UNIVERSITY PHYSICS II HONORS PROJECT

BUILDING LOGIC GATES WITH TRANSISTORS

INSTRUCTOR:

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LAB SECTION S5

BY

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A logic gate is an electronic-physical device that implements Boolean functions. It performs a logical operation depending on the input signal. Logic gates then according to the specific Boolean algebra, outputs a signal. There many types of logic gates. AND, NAND, OR, NOR, XOR, XNOR and NOT are most common logic gates that are being used today. Some of these also have the variation of 2, 3 or even 4 input gates. I will be constructing 2 input NAND, NOR and AND gates using transistors.

In almost every electronic device we use today, which includes smart phones, laptop computers, TVs, projectors, has millions of logic gates implemented inside their circuits. There are also several logic families that are being used today for different purposes (power consumption, speed, cost, size) such as: RDL (Resistor-Diode Logic), RTL(Resistor-Transistor Logic), DTL (Diode-Transistor Logic), TTL (Transistor-Transistor Logic) and CMOS (complementary metal oxide semiconductor). Today, logic gates can most commonly be found as an integrated circuit (IC). Figure 1 shows an NAND logic gate which is also known as 7400 series as an IC.

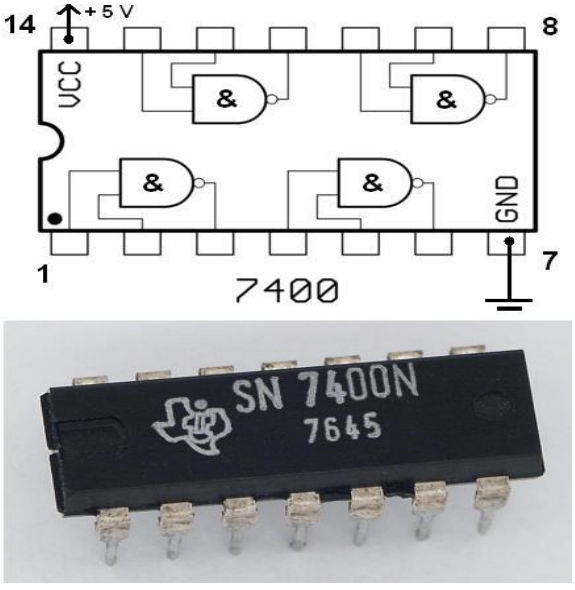

Figure 1: NAND gate

As technology has moved a long way, logic gates are integrated into the circuits as very small chips. As these chips get smaller, it may also get harder to understand how they actually work. This is the reason why I decided to do this project, to show in a much larger scale, how these logic gates actually perform a Boolean function.

In this project I will be building 2 input NAND gate, 2 input NOR gate and 2 input XOR gate. To understand what these logic gates actually do, we need to take a look at the truth table.

Input_1	Input_2	Output
0	0	1
0	1	1
1	0	1
1	1	0

Figure 2: Truth table of a NAND gate

Input_1	Input_2	Output
0	0	1
0	1	0
1	0	0
1	1	0

Figure 3: Truth table of a NOR gate

Input_1	Input_2	Output
0	0	0
0	1	0
1	0	0
1	1	1

Figure 4: Truth table of a AND gate

On the circuit, 1 is for high-voltage and 0 is for low-voltage. So to say, if I have two low voltage inputs to NOR gate, I should see a high-voltage output and so on. Following diagrams shows the circuit of logic gates I will be building:

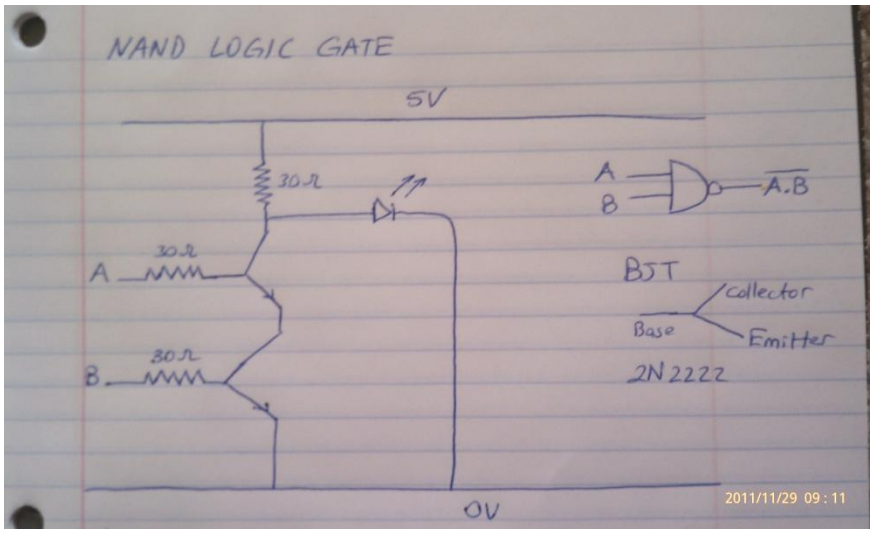

Diagram 1: NAND logic gate

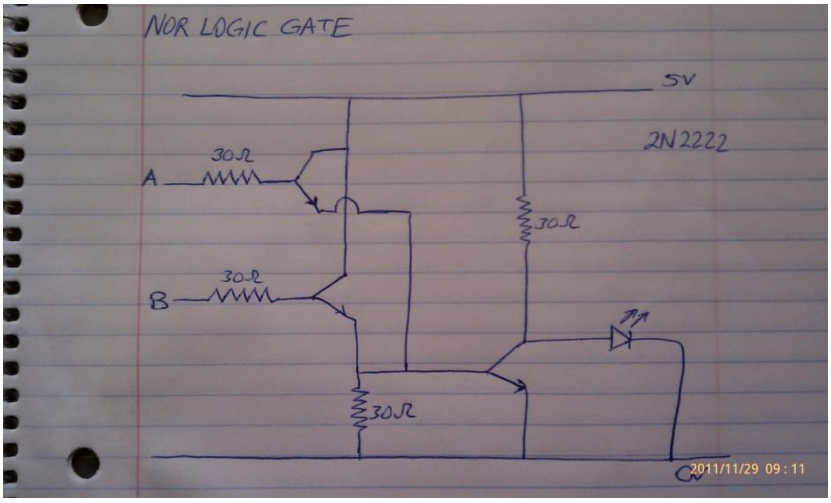

Diagram 2: NOR logic gate

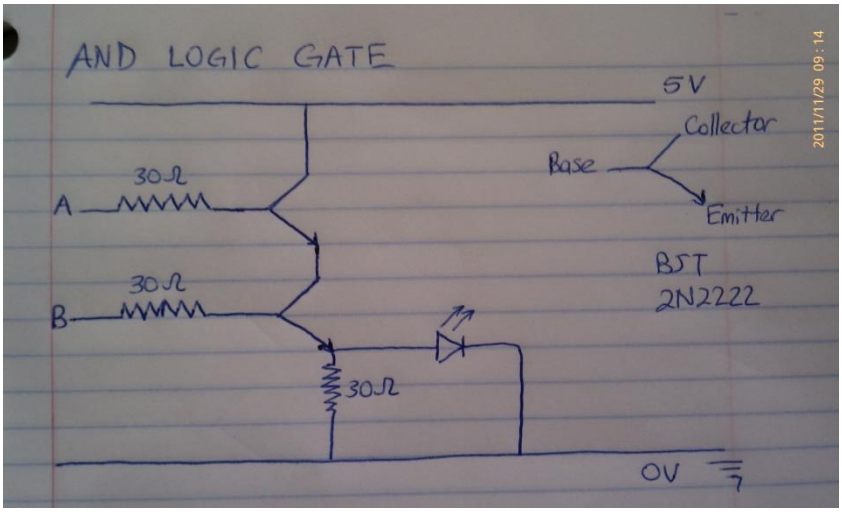

Diagram 3: AND logic gate

The types of transistors I'm using are called Motorola MPS2222A NPN Silicon General Purpose Transistor and Motorola MPS2907A PNP Silicon General Purpose Transistor. I'm also using 30K Ohm Resistors.

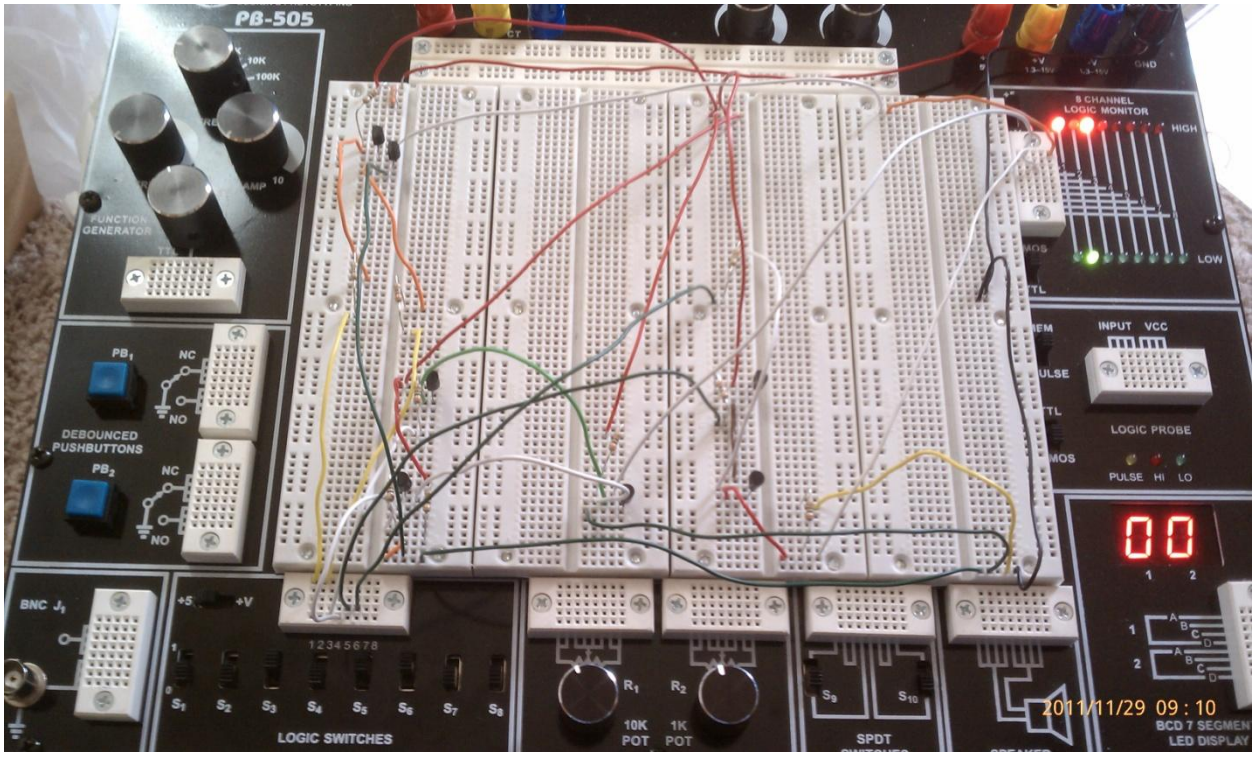

Diagram 5: Three logic gates built with transistors on a breadboard

Almost every step of this circuit is physics. From 5V electric to resistors, from transistors to the ground and wires, it is all about physics. The resistors will be modeled by Ohm's law, which states that the electric current flowing in the resistor is related to the voltage difference across the ends by the equation: $V = I\ x\ R$. (This is of course only an approximate model but it is sufficiently accurate for logic circuit design at any level of detail).

We will start with a very simple, procedural model of a transistor. It has three terminals marked G, S, D, standing for G (Gate), S (Source) and D (Drain) and it obeys the following rules:

1) There is no connection between G and D and G and S.
2) If the voltage between G and D (Vgd) is less than 2 volts the switch is open and there is no connection between D and S (no current is flowing).

3) If the voltage Vgd is greater than 2 volts, the switch is closed and D is connected directly to S.

The diagram below shows the physics behind the transistors:

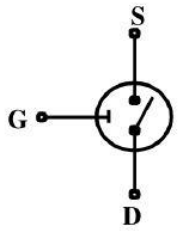

Diagram 4: Inside a transistor

Although this is highly simplified model, it contains the sufficient detail to explain how the gates are constructed to compute the correct logic.

Conclusion: This project explains what logic gates are, how they are made, and how they can be made by using transistors. The circuit works as expected and computes the outputs accordingly with the corresponding truth table.

References:

1) Jaeger, Richard C. *Microelectronic Circuit Design*. McGraw-Hill

   Science/Engineering/Math, 1997

2) Transistor Gates, Georgia State University Department of Physics and Astronomy Last modified August 2010, http://230nsc1.phy-astr.gsu.edu/hbase/Electronic/trangate.html

3) Michael D. Ciletti, Advanced Digital Design with the Verilog HDL (New Jersey: Pearson, 2011)- Chapter 2

4) Simple Basic Digital Logic Gates, Electronics-tutorials, last modified: September 2011, http://www.electronics-tutorials.ws/logic/logic_1.html