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Digital Electronics and Logic Design

Binary Codes

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Binary coded decimal

■ BCD

- Binary coded decimal (BCD) is a way to express each of the decimal digits with a binary code.
- There are only ten code groups in the BCD system.
- In BCD, 4 bits represent each decimal digit.
- The **8421** code is a type of BCD.
- BCD means that each decimal digit, 0 through 9, is represented by a binary code of four bits.
- The designation 8421 indicates the binary weights of the four bits (**2^3 , 2^2 , 2^1 , 2^0**).

Complements

Decimal/binary conversion

DECIMAL DIGIT	0	1	2	3	4	5	6	7	8	9
BCD	0000	0001	0010	0011	0100	0101	0110	0111	1000	1001

■ **Decimal/binary conversion**

- With four bits 16 numbers (0000 through 1111) can be represented.
- In BCD only ten of these are used.
- The six code combinations that are not used.
- 1010, 1011, 1100, 1101, 1110, and 1111-are invalid in the 8421 BCD code.

- To express any decimal number in BCD, simply replace each decimal digit with 4-bit code,
- Convert each of the following decimal numbers to BCD:
- (a) 35 (b) 98 (c) 170 (d) 2469

Solution

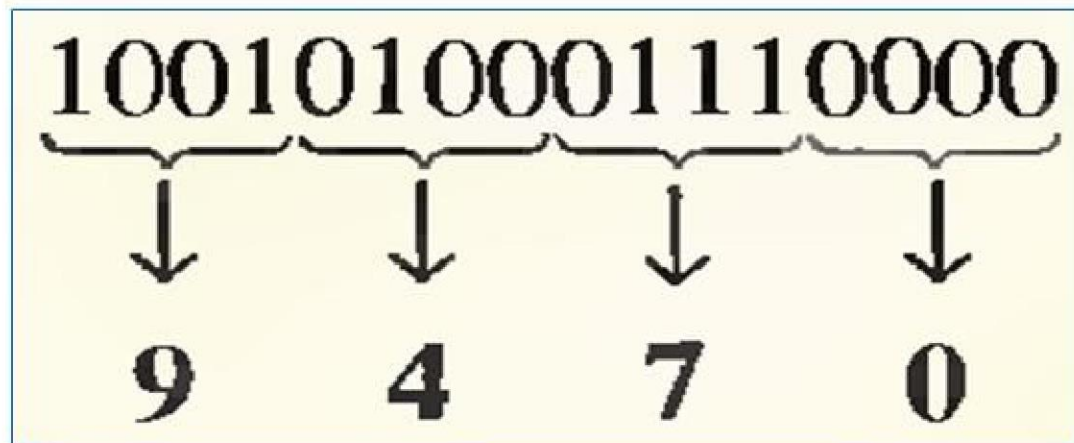
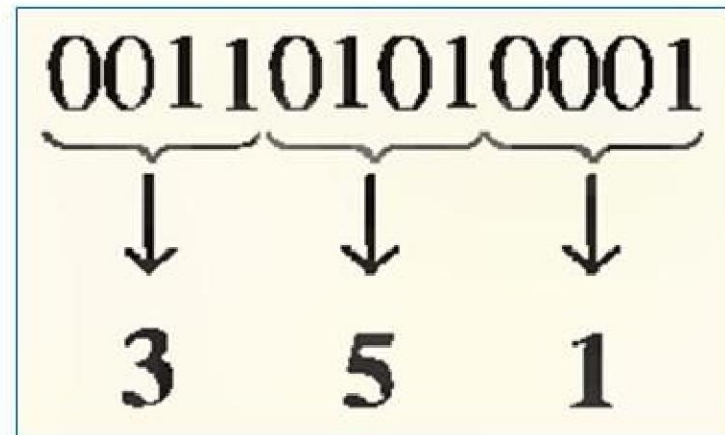
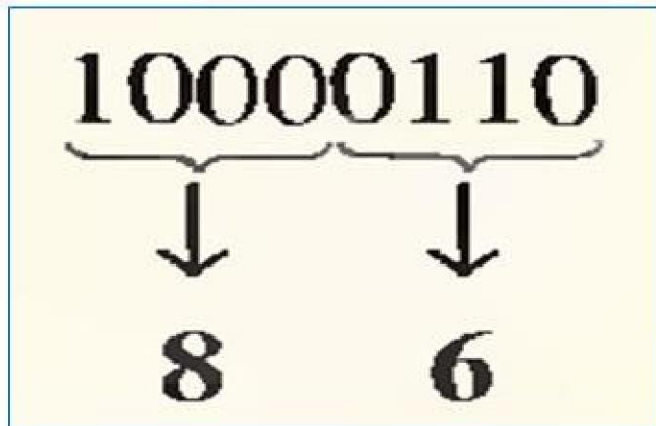
$$\begin{array}{cc}
 \text{(a)} & 3 & 5 \\
 & \downarrow & \downarrow \\
 & \overbrace{0011} & \overbrace{10101} \\
 & & \text{00110101}
 \end{array}$$

$$\begin{array}{cc}
 \text{(b)} & 9 & 8 \\
 & \downarrow & \downarrow \\
 & \overbrace{1001} & \overbrace{1000} \\
 & & \text{10011000}
 \end{array}$$

$$\begin{array}{ccc}
 \text{(c)} & 1 & 7 & 0 \\
 & \downarrow & \downarrow & \downarrow \\
 & \overbrace{0001} & \overbrace{1011} & \overbrace{10000} \\
 & & & \text{000101110000}
 \end{array}$$

$$\begin{array}{cccc}
 \text{(d)} & 2 & 4 & 6 & 9 \\
 & \downarrow & \downarrow & \downarrow & \downarrow \\
 & \overbrace{0010} & \overbrace{0100} & \overbrace{0110} & \overbrace{1001} \\
 & & & & \text{0010010001101001}
 \end{array}$$

Some more examples



- Here is how to add two BCD numbers
 - Add the two BCD numbers, using the rules for binary addition.
 - If a 4-bit sum is equal to or less than 9, it is a valid BCD number.
 - If a 4-bit sum is greater than 9, or if a carry out of the 4-bit group is generated, it is an invalid result. Add 6 (0110) to the 4-bit sum in order to skip the six invalid states and return the code to 8421. If a carry results when 6 is added, simply add the carry to the next 4-bit group.

examples

- The decimal number additions are shown for comparison.

$$\begin{array}{r} \text{(a)} \quad 0011 \quad 3 \\ + 0100 \quad + 4 \\ \hline 0111 \quad 7 \end{array}$$

$$\begin{array}{r} \text{(c)} \quad 1000 \quad 0110 \quad 86 \\ + 0001 \quad 0011 \quad + 13 \\ \hline 1001 \quad 1001 \quad 99 \end{array}$$

$$\begin{array}{r} \text{(b)} \quad 0010 \quad 0011 \quad 23 \\ + 0001 \quad 0101 \quad + 15 \\ \hline 0011 \quad 1000 \quad 38 \end{array}$$

$$\begin{array}{r} \text{(d)} \quad 0100 \quad 0101 \quad 0000 \quad 450 \\ + 0100 \quad 0001 \quad 0111 \quad + 417 \\ \hline 1000 \quad 0110 \quad 0111 \quad 867 \end{array}$$

Examples (Invalid Cases)

Example 1

The decimal number additions are shown for comparison.

(a)	1001		9
	<u>+ 0100</u>		<u>+4</u>
	1101	Invalid BCD number (>9)	13
	<u>+ 0110</u>	Add 6	
	<u>0001</u>	Valid BCD number	
	<u>0011</u>		
	↓		
	1		
	↓		
	3		

BCD Addition (Invalid cases)

Example 2

(b)

	1001		9
	+ 1001		+ 9
1	0010	Invalid because of carry	18
	+ 0110	Add 6	
<u>0001</u>	<u>1000</u>	Valid BCD number	
↓	↓		
1	8		

BCD Addition (Invalid cases)

Example 3

(c)	0001	0110		16
	+ 0001	0101		+ 15
	<hr/>			
	0010	1011	Right group is invalid (>9),	31
			left group is valid.	
		+ 0110	Add 6 to invalid code. Add	
			carry, 0001, to next group.	
	<hr/>		Valid BCD number	
	<u>0011</u>	<u>0001</u>		
	↓	↓		
	3	1		

BCD Addition (Invalid cases)

Example 4

(d)

0110

+ 0101

1011

+ 0110

0001



1

0010



2

0111

+ 0011

1010

+ 0110

0000



0

67

+ 53

120

Both groups are invalid (>9), so add 6 to both groups.

Valid BCD Number

- BCD code is a numeric code.
- Some other codes are alphanumeric.
 - they are used to represent numbers, letters, symbols, and instructions.
 - That is they are used to represent letters, numbers, symbols,
 - For example Gray code, ASCII Code.
 - Reading Assignment (Alphanumeric, EBCDIC, Error Detection and Correction code etc)

- Gray code has the following conventions,
 - It is unweighted code also not arithmetic code.
 - there are no specific weights assigned to the bit positions.
 - The important feature of the Gray code is that it exhibits only a single bit change from one code word to the next in sequence.
 - Like binary numbers. the Gray code can have any number of bits.

Gray Code

Table below shows the 4-bit Gray code for decimal numbers 0 through 15.

DECIMAL	BINARY	GRAY CODE	DECIMAL	BINARY	GRAY CODE
0	0000	0000	8	1000	1100
1	0001	0001	9	1001	1101
2	0010	0011	10	1010	1111
3	0011	0010	11	1011	1110
4	0100	0110	12	1100	1010
5	0101	0111	13	1101	1011
6	0110	0101	14	1110	1001
7	0111	0100	15	1111	1000

Binary to Gray Code Conversion

- Convention to be used for conversion,
 - The most significant bit (left-most) in the Gray code is the same as the corresponding MSB in the binary number.
 - Going from left to right, add each adjacent pair of binary code bits to get the next Gray code bit. Discard carries.

Binary to Gray Code Conversion

For example, the conversion of the binary number **10110** to Gray code is as follows:

1	-	+	→	0	-	+	→	1	-	+	→	1	-	+	→	0	Binary
↓				↓				↓				↓				↓	
1				1				1				0				1	Gray

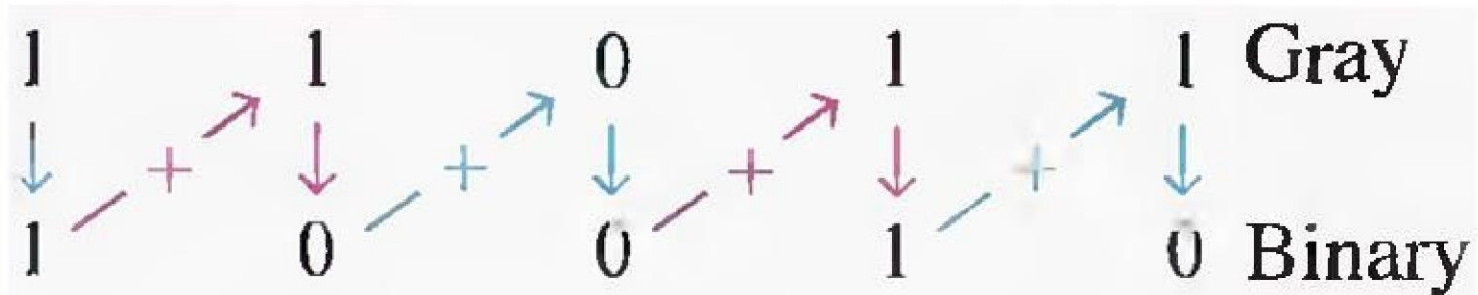
The Gray code is 11101.

Gray Code to Binary Conversion

- Convention to be used for conversion,
 - The most significant bit (left-most) in the binary code is the same as the corresponding bit in the Gray code.
 - Add each binary code bit generated to the Gray code bit in the next adjacent position. Discard carries.

Binary to Gray Code Conversion

For example, the conversion of the Gray code word **11011** to binary is as follows:



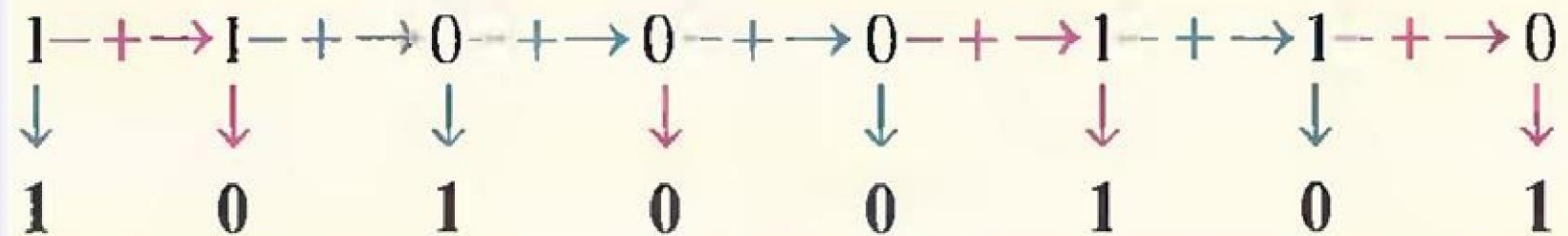
The Binary code is 10010.

Conversion Examples

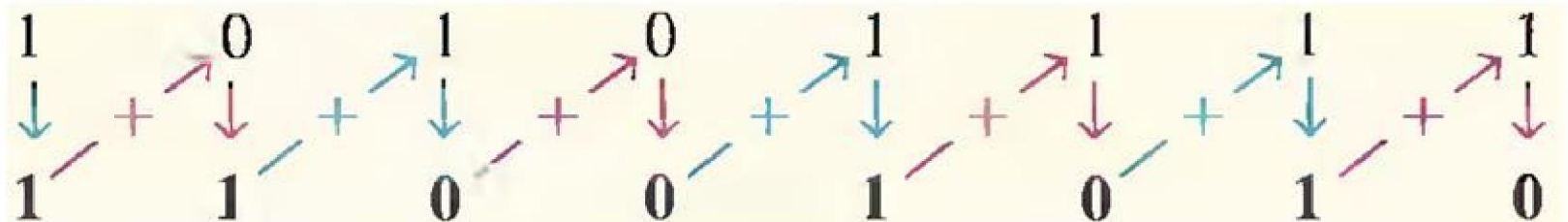
- (a) Convert the binary number 11000110 to Gray code.
- (b) Convert the Gray code 1010111 to binary.

Solution

(a) Binary to Gray code:



(b) Gray code to binary:



ASCII Code

- **ASCII** is the abbreviation for American Standard Code for Information Interchange.
- **ASCII** is a universally accepted alphanumeric code used in most computers and other electronic equipment.
- When you enter a letter, a number, or control command, the corresponding **ASCII** code goes into the computer.
- **ASCII** has 128 characters and symbols represented by a 7-bit binary code.
- Actually, ASCII can be considered an 8-bit code with the MSB always 0.

- The first thirty-two ASCII characters are nongraphic commands that are never printed or displayed.
- These are used for control purposes.
 - E.g. line of feed, null, start of text, escape etc.
- The other characters are graphic symbols that can be printed includes,
 - Letter of alphabet, 10 decimal digits, punctuation symbols and other commonly used symbols.

CONTROL CHARACTERS				GRAPHIC SYMBOLS											
NAME	DEC	BINARY	HEX	SYMBOL	DEC	BINARY	HEX	SYMBOL	DEC	BINARY	HEX	SYMBOL	DEC	BINARY	HEX
NUL	0	0000000	00	space	32	0100000	20	@	64	1000000	40	~	96	1100000	60
SOH	1	0000001	01	!	33	0100001	21	A	65	1000001	41	a	97	1100001	61
STX	2	0000010	02	"	34	0100010	22	B	66	1000010	42	b	98	1100010	62
ETX	3	0000011	03	#	35	0100011	23	C	67	1000011	43	c	99	1100011	63
EOT	4	0000100	04	\$	36	0100100	24	D	68	1000100	44	d	100	1100100	64
ENQ	5	0000101	05	%	37	0100101	25	E	69	1000101	45	e	101	1100101	65
ACK	6	0000110	06	&	38	0100110	26	F	70	1000110	46	f	102	1100110	66
BEL	7	0000111	07	'	39	0100111	27	G	71	1000111	47	g	103	1100111	67
BS	8	0001000	08	(	40	0101000	28	H	72	1001000	48	h	104	1101000	68
HT	9	0001001	09	)	41	0101001	29	I	73	1001001	49	i	105	1101001	69
LF	10	0001010	0A	*	42	0101010	2A	J	74	1001010	4A	j	106	1101010	6A
VT	11	0001011	0B	+	43	0101011	2B	K	75	1001011	4B	k	107	1101011	6B
FF	12	0001100	0C	,	44	0101100	2C	L	76	1001100	4C	l	108	1101100	6C
CR	13	0001101	0D	-	45	0101101	2D	M	77	1001101	4D	m	109	1101101	6D
SO	14	0001110	0E	.	46	0101110	2E	N	78	1001110	4E	n	110	1101110	6E
SI	15	0001111	0F	/	47	0101111	2F	O	79	1001111	4F	o	111	1101111	6F
DLE	16	0010000	10	0	48	0110000	30	P	80	1010000	50	p	112	1110000	70
DC1	17	0010001	11	1	49	0110001	31	Q	81	1010001	51	q	113	1110001	71
DC2	18	0010010	12	2	50	0110010	32	R	82	1010010	52	r	114	1110010	72
DC3	19	0010011	13	3	51	0110011	33	S	83	1010011	53	s	115	1110011	73
DC4	20	0010100	14	4	52	0110100	34	T	84	1010100	54	t	116	1110100	74
NAK	21	0010101	15	5	53	0110101	35	U	85	1010101	55	u	117	1110101	75
SYN	22	0010110	16	6	54	0110110	36	V	86	1010110	56	v	118	1110110	76
ETB	23	0010111	17	7	55	0110111	37	W	87	1010111	57	w	119	1110111	77
CAN	24	0011000	18	8	56	0111000	38	X	88	1011000	58	x	120	1111000	78
EM	25	0011001	19	9	57	0111001	39	Y	89	1011001	59	y	121	1111001	79
SUB	26	0011010	1A	:	58	0111010	3A	Z	90	1011010	5A	z	122	1111010	7A
ESC	27	0011011	1B	;	59	0111011	3B	[	91	1011011	5B	{	123	1111011	7B
FS	28	0011100	1C	<	60	0111100	3C	\	92	1011100	5C	|	124	1111100	7C
GS	29	0011101	1D	=	61	0111101	3D	]	93	1011101	5D	}	125	1111101	7D
RS	30	0011110	1E	>	62	0111110	3E	^	94	1011110	5E	~	126	1111110	7E
US	31	0011111	1F	?	63	0111111	3F	_	95	1011111	5F	Del	127	1111111	7F

Examples

- The **first thirty-two ASCII** characters are called the control characters.
- These are used to allow devices such as a computer and printer to communicate with each other when passing information and data.
- The **extended ASCII** characters are represented by an 8-bit code.
- Extended ASCII has additional 128 characters to present other symbols.
- The extended ASCII character set is presented in the table.

SYMBOL	DEC	HEX	SYMBOL	DEC	HEX	SYMBOL	DEC	HEX	SYMBOL	DEC	HEX
Ç	128	80	á	160	A0	Ł	192	C0	α	224	E0
ü	129	81	í	161	A1	⊥	193	C1	β	225	E1
é	130	82	ó	162	A2	⊥	194	C2	Γ	226	E2
â	131	83	ú	163	A3	⊥	195	C3	π	227	E3
ä	132	84	ñ	164	A4	—	196	C4	Σ	228	E4
à	133	85	Ñ	165	A5	+	197	C5	σ	229	E5
ã	134	86	ã	166	A6	⊥	198	C6	μ	230	E6
ç	135	87	Ω	167	A7	⊥	199	C7	τ	231	E7
ê	136	88	ı	168	A8	⊥	200	C8	Φ	232	E8
ë	137	89	┌	169	A9	⊥	201	C9	Θ	233	E9
è	138	8A	└	170	AA	≡	202	CA	Ω	234	EA
ÿ	139	8B	½	171	AB	≡	203	CB	δ	235	EB
î	140	8C	¼	172	AC	⊥	204	CC	∞	236	EC
ì	141	8D	ı	173	AD	≡	205	CD	φ	237	ED
Ä	142	8E	«	174	AE	⊥	206	CE	ε	238	EE
Å	143	8F	»	175	AF	≡	207	CF	∩	239	EF
É	144	90	■	176	B0	⊥	208	DO	≡	240	F0
æ	145	91	■	177	B1	≡	209	D1	⊥	241	F1
Æ	146	92	■	178	B2	⊥	210	D2	≡	242	F2
ô	147	93	|	179	B3	⊥	211	D3	≡	243	F3
ö	148	94	└	180	B4	⊥	212	D4	┌	244	F4
ò	149	95	≡	181	B5	⊥	213	D5	└	245	F5
û	150	96	≡	182	B6	⊥	214	D6	+	246	F6
ù	151	97	⊥	183	B7	≡	215	D7	≡	247	F7
ÿ	152	98	≡	184	B8	⊥	216	D8	•	248	F8
Ö	153	99	≡	185	B9	⊥	217	D9	•	249	F9
Ü	154	9A	≡	186	BA	┌	218	DA	•	250	FA
é	155	9B	≡	187	BB	■	219	DB	✓	251	FB
£	156	9C	≡	188	BC	■	220	DC	η	252	FC
¥	157	9D	⊥	189	BD	■	221	DD	²	253	FD
₪	158	9E	└	190	BE	■	222	DE	■	254	FE
f	159	9F	└	191	BF	■	223	DF	□	255	FF