UNIVERSITI TEKNOLOGI MALAYSIA
www.utm.my

SCSR1013 DIGITAL LOGIC

MODULE 1: INTRODUCTORY CONCEPTS

FACULTY OF COMPUTING

CONTENTS

MODULE 1:
DIGITAL LOGIC OVERVIEW

Digital and Analog Quantities

Binary Digits, Logic Levels and Digital Waveform

Introduction to Logic Operations

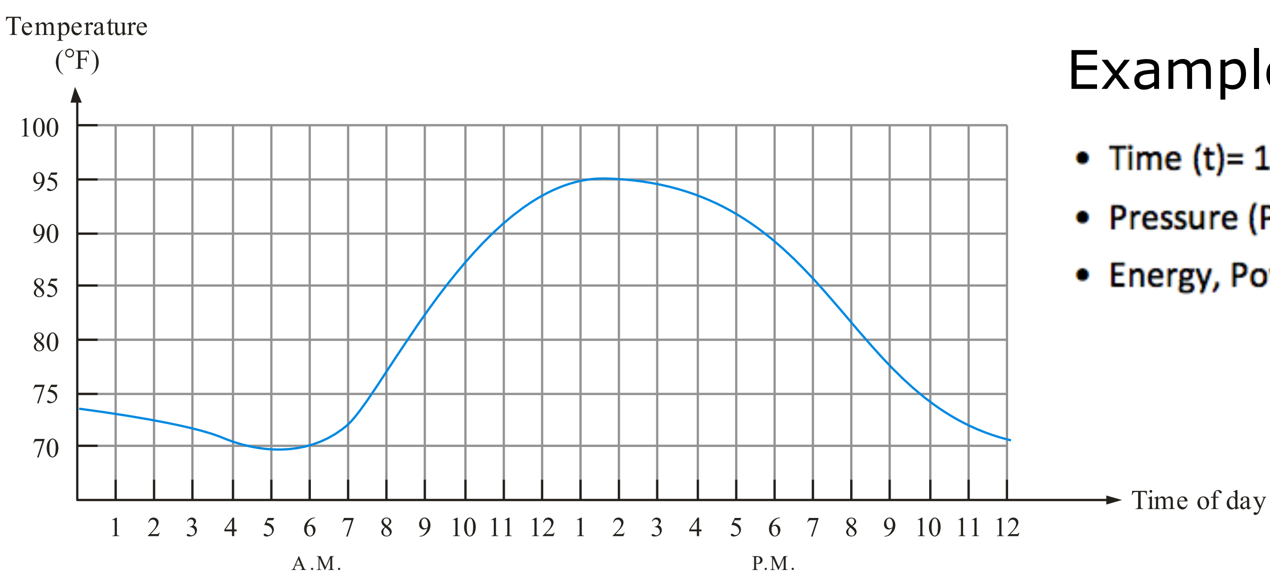
Overview of Logic Functions

Fixed-Function IC

Programmable Logic Devices (PLD)

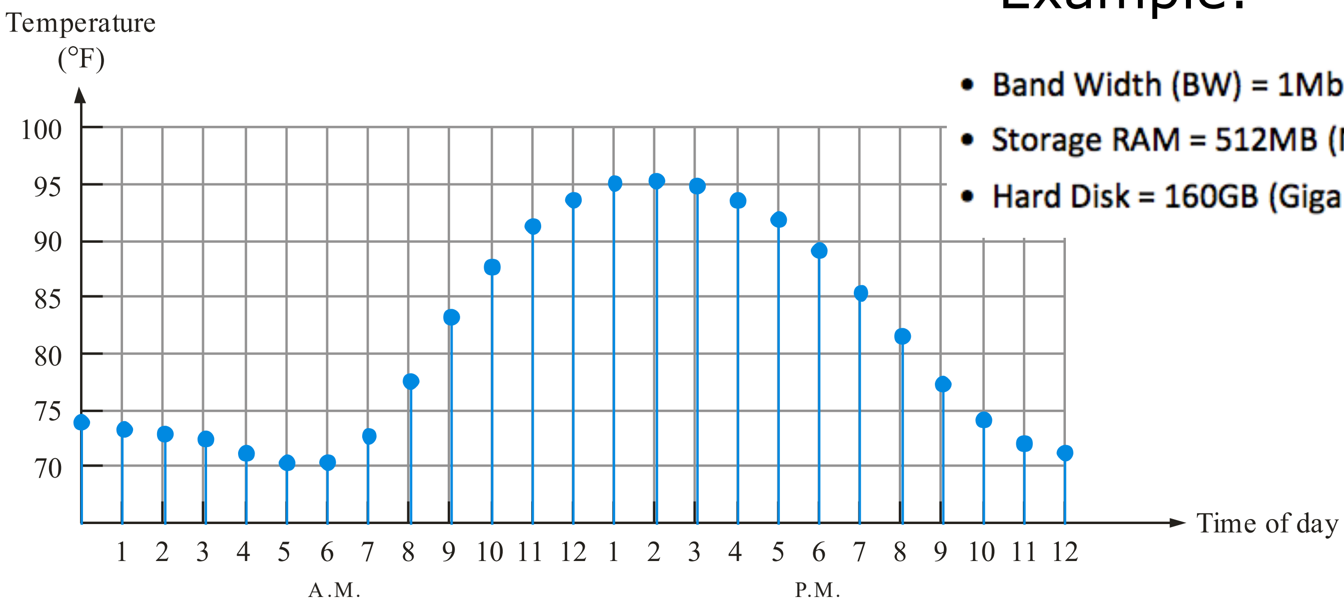
Digital and Analog Quantities

- Most natural quantities that we see are **analog** and vary continuously.
- Analog systems can generally handle higher power than digital systems.



Example:

- Time (t)= 10.16s (second)
- Pressure (P)=220.10KPa (Kilo Pascal)
- Energy, Power = 100.5KW (Kilo Watts)



Example:

- Band Width (BW) = 1Mbps (Mega Bits Per Second)
- Storage RAM = 512MB (Mega Byte)
- Hard Disk = 160GB (Giga Byte)

- Digital systems can **process**, **store**, and **transmit** data more efficiently but can only assign discrete values (discontinuous) to each point.

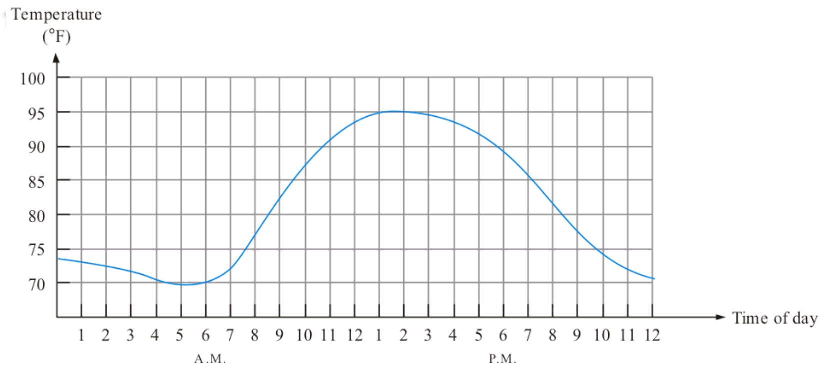
Analog vs Digital

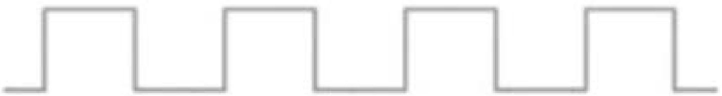
Analog

- Use base 10 (decimal)
- Represented by 10 different level: 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9.
- Analog system: A combination of devices that manipulate values represented in analog form

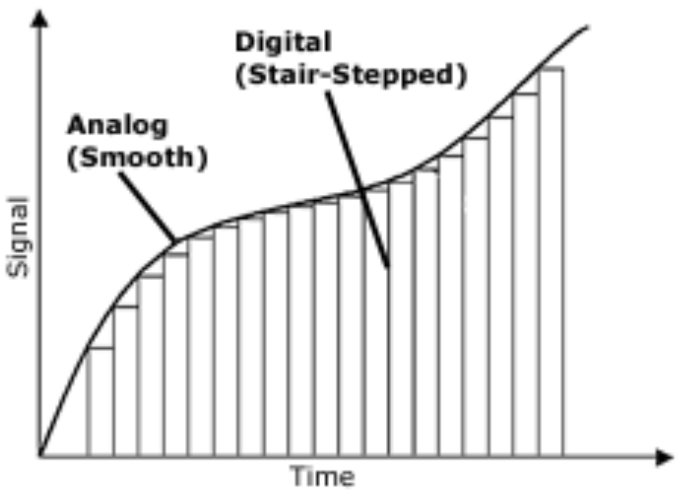
Digital

- Use base 2 (binary)
- Represented by 2 different level: 0 and 1 or low and high.
- Digital system: A combination of devices that manipulate values represented in digital form.

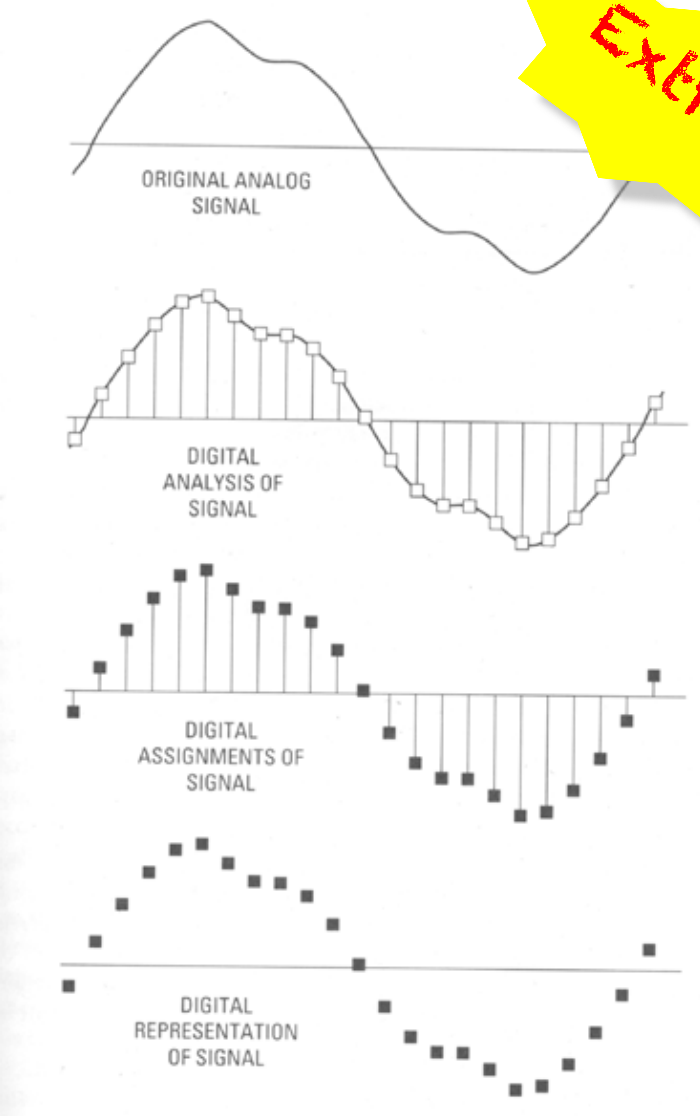




Example of sampling analog-to-digital (frequency at least 2 times higher than analog)



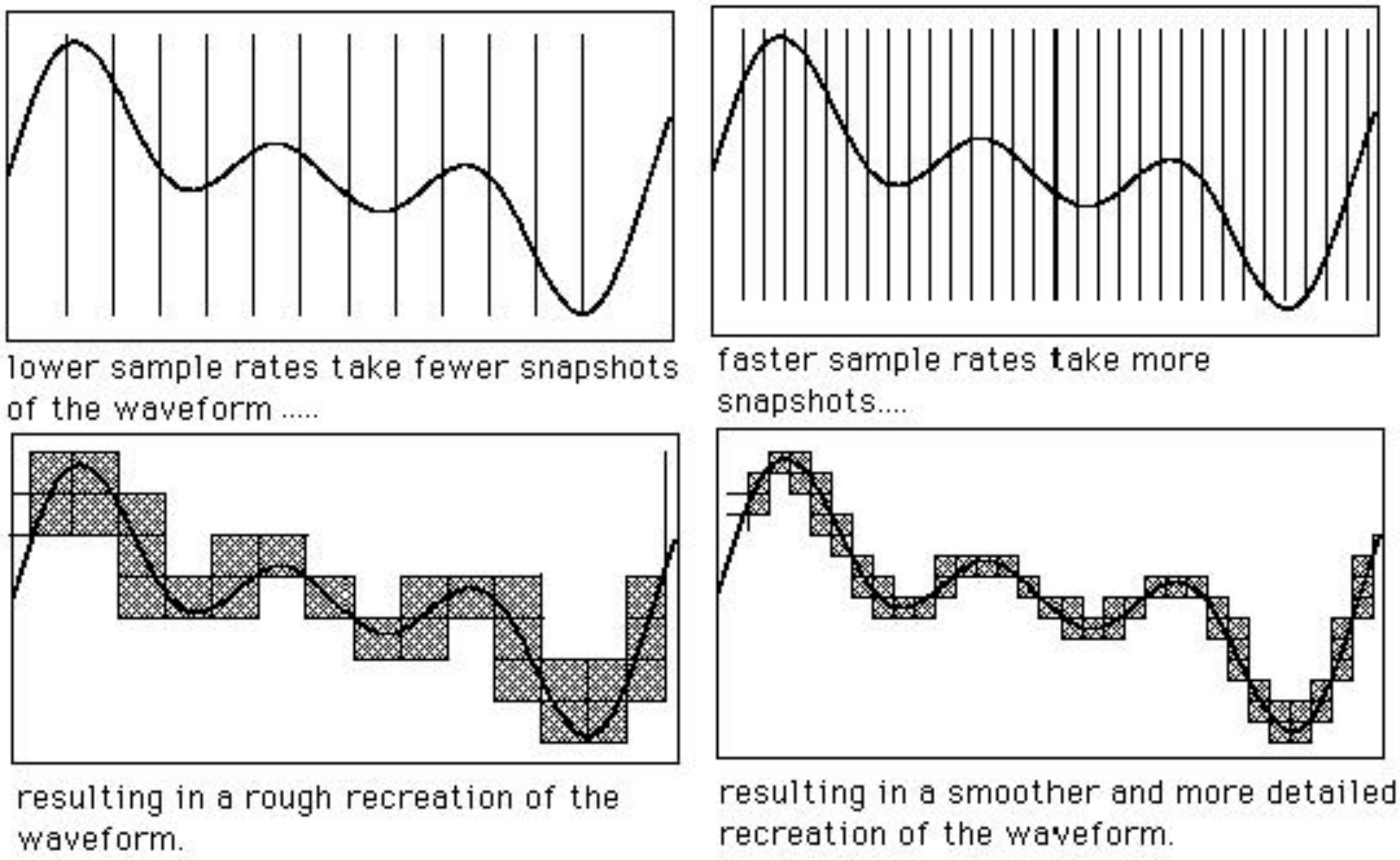
http://www.blazeaudio.com/howto/bg-digital.html



Extra

http://www.geardiary.com/2011/04/01/music-diary-notes-the-brave-new-world-of-digital-music/digital_sampling/

Extra



http://musicandcomputers306.blogspot.com/2010/10/waveforms-ad-conversion-sampling.html

Extra

Self-Test: Which of the following belong to analog system?

(a)

(b)

(c)

(d)

(e)

(f)

Extra

Answer

(a)

(c)

(e)

Extra

Example: Analog systems

Resource: Google searched

Extra

Example: Digital systems

- Digital technology is relatively new compared to analog technology, but a lot of analog systems has been changed to a digital systems, Examples:
  - Computers
  - Manufacturing systems
  - Medical Science
  - Transportation
  - Entertainment
  - Telecommunications

*DSL-2320B (ADSL Modem)

Digital

Exercise: Match the picture to which digital application system it belong to.

(b)

(a) Computers
(b) Manufacturing systems
(c) Medical Science
(d) Transportation
(e) Entertainment
(f) Telecommunications

(f)

(e)

(a)

(d)

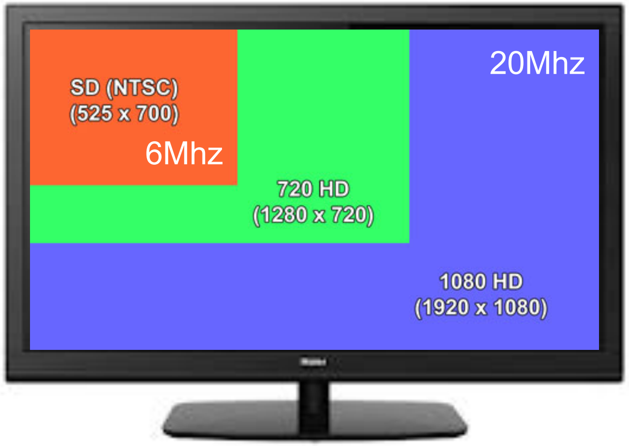
(c)

The Digital Advantages

- Ease of design
- Ease of storage
- Accuracy and precision are easier to maintain
- Programmable operation
- Less affected by noise
- Ease of fabrication on IC chips

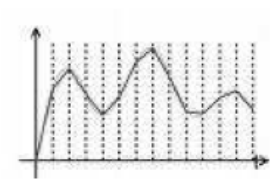
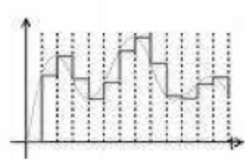
- Thus, the digital systems is more efficient and reliable for:
  - Data Processing
  - Data Transmission
  - Data Storage

Digital Disadvantages



- Greater bandwidth
- Sampling error

Sampling Error (Quantization Error): is derived from Analog to Digital Conversion Process:

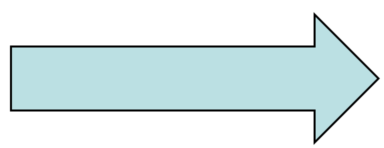
 →  → 

Analog | Sampling & Quantization | Bit 0 and 1

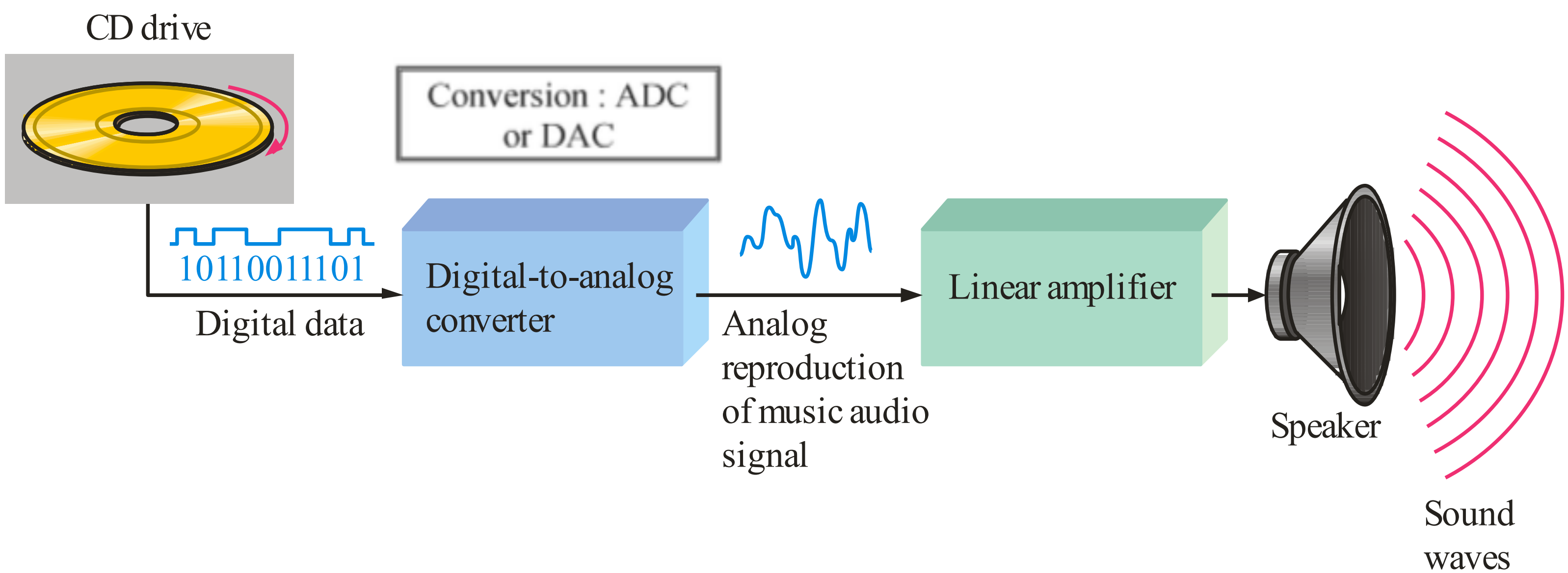
- Compatibility with existing analog systems
- Short product half life

Laserdisc, CD, minidisc

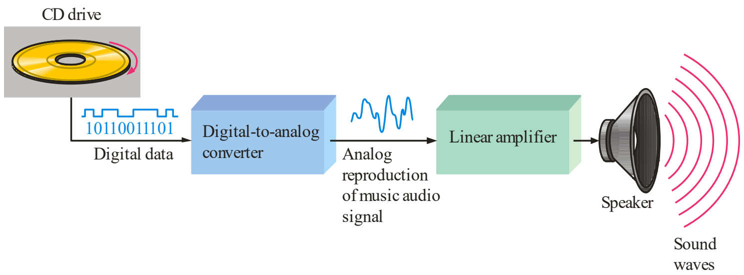
- Many systems use a mix of analog and digital electronics to take advantage of each technology.
- A typical CD player accepts digital data from the CD drive and converts it to an analog signal for amplification.



http://www.it-echo.com/2009/11/14/bose-wave-music-system-and-multi-cd-changer-bundle.html
http://cdn-static.zdnet.com/i/story/61/18/006128/31929466-2-440-overview-1.gif



1. Convert digital sound (CD) to analog
2. Process (amplify) the analog information
3. Convert the analog signal to sound



Hybrid System

- The audio CD is a typical hybrid (Analog & Digital) system.
  - Analog sound is converted into analog voltage using a microphone.
  - Analog voltage is changed into digital through an ADC in the recorder.
  - Digital information is stored on the CD .
  - At playback the digital information is changed into analog by a DAC in the CD player.
  - The analog voltage is amplified and used to drive a speaker that produces the original analog sound.

Conversion:

http://www.idt.com/products/data-converters

Analog to Digital Converter (ADC):

- Convert analog signal into digital signal using process such as sampling, quantization process and digital conversion.
- Error will occur during the sampling and quantization, hence loss of information can happen.

Digital to Analog Converter (DAC):

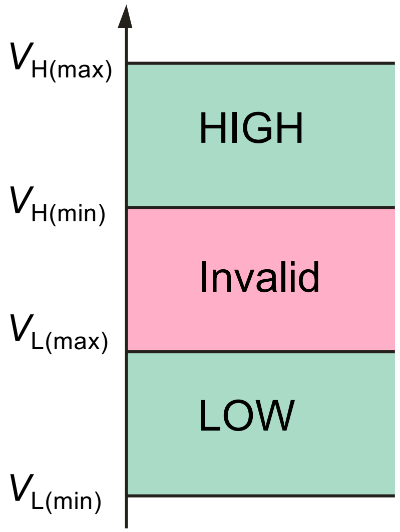
- Needed if the speaker is using analog system.
- Need to convert the digital data to analog signal in order for the speaker works properly and the sound can heard by human.

http://thesoundviewstudio.com/audio-rentals.html

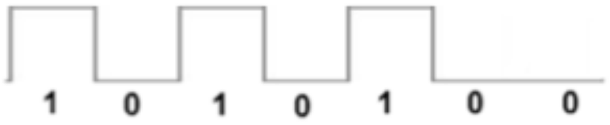
Digits, Logic Levels and Digital Waveform

Digital electronics uses circuits that have two states, which are represented by two different voltage levels:

- HIGH (bit 1)
- LOW (bit 0)

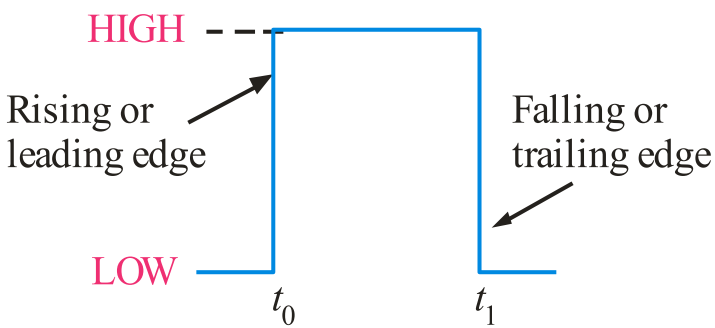


A bit can have the value of either a 0 or a 1, depending on if the voltage is **HIGH** or **LOW**.

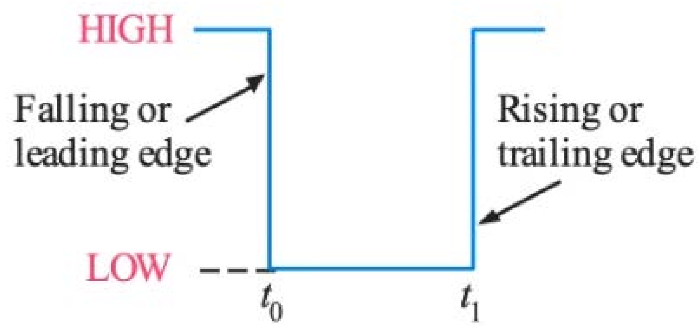


1010100 represented as electrical signal

- **Digital waveforms** change between the LOW and HIGH levels.
- A positive going pulse is one that goes from a normally LOW logic level to a HIGH level and then back again.
- **Digital waveforms** are made up of a series of pulses.



(a) Positive–going pulse



(b) Negative–going pulse

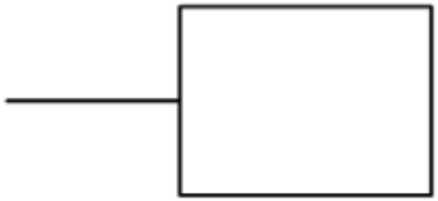
Positive Logic (active high)

High = 1 (Bit 1)
Low = 0 (Bit 0)

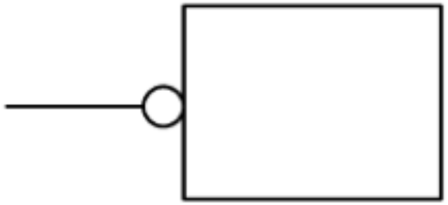
Negative logic (active low)

High =0
Low =1

Symbols to show the input state of "active high" *and* "active low":



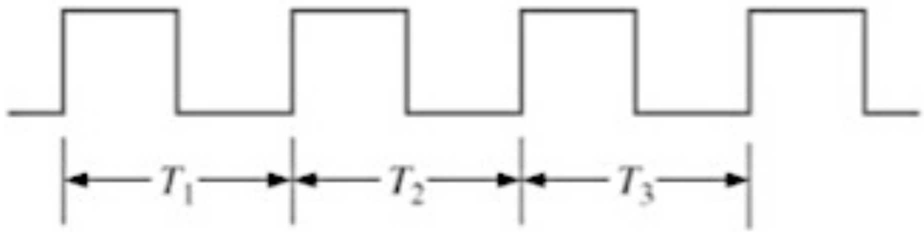
"active high"



"active low"

Digital Waveforms

- Two type of squarewave
  - Periodic
    - The signal keep on repeating after a period of time



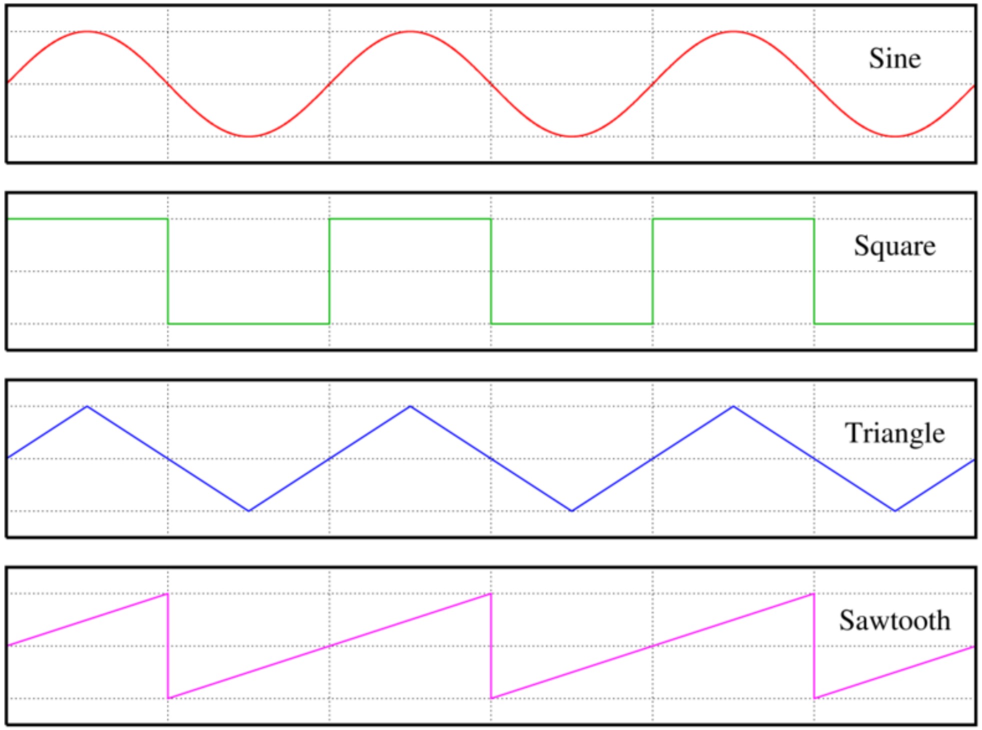
$$\text{Period} = T_1 = T_2 = T_3 = \ldots = T_n$$

$$\text{Frequency} = \frac{1}{T}$$

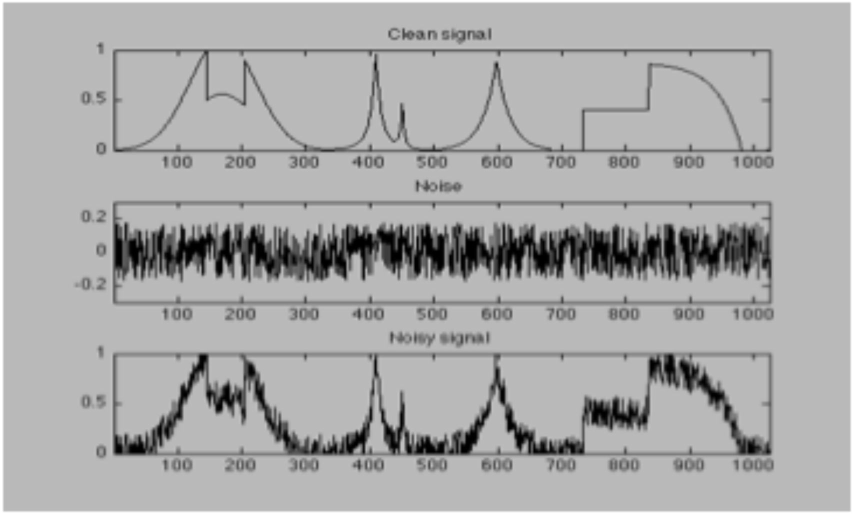
  - Non-Periodic / Aperiodic
    - Doesn't have a period

Periodic signal

Aperiodic signal



http://commons.wikimedia.org/wiki/File:Waveforms.png



Periodic Signal Parameter

- Frequency (f) is the rate at which the signal repeat itself at a fixed interval. Is measured in cycles per second or Hertz (Hz)

$$f = \frac{1}{T} \quad \text{Hz}$$

- Period (T) is the time from the edge of one pulse to the corresponding edge of the next pulse. Is measured in second

$$T = \frac{1}{f} \quad \text{seconds}$$

Example:

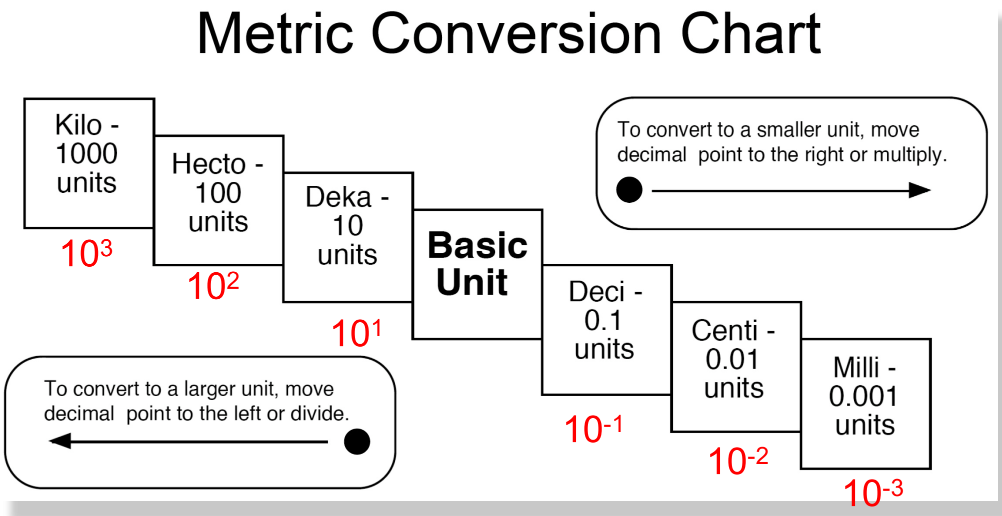
- clock frequency : $f = 100Hz$,
  so, period : $T = 1/100Hz = \underline{0.01s} = 10\times 10^{-3} = \underline{10\ ms}$

s → ms (x 10^{3})
ms → s (x 10^{-3})

Some examples of periodic signal display on the oscilloscope:

(a) Square waveform

(b) Sinusoid waveform



http://ruthpawson.rbe.sk.ca/johnson_math0910

Unit Conversion

- Kilo (K)= 10^3
- Mega (M)= 10^6
- Giga (G)= 10^9
- Tera (T)= 10^{12}
- Mili (m)= 10^{-3}
- Micro (μ) = 10^{-6}
- Nano (n)= 10^{-9}
- Piko (p) = 10^{-12}

- Mili (m)= 10^{-3}
- Micro (µ) = 10^{-6}
- Nano (n)= 10^{-9}
- Piko (p) = 10^{-12}

Example : $f = 100KHz$, So

$$T = 1/f$$
$$= 1/(100*10^3 Hz)$$
$$= 0.01 * 10^{-3}\ s$$
$$= 0.01 ms$$
$$= 10\ \mu s$$

$$= (0.01 * 10^{-3})\ s \times 10^3$$
$$= (0.01 * 10^{-3+3})\ ms$$
$$= (0.01 * 10^0)\ ms$$
$$= 0.01\ ms$$

$$= (0.01 * 10^{-3})\ s \times 10^6$$
$$= (0.01 * 10^{-3+6})\ \mu s$$
$$= (0.01 * 10^3)\ \mu s$$
$$= 10\ \mu s$$

Exercise 1.1 : Calculate the frequency of signals if time period are given as the following:

a) $10ms =$ __________ Hz

b) $100\mu s =$ __________ KHz

c) $100ns =$ __________ MHz

d) $1000 ps =$ __________ GHz

Extra

Solution 1.1 :

(Convert to second)

a) $10ms$ $= (\frac{10}{10^3})s = (\frac{1}{10^2})s = 0.01s$ $\qquad f = \frac{1}{0.01} = 100Hz$

b) $100\mu s$ $= (\frac{100}{10^6})s = (\frac{1}{10^4})s = 0.0001s$ $\qquad f = \frac{1}{0.0001} = 1\times 10^4 Hz = \frac{1\times 10^4}{10^3} = 10KHz$

c) $100ns$ $= (\frac{100}{10^9})s = (\frac{1}{10^7})s = 10^{-7}s$ $\qquad f = \frac{1}{10^{-7}} = 1\times 10^7 Hz = \frac{1\times 10^7}{10^6} = 10MHz$

d) $1000ps$ $= (\frac{1000}{10^{12}})s = (\frac{1}{10^9})s = 10^{-9}s$ $\qquad f = \frac{1}{10^{-9}} = 1\times 10^9 Hz = \frac{1\times 10^9}{10^9} = 1GHz$

Exercise 1.2 : Calculate the time period of signals if the frequencies are given as the following:

a) $1000KHz =$ ___________ μs

b) $100MHz =$ ___________ ns

c) $1000GHz =$ ___________ ps

d) $100THz =$ ___________ ps

Extra

Solution 1.2 :

(Convert to Hz)

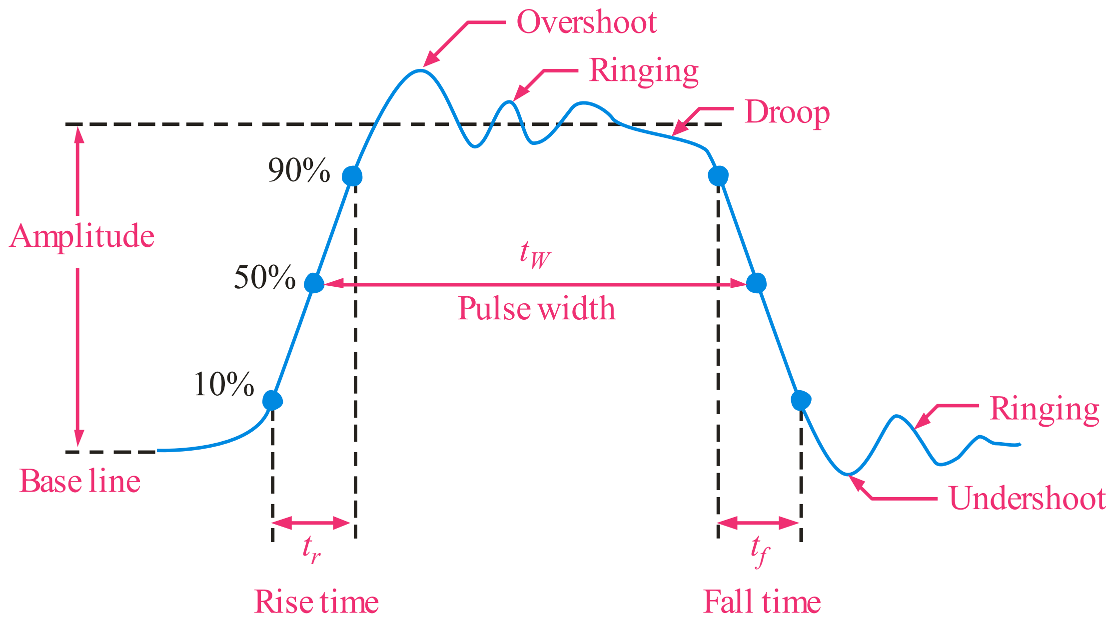
a) $1000\,KHz = 1000 \times 10^{3}\,Hz = 10^{6}\,Hz$ $\quad T = \dfrac{1}{10^{6}} = 10^{-6}\,s = 10^{-6} \times 10^{6} = 1\,\mu s$

b) $100\,MHz = 100 \times 10^{6}\,Hz = 10^{8}\,Hz$ $\quad T = \dfrac{1}{10^{8}} = 10^{-8}\,s = 10^{-8} \times 10^{9} = 10\,ns$

c) $1000\,GHz = 1000 \times 10^{9}\,Hz = 10^{12}\,Hz$ $\quad T = \dfrac{1}{10^{12}} = 10^{-12}\,s = 10^{-12} \times 10^{12} = 1\,ps$

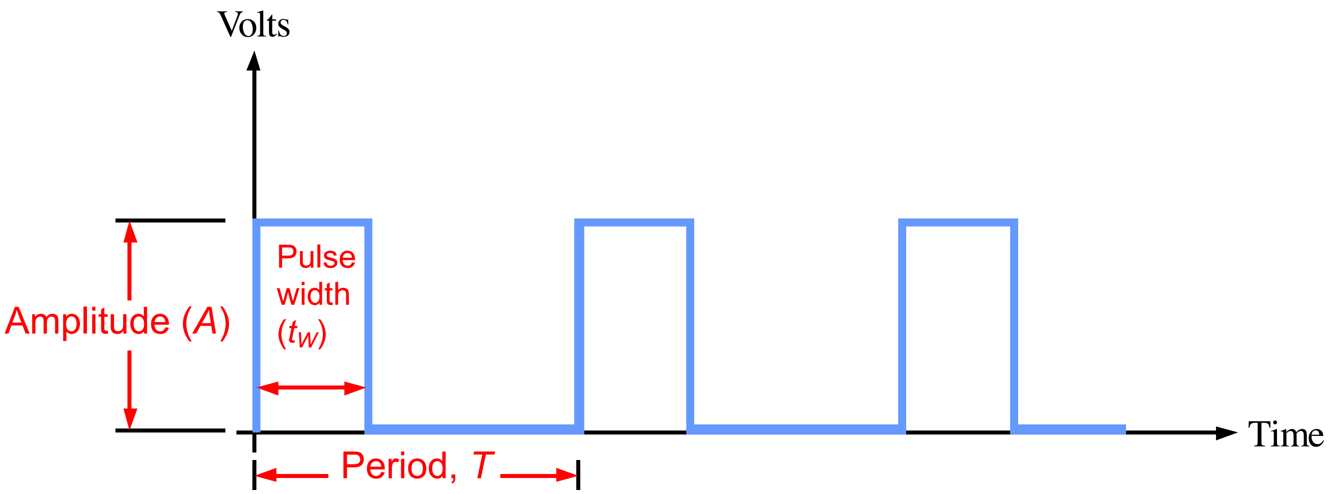
d) $100\,THz = 100 \times 10^{12}\,Hz = 10^{14}\,Hz$ $\quad T = \dfrac{1}{10^{14}} = 10^{-14}\,s = 10^{-14} \times 10^{12} = 0.01\,ps$

- Pulse is a rapid, transient change in the amplitude of a signal from a baseline value to a higher or lower value, followed by a rapid return to the baseline value.
- Pulse width (t_W): A measure of the duration of the pulse.
- Rise time and fall time is a measure of how fast the pulse change.



Repetitive Pulse Waveform

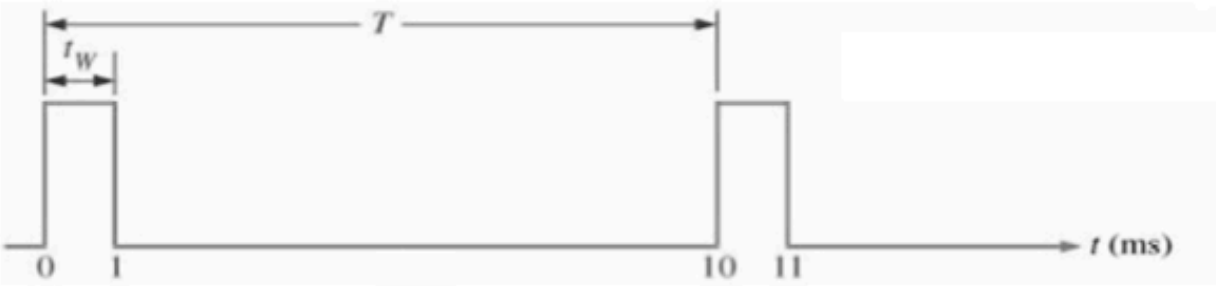
- In addition to frequency and period, repetitive pulse waveforms are described by the **amplitude** (A), **pulse width** (t_W) and **duty cycle**.
- Duty cycle is the ratio of t_W to T.



Duty Cycle

- Duty cycle is the fraction of time that a system is in an "active" state (operated), defined as

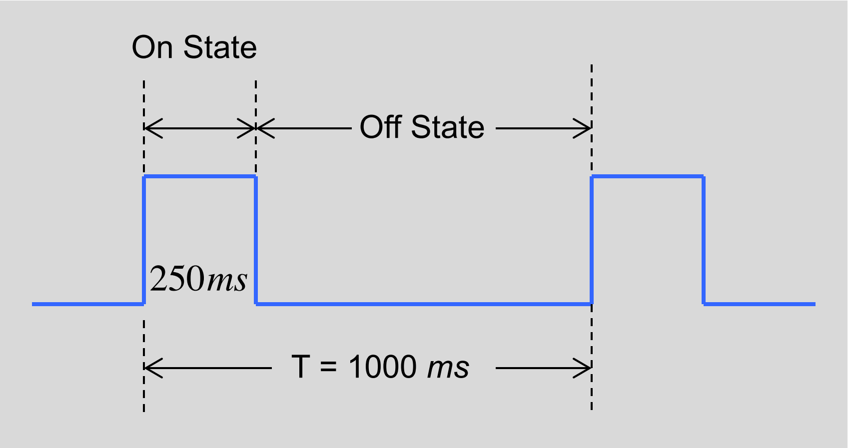
$$\text{Duty cycle} = (t_w/T)100\%$$



Example : a periodic digital waveform has a pulse width (t_w) 1ms and period time (T) 10ms, calculate duty cycle?

Duty cycle = 1ms/10ms * 100% = 10%

Exercise 1.3: Given the duration or period of a system is 1000ms, determine the *on state* and *off state* of the system that operate with the ratio of duty cycle is 25%. Show your works.



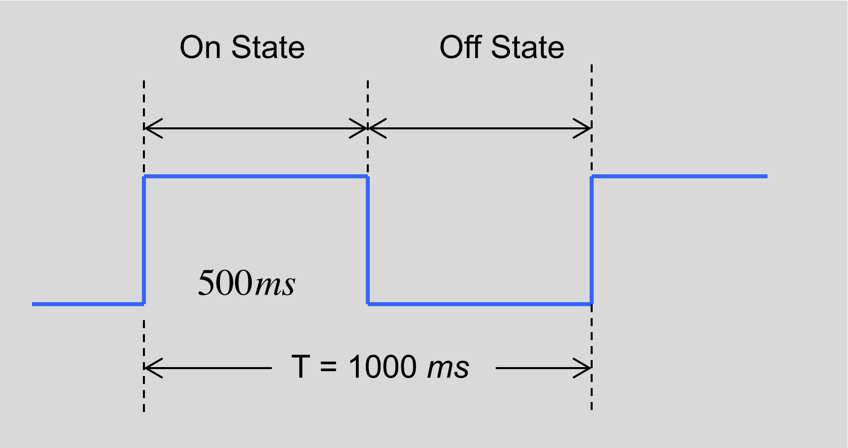
Solution 1.3:

Duty cycle → on state

$$= 25\% \times 1000ms = \frac{25}{100} \times 1000ms = \frac{1}{4} \times 1000ms = 250ms$$

Off state : $= 1000ms - 250ms = 750ms$

Exercise 1.4: Given the duration or period of a system is 1000ms, determine the *on state* and *off state* of the system that operate with the ratio of duty cycle is 50%. Show your works.



Solution 1.4:

Duty cycle → on state

$$= 50\% \times 1000ms = \frac{50}{100} \times 1000ms = \frac{1}{2} \times 1000ms = 500ms$$

Off state : $= 1000ms - 500ms = 500ms$

Exercise 1.5: Given the *duty cycles* of a system is 40% for a duration of a system is 500ms.

a) Calculate the pulse width of the system.

b) Determine the *off state* of the system that operate with the ratio of duty cycle.

Show your works.

Solution 1.5:

a)

$$DutyCycle = (\frac{t_W}{T})100$$

$$40 = (\frac{t_W}{500})100$$

$$t_W = \frac{40(500)}{100} = 200s$$

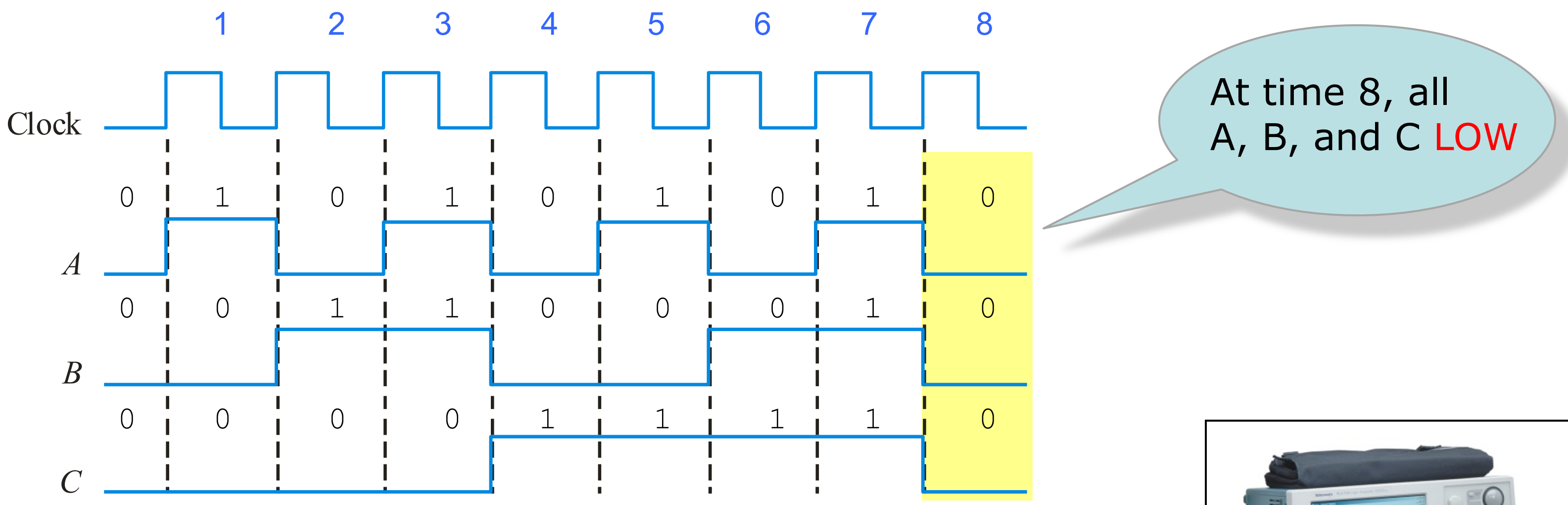
b)

$$Period = 500ms$$

$$OnState = t_W = 200ms$$

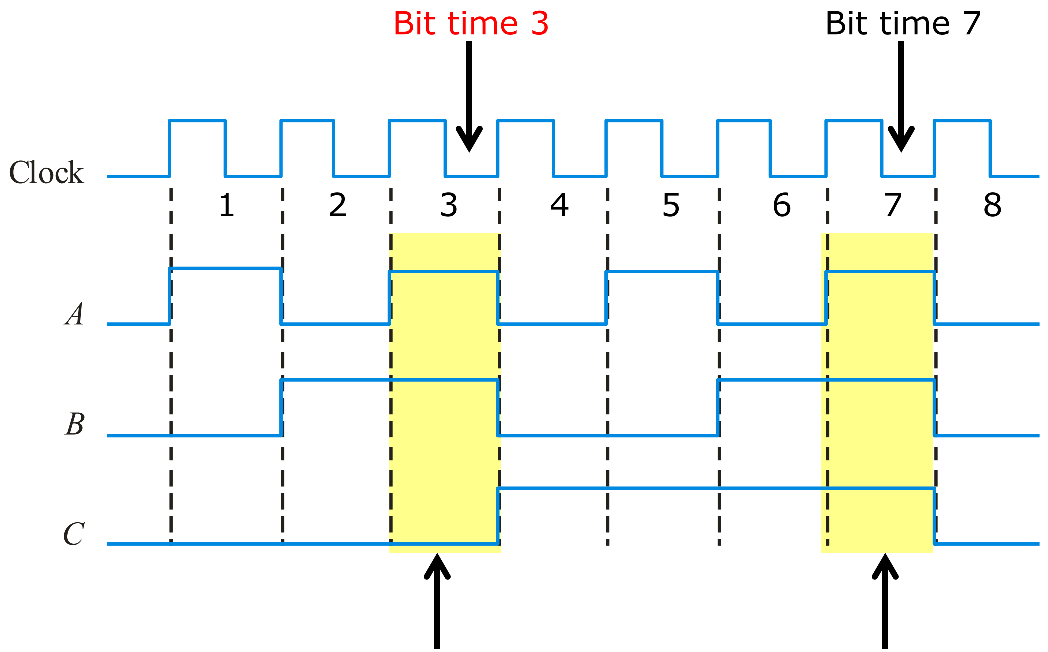
$$\therefore 500 - 200 = 300ms$$

A timing diagram is used to show the relationship between two or more digital waveforms,



A diagram like this can be observed directly on a logic analyzer.

Example: Timing Diagram

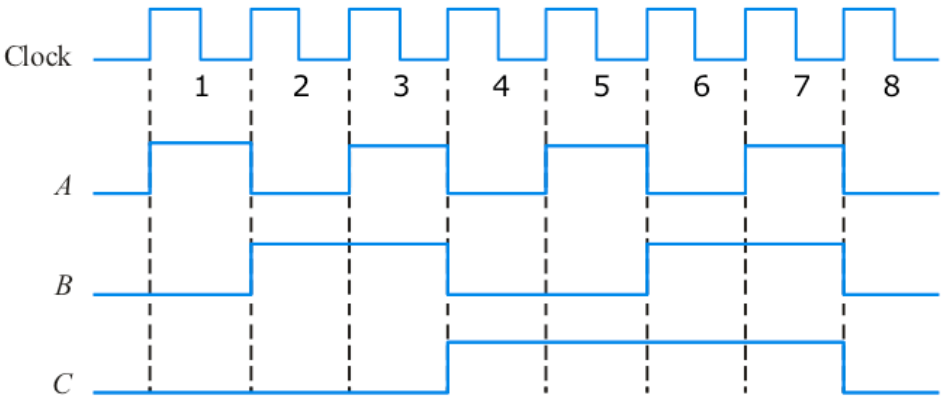


A = ?, B = ?, C = ?

A and B = HIGH = 1,
C = LOW = 0

A, B, and C HIGH
A = 1,
B = 1,
C = 1

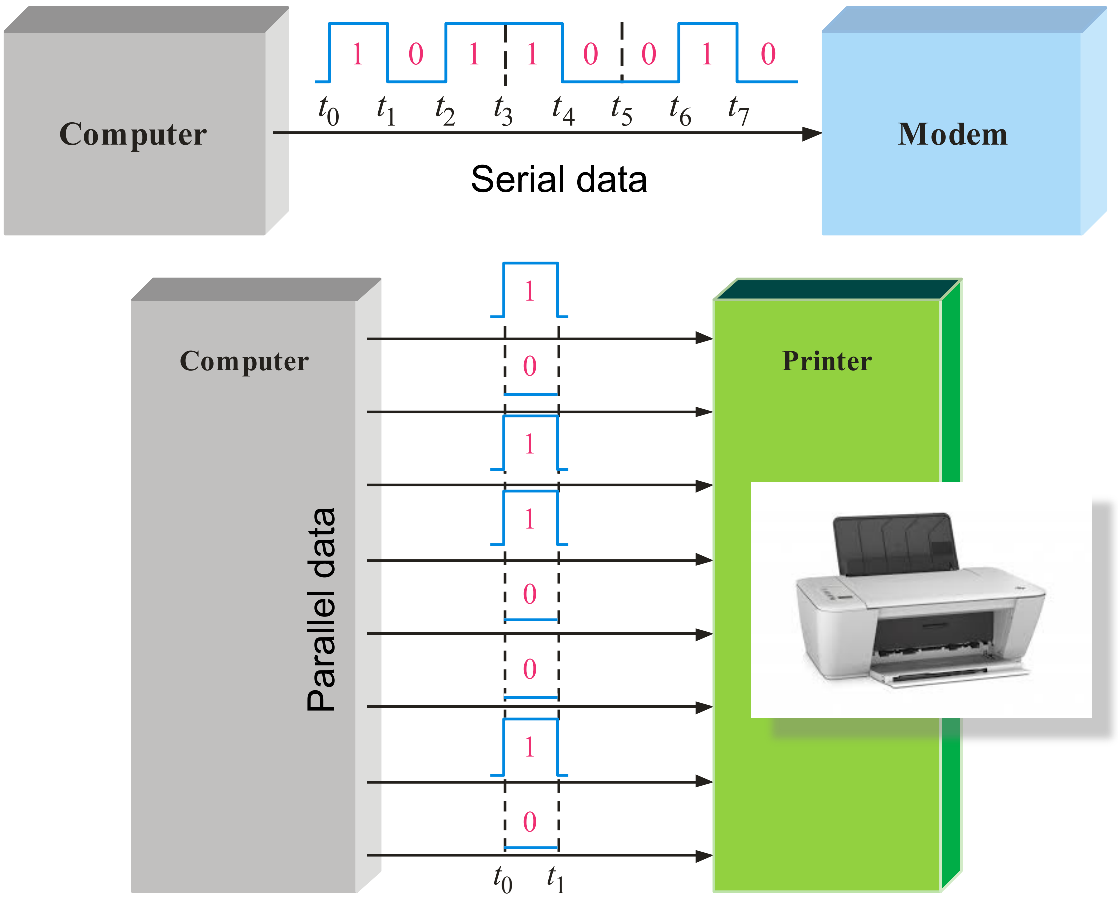
Example: Timing Diagram



Clock (↑)	Input		Output
	A	B	C
1	1	0	0
2	0	1	0
3	1	1	0
4	0	0	1
5	1	0	1
6	0	1	1
7	1	1	1
8	0	0	0

Exercise: Complete the truth table.

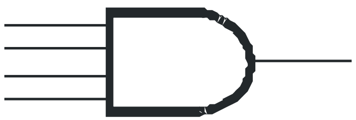
Data can be transmitted by either **serial** transfer or **parallel** transfer.



Introduction
to
Logic Operations

AND

True only if ***all*** input conditions are true.

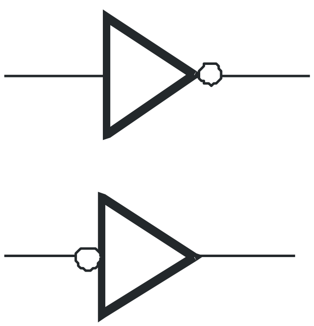


OR

True only if ***one or more*** input conditions are true.

NOT

Indicates the ***opposite*** condition (inverter).



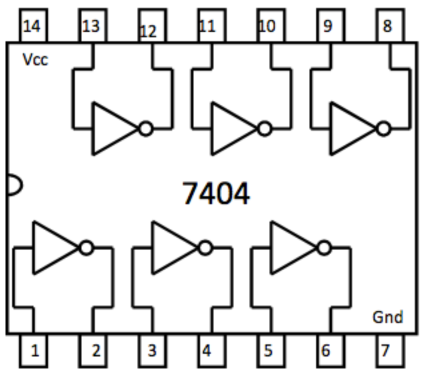
Logic Gates: NOT

NOT operation

Truth table shows the relationship between output and the input.

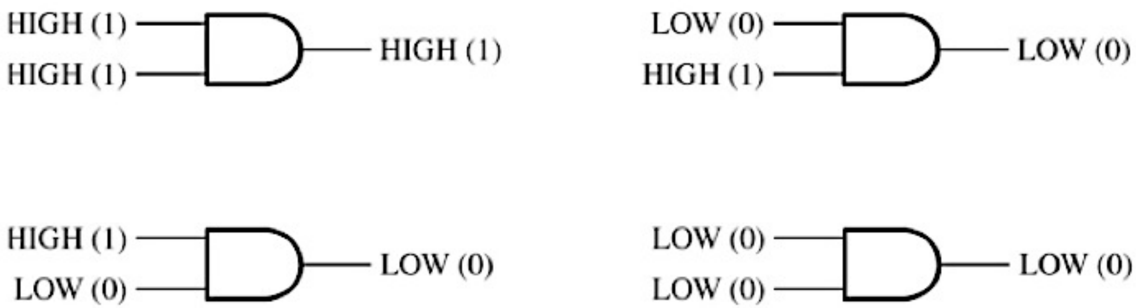
Truth Table for NOT

X	Z
0	1
1	0



7404 IC six inverters

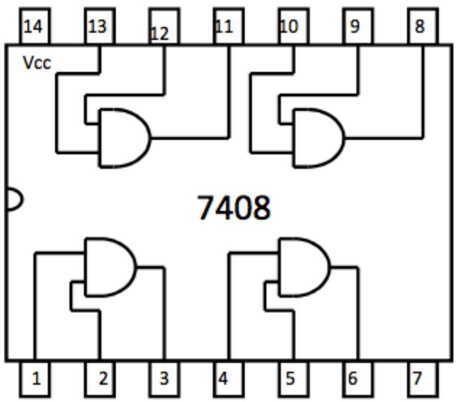
Logic Gates: AND



AND operation

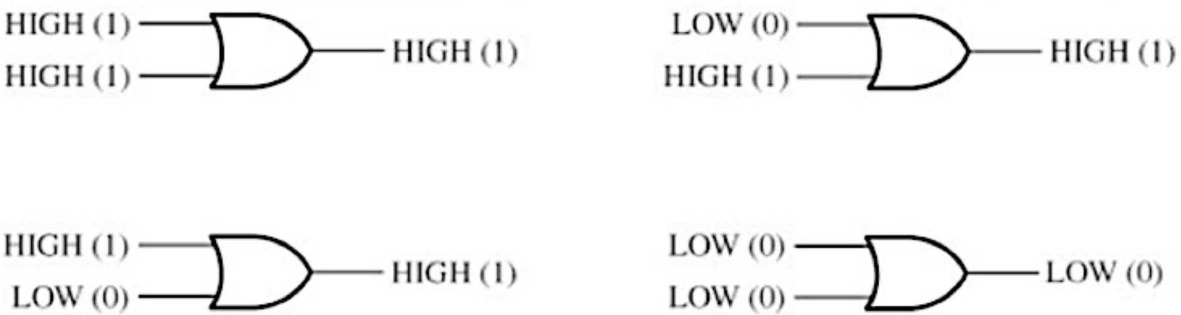
Truth Table AND

X	Y	Z
0	0	0
0	1	0
1	0	0
1	1	1



7408 IC four (Quad) AND gates

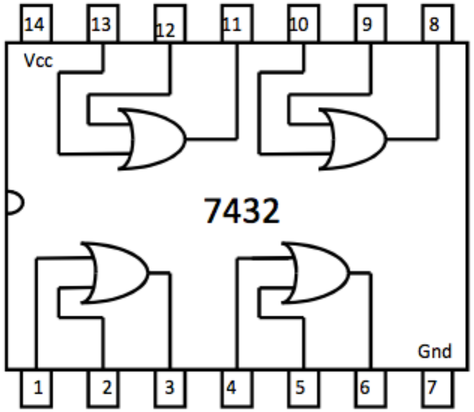
Logic Gates: OR



OR operation

Truth Table OR

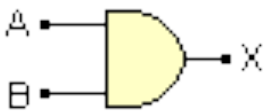
X	Y	Z
0	0	0
0	1	1
1	0	1
1	1	1



7432 integrated circuit provides four (Quad) two-inputs OR gates

Summary

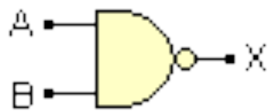
AND



$X = A \cdot B$

A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

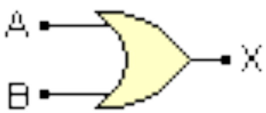
NAND



$X = \overline{A \cdot B}$

A	B	X
0	0	1
0	1	1
1	0	1
1	1	0

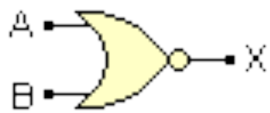
OR



$X = A + B$

A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

NOR



$X = \overline{A + B}$

A	B	X
0	0	1
0	1	0
1	0	0
1	1	0

XOR

$X = A \oplus B$

A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

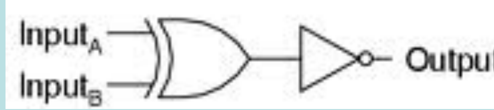
XNOR

$$X = \overline{A \oplus B}$$

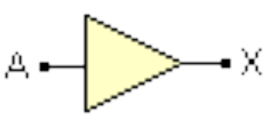
Exclusive-NOR gate

A	B	Output
0	0	1
0	1	0
1	0	0
1	1	1

Equivalent gate circuit



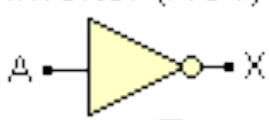
Buffer



$X = A$

A	X
0	0
1	1

Inverter (NOT)



$X = \overline{A}$

A	X
0	1
1	0

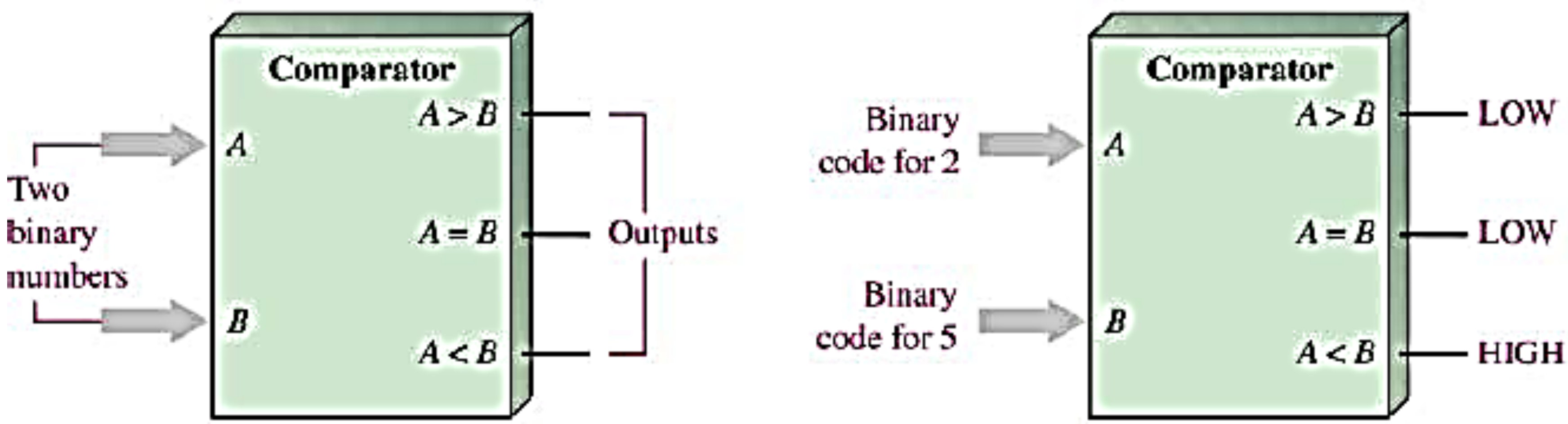
Resource: http://www.chem.uoa.gr/applets/appletgates/Images/Image1.gif

Overview of Logic Functions

Basic Logic Functions

- Any digital systems has one or more of the following function.
  - This functions are built from the basic gates.
    - Comparison Function
    - Arithmetic Functions
    - Code conversion function
    - Encoding function
    - Decoding function
    - Data selection function
    - Data storage function
    - Counting function

Comparison Function

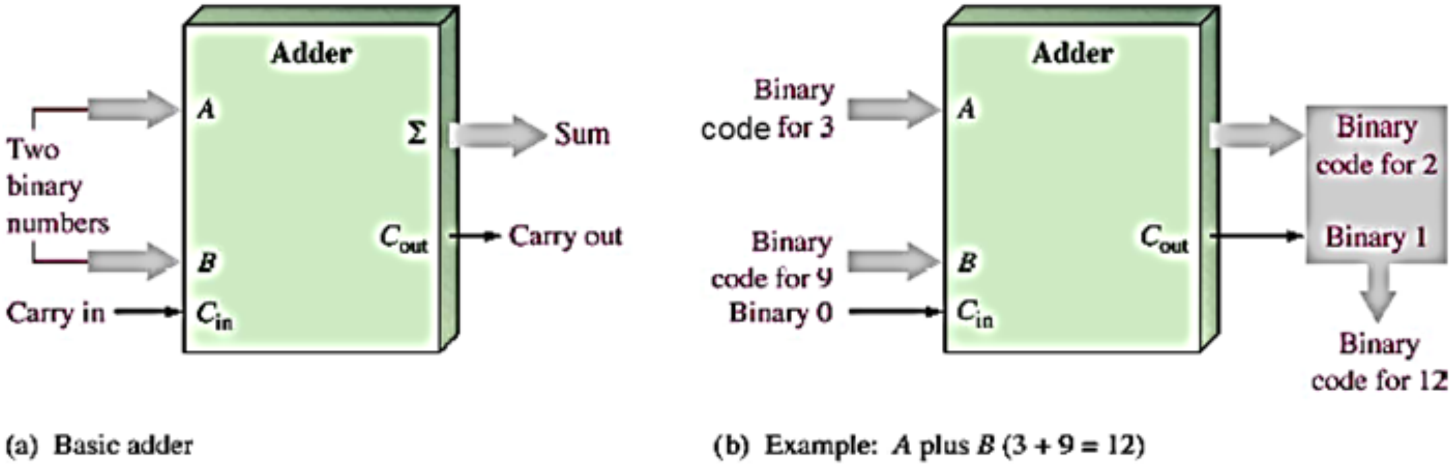


(a) Basic magnitude comparator

(b) Example: A is less than B ($2 < 5$) as indicated by the HIGH output ($A < B$)

Arithmetic Functions

- Adder



- Subtractor
- Multiplier
- Division

All the other arithmetic operations can be derived from adder:

- ❑ Subtraction is and addition of negative number such as A–B = A+(-B)
- ❑ Multiplication is a repeated addition such as A*3=A+A+A
- ❑ Division is a repeated subtraction which is a repeated addition such as

  6/3=6-3-3=6+(-3)+-(3)

  - subtract until the remainder = 0
  - total number of subtraction = 2 which is the answer

Code Conversion Function

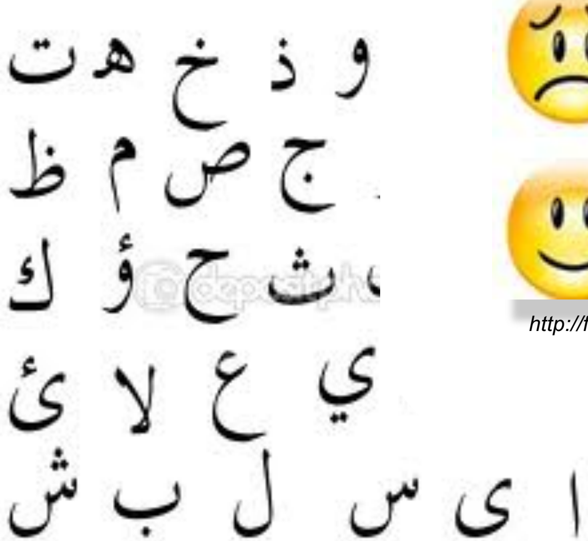
- A code is a set of bits arranged in a unique pattern and used to represent specified information.
  - Examples : BCD, ASCII

- The usage of codes allow a faster and more efficient data processing.

http://www.ehow.com/how_7162480_

symbols.com

http://facebooksmileysinfo.com/wp-content/uploads/2012/04/Smiley-Facebook-emoticons.jpg



http://depositphotos.com/2746252/stock-illustration-Arabic-alphabet.html

http://allenmathblog.files.wordpress.com/2012/01/integers.jpg http://msdn.microsoft.com/en-us/library/60ecse8t(v=vs.80).aspx

Extra

Ctrl	Dec	Hex	Char	Code
^@	0	00		NUL
^A	1	01		SOH
^B	2	02		STX
^C	3	03		ETX
^D	4	04		EOT
^^	30	1E	▲	RS
^-	31	1F	▼	US

Dec	Hex	Char
32	20	
33	21	!
34	22	"
35	23	#
36	24	$
62	3E	>
63	3F	?

Dec	Hex	Char
64	40	@
65	41	A
66	42	B
67	43	C
68	44	D
		E
		F
		G
		H
		I
		J
		K
		L
		M
		N
		O
		P
		Q
		R
		S
		T
		U
		V
		W
		X
		Y
		Z
		[
		\
		]
94	5E	^
95	5F	_

Dec	Hex	Char
		'
101		
102	66	f
103	67	g
104	68	h
105	69	i
106	6A	j
107	6B	k
108	6C	l
109	6D	m
110	6E	n
111	6F	o
112	70	p
113	71	q
114	72	r
115	73	s
116	74	t
117	75	u
118	76	v
119	77	w
120	78	x
121	79	y
122	7A	z
123	7B	{
124	7C	¦
125	7D	}
126	7E	~
127	7F	⌂

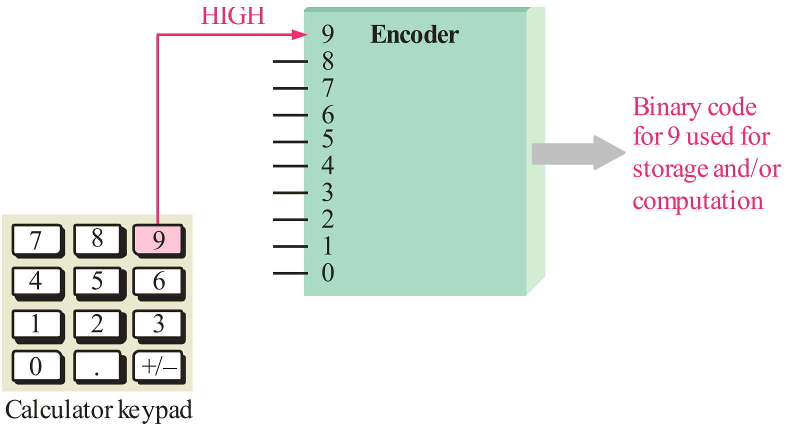
* ASCII code 127 has the code DEL. Under MS-DOS, this code has the same effect as ASCII 8 (BS). The DEL code can be generated by the CTRL + BKSP key.

To send this:	Type this:		
Smile	:-) or :)	Open-mouthed	:-D or :d
Surprised	:-O or :o	Tongue out	:-P or :p
Wink	;-) or ;)	Sad	:-(or :(
Confused	:-S or :s	Disappointed	:-| or :|
Crying	:'(	Embarrassed	:-$ or :$
Hot	(H) or (h)	Angry	:-@ or :@
Angel	(A) or (a)	Devil	(6)
Don't tell anyone	:-#	Baring teeth	8o|
Nerd	8-|	Sarcastic	^o)
Secret telling	:-*	Sick	+o(
I don't know	:^)	Thinking	*-)
Party	<:o)	Eye-rolling	8-)

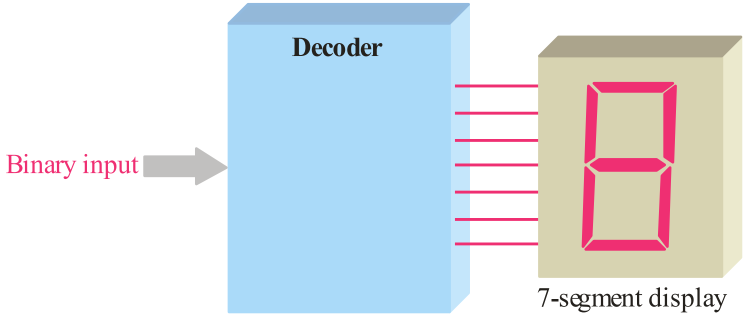
http://www.cool-smileys.com/wp-content/uploads/2009/06/regular-msn-emoticons.jpg

Encoding & Decoding Function

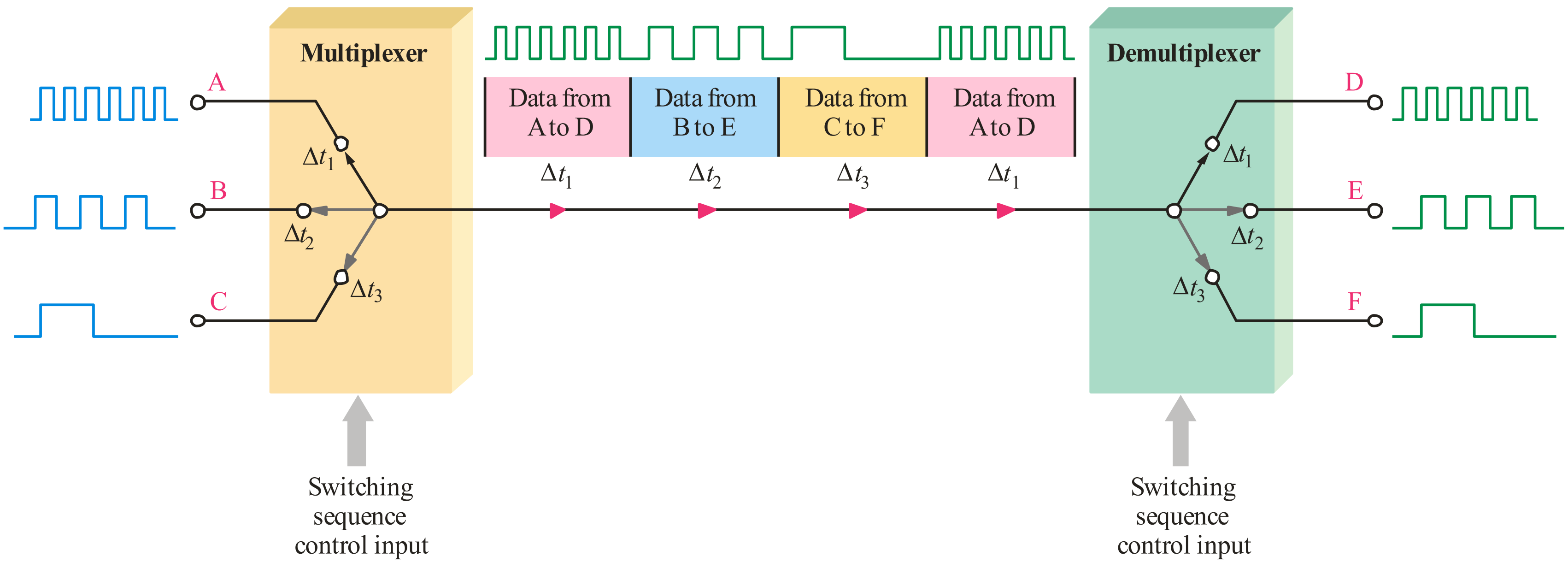
The encoding function



The decoding function



Data Selection Function: MUX & DeMUX



Problem:

Many inputs (e.g. A, B and C) wanted to use a single transmission line for their data transmission. How to make sure the data is transferred in a proper manner (issue of cost, synchronization, conflict , crash, loss?)

Source (A, B, C) and Destination (D, E, F)

A → D, B → E, C → F

Solution:

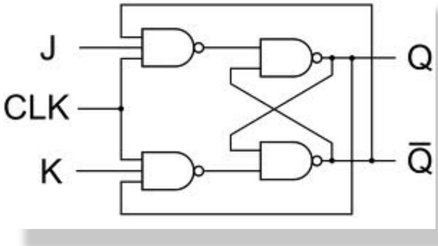
MUX: select and permit only one device can use the line and transfer its data at one time.

Data in the transmission line would be arranged as A, B, C

DEMUX: select and route the data to their originate destination

A → D, B → E, C → F

Data Storage Function



Flip-flop

- Flip-flop stores a 1 or 0 only
- Registers
  - Formed by combining several flip-flops
  - 8-bit register ➔ from 8 flip-flops
- Semiconductor Memories
  - e.g. RAM, ROM, Flash
- Magnetic/Optical Memories
  - For mass storage ➔ e.g. hard disk, tape, DVD, Blu-Ray

Semiconductor Memories

Blu-ray Disc™

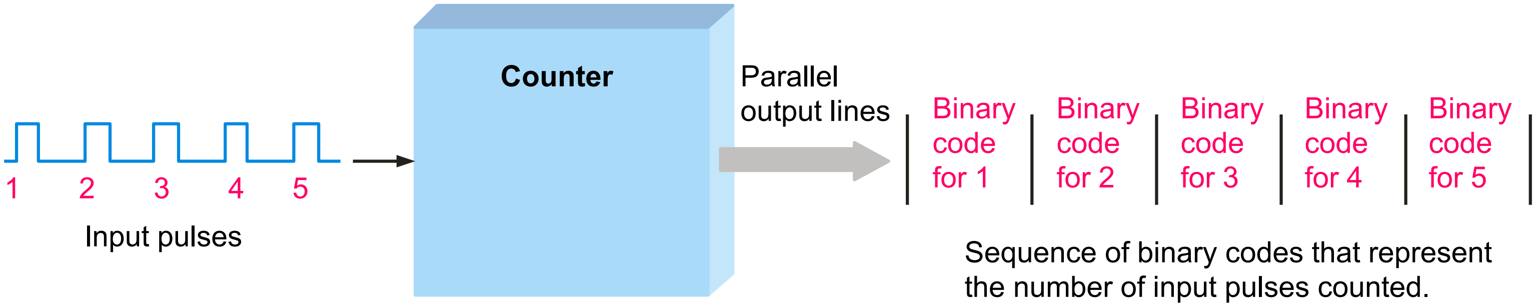
Optical Memories

Counting Function

Examples:

- Traffic light
- Washing machine
- Vending machine
- Xerox machine
- ATM machine
- etc.

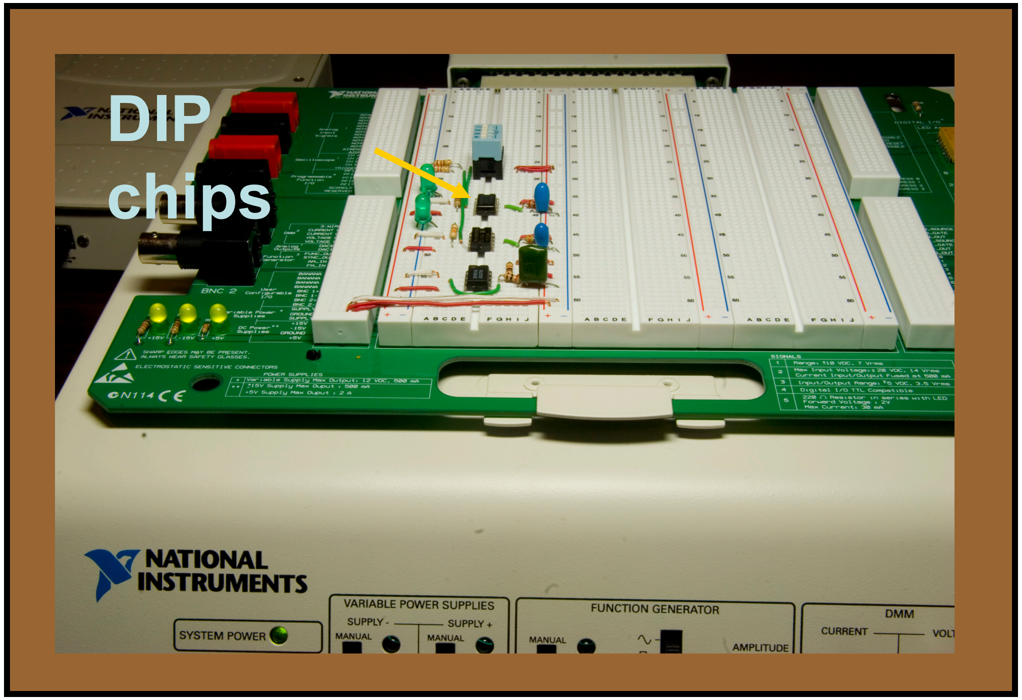
- Counter
  - To count the occurrence at the input.
  - to initiate a controller after a certain count (period).



Fixed-Function Integrated Circuit (IC)

An example of laboratory prototyping is shown. The circuit is wired using DIP chips and tested.

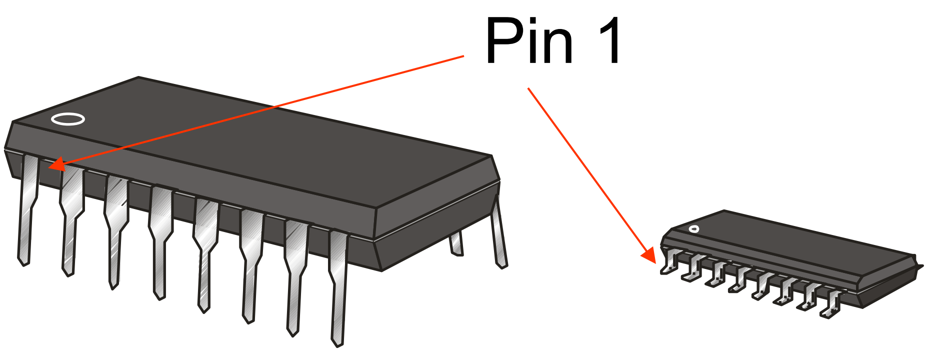
In this case, testing can be done by a computer connected to the system.



(Dual In-line Package)

IC Packages

DIP chips and surface mount chips



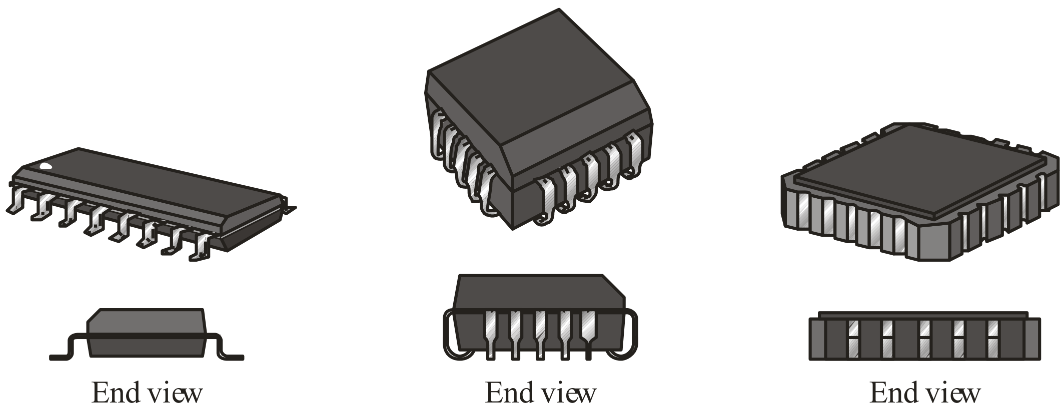
Dual in-line package

(DIP)

Small outline IC

(SOIC)

Other surface mount technology (SMT) packages:



SOIC

(Small-outline IC)

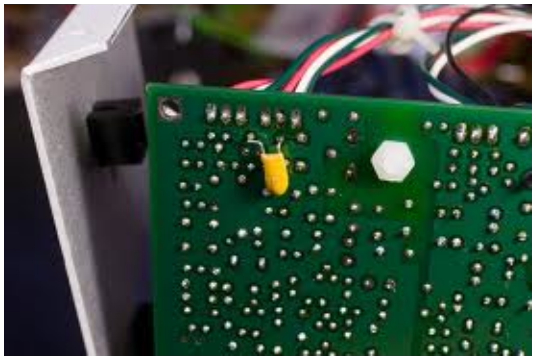
PLCC

(Plastic Leaded Chip Carrier)

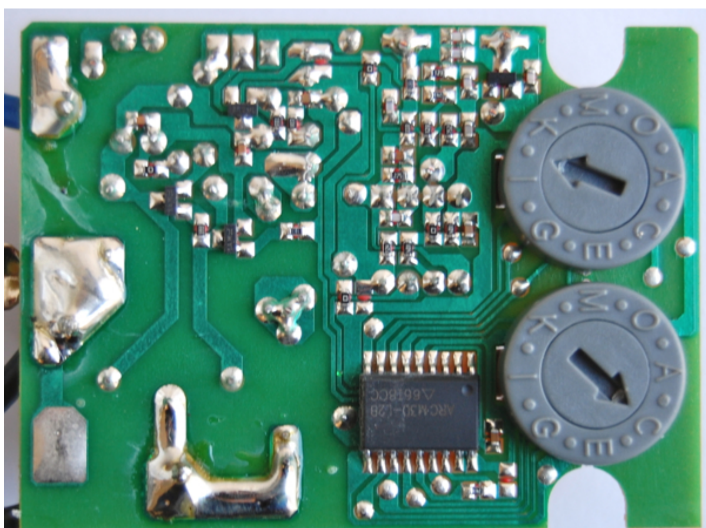
LCCC

(Leadless Ceramic Chip Carrier)

IC and conventional **through-hole** technology

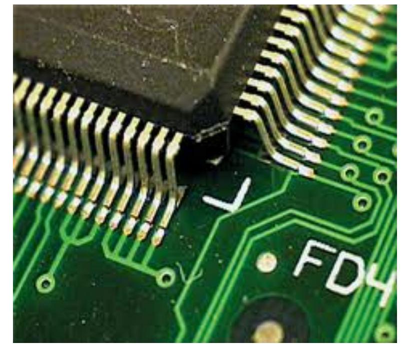


http://aa7ee.wordpress.com/page/4/



http://jeelabs.org/tag/teardown/

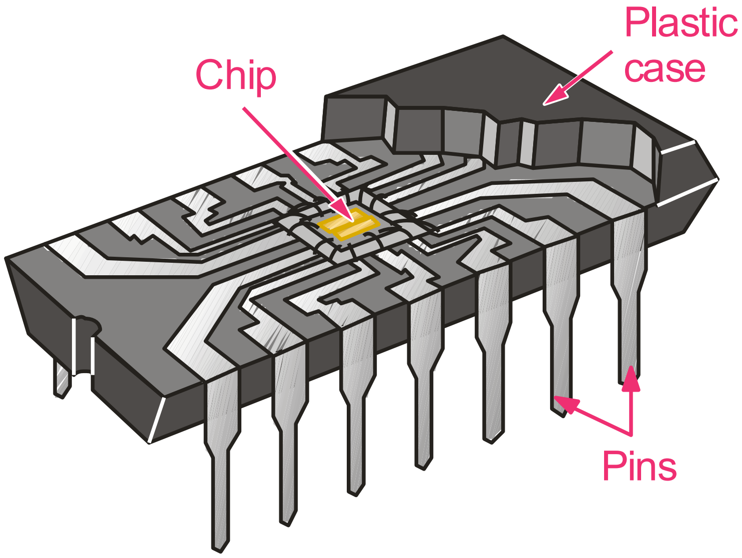
Surface Mount PCB



https://neuromorphs.net/ws2007/wiki/smd

http://www.pcb-manufacturers.co.uk/pcb-production-examples-c.html

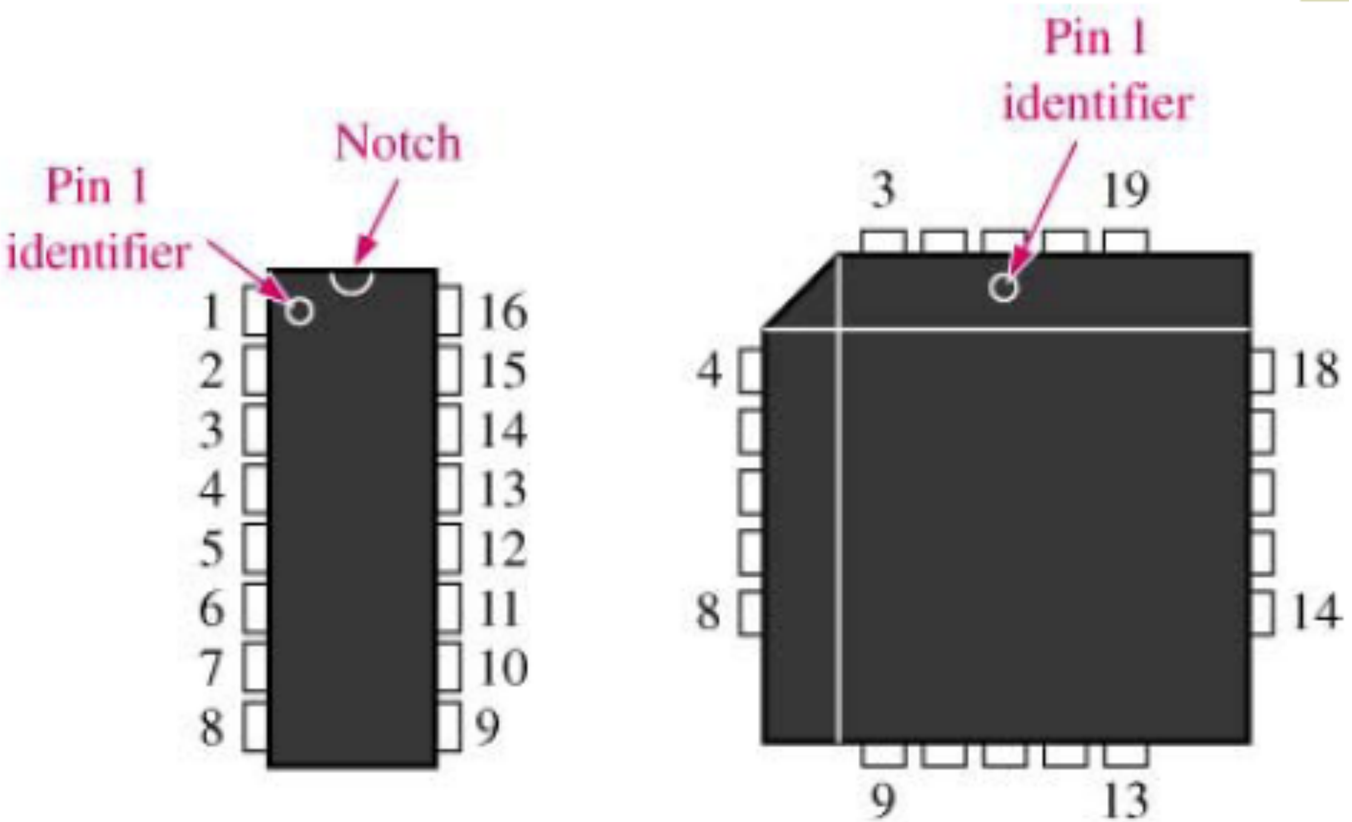
Cutaway view of DIP (Dual-In-line Pins) chip:



IC Packaging: Why we need packaging?

- To protect the IC (circuit)
- Have a pin system so that can connect to other circuit

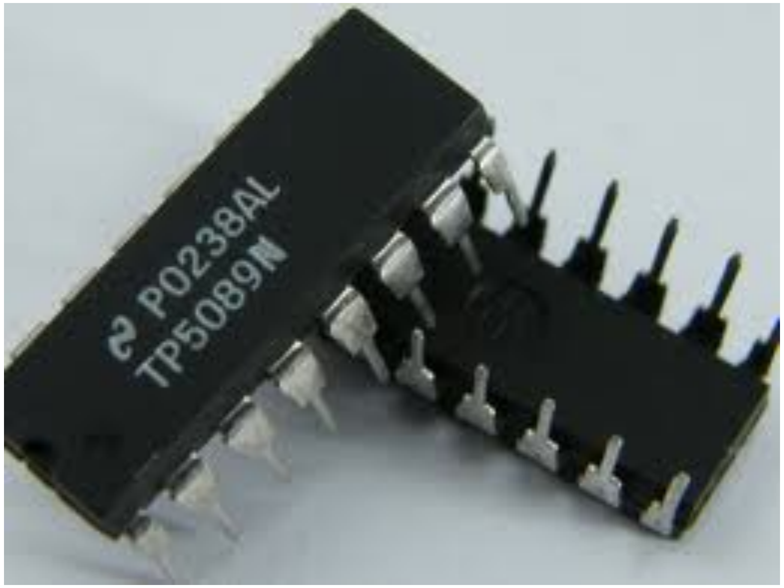
Pin Numbering



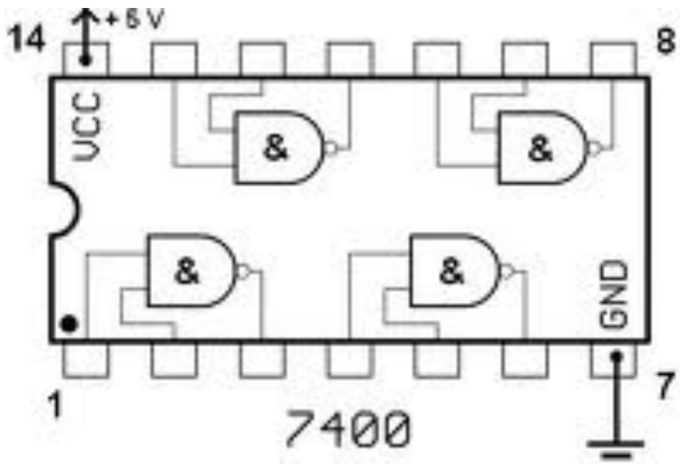
(a) DIP or SOIC (b) PLCC or LCCC

Extra

http://www.rkonlinestore.co.uk/556-dual-timer-ic-16-pin-dip-pack-of-4-391-p.asp



http://www.ebay.com/itm/10pcs-IC-TP5089N-DIP-16-PIN-TP5089-/310306081949



http://electroschematics.com/6529/7400-datasheet/

Complexity Classifications for Fixed-Function ICs

http://www.visual6502.org/images/263P/SSI_263P_8404_chip1_package_top.jpg

- Small-scale integration (SSI)
  have up to 12 gates on a single chip
- Medium-scale integration (MSI)
  have from 12-99 gates on a single chip
- Large-scale integration (LSI)
  have from 100-9999 gates on a single chip
- Very large-scale integration (VLSI)
  have from 10,000-99,999 gates on a single chip
- Ultra large-scale integration (ULSI)
  have from 100,000 and greater equivalent gates on a single chip

http://www.nysemagazine.com/lsicorp

Integrated Circuit Technologies

Some examples of IC technologies:

- TTL (Transistor-transistor Logic)
- ECL (Emitter-Coupled Logic)
- CMOS (Complementary Metal–Oxide–Semiconductor)
- NMOS (N-Type Metal–Oxide–Semiconductor)
- BiCMOS (Bipolar and Metal–Oxide–Semiconductor)

CMOS –

http://www.creativeplanetnetwork.com/dcp/news/cmos-technology-primer/40995

Programmable Logic Devices (PLD)

Overview of PLD

- **Fixed function**
  - A specific logic function is contained in the IC (hardwired) and can never be changed.
- **PLD**
  - Logic function programmed by the user.
    - Some, can be reprogrammed many times.
  - Advantage
    - More logic circuit can be ‘stuffed’ into much smaller area.
    - Certain PLD, design can be changed without rewiring or replacing components.
    - Can be implemented faster once the required programming language is mastered.

Types of PLD

3 major types (SPLD, CPLD, FPGA)

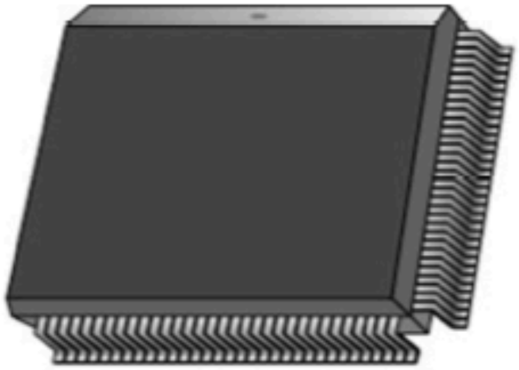
1. Simple **P**rogrammable **L**ogic **D**evices (SPLD)

- Can replace several fixed-function SSI or MSI
- First type available
- A few categories
  - PAL (programmable Array Logic)
  - GAL (Generic Array Logic)
  - PLA (Programmable Logic Array)
  - PROM (Programmable Read-Only memory)

Types of PLD: CPLD

2. **C**omplex **P**rogrammable **L**ogic **D**evices (CPLD)
   - Much higher capacity than SPLD (2-64 SPLD)
     - More complex logic circuits can be programmed
     - Typically in 44 – 160 pin package

(a) 84-pin PLCC package



(b) 128-pin PQFP package

Resource: http://upload.wikimedia.org/wikipedia/commons/thumb/a/a3/Altera_MAX_7128_2500_gate_CPLD.jpg/300px-Altera_MAX_7128_2500_gate_CPLD.jpg

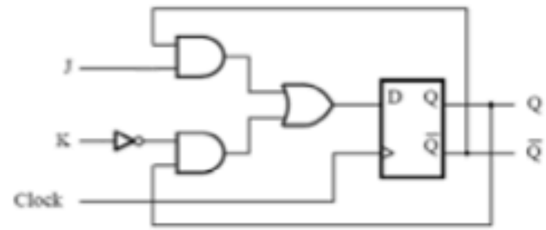
Types of PLD: FPGA

- 3. **F**ield-**P**rogrammable **G**ate **A**rrays (FPGA)
  - Different internal organization than SPLD and CPLD
  - Greatest logic capacity
    - Consist of 64- thousands logic block (logic gate groups)
  - Classes
    - Fine grain (smaller logic block)
    - Coarse grain (large logic block)

Resource: http://upload.wikimedia.org/wikipedia/commons/thumb/f/fa/Altera_StratixIVGX_FPGA.jpg/300px-Altera_StratixIVGX_FPGA.jpg

PLD Programming

- Logic circuit entered using 2 basic method
  - Graphical entry
    - schematic diagram



  - Text-based entry (language based entry)
    - Using Hardware Description Language (HDL)
      - Eg . ABEL, CUPL, WinCUPL
      - Becoming widely used especially for CPLD and FPGA
        - VHDL
        - Verilog

```
MODULE decoder
TITLE 'decoder'
A,B,C,D          pin          1,2,3,4;
W,X,Y,Z          pin          14,15,16,17;

equations

W=!B & C # !B & D # C & D # A;
X=!A & D # B # C;
Y=!A & !B & D # C;
Z=!B & C # D;
```