Name: ______________________ Lab section/TA: ______________________

Homework 3

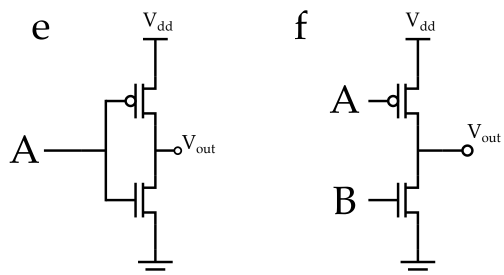
Problem 1: CMOS Logic Gates

(8 Points) The output of a valid logic gate should always be connected to either V_{dd} or ground, and never both at the same time. For each of the two circuits below:

(a) State whether or not it is a valid logic gate.

(b) If it does not form a valid logic gate, state why. If it is a valid logic gate, describe its function.

Assume the wires labeled A and B are digital logic signals that can be either V_{dd} or ground (”high” or ”low”).



Problem 2: NOR gate design with transistors

(10 Points) Draw a schematic for a three input NOR gate. The logic formula for NOR is $!(A|B|C)$. Be sure to clearly label the inputs and output.

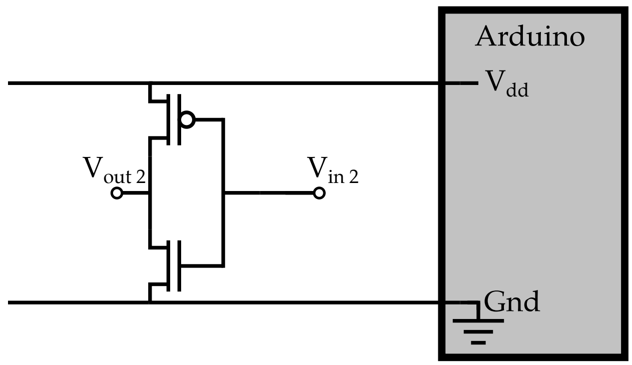
Besides the input and output wires, you are ONLY allowed to use the following: additional wires, discrete NMOS and PMOS transistors, V_{dd} and ground.

Problem 3: When your transistors get hot

(8 Points) Below is a power inverter that is used in the useless box lab 2B.

A team of students built their power inverter in lab, and they connected it the V_{dd} and ground pins of their arduino. They wanted to verify that their code ran correctly before making any more connections, so they did not connect $V_{in\,2}$ to arduino digital I/O pins, nor did they connect $V_{out\,2}$ to the motor. After setting aside the circuit to test their code, they noticed that the transistors became rather warm. What can happen to an inverter if you leave the input floating that might make the transistors get warm?

Do not make this mistake in lab. Make sure the inputs to the inverters are connected to V_{dd}, ground, or a driven output pin.



Problem 4: Binary arithmetic and negative numbers

(8 Points) Representing positive numbers in binary is straightforward, but negative numbers are a little more tricky. One solution would be to use the most significant bit (MSB) to represent the sign, and to use the rest of the bits to represent the magnitude of the number. However, this requires some rather complex logic to detect the sign and handle addition and subtraction properly.

A better solution, and the one most commonly used, is known as "two's complement notation." In two's complement, positive numbers are represented just as usual, and the MSB of a positive number is always zero. To find the two's-complement representation for a negative number, take the binary representation of its absolute value, invert all of its bits, and add one.

Thus, to represent -1 with four bits:

- The four-bit binary representation of $|-1| = 1$ is 0001
- Inverting all bits, we get 1110
- Adding 1, we get 1111

What is the four-bit two's complement for -7?

Write the two's complement for -4 and $+6$, and do the binary addition. You'll have to discard any carries from the fourth bit, but otherwise you should do normal addition. *Hint: If you don't get* $+2$ *as a result, you've done something wrong!*

In this scheme, what is the most negative number that can be represented with 8 bits? With 16 bits?

What is the largest signed number that can be represented with 8 bits and with 16 bits?

For each of the following bits of code, what number will be printed? Briefly explain why. Assume that an `int` is 16 bits, and a `char` is 8 bits (which is the case on most Arduino boards). *Hint 1: Each of these is doing something a little bit weird. Hint 2: If you're stuck or have doubts, try running the code on your Arduino.*

```
char x = -56;
unsigned char y = x;
Serial.println(y);
```

```
char x = 128;
int y = x;
Serial.println(y);
```

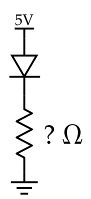
```
unsigned int x = 0;
unsigned int y = x - 1;
Serial.println(y);
```

```
int x = 0;
int y = x - 1;
unsigned int z = y;
Serial.println(z);
```

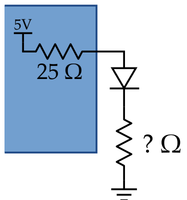
Problem 5: Current-limiting resistors

(3 Points)

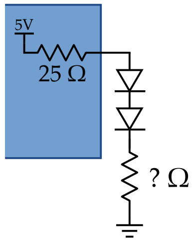
It is important to use resistors to limit the current through your LEDs, because too much current can quickly burn out an LED. Suppose we have a green LED with a forward voltage of 3 V. If we connect it as shown below, what resistance should we use to limit the current to 20 mA?



If we drive this LED with the Arduino, we should also account for the fact that the Arduino pins have an internal resistance of about 25 Ω. What resistance should we pick so that the current is still 20 mA?



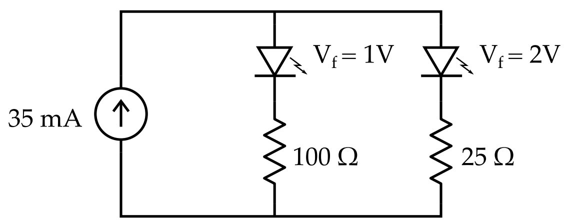
Now we replace the green LED with two red LEDs in series, each having a forward voltage of 2 V. What resistance should we pick so that 20 mA flows through the LEDs?



Problem 6: More LEDs!

(6 Points)

Suppose we have the circuit below, where the left LED has a forward voltage of 1 V and the right LED has a forward voltage of 2 V. What is the current through each LED? *This is a rather contrived problem and doesn't have direct application. It's intended to help you practice combining a number of concepts you've learned up to this point in the class.*



Problem 7: Reflection

(2 Points) How long did it take you to complete this assignment?

Which problem did you learn the most from, or which problem best solidified your understanding?