ELECENG 2EI4

Design Project 2 - Research Document

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Ideal Switch Properties

Zero ON Resistance:

When an ideal switch is in the **ON** state, it behaves as a perfect conductor, meaning that its resistance is exactly zero. This ensures that no power is lost when current flows through the switch. In practical terms, this means that there is no voltage drop across the switch itself (V_{switch}= 0V), allowing the input and output voltages (V1 and V2) to be identical. This property ensures that the switch does not interfere with the signal or power passing through it. However, in real-world switches, there is always a small but nonzero resistance (R_{on}), which results in a minor voltage drop and some power dissipation in the form of heat.

Infinite OFF Resistance:

When the switch is in the **OFF** state, it behaves as a perfect insulator, meaning that its resistance is infinite. This ensures that no current flows through the switch when it is open, completely isolating the two sides of the circuit. In other words, when the switch is OFF, it ideally prevents any electrical connection between its terminals. In reality, however, even an open switch has some tiny amount of leakage current (I_{off}) due to imperfections in the materials used. While real switches aim to have extremely high OFF resistance, it is never truly infinite.

Unlimited Voltage Range for V1 and V2:

An ideal switch can handle any voltage applied across its terminals without breaking down. Whether the input and output voltages are a few millivolts or several thousand volts, the switch will continue to operate without issues. This means an ideal switch does not have a voltage limitation and can function in any circuit regardless of the voltage levels involved. However, real switches have strict voltage ratings, beyond which they may fail due to insulation breakdown, arcing, or material limitations. For example, mechanical relays and semiconductor-based switches (like MOSFETs) have maximum voltage ratings beyond which they can no longer function safely.

Bidirectional Current Flow:

An ideal switch allows current to flow equally well in both directions, meaning that it does not impose any preference on the direction of current flow. This makes it fully bidirectional, which is useful in applications where current direction can change, such as AC circuits. In contrast, real-world switches, particularly those based on semiconductor devices like

MOSFETs or diodes, often have a preferred direction of conduction. Some real switches allow current in both directions but may exhibit different resistances depending on the flow direction, which can affect performance in certain applications.

Summary of Ideal Switches:

Property	Ideal Switch Behavior
ON Resistance (R_{on})	0 Ω
OFF Resistance (R_{off})	∞ Ω
Voltage Range	Unlimited
Bidirectionality	Fully bidirectional

Non-Idealities

Value of I_{off} Measures Non-Ideality in Switch When OFF:

In an ideal switch, when it is OFF, it has infinite resistance ($R_{off} = \infty$), meaning no current can flow through it. However, in reality, every switch has a small leakage current, known as I_{off}, which flows even when the switch is open. This leakage current can be due to imperfections in the materials, stray capacitance, or semiconductor behavior in MOSFETs and transistors. While I_{off} is usually very small (usually in nanoamps), in sensitive circuits like low-power applications, it can cause unintended power consumption or interfere with signal integrity. Engineers try to minimize I_{off} to ensure better isolation when the switch is off.

Value of R_{on} Measures Non-Ideality in Switch When ON:

In an ideal switch, the ON resistance (R_{on}) is exactly zero, meaning there is no voltage drop across the switch when it is conducting. However, in real-world switches, there is always some small but nonzero ON resistance. This resistance causes a slight voltage drop ($V_{switch} = I \cdot R_{on}$), meaning the output voltage is not exactly equal to the input voltage. This voltage drop leads to power dissipation ($P=I^2 \cdot R_{on}$), which can generate heat and reduce efficiency.

The lower the R_{on}, the closer the switch behaves to an ideal one. In power electronics and signal switching applications, engineers aim to minimize R_{on} to reduce losses and improve performance.

$V_{min} < V_1$ and $V_2 < V_{max}$:

An ideal switch should be able to handle any voltage across its terminals, meaning it should work regardless of how high or low the applied voltage is. However, in real-world switches, there is always a voltage rating that defines the safe operating range of the switch. The switch must operate within a minimum voltage (V_{min}) and a maximum voltage (V_{max}), beyond which it may fail. If the voltage exceeds V_{max}, the switch could break down, leading to failure, insulation breakdown, or even electrical arcing. Conversely, if the voltage is too low ($V < V_{min}$), the switch may not function as intended, especially in semiconductor-based switches where a minimum gate voltage is required to turn them on.

Same Value of R_{on} for $V_1 < V_2$ and $V_1 > V_2$:

For a perfect switch, the ON resistance (R_{on}) should remain constant regardless of the direction of current flow or the voltage polarity. This means that whether $V_1 > V_2$ (current flowing in one direction) or $V_1 < V_2$ (current flowing in the opposite direction), the switch should exhibit the same resistance. However, in real switches, especially semiconductor-based ones like MOSFETs and BJTs, the resistance can vary depending on the voltage applied and the direction of current flow. Some switches are optimized for one direction, meaning their resistance is lower in one direction than the other, making them less ideal for AC or bidirectional applications. A truly bidirectional switch would have a constant R_{on} regardless of voltage direction.

Research Conclusions:

Property	Ideal Behavior	Real-World Behavior
ON Resistance (R_{on})	$0\ \Omega$	Small but nonzero resistance, causing voltage drop and heat dissipation
OFF Resistance (R_{off})	$\infty\ \Omega$	Small leakage current, reducing isolation when switch is off

Voltage Range	Unlimited	Limited by Vmax and Vmin, crossing these limits could potentially result in failure
Bidirectionality	Fully bidirectional	May vary depending on switch type and voltage direction