

You may hand in your solution via email (cs141-2009-staff@eecs.harvard.edu) or in person at MD 311.

## 1 Required Reading

Please read 1.1-1.6, 1.7.5-1.7.7, 1.9, 2.1-2.5

## 2 Suggested Reading

The remainder of section 1.7 is helpful if you want to know more about transistors. Section 1.8 explains why digital circuits use energy.

## 3 Problems (50 total points)

Please show your work in your solutions. If you need any help, please contact the TFs with questions.

### Problem 1: Number Systems (20 pts)

- A. Convert  $173_{10}$  into binary
- B. Convert  $100001101111_2$  into decimal and hexadecimal. Which was easier? Why?
- C. Write  $-99_{10}$  into Two's Complement using 8 bits. Express your answer in binary.
- D. Subtract  $00010011_2 - 00011001_2$ . Both numbers are expressed in 8 bit Two's Complement. Perform your calculation in Two's Complement, and then convert the result to decimal.
- E. Give two reasons why two valid Two's Complement numbers might add incorrectly? Please illustrate each reason with an example.

### Problem 2: Transistor Logic (10 pts)

We're going to design the CMOS transistor gate schematic for the equation:

$$Y = (\bar{A} \cdot B) + C.$$

- A. Write the equation for  $\bar{Y}$
- B. Design the transistor gate schematic. You may use  $A, \bar{A}, B, \bar{B}, C$  and  $\bar{C}$  as inputs. (Hint: use the equation for  $Y$  to design the pMOS half and the equation for  $\bar{Y}$  for the nMOS half)

### Problem 3: Combinational Logic Design (20 pts)

Let's design a 3-input majority gate. The majority gate has three 1-bit inputs --  $A, B,$  and  $C$  -- and a 1-bit output ( $Y$ ). If two or more inputs are equal to 1,  $Y$  will also be 1. Otherwise,  $Y$  will equal 0. For example, if  $A=1, B=0, C=1$  then  $Y=1$ . However, if  $A=0, B=0, C=0$  then  $Y=0$ .

- A. Design a truth table for  $A, B, C, Y$  and  $\bar{Y}$ . Include minterms for  $\bar{Y}$ .
- B. Write an equation for  $Y$  using the truth table minterms. Your answer should be in sum-of-products form.
- C. Simplify the equation for  $Y$
- D. Draw a circuit diagram for  $Y$ , using only inverters, AND gates, and OR gates. You may only use  $A, B,$  and  $C$  as inputs.
- E. Redraw the circuit diagram using inverters, NAND gates, and NOR gates. (Hint: bubble-pushing is helpful)