

# Digital Electronics

Swati Nagpal

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# DIGITAL ELECTRONICS

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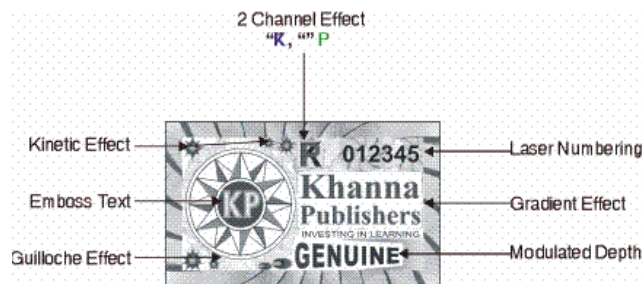
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# Preface

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The idea of present book emerged gradually after the completion of my book entitled “Basic Electronics (with simulations & experiments)”, where a complete chapter was dedicated to Digital Electronics. As known Digital Electronics is the foundation of all circuits in the regime of digital ICs -whether in mobile phones, computers, satellites, auto-industry, medical industry or elsewhere. Besides being used in ICs, digital circuits are also used as discrete circuits in smaller applications. In other words, digital electronics is an indispensable part of all machines and appliances and hence the evolution of this book especially for higher education sector.

A special feature of this book which is not found in other books is that the reader is not required to have any pre-requisites of any understanding from high school or elsewhere. It is relevant to high school students, engineering and science colleges, diploma institutes, entrepreneurs and other industrial applications. An attempt has thus been made to make the text as simple as possible yet holding on to the complexities and advancement of the subject. The present book covers syllabi pertaining to technical institutes, engineering colleges and pure science colleges which offer electronics or physics as a core or a generic subject. In other words, it is a compendium containing chapters related to AICTE, UGC and other boards in India and across the world.

The first chapter is purely dedicated to the pre-requisites a reader should have before starting on a book on digital electronics. It clearly elaborates on the differences between Analog and Digital Electronics, the principles of digital circuits, meaning of words like Signal, Transducer, Noise, Digitization, Data and Clock etc. Other jargons used in daily life like Coders, Decoders, Multiplexers, LED display etc. have also been explained in a very simple but unique style. Besides the subjects mentioned above, it also touches upon the origin of the word “MECHATRONICS” and how it is connected with digital electronics. It also throws extra light upon the concepts in PLDs and a flow chart explaining their origin and then (the context of) VHDL programming too. Thus, this chapter is like a leaflet which shows all connections starting from a signal, the data and up to the fabrication of ICs. The link between VHDL and hardware design has also been explained in this chapter.

Chapter two touches upon details on different number systems and codes like ASCII and EBCDIC. It also contains laws of Boolean Algebra and rules for code conversions in a pictorial way to make the understanding easier. This pictorial way of explanations is a unique and new feature of this book. Logic gates, universal gates, canonical forms, SOP and POS methods are some of the unique features of chapter three. It also covers the rules of Karnaugh-Maps.

Chapters four and five are dedicated to Combinational circuits and Sequential circuits respectively. In an illustrative way, this chapter covers the daily applications e.g. how the keypad works (connected to the circuits of a machine or a computer) or how a bank counter works. It covers encoders, decoders, MUX and DEMUX up to registers and counters. Thus, these chapters are the chapters for building of concepts for higher level circuits in embedded systems and ICs.

Chapter six is dedicated to Digital to Analog (DAC) and Analog to Digital (ADC) converters. These converters are the main core concepts to understand how humans (and other analog signals e.g. temperature) interact with machines, appliances and computers. As one knows, all the external data is in analog form (for instance voice, video, atmospheric conditions etc) and all the data being processed inside ICs is in digital form. Hence a continuous exchange of the data in between two forms is required consistently.

The next chapter explains Logic Families which actually elaborates the classification of ICs as per their complexities, speed and memory capacities. Why and how a particular IC is made up of a single type of device like either a BJT or a FET. The whole story behind has been explained with examples and pictures in this chapter. Nothing in machines, computers or appliances can work without memories. For instance, when a cell phone or a laptop is switched on why pictures and messages on a particular screen appear, or whether it is an android or windows or MAC based system – All this information is stored in memory chips embedded in the machine. Besides, it is also very important to know about the main classifications, main chips being used their nomenclature (e.g. 2 Mb pixel) and common jargons being used in everyday life. Hence in a very simple way this chapter climbs up the ladder starting from simple flip flops, memory capacities, up to the explanations of hard discs, flash drives and other reusable memories.

Chapter nine is about Programmable Logic Devices (PLD) and the programming language for hardware implementation called VHDL. Those devices or ICs that can be programmed at the user's end are very much in demand because the flexibility of an IC chip gets increased. To elaborate further one must know that a microprocessor chip or a PROM chip gets manufactured by the manufacturer and supplied to the user for a particular application, which can not be changed. On the other hand there are requirements at times to change the circuits in ICs by the user, wherein comes the role of PLDs, different classifications and details pertaining to PLDs have been provided with pictorial explanations. Then towards the end of the chapter, a section is dedicated to VHDL programming which is one of the main software tools for the programming of PLDs.

All the chapters contain ample number of solved and unsolved problems. The problems are new and also include examples of previous years question papers from many universities. Again for a digital electronics book, this feature is being introduced for the first time.

—Prof. Swati Nagpal

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## *From Analog to Digital : The Way to a Microprocessor*

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### **1.1. INTRODUCTION**

The present chapter introduces the students to the world of DIGITAL ELECTRONICS, its advent from a simple analog voltage signal to the operation and fabrication of digital circuits. The first part of this chapter discusses the origin of an analog signal, digital signal, circuits, noise and mechatronics. This is followed by the concepts on digital bits, data, parameters of a pulse waveform, clock, frequency etc. The basic logic gates, basic logic operations and mathematics has been introduced too. A basic introduction to common terminologies like encoders, decoders, multiplexers and de-multiplexers is also given in a layman language. Like human memory, any digital or analog systems may also have memories which are required to implement software and hardware in circuits. Since memories are important, the basic unit of memory which is a FLIP FLOP has been mentioned alongwith different storage devices. This is followed by different types of memories like ROM, RAM, Hard Disc, flash drive etc. Since integrated circuits (IC's) are the main components of any device like computers, cell phones, washing machine etc., hence basic concept has been developed about the types of IC's, their classification and fabrications families (logic families). Besides IC's which are known to a common man, there are other devices which are used for implementation of various digital systems using software's and hardware. These come in the category of Programmable Logic Devices (PLD). So different classes of PLD's. and the full design flow process for the implementation of circuits on a PLD has also been introduced in this chapter. Hence on the whole, this chapter is a window from a simple analog voltage signal or a digital signal to the world of advanced digital systems.

### **1.2. CONCEPTS OF DIGITAL AND ANALOG SYSTEMS**

The word DIGITAL is derived from the word DIGIT. This basically means digitization of voltage and logic levels. Analog simply means a continuously varying signal. Refer to Fig. 1.1(a) which represents an analog signal which is a continuously varying signal. In this figure there is a variation of temperature with time, on a particular day.

Fig. 1.1(b), shows the same variation of temperature as shown in Fig. 1.1(a), but the data is taken at defined intervals. This graph has been obtained by taking samples of data from Fig. 1.1(a), at equal intervals of one hour. Thus one has discrete values of the data, for variation of temperature, as shown in Fig. 1.1(b). These discrete values, which are (represented as) decimal numbers, can now be converted into another mathematical code, such as binary numbers. Like decimal numbers has 10 digits (0-9), the binary system has a base two and has only two digits namely "0" and "1".

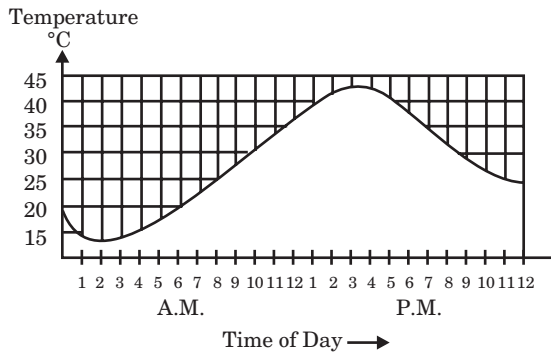


Fig. 1.1(a) An analog signal representation of continuous variation of temperature (in °C) on a particular day.

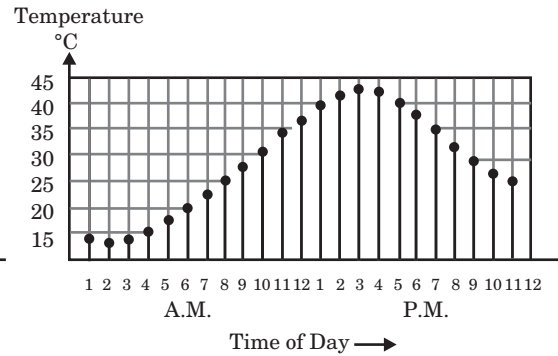


Fig. 1.1(b) Samples taken for variation of temperature from fig 1.1

When this signal of Fig 1.1(b), gets converted into a binary form, (after sampling) it becomes a digital signal. The digital signal has a very big advantage over its analog counterpart, because it is more immune to noise. Especially during communication, when electrical signals, in the form of voltage (or current) are sent, then noise gets superimposed and the signal gets distorted. The noise is in the form of voltage spikes ( from atmosphere or devices), which distorts the signal.

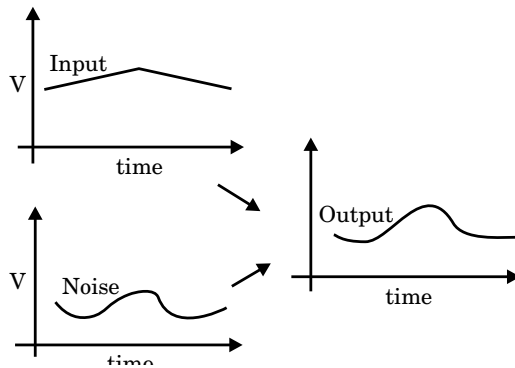


Fig. 1.2(a). Signal of analog type gets distorted by noise Signal.

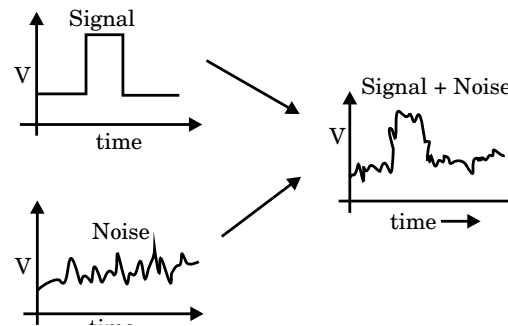


Fig. 1.2(b) Signal of digital type being Distorted by a noise signal

As shown in Fig. 1.2(a) the top most graph is that of a pure analog signal. The noise signal is shown as a voltage variation in lower graph. This noise signal could arise due to disturbance in atmosphere (like thunder storms) or due to fluctuation in the circuit (like devices fluctuations or voltage fluctuations). When this strong noise is superimposed on the analog signal, the output signal gets distorted as shown in the output graph. On the other hand, if instead of communicating the analog voltage levels, the signal is converted to binary codes and then transferred, then it is more immune to noise. When signal is converted to binary codes, it is only a series of pulses. So, when a noise, is superimposed on square voltage pulse, it is lesser immune to noise. This is shown in Fig. 1.2(b). In the output of Fig. 1.2(b), which is a sum of square pulse and noise, one can interpret by logic, that this was a square pulse only.

For a digital system, the binary codes are sent from the transmitter. When these codes are received at the receiver, the codes are decoded. This way, when the original signal is retrieved, the effect of noise is the least, as was seen from Fig. 1.2(b). Another major advantage of digital

system is that of the storage. Digital storage takes lesser space and is free of any noise. Analog storage takes a bigger space and hence is more expensive and lesser immune to noise too.

To understand a pure analog system, consider the picture in Fig. 1.3 of an AUDIO AMPLIFIER. This amplifier amplifies an audio signal. On the left, some audio signal is shown as sound waves. It goes to a device called the microphone which acts like a transducer. A transducer is a device which can convert the signal from one form to another energy form. Here the conversion takes place from sound energy to electrical energy. Hence, the signal in form of sound waves is converted to an electrical signal as represented by an analog audio signal. This is called an analog signal since the values of the voltage are continuous. It is then amplified via a block, marked as linear amplifier. The amplified signal is shown at the output of linear amplifier block. After that the signal is fed to the speaker which is another kind of transducer. This speaker converts the electrical signal back into the sound waves.

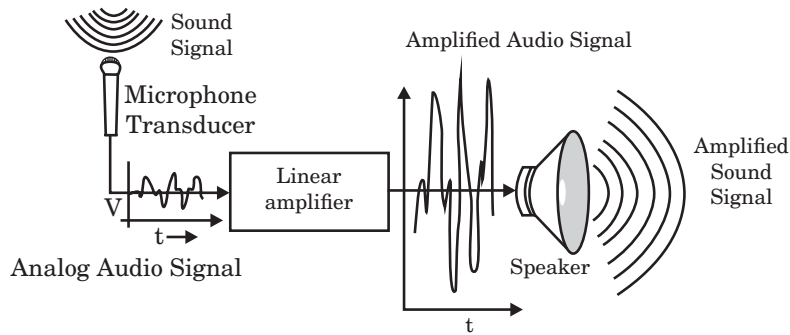


Fig. 1.3. An analog system for amplification of sound signal via analog technique.

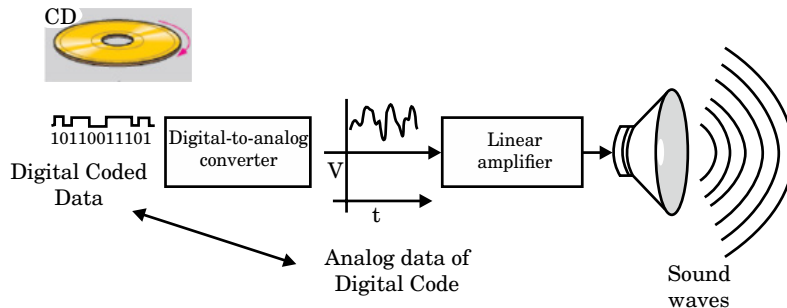


Fig. 1.4. Production of music (sound) from a digital stored data

To differentiate a pure analog system from a digital system, consider Fig. 1.4, which is a combination of analog and digital systems. In this figure, music is produced from a CD, via a sound system. On the left is shown a CD, where the data is stored in digital form. Digital form simply means discrete digits indicated by “0” and “1”. This is represented as square pulses and shown as a combination of digits 10110011101. Since the linear amplifier requires an analog signal at its input (Fig. 1.3), one needs to convert this digital pattern into analog form. This is achieved by a device called DIGITAL TO ANALOG CONVERTER (DAC). As the name suggests, it has converted the digital data into its analog form, and which is shown by the electrical analog signal. Now the task is to convert this electrical energy into sound energy, so as to reproduce the music. This analog signal needs to be linearly amplified by the linear amplifier so as to be comfortably heard. This amplified analog signal is given to the transducer (speaker) to convert it back into sound waves. Thus the system in Fig. 1.4 is a combination of analog and digital systems.

### 1.3. MECHATRONICS

As the name MECHATRONICS indicates it is like a fusion of the words MECHANICS and ELECTRONICS. Mechatronics is actually a fusion of mainly Mechanical, Computers, Controls and Electronics which are shown as sub parts on the bottom, left, top and right hand sides of Fig. 1.5. An intersection of computer programming and mechanics shows mechanical CAD (Computer Aided Design). Similarly a handshake between electronics and mechanics shows Electromechanics. Similarly, a cohesion of control systems and computer software leads to Digital control systems. Electronics plus Control Systems can create Control Electronics. Now an amalgamation of all the fields mentioned above leads to a MECHATRONICS.

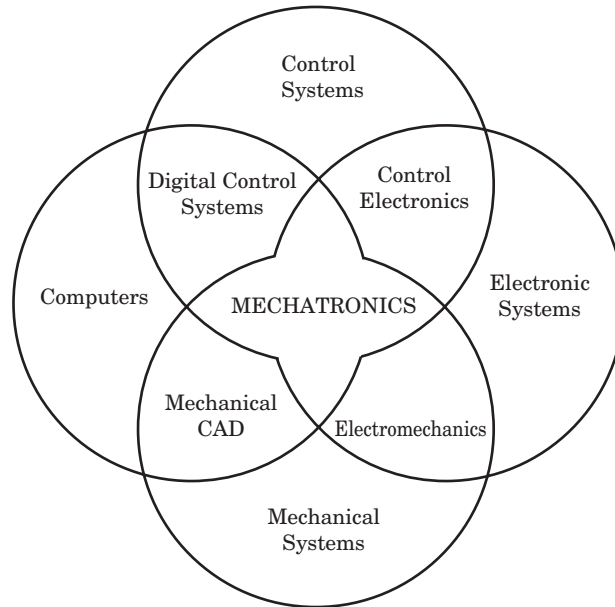


Fig. 1.5. A Representation of a MECHATRONICS SYSTEM arising from cohesion of various branches.

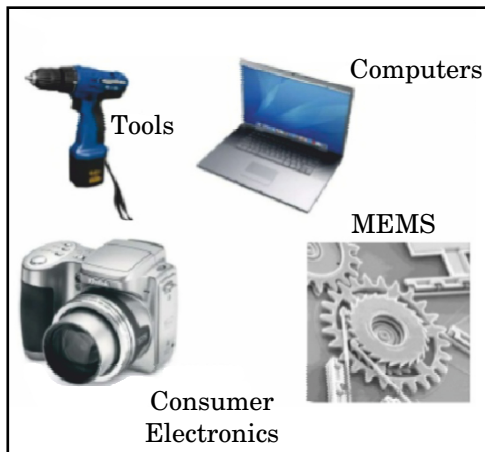


Fig. 1.6. Few examples of mechatronic systems in our daily life viz; tools, consumer electronics.

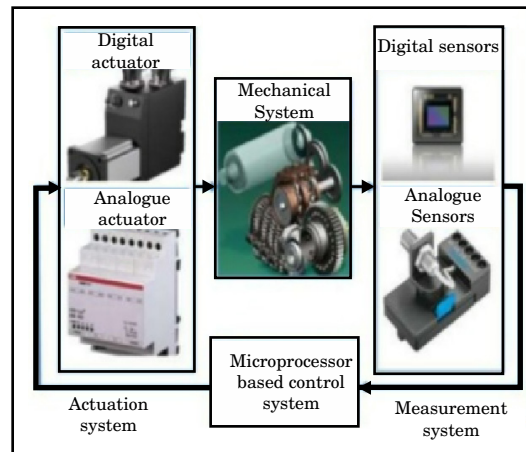


Fig. 1.7. A block diagram showing a mechatronic system involving, electronics, electromechanical and mechanical systems. The rotation of gears is being controlled by the sensor.

A few common examples of a mechatronic systems are a washing machine, an air conditioner, a lift, robot, consumer electronics and others which are shown in Fig. 1.6. Almost any system where there exists a control via push buttons or digital numbers on any kind of mechanical movement, comes under mechatronics.

Refer to Fig. 1.7, which shows the movement of gears, being controlled by digital and/or analog sensors. This is a clear example of a MECHATRONIC MECHANISM. In this figure, the sensors sense the requirement of future movement or rotation. On sensing, the sensors send an instruction to a microprocessor based system. The microprocessor thus gives a control signal to an actuator, which further controls the movement of the gears. An actuator is a device, that is essentially controlled by a software and actuates the movement of a mechanical system. It could be an electromechanical system like a motor.

### 1.4. IMPORTANT TERMINOLOGIES

#### 1.4.1. Logic Levels, Binary Bits, Data, Clock, Rise Time, Fall Time

As mentioned earlier, digital systems deal with only two digits: “0” and “1” which represent “LOW” and “HIGH” levels respectively in a pulse waveform. These levels are used to perform various logical operations in nature hence the name logic levels. The basic logical operations are ‘ NOT ’ ‘ AND ’ and ‘ OR ’. As far as digital circuits are concerned the two bits correspond to two distinct voltage levels, namely “ HIGH ” and “ LOW ” which represent digits “1” and “0” respectively. This is shown in Fig 1.8 (a) as a pulse/square wave.

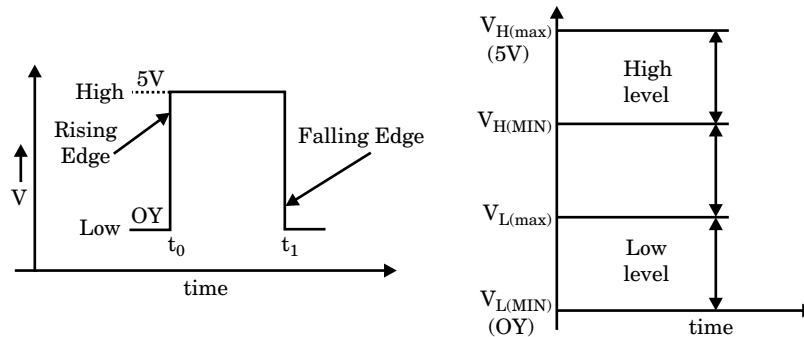


Fig 1.8. (a) A Positive going pulse with LOW and HIGH levels. (b) Voltage level bands corresponding to LOW and HIGH levels.

As seen in part (a) of Fig. 1.8, 0 volts corresponds to LOW level or “0” bit. Five volt corresponds to “ HIGH ” level or “1” bit. When the voltage rises from 0 to 5 V, that part or edge is called the rising edge. On the other hand when the voltage falls from 5 V to 0 V, that edge is called the falling edge. In part (b) of the Fig, the same pulse is shown with some voltage bands. 5V corresponds to  $V_{HMAX}$  and 0 V corresponds to  $V_{LMIN}$ . Due to fluctuations in devices or input voltage source, due to noise (example) the voltage level fluctuates in circuits. In part (b), it is shown that there is a range from  $V_{H(MIN)}$  to  $V_{H(MAX)}$ , near 5V. This whole range of voltage represents “HIGH” level or bit “1”. Suppose  $V_{HMIN}$  corresponds to 3.6 V, then that means from 3.6 V to 5V, the circuit recognises it as bit “1”. Similarly from  $V_{LMAX}$  to  $V_{LMIN}$ , this voltage is recognised as bit “0”. The middle range which is from  $V_{HMIN}$  to  $V_{LMAX}$  is an intermitent range. This range is non permissible for any bit. Also it is very unlikely that the voltage value in the circuit, at any time, could fluctuate in the range of the non-permissible level.

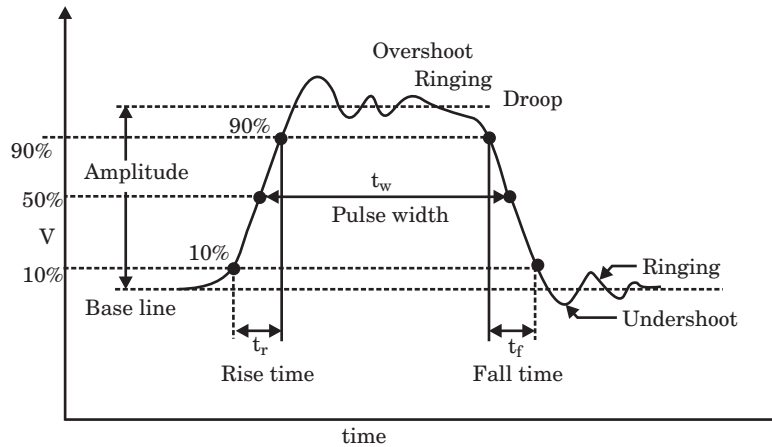


Fig. 1.9. Characteristics of a practical pulse waveform.

Fig. 1.8(a) showed the ideal square wave whereas Fig. 1.9. shows a practical pulse waveform. It is clearly seen that the practical pulse waveform is different from an ideal one, as shown in Fig. 1.8(a). Instead of rising vertically up, it takes certain time to rise as shown. A similar trend is observed for the falling part also. Thus an important parameter called the **RISE TIME** and the **FALL TIME** needs to be defined: **Rise time** is the time taken for the voltage to rise from 10% to 90% of its peak value. This is also shown as  $t_r$  in Fig. 1.9. Similarly, **fall time or ( $t_f$ )** is the time taken for a pulse to fall from 90% to 10% of its peak value. It is worthwhile to mention here, that the rise time and fall time's are never zero (0) practically. Since these voltage pulses are generated through a capacitive circuit, they certainly have charging and discharging time's respectively. This is the main reason for the existence of  $t_r$  and  $t_f$ . When the voltage finally reaches its peak value, it is certainly not stable there. There is an overshoot, ringing and droop involved, as shown in Fig. 1.9.

#### 1.4.2. Clock, Data of Bits

A clock is nothing but a train of pulses repeating periodically and thus have a particular time period or frequency. Refer Fig 1.10, where the upper part shows a clock (train of pulses) with a constant time period for both low level and high levels respectively. Here "T" represents the time period of one pulse, that is the time between the start of two consecutive pulses. The frequency (F) is given by the reciprocal of this time period "T" or  $F = 1/T$ . High state of the pulse represents bit 1, whereas low state is bit 0. A clock is necessary for digital circuits, since it is required that all the devices work in synchronization with the clock pulses.

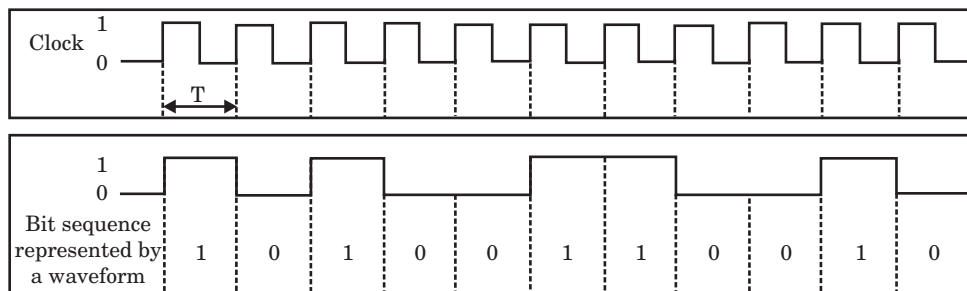
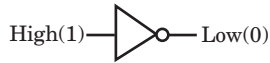
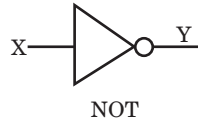


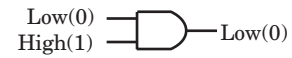
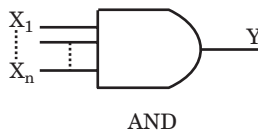
Fig. 1.10. Representation of clock with time period T. A pulse wave form representing 10100110010.

The lower part of the Fig. 1.10, shows a waveform which represents some data. The data is nothing but a group of bits. A bit (LOW or HIGH) is represented by voltages, as was mentioned before. By decoding HIGH and LOW as “1” and “0” respectively the total wave train shown represents the group of bits as: 10100110010 and is called as DATA.

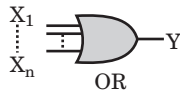
**1.5. LOGIC GATES**



(a) NOT gate with inputs and outputs



(b) AND gate with inputs and output



(c) OR gate with inputs and outputs

Fig. 1.11. (a) Symbol of “NOT gate with logic levels for inputs and outputs. (b) Symbols of “AND gate with four options for inputs and outputs. (c) symbols for “OR” gate with four option for inputs and output.

As was mentioned earlier, the bits represent logic levels. For various applications in a digital system like a microprocessor, mathematical and logical operations are required to be performed on data. The three basic logical / mathematical operations namely, INVERSION, ANDing (multiplication) and ORing (addition) are done by three basic units called “NOT”, “AND” and “OR” gates respectively. The gates are circuits comprising of discrete components like diodes, resistors and transistors which operate on two voltage levels only. The symbols of these basic gates are given in Fig. 1.11. On the left are shown inputs ( $X_1, X_2, \dots, X_n$ ) which are multiple inputs labelled 1 to  $n$  and the right side shows one single output ( $Y$ ).

**1.6. TRUTH TABLE**

$X_1$	$X_2$	AND $X_1 \cdot X_2 = Y$	OR $X_1 + X_2 = Y$
0	0	0	0
0	1	0	1
1	0	0	1
1	1	1	1

Fig. 1.12. Truth table with inputs  $X_1, X_2$  and output  $Y$  for AND and OR gates

In digital electronics, a truth table is a grid or table of bits, which gives a relation between inputs and outputs, as per the logic function of a gate (or any digital circuit). Refer to Fig. 1.12 which gives a table for “AND” and “OR”. The columns with “X’s” represent inputs and that of “Y” give the output. The outputs are for AND and OR gates. Looking at the truth table it becomes convenient to see the inputs and outputs at a glance.

### 1.7. ENCODERS, DECODERS, MULTIPLEXERS, DEMULTIPLEXERS

When a character, number or a special character is inputted from a keypad of any device like a calculator, phone, computer or remote, it first gets converted into a binary code by the circuits inside the device. A circuit which converts a decimal data (or alphanumeric characters or decimal number) into a binary code, is called an encoder. Refer Fig. 1.13(a), which shows the block diagram of a circuit, to convert a numeral from a keypad to a binary code. (this conversion is required because the digital circuits inside the device, work only on binary system). Similarly, after the processing of data in binary language, the data needs to be converted back to normal english text or decimal numbers as these are comprehensible to the reader. The task of decoding is performed by a circuit called a decoder, whose block diagram is shown in Fig. 1.13(b).

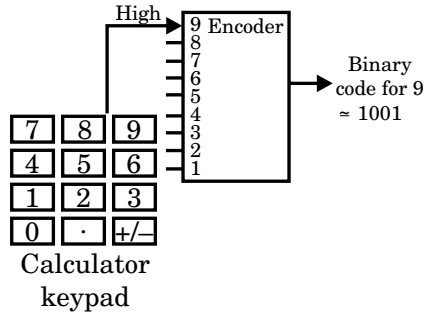


Fig. 1.13(a). Block diagram of a numeral converted to binary (1001) by an encoder

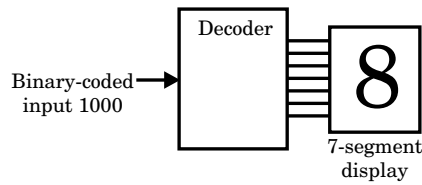


Fig. 1.13(b). Block diagram of a binary code decoded to decimal number 8

In communication (telephones or cellular network) or other circuits, there are requirements when a stream of data has to be distributed to specific lines. This is a very common requirement in cellular network. Such a distribution for data is done with the help of multiplexers (MUX) and demultiplexers (DE-MUX). A MUX is a device / circuit, which selects data from multiple input lines and sends it on a single line. One of the multiple lines is selected by the MUX only with the help of controls. Another name for a MUX is “MANY TO ONE”. The De-MUX does the opposite task as that of a MUX; *i.e.*, it selects data from one line and distributes it over to multiple lines, again selected by a control.

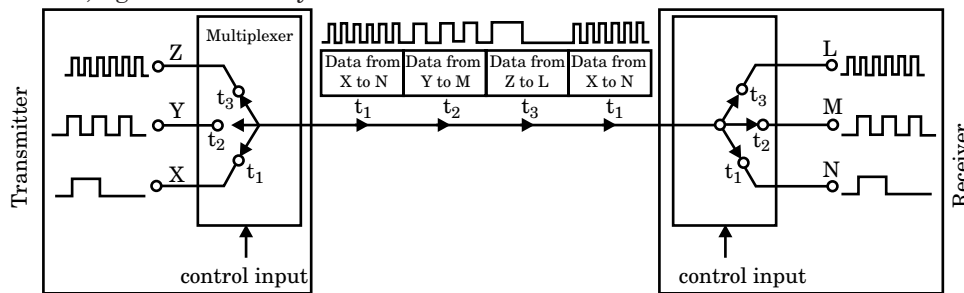


Fig. 1.14. Block diagram to show the role of MUX and DEMUX in communication.

Let us consider the block diagram in Fig. 1.14 for distribution of data from many transmitters to many receivers. In Fig. 1.14, the left side shows a transmitter, which needs to send three different data over a single channel. The data groups are “X”, “Y” and “Z” respectively with their pulses, as shown. The time intervals to capture are  $t_1$ ,  $t_2$  and  $t_3$  for data’s of X, Y and Z respectively. On the right-hand side is the receiver’s end, where the data’s are to be received by lines N, M and L from transmitters X, Y and Z respectively. The data is selected from the transmitter, by the MUX using a control signal input. It selects one data at a time and sends it over the (communication) channel. For instance, data X for time  $t_1$ , data Y for time  $t_2$  and data Z for time  $t_3$ . The distribution of one (data group), over to different receivers is done by the De-multiplexer. So, the demultiplexer selects the data X for time  $t_1$ , and sends it to channel N, data Y to channel M in time  $t_2$  and data Z to channel L in time  $t_3$ .

**1.8. FLIP FLOPS, REGISTERS, STORAGE MEMORIES, LOGIC FAMILIES**

Memories are required in digital systems and a few common examples are a CD, a Hard disc, a flash drive, ROM and RAM etc. The basic storage element in digital circuits is called a FLIP FLOP. As the name suggests a flip flop is a unit whose output flips in between two states, which are “0” and “1” respectively. Flip flops are made up of latched gates, or transistors. These Flip flops are used for various purposes like: (i) Storage of bits or data, (ii) To create a delay in data transfer, (iii) Toggeling of data for counters and (iv) Creation of REGISTERS. Fig. 1.15, gives block diagrams of basic types of flip flops, that is R–S, J–K, D and T flip flops.

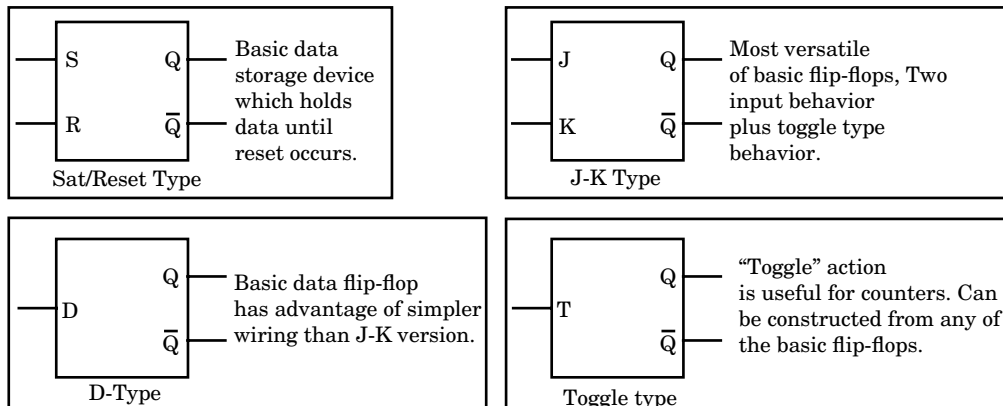


Fig. 1.15. Block diagrams of basic types of flip flops with their functions.

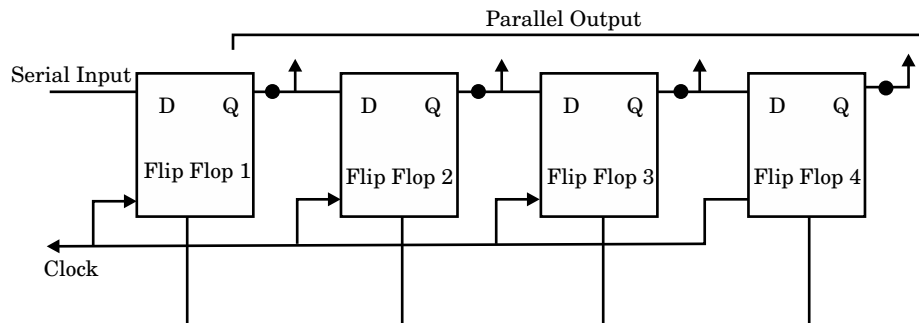


Fig. 1.16. A register made from four D flip flops to convert serial data to parallel.

REGISTERS in digital electronics are groups of flip flops connected together to perform a certain function. The tasks could be like those of transformation of serial data to parallel data or vice versa Fig. 1.16 gives the cascaded block diagram of four D flip flops. Here it is shown that the data is entered serially from the left and is taken out parallelly from the outputs of each flip flop. Thus it becomes a 4-bit Serial in Parallel–out register.

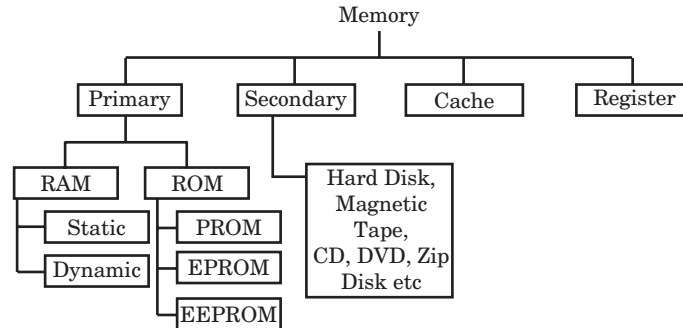


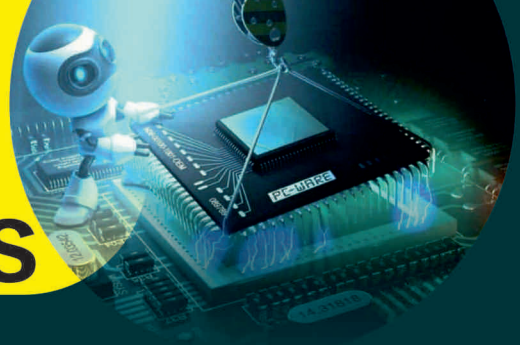
Fig. 1.17. Classification of memories

MEMORIES are required to store and retrieve data. One is well aware of ROM, RAM, CD, hard disc and memory cards in context of computers and cell phones etc. All such devices need to store data in memory and retrieve it. Memories can be made from flip flops or basic semiconductor devices. They can be of various categories like volatile, non-volatile, magnetic, optical, semiconductor, magneto-optical etc. Depending upon the memory storage capacity, speed, cost and applications different memories are used at different places. Fig. 1.17 shows classifications of different types of memories.

## 1.9. INTEGRATED CIRCUITS (IC)

There are two types of circuits available in any electronic device, *viz*;, (i) Discrete circuits and (ii) Integrated circuits. Mother board is an example that has a combination of both discrete and integrated circuits. A discrete circuit simply means a circuit made up of discrete components that are wired together (as seen in the upper part of Fig. 1.18). One can see capacitors, resistors, transistors which are wired together. So here, each component has a physical size and is soldered and wired on a PCB. An integrated circuit means that all the components in a circuit are fabricated and integrated on a small silicon chip. The chip can be as small as a millimeter in size and is made up of semiconductors like Si or Ge. This chip can contain from 10 to 1000,000 components. It has been feasible to fabricate 1000,000 components on a single centimeter size chip because of IC fabrication techniques. Such chips have been shown on the lower part of Fig. 1.18 with an identification number 5183 and 8344 respectively. This chip has been shown with an approximate cut open view also in Fig. 1.18 (b). Such a small scale and precision fabrication has been possible since components as small a size as 1 nm have been possible with the advent of NANOTECHNOLOGY. In fact IBM has come out with a 1 nm transistor. A circuit having 1000,000 components would not have been possible at all, if IC fabrication technology had not progressed to the present day stage. All microprocessors, micro controllers etc. have been an outcome of this development.

# Digital Electronics



## About the Book

The present book on Digital Electronics pertains to basic concepts as well as complexities and advancement in the subject. Any student, entrepreneur, researcher or enthusiast of Digital Electronics can easily refer to this book, without any prerequisite knowledge in the subject. It starts from the basic concepts to differentiate between Analog and Digital, Data, Clocks, Signal, Rise Time, Fall Time, going up to the 2<sup>nd</sup> step of Number Systems, Codes And Boolean Algebra. Then it catches up with Logic Gates, Combinational and Sequential Circuits, Analog to Digital (ADC) and Digital to Analog (DAC) Converters, Logic Families, Memories, Programmable Logic Devices and VHDL. Sufficient and comprehensible methods have been adopted to explain the programming in VHDL. An attempt has been made to cover syllabi from AICTE and UGC covering Science, ITI, Diploma and Engineering streams. A plethora of solved and unsolved problems have been included along with samples of previous year question papers. A basic understanding of Mechatronics has been covered too to equip the readers with the modern advancement in the Tech world.

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