Unit-I

Number Systems, Binary Codes, Logic gates

Digital systems: A digital system is the one that handles only discrete values or signals

The word digital describes any system based on discontinous data or events.

Digital is the method of storing, processing and transmitting information through the use of distinct electronic pulses that represents binary digits 0 & 1.

There is no in between values

Advantages:

1. Noise margin (resistance to noise/robustness)

2. Error correction and detection

3. Easily programmable

4. Cheap electronic devi circuits.

Disadvantages:

1. Analog to digital conversion is required.

2. Uses more energy.

Number Systems: A digital system can understand positional number system only where there are a few symbols called digits and these symbols represent different values depending on the position they occupy in the number

→ The value of each digit in a number can be determined using the digit. the position of the digit in the number and the base of the number system.

Base or radix : Base is defined as the total no. of symbols available in the number system

Types of number systems:

1. Positional number systems

2. non- positional weighted number systems

1. Positional weighted number systems:

Ex:- decimal, binary, octal, hexadecimal

1. decimal number system – base is 10. (0,1,2,3,4,5,6,7,8,9)

2. binary number system – base is 2. (0,1)

3. octal number system – base is 8, (0,1,2,3,4,5,6,7)

4. Hexa decimal number system - base is 16, (0 to 9, A, B, C, D, E, F)

Eg for all 4 number decimal systems

$(A)_{16} = (10)_{10} = (1010)_2 = (12)_8$

$\downarrow$ hexadecimal, $\downarrow$ decimal, $\downarrow$ binary, $\downarrow$ octal

Decimal number system: Mixed decimal number is represented by,

$$\underbrace{a_n a_{n-1} a_{n-2} \cdots a_3 a_2 a_1 a_0}_{\text{integer}} \underset{\text{decimal point}}{\cdot} \underbrace{a_{-1} a_{-2} a_{-3} \cdots a_{-k}}_{\text{fraction}}$$

It is a positional weighted number system. It has 10 unique symbols (0,1,2,3,4,5,6,7,8,9)

The base or radix is 10

For any decimal number, the representation is

$(a_{n-1} \times 10^{n-1}) + \cdots (a_2 \times 10^2) + (a_1 \times 10^1) + (a_0 \times 10^0) + (a_{-1} \times 10^{-1}) + (a_{-2} \times 10^{-2})$

$+ \cdots + (a_{-k} \times 10^{-k})$.

Eg:- $454.76_{10} = (4 \times 10^2) + (5 \times 10) + (4 \times 10^0) \cdot + (7 \times 10^{-1}) + (6 \times 10^{-2})$

$= 400 + 50 + 4 + 0.7 + 0.06$

$= 454.76_{10}$

Binary Number System:

It is a positional weighted number system

It has two unique symbols (0, 1)

The base or radix is 2.

Mixed binary number is given by

$a_{n-1} a_{n-2} \cdots a_2 a_1 a_0 \overset{\text{binary point}}{\cdot} a_{-1} a_{-2} a_{-3} \cdots a_{-k}$

For any given binary number the representation in decimal form is

$$(a_{n-1}\times 2^{n-1})+\dots+(a_2\times 2^2)+(a_1\times 2^1)+(a_0\times 2^0)+(a_{-1}\times 2^{-1})+(a_{-2}\times 2^{-2})+\dots+(a_{-k}\times 2^{-k})$$

Eg:- $1001.1 = (1\times 2^3)+(0\times 2^2)+(0\times 2^1)+(1\times 2^0)+(1\times 2^{-1})$

$2^3 2^2 2^1 2^0 . 2^{-1}$

$= 8+1+0.5$

$= 9.5_{10}$

Octal number system:

→ It is a positional weighted system

→ It has 8 unique symbols (0,1,2,3,4,5,6,7)

→ The base or radix is 8.

Mixed octal number is given by

$$\underbrace{a_{n-1}\,a_{n-2}\cdots a_2 a_1 a_0}_{\text{Integer}}\;\underset{\text{octal point}}{.}\;\underbrace{a_{-1}a_{-2}a_{-3}\cdots a_{-k}}_{\text{fraction}}$$

For any given octal number the represention in decimal form is

$$(a_{n-1}\times 8^{n-1})+\dots+(a_2\times 8^2)+(a_1\times 8)+(a_0\times 8^0)+(a_{-1}\times 8^{-1})+\dots+(a_{-k}\times 8^{-k})$$

Eg:- $13_8 = 1\times 8^1+3\times 8^0 = 8+3 = 11_{10}$

* In ~~octal~~ binary number system 3 bits or binary digits is equal to one octal digit

Hexa decimal number system:

→ It is a positional weighted number system

→ It has 16 unique symbols (0, 1, ... 9, A, B, C, D, E, F)
$\downarrow$ 10 11 12 13 14 15

Mixed hexa decimal number is given by

$$\underbrace{a_{n-1}a_{n-2}\dots a_2a_1a_0}_{\text{Integer}} \; \underset{\substack{\text{hexa}\\ \text{decimal}\\ \text{point}}}{\cdot} \; \underbrace{a_{-1}a_{-2}a_{-3}\dots a_{-k}}_{\text{fraction}}$$

→ The base or radix is 16

For any given hexadecimal number, the representation in decimal form is

$$(a_{n-1}\times 16^{n-1})+\dots(a_2\times 16^2)+(a_1\times 16)+(a_0\times 16^0)+(a_{-1}\times 8^{-1})+\dots+(a_{-k}\times 16^{-k})$$

Eg:- $(100)_{16} = 1\times 16^2+0\times 16+0\times 16^0 = 256_{10}$

$(6A)_{16} = 6\times 16+\underset{\substack{\downarrow\\10}}{A}\times 16^0 = 96+10 = 106_{10}$

Conversion from one number system to another

Binary counting

decimal no	binary no
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	10011
8	1000

decimal no	binary no
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
17	10001
18	10010
19	10011

Binary addition

$$\begin{array}{r}0\\+0\\\hline 0\end{array}\quad\begin{array}{r}1\\+0\\\hline 1\end{array}\quad\begin{array}{r}0\\+1\\\hline 1\end{array}\quad\begin{array}{r}1\\+1\\\hline 10\end{array}$$

10 → carry, sum

MSB — 10101 → LSB

MSB: most significant bit

LSB: Last significant bit

Octal counting

decimal no	octal no
0	00
1	01
2	02
3	03
4	04
5	05
6	06
7	07
8	10
9	11

decimal no	octal no
10	12
11	13
12	14
13	15
14	16
15	17
16	20
17	21
18	22
19	23

Hexa decimal counting

decimal no	hexa decimal no
0	00
1	01
2	02
3	03
4	04
5	05
6	06
7	07
8	08
9	09

decimal no	hexa decimal
10	0A
11	0B
12	0C
13	0D
14	0E
15	0F
16	10
17	11
18	12
19	13
20	14

Conversion of any radix to decimal

1. Binary to decimal:

Eg:- (1101)

$2^3\,2^2\,2^1\,2^0$

$= (1\times2^3)+(1\times2^2)+(0\times2)+(1\times2^0)$

$= 8+4+1$

$= 13_{10}$

ii) $(11001\cdot010)_2 = (1\times2^4+1\times2^3+0\times2^2+0\times2^1+1\times2^0+0\times2^{-1}+1\times2^{-2}+0\times2^{-3})$

$2^4\,2^3\,2^2\,2^1\,2^0\;\;2^{-1}\,2^{-2}\,2^{-3}$

$= 16+8+0+0+1+0+0\cdot25+0$

$= 25\cdot25_{10}$

iii $(0101111\cdot001)_2 = (0\times2^6+1\times2^5+0\times2^4+1\times2^3+1\times2^2+1\times2^1+1\times2^0+0\times2^{-1}+0\times2^{-2}+1\times2^{-3})$

$2^6\,2^5\,2^4\,2^3\,2^2\,2^1\,2^0\;\;2^{-1}\,2^{-2}\,2^{-3}$

$= 32+8+4+2+1+0.125$

$= 47.125_{10}$

iv $(0\cdot111)_2 = (0\times2^0+1\times2^{-1}+1\times2^{-2}+1\times2^{-3})$

$2^0\;\;2^{-1}\,2^{-2}\,2^{-3}$

$= 0+0\cdot5+0\cdot25+0\cdot125$

$= 0\cdot875_{10}$

2. Octal to decimal

Eg:- $(27)_8 = (2\times8^1+7\times8^0)$

$= 16+7$

$= 23_{10}$

ii) $(245)_8 = (2\times8^2+4\times8+5\times8^0)$

$= 2\times64+32+5$

$= 165_{10}$

iii $(0.52)_8 = (0\times8^0+5\times8^{-1}+2\times8^{-2}) = 0.65625_{10}$

iii $(34.62)_8 = (3\times8^1+4\times8^0+6\times8^{-1}+2\times8^{-2})$

$= 24+.7781$

$= 24.78125_{10}$

iv) $(266)_8 = (2\times8^2+6\times8+6\times8^0)$

$= 182_{10}$

Hexadecimal to decimal

i) $(FF)_{16} = (F\times16^1)+(F\times16^0)$

$= 15\times16+15$

$= 255_{10}$

ii $(101)_{16} = 1\times16^2+0\times16^1+1\times16^0$

$= 256+1$

$= 257_{10}$

iii $(ABC)_{16} = A\times16^2+B\times16+C\times16^0$

$= 10\times256+11\times16+12$

$= 2748_{10}$

iv $(0.3D)_H = 0\times16^0+3\times16^{-1}+13\times16^{-2}$

$= 0+0.238$

$= 0.2382_{10}$

v $(AB.C)_{16} = 10\times16+11\times16^0+C\times16^{-1}$

$= 160+11+12\times16^{-1}$

$= 171.75_{10}$

vi $(DD.D)_{16} = 13\times16+13\times16^0+13\times16^{-1}$

$= 221.81_{10}$

Conversion of decimal to any radix

Double Dabble method

Integer – sucessive division method

fraction – sucessive multiplication method

Eg:- $(26.75)_{10} = (?)_2$

For integer part $26 =$

2	26	
2	13	– 0 → LSB
2	6	– 1
2	3	– 0
MSB ←	1	– 1

$26 = 11010$

For fraction part $0.75 = 0.75 \times 2 = 1.50$ M.S.B

$0.50 \times 2 = 1.00$

$00 \times 2 = 0.00$ L.S.B

$0.75 = 0.110$

$(26.75)_{10} = (11010.11)_2$

i) $244_{10} = (?)_2$

$244 =$

2	244	
2	122	– 0
2	61	– 0
2	30	– 1
2	15	– 0
2	7	– 1
2	3	– 1
	1	– 1

$244 = 11110100$

$244_{10} = (11110100)_2$

ii $26.025_{10} = (?)_2$

$26 = 11010$ $0.25 = 0.25 \times 2 = 0.50$

$0.50 \times 2 = 1.00$

$00 \times 2 = 0$

$0.025 \times 2 = 0.05$

$0.05 \times 2 = 0.1$

$0.1 \times 2 = 0.2$

$0.2 \times 2 = 0.4$

$0.4 \times 2 = 0.8$

$0.8 \times 2 = 1.6$

$0.025 = 000001$

$26.025 = (11010.000001)_2$

iii 37.25_{10}

$37 = 2\,|\,37$
$2\,|\,18 - 1$
$2\,|\,9 - 0$
$2\,|\,4 - 1$
$2\,|\,2 - 0$
$1 - 0$

$37 = \cancel{10001}\ 100101$

$0.25 = 0.25 \times 2 = 0.50 \times$
$0.50 \times 2 = 1.00$
$0.00 \times 0 = 0.00$

$0.25 = 0\cancel{1}010 \Rightarrow 37.25_{10} = \cancel{10001}.010$ 100101

iv $(52)_{10}$

$52 = 2\,|\,52$
$2\,|\,26 - 0$
$2\,|\,13 - 0$
$2\,|\,6 - 1$
$2\,|\,3 - 0$
$1 - 1$

$52_{10} = (110100)_2$

Decimal to octal

i) $(160)_{10}$

$160 = 8\,|\,160$
$8\,|\,20 - 0$
$2 - 4$

$160 = (240)_8$

ii $(0.52)_{10} = (?)_8$

$0.52 = 0.52 \times 8 = 4.16$
$0.16 \times 8 = 1.28$
$0.28 \times 8 = 2.24$
$0.24 \times 8 = 1.92$
$0.92 \times 8 = 7.36$
$0.36 \times 8 = 2.88$

$(0.52) = (0.412172)_8$

iii $756.32_{10} = ()_8$

$756 = 8\,|\,756$
$8\,|\,94 - 4$
$8\,|\,11 - 6$
$1 - 3$

$756 = 1364$

$0.32 = 0.32 \times 8 = 2.56$
$0.56 \times 8 = 4.48$
$0.48 \times 8 = 3.84$
$0.84 \times 8 = 6.72$
$0.72 \times 8 = 5.76$

$0.32 = 0.24365$

$756.32_{10} = (1364.24365)_8$

iv $(45.23)_{10} = ( )_8$

$45 = 8 \underline{|45}$
$\quad 5 - 5$

$45 = 55$

$0.23 = 0.23 \times 8 = 1.84$

$0.84 \times 8 = 6.72$

$0.72 \times 8 = 5.76$

$0.76 \times 8 = 6.08$

$0.23 = 0.1656$

$(45.23)_{10} = (55.1656)_8$

v $0.078_{10} = ( )_8$

$0.078 = 0.078 \times 8 = 0.624$

$= 0.624 \times 8 = 4.992$

$= 0.992 \times 8 = 7.936$

$= 0.936 \times 8 = 7.488$

$= 0.488 \times 8 = 3.904$

$0.078 = (0.04773)_8$

Decimal to hexadecimal:

i $(255)_{10} = ( )_{16}$

$16 \underline{|255}$
$\quad 15 - 15$

$16 = 15, 15 = (FF)_{16}$

ii (45.732)

$45 = 16 \underline{|45}$
$\quad 2 - 13$

$45 = 2D$

$0.732 = 0.732 \times 16 = 11.712$

$0.712 \times 16 = 11.392$

$0.392 \times 16 = 6.272$

$0.272 \times 16 = 4.352$

$0.4352 \times 16 = 5.632$

$0.732 = (BB645)$

$(45.732)_{10} = (2D.BB645)_{16}$

iii $(2598)_{10} =$

$2598 = 16 \underline{|2598}$
$16 \underline{|162} - 6$
$\quad 10 - 2$

$2598 = (A26)_{16}$

iv $(0.6752)_{10}$

$0.6752 = 0.6752 \times 16 = 10.8032$

$= 0.8032 \times 16 = 12.8512$

$= 0.8512 \times 16 = 13.6192$

$= 0.6192 \times 16 = 9.9072$

$= 0.9072 \times 16 = 14.5152$

$(0.6752)_{10} = (0.ACD9E)_{16}$

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Binary to Octal:-

Base of octal number system $8 = 2^3$

group of 3 binary bits = 1 octal digit

Octal	Binary
0	000
1	001
2	010
3	011
4	100
5	101
6	110
7	111

Eg:- $(1110011)_2 = (163)_8$

= 001 110 011

= 1 6 3

→ $(11101\cdot0011)_2$

011 101 0001 0100

3 5 · 0 3 1 4

∴ $(11101\cdot0011) = 35\cdot\cancel{03}14$

→ $(10101\cdot1111)_2$

= 010 101 · 111 100

= 2 5 · 7 4

∴ $(10101\cdot1111)_2 = 25\cdot74$

→ $(10\cdot01)_2$

= 010 · 010

= 2 · 2

∴ $(10\cdot01)_2 = (2\cdot2)_8$

→ $(0010\cdot0010000111)_2$

= 000 010 · 001 000 011 100

= 0 2 · 1 0 3 4

∴ $(0010\cdot0010000111)_2 = 02\cdot1034$

→ $(0\cdot0100)_2$

000 010 000

0 · 2

∴ $(0\cdot01000)_2 = 0\cdot2$

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Binary to hexadecimal

Base of hexa decimal number system $16 = 2^4$

group of 4 binary bits = 1 hexa decimal digit

hexadecimal	binary
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
(A) 10	1010
B	1011
C	1000
D	1101
E	1110
F	1111

Eg:- $(1110011)_2$

= 0111 0011

= 7 3

$\therefore (1110011)_2 = (73)_{16}$

→ $(11101 \cdot 0011)_2$

= 0001 1101 0011

= 1 D 3

$\therefore (11101 \cdot 0011)_2 = (1D.3)$

→ $(10101 \cdot 1111)_2$

= 0001 0101 1111

= 1 5 F

$\therefore (10101 \cdot 1111)_2 = (15 \cdot F)_{16}$

→ $(10 \cdot 01)_2$

= 0010 0100

= 2·4

$\therefore (10 \cdot 01)_2 = (2 \cdot 4)_{16}$

→ $(0010 \cdot 0010000111)_2$

0010   0010   0001   1100

2   2   1   C

$\therefore (0010 \cdot 0010000111)_2 = (2 \cdot 21C)_{16}$

→ $(0 \cdot 0100)$

0000   0100

0   4

$(0 \cdot 0100)_2 = (0 \cdot 4)_{16}$

Octal to binary

Eg:- $(25 \cdot 76)_8$

$(25 \cdot 76) =$ 2 5 7 6 ↓ 010 101 111 110

$(25 \cdot 76)_8 = (010101 \cdot 111110)_2$

→ $(6574 \cdot 25)_8$

= 6   5   7   4   2   5

= 110   101   111   100   010   101

= $(110101111100 \cdot 010101)_2$

→ $(0 \cdot 763)_8$

= 0   7   6   3

= 000   111   110   011

= $(0 \cdot 111110011)_2$

→ $(12345)_8$

= 1   2   3   4   5

= 001   010   011   100   101

$= (0010100111001011)_2$

Hexadecimal to Binary

→ $(FAC \cdot 35)_{16}$

= F A C 3 5

= 1111 1010 1100 0011 0101

$= (111110101100 \cdot 00110101)_2$

→ $(12AB)_{16}$

= 1 2 A B

= 0001 0010 1010 1011

$= (0001001010101011)_2$

→ $(0 \cdot 012)_{16}$

= 0 0 1 2

= 0 0000 0001 0010

$= (0 \cdot 000000010010)_2$

→ $(AB.58)_{16}$

= A B 5 8

= 1010 1011 0101 1000

$= (10101011 \cdot 01011)_2$

Octal to hexadecimal

$O \xleftrightarrow{B} H$

→ $(25 \cdot 434)_8$

2 5 4 3 4

010 101 100 011 100

$= (10101 \cdot 1000111)_2$

= 0001 0101 · 1000 1110

= 1 5 · 8 E

$= (15{\cdot}8E)_{16}$

→ $(57{\cdot}34)_8$

= 5 7 3 4

= 101 111 011 100

$= (101111 \cdot 011100)_2$

= 0010 1111 0111 0000

= 2 F · ~~3~~7

= (2F·7)

→ $(0{\cdot}774)_8$

= 0000 7 7 4

= 0 0111 0111 100

$= (0{\cdot}111111100)_2$

= 0 1111 1110

= 0· FE

$= (0{\cdot}FE)_{16}$

→ $(1754)_8$

= 1 7 5 4

= 0001 111 101 100

$= {}^{00}(1111101100)_2$

= ~~1111~~ 1011 0011 1110 1100

= F B 3 E C

$= (FB)_{16}$ $(3EC)_{16}$

Hexadecimal to octal

$H \xleftrightarrow{B} O$

$(5AC)_{16}$

5	A	C	
0101	1010	1100	
010	110	101	100
2	6	5	4

$= (2654)_8$

(58.56)

→ $(A12.5)_{16}$

A 1 2 5

= 1010 0001 0010 0101

= 101 000 010 010 010 100

= 5 0 2224

$= (50222.4)_8$

→ $(2018)_{16}$

= 2 0 1 8

= 0010 0000 0001 1000

= 001 000 000 000 011 000

= 100140

$= (100140)_8$

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$= (10101 \cdot 100011)_2$

$= 0001 \quad 0101 \quad 1000 \quad 1110$

$= 1 \quad 5 \quad 8 \quad E$

$= (15 \cdot 8E)_{16}$

$\rightarrow (57 \cdot 34)_8$

$= 5\,7 \quad 3 \quad 4$

$= 101 \quad 111 \quad 011 \quad 100$

$= (10111 \cdot 011100)_2$

$= 0010 \quad 1111 \quad 0111 \quad 0000$

$= 2 \quad F \quad 7$

$= (2F \cdot 7)_{16}$

$\rightarrow (0 \cdot 774)_8$

$= 0 \quad 7 \quad 7 \cdot 4$

$= 0 \quad 111 \quad 111 \quad 100$

$= (0 \cdot 111111100).$

$= 0 \quad 1111 \quad 1110$

$= 0 \quad E \quad F$

$= (0 \cdot EF)_{16}$

$\rightarrow (1754)_8$

$= 1 \quad 7 \quad 5 \quad 4$

$= 0001 \quad 111 \quad 101 \quad 100$

$= (001111101100)$

$= 0011 \quad 1110 \quad 1100$

$= (3EC)_{16}$

Hexadecimal to octal

$H \xleftrightarrow{B} O$

$(5AC)_{16}$

5 A C

= 0101 1010 1100

= 010 110 101 100

= 2 6 5 4

$= (2654)_8$

→ $(A12.5\emptyset)_{16}$

A 1 2 5 .

= 1010 0001 0010 0101

= 101 000 010 010 010 100

= 5 0 2 2 2 4

$= (502224)_8$

→ $(2018)_{16}$

= 2 0 1 8

= 0010 0000 0001 1000

= 001 000 000 001 100

= 1 0 0 1 4

$= (10014)_8$

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Conversion of any radix to radix

$(12)_3 \xrightarrow{D} ()_4$

$12 = 1\times3^1+2\times3^0$

$= 3+2$

$= 5_{10}$

$5_{10} = 4\underline{|5}$
$\quad 1-1$

$= (11)_4$

Binary arithmetic

Binary addition

$$\begin{array}{r} 1100 \\ +111 \\ \hline 10011 \end{array} \quad \begin{array}{r} \rightarrow 12 \\ \rightarrow 7 \\ \hline 19 \end{array}$$

Binary subtraction

$$\begin{array}{r} 1101 \\ 101 \\ \hline 1000 \end{array} \begin{array}{r} \rightarrow 13 \\ \rightarrow 5 \\ \hline 8 \end{array} \qquad \begin{array}{r} 1001 \\ 110 \\ \hline 011 \end{array} \begin{array}{l} \rightarrow 9 \\ \rightarrow 6 \\ \rightarrow 3 \end{array}$$

i $(58\cdot56)_{10}$

$58 = 8\underline{|58}$
$\quad 7-2$

$0\cdot56 = 0\cdot56\times8 = 4\cdot48$

$= 0\cdot48\times8 = 3\cdot84$

$= 0\cdot84\times8 = 6\cdot72$

$= 0\cdot72\times8 = 5\cdot76$

$= 0\cdot76\times8 = 6\cdot08$

$(58.56)_{10} = (72\cdot43656)_8$

$58 = 2\underline{|58}$
$2\underline{|29} - 0$
$2\underline{|14} - 1$
$2\underline{|7} - 0$
$2\underline{|3} - 1$
$\quad 1 - 1$

$0\cdot56 = 0\cdot56\times2 = 1\cdot12$

$0\cdot12\times2 = 0\cdot24$

$0\cdot24\times2 = 0\cdot48$

$0\cdot48\times2 = 0\cdot96$

$(58\cdot56)_{10} = (111010\cdot1)_2$

$58 = 16\underline{|58}$
$\quad 3-10$

$0\cdot56 = 0\cdot56\times16 = 8\cdot96$

$0\cdot96\times16 = 15\cdot36$

$0\cdot36\times16 = 5\cdot76$

$0\cdot76\times16 = 12\cdot16$

$0\cdot16\times16 = 0\cdot56$

$(58\cdot56)_{10} = (3A\cdot8F5$

ii $(46.58)_{16}$

$46.58 = 4\times16 + 6\times16^{0} + 5\times16^{-1} + 8\times16^{-2}$

$= 64 + 6 + 0.3125 + 0.03125$

$= 70.34375_{10}$

$70 = 2|70$
$2|35 - 0$
$2|14 - 1$
$2|7 - 0$
$2|3 - 1$
$1 - 1$

$0.34375 = 0.34375\times2 = 0.6875$

$0.6875\times2 = 1.375$

$0.375\times2 = 0.75$

$0.75\times2 = 1.5$

$0.5\times2 = 1$

$0\times2 = 0$

$= (111010.01011)_2$

$70 = 8|70$
$8|8 - 6$
$1 - 0$

$0.34375 = 0.34375\times8 = 2.75$

$0.75\times8 = 6$

$0\times8 = 0$

$= (106.26)_8$

iii $(110111101.00110)_2$

$= 1\times2^{8} + 1\times2^{7} + 0\times2^{6} + 1\times2^{5} + 1\times2^{4} + 1\times2^{3} + 1\times2^{2} + 0\times2^{1} + 1\times2^{0} + 0\times2^{-1}$

$+ 0\times2^{-2} + 1\times2^{-3} + 1\times2^{-4} + 0\times2^{-5}$

$= 256 + 128 + 0 + 32 + 16 + 8 + 4 + 1 + 1/8 + 1/16$

$= (445.21875)_{10}$

$445 = 8|445$
$8|55 - 5$
$6 - 7$

$0.21875 = 0.21875\times8 = 1.75$

$= 0.75\times8 = 6.0$

$= 0\times8 = 0$

$= (675.16)_8$

$445 = 16|445$
$16|27 - 13$
$1 - 11$

$0.21875 = 0.21875\times16 = 3.5$

$0.5\times16 = 8$

$0\times16 = 0$

iv $(257.12)_8$

$= 2\times8^2+5\times8+7\times8^0+1\times8^{-1}+2\times8^{-2}$

$= (175.15625)_{10}$

$175 =$ 2 | 175
2 | 87 − 1
2 | 43 − 1
2 | 21 − 1
2 | 10 − 1
2 | 5 − 0
2 | 2 − 1
1 − 0

$0.15625 = 0.15625\times2 = 0.3125$

$0.3125\times2 = 0.625$

$0.625\times2 = 1.25$

$0.25\times2 = 0.5$

$0.5\times2 = 1$

$175 = (10101111.00101)_2$

$175 =$ 16 | 175
10 − 15

$0.15625 = 0.15625\times16 = 2.5$

$0.5\times16 = 8$

$0\times16 = 0$

$= (AF.28)_{16}$

v $(25)_6$

$= 2\times6+5\times6^0$

$= 12+5$

$= (17)_{10}$

$17 =$ 7 | 17
2 − 3

$= (23)_7$

$17 =$ 4 | 17
4 − 1

$= (41)_4$

Octal arthmetic

Octal addition

$$
\begin{array}{r}
\overset{1}{4}\,6_8 \\
6\,4\,8 \\
\hline
1\,3\,2_8
\end{array}
\qquad
\begin{array}{r}
\rightarrow \; 10\overset{1}{0} \;\; 110 \\
\rightarrow \; 110 \;\; 100 \\
\hline
1011 \;\; 010_2 \\
1 \;\; 3 \;\; 2_8
\end{array}
$$

Octal subtraction

$$
\begin{array}{r}
\overset{4}{5}\;\overset{5+8}{6}\;\; 4+8 \\
7\;\;5 \\
\hline
4\;\;6\;\;7_8
\end{array}
\qquad
\begin{array}{r}
\rightarrow \; \overset{+0}{101} \;\; \overset{221}{110} \;\; \overset{212}{100} \\
111 \;\; 101 \\
\hline
100 \;\; 110 \;\; 111_2 \\
4 \;\; 6 \;\; 7_8
\end{array}
$$

Hexa decimal arthmetic

Hexa decimal addition

$$
\begin{array}{r}
\overset{1}{9}\;\;8 \\
+\;1\;\;8 \\
\hline
B\;\;0_{16}
\end{array}
\qquad
\begin{array}{r}
\rightarrow \; 10\overset{11}{01} \;\; 1000 \\
\rightarrow \; 0001 \;\; 1000 \\
\hline
1011 \;\; 0000_2 \\
B \;\; 0_{16}
\end{array}
\qquad
\begin{array}{r}
1 \\
+1 \\
\hline
10 \\
+1 \\
\hline
11 \rightarrow \text{sum}
\end{array}
$$

$\downarrow$ carry

hexa decimal subtraction

$$
\begin{array}{r}
54\overset{16}{0} \\
-009 \\
\hline
537_{16}
\end{array}
\qquad
\begin{array}{r}
\rightarrow \; 0101 \;\; 01\overset{11}{00} \;\; \overset{1112}{0000} \\
0000 \;\; 0000 \;\; 1001 \\
\hline
0101 \;\; 0011 \;\; 0111_2 \\
5 \;\; 3 \;\; 7_{16}
\end{array}
$$

Signed and unsigned numbers representation

Unsigned numbers $\longrightarrow$ all positive numbers

Signed → +ve – signed magnitude

Signed → -ve

→ signed magnitude

$(r-1)_s$ → 1s complement – diminished radix complement

r_s → 2s complement – radix complement

Binary Complements:

radix = 2

radix complement → r's → 2's

diminished radix complement → (r-1)'s → 1's

→ to find diminished radix complement,

$(r^n - r^{-m} - N)$

→ to find radix complement, $(r^n - r^{-m} - N) + 1$

n → no. of integer digits

m → no. of fraction digits

r → radix of the number system

N → given number

Eg:- $(1011)_2$ find 1's and 2's complements.

1's complement → $(r^n - r^{-m} - N)$

$n = 4$ → $(2^4 - 2^{-0} - 1011)$

$m = 0$ → $(16 - 1 - 1011_2)$

$r = 2$ → $(15)_{10} - (1011)_2$

$N = 1011$ → $1111 - 1011$

→ 0100

2's complement = $0100+1$

$= 0101_2$

$(1110)_2$

$n=4 \quad \Rightarrow (r^n - r^{-m} - N)$

$m=0 \quad \Rightarrow (2^4 - 2^{-0} - 1110)$

$r=2 \quad \Rightarrow (15)_{10} - (1110)_2$

$N=1110 \quad \Rightarrow 1111-1110$

$\Rightarrow 0001$

1's complement = 0001

2's complement = $0001+1$

$= 0010$

Decimal complements:

radix complement ⟶ 10's complement

diminished radix complement ⟶ 9's complement

Find 9's & 10's complement of given numbers

→ 45_{10}

$n=2 \quad m=0 \quad r=10 \quad N=45$

9's complement = $(10^2 - 10^0 - 45)$

$= (100-1-45)$

$= (99-45)$

$= 54_{10}$

10's complement = $54+1$

$= 55_{10}$

→ 74.01_{10}

$n=2 \quad m=2 \quad r=10 \quad N=74.01$

9's complement = $(10^2 - 10^{-2} - 74.01)$

$= (100 - 0.01 - 74.01)$

$= 25.98$

10's complement = $25.98+1$

$= 26.98_{10}$

Unsigned arithmetic:

Subtraction by using (r-1)'s complement form:

Case i:- Subtraction of smallest number from largest number

Procedure:

1. Determine (r-1)'s complement of subtrahend (smallest number)

2. Add the complement to the minuend (largest number)

3. After the addition the carry will be generated, i.e., known as end around carry (EAC)

4. Remove the carry and add it to the LSB(LSD) of the result.

Eg:- Subtract $85_{10}-42_{10}$ using 9's complement form

1. 9's complement of 42

$$\begin{array}{r} 99 \\ -42 \\ \hline 57_{10} \end{array}$$

2. $85+57 = 143_{10}$

3. carry is 1

4. Add carry to LSD i.e., 43

Eg:- $1110_2 - 0110_2$ using 1's complement form

1's complement 0110 is 1001

$$\begin{array}{r} 1110 \\ 1001 \\ \hline 10111 \end{array}$$

$$\begin{array}{r} 0111 \\ +1 \\ \hline 1000 \end{array}$$

eg:- $(70)_8 - (52)_8$

1. 7's complement of 52

$= (8^2 - 8^{-0} - 52)$

$= ((64-1)-52)$

$= (77-52) = 25$

2. $70 + 25 = 115$

$= 15$
$+1$
$= -16$

$(IF)_{16} - (13)_{16}$

15's complement of 13

$= (8^2 - 8^{-0} - 13)$

$= ((64-1)-13)$

$= (77-13) = 64$

1F
64
90

IF
-13
2

Case ii :- Subtracting largest number from smallest number

Procedure :

1. Determine (r-1)'s complement of subtrahend (largest number)

2. Add the complement to the minuend (smallest number)

3. After the addition no carry will be generated i.e., the result is -ve and it is in the complement form.

4. Take the complement of the obtain result to get the true value and place -ve sign

Eg:- subtract using 1's complement form

$101_2 - 110_2$

minuend subtrahend

1's complement of 110 = 001

101
001
110 → result in complemented form

1's complement of 110 = -001

$(4450)_{10} - (8461)_{10}$

1. 9's complement of 8461

9999
8461
1538_{10}

2. 7450
   1538
   8988

3. 9's complement of 8988

$$\begin{array}{r} 9999 \\ 8988 \\ \hline 1011 \end{array}$$

Result = -1011

$(101)_8 - (52)_8$

The 7's complement of 52 is

$= (8^2 - 8^{-0} - 52)$

$= ((64-1)-52)$

$= (77-52)$

$= 25$

2. 14_8
   25_8
   41

3. 7's complement of 41 is

$= (8^2 - 8^{-0} - 41)$

$= ((64-1)-41)$

$= 77-41$

$= -36$

iv $(20)_{16} - (95)_{16}$

The 15's complement of 95 is

$= (16^2 - 16^{-0} - 95)$

$= (256 - 1 - 95)$

$= (255) - (95)$

$= (FF) - 95$

$= 6A$

16 | 255
15 - 15

15 15
FF
95
6 A

$$\begin{array}{r} 20 \\ +6A \\ \hline 8A \end{array}$$

The 15's complement of 8A is

$= (16^2 - 16^{-0} - 8A)$

$= (255 - 8A)$

$= FF - 8A$

$= 75$

$$\begin{array}{r} FF \\ -\ 8A \\ \hline 75 \end{array}$$

Find 8's complement of 35_8

8's complement of 35 is

$= (8^2 - 8^{-0} - 35) + 1$

$= (64 - 1 - 35) + 1$

$= (63 - 35) + 1$

$= 77 - 35 + 1$

$= 43_8$

Find 16's complement of $1A2_{16}$

16's complement of 1A2 is

$= (16^3 - 16^{-0} - 1A2) + 1$

$= (255 - 1A2) + 1$

$= (FF - 1A2) + 1$

$= 15D + 1$

$= 15E$

Subtraction using radix complement form

Case i:- Subtracting smallest number from largest number

1. Determine r's complement to subtrahend (smallest number)

2. Add the complement to the minued (largest number)

3. After the addition the end around carry will be

generated. Discard the carry and sum itself is the result

Subtract using 2's complement form

Eg:- $1110_2 - 0111_2$

2's complement of 0111 is 1001

$$\begin{array}{r} 1110 \\ 1001 \\ \hline \text{discard} \leftarrow 1\,\underbrace{0111}_{\text{result}} = 7 \end{array}$$

$$\begin{array}{r} 0111 \\ +1 \\ \hline 1000 \end{array}$$

i $58_{10} - 42_{10}$

10's complement of $42 = 58$

$$\begin{array}{r} 58 \\ 58 \\ \hline \text{discard} \leftarrow 1\underbrace{16}_{\text{result}} \end{array}$$

2. $14_{8} - 10_8$

8's complement of $10 = (8^2 - 8^{-0} - 10) + 1$

$= (64-1-10)+1$

$= (77-10)+1$

$= (67)+1$

$= 68$

$$\begin{array}{r} 14 \\ 68 \\ \hline 1\underbrace{04}_{\text{result}} \end{array}$$

3. $FF_{16} - 70_{16}$

16's complement of $70 = (16^2 - 16^{-0} - 70)+1$

$= (255-70)+1$

$= 8F+1$

$= 90$

$$\begin{array}{r} FF \\ 70 \\ \hline 8\,15 \end{array}$$

$$\begin{array}{r} 8F \\ +1 \\ \hline 90 \end{array}$$

$$\begin{array}{r} FF \\ 90 \\ \hline 18F \end{array}$$

$FF+90 = 1\underbrace{8F}_{\text{result}}$

Case ii:- Subtracting largest no. from smallest no

1. Determine r's complement to the subtrahend (largest no.)

2. Add the complement to the minued (smallest no)

3. After the addition no carry will be generated

4. Therefore result is -ve take the complement of result to get the true value and place -ve sign

Subtract using 2's complement form 0111 - 1110

2's complement of $1110 = 0010_2$

$$\begin{array}{r} 0111 \\ 0010 \\ \hline 1001 \end{array}$$

2's complement of $1001 = -0111_2$

$10_8 - 12_8$

$42_{10} - 60_{10}$

$15\,8_{16} - 542_{16}$

10's complement of 60 = 40

$$\begin{array}{r} 42 \\ 40 \\ \hline 82 \end{array}$$

10's complement of 82 = 18

$15_8 - 12_8$

8's complement of $12 = (8^2 - 8^{-0} - 12) + 1$

$= (64-1-12)+1$

$= (77-12)+1$

$= 66$

$$\begin{array}{r} 15 \\ 66 \\ \hline 103 \end{array}$$

8's complement ~~of~~ ~~103~~ $= (8^3 - 8^{-0} - 103) + 1$

$= (512 - 1 - 103) + 1$

$=$ [illegible]

Signed Binary arithmetic

Represent using 8 bits

+12 → 00001100 → signed magnitude form

−12 → 10001100 → signed magnitude form

−12 → 11110011 → 1's complement form

−12 → 11110100 → 2's complement form

Signed binary arithmetic using 2's complement form

1. Determine 2's complement of −ve numbers
2. Add the numbers.
3. After the arithmetic operation discard the carry if any
4. If MSB is 1 then the result is −ve and take 2's complement of the ~~magnitude~~ of the result to get the true value
5. If MSB is 0 the result is +ve and the sum itself is the result.

Eg:-

$$\begin{array}{rcl} +7 & \rightarrow & 00000111 \\ +\ +3 & \rightarrow & 00000011 \\ \hline 10 & \rightarrow & 00001010 \end{array}$$

ii)

−7 → 10000111 → 01111000

$$\begin{array}{rl} -7 & \\ +\ +3 & 00000011 \\ \hline \end{array}$$

2's complement of −7 = 011111001

$$\begin{array}{r} 11111001 \\ +\ 00000011 \\ \hline 11111100 \end{array}$$

2's complement of 11111100 is 00000100

$$\begin{array}{r} -A \\ -B \\ \hline \end{array} \cong \begin{array}{r} -A \\ +B \\ \hline \end{array} \quad - \begin{array}{r} -A \\ +B \\ \hline \end{array} \cong \begin{array}{r} -A \\ +-B \\ \hline \end{array} \quad \begin{array}{r} +A \\ -B \\ \hline \end{array} \cong \begin{array}{r} +A \\ +B \\ \hline \end{array}$$

$$\begin{array}{r} +A \\ -\ +B \\ \hline \end{array} \cong \begin{array}{r} +A \\ +-B \\ \hline \end{array}$$

i) $(-17)_{10} - (-10)_{10}$

$-17 \longrightarrow 10010001$

$+ \ +10 \longrightarrow 00001010$

$$\begin{array}{r} 1\cancel{0}01110 \\ +1 \\ \hline 1101111 \end{array}$$

2's complement of $-17 = 1110111$

$(+257) - (+32)$

$+(-32)$

$$\begin{array}{r} 11101111 \\ 00001010 \\ \hline 11111001 \end{array}$$

2's complement of $11111001 = 00000111$

ii $(10001100)_2 - (10001111)_2$

$= (+10001100)_2 + (-10001111)$

2's complement of $10001111 = 01110001$

$$\begin{array}{r} 10001100 \\ 01110001 \\ \hline 1|01111101 \end{array}$$

2's complement of $01111101 = 10000011$

10001100

+ 00001111

2's complement of 10001100 is = 11110100

$$\begin{array}{r} 11110100 \\ 00001111 \\ \hline 1]00000011 \end{array}$$

The result is +00000011

$(+12)_8 - (+11)_8$

$(+12)_8 + (-11)_8 = 00001010 + (10001001)$

2's complement of 10001001 = 01110111

$$\begin{array}{r} 00001010 \\ 10111011 \\ \hline 1]00000001 \end{array}$$

Result is = +00000001

$(25)_{10} - (-10)_{10}$ using 1's complement, 2's complement

$(25)_{10} - (-10)_{10} = (25)_{10} + (10)_{10}$

$$\begin{array}{rr} (25)_{10} = & 0001\ 1001 \\ +10 = & 0000\ 1010 \\ \hline & 0010\ 0011 \end{array}$$

Binary Codes:

Binary codes
- Numeric codes eg:- BCD codes
- Alphanumeric codes eg:- ASCII, EBCDIC

Numeric codes
- weighted codes
  - positively weighted codes Eg:- 8421, 5421, 2421 etc
  - negatively weighted codes Eg:- 84-2-1, 642-3 etc
- non weighted codes $\longrightarrow$ Excess$_3$(XS-3), gray code

Decimal digit	8421	2421	5421	642-3	84-2-1	XS-3
0	0000	0000	0000	0000	0000	0011
1	0001	0001	0001	0101	0111	0100
2	0010	0010	0010	0010	0110	0101
3	0011	0011	0011	1001	0101	0110
4	0100	0100	0100	0100	0100	0111
5	0101	1011	1000	1011	1011	1000
6	0110	1100	1001	0110	1010	1001
7	0111	1101	1010	1101	1001	1010
8	1000	1110	1011	1010	1000	1011
9	1001	1111	1100	1111	1111	1100
Unused bit combinations	1010	0101	0101	0001	0001	1101
	1011	0110	0110	0011	0010	1110
	1100	0111	0111	0111	0011	1111
	1101	1000	1101	1000	1100	10000
	1110	1001	1110	1100	1101	10001
	1111	1010	1111	1110	1110	10010

Binary code division arthmetic

→ BCD addition

1. Represent the BCD numbers in BCD form
2. Add the two BCD numbers using ordinary binary addition
3. If four bits sum is equal or less than '9', no correction is required and the sum is in BCD form.
4. If four bits sum is greater than 9 (or) if a carry is generated from four bits sum that sum is invalid
5. To correct this invalid sum add 0110 (6) to the four bit sum

Eg:- 12+15

```
 12  →  0001  0010
+15  →  0001  0101
 27     0010  0111
         <9    <9
          2     7
```

48+58

```
 48 → ~~0000~~ ~~1110~~   0100   1000     (48 in BCD)
 58   ~~0101~~ ~~1110~~   0101   1000     (58 in BCD)
106           ~~0000~~    1010  10000
                          carry
                        propagated
                       to next grp

                    1010   0000     (2 groups sums are >9
                    0110   0110      Add correction factor
              0001  0000   0110      '0110' to two groups to
                 1     0      6      skip invalid stages)
                                     (Result in BCD form)
```

24 + 18

```
 24  → 0010  0100
+18  → 0001  1000
 42    --------------
       0011  1100 >9
       0000  0110
       --------------
       0100  0010
          1
       4     2
```

175+326

```
 175 → 0001      0111      0101
 326 → 0011      0010      0110
 501   ------------------------------
       0100(4)   1001(9)   1011 >9
       0000      0000      0110
       ------------------------------
       0100(4)   1010>9    0001 (1)
       0000      0110      0000
       ------------------------------
       0101      0000      0001
       5         0         1
```

589 + 199

```
 589 → 0101      1000        1001
 199 → 0001      1001        1001
 788   ----------------------------------
       0111      10010(18)   10010 (18)
       0000      0110        0110
       ----------------------------------
       0111      1000        1000
       7         8           8
```

BCD subtraction using complement method

$20_{10} - 14_{10}$

```
 20   --BCD-->                       0010    0000
-14   --14 in 9's complement-->      1000    0101
                                     1010    0101
                                     0110    0000
                               EAC  1|0000   0101
                                                1
                                     -------------
                                     0000    0110 → 6
```

8 - 2 (using 10's complement)

```
 8   --BCD-->              1000
-2   --10's complement-->  1000
                           10000
```

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```
 0000
 0110
 ----
 0110 → 6
```

28-13 using 10's complement

```
  28  --BCD-->      0010   1000
 -13  --10's com--> 00
                    1000   0111
                    ----   ----
                    1010   1111
                    0110   0110
                   -----   ----
                  1 0001   0101
                      15
```

79-26 using 9's complement

```
  79  --BCD-->      0111   1001        0111   1001
 -26  --9's com-->  0010   0110        0111   0011
 ----               ----   ----        ----   ----
  53                1001   1111        1110   1100
                                       0110   0110
                                      -----   ----
                                     1 0101   0010
                                       00       +1
                                       ----   ----
                                       0101   0011
                                        5      3
```

89-54 using 9's complement

```
  89  →  1000   1001
 -54  →  0100   0101
 ----    ----   ----
  35     1100   1110
         0110   0110
        -----   ----
       1 0011   0100
                  +1
         ----   ----
         0011   0101
          3      5
```

XS-3 Arthmetic

XS-3 addition

1. Represent the given numbers in XS-3 form

2. Add XS-3 number by adding four bit group in each column

Starting from LSD

3. If there is no carry from addition of four bit groups subtract 0111(3) from the sum of these groups.

Add 6 and 3 in X-S-3 arithmetic

6 → ~~1001~~ 1100 1001

3 → ~~0110~~ 0110

~~1111~~ 1111

(-) ~~0110~~ 0011

~~1010 1~~ (-)

~~1001~~ 1100 → 9

12+20

12 → 0001 0010 0100 0101

20 → 0010 0000 0101 0011

0011 0010 1001 1000

(-) 0011 0011 0011 0011

1 0110 0101

↓ ↓

3 in X-S 2 in X-S

37 + 28

37 → 0110 1010

28 → 0101 1011

1100 0101

1

247.6+359.4

X-S-3 subtraction using complements method

Subtract $24_{10} - 10_{10}$ using 9's complement form

9's complement of 10   99 − 10 = 89

```
24  --XS-3-->   0101   0111
89  --XS-3-->   1011   1100
              ---------------
               10001   10011
                0011    0011
              ---------------
              1 0100    0110
                           1
              ---------------
                0100    0111
                  1       4
```

```
24  --XS-3-->   0101   0111
90  -------->   1100   0000
              ---------------
               10001   10010
             (+)0011 (-)0011
              ---------------
discard  1 |    0100    0111
                  1       4
```

37 − 28 using 10's complement form

10's complement of 28 is 72

```
37  --XS-3-->   0110   1010
72  --XS-3-->   1010   0101
              ---------------
               10000   1111
             (+)0011 (-)0011
              ---------------
             1| 0011   1100
                  0      9
```

687 − 348 9's

246 − 592 using 10's complement form

354 − 672 10's

```
246  -------->  0101   0111   1001
408  -------->  0111   0011   1011
              ----------------------
                1100   1011  10100
                0011   0011   0011
                (-)    (-)    (+)
              ----------------------
                1001   1000   0111
```

9's complement of 1001 1000 0111 is 0110 0111 1001

3   4   6

687-348 using 9's complement

687 → 1001 1011 1010

651 → 1001 1000 0000

10011 10011 1110

(+)0011 (+)0011 (-)0011

1|0110 0110 1011

3 3 9+1

0110 0110 1100

3 3 9

354-672 using 10's complement

354 → 0110 1000 0111

328 → 0110 0101 1011

1100 1110 10010

0011 0011 0011

(-) (-) (+)

1001 1011 0101

2's complement of 1001 1011 0101 is -0110 0100 1011

-3 1 8

Grey code:

→ non-weighted code

→ unit distance code

→ Reflexive code

→ Used in data acquiston, A/D convertors etc

→ Not used for arithmetic operations

Binary number → $B_n B_{n-1} B_{n-2} \dots B_1$

Grey number → $G_n G_{n-1} G_{n-2} \dots G_1$

Binary to grey code conversion

$G_n = B_n$

$G_{n-1} = B_n \oplus B_{n-1}$

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$$G_{n-2} = B_{n-1} \oplus B_{n-2}$$

$\vdots$

$$G_1 = B_2 \oplus B_1$$

Grey to Binary conversion

$$B_n = G_n$$

$$B_{n-1} = B_n \oplus G_{n-1}$$

$$B_{n-2} = B_{n-1} \oplus G_{n-2}$$

$\vdots$

$$B_1 = B_2 \oplus G_1$$

A	B	EX-OR
0	0	0
0	1	1
1	0	1
1	1	0

B → G G → B

Binary → 1010 Grey → ~~1111~~ 1111

Grey → 1111 Binary → 1-0-1 0 1010

convert into gray code
i) 25_{10} ii) 567_{10}
110 1101 to gray code

Draw the tabular form of conversion of 3 bit binary to grey code and also 4 bit binary to grey code

Binary $B_3B_2B_1$	Gray $G_3G_2G_1$
000	000
001	001
010	011
011	010
100	110
101	111
110	101
111	100

Binary $B_4B_3B_2B_1$	Gray $G_4G_3G_2G_1$
0000	0000 → 0
0001	0001 → 1
0010	0011 → 3
0011	0010 → 2
0100	0110 → 6
0101	0111 → 7
0110	0101 → 5
0111	0100 → 4
1000	1100 → 12
1001	1101 → 13
1010	10111 → 15
1011	1110 → 14
1100	1010 → 10
1101	1011 → 11
1110	1001 → 9
1111	1000 → 8

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