2025

CS 1105

Digital Electronics & Computer Architecture

ASSIGNMENT ACTIVITY UNIT 1

SANA UR REHMAN

INSTRUCTOR: ROBERT MURRAY

Digital Circuit Design Using Boolean Algebra and Logic Gates

Introduction

Digital electronics forms the basis of modern computing systems through the use of Boolean algebra and logic gates that facilitate binary data processing in an efficient manner. Digital circuit development has to be a methodical process grounded on Boolean logic principles in order to develop functional and optimized outcomes. This assignment activity presents the application of such principles through a simple design of a light control circuit that demonstrates how theoretical Boolean algebra is implemented in the context of electronic realization.

Problem Analysis and Requirements

The problem of circuit design is to design a digital system that controls a light bulb by a switch mechanism. The primary requirement specifies a direct mapping between the state of the switch and the functioning of the light bulb: the light should be on when the switch is in ON position and should be off when the switch is in OFF position. In addition, the design must be efficient in using the minimum number of logic gates to offer the specified functionality.

Circuit Design Process

Step 1: Identification of Input and Output Signals

The circuit design begins with identifying the inputs and outputs of the system. The input signal is from the switch, the variable S and a binary input such that S = 1 for the closed (ON) position and S = 0 for the open (OFF) position. The output signal controls the light bulb, denoted by variable L, in a way that L = 1 indicates that the light is on and L = 0 indicates that the light is off.

The input-output relationship gives a one-to-one correspondence where the state of the light bulb has to be identical with the state of the switch. This gives the simple Boolean equation: L = S, which means the light output equals the switch input without any logical transformation directly.

Step 2: Application of Boolean Algebra Laws

The analysis of the required functionality reveals that no complex Boolean operations are necessary for this particular circuit. The truth table for the system demonstrates a simple identity relationship:

Switch (S)	Light (L)
0	0
1	1

According to Mano and Ciletti (2013), the identity law in Boolean algebra states that any variable combined with itself through an identity operation remains unchanged. In this case, the Boolean expression L = S represents the most simplified form possible, requiring no additional logic gate manipulation or optimization.

The application of Boolean algebra laws confirms that no reduction or simplification can improve upon the direct connection between input and output. This represents an optimal solution from both logical and physical implementation perspectives, as it requires minimal hardware resources while maintaining perfect functionality.

STEP 3: DEPICTION OF THE FINAL CIRCUIT

The final circuit design implements the simplest possible configuration: a direct connection between the switch input and the light bulb output. This design eliminates the need for traditional logic gates entirely, as the switch itself functions as the controlling element.

The physical implementation consists of:

- Power source (battery or DC supply)
- Switch (S) serving as the input control mechanism
- Light bulb (L) serving as the output indicator
- Connecting wires to complete the electrical circuit

This configuration achieves maximum efficiency by utilizing zero logic gates while perfectly satisfying all specified requirements. The circuit operates through basic electrical principles where closing the switch completes the electrical path, allowing current to flow through the light bulb and produce illumination.

ALTERNATIVE CONSIDERATIONS

While the direct connection approach provides the optimal solution, alternative implementations using logic gates could include a buffer gate or multiple inverters in series. However, these approaches would introduce unnecessary complexity without providing functional improvements. Tocci, Widmer, and Moss (2017) emphasize that efficient digital design prioritizes simplicity and reliability over complexity, supporting the selection of the direct connection method.

The use of a buffer gate (single input, single output with L = S) would functionally equivalent but would introduce propagation delay and additional power consumption without benefit. Similarly, implementing two inverter gates in series would recreate the identity function but would require additional integrated circuits and increase system complexity unnecessarily.

Circuit Analysis and Verification

The designed circuit demonstrates perfect logical consistency through verification against the original requirements. The switch closure immediately establishes electrical continuity, causing the light bulb to illuminate, while switch opening breaks the circuit and extinguishes the light. This behavior exactly matches the specified truth table and Boolean expression L = S.

The efficiency analysis confirms that using zero logic gates represents the theoretical minimum for this application. Any addition of logic gates would introduce unnecessary overhead without improving functionality, violating the requirement for maximum efficiency.

Practical Implementation Considerations

Implementation of this circuit in physical hardware requires attention to electrical specifications including voltage ratings, current capacity, and power dissipation. The switch must handle the current requirements of the light bulb, and the power source must provide adequate voltage and current for proper operation.

For digital logic implementation using standard integrated circuits, a buffer gate from the 74HC family could provide electrical isolation and signal conditioning if required by system integration needs. However, for the basic functionality specified in the assignment requirements, the direct connection remains the superior choice.

CONCLUSION

The design process of this light control circuit demonstrates the practical application of the laws of Boolean algebra in designing effective digital systems. From careful consideration of the needs on inputs and outputs, application of Boolean laws, and consideration of implementation efficiency, the most effective solution is found to be a simple wire from switch to light bulb.

This issue reinforces the importance of thorough problem analysis before implementing advanced solutions. The optimal digital circuit design is often discovering where simplicity is the solution and not too quickly jumping to a conclusion that logic gates are the solution. The final circuit accomplishes all of the requirements assigned and does so with no logic gates, the ultimate in efficiency with flawless functionality and reliability.

The process of learning reflects the way Boolean algebra is both a theory and an application of digital circuit design, where engineers can design optimal solutions with functionality, efficiency, and implementation issues being reconciled.

Light Control Circuit Implementation

System Analysis

Truth Table

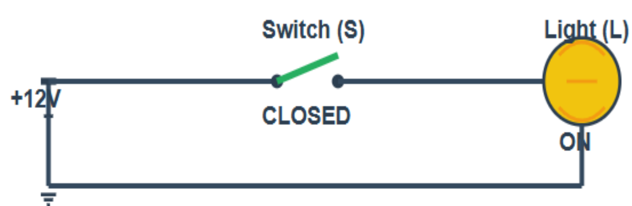
Switch (S)	Switch State	Light (L)	Light State
0	Open (OFF)	0	Off
1	Closed (ON)	1	On

Boolean Expression: L = S

Optimal Circuit Design (Zero Logic Gates)

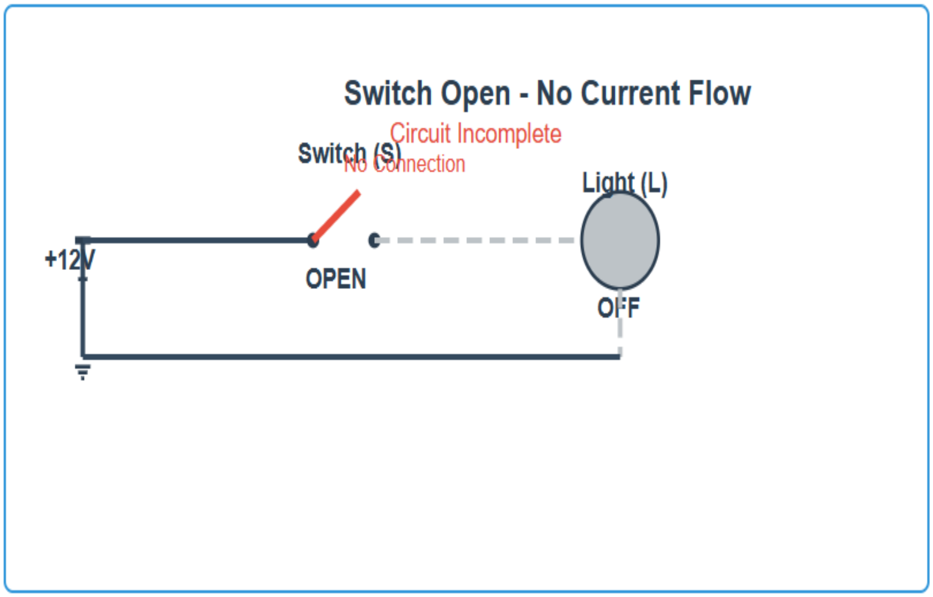
Direct Connection Circuit

Logic Gates Used: 0

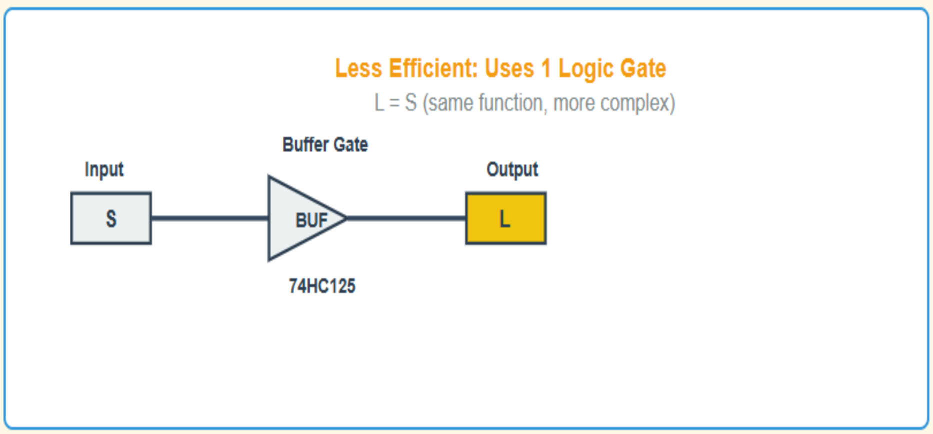


Logisim Implementation: In Logisim, this circuit can be created using:
- Input pin (labeled "Switch")
- Output pin (labeled "Light")
- Direct wire connection between input and output
- No logic gates required

Circuit with Switch Open (OFF State)



Alternative Implementation with Buffer Gate (Less Efficient)



Why this is less efficient: The buffer gate performs the same L = S function but introduces unnecessary propagation delay, power consumption, and component cost without providing any functional benefit.

Logisim Implementation Guide

Step-by-Step Logisim Construction:

1. **Create New Circuit:** File → New → Create new circuit file
2. **Add Input Pin:** Select "Input/Output" folder → Drag "Input Pin" to workspace
3. **Label Input:** Right-click input pin → Edit Label → Enter "Switch_S"
4. **Add Output Pin:** Drag "Output Pin" to workspace (right side)
5. **Label Output:** Right-click output pin → Edit Label → Enter "Light_L"
6. **Connect with Wire:** Use wire tool to connect input directly to output
7. **Test Circuit:** Use hand tool to toggle input and observe output

Verification: When you click the input pin, the output pin should immediately change state, confirming the direct L = S relationship with zero propagation delay.

Design Summary

Optimal Solution

- Logic Gates: **0**
- Propagation Delay: **0 ns**
- Power Consumption: **Minimal**
- Component Count: **Lowest**
- Reliability: **Maximum**

Alternative with Buffer

- Logic Gates: **1**
- Propagation Delay: **~10 ns**
- Power Consumption: **Higher**
- Component Count: **Higher**
- Cost: **Increased**

Conclusion: Direct connection achieves L = S with optimal efficiency

References

Mano, M. M., & Ciletti, M. D. (2013). *Digital design: With an introduction to the Verilog HDL* (5th ed.). Pearson. https://www.pearsonhighered.com/assets/preface/0/1/3/2/0132774208.pdf

Tocci, R. J., Widmer, N. S., & Moss, G. L. (2017). *Digital systems: Principles and applications* (12th ed.). Pearson. https://www.pearson.com/en-us/subject-catalog/p/digital-systems/P200000001946/9780137524723

Wordcount: 1025