2EI4 Project #2 – Idealities of a Switch

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Ideal & Non-ideal Switches

Idealities

The ideal switch has many important properties however for this project, we will be focusing on the following properties:

1. $R_{ON} = 0$; OR $V_{switch} = 0$ when ON; OR $V_1 = V_2$ when ON

This property will ensure that all current flows through the switch without any resistance causing the voltage to be the same when switch is ON (essentially acts like a wire).

2. R_{off} = infinity OR I = 0 when OFF

This would mean that there would be a short circuit when OFF. This only occurs when R_{off} is infinity which cause current to be 0.

3. Range of V_1 and V_2 unlimited

In an ideal switch, the voltage throughout needs to be unlimited. For example, is V_1 = 10000V then across the switch at V_2, the value needs to be 10000V as well.

4. Bidirectional (can work both ways)

An ideal switch shouldn't have a polarity. Meaning that the drop across both ways of the switch should be equal.

Non-idealities

With this being said, this is only the case for an ideal switch and in the real world, nothing can be truly ideal however, you may come close to being ideal. This leads to the switch consisting of non-ideal parameters. The following non-idealities are:

1. Value of R_{ON} when ON

In a real switch, the resistance through it can never be zero when it is on. Because of this, there is a slight voltage drop across the switch itself. This value can be quantified by measuring the voltage drop and the current through it and using Ohms Law.

2. Value of I_{OFF} when OFF

When the switch is OFF, there is always a leakage current, I_{OFF}. This means that if measuring the current for when the switch is on, or off, the current which is measured is different from the current which is expected.

3. Voltage Range Limitations ($V_{min} < V_1, V_2 < V_{MAX}$)

Real switches have practical voltage ranges that they can handle. This means having "infinite" voltage through the switch isn't possible. Quantitatively, these limitations are expressed by specifying the minimum and maximum voltages (V_{min} and V_{max}) within which the switch is expected to operate reliably.

4. Same R for $V_1 < V_2$ and $V_2 < V_1$

Ideally, in both directions, the Resistance of the switch should be the same (which is zero). However, in the real world, there may be slight variations in the construction of the switch which leads to slightly different R_{ON} values in different directions. Quantitatively, this non-ideality can be measured by comparing the R_on values for bidirectional operation. A small difference in resistance values indicates the asymmetry introduced by the non-ideality.

Test Plan

Value of R_{on}

To test this ideality, the current and the voltage will be measured through the switch. For any drop there is between the Voltage, ohm's law will be used to find the Resistance.

$V_{control}$ = 0V for circuit to be on, and V_1 & V_{supply} = 5V

Value of I_{off}

In order to test this, the current before the switch and after the switch will be measured. If there is any current drop, the value would be considered as I_{off}.

$V_{control}$ = 5V for circuit to be off, and V_1 & V_{supply} = 5V

$V_{control}$ = 0V for circuit to be on, and V_1 & V_{supply} = 5V

Then after obtaining current value, compared the leakage current to expected value.

Voltage Limitations

As there is no way to test this with low voltages with the AD2, is there was a higher voltage supply available, that would be used to test the voltage limitations of the switch.

Same Value of R_{on}

To test this, the source and the drain of the MOSFET will be swapped ("swapping the switch"). The output voltage will then be measured and if it is the same as the original circuit output voltage, then that indicates that the switch is bi-directional and therefore, indicate the same R_{ON}.

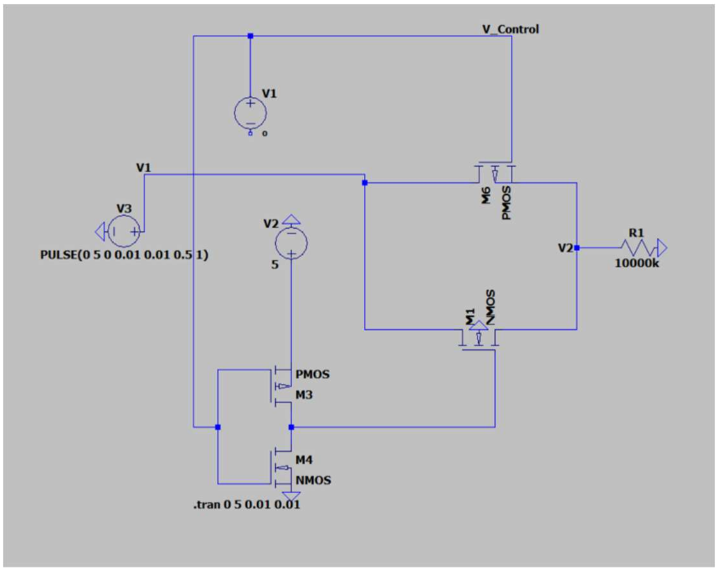
$V_{control}$ = 0V for circuit to be on, and V_1 & V_{supply} = 5V

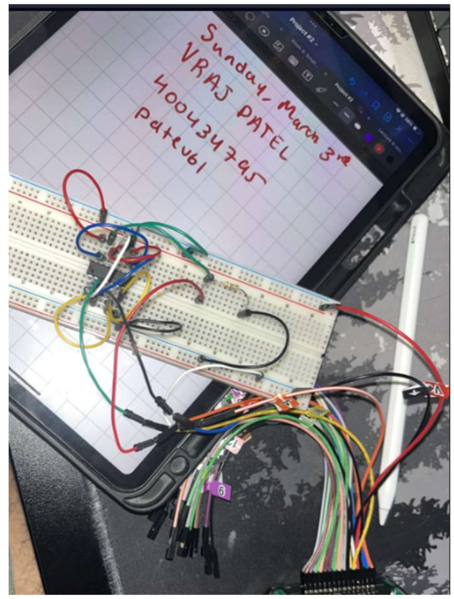
$V_{control}$ = 0V for circuit to be off, and V_1 & V_{supply} = 5V

Compare both directions and check if the graph yielded is the same for both directions in both cases, when $V_{control}$ is HIGH and LOW.

Switch Type 1

Circuit Schematic:

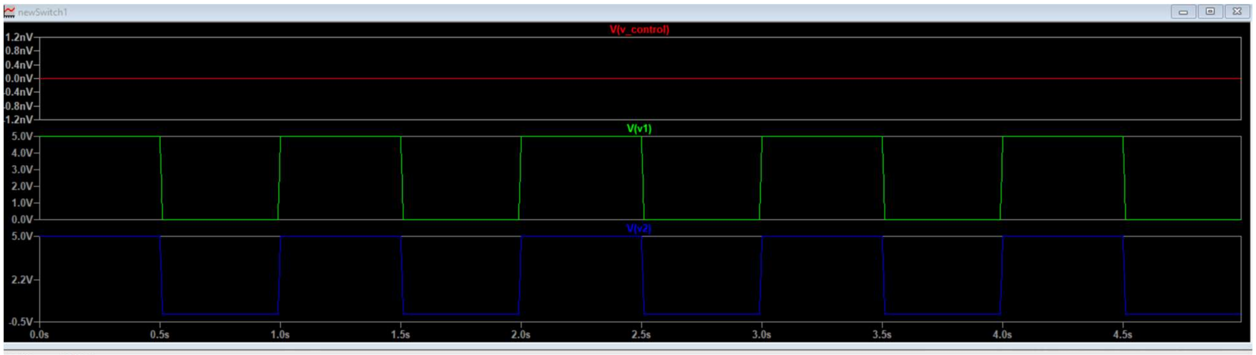




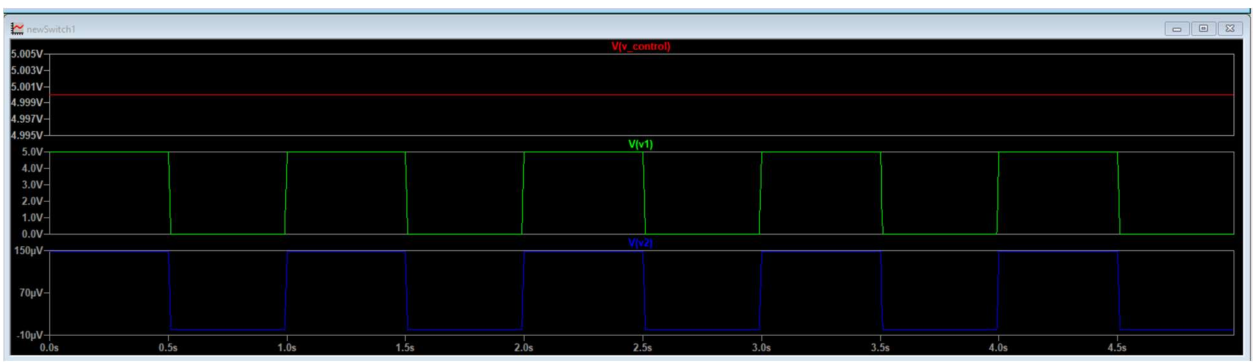
The circuit schematics above are switch type 1. As shown in the schematic, I have a square wave which varies from 0V – 5V every 0.5 seconds to test whether V_2 is really equal to V_1 when the control voltage is 0V. The resistor value is set to 10000k ohms because of functionality's sake, for AD2, circuit a lower resistance will be used.

Simulation Results (LTSpice):

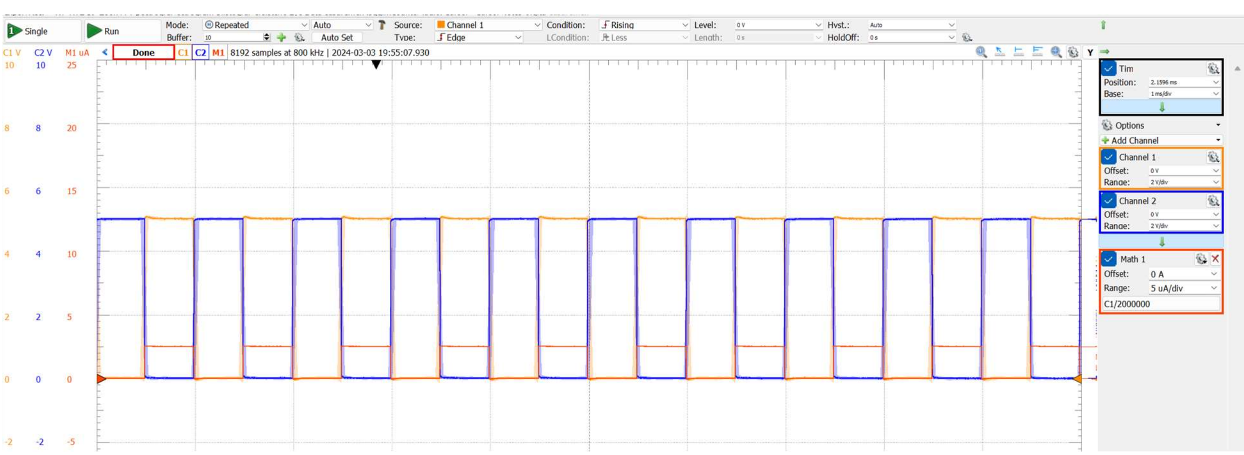
Red → Control Voltage Blue → Output Voltage Green→ Input Voltage



As seen in the simulation above, whenever the control voltage is 0V, $V_2 = V_1$ which indicates that it successfully acts like a wire. This is also true for when $V_{control} = 5V$:

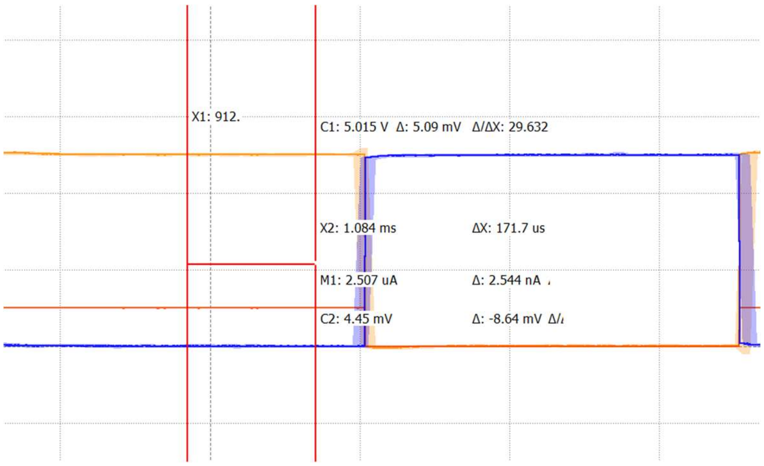


V_2 is still a square wave but as seen from the scale, the voltage is incredibly low meaning that the current through the switch is close to 0A and V_2 doesn't equal to V_1.



The AD2 simulation also shows that the schematic is correct. When the control voltage (Blue) is low, the output voltage (Channel 1) is HIGH as well as the current through the switch (Red). When $V_{control}$ = 5V, V_2 = 0V, and the opposite is also true. The input voltage as seen from the picture of the circuit is simply a 5V DC.

Test Plan R_{on}

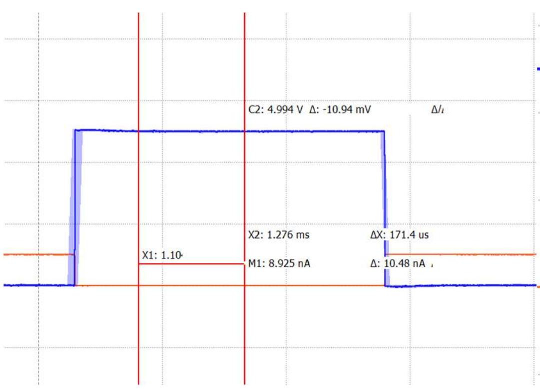


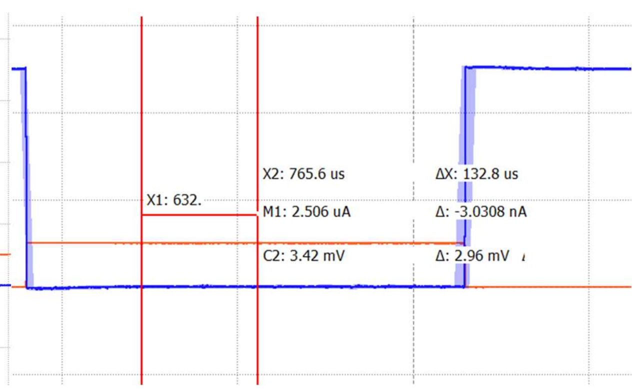
As seen from the picture above, the voltage drop is extremely low however, there is a voltage drop and the output of the voltage isn't exactly 5V (input). This means that there is indeed a value of R_{ON} which isn't equal to 0.

Voltage Limitations

For this test, I achieved the maximum possible voltage with the AD2, and still achieved the same results. This indicates that I need a higher voltage to find a breaking point of the switch and this can be done using external voltage suppliers.

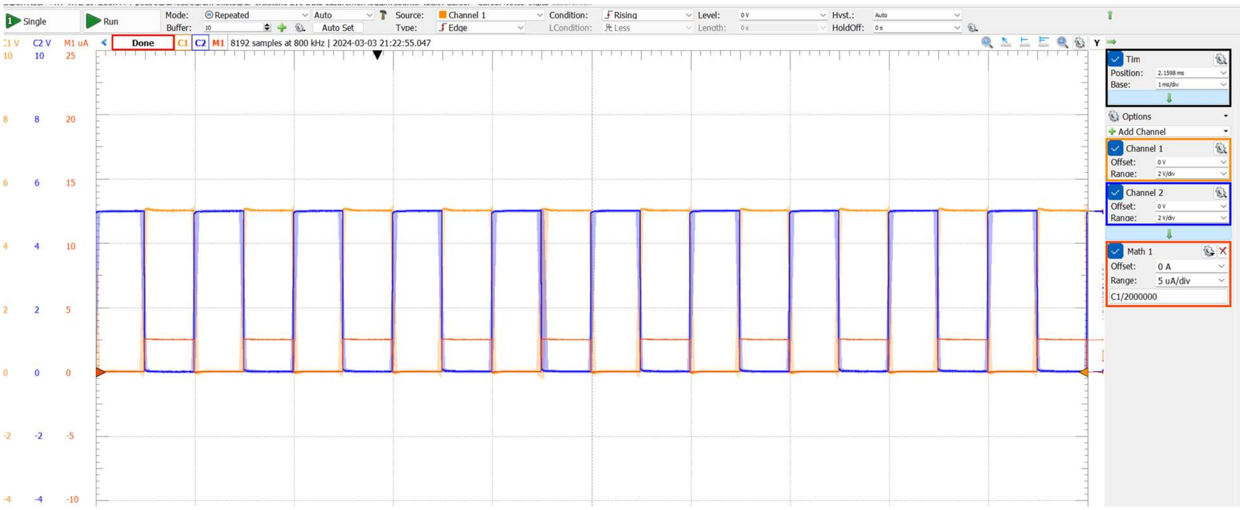
Test of I_{off}





As seen from the pictures above, when the switch is OFF, the current is expected to be 0A, but it is a little more than a perfect 0A. The same application applies to when the switch is ON where it is expected to be a perfect value of 2.5 Microamps but it is a little more.

Same Value for R_{ON}



As seen from the simulation, even after the input voltage was being driven from the other side, the switch is bidirectional, outputting the same simulation graph for both directions.

Theoretical Explanation:

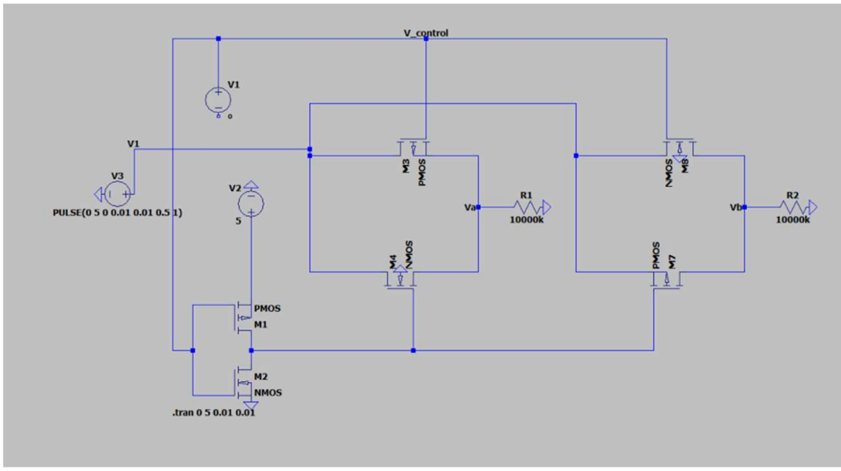
The values that were obtained from the simulation compared to the quantitative results from the theory did differ a little. This is because of various factors. In theory, we are working with a "perfect world" however, when building the circuit in real life, multiple factors arise such as resistance in wires, the internal resistance of the chip, etc. Because of factors like these, the values can differ by a small margin. With this being said, the values were in accordance with theory and most of the test plans passed.

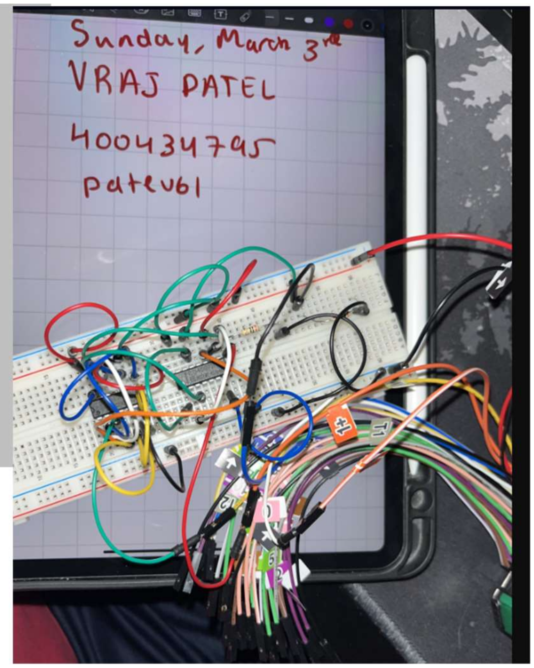
Trade-offs:

The design trade-off made within this circuit is accuracy vs complexity. In this circuit, 4 MOSFETs were used. 2 for an inverter, and the other two for a transmission gate instead of using a single MOSFET. This trade-off did allow for increased accuracy however to implement it in real life, it was quite challenging and there were all sorts of problems that I ran through before obtaining the preferable results.

Switch Type 2

Circuit Schematic:

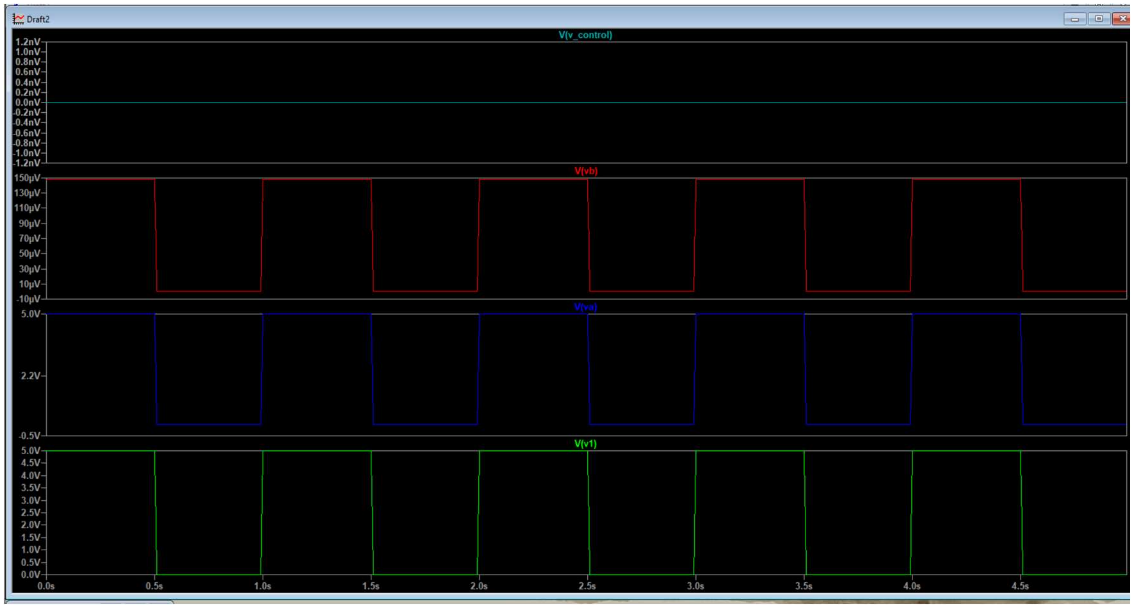




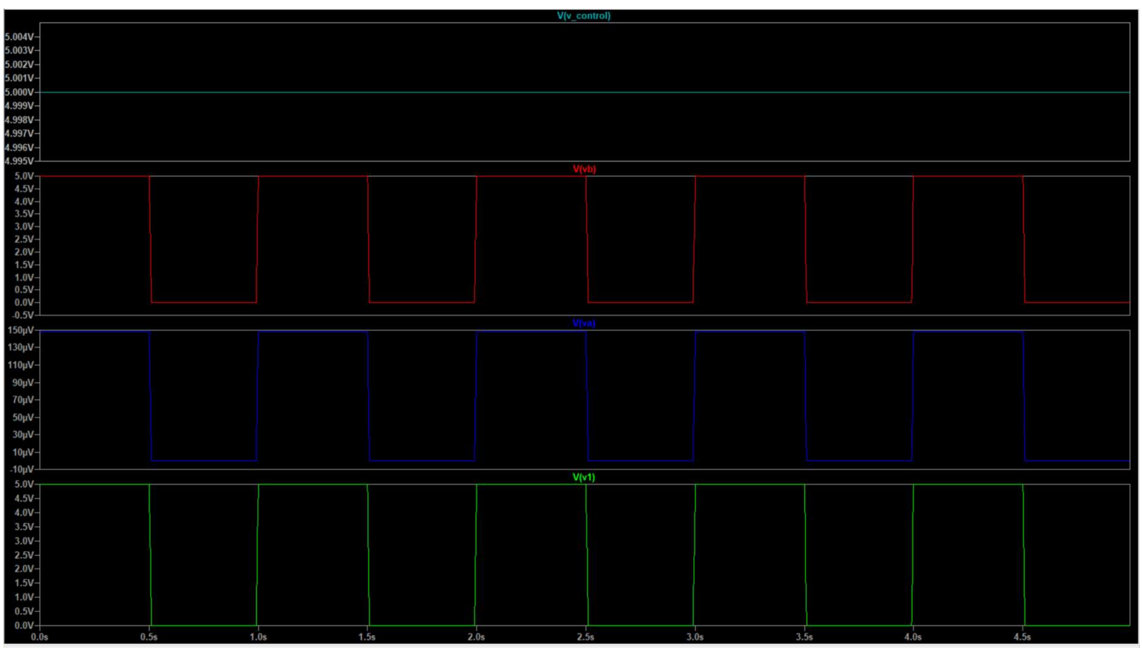
The circuit schematic to the left is for switch type 2. The difference between the first circuit and this one is simply that V_a is being fed as the input voltage for the new transmission gate. Again the resistor values are extremely large only for functionality. The

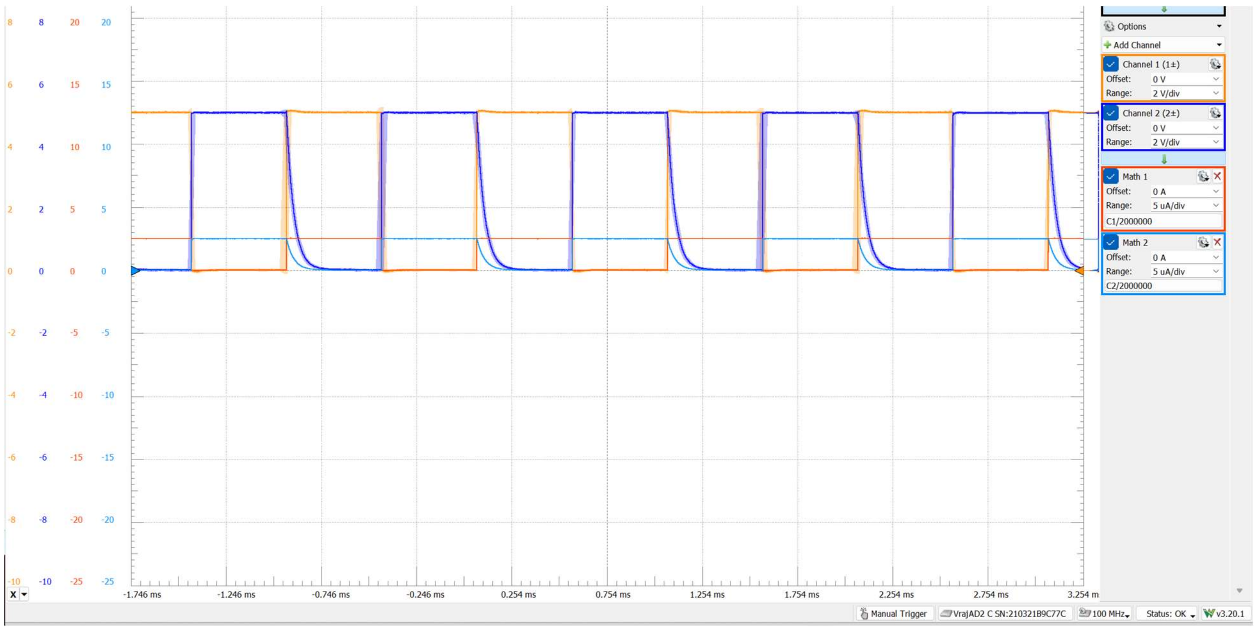
Simulation Results (LTSpice):

Red → Control Voltage   Blue → V_a Voltage   Green→ V_B Voltage   Light Blue → Control Voltage



As seen from the graph above, whenever the control voltage is 0V, $V_a = V_1$ which guarantees that the circuit above is switch type 2. To further validate this circuit whenever control voltage is 5V, $V_b = V_1$ is expected and V_a to be a zero value, the graph shows the following which was stated:



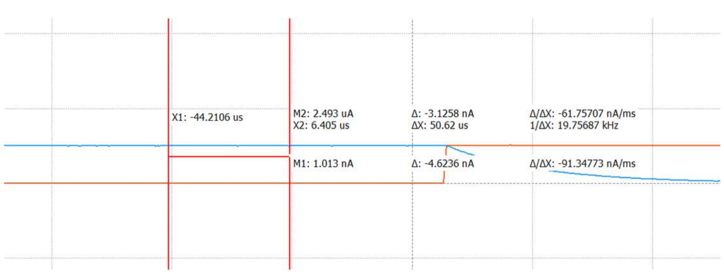


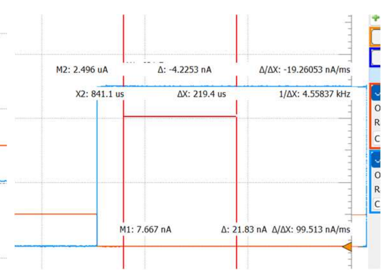
As seen from the AD2 simulation, Channel 1 represents V_a whereas Channel 2 represents V_b. As shown in the simulation, when the control voltage (which is a square waveform but isn't shown due to not there being another channel) is LOW, $V_a = V_1$ (which is a 5V dc voltage), and when the control voltage is HIGH, $V_b = V_1$, turning V_1 as LOW. This would mean that in this case when V_a is HIGH, V_b would remain LOW and the opposite would be true. This is shown in the simulation which verifies the functionality of the switch.

Test Plan R_{ON}

Since this switch could never be "off," there will always been an on resistance. As seen in the picture that the voltage value of V_a and V_b aren't exactly 5, this means that there is a resistance through the switch when it is on.

Test of I_{off}

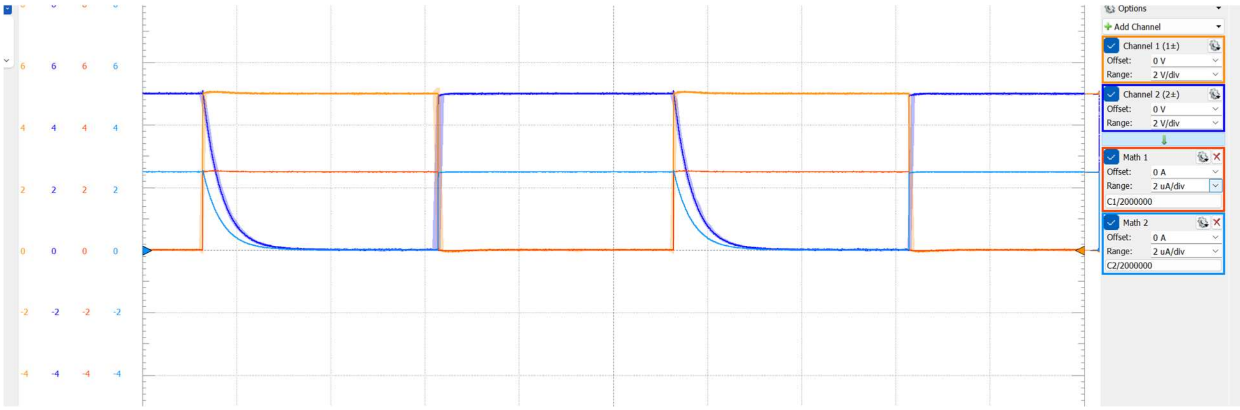




As seen from the graphs above, for both the current through the first resistor and second resistor, the values aren't exact 2.5 micro-amps, and they are a bit deivated from that value. This indicates that there is a current leakage for the switch, however it is an extremely small value.

Same Value for R_{ON}

When the input voltage was driven from the output terminal and vice-versa, the same graph was produced. This means that the resistance of the switch when it is on is the same for both directions, passing this test plan.



Voltage Limitations

For this test, I achieved the maximum possible voltage with the AD2, and still achieved the same results as for switch type 1. This indicates that I need a higher voltage to find a breaking point of the switch, and this can be done using external voltage suppliers.

Theoretical Explanation

The values that were calculated and found from the AD2 simulation do indeed match the quantitative results from the theory. V_b is supposed to be HIGH whenever V_a is LOW and vice-versa which is indicated from the graphs above. It is also noteworthy that the current is also supposed to stay around the same since the switch is always closed and the same resistor is used for both outputs. This is also denoted in the graph with the red and the light blue lines. The transient behavior of the Channel 2 (V_b) can result from a couple of factors. The major factor is that there is circuit resistance. Channel 2 is configured with another chip, which means that the way that it is connected there can be some circuit resistance within the chip and its configuration causing a transient-like behavior in Channel 2.

Design Trade-off:

As mentioned before the main design trade-off in the circuit is accuracy vs complexity similarly to switch type 1. Working with 2 chips and 6 MOSFETs is challenging and hard to build. Another trade-off that I would like to mention is functionality vs ease of use. The circuit that was designed provided quite a bit of functionality and at the end completed its task however, more functionalities would require a harder ease of use.