



DIGITAL ELECTRONICS

Student Handbook

**CLASS
XI**



CENTRAL BOARD OF SECONDARY EDUCATION

Shiksha Kendra, 2 Community Centre, Preet Vihar, Delhi-110092

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भारत का संविधान

उद्देशिका

हम, भारत के लोग, भारत को एक सम्पूर्ण प्रभुत्व-संपन्न समाजवादी पंथनिरपेक्ष लोकतंत्रात्मक गणराज्य बनाने के लिए, तथा उसके समस्त नागरिकों को:

सामाजिक, आर्थिक और राजनैतिक न्याय,
विचार, अभिव्यक्ति, विश्वास, धर्म

और उपासना की स्वतंत्रता,
प्रतिष्ठा और अवसर की समता

प्राप्त कराने के लिए

तथा उन सब में व्यक्ति की गरिमा

और राष्ट्र की एकता और अखंडता

सुनिश्चित करने वाली बंधुता बढ़ाने के लिए

दृढसंकल्प होकर अपनी इस संविधान सभा में आज तारीख 26 नवम्बर, 1949 ई० को एतद्वारा इस संविधान को अंगीकृत, अधिनियमित और आत्मार्पित करते हैं।

1. संविधान (बयालीसवां संशोधन) अधिनियम, 1976 की धारा 2 द्वारा (3.1.1977) से "प्रभुत्व-संपन्न लोकतंत्रात्मक गणराज्य" के स्थान पर प्रतिस्थापित।
2. संविधान (बयालीसवां संशोधन) अधिनियम, 1976 की धारा 2 द्वारा (3.1.1977) से "राष्ट्र की एकता" के स्थान पर प्रतिस्थापित।

भाग 4 क

मूल कर्तव्य

51 क. मूल कर्तव्य - भारत के प्रत्येक नागरिक का यह कर्तव्य होगा कि वह -

- (क) संविधान का पालन करे और उसके आदर्शों, संस्थाओं, राष्ट्रध्वज और राष्ट्रगान का आदर करे;
- (ख) स्वतंत्रता के लिए हमारे राष्ट्रीय आंदोलन को प्रेरित करने वाले उच्च आदर्शों को हृदय में संजोए रखे और उनका पालन करे;
- (ग) भारत की प्रभुता, एकता और अखंडता की रक्षा करे और उसे अक्षुण्ण रखे;
- (घ) देश की रक्षा करे और आह्वान किए जाने पर राष्ट्र की सेवा करे;
- (ङ) भारत के सभी लोगों में समरसता और समान भ्रातृत्व की भावना का निर्माण करे जो धर्म, भाषा और प्रदेश या वर्ग पर आधारित सभी भेदभाव से परे हों, ऐसी प्रथाओं का त्याग करे जो स्त्रियों के सम्मान के विरुद्ध हैं;
- (च) हमारी सामासिक संस्कृति की गौरवशाली परंपरा का महत्त्व समझे और उसका परिरक्षण करे;
- (छ) प्राकृतिक पर्यावरण की जिसके अंतर्गत वन, झील, नदी, और वन्य जीव हैं, रक्षा करे और उसका संवर्धन करे तथा प्राणी मात्र के प्रति दयाभाव रखे;
- (ज) वैज्ञानिक दृष्टिकोण, मानववाद और ज्ञानार्जन तथा सुधार की भावना का विकास करे;
- (झ) सार्वजनिक संपत्ति को सुरक्षित रखे और हिंसा से दूर रहे;
- (ञ) व्यक्तिगत और सामूहिक गतिविधियों के सभी क्षेत्रों में उत्कर्ष की ओर बढ़ने का सतत प्रयास करे जिससे राष्ट्र निरंतर बढ़ते हुए प्रयत्न और उपलब्धि की नई उंचाइयों को छू ले;

¹(ट) यदि माता-पिता या संरक्षक है, छह वर्ष से चौदह वर्ष तक की आयु वाले अपने, यथास्थिति, बालक या प्रतिपाल्य के लिये शिक्षा के अवसर प्रदान करे।

1. संविधान (छयासीवां संशोधन) अधिनियम, 2002 की धारा 4 द्वारा प्रतिस्थापित।

THE CONSTITUTION OF INDIA

PREAMBLE

WE, THE PEOPLE OF INDIA, having solemnly resolved to constitute India into a **'SOVEREIGN SOCIALIST SECULAR DEMOCRATIC REPUBLIC'** and to secure to all its citizens :

JUSTICE, social, economic and political;

LIBERTY of thought, expression, belief, faith and worship;

EQUALITY of status and of opportunity; and to promote among them all

FRATERNITY assuring the dignity of the individual and the² unity and integrity of the Nation;

IN OUR CONSTITUENT ASSEMBLY this twenty-sixth day of November, 1949, do **HEREBY ADOPT, ENACT AND GIVE TO OURSELVES THIS CONSTITUTION.**

-
1. Subs. by the Constitution (Forty-Second Amendment) Act, 1976, sec. 2, for "Sovereign Democratic Republic" (w.e.f. 3.1.1977)
 2. Subs. by the Constitution (Forty-Second Amendment) Act, 1976, sec. 2, for "unity of the Nation" (w.e.f. 3.1.1977)
-

THE CONSTITUTION OF INDIA

Chapter IV A

FUNDAMENTAL DUTIES

ARTICLE 51A

Fundamental Duties - It shall be the duty of every citizen of India-

- (a) to abide by the Constitution and respect its ideals and institutions, the National Flag and the National Anthem;
- (b) to cherish and follow the noble ideals which inspired our national struggle for freedom;
- (c) to uphold and protect the sovereignty, unity and integrity of India;
- (d) to defend the country and render national service when called upon to do so;
- (e) to promote harmony and the spirit of common brotherhood amongst all the people of India transcending religious, linguistic and regional or sectional diversities; to renounce practices derogatory to the dignity of women;
- (f) to value and preserve the rich heritage of our composite culture;
- (g) to protect and improve the natural environment including forests, lakes, rivers, wild life and to have compassion for living creatures;
- (h) to develop the scientific temper, humanism and the spirit of inquiry and reform;
- (i) to safeguard public property and to abjure violence;
- (j) to strive towards excellence in all spheres of individual and collective activity so that the nation constantly rises to higher levels of endeavour and achievement;
- ¹(k) who is a parent or guardian to provide opportunities for education to his/her child or, as the case may be, ward between age of 6 and 14 years.

-
1. Subs. by the Constitution (Eighty - Sixth Amendment) Act, 2002



Preface

Technology has made our life more comfortable and enjoyable than before. People living in the modern world are fully dependent on technology driven products. Millions of people around the world rely on various electronic gadgets in their every walk of life. Owing to inherent advantages, majority of these equipment employ digital technology. Increasing use of such products pose a strong demand for skilled electronic technicians and related professionals for maintenance and servicing. To equip students with such skill through specialized vocational training; CBSE has introduced Electronics Technology as vocational course at Senior Secondary level in class-XI (Level-3) and class-XII (Level-4).

This Student Handbook titled “Digital Electronics” for class-XI prepared by CBSE for the benefit of the students for easy understanding of the concept of digital electronics and the applications of various digital devices and integrated circuits, which becomes essential for successful participation in almost all professions.

Ample care has been taken to align the subject with National Occupation Standards (NOS) which are competency standards identified by the Electronics and Telecom Sector Skill Councils to train students in knowledge and skills that equip students to perform effectively with confidence.

The language used in this book is simple and easily understandable to the student at class-XI level. Relevant pictorial illustrations, tables, examples and simplified concepts help the student to learn with ease and comfort.

This book is authored by competent educationists in the field of Electronic and Communication in association of CBSE with focus on helping the students to learn without any difficulty and use this book as a tool for easy learning.

I congratulate everyone who is associated in developing this book which is a very useful resource for the benefit of the students.

Comments and suggestions are welcome for further improvement of the Book.

Chairperson, CBSE



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UNIT - 1

NUMBER SYSTEMS AND BOOLEAN ALGEBRA

1.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource material
- Duration
- Learning outcomes
- Assessment plan

1.1 Basics of Analog and Digital

1.2 Number systems: Binary, Octal and Hexadecimal, Number system conversions, 1's and 2's complement, Fixed point representation, Floating point representation, Binary arithmetic, Digital codes.

1.3 Boolean Algebra - Basic laws, De Morgan's Theorem, Truth table.

1.4 K-Map

1.5 Summary

1.0 UNIT OVERVIEW AND DESCRIPTION

Overview:

This chapter introduces the analog and digital signals. A comparison of analog and digital systems justifies as to why digital systems are taking over analog systems. Binary number system and its relationship to other systems such as decimal, hexadecimal, and octal is discussed in detail. The binary number system and digital codes are fundamental to computers. A discussion of arithmetic operations with binary numbers provides a basis for understanding how computers and many other types of digital systems work. An introduction to Binary coded decimal (BCD), and alpha numeric codes is also provided. Binary logic gates are explained with the help of logic diagram, block diagram and truth table. Basic laws of Boolean Algebra are given. De- Morgan's theorems are also stated and proved.



Knowledge and skill outcomes:

- Understand the basics of Analog and Digital.
- Understand the binary, octal and hexadecimal number systems.
- Convert from one number system into another.
- Differentiate between 1's complement and 2's complement.
- Understand fixed and floating point number representation.
- Apply arithmetic operations to binary numbers.
- Understand BCD codes, Gray codes and ASCII codes.
- Apply the basic laws of Boolean algebra.
- Apply De-Morgan's theorems to Boolean expressions.
- Reduce Boolean expressions using Boolean laws.
- Use K-Map for Boolean reduction.

Resource Materials :

1. Digital Logic and Computer Design by M. Morris Mano, Prentice Hall India Publication, New Delhi, 2002.
2. Digital Principles and Applications by A. P Malvino & D. P. Leach, Tata McGraw-Hill Publication, New Delhi 1995.
3. Modern Digital Electronics by R. P. Jain, Tata McGraw-Hill Publication, New Delhi 2010.
4. Digital Electronics – An introduction to theory and practice by W. H. Gothmann, Prentice Hall India Publication, New Delhi, 1996.
5. Digital Circuits and Design by S. Salivahanan & S Arivazhagan, Vikas Publishing, Noida, Uttar Pradesh, 2012
6. <http://www.electrical4u.com/digital-electronics>
7. <http://www.csbdu.in/econtent/Digital%20Electronics%20&%20Microprocessors/UNIT%201.pdf>
8. <http://www.ntu.edu.sg/home/ehchua/programming/java/DataRepresentation.html>
9. <http://www.geeksforgeeks.org/floating-point-representation-basics/>
10. <http://www.ee.surrey.ac.uk/Projects/Labview/minimisation/karrules.html>



Duration: Total Hours 14

Learning Outcomes:

Unit-1: Number systems and Boolean algebra	Outcomes
1.1 Basics of Analog and Digital	Differentiate between analog and digital circuits and signals.
1.2 Number systems: Binary, Octal and Hexadecimal, Number system conversions, 1's and 2's complement, Fixed point representation, Floating point representation, Binary arithmetic, Digital codes.	<ul style="list-style-type: none"> (i) Understand binary, octal and hexadecimal numbers. (ii) Convert from any given number system to other number system. (iii) Understand number representation using 1's and 2's complement. (iv) Differentiate between fixed and floating point number representation. (v) Perform addition of binary numbers. (vi) Perform 1's and 2's complement subtraction. (vii) Understand BCD, gray and ASCII codes.
1.3 Boolean Algebra - Basic laws, De-Morgan's Theorem, Truth table.	<ul style="list-style-type: none"> (i) Understand laws and theorems of Boolean Algebra. (ii) Reduce Boolean expressions using laws. (iii) Understand truth tables.
1.4 K-Map	<ul style="list-style-type: none"> (i) Understand K-Map representation of Boolean expression. (ii) Reduce Boolean expression using K-Map.

Assessment Plan: (For the Teachers)

Unit-1	Topic	Assessment Method	Time Plan	Remarks
1.1	Basics of Analog and Digital	Exercise : Question & Answer		
1.2	Number systems: Binary, Octal and Hexadecimal, Number system	Exercise : Question & Answer		



	conversions, 1's and 2's complement, Fixed point representation, Floating point representation, Binary arithmetic, Digital codes.			
1.3	Boolean Algebra - Basic laws, De-Morgan's Theorem, Truth table.	Exercise : Question & Answer		
1.4	K-Map	Exercise : Question & Answer		

1.1 ANALOG VS. DIGITAL

Analog signals are signals with continuous values i.e., they are continuous in both time and magnitude. Analog signals are used in many systems, although their use has declined with the advent of cheap digital signals. Digital signals are discrete in time and magnitude. They are signals that are represented by binary numbers, "1" or "0".

Digital signals are sampled, quantized & encoded version of continuous time signals which they represent. In addition, some techniques also make the signal undergo encryption to make the system more tolerant to the channel.

Analog systems are less tolerant to noise, make good use of bandwidth, and are easy to manipulate mathematically. However, analog signals require hardware receivers and transmitters that are designed to perfectly fit the particular transmission. Change of analog signal requires complete change of transmitters and receivers.

Digital signals on the other hand are more tolerant to noise, but can be completely corrupted in the presence of excess noise. In digital signals, noise could cause a 1 to be interpreted as a 0 and vice versa, which makes the received data different than the original data. The primary benefit of digital signals is that they can be handled by simple, standardized receivers and transmitters, and the signal can be then dealt with in software (which is comparatively cheap to change).

Digital signals are different from discrete time signals which are discrete only in time and not in magnitude. Digital quantity may be either 0 or 1, but discrete may be any numerical value i.e. 0,1....9.

Analog signals can be converted to digital signals. Likewise, Digital signals can be converted to analog signals. The process of converting from analog data to digital data is called "sampling". The recreation of an analog signal from a digital one is done by "reconstruction".



1.2 NUMBER SYSTEMS

Number systems relate quantities and symbols. The number of digits or basic symbols in a particular number system is represented by the base or radix of the number system. Human beings use decimal (base 10) number systems for counting and measurements. Computers use either binary (base 2) number system or hexadecimal (base 16) or octal (base 8) number system as a compact form to represent binary numbers.

1.2.1 Decimal (Base 10) Number System

There are ten symbols: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9, in the Decimal number system. This system uses positional notation. That is, the least-significant digit (right-most digit) is of the order of 10^0 (units or ones), the second right-most digit is of the order of 10^1 (tens), the third right-most digit is of the order of 10^2 (hundreds), and so on. For example,

$$8735 = 8 \times 10^3 + 7 \times 10^2 + 3 \times 10^1 + 5 \times 10^0$$

If ambiguity arises, an optional suffix D will be used in the chapter two denote a decimal number.

1.2.2 Binary (Base 2) Number System

The binary number system uses only two basic symbols. Each digit in binary number is called a bit. The digits can be either 0 or 1. The right most bit of a binary number is called LSB (Least Significant Bit) whereas the left most bit of a binary number is called as MSB (Most significant Bit). The LSB has a weight or value of 2^0 , the second from the right has a value of 2^1 , the next 2^2 , etc. In case of fractions, the weights starting from the right of the fraction point are 2^{-1} , 2^{-2} , 2^{-3} and so on. Eight bits is called a BYTE.

The binary equivalent for some decimal numbers is:

Decimal	0	1	2	3	4	5	6	7	8	9	10
Binary	0	1	10	11	100	101	110	111	1000	1001	1010

1.2.3 Octal (Base 8) Number System

Octal number has eight basic symbols which are the first eight decimal digits 0, 1, 2, 3, 4, 5, 6, 7. Each digit in the octal number system corresponds to the powers of 8. The weight of positions in octal number is as follows ... 8^4 8^3 8^2 8^1 8^0 . 8^{-1} 8^{-2} 8^{-3} ...

1.2.4 Hexadecimal (Base 16) Number System

The hexadecimal number system has 16 symbols from 0-9 and A-F. The weight of each digit of hexadecimal number is ... 16^3 16^2 16^1 16^0 . 16^{-1} 16^{-2} 16^{-3}



Decimal	Hexadecimal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

1.2.5 Number System Conversions

Many times a need to convert between different systems arises. The following section discusses about the inter-conversions in detail.

Binary to decimal conversion:

To convert a binary number to decimal each digit of binary number is multiplied with its corresponding weight and the result thereafter for each product is added.

$$(1101)_2 = (X)_{10}$$



$$1101 = 1x2^3 + 1x2^2 + 0x2^1 + 1x2^0$$

$$= 8 + 0 + 2 + 1$$

$$(1001)_2 = (11)_{10}$$

$$(0.0011)_2 = (X)_{10}$$

$$= 0x2^{-1} + 1x2^{-2} + 0x2^{-3} + 1x2^{-4}$$

$$= 0 \times 0.5 + 0 \times 0.25 + 1 \times 0.125 + 1 \times 0.0625$$

$$= (0.1875)_{10}$$

$$(1001.101)_2 = (X)_{10}$$

$$= 1x2^3 + 0x2^2 + 0x2^1 + 1x2^0 + 1x2^{-1} + 0x2^{-2} + 1x2^{-3}$$

$$= 8 + 0 + 0 + 1 + 0.5 + 0 + 0.125$$

$$= (9.625)_{10}$$

Decimal to binary conversion:

The process to convert a decimal number to binary is to divide the decimal number by 2 progressively and take the remainders in the reverse order to form the binary number

$$(12)_{10} = (X)_2$$

Start by dividing by 2 and keep noting the remainder (R) at each stage.

$$12/2=6 \text{ Remainder}=0$$

$$6/2=3 \text{ Remainder}=0$$

$$3/2=1 \text{ Remainder}=1$$

$$1/2=0 \text{ Remainder}=1$$

Now reading the remainders in reverse order gives the binary equivalent number.

$$(12)_{10} = (1100)_2$$

$$(21)_{10} = (X)_2$$

$$(21)_{10} = (10101)_2$$

To convert a fraction to binary, it is multiplied by 2 and the carry in the integer position is written after each multiplication in the forward order to get the corresponding binary equivalent.

$$(0.4375)_{10} = X_2$$

Multiply the decimal fraction by 2 and keep noting the integral part (I).



$$2 \times 0.4375 = 0.8750 \quad \text{Integer} = 0$$

$$2 \times 0.8750 = 1.750 \quad \text{Integer} = 1$$

$$2 \times 0.750 = 1.5 \quad \text{Integer} = 1$$

$$2 \times 0.5 = 1.0 \quad \text{Integer} = 1$$

Now reading the integers in forward order we get the binary equivalent

$$(0.4375)_{10} = (0.0111)_2$$

Octal to decimal conversion:

Multiplying each octal digit by its weight followed by adding the resulting products. Converts a number from octal to decimal number system.

$$(47)_8 = (X)_{10}$$

$$47 = 4 \times 8^1 + 7 \times 8^0$$

$$= 32 + 7$$

$$= 39$$

$$(47)_8 = (39)_{10}$$

$$(22.34)_8 = (X)_{10}$$

$$22.34 = 2 \times 8^1 + 2 \times 8^0 + 3 \times 8^{-1} + 4 \times 8^{-2}$$

$$= 16 + 2 + 3 \times 1/8 + 4 \times 1/64$$

$$= 18.4375$$

$$(22.34)_8 = (18.4375)_{10}$$

Decimal to octal conversion:

To convert a decimal number to octal, divide the number by 8 progressively and note the remainder each time. Finally write the remainders in the reverse order to form the octal number. If the number has a fraction part, that part is multiplied by 8 and carry the integer part is taken. Finally the carries are taken in the forward order.

$$(19.11)_{10} = (X)_8$$

$$19/8=2 \quad \text{Remainder} = 3$$

$$2/8=0 \quad \text{Remainder} = 2$$

$$0.11 \times 8 = 0.88 \quad \text{Integer} = 0$$



$$0.88 \times 8 = 7.04 \quad \text{Integer} = 7$$

$$0.04 \times 8 = 0.32 \quad \text{Integer} = 0$$

$$0.32 \times 8 = 2.56 \quad \text{Integer} = 2$$

$$0.56 \times 8 = 4.48 \quad \text{Integer} = 4$$

Now write the remainders in reverse order before the octal point and the integers in forward order after the octal point to get the octal equivalent number.

$$(19.11)_{10} = (23.07024)_8$$

Octal to binary conversion:

Each octal number is converted into its equivalent binary digit of length three as the base $8 = 2^3$.

$$(21.357)_8 = (X)_2$$

2	1	.	3	5	7
010	001	.	011	101	111

$$(21.357)_8 = (010001.011101111)_2$$

Binary to octal:

Starting from the octal point, the given binary number is grouped into group of 3 bits and each group is converted into its octal equivalent.

$$(1100111.1011)_2 = (X)_8$$

001	100	111	.101	100
1	4	7	.5	4

$$(1100111.1011)_2 = (147.54)_8$$

Binary to hexadecimal:

The binary number is grouped into bits of 4 (since base $16 = 2^4$) from the binary point and then the corresponding hexadecimal equivalent is written.

$$(100111011.10011)_2 = (X)_{16}$$

0001	0011	1011	.1001	1000
1	3	B	.9	8

$$(100111011.10011)_2 = (13B.98)_{16}$$



Hexadecimal to binary:

Each hexadecimal number is converted into its equivalent binary digit of length four.

$$(6D.4A)_{16} = (X)_2$$

6	D	.4	A
0101	1101	.0100	1010

$$(6D.4A)_{16} = (01101101.01001010)_2$$

Decimal to hexadecimal:

Decimal number to hexadecimal conversion is done by dividing the decimal number by 16 and writing the remainders after each division in the reverse order. The integer part, obtained by multiplying the fractional part of decimal number by 16, is taken in the forward order.

$$(3287.645)_{10} = (X)_{16}$$

3287/16=205	Remainder=7
205/16=12	Remainder=13(D)
12/16=0	Remainder=12(C)
16 x 0.645 = 10.320	Integer = 10 (A)
16 x 0.320 = 5.120	Integer = 5
16 x 0.120 = 1.92	Integer = 1
16 x 0.92 = 14.72	Integer = 14(E)
16 x 0.72 = 11.52	Integer = 11(B)

$$(3287.645)_{10} = (CD7.A51EB)_{16}$$

Hexadecimal to decimal:

Each digit of the hexadecimal number is multiplied by its weight and then added.

$$(61.24)_{16} = (X)_{10}$$

$$= 6 \times 16^1 + 1 \times 16^0 + 2 \times 16^{-1} + 4 \times 16^{-2}$$

$$= 6 \times 16 + 1 \times 1 + 2/16 + 4/162$$

$$= (97.1497)_{10}$$

$$(61.24)_{16} = (97.1497)_{10}$$



1.2.6 1's and 2's Complement

Can we represent the negative numbers in binary number system? The concept of negative sign is not there in binary number system. Although various methods have been developed, the most popular of them all are 1's complement and 2's complement. Though 2's complement dominates the 1's complement in popularity but 1's complement is also used due to simpler concepts and simpler design in hardware.

1's complement:

The sign bit which is the most significant bit (MSB) in 1's complement, is 0 for positive integers and 1 for negative integers. 1's complement of a binary number is obtained by subtracting each bit of the number from 1. Thus put simply, 1's complement of a binary number is obtained by flipping each 0 to a 1 and each 1 to a 0. The absolute integral value of the remaining $n-1$ bits after the sign bit represents the magnitude of the positive integer. For negative integers, the absolute value of the integer is equal to the magnitude of the 1's complement of the $(n-1)$ bit binary pattern.

Binary number	1's Complement	Decimal Number
0101	1010	+5
1001	0110	-6

In the above examples, the MSB in the first case is 0. Hence the decimal equivalent number is +5. In the second case, MSB is 1, which indicates a negative number. The decimal equivalent number is -6.

2's complement:

In 2's complement representation, similar to 1's complement, the most significant bit (MSB) is the sign bit, with value of 0 representing positive integers and 1 representing negative integers. 2's complement of a number is obtained when we add '1' to 1's complement of the given number i.e., 2's complement = 1's complement + 1. The absolute integral value of the remaining $n-1$ bits after the sign bit represents the magnitude of the positive integer. For negative integers, the absolute value of the integer is equal to the magnitude of the 2's complement of the $(n-1)$ bit binary pattern.

Binary Number	1's complement	2's complement	Decimal Number
1010	0101	0110	-6
0101	1010	1011	+5



In the first case, MSB is 1 hence it represents a negative number. The remaining bits are 010. So the negative absolute value is its 2's complement i.e., 110. Thus the number is -6. In the next case, 0 in the MSB represents a positive number, +5.

1.2.7 Fixed point number representation

Real numbers refer to both integers and fractional numbers. In computers, we use the binary number system. Just as a decimal point separates the integral and fractional parts in a decimal number, similarly, a binary point divides the integral and fractional part of a binary number. All digits to the left of a binary point carry the weights $2^0, 2^1, 2^2$ and so on and those to the right have weights $2^{-1}, 2^{-2}, 2^{-3}$ and so on.

Consider the bit pattern of 9.

$$9_{10} = 1001_2$$

Next, consider $4.5_{10} = 100.1_2$

In general, if binary point position is fixed, then 1 bit right shift of the bit pattern of a number is equivalent to dividing the number by 2. Similarly, 1 bit left shift of a number is equivalent to multiplying the number by 2. The shifting process above is the key to understand fixed point number representation. Real number representation is done by defining a fixed binary point number type and then adhering to this implicit convention. Two parameters are required to define a fixed point type number. They are width of the number representation and binary point position within the number.

We use the notation $\text{fixed}\langle w, b \rangle$, where w denotes the total number of bits used (the Width of a number), and b denotes the binary point counted from the least significant bit (counting from 0).

For example, $\text{fixed}\langle 5, 4 \rangle$ denotes a 5-bit fixed point number, of which 4 right most bits are fractional. Therefore, the bit pattern:

$$1.001_2 \text{ represents } 1.0625_{10}$$

$\text{Fixed}\langle 5, 2 \rangle$ for the same bit pattern is 100.01_2 representing 4.25 and as already seen 1000.1_2 which is $\text{fixed}\langle 5, 1 \rangle$ is 8.5 and when treated as an integer is 17.

1.2.8 Floating point number representation

Real numbers are numbers containing fractional part such as 3.0, -111.5, $\frac{1}{2}$, $3E-5$ etc. The last example is computer shorthand for scientific notation implying 3×10^{-5} .

In essence, computers are integer machines that use complex codes such as IEEE Floating-Point Standard for representing real numbers. The floating point terminology refers to the



absence of standard as regards fixed number of digits before and after the decimal point; i.e., the decimal point can float. In contrast, fixed-point representations have set number of digits before and after the decimal point. In general, floating-point representations have a large number range but are slower and less accurate than fixed-point representations.

A real number in binary has an integral and a fraction part where each bit is either 0 or 1. A number in floating point representation has three fields- sign(s), exponent(e) and significand(m). The numerical value of real number is evaluated as

$$(-1)^s * m * 2^e \quad \text{where } m < |2|$$

There are two types of base 2 formats - the binary32 for single precision and the binary64 for double precision. The difference lies in the number of bits used to encode various components.

Table: Precision Representation

Precision	Base	Sign	Exponent	Significand
Single precision	2	1	8	23+1
Double precision	2	1	11	52+1

Single Precision Format:

The 32 bit single precision format has 23 significand bits (1 represents implied bit), 8 exponent bits and 1 sign bit. The range of exponent in single precision format is -126 to +127.

For example, conversion of the rational number $21 \div 4$ to single precision float format is done as follows,

$$\begin{aligned} 21_{(10)} \div 4_{(10)} &= 5.25_{(10)} = 101.01_{(2)} \\ &= 1.0101_{(2)} \times 2^2 \quad (\text{normalized form with leading 1 bit}) \end{aligned}$$

Bits after the binary point give the mantissa of float number. A normalized number is more accurate than a corresponding de-normalized number as the implied MSB can be used to represent even more accurate significand ($23 + 1 = 24$ bits). This is called subnormal representation. The floating point numbers are represented in normalized form.

Double Precision Format:

The 64 bit double precision format has 52 significand bits (1 represents implied bit), 10 exponent bits and 1 sign bit. Apart from size of various components, all other definitions for double precision format are the same as for Single Precision Format.



1.2.9 Binary Arithmetic

Binary Addition:

Addition of two or more binary numbers follows the following rules:

$$0 + 0 = 0$$

$$0 + 1 = 1$$

$$1 + 0 = 1$$

$$1 + 1 = 0 \quad \text{and a carry ahead of 1}$$

Carry ahead is in a manner similar to decimal arithmetic.

111	1010	011.01
+110	+1101	+101.11
<hr/>	<hr/>	<hr/>
1101	10111	1001.00
<hr/>	<hr/>	<hr/>

Binary Subtraction:

Binary subtraction follows the following rules:

$$0 - 0 = 0$$

$$1 - 0 = 1$$

$$1 - 1 = 0$$

$$0 - 1 = 1 \quad \text{with a borrow of 1 i.e., equivalent to } 10 - 1 = 1$$

111	110.01
-010	-100.10
<hr/>	<hr/>
101	001.11
<hr/>	<hr/>

1's complement subtraction:

In order to perform 1's complement subtraction, the following steps must be followed:

1. Write the minuend as such.
2. Write the 1's complement of subtrahend.
3. Add the two numbers.
4. Add the carry that arises from the addition (called "end around carry") with the sum obtained in step 3 to get the result.
5. If there is no end around carry, compute the 1's complement of the sum obtained in step 3 and put a negative sign before the result.



We know that

$$\begin{array}{r}
 9 \qquad 1001 \\
 -5 \qquad -0101 \\
 \hline
 4 \qquad 0100
 \end{array}$$

Now repeating the same using 1's complement, we have

$$\begin{array}{r}
 1001 \\
 +1010 \text{ (1's complement of 5)} \\
 \hline
 10011
 \end{array}$$

Here the end carry is 1 which is added to 0011 to get the result as

$$0011 + 1 = 0100$$

The absence of END AROUND CARRY in the 1's complement subtraction, is indicative of a negative result requiring 1's complement to get the final result.

$$\begin{array}{r}
 6 \qquad 0110 \\
 -9 \qquad +0110 \text{ (1's complement)} \\
 \hline
 -3 \qquad 0100
 \end{array}$$

Now since there is no END AROUND CARRY, the answer would be 1's Complement of 0100 i.e., 1011 which is -3.

2's Complement Subtraction:

In order to perform 2's complement subtraction, we must follow the under mentioned steps:

1. Write the minuend as such.
2. Write down the 2's complement of the subtrahend.
3. Add the two numbers.
4. Discard carry, if any. The sum is the result (positive).
5. If there is no carry, find out the 2's complement of the sum and put negative sign before the result as the result is negative.

Consider,

$$\begin{array}{r}
 9 \qquad (1001) \qquad 1001 \\
 -3 \qquad (0011) \qquad +1101 \text{ (2's Complement of 3)} \\
 \hline
 6 \qquad \qquad \qquad 10110
 \end{array}$$



Now, since we have a carry, we discard it (neglect it) and the result is 0110 i.e., 6.

Next consider,

$$\begin{array}{r}
 3 \quad (0011) \quad 0011 \\
 -9 \quad (1001) \quad +0111 \\
 \hline
 -6 \quad \quad \quad 1010 \\
 \hline
 \end{array}$$

In the absence of a carry, we determine the 2's complement of the result obtained and place a negative sign. So here we have 1010 for which the 2's complement would be 0110 which is 6. Hence the answer after prefixing the negative sign is -6.

1.2.7 Digital codes

To identify a character as numeric, alphabet or special symbol, each character is assigned a 7 or 8 bit binary code that is used for information processing by computers and other digital circuits. Example - Binary number 1000001 represents 65(decimal) in straight binary code, alphabet A in ASCII code and 41(decimal) in BCD code.

BCD (Binary-Coded Decimal) code:

BCD or Binary Coded Decimal is that number system that employs binary numbers or digits to represent a decimal number. A decimal number contains 10 digits (0-9). Each decimal digit is represented by its four bit binary equivalent in BCD coded representation. Thus, in BCD we can use the binary equivalents of 0-9 as 0000-1001. 1010, 1011, 1100, 1101, 1110, and 1111 are INVALID CODE in BCD code.

A single digit decimal number is represented by its four bit equivalent in BCD code. A double digit decimal number (eg. 12) will be represented by eight bits in BCD - Four bits for the first decimal digit and next four for the second decimal digit. Thus, $(12)_{10}$ will be expressed as 0001 0010 in BCD. Four bits from L.S.B are binary equivalent of 2 and next four are the binary equivalent of 1.

For 0 to 9 decimal numbers, both binary and BCD are equal but when decimal number is more than one digit BCD differs from binary. Example - $(37)_{10}$ is represented as 0011 0111 using BCD code, rather than $(100101)_2$ in binary code. Thus BCD code requires more bits than binary code. Table given below shows the binary and BCD codes for the decimal numbers 0 to 15.

Decimal number	Binary number	Binary Coded Decimal(BCD)
0	0000	0000
1	0001	0001



2	0010	0010
3	0011	0011
4	0100	0100
5	0101	0101
6	0110	0110
7	0111	0111
8	1000	1000
9	1001	1001
10	1010	0001 0000
11	1011	0001 0001
12	1100	0001 0010
13	1101	0001 0011
14	1110	0001 0100
15	1111	0001 0101

ASCII (American Standard Code Information Interchange) code:

Alphanumeric codes or character codes are basically binary codes used for alphanumeric data, i.e., alphabets, numbers, mathematical symbols and punctuation marks. Interfacing of Input-Output devices such as keyboards, monitors, mouse is done using these codes owing to their ease of computer processing. ASCII code, EBCDIC code and Unicode are the most popular alphanumeric codes in use.

ASCII code, first published in 1967, is a seven bit code based on the English alphabet. Some characters of ASCII code are tabulated below.

DEC	OCT	HEX	BIN	Symbol	Description
0	000	00	00000000	NUL	Null char
1	001	01	00000001	SOH	Start of Heading
2	002	02	00000010	STX	Start of Text
3	003	03	00000011	ETX	End of Text
4	004	04	00000100	EOT	End of Transmission
5	005	05	00000101	ENQ	Enquiry
6	006	06	00000110	ACK	Acknowledgment



7	007	07	00001111	BEL	Bell
8	010	08	00001000	BS	Back Space
9	011	09	00001001	HT	Horizontal Tab
10	012	0A	00001010	LF	Line Feed
11	013	0B	00001011	VT	Vertical Tab
12	014	0C	00001100	FF	Form Feed
13	015	0D	00001101	CR	Carriage Return
14	016	0E	00001110	SO	Shift Out / X-On
15	017	0F	00001111	SI	Shift In / X-O

ASCII is 7-bit alphanumeric code which supports 127 characters. 00h-1Fh are used as control characters and 20h-7Fh as graphics symbols. Extended ASCII is an 8-bit code supporting 256 symbols where special graphics and math's symbols are added. Extended ASCII series starts from 80h to FFh.

Gray code:

Gray Code is a non-weighted code with two adjacent code numbers differing from each other by only one bit. This code finds application in ADCs and in some input/output devices. The table of Gray Code given below depicts the difference of binary code from gray code for their respective decimal numbers.

Decimal Number	Binary code	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101



10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

Gray coding involves changing only one bit at each step, starting from the right side i.e., from L.S.B towards the M.S.B changes. The first three bits are initially held constant i.e., 000 and the fourth bit changes from 0 to 1. Then the next bit from L.S.B i.e 3rd bit, is changed from 0 to 1 which is the decimal equivalent for 2. Now, keeping the first three bits constant i.e 001 the 4th bit is changed from 1 to 0. Thus the gray code for decimal number 3 is 0010. Next we change the second bit as all possible combinations for bit 3 and 4 are over. It may be observed here that we can't change the third bit again (which is also a one bit change from its previous), as changing it would give the equivalent gray code 0000 which has occurred earlier and must not be repeated. So the equivalent code for 4 will be 0110. Now again holding first and second bit constant, we find the possible combinations of the third and the fourth bit by only changing 1 bit in each step. All other equivalent representations are found in a similar manner.

1.3 BOOLEAN ALGEBRA

Boolean Algebra is a unique system of mathematical logic. Every number in Boolean, unlike ordinary algebra is either a 0 or 1. Negative number and fractions do not exist in Boolean algebra. Thus, if $A=0$, then $A \neq 1$ and if $A=1$, then $A \neq 0$. Boolean Algebra simplifies the procedure for solving logic circuits by minimizing the number of components used to realize it.

In Boolean algebra, truth tables are used. The truth table examines all possible states and decides whether the output would be TRUE (1) or FALSE (0). Given n variables, the truth table defines the output for 2^n different combinations.

Three operators used in Boolean Algebra are AND, OR and NOT.

The AND operator is similar to multiplication in ordinary algebra. It is defined by the use of dot(.) or no operator symbol at all. Consider $A.B=C$. This implies that if A is TRUE and B is TRUE, then C is TRUE and under all other conditions C is FALSE. The possible combinations of input and corresponding output for AND operator are shown in the truth table.



A	B	C
0	0	0
0	1	0
1	0	0
1	1	1

The OR operator is indicated by the use of plus (+) sign. If $A+B=C$, then C is TRUE if either A or B is TRUE. If both A and B are FALSE then only C is FALSE. The truth table for OR operator is as shown.

A	B	C
0	0	0
0	1	1
1	0	1
1	1	1

The NOT operator changes the sense of an argument. It is indicated by an overscore. Thus, $\bar{A}=B$ implies that if A is TRUE then B is FALSE and if A is FALSE then B is TRUE.

A	B
0	1
1	0

1.3.1 Basic Laws of Boolean Algebra

Commutative law:

1. $A + B = B + A$
2. $A \cdot B = B \cdot A$

Associative law:

1. $A + (B + C) = (A + B) + C$
2. $A \cdot (B \cdot C) = (A \cdot B) \cdot C$

Distributive law

1. $A \cdot (B + C) = A \cdot B + A \cdot C$
2. $A + (B \cdot C) = (A + B) \cdot (A + C)$



$$3. \quad A + \bar{A}B = A + B$$

OR laws

$$1. \quad A + 0 = A$$

$$2. \quad A + 1 = 1$$

$$3. \quad A + A = A$$

$$4. \quad A + \bar{A} = 1$$

AND laws

$$1. \quad A \cdot 0 = 0$$

$$2. \quad A \cdot 1 = A$$

$$3. \quad A \cdot A = A$$

$$4. \quad A \cdot \bar{A} = 0$$

Laws of complementation

$$1. \quad \bar{\bar{A}} = A$$

$$2. \quad \bar{0} = 1$$

$$3. \quad \bar{1} = 0$$

$$4. \quad \text{If } A=0, \text{ then } \bar{A} = 1$$

$$5. \quad \text{If } A=1, \text{ then } \bar{A} = 0$$

1.3.2 De Morgan's Theorems:

I Theorem statement:

The complement of a sum is equal to the product of the complements.

$$\overline{(A+B)} = \bar{A} \cdot \bar{B}$$

A	B	\bar{A}	\bar{B}	A+B	$\overline{(A+B)}$	$\bar{A} \cdot \bar{B}$
0	0	1	1	0	1	1
0	1	1	0	1	0	0
1	0	0	1	1	0	0
1	1	0	0	1	0	0



II Theorem Statement:

The complement of a product is equal to the sum of the complements.

$$\overline{(A.B)} = \bar{A} + \bar{B}$$

A	B	\bar{A}	\bar{B}	A.B	$\overline{(A.B)}$	$\bar{A} + \bar{B}$
0	0	1	1	0	1	1
0	1	1	0	0	1	1
1	0	0	1	0	1	1
1	1	0	0	1	0	0

Boolean expressions must be reduced to the simplest form to reduce implementation cost. This task is accomplished using the laws of Boolean Algebra and De Morgan's Theorem. The following steps can be used for most cases:

1. Remove all parentheses in the expression.
2. Drop one term if identical terms appear.
3. Drop terms if variable and its negation coexist.
4. Reduce pairs of terms that are identical except for one variable.

Consider reducing the following expression

$$\begin{aligned} & \overline{\bar{A}\bar{B} + \bar{A} + AB} \\ &= \overline{\bar{A} + \bar{B} + \bar{A} + AB} \\ &= \overline{\bar{A} + \bar{B} + AB} \\ &= \overline{\bar{A} + \bar{B} + A} \\ &= \overline{1 + \bar{B}} \\ &= \bar{1} \\ &= 0 \end{aligned}$$

Next consider reducing

$$\begin{aligned} & \overline{(\bar{A}\bar{B}+ABC)(\bar{A}\bar{B}C)} \\ &= \overline{(\bar{A} + \bar{B} + ABC)(\bar{A}\bar{B}C)} \\ &= \overline{\bar{A}\bar{A}\bar{B}C + \bar{B}\bar{A}\bar{B}C + ABC\bar{A}\bar{B}C} \end{aligned}$$



$$\begin{aligned}
 &= \overline{0 + A\bar{B}C + 0} \\
 &= \overline{A\bar{B}C} \\
 &= \bar{A} + B + \bar{C}
 \end{aligned}$$

1.4 KARNAUGH MAP (K-MAP)

K-Map is a tool for Boolean expression representation where each entry is 1 or 0 of SOP (Sum of Products) or POS (Product of Sum representation).

A function of the form $f = xyz + x'yz + xyz' + \dots$ is called the SOP form. (x' , y' , z' denote complement of x , y , z respectively). Each product term in SOP form is called a minterm, where each input variable appears exactly once. A function with n variables has 2^n minterms. Consider a three variable function, $f(x,y,z)$. It has 8 minterms.

$x'y'z'$	0
$x'y'z$	1
$x'yz'$	2
$x'yz$	3
$xy'z'$	4
$xy'z$	5
xyz'	6
xyz	7

From a truth table for a function, sum of minterms form of expression is written by picking entries where the function output is 1.

Consider for example,

x	y	z	F1	F2
0	0	0	1	1
0	0	1	1	0
0	1	0	0	1
0	1	1	1	0
1	0	0	1	1
1	0	1	0	1
1	1	0	0	0
1	1	1	0	1



Now, $F1 = x'y'z' + x'y'z + x'yz + xy'z' = \Sigma m(0,1,3,4)$

Similarly, $F2 = \Sigma m(0,2,4,5,7)$.

A n variable K-Map has 2^n cells arranged in such a manner that adjacent cells correspond to truth rows that differ in only one bit position.

2-Variable K-Map

A 2-variable K-Map has 2 rows and 2 columns. The minterms are shown in the corresponding cells. If a minterm is present in a function, then it is represented by a 1 in the corresponding cell and if it is absent then a 0 is placed.

	A=0	A=1
B=0	m(0)	m(2)
B=1	m(1)	m(3)

If $f = A'B + AB'$, then it is entered in K-Map as

0	1
1	0

3-Variable K-Map

A 3 variable map has 2 rows and 4 columns. The minterm locations are as shown.

	A'B'	A'B	AB	AB'
C'	m(0)	m(2)	m(6)	m(4)
C	m(1)	m(3)	m(7)	m(5)

$F = A'B'C + A'BC' + A'BC + ABC = \Sigma m(1,2,3,7)$

0	1	0	0
1	1	1	0

4-Variable K-Map

A 4 variable K-Map has 4 rows and 4 columns.

	A'B'	A'B	AB	AB'
C'D'	m(0)	m(4)	m(12)	m(8)
C'D	m(1)	m(5)	m(13)	m(9)
CD	m(3)	m(7)	m(15)	m(11)
CD'	m(2)	m(6)	m(14)	m(10)



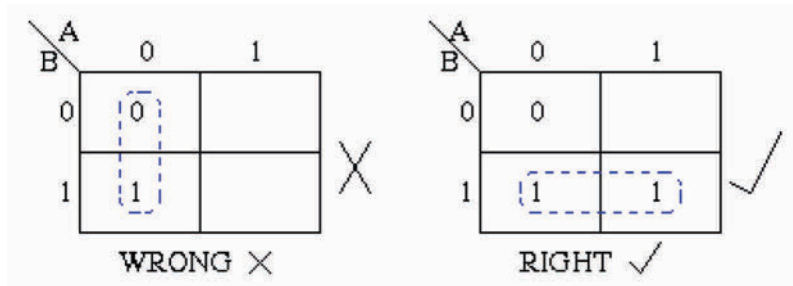
$$F = A'B'C'D + A'B'CD' + AB'C'D + ABCD = \Sigma m(1, 2, 9, 15)$$

0	0	0	0
1	0	0	1
0	0	1	0
1	0	0	0

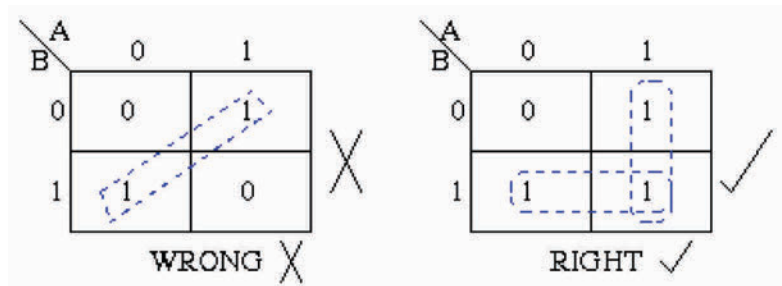
Rules of simplification for K-Map:

The K-Map uses the following rules for the simplification of expressions by grouping together adjacent cells containing ones

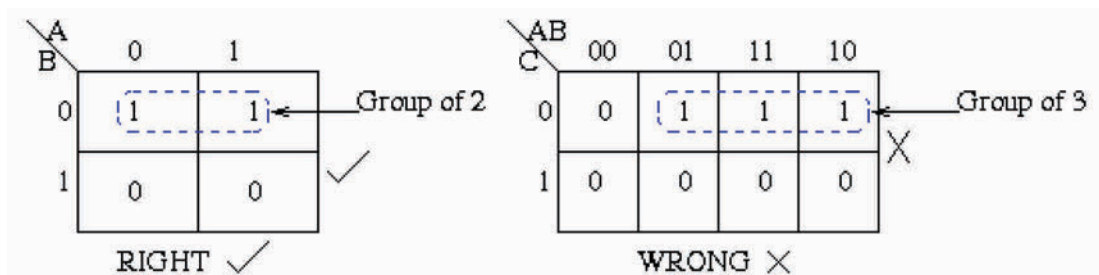
- Groups may not include any cell containing a zero

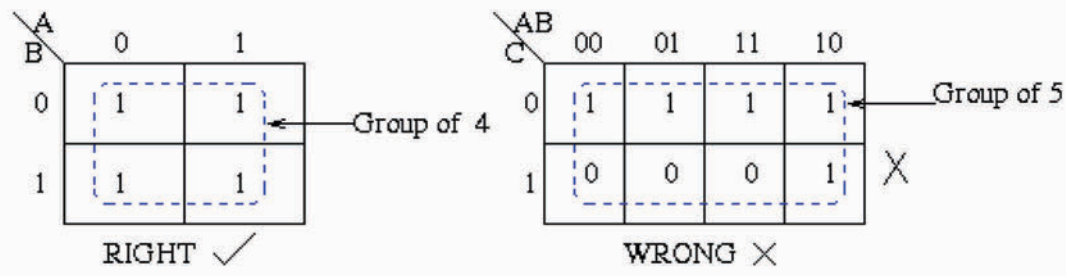


- Groups may be horizontal or vertical, but not diagonal.

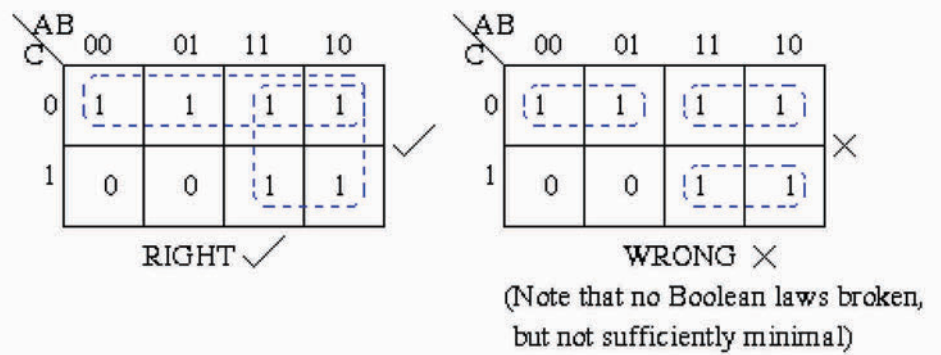


- Groups must contain 1, 2, 4, 8, or in general 2^n cells. That is if $n = 1$, a group will contain two 1's since $2^1 = 2$. If $n = 2$, a group will contain four 1's since $2^2 = 4$.

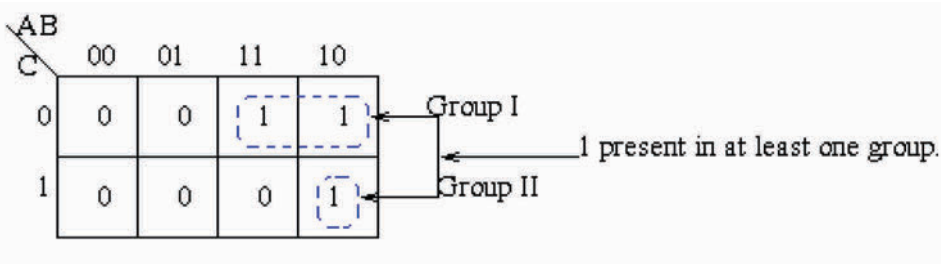




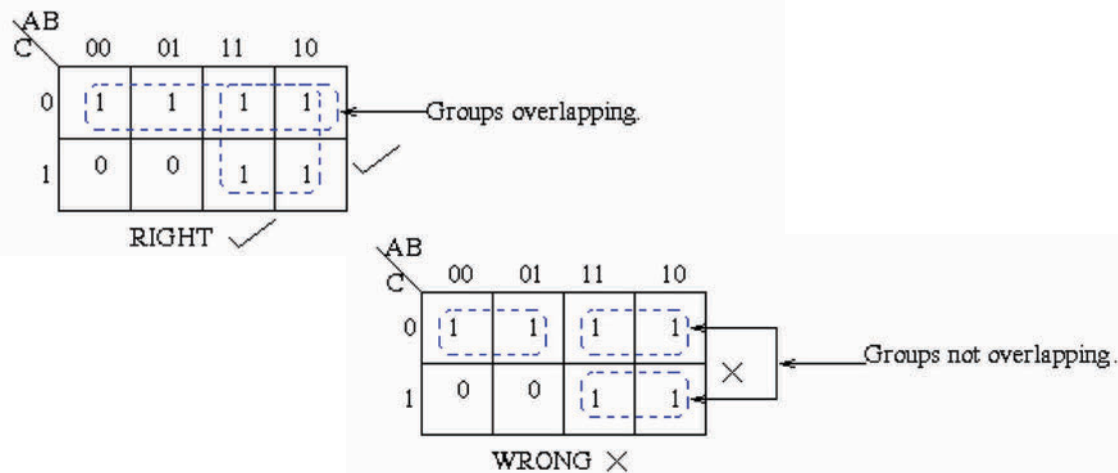
- Each group should be as large as possible.



- Each cell containing a one must be in at least one group.

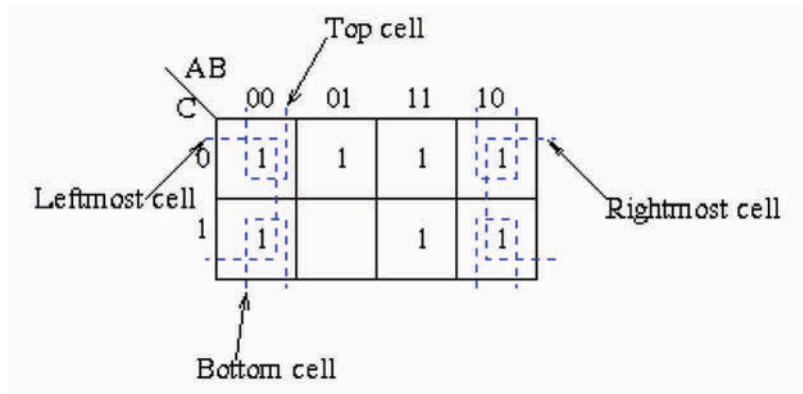


- Groups may overlap.

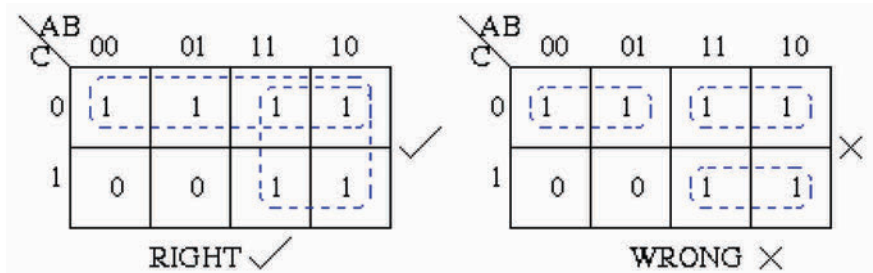




- Groups may wrap around the table. The leftmost cell in a row may be grouped with the rightmost cell and the top cell in a column may be grouped with the bottom cell.



- There should be as few groups as possible, as long as this does not contradict any of the previous rules.



1.5 SUMMARY

The use of fingers as counting devices is considered to be the origin of digital method of arithmetic. It differs from the analog method where numbers are expressed using directly measurable quantities. Digital systems use different number systems. Hardware uses the binary number system. Octal and Hexadecimal number systems are used as shorthand language for representing binary number systems. Most computers use 2's complement to represent negative numbers and binary fractions to represent fixed point numbers less than one. The widest range of binary numbers is provided by floating point numbers. Alphabetic letters can be represented as binary code. ASCII is used for scientific, binary oriented machines. Using Boolean operators-AND, OR, NOT and rules, any logic expression can be reduced to its simplest form, thereby reducing the implementation cost.

Exercise Questions:

- Q1. Differentiate between the term analog and digital.
- Q2. What are floating point numbers?



Q3. Convert the following binary numbers to decimal:

- a. 1010.11 b. 10101111.01

Q4. Convert the following decimal numbers to binary:

- a. 27.2 b. 33.333

Q5. Convert the following binary number to hexadecimal:

- a. 111100101 b. 00110011

Q6. Convert the following hexadecimal number to binary:

- a. 7CA3 b. A13B

Q7. Convert the following binary number to octal:

- a. 110010 b. 100110001

Q8. Convert the following octal number to binary:

- a. 3527 b. 7365

Q9. Perform the arithmetic operations on binary numbers as shown

- a. 101011+110101 b. 101010-1010

Q10. Find the eight bit 2's complement of

- a. -23 b. -123

Q11. Reduce the following Boolean expression:

- a. $(A \bar{B} + A \bar{C})(B C + B \bar{C}) ABC$ b. $\overline{ABC + \bar{A} \bar{B} + BC}$



Multiple Choice: Choose the Correct Answer

- 1) Any number with an exponent of zero is equal to:
 - a) Zero
 - b) one
 - c) that number
 - d) ten

- 2) Which of the following statements does NOT describe an advantage of digital technology?
 - a) The values may vary over a continuous range.
 - b) The circuits are less affected by noise.
 - c) The operation can be programmed.
 - d) Information storage is easy.

- 3) The 2's complement of the number of 1010101
 - a) 0101011
 - b) 0101010
 - c) 1101010
 - d) 1110011

- 4) Convert the 187₁₀ to 8-bit binary.
 - a) 10111011₂
 - b) 11011101₂
 - c) 10111101₂
 - d) 10111100₂

- 5) A binary number's value changes most drastically when the _____ is changed.
 - a) MSB
 - b) LSB
 - c) MSB-1
 - d) LSB+1

- 6) Hexadecimal letters A through F are used for decimal equivalent values from:
 - a) 1 through 6
 - b) 9 through 14
 - c) 10 through 15
 - d) 11 through 17

- 7) Which is typically the longest: bit, byte, nibble, word?
 - a) Bit
 - b) Byte
 - c) Nibble
 - d) Word



UNIT - 2

LOGIC CIRCUITS

2.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource material
- Duration
- Learning outcomes
- Assessment plan

2.1 Introduction to Logic gates: Negative logic and positive logic, AND, OR, NOT, NOR, NAND, XOR and XNOR gates.

2.2 Introduction to combinational circuits.

2.2.1 Arithmetic Circuits: Half adder, Full adder, Half subtractor and Full subtractor.

2.2.2 Data Processing Circuits: Encoders, Decoders, Multiplexers, De-Multiplexers, Code converters and Comparators.

2.3 Summary

2.0 UNIT OVERVIEW AND DESCRIPTION

Overview:

This unit starts with the difference between positive and negative logic. It includes description of various types of gates with their symbols, Boolean expressions and truth tables. AND, OR and NOT gates are called as basic gates and are described with equivalent circuits. Universal logic gates, namely NAND and NOR along with two other gates, XOR and XNOR are presented. This unit differentiates between combinational and sequential circuits, focuses on describing types of addition and subtraction circuits. Working principles and designs of data processing combinational circuits like encoders, decoders, multiplexers, de-multiplexers, code converters and comparators are discussed with appropriate figures. Brief information about some of the TTL ICs used as readymade solution for different types of data processing circuits is shared.



Knowledge and skill outcomes:

- i) Difference between positive and negative logic.
- ii) Understanding of various types of logic gates.
- iii) Identification of basic gates and universal gates.
- iv) Difference between sequential and combinational circuits.
- v) Learn about broad categories of combinational circuits.
- vi) Identification of various types of logic circuits used for addition and subtraction.
- vii) Knowledge about design procedure and working principle of various types of data processing circuits.
- viii) Overview about some of the off-the shelf TTL ICs implementing different types of data processing circuits.

Resource Materials

1. Digital Logic and Computer Design by M. Morris Mano, Prentice Hall India Publication, New Delhi, 2002.
2. Digital Principles and Applications by A. P Malvino & D. P. Leach, Tata McGraw-Hill Publication, New Delhi 1995.
3. Modern Digital Electronics by R. P. Jain, Tata McGraw-Hill Publication, New Delhi 2010.
4. Digital Electronics by G. K. Kharate, Oxford University Press Publication, New Delhi 2011.
5. Digital Electronics: Principles and Integrated Circuits by A. K. Maini, Wiley India Publication, New Delhi 2010.
6. Digital Technology: Principles and Practice by Virendra Kumar, New Age International Publishers, New Delhi 2002.
7. Digital Circuits and Design by S. Salivahanan & S Arivazhagan, Vikas Publishing, Noida, Uttar Pradesh, 2012.



Duration: Total Hours 18

Learning Outcomes :

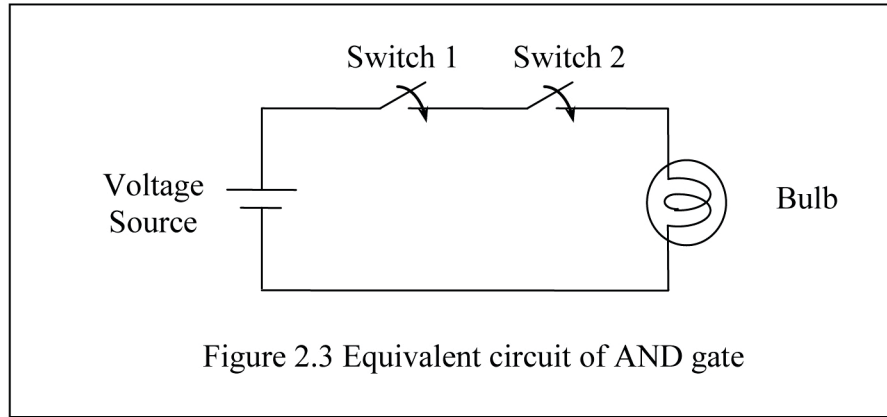
Unit-2: Logic Circuits	Outcomes
2.1 Introduction to Logic gates: Negative logic and positive logic, AND, OR, NOT, NOR, NAND, XOR and XNOR gates.	(i) Differentiate between positive logic and negative logic. (ii) Identify the various types of logic gates used in digital electronics and their background.
2.2 Introduction to combinational circuits. Arithmetic Circuits: Half adder, Full adder, Half subtractor and Full subtractor. Data Processing Circuits: Encoders, Decoders, Multiplexers, De-Multiplexers, Code converters and Comparators.	(i) Differentiate between combinational and sequential circuits. (ii) Identify various types of adder and subtractor circuits used in digital electronics. (iii) Identify following types of data processing circuits with their working principle: Encoders, Decoders, Multiplexers, De-Multiplexers, Code converters and Comparators. (iv) Idea about some of the off-the-shelf ICs for combinational circuits.

Lassessment Plan: (For the Teachers)

Unit-2	Topic	Assessment Method	Time Plan	Remarks
2.1	Introduction to Logic gates: Negative logic and positive logic, AND, OR, NOT, NOR, NAND, XOR and XNO gates.	Exercise : Question & Answer		
2.2	Introduction to combinational circuits. Arithmetic Circuits: Half adder, Full adder, Half subtractor and Full subtractor. Data Processing Circuits: Encoders, Decoders, Multiplexers, De-Multiplexers, Code converters and Comparators.	Exercise : Question & Answer		



The AND gate operation can also be understood with the help of the following circuit diagram.



Student Activity: In Figure 2.3, determine the status of bulb (glowing or extinguished) for all possible combination of switch 1 and 2.

2.1.2.2 OR Gate

An OR gate is a logic circuit whose output remains at logic '1' when any one or all of the inputs are at logic '1'. On the other hand, if all the inputs are at logic '0' the output will be at logic '0'. This gate has one output and many inputs. The symbol, Boolean expression and truth table of OR gate is as follows:

(a) Symbol

$$Y = A + B$$

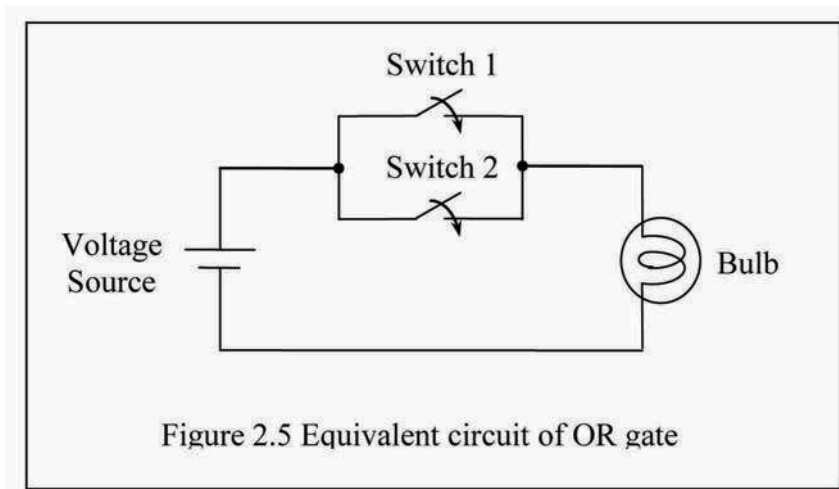
(b) Boolean expression

<i>A</i>	<i>B</i>	<i>Y</i>
0	0	0
0	1	1
1	0	1
1	1	1

(c) Truth table

Figure 2.4 Symbol, Boolean expression and truth table of OR gate

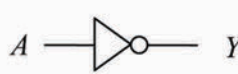
The OR gate operation can also be understood with the help of the following circuit diagram.



Student Activity: In Figure 2.5, determine the status of bulb (glowing or extinguished) for all possible combination of switch 1 and 2.

2.1.2.3 NOT Gate:

A NOT gate is a logic circuit whose output remains at logic '1' when the input is at logic '0' and vice versa. It is also known as inverter. This gate has one input and one output. The symbol, Boolean expression and truth table of NOT gate is as follows:



(a) Symbol

$$Y = \bar{A}$$

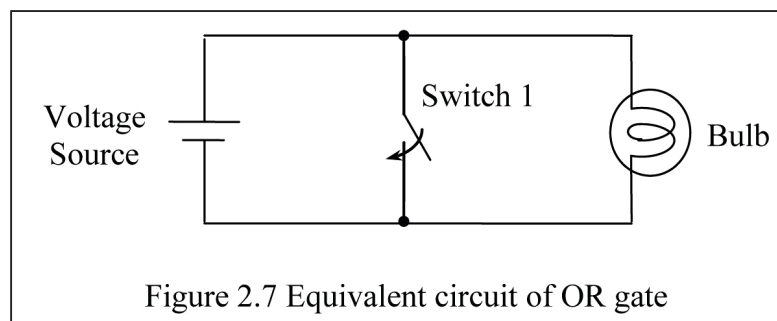
(b) Boolean expression

A	Y
0	1
1	0

(c) Truth table

Figure 2.6 Symbol, Boolean expression and truth table of NOT gate

The NOT gate operation can also be understood with the help of following circuits diagram.



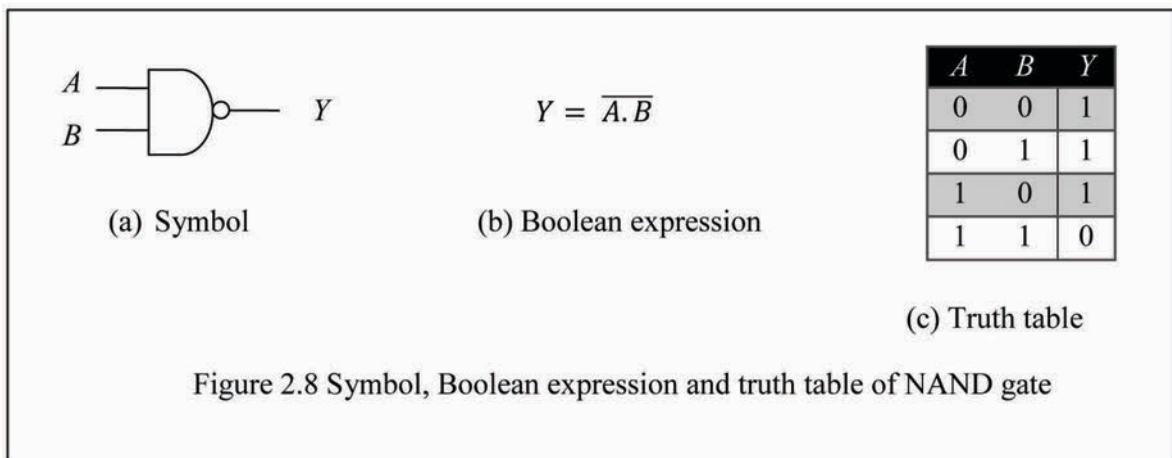


Student Activity: In Figure 2.7, determine the status of bulb (glowing or extinguished) for all possible combination of switch 1.

Note: AND, OR and NOT gates are known as basic gates as they implement the three basic logic operations.

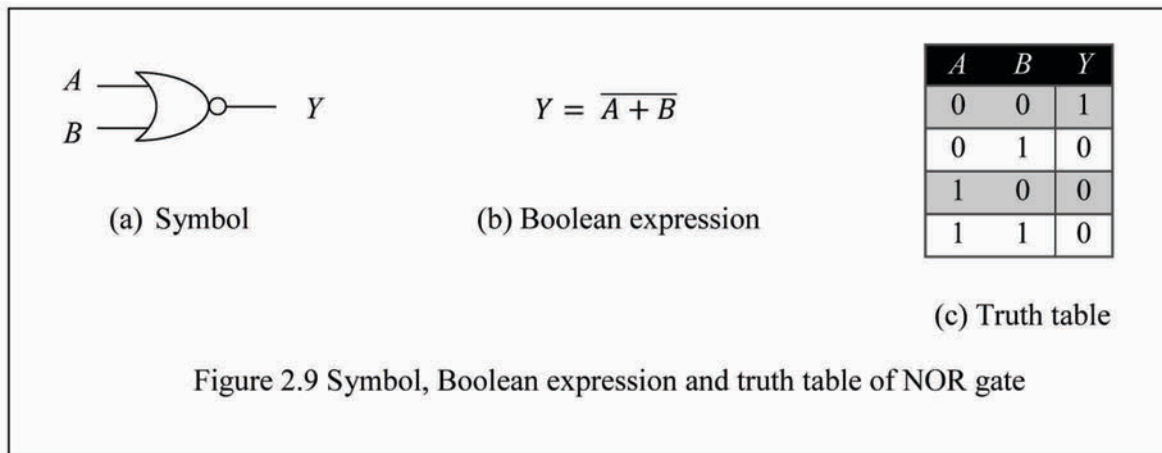
2.1.2.4 NAND Gate:

NAND gate can also be obtained by connecting a NOT gate at the output of an AND gate. It is defined as a logic circuit whose output remains at logic '1' if any or all the inputs are at logic '0'. Conversely, the output remains at logic '0' if all the inputs are at logic '1'. This gate has one output and many inputs. The symbol, Boolean expression and truth table of NAND gate is as follows:



2.1.2.5 NOR Gate:

NOR gate can also be obtained by connecting a NOT gate at the output of an OR gate. It is defined as a logic circuit whose output remains at logic '1' if all the inputs are at logic '0'. Conversely, the output remains at logic '0' if any or all the inputs are at logic '1'. This gate has one output and many inputs. The symbol, Boolean expression and truth table of NOR gate is as follows:

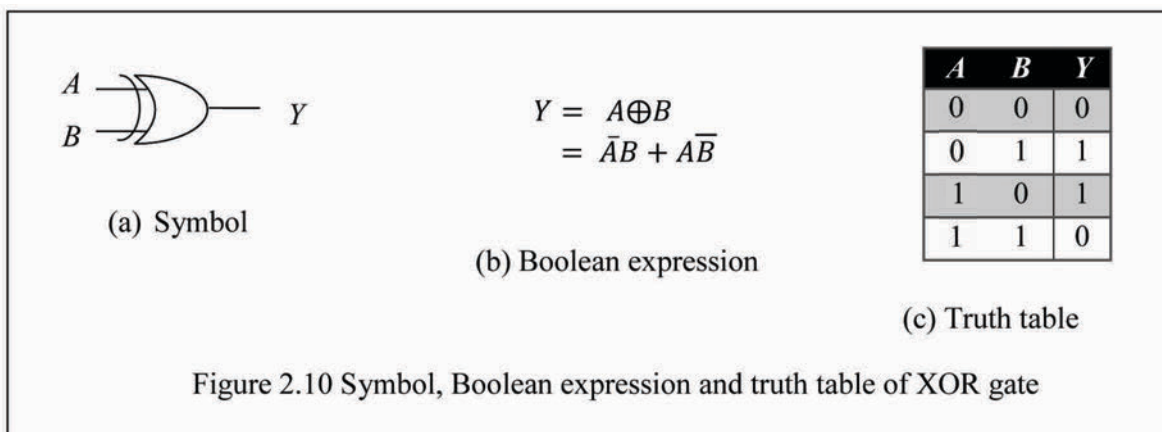


Note : NAND and NOR gates are also known as universal gates as all other gates can be derived from them.

Student Activity: Derive AND, OR and NOT gate from universal gates.

2.1.2.6 XOR Gate:

The exclusive- OR (XOR) is a logic circuit whose output is at logic '1' when odd numbers of inputs are at logic '1'. On the contrary, the output is at logic '0' when either all the inputs are at logic '0' or even number of inputs are at logic '1'. It has two inputs and one output.

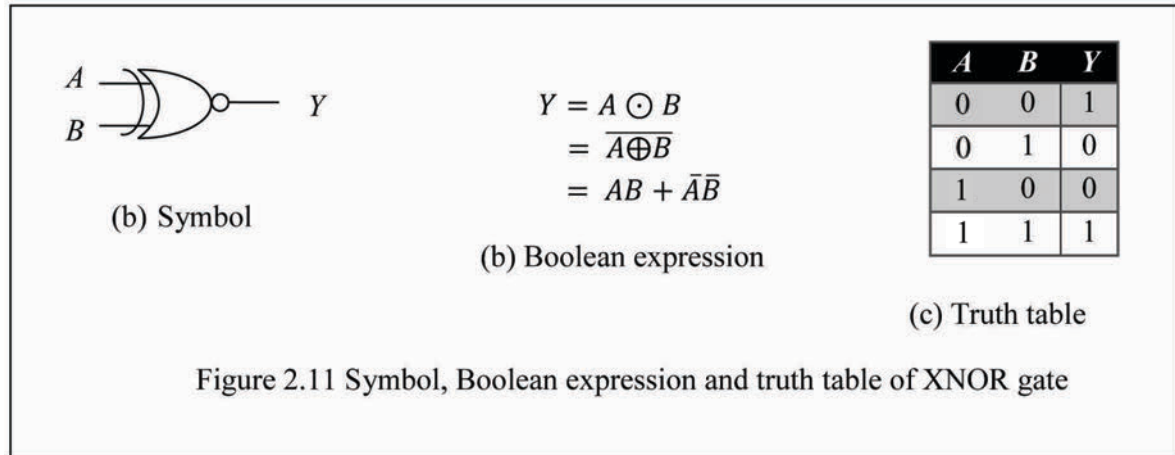


2.1.2.7 XNOR Gate:

The exclusive- NOR (XNOR) is a logic circuit whose output is at logic '0' when odd numbers of inputs are at logic '1'. On the contrary, the output is at logic '1' when either all the inputs are at



logic '0' or even number of inputs are at logic '1'. XNOR gate can also be obtained by connecting a NOT gate at the output of an XOR gate. It also has two inputs and one output.



Student Activity: Derive XOR and XNOR gates from universal gates.

2.2 COMBINATIONAL CIRCUITS

Digital circuits are broadly classified into following two categories: Combinational Circuits and Sequential Circuits.

A digital circuit is said to be combinational if the output of the circuit at any instant of time depends only on the present inputs. Examples of combinational circuits are: Adder, Multiplexer, Decoder etc. On the other hand, a digital circuit is termed as sequential if the output of the circuit at any instant of time depends not only on the present inputs but also on the past state stored in the memory elements. Flip flop, counter, register etc. are the examples of sequential circuits. A sequential circuit may have two parts: combinational circuit and memory element.

2.2.1 Arithmetic Circuits

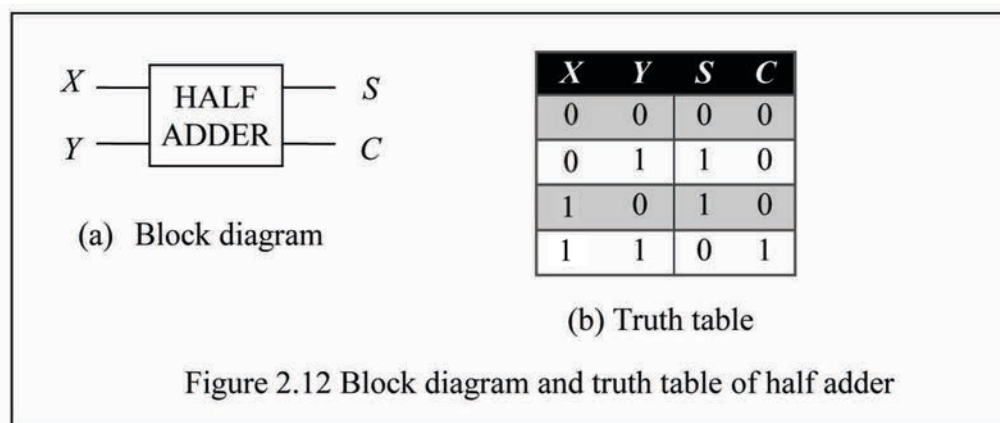
Addition and subtraction are the two most fundamental arithmetic operations performed on binary numbers. Half adder and full adder are basically used to perform addition operation on binary data. Similarly, subtraction operation is often accomplished with the help of half subtractor and full subtractor circuits.

2.2.1.1 Half Adder

A half adder is an arithmetic circuit which performs addition operation on two input bits and produces result as sum and carry in the output. It has two input and two output lines. It is usually



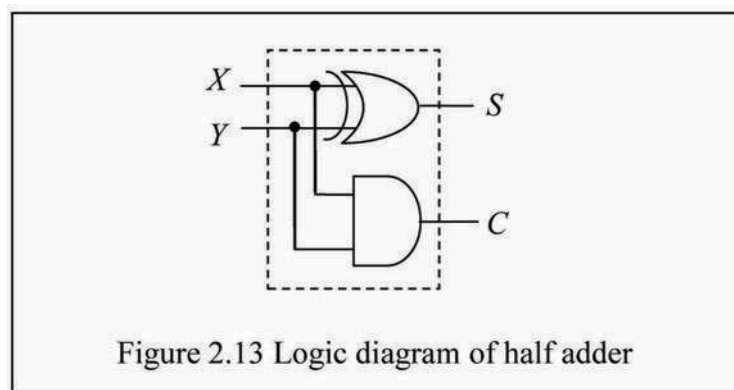
used to add the first column of two binary numbers. The block diagram and truth table of the half adder circuit is shown in Figure 2.12.



From the truth table, the Boolean expression for Sum (*S*) and Carry (*C*) can be written as

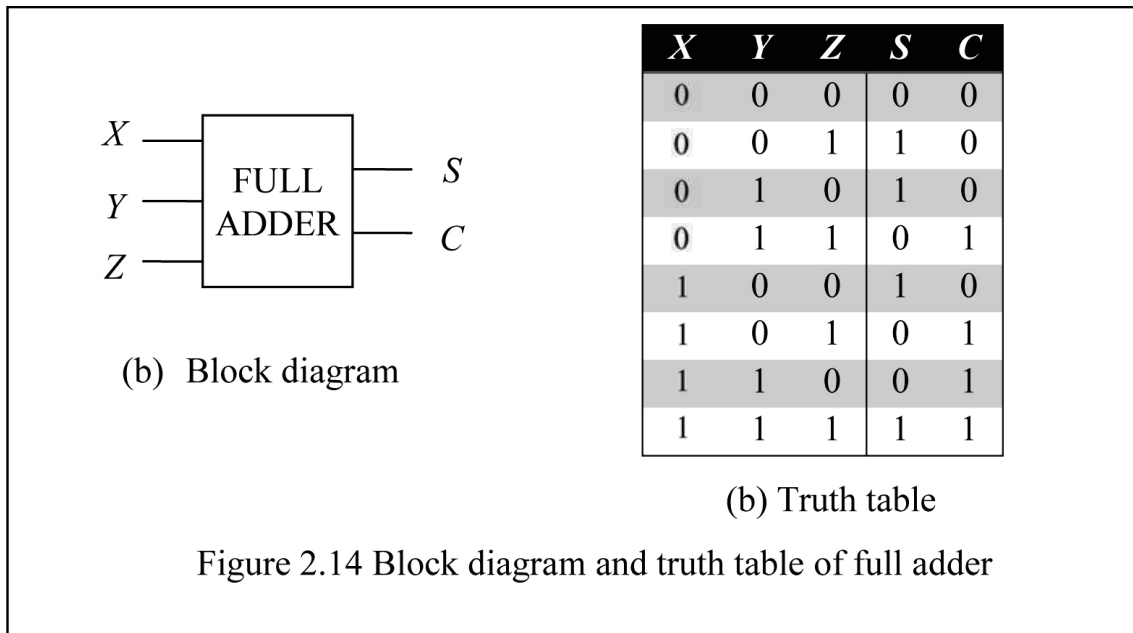
$$S = X \oplus Y ; C = X Y$$

The implementation of the expressions for *S* and *C* using gates give the circuit of half adder as shown in Figure 2.13.



2.2.1.2 Full Adder

A full adder is an arithmetic circuit which performs addition operation on three input bits and produces result as sum and carry. It has three input and two output lines. Unlike, half adder, it can be used for addition of any column of two binary numbers. The block diagram and truth table of the full adder circuit is shown in Figure 2.14.



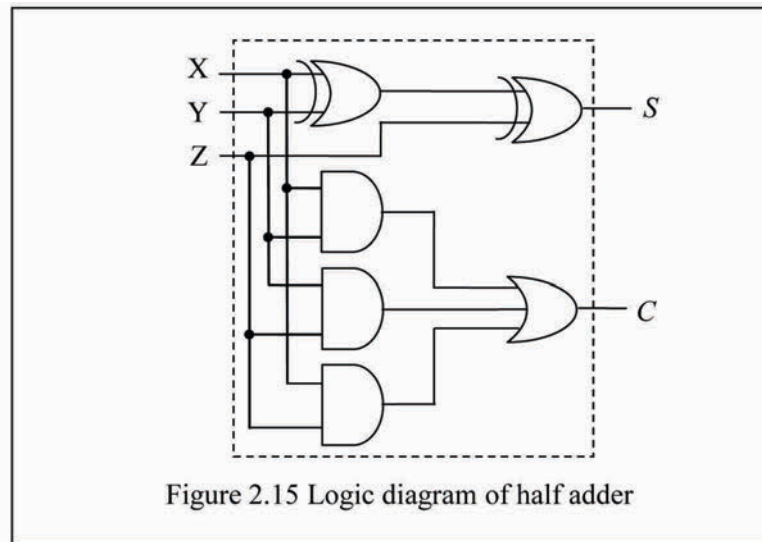
From the truth table, the Boolean expression for S and C can be written as

$$\begin{aligned}
 S &= \bar{X}\bar{Y}Z + \bar{X}Y\bar{Z} + X\bar{Y}\bar{Z} + XYZ \\
 &= (XY + \bar{X}\bar{Y})Z + (\bar{X}Y + X\bar{Y})\bar{Z} \\
 &= (\bar{X}\oplus\bar{Y})Z + (X\oplus Y)\bar{Z} \\
 &= (X\oplus Y) \oplus Z \\
 &= X\oplus Y\oplus Z
 \end{aligned}$$

and

$$\begin{aligned}
 C &= \bar{X}YZ + X\bar{Y}Z + XY\bar{Z} + XYZ \\
 &= XYZ + \bar{X}YZ + XYZ + X\bar{Y}Z + XYZ + XY\bar{Z} \quad (\because A + A + A = A) \\
 &= XY(Z + \bar{Z}) + YZ(X + \bar{X}) + XZ(Y + \bar{Y}) \\
 &= XY + YZ + XZ
 \end{aligned}$$

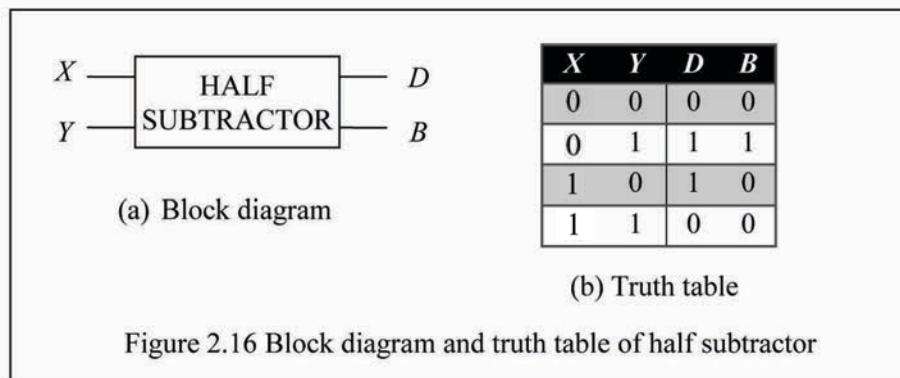
The Implementation of expressions for S and C completes the design of full adder.



Student Activity: Construct a full adder using two half adders. Use gates if required.

2.2.1.3 Half Subtractor

A half subtractor is an arithmetic circuit which performs subtraction operation on two input bits and produces result as difference and borrow in the output. It has two input and two output lines. It is usually used to subtract the first column of two binary numbers. The block diagram and truth table of the half subtractor circuit is shown in Figure 2.16. Treat X as minuend and Y as subtrahend and the subtraction operation is designated by $X - Y$. During subtraction, if a borrow is taken, the output signal, B becomes '1'.



From the truth table, the Boolean expression for D and B can be written as

$$D = X \oplus Y ; B = \bar{X}Y$$

The implementation of the expressions for D and B using gates gives the circuit of half subtractor.

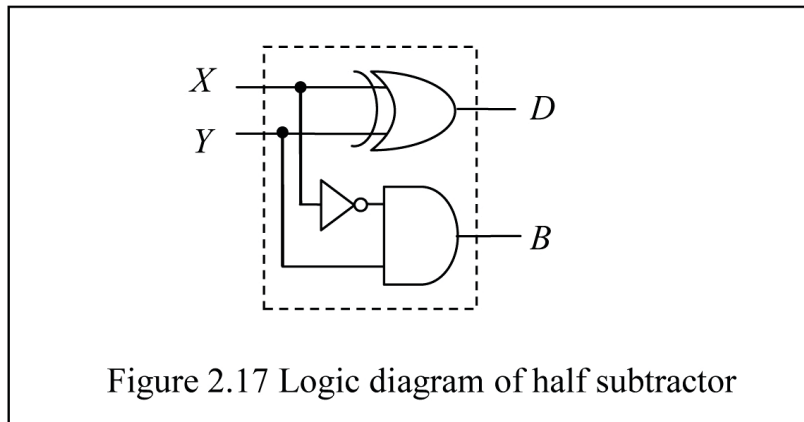


Figure 2.17 Logic diagram of half subtractor

2.2.1.4 Full Subtractor

A full subtractor is an arithmetic circuit which performs subtraction operation between two input bits with consideration that a borrow has been taken by a column lower to it and produces result as difference and borrow. It has three input and two output lines. Unlike, half subtractor, it can be used for subtraction of any column of two binary numbers. The block diagram and truth table of the full subtractor circuit is shown in Figure 2.18. Treat X as minuend, Y as subtrahend and Z as previous borrow. The subtraction operation is designated by $X - Y - Z$.

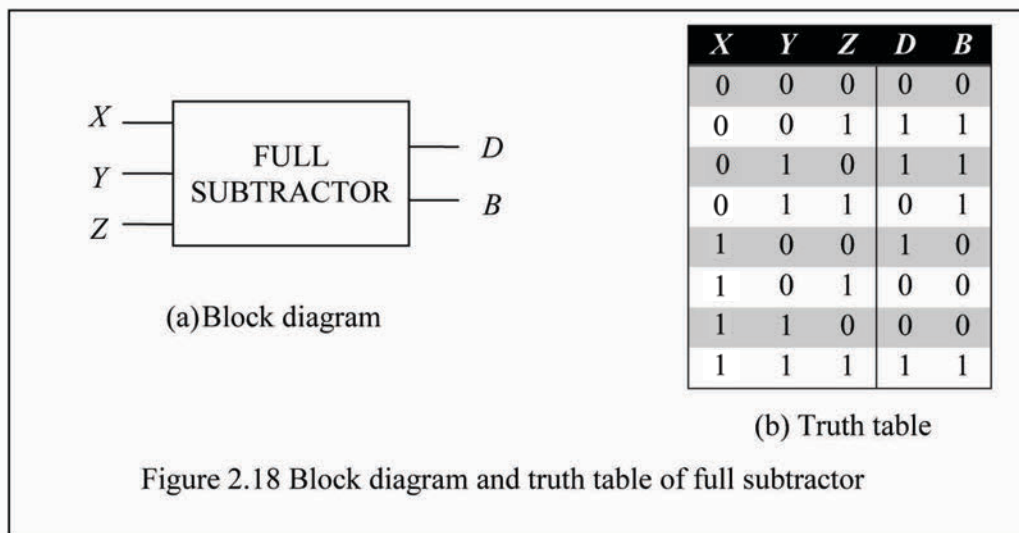


Figure 2.18 Block diagram and truth table of full subtractor

From the truth table, the Boolean expression for D and B can be written as

$$\begin{aligned}
 D &= \bar{X}\bar{Y}Z + \bar{X}Y\bar{Z} + X\bar{Y}\bar{Z} + XYZ \\
 &= (XY + \bar{X}\bar{Y})Z + (\bar{X}Y + X\bar{Y})\bar{Z} \\
 &= (\bar{X} \oplus \bar{Y})Z + (X \oplus Y)\bar{Z}
 \end{aligned}$$



$$= (X \oplus Y) \oplus Z$$

$$= X \oplus Y \oplus Z$$

and

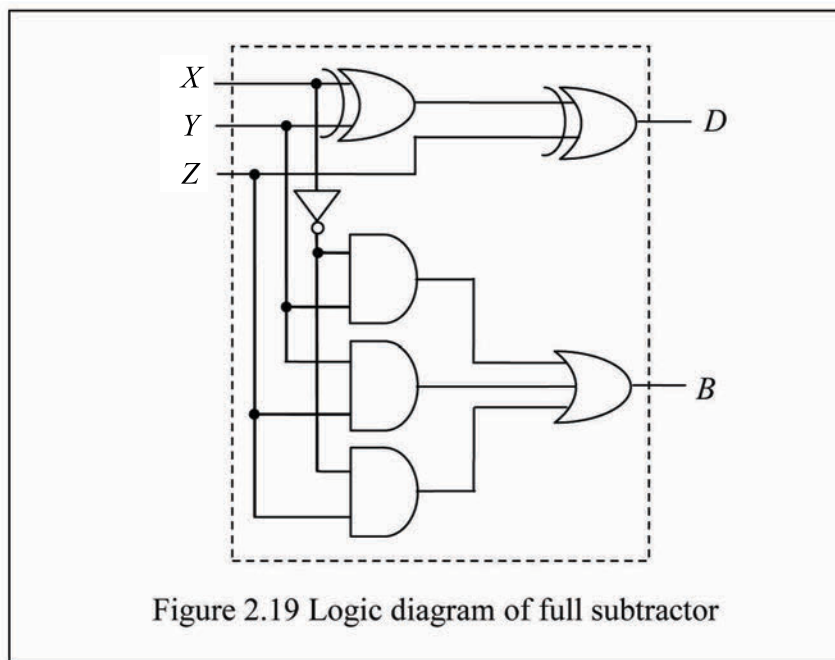
$$B = \bar{X}\bar{Y}Z + \bar{X}Y\bar{Z} + \bar{X}YZ + XYZ$$

$$= \bar{X}YZ + \bar{X}Y\bar{Z} + \bar{X}YZ + \bar{X}Y\bar{Z} + \bar{X}YZ + \bar{X}YZ \quad (\because A + A + A = A)$$

$$= \bar{X}Z(Y + \bar{Y}) + \bar{X}Y(Z + \bar{Z}) + XY(X + \bar{X})$$

$$= \bar{X}Y + YZ + \bar{X}Z$$

The Implementation of expressions for D and B completes the design of full subtractor.



Student Activity: Construct a full subtractor using two half subtractors. Use gates if required.

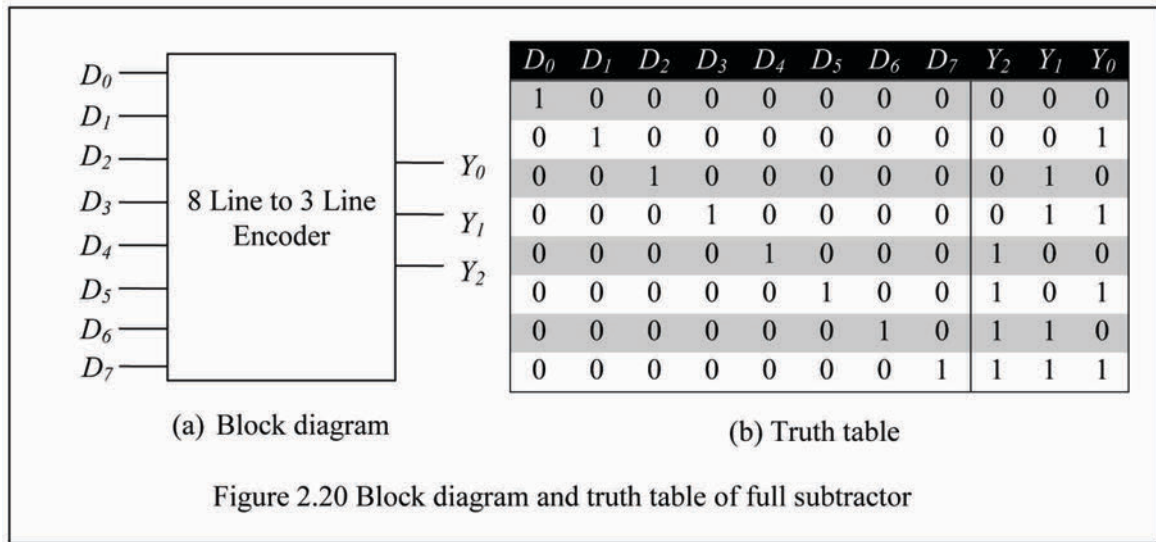
2.2.2 Data Processing Circuits

The combinational circuits that are used to process the binary data in various manners and for different purposes are called data processing circuits. Encoders, decoders, multiplexers, demultiplexers, code converters, comparators etc. are the example of data processing circuits.



2.2.2.1 Encoder

An encoder is a combinational circuit which generates a coded output signal in response to an active input signal. If an encoder has n number of output lines, it can have 2^n or lesser number of input lines. Encoders are typically used to convert a decimal keyboard, like that of a calculator into a binary or BCD output. Figure 2.20 shows the block diagram and truth table of an 8 line to 3 line encoder which is also known as octal to binary encoder.



The Boolean expressions for the encoder can be determined by careful examination of the truth table. Output line Y_2 is at logic '1' when D_4 or D_5 or D_6 or D_7 is at logic '1'. Similarly we can determine the expressions for Y_1 and Y_0 as well and can be written as

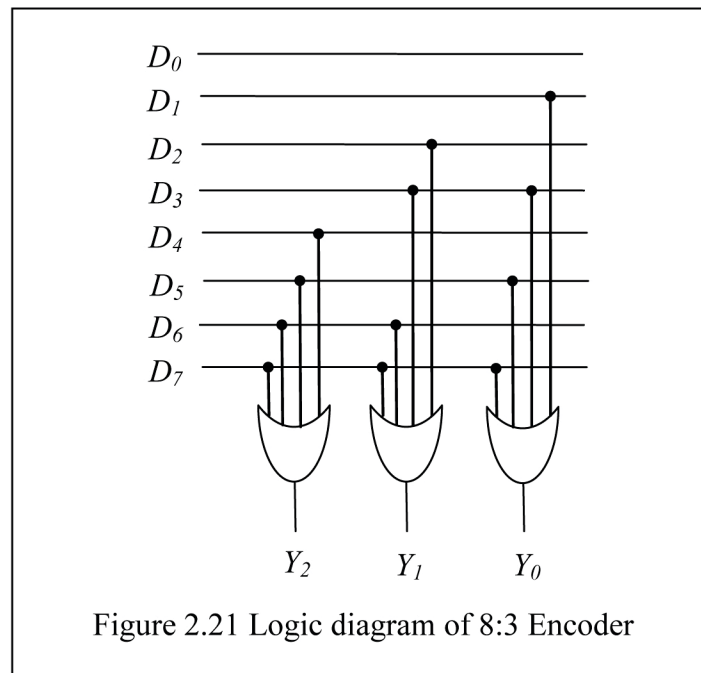
$$Y_2 = D_4 + D_5 + D_6 + D_7$$

$$Y_1 = D_2 + D_3 + D_6 + D_7$$

$$Y_0 = D_1 + D_3 + D_5 + D_7$$

Implementation of expression for Y_2 , Y_1 and Y_0 is shown in Figure 2.20 which basically describes the octal to binary encoder.

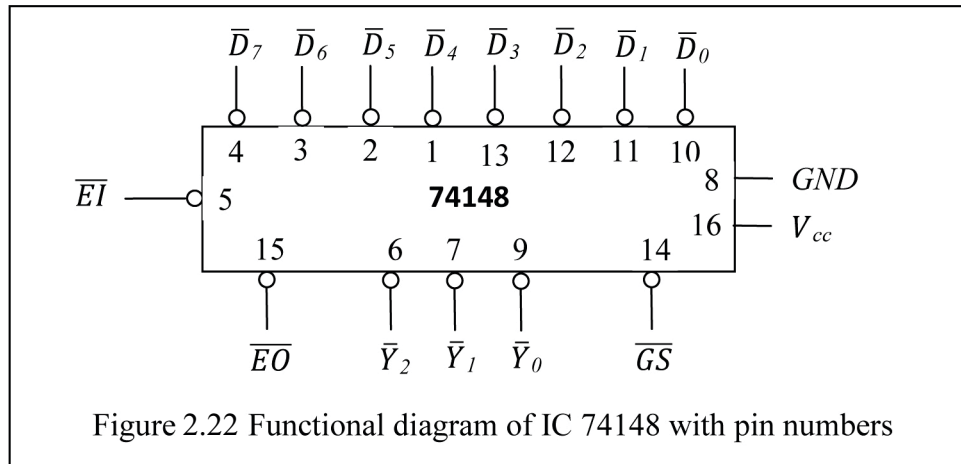
Other popular encoders are 10 line to 4 line encoder (i.e. decimal to BCD encoder) and 16 line to 4 line encoder (i.e. hexadecimal to binary encoder).



Student Activity: Design decimal to BCD and hex to binary encoders.

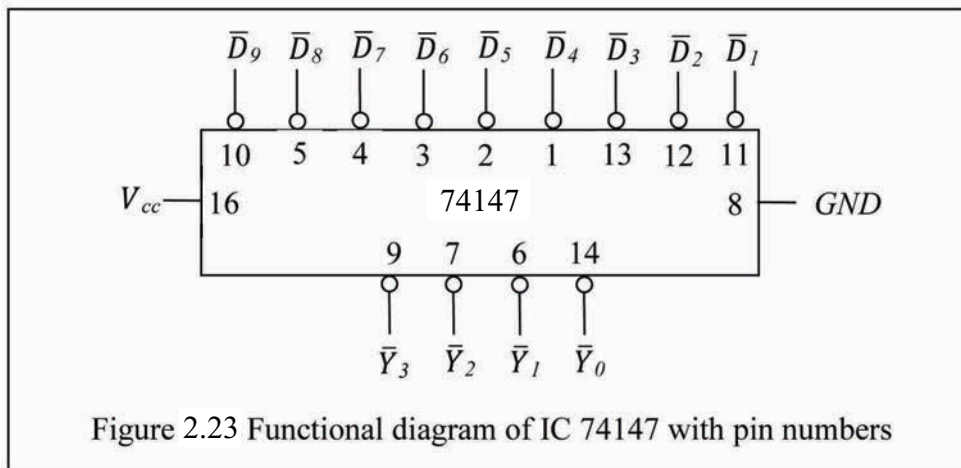
IC 74148: 8 line to 3 line Priority Encoder

The TTL IC 74148 is an 8-input priority encoder accepts data from eight active low inputs (\bar{D}_0 to \bar{D}_7) and provides a binary representation on the three active low outputs (\bar{Y}_0 to \bar{Y}_2). A priority is assigned to each input so that when two or more inputs are simultaneously active, the input with the highest priority is represented on the output, with input \bar{D}_7 having the highest priority. The active low Enable Input (\bar{EI}) is kept at logic '0' for normal operation of the encoder. The Group Signal (\bar{GS}) and Enable Output (\bar{EO}) are two active low output lines provided for additional information like whether any of the input is active (then $\bar{GS} = '0'$) or whether all the inputs are de-active (then $\bar{EO} = '0'$).



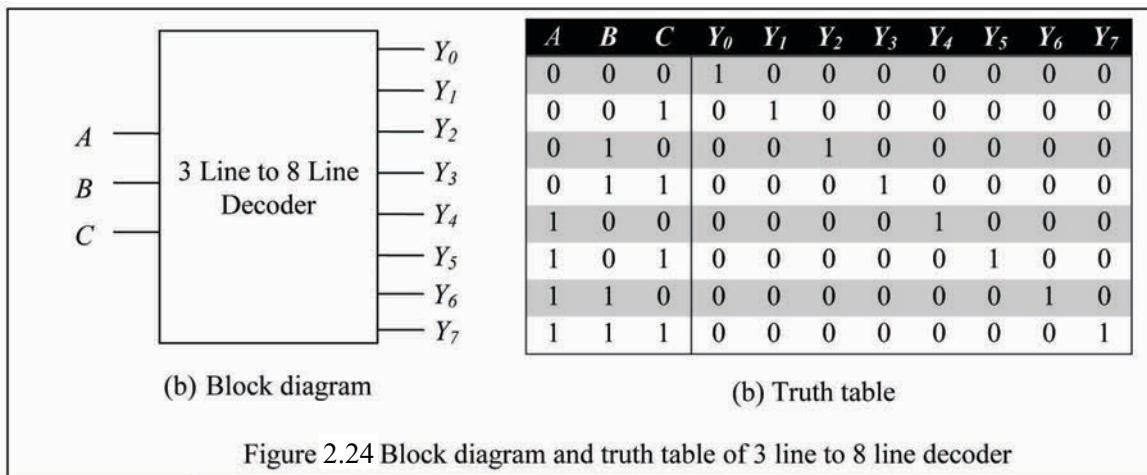
IC 74147: 10 line to 4 line Priority Encoder

The TTL IC 74147 is a decimal to BCD priority encoder. This IC uses 9 out of 10 input lines as the D_0 line is not connected with rest of the circuitry and is shown in Figure 2.21. The inputs are active low (\bar{D}_1 to \bar{D}_9). It has four active low outputs (\bar{Y}_0 to \bar{Y}_3).



2.2.2.2 Decoder

A decoder is a combinational circuit which generates 2^n or lesser unique output lines from coded information received on n -bit input lines. It is used to decode the binary state contained in a piece of coded information. Decoders can be used in chip select logic of memory ICs, making one of the output line active at a time etc. Figure 2.24 shows the block diagram and truth table of a 3 line to 8 line decoder (also known as binary to octal decoder).

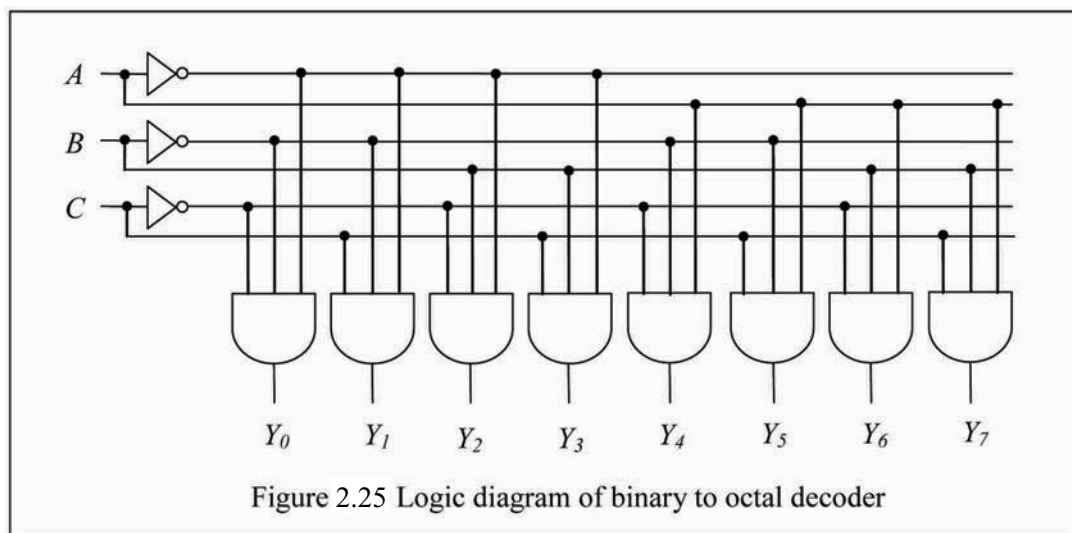


The Boolean expression for each output can be derived from the truth and can be written as

$$Y_0 = \bar{A}\bar{B}\bar{C} \quad Y_2 = \bar{A}B\bar{C} \quad Y_4 = A\bar{B}\bar{C} \quad Y_6 = A\bar{B}C$$

$$Y_1 = \bar{A}B C \quad Y_3 = A\bar{B}C \quad Y_5 = A\bar{B}\bar{C} \quad Y_7 = ABC$$

In order to implement the above expressions, we need the hardware shown in Figure 2.25 and is termed as binary to octal decoder.

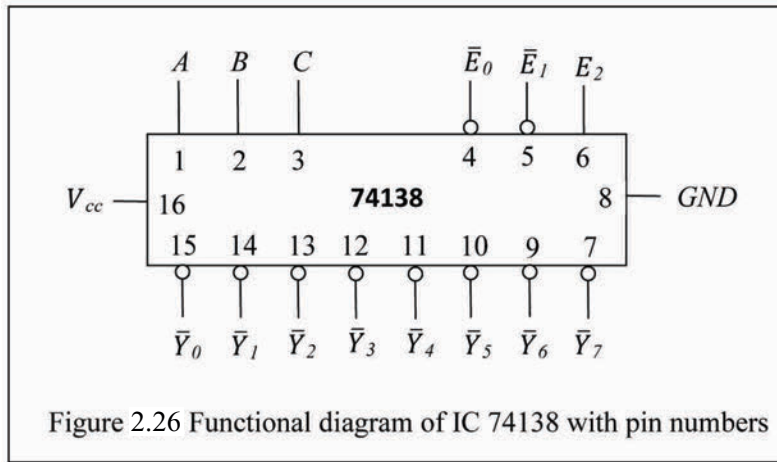


Student Activity: Design BCD to decimal and binary to hex decoder.



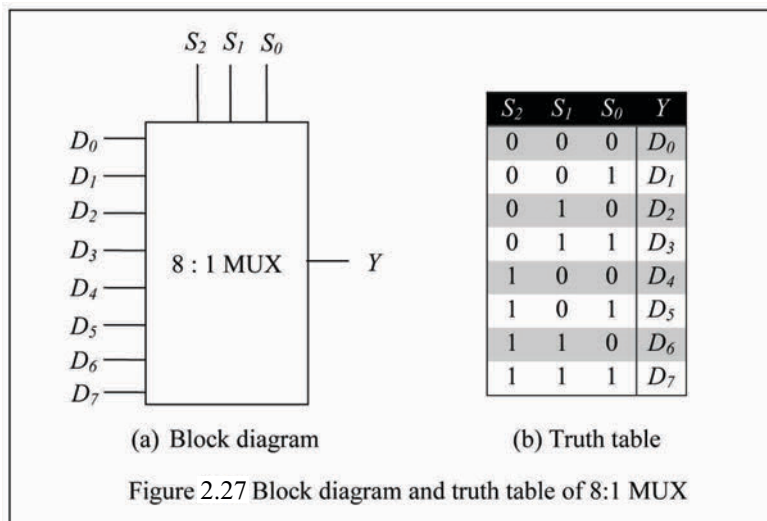
IC 74138: 3 line to 8 line Decoder

Medium Scale Integration (MSI) TTL IC 74138 is often used to perform the operation of a binary to octal decoder. Figure 2.26 shows its functional diagram with pin numbers. It has eight active low output (\bar{Y}_0 to \bar{Y}_7) i.e. the outputs are in opposite state in comparison with that described in the truth table of Figure 2.26. It has three enable inputs (\bar{E}_0 to E_2) which must be kept in active state for the circuits to function. A, B and C are the inputs to the decoder.



2.2.2.3 Multiplexer (MUX)

A Multiplexer, abbreviated as MUX has many data input lines, few select lines and one output line. If there are n numbers of select lines, the MUX can have 2^n or lesser number of input data lines. A MUX is also known as data selector or data router. It is usually used for many to one conversion. The block diagram and truth of an 8 line to 1 line (or 8:1) MUX is shown in Figure 2.27.

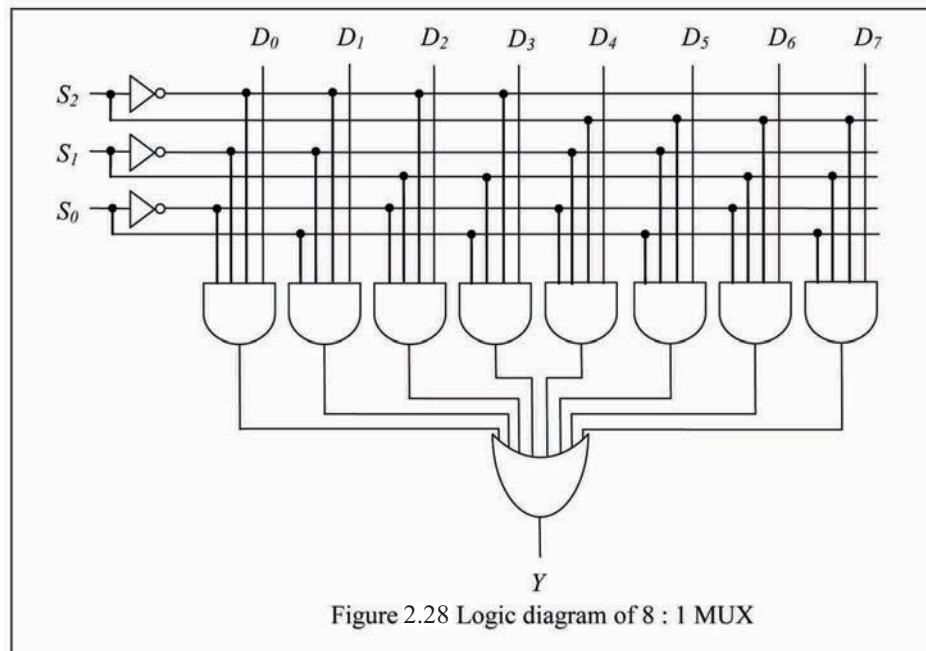




The Boolean expression for the output variable Y can be written as

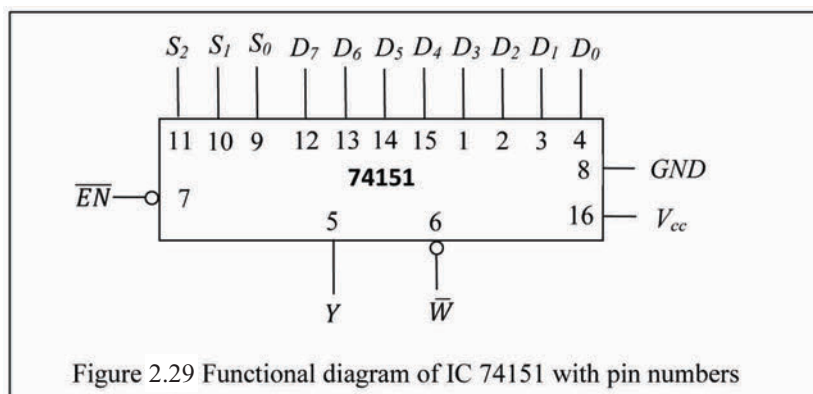
$$Y = D_0\bar{S}_2\bar{S}_1\bar{S}_0 + D_1\bar{S}_2\bar{S}_1S_0 + D_2\bar{S}_2S_1\bar{S}_0 + D_3\bar{S}_2S_1S_0 + D_4S_2\bar{S}_1\bar{S}_0 + D_5S_2\bar{S}_1S_0 + D_6S_2S_1\bar{S}_0 + D_7S_2S_1S_0$$

When this expression is implemented by digital logic gates we get structure as shown in Figure 2.28.



IC 74151: 8 line to 1 line Multiplexer

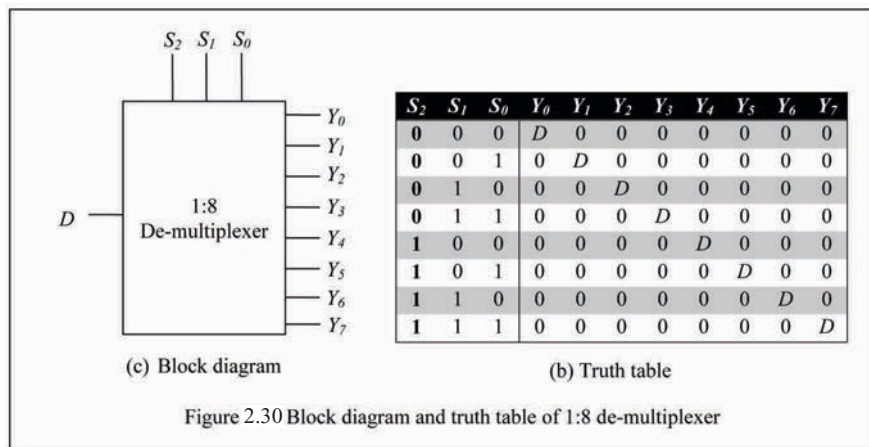
The MSI TTL IC 74151 is the off-the-shelf available 8:1 MUX with active low Strobe (\overline{EN}) input. Figure 2.29 shows its functional diagram with pin numbers. It has eight data inputs (D_0 to D_7), three select inputs (S_1 to S_0). The circuit has two output, one is active high (Y) and the other is active low \overline{W} .





2.2.2.4 De-multiplexer (DEMUX)

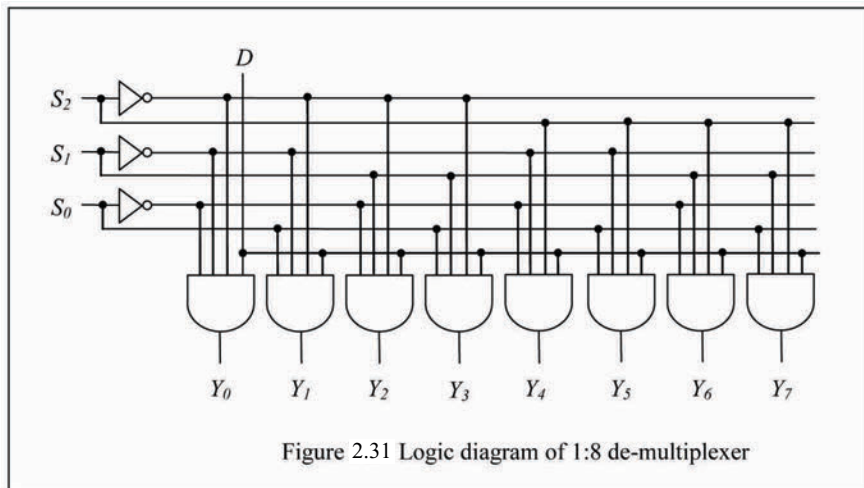
A de-multiplexer (DEMUX) is a combinational logic circuit, which has one data input line, few select lines and many output lines. If there are n numbers of select lines, the de-multiplexer can have 2^n or lesser number of output lines. A de-multiplexer is also known as data distributor and performs the inverse function of that of a multiplexer. By applying appropriate value on the select line, the input signal can be steered into one of the output lines. It is usually used for one to many conversion. The block diagram and truth of a simple 1 line to 8 line (or 1:8) de-multiplexer is shown in Figure 2.30.



The Boolean expression for the four output line can be written from the truth table as follows:

$$\begin{aligned}
 Y_0 &= \bar{S}_2 \bar{S}_1 \bar{S}_0 D & Y_2 &= \bar{S}_2 S_1 \bar{S}_0 D & Y_4 &= S_2 \bar{S}_1 \bar{S}_0 D & Y_6 &= S_2 S_1 \bar{S}_0 D \\
 Y_1 &= \bar{S}_2 \bar{S}_1 S_0 D & Y_3 &= \bar{S}_2 S_1 S_0 D & Y_5 &= S_2 \bar{S}_1 S_0 D & Y_7 &= S_2 S_1 S_0 D
 \end{aligned}$$

Implementation of the above expression using logic gates depicts the hardware required for 1:8 de-multiplexer and is shown in Figure 2.31.





IC 74138: 1 line to 8 line De-multiplexer

In addition to its use as 3:8 decoder, IC 74138 can also be used as 1:8 de-multiplexer. The third enable input (E_2) is to be used as data input leaving the E_0 and E_1 as enable inputs. It is obvious that the DEMUX has active low outputs.

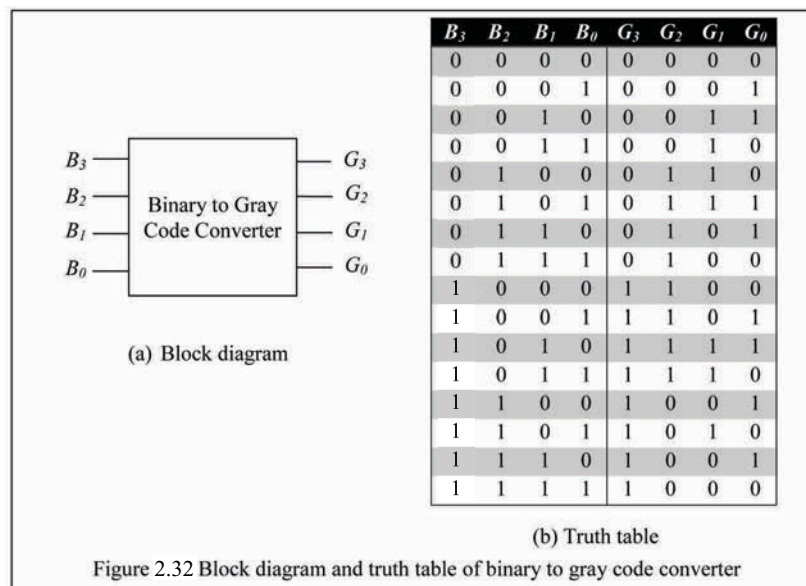
2.2.2.5 Code Converters

Various types of binary codes are used in digital systems. Some of these codes are Binary Coded Decimal (BCD), Excess-3, Gray code etc. Often, we need to convert these codes from one to the other. To accomplish this task, we require code converters. Some of the popular code converter circuits are:

- Binary to Gray Code Converter
- Gray to Binary Converter
- Binary to BCD Converter
- BCD to Binary Converter
- BCD to Excess-3 Converter
- Excess-3 to BCD converter etc.

2.2.2.5.1 Binary to Gray Code Converter

This type of converter is responsible to convert a four bit binary word into four bit equivalent gray code word. Accordingly it has four inputs and four outputs. The block diagram and truth table of binary to gray code converter is shown in Figure 2.32.

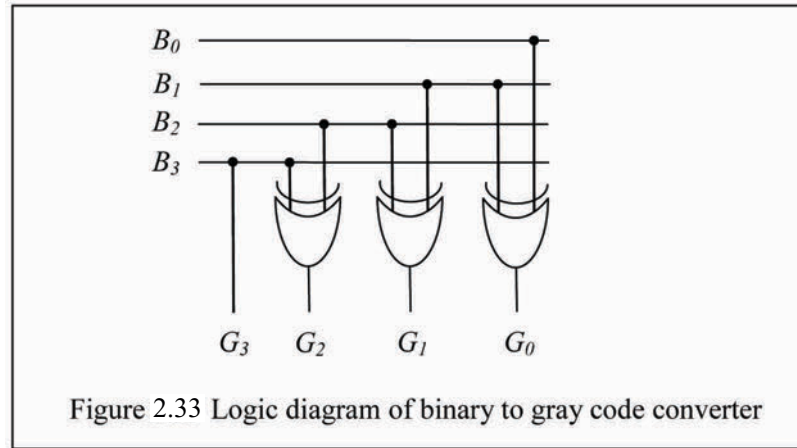




The Boolean expression for the outputs of the converter can be obtained from the truth table using K-map as follows:

$$G_3 = B_3; \quad G_2 = B_3 \oplus B_2; \quad G_1 = B_2 \oplus B_1; \quad G_0 = B_1 \oplus \bar{B}_0$$

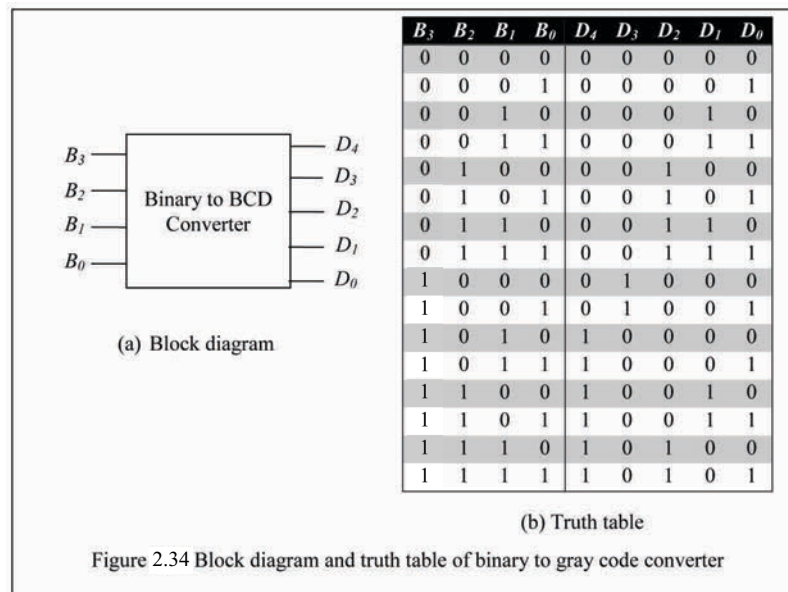
The logic diagram of binary to gray code converter is shown in Figure 2.33.



Student Activity: Design gray code to binary converter.

2.2.2.5.2 Binary to BCD Converter

The Binary Coded Decimal (BCD) is a 4-bit straight representation of decimal numbers in the form of '1' and '0'. A 4 bit binary number is represented by a BCD number with 5-bit width. The block diagram and truth table of binary to BCD converter is shown in Figure 2.34.



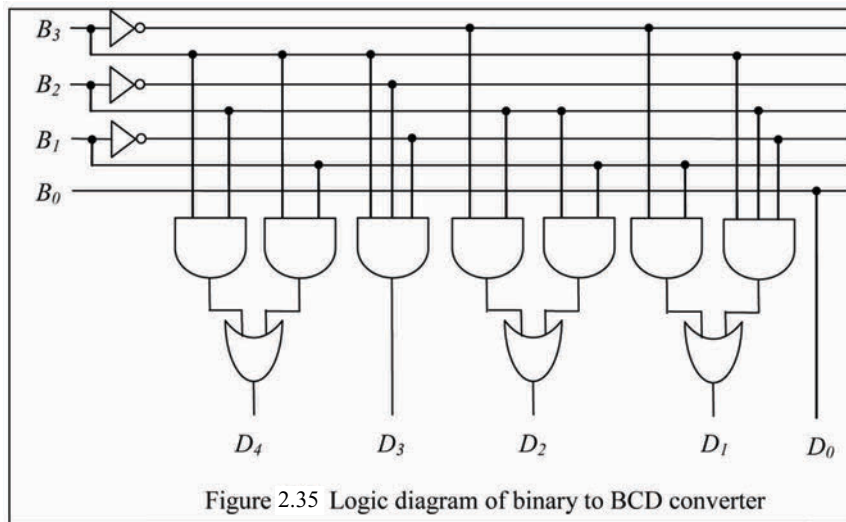


The Boolean expression for the outputs of the converter can be obtained from the truth table using K-map as follows:

$$D_4 = B_3B_2 + B_3B_1 \quad D_2 = \bar{B}_3B_2 + B_2B_1 \quad D_0 = B_0$$

$$D_3 = B_3\bar{B}_2\bar{B}_1 \quad D_1 = \bar{B}_3B_1 + B_3B_2\bar{B}_1$$

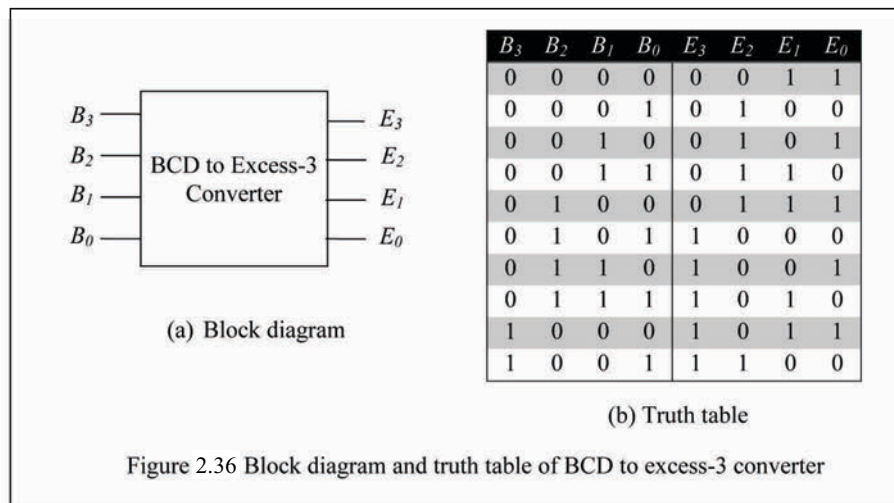
The logic diagram of the binary to gray code converter is shown in Figure 2.35.



Student Activity: Design BCD to binary converter.

2.2.2.5.3 BCD to Excess-3 Converter

Excess-3 code is obtained by adding 3 to BCD code. The logic circuit used to convert a code from BCD to excess-3 has four inputs and four outputs. The block diagram and truth table of binary to BCD converter is shown in Figure 2.36.



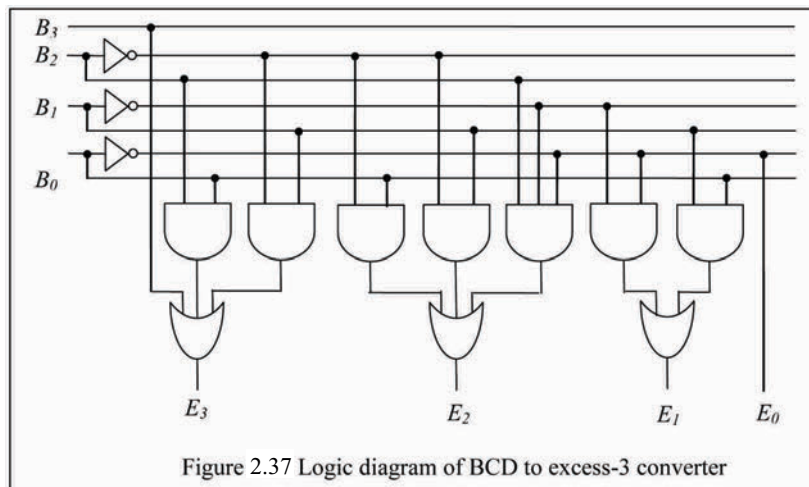


The Boolean expression for the outputs of the converter can be obtained from the truth table using K-map as follows:

$$E_3 = B_3 + B_2B_0 + B_2B_1 \qquad E_1 = \overline{B_1}\overline{B_0} + B_1B_0$$

$$E_2 = \overline{B_2}B_0 + \overline{B_2}B_1 + B_2\overline{B_1}\overline{B_0} \qquad E_0 = \overline{B_0}$$

The logic diagram of the binary to gray code converter is shown in Figure 2.37.



Student Activity: Design excess-3 to BCD converter.

2.2.2.6 Comparator

A comparator or magnitude comparator is a combinational logic circuit which compares two binary numbers, e.g. A and B, and produces result as $A > B$, $A = B$ or $A < B$ in the output. Let A and B are the two bit binary numbers and is represented as

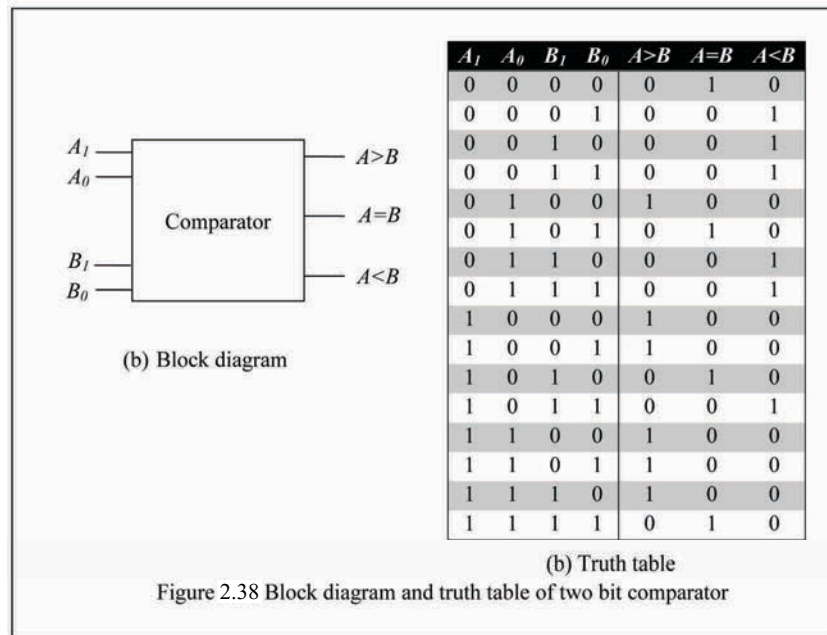
$$A = A_1A_0$$

$$B = B_1B_0$$

The procedure used for comparing the above two numbers is as follows:

- If $A_1 > B_1$ then we conclude that $A > B$
- If $A_1 < B_1$ then we conclude that $A < B$
- If $A_1 = B_1$ and $A_0 > B_0$ then we conclude that $A > B$
- If $A_1 = B_1$ and $A_0 < B_0$ then we conclude that $A < B$
- If $A_1 = B_1$ and $A_0 = B_0$ then we conclude that $A = B$

Figure 2.38 shows the block diagram and truth table of a two bit comparator.



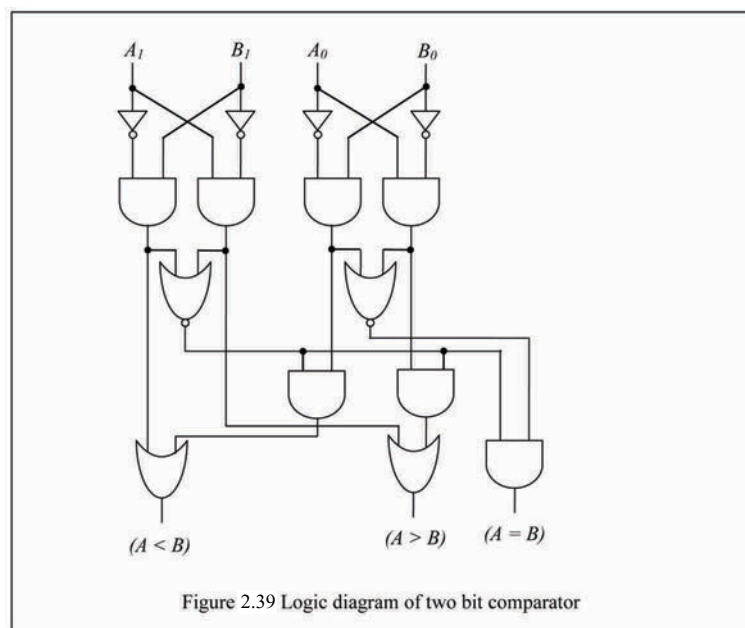
The Boolean expression for the outputs of the comparator can be obtained from the truth table using K-map as follows:

$$(A > B) = A_1 \bar{B}_1 + A_0 \bar{B}_0 (A_1 B_1 + \bar{A}_1 \bar{B}_1)$$

$$(A = B) = (A_1 B_1 + \bar{A}_1 \bar{B}_1) (A_0 B_0 + \bar{A}_0 \bar{B}_0)$$

$$(A < B) = \bar{A}_1 B_1 + \bar{A}_0 B_0 (A_1 B_1 + \bar{A}_1 \bar{B}_1)$$

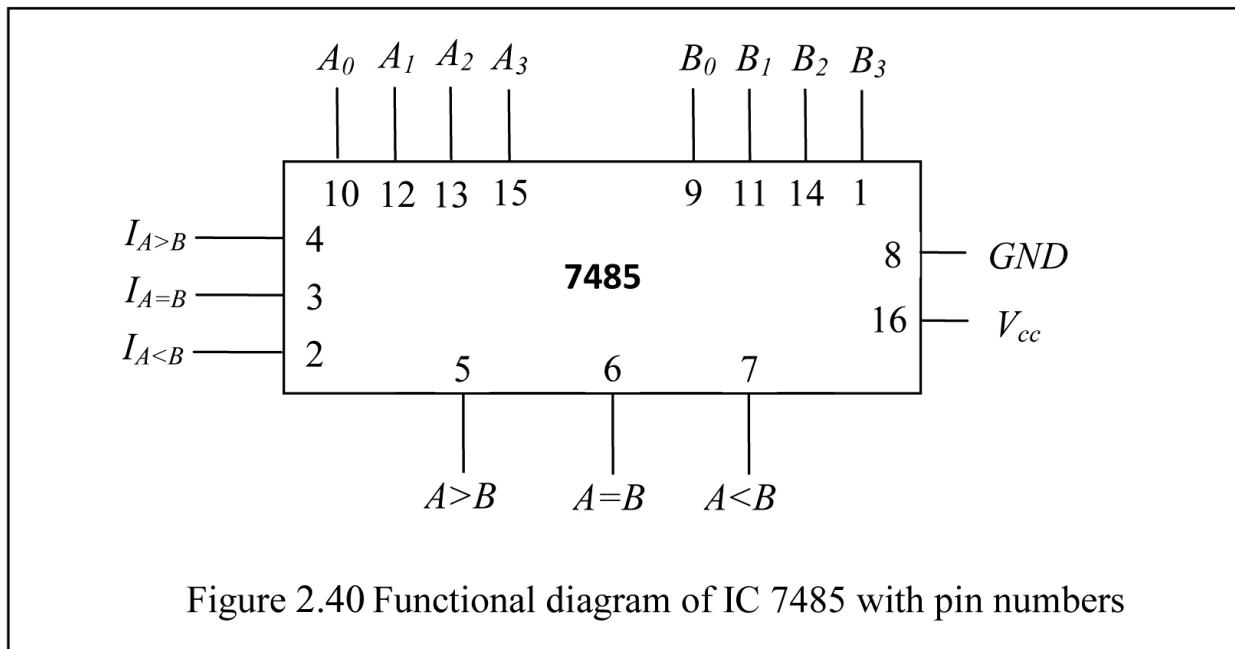
The logic diagram of the two bit comparator is shown in Figure 2.39.





IC 7485: 4 - bit Magnitude Comparator

The TTL IC 7485 compares two 4-bit binary, or BCD numbers, and presents the three possible magnitude results at the outputs as ($A > B$), ($A = B$) or ($A < B$). The 4-bit inputs are weighted (A_0 to A_3) and (B_0 to B_3) where A_3 and B_3 are the most significant bits. It can be expanded to almost any length using expansion inputs $I_{A>B}$, $I_{A<B}$ and $I_{A=B}$. Figure 2.40 shows the functional diagram with pin numbers.



2.3 SUMMARY

This unit introduces types of logic in the beginning. It describes the various types of logic gates used in digital electronics with their symbol, Boolean expression and truth table. Combinational digital circuits are classified into two broad categories: arithmetic and data processing. Design procedure of half adder, full adder, half subtractor and full subtractor are presented. Data processing circuits like encoders, decoders, multiplexers, de-multiplexers, code converters, and comparators have been discussed in respect of their design procedure. Brief idea about some of the off-the-shelf TTL ICs is also given in this unit.

Exercise Questions:

- 1) What do you mean by positive and negative logic?



- 2) Identify the basic gates. Draw symbol, write truth table and Boolean expression for these gates.
- 3) How can you obtain NOR gate from OR and NOT gate?
- 4) Why NAND and NOR gates are called universal gates?
- 5) Identify the logic gate(s) with two inputs whose output is complement of an input when the other is held at logic '0'.
- 6) Design half adder using NAND gate.
- 7) Using NOR gate, design full subtractor.
- 8) What will be the number of select line if a MUX has 10 data input lines?
- 9) Describe the procedure for comparing two three bit numbers.
- 10) Explain why a four bit binary number may require more than four bit BCD representation?



Multiple Choice: Choose the Correct Answer

- 1) Which of the following gates is not a basic gate?
 - a) XOR
 - b) AND
 - c) OR
 - d) NOT
- 2) Identify the universal gate.
 - a) OR
 - b) NAND
 - c) NOT
 - d) AND
- 3) Which of the following gate is represented by the Boolean expression $Y = \overline{\overline{A} + \overline{B}}$
 - a) OR
 - b) XNOR
 - c) AND
 - d) NOR
- 4) Which of the following is equal to the Boolean expression $Y = A + \overline{A}B$
 - a) $A + \overline{A}$
 - b) $A + B$
 - c) AB
 - d) $\overline{A}B$
- 5) When one input is held high, the output becomes inverse of the other input. Identify the gate.
 - a) AND
 - b) OR
 - c) NOT
 - d) XOR
- 6) How many select input lines are required for a 32:1 MUX?
 - a) 16
 - b) 8
 - c) 6
 - d) 5
- 7) What is the number of OR IC?
 - a) 7402
 - b) 7486
 - c) 7432
 - d) 7404



- 8) Combinational circuit has
- | | |
|--------------|--------------|
| a) Memory | b) No memory |
| c) flip-flop | d) counter |
- 9) Identify the gate for which “Y is FALSE only if a is TRUE and b is TRUE” is applicable.
- | | |
|---------|--------|
| a) NAND | b) NOR |
| c) AND | d) OR |
- 10) Two way switch in a corridor is an analogy of which of the following gate?
- | | |
|---------|--------|
| a) NAND | b) NOR |
| c) AND | d) OR |



UNIT - 3

LATCHES AND FLIP FLOPS

3.0 Unit Overview and Description

- Overview
- Knowledge and Skill Outcomes
- Resource Material
- Duration
- Learning Outcomes
- Assessment Plans

3.1 Introduction to Latches, Types of Latches, SR latch.

3.2 Introduction to Flip flops: SR Flip flop, JK Flip flop, D Flip flop, T Flip flop, Flip flop as basic memory.

3.3 Introduction to Counters, Types of Counter: Asynchronous and Synchronous.

3.4 Introduction to shift register, types of shift register, Universal shift register.

3.5 Summary

3.0 UNIT OVERVIEW AND DESCRIPTION

Overview:

This unit starts with the understanding of latches and flip-flop as memory element. It includes description of various types of latches and flip-flops with their graphic symbol, circuit diagrams and truth tables. Working principle and design of S-R, J-K, D and T flip-flops are presented and discussed in detail with the help of suitable figures. This unit describes the working of counters and their types. Difference between synchronous and asynchronous counters is discussed briefly. Brief information about shift registers and their modes of operation is shared including the introductory knowledge about bidirectional and universal shift register.

Knowledge and skill outcomes

- i) Understanding of latches and flip-flops as memory element.
- ii) Difference between latch and flip-flop.



- iii) Knowledge of various types of latches.
- iv) Knowledge about circuit diagram and working principle of S-R latch.
- v) Identification of various types of flip-flops.
- vi) Understanding design procedure, circuit diagram and working principle of S-R, J-K, D and T flip-flop.
- vii) Learn about truth tables of various flip-flops.
- viii) Learn about counters and their types.
- ix) Understanding difference between Asynchronous and synchronous counters.
- x) Understanding of Shift registers and various mode of operation.
- xi) Knowledge about universal shift register.

Resource Materials

1. Digital Logic and Computer Design by M. Morris Mano, Prentice Hall India Publication, New Delhi, 2002.
2. Digital Principles and Applications by A. P. Malvino & D. P. Leach, Tata McGraw-Hill Publication, New Delhi, 1995.
3. Modern Digital Electronics by R. P. Jain, Tata McGraw-Hill Publication, New Delhi, 2010.
4. Digital Electronics by G. K. Kharate, Oxford University Press Publication, New Delhi, 2011.
5. Digital Electronics: Principles and Integrated Circuits by A. K. Maini, Wiley India Publication, New Delhi, 2010.
6. Digital Technology: Principles and Practice by Virendra Kumar, New Age International Publishers, New Delhi, 2002.
7. Digital Circuits and Design by S. Salivahanan & S Arivazhagan, Vikas Publishing, Noida, Uttar Pradesh, 2012

Duration: Total Hours 18

Learning Outcomes:

Unit-3: Latches and Flip-flop	Outcomes
3.1 Introduction to Latches, Types of Latches, SR latch.	(i) Understanding of latches and flip-flops as memory element. (ii) Difference between latch and flip-flop.



	(iii) Knowledge of various types of latches. (iv) Working principle of basic S-R latch.
3.2 Introduction of Flip flops: SR Flip-flop, JK Flip-flop, D Flip-Flop, T Flip-flop, Flip flop as basic memory unit.	(v) Identification various types of flip-flops. (vi) Working principles of S-R, J-K, D and T flip-flops. (vii) Learn about circuit diagram and truth tables of various flip-flops.
3.3 Introduction to Counters, Types of Counter : Asynchronous and Synchronous.	(viii) Learn about counters and their types. (ix) Difference between asynchronous and synchronous counters.
3.4 Introduction to shift registers, types of shift registers, Universal shift register.	(x) Understanding of Shift registers and their mode of operation. (xi) Knowledge about universal shift registers.

Assessment Plan : (For the Teachers)

Unit-3	Topic	Assessment Method	Time Plan	Remarks
3.1	Introduction to Latches, Types of Latches, RS latch	Exercise: Question & Answer		
3.2	Flip-flops: S-R flip-flop, J-K flip-flop, D flip-flop T flip-flop	Exercise: Question & Answer		
3.3	Introduction to Counters, Types of Counter: Asynchronous and Synchronous	Exercise: Question & Answer		
3.4	Introduction to shift registers, types of shift registers, Universal shift register	Exercise: Question & Answer		



3.1 LATCHES

Latches are the memory elements used to store information. One latch can store one bit of information either '1' or '0'. It is called a 'latch' because it can lock or latch one bit of information. Latch is also known as bistable element.

A bistable element is the simplest storage element which is constructed with two inverters connected sequentially in a loop as shown in figure 3.1. The circuit has two outputs Q and \bar{Q} but no input.

Let us assume that initially $Q = 1$. Q being the input to the bottom inverter makes the output of bottom inverter $\bar{Q} = 0$. This '0' in input to top inverter and gives the output as '1'. Therefore $Q = 1$ and $\bar{Q} = 0$ is a stable state of the element.

Similarly, if we assume $Q = 0$, we get that $Q = 0$ and $\bar{Q} = 1$ is also the stable state. Therefore, we can say this element has two stable states $Q = 1, \bar{Q} = 0$ and $Q = 0, \bar{Q} = 1$.

As discussed, if the circuit is in '1' or '0' state, it remains latched or locked in the same stable state. This shows that a latch can store one bit of information.

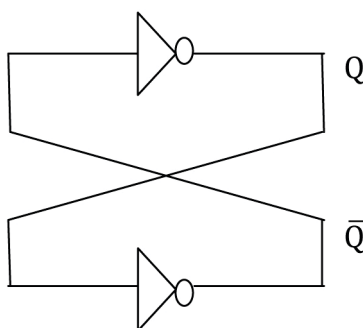


Figure 3.1: Basic Latch: Cross coupled inverters

3.1.1 Types of Latches:

There are four types of latches namely S-R, J-K, T and D latch. Design and working principle of basic S-R latch with the help of NOR gate is discussed in detail in section 3.1.2.

3.1.2 SR Latch (SET-RESET Latch):

The S-R latch requires two inputs S and R and provides two outputs Q and \bar{Q} . The two outputs Q and \bar{Q} are complementary to each other. S and R denote Set and Reset condition respectively. The S-R latch can be constructed using NOR gates or NAND gates. Circuit diagram and block diagram of NOR based S-R latch is shown below in figure 3.2. Truth table of NOR based S-R latch is given in table 3.1

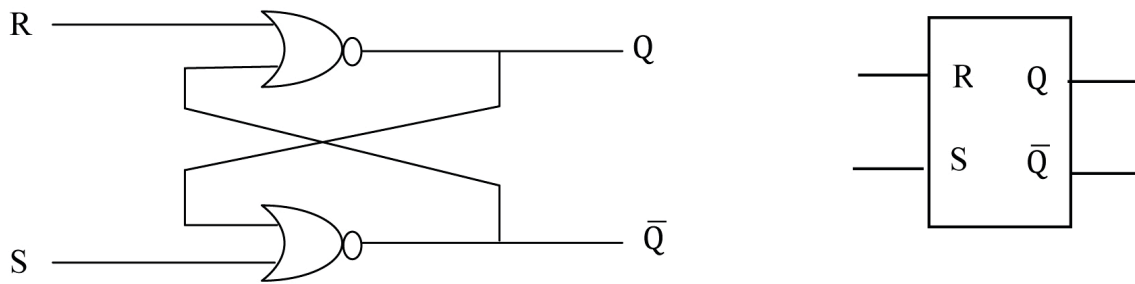


Figure 3.2 a) Circuit Diagram

b) Block Diagram

Table 3.1 Truth Table of NOR based S-R latch

Inputs		Outputs		Action
S	R	Q_{n+1}	\bar{Q}_{n+1}	
0	0	Q_n	\bar{Q}_{n+1}	No Change
0	1	0	1	Reset
1	0	1	0	Set
1	1	?	?	Forbidden

Four possible input combinations exist for S-R latch and Output behavior is described below for each input:

1. When $S = 0, R = 0$: the latch remains in its present state. The next state of the latch Q_{n+1} remains the same as its present state Q_n .
2. When $S = 0, R = 1$: The '1' at the reset input (R) forces the output Q_n to become '0' and \bar{Q}_{n+1} to become '1'. It is known as 'reset' state.
3. When $S = 1, R = 0$: The '1' at set input (S) forces the output \bar{Q}_{n+1} to become '0' and Q_{n+1} to become '1'. It is known as 'set' state.
4. When $S = 1, R = 1$: It will produce '0' at both the outputs i.e. $Q_{n+1} = 0$ and $\bar{Q}_{n+1} = 0$. This contradicts the fact that Q_{n+1} and \bar{Q}_{n+1} are complimentary to each other. Normally this condition is avoided. It is known as 'forbidden' state.

Student Activity: Realize S - R latch using NAND gates.



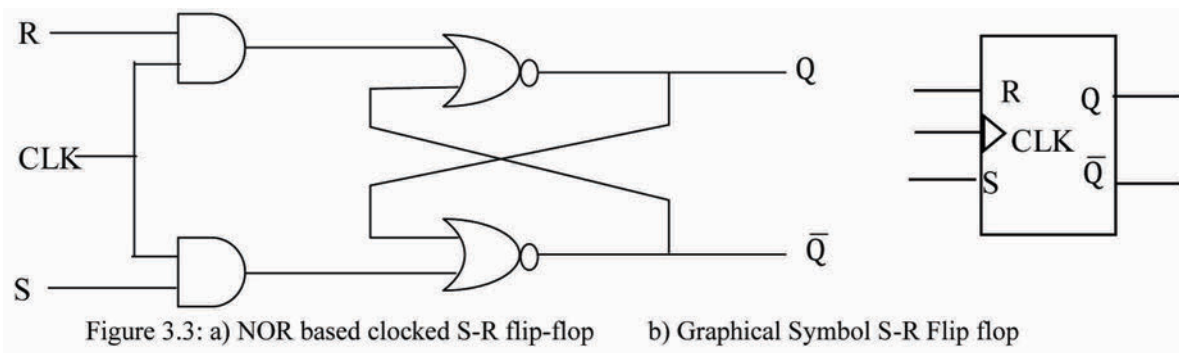
3.2 FLIP FLOPS

The latch with additional control input is known as flip-flop. This control input is either the clock or enable input. Flip-flops are synchronous circuits which change their state when clock pulse is applied.

3.2.1 Types of Flip-flops:

There are four basic types namely S-R, J-K, D and T flip-flops.

3.2.1.1 S-R Flip flop: S-R flip flop consists of two additional AND gate at the S and R input of S-R latch as shown in figure.



In this circuit when clock is low, the output of both the AND gate is low '0'. In this case the output Q of the flip flop will not change. When clock becomes high, the values at S and R input will be passed to the output of respective AND gates and the final output of the flip-flop will change according to the changes in S and R input.

The realization of S-R flip flop with basic NAND latch and two other NAND gates is shown in figure 3.3 c.

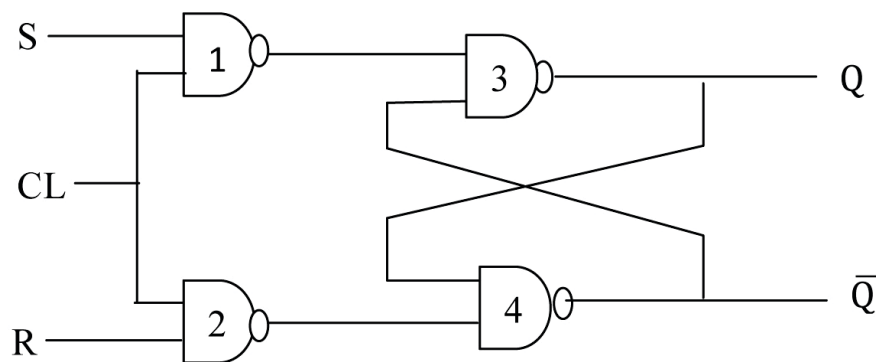


Figure 3.3 : c) NAND based clocked S-R flip-flop



Output behavior for various input combination is described for S-R flip-flop :

1. When $S = 0$, $R = 0$ and $CLK = 0$, the flip-flop remains in its present state i.e. Q_n remains unchanged. Even for $S = 0$, $R = 0$ and $CLK = 1$, the flip-flop remains in its present state i.e. $Q_{n+1} = Q_n$.
2. When $S = 0$, $R = 1$ and $CLK = 0$, the flip-flop remains in its present state. But when $CLK = 1$, the output Q becomes 0. Thus for $S = 0$, $R = 1$ and $CLK = 1$, the flip-flop RESETS to the 0 state.
3. When $S = 1$, $R = 0$ and $CLK = 0$, the flip-flop remains in its present state. But when $CLK = 1$, the output Q becomes 1. Thus for $S = 1$, $R = 0$ and $CLK = 1$, the flip-flop SETS to the 1 state.
4. When all the inputs S , R and CLK are equal to 1, an indeterminate state arises and both the output Q and \bar{Q} becomes equal to 1. This state is known as forbidden state.

The truth table of S-R flip flop is shown in table Table 3.2.

Table 3.2 Truth table of S-R flip-flop

Clock Input CLK	Input S	Input R	Present State Q_n	Next State Q_{n+1}	Action
0	0	0	0	0	No Change
0	0	0	1	1	No Change
0	0	1	0	0	No Change
0	0	1	1	1	No change
0	1	0	0	0	No Change
0	1	0	1	1	No change
0	1	1	0	0	No Change
0	1	1	1	1	No change
1	0	0	0	0	No Change
1	0	0	1	1	No change

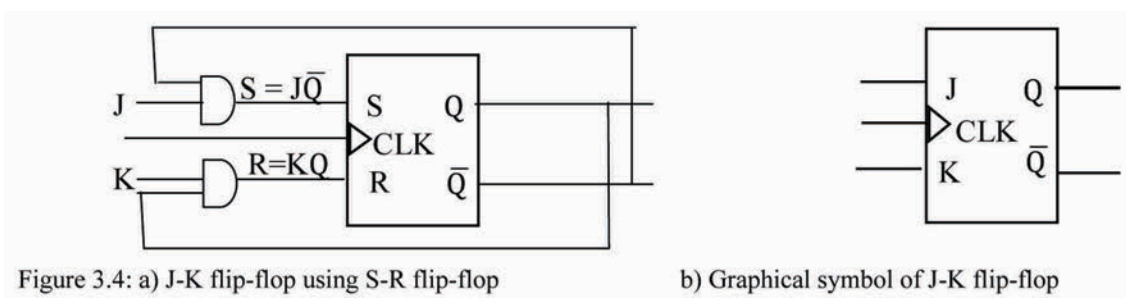


1	0	1	0	0	Reset
1	0	1	1	0	Reset
1	1	0	0	1	Set
1	1	0	1	1	Set
1	1	1	0	?	Forbidden
1	1	1	1	?	Forbidden

Student Activity: Draw the truth - table for NOR based S - R flip flop.

3.2.1.2 J-K Flip-flop:

A J-K flip-flop can be constructed from the clocked S-R flip-flop by adding two AND gate as shown in figure 3.4. The input $J\bar{Q}$ is applied to input S and KQ is applied to input R of S-R flip-flop. The graphic symbol of J-K flip-flop is shown in figure 3.4 b.



The working of J-K flip-flop is described below:

1. When J and K both are 0, the input of the basic S-R flip-flop are $S = 0$ and $R = 0$. Under this condition the flip-flop remains in the same state i.e. Q_n .
2. When $J = 0$ and $K = 1$ and if S-R flip-flop is in SET state i.e. $Q_n = 1$ and $\bar{Q}_n = 0$. The J-K flip-flop resets on the application of clock pulse i.e. $Q_n = 0$ and $\bar{Q}_n = 1$. If the previous state of S-R flip-flop is already RESET i.e. $Q_n = 0$ and $\bar{Q}_n = 1$, In this case flip-flop will remain in the same state.



3. When $J = 1$ and $K = 0$ and if the previous state of S-R flip-flop is SET $Q_n = 1$ and $\bar{Q}_n = 0$, the output of J-K flip-flop will be in SET state on application of clock pulse. If the previous state of S-R flip-flop is RESET i.e. $Q_n = 0$ and $\bar{Q}_n = 1$, the output of J-K flip-flop will also remain in SET condition.
4. The condition $J = 1, K = 1$ need to be discussed carefully. When $J = 1, K = 1$, and previous state is a SET state i.e. $Q_n = 1$ and $\bar{Q}_n = 0$, then $S = J \cdot \bar{Q}_n = 0$ and $R = K \cdot Q_n = 1$. Since $S = 0$ and $R = 1$, this resets the flip-flop on the application of a clock pulse i.e. flip-flop toggles from SET to RESET state. Toggle means to switch to the opposite state.

Similarly when $J = 1, K = 1$, if the previous state is a RESET state, flip-flop toggles from RESET to SET state on the application of a clock pulse. Hence when $J = 1, K = 1$ flip-flop toggles on application of next clock pulse.

The characteristic equation of J-K flip-flop is $Q_{n+1} = J \cdot \bar{Q}_n + K \cdot Q_n$

The truth table of J-K flip-flop is shown in table 3.3.

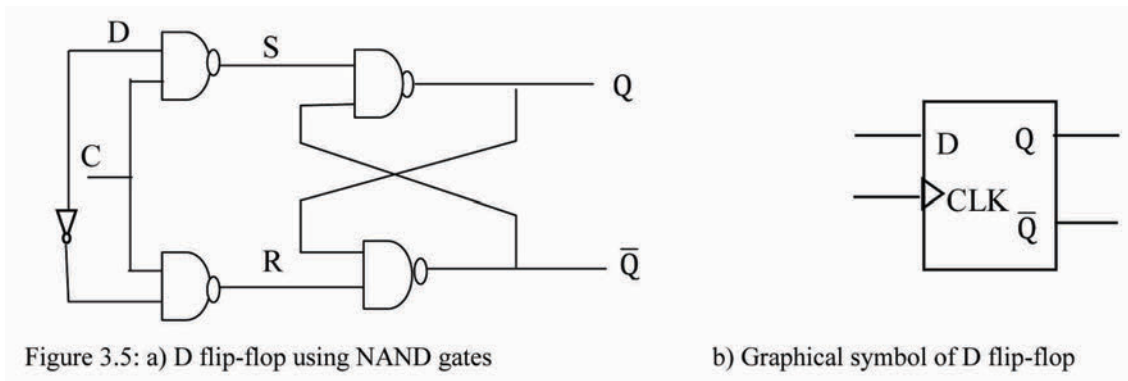
Table 3.3 Truth table of J K Flip-flop

CLK	Input		Output	Action
	J	K		
X	0	0	Q_n	No Change
1	0	1	0	Reset
1	1	0	1	Set
1	1	1	\bar{Q}_n	Toggle

Student Activity: Learn the race around condition and master - slave J - K flip-flop.

3.2.1.3 D Flip-Flop:

The D (delay) flip-flop has only one input and two outputs Q and \bar{Q} . It can be constructed from an S-R flip-flop using an inverter between S and R inputs and assigning the symbol D to S input. Circuit diagram using NAND gates and graphic symbol have been shown at figure 3.5.



The truth table of D flip-flop is shown in table 3.4

Table 3.4 : Truth table of D flip flop

Delay input D	Present State Q_n	Next State Q_{n+1}
0	0	0
1	0	1
0	1	0
1	1	1

The characteristic equation of D flip-flop is $Q_{n+1} = D$

Student Activity: Find out the applications of D flip - flop.

3.2.1.4 T Flip-Flop:

T flip-flop is known as toggle flip-flop. It has only one data input T, a clock input and two output Q and \bar{Q} . The T-type flip-flop can be realized from a J-K flip-flop by connecting its J and K inputs together.



Figure: 3. 6a) Block Diagram of T flip-flop b) T flip-flop using a J-K flip-flop



When $T = 0$, then $Q_{n+1} = Q_n$, i.e. the flip-flop remains in the same state. When $T = 1$, then $Q_{n+1} = \bar{Q}_n$, i.e. the flip-flop toggles.

The characteristic equation of T flip-flop is : $Q_{n+1} = T\bar{Q}_n + TQ_n$.

Table 3.5 shows the truth table of T flip-flop.

Input T	Present State Q_n	Next State Q_{n+1}
0	0	0
1	0	1
0	1	1
1	1	0

Student Activity: Realize T flip flop using S - R flip-flop.

3.3 COUNTERS

Counter is a special sequential circuit which is used to count the clock pulse. Counter circuit possess memory because it has to remember its past states. Flip-flops are used to design the counter circuit. Number of states of a counter depends upon the number of flip-flops used in the circuit and sequence of states depends upon the way flip-flops are connected.

Modulus or Mod of a counter is defined as the number of output states that the counter will go through during counting before it comes back to original state. An N-bit counter can count up to 2^N state. For example, a 3-bit counter can have maximum 8 ($=2^3$) counts and is called Mod-8 counter.

Counters are divided in two categories, these are:

1. Asynchronous (Ripple) Counters – In asynchronous counters, first flip-flop is clocked by the external clock pulse and then each successive flip-flop is clocked by the output of the previous flip-flop.
2. Synchronous (Parallel) Counters - In synchronous counters, all flip-flops are triggered by the same clock simultaneously. Synchronous counters are also known as parallel counters.



3.3.1 Asynchronous Counter:

In Asynchronous counter, flip-flops are connected serially. First flip flop is clocked by an external clock and other flip-flops are clocked by the output of previous flip-flop. In this case output of flip-flops does not change simultaneously. These counters are also known as ripple counter. Figure 3.7 shows 2-bit asynchronous (ripple) counter.

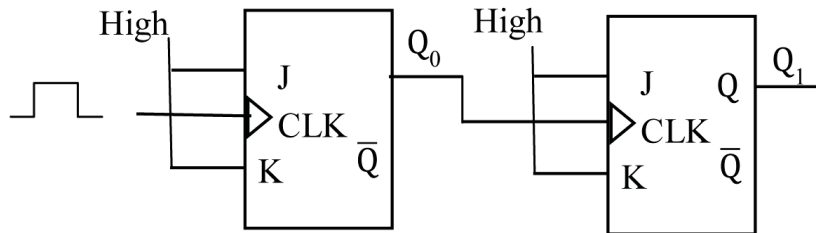


Figure 3.7: 2-bit Asynchronous (ripple) counter

The four state of 2-bit counter is shown in figure 3.8 below. As shown in the figure 3.7, J and K inputs are connected together. As we already known when $J = K = 1$ and Clock is high, flip-flop toggles. The counter counts starting from 00(0) state to 11(3) state. This is also known as Mod-2 counter where Q_1 and Q_0 represent the most significant bit (MSB) and the least significant bit (LSB) of the counter respectively. The state diagram and truth table of 2-bit asynchronous (ripple) counter is shown in figure 3.8 and Table 3.6 respectively.

Table 3.6: Truth table of 2-bit ripple counter

Clock Pulse	Output	
	Q_1	Q_0
1	0	0
2	0	1
3	1	0
4	1	1
5	0	0

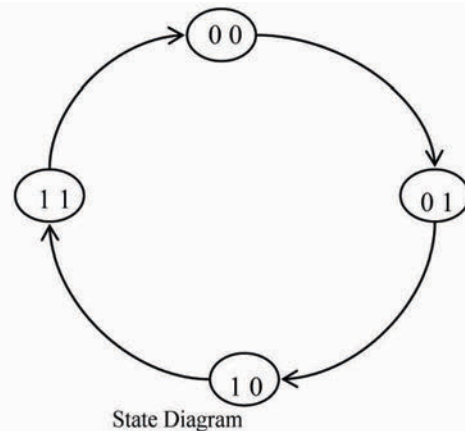


Figure 3.8 :State Diagram 2-bit Asynchronous (ripple) counter

Student Activity: Design 3 - bit asynchronous counter using T/ J-K flip-flops. Design Mod-16 counter.

3.3.2 Synchronous Counter:

Synchronous Counter is a counter in which clock pulse is applied simultaneously to all the flip-flops and the output of all the flip-flop changes at the same time. Figure 3.9 shows 3-bit synchronous counter.

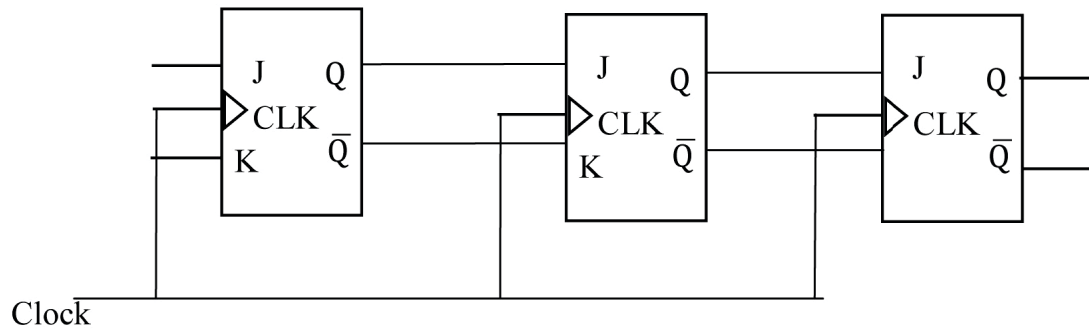


Figure 3.9: 3-bit Synchronous counter

Student Activity: Identify five applications of counters in our day to day life.

3.4 REGISTER

Register is a sequential circuit formed by combination of flip-flops and logic gates. Registers are basically of two kinds:

1. Buffer Register
2. Shift Register

Buffer register is used to store information whereas shift registers are used for movement of information from one place to another. The flip-flops store the information while the gates control the flow of information into the register.

3.4.1 Shift Register

A shift register moves the stored bits left or right. Each flip-flop (stage) in a shift register represents one bit of storage. On the application of clock pulse, a shift register can shift the data from one stage to another stage.

3.4.2 Types of Shift Registers

A shift register can be used in different modes depending upon the way in which data is entered into and taken out of it. The four categories of shift registers are:

1. Serial input, Serial output (SISO)
2. Parallel input, Serial output (PISO)
3. Serial input, Parallel output (SIPO)
4. Parallel input, Parallel output (PIPO)



3.4.2.1 Serial input, Serial output (SISO)

In this type of register entry and exit movement of data is done serially. Figure 3.10 shows that data is shifted right. Here arrow indicates serial movement of bits in right direction.

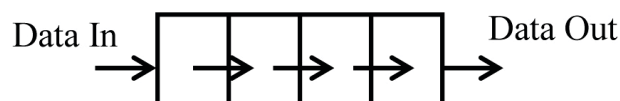


Figure 3.10: Serial in Serial out

3.4.1.2 Parallel input, Serial output (PISO)

Data is entered simultaneously but shifted serially on the application of clock pulse as shown in Figure 3.11.

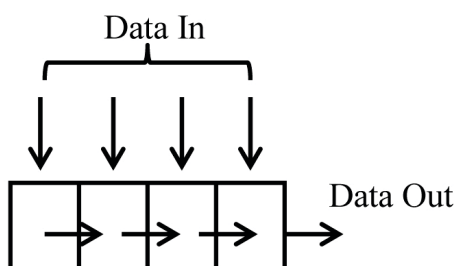


Figure 3.11: Parallel in Serial out

3.4.1.3 Serial input, Parallel output (SIPO)

Data is loaded serially and can be read simultaneously as shown in the Figure 3.12.

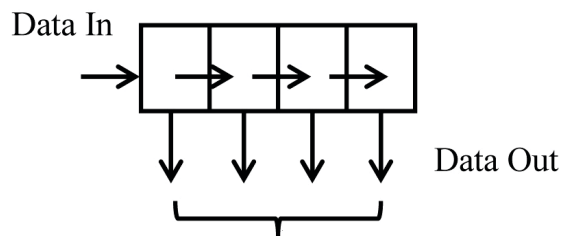


Figure 3.12: Serial in Parallel out

3.4.1.4 Parallel input, Parallel output (PIPO)

Data can be loaded simultaneously and also can be taken out simultaneously (Figure 3.13).

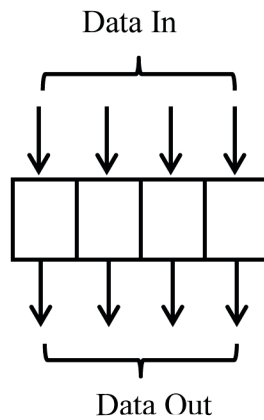


Figure 3.13: Parallel in Parallel out

Circuit for shifting 3 bit data to the right and left using J-K flip-flop is shown in figure 3.14 and 3.15 respectively.

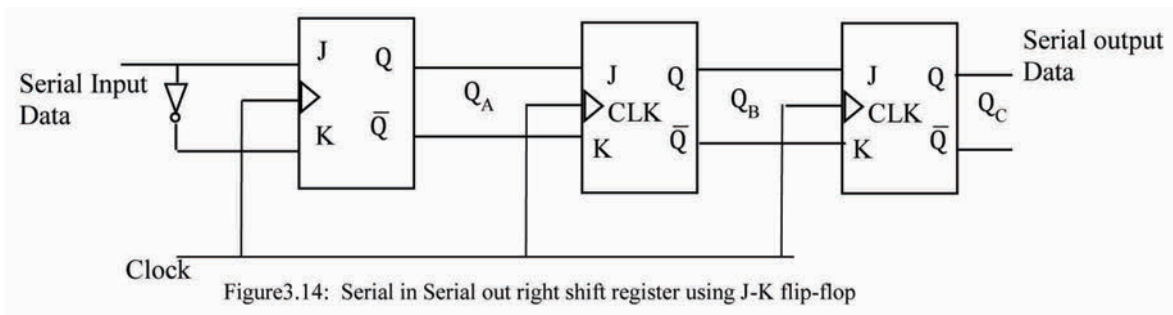


Figure3.14: Serial in Serial out right shift register using J-K flip-flop

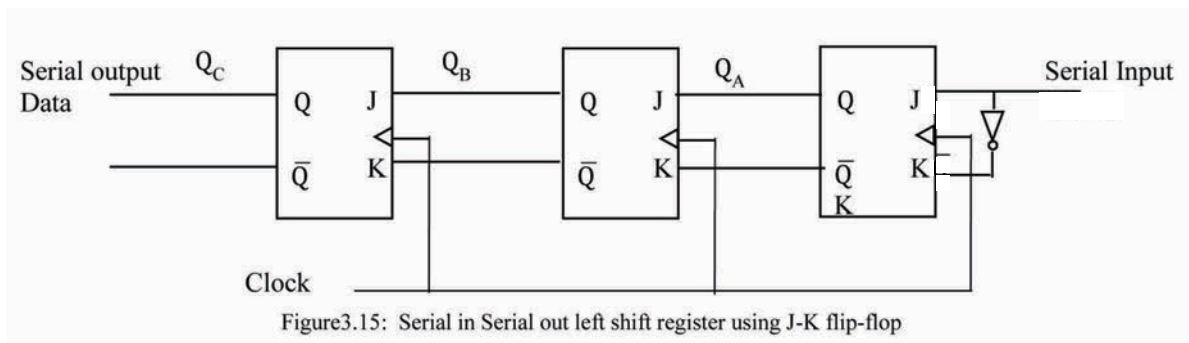


Figure3.15: Serial in Serial out left shift register using J-K flip-flop

3.4.3 Bidirectional Shift Register

A bidirectional shift registers can shift data in both left and right direction.

3.4.4 Universal Shift Register

Universal shift register can be operated in all possible modes i.e. SISO, SIPO, PISO and PIPO and also as a bidirectional (left and right shift) register.



Student Activity: Draw the circuit diagram for bidirectional and universal shift registers using flip - flops.

3.5 SUMMARY

This unit introduces latches as memory element. It describes the various types of flip-flops used in digital electronics with their symbol, Boolean expression and truth table. Working principle of S-R, J-K, D and T flip-flop has been described in detail. Application of flip-flop as counter circuit is discussed in brief. Introductory idea about shift registers and their mode of operation has been provided in this unit

Exercise Questions:

- 1) How do you differentiate between a latch and a flip-flop?
- 2) Draw symbol, truth table and Boolean expression for S-R, J-K, D and T flip-flop.
- 3) What is the meaning of 'toggle'?
- 4) What is race around condition? How this problem can be avoided?
- 5) What is the difference between synchronous and asynchronous counter? List application of counters.
- 6) What do you understand by ripple (asynchronous) counter? Draw the circuit for 3 bit ripple counter using J-K flip-flop?
- 7) What is modulus counter?
- 8) Design a BCD up/down counter using flip-flops.
- 9) What is shift register? What are its various mode of operation?
- 10) What do you mean by universal shift register?



Multiple Choice Questions: choose the correct Answer

1. Flip-Flops are
 - a) Chip
 - b) Memory element
 - c) Integrated circuit
 - d) None of the above
2. In a computer _____ is capable to store single binary bit.
 - a) Capacitor
 - b) Flip-Flop
 - c) Inductor
 - d) Register
3. SR latch is made by two cross coupled
 - a) AND gates
 - b) OR gates
 - c) XOR gates
 - d) NAND gates
4. SR flip-flop can not accept following inputs:
 - a) Both input zero
 - b) Both input one
 - c) $S = 1, R = 0$
 - d) $S = 0, R = 1$
5. What does 'D' stands for in D flip-flop
 - a) Decode
 - b) Delay
 - c) Dynamic
 - d) Direct
6. How is a J-K flip flop made to toggle
 - a) $J = 0, K = 1$
 - b) $J = 1, K = 1$
 - c) $J = 1, K = 0$
 - d) $J = 0, K = 0$
7. Fastest operating shift-register is
 - a) PIPO
 - b) SIPO
 - c) PISO
 - d) SISO
8. Slowest operating shift-register is
 - a) SIPO
 - b) PIPO
 - c) SISO
 - d) PISO
9. Counter is used to count
 - a) Flip-flops
 - b) Registers
 - c) Delay time
 - d) Clock pulse
10. How many flip-flops are required to make MOD-16 counter?
 - a) 5
 - b) 3
 - c) 6
 - d) 4



UNIT - 4

INTRODUCTION TO DISPLAY DEVICES

4.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource material
- Duration
- Learning outcomes
- Assessment plan

4.1 Light Emitting Diode (LED)

4.1.1 Working Principle of LED

4.2 Liquid Crystal Display (LCD)

4.2.1 Working Principle of LCD

4.3 Seven Segment Display

4.3.1 Common Anode Configuration

4.3.2 Common Cathode Configuration

4.3.3 Driving 7-segment Display

4.4 Summary

4.0 UNIT OVERVIEW AND DESCRIPTION

Overview:

This unit begins with the description about LED, its difference with p-n junction diode and application. It includes working principle and brief idea about constructional feature of LED. Discussion about LCD with working principle, types and constructional feature is presented in the unit. This unit describes about seven segment display and its application. Working principle of both types of seven segment display is presented in detail. The unit concludes with the description of interfacing of display devices. The learner will get a fair idea about the technique of driving seven segment display by TTL and CMOS driver ICS.



Knowledge and skill outcomes

- i) Understanding of LED with its working principle.
- ii) Learn about working principle of LCD.
- iii) Overview of seven segment display and its applications.
- iv) Classification of seven segment displays and their working principle.
- v) Knowledge about interfacing of seven segment display with driver circuit.

Resource Materials

1. Digital Principles and Applications by A. P Malvino & D. P. Leach, Tata McGraw-Hill Publication, New Delhi, 1995.
2. Electronic Devices and Circuit Theory by Robert Boylestad and Louis Nashelsky, Prentice Hall India Publication, New Delhi, 1994.
3. Electronic Devices and Circuits by J. B. Gupta, S K Kataria & Sons, New Delhi, 2008.
4. Digital Fundamentals by Floyd & Jain, Pearson Education, 2007.
5. <http://www.electronics-tutorials.ws/blog/7-segment-display-tutorial.html>

Duration: Total Hours 8

Learning Outcomes:

Unit-4: Introduction to Display Devices	Outcomes
4.1 Light Emitting Diode (LED)	(1) Identify LEDs. (2) Identify the anode and cathode terminal of LED. (3) Familiarity to the working principle.
4.2 Liquid Crystal Display (LCD)	(1) Understand the difference between LCD and LED. (2) Familiarity to working principle of LCD.
4.3 Seven Segment Display	(1) Identify the Seven segment display. (2) Differentiate between CC and CA configuration of Seven segment. (3) Familiarity to the use of drivers/decoders for Seven segment display.



Assessment Plan: (For the Teachers)

Unit-4	Topic	Assessment Method	Time Plan	Remarks
4.1	Light Emitting Diode (LED), Working Principle of LED	Exercise: Question & Answer		
4.2	Liquid Crystal Display (LCD), Working Principle of LCD	Exercise: Question & Answer		
4.3	Seven Segment Display, Common Anode Configuration, Common Cathode Configuration, Driving 7-Segment Display	Exercise: Question & Answer		

4.1 LIGHT EMITTING DIODE (LED)

An LED is a special type of p-n junction diode which emits light when forward biased. We know that when a p-n junction is energized with forward biasing, recombination of holes and electrons takes place. In this process, some energy is released, mostly in the form of heat in ordinary p-n junction diode made of silicon or germanium. The percentage of light energy emitted in such p-n junction diode is negligible and as a result no visible effect can be noticed.

Some special materials like Gallium Arsenide Phosphide (GaAsP) or Gallium Phosphide (GaP), can be used for construction of p-n junction wherein greater percentage of energy released during recombination process is in the form of visible light. In today's world LEDs have wide spread application ranging from simple indicator used to show the power on condition in various gadgets like adapter, stabilizer, TV, VCD, monitor etc. to sophisticated LED TV, giant LED display in business places, shopping malls etc. One of the important application of LEDs is in seven segment displays used in calculators, digital clocks etc. In addition, incandescent bulb, tube light and Compact Florescent Light (CFL) are being quickly replaced by LED lights.

4.1.1 Working Principle of LED

When a p-n junction is subjected to an electric field by applying forward bias, recombination of holes from P region (represented by '+') and electrons from N region (represented by '-') takes place in the manner shown in Fig. 4.1. As a result, energy is released in the form of photon of light energy. This process of emitting light by applying electrical source of energy is known as electroluminescence. To permit emission of maximum number of such photon, the conducting plate connected with the P region is made smaller. Absorption of some of the photon may take



place in the material itself, whose percentage is quite small in comparison with the outbound photons. Consequently, visible light can be seen emitted from the junction. Proper packaging arrangement and use of lens is done for longer life and to increase illumination respectively. Initially LEDs were available in limited colours like Red, Green, and Blue, but presently they are manufactured in variety colours like orange, yellow, white etc apart from the basic colours. Figure 4.2 shows a off the self available LED.

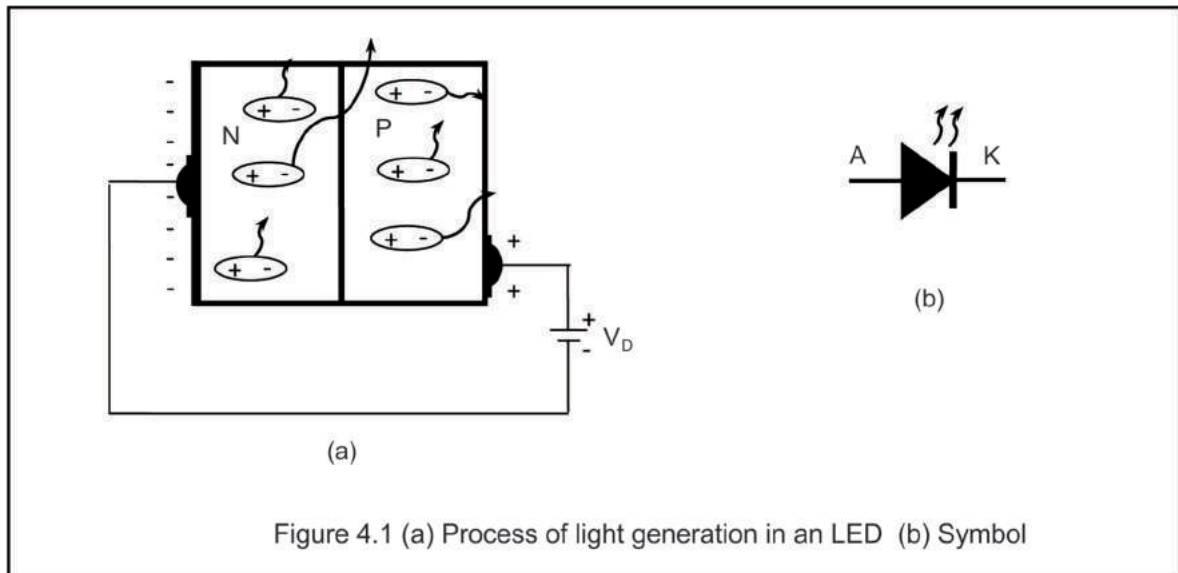


Figure 4.1 (a) Process of light generation in an LED (b) Symbol

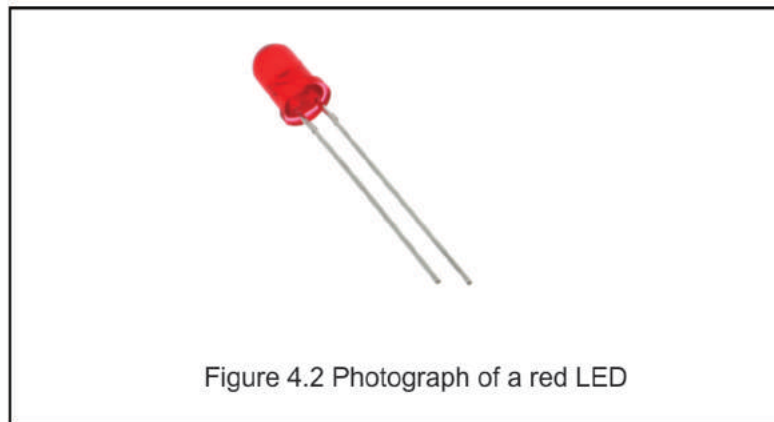


Figure 4.2 Photograph of a red LED

Student Activity: Collect LEDs of various colour, try to identify anode and cathode terminal with the help of teacher. List some more applications of LED.



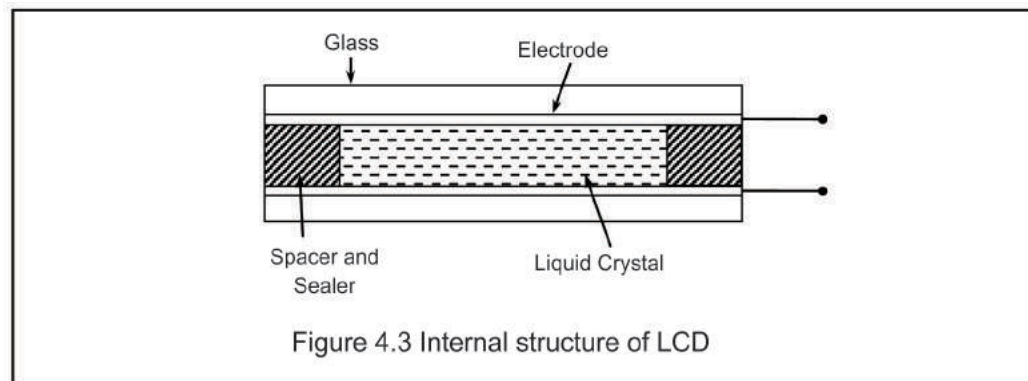
4.2 LIQUID CRYSTAL DISPLAY (LCD)

A liquid crystal is a material that remains in a state between solid and liquid but exhibits properties of both. LCDs have extremely low power devices in comparison to LEDs. But the principal disadvantage is that they need additional internal or external light source. LCDs are popular display devices to be used in calculators, remote controllers, vending machines, wrist watch etc. more specifically in battery operated devices. In early days, LCDs were only monochrome, but with advancement in technologies, colour LCDs are becoming present days popular choice.

4.2.1 Working Principle of LCD

The Molecules in liquid crystals attempts to move until they all align themselves in a particular direction. When not in an electrical field, the crystals are organized in a random pattern. When an electric current is applied to these liquid crystals, the molecules will rotate them to varying degrees, depending on the applied voltage. Liquid crystals are used in LCDs as because they respond to electric current in desired manner to control light passage them.

A liquid crystal cell shown in Fig. 4.3 consists of a thin layer of a liquid crystal enclosed between two glass sheets with transparent electrodes connected on their inside faces. If both the glass sheets are transparent it is called transmissive and if one of them is reflective then it is called reflective type cell. Broadly, LCDs available can be categorized into two categories: Dynamic scattering display and Field effect display. In Dynamic scattering display, the energized molecules become turbulent and scatter light in all directions. As a result, this area's appearance becomes silver coloured and rest remains translucent. In the other type of LCD, front and back polarizer exist at right angle to each other. When no excitation is applied, light coming from the front polarizer is rotated 90° in the liquid, passes through the rear polarizer, and is reflected back by the mirror. When excitation is applied, the front polarizer is rotated by 90° , as a result light is not rotated by 90° and is absorbed in the rear polarizer. Consequently, the excited area becomes dark and rest remains unchanged. Fig. 4.4 shows a 16x2 character LCD module.



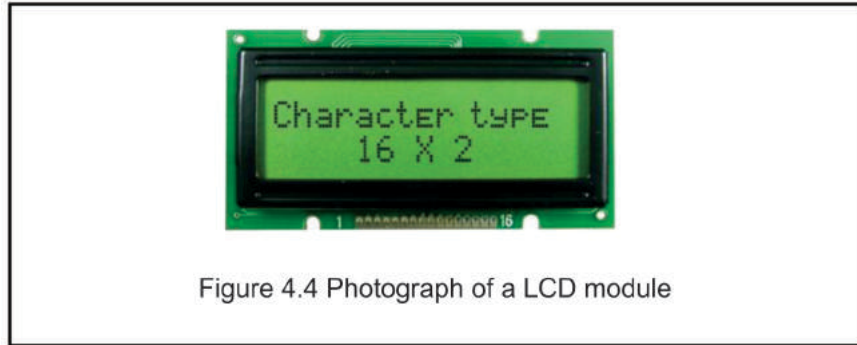


Figure 4.4 Photograph of a LCD module

Student Activity: Collect LCD module. Identify various terminals with the help of teacher. Learn how to interface LCD with other module of various circuits.

4.3 SEVEN SEGMENT DISPLAY

Seven Segment display is the most common and fundamental display device which is used in many Electronic Gadgets and Appliances like Electric stove, Microwave Oven, Digital Clocks and also in many Digital Meters like Multimeter. Seven segment display is so called as it has seven segments which can be individually controlled (ON/OFF) to display numbers from 0 to 9 and hexadecimal letters A to F. The seven elements (segments) are arranged in the form of, a slightly right inclined (to improve the readability), square shaped “8”. Some seven segment displays have an additional dot element which can be useful while displaying non integer number. The segments may be based on incandescent bulbs, fluorescent lamps, LCD or LED.

In an LED 7 segment display, as the name indicates the 7 segments plus the dot segment are based on LEDs. A seven segment is generally available in ten pin package. While eight pins correspond to the eight LEDs, the remaining two pins (at middle) are common and internally shorted.

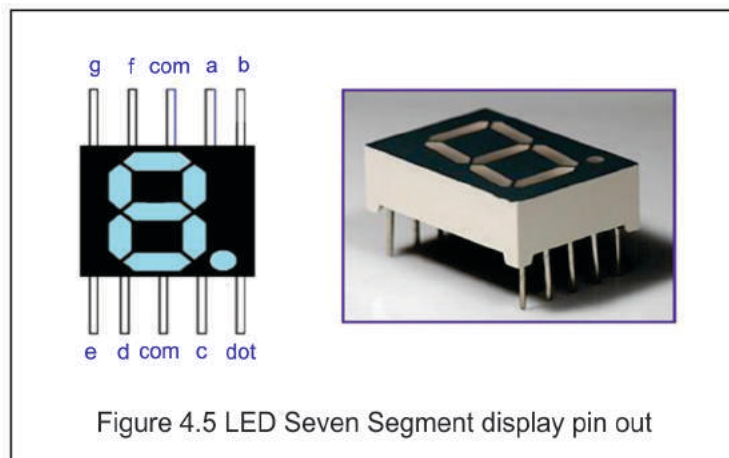
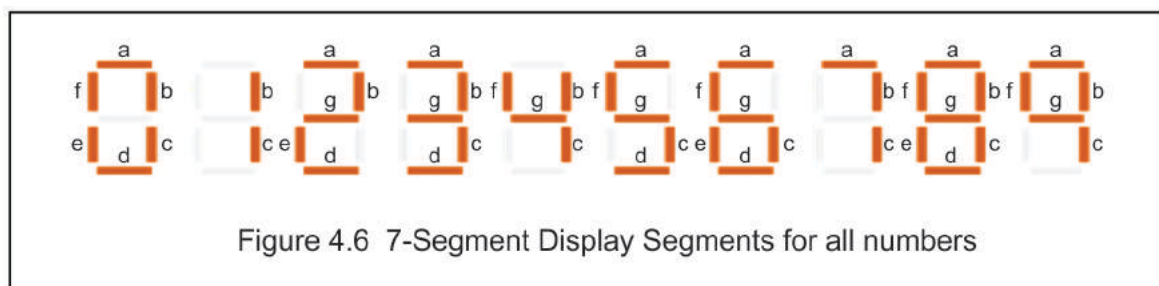


Figure 4.5 LED Seven Segment display pin out



The seven LEDs and the dot in the display is given a positional segment as shown in Figure 4.5. One connection from these segments are brought out from the plastic package as pin to interface with the external world. These pins are labeled as a to g and dot. The other ends of LED segments are tied together and brought out of the plastic package which is designated as com.

In order to generate a number on the display, one has to forward bias the appropriate LED segments through respective pins. As a result, these forward biased segments will glow and others will be off thereby generating the desired number on the display. In this manner all the ten decimal digits, 0 through 9 can be generated on the 7-segment display. As an example, to generate decimal digit 5, one has to forward bias five number of LED segments corresponding to a, c, d, f and g. Similarly to generate digit 0, six LED segments namely, a, b, c, d, e, and f are to be forward biased and so on. In addition, hexadecimal digits like A, B, C, D, E, F can also be displayed using seven segment display in similar way.



Based on the common pin, the 7-segment displays can be categorized into two types. LEDs have two connecting terminals, one called the “Anode” and the other called the “Cathode”. Accordingly, the 7-segment displays are classified as: Common Cathode (CC) and Common Anode (CA). In the CC configuration, all the cathodes of LED segments in the display are tied together whereas in the CA configuration all the anodes are connected together.

4.3.1 Common Anode configuration

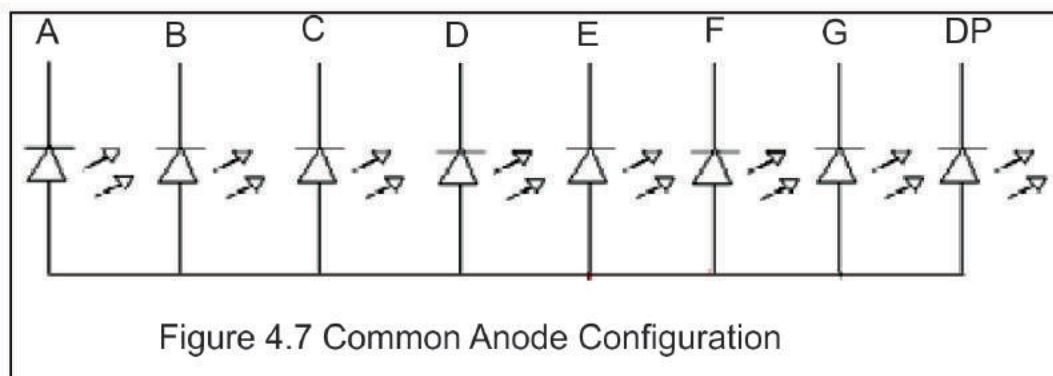
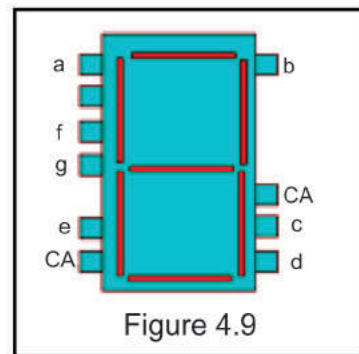
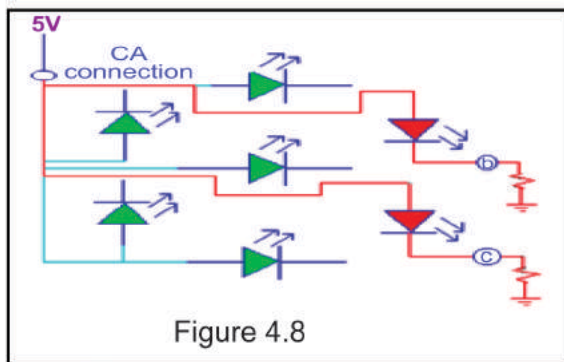




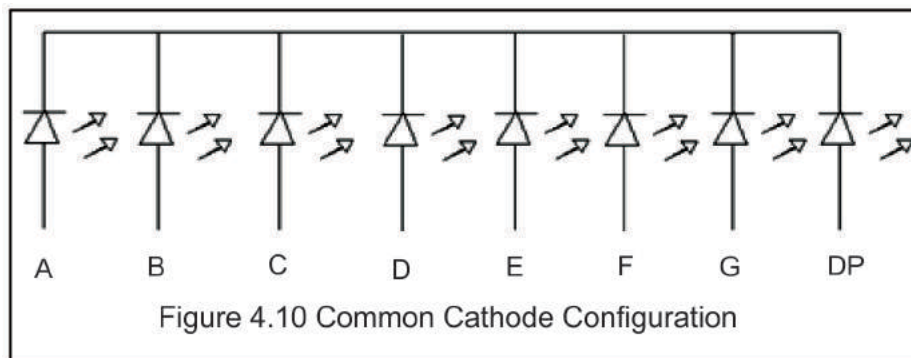
Figure 4.7 shows the CA configuration in which all the anode segments are connected together. In CA seven segment display, power supply is connected externally to all the segments through the common anode connection. Now by applying a ground to a particular segment connection (a-g), the appropriate segment will forward bias and the LED will light up. An external resistor need to be connected in the circuit to limit the amount of current flowing through each LED segment.

The diagram on the left (figure 4.8), shows the instance when power is applied to the CA connection and segments b & c are grounded causing these two segments to light up.



A typical pinout for a seven segment common anode display is shown below in figure 4.9.

4.3.2 Common Cathode configuration



A common cathode seven segment is different from a common anode segment in that the cathodes of all the LEDs are connected together, as shown in figure 4.10. In CC seven segment, the common cathode connection must be grounded and power must be applied to appropriate segment in order to illuminate that segment.

4.3.3 Driving a 7-segment Display

A 7-segment display may be considered as a single display, but in fact, it is a combination of seven individual LEDs within a single package in which each LEDs need to be protected against



over-current. A forward biased LED produce light and the amount of light emitted is proportional to the forward current, i.e., a LEDs light intensity increases in an approximately linear manner with an increasing current. So this forward current must be regulated to a safe value using external resistor to prevent burn out to the LED segments.

The level of voltage required to forward bias LEDs of different colour are different. The forward voltage drop across a red LED is relatively lower and in the range of 2 - 2.2 volts whereas for blue and white LEDs it can be as high as 3.6 volts. In order to maintain proper illumination, the voltage applied to the LED segments should be higher than that of their respective forward voltage and to be connected with a series resistance of appropriate value to limit the current flowing through each of the segments.

Practically, a power supply (V_{cc}) of +5V or higher is used to power the display. In order to ensure that the LED doesn't burn, it is necessary to connect series resistor to the Anode pins in CC configuration or to the Cathode Pins in CA configuration.

Here's how the series resistor value is computed.

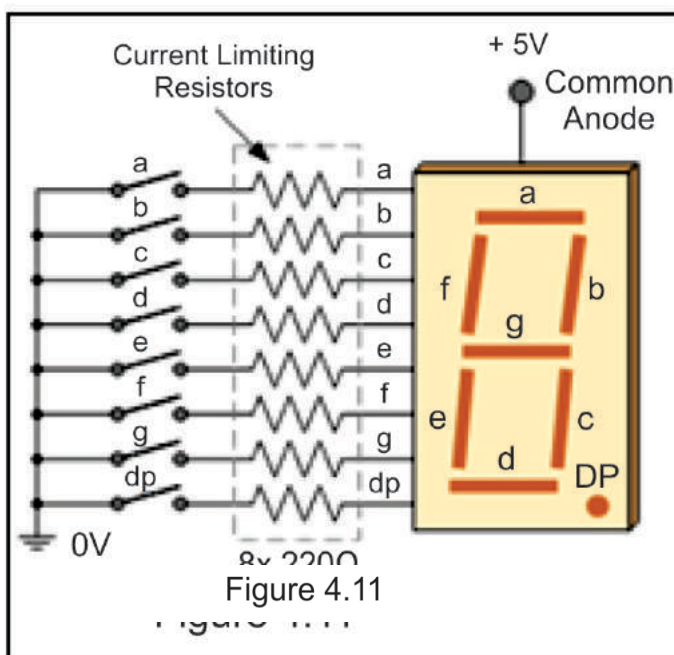
Forward bias voltage: 2V

Maximum forward current: 15mA

Resistor value (ohm) = $(V_{cc} - 2)/0.015$ ohms

Let, $V_{cc} = +5$ V, then the value of series resistor = $(5-2)/0.015=200$ ohms. Nearest higher value commercially available is 220Ω.

As shown in figure 4.11, the desired segment of a CA display can be illuminated using switches, (a, b, c, ..., dp). Suppose, switch b is made on, now current will flow from the +5V power supply through the "b" segment of the LED via the current limiting resistor of 220 ohm to the ground point which is at 0 volt. In this situation, only segment b will be illuminated. So a LOW condition (switch to ground) is required to illuminate the LED segments on this CA display. Suppose decimal number "4" is to be displayed, then switches b, c, f and g would be made on to light the corresponding LED segments. Similarly, for a decimal number "3", switches a, b, g, c, d would be switched on. But illuminating 7-segment displays using individual switches is not very practical and has been discussed here to provide clear understanding of the topic of the reader.





7-segment Displays are commonly driven by a special type of integrated circuit (IC) and are termed as a 7-segment decoder/driver. Some examples are CMOS CD4511 or TTL 74LS47 and 74LS48. The 7-segment display driver, known as a Binary Coded Decimal or BCD to 7-segment display decoder/driver, is capable of illuminating either CA or CC displays. The BCD-to-7 segment decoder/driver receives a four-bit BCD input labeled as A, B, C and D having binary weight of 1, 2, 4 and 8 respectively and has seven output lines that pass the current through the appropriate segments to display the desired decimal digit in the display. The CMOS CD4511 display/driver can supply current as high as 25mA to directly facilitating different coloured LED displays to be used and driven.

Common Cathode 7-segment Display Driving using CD 4511

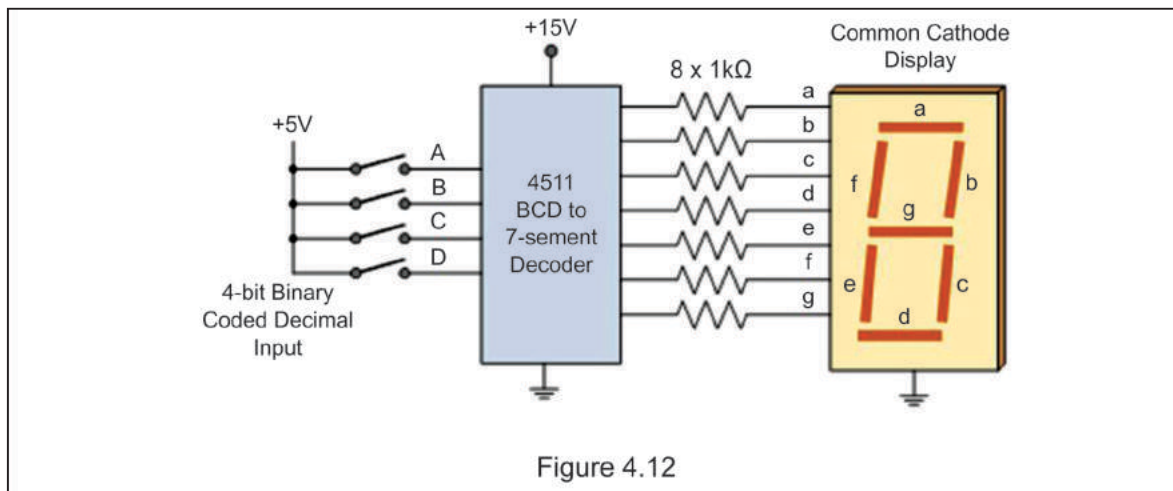


Figure 4.12 shows a simple circuit in which each LED segment of the CC display has its own anode terminal connected directly to the CD 4511 driver. As shown in the figure, the common cathodes are connected to ground. The current from each output flows through a 1k series resistor which limit the current within safe range. The four switches provides binary input to the 4511. Thus, using a BCD to 7-segment display/driver like CD 4511, the LED display can be controlled using only four switches (unlike 8 switches in previous case) or a 4-bit binary signal permitting maximum 16 different combinations.

4.4 SUMMARY

This unit describes about two most popular types display devices, LED and LCD used with numerous electronic gadgets. The working principle, constructional features and types of these display devices are discussed to give brief detail to the learner. Seven segment display with their interfacing techniques are described to equip the learner with fundamental concept of interfacing display devices with TTL and CMOS ICS.



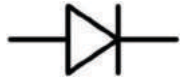



Exercise Questions:

- 1) What do you mean by LED?
- 2) What form of energy is converted into what form by LED?
- 3) Mention five important applications of LCD.
- 4) What are the two major types of LCD?
- 5) Compare LED with LCD.
- 6) Generate a truth table for displaying numbers 1-9 and alphabets A, B, C, D, E and F, indicating each segment illumination state.
- 7) Discuss why hexadecimal b and d cannot be displayed as capital alphabets.
- 8) Compute the value of resistor required for illuminating a blue LED connected to a 5V supply when forward bias current is 7mA.
- 9) Discuss the need for BCD to 7 segment decoder.
- 10) Differentiate between CA and CC configuration.

Multiple Choice Questions: Choose the Correct Answer

- 1) 7 segment generates output?
 - a) a to b
 - b) a to f
 - c) a to g
 - d) a to z
- 2) Which Outputs e and f of 7 segment decoder IC are at logic HIGH, the rest are at logic LOW. If a CA display is connected to IC, the numeral displayed is
 - a) 4
 - b) 3
 - c) 1
 - d) 0
- 3) Outputs c, d, e, f and g of 7 segment decoder IC are at logic HIGH, the rest are logic LOW. If a CC display is connected to IC, the numeral displayed is
 - a) 9
 - b) 2
 - c) 0
 - d) 6
- 4) The BCD input to a 7 segment display decoder is 1001. The digit displayed will be
 - a) 7
 - b) 8
 - c) 9
 - d) 0



- 5) What is IC Cd4511?
- a) BCD to seven segment decoder b) Binary to seven segment decoder
c) BCD to LCD driver d) Binary to LCD driver
- 6) Gallium Arsenide Phosphide is used in which of the following?
- a) LCD b) p-n junction diode
c) LED d) Transistor
- 7) Which one of the following is the symbol of LED?
- a)  b) 
- c)  d) 
- 8) Power consumption of LCD in comparison with LED is
- a) More b) Less
c) Equal d) Extremely more
- 9) A light emitting diode is
- a) an amplifying device b) a storage device
c) a display device d) an input device
- 10) An LED is forward-biased. The diode should be on, but no light is showing. A possible trouble might be
- a) The diode is open b) The series resistor is too high
c) The power supply is too low d) All of the above



UNIT - 5

INTEGRATED CIRCUITS AND MEMORIES

5.0 Unit Overview & Description

- Overview
- Knowledge and skill outcomes
- Resource material
- Duration
- Learning outcomes
- Assessment plan

5.1 Introduction to IC's

5.1.1 Importance of IC

5.1.2 Applications of IC

5.1.3 Linear vs. Digital IC's

5.2 Evolution of IC- SSI to VLSI

5.3 Memory

5.3.1 Memory Organization

5.3.1.1 Memory Hierarchy

5.3.2 Memory Operation

5.3.3 Classification of Memory

5.3.3.1 Primary Memory (Main Memory)

5.3.3.2 Secondary Memory

5.4 Microprocessor

5.4.1 Microprocessor Based System

5.5 Microcontroller

5.5.1 Block Diagram of Microcontroller

5.6 Applications of Microprocessors and Micro-controllers

5.7 Summary



5.0 UNIT OVERVIEW AND DESCRIPTION:

Overview:

This unit begins with the definition of an integrated circuit. Concept is developed and reasons are discussed as to why vacuum tube devices were replaced with integrated circuits. Advantages of IC's over discrete components are discussed at length. There after the typical application areas of IC's are discussed also taking into account the different types of integrated circuits. It also includes the evolution of the IC from SSI to VLSI. Next part of the unit starts with the introduction to semiconductor memory and its storage capacity in terms of word length. The hierarchy of memory is discussed in the next section followed by the process involved for writing in and reading from any memory location. The next section gives the detailed classification of memory depending upon whether a read, write operation or simply read operation can be performed and also the write operation is performed. This chapter concludes with the introduction to a microprocessor, its architecture. Also a description of a microprocessor based system is given followed by the micro-controller and its application.

Knowledge and skill outcomes

- i) Understanding of an integrated circuit.
- ii) Conceptual understanding of why IC's replaced discrete electronic components.
- iii) Classification of IC depending on analog or digital input along with applications.
- iv) Knowledge of semiconductor memory, its size and the concept of read/write operation from the addressed memory location.
- v) Differentiating the different types of memory.
- vi) Understanding the microprocessor based system and the application of micro-controller in day to day life.

Resource Materials

1. Digital Principles and Applications by A. P Malvino & D. P. Leach, Tata McGraw-Hill Publication, New Delhi 1995.
2. Modern Digital Electronics by R. P. Jain, Tata McGraw-Hill Publication, New Delhi 2010
3. Fundamentals of Digital Electronics & Microprocessors by Anokh Singh & A.K. Chabra
4. Digital Fundamentals of Digital Circuits by Anand Kumar, PHI.



Duration: Total Hours 15

Learning Outcomes:

Unit-5: Integrated Circuits, Semiconductor memory and Microprocessor	Outcomes
5.1 Integrated Circuit (IC)	<ol style="list-style-type: none"> 1. Definition. 2. Application.
5.2 IC – SSI to VLSI	<ol style="list-style-type: none"> 1. Evolution from SSI to VLSI.
5.3 Level of Integration	<ol style="list-style-type: none"> 1. Concept of memory. 2. Addressing of a memory location. 3. Read/Write operation in a memory. 4. Differentiating the different types of memory.
5.4 Microprocessor 5.5 Micro-Controller 5.6 Applications of Microprocessors and Micro-controllers	<ol style="list-style-type: none"> 1. Idea of a microprocessor and its internal architecture. 2. Application of a microprocessor and micro-controller based system relate to the daily life.

Assessment Plan: (For the Teachers)

Unit-5	Topic	Assessment Method	Time Plan	Remarks
5.1	Integrated Circuit (IC)	Exercise: Question & Answer		
5.2	IC – SSI to VLSI	Exercise: Question & Answer		
5.3	Level of Integration	Exercise: Question & Answer		
5.4	Microprocessor	Exercise: Question & Answer		
5.4	Micro-Controller	Exercise: Question & Answer		
5.4	Applications of Microprocessor and Micro-controllers	Exercise: Question & Answer		



5.1 INTRODUCTION TO IC'S:

An assembly of many different electronic components consisting of resistors, capacitors, diodes, transistors, gates and flip-flops all integrated on a small single silicon wafer is called an integrated circuit (IC). In other words, an integrated circuit is defined as “A circuit in which all or some of the elements are inseparably associated and electrically interconnected so that it is considered to be indivisible for the purpose of construction and commerce.” This integrated circuit (IC) is also called a chip or a microchip because it is basically a collection of discrete circuits on a small semiconductor material chip like Silicon. Today's IC's have billions and billions of these electronic components fabricated on a single chip that is equal to the size of a fingernail. All the electronic equipments today use a number of integrated circuits and these circuits can perform a number of operations such as rectification and amplification, produce oscillation, act as memory storage element and perform arithmetic and logical operations.

5.1.1 Importance of IC

Vacuum tubes were initially used to perform the process or amplification. These vacuum tubes consisted of electrodes inside a glass tube filled with vacuum. They were much bigger in size, slow in operation, consumed more power and were expensive.

A discrete circuitry consists of transistors, resistors, diodes, capacitors and many other discrete devices. These components are soldered on the printed circuit board (PCB) according to the need of the circuit. The PCB will occupy a large space. Also, the soldered components will show less reliability due to the use of many components. Both these factors made the engineers think and invent microcircuits that are more reliable and consume less power.

For the technical advancement, it became necessary to increase the number of components and this resulted in the increased size and cost. Also, previously all the components were individually connected. In an IC, the different components are printed on a single unit using photo lithographic process. Very thin paths of copper and aluminium are laid directly on the same piece of material. These thin paths function like wires and electrically connect all the different components of the integrated circuit.

5.1.2 Applications of IC

Applications of ICs are growing exponentially day by day. Due to advancement in technology, higher number of discrete components can be integrated inside an IC resulting in both miniaturization of circuits and reduction of cost.

ICs are available in wide range depending on the applications like audio amplifiers, video processors, logic circuits, memory, switches, toys, digital clocks, radio receivers, mobile



phones, desktop computers, laptops, digital cameras, calculators and many more. Infact all the electronic gadgets that we find in our day to day life contains one or more IC within it. Within limits, anything that can be designed and built with discrete components can be put into an IC.

IC's find applications in every field, starting from televisions, computers, microwaves, portable devices like laptop, MP3, play stations, cameras, cellular phones to cars (automotive controls) ship equipments, aeroplanes, space-crafts. These are also used in switching telephone circuits and data processing circuits. These ICs also find application in military equipments.

The most common application of an IC is a digital clock which tells hour, minute and seconds, day and month. Another common application is a scientific calculator which can perform basic calculation like addition, subtraction, multiplication, division and complex function like square-root, cube, trigonometric function etc.

5.1.3 Linear vs. Digital IC's

ICs are classified in different ways depending on the application as well as the output response.

ICs can thus be classified as:

1. Linear IC
2. Digital IC.

In a linear IC, the output voltage or current is continuous in nature and follows the input continuously. For example, ICs used to amplify voltage signal from a microphone are linear in nature. Linear ICs are used in cases when the relationship between the input and output of a circuit is linear in nature. The output available from linear ICs will appear as a continuous wave if observed on an oscilloscope. ICs like 741 (Operational amplifier), 555 (Timer), 7805 (Voltage Regulator) etc. are the examples of some popular linear ICs.

Linear IC's also known as Analog Integrated circuits.

Linear IC's find application in:

1. Power amplifiers
2. Small-signal amplifiers
3. Operational amplifiers
4. Microwave amplifiers
5. RF and IF amplifiers
6. Voltage comparators



7. Multipliers
8. Radio receivers
9. Voltage regulators

The ICs that accept the input voltage in two discrete levels and generate the output in the same two discrete levels are known as digital ICs. Typically, logic '0' (0 volt) and logic '1' (+5 volt) are used to describe the two voltage levels of a digital IC. Some common examples of digital ICs are 7400 (NAND gate), 74150 (Multiplexer), 7474 (Flipflop), 8085 (Microprocessor) etc.

Digital IC's are mostly used in computers. They are also referred to as "the switching circuits" because their input and output voltages are fixed at two levels - high and low i.e. a binary system. They include:

1. Flip-flops
2. Logic gates
3. Timers
4. Counters
5. Multiplexers
6. Calculator chips
7. Memory chips
8. Clock chips
9. Microprocessors
10. Microcontrollers
11. Temperature sensors

Student Activity: Identify two applications of each of the following ICs:
741, 555, 7805, 7400, 74150, 7474 and 8085.

5.2 EVOLUTION OF IC - SSI TO VLSI

Integrated Circuits were not the same since the day of their invention. The earlier developed IC's had only few electronic components on the chip. In the earlier 1960's Small Scale Integration (SSI) circuits were manufactured. SSI circuits consisted of few tens of components on the chip. By late 1960's, Medium Scale Integration (MSI) devices came into existence which had 100's of transistors on the same chip. MSI devices were less expensive and allowed more complex systems in less space.

Further development in the mid 70's led to LSI (Large Scale Integration) which has thousands of



transistors per chip of silicon. 1 KB Ram is an example of LSI device.

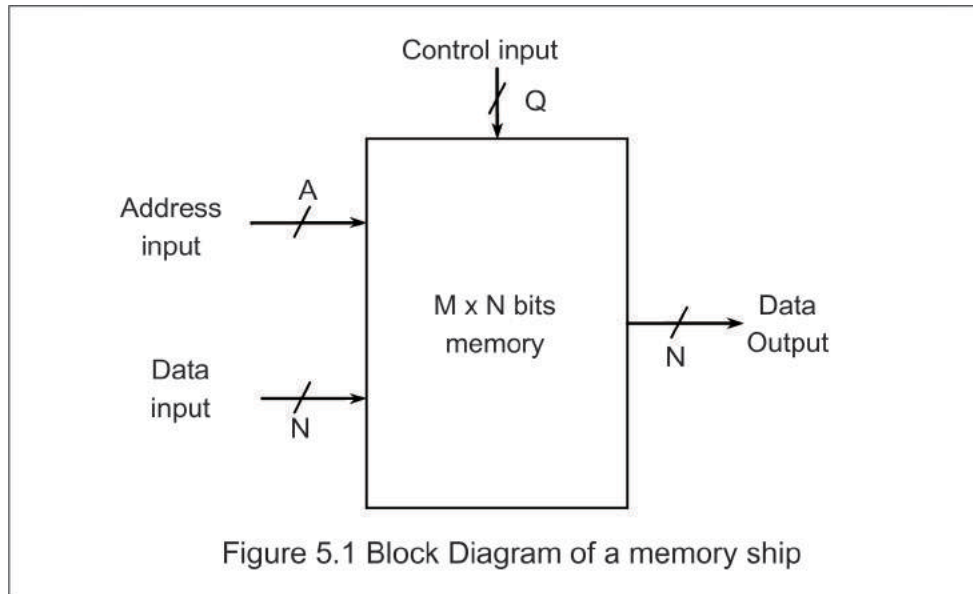
Then in early 80's VLSI (Very Large Scale Integration) was introduced. Today we have very complex devices such as ULSI (Ultra large scale integration), SOC(System on chip), WSI(Wafer scale integration) and 3D-IC(Three dimensional integrated circuit).

5.3 MEMORY

The digital processing system requires a facility for storing the digital information. The information consists of instructions (processing steps) coded in binary form, data to be processed, intermediate and final results, etc. The sub-system of a digital processing system which provides this storage facility is called the memory. The memory of any digital processing system can be compared to a human brain. Computer memory is the storage space in a computer where the data to be processed and the instructions required for processing are stored. Initially, the memories used were of the magnetic types. With the advancement in semiconductor technology, it became possible to make semiconductor memories of various types and sizes. These semiconductor memories have gained popularity due to their small size, low cost, high speed, high reliability and also the ease of expansion of the memory size.

5.3.1 Memory Organization

Semiconductor memories are available in the form of Chips. The basic element of a semiconductor memory is a flip-flop and the information is stored in the form of a bit. The memory chip is divided into large number of small parts called cells which can store one bit. Each location or cell has a unique address which varies from zero to memory size minus one and is meant to store one word. Based on the number of locations and number of bits in each location, the size of a memory IC may vary. Usually size of a memory chip is specified by $M \times N$ bits, where M is the number of words and N represents the number of bits in each word. Figure 5.1 shows the organizational block diagram of a typical memory chip. In the figure, $2A = M$ and Q represents number of control signals like memory read, memory write, chip select etc.



For example, if memory chip has 1kbyte capacity, then the organization of the chip may be 1024 x 8 bit meaning $M = 1024$ (therefore $A = 10$) and $N = 8$.

5.3.1.1 Memory Hierarchy

In a computer system, memory is arranged in the following hierarchical pattern.

Cache Memory: It is a special type of very-high-speed memory used to increase the processing speed. It is used in computer system to bridge the speed gap between CPU and main memory. Cache memory being costly used in small quantity.

Main Memory: This memory unit communicates between the CPU and Cache memory. It is relatively larger and slower than cache memory and is used to store the data and program during execution of any instruction.

Auxiliary Memory: Memory devices that are used to provide backup storage are known as auxiliary memory. Being low cost, large amount of such memory is used to store programs in a computer system. Magnetic/optical disk and tape memories are used as back up memory.

5.3.2 Memory Operation

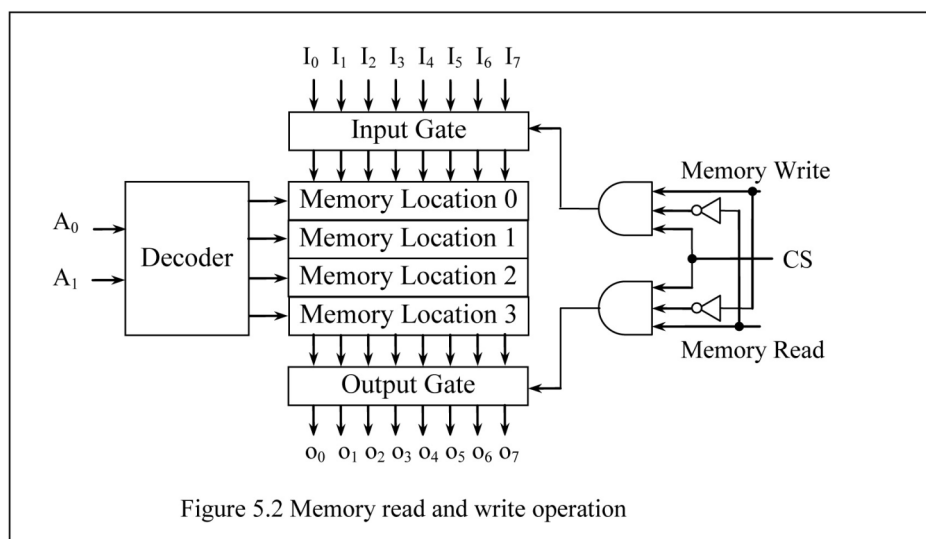
Read and write are the two operations performed on memory. A number of control inputs are required to give command to the device to perform the desired operation. For example, a command signal is required to tell the memory whether a read or a write operation is desired along with a Chip Select (CS) signal. Both read and write operation can be understood with the help of Figure 5.2.

Write Operation: Apply the address of the desired memory location in the address lines A_7A_0 . Allow the data to appear in the input lines (I_7-I_0). Enable the chip with $CS = 1$. Make Memory



Write = 1 and Memory Read = 0 to enable the input gate. This series of actions writes the desired data byte in the appropriate memory location (e.g. with $A_1A_0 = 01$ Memory Location 1 is written).

Read Operation: In order to read the contents of a memory location, first apply the address in A_1A_0 lines. Make CS = 1. Thereafter the two control signal status should be Memory write = 0 and Memory Read = 1. This enables the output gate so that the contents of the selected location will appear at the data outputs line $O_0 - O_7$.



5.3.3 Classification of Memory

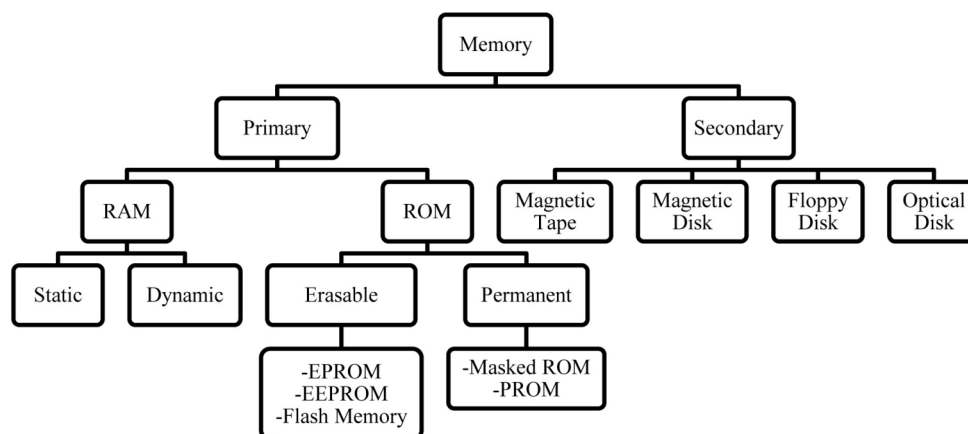


Figure 5.3 - Classification of Memory

Figure 5.3 - Classification of Memory



The memory is mainly divided into two types.

- Primary Memory
- Secondary Memory

5.3.3.1 Primary Memory (Main Memory)

Primary memory is also termed as the main memory. It holds only those data and instructions on which computer is currently working. It has limited capacity and data is lost when power is switched off. It is generally made up of a semiconductor device. These memories are not as fast as registers. The data and instruction required to be processed resides in main memory.

Characteristics of Main Memory

- These are semiconductor memories.
- It is known as main memory.
- Usually volatile memory.
- Data is lost in case power is switched off.
- It is working memory of the computer.
- Faster than secondary memories.
- A computer cannot run without primary memory.

The main or the primary memory is further divided into two subcategories: RAM and ROM.

Random Access Memory (RAM)

- Read and write memory.
- Most common form of Main Memory.
- Fast and consumes less power.
- RAM is normally located on the motherboard and so is typically less than 12 inches from the CPU.
- RAM is used to hold both program code (instructions) and data (numbers, strings etc).

RAM is further subdivided into:

Static RAM (SRAM)

Dynamic RAM (DRAM)

Static RAM:- It remains active as long as the power is ON and loses its data when the power is turned off. The speed of operation is fast but is most expensive. Due to its cost it is not used as main memory but rather for cache memory. Each bit requires a 6-transistor circuit.



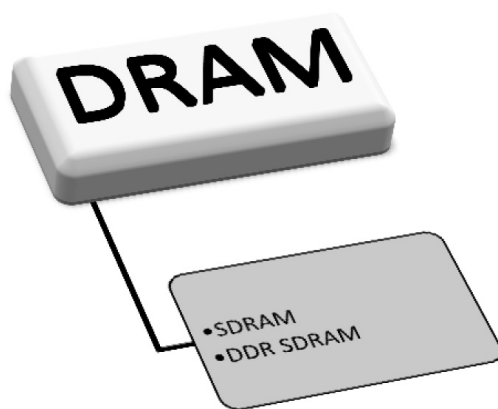
Dynamic RAM:- This memory loses its contents in very short time even if its power is ON. DRAM (Dynamic RAM) is not as fast as SRAM but is cheaper and is used for main memory. Each bit uses a single capacitor and a single transistor circuit. Since capacitors lose their charge, DRAM needs to be refreshed after every few milliseconds.

There are many implementations of DRAM.

- SDRAM
- DDR SDRAM

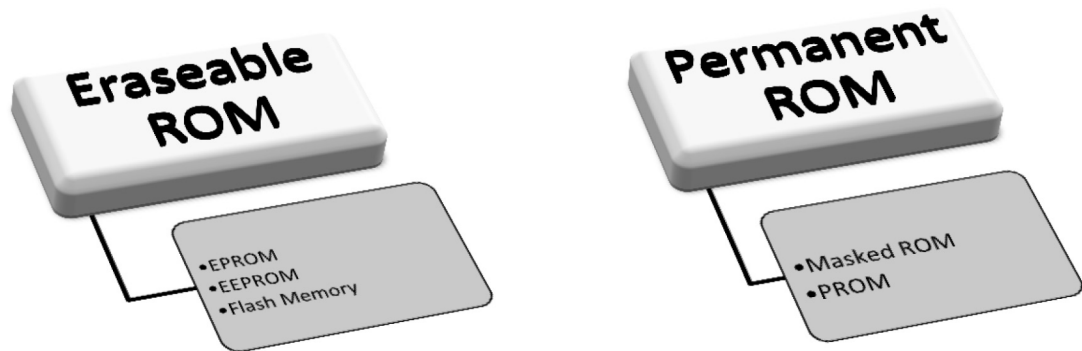
SDRAM (Synchronous DRAM) is a form of DRAM that is synchronized with the clock of the CPU's system bus, sometimes called the front-side bus (FSB). As an example, if the system bus operates at 167Mhz over an 8-byte (64-bit) data bus, then an SDRAM module could transfer $167 \times 8 \sim 1.3\text{GB/sec}$.

DDR SDRAM (Double-Data Rate SDRAM) is an optimization of SDRAM that allows data to be transferred on both the rising edge and falling edge of a clock signal, effectively doubling the amount of data that can be transferred in a period of time. For example a PC-3200 DDR-SDRAM module operating at 200Mhz can transfer $200 \times 8 \times 2 \sim 3.2\text{GB/sec}$ over an 8-byte (64-bit) data bus. DDR3 continues the trend, doubling the minimum read or write unit to 8 consecutive words.



ROM (Read Only Memory)

- Permanent memory where the contents remain even when the power supply is switched off.
- Used to store those programs that do not need alteration.
- Can be written only once.
- ROM was used to store the “boot” or start-up program (so called firmware) that a computer executes when the power is turned on, although it has now fallen out-of-favour to more flexible memories that support occasional writes. ROM is still used in systems with fixed functionalities, e.g. controllers in cars, household appliances etc.
- ROM is again subdivided into:
 - Erasable ROM



- Permanent ROM

ERASEABLE ROM

- Can be erased easily.
- Can be used again and again.

EPROM (Erasable Programmable ROM) : As the name suggests we can erase the contents of the chip using Ultra-violet light and rewrite it again with new contents, typically several thousand times. It is commonly used to store the “boot” program of a computer, known as the firmware. PCs call this firmware, the BIOS (Basic I/O System). Other systems use Open Firmware. Intel-based Macs use EFI (Extensible Firmware Interface).

EEPROM (Electrically Erasable Programmable ROM): As the name implies the contents of EEPROMs are erased electrically. EEPROMs are also limited to the number of erase-writes that can be performed (e.g, 100,000) but support updates (erase-writes) to individual bytes whereas EPROM updates the whole memory and only supports around 10,000 erase-write cycles.

FLASH memory is a cheaper form of EEPROM where updates (erase-writes) can only be performed on the blocks of memory and not on individual bytes. Flash memories are found in USB sticks, flash cards and typically range in size from 1GB to 32GB. The number of erase/write cycles to a block is typically several hundred thousand before the block can no longer be written.

PERMANENT ROM

- Data written in it cannot be altered.
- Data is permanently stored in it.

Masked ROM: It is used for large scale manufacturing; mask prepared for foundry. A finalized ROM image of the system program and data, pictograms, image pixels, pixels for the fonts of a language, combination-circuits implementing a truth-table.



PROM (Programmable ROM) : It is like a ROM but allows end-users to write their own programs and data. It requires special PROM writing equipment. The user can write only once in a PROM.

5.3.3.2 Secondary Memory

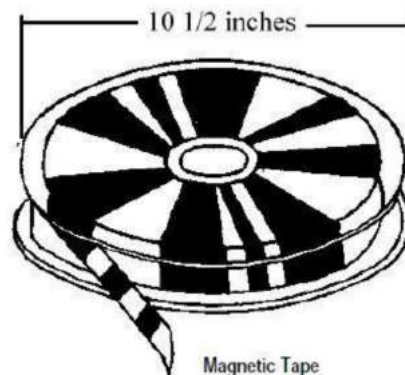
This type of memory is also known as external memory or non-volatile. It is slower than main memory. These are used for storing data/Information permanently. CPU directly does not access these memories, instead they are accessed via input-output routines. Contents of secondary memories are first transferred to the main memory, and then the CPU can access it. For example: disk, CD-ROM, DVD etc.

Characteristic of Secondary Memory

- It is a non-volatile memory.
- It is known as backup memory.
- These are magnetic and optical memories.
- Data is permanently stored even if the power is turned off.
- It is used for storage of data in a computer.
- Computer may run without secondary memory.
- Slower than primary memories.

Magnetic Tape

- Magnetic tapes are used for large computers like mainframes where large volume of data is stored for a longer time.
- The cost of storing data in tapes is inexpensive.
- Copying of data is easy and fast.



Magnetic Disk

- Magnetic disks are most popularly used as the direct access storage device.
- Magnetic disks used in computer are made of circular disc coated with magnetic material.
- Data is stored on both the surface of the disk.
- Each disk consists of a number of invisible concentric circles called tracks.





Floppy Disk

- The floppy is a low cost device particularly suitable for personal computer system.
- Similar to magnetic disk.
- They are 5.25 inch or 3.5 inch in diameter.
- They come in single or double density and recorded on one or both surface of the diskette.
- The capacity of a 5.25-inch floppy is 1.2 mega bytes whereas for 3.5 inch floppy the storage capacity is 1.44 mega bytes.
- Cheaper than any other storage devices and is portable.



Optical Disk

With every new application and software there is greater demand for memory capacity. It is the necessity to store large volume of data that has led to the development of optical disk storage medium.

5.4 MICROPROCESSOR

A microprocessor is a multipurpose, programmable, clock-driven, register-based electronic device that reads binary instructions from a storage device called memory, accepts binary data as input, processes data according to those instructions and provides results as output. Microprocessor is nothing but a Central Processing Unit (CPU) on a single chip. A microprocessor is often categorized with number of bits it can handle at a time. For example, Intel 8085 is an 8-bit microprocessor meaning that it can perform operations on 8-bit data.

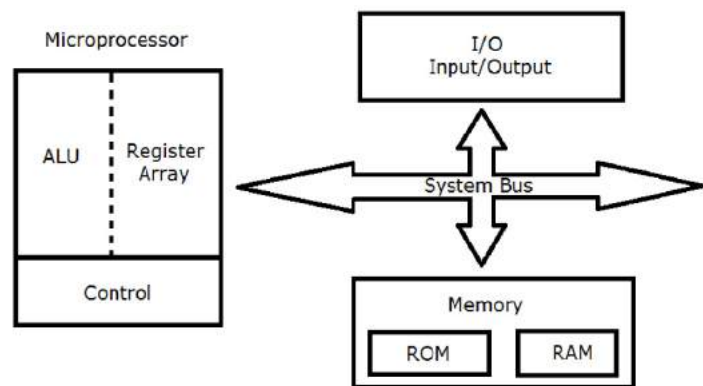


Figure 5.4 Block Diagram of Microprocessor Based System

5.4.1 Microprocessor Based System

A microprocessor alone is not capable of making a complete system. It requires certain associated blocks working with it to make a complete system which is usable in an application. A microprocessor based system usually comprises of the following fundamental blocks:



Arithmetic Logical Unit (ALU)

- An ALU is the area of microprocessor where various computing functions are performed on the data.
- The ALU is used for arithmetic operations like addition, subtraction, multiplication etc. and logical operations like AND, OR, XOR etc.
- Results are stored either in registers or in memory.

Register Array

- Registers are primarily used to store data temporarily during the execution of a program and are accessible to the user through instructions.
- Collection of Registers is known as register array. Each processor has a register array with certain specifications and nomenclature to support the execution of instructions.
- Some of the registers are general purpose and some other have specific function assigned to them.

Control Unit

- It provides timing and control signal to synchronize the entire operation of the microprocessor.
- It controls data which is passing from input port to output port or vice versa.
- Control the flow of data between the microprocessor and memory and peripherals.
- Some of the control signals are memory read (MEMRD), input read (IORD) etc.

Memory

- Memory stores binary information as instructions and data, and provides that information to the microprocessor whenever necessary.
- The ROM is used to store programs that do not need alterations.
- Program stored in ROM can only be read.
- The monitor program of a single-board microcomputer is generally stored in ROM. This program interprets the information entered through a keyboard and provides equivalent binary digits to microprocessor.
- The RAM is also known as the Read/Write memory.
- The information stored in this memory can be easily read and altered.
- It is used for temporary storage of data.

Input/Output (I/O)



- A microprocessor communicates with the outside world through input / output devices.
- Data from external devices are received through input devices. For example, keyboard, switch, mouse, analog to digital converter etc. are some of the input devices.
- Similarly devices such as LED, seven segment display, speaker, LCD, Digital to analog converter etc. send data out of the microprocessor and are examples of output devices.
- These I/O devices are also known as peripherals.

System Bus

- The system bus is a communication path between the microprocessor and peripherals including memory.
- It is nothing but a group of wires to carry information (in bit form).
- All the peripherals including memory share the same bus and only one peripheral at a time can be connected to the microprocessor.
- Three types of communication lines namely address bus, data bus and control bus are used to carry three different types of information (address, data and control signals).

5.5 MICROCONTROLLER

A microcontroller is a highly integrated IC, which includes all or most of the parts needed for a controller on single chip. It typically includes: CPU, RAM, EPROM/PROM/ROM, I/O– serial and parallel, timers, interrupt controller within the chip. A microcontroller is nothing but a computer on a single chip and is made through VLSI fabrication. It is also called an embedded controller because the microcontroller and its support circuits are often built into, or embedded in, the devices they control. A microcontroller is available in different word lengths like microprocessors (4-bit, 8-bit, 16-bit, 32-bit, 64-bit and 128-bit microcontrollers are available today).

5.5.1 Block Diagram of Microcontroller

Microprocessor Unit (MPU):

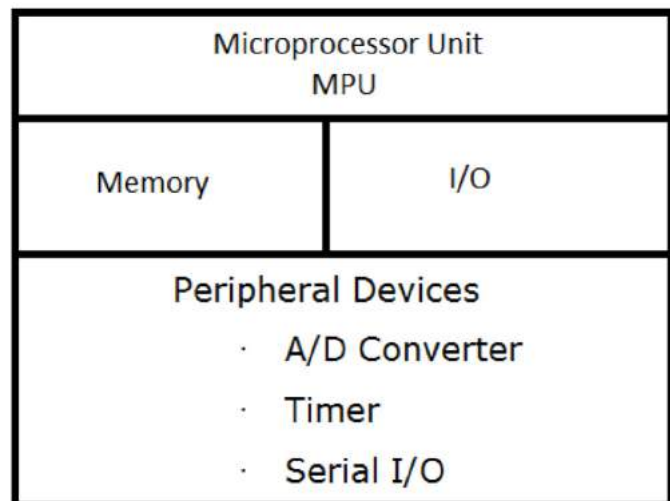


Figure 5.5 Block diagram of a Microcontroller



The MPU or CPU is a unit which monitors and controls all processes within the microcontroller. It consists of several smaller subunits, out of which the most important are:

- Instruction decoder and Control is a part of the electronics which recognizes program instructions and instructs the control unit to generate necessary timing and control signal for synchronizing different micro operation.
- Arithmetical Logical Unit (ALU) performs all arithmetic and logical operations upon data.
- Accumulator is a Special Function Register (SFR) closely related to the operation of ALU. It usually holds one of the operand of an instruction and also stores the result of such operation. It is also associated with another SFR called the Status Register, showing the "status" of a number stored in the accumulator after result available in the accumulator. In addition, a microcontroller contains certain SFRs to control or monitor variety types of operations.

Memory:

A typical microcontroller contains some amount of internal memory for storing small programs and data. Usually, program memory is non volatile type and data memory is volatile. For large programmes which do not fit into the internal program memory, external memory may be used. For example, Intel 8051 microcontroller has 4Kbyte program memory and 128 byte data memory inside it. In addition it can interface 64Kbyte program memory and equal amount of data memory externally.

Input / Output (I/O):

A microcontroller usually posses certain I/O ports to interface with the external world. These ports can be programmed to function as either input port or output port. Intel 8051 has four such 8-bit ports.

Peripheral Devices:

Student Activity: Identify 8 - bit, 16 - bit and 32 - bit microcontrollers and mention their applications

Peripheral circuits like ADC converter, DAC, D/A converter, timer, counter etc. inside the microcontroller. Due to the integration, the overall circuit operation can be made faster. In addition, the design takes relatively smaller space on the PCB.

5.6 APPLICATIONS OF MICROPROCESSORS AND MICRO-CONTROLLERS



Microprocessors and microcontrollers are used in large number of applications in business machines, automotive electronics, home appliances, electronic toys and variety of other applications in industrial products etc. In fact, today there is no field in which microprocessors and microcontrollers have not made their presence felt. Some of the important areas are mentioned below:

Instrumentation and Control:

Microprocessor and microcontrollers are very useful in the field of instrumentation and control. Frequency counters, function generators, frequency synthesizers, spectrum analyser and many other instruments are available, where microprocessors are used as controller. In addition they are used in medical instrumentation as well.

Home appliances, such as microwave oven, washing machine etc. contains microprocessors to control various parameters like speed, pressure, temperature etc. These are used with the help of suitable transducer. Traffic light controller is another popular application of microcontrollers.

Communication:

Microprocessors are being used in a wide range of communication systems. In telephone industry, these are used in digital telephone sets, telephone exchanges and modem etc. Television receivers, Set top boxes, remote controllers etc. uses some or other types of microprocessors/microcontrollers.

Office Automation and Publication:

Microprocessor and microcontrollers based system with software packages has changed the office environment. Desktop and laptop computers containing microprocessors are being used for word processing, spread sheet operations, storage etc. Biometric finger print attendance system is becoming almost inevitable in modern offices. The microprocessor has revolutionized the publication technology by offering wide range of printing machines.

Consumer:

The use of microprocessor and microcontrollers in toys, entertainment equipment and home applications is making them more entertaining and full of features. The use of microprocessors in consumer product is more widespread and popular. Few applications of microprocessor in consumer electronic products are

1. Mobile phones



2. Calculators
3. Cash register machine
4. Gaming machine
5. VCD/DVD Players etc.

5.7 SUMMARY

This chapter starts with the definition of an integrated circuit. The advantages of IC's over discrete components are discussed at length. The two major types of IC's are introduced along with their typical applications.

Semiconductor memories have become very popular in recent years. Various types of memories have been introduced. Their organization and operation have been discussed.

The topic of microprocessor has been introduced in such a way as to enable a novice to understand the basic concepts involved. A variety of microprocessors have also been evolved with the principal of operation more or less similar, with only the difference being in their architecture and instruction sets.

Exercise Questions:

- 1) What do you mean by an integrated circuit?
- 2) Give the merits of an IC over discrete circuit.
- 3) Give the various applications of the two types of IC's.
- 4) Define the term memory.
- 5) Explain how a memory location is addressed .
- 6) Name the different types of semiconductor memories.
- 7) Explain the read and write operation in a semiconductor memory location.



Multiple Choice Questions: Choose the Correct Answer

- 1) What is the number of address lines required to address a 512 x 8 bit RAM chip?
 - a) 10
 - b) 9
 - c) 12
 - d) 8
- 2) Which of the following signal not available in a ROM chip?
 - a) Write
 - b) Read
 - c) Address
 - d) Chip select
- 3) Identify the odd one
 - a) 7400
 - b) 7432
 - c) 7486
 - d) 741
- 4) Which of the following is fastest type of memory
 - a) Cache
 - b) Hard disk
 - c) CD ROM
 - d) RAM
- 5) What will be the specification of a decoder used to address a 64 x 8 bit memory chip?
 - a) 5:32
 - b) 6:64
 - c) 10:1024
 - d) 3:8
- 6) Which of the following types of memory requires refreshing?
 - a) Static RAM
 - b) Dynamic RAM
 - c) Hard disk
 - d) Magnetic Tape
- 7) Identify the memory which is erased using UV rays
 - a) PROM
 - b) Flash
 - c) EPROM
 - d) EEPROM
- 8) Which of the following is used to store data temporarily inside a microprocessor?
 - a) Register
 - b) ALU
 - c) Control unit
 - d) System bus
- 9) Intel 8051 is an example of
 - a) Memory
 - b) Microprocessor
 - c) Multiplexer
 - d) Microcontroller
- 10) Which unit in a microprocessor is responsible for generation of the signal write?
 - a) ALU
 - b) Register array
 - c) Control unit
 - d) Input-Output unit



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