, B, C, D   Output: F

Figure 1: Layout of a mystery logic function



$F = \overline{A} + \overline{B}\,\overline{C}\,\overline{D}$

$A = 0 \rightarrow F = 1$

A	B	C	D	F
1	0	0	0	1
1	0	0	1	0
1	0	1	0	
1	0	1	1	
1	1	0	0	
1	1	0	1	
1	1	1	0	
1	1	1	1	0