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**Score: \_\_\_\_\_**

**Lab01 – Transistors and Switching**

COMP256 – Computing Abstractions

Dickinson College

Spring 2022

Prof. Grant Braught

**Names:** (List both partners. One submission per group.)

**Introduction:**

This lab will introduce you to building electronic circuits using a *breadboard*. You will see how to use a *voltmeter* to measure voltages and logic values in a circuit. You will experiment with switches and observe first-hand that NMOS and PMOS transistors do in fact behave just like switches. Finally, you will build a circuit directly from transistors that performs a computation.

**Breadboards:**

When designing new circuits it is common to use a *Breadboard*. The figure below shows a breadboard with a *Pushbutton*, a Light bulb, a *Coin battery* and a few wires. Wires and components can be connected by inserting them into the little holes in the breadboard. This makes it easy to add, remove and adjust wires and electronic components in a circuit. Your instructor will have demonstrated the use of the TINKERCAD breadboard at the start of lab.



**Extra Breadboard Resources:**

This section is optional and just provides a little more information about breadboards that you can come back to later if you are interested. We’ll be using breadboard’s in TINKERCAD to build and test our circuits. However, physical breadboards are often used for circuit design as well. If you would like to see how a physical breadboard is used you can watch the video *How to Use a Breadboard* from Ben Finio at Science Buddies

* <https://www.youtube.com/watch?v=6WReFkfrUIk> (12:20)

If you would find an example of using a breadboard directly in TINKERCAD helpful, you can watch Remi Wauthy’s video *Introduction to Tinkercad Circuits & Breadboarding - Part 1*.In that video he demonstrates building the resistor/LED circuit from the *How to Use a Breadboard* video above but using TINKERCAD.

* + <https://www.youtube.com/watch?v=LrOM2GABK1g> (15:58)

**Your First Circuit:**

🔑 1. Log into our course in TINKERCAD (use the link in Moodle and your Dickinson username as your nickname) and create a new circuit named Lab01-Switch.

🔑 2. Build and simulate the circuit from the figure on the first page of the lab.

Note: When you build your circuit, it is not necessary that every component and wire be plugged into the same breadboard holes as in the figure. However, you should aim to keep all of your circuits neat and well organized. Rotate and arrange components so that they are oriented and spread out in ways that give you space to work. Add points to route your wires in ways that make them easy to follow. Use different colored wires to make your circuit easy to understand. Think of this kind of like writing well-organized and commented code in a program. It will make it easier for others (i.e. me) to understand your circuit and also easier for you to debug it when it doesn’t work correctly.

🔑 3. Simulate the circuit and then follow the directions in parts a and b below to fill in the cells in the following table.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  | **Push Button** | **Light Bulb** | **“Switch”** |  |
|  | Released |  |  |  |
|  | Pressed |  |  |  |
|  |  |  |  |  |

a. Press (i.e. click) and release the push button a few times and observe the behavior. Then fill in the rows in the “Light Bulb” column with “On” or “Off” to indicate whether the light is on or off when the push button is pressed or not.

b. The push button behaves like the switches in our metaphor from class and can be either “Open” or “Closed”.

A picture containing text, device

Description automatically generated

Based on the behavior you observed, fill each row in the “Switch” column with “Open” or “Closed” to indicate if the switch hidden inside the push button is open or closed.

**Transistors are Switches:**

Now recall from class that NMOS (and PMOS) transistors behave like electrically controlled switches. That is, the signal on the Gate will determine if the transistor *behaves like* there is an open switch (left in image below) or closed switch (right) between the Source and the Drain.

 

In this section we will replace the Pushbutton with an NMOS transistor (which remember behaves like a switch) and use a 0 or a 1 to open or close it imaginary “switch.” If all goes well, the circuit will behave just like it did when we opened and closed the switch inside the Pushbutton by clicking it.

🔑 4. Duplicate your Lab01-Switch circuit in TINKERCAD and name the copy Lab01-Transistor-Switch.

* Go to your “Circuits” page that shows all of your circuits.
* Point at your Lab01-Switch circuit.
* Click the “gear” icon that appears.
* Click “Duplicate”
* When the new circuit appears, click the name in the upper right and rename it.

🔑 5. Modify your Lab01-Transistor-Switch circuit to look like the circuit below by deleting the Pushbutton and replace it with a *small signal nMOS transistor* (not an NPN BJT or MOSFET which look or seem similar but are different transistors and thus will behave differently).

Diagram

Description automatically generated

🔑 6. If you look closely at the NMOS transistor you will see its three “legs” are labeled D, G, and S for Drain, Gate and Source. Just like our abstraction from class. The gate (G) on the NMOS transistor is not yet connected to anything.

a. Use a wire to connect the gate to a 0 (i.e. ground or the – rail). What happens when you simulate the circuit? What can you infer about the imaginary “switch” inside the transistor?

b. Change the circuit so that the gate is connected to a 1 (i.e. the + rail). What happens now when you simulate the circuit? What does this tell you about the imaginary “switch” inside the transistor?

7. We know that the PMOS transistor is complementary to the NMOS transistor. Let’s see that in action too. Replace the NMOS transistor in your Lab01-Transistor-Switch circuit with a small signal PMOS transistor.

a. Use a wire to connect the gate to a 0 (i.e. ground or the – rail). What happens when you simulate the circuit? What can you infer about the imaginary “switch” inside the transistor?

b. Change the circuit so that the gate is connected to a 1 (i.e. the + rail). What happens now when you simulate the circuit? What does this tell you about the imaginary “switch” inside the transistor?

**Using a Slidewitch for Inputs:**

Stopping the simulation and rewiring the input (i.e. the gate) each time is a little inconvenient. There is another component, called a *Slidewitch* that can help here.

🔑 8. Modify your Lab01-Transistor-Switch circuit to look like the one below by adding a Slideswitch component. Be sure to remove the PMOS transistor and place the NMOS transistor back into the circuit.

A picture containing text, electronics

Description automatically generated

🔑 9. Simulate your circuit and experiment with the Slideswitch.

a. Qualitatively describe the behavior of your circuit as you move the Slideswitch. What happens when the switch is slid to the left? What happens when it is slid to the right?

b. Based on your observations, fill in each row of the “Logic Level at Gate” column in the table below with a 0 or a 1 to indicate the logic level that is being applied to the gate of the transistor.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
|  | **Slideswitch**  **Position** | **Logic Level**  **(0 or 1) at Gate** |  |
|  | Left |  |  |
|  | Right |  |  |
|  |  |  |  |

**Measuring Electrical Voltages:**

The 0’s and 1’s that we think of the computer operating on are, as we now know, just electrical signals. In this section, we’ll step down one level of abstraction and see how we can look at the voltages that we have been abstracting into 1’s and 0’s.

A *voltmeter* is a device that we can use to directly measure electric voltages, which we can then interpret as 0’s and 1’s. In TINKERCAD a voltmeter looks as shown below.

A screenshot of a cell phone

Description automatically generated

Technically this is a *multimeter*, which is a multifunction meter with one of its functions being that of a voltmeter. When the V on its right side is shaded in, the multimeter is operating as a voltmeter as opposed to one of its other functions. For our purposes I will just refer to the multimeter as a voltmeter because we will not be using of its other functions in this class.

To use a voltmeter to measure voltages, you will always connect the black (negative) lead to ground (or the “–“ terminal of the power source) and then connect the red (positive) lead to the point where you want to measure the voltage.

🔑 10. Just quick fact check of an important point to be sure you are reading…

To use the multimeter to measure voltages connect the…

a. black lead to …

b. red lead to …

🔑 11. Add a voltmeter to your Lab01-Transistor-Switch circuit and use it to measure the the voltages at the locations indicated in the table below. For now, leave the “Logic Level” column empty. You’ll fill that in later.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | |  |  | |  | |  | |
|  | **Location** | | | **Voltage (V)** | | **Logic Value** | |  |
|  | + Rail | | |  | |  | |  |
|  | - Rail | | |  | |  | |  |
|  | NMOS Gate with Slideswitch left | | |  | |  | |  |
|  | NMOS Gate with Slideswitch right | | |  | |  | |  |
|  | |  |  | |  | |  | |

**Abstracting to 0’s and 1’s:**

As you just saw, the voltages at different points in a circuit will range between ground (0V) and the maximum voltage determined by the power supply (i.e. the battery). This maximum is often referred to as Vss. Where the “S” comes from “supply” which is just short for power supply.

🔑 12. What is the Vss voltage in your Lab01-Transistor-Switch circuit?

The voltages that correspond to logical 0’s and 1’s are typically defined by dividing the range of possible voltages into three ranges. Voltages in the bottom 1/3 of the range (between 0 and (1/3)\*Vss) are defined to be a logical 0. Voltages in the top 1/3 of the range (between (2/3)\*Vss and Vss) are defined to be a logical 1. Voltages in the middle third are neither a 0 nor a 1. Separating the 0 and 1 by this buffer region ensures that if there is some electrical noise in the circuit it will still be possible to distinguish the 0’s from the 1’s.

🔑 13. The voltages (1/3)\*Vss and (2/3)\*Vss are called the *cutoff voltages* for 0 and 1 respectively. What are the cutoff voltages for 0 (Vc0) and 1 (Vc1) for our Vss?

Vc0 =

Vc1 =

🔑 14. Using the cutoff voltages you just determined, fill in the Logic Value column of the table in question #11 indicating if each voltage that you measured would be interpreted as a logical 0 or a logical 1 or neither.

🏆 15. Which earlier question do the logic levels you just measured relate to? How? Do they agree?

**A CMOS Circuit:**

In class we saw the CMOS circuit shown below.



🏆 16. Create a new circuit in TINKERCAD named Lab01-CMOS-Circuit. Use an NMOS and PMOS transistor to Implement the above circuit with the following considerations:

* Pay close attention to the NMOS and PMOS transistors in TINKERCAD. Their “legs” are labeled with S, G, D. Be sure they are connected as shown in the circuit above. If the sources and drains are reversed the circuit will not work properly.
* Use a Slideswitch, like the one in question #8 to provide a 0 or a 1 as the input.
* Use a voltmeter to measure the voltage at the output.
* Do not include a lightbulb in the circuit. If the output is connected to a lightbulb the circuit will not work correctly.
* Be sure to keep the components and wires of your circuit neatly organized and use wire colors to make your circuit easier to understand.

🏆 17. Use your circuit to complete the following table.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
|  | **Switch  Position** | **Logic Value at Input** | **Voltage at Output** | **Logic Value at Output** |  |
|  | Left |  |  |  |  |
|  | Right |  |  |  |  |
|  |  |  |  |  |  |

Optional: To help me improve and scope these activities for future semesters please consider providing the following feedback.

a. Approximately how much time did you spend on this Lab (include the 2-hour lab period in your total)?

b. Please comment on any particular challenges you faced in completing this Lab.