EE434

ASIC and Digital Systems

Midterm Exam 2

Apr. 8, 2020. (2:10pm – 3pm)

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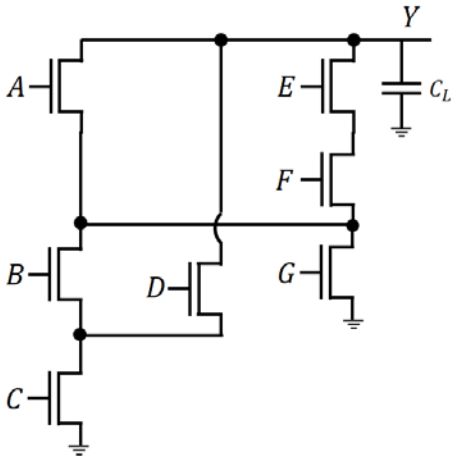
Name:

WSU ID:

Problem	Points	
1	10	
2	10	
3	20	
4	10	
5	10	
6	10	
7	10	
Total	80	

Problem #1 (Transistor Sizing, 10 points)

Size the transistors in the following NFET network. Timing constraint: $\tau \leq R_n C_L$. $\frac{\mu_n}{\mu_p} = 2$. R_n is the resistance of a 1X NFET. Try to minimize the total TR width heuristically.

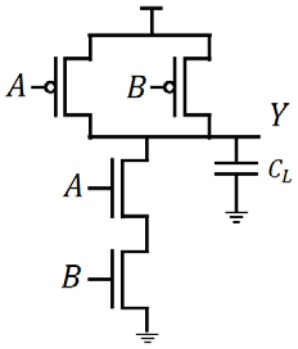


The longest path is EFBC, so we upsize them to 4X. The next longest path is ABC or DBG. For ABC, A becomes 2X. For DBG, D and G becomes $\frac{8}{3}$X.

A: 2X
B: 4X
C: 4X
D: $\frac{8}{3}$X
E: 4X
F: 4X
G: $\frac{8}{3}$X

Problem #2 (Transistor Sizing + Timing Analysis, 10 points)

In this problem, we will size the transistors of a gate for more complex timing constraints. $\frac{\mu_n}{\mu_p} = 2$. R_n is the resistance of a 1X NFET. Timing constraint: $\tau \leq R_n C_L$.



We usually assume that A and B are available at time 0, so the output Y should be ready by time $R_n C_L$. In this problem, A is available at time $t = 0$ (i.e., the arrival time of signal A is 0), but B is available at time $t = \frac{R_n C_L}{2}$ (i.e., the arrival time of signal B is $\frac{R_n C_L}{2}$). The output Y should be ready by time $t = R_n C_L$. Size the transistors to satisfy the timing constraint (and you should try to minimize the total TR width).

NFETs: Now, the timing constraint is $\frac{R_n C_L}{2}$. Thus, A and B should be 4X.

PFETs: For signal A, the timing constraint is $R_n C_L$, so A should be 2X. For signal B, the timing constraint is $\frac{R_n C_L}{2}$, so B should be 4X.

NFETs

A: 4X

B: 4X

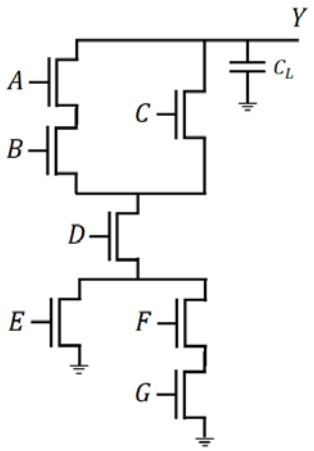
PFETs

A: 2X

B: 4X

Problem #3 (Transistor Sizing + Timing Analysis, 20 points)

This problem is similar to Problem #2. $\frac{\mu_n}{\mu_p} = 2$. R_n is the resistance of a 1X NFET. Timing constraint: $\tau \leq R_n C_L$. The following shows the NFET network of $Y = \overline{(AB + C)D(E + FG)}$.



The following shows the arrival times of the input signals. Size the transistors properly to satisfy the timing constraint (and you should try to minimize the total TR width).

- $A: t = \frac{R_n C_L}{6}$
- $B, D, E, G: t = \frac{R_n C_L}{8}$
- $C: t = \frac{R_n C_L}{4}$
- $F: t = \frac{R_n C_L}{16}$

For path ABDFG: delay should be $\leq R_n C_L - \frac{R_n C_L}{6} = \frac{5R_n C_L}{6}$

For path ABDE: delay should be $\leq R_n C_L - \frac{R_n C_L}{6} = \frac{5R_n C_L}{6}$

For path CDFG: delay should be $\leq R_n C_L - \frac{R_n C_L}{4} = \frac{3R_n C_L}{4}$

For path CDE: delay should be $\leq R_n C_L - \frac{R_n C_L}{4} = \frac{3R_n C_L}{4}$

Optimize ABDFG first: Size all of them to aX. Then, $\frac{R_n}{a} * 5 * C_L \leq \frac{5R_n C_L}{6}$, so $a = 6$X.

Then, optimize CDFG: Size C to cX. Then, $(\frac{R_n}{c} + \frac{R_n}{6} * 3) * C_L \leq \frac{3R_n C_L}{4}$, so $c = 4$X.

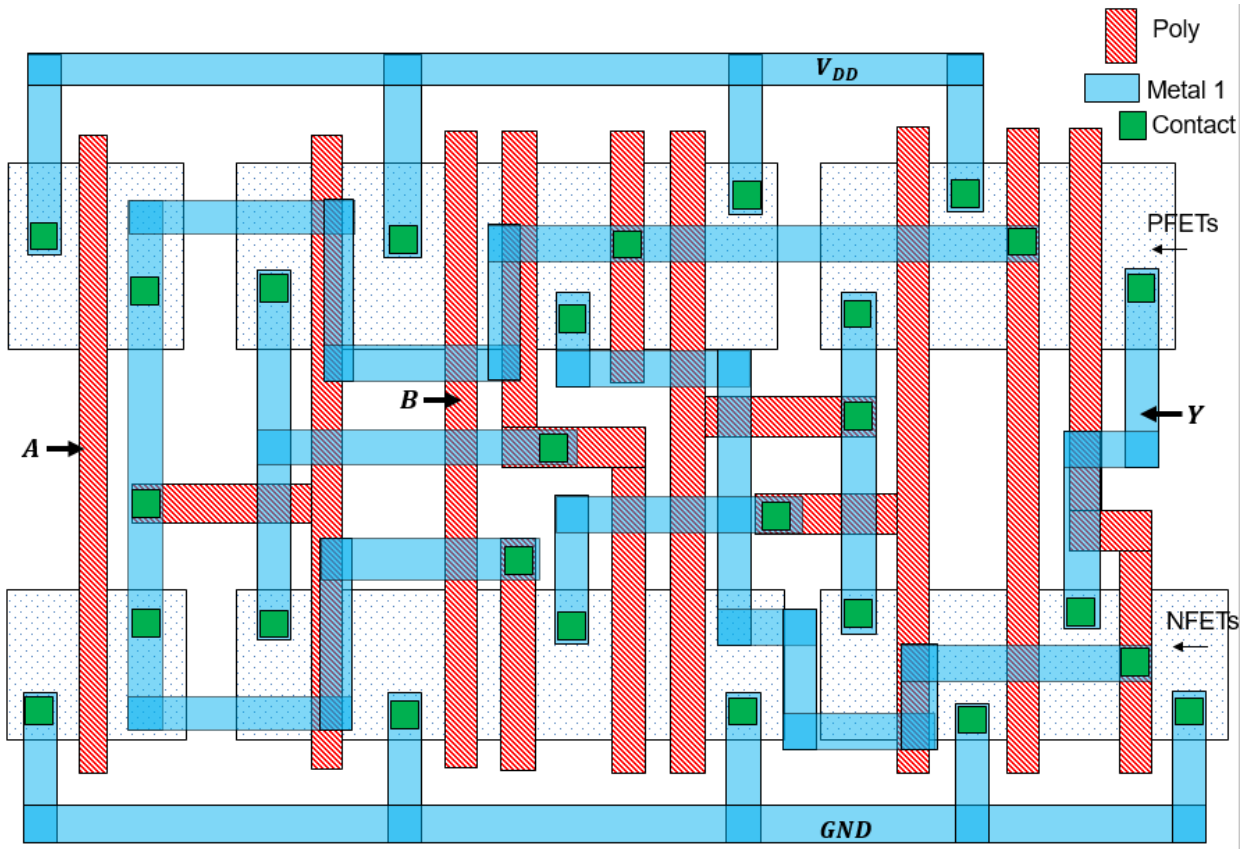
Then, optimize CDE: Size E to eX. Then, $(\frac{R_n}{e} + \frac{R_n}{4} + \frac{R_n}{6}) * C_L \leq \frac{3R_n C_L}{4}$, so $e = 3$X.

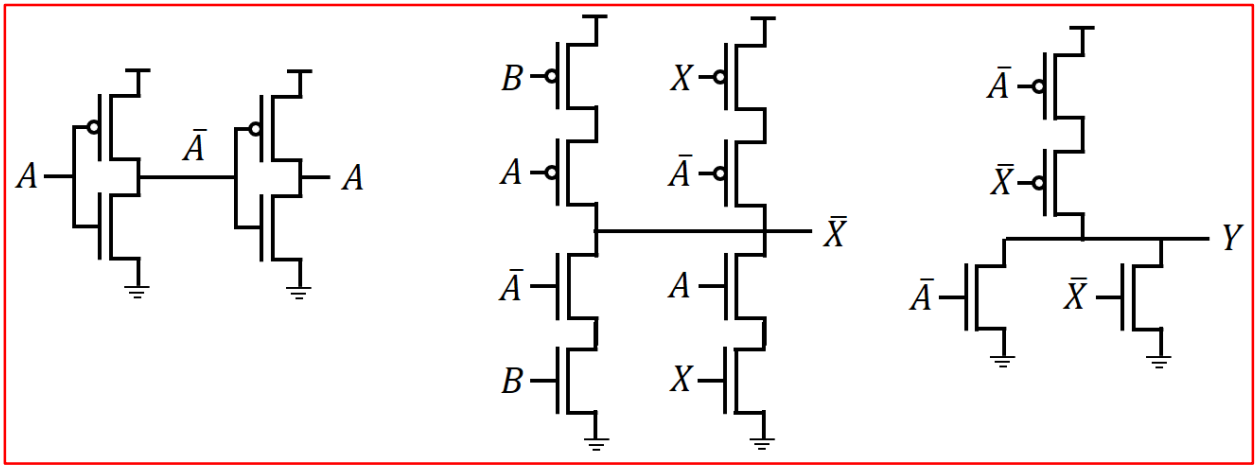
For ABDE: Delay = $\left(\frac{R_n}{6} * 3 + \frac{R_n}{3}\right) * C_L = \frac{5R_n C_L}{6} \leq \frac{5R_n C_L}{6}$ (satisfies the timing constraint).

Answer) A, B, D, F, G: 6X. C: 4X. E: 3X.

Problem #4 (Layout, 20 points)

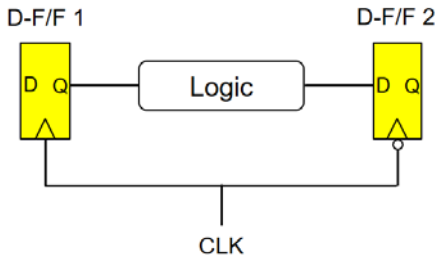
Draw a transistor-level schematic for the following layout.





Problem #5 (Static Timing Analysis, 10 points)

If the clock skew for the following logic is too negative or too positive (i.e., too large), it won't work correctly (the signals won't be captured correctly). Derive two inequalities that the clock skew should satisfy.



Use the following constants:

- Setup time of D-FF 1, 2: s_1, s_2
- Hold time of D-FF 1, 2: h_1, h_2
- Clock period: T_{CLK}
- Logic delay: T_{logic}
- C-Q delay of D-FF 1, 2: c_1, c_2
- Delay from the CLK source to D-FF 1, 2: d_1, d_2
- The clock skew is defined by $T_{skew} = d_2 - d_1$

If the skew is too large (i.e., $d_2 \gg d_1$), the hold time violation at D-FF2 will be a problem. If the skew is too small (i.e., $d_1 \gg d_2$), the setup time violation at D-FF2 will be a problem. Thus, the result of the logic ($d_1 + c_1 + T_{logic}$) should be available after D-FF2 captures its input correctly ($d_2 + h_2$), but before D-FF2 captures the result of the logic ($d_2 + T_{CLK} - s_2$).

$$d_2 + h_2 \leq d_1 + c_1 + T_{logic} \leq d_2 + T_{CLK} - s_2$$

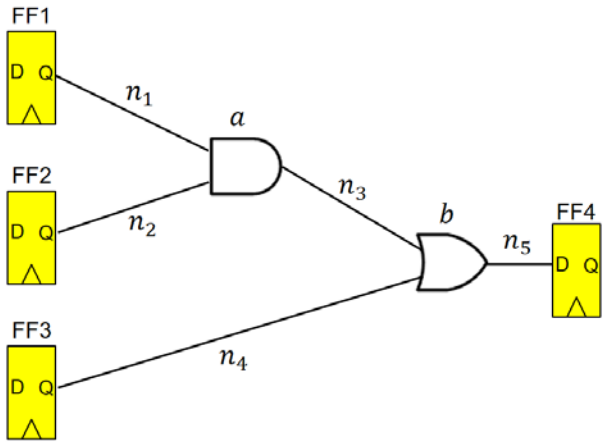
Thus,

Answer: $$c_1 + T_{logic} - T_{CLK} + s_2 \leq T_{skew} \leq c_1 + T_{logic} - h_2$$

(Notice that this is just a rearrangement of the setup- and hold-time inequalities we studied.)

Problem #6 (Static Timing Analysis, 10 points)

Find setup and hold time inequalities that the following logic has to satisfy.



Use the following constants:

- Setup time of D-FF 1, 2, 3, 4: s_1, s_2, s_3, s_4
- Hold time of D-FF 1, 2, 3, 4: h_1, h_2, h_3, h_4
- Clock period: T_{CLK}
- C-Q delay of D-FF 1, 2, 3, 4: c_1, c_2, c_3, c_4
- Delay from the CLK source to D-FF 1, 2, 3, 4: d_1, d_2, d_3, d_4
- Net and gate delays: n_1, n_2, n_3, n_4, a, b

You can also use MAX and MIN operators.

Setup:

$$MAX[MAX(d_1 + c_1 + n_1, d_2 + c_2 + n_2) + a + n_3, d_3 + c_3 + n_4] + b + n_5 \leq d_4 + T_{CLK} - s_4$$

Hold:

$$MIN[MIN(d_1 + c_1 + n_1, d_2 + c_2 + n_2) + a + n_3, d_3 + c_3 + n_4] + b + n_5 \geq d_4 + h_4$$

Problem #7 (Static Timing Analysis + Pipelining, 10 points)

Suppose an (ideally-partitionable) logic is given. Its delay is d. If we partition it into p equally-distributed pipeline stages, the delay of the sub-logic in each pipeline stage becomes $\frac{d}{p}$ (Notice that $p \geq 1$).

If we run N instructions sequentially in the pipeline, it takes total $\#(N + p - 1)$ clock cycles to execute all the instructions. The total execution time is $(N + p - 1) \cdot T_p$ where T_p is the clock period for the p-pipelined system.

All the flip-flops have the same characteristics:

- C-Q delay: c
- Setup time: s
- Hold time: h

Answer the following questions.

The system should satisfy the typical setup and hold time constraints.

$$h - c \leq \frac{d}{p} \leq T_p - (c + s)$$

(1) Assume $c > 0, s > 0, h > 0, h > c$, and the clock skew is zero. Find the maximum value of p that does not lead to hold-time violations.

From the inequality above, the maximum value of p is $\frac{d}{h-c}$.

(2) Assume $c > 0, s > 0, h > 0$, and the clock skew is zero. Find the minimum value of T_p that does not lead to setup-time violations.

From the inequality above, the minimum value of T_p is $\frac{d}{p} + c + s$.

(3) If $c = 0, s = 0, h = 0$, we should always increase p to reduce the execution time (**True** / False).

In this case, $T_p = \frac{d}{p}$, so the execution time is $\frac{d}{p} \cdot (N + p - 1) = d + \frac{d(N-1)}{p}$, so we should increase p as much as we can.

(4) If $c > 0, s = 0, h = 0$, we should always increase p to reduce the execution time (True / **False**).

$T_p = \frac{d}{p} + c$, so the execution time is $\left(\frac{d}{p} + c\right) \cdot (N + p - 1) = d + \frac{d(N-1)}{p} + c(N - 1) + cp$. Thus, p has a certain optimal value. (If you want to compute, you can. From $-\frac{d(N-1)}{p^2} + c = 0$, we get $p = \sqrt{\frac{d(N-1)}{c}}$)

(5) If $c = 0, s > 0, h = 0$, we should always increase p to reduce the execution time (True / **False**).

$T_p = \frac{d}{p} + s$, which is similar to case (2).

(6) If $c = 0, s = 0, h > 0$, we should always increase p to reduce the execution time (True / **False**).

In this case, $T_p = \frac{d}{p}$. However, since $h \leq \frac{d}{p}$, p cannot be greater than $\frac{d}{h}$.