Homework Assignment #8

ECE 0257 – Spring 2019

Name

Avery Peiffer

Collaborators

Daniel Stumpp

Book Problems

Sedra & Smith 14.2
Sedra & Smith 14.16
Sedra & Smith 14.24
Sedra & Smith 14.31
Sedra & Smith 14.49
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Sedra & Smith 14.63
Sedra & Smith 14.64

Simulation Problems

Resistive Loaded NMOS Inverter (Parts 1 – 5)

CMOS Inverter (Parts 1 – 6)

Check-list Before Submission

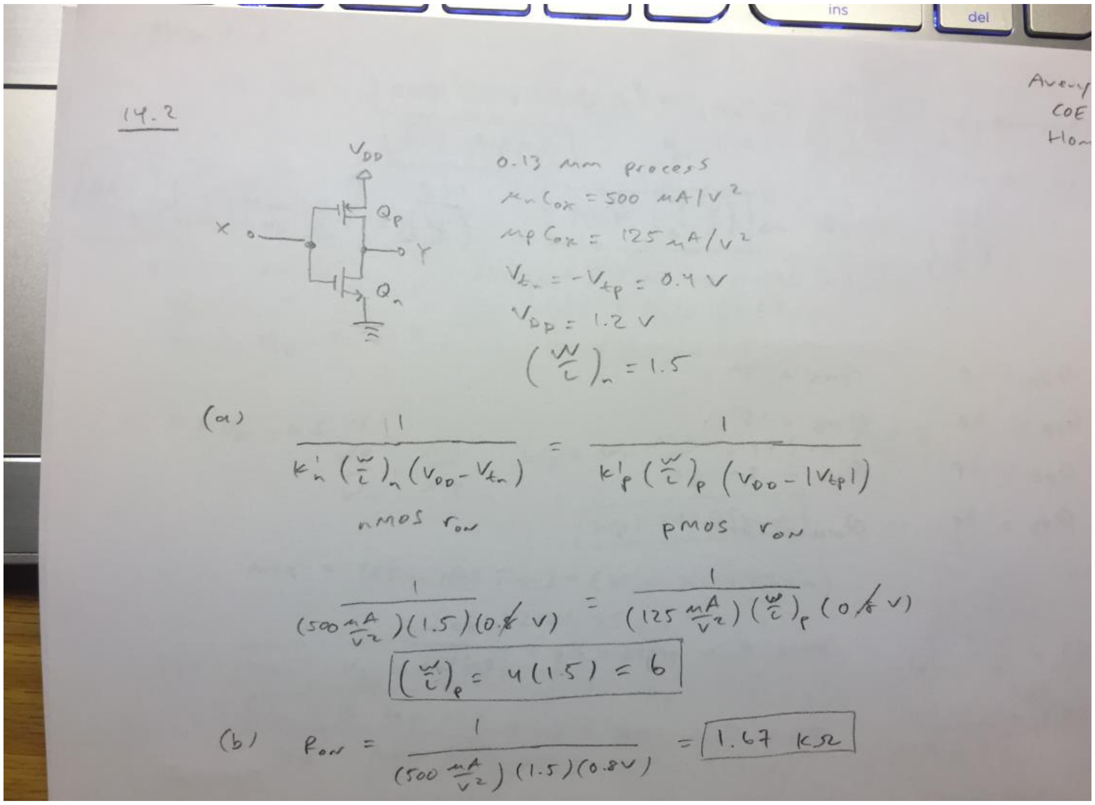
☐ Write within boxes, no boxes are moved

☐ Write your full names in designated area

☐ Save this file as a PDF before uploading, keep the number of pages (**15**) unchanged

☐ Notify "TO BE CONTINUED" accordingly if you used the extra pages (page 12-15)

Sedra & Smith 14.2



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14.2

0.13 μm process

$\mu_n C_{ox} = 500\ \mu A/V^2$

$\mu_p C_{ox} = 125\ \mu A/V^2$

$V_{tn} = -V_{tp} = 0.4\ V$

$V_{DD} = 1.2\ V$

$\left(\frac{W}{L}\right)_n = 1.5$

(a) $$\frac{1}{k_n'\left(\frac{W}{L}\right)_n(V_{DD}-V_{tn})} = \frac{1}{k_p'\left(\frac{W}{L}\right)_p(V_{DD}-|V_{tp}|)}$$

nMOS r_{on} pMOS r_{on}

$$\frac{1}{(500\frac{\mu A}{V^2})(1.5)(0.\cancel{8}\ V)} = \frac{1}{(125\frac{\mu A}{V^2})\left(\frac{W}{L}\right)_p(0.\cancel{8}\ V)}$$

$$\boxed{\left(\frac{W}{L}\right)_p = 4(1.5) = 6}$$

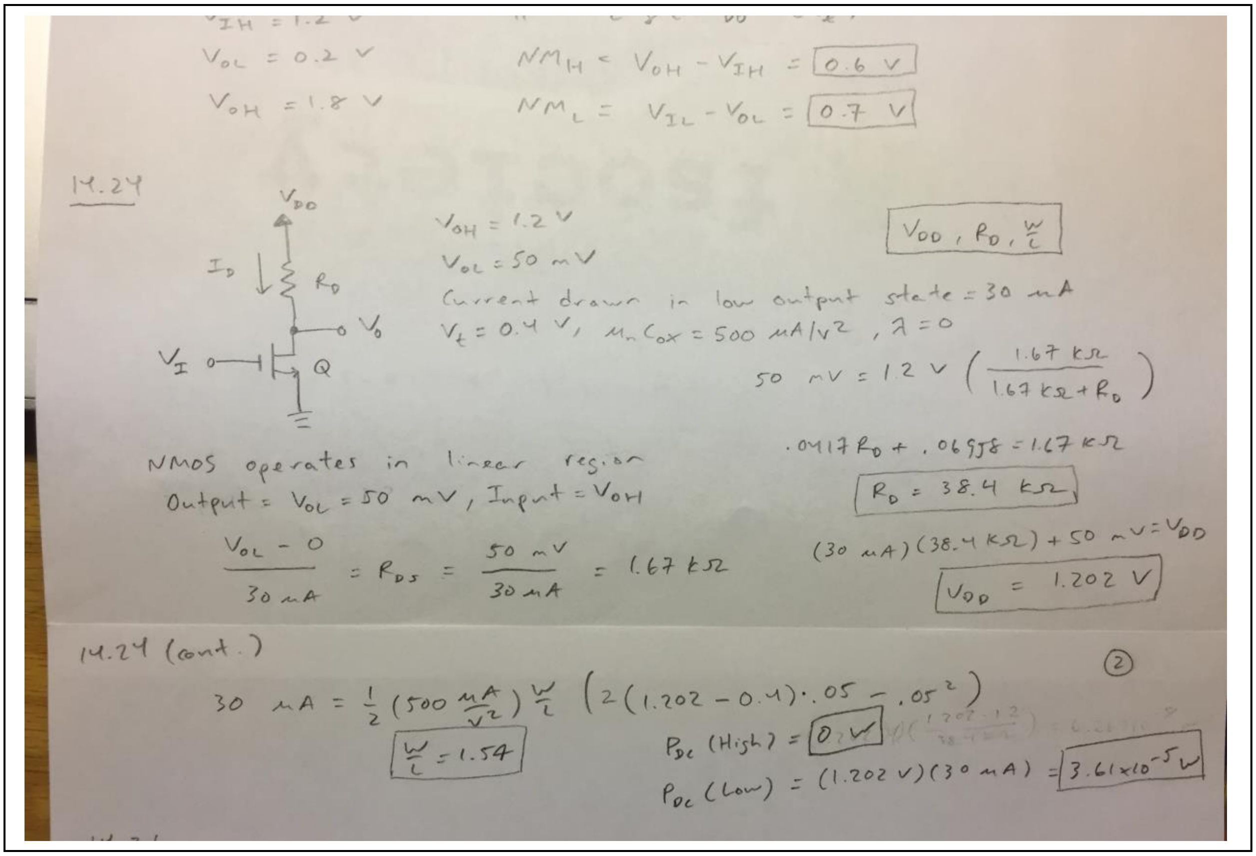
(b) $$R_{on} = \frac{1}{(500\frac{\mu A}{V^2})(1.5)(0.8V)} = \boxed{1.67\ k\Omega}$$

Sedra & Smith 14.16

NMh = Voh – Vih = 1.8 V – 1.2 V = **0.6 V**

NMl = Vil – Vol = 0.9 V – 0.2 V = **0.7 V**

Sedra & Smith 12.24


$V_{OL} = 0.2$ V $NM_H < V_{OH} - V_{IH} = \boxed{0.6\text{ V}}$

$V_{OH} = 1.8$ V $NM_L = V_{IL} - V_{OL} = \boxed{0.7\text{ V}}$

14.24

$V_{OH} = 1.2$ V

$V_{OL} = 50$ mV

Current drawn in low output state = 30 μA

$V_t = 0.4$ V, $\mu_n C_{ox} = 500\ \mu A/V^2$, $\lambda = 0$

$\boxed{V_{DD},\ R_D,\ \frac{W}{L}}$

$$50\text{ mV} = 1.2\text{ V}\left(\frac{1.67\text{ k}\Omega}{1.67\text{ k}\Omega + R_D}\right)$$

$$.0417 R_D + .06958 = 1.67\text{ k}\Omega$$

$$\boxed{R_D = 38.4\text{ k}\Omega}$$

NMOS operates in linear region

Output = $V_{OL} = 50$ mV, Input = V_{OH}

$$\frac{V_{OL} - 0}{30\ \mu A} = R_{DS} = \frac{50\text{ mV}}{30\ \mu A} = 1.67\text{ k}\Omega$$

$$(30\ \mu A)(38.4\text{ k}\Omega) + 50\text{ mV} = V_{DD}$$

$$\boxed{V_{DD} = 1.202\text{ V}}$$

14.24 (cont.)   ②

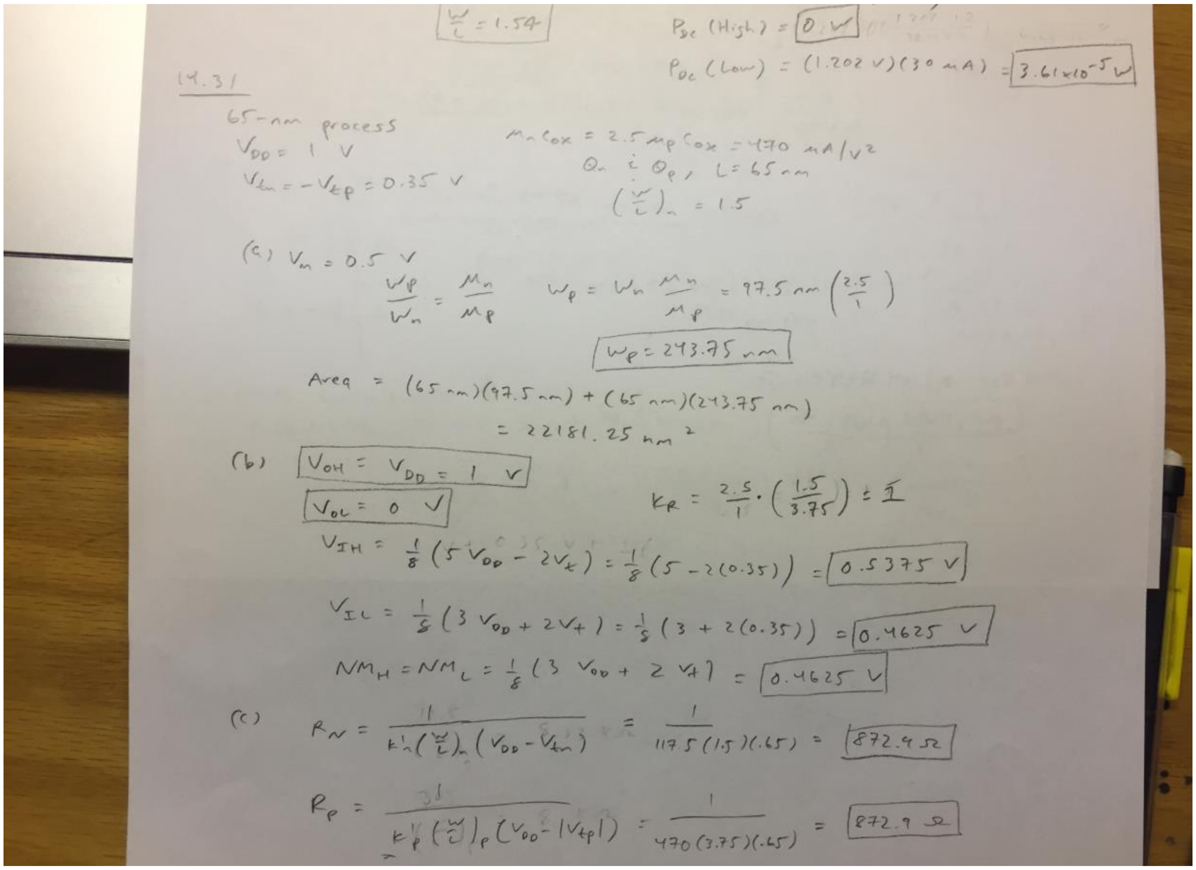
$$30\ \mu A = \frac{1}{2}\left(500\frac{\mu A}{V^2}\right)\frac{W}{L}\left(2(1.202 - 0.4)\cdot .05 - .05^2\right)$$

$$\boxed{\frac{W}{L} = 1.54}$$

P_{DC} (High) = $\boxed{0\text{ W}}$

P_{DC} (Low) = (1.202 V)(30 μA) = $\boxed{3.61\times10^{-5}\text{ W}}$

Sedra & Smith 14.31



$\boxed{\frac{W}{L} = 1.54}$

$P_{DC}\ (\text{High}) = \boxed{0\ W}$

$P_{DC}\ (\text{Low}) = (1.202\ V)(30\ mA) = \boxed{3.61 \times 10^{-5}\ W}$

14.31

65-nm process

$V_{DD} = 1\ V$

$V_{tn} = -V_{tp} = 0.35\ V$

$\mu_n C_{ox} = 2.5 \mu_p C_{ox} = 470\ \mu A/V^2$

Q_n & Q_p, $L = 65\ nm$

$\left(\frac{W}{L}\right)_n = 1.5$

(a) $V_m = 0.5\ V$

$$\frac{W_p}{W_n} = \frac{\mu_n}{\mu_p} \qquad W_p = W_n \frac{\mu_n}{\mu_p} = 97.5\ nm \left(\frac{2.5}{1}\right)$$

$\boxed{W_p = 243.75\ nm}$

$$\text{Area} = (65\ nm)(97.5\ nm) + (65\ nm)(243.75\ nm) = 22181.25\ nm^2$$

(b) $\boxed{V_{OH} = V_{DD} = 1\ V}$

$\boxed{V_{OL} = 0\ V}$

$$k_R = \frac{2.5}{1} \cdot \left(\frac{1.5}{3.75}\right) = 1$$

$$V_{IH} = \frac{1}{8}(5 V_{DD} - 2V_t) = \frac{1}{8}(5 - 2(0.35)) = \boxed{0.5375\ V}$$

$$V_{IL} = \frac{1}{8}(3 V_{DD} + 2V_t) = \frac{1}{8}(3 + 2(0.35)) = \boxed{0.4625\ V}$$

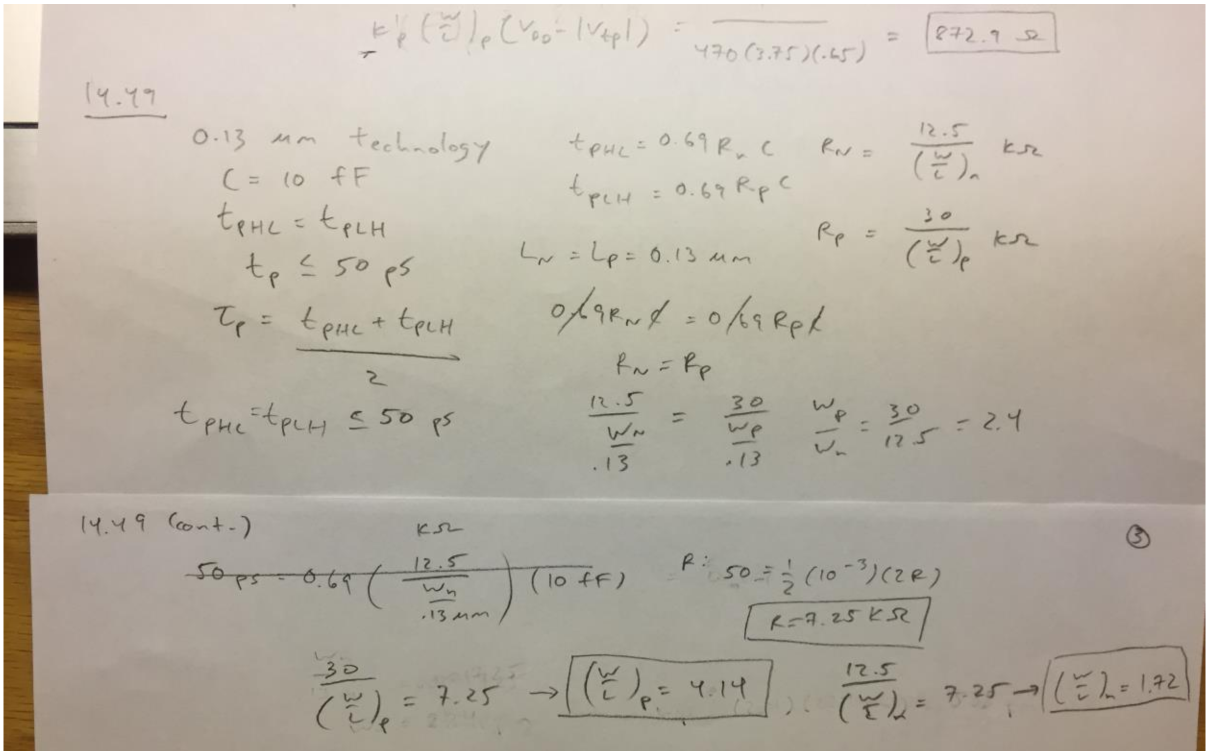
$$NM_H = NM_L = \frac{1}{8}(3 V_{DD} + 2 V_t) = \boxed{0.4625\ V}$$

(c)

$$R_N = \frac{1}{k'_n \left(\frac{W}{L}\right)_n (V_{DD} - V_{tn})} = \frac{1}{117.5(1.5)(.65)} = \boxed{872.4\ \Omega}$$

$$R_P = \frac{1}{k'_p \left(\frac{W}{L}\right)_p (V_{DD} - |V_{tp}|)} = \frac{1}{470(3.75)(.65)} = \boxed{872.9\ \Omega}$$

Sedra & Smith 14.49



$k_p'\left(\frac{W}{L}\right)_p(V_{DD}-|V_{tp}|) = \frac{}{470(3.75)(.65)} = \boxed{872.9\ \Omega}$

14.49

0.13 μm technology

$C = 10$ fF

$t_{PHL} = t_{PLH}$

$t_p \le 50$ ps

$\tau_p = \frac{t_{PHL}+t_{PLH}}{2}$

$t_{PHL} = t_{PLH} \le 50$ ps

$t_{PHL} = 0.69 R_n C$

$t_{PLH} = 0.69 R_p C$

$L_n = L_p = 0.13$ μm

$\cancel{0.69} R_n \cancel{C} = \cancel{0.69} R_p \cancel{C}$

$R_n = R_p$

$\frac{12.5}{\frac{W_n}{.13}} = \frac{30}{\frac{W_p}{.13}} \quad \frac{W_p}{W_n} = \frac{30}{12.5} = 2.4$

$R_N = \frac{12.5}{\left(\frac{W}{L}\right)_n}$ kΩ

$R_p = \frac{30}{\left(\frac{W}{L}\right)_p}$ kΩ

14.49 (cont.)

③

~~$50\text{ ps} = 0.69\left(\frac{12.5}{\frac{W_n}{.13\text{ mm}}}\right)(10\text{ fF})$~~ kΩ

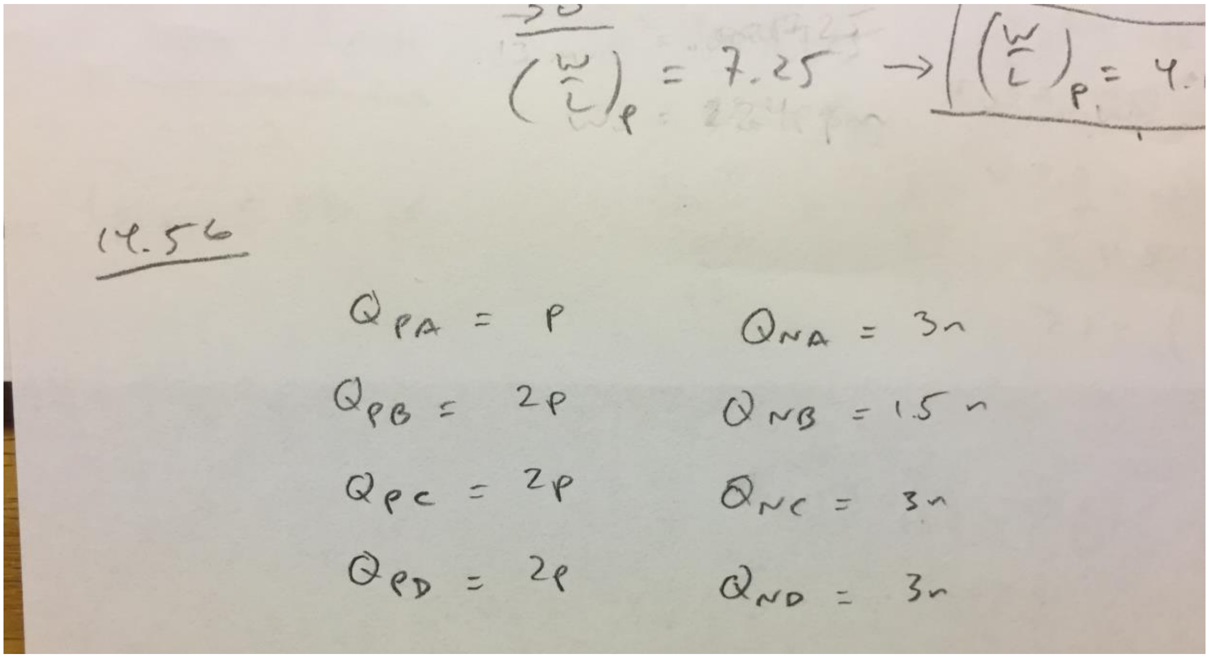
$R: 50 = \frac{1}{2}(10^{-3})(2R)$

$\boxed{R = 7.25\ \text{k}\Omega}$

$\frac{30}{\left(\frac{W}{L}\right)_p} = 7.25 \rightarrow \boxed{\left(\frac{W}{L}\right)_p = 4.14}$

$\frac{12.5}{\left(\frac{W}{L}\right)_n} = 7.25 \rightarrow \boxed{\left(\frac{W}{L}\right)_n = 1.72}$

Sedra & Smith 14.56



$\frac{30}{\left(\frac{W}{L}\right)_p} = 7.25 \rightarrow \boxed{\left(\frac{W}{L}\right)_p = 4.}$

14.56

$Q_{PA} = p$

$Q_{PB} = 2p$

$Q_{PC} = 2p$

$Q_{PD} = 2p$

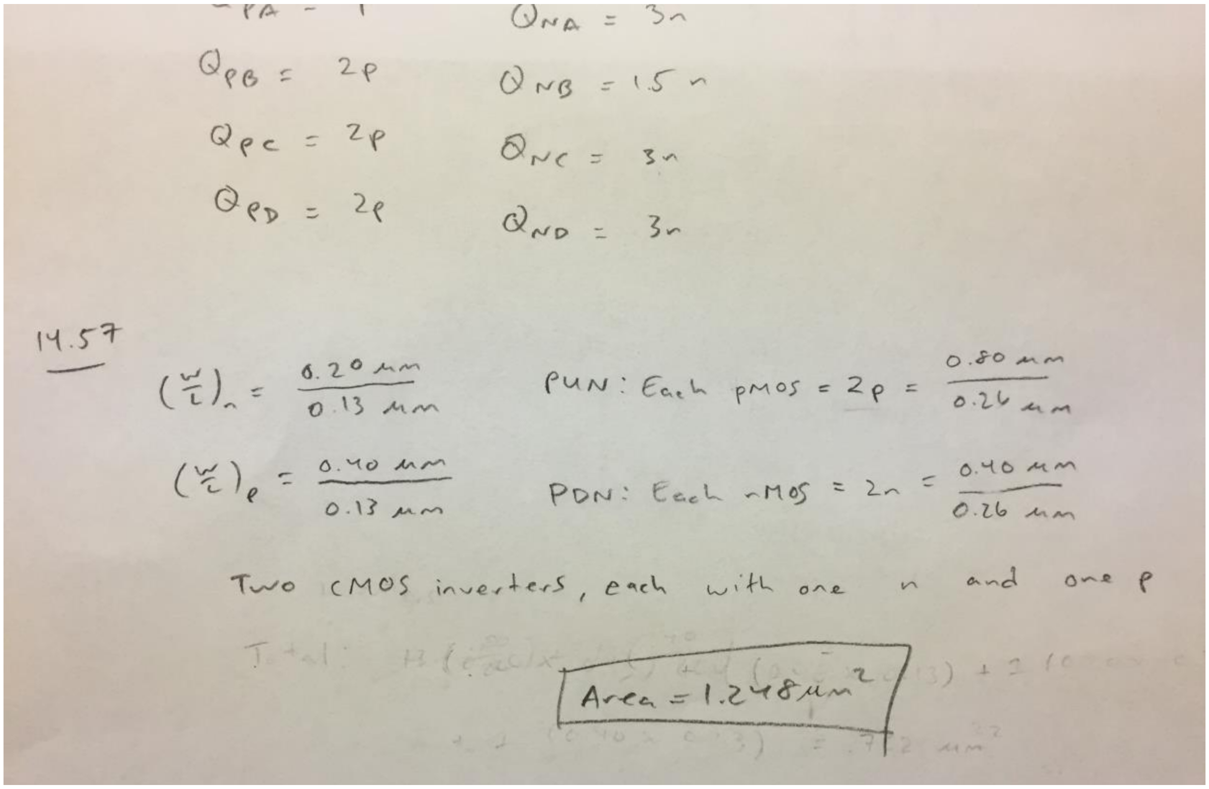
$Q_{NA} = 3n$

$Q_{NB} = 1.5n$

$Q_{NC} = 3n$

$Q_{ND} = 3n$

Sedra & Smith 14.57



$_{PA} = 1$ $Q_{NA} = 3n$

$Q_{PB} = 2p$ $Q_{NB} = 1.5n$

$Q_{PC} = 2p$ $Q_{NC} = 3n$

$Q_{PD} = 2p$ $Q_{ND} = 3n$

14.57

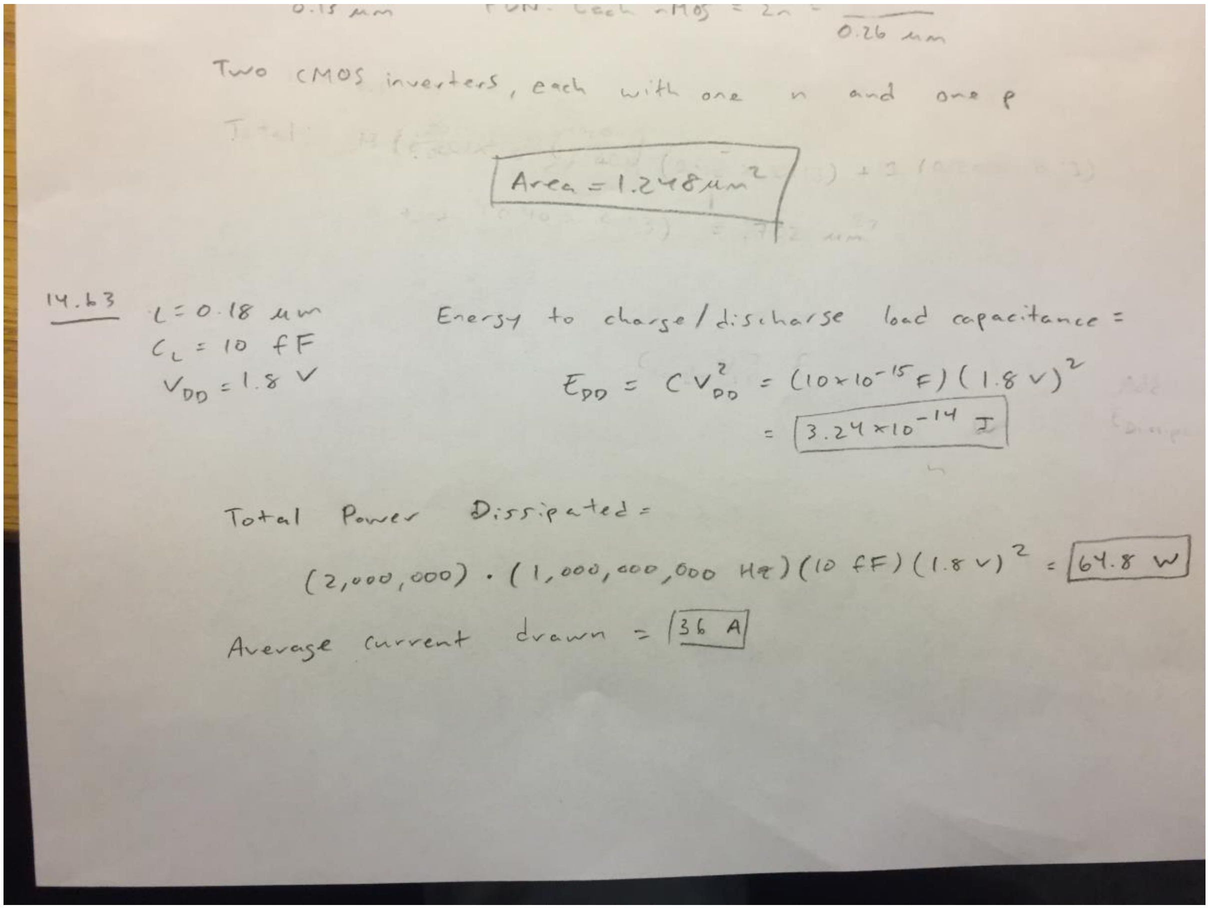
$\left(\frac{W}{L}\right)_n = \frac{0.20\ \mu m}{0.13\ \mu m}$ PUN: Each pMOS = 2p = $\frac{0.80\ \mu m}{0.26\ \mu m}$

$\left(\frac{W}{L}\right)_p = \frac{0.40\ \mu m}{0.13\ \mu m}$ PDN: Each nMOS = 2n = $\frac{0.40\ \mu m}{0.26\ \mu m}$

Two CMOS inverters, each with one n and one p

$\boxed{\text{Area} = 1.248\ \mu m^2}$

Sedra & Smith 14.63



0.15 μm PUN: Each nMOS = 2n = 0.26 μm

Two CMOS inverters, each with one n and one p

$\boxed{\text{Area} = 1.248 \mu m^2}$

14.63

$L = 0.18\ \mu m$

$C_L = 10\ fF$

$V_{DD} = 1.8\ V$

Energy to charge/discharge load capacitance =

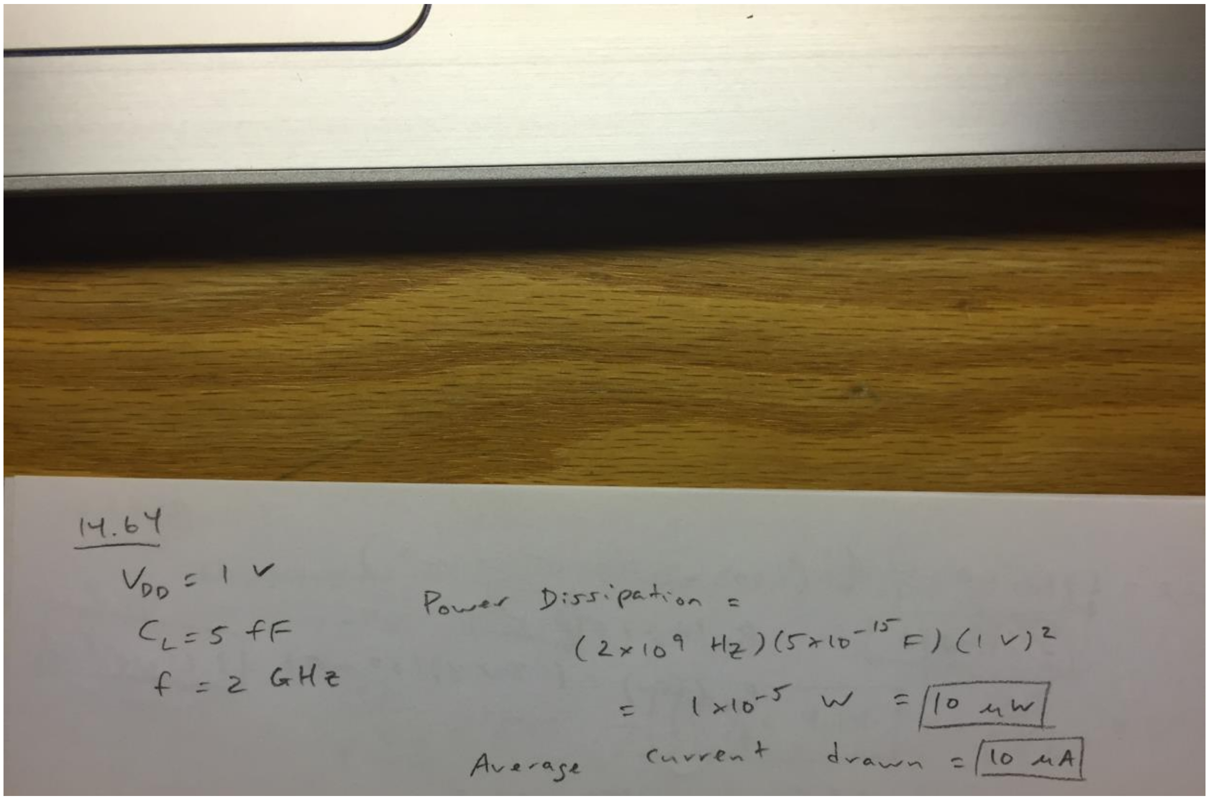
$$E_{DD} = C V_{DD}^2 = (10 \times 10^{-15} F)(1.8 V)^2 = \boxed{3.24 \times 10^{-14}\ J}$$

Total Power Dissipated =

$$(2{,}000{,}000) \cdot (1{,}000{,}000{,}000\ Hz)(10\ fF)(1.8\ V)^2 = \boxed{64.8\ W}$$

Average current drawn = $\boxed{36\ A}$

Sedra & Smith 14.64



14.64

$V_{DD} = 1\ V$

$C_L = 5\ fF$

$f = 2\ GHz$

Power Dissipation =

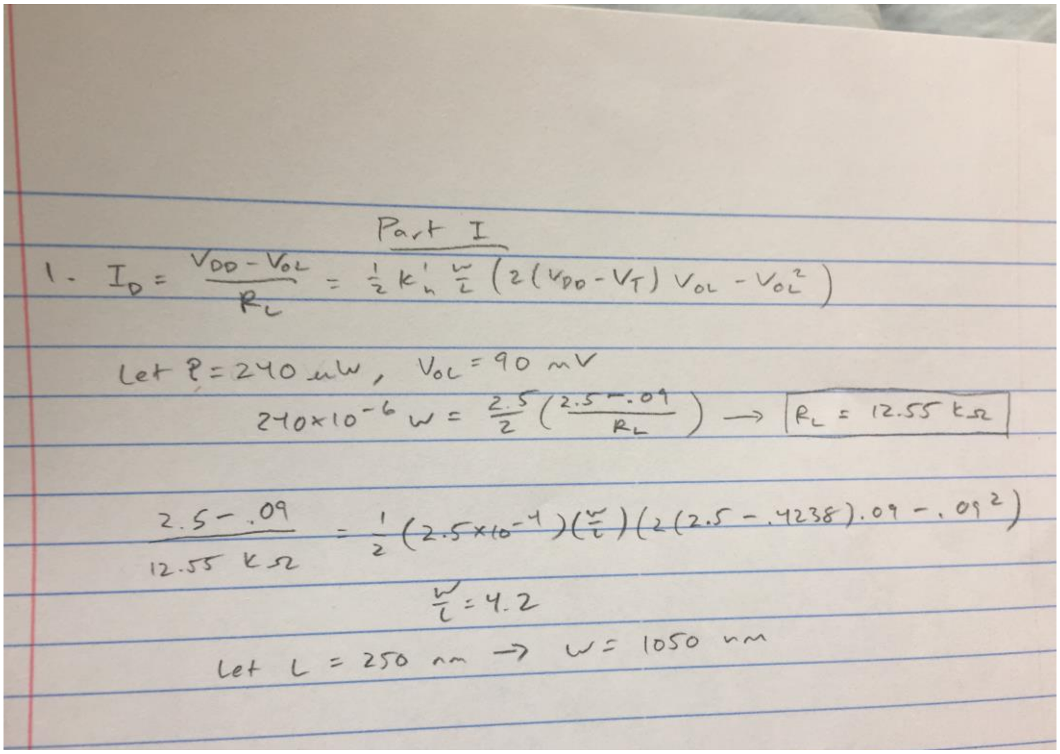
$(2\times10^{9}\ Hz)(5\times10^{-15}\ F)(1\ V)^2$

$= 1\times10^{-5}\ W = \boxed{10\ \mu W}$

Average current drawn $= \boxed{10\ \mu A}$

Resistive Load NMOS Inverter (1)

$W = 1050$ nm $L = 250$ nm $R = 12.55$ kilo-ohms



Part I

$$1.\ I_D = \frac{V_{DD} - V_{OL}}{R_L} = \frac{1}{2} k_n' \frac{W}{L}\left(2(V_{DD}-V_T)V_{OL} - V_{OL}^2\right)$$

Let $P = 240\ \mu W$, $V_{OL} = 90\ mV$

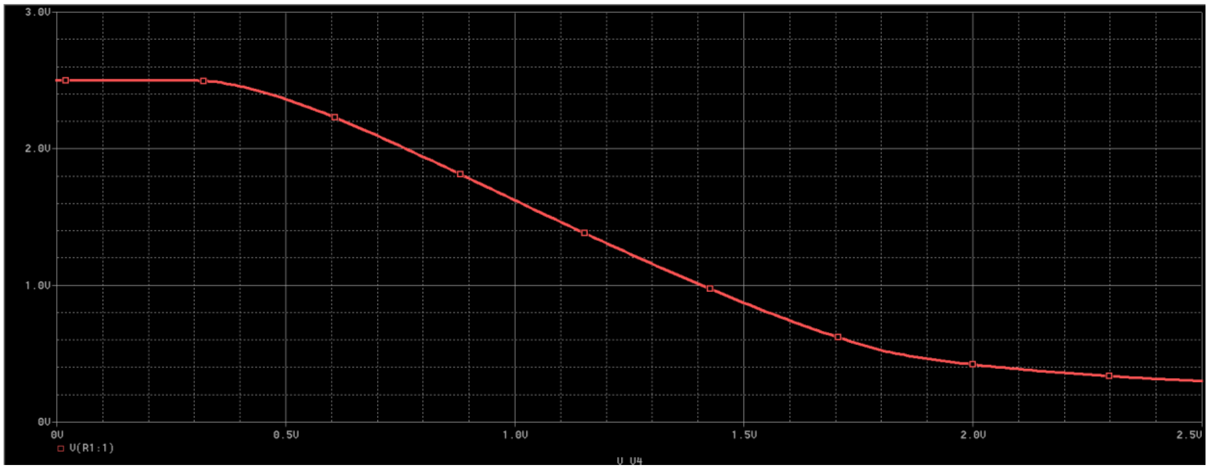
$$240\times10^{-6}\ W = \frac{2.5}{2}\left(\frac{2.5 - .09}{R_L}\right) \longrightarrow \boxed{R_L = 12.55\ k\Omega}$$

$$\frac{2.5 - .09}{12.55\ k\Omega} = \frac{1}{2}(2.5\times10^{-4})\left(\frac{W}{L}\right)\left(2(2.5 - .4238).09 - .09^2\right)$$

$$\frac{W}{L} = 4.2$$

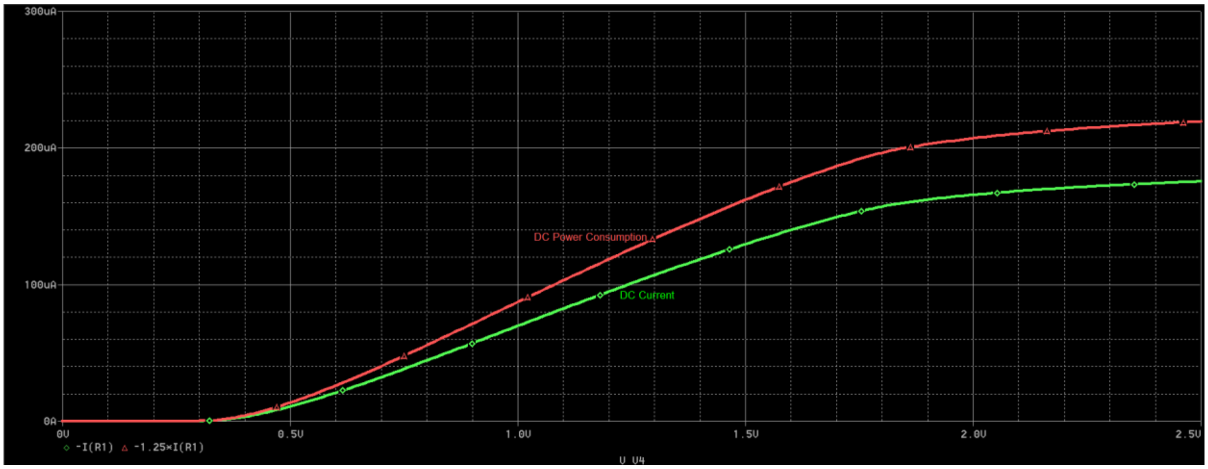
Let $L = 250\ nm \rightarrow W = 1050\ nm$

Resistive Load NMOS Inverter (2)



Resistive Load NMOS Inverter (3)

$DC\ Power\ Consumption =$ 218.75 uW



Resistive Load NMOS Inverter (4)

$VOL =$ 300 mV

$VIL =$ 463 mV

$VTH =$ 1.2429 V

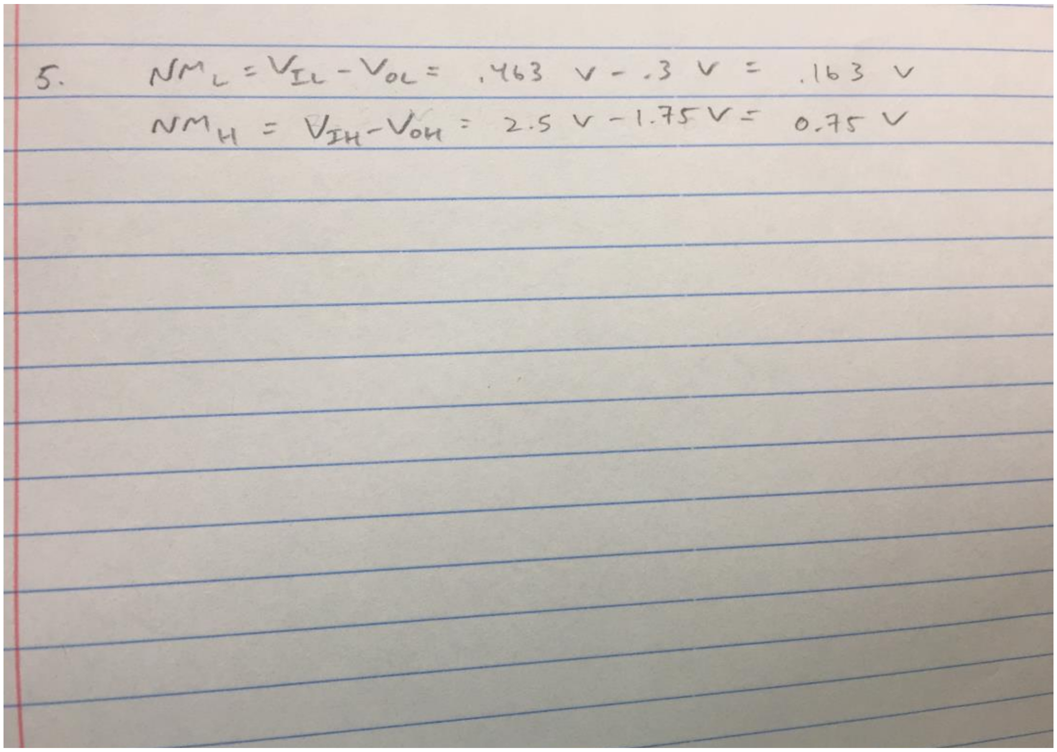
$VOH =$ 2.5 V

$VIH =$ 1.75 V

Resistive Load NMOS Inverter (5)

$NML =$ .163 V

$NMH =$ .75 V



5. $NM_L = V_{IL} - V_{OL} =$ .463 V - .3 V = .163 V

$NM_H = V_{IH} - V_{OH} =$ 2.5 V - 1.75 V = 0.75 V

CMOS Inverter (1)

For the NMOS Transistor:

$W =$ 360 nm

$L =$ 250 nm

For the PMOS Transistor:

$W =$ 1200 nm

$L =$ 250 nm

CMOS Inverter (2 and 3)

$VOL = 0$ V

$VIL = 1.0579$ V

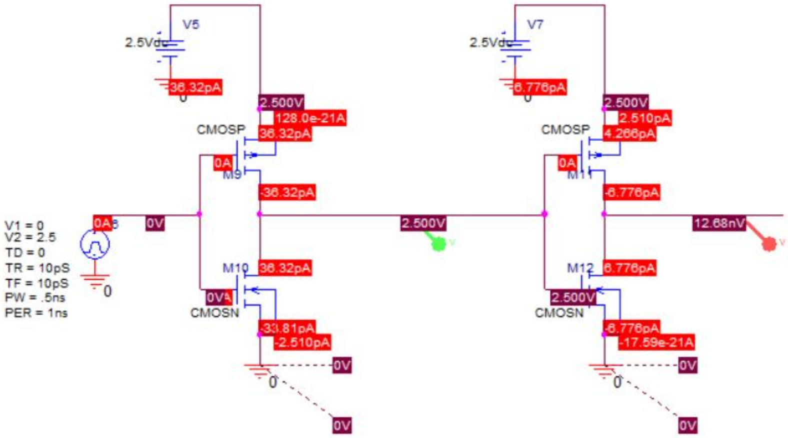
$VTH = 1.2556$ V

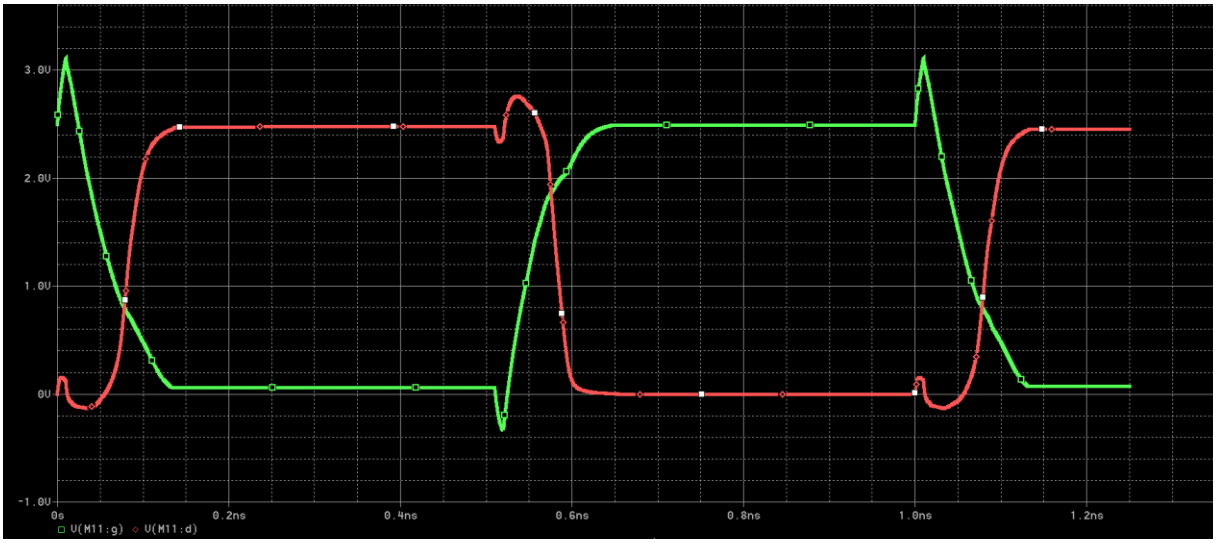
$VOH = 2.5$ V

$VIH = 1.4421$ V

$Average\ Power\ Consumption = 0$ W

CMOS Inverter (4)





CMOS Inverter (5)

Please enter your re-measured values for:

$T_R =$ 126.29 pS

$T_{PLH} =$ 35.3 pS

$T_{Pavg} =$ 33.7 pS

$T_F =$ 153.7 pS

$T_{PHL} =$ 32.1 pS

The second inverter increased the delay measurements because it effectively increases the capacitance. When the circuit is modeled as an RC-switching circuit, this increase to the capacitance will result in an increase to the RC time constant, meaning that there will be more of a delay for the transistor to reach a certain voltage value.

CMOS Inverter (6)

$Dynamic\ Power\ Consumption =$ 186.31 uW

I used the equations for Tphl and Tplh to solve for the load capacitance value from the perspective of each propagation delay. I then averaged the two values to get an average load capacitance of 2.98 x 10^-14 F. I then used this equation to solve for the average dynamic power, the equation for it being P = CL * (Vdd)^2 * f.

EXTRA PAGES

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