

You may hand in your solution via email ([cs141-2009-staff@eecs.harvard.edu](mailto:cs141-2009-staff@eecs.harvard.edu)) or in person at the beginning of the lecture

## 1 Required Reading

Sections 4.1, 4.2 (ignore sections on VHDL), 4.3, 5.1, 5.2.1 – 5.2.7, 5.6.1

## 2 Optional Reading

Sections 5.5.6, 5.6.2 – 5.6.3

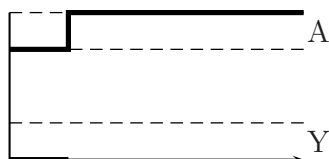
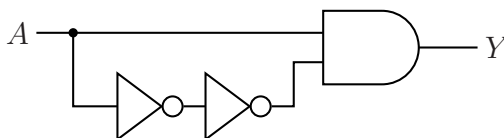
## 3 Problems (50 total points)

Please show your work in your solutions.

1. (8 points) Draw schematics for the functions below using only NAND or NOR gates.

- a.  $A\bar{B}C + AB + B\bar{C}$  using only NOR gates
- b.  $(A + \bar{B})(\bar{B} + C + \bar{D})(\bar{A} + B)$  using only NAND gates
- c.  $\bar{A}B(\bar{B} + C)D + A$  using only NAND gates

2. (8 points) Complete the timing diagram and explain the function of the circuit in diagram below. Assume that the propagation delay of an AND gate is  $t_{AND}$  and of an inverter –  $t_{INV} = t_{AND}$ .



3. (12 points) Design a circuit that has two data inputs ( $A$  and  $B$ ) and three control inputs ( $C_0$ ,  $C_1$  and  $C_2$ ). The circuit should implement the function  $F$  specified in the functional truth table below. Please give the boolean equation for  $F$  and show how to implement this function using a programmable logic array (PLA) with 5 inputs and 1 output. Draw the AND and OR array, and indicate which connections must be made to implement the function using the shorthand PLA notation. Minimize your design. Components of this type find wide application in microprocessor datapaths.

$C_0$	$C_1$	$C_2$	$F$	Comments
0	0	0	1	always 1
0	0	1	$A + B$	OR
0	1	0	$\sim (A B)$	NAND
0	1	1	$A \oplus B$	XOR
1	0	0	$\sim (A \oplus B)$	XNOR
1	0	1	$A B$	AND
1	1	0	$\sim (A + B)$	NOR
1	1	1	0	always 0

4. (12 points) Below we present four functions of either three or four variables. The latter two expressions feature C-style operators: equality, inequality, boolean and, boolean or. Determine the shorthand ( $\Sigma$ ) notation for expressions in (c) and (d) and find the minimized sum-of-products expressions for all four expressions.

a.  $f(A, B, C, D, E) = \Sigma_{A,B,C,D,E}(13, 15, 16, 17, 23, 24, 25, 29, 31)$

b.  $f(A, B, C, D, E) = \Sigma_{A,B,C,D,E}(0, 3, 7, 8, 11, 13, 15, 16, 24, 25, 28, 29, 31)$

c.  $f(A, B, C) = (A == (B \& C))$

d.  $f(A, B, C) = (A != (B | C))$

5. (10 points) Implement a combinational logic circuit that converts a 4-bit sign and magnitude number into the corresponding 4-bit 2s-complement number. Draw the truth table, K-maps and the minimized two-level boolean logic equations