

Combinational Logic Circuits: Principles, Design, and Modern Applications

Abstract

The study of Combinational Logic Circuits how digital systems perform operations based solely on present inputs signals, making them essential components of modern electronic design. Previous textbooks and foundational literature in logic design provide the theoretical background for understanding logic gates, Boolean algebra, and circuit simplification methods. Building on these foundations, this paper applies design and analytical techniques including, truth tables, Boolean simplification, and Karnaugh Maps, and logic diagram synthesis to demonstrate how efficient and how reliable CLCs are developed for digital applications. The study demonstrates that proficiency in combinational logic design enhances digital systems efficiency. a

Introduction

Combinational Logic Circuits (CLC) are digital circuits where the output depends only on the present input values. These circuits do not use memory or feedback, which means their response changes immediately, when the input changes. They are used to perform logical and arithmetic operations that are essential in computers, calculators, and other digital systems. In combinational circuit, the logic gates are connected in such a way that the output is a direct result of the specific combination of input signals applied. This type of circuit is commonly used in designing Adders, Multiplexers, Decoders, and other components that process binary information. Since CLC's operation is purely based on logic relationship, they are faster and simpler to design compared to sequential circuits. [2]

In this paper, the concept of design of combinational logic circuit were reviewed and applied using examples from textbooks.

The foundation of digital circuits lies in basic combinational logic gates such as AND, OR, and NOT (inverter), NAND, NOR, XOR, XNOR, which implement foundational logical operations based on current input signals. These gates are building blocks of combinational logic circuits.^[2] Boolean algebra is the mathematical system used to analyze and simplify these digital circuits, where variables, represents logic levels (typically '1' for High/True and '0' for Low/False) and operations corresponds to the logic gates.^[1] By applying the laws and theorems of Boolean Algebra, complex logical expression can be systematically reduced to their simplest, most efficient form, which translates directly to minimizing the number of gates and interconnections required in the final hardware design.^[1]

The systematic design of a combinational circuit is a multi-step process that efficiently transforms a set of requirements into a physical circuit^[2]. This process starts by defining the inputs and outputs to create a precise truth table, which accurately maps every possible input combination to its desired output. Once the truth table is generated. The next vital step is simplification, which where the Karnaugh Map (K-map) comes into play. As a graphical tool, the K-map allows designers to visually identify and group adjacent '1' entries on a grid, directly leading to simplified Boolean Expression. These simplified expressions are directly translated into the final logic diagram for hardware implementation and verification.^[2]

Key Devices

1. Adder

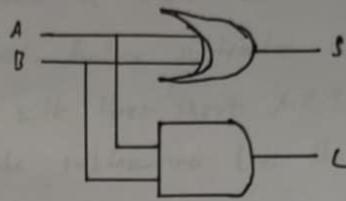
Adders are fundamental arithmetic circuits used extensively in the Arithmetic Logic Unit (ALU) of processors. The Half Adder is the most basic form. Half Adder is a CLC with two inputs and two outputs. It is designed to add two single bit binary A and B. It is also the basic building block for addition of two single bit numbers.^[3]

Example:

Truth table:

Input		Output	
A	B	S	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Logic Diagram



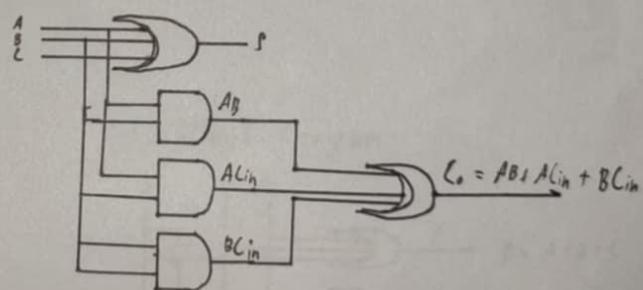
1.2 Full Adder is developed to overcome the drawback of Half adder circuit. It can add two one-bit numbers A and B, carry C. The full adder is a three input and two output combinational circuit. [3]

Example.

Truth table

Input		Output	
A	B	S	C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Logic Diagram



1.3 N-Bit Parallel Adder is developed to add two N-bit binary numbers.

It uses a number of full adders in cascade. The carry output of the previous full adder is connected to carry input of the next full adder. [3]

2. Subtractor

Subtractors perform binary subtraction. A Half subtractor subtracts two bits and produces a difference and a Borrow-out. It is a combination circuit with two inputs and two outputs. Another subtractor is a Full subtractor, it is also a combinational circuit with three inputs A, B, C and two outputs D and C . A is the minuend B is the subtrahend, C is the borrow. D is the Difference C is the borrow output. [3]

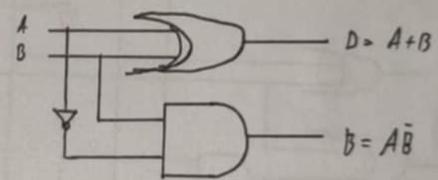
Example

2.1 Half Subtractor

Truth Table

Input		Output
A	B	$(A-B) \text{ Borrow}$
0	0	0 0
0	1	1 1
1	0	1 0
1	1	0 0

Logic Diagram

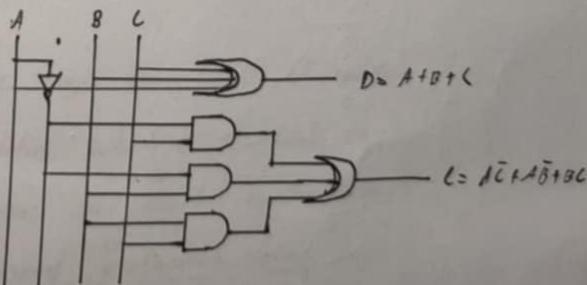


2.2 Full Subtractor

Truth Table

Input			Output
A	B	C	$(A-B-C) C'$
1	0	0	0 0
0	0	1	1 1
0	1	0	1 1
0	1	1	0 1

Logic Diagram



3. Encoder

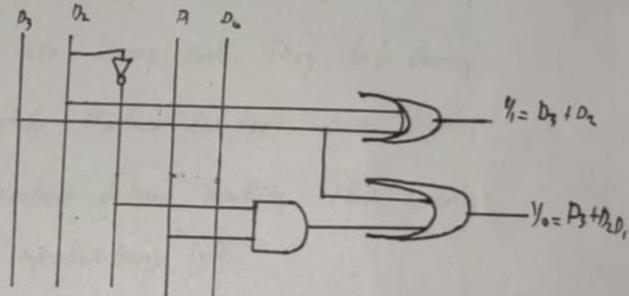
An encoder performs the inverse functions of a decoder. An encoder has n number of input lines and m number of output lines. An encoder produces an m bit binary code corresponding to the digital input number. The encoder accepts an n input digital word and converts it into an m bit another digital word. [3]

Example: Priority Encoder is a key type that assigns priority to the input with the highest index.

Truth table

Logic Circuit

Highest	Inputs	Lowest	Output
D_3	$D_2 D_1$	D_0	$y_0 \quad y_1$
0	0 0	0	X X
0	0 0	1	0 0
0	0 1	X	0 1
0	1 X	X	1 0



Modern Applications

Adders

Adders are widely used in Arithmetic Logic Units (ALU) of modern processors. They perform fast binary addition, which is essentials in calculations done by computers, smartphones, and digital systems. Recent designs focus on low-power and high-speed performance using pass transistor logic. This makes Adders more efficient for use in compact devices like embedded systems and digital signal processors. [3]

Subtractors

Subtractors are used in digital control systems and micro-controllers for arithmetic operations that require subtraction, such as signal processing or sensor data collection. Modern subtractor designs use CMOS and VLSI technology to reduce power consumption and increase speed. This makes them important in embedded applications like robotics, calculators, and smart devices. [4]

Encoders

Encoders are commonly used in touchscreens, robotics, and automation systems to convert user or sensor inputs into binary code. They help devices interpret signals faster and more accurately. Modern encoders use digital logic circuits to improve precision and reduce delay, making them essential for smart sensors and motion control applications. [5]

Conclusion

Combinational Logic Circuits (CLC) like Adders, subtractors, and encoders etc. remain vital because they formed the foundation of all digital systems. They allow data to process quickly and accurately without needing memory. In modern technology CLCs are essential in computers, automation, smart electronics. Their future lies in faster and more power efficient designs, which will continue to improve the performance of next-generation processors and embedded systems.

Reference:

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