Remember, you are expected to show up at lab with a paper solution to every part of this lab already in hand! You should NOT begin your design process during lab! You should be able to immediately being building your circuit when you arrive!

Overview:

Today's lab is a design project that might be a small part of the control and warning system on the space shuttle. The space shuttle consists of the orbiter (the main spacecraft having 3 engines), the large liquid fuel tank (the large cylinder under the orbiter), and the two booster rockets (for use during lift off).

The orbiter is the only component to orbit the earth. At the end of its mission it returns to the ground by gliding. The two solid rocket boosters are used during the first three minutes of the launch, and are then jettisoned and land in the ocean. They are retrieved by special ships and reused. The cryogenic fuel tank is connected to the Orbiter for about ten minutes. It carries the fuel (at a temperature of less than –200°C) for the three main engines on the back of the Orbiter (but not for the booster rockets). Once emptied, it is jettisoned and burns up in the atmosphere.

This lab contains instructions other than just building a circuit. The instructor will look over that work when the circuits are checked, but nothing will be collected.

Part A: NAND substitution

Any gate can be removed and replaced by some number of NAND gates. For example, if you NAND something ("A") with itself, you get $\overline{A \cdot A}$, which we know is merely $\overline{A}$. So, NANDing a signal with itself is equivalent to an inverter. Here is a list of a few gates and how to make them with nothing but NAND's.
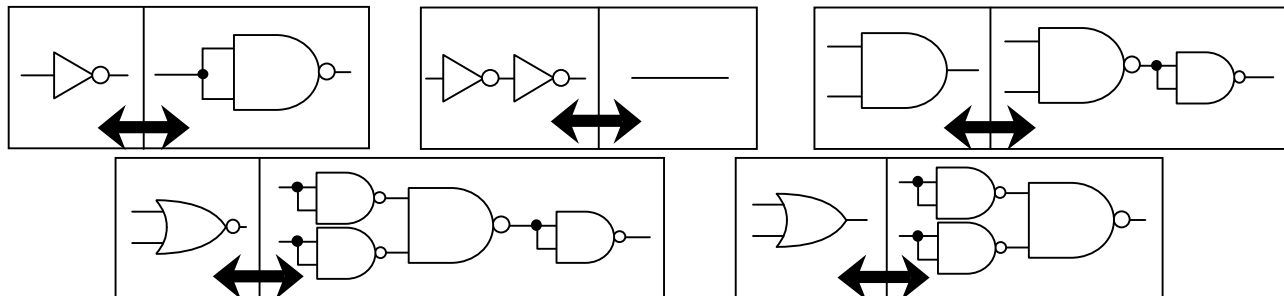
Build a circuit to help protect the shuttle and its occupants during launch. During launch, there are five total engines: the two boosters, and the three main engines. The shuttle is safe to fly with any two or more engines and both solid rocket boosters. You must build a circuit that monitors the three engines and the two solid rocket boosters. Your circuit should use five inputs (switches) and one output. The output is a warning light (LED #7), which illuminates when the shuttle is **not** safe to fly.

Use switches 0 and 1 for the booster rockets, and switches 2, 3, and 4 for the orbiter main engines. Any engine will be considered "on" when the switch output is high. If you want any help in lab with this, you'll need to have neat, full page diagrams for the instructor to look at.

Part A Instructions

- Complete a truth table for the warning light. Of the 32 possible combinations of engine status, only 4 are safe to fly!
- Write an expression for "S", when the shuttle **is safe** to fly, using words (e.g., "safe when booster #1 AND booster #2 OR…"). Then translate that into a Boolean expression.
- Convert your English expression into a circuit using AND's, OR's, etc. You should have five 2-input AND's and two 2-input OR's in your diagram at this point.
- Replace ALL of the gates with NAND gates. You should find that 4 pairs of NANDS being used as inverters cancel out, leaving you with 9 NAND gates.
- Change this expression into an expression for the warning light "W" by adding an inverter just before the final output.
- Build the circuit on a proto-board, and have the instructor verify that it works. (And is neat.) (And correctly obeys wire color rules.)

Part B: Counting

We also want to build a circuit that can count the number of main engines that are active, which can range from zero to three. If none of the engines are on, then LED 0 should light. If one of them is active, then LED 1 should light. If two are active, then LED 2 should light, and of course if all three are active, then LED 3 should be lit. Only one LED at a time should be lit. This entire part can be done with only 5 chips, if you use only NAND and NOR gates. However, you may use as many gates as you want, of any type, provided that they fit into your PAD-234A kit.

Part B Instructions

- Create 4 truth tables, one for each LED.
- Build the circuits for LED 0, 1, and 3.
- LED 2 is on whenever none of the others are on. In other words, $L_2 = \overline{L}_0 \cdot \overline{L}_1 \cdot \overline{L}_3$. Use this idea to build a circuit for LED 2.
- Have the instructor verify that all four of these circuits work.