Lab #3 - Practical Logic Design Problem.

OBJECTIVE: The purpose of this lab exercise is to introduce you to the process of a practical logic circuit design.

EQUIPMENT:

protoboard, preferably with switches
7400 Quad NAND Gate
7404 Hex Inverter
7408 Quad AND Gate
7432 Quad OR Gate
LEDs (Red, Yellow, Green with limiting resistor (220Ω)).

THEORY: The previous experiments introduced some of the basic logic functions and gates that are available. These gates can be thought of as the building blocks of all modern digital control circuits. We'll look at a relatively simple example in this experiment. However these same components can be combined in single integrated circuits containing hundreds, thousands and millions of these gates. This will produce circuits such as digital clocks, fuel injection controls, microprocessors, cell phones and computers. In this exercise, you will construct several circuits that use basic logic gates to solve the specified problem.

Remember: Integrated circuits are *active devices* and **require power and a ground connections**. It is common for these power connections to be implied and not shown on schematics, but they MUST be made or the circuit won't function properly. ***IMPORTANT: Power should be disconnected or shut-off during the construction of or whenever making changes to your circuit.***

PROBLEM

Design a seatbelt warning light system that will light the light under the specified conditions. We want the light to go on if the ignition is on, the seat is occupied and the seatbelt is unfastened. (While we could possibly improve upon this example, we'll keep it simple for starters, and then work on improvements.)

SOLUTION: This type of problem lends itself nicely to digital logic circuits. Thinking about what needs to be defined for this circuit we can simplify the the problem to four parameters: **Ignition** (*on/off*), **Seat** (*occupied/unoccupied*), **Belt** (f*astened/unfastened*) and **Light** (*on/off*). Looking at the states of each parameter (*on/off*, *occupied/unoccupied*, *fastened/unfastened*) clearly demonstrates the relationship to the digital electronics states of (0/1). That is, these are all binary relationships. There are only two possible states.

So, the process is:

1.) Define each variable in terms of 0's and 1's
2.) Construct a truth table relating the input/output combinations.
3.) Build the circuit.

STEP #1: Define the Variables.

As stated above, there are 4 variables used in this problem: three for the inputs and one for the output. The actual definitions might depend upon the switches/sensors used for the problem, but since we don't know anything about those, we have the freedom to choose our own.

Inputs:

I = Ignition: 0 = ignition is off
1 = ignition is on

S = Seat: 0 = seat is unoccupied
1 = seat is occupied

B = Belt: 0 = belt is unfastened
1 = belt is fastened.

Output:

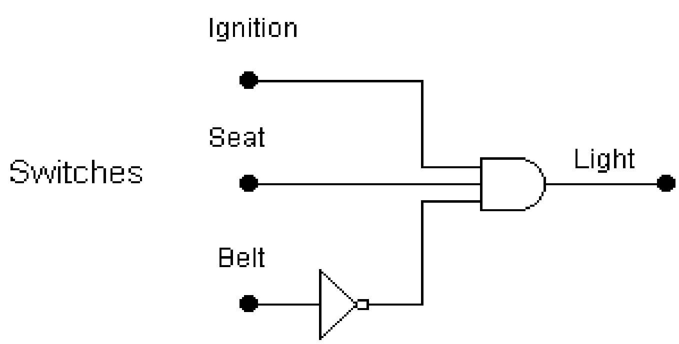
L = Light: 0 = light is off
1 = light is on

Our truth table will have 3 input variables (I, S, B) and a single output variable (L).

STEP #2: TRUTH TABLE

Row #	I	S	B	L	Comments
0	0	0	0	0	Ignition is off, so Light is *off*. S & B don't matter.
1	0	0	1	0	Ignition is off, so Light is *off*. S & B don't matter.
2	0	1	0	0	Ignition is off, so Light is *off*. S & B don't matter.
3	0	1	1	0	Ignition is off, so Light is *off*. S & B don't matter.
4	1	0	0	0	Ign. is on, but no one in seat, not belted, Light is *off*.
5	1	0	1	0	Ign. is on, no one in seat, belted, Light is *off*.
6	**1**	**1**	**0**	**1**	**Ign. is on, seat occupied, not belted, Light is *on*.**
7	1	1	1	0	Ign. is on, seat occupied, belted, Light is *off*.

From the truth table above, we see that there is a single condition when the light will be ***on*** (1): When the Ignition is on AND when the seat is occupied AND the belt is unfastened. Using our definitions: If I=1 AND S=1 AND B=0 then L=1. Under all of the other conditions, L=0. This can be accomplished with an AND gate and an INVERTER (NOT gate). The INVERTER will complement the value of B so that when the switches for ISB = 110, the AND gate will see the input combination 111, causing the output to become 1 and lighting the warning light. **This is called *minterm* design: Designing the logic circuit to implement the 1's in the truth table.**

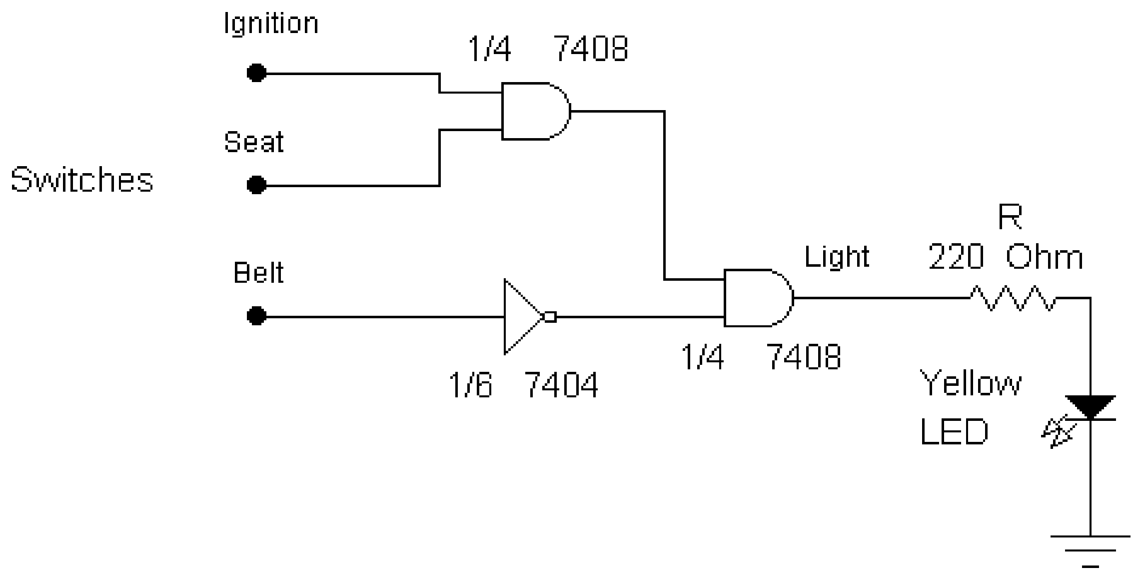


STEP #3: Build the Circuit.

(NOTE: To aid in construction, it is recommended that you write the pin numbers for each gate on the schematic diagram before you attempt to wire the circuit.)

PROCEDURE:

1.) Construct the circuit shown below using a single 7408 Quad 2-input AND gate, a single 7404 Hex INVERTER, a yellow LED and a resistor as shown. You should recognize this circuit as the solution outlined above. Note that the 3-input AND gate is being implemented using 2 2-input AND gates. Also remember that all IC chips require +5V and ground connections in order to work. Be sure to use a separate yellow LED for this circuit. (Do not use the red LEDs contained on the protoboards, if so equipped.)



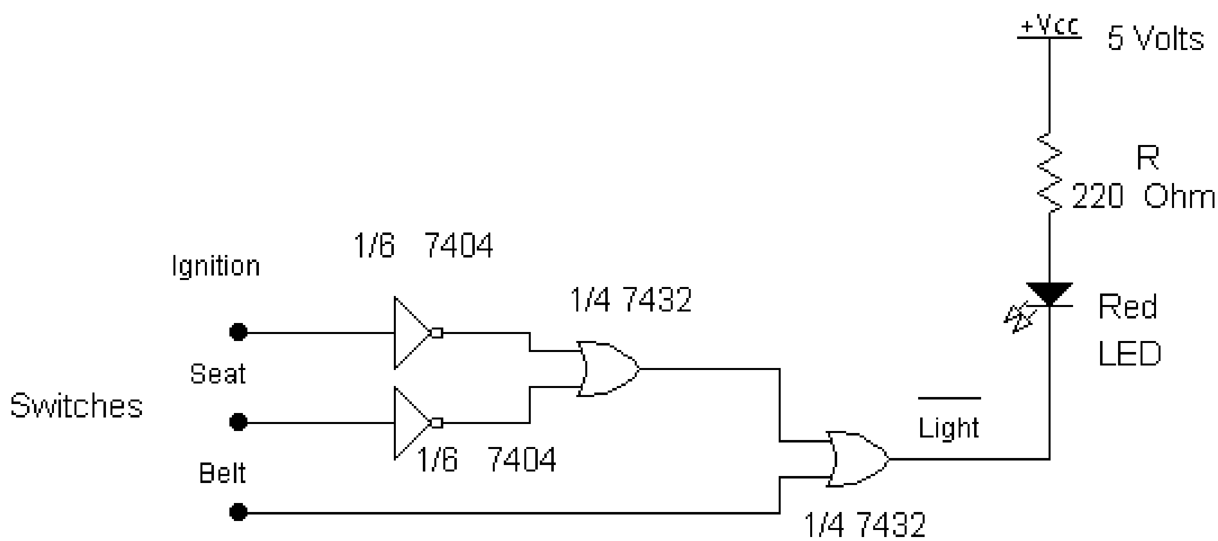
Circuit #1

2.) Once your circuit is built, complete the column labelled ***Circuit #1*** in the truth table below and verify that your circuit performs as expected. Keep Circuit #1 connected.

Row #	I	S	B	L	*Circuit #1 (Yellow)*	*Circuit #2 (Red)*	*Circuit #3 (Green)*
0	0	0	0	*off*			
1	0	0	1	*off*			
2	0	1	0	*off*			
3	0	1	1	*off*			
4	1	0	0	*off*			
5	1	0	1	*off*			
6	**1**	**1**	**0**	***on***			
7	1	1	1	*off*			

3.) Circuit designers often have a lot of freedom in their design. The circuit constructed in step #1 above caused the LED to light when the L signal was a HIGH or 1. The circuit below should light the LED with the same combination of I, S & B, however it is wired such that the LED will light when the L signal is a LOW or 0. Note that the circuit output is now labelled $\overline{\text{Light}}$ to indicate the light will light when the signal is LOW. (This is called an “Active Low” signal.) **This is called *maxterm* design: Designing the logic circuit to implement the 0's in the truth table.**

The important thing to observe here is that the lights on both circuits should be on and off at the same time, showing that the circuits are identical. Construct this circuit using a single 7432 Quad 2-input OR gate, a 7404 Hex INVERTER, a Red LED and the resistor. NOTE: Use the same switches used in the previous circuit so that you can test both circuits simultaneously. Note that the 2-input OR gates are used to construct a 3-input OR function. The LED must be wired in as shown, notice that it is now connected to power and the output of the gate, instead of the gate output & ground as done previously.



Circuit #2

4.) Operate the 3 switches once again and complete the ***Circuit #2*** column in the truth table in step #2.

Do both circuits light their LEDs under the same I, S & B switch conditions? _____________

5.) Have your instructor verify that you have both circuits constructed and working properly. Keep both circuits connected.

Instructor initial _____________________

6.) Convert your *Circuit #2* to all NAND gates (use this link as a guide http://electronicsclub.info/gates.htm and scroll to the bottom to *Substituting One Type of Gate for Another*), draw the schematic diagram below (use a green LED for the output), construct the circuit and verify that it works properly. Use the same switches used in *Circuit #1* and *Circuit #2* so that all circuits will operate together. Complete the Truth Table for *Circuit #3*.

Did all three LEDs light up under the same switch conditions? _________________

Is the output of the NAND circuit active HIGH or active LOW? ____________________________

Have your instructor verify the circuit.

Instructor initial _____________________

7.) Use https://circuitverse.org/ to construct each of the three circuits. Have your instructor verify each of your simulated circuits.

Circuitverse.org Simulation Results

Row #	**I**	**S**	**B**	**L**	***Circuit #1 (minterm)***	***Circuit #2 (maxterm)***	***Circuit #3 (NAND)***
0	0	0	0	*off*			
1	0	0	1	*off*			
2	0	1	0	*off*			
3	0	1	1	*off*			
4	1	0	0	*off*			
5	1	0	1	*off*			
6	**1**	**1**	**0**	***on***			
7	1	1	1	*off*			
Instructor Initial:							

QUESTIONS:

1.) How many inputs and outputs did this design problem have?

2.) If this circuit was to be modified to also include a seatbelt switch and seat sensor for the passenger seat, how many rows would the truth table be required to have?

3.) Based upon the integrated circuit count, which of the three circuits would be the most expensive to build?

4.) Based upon the integrated circuit count, which of the three circuits would be the least expensive to build? Why?

5.) For 7400 series logic chips, is an unconnected input (aka floating input) interpreted by the IC as a logic LOW or a logic HIGH?

6.) What is the difference between an active HIGH signal and an active LOW signal? Which circuits in this lab used a.) an active HIGH output signal? b.) an active LOW output signal?

7.) For the active HIGH output circuit(s), did the output gate *sink* or *source* current to the LED?

8.) For the active LOW output circuit(s), did the output gate *sink* or *source* current to the LED?

9.) Why might a designer choose to use active LOW signals in a system?

WHAT TO SUBMIT:
Make sure you have your instructor's initials where required and that you answered any questions. Then submit these lab sheets to your instructor. Make a post on the *cset.stcc.edu/forums* under EET-210 Lab Week #4 stating that you have completed this experiment.