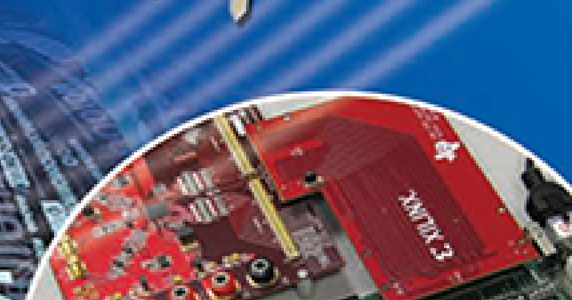
Revised Edition

A Textbook of Digital Electronics



Dr. R.S. SEDHA

S. CHAND

A TEXTBOOK OF

DIGITAL ELECTRONICS

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[For the students of B.E./B.Sc.(Engg.) / B.Tech. in Electronics, Communication, Computer Science, Information Technology, Grade IETE, AMIE(I), B.Sc. of all Indian Universities, UPSC Engineering/Civil Services and Other Competitive Examinations]

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PREFACE TO THE SECOND EDITION

I feel extremely happy presenting the revised edition of this book to the students and faculty members of the universities, engineering colleges in India and abroad.

The present book has been thoroughly revised and 5 new chapters have been added to widen the scope of the book. These new chapters are:

1. D/A and A/D Converters,
2. Semiconductor Memories,
3. Programmable Logic Devices,
4. Fundamentals of Microprocessors,
5. Digital System Design using VHDL.

The chapter on **Fundamentals of Microprocessors** has been added because the 'brains' behind the most high-level digital systems is the microprocessors. The basic understanding of microprocessor software and hardware is imperative for the electronics engineer to design and troubleshoot digital systems. A new chapter on **Digital System Design using VHDL** has been added knowing the fact that with the advance of the semiconductor and communication industries, the use of **System-on-Chip** (SoC) has become an essential technique to decrease product costs. As a result, it is important for electronic engineers to develop a good understanding of the key stages of hardware description language (HDL) design flow based on cell based libraries of field-programmable gate array (FPGA) devices.

I will take this opportunity to share with faculty members about some teaching strategies that I have developed over the past 30 years. We all know that the students these days, have become very excited about learning digital electronics because of the expanding job opportunities for digital engineers. Students are also attracted to this subject area because of the availability of inexpensive digital IC's and CPLDS/FPGAs. This helps them to build digital circuits in the lab or at home at a lower cost. As a faculty member, we should give the students a greater opportunity for hands-on laboratory experience. An important feature of this book is that it gives a lot of information to build the circuits. The students should be encouraged to build circuits such as 5-V power supply, 50-Hz pulse generator, the cross-NAND switch debouncer, a digital clock with a seven segment LED display for displaying hours, minutes and seconds. The students should also be encouraged to do simulations using ORCAD, MultiSIM tools. These tools help the student to create a schematic of given circuit faster and test the functionality of the circuit.

I would like to share some thoughts with the students as well. As you know digital electronics is the foundation course for computers and microprocessor / microcontroller-based systems found in notebooks, mobile phones, home-entertainment systems, Microsoft X-box, Nintendo game systems, automobiles, industrial control systems, and many more. You are beginning your study of digital electronics at a good time. Technological advances made during the last 50 years have provided us with IC's that can perform complex tasks. Before you are finished studying this book, you will be designing, fabricating and testing the exciting circuits. The study of digital electronics also provides you the prerequisites for future studies in microprocessor and microcontroller based systems. The subject provides the job skills for you to become a computer technician, production test technician, or digital design technician or to fill any other positions related to computer and microprocessor / microcontroller-based systems. This book is written as a learning tool in simple language. There are several solved examples. At the end of every chapter, there are review questions and multiple choice questions. Work-out the solution of the unsolved problems to build up your understanding further. Take advantage of the simulation tools from Cadence, MultiSIM, Altera and Xilinx.

I wish to express my sincere thanks to my numerous fellow colleagues and students, both at home and abroad for patronizing this book and recommending it to their students and friends. I hope they will continue to patronize this book in the future also.

Any errors, omissions and suggestions for the improvements of this book, brought to my notice, will be thankfully acknowledged and incorporated in the next edition.

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Dr. R.S. SEDHA

CONTENTS

1.	Introduction	...	1
2.	Number Systems and Codes	...	21
3.	Logic Gates	...	66
4.	Boolean Algebra and Logic Simplification	...	119
5.	Flip-flops and Related Devices	...	186
6.	Arithmetic Operations and Circuits	...	253
7.	Counters and Shift Registers	...	292
8.	Integrated Circuit Logic Families	...	349
9.	Medium-Scale Integrated Logic Circuits	...	376
10.	D/A and A/D Converters	...	426
11.	Semiconductor Memories	...	477
12.	Programmable Logic Devices	...	520
13.	Fundamentals of Microprocessors	...	560
14.	Digital System Design Using VHDL	...	605
	Appendix A Data Sheets of Selected Digital Integrated Circuits	...	621
	Appendix B List of 7400 TTL series Integrated Circuits (Includes Standard TTL, LS, ALS, F and HCMOS ICs	...	676
	Appendix C TTL Pin Configurations	...	677
	Appendix D Conversions Among Different Number Systems	...	682
	Index	...	685

1

INTRODUCTION

Outline

1-1 Introduction
1-2 Numerical Representation
1-3 Analog Representation
1-4 Digital Representation
1-5 Digital and Analog Systems
1-6 Advantages of Digital Techniques
1-7 Limitations of Digital Techniques
1-8 The Future is Digital
1-9 The Binary Digits
1-10 Logic Levels
1-11 Representation of a Digital Waveform
1-12 The Pulse Characteristics
1-13 Waveform Characteristics
1-14 A Digital Waveforms carries Binary Information
1-15 Timing Diagram
1-16 Data Transfer
1-17 Parallel Data Transfer
1-18 Serial Data Transfer
1-19 Comparison Between Serial and Parallel Data Transfer
1-20 Digital Integrated Circuits
1-21 Memory
1-22 Digital Computers
1-23 Major Parts of a Computer
1-24 Central Processing Unit
1-25 Types of Computers
1-26 Microcomputers
1-27 Microcontrollers
1-28 Simulation Tools

Objectives

Upon completion of this chapter, you should be able to:

- Distinguish between analog and digital representations.
- Know advantages and limitations of digital techniques compared with analog.
- Understand the need for analog-to-digital converters (ADCs) and digital-to-analog converters (DACs).
- Show how voltage levels are used to represent digital quantities.
- Describe various parameters of pulse waveform such as, rise time, fall time, pulse width, frequency, period and duty cycle.
- Identify a timing diagram.
- Describe the major parts of a computer and understand their functions.
- Distinguish among microcomputers, microprocessors and microcontrollers.

1-1 Introduction

The term *digital* is derived from the way the computers perform operations, by counting digits. For many years, applications of digital electronics were confined to computer systems. In today's world, the term digital has become part of our everyday vocabulary because of the dramatic way that digital circuits and digital techniques have become so widely used in almost all areas of life: computers, automated machine control, robots, energy monitoring and control, inventory management, medical science and technology, transportation, entertainment and space exploration.

In a modern home, digital circuitry controls the appliances, alarm systems and heating/cooling systems. Under the control of digital circuitry and microprocessors, newer automobiles have added safety features, are more energy efficient, and are easier to diagnose and correct when malfunction arise. Effective control of heating, ventilating and air-conditioning can reduce energy bills significantly. More and more grocery stores are using the universal product code (UPC) to check out the total sale of grocery orders, as well as to control inventory and replenish stock automatically. The area of medical electronics uses digital thermometers, life-support systems and monitors. The digital electronics is used extensively in reproduction of music. Digital reproduction is less susceptible to electrostatic noise and therefore can reproduce music with greater *fidelity*.

Digital electronics evolved from the principle that transistor circuitry could easily be designed and fabricated to output one of the two voltage levels based on the levels placed at its inputs. The two distinct levels (usually 5 V and 0 V) are HIGH and LOW and can be represented by 1 and 0. Now we will begin our exciting educational journey in which we will discover the fundamental principles, concepts and operations that are common to all digital systems.

1-2 Numerical Representation

As a matter of fact, in science, technology, business and in all other fields of endeavor, we are constantly dealing with quantities. Quantities are measured, monitored, recorded, manipulated arithmetically, or in some other way utilized in most physical systems. It is extremely important, when dealing with various quanitities that we be able to represent their values efficiently and accurately.

Basically there are two ways of representing the numerical values of quantities namely **analog** and **digital.** Now we will discuss these quantities one by one in the following pages.

1-3 Analog Representation

The numerical representation in which a quantity is represented by a voltage, current or meter movement that is proportional to the value of that quantity is called **analog representation**. An example of an analog quantity is an automobile speedometer, in which the deflection of the needle is proportional to the speed of the auto. The angular position of the needle represents the value of auto's speed and the needle follows any changes that occur as the auto speeds up or slows down.

Another example of an analog quantity is the electric iron thermostat in which the bending of the bimetallic strip is proportional to the filament temperature. As the temperature changes gradually, the curvature of the strip changes proportionally.

Still another example of an analog quantity is found in the familiar audio microphone. In this device an output voltage is generated in proportion to the amplitude of the sound waves that impinge on the microphone. The variations in the output voltage follow the same variations as the input sound.

Analog quantities such as those mentioned above have an important characteristics: *they can vary over a range of values*. The automobile speed can have any value between zero and say 100 km per hour. Similarly the microphone output might be anywhere with in the range of zero to 20 mV.

1-4 Digital Representation

The numerical representation in which a quantity is represented by the symbols called *digits* is known as digital representation . As an example, consider the digital watch, which provides the time of the day in the form of decimal digits which represent hours, minutes and seconds. As we know, the time of the day changes continuously but the digital watch reading does not change continuously; rather it changes in steps of one per second. In other words, this digital representation of the time of the day changes in discrete steps as compared with the representation of time provided by an analog watch, where the dial reading changes continuously.

Let us summarize the major difference between analog and digital quantities:

Analog = Continuous

Digital = Discrete (i.e., step by step)

Example 1-1. *Which of the following are analog quantities and which are digital?*

(*a*) *number of atoms in a sample of material*

(*b*) *pressure in a bicycle tire*

(*c*) *altitude of an aircraft*

(*d*) *current through a speaker*

(*e*) *timer setting on a microwave oven*

Solution.

(*a*) number of atoms in a sample of material:	digital — because it is a fixed value.
(*b*) pressure in a bicycle tire:	analog — because it could vary over a range of values.
(*c*) altitude of an aircraft:	analog — because it could vary over a range of values.
(*d*) current through a speaker:	analog — because it is a fixed value.
(*e*) timer setting on a microwave oven:	digital — because it is a fixed value.

1-5 Digital and Analog Systems

It will be interesting to know that a digital system is a combination of devices that are designed to manipulate logical information or physical quantities which are represented in digital form. In other words, these quantities can take only discrete values. The devices are most often electronic but they can be mechanical, magnetic or pneumatic. Some of the more familiar digital systems include digital computers, digital camera, calculators, digital audio and video equipment, and the telephone (corded and cordless and cellular phones). It may be noted carefully that the telephone system is considered as the world's largest digital system.

On the other hand, an analog system contains devices that manipulate physical quantities that are represented in analog form. In an analog, system, the quantities can vary over a continuous range of values. For example, the amplitude of the output signal to a speaker in a CD player can have any value between zero and its maximum limit. Other common analog systems are audio amplifiers, magnetic tape (audio and video) recording and playback equipment and a simple light dimmer switch.

Fig. 1-1 shows a block diagram of a public address system used to amplify a sound that can be heard by a large audience. The diagram indicates that sound waves (which are analog in nature) are picked up by a microphone and converted to a small analog voltage called the audio signal. This voltage varies continuously as the volume and frequency of the sound changes and is applied to the input of the amplifier. The output of the amplifier (which is an increased reproduction of input voltage) goes to the speaker. The speaker changes the amplified audio signal back to sound waves picked up by the microphone.

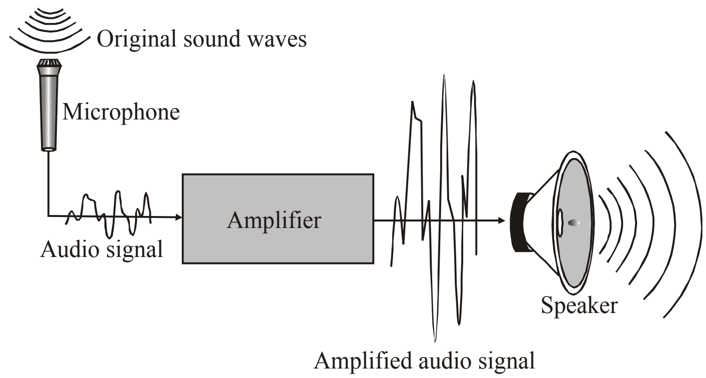

Fig. 1-1. A basic public address system

Let us now take an example of a system in which both digital and analog circuits are used. Fig. 1-2 illustrates the basic principle of a compact disk (CD) player. The diagram indicates that the music is stored on the compact disc in digital form. An optical system using laser diode picks up the digital data from the rotating disk. Then, this system transfers the data to the digital-to-analog converter (DAC). The DAC changes the digital data back to analog signal which is an electrical reproduction of the original music. The signal is amplified and sent to the speaker for the listener to enjoy.

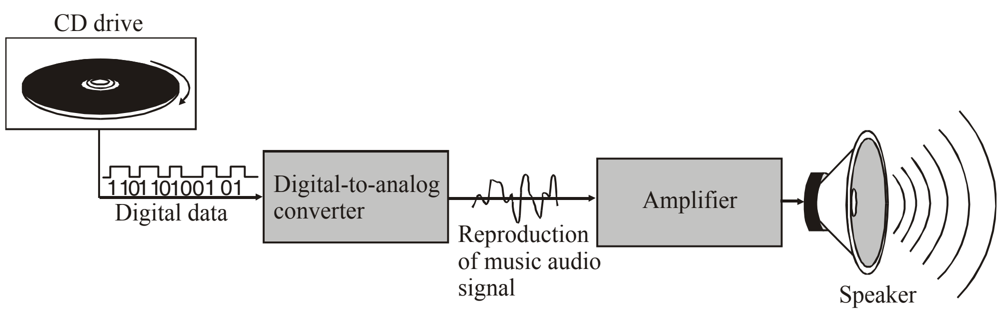

Fig. 1-2. Illustrating the basic principle of a CD player

1-6 Advantages of Digital Techniques

A majority of applications in the field of electronics, as well as in most other technologies, use digital techniques to perform operations that were once performed by analog methods. Following are some of the reasons which are responsible for the shift from analog to digital technology.

1. **Digital systems are easier to design.** It is due to the fact that the circuits which are used in digital systems are switching circuits. In such circuits, exact values of voltage or current are not important, rather it is the range (HIGH or LOW) in which they fall.
2. **Storage of information is easy.** This is accomplished by special switching circuits that can latch onto information and hold it for a time as long as it is necessary.
3. **Greater accuracy and precision.** Digital systems have a capability to handle as many digits of precision as we need simply adding more switching circuits. On the other hand, in analog systems, precision is usually limited to three or four digits because the values of voltage and current are directly dependent on the circuit component values. Moreover it is affected by random fluctuations (or noise).
4. **Operation can be controlled by a program.** It is quite easy to design digital systems whose operation is controlled by a set of stored instructions called a program. With the progress in technology day by day, it is becoming even more easier. It is possible to program analog systems. But the variety and the complexity of the available operations are limited.

5. **Digital systems are less affected by noise.** Unwanted fluctuations (or noise) in voltage are not as critical in digital systems as it is in analog systems. It is due to the fact that in digital systems, the exact value of the voltage is not important, as long as the noise is not large enough to prevent us from distinguishing a HIGH voltage level from a LOW voltage level.
6. **More digital circuitry can be fabricated on integrated circuit (IC) devices.** With the tremendous advancement of integrated circuit (IC) technology, both the digital and analog circuitry has benefited. But the benefit is comparatively less in analog because of the relative complexity and its use of devices that cannot be economically integrated. The example of such devices are high-value capacitors, precision resistors, inductors and transformers. This problem has prevented analog systems from achieving the same degree of integration as that of digital systems.

1-7 Limitations of Digital Techniques

We have already discussed several advantages of digital techniques in the last article. Let us now look at the limitations also. There is only one major drawback with the digital techniques, i.e., **The real-world problems are analog.** Thus most of the physical quantities in nature are analog. These quantities are usually the inputs and outputs that are being monitored and controlled by a system. For example, temperature, pressure, position, velocity, liquid level, flow rate etc. all are analog quantities.

In order to take advantage of digital techniques when dealing with analog quantities, we use the following three steps:

1. Convert the real-world inputs to digital form
2. Process the digital information
3. Convert the digital outputs back to real-world analog form.

In order to illustrate this concept further let us consider an example of a flow rate measurement and control system. Fig. 1-3 shows a block diagram for such a system. As indicated in the diagram, the flow rate (i.e., an analog quantity) is measured and its value is converted to a digital quantity by an electronic device called analog-to-digital converter (ADC). Then the digital quantity is processed by a digital circuitry. Finally the digital quantity is converted back to an analog quantity by another electronic device called digital-to-analog (DAC) converter. This analog output is fed to a controller which takes some kind of action to adjust the flow rate.

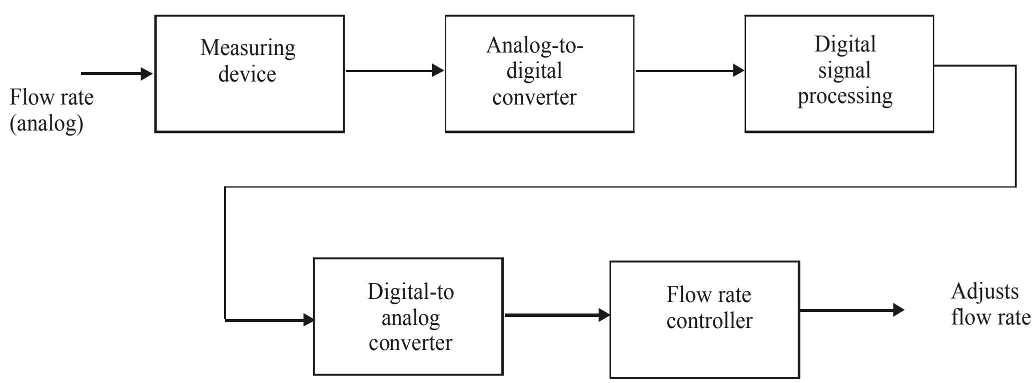

Fig. 1-3. Illustrating a flow measurement and control system

It is evident from the above example, that there is a need for conversion between analog and digital forms of information in most of the control systems realized using digital techniques. This can be considered as a drawback because of the added complexity and expense. In addition to this, an extra time is required to perform these conversions. However, we must understand that, these factors are outweighed by the numerous advantages of using digital techniques.

1-8 The Future is Digital

Most of the advances in many areas of technology have taken place in the area of digital technology and many more will take place in future.

We have digital mobile phones with a variety of features in them. Digital audio transmission is quite common in the radio broadcast. The quality of the radio sound has improved drastically with the digital broadcast. The internet information at present contains multimedia information, i.e., text, graphics, video, audio, and animated images. The speed to down load the video files (which is considered to be low at present) will increase drastically in future. More devices in future will be having many more features than at present. A digital watch with a mobile phone may be a common thing. We have telephones that are able to receive, sort, and respond to incoming calls like a well trained secretary.

The rapid pace of these advances may even exceed the phenomenal growth we have been experiencing in the past few years-period in which we have seen the availability of computers, modems, CD-ROM drives, modem automobiles making use of microprocessor ICs teenagers with personal computers at home. In future we will have more computer power than our present home or office computer. Children in schools will be able to gather ideas and information and socialize with other children all over the world through the wide spread use of internet. When we watch television for an hour, what we see will have been delivered to home in less than a second and stored in our TVs (or computer's) memory for viewing at our convenience. Reading about a place 5,000 or 10,000 kilometers away may include the sensory experience of being there. In other words, digital technology will continue its high speed incursion into current areas of our lives as well as breaking new ground in ways we may not even have thought about. All we can do is try to learn as much as we can about this technology and enjoy the benefits of new digital systems to be introduced in future.

1-9 The Binary Digits

The binary number system (which you will study in chapter 2) makes use of two digits 1 and 0. These two digits are called **bits** .The term bit is a contraction of binary digit. In digital circuits, two different voltage levels are used to represent the two bits. A 1 is represented by the higher voltage, which is referred to as a HIGH. On the other hand, a 0 is represented by the lower voltage and is referred to as a LOW. This is called positive logic and will be used throughout the book. Thus,

$$\text{HIGH} = 1 \text{ and LOW} = 0$$

A much less common system in which a 1 is represented by a LOW Voltage and a 0 is represented by a HIGH is called negative logic.

In order to represent numbers, letters, symbols instructions and anything else required in a given application (to be implemented by a digital systems), we make use of groups of bits. Such groups of bits are called **codes**. There are several different types of codes used in the field of digital electronic systems. You will study about the different codes in Chapter 2.

1-10 Logic Levels

We have already discussed in the last article that a digital system makes use of bits (i.e., 1 and 0) to represent numbers, letters, symbols, instructions etc. The voltage used to represent these bits (1 and a 0) are called logic levels. Ideally speaking, one voltage level represents a HIGH and the other voltage level represents a LOW. In a practical digital circuit, however, a HIGH can be any voltage between a specified minimum value and a specified maximum value. Likewise, a LOW can be any voltage between a specified minimum and a specified maximum.

Fig. 1-4 illustrates the general range of LOW and HIGH voltages for a digital circuit. The variable $V_{H(max)}$ represents the maximum HIGH voltage value, and $V_{H(min)}$ represents the minimum HIGH voltage value. Similarly the maximum LOW voltage value is represented by $V_{L(max)}$ and the minimum LOW voltage value is represented by $V_{L(min)}$. The range of voltages between $V_{L(max)}$ and $V_{H(min)}$ is a range of uncertainty. A voltage in the range of uncertainty can appear as either a HIGH or a LOW to a given circuit; one can never be sure. Therefore, the values in the uncertain range are not use in digital circuits. For example, the HIGH values for a certain type of digital circuit may range from 2 V to 5 V and LOW values may range from 0 V to 0.8 V. So, if a voltage of 3.9 V is applied, the circuit will accept is as a HIGH or binary 1. On the other hand, if a voltage of 0.5 V is applied, the circuit will accept it as a LOW or binary 0.

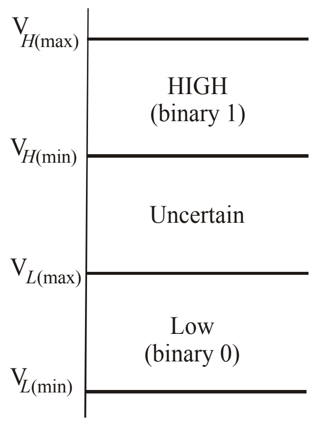

Fig. 1-4. Illustrating logic levels in a digital circuit

1-11 Representation of Digital Waveforms

A digital waveforms consist of voltage levels that are changing back and forth between the HIGH and LOW states. These can also be described as the one that is composed of series of pulses, or a pulse train as shown in Fig. 1-5.

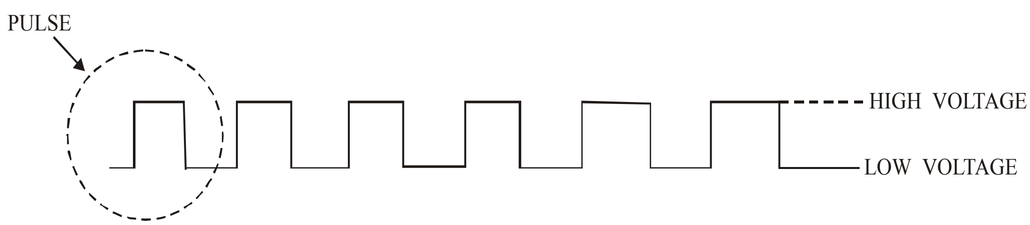

Fig. 1-5. Representation of a digital waveform

Fig. 1-6 (a) and (b) shows the representation of a pulse separately. Notice that the pulse shown in Fig. 1-6(a) is referred to as a positive going pulse because this pulse is generated when the voltage (or the current) goes from its normally LOW level to its HIGH level. On the other hand, the pulse shown in Figure 1-6 (b) is generated when the voltage (or current) goes from its normally HIGH level to its LOW level and then back to its HIGH level. It may also be noted that a pulse has two edges: (1) a rising edge and (2) a falling edge. A rising edge is a one that occurs when a voltage (or a current) goes from its normally LOW level to its HIGH level. On the other hand, a falling edge is a one that occurs when a voltage (or current) goes from its HIGH level back to LOW level. The rising edge in a positive-going pulse is also known as leading edge and the falling edge as the trailing edge. The reason for this is that the leading edge occurs first at time 't_0' while the trailing edge occurs later at time 't_1'. The pulses in Fig. 1-6 are **ideal** because the rising and falling edges change in zero time *(instantaneously)*. In actual practice, these transitions never occur instantaneously, although for most digital working, we can assume pulses to be an ideal one.

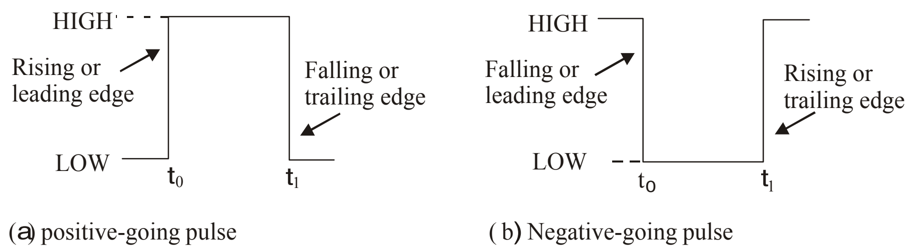

Fig. 1-6. Representation of a digital waveform

1-12 The pulses Characteristics

We have already discussed in the last article about an ideal pulse. Now we shall discuss about a non-ideal pulse i.e. a pulse which is generated by the practical digital circuit. Such a pulse has the following important five characteristics:

1. Rise time
2. Fall time
3. Pulse width
4. Overshoot
5. Ringing

Fig. 1-7 shows a positive- going non-ideal pulse. The time required for the pulse to go from its LOW voltage level to its HIGH voltage level is called the **rise time** (t_r) while the time required for the transition from the HIGH voltage level to the LOW voltage level is called the **fall time** (t_f). In actual practice, it is common to measure rise time from 10% of the pulse amplitude i.e. (height from baseline) to 90% of the pulse amplitude and to measure the fall time from 90 % to 10% of the pulse amplitude, as indicated in Figure 1-7. It may be noted that the bottom 10% and the top 10% of the pulse are not included in the rise and fall times because of the non-linearities in the waveform in these areas.

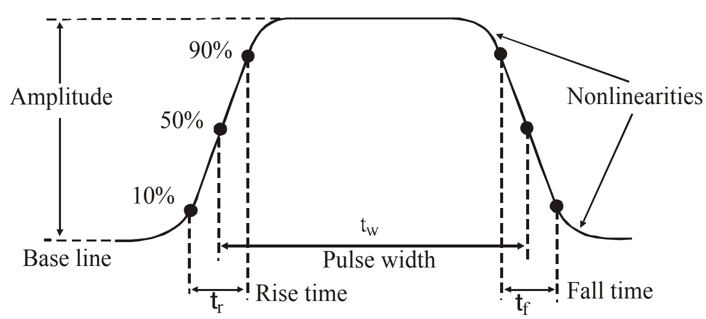

Fig. 1-7. Non-ideal pulse Characteristics

The Pulse Width (t_w) is a measure of the duration of the pulse and is often defined as the time interval between the 50% points on the rising and falling edges, as indicated in Fig. 1-7.

Overshoot and Ringing. These are undesirable pulse characteristics. The overshoot could be positive and negative. The overshoot is caused by a capacitive effect in the circuit or measuring instrument that results in the voltage exceeding the normal HIGH and LOW levels for a short time on the rising and falling edges, as indicated in Fig. 1-8 (a). Ringing on the rising and falling edges of a pulse is actually an oscillation caused by capacitance and inductance in the circuit, as indicated in Fig. 1-8(b). Notice that the ringing dies out after a short time.

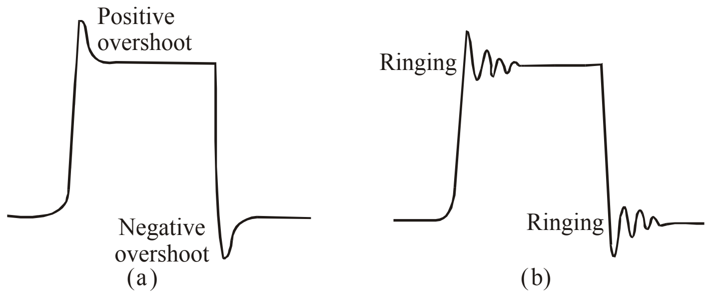

Fig. 1-8. Overshoot and Ringing

1-13 Waveform Characteristics

We have already discussed in the Article 1-11 that the waveforms encountered in digital electronic systems are composed of series of pulses, or pulse trains. These can be classified as either periodic or non-periodic. A periodic pulse waveform is one that repeats itself at a fixed interval, called a period (T). The frequency (f) is the rate at which it repeats itself and is measured in hertz (HZ). A non-periodic pulse wave form, of course, does not repeat itself at fixed intervals and may be composed of pulses of differing pulse widths and/or differing time intervals between the pulses. An example of each type is shown in Fig. 1-9.

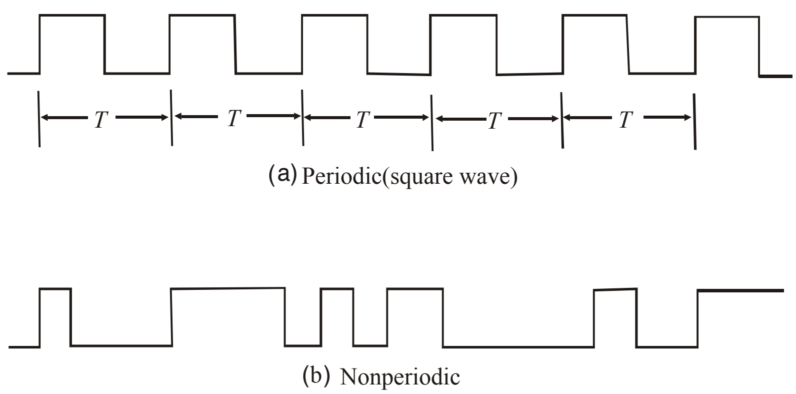

Fig. 1-9. Digital Waveforms

The frequency (f) of a pulse waveform is the reciprocal of the period. The relationship between frequency and period is given by the equation:

$$f = \frac{1}{T} \quad \text{(Hz)}$$

or

$$T = \frac{1}{f} \quad \text{(s)}$$

An important characteristic of a periodic digital waveform is its **duty cycle**. The duty cycle is defined as the ratio of the pulse width (t_w) to the period (T) expressed as a percentage, i.e.

$$Duty\ \ cycle = \frac{Pulse\ width}{Period} \times 100\%$$

$$= \frac{t_w}{T} \times 100\%$$

Example 1-2. *Figure* 1-10 *shows a portion of a periodic digital waveform. The measurements are in milliseconds. Determine the following*:

(*a*) *period* (*b*) *frequency* (*c*) *duty cycle*

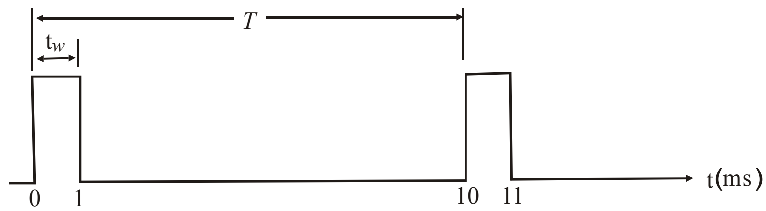

Fig. 1-10.

Solution. Given : A portion of the periodic digital waveform whose time period is indicated as 10 ms.

(*a*) *Period*

We know that time period of the waveform.

T= 10 ms **Ans.**

(*b*) *Frequency*

We know that frequency of the waveform,

$$f = \frac{1}{T} = \frac{1}{10\,ms} = \frac{1}{10 \times 10^{-3}} = 100\,Hz \textbf{ Ans.}$$

(*c*) *Duty cycle*

We know that duty cycle of the waveform,

$$\text{Duty cycle} = \left(\frac{t_w}{T}\right) \times 100\%$$

$$= \left(\frac{1}{10}\right) \times 100\% = 10\% \textbf{ Ans.}$$

1-14 A Digital Waveform Carries Binary Information

It will be interesting to know that binary information handled by digital systems appears as waveforms that represent sequences of bits. When the waveform is HIGH, a binary 1 is present. Similarly when the waveform is LOW, a binary 0 is present. Each bit in a sequence occupies a defined time interval called a **bit time.**

In many digital systems, all waveforms are synchronized with a basic timing waveform called the **clock.** The clock is a periodic waveform in which each interval between pulses (the period) equals one bit time. Fig. 1-11 shows an example of a clock waveform.

Notice that, in this case, each change in level of waveform A occurs at the leading edge of the clock waveform. In other cases, level changes occur at the trailing edge of the clock. During each bit time of the clock, waveform X is either HIGH or LOW. These HIGHs and LOWs represent a sequence of bits as indicated. A group of several bits can be used as a piece of binary information such as a number or a letter.

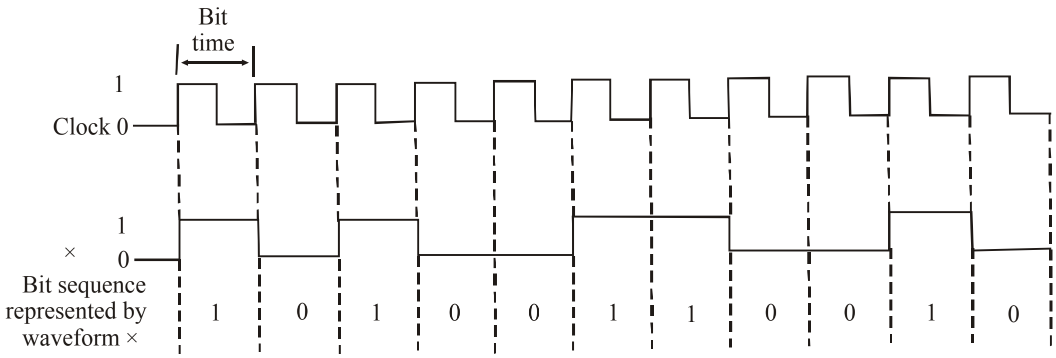

Fig. 1-11. A clock waveform illustrating a synchronization with a waveform representation of a sequence of bits

1-15 Timing Diagram

A timing diagram is a graph of digital waveforms showing the proper time relationship of all the waveforms and how each waveform changes in relation to the others. Fig. 1-12 is an example of a simple timing diagram that shows how the clock waveform and waveform X are related.

A timing diagram can consist of any number of related waveforms. By looking at a timing diagram we can determine the states (HIGH and LOW) of all the waveforms at any specified point in time and the exact time that a waveform changed state relative to the other waveforms. Fig. 1-12 is an example of a timing diagram made up of four waveforms.

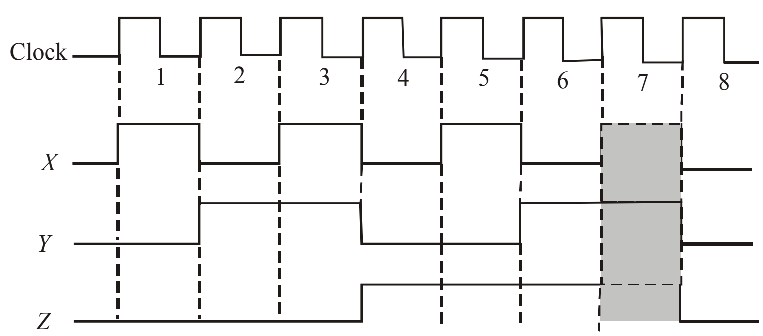

Fig. 1-12. Example of a timing diagram

From this timing diagram we can see, that all the three waveforms i.e. (X, Y, and Z) are HIGH only during bit time 7 and they all change back LOW at the end of bit time 7.

Example l-3. *Draw a timing diagram for a digital signal that continuously alternates between* 0.2 (*binary* 0) *for* 2 *ms and* 4.4 *V* (*binary*) *for* 4 *ms*.

Solution. Given: a digital signal that alternates between 0.2 and 4.4 V.

We know that for a digital signal that continuously alternates between 0.2 V (binary 0) for 2 ms is indicated by a line at a LOW voltage and 4.4 V(binary) for 4 ms by a line at a HIGH voltage as shown in Fig. 1-13 (*a*) **Ans.**

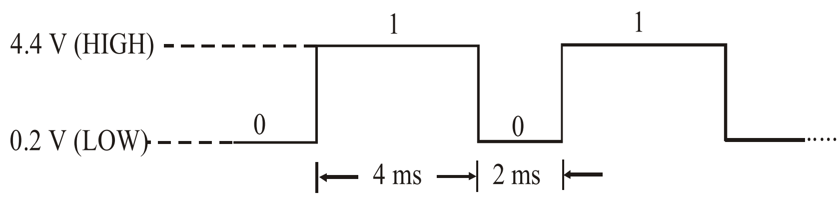

Fig. 1-13.

1-16 Data Transfer

The transmission of information in any digital system from one place to another is the most common operation in today's fast moving world. The information can be transmitted over a short distance of few centimeters on the same circuit board, or over a distance of several kilometers when an operator at a computer terminal in one city is communicating with a computer in another city. The information (called **data)** that is transmitted is in binary form. It is generally represented as voltages at the outputs of a sending circuit that are connected to the inputs of a receiving circuit.

There are two methods for the transmission of digital information namely parallel- and serial-data transfer. Both these methods are discussed one by one in the following pages.

1-17 Parallel Data Transfer

In this method of data transfer all the bits with in a group are sent out on separate lines at the same time. In other words, there is one line for each bit. To illustrate this point let us consider the following example. Suppose we wish to transfer a group of bits (called binary number) 10110 from a circuit (or a system) X to circuit (or a system) Y using parallel transmission. Then as shown in Fig. 1.14 (*b*), each bit of the binary number is represented by one of the circuit X outputs. The output X_4 of the circuit X is the most-significant bit (MSB) and the output Xo is the least-significant bit (LSB). Notice that each of the circuit X outputs is connected to the corresponding input of circuit Y. So that all the five bits of information are transmitted simultaneously (i.e. in parallel).

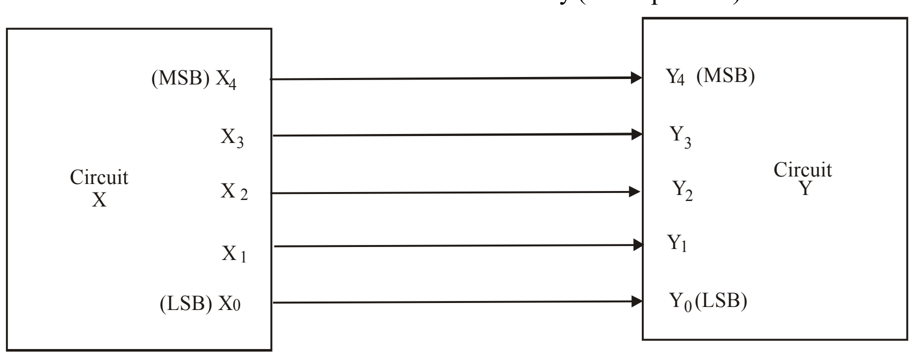

Fig. 1-14. Illustrating parallel transmission of data from circuit X to circuit Y

1-18 Serial Data Transfer

In this method of data transfer, the bits within a group are sent one at a time along a single conductor (or single line). In other words, there is no separate lines as in parallel data transfer. Consider an example to illustrate the point. Suppose we wish to transfer the same binary number we used for parallel data transfer i.e. 10110. Fig. 1-15 shows how the bits of the number are transmitted serially from circuit X to circuit Y. Here the output of circuit X will produce a digital signal whose voltage level will charge at regular intervals in accordance with the binary number being transmitted. In this way, the information is being transmitted a bit at a time (serial) over the one conductor.

The timing diagram shown in Fig. 1-15 indicates how the signal level varies with time. During the first time interval, T_0, the signal is at the 0 level; during the interval T_1, the signal is at the level 1; and so on. It may be noted that the most-significant bit (MSB) of the number is transmitted first and the least-significant bit (LSB), at the end.

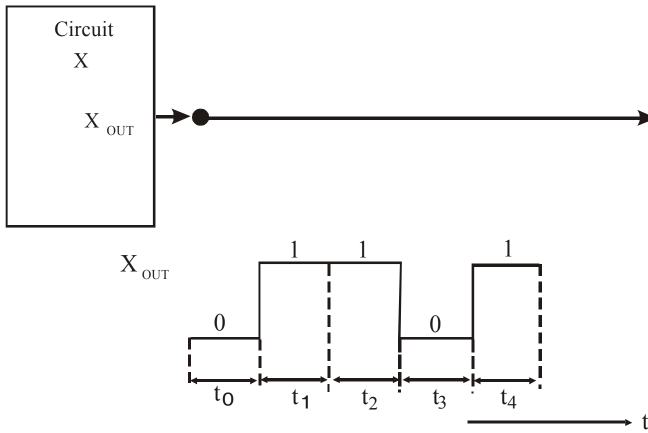

Fig. 1-15. Illustrating serial transmission of data from circuit X to circuit Y

1-19 Comparison Between Parallel and Serial Data Transfer

We have already discussed in the Art. 1-17, that in parallel data transfer all the bits with in a group are sent out on separate lines at the same time. On the other hand, in serial data transfer, the bits within the group are sent one at a time along a single line.

The difference between the parallel and serial data transfer can be discussed on the basis of speed and circuit simplicity, some of the major differences is as given in table 1-1.

Table 1-1. Comparison between parallel and serial data transfer

Sr. No.	*Parallel*	*Serial*
1.	In this method of data transfer number of lines required is equal to the number of bits to be transferred at one time.	In this method of data transfer, only one line is required for any number of bits to be transferred.
2.	This method is a fast way of data transfer as all the bits are transferred simultaneously.	This method is a slow way of data transfer as only one bit is transferred at a time.

The comparison between parallel and serial method of data transfer will be encountered many times in discussions through out the text in this book.

Example1- 4. *Determine the total time required to serially transfer the eight bits contained in waveform A of Figure* 1-15 *and indicate the sequence of bits. The left most bit is the first to be transferred. The* 100 *kHz clock is used as reference.*

(*a*) *What is the total time to transfer the same eight bits in parallel*?

(*b*) *Total time to transfer eight bits in parallel.*

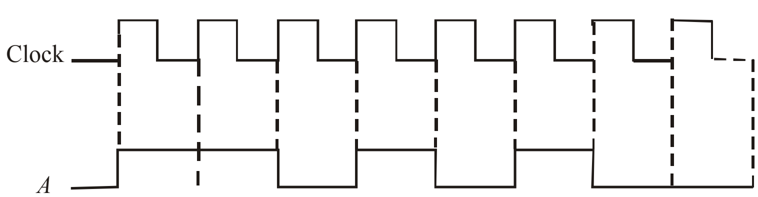

Fig. 1-16.

Solution. Given : Frequency of the clock, f = 100 kHz = 100 × 10^3 Hz.

(*a*) *Total time required and sequence of bits*

Total time required

We know that the time period,

$$T = \frac{1}{f} = \frac{1}{100 \times 10^3} = 10 \times 10^{-6} s = 10 \mu s$$

Since each bit is to be transmitted serially requires one clock cycle (or 10 μs), therefore time required to transfer eight bits serially,

$$t_{\text{serial}} = 8 \times 10 \mu s = 80 \mu s \textbf{ Ans.}$$

Sequence of bits

To determine the sequence of bits, let us examine the waveform in Fig. 1-15 during each bit time. If waveform A is HIGH during the bit, a 1 is transferred. If waveform A is low during the bit time, a 0 is transferred. The bit sequence is illustrated in Fig. 1-17. The left-most bit is the first to be transferred.

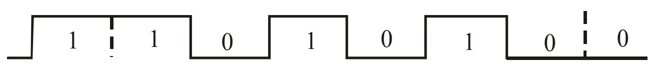

Fig. 1-17.

(*b*) *Total time to transfer eight bits in parallel.*

We know that in parallel data transfer, all the eight bits will be transmitted simultaneously. Therefore, the total time required to transfer eight bits in parallel,

$$t_{\text{parallel}} = 10 \mu s \textbf{ Ans.}$$

1-20 Digital Integrated Circuits

It will be interesting to know that most of the digital circuits used in modern digital systems are integrated circuits called ICs in short. There is a wide variety of ICs available in the market than their discrete-component counterparts.

There are several integrated-circuit fabrication technologies which are used to produce digital ICs. The most common fabrication technologies are TTL, CMOS, ECL and BiCMOS. Each differs in the type of circuitry used to provide the desired logic operation. For example, TTL (transistor-transistor logic) uses the bipolar transistor as its main circuit element, while CMOS (complementary metal-oxide-semiconductor) uses the enhancement-mode MOSFET as its principal circuit element. We will learn about the various IC technologies, their characteristics, and their relative advantages and disadvantage in Chapter 8.

1-21 Memory

When an input signal is applied to some electronic devices or circuits, the output somehow changes in response to the input, and when the input signal is removed the output returns to its original state. The circuits do not exhibit the property of memory, since their outputs revert back to normal. However there are certain types of devices and circuits that do have memory. When an input is applied to such a circuit, the output will change its state, but it will remain in the new state even

A Textbook of Digital Electronics