2EI4

Electronic Devices and Circuits I

Project #2- Voltage Controlled Switches

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The Properties of an Ideal Switch:

- There is zero voltage drop across the two terminals of the switch when it is on, making the voltage the same going in and coming out [1]

- When the ideal switch is off it's regarded as an open circuit making the current flowing through the switch equal to zero [1].

- An ideal switch will work with any voltage on each terminal making the voltage range unlimited, and not a factor which affects the operation of a switch [1].

- The ideal switch allows for current to flow either way when it is on making it bidirectional [1].

The Properties of Non-Idealities:

- With real switches when they are on, there is a voltage drop as the resistance can't be regarded as 0. This resistance can be measured by an equation where resistance when switch is on equals voltage drop over current ($R_{on}=V_{drop}/I$) [2].

- Unlike ideal switches real switches actually have a range for their Voltage input and output where $V1>V_{minimum}$ and $V2<V_{maximum}$ these limits are specific to the hardware and will ensure that the switch operates correctly if the voltage is in between this range [2]

- When a real switch is off there is current leakage which doesn't exist for ideal switches. This non ideality can be evaluated by measuring the current through the switch when it is off [3].

- Ideal switches allow for current to flow either way however for real switches to find out if it has the bidirectional property you have to measure the resistance when the switch is on. First by finding resistance when V1>V2 and then when V2>V1, if both resistances are the same then the switch is bidirectional [3].

Test Plan:

Switch 1:

For switch one the test plan will consist of values where V_1=5V, V_{Supply}=5V and $V_{control}$ will either be 0V or 5V depending on if the switch needs to be on or off for the non-ideality property. The first non-ideality that will be tested is when the switch is on so $V_{control}$=0V there should be a small voltage drop as this non-ideality can be seen for real switches. The testing for this will occur by using the Pspice simulation and the ad3 to measure the output vs the input voltage and a decrease should be seen. The next testing will be for how real switches have a range where they correctly operate, to test this a ramping function will be utilized from 0V-5V and then I can see what the minimum and maximum value of the range of operation for my switch is. Next when the switch is off, $V_{control}$=5V there will naturally be some current leakage as this is a non ideality of a real switch. To measure the leakage I will measure the current when the Vcontrol is off. Finally, the last non ideality which is how in a real switch we are unsure if it has the bidirectional property. To find out I will swap the resistor that is being used at the output with the input voltage, and it should function the same as it did before.

Switch 2:

Switch two will follow a similar test plan to test all the non idealities. V_1=5V, V_{Supply}=5V and $V_{control}$ will either be 0V or 5V, where $V_{control}$ is a square wave. The first non-ideality that will be tested is when the switch is on so $V_{control}$=0V there should be a small voltage drop as this non-ideality can be seen for real switches. The testing for this will occur by using the ad3 and the Pspice simulation to measure the output which for this switch will have two output nodes vs the input voltage and a decrease should be seen. To test the range where the switch correctly operates a ramping function will be utilized from 0V-5V and then I can see what the minimum and maximum value of the range of operation for my switch is. To measure current leakage same testing plan will be used where using the ad3 I will measure the output voltage and divide it by the resistance to find how much current is leaking. Finally for bidirectional I will swap the resistor that is being used at the output with the input voltage, and it should function the same as it did before this will be done with both output resistors and the voltages will be measured to see if they behave the same.

Switch 1:

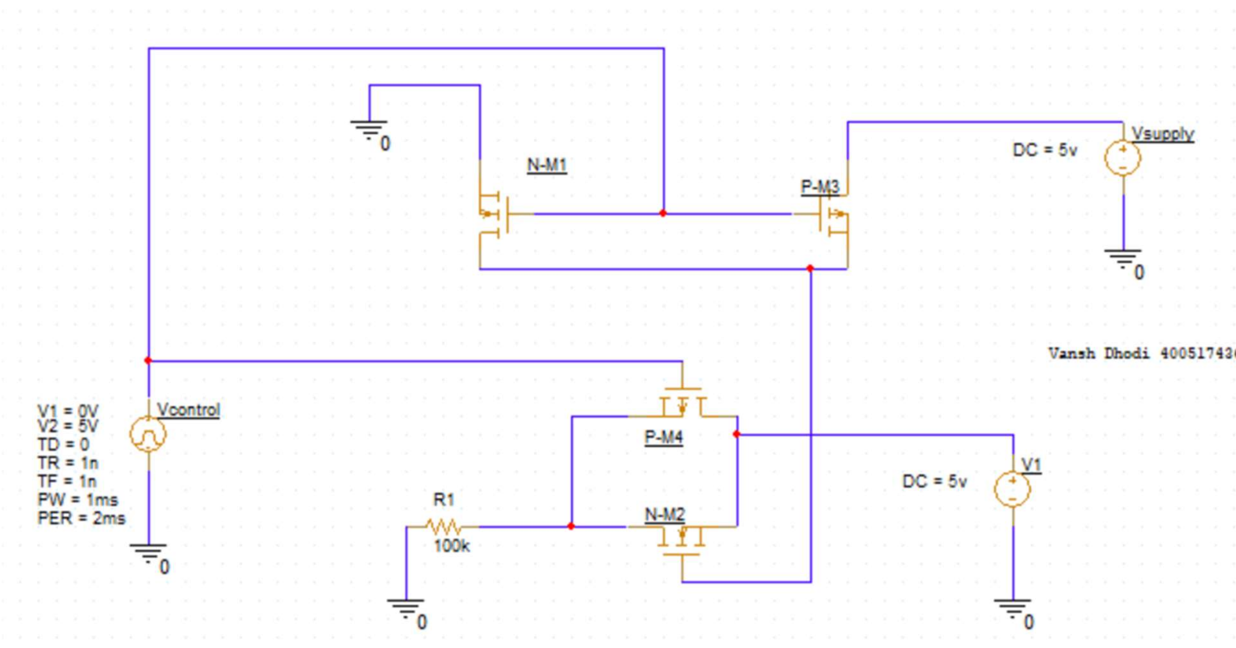

Figure 1: Schematic for switch 1

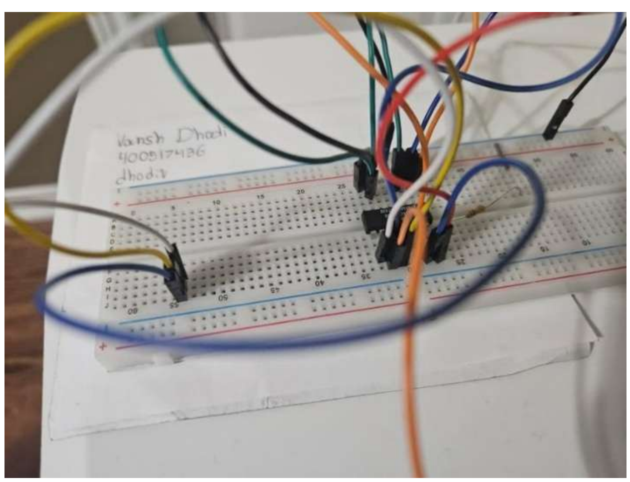

Figure 2: Physical Implementation

Measurements/Simulation:

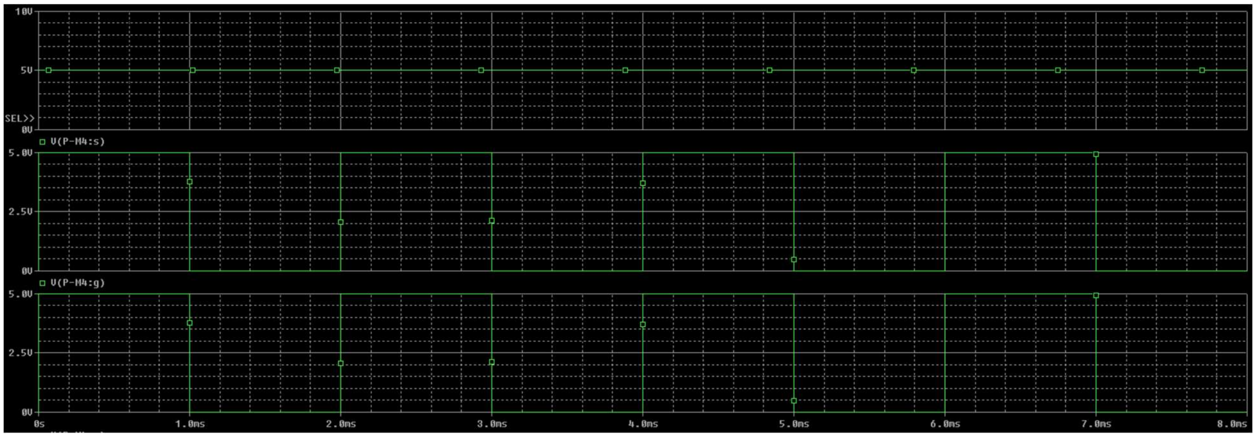

Figure 3: Voltage output

It can be seen through the simulation that the circuit is functional as when V1 equals 5V the output and the Vcontrol are in phase and providing perfect squares waves. Now when doing this on the ad3 it could be seen that this isn't applicable as the ending of the square waves have some curve to them and they don't create a perfect square wave.

Voltage Drop

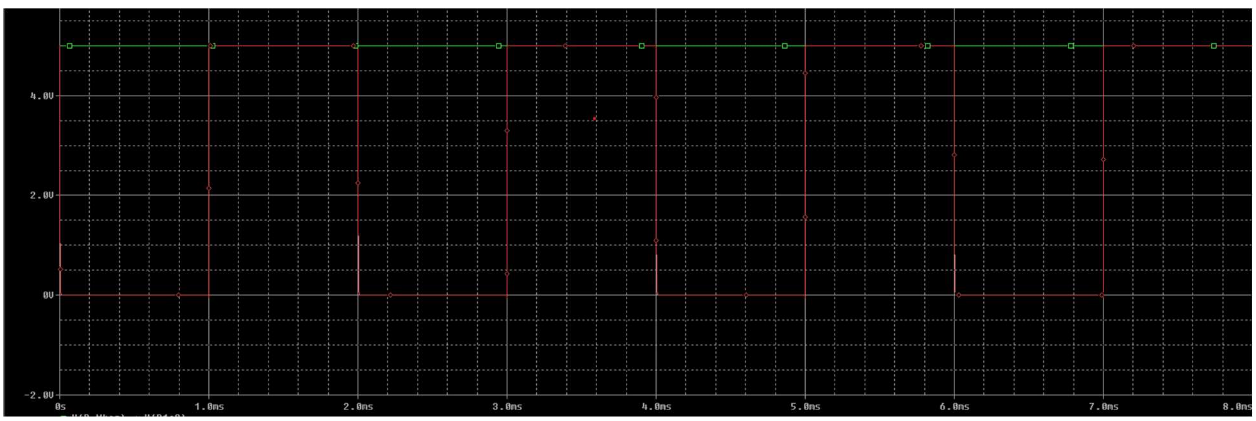

Figure 4: Measuring volage drop when switch is on

The simulation dictates a perfect voltage of 5V as the Vinput in green is 5V and when the Vcontrol is 0V the red graph which is our output lines up with the input. This showcases an ideal switch. When implementing this on the ad3 this isn't the case. The ad3 when tested with a Vinput=5V gave the measurement; V_{in}-V_{out}=5V-4.83V=0.17V which was the voltage drop.

Voltage Threshold

To check the minimum voltage required to get the correct output the testing plan required me to use the ramping function which would only range from 0-5V. When tested in the simulation and in real life it was found that up to 1.9V there was unintended behaviour as seen in the graph below it did not exhibit a perfect square wave.

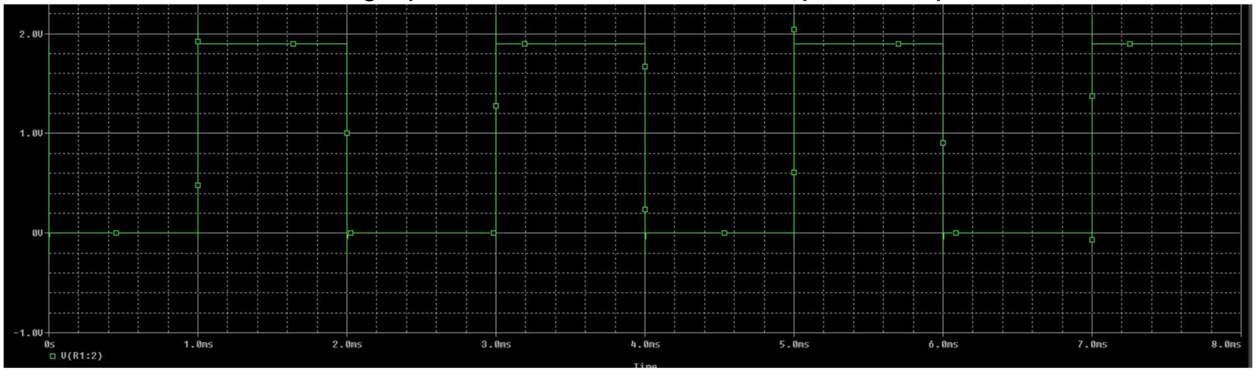

Figure 5:Voltage threshold

Current Leakage

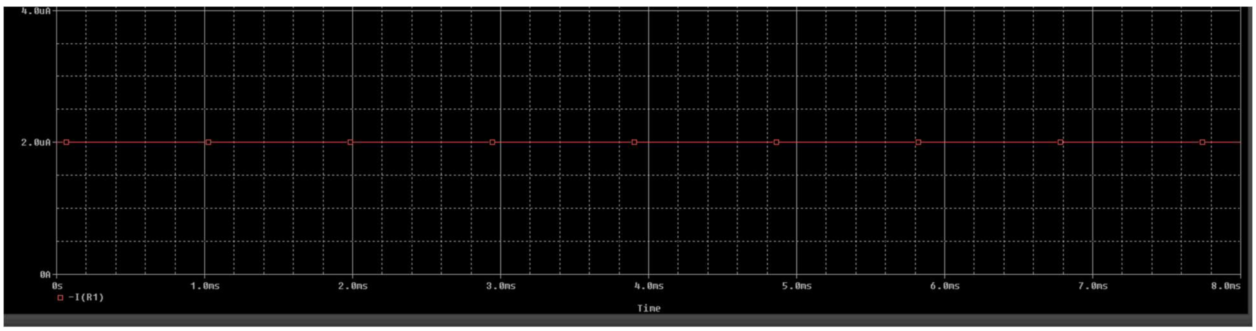

Figure 6: Current leakage

The current leakage was shown to be 2uA for the simulation when this was tested on the ad3 a similar value of 2.2uA was show and this shows that the simulation and ad3 values were quite similar.

Bidirectional property

By swapping R1 with V1 it could be seen in the simulation that there is a difference in functionality. When V1 is set to 5V the output voltage isn't the perfect square wave that was exhibited before there is a slight voltage drop of 0.1V proving that it isn't bidirectional.

Theoretical Application:

When comparing the experimental results to the qualitative results it can be seen that there are minor differences, but this was to be expected. The qualitative results showcased results without any outside environmental factors affecting it which wasn't going to be the results that the experimental would show. When implementing the circuit onto the breadboard the wires have internal resistance, these voltage loss and various other issues that can cause the results not to be the same as the qualitative measurements. However, when it comes to comparing the results to the test plan it was inferred that these issues would arise, so the results are not far off from my expectations. They also align with some of the qualitative results such as current leakage and voltage drop both are very similar to each other. This showcases how outside factors didn’t cause too much of a difference from the simulation results but when it came to non-idealities in the testing plan that needed perfect values such as bidirectional property the circuit fell a bit short as it wasn’t able to achieve the bidirectional property as there was some voltage drop off.

Design Trade Offs:

Utilizing four mosfets in the design allowed for the output to be of higher accuracy. Using four mosfets instead of one allowed for better results when it came to the bidirectional ideality as there was only a slight discrepancy between the reverse current flow. Utilizing a higher ohm resistor also allowed for a lower current leakage making the data more accurate. However, using this design did make the circuit more complicated. Implementing four mosfets proved to be a challenging task when coming up with the circuit design and when creating it in real life it will cost more than using one mosfet.

Switch 2:

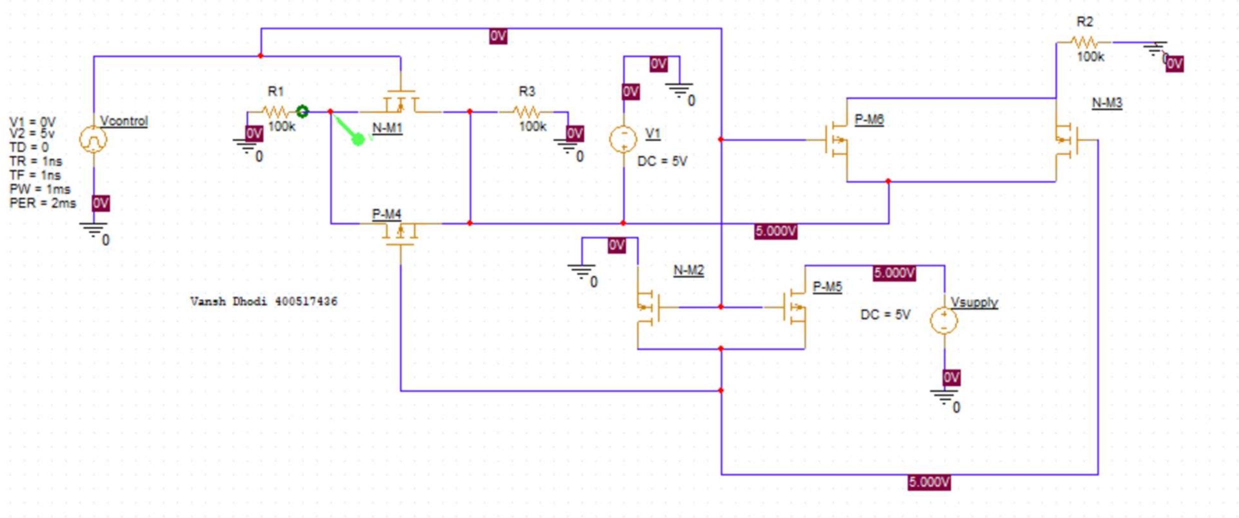

Figure 7: Schematic switch 2

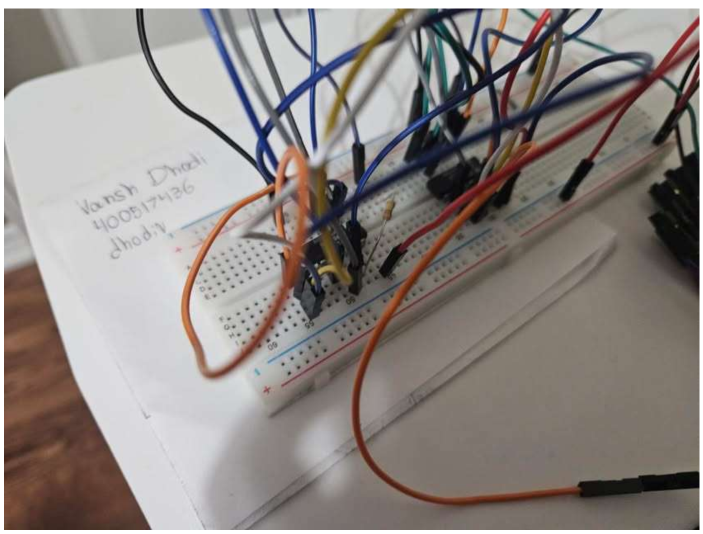

Figure 8: Physical implementation of switch 2

Measurements/Simulation:

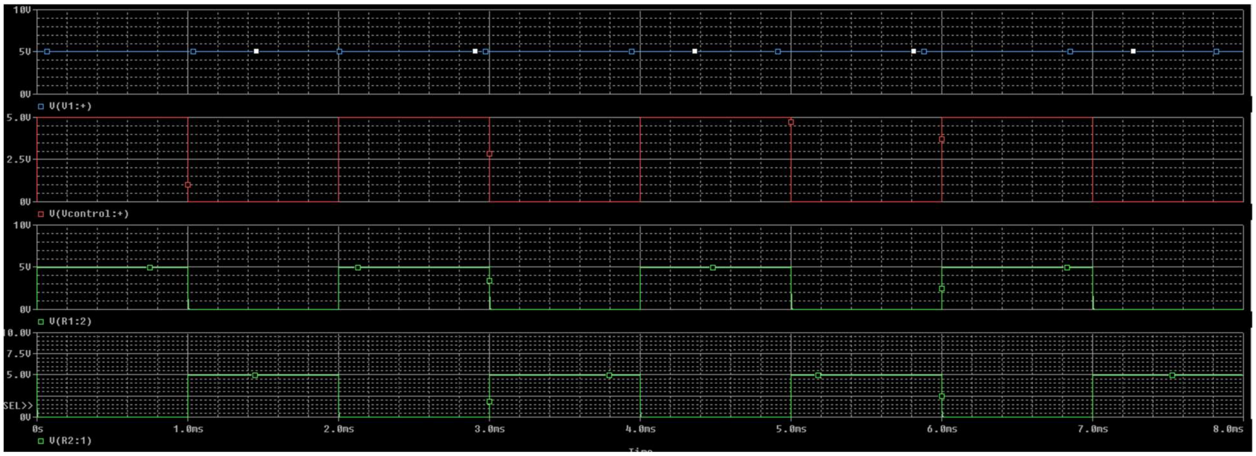

Figure 9: Voltages for switch 2

The green graphs represent the two outputs and it can be seen that when one output is on the other if off matching the functionality of the switch. They are also responding correctly to Vcontrol and ranging from 0-5V proving the circuit is working correctly

Voltage Drop

From the figure above it can be seen that there is no voltage drop in the simulation, and this displays how for the simulation the circuit is showcasing an ideality rather than the expected non ideality from the test plan. When physically implementing this onto a breadboard and measuring the voltage drops for both outputs this was not the case. The voltage drop across R1 was 5V-4.77V=0.23V while for R2 the voltage drop off was 5V-4.79V=0.21V. This makes sense as real world factors would cause for a voltage drop to occur.

Voltage Threshold

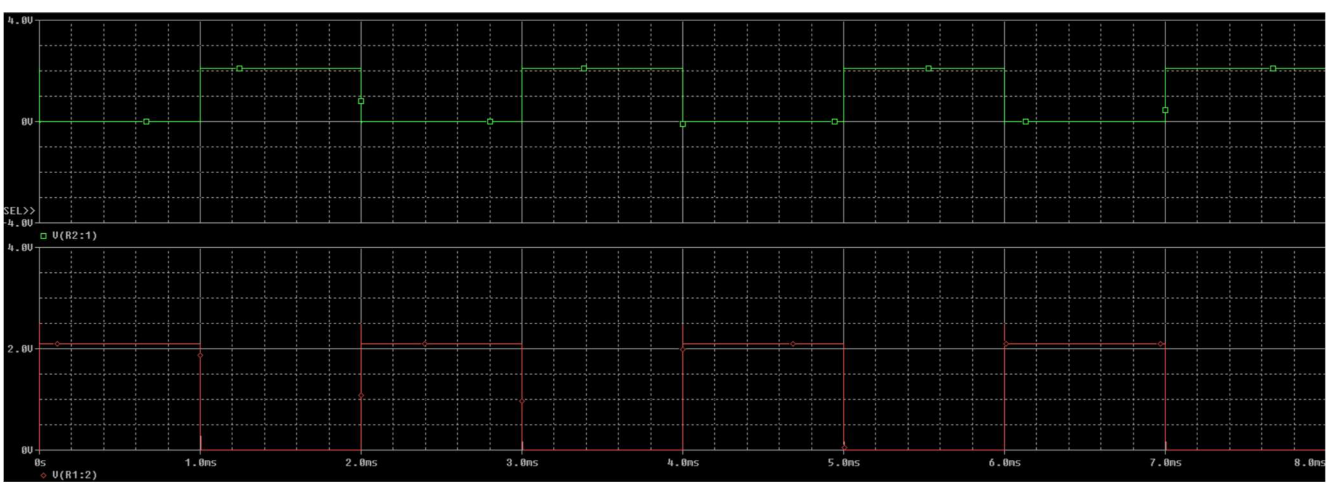

Figure 10: Switch 2 voltage threshold

When utilizing the ramping function, it can be seen on the simulation that 2.1V seems to be the lower bound until the circuit starts acting as expected. Now upper bound cannot be tested due to a limit of 5V. But it can be seen that for R2 2.1V is when it is slightly off from the intended square wave voltage as its not 2.1V exactly and for R1 there is a random spike when a wave starts which disappears after 2.1V and then produces the expected values. Similarly, when conducting this on the breadboard a similar value of 2.2V was found for the threshold.

Current Leakage

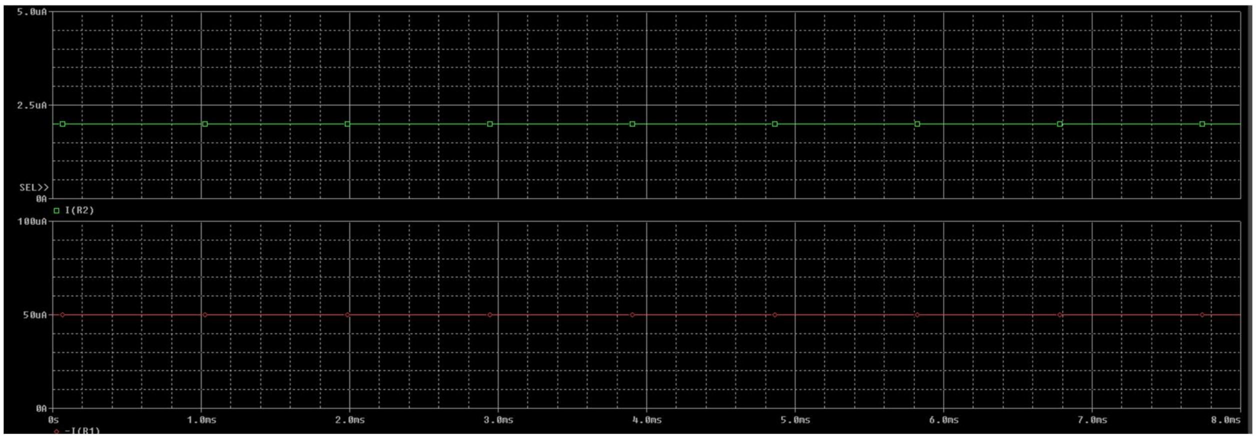

Figure 11: Current leakage of both outputs

From the simulation it can be seen the current leakage across R2 was 2.5uA while for R1 it was 50uA. This was expected from the test plan as real switches have current leak. When testing with a breadboard the results were different where R1 was 60uA and R2 was 25uA.

Bidirectional property

The bidirectional property can be confirmed using the testing plan by swapping V1 with the different output resistors. First, I swapped V1 and R1 and tested the voltage output then swapped V1 and R2 and both findings provided results that let to the fact that the output was not a perfect 5V square wave as was intended. There would be a minor voltage drop of 0.05-0.1V meaning that it did not achieve the bidirectional ideality.

Theoretical Application:

When comparing the qualitative values to the experimental it can be seen that a lot of the qualitative values done from the simulation and expected values match with the experimental results. This can be seen through the Voltage threshold and current leakage. The expected results from the test plan were that there would be a voltage threshold and a current leakage that was displayed in both the simulation and the physical implementation. The values for the two tests between the simulation and experimental results was similar too. Now voltage drop didn't occur for the simulation, but it did for experimental and this was expected to occur as it’s a real switch with environmental factors affecting the circuit. The bidirectional property didn’t uphold unfortunately, and this is primarily due to the outside factors affecting the circuit, but this was once again expected.

Design Trade Offs:

The design trade offs are similar to the 4 four mosfet switch as using 6 mosfets make the physical circuit and schematic quite difficult to build. It also will have a higher cost as using the 6 mosfets requires more wires and the mosfets itself. However, the trade off of using more is that the efficiency and accuracy far exceeds that of using 2 mosfets. Now this design was necessary to fulfil the conditions and requirements set for the project but it as seen came at the cost of an increased budget being needed to implement in real life.

References

[1] R. Erickson, "Lecture 18: Switch Realization," Colorado State University, ECE 562 Power Electronics, Fall 1998. [Online]. Available: https://www.engr.colostate.edu/ECE562/98lectures/l18.pdf. [Accessed: 15-Feb-2025].

[2] M. F. Robbins, "Switches," Ultimate Electronics: Practical Circuit Design and Analysis, CircuitLab, Inc., 2021. [Online]. Available: https://ultimateelectronicsbook.com/switches/. [Accessed: 16-Feb-2025].

[3] Keithley Instruments, Inc., "E-Handbook Guide to Switch Considerations by Signal Type," 2014. [Online]. Available: https://www.tek.com/fr/documents/fact-sheet/e-handbook-guideswitch-considerations-signal-type. [Accessed: 16-Feb-2025].

[4] Electronics Tutorials, "MOSFET as a Switch." [Online]. Available: https://www.electronics-tutorials.ws/transistor/tran_7.html. [Accessed: 28-Feb-2025].