ELECENG 2EI4

DP #2 Research: Voltage Controlled Switch

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Summary

This project involves designing and building a voltage-controlled switch that approximates ideal switch behaviour. Part one focused on researching key characteristics of ideal and non-ideal switches to understand real-world limitations. Using this knowledge, a test plan was developed to quantify switch performance based on voltage limits, resistance, and leakage current. The second phase will involve implementing the design using MOSFETs, diodes, resistors, and capacitors while complying with the given constraints.

Ideal Switches

An ideal switch has four main properties. First, when the switch is ON, it is closed and behaves like a perfect wire. This means it has zero resistance and, by Ohm's Law, experiences a voltage drop of zero [1], as seen in (1). This results in the voltage at one end of the switch being equal to the voltage at the other end ($V_1 = V_2$), with respect to the ground.

$$V = RI \text{ where } R = 0 \qquad (1)$$
$$\therefore V = 0I = 0$$

Second, when a switch is OFF, it behaves like an open circuit, preventing any current flowing through it. Therefore, by Ohm's Law, its resistance is infinite [1] as seen in (2).

$$V = RI \text{ where } I = 0 \qquad (2)$$
$$\therefore R = \frac{V}{0} = \infty \text{ , where V is any finite value}$$

Third, because an open switch has infinite resistance, there is no limit on the voltage across it [1]. As seen in (2), the voltage can take any finite value. Finally, an ideal switch is bidirectional, meaning that when it is closed, it behaves like a perfect wire, allowing current to flow in either direction [2].

Switch Non-Idealities

Real switches exhibit four main non-idealities that affect their performance. When closed, real switches have internal non-zero resistance, which leads to a voltage drop across the switch, so that $V_1 \neq V_2$ [3]. This results in power loss and reduced circuit efficiency. The resistance typically ranges from 50mΩ to 100mΩ, depending on factors such as usage, environmental conditions and material properties [4].

Secondly, when open, real switches have a small leakage current ranging from 0.5mA and 1mA [5]. This indicates that the resistance across the switch is very high but finite, allowing for a small voltage drop. Real switches also have voltage limits when open [3], ranging from 125 V to 250 V AC/DC [6] for small switches like the one in this project. Exceeding these limits can damage both the switch and connected components.

Finally, when a switch is on, the resistance across it remains the same regardless of the direction of current flow [7]. This can be seen by Ohm's law, as it states that the current flowing through a conductor is directly proportional to the voltage drop, and thus resistance of a conductor is constant.

Test Plan

Listed below are experiments to be conducted for each non-ideality above. This will identify the performance of the design.

Non-ideality 1 : Closed switches have internal resistance

Set Values:

- $V_{control} = 0$ (to keep the switch closed)
- $V_{supply} = 5V$
- V_1 = multiple values (e.g., 1V, 2V, 3V, 4V) to observe effects

Measure:

- V_2 (output voltage)

Expected Observation:

- If $V_2 \neq V_1$, it confirms a voltage drop across the switch, indicating a non-zero resistance.

Non-ideality 2: Real switches have a small leakage current when open

Set Values:

- $V_{control} = 5V$ (to keep the switch open)
- $V_{supply} = 5V$
- V_1 = multiple values (e.g., 1V, 2V, 3V, 4V) to observe effects

Measure:

- V_2 (output voltage)

Expected Observation:

- If $V_2 \neq 0$, this means some voltage "leaks" through the switch because a tiny current is still flowing through the open switch.

Non-ideality 3: Real switches have voltage limits when open:

Set Values:

- $V_{control} = 5V$ (to keep the switch open)
- $V_{supply} = 5V$
- V_1 = multiple values (e.g., ±1V, ±2V, ±3V, ±4V) to observe effects

Measure:

- V_2 (output voltage)

Expected Observation:

- If V_1 exceeds V_{max}, then this could cause excessive leakage current, or a short circuit. Instead of zero, the output voltage will be $V_2 \approx V_1$.
- If V_1 drops below V_{min}, then this could cause a small leakage current. Instead of zero, the output voltage will be $0 < V_2 \leq V_1$.

Non-ideality 4: When a real switch is on, its resistance remains the same regardless of the current's direction.

Set Values:

- $V_{control} = 0V$ (to keep the switch closed)
- $V_{supply} = 5V$
- V_1 = multiple values (e.g., ±1V, ±2V, ±3V, ±4V) to observe effects in both directions

Measure:

- V_2 (output voltage)
- I (current through switch)

Calculate:

- Resistance in Direction 1:

$$R_1 = \frac{V_2 - V_1}{I}$$

- Resistance in Direction 2 (when polarity is reversed):

$$R_2 = \frac{V_1 - V_2}{I}$$

Expected Observation:

- If $R_1 \approx R_2$, the switch behaves symmetrically, meaning its resistance does not depend on current direction.

References

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