ELEC ENG – 2EI4

Design Project #2

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Ideal Switches

An ideal switch is a theoretical concept that is used in branches of electrical engineering and circuit design. The ideal switch is utilized to represent a switch that features a perfect / ideal characteristic. The properties of an ideal switch consist of the following: when the switch is in its on-state, it acts as a short circuit, there is no resistance within the switch prohibiting voltage drop across the switch thus, V1 = V2. When the switch is in its off-state, it acts as an open circuit, the resistance across the switch is infinite thus, the current across the switch is zero. In a switch, the voltage ranges of V1 and V2 are both unlimited, there is no limit for the voltage. It is also bidirectional.

Switch Non-Idealities

Qualitative Description

Unfortunately, switches are far from ideal and feature many non-idealities. Real switches exhibit several non-idealities that deviate from the ideal characteristics. Firstly, when the switch is in its on-state, the resistance is non-zero. This results in a voltage drops and power dissipation as the current flows through the switch. Furthermore, when the switch is in the off state, there is a leakage current present. This may arise due to imperfections in the chosen materials for construction or due to the manufacturing process. In addition, real switches feature an operational limit. This operational limit is represented through $V_{min} < V_1, V_2 < V_{max}$. If this operational limit is exceeded, erratic behavior may arise which may potentially damage the switch. Finally, the resistance present in the switch is constant irrespective of the voltage that is being applied to the switch. This implies that a switch is not bidirectional. These non-idealities must be considered upon the design of a circuit.

Quantitative Description

The qualitative descriptions describing the non-idealities of a real switch feature quantitative descriptions. Firstly, with the presence of a resistance when the switch being in its on-state, there will be voltage drops and dissipation of power. As this on-state resistance is increased, the voltage drop across the switch and its power dissipation will also increase. In addition, with the leakage current present when the switch is in its off state, there will be a value for current as the switch is off. When the leakage current value is lower, the switch is closer to its ideal counterpart. Furthermore, the operating voltage range of the switch defines the minimum and maximum voltages that the switch is capable of handling prior to breaking. Finally, when the switch is in its on-state, the resistance is constant irrespective of the applied voltage. This implies that the resistance value is independent of the voltage of the switch and that the switch is not entirely bidirectional.

Non-Ideality:	**Expression:**
1	$R_{ON} \neq 0$
2	$I_{OFF} \neq 0$
3	$V_{MIN} < V_1$ $V_2 < V_{MAX}$
4	$R_{ON}(V_1, V_2)$

Figure 1 - Expressions for Non-Idealities

Test Plan

Chosen Voltage Values

Switch Type 1			**Switch Type 2**	
Parameter:	**Values:**		**Parameter:**	**Values:**
$\mathbf{V_{CONTROL}}$	*0 – 5 V*		$\mathbf{V_{CONTROL}}$	*0 - 5 V*
$\mathbf{V_{SUPPLY}}$	5 V		$\mathbf{V_{SUPPLY}}$	5 V
$\mathbf{V_1}$	5 V		$\mathbf{V_1}$	5 V

Note: $V_{CONTROL}$ is a square wave oscillating between 0 and 5 V.

Explanation – Switch Type 1

The first switch must be tested against the four non-idealities mentioned under *Switch Non-Idealities*. To commence, the first non-ideality is that a resistance is present in the on-state of the switch, when the $V_{CONTROL}$ voltage is 0 V, resulting in a voltage drop is to be expected across the switch – $V_{OUT} < V_{IN}$. To test against this non-ideality, an input voltage will be applied to the switch and measurements will be taken at the input and output nodes of the switch. This will determine whether there is voltage drop present across the switch. In addition, the second non-ideality of the switch is that there is leakage current when the switch is in its off state, when the $V_{CONTROL}$ voltage is 5 V, implying that there is non-infinite resistance in this state. To test against this non-ideality, the voltage at the output node of the switch and the switch's resistance will be determined. These measurements will be used alongside I = V / R to determine the current flowing through the switch. Furthermore, the third non-ideality is that the switch features an operating voltage range implying that the switch can only operate when it is within these boundaries. This non-ideality will be tested against by inputting a RampUp function from 0 – 5 V. It will be noted when the switch begins to experience abnormal behavior. Finally, the final non-ideality of a switch is that the resistance of the switch is constant irrespective of the voltage being applied implying that it is non-bidirectional. The non-bidirectionality of the switch will be tested against through the voltage drop and leakage current tests. Utilizing these test cases, the non-idealities of Switch Type 1 will be tested against.

Explanation – Switch Type 2

Much like the first switch, the second switch must also be tested against the four non-idealities mentioned under *Switch Non-Idealities*. To commence, the first non-ideality is that a resistance is present in the on-state of the switch, when the $V_{CONTROL}$ voltage is 0 V, resulting in a voltage drop is to be expected across the switch – $V_{OUT} < V_{IN}$. To test against this non-ideality, an input voltage will be applied to the switch and measurements will be taken at the input and output nodes of the switch. This will determine whether there is voltage drop present across the switch. In addition, the second non-ideality of the switch is that there is leakage current when the switch is in its off state, when the $V_{CONTROL}$ voltage is 5 V, implying that there is non-infinite resistance in this state. To test against this non-ideality, the voltage at the output node of the switch and the switch's resistance will be determined. These measurements will be used alongside I = V / R to determine the current flowing through the switch. Furthermore, the third non-ideality is that the switch features an operating voltage range implying that the switch can only operate when it is within these boundaries. This non-ideality will be tested against by inputting a RampUp function from 0 – 5 V. It will be noted when the switch begins to experience abnormal behavior. Finally, the final non-ideality of a switch is that the resistance of the switch is constant irrespective of the voltage being applied implying that it is non-bidirectional. The non-bidirectionality of the switch will be tested against through the voltage drop and leakage current tests. Utilizing these test cases, the non-idealities of Switch Type 2 will be tested against.

Switch Type 1

Circuit Schematic

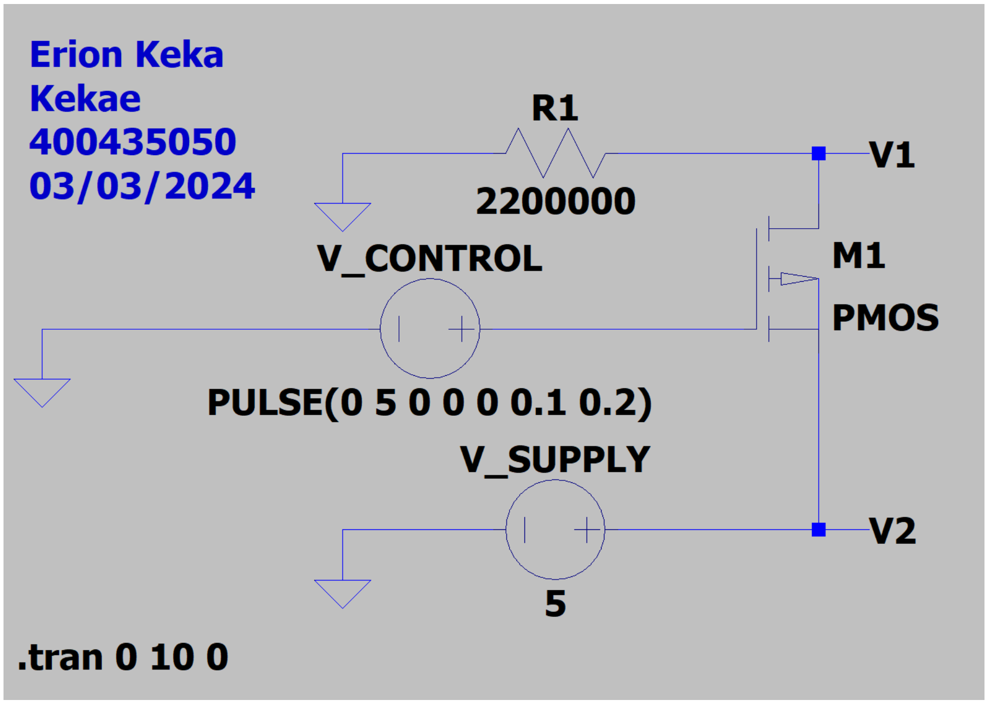

Figure 2 - Switch Type 1 Circuit

Simulation Measurements

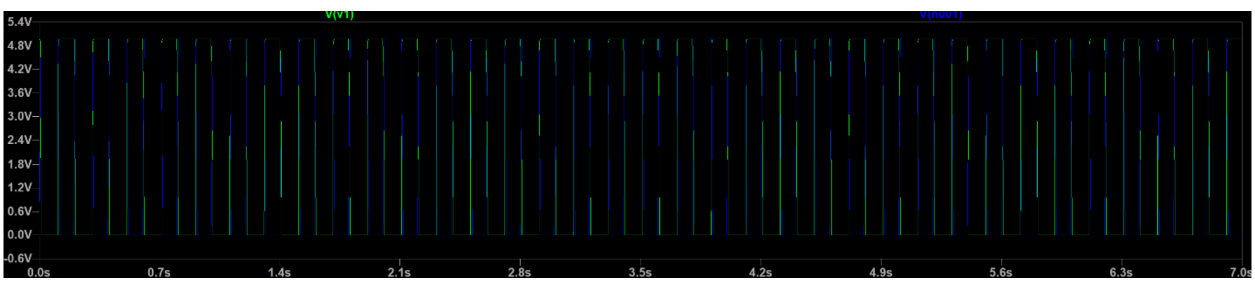

Figure 3 – Voltage of Both Nodes of Switch (Blue) VS Input Voltage (Green)

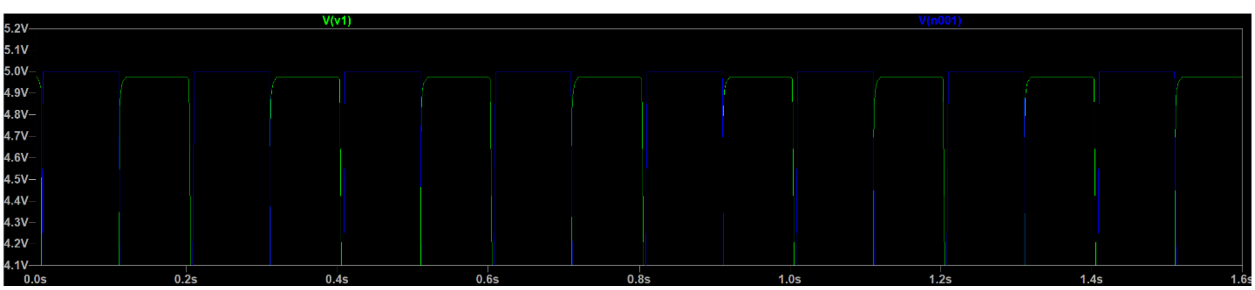

Figure 4 - (Enlarged) Voltage of Both Nodes of Switch (Blue) VS Input Voltage (Green)

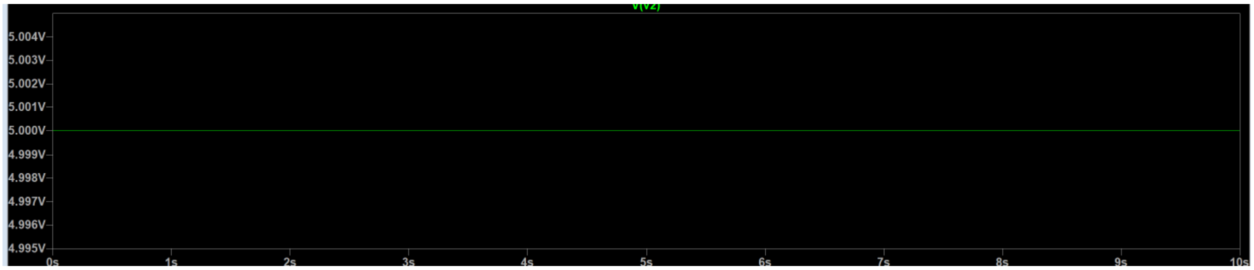

Figure 5 - Supplied Voltage

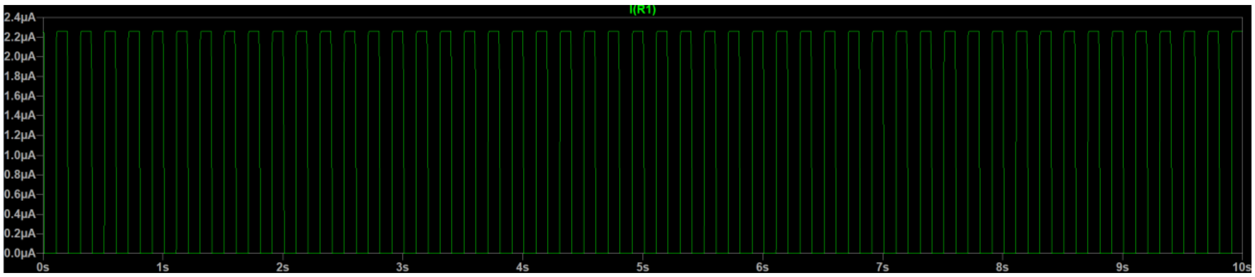

Figure 6 - Current Flowing Across R1

Physical Measurements

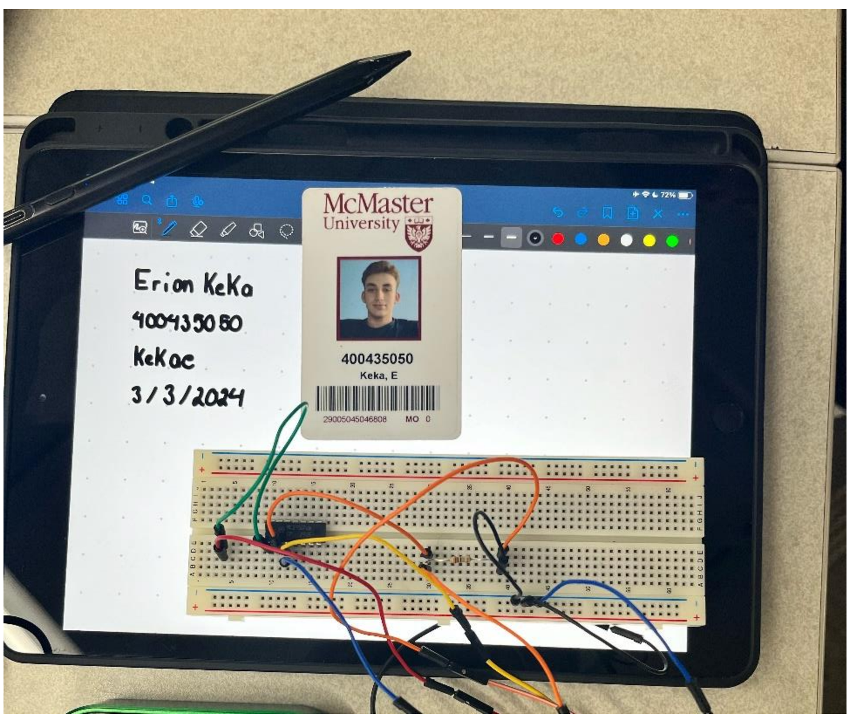

Figure 7 - Physical Circuit of Switch Type 1

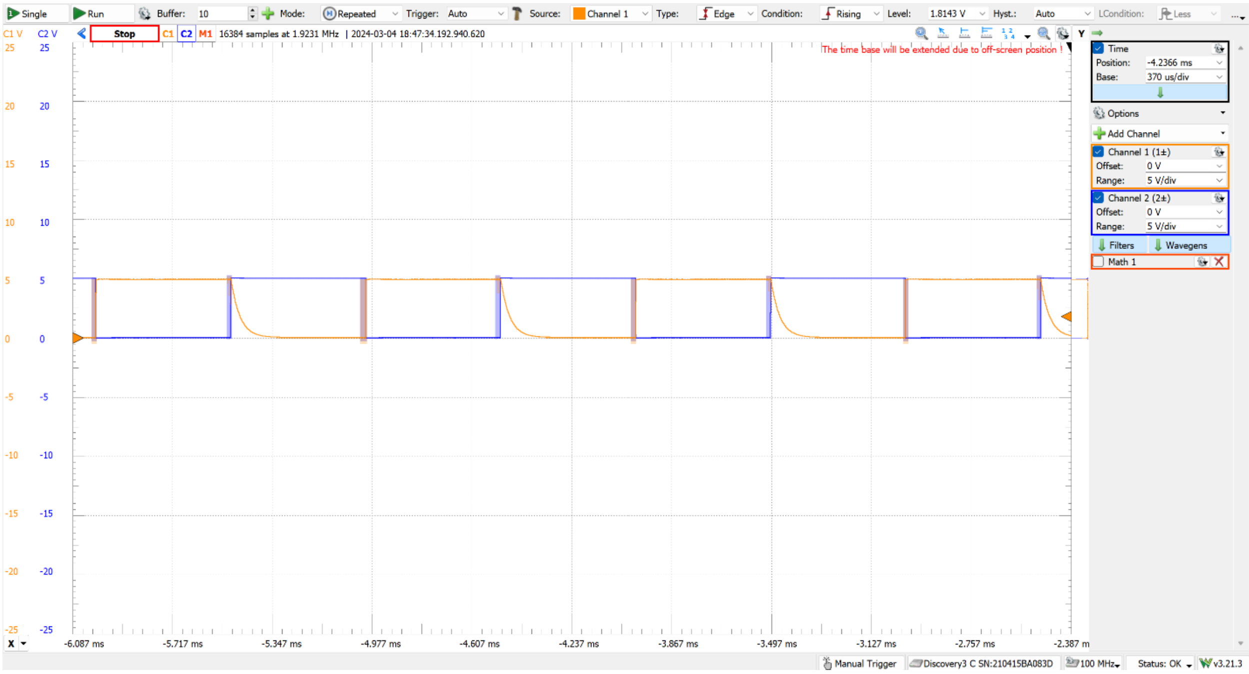

Figure 8 - Voltage of Both Nodes of Switch (Orange) VS Input Voltage (Blue)

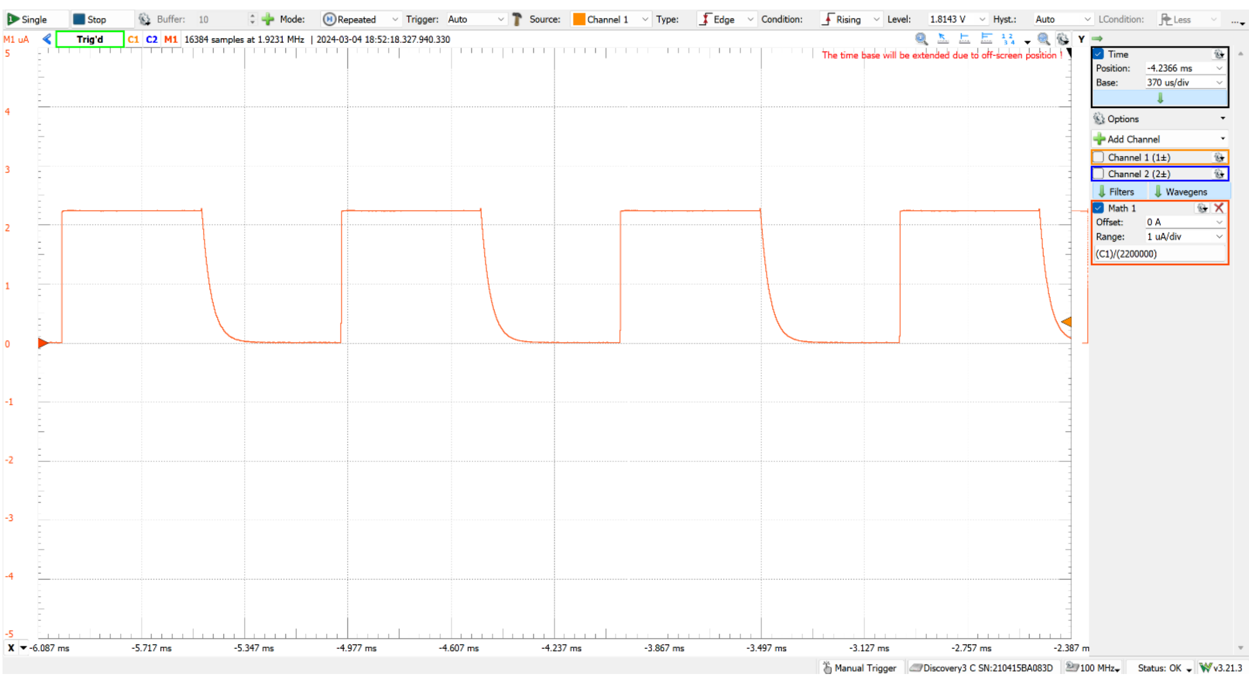

Figure 9 – Current Flowing Through Resistor

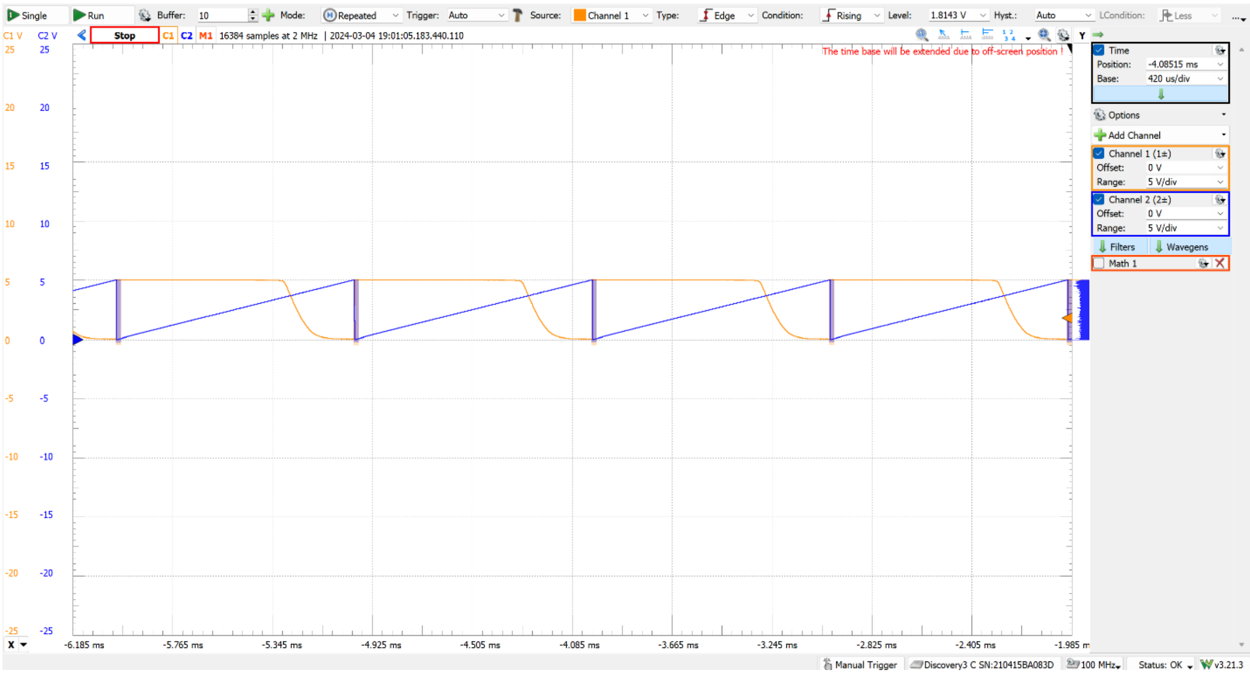

Figure 10 - Inputting RampUp to View Switch Transition

Theoretical Explanation and Comparison

After testing the circuit design via the simulation and the physical measurements, we can observe each of the switch non-idealities. Firstly, we can notice through both the simulation and the physical measurements that there is a voltage drop present confirming that there is an on-resistance present alongside it. In the simulation, the output voltage was determined to be 4.97 V which is smaller than the input voltage of 5 V. This implies that there is a voltage drop across the switch of 5 V – 4.97 V = 0.03 V. This shows that the on-resistance is non-zero. The same occurs in the physical analysis in which there is a small voltage drop of 0.04 V (5 V – 4.96 V). This shows that the on-resistance is also non-zero. In addition, through both the simulated and physical analysis, it also noted that there is a leakage current present within the off state of the switch. In the simulation, the leakage current is found to be 2.26 μA. Similarly to the physical circuit, the leakage current is found to be 2.23 μA. Therefore, aligning with the non-ideality stated previously. Utilizing the leakage current and the value of voltage drop across the switch, the on-resistance in the simulation is determined to be approximately 0.0133 Ω from the R = V / I formula. Similarly in the physical circuit, the on-resistance is calculated to be approximately 0.0179 Ω again from the R = V / I formula. Furthermore, as mentioned in the theoretical analysis, there is an operational voltage range that occurs with the usage of a switch. In the physical analysis, it can be seen in Figure 9 that the switch's transitions occur prior to it having reached either 0 V (on-state) or 5 V (off-state). Finally, it can also be noted through the initial two tests, that the switch is non-bidirectional as it was mentioned under the *Switch Non-Idealities*.

Design Tradeoffs

Switch Type 1 features a simple design. It features a sole P-Type MOSFET and a singular 2.2-million-ohm resistor. This results in an economical switch design. The supply range of the V_{SUPPLY} results in a simpler and more versatile circuit as it can be utilized with various wave generators including the Analog Discovery 3 utilized in the design project. The switch designed is very close to featuring the properties of an ideal switch; however, there are still non-idealities present. To conclude, the Switch Type 1 is a simple, economical, and versatile switch design.

Switch Type 2

Circuit Schematic

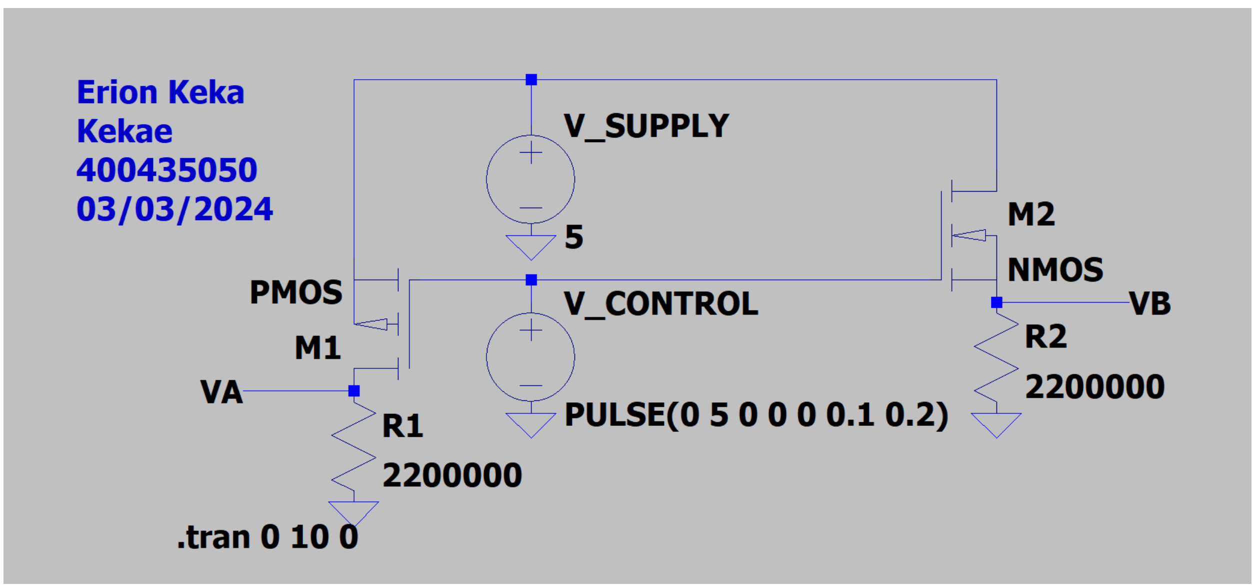

Figure 11 - Switch Type 2 Circuit

Simulation Measurements

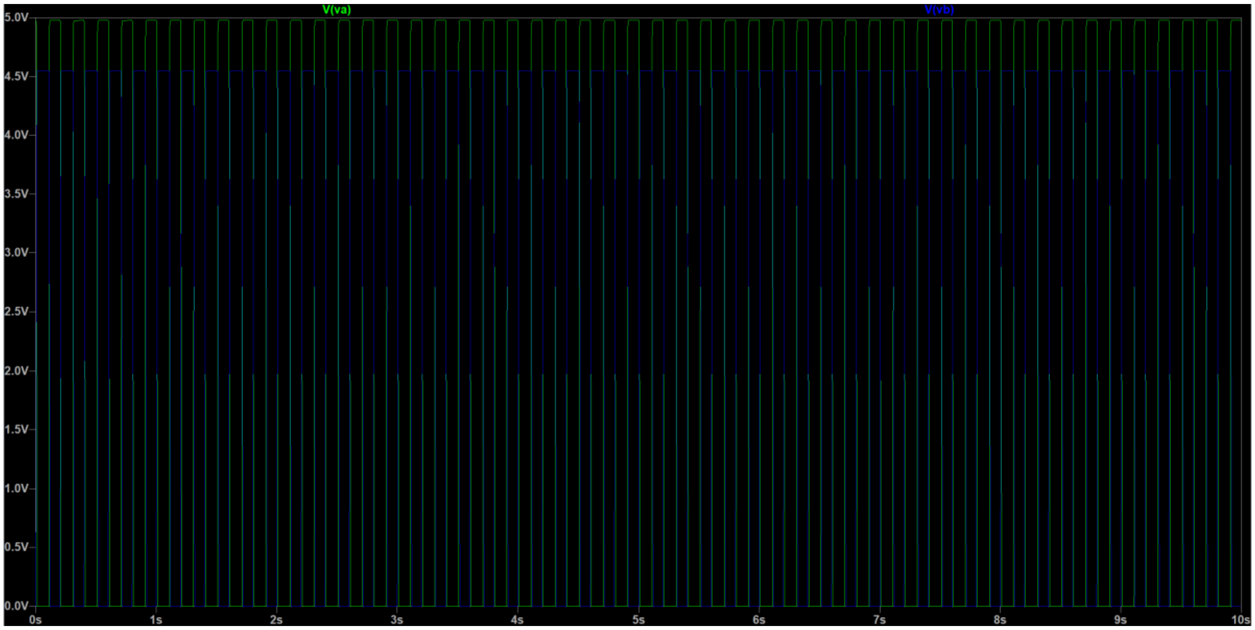

Figure 12 - Voltage of Both Nodes of Switch (Blue) VS Input Voltage (Green)

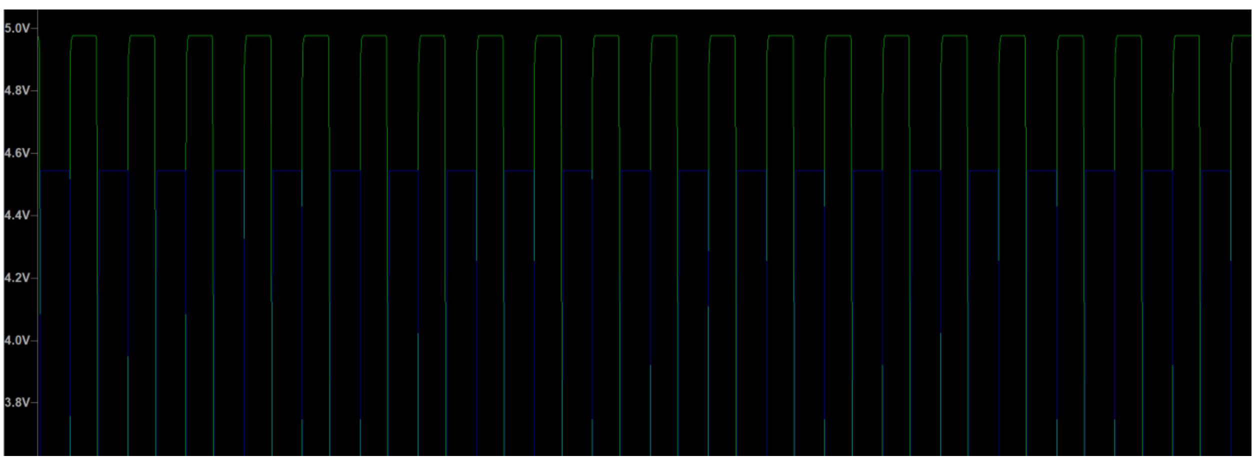

Figure 13 - (Enlarged) Voltage of Both Nodes of Switch (Blue) VS Input Voltage (Green)

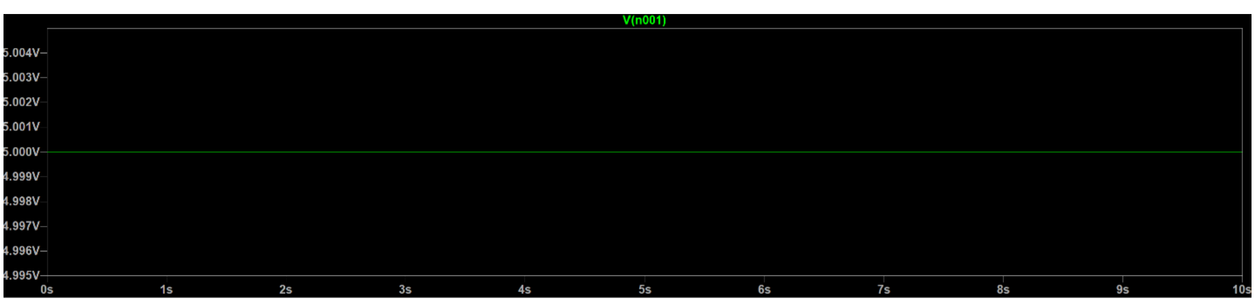

Figure 14 - Supplied Voltage

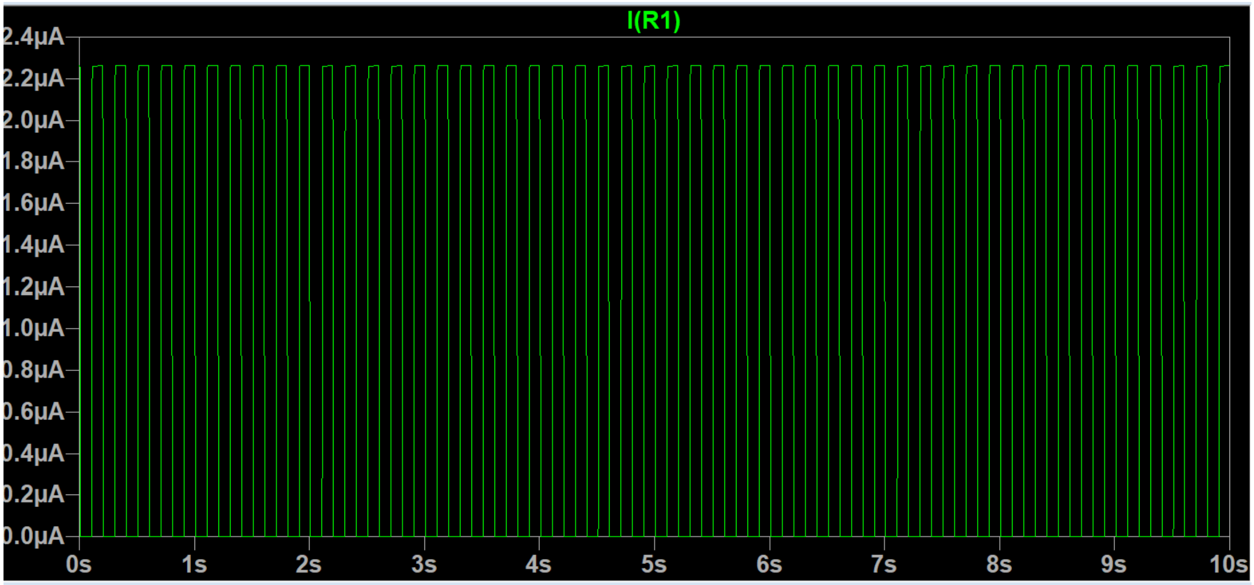

Figure 15 - Current Across R1

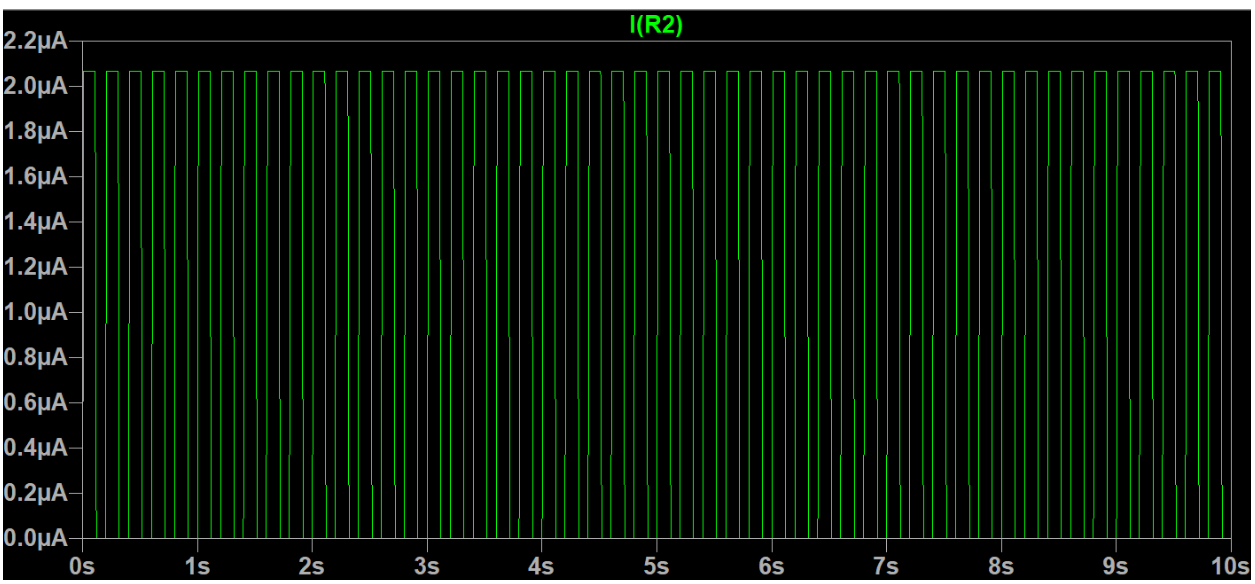

Figure 16 - Current Across R2

Physical Measurements

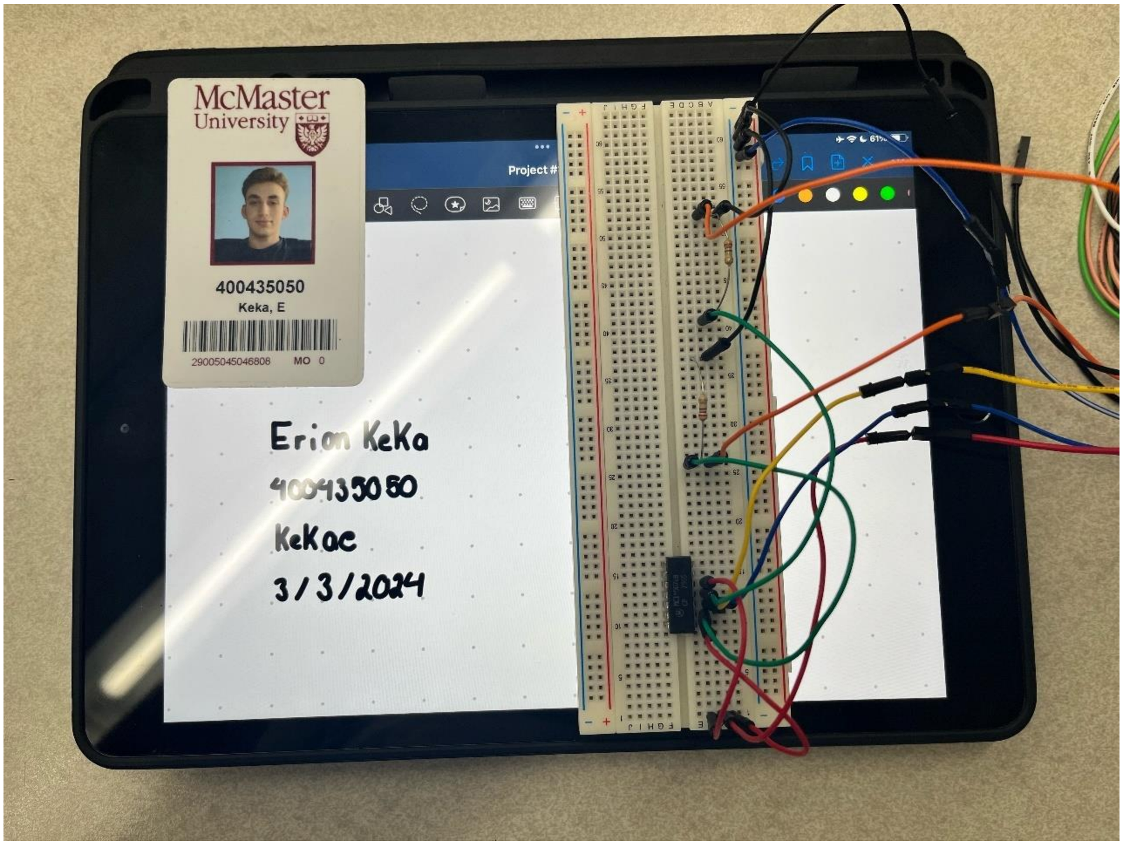

Figure 17 - Physical Circuit of Switch Type 2

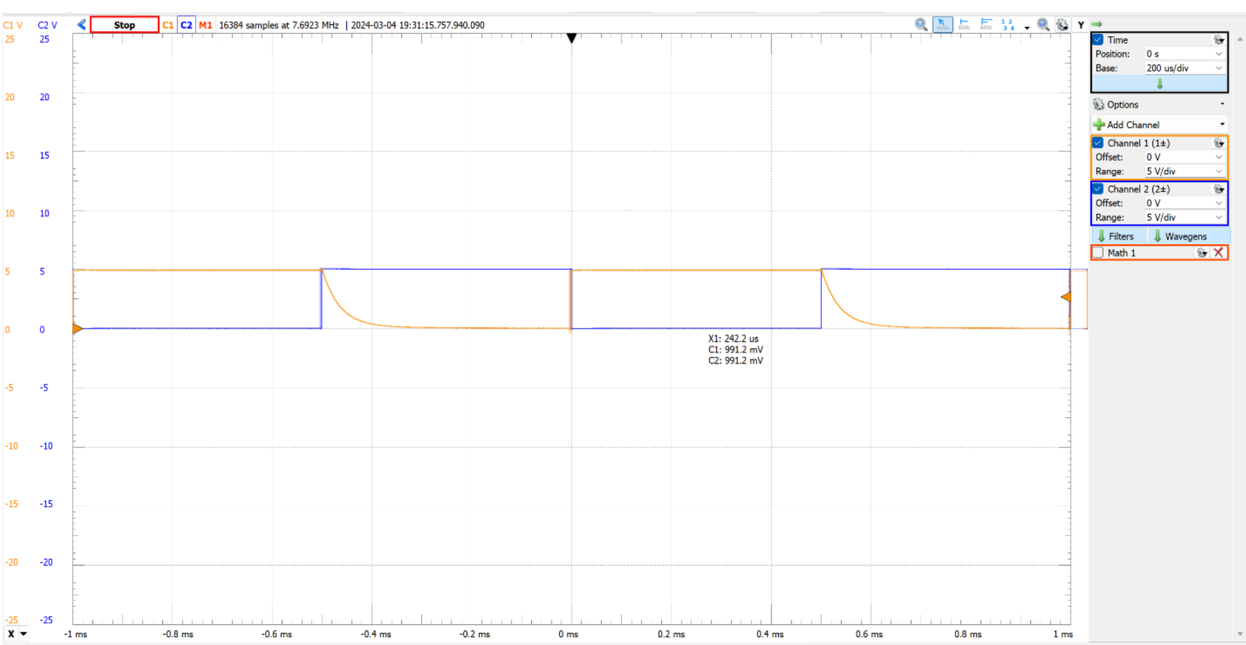

Figure 18 - Voltage of Both Nodes of Switch (Orange) VS Input Voltage (Blue)

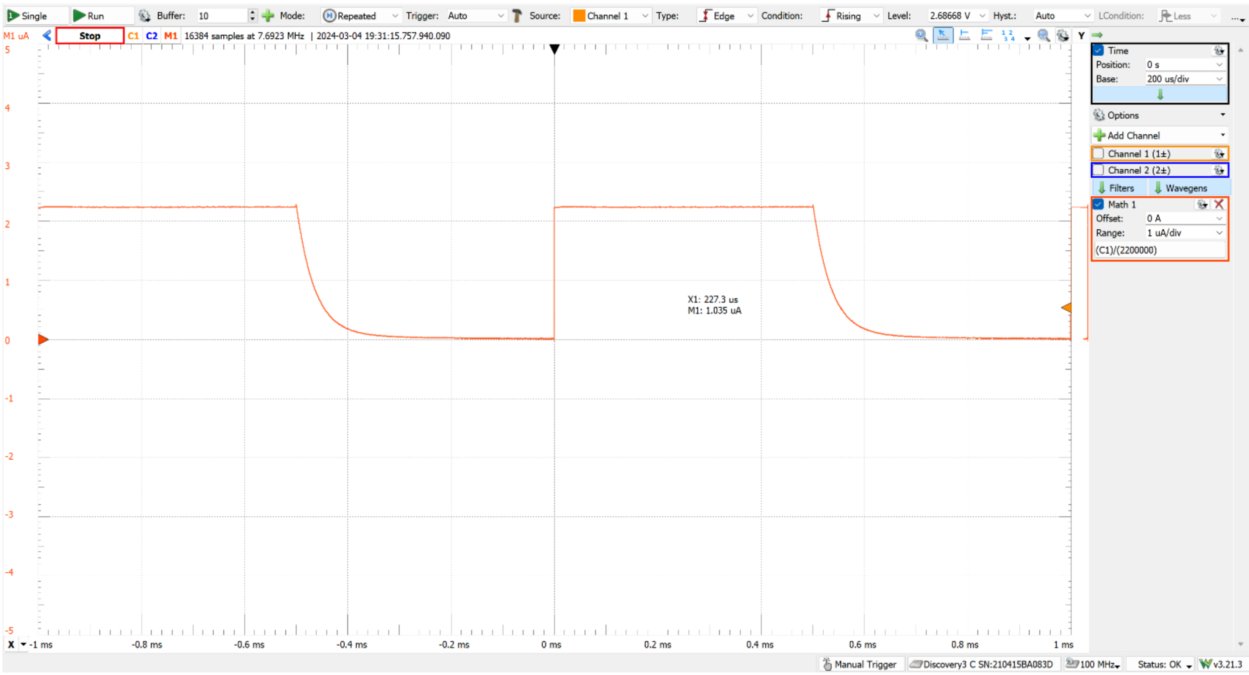

Figure 19 - Current Flowing Through Resistor

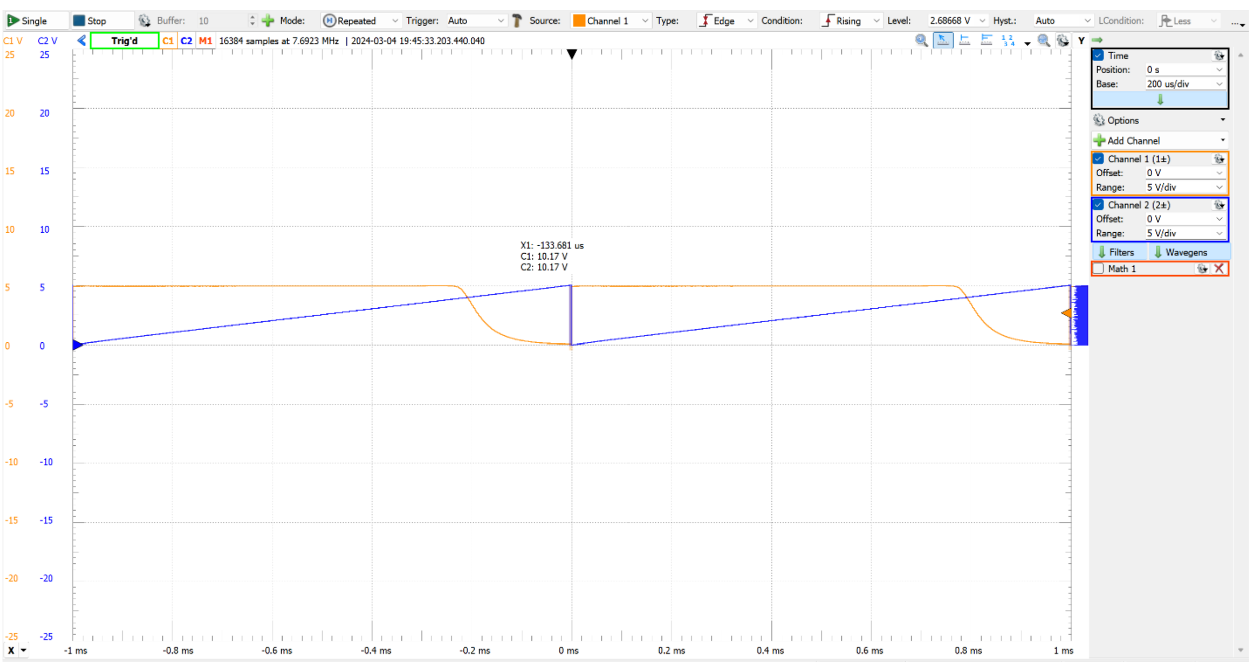

Figure 20 - Inputting RampUp to View Switch Transition

Theoretical Explanation and Comparison

After testing the second circuit design via the simulation and the physical measurements, we can observe each of the switch non-idealities. Firstly, we can notice through both the simulation and the physical measurements that there is a voltage drop present confirming that there is an on-resistance present alongside it. In the simulation, the output voltage was determined to be 4.98 V which is smaller than the input voltage of 5 V. This implies that there is a voltage drop across the switch of 5 V – 4.98 V = 0.02 V. This shows that the on-resistance is non-zero. The same occurs in the physical analysis in which there is a small voltage drop of 0.01 V (5 V – 4.99 V). This shows that the on-resistance is also non-zero. In addition, through both the simulated and physical analysis, it also noted that there is a leakage current present within the off state of the switch. In the simulation, the leakage current is found to be 2.07 μA. Similarly to the physical circuit, the leakage current is found to be 2.20 μA. Therefore, aligning with the non-ideality stated previously. Utilizing the leakage current and the value of voltage drop across the switch, the on-resistance in the simulation is determined to be approximately 0.0097 Ω from the R = V / I formula. Similarly in the physical circuit, the on-resistance is calculated to be approximately 0.00454 Ω again from the R = V / I formula. Furthermore, as mentioned in the theoretical analysis, there is an operational voltage range that occurs with the usage of a switch. In the physical analysis, it can be seen in Figure 9 that the switch's transitions occur prior to it having reached either 0 V (on-state) or 5 V (off-state). Finally, it can also be noted through the initial two tests, that the switch is non-bidirectional as it was mentioned under the *Switch Non-Idealities*.

Design Tradeoffs

Upon comparing the second switch design to the first switch design, it can be noted that the second switch can perform closer to the ideal properties of a switch. The first switch featured higher values of the on-resistance which resulted in a higher voltage drop and leakage current. In comparison to the second switch, these values were smaller than with the first switch design. The second switch featured the utilization of two MOSFETS unlike the first, it featured both a P-Type and an N-Type MOSFET. This made the circuit more confusing to build; however, resulted in better performance. In the future, the number of MOSFETs should be increased further to further improve the performance of the switch.

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