EE434

ASIC and Digital Systems

Midterm Exam 2

April 8, 2015. (5:10pm – 6pm)

Instructor: Dae Hyun Kim (daehyun@eecs.wsu.edu)

Name:

WSU ID:

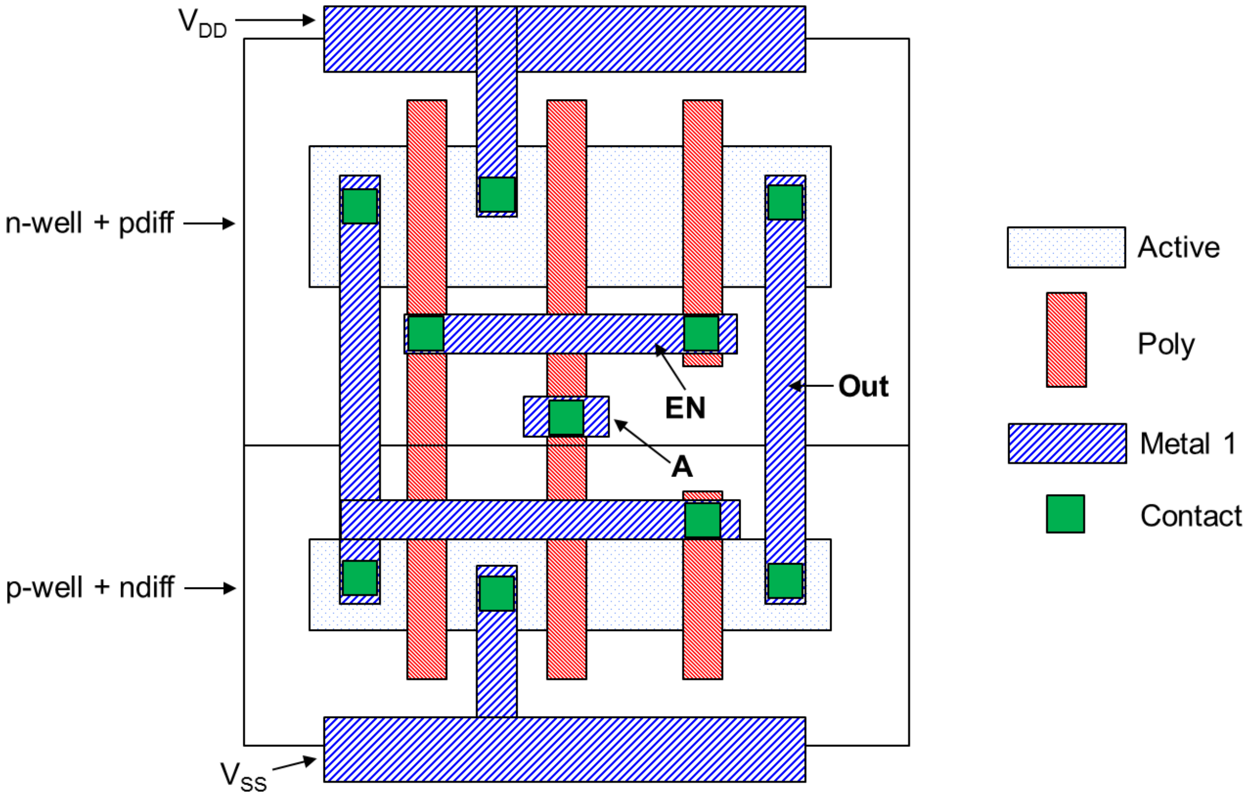
Problem	Points	
1	20	
2-1	13	
2-2	7	
3-1	10	
3-2	10	
4	20	
Total	80	

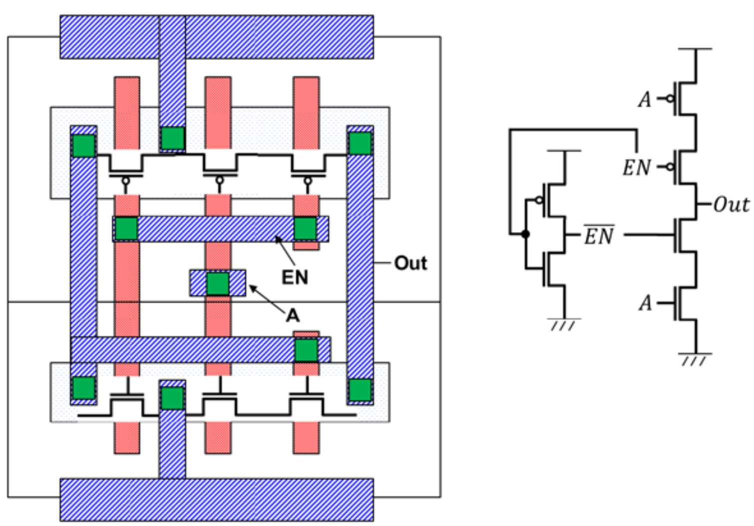
* Allowed: Textbooks, cheat sheets, class notes, notebooks, calculators, watches

* Not allowed: Electronic devices (smart phones, tablet PCs, laptops, etc.) except calculators and watches

Problem #1 (Layout, 20 points).

Represent Out as a Boolean function of EN and A or describe the function of the following layout in as much detail as possible (Primary inputs: A, EN. Primary output: Out).

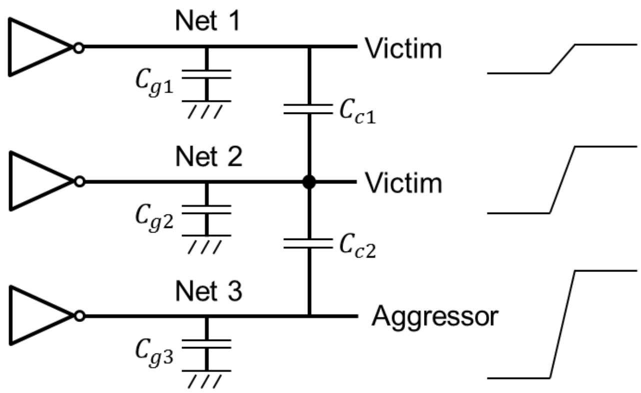




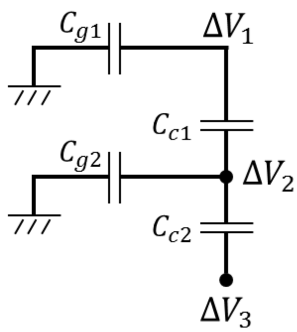
This is an active-low tri-state inverter. $Out = \overline{EN} \cdot \bar{A} + EN \cdot Z$ (where Z is high-impedence).

Problem #2 (Coupling Analysis, 20 points).

Three nets are coupled through C_{c1} and C_{c2} as shown in the following figure:



Net 3 is the only aggressor and Net 2 and Net 1 are victims. Although Net 1 is not directly connected to Net 3, Net 1 is affected by the potential change of Net 2 when Net 3 switches. The above figure can be simplified as follows:



1 – 12 points) Derive ΔV_2 and ΔV_1 as a function of $\Delta V_3, C_{g1}, C_{g2}, C_{c1},$ and C_{c2}.

$$i_{32} = C_{c2}\frac{d(V_3 - V_2)}{dt} = C_{g2}\frac{dV_2}{dt} + C_{c1}\frac{d(V_2 - V_1)}{dt}$$

$$i_{21} = C_{c1}\frac{d(V_2 - V_1)}{dt} = C_{g1}\frac{dV_1}{dt}$$

From i_{21}: $C_{c1}(\Delta V_2 - \Delta V_1) = C_{g1}\Delta V_1 \quad \rightarrow \quad \Delta V_1 = \frac{C_{c1}}{C_{g1}+C_{c1}}\Delta V_2$

From i_{32}: $C_{c2}(\Delta V_3 - \Delta V_2) = C_{g2}\Delta V_2 + C_{c1}(\Delta V_2 - \Delta V_1)$

$$\rightarrow \quad C_{c2}\Delta V_3 = (C_{g2} + C_{c1} + C_{c2})\Delta V_2 - C_{c1}\Delta V_1 = \left(C_{g2} + C_{c1} + C_{c2} - \frac{{C_{c1}}^2}{C_{g1} + C_{c1}}\right)\Delta V_2$$

$$\rightarrow \quad C_{c2}\Delta V_3 = \left(\frac{C_{g1}C_{g2}+C_{g2}C_{c1}+C_{g1}C_{c1}+C_{g1}C_{c2}+C_{c1}C_{c2}}{C_{g1}+C_{c1}}\right)\Delta V_2$$

$$\therefore \; \Delta V_2 = C_{c2}\left(\frac{C_{g1}+C_{c1}}{C_{g1}C_{g2}+C_{g2}C_{c1}+C_{g1}C_{c1}+C_{g1}C_{c2}+C_{c1}C_{c2}}\right)\Delta V_3$$

$$\Delta V_1 = \left(\frac{C_{c1}C_{c2}}{C_{g1}C_{g2}+C_{g2}C_{c1}+C_{g1}C_{c1}+C_{g1}C_{c2}+C_{c1}C_{c2}}\right)\Delta V_3$$

2 – 8 points) True/False questions (Hint: Use your intuition or the formulas you derived in the above problem).

a) If C_{g1} increases, ΔV_1 increases (true/false).

$$\Delta V_1 = \left(\frac{C_{c1}C_{c2}}{(C_{g2}+C_{c1}+C_{c2})\boldsymbol{C_{g1}}+C_{g2}C_{c1}+C_{c1}C_{c2}}\right)\Delta V_3 \quad \rightarrow \quad \Delta V_1 \; decreases.$$

b) If C_{g1} increases, ΔV_2 increases (true/false).

$$\Delta V_2 = \frac{C_{c2}}{\left(C_{g2}+C_{c1}+C_{c2}-\frac{C_{c1}{}^2}{\boldsymbol{C_{g1}}+C_{c1}}\right)}\Delta V_3 \quad \rightarrow \quad \Delta V_2 \; decreases.$$

c) If C_{g2} increases, ΔV_1 increases (true/false).

$$\Delta V_1 = \left(\frac{C_{c1}C_{c2}}{(C_{g1}+C_{c1})\boldsymbol{C_{g2}}+C_{g1}C_{c1}+C_{g1}C_{c2}+C_{c1}C_{c2}}\right)\Delta V_3 \quad \rightarrow \quad \Delta V_1 \; decreases.$$

d) If C_{g2} increases, ΔV_2 increases (true/false).

$$\Delta V_2 = C_{c2}\left(\frac{C_{g1}+C_{c1}}{(C_{g1}+C_{c1})\boldsymbol{C_{g2}}+C_{g1}C_{c1}+C_{g1}C_{c2}+C_{c1}C_{c2}}\right)\Delta V_3 \quad \rightarrow \quad \Delta V_2 \; decreases.$$

e) If C_{c1} increases, ΔV_1 increases (true/false).

$$\Delta V_1 = \left(\frac{C_{c2}}{K_1+\frac{K_2}{\boldsymbol{C_{c1}}}}\right)\Delta V_3 \quad \rightarrow \quad \Delta V_1 \; increases.$$

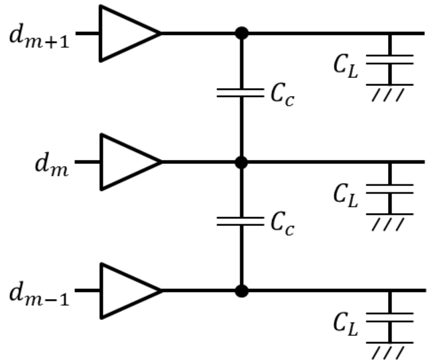
f) If C_{c2} increases, ΔV_1 increases (true/false).

$$\Delta V_1 = \left(\frac{C_{c1}}{K_1+\frac{K_2}{\boldsymbol{C_{c2}}}}\right)\Delta V_3 \quad \rightarrow \quad \Delta V_1 \; increases.$$

g) If C_{c2} increases, ΔV_2 increases (true/false).

$$\Delta V_2 = \frac{1}{\left(1+\frac{K}{\boldsymbol{C_{c2}}}\right)}\Delta V_3 \quad \rightarrow \quad \Delta V_2 \; increases.$$

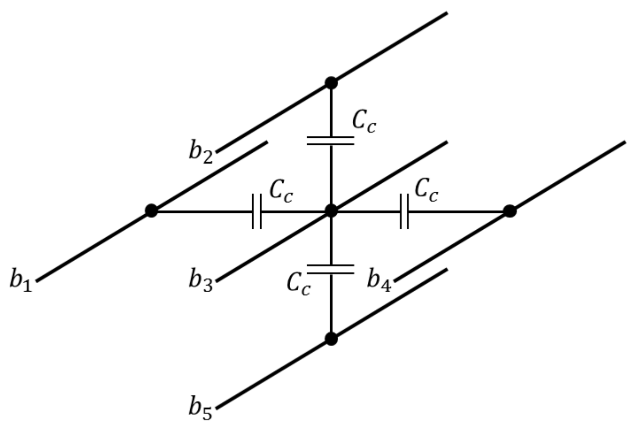
Problem #3 (Coupling Minimization, 20 points).



1 – 10 points) Compute effective capacitance for the net in the middle (d_m) for the following transition patterns:

Transition patterns (d_{m+1} d_m d_{m-1})	Effective cap of d_m
010 → 000	C_L+2C_c
010 → 001	C_L+3C_c
010 → 100	C_L+3C_c
010 → 101	C_L+4C_c

2 – 10 points) A bus consisting of five bits (b_1 b_2 b_3 b_4 b_5) is routed in three metal layers. Due to some unknown reasons, four of them (b_1 b_2 b_4 b_5) are routed in parallel with b_3. The following shows the coupling capacitance among the five nets.



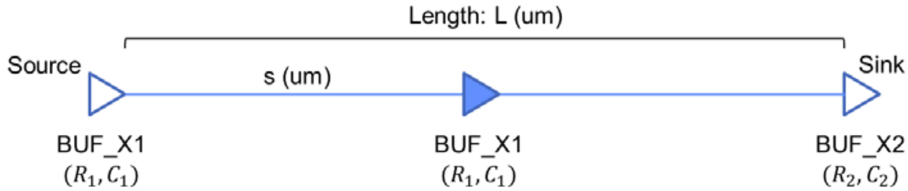
Due to the coupling between b_3 and b_k, the worst-case effective coupling capacitance that b_3 experiences will be $8 \cdot C_c$. List all transition patterns that make b_3 experience $8 \cdot C_c$ and $7 \cdot C_c$.

$8C_c$: 00100 ↔ 11011

$7C_c$: 00100 ↔ 11010 / 00100 ↔ 11001 / 00100 ↔ 10011 / 00100 ↔ 01011

11011 ↔ 00101 / 11011 ↔ 00110 / 11011 ↔ 01100 / 11011 ↔ 10100

Problem #4 (Buffer Insertion, 20 points).



A source (type: BUF_X1) drives a sink (type: BUF_X2) through a net and you are supposed to insert a buffer (type: BUF_X1) between them as shown in the above figure. Find an optimal location of the buffer minimizing the total delay, i.e., represent “s” as a function of the following parameters.

- Output resistance of BUF_X1: R_1
- Input capacitance of BUF_X1: C_1
- Input capacitance of BUF_X2: C_2
- Total length of the net: L (um)
- Total wire resistance: R_w
- Total wire capacitance: C_w
- $(C_w + C_2 > C_1)$

Delay = $\tau = \left(R_1\left(C_w \cdot \frac{s}{L} + C_1\right) + R_w \cdot \frac{s}{L} \cdot C_1 + \frac{1}{2}\left(R_w \frac{s}{L}\right)\left(C_w \frac{s}{L}\right)\right)$

$$+\left(R_1\left(C_w \cdot \frac{L-s}{L} + C_2\right) + R_w \cdot \frac{L-s}{L} \cdot C_2 + \frac{1}{2}\left(R_w \frac{L-s}{L}\right)\left(C_w \frac{L-s}{L}\right)\right)$$

$$= R_1 C_w + R_1 C_1 + R_1 C_2 + R_w\left(\frac{s}{L} \cdot C_1 + \frac{L-s}{L} \cdot C_2\right) + \frac{1}{2L^2} R_w C_w (s^2 + s^2 - 2Ls + L^2)$$

$$\frac{d\tau}{ds} = \frac{R_w C_1}{L} - \frac{R_w C_2}{L} + \frac{R_w C_w}{2L^2}(4s - 2L) = 0$$

$$s\left(\frac{2R_w C_w}{L^2}\right) = \frac{R_w C_w}{L} + \frac{R_w (C_2 - C_1)}{L}$$

$$\therefore s = \frac{L(C_w + C_2 - C_1)}{2C_w}$$