Project 2 - Report

ELECENG 2EI4

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As a future member of the engineering profession, the student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University and the Code of Conduct of the Professional Engineers of Ontario. Submitted by **[Edison He,hee6, 400449140]**

Introduction

Electrical switches are used in a multitude of practical applications. They range from simple applications such as lights to computers and microelectronics. The purpose of this project is to understand the ideal characteristics of a switch in comparison to a practical real life switch. Understanding the deviations from the ideal model of a switch is essential to engineering design to improve circuit reliability, performance, and ensure target requirements are met.

Ideal Switches Characteristics

There are four main ideal characteristics for an ideal switch. These characteristics include infinite resistance in the open stage, zero resistance in the closed state, instantaneous transition phase, and a bidirectional ability. If the switch is in the open position, it must have infinite resistance, or act like an open circuit. The switch must have zero current flow between both ends. On the other hand, if the switch is closed, it must display an unrestricted current flow. In other words, it must inhibit zero internal resistance. This ensures that there is zero voltage drop between the nodes. When in the transition phase between open to close or vice versa, the transition must happen instantaneously with no delay. Finally, the switch must be bidirectional. Its behavior is akin to an ideal wire in the sense that it can conduct current from both terminals[1].

In addition to the four main ideal characteristics, there are other characteristics that an ideal switch should exhibit. An ideal switch must not degrade or generate heat as a byproduct. The electrical elements in the switch must not degrade over time when used with any voltage or current level. It must also be able to handle both AC and DC states. Additionally, in both the open and closed states, the switch should not dissipate heat as a byproduct. This means there must be zero power dissipation in all states in any conditions[1].

Non-Ideal Characteristics

Similar to circuits in laboratory experiments, a real world switch has many deviations from the ideal switch. Like an ideal wire, a switch in the closed state has an internal resistance. This resistance has a snowball effect on the switches performance. The internal resistance results in a voltage drop across the switch and in turn, inhibits the flow of current. Even if the internal resistance is minimal, in applications with large amperage result in a significant voltage drop. Additionally, the internal resistance dissipates power in the form of heat. Heat and mechanical wear from friction can degrade the electrical components overtime and can be worn down further in certain conditions, especially when operating past voltage and current thresholds. Finally, a practical switch does not have an instantaneous transition phase and can introduce electrical noise within the circuit[2].

Knowing the limitations of non-ideal switches is essential to circuit design. If a design engineer understands the limitations, they can work around or compensate for the faults. This can be done through quantification of the drops. Knowing the internal resistance or the voltage drop from the switch can be accounted for in the battery to achieve the target voltage and current values. Through Ohm's law the current leakage and power can be found through a measured voltage and resistance. The time of the transient state can be quantified or viewed as a graph to ensure vital operations do not occur in this period, especially important to face paced circuits[2].

Test Plan

As listed above, real world switches have non-idealities which must be considered before the application of a design. In the testing phases, V_{supply}, $V_{control}$, and V_1 must be consistent. In this case, V_{supply} is 5V, $V_{control}$ is either 0V or 5V depending on the state and V_1, will be set to 5V. The non-ideal characteristic of a voltage drop over the switch will be tested first as there is an expected resistance in the switch. This can be done by finding the difference between the voltage difference between the input and output nodes. The second non-ideality that will be tested is the current leakage. This can be tested by measuring the current through the load resistor. As the AD3 does not have an ammeter, the current through the load resistor can be calculated with its voltage divided by the resistance. The third non-ideality that is being tested is the operational voltages. In this test case, the supply voltage will vary from 0 to 5V for multiple voltage cases. A maximum of 5V was used due to the design constraints. A sine wave with an offset can be used as an input to test this characteristic. Finally, bidirectionality can be verified by measuring the voltage and current drop on both sides.

Switch 1

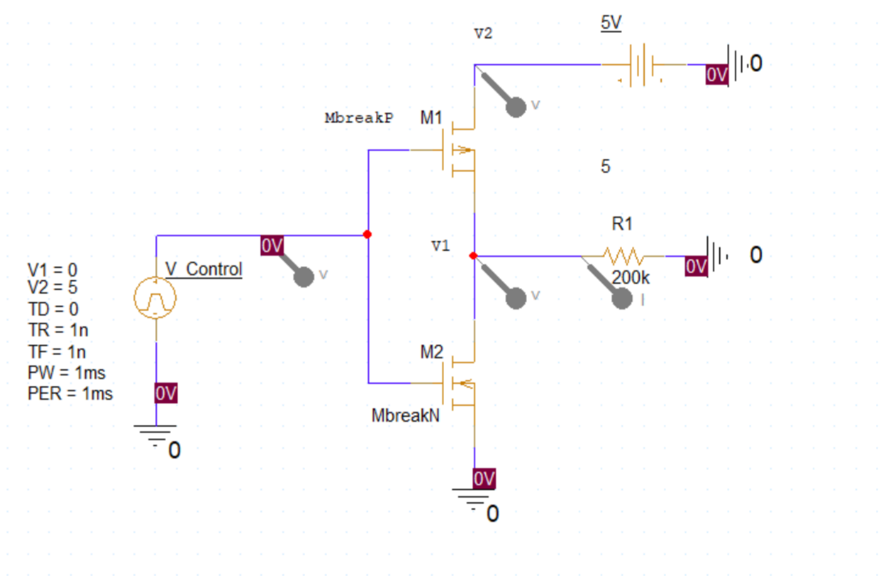

Figure 1: Switch 1 PSpice Circuit Schematic

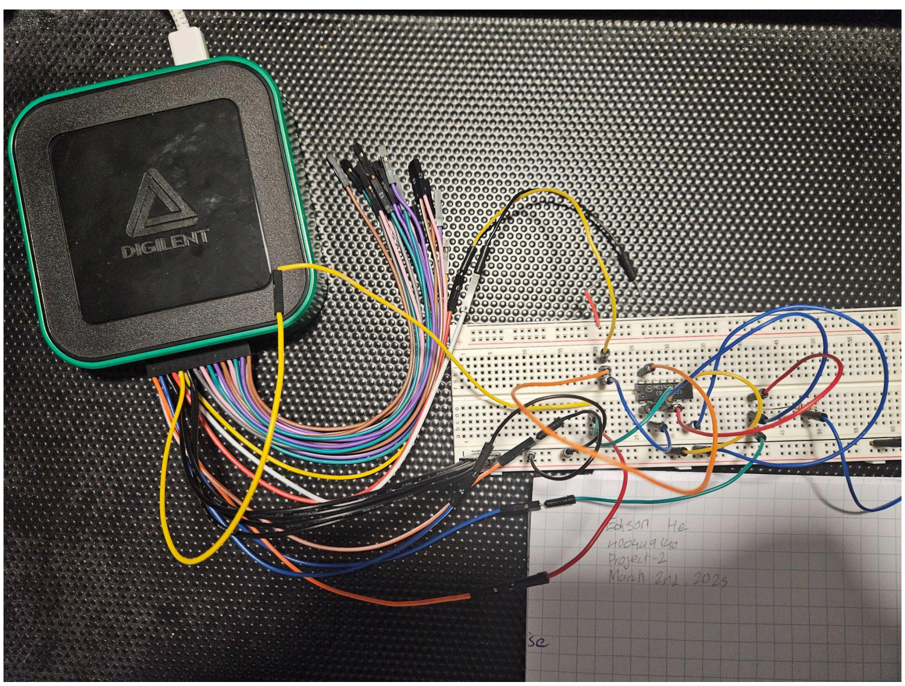

Figure 2: Built Circuit

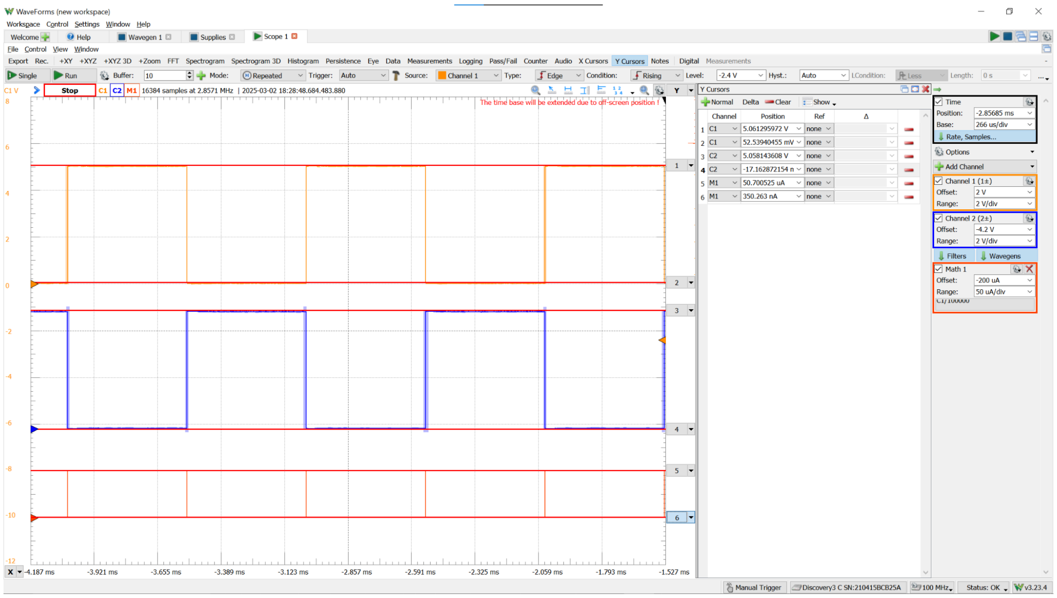

Figure 3: Switch 1 AD3 Output

Theoretical Explanation

From the figure above, it is clear to see that it checks off the criteria of an ideal switch. The switch is bidirectional due to the use of both p and n-type MOSFETs. In this case, channel 1 measured the control voltage while channel 2 measured V_2, the voltage across the 100k resistor. When the control voltage is at 5 volts, the switch should be off and the opposite should happen when at 0 volts. In the output above this is verified as V_2 has a waveform that is the inverse of the control voltage.

Additionally, the current values should also be 0. In the output above, the current values were not measured, but rather calculated with the math channel by dividing voltage by the resistor value of 100kΩ. While the experimental values were not zero, they are a very miniscule amount which is mostly ideal. Similarly, the V_2 is around the same voltage as the control voltage, revealing that there is no voltage drop over the switch.

Finally, the transition time for an ideal switch is instantaneous. The time to change was not measured in this experiment, but the instantaneous characteristic can still be mostly verified. This can be seen as when the switch transitions between the ON and OFF stage, aka the 5V to 0V, a vertical line can be seen. This represents an instantaneous or near instantaneous switch between the stages.

Design Tradeoffs

A design trade off that I made in this design is using more MOSFETs than needed. Only one is needed, but having two allows the switch to operate bidirectionally. This was done as the circuit in Switch 2's design was more complex, and I wanted to observe the behavior of both sides. The downside to a bidirectional MOSFET with regards to Switch 1's design is the increase in complexity. The complexity adds to the overall cost of the circuit. In reality, the parts are under one dollar. However, if the circuit was created in bulk it would not be ideal. The increase in components may cause systemic error throughout the circuit which makes measuring the values more inaccurate. Additionally, as the circuit has more parts, there are more points of failure to troubleshoot.

Switch 2

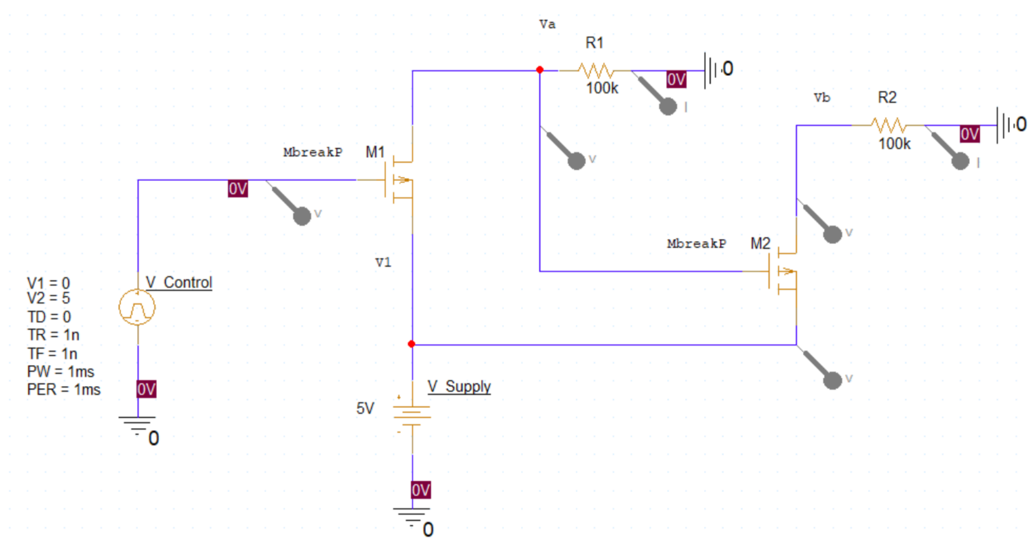

Figure 4: Switch 2 Circuit Schematic

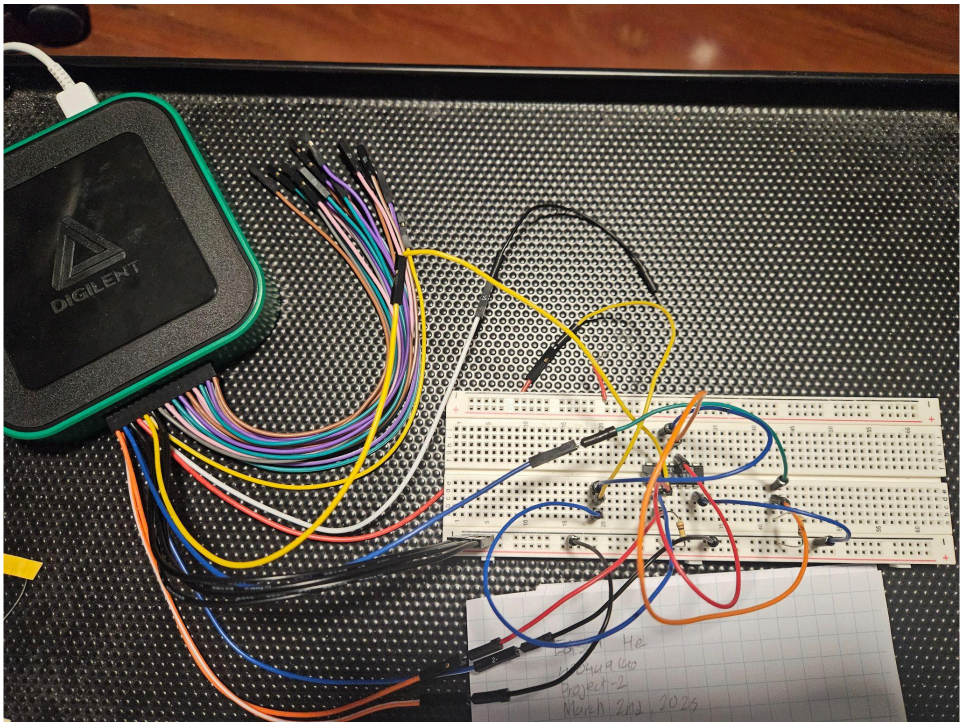

Figure 5: Built Circuit

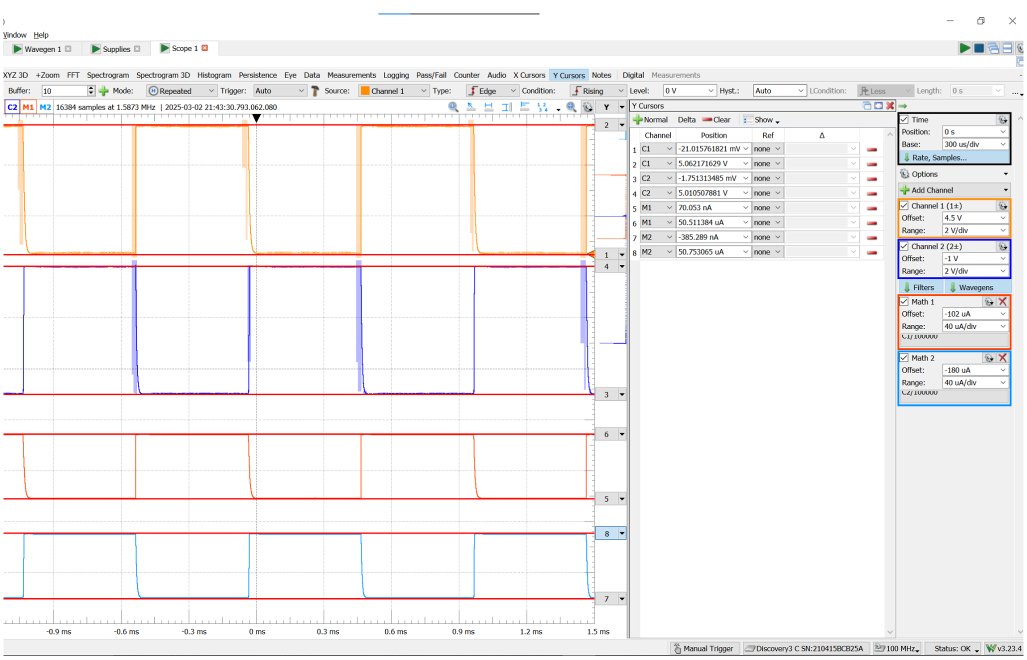

Figure 6: Switch 2 AD3 Output

Theoretical Explanation

Figure 6 above shows the output. The orange and blue output waves represent the voltages of V_1 and V_2 respectively and they move between around 0 to 5 volts in the off and on states. When V_1 is 5V, V_2 is 0 volts. The same is true for the inverse. This showed the circuit functions correctly and is able to switch between the voltage values based on the inputs. The light blue and red waveforms represent the output current through the resistors of V_2 and V_1 respectively. The values are very accurate and show that there is a miniscule voltage drop.

The current values were calculated in a similar way, by dividing the respective voltage values by 100kΩ. The current values are almost zero, in which the highest is around 50.8 uA on the on state and 70.1 nA in the off state. This almost matches up with the ideal current value of 0. The transition time this time however, is not as accurate. This can be seen as the vertical transition lines are not as straight as in switch 2. This switch is a more accurate representation of a non-ideal switch.

Design Tradeoffs

A design with 4 MOSFETs in addition to n-type similar to switch was possible to make. However, a design trade off I made in this design is using two P-type MOSFETs for a multiple of reasons. Using two P-type MOSFETs results in a more accurate data reading due to the lower risk of running into manufacturing issues, and less voltage drops over each MOSFET. In addition, using two MOSFETs instead of 4 MOSFETs is a more simplistic design which results in a cheaper overall circuit and a lower chance of failure. However, as a tradeoff, the design loses its bidirectionality, a property of an ideal switch. In the end, I was able to create both working and non-working bidirectional switches and learn both of their behaviours as an added bonus.

References

[1] M. Razavi, Design of Integrated Circuits for Optical Communications. 2nd ed. New York, NY: McGraw-Hill Education, 2012.

[2] All About Engineering. 2019. What is an Ideal Switch & Characteristics of an Ideal Switch. Retrieved from https://allabouteng.com/characteristics-of-an-ideal-switch/