ELECTRICAL ENGINEERING

Digital Electronics

Comprehensive Theory
with Solved Examples *and* Practice Questions

MADE EASY PUBLICATIONS

www.madeeasypublications.org

MADE EASY Publications Pvt. Ltd.
Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016 | **Ph. :** 9021300500
Email : infomep@madeeasy.in | **Web :** www.madeeasypublications.org

Digital Electronics

EDITIONS

First Edition : 2015
Second Edition : 2016
Third Edition : 2017
Fourth Edition : 2018
Fifth Edition : 2019
Sixth Edition : 2020
Seventh Edition : 2021
Eighth Edition : 2022
Ninth Edition : 2023

Tenth Edition : 2024

CONTENTS

Digital Electronics

■■■■

CHAPTER

1

Number Systems

INTRODUCTION

Electronic systems are of two types:

(i) Analog systems (ii) Digital systems

Analog systems are those systems in which voltage and current variations are continuous through the given range and they can take any value within the given specified range, whereas a digital system is one in which the voltage level assumes finite number of distinct values. In all modern digital circuits there are just two discrete voltage level.

Digital circuits are often called switching circuits, because the voltage levels in a digital circuit are assumed to be switched from one value to another instantaneously. Digital circuits are also called logic circuits, because every digital circuit obeys a certain set of logical rules.

Digital systems are extensively used in control systems, communication and measurement, computation and data processing, digital audio and video equipments, etc.

Advantages of Digital Systems

Digital systems have number of advantages over analog systems which are summarized below:

1. **Ease of Design:** The digital circuits having two voltage levels, OFF and ON or LOW and HIGH, are easier to design in comparison with analog circuits in which signals have numerical significance ; so their design is more complicated.
2. **Greater Accuracy and Precision:** Digital systems are more accurate and precise than analog systems because they can be easily expanded to handle more digits by adding more switching circuits.
3. **Information Storage is Easy:** There are different types of semiconductor memories having large capacity, which can store digital data.
4. **Digital Systems are More Versatile:** It is easy to design digital systems whose operation is controlled by a set of stored instructions called program. However in analog systems, the available options for programming is limited.
5. **Digital Systems are Less Affected by Noise:** The effect of noise in analog system is more. Since in analog systems the exact values of voltages are important. In digital system noise is not critical because only the range of values is important.

6. Digital Systems are More Reliable

As compared to analog systems, digital systems are more reliable.

Limitations of Digital System

(*i*) The real world is mainly analog.

(*ii*) Human does not understand the digital data.

1.1 DIGITAL NUMBER SYSTEM

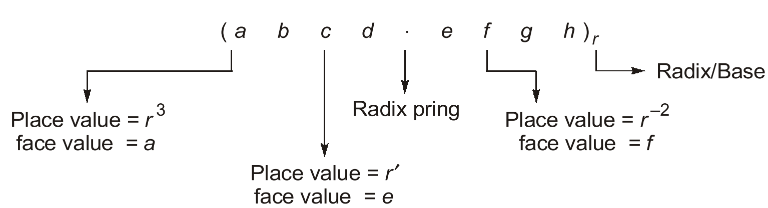
A number system is simply a way to count. The number of systems are called position weighted systems, since the weight of each digit depends on its relative position within the number. Many number systems are used in digital technology.

Base (or) Radix of System

It is defined as the number of different symbols (digits (or) character) used in that number system.

- If the base of the number system is '*r*', the number of different symbols used in the system is '*r*' i.e. the different symbols are '0 to (r – 1)'.
- The largest value of digits in base '*r*' system is '(r – 1)'.

	General	Binary	Octal	Decimal	Hexadecimal
Base	***r***	**2**	**8**	**10**	**16**
Symbols	0, 1, 2, ... (r – 1),	0, 1	0, 1, 2, 3, 4, 5, 6, 7	0, 1, 2, 3, 4, 5, 6, 7, 8, 9	0, 1, 2, 3, 4, 5, 6, 7 8, 9, *A*, *B*, *C*, *D*, *E*, *F*
Maximum digit	(r – 1)	1	7	9	*F*



Place value = Positional weight

The digit present in greatest positional weight = Most Significant Digit (MSB)

The digit present in lowest positional weight = Least Significant Digit (LSD)

EXAMPLE : 1.1 In a particular number system, 24 + 17 = 40. Find the base of the system.

Solution :

$$[(2\times r)+(4\times 1)]+[(1\times r)+(7\times 1)] = (4 \times r) + (0 \times 1)$$

$$3r + 11 = 4r$$

$$r = 11$$

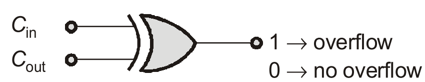
1.5 OVER FLOW CONCEPT

- If we add two same sign numbers and in the result if sign is opposite then it indicates "OVERLFLOW".
- When "OVERFLOW" occurs, then number of bits being increased by "1-bit in MSB".

1.5.1 Overflow Condition

- If X and Y are the MSB's of two number and Z is the resultant MSB after adding two numbers then overflow condition is, $\boxed{\bar{X}\,\bar{Y}\,Z + X\,Y\,\bar{Z}}$
- In 2's compliment arithmetic operation, if carry in and carry out from last bit position are different then overflow will occur.

1.5.2 EX-OR Logic Diagram for overflow



where, C_{in} = Carry into MSB
C_{out} = Carry from MSB
[Since, $A \oplus A = 0$ and $A \oplus \bar{A} = 1$]

OBJECTIVE BRAIN TEASERS

Q.1 If we convert a binary sequence, $(1100101 \cdot 1011)_2$ into its octal equivalent as $(X)_8$, the value of 'X' will be
(a) (145.13) (b) (145.54)
(c) (624.54) (d) (624.13)

Q.2 A binary $(11011)_2$ may be represented by following ways:
1. $(33)_8$ 2. $(27)_{10}$
3. $(10110)_{GRAY}$ 4. $(1\,B)_H$
Which of these above is/are correct representation?
(a) 1, 2 and 3 (b) 2 and 4
(c) 1, 2, 3 and 4 (d) only 2

Q.3 Consider $X = (54)_b$ where 'b' is the base of the number system. If $\sqrt{X} = 7$ then base 'b' will be
(a) 7 (b) 8
(c) 9 (d) 10

Q.4 Regarding ASCII codes, which one of the following characteristics is NOT correct?
(a) It is an Alphanumeric code.
(b) It is an 8-bit code.
(c) It has 128 characters including control characters.
(d) The minimum distance of ASCII code is '1'.

Q.5 Addition of all gray code to convert decimal (0 – 9) into gray code is
(a) 129 (b) 108
(c) 69 (d) 53

Q.6 The decimal equivalent of hexadecimal number of '2A0F' is
(a) 17670 (b) 17607
(c) 17067 (d) 10767

Q.7 A new Binary Coded Pentary (BCP) number system is proposed in which every digit of a base-5 number is represented by its corresponding 3-bit binary code. For example, the base-5 number 24 will be represented by its BCP code 010100. In this numbering system, the BCP code 100010011001 corresponds to the following number in base-5 system
(a) 423 (b) 1324
(c) 2201 (d) 4231

ANSWERS KEY

1. (b) 2. (c) 3. (c) 4. (b) 5. (d)
6. (d) 7. (d)

HINTS & EXPLANATIONS

1. (b)

Given binary sequence,

$$(1100101 \cdot 1011)_2$$

The given sequence can be written as,

$$\underbrace{001}_{1}\underbrace{100}_{4}\underbrace{101}_{5} \cdot \underbrace{101}_{5}\underbrace{100}_{4}$$

$\therefore$ The octal equivalent value of X is 145.54.

So, option (b) is correct.

2. (c)

Given binary number $(11011)_2$

1. $(33)_8 = (011011)_2$
2. $(27)_{10} =$

$$\begin{array}{c|l|c}
2 & 27 & \\ \hline
2 & 13 & 1 \\ \hline
2 & 6 & 1 \\ \hline
2 & 3 & 0 \\ \hline
 & 1 & 1
\end{array} \quad \therefore (11011)_2$$

3. $(10110)_{Gray}$

   Now, we need to convert Gray code to binary code.

$$\begin{array}{ccccc} 1 & 0 & 1 & 1 & 0 \\ \oplus & \oplus & \oplus & \oplus & \\ (\,1 & 1 & 0 & 1 & 1\,)_2 \end{array}$$

4. $(1\,B)_H = (1\,B)_{16} = 1 \times 16^1 + 11 \times 16^\circ = (27)_{10}$

From solution of case 2: $(27)_{10} = (11011)_2$.

So, the given option (c) is correct.

3. (c)

Given, $\quad X = (54)_b$

Also given, $\sqrt{X} = 7 \Rightarrow X = 49$

But, $\quad X = 5b + 4$

$\therefore \quad 5b + 4 = 49$

$5b = 45$

$\therefore \quad b = 9$

4. (b)

ASCII code is 7-bit code.

5. (d)

Decimal	Binary code	Gray code
0 →	0 0 0 0 →	0 0 0 0 (0)
1 →	0 0 0 1 →	0 0 0 1 (1)
2 →	0 0 1 0 →	0 0 1 1 (3)
3 →	0 0 1 1 →	0 0 1 0 (2)
4 →	0 1 0 0 →	0 1 1 0 (6)
5 →	0 1 0 1 →	0 1 1 1 (7)
6 →	0 1 1 0 →	0 1 0 1 (5)
7 →	0 1 1 1 →	0 1 0 0 (4)
8 →	1 0 0 0 →	1 1 0 0 (12)
9 →	1 0 0 1 →	1 1 0 1 (13)

$\therefore$ Addition of all gray code:

$1 + 3 + 2 + 6 + 7 + 5 + 4 + 12 + 13 = 53$

Hence, option (d) is correct.

6. (d)

Given hexadecimal number, 2A0F

$(2A0F)_{16} = 2 \times 16^3 + 10 \times 16^2 + 0 \times 16^1 + 15 \times 16^0$

$= 2 \times 4096 + 10 \times 256 + 0 + 15 = (10767)_{10}$

Hence, option (d) is correct.

7. (d)

Given, Binary Coded Pentary (BCP) number

$$\left[\underbrace{100}_{4}\underbrace{010}_{2}\underbrace{011}_{3}\underbrace{001}_{3}\right]$$

$\therefore \quad (4231)_5$ option (d) is correct.

CONVENTIONAL BRAIN TEASERS

Q.1 List out the rules for the BCD (Binary Coded Decimal) addition with corresponding examples?

1. (Sol.)

Introduction to BCD: BCD stands for binary Encoded Digital. In BCD every decimal number is represented by four binary bits.

Ex: 190 in decimal is equivalent to 0001 1001 000 in binary encoded decimal.

0 to 9 in decimal can be represented in binary using four digits and all integers can be represented by these 10 digits.

BCD Addition: In *BCD* addition of two involve following rules:

Step-1: Maximum value of the sum for two digits
= 9(max digit) + 9(max digit 2) + 1 (Previous addition carry) = 9

Step-2: If sum of two BCD digits is less than or equal to 9(1001) without carry then the result is a correct *BCD* number.

Step-3: If the sum of two *BCD* digits is greater than or equal to 10(1010) the result is incorrect *BCD* number perform step 4 for correct *BCD* sum.

Step-4: Add 6(0110) to the result.

Example:

Perform *BCD* addition of two decimal numbers 599 and 84?

BCD	1	2	3
599	0101	1001	1001
+ 984	1001	1000	0100
Sum	1110	10001	1101

here, binary sum of (1), (2) and (3) are greater than 1010, so from step 3, 4 in the rules specified for binary addition odd correction factor 0110.

Carry 1	Carry 1	Carry 1	
Result	1110	10001	1101
+ 6	0110	0110	0110
End carry 1	$0101_{(5)}$	$1000_{(8)}$	$0011_{(3)}$

∴ Result of BCD addition is 1583.

■■■■

CHAPTER

2

Boolean Algebra and Logic Gates

INTRODUCTION

- The binary operations performed by any digital circuit with the set of elements 0 and 1, are called logical operations or logic functions. The algebra used to symbolically represent the logic function is called Boolean algebra. It is a two state algebra invented by George Boole in 1854.
- Thus, a Boolean algebra is used to simplify the design of logic circuits.
- A variable or function of variables in Boolean algebra can assume only two values, either a '0' or a '1'.
- This algebra deals with the rules by which the logical operations are carried out.
- Here, a digital circuit is represented by a set of input and output symbols and the circuit function expressed as a set of Boolean relationships between the symbols.

2.1 LOGIC OPERATIONS

In Boolean algebra, all the algebraic functions performed is logical. These actually represent logical operations. The AND, OR and NOT are the basic operations that are performed in Boolean algebra. In addition to these operations, there are some derived operation such as NAND, NOR, EX-OR, EX-NOR that are also performed in Boolean algebra. Their operations will be discussed in detail in the next chapter.

2.1.1 AND Operation

The AND operation in Boolean algebra is similar to the multiplication in ordinary algebra. It is a logical operation performed by AND gate.

AND operation

$A \cdot A = A$
$A \cdot 0 = 0$ → Null law
$A \cdot 1 = A$ → Identity law
$A \cdot \bar{A} = 0$

2.1.2 OR Operation

The OR operation in Boolean algebra is performed by OR-gate.

OR operation

$A + A = A$
$A + 0 = A$ → Null law
$A + 1 = 1$ → Identity law
$A + \bar{A} = 1$

2.1.3 NOT Operation

The NOT operation in Boolean algebra is similar to the complementation or inversion in ordinary algebra.

The NOT operation is indicated by a bar (¯) or (') over the variable.

Example: $A \xrightarrow{NOT} \bar{A}$ or A' (complementation law)

and $\bar{\bar{A}} = A \Rightarrow$ double complementation law.

2.1.4 NAND Operation

The NAND operation in Boolean algebra is performed by AND operation with NOT operation i.e. the negation of AND gate operation is performed by the NAND gate.

2.1.5 NOR Operation

The NOR operation in Boolean algebra is performed by OR operation with NOT operation. i.e. the negation of OR gate operation is performed by the NOR gate.

2.2 LAWS OF BOOLEAN ALGEBRA

The Boolean algebra is governed by certain well developed rules and laws.

2.2.1 Commutative Laws

- The commutative law allows change in position of AND or OR variables. There are two commutative laws.
  (*i*) $A + B = B + A$
  Thus, the order in which the variables are ORed is immaterial.
  (*ii*) $A \cdot B = B \cdot A$
  Thus, the order in which the variables are ANDed is immaterial.
- This law can be extended to any number of variables.

2.2.2 Associative Laws

- The associative law allows grouping of variables. There are two associative laws
  (*i*) $(A + B) + C = A + (B + C)$
  Thus, the way the variables are grouped and ORed is immaterial.
  (*ii*) $(A \cdot B) \cdot C = A \cdot (B \cdot C)$
  Thus, the way the variables are grouped and ANDed is immaterial.
- This law can be extended to any number of variables.

2.2.3 Distributive Laws

- The distributive law allows factoring or multiplying out of expressions. There are two distributive laws.
  (*i*) $A(B + C) = AB + AC$
  (*ii*) $A + BC = (A + B)(A + C)$
- This law is applicable for single variable as well as a combination of variables.

2.2.4 Idempotent Laws

Idempotent means the same value. There are two Idempotent laws

(*i*) $A \cdot A = A$
i.e. ANDing of a variable with itself is equal to that variable only.

(*ii*) $A + A = A$
i.e. ORing of a variable with itself is equal to that variable only.

2.2.5 Absorption Laws

There are two absorption laws

(*i*) $A + AB = A(1 + B) = A$ (*ii*) $A(A + B) = A$

EXAMPLE : 2.36

In a power plant, the three digital signals : drum level (D), water flow (W) and steam temperature (S) are used to control a particular system by a feedback signal (F) that comes from the field to the control room. A logic circuit is to be designed to generate a high feedback signal (F) whenever any one of the following conditions is satisfied.

C1 : All the levels are at zero.
C2 : Level D and S set to zero.
C3 : Level W and S set to zero.
C4 : Level D set to zero.
C5 : All the levels are high

Find the minimal expression for the feedback signal F.

Solution :

As per the given requirement the truth table can be drawn as,

Inputs			Output
D	W	S	F
0	0	0	1
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	0
1	1	1	1

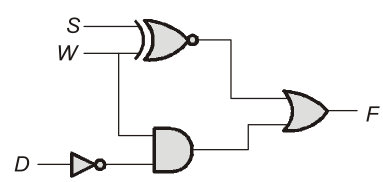
$$F = \Sigma m(000, 010, 011, 100, 111)$$

Using K-map, we get

$D \backslash WS$	$\bar{W}\bar{S}$	$\bar{W}S$	WS	$W\bar{S}$
$\bar{D}$	1		1	1
D	1		1	

$$F = \bar{W}\bar{S} + WS + W\bar{D} = (W \odot S) + W\bar{D}$$

Thus, the logical circuit can be



OBJECTIVE BRAIN TEASERS

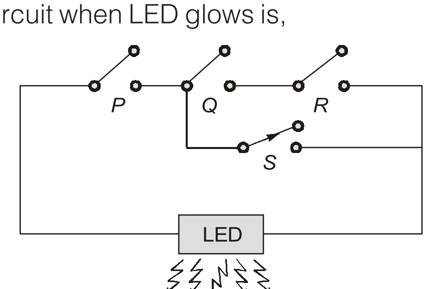
Q.1 The sign-magnitude form and 2's complement form of a signed binary number $(10111)_2$ are:

(a) –23 and –25 (b) –23 and –9
(c) –7 and –23 (d) –7 and –9

Q.2 For an 8-bit microprocessor, the maximum possible number of self dual-functions equals to

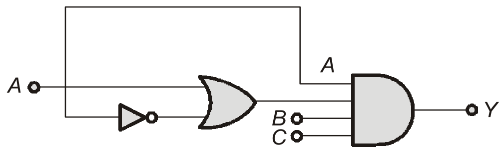
(a) $(16)^8$ (b) $(16)^{16}$
(c) $(16)^{32}$ (d) $(16)^{64}$

Q.3 For the switching circuit shown below, taking open as '0' and closed as '1', the expression for the circuit when LED glows is,



(a) $P + (Q + R)\,S$ (b) $P(QR + S)$
(c) $P + QR + S$ (d) LED can not glow

Q.4 The Boolean expression for the output in the logic circuit is



(a) $A\bar{B}C$ (b) ABC

(c) $\bar{A}BC$ (d) $\bar{A}\bar{B}\bar{C}$

Q.5 Which one of the following statements is correct? For a 4-input NOR gate, when only two inputs are to be used, the best option for the unused input is to

(a) Connect them to the ground

(b) Connect them to V_{CC}

(c) Keep them open

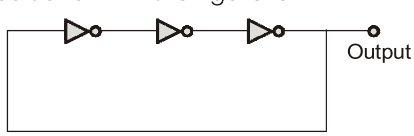
(d) Connect them to the used inputs

Q.6 A gate is disabled when its disable input is at logic 0. The gate is

(a) OR (b) AND

(c) NOR (d) EX-OR

Q.7 The circuit shown in the figure is



(a) an oscillating circuit and its output is a square wave

(b) one whose output remains stable in '1' state

(c) one whose output remains stable in '0' state

(d) having a single pulse of 3 times of propagation delay

Q.8 Consider a 4-input NAND gate, how many number of input conditions are possible, that will produce output "HIGH".

(a) 0 (b) 1

(c) 2 (d) 15

Q.9 If $A \neq B$, then the value of Boolean expression,

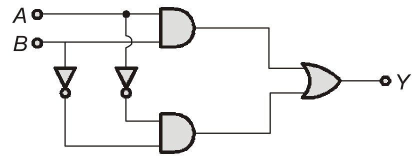
$\overline{\overline{(\bar{A}+B)}+\overline{(A+\bar{B})}}+\overline{(\bar{A}B)}\,\overline{(A\bar{B})}$ equals to,

(a) 0 (b) 1

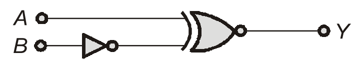
(c) $A + B$ (d) AB

Q.10 Which one of the following digital circuits does not represents the 'Stair-case switch"?

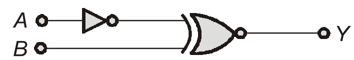
(a)



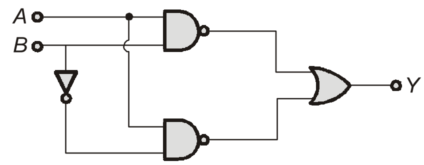
(b)



(c)



(d)



Q.11 After the simplification of a 3-variable Boolean function,

$f(A, B, C) = (A \oplus B \oplus AB)\,(A \oplus C \oplus AC)$

we requires,

(a) 1-AND and 1-OR gate

(b) 1-AND and 2-OR gate

(c) 2-AND and 1-OR gate

(d) Only 1-AND gate

ANSWERS KEY

1. (d)	2. (c)	3. (b)	4. (b)	5. (a)
6. (b)	7. (a)	8. (d)	9. (a)	10. (d)
11. (a)				

HINTS & EXPLANATIONS

1. (d)

Given signed binary number $(10111)_2$

Sign-magnitude form:

Since MSB bit is '1' hence it is a negative number.

MSB

$\underline{1}\ \underline{0\ 1\ 1\ 1}$

7

–7

2's complement form: –(01001) = –9.

Hence, option (d) is correct.