Digital Electronics

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About the Tutorial

This is a comprehensive tutorial on Digital Electronics. You can use this tutorial to learn the following topics:

- Basics of digital signals and systems
- Different types of number systems and their conversions
- Binary codes and their conversions
- Boolean functions and their minimization
- Implementation of Boolean expressions
- Combinational logic circuits and their applications
- Sequential circuits and their applications
- Memory devices
- Logic Families

The topics covered in this tutorial are relevant in various technical exams like GATE, engineering services exams, university exams, and various other competitive exams.

Also, you can use the knowledge gained in this tutorial in different industrial applications such as PLC programming, software development, embedded system design, control and automation system design, and more.

What is Digital Electronics?

Digital electronics is a subdomain in electrical and electronics engineering that deals with the study of digital signals and systems, processing of digital signals and their applications. Under digital electronics, several important concepts are covered such as logic gates, Boolean operations, logic functions, combinational circuits, sequential circuits, logic families, and more.

Digital electronics plays a vital role in a wide range of practical applications such as computers, communication systems, consumer electronics, automation and control systems, and many other fields that rely on digital signals.

What are the applications of Digital Electronics?

The knowledge of Digital Electronics plays an indispensable role in several important fields such as computer science and information technology, communication systems, telecom networks, wireless communication, consumer electronics like TV, smartphones, laptops, etc., medical equipment, and industrial automation and robotics engineering.

Why is Digital Electronics important in Computer Organization?

Computer organization is a branch of computer engineering that deals with the study of the physical components of a computer system and their functioning. It allows us to understand how different components of a computer system interact with each other to process data instructions and perform tasks.

Under computer organization, we study about the hardware architecture and design principles of a computer system. Therefore, computer organization helps computer engineers and system designers to develop more efficient computer systems.

Here are the key points that highlight the importance of Digital Electronics in the field of Computer Organization:

- The binary representation of digital electronics is used to design different circuits of a computer system.
- Digital electronics provide logic gates and other digital circuits which are used in designing different components of a computer system like control units, arithmetic logic units (ALUs), memory unit, and more.
- Digital electronics provide principles for design memory units and data storage systems in computers.
- Digital electronics principles also empower computers to perform various digital signal processing tasks such as modulation, demodulation, filtering, etc.

Digital electronics is the fundamental building block of computer organization which provides all the important tools and techniques required for designing and implementing circuits and systems of a computer.

Audience

This tutorial is a complete reference for digital electronics enthusiasts. Anyone who wants to understand the basics and implementation of digital circuits can go through this tutorial and can excel his/her digital electronics skills.

Prerequisites

This tutorial is so designed that anyone with a basic knowledge on the initial concepts of Digital Electronics can understand the topics covered in this tutorial without the need of any parallel resource.

Frequently Asked Questions (FAQs)

How does Digital Electronics differ from Analog Electronics?

The primary difference between digital and analog electronics is that digital electronics process data in the form of discrete or discontinuous time signals, while analog electronics use continuous signals for processing purposes.

What are the advantages of Digital Electronics over Analog Electronics?

Some of the key advantages of digital electronics over analog electronics are listed here:

- Digital electronic systems are more precise and accurate as compared to analog electronic system.
- Digital electronic systems can process, store, and transmit signals and information more efficiently.
- Digital signals and systems are highly immune against noise and interferences.
- Digital systems can be programmed and reprogrammed easily to meet the requirements of a specific application, on the other hand analog systems require changes at hardware level.
- Digital systems are highly cost-effective and also scalable.

What are Logic Gates and how are they used in Digital Electronics?

Logic gates are digital circuits used as the fundamental building blocks in digital system designs. They are binary devices that perform logical operations on inputs as per a predefined set of functions.

In digital electronics, seven common logic gates are widely used and they are AND gate, OR, gate, NOT gate, NAND gate, NOR gate, XOR gate, and XNOR gate.

They are used to design and implement the following:

- Boolean functions and expressions
- Arithmetic operations like addition, subtraction, etc.
- Combination circuit design such as multiplexers, demultiplexers, encode, decoder, etc.
- Sequential circuit design like counters, flip-flops, registers, timers, etc.
- Memory devices and many more digital systems.

What is the significance of Boolean Algebra in Digital Electronics?

Boolean algebra is an important tool used in digital electronics. It provides a mathematical framework to perform data manipulation in binary format. Boolean algebra provides a complete set of laws and operations to simplify complex logical expressions and implement optimized digital systems.

How do Combinational and Sequential Circuits differ?

A combinational logic circuit is simply an interconnected set of logic gates that produces an output depending on the inputs applied. On the other hand, a sequential circuit is a group of combinational circuit and memory element. Thus, the output of the sequential circuit is governed by the present inputs and past outputs.

What are Flip-Flops and how are they used in Digital Electronics?

Flip-flops are the most elementary memory elements. They are used to hold one bit of digital information in a system. In digital electronics, flip-flops are used to design several complex digital systems like counters, memory devices, registers, timers, and more.

What are Field-Programmable Gate Arrays (FPGAs) and their role in Digital Electronics?

Field Programmable Gate Arrays (FPGAs) are digital devices in which a matrix of configurable logic blocks (CLBs) is connected together through programmable interconnects.

A user can reprogram an FPGA to meet the needs of a desired application. Therefore, it allows us to design a wide range of custom digital circuits, such as combinational and sequential circuits, arithmetic logic units, memory blocks, control systems, data processing systems, etc.

What is the role of digital logic design in Integrated Circuit (IC) fabrication?

Digital logic design is an important concept in integrated circuit fabrication. It helps the designer in the following processes:

- Determine the specifications and design parameters of the IC.
- Technology mapping i.e., selection and mapping of logic gates and other components.
- Prepare the physical design and structure to understand the position and interconnection of components.
- Test and verify the design for any error or bug.
- Final product production at mass level.

What role does Digital Electronics play in the development of modern consumer electronics?

"Digital Electronics" plays an important role in the design and development of modern consumer electronic devices. It builds the foundation of modern computer science and information technology. Digital electronics helps to improve the functionality and performance of modern devices like smartphones, laptops, computers, etc.

Digital electronics is used to develop reliable systems and embed advanced features like high-speed internet connectivity, responsive user interface, audio processing, etc. It also provides the tools and technologies required for the development of HD displays, digital audio systems, touch screen interfaces, wireless systems, digital camera technologies, and much more.

In communication systems, digital electronics is used to design and implement various communication algorithms. It provides a set of tools for data transmission, processing, and receiving.

Digital electronics also empower various other industries such as medical diagnostics, automotive, robotics, etc.

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Unit 1 – Digital Electronics Basics

1. Types of Digital Systems

A **system** is defined as a group of various components interconnected together to perform a specific task. For example, a digital computer consists of several components such as monitor, CPU (Central Processing Unit), memory, keyboard, mouse, printer, and more. All these components are connected together to accomplish certain tasks. Hence, a computer can be termed as a system.

We can broadly classify systems into the following two categories:

- Analog Systems
- Digital Systems

An analog system is a type of system that operates on continuous time signals, while a digital system is one that can work on discrete time signals.

Read this chapter to learn the basics of digital systems and their types.

What is a Digital System?

A type of electronic system that is designed to store, manipulate, and communicate digitally represented information is termed as a **digital system**. Some common examples of digital systems include smartphone, laptops, smartwatch, tablet, desktop computers, etc.

The working of a digital system is entirely based on digital signals or binary signals. Where, a digital signal is a type of signal that is represented as a discrete-elements. It can have two possible states namely high or low. The high state is denoted by the logic 1 and the low state is denoted by the logic 0.

In a digital system, if the state of the signal is logic 1, the system will be on, and if the state of the signal is 0, the system will be off.

Characteristics of Digital Systems

Today, digital systems are widely used in almost every aspect of life. This is because of their high reliability and efficiency. The following are some key characteristics of digital systems:

- Digital systems are relative less complex to implement as they use binary number system having only two digits to represent the state of a system.
- In digital systems, the information is represented in the form of a group of 0s and 1s i.e., bits. This is called binary or digital representation of information.
- Digital systems rely on digital signals having two well-defined discrete states. This makes digital systems more reliable and efficient in terms of processing, storage, and communication of information.
- Digital systems use logical mathematics and operations to perform computing tasks.
- Digital systems can be manufactured in the form of integrated circuits (ICs) of very small sizes.
- Digital systems can be easily programmed to perform repeated tasks that reduces human efforts and cost.
- Digital systems are highly immune to noise and distortions.

Types of Digital Systems

Digital systems can be classified based on various parameters. Here are some important types of digital systems that we commonly use in practice:

(1) Combinational Digital Systems

A combinational logic circuit or system is a type of digital circuit that performs logical operations and produces output depending on the present inputs. Hence, the output of a combinational digital circuit does not depend on the past inputs and outputs of the system.

Examples: The common examples of combinational digital systems are binary adders, subtractors, logic gates, multiplexers, demultiplexers, etc.

(2) Sequential Digital Systems

A type of digital system that has a memory element to store past history of the system operation is called a sequential digital system. Therefore, the output of a digital system depends on both present inputs and past outputs of the system.

Examples of sequential digital systems are flip-flops, registers, memory devices, counters, etc.

(3) Programmable Logic Devices (PLDs)

A programmable logic device is one that can be programmed to perform a specific task automatically.

Examples of programmable logic devices are microcontrollers, PLCs, etc.

(4) Digital Communication Systems

A digital communication system is a type of digital system used for transmission and reception of information in the form of digital signals.

Examples of digital communication systems are internet, intranet, mobile communication system, Wi-Fi, etc.

(5) Digital Control Systems

A digital control system is a computerized control system used to monitor and regulate the behavior of a dynamic system.

Examples: Digital control systems are extensively used in robotics, industrial automation, etc.

Conclusion

In conclusion, digital systems are modern systems known for their high speed and reliability. A digital system utilizes digital signals to store, process, and communicate the information.

In this chapter, we explained the basics of digital systems and their types. Traverse to the next chapter to learn all about the types of signals used in the field of electronics engineering.

2. Types of Signals

In electronics engineering, an electrical quantity like voltage or current or electromagnetic wave that is used for transmission of data or information is called a **signal**.

Signals are considered the heart of any data communication or processing system like the Internet. Signals instruct the electronics hardware components to perform a certain task such as convey the information from one point to another.

Apart from voltage, current or electromagnetic signals, we also have **optical signals**, where the information is represented and transmitted in the form of light.

This chapter will explain the concept of signal and different types of signals used in electronics engineering.

What is a Signal?

A physical quantity that has capability to transmit information from one point to another is called a **signal**. Some common **examples** of signals include voltage, current, electromagnetic wave, optical signals, etc.

Signals are the backbone of any electronic processing or communication system. These can be transmitted through various types of communication channels like wires, space (electromagnetic waves), optical fibers, etc.

Properties of Signals

In electronics, a signal is characterized by the following important properties:

- **Magnitude** – The intensity or maximum value of a signal is termed as its magnitude.

- **Frequency** – The number of oscillations per second is called frequency of the signal.

- **Time period** – The time taken to complete one oscillation is called the time period of the signal.

Types of Signals

In electronics, there are mainly two types of signals used, they are:

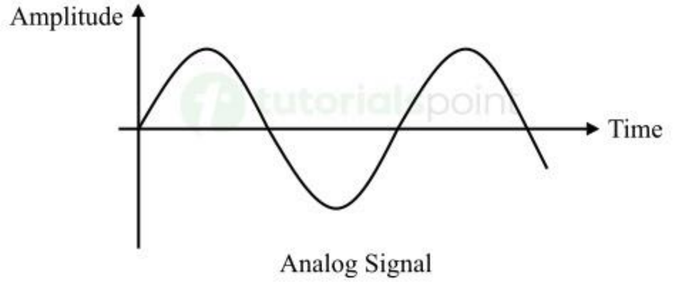
- Analog Signals
- Digital Signals

Let us discuss these two types of signals in detail.

What is an Analog Signal?

A type of electronic signal that has continuous values within a given range is called an analog signal. Analog signals are expressed as the continuous functions of time. They are represented as the waveforms of continuously varying current or voltage.

Examples of analog signals are voice, speed, pressure, temperature, etc.



Analog Signal

An important characteristic of analog signals is that they have a definite value at every instant of time, known as **instantaneous value of the signal**.

Analog signals have smooth waveforms as they are continuous in both amplitude and time. That meant, there is no interruptions in their representation over time.

Properties of Analog Signals

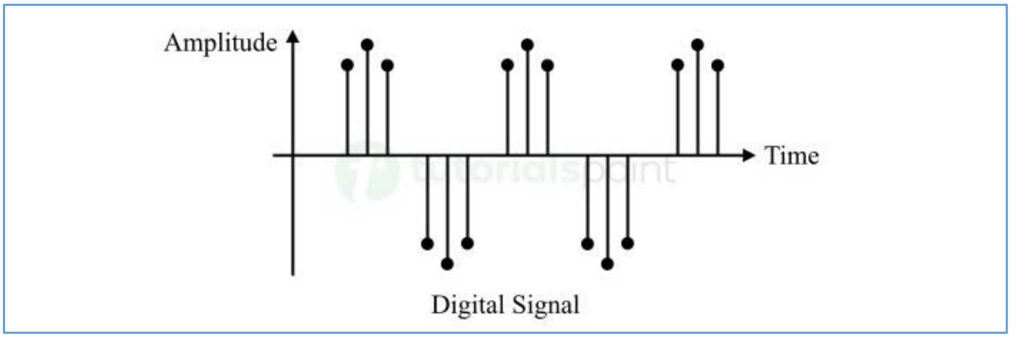
The following are main properties of analog signals:

- Analog signals are continuous signals in both amplitude and time.
- Analog signals have a certain value or magnitude at any given instant of time.
- Analog signals have infinite resolution.
- Analog signals are best suited for representing the real-world phenomena.

- Analog signals are represented by the continuously varying smooth waveforms.

What is a Digital Signal?

A **digital signal** is a type of electronic signal that has a finite set of discrete values representing information.



Digital signals are also called binary signals, as they use binary 0 or 1 to represent the state of a signal. Where, the binary 0 represents the off or low state of the signal, while the binary 1 represents the on or high state of the signal.

Thus, digital signals are expressed as discontinuous functions of time.

Properties of Digital Signals

The following are some key characteristics of digital signals:

- Digital signals have discrete or discontinuous values in terms of both amplitude and time.
- Digital signals do not have values defined between any two distinct instants of time.
- Digital signals are represented using binary system by sampling the values of the signals at specific time instants.
- Digital signals represent information in the form of a sequence of binary 0s and 1s.
- Digital signals have a finite resolution.
- Digital signals are capable to perform logical operations.
- Digital signals are more efficient and reliable when it comes to storage and transmission.

Difference between Analog and Digital Signals

Let us now discuss the important differences between analog and digital signals:

Key	Analog Signals	Digital Signals
Representation	Analog signals are represented as continuous functions or waveforms of time.	Digital signals are represented as discrete functions of time.
Nature	Analog signals are continuous as they have infinite values within a specified range.	Digital signals are discontinuous as they have distinct values sampled at specific time instants.
Resolution	Analog signals have infinite resolution.	Digital signals have a finite resolution.
Accuracy	Analog signals are more accurate.	Digital signals are relatively less accurate.
Storage	Analog signals are difficult to store.	Digital signals are efficient to store.
Noise immunity	Analog signals are less immune to noise.	Digital signals have high immunity against noise.
Examples	Voice signals, temperature, speed, etc.	Data transmitted over internet, computer generated signals, etc.

Applications of Signals

Both analog and digital signals are widely used in the field of electronics. The following are some key applications of signals:

- Signals are used for storage and transmission of information.
- Signals are used in control systems to regulate their behavior.
- Signals are also used in measurement of physical quantities like temperature, pressure, speed, sound, light, and more.
- Signals are used in computing systems for data processing, etc.

Conclusion

In electronics engineering, signals are most significant elements of a system. Signals are nothing but physical quantities like voltage, current, electromagnetic waves, light pulses, etc. used to convey information from one point to another.

In this chapter, we covered different types of signals and their properties. In the next chapter, we will cover the concept of logic levels and pulse waveform.

3. Logic Levels and Pulse Waveforms

A **digital system** is a type of electronic system that utilizes the binary number system to work. In other words, a digital system is a two-state electronic system used to represent two binary digits 0 and 1, where 0 represents the low or "off" state and 1 represents the high or "on" state of the system.

In the field of digital electronics, different voltage levels are used to represent the two binary values, i.e., 0 and 1 in a digital signal. These voltage levels are known as **logic levels**.

In this chapter, we will learn the concept of logic levels and pulse waveforms.

What is a Logic Level?

In digital electronics, a voltage level that represents a specific binary value either 0 or 1 is called a **logic level**. Here, the binary value 0 represents the low voltage level while the binary value 1 represents the high value level.

Hence, the logic levels can be classified into the following two types:

- High Logic Level
- Low Logic Level

Let's discuss these two logic levels in detail.

High Logic Level

In the case of a digital system, the voltage level closer to the maximum voltage level that the system can handle without getting damaged is called **high logic level**.

The high logic level is represented by the binary digit "1". The voltage level for a high logic level depends on the technological standard used to design the system. Typically, the voltage value between 2 V and 5 V represents the high logic level or 1.

Low Logic Level

In a digital system, the **low logic level** is defined as the maximum voltage level for which the system will remain in the OFF state.

The low logic level is represented by the binary digit "0". Similar to the high logic level, the voltage level for a low logic level depends on the technology standard used to design the system. In actual practice, the voltage value between 0 V and 0.8 V represents the low logic level or logic 0.

In most practical digital system, the ground voltage is used to represent the low logic level.

Note – The voltage range between the voltage values 0.8 V and 2 V is known as the indeterminate logic range. If a digital signal lies between the value 0.8 and 2 V, the response of the system is not predictable.

What is a Pulse?

A **pulse** is a type of an electronic signal that can change suddenly between two possible states i.e., high state and low state.

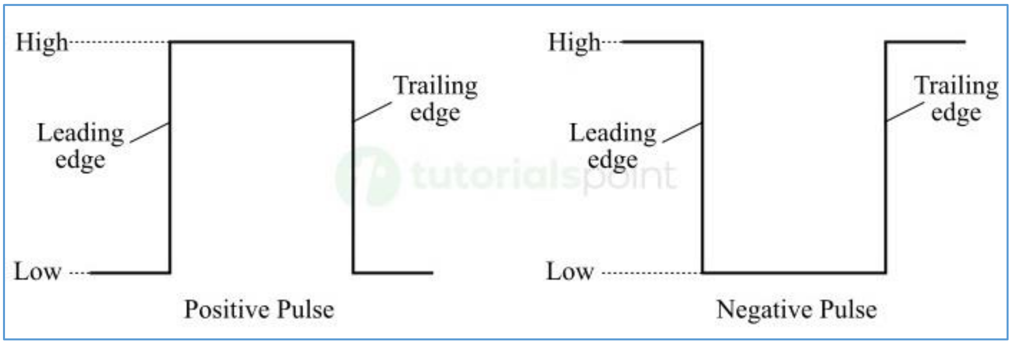
The graph used to represent the transition of a pulse is called the **pulse waveform**. Pulses are very important in the operation of digital systems, communication systems, and many other electronics devices and circuits.

Depending on the switching characteristics, the pulses can be classified into the following two types:

- **Positive Pulse** – When a signal normally goes from low logic level to the high logic level and then returns to its normal low logic level, then it is called a positive pulse.

- **Negative Pulse** – When a signal normally goes from high logic level to the low logic level and then returns to its normal high logic level, then it is known as a negative pulse.

The pulse waveforms for positive and negative pulses are depicted in the following figure.



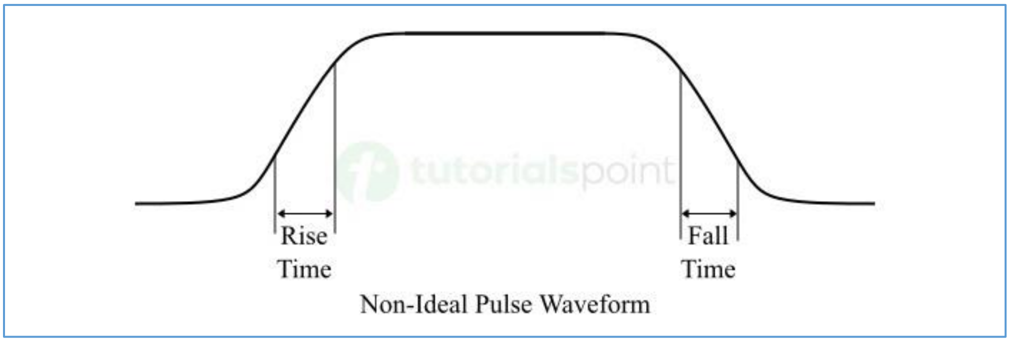
A pulse has two edges namely, a **leading edge** and a **trailing edge**.

In the case of a positive pulse, the edge going from low logic level to high logic level is called the leading edge, and the edge going from high logic level to low logic level is called the trailing edge.

In the case of a negative pulse, the edge going from high logic level to low logic level is called the leading edge, whereas the edge going from low logic level to high logic level is called the trailing edge.

The positive and negative pulse waveforms shown in the above figure are ideal pulse waveforms, because their leading and trailing edges change instantaneously i.e., in zero time. But in actual practice, the edges of pulses do not change instantaneously from low logic level to high logic level or from high logic level to low logic level.

The pulse waveforms that take a finite time to change from low logic level to high logic level and vice-versa are known as **non-ideal pulse waveforms**.



In the case of a non-ideal pulse waveform, the time taken by the pulse to go from low logic level to high logic level is called the **rise time**. The time taken by the pulse to go from the high logic level to the low logic level is called the **fall time**.

Types of Pulse Waveforms

The pulse waveforms used in digital systems are mainly classified into the following two types:

Periodic Waveforms

A pulse waveform that repeats itself at regular intervals of time is called a periodic waveform. The time taken to complete one cycle is called the **time period** of the periodic waveform.

Non-periodic Waveforms

A pulse waveform which does not repeat itself at regular intervals of time is termed as a non-periodic or **aperiodic waveform**.

Conclusion

In conclusion, "logic level" is a concept used in digital systems to represent the state of the system. There are two possible logic levels in the case of digital systems namely, high logic level and low logic level. The high logic level is represented by the binary 1 while the low logic level is represented by the binary 0.

The graphical representation of a digital signal or a pulse is termed as the "pulse waveform". Pulse waveforms are used to represent the transition of a pulse or digital signal or the states of a digital system. In this chapter, we have discussed the concept of logic levels and pulse waveforms. In the next chapter, we will learn about "components of a digital system".