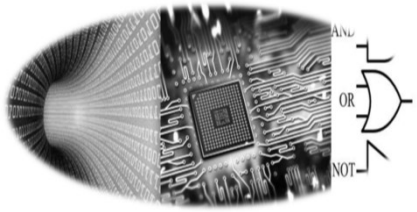
DIGITAL ELECTRONICS

Lecture Note 02: Number Systems



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Date: Jan-Jun, 2022

Number Systems

- **A number system defines a set of values used to represent different quantities of the parameters.**
- **Examples:**
  - **Number of students** in a class
  - **Number of players** playing a cricket match in a stadium
  - **Numbers of books** in a library
  - **Numbers of coins** in your purse etc.
- The **digital computer internally uses the binary numbers system to represent data and information (includes video, audio, graphics, text, and numbers) or to perform the arithmetic calculations.**
- **Base or Radix: The base or radix is the total numbers of digit used in a number system.**
- It is, sometimes, written after the number as a subscript.

https://examstop.com/2018/09/27/number-system-in-a-computer/

Different Number Systems

- **Types of Number Systems**
- Some important number systems are as follows:
  - **Decimal (comes from the Latin word "decimus (ten)")**
  - **Binary (comes from the Latin word "bīnārius (two)")**
  - **Octal (comes from the Latin word "octo (eight)")**
  - **Hexadecimal (comes from the Greek word "hexa (six)")**
- **Base of Number Systems**
- **Each number system has a base**
  - **Decimal: Base 10 (Digits: 0 1 2 3 4 5 6 7 8 9)**
  - **Binary: Base 2 (Digits: 0 1)**
  - **Octal: Base 8 (Digits: 0 1 2 3 4 5 6 7)**
  - **Hexadecimal: Base 16 (Digits: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F)**

Decimal number System

- **It is the most widely used Number System in a Computer.**
- **Base:** Decimal Number System is a base 10 number system.
- **Digits:** Consists of ten digits from 0 to 9: 0,1,2,3,4,5,6,7,8,9.

BASE = 10

$$X = \sum_{0}^{n-1} D_n \times 10^n$$

$$X = D_{n-1} \times 10^{n-1} + D_{n-2} \times 10^{n-2} + \ldots + D_1 \times 10^1 + D_0 \times 10^0$$

$$X = \sum_{0}^{n-1} D_n \times 10^n = D_{n-1} \times 10^{n-1} + D_{n-2} \times 10^{n-2} + \ldots + D_1 \times 10^1 + D_0 \times 10^0$$

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Decimal number System

- Any decimal number can be formed using the base and these 10 digits.

0, 1, 2, 3, 4, 5, 6, 7, 8, 9

- Each value in a decimal number could be represented as the summation of the digits multiplied by a power of 10 i.e. $D_n * 10^n$, where n ranges from 0 to n-1.
- Example: Say, $\mathbf{5733}_{10,}$ it has four digits so it can be represented as

$$X = \sum_{0}^{n-1} D_n \times 10^n$$

- Example: $(\mathbf{5733})_{10} = \mathbf{5}*10^3 + \mathbf{7}*10^2 + \mathbf{3}*10^1 + \mathbf{3}*10^0$

$= \mathbf{5000 + 700 + 30 + 3}$

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Digit Representation (Decimal)

- **Numbers are used to represent a magnitude of any parameter.**
- **Each number can be represented with a base and value/multiplier.**

MSB LSB

$X = D_3 D_2 D_1 D_0$ ⇨ $X = \sum_{0}^{n-1} D_n \times B^n$

Digit Positions 3 2 1 0

$X = D_3\ D_2\ D_1\ D_0$

Example (Decimal):

$\mathbf{D_3\ D_2\ D_1\ D_0} = \mathbf{D_{n=3}} * 10^{n=3} + \mathbf{D_{n=2}} * 10^{n=2} + \mathbf{D_{n=1}} * 10^{n=1} + \mathbf{D_{n=0}} * 10^{n=0}$

$\mathbf{D_3\ D_2\ D_1\ D_0} = \mathbf{D_3} * 10^3 + \mathbf{D_2} * 10^2 + \mathbf{D_1} * 10^1 + \mathbf{D_0} * 10^0$

Example: $\mathbf{4967} = \mathbf{5} * 10^3 + \mathbf{9} * 10^2 + \mathbf{6} * 10^1 + \mathbf{7} * 10^0$

Binary Number System

BASE = 2

$$X = \sum_{0}^{n-1} D_n \times 2^n$$

- It is **Very Efficient for Computers**, but not for human.
- The digital computer represents all data and information in the form of a binary digit.
- Binary Number system consists of two symbols '0' and '1' that represent quantities.
- It has a base of 2: i.e. a binary number can be represented in a combination of binary digit i.e. 0 & 1 (no more digits are there).
- Each place value in binary number has a power of 2.
- Example: $(\mathbf{1010})_2 = \mathbf{1}*2^3 + \mathbf{0}*2^2 + \mathbf{1}*2^1 + \mathbf{0}*2^0$

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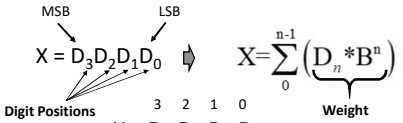
Digit Representation (Binary)

❑**Number Systems**

- **Numbers are used to represent a magnitude of any parameter.**
- **Each number can be represented with a base and value/multiplier.**



$X = D_3\ D_2\ D_1\ D_0$

Example (Binary):

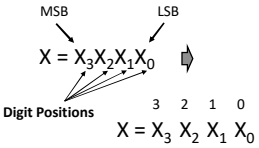
$\mathbf{D_3\ D_2\ D_1\ D_0} = \mathbf{D_3}*2^3 + \mathbf{D_2}*2^2 + \mathbf{D_1}*2^1 + \mathbf{D_0}*2^0$

$\mathbf{1010} = \mathbf{1}*2^3 + \mathbf{0}*2^2 + \mathbf{1}*2^1 + \mathbf{0}*2^0 \equiv \mathbf{10}_{10}$

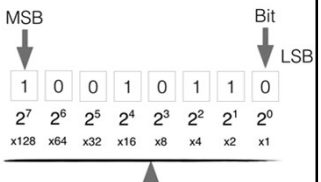
Number Systems: LSB and MSB

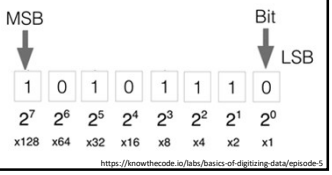
❑**LSB and MSB**

- **LSB: least significant bit**
- **MSB: most significant bit**



$X = X_3\ X_2\ X_1\ X_0$



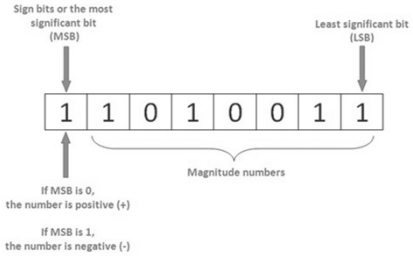


https://knowthecode.io/labs/basics-of-digitizing-data/episode-5

Sign Bit

❑**Sign bits**

- **0: Positive**
- **1: Negative**



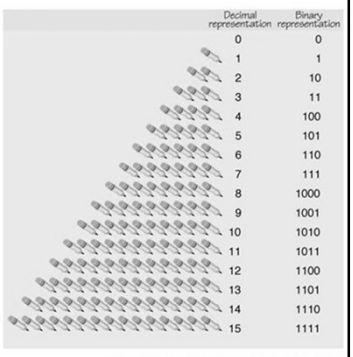
https://lings2mi.wordpress.com/2012/10/21/complement-number-system/

Binary Number Representations

- **Example: 4-Bit Binary Number**

Binary number system - a system that denotes all numbers and combinations of two digits.

The binary system uses two digits to represent the numbers 0 and 1.



https://slideplayer.com/slide/4667193/

Bit Dependent Binary Numbers

- 1-Bit Binary Number (0, 1)
- 2-Bit Binary Number (00, 01, 10, 11)
- 3-Bit Binary Number (000, 001, 010, 011, 100, 101, 110, 111)
- 4-Bit Binary Number (0000, 0001, 0010, 0011, 0100, 0101, 0110, 0111, 1000, 1001, 1010, 1011, 1100, 1101, 1110, 1111)
- Etc.

$$L_{Binary} = 2^n$$

D0
0
1

$L_{Binary} = 2^1 = 2$

D1	D0
0	0
0	1
1	0
1	1

$L_{Binary} = 2^2 = 4$

D2	D1	D0
0	0	0
0	0	1
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1

$L_{Binary} = 2^3 = 8$

D3	D2	D1	D0
0	0	0	0
0	0	0	1
0	0	1	0
0	0	1	1
0	1	0	0
0	1	0	1
0	1	1	0
0	1	1	1
1	0	0	0
1	0	0	1
1	0	1	0
1	0	1	1
1	1	0	0
1	1	0	1
1	1	1	0
1	1	1	1

$L_{Binary} = 2^4 = 16$

Note: All Complete Binary Number Series starts from binary 0

Writing Long Binary Number Series

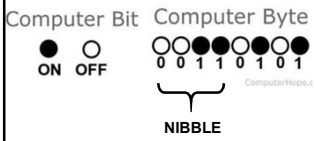
$$L_{Binary} = 2^n$$

$$N_{Alt_{ni}} = 2^{n_i}$$

D_3	D_2	D_1	D_0	D_3	D_2	D_1	D_0
0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	1
0	0	1	0	0	0	1	0
0	0	1	1	0	0	1	1
0	1	0	0	0	1	0	0
0	1	0	1	0	1	0	1
0	1	1	0	0	1	1	0
0	1	1	1	0	1	1	1
1	0	0	0	1	0	0	0
1	0	0	1	1	0	0	1
1	0	1	0	1	0	1	0
1	0	1	1	1	0	1	1
1	1	0	0	1	1	0	0
1	1	0	1	1	1	0	1
1	1	1	0	1	1	1	0
1	1	1	1	1	1	1	1

Data Representation: Data Size

- **BIT**: A single digit is called a bit (binary digit) which is the smallest unit f data that the computer can represent.



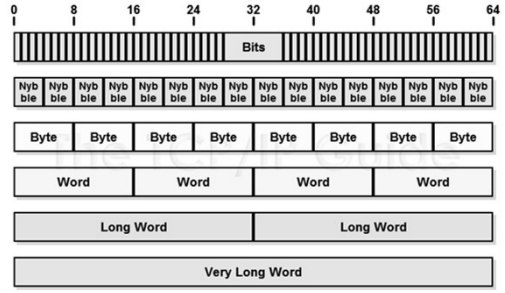
- **Kilobyte (KB)**: 1KB=1024 (2^{10}).
- **Megabyte (MB)**: 1MB = 1024 KB (2^{20})
- **Gigabyte (GB)**: 1GB = 1024 MB (2^{30})
- **Terabyte (TB)**: 1TB = 1024 GB (2^{40})
- **Petabyte (PB)**: 1PB = 1024 TB (2^{50})

Bit (b)	Value
Bits in a Bit (b)	1
Bits in a Nibble (N)	4
Bits in a Byte (B)	8
Bits in a Kilobit (Kb)	1,000
Bits in a Kilobyte (KB)	8,000
Bits in a Kibit (Kib)	1,024
Bits in a Kibibyte (KiB)	8,192
Bits in a Megabit (Mb)	1,000,000
Bits in a Megabyte (MB)	8,000,000
Bits in a Mebibit (Mib)	1,049,000
Bits in a Mebibyte (MiB)	8,389,000
Bits in a Gigabit (Gb)	1,000,000,000
Bits in a Gigabyte (GB)	8,000,000,000
Bits in a Gibibit (Gib)	1,000,000,000
Bits in a Gibibyte (GiB)	8,590,000,000
Bits in a Terabit (Tb)	1,000,000,000,000
Bits in a Terabyte (TB)	8,000,000,000,000
Bits in a Tebibit (Tib)	1,100,000,000,000
Bits in a Tebibyte (TiB)	8,796,000,000,000
Bits in a Petabit (Pb)	1,000,000,000,000,000
Bits in a Petabyte (PB)	8,000,000,000,000,000
Bits in a Pebibit (Pib)	1,126,000,000,000,000
Bits in a Pebibyte (PiB)	9,007,200,000,000,000
Bits in an Exabit (Eb)	1,000,000,000,000,000,000
Bits in an Exabyte (EB)	8,000,000,000,000,000,000
Bits in an Exbibit (Eib)	1,152,921,000,000,000,000
Bits in an Exbibyte (EiB)	9,223,372,040,000,000,000
Bits in a Zettabyte (ZB)	8,000,000,000,000,000,000,000
Bits in a Yottabyte (YB)	8,000,000,000,000,000,000,000,000

https://www.computerhope.com/jargon/e/exabyte.htm
https://www.computerhope.com/jargon/b/bit.htm
https://examstop.com/2018/09/27/number-system-in-a-computer/

Data Representation in a Computer

- **Bit: Smallest allocation in the memory**
- **Nibble** : A **nibble** is a collection of **four bits**.
- **Byte** : A **byte** is a group of **eights bits**.
- **Word** : A **word** is a contiguous group of **bytes**.



https://examstop.com/2018/09/27/number-system-in-a-computer/

Computational Code: ASCII

- **All writing elements/characters are symbolized**
- **ASCII: American Standard Code for Information Interchange**
  - **Numbers**
  - **Alphabets Capital Letter**
  - **Alphabets Small Letters**
  - **Special Symbols**

Binary	Decimal	Character
0110000	48	0
0110001	49	1
0110010	50	2
0110011	51	3
0110100	52	4
0110101	53	5
0110110	54	6
0110111	55	7
0111000	56	8
0111001	57	9

Computational Code: ASCII

- **ASCII** abbreviated from **American Standard Code for Information Interchange**, is a character encoding standard for electronic communication. ASCII codes represent text in computers, telecommunications equipment, and other devices. Most modern character-encoding schemes are based on ASCII, although they support many additional characters.
- The Internet Assigned Numbers Authority (IANA) prefers the name **US-ASCII** for this character encoding.[2]
- ASCII is one of the IEEE milestones.

Character	Binary Code	Character	Binary Code	Character	Binary Code	Character	Binary Code	Character	Binary Code
A	01000001	Q	01010001	g	01100111	w	01110111	-	00101101
B	01000010	R	01010010	h	01101000	x	01111000	.	00101110
C	01000011	S	01010011	i	01101001	y	01111001	/	00101111
D	01000100	T	01010100	j	01101010	z	01111010	0	00110000
E	01000101	U	01010101	k	01101011	!	00100001	1	00110001
F	01000110	V	01010110	l	01101100	"	00100010	2	00110010
G	01000111	W	01010111	m	01101101	#	00100011	3	00110011
H	01001000	X	01011000	n	01101110	$	00100100	4	00110100
I	01001001	Y	01011001	o	01101111	%	00100101	5	00110101
J	01001010	Z	01011010	p	01110000	&	00100110	6	00110110
K	01001011	a	01100001	q	01110001	'	00100111	7	00110111
L	01001100	b	01100010	r	01110010	(	00101000	8	00111000
M	01001101	c	01100011	s	01110011	)	00101001	9	00111001
N	01001110	d	01100100	t	01110100	*	00101010	?	00111111
O	01001111	e	01100101	u	01110101	+	00101011	@	01000000
P	01010000	f	01100110	v	01110110	,	00101100	_	01011111

Bit Dependent Binary Numbers

- ASCII

ASCII Code: Character to Binary

0	0011 0000	O	0100 1111	m	0110 1101
1	0011 0001	P	0101 0000	n	0110 1110
2	0011 0010	Q	0101 0001	o	0110 1111
3	0011 0011	R	0101 0010	p	0111 0000
4	0011 0100	S	0101 0011	q	0111 0001
5	0011 0101	T	0101 0100	r	0111 0010
6	0011 0110	U	0101 0101	s	0111 0011
7	0011 0111	V	0101 0110	t	0111 0100
8	0011 1000	W	0101 0111	u	0111 0101
9	0011 1001	X	0101 1000	v	0111 0110
A	0100 0001	Y	0101 1001	w	0111 0111
B	0100 0010	Z	0101 1010	x	0111 1000
C	0100 0011	a	0110 0001	y	0111 1001
D	0100 0100	b	0110 0010	z	0111 1010
E	0100 0101	c	0110 0011	.	0010 1110
F	0100 0110	d	0110 0100	,	0010 0111
G	0100 0111	e	0110 0101	:	0011 1010
H	0100 1000	f	0110 0110	;	0011 1011
I	0100 1001	g	0110 0111	?	0011 1111
J	0100 1010	h	0110 1000	!	0010 0001
K	0100 1011	I	0110 1001	'	0010 1100
L	0100 1100	j	0110 1010	"	0010 0010
M	0100 1101	k	0110 1011	(	0010 1000
N	0100 1110	l	0110 1100	)	0010 1001
				space	0010 0000

Bit Dependent Binary Numbers

- ASCII

Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char	Decimal	Hex	Char
0	0	[NULL]	32	20	[SPACE]	64	40	@	96	60	`
1	1	[START OF HEADING]	33	21	!	65	41	A	97	61	a
2	2	[START OF TEXT]	34	22	"	66	42	B	98	62	b
3	3	[END OF TEXT]	35	23	#	67	43	C	99	63	c
4	4	[END OF TRANSMISSION]	36	24	$	68	44	D	100	64	d
5	5	[ENQUIRY]	37	25	%	69	45	E	101	65	e
6	6	[ACKNOWLEDGE]	38	26	&	70	46	F	102	66	f
7	7	[BELL]	39	27	'	71	47	G	103	67	g
8	8	[BACKSPACE]	40	28	(	72	48	H	104	68	h
9	9	[HORIZONTAL TAB]	41	29	)	73	49	I	105	69	i
10	A	[LINE FEED]	42	2A	*	74	4A	J	106	6A	j
11	B	[VERTICAL TAB]	43	2B	+	75	4B	K	107	6B	k
12	C	[FORM FEED]	44	2C	,	76	4C	L	108	6C	l
13	D	[CARRIAGE RETURN]	45	2D	-	77	4D	M	109	6D	m
14	E	[SHIFT OUT]	46	2E	.	78	4E	N	110	6E	n
15	F	[SHIFT IN]	47	2F	/	79	4F	O	111	6F	o
16	10	[DATA LINK ESCAPE]	48	30	0	80	50	P	112	70	p
17	11	[DEVICE CONTROL 1]	49	31	1	81	51	Q	113	71	q
18	12	[DEVICE CONTROL 2]	50	32	2	82	52	R	114	72	r
19	13	[DEVICE CONTROL 3]	51	33	3	83	53	S	115	73	s
20	14	[DEVICE CONTROL 4]	52	34	4	84	54	T	116	74	t
21	15	[NEGATIVE ACKNOWLEDGE]	53	35	5	85	55	U	117	75	u
22	16	[SYNCHRONOUS IDLE]	54	36	6	86	56	V	118	76	v
23	17	[ENG OF TRANS. BLOCK]	55	37	7	87	57	W	119	77	w
24	18	[CANCEL]	56	38	8	88	58	X	120	78	x
25	19	[END OF MEDIUM]	57	39	9	89	59	Y	121	79	y
26	1A	[SUBSTITUTE]	58	3A	:	90	5A	Z	122	7A	z
27	1B	[ESCAPE]	59	3B	;	91	5B	[	123	7B	{
28	1C	[FILE SEPARATOR]	60	3C	<	92	5C	\	124	7C	|
29	1D	[GROUP SEPARATOR]	61	3D	=	93	5D	]	125	7D	}
30	1E	[RECORD SEPARATOR]	62	3E	>	94	5E	^	126	7E	~
31	1F	[UNIT SEPARATOR]	63	3F	?	95	5F	_	127	7F	[DEL]

Number Systems: Applications

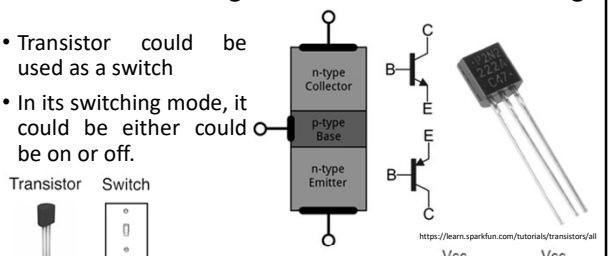
Machine Language: Number System

- **Machine language**
- **Machine code can be developed with the binary number system: a number system with base 2: either a 1 or 0.**
- **Machine code can also be expressed in hex-format *(hexadecimal)* - a number system with base 16**.
- Binary and hex numbers are interrelated and easily to converted from one to another.
- As hex is much more readable and useful than binary - it's often used and shown.
- Let us take a binary sequence: 1001111000001010 : it can easily be converted to hex by grouping in blocks - each block consisting of four bits.

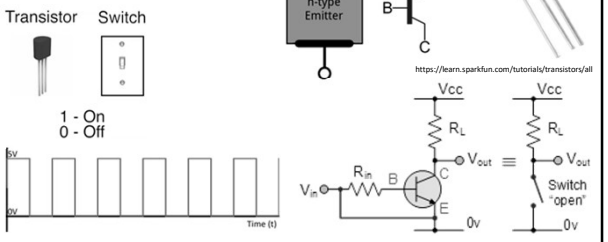
```
1001 1110 0000 1010 => 9  14 0 10 which in hex becomes: 9E0A.
```

How 1s and 0s are generated: Transistor Switching

- Transistor could be used as a switch
- In its switching mode, it could be either could be on or off.



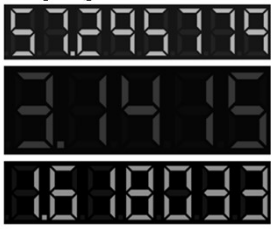
https://learn.sparkfun.com/tutorials/transistors/all



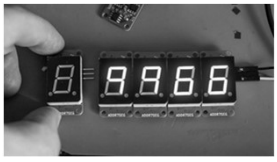
https://www.youtube.com/watch?v=EXZWHumclx0

Electronic Display

- Electronic Displays are very common in our society.
- The electronic display is used for displaying the numbers and letters
- The words and sentences are also possible to be displayed
- The display may be static or dynamic
- Examples:
  - Electronic watch
  - Railway notice board



https://javascript.plainenglish.io/

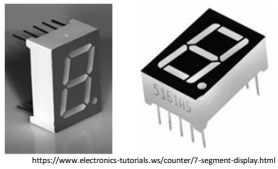


https://www.adafruit.com/product/865

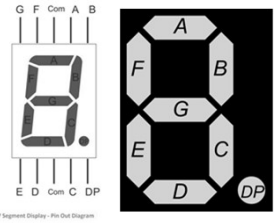
https://hackaday.com/2019/01/12/addressable-7-segment-displays-may-make-multiplexing-a-thing-of-the-past/

Electronic Display

- Electronic Displays are very common in our society.
- The Display board is developed with "Seven Segment Display Unit (SSDU)".
- SSDU is developed with a combination of seven LEDs.
- The LEDs in a SSDU is made with a rectangular shape.
- A single SSDU is used to display a number or letter.



https://www.electronics-tutorials.ws/counter/7-segment-display.html

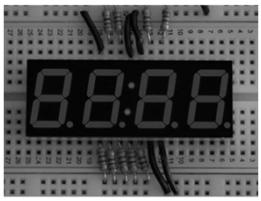


https://commons.wikimedia.org/wiki/File:7_Segment_Display_with_Labeled_Segments.svg

Electronic Display

- The display may be static fixed over time time
- It can be dynamic (change with time)





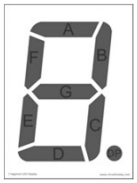
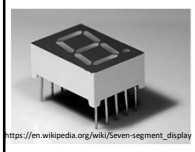
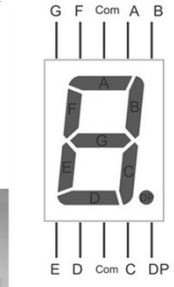

https://www.adafruit.com/product/865

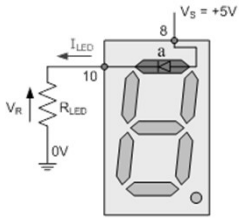
https://www.adafruit.com/product/813

Applications : Seven Segment Display

Seven Segment Display

A seven segment display is a LED based electronic display component which is used for displaying numbers and letters



https://en.wikipedia.org/wiki/Seven-segment_display

http://www.circuitstoday.com/arduino-and-7-segment-display

https://www.electronics-tutorials.ws/counter/7-segment-display.html

Applications : Seven Segment Display

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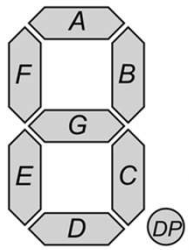

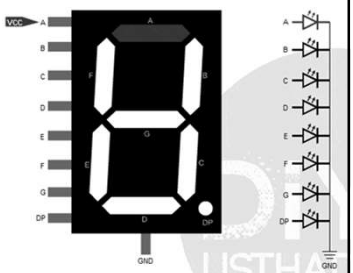

https://diyusthad.com/2020/05/all-about-7-segment-

Applications : Seven Segment Display

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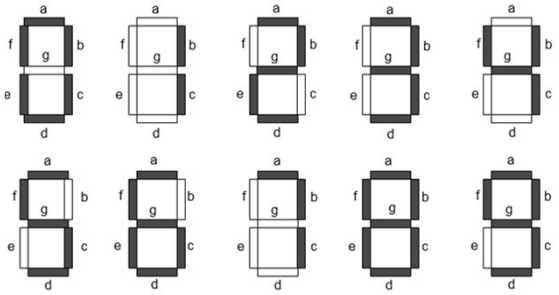

https://electronics-fun.com/7-segment-hex-decoder/

Applications : Seven Segment Display

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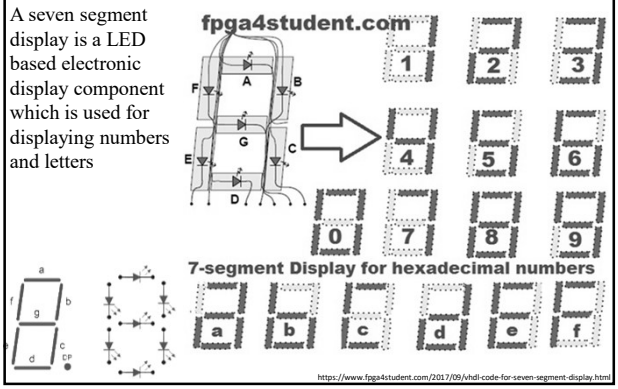

https://www.fpga4student.com/2017/09/vhdl-code-for-seven-segment-display.html

Applications : Seven Segment Display

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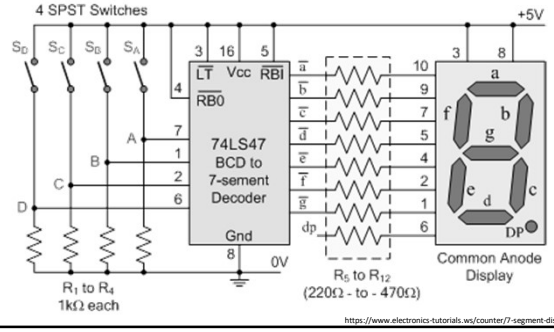

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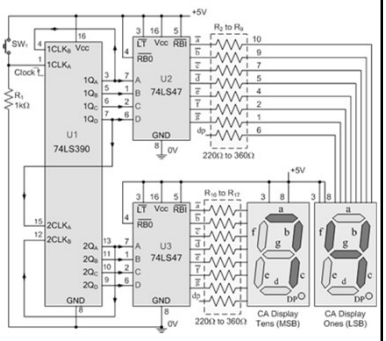

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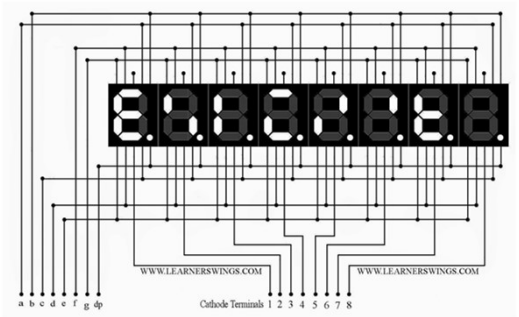
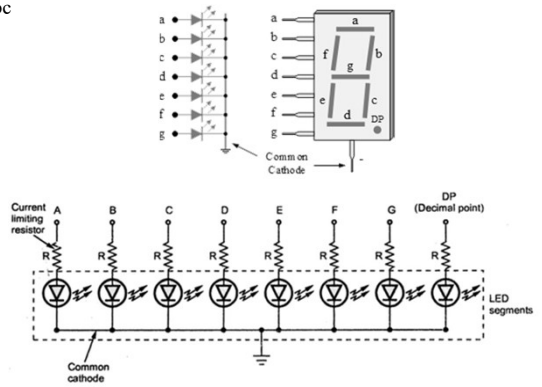


http://www.learnerswings.com/2014/09/how-to-consider-segments-of-cluster-of.html

Seven Segment Display: Common Cathode

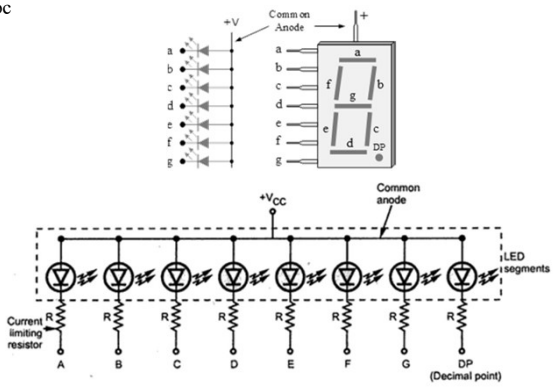
Abc



Note: Resistors are used to limit the current through the LEDs

Seven Segment Display: Common Cathode

Abc

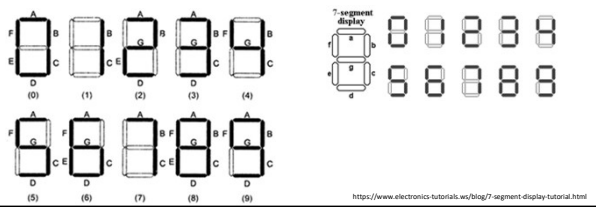


Note: Resistors are used to limit the current through the LEDs

Applications : Seven Segment Display

Seven Segment Display

- Depending upon the digit to be displayed, the particular set of LEDs is forward biased.
- By forward biasing different LEDs, we can display the digits 0 through 9.
- To display a zero, the LEDs A, B, C, D, E and F are to be forward biased.
- To light up a 5, we need to forward bias segments A, F, G, C, D.



https://www.electronics-tutorials.ws/blog/7-segment-display-tutorial.html

Seven Segment Display: LED Driver

Seven Segment Display

- The output of a digital circuit is logical '0' or '1'. The '0' means low while '1' means high. In the high state the output voltage is nearly 5 V while in low state, it is almost 0 V.
- If LED is to be driven by such digital circuit, it can be connected as shown in the Fig. 5. When output of digital circuit is high, both ends of LED are at 5 V and it can not be forward biased hence will not give light. While when output of digital circuit is low, then high current will flow through LED as it becomes forward biased, and it will give light.

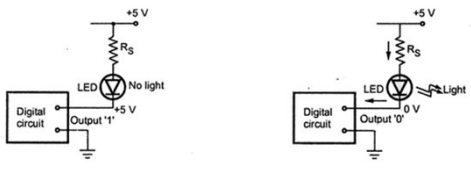
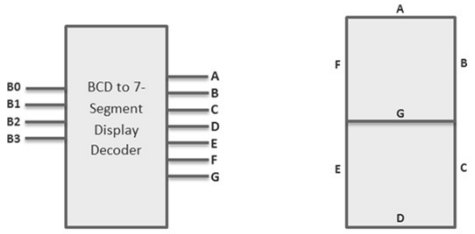


Fig. 5

Seven Segment Display: LED Driver

- In practice seven segment displays are used at the output of digital integrated circuits, the output of which is in binary coded decimal form (BCD). Such output has only four lines and it cannot drive seven segments of the displays directly. In such a case a driver circuit is used which is a BCD to 7 segment decoder. It converts 4 BCD lines into 7lines. A typical LED seven segment display with its driver circuit is shown in the Fig. 6. The common anode type display is used.



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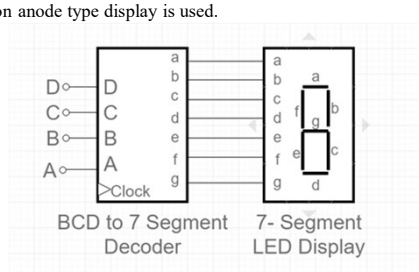

Seven Segment Display: LED Driver

- Notice that, an additional LED corresponding to the decimal point is also provided in the seven segment display, which again has a current limiting series resistance. Hence a positive voltage is applied to the common anode. Therefore selected LEDs are illuminated by making their respective cathodes low (0 V).

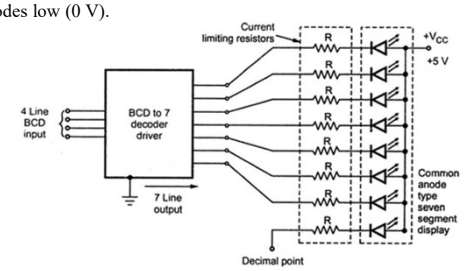

Fig. 6 Typical 7-segment LED display with its driver

Seven Segment Display: LED Driver

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Decimal	Binary DCBA	7 Segment Code a b c d e f g
0	0000	1 1 1 1 1 1 0
1	0001	0 1 1 0 0 0 0
2	0010	1 1 0 1 1 0 1
3	0011	1 1 1 1 0 0 1
4	0100	0 1 1 0 0 1 1
5	0101	1 0 1 1 0 1 1
6	0110	0 0 1 1 1 1 1
7	0111	1 1 1 0 0 0 0
8	1000	1 1 1 1 1 1 1
9	1001	1 1 1 0 0 1 1

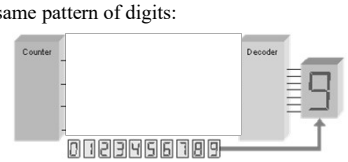
Applications: Binary Counters

Binary Counters

A binary counting sequence for numbers from zero to fifteen is shown.

Notice the pattern of zeros and ones in each column.

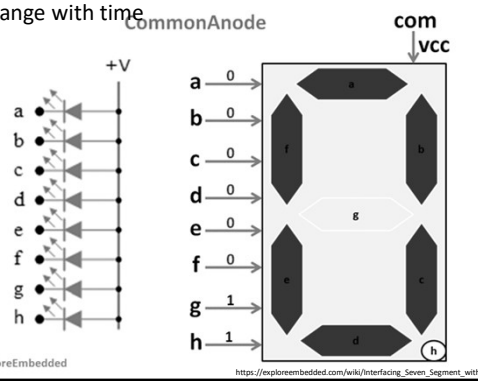
Digital counters frequently have this same pattern of digits:



Decimal Number	Binary Number
0	0 0 0 0
1	0 0 0 1
2	0 0 1 0
3	0 0 1 1
4	0 1 0 0
5	0 1 0 1
6	0 1 1 0
7	0 1 1 1
8	1 0 0 0
9	1 0 0 1
10	1 0 1 0
11	1 0 1 1
12	1 1 0 0
13	1 1 0 1
14	1 1 1 0
15	1 1 1 1

Electronic Display

- The display may be for a long time
- It can change with time



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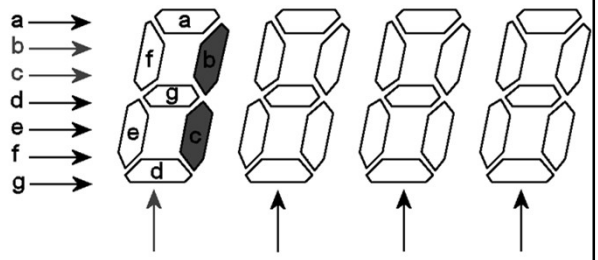

https://instrumentationtools.com/seven-segment-display-working-principle/

Electronic Display

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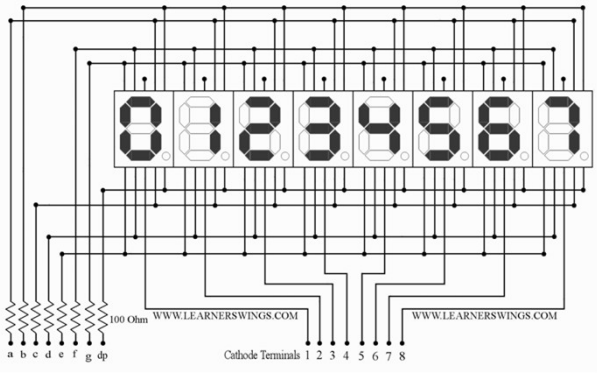
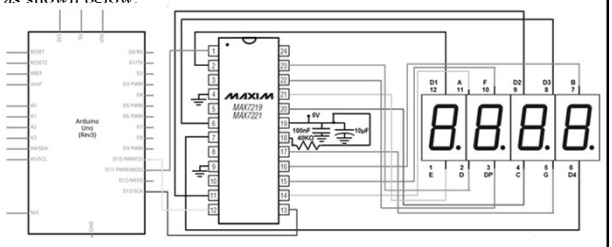


http://www.learnerswings.com/2014/09/scrolling-number-display-in-cluster-of.html

Applications : Multiple Seven Segment Display

Seven Segment Display

Display of numbers could be obtained by feeding the voltage signal (5V) as shown below:

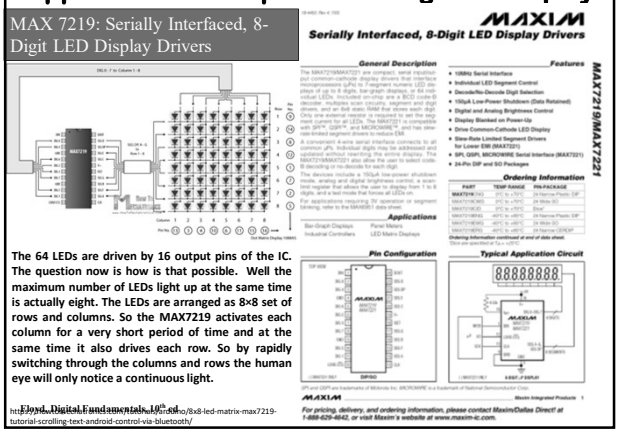


https://www.crossfithartford.com/dummies_seven_segment_led_circuit_diagram.php

Floyd, Digital Fundamentals, 10th ed

Applications : Multiple Seven Segment Display

MAX 7219: Serially Interfaced, 8-Digit LED Display Drivers



The 64 LEDs are driven by 16 output pins of the IC. The question now is how is that possible. Well the maximum number of LEDs light up at the same time is actually eight. The LEDs are arranged as 8×8 set of rows and columns. So the MAX7219 activates each column for a very short period of time and at the same time it also drives each row. So by rapidly switching through the columns and rows the human eye will only notice a continuous light.

https://www.crossfithartford.com/dummies_seven_segment_led_circuit_diagram.php

Floyd, Digital Fundamentals, 10th ed