CHAPTER ONE

INTRODUCTION

The computer lies at the heart of computing. Without it most of the computing disciplines today would be a branch of theoretical mathematics. To be a professional in any field of computing today, one should acquire some understanding and appreciation of a computer system's functional components, their characteristics, their performance, and their interactions. We need to understand computer architecture in order to structure a program so that it runs more efficiently on a real machine. In selecting a system to use, they should be able to understand the tradeoff among various components, such as **CPU clock speed vs. memory size.**

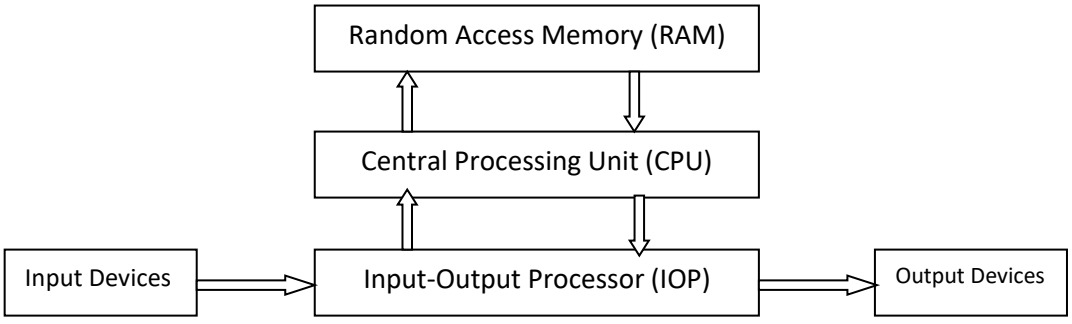
Suppose a graduate enters the industry and is asked the most cost-effective computer for use throughout a large organization. An understating of the implications of spending more for various alternatives, such as larger cache or a higher processor clock rate, is essential to making the decision.

Digital computers use the binary number system, which has two digits; 0 and 1. *Because of the physical restriction of components i.e., inside the computer, there are integrated circuits with thousands of transistors. These transistors are made to operate on two-state. By this design, all the input and output voltages are either HIGH or LOW. Low voltage represents binary 0 and high voltage represents binary 1*.

A binary digit is called a bit. Information is represented in digital computers in groups of bits. By using various coding techniques, groups of bits can be made to represent not only binary numbers but also other discrete symbols, such as decimal digits or letters of the alphabet and to develop complete sets of instructions for performing various types of computations.

A computer system is subdivided into two functional entities: Hardware and Software. The hardware of the computer consists of all the electronic components and electromechanical devices that comprise the physical entity of the device. Computer software consists of the instructions and data that the computer manipulates to perform various data-processing tasks. A sequence of instructions for the computer is called a Program.

The hardware of the computer is usually divided into three major parts.



--Block diagram of a digital computer—

The **Central Processing Unit (CPU)** contains an arithmetic and logic unit for manipulating data, a number of registers for storing data, and control circuits for fetching and executing instructions. The memory of a computer contains storage for instructions and data. It is called a **Random Access Memory (RAM**) because the CPU can access any location in memory at random and retrieve the binary information within a fixed interval of time. The **Input and output processor (IOP)** contains electronic circuits for communicating and controlling the transfer of information between the computer and the outside world. The input and output devices connected to the computer include keyboards, printers, terminals, and other communication devices.

Computer Architecture

Those attributes of the system that is visible to a programmer. It is concerned with the structure and behavior of the computer as seen by the user. Those attributes that have a direct impact on the execution of a program.

- Instruction sets
- Data representation – number of bits used to represent data
- Input/output mechanisms
- Memory addressing techniques

Computer Organization

The operational units and their interconnections that realize the architectural specifications. It is concerned with the way the hardware components operate and the way they are connected together to form the computer system. Those hardware attributes that are transparent to the programmer.

- Control signals
- Interfaces between the computer and peripherals
- Memory technology

Computer Design

It is concerned with hardware design of the computer. Once the computer specifications are formulated, it is the task of the designer to develop hardware for the system. This is sometimes referred to as computer implementation.

LOGIC GATES

A logic gate is an elementary building block of a digital circuit. It is a circuit with one output and one or more inputs. At any given moment, logic gate takes one of the two binary conditions low (0) or high (1), represented by different voltage levels.

A voltage level will represent each of the two logic values. For example +5V might represent a logic 1 and 0V might represent a logic 0.

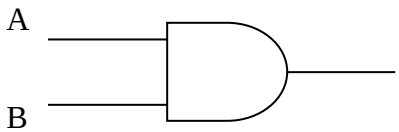
There are three fundamental logic gates namely, AND, OR and NOT. Also we have other logic gates like NAND, NOR, XOR and XNOR. Out of these NAND and NOR gates are called the **Universal Gates**. The circuit symbol and the truth table of these logic gates are explained here.

AND Gates

The AND Gate has two or more input signals but only one output signal. All the inputs must be high to get a high output. If we have two inputs to this AND gate and both the inputs are high then the output will be high otherwise the output will be low. All the possible inputs and outputs are shown in the following table.

Truth Table

A	B	Y
0	0	0
0	1	0
1	0	0
1	1	1



AND Gate symbol

Y = A . B

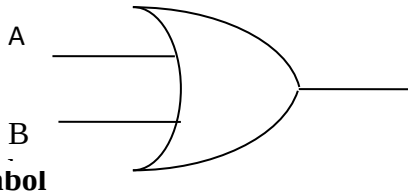
AND function

OR Gates

The OR gates has two or more input signals but only one output signal. If any input signal is high, the output signal is high. If we have two inputs to this OR gate and any of the two inputs is high then the output will be high. This can be shown in a table below with all the possible inputs and corresponding outputs.

Truth Table

A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

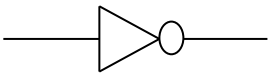


OR Gate symbol **A+B** **OR** function

NOT or Inverter:

A Low input produces a high output, and a high input produces low output. In binary format if the input is 0 the output will be 1 and if the input is 1 then the output will be 0. The table shows the input and output possibilities.

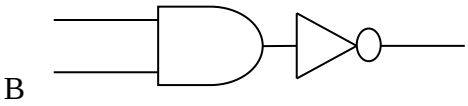
Input	Output
0	1
1	0

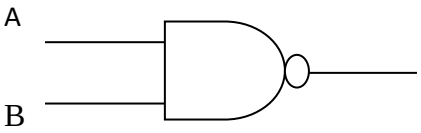


NOT Gate symbol $\mathbf{Y = \overline{A}}$ **NOT** function

NAND Gate

NAND Gate is a combination of an AND gate with an inverter. An AND Gate followed by an inverter.





Whatever the output of the AND gate, it will be inverted by the inverter. This is the formation of NAND gate. The sign and the table is shown below. The NAND operation is called Universal Operation or gate.

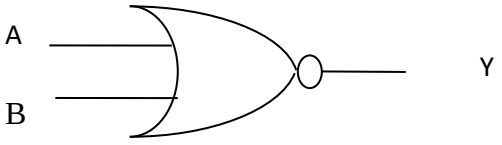
$Y = \overline{AB}$

NAND Sign

A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

NOR Gate

NOR Gate is a combination of an OR gate with an inverter. An NOR Gate followed by an inverter.
The NOR operation is also a Universal Operation or Gate.



$Y = \overline{A+B}$

NOR Sign

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

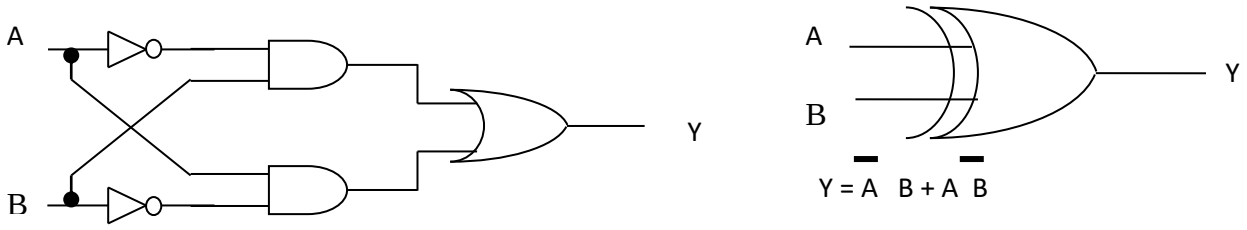
Exclusive OR Gate

An OR Gate recognizes with one or more 1s as inputs and gives output as 1. The Exclusive-OR is different; it recognizes only that have odd number of 1s. The following table shows different inputs and outputs.

Y= A XOR B
Y= A⊕ B
Ex-OR sign

A	B	Y (Output)
0	0	0
0	1	1
1	0	1
1	1	0

XOR GATE Input Output



Exclusive NOR Gate or XNOR

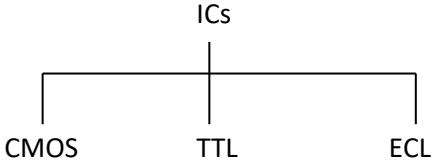
Exclusive NOR Gate is abbreviated as XNOR. This is logically equivalent to and XOR gate followed by an inverter. Following figure shows the XNOR gate and the table of input and outputs.

Y= A ENOR B
Y= $\overline{A \oplus B}$
Ex-NOR sign

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	1

List of Logic Gate Ics

There are different Integrated Circuit (IC) technologies are used to implement the basic logic gates



They are CMOS (Complementary Metal – Oxide Semiconductor), TTL (Transistor – Transistor Logic) and ECL (Emitter – Coupled Logic).

BOOLEAN ALGEBRA

Boolean algebra is mathematical system for formulating logical statements with symbols so that problems can be solved in a manner to ordinary algebra. Boolean algebra is the mathematics of digital systems A basic knowledge in the Boolean algebra required to study and analysis of logic circuits. It is a convenient and systematic way of expressing and analyzing the operations of logic circuits.

Rule Number	Boolean Expression
1	A + 0 = A
2	A + 1 = 1
3	A . 0 = 0
4	A.1 =A
5	A + A = A
6	$A + \bar{A} = 1$
7	A .A = A
8	$A . \bar{A} = 0$
9	$\bar{\bar{A}} = A$
10	A + AB =A
11	$A + \bar{A} B = A + B$
12	(A + B) (A + C) = A + BC

Commutative Law :	A + B = B + A	AB = BA
Associative Law :	A+(B+C) = (A+B)+C	A(BC) = (AB)C
Distributive law:	A(B+C) = AB + AC	A +(BC) = (A+B). (A+C)
De morgan's Theorems :	$\overline{A + B} = \bar{A} . \bar{B}$	$\overline{A.B} = \bar{A} + \bar{B}$

Karnaugh Map Method

The Karnaugh map method is a graphical technique for simplifying Boolean functions. It is a two-dimensional of a Truth Table. It provides a simpler method for minimizing logic expressions. The map method is ideally suited for four or less variables.
A Karnaugh map for n variables is made up of 2^n squares. Each square designates a product term of a Boolean expression. For product terms which are present in the expression, 1s are written in the corresponding squares; 0s are written in those squares which correspond to product terms not present in the expression.

Consider a map of two variables:

	$\bar{A}$	A
$\bar{B}$	$\bar{A}\,\bar{B}$	$A\,\bar{B}$
B	$\bar{A}\,B$	A B

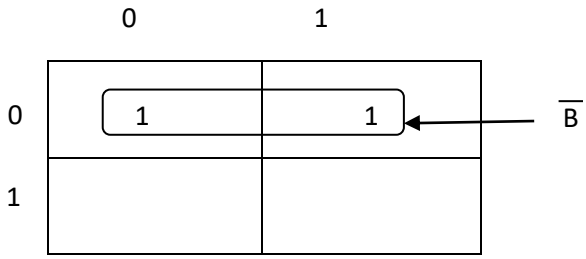
B \ A	0	1
0	$\bar{A}\,\bar{B}$	$A\,\bar{B}$
1	$\bar{A}\,B$	A B

In the map, 0 represents $\bar{A}$, and 1 represents A. Similarly, for variable B.

For example, for the Boolean functions Y = $A\,\bar{B}$ + AB

	∪	1
0		1
1		1

Example : simplify $Y = \overline{A}\,\overline{B} + A\overline{B}$



Two adjacent squares containing 1 have been grouped together. To show the grouping, they have been encircled. For simplification we have to see that which variable is common to both squares. In this case $\overline{B}$ is common to both as the 1st row is for $\overline{B}$.

So their simplification will result $Y = \overline{B}$

This can be verified also algebraically as follows:

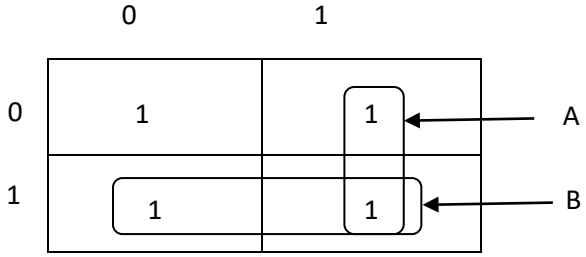
$Y = \overline{A}\,\overline{B} + A\overline{B}$

$= \overline{B}\,(\overline{A} + A)$

$= \overline{B}$

So the variable which is common to adjacent squares is selected, and the variable which is not common is discarded.

Example : simplify $Y = \overline{A}\,B + AB + A\overline{B}$



Simplification result $Y = \overline{A}\,B + AB + A\overline{B} = B + A$

The result obtained by map method can also be verified algebraically as follows:

$Y = \overline{A}\,B + AB + A\overline{B}$

$= \overline{A}\,B + AB + AB + A\overline{B}$

$= B\,(\overline{A} + A) + A\,(B + \overline{B})$

$= B + A$

Karnaugh Map for Three variables:

$\overline{A}\,\overline{B}$ $\overline{A}\,B$ $A\,B$ $A\,\overline{B}$

$\overline{C}$				
	$\overline{A}\ \overline{B}\ \overline{C}$	$\overline{A}\ B\ \overline{C}$	$A\ B\ \overline{C}$	$A\ \overline{B}\ \overline{C}$
C	$\overline{A}\ \overline{B}\ C$	$\overline{A}\ B\ C$	$A\ B\ C$	$A\ \overline{B}\ C$

The ordering of the variables, ie., 00,01,11,10 is in gray code.

C \ AB	00	01	11	10
0	$\overline{A}\ \overline{B}\ \overline{C}$	$\overline{A}\ B\ \overline{C}$	$A\ B\ \overline{C}$	$A\ \overline{B}\ \overline{C}$
1	$\overline{A}\ \overline{B}\ C$	$\overline{A}\ B\ C$	$A\ B\ C$	$A\ \overline{B}\ C$

Example: simplifying the function $Y = AB\overline{C} + ABC$

C \ AB	00	01	11	10	
0			1		AB
1			1		

The simplified function will be $Y = AB$

Example: simplifying the function $Y = \overline{A}\ \overline{B}\ \overline{C} + \overline{A}\ B\ \overline{C} + \overline{A}\ \overline{B}\ C$

C \ AB	00	01	11	10	
0	1	1			$\overline{A}\overline{C}$
1	1				$\overline{A}\ \overline{B}$

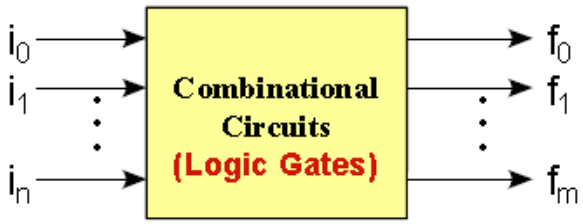
The simplified function will be $Y = \overline{A}\ \overline{B} + \overline{A}\ \overline{C}$

COMBINATORIAL CIRCUITS AND FLIP FLOPS

Combinational Circuits:

A connected arrangement of logic gates with a set of inputs and outputs

Block diagram of a combinational circuit

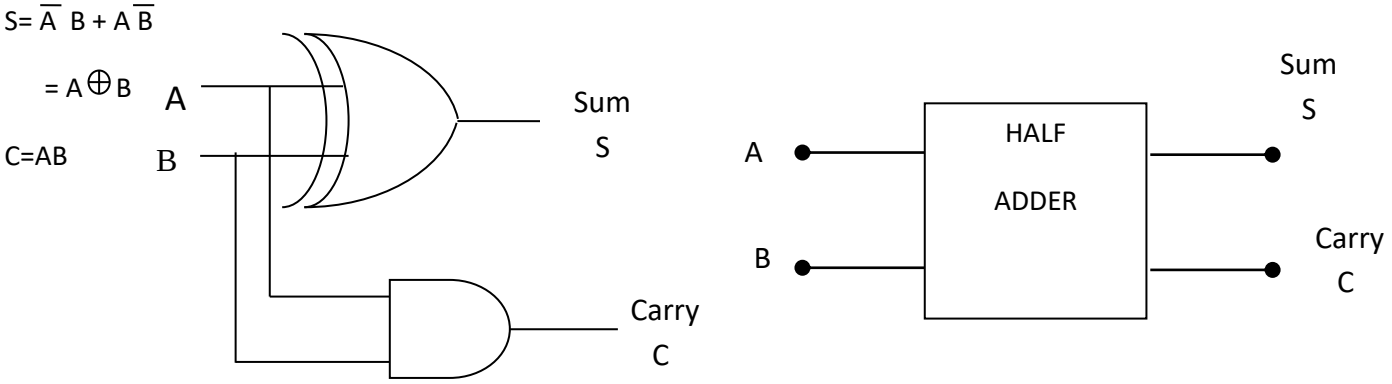


Combinational circuits are those logic circuits whose operations can be completely described by a truth table / Boolean expression. A combinational circuit is realized using AND, OR, NOT gates (or NAND OR NOR gates). Examples of combinational circuits are: adder, subtractors, code converters, decoders, encoders, digital multiplexers, demultiplexers, programmable logic arrays, ROMs etc.,
Logic circuits for some important arithmetic operations are half-adder and full adder.

HALF ADDER:
A logic circuit which performs addition of two binary bits is called a half-adder.
Truth table for the addition of two binary bits.

Inputs		Outputs	
A	B	Sum S	Carry C
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

It is concluded that the sum is equal to A XOR B. It means that the outputs of an EXCLUSIVE-OR gate will give the sum. The carry is equal to A AND B. The output of an AND gate will give the carry.

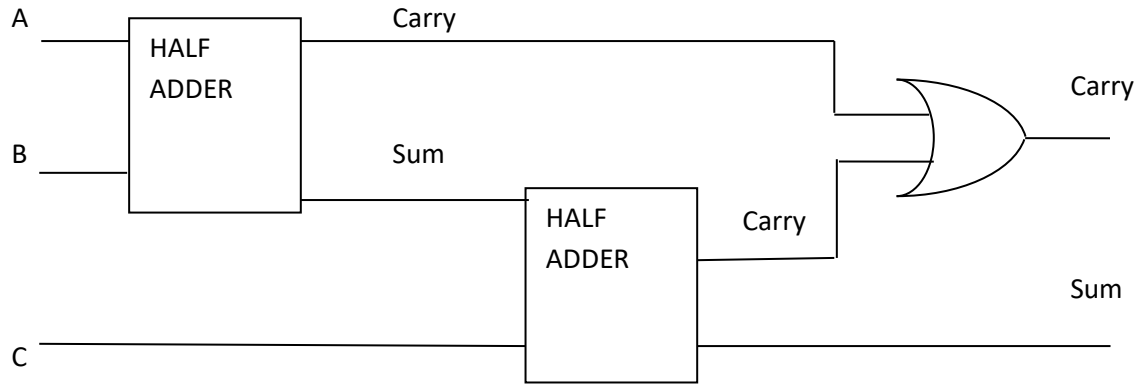


FULL ADDER

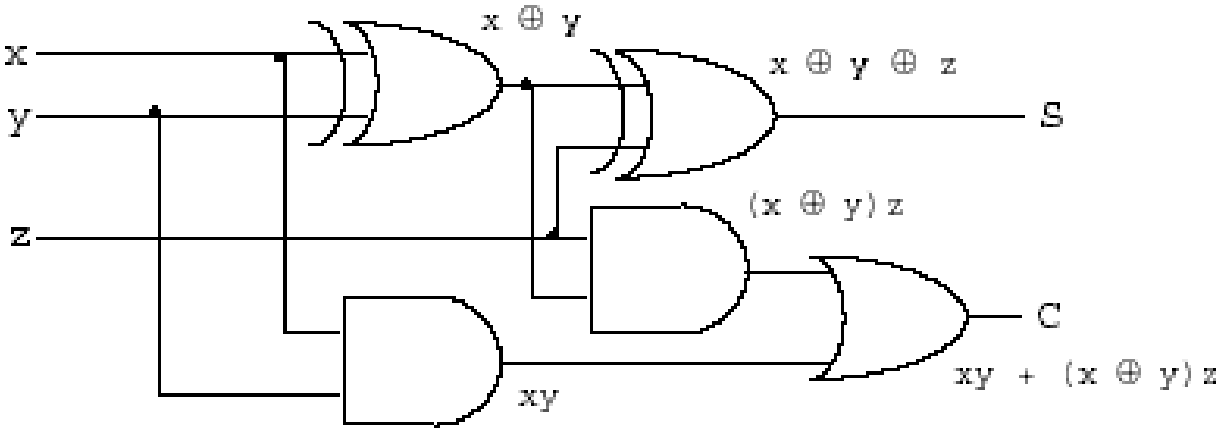
A logic circuit which performs addition of three binary bits is called a Full-adder.
A full adder can be built using two half adders and an OR gate.

Inputs			Outputs	
A	B	C	Sum S	Carry C
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

$S = x \oplus y \oplus z$
$C = z(x \oplus y) + xy$



The logic diagram for the full adder



FLIP FLOPS:

Flip flops is a binary cell capable of storing one bit of information.

The flip flop is a bistable device. It exists in one of two states and, in the absence of input, remains in that state. Thus, the flip flop can function as a 1 bit memory.

The flip flop has two outputs, which are always the complementary of each other; these are generally labelled Q and $\overline{Q}$

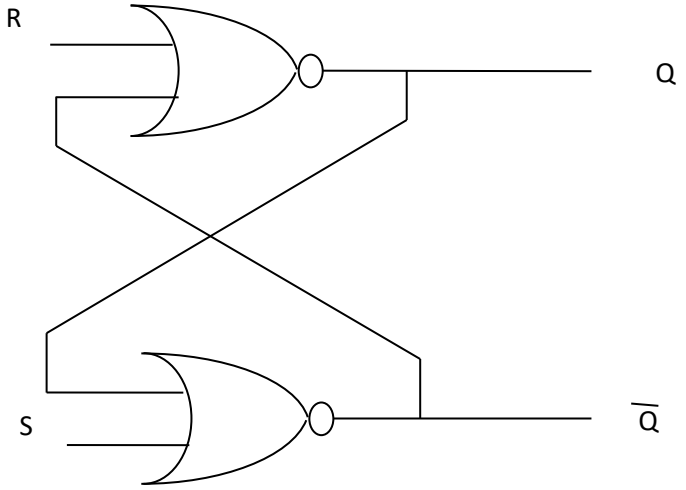
The S-R Flip flop:

The circuits has two inputs, s(Set) and R (Reset) and two outputs $\overline{Q}$ and Q and consists of two NOR gates connected in a feedback arrangement.

First, Let us show that the circuit is bistable. Assume that both S and R are 0 and that Q is 0. The inputs to the lower NOR gate are Q = 0 and S = 0. Thus, the output $\overline{Q}$ = 1 means that the inputs to the upper NOR gate are Q=1 and R=0, which has the output $\overline{Q}$ = 0.

Thus, the state of the circuit is internally consistent and remains stable as long as S = R = 0. A similar line of reasoning shows that the state Q = 1, $\overline{Q}$ = 0 is also stable for R = S = 0.

Thus, this circuit can function as a 1-bit memory. Suppose that S changes to the value 1. Now the inputs to the lower NOR gate are S =1 , C After some time delay t, the output of the lower NOR gate will be $\overline{Q} = 0$.



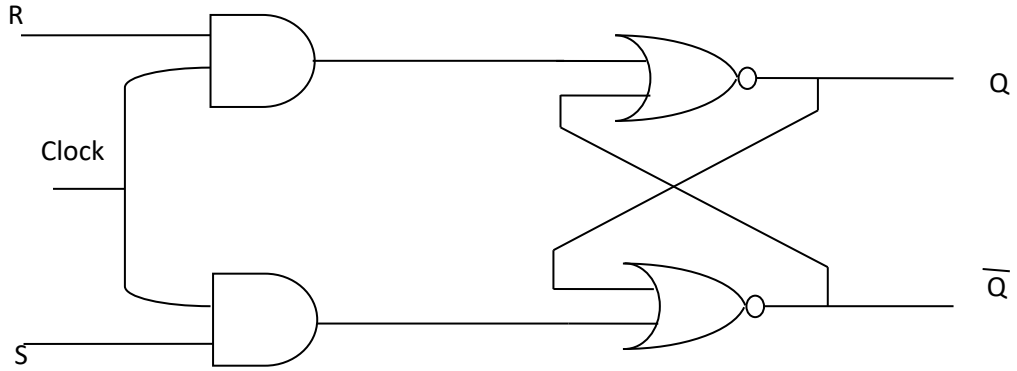
characteristic Table

S	R	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	--

So, at this point in time, the inputs to the upper NOR gate become R=0 , $\overline{Q}$ = 0. After another gate delay of t, the output Q becomes 1. This is again a stable state. The inputs to the lower gate are now S = 1, $\overline{Q}$=1, which maintain the output Q=0. As long as S =1 and R =0, the outputs will remain Q =1, Q = 0. Furthermore, if S returns to 0, the outputs will remain unchanged.
Observe that the inputs S = 1, R =1 are not allowed, because these would produce an inconsistent output (both $\overline{Q}$ and Q equal 0).

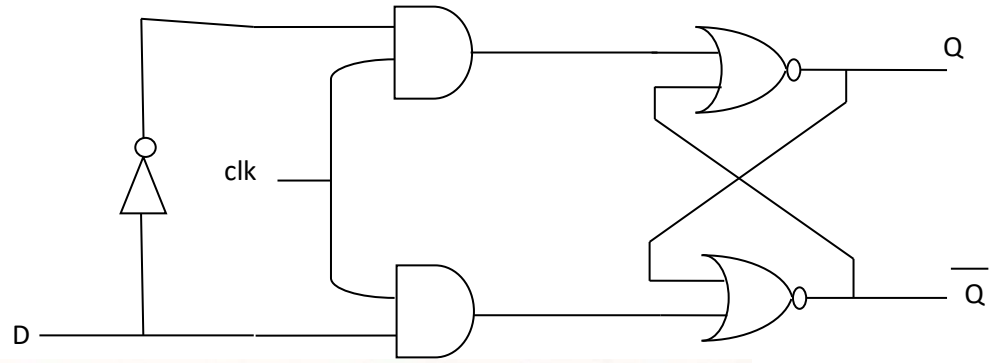
<u>Clocked S-R Flip-Flop:</u>

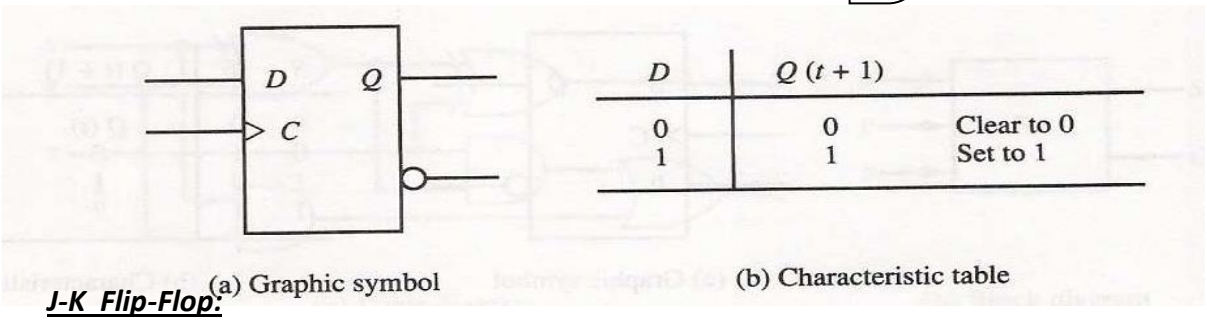
The output of the S-R latch changes, after a brief time delay, in response to a change in the input. This is referred to as asynchronous operation. More typically, events in the digital computer are synchronized to a clock pulse, so that changes occur only when a clock pulse occurs. This type of device is referred to as a clocked S-R flip-flop. Note that the R and S inputs are passed to the NOR gates only during the clock pulse.



<u>D Flip – Flop:</u>

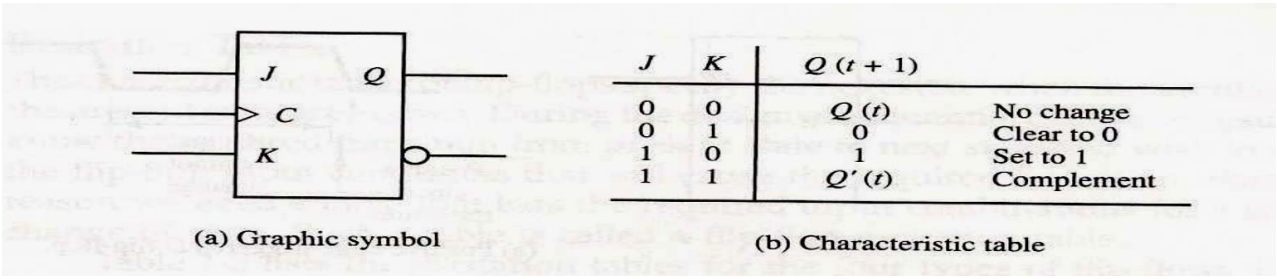
One problem with S-R flip flop is that the condition R = 1, S = 1 must be avoided. One way to do this is to allow just a single input. The D flip flop accomplishes this. By using an inverter, the two AND gates are guaranteed to be the opposite of each other.
The D flip flop is sometimes referred to as the data flip flop because it is, in effect, storage for one bit of data. the output of the D flip flop is always equal to the most recent value applied to the input. Hence, it remembers and produces the last input. It is also referred to as the delay flip flop, because it delays a 0 or 1 applied to its input for a single clock pulse.





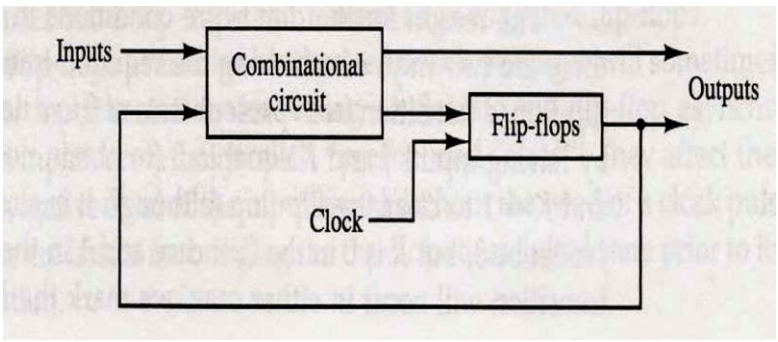
J-K Flip-Flop:

Like the S-R flip flop, it has 2 inputs. However, in this case all possible combinations of input values are valid. In its characteristic table, we can note that the first three combinations are the same as for the S-R flip-flop. With no input, the output is stable. The J input alone performs a set function, causing the output to be 1; the K input alone performs a reset function, causing the output to be 0. When both J and K are 1, the function performed is referred to as the toggle function: the output is reversed.



SEQUENTIAL CIRCUITS

A sequential circuit is an interconnection of Flip-flops and Gate. A sequential circuit consists of a combinational logic and storage elements. The output of a sequential circuit is not only a function of a present inputs but also of past inputs.



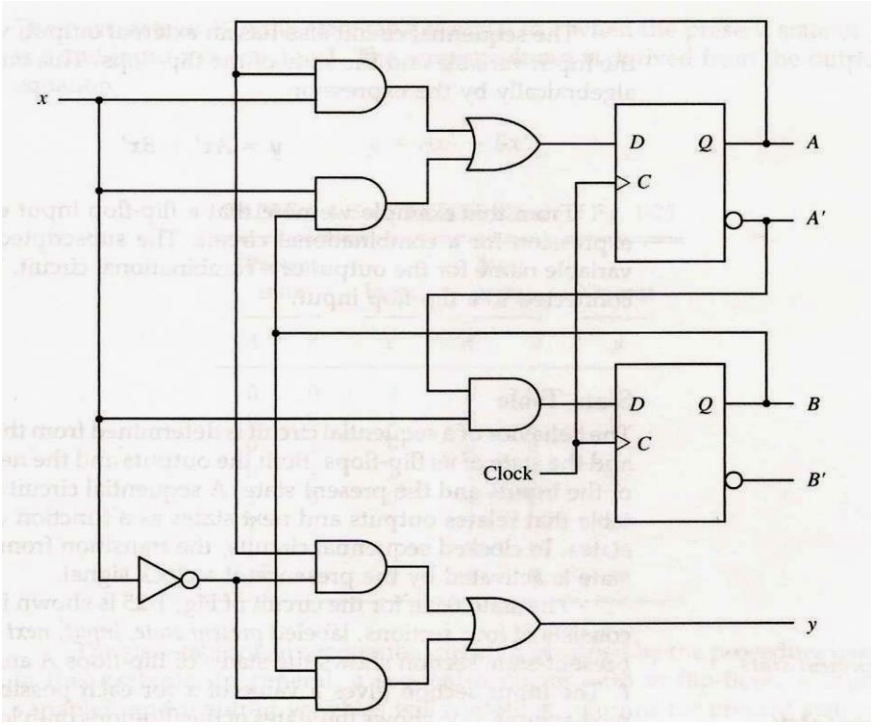
The state of the storage elements depends upon the preceding inputs and the preceding states of the elements. To realize sequential circuits in addition to AND, OR and NOT gates, flip-flops are also required.

Examples of sequential circuits are: registers, shift registers, counters, etc.,

The two major uses of sequential circuits in digital systems are:

1) As memories to store information while processing

2) As control circuits to generate control signals which are essential to select and enable a sequence of data transfer or data processing steps in the execution of multistep tasks.



The sequential circuits which employ clock are called synchronous sequential circuits. In a synchronous sequential circuit all memory elements are clocked latches or clocked flip flops. The design and operation of sequential circuits is greatly simplified by the use of clock signals.

Example of a Sequential Circuits

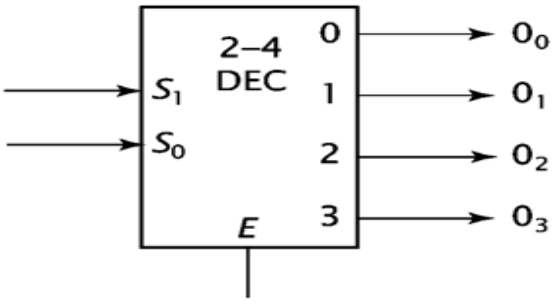
The sequential circuits which do not employ clock are known as unclocked or asynchronous sequential circuits. Unclocked sequential circuits are difficult to design and therefore, they are relatively uncommon.

It has one input variable x, one output variable y, and two clocked D flip flops. The AND gates, OR gates, and inverter form the combinational logic part of the circuit. The interconnections among the gates in the combinational circuit can be specified by a set of Boolean expression. The part of the combinational circuit that generates the inputs to flip-flops are described by a set of Boolean expressions called flip-flop input equations.

Decoder

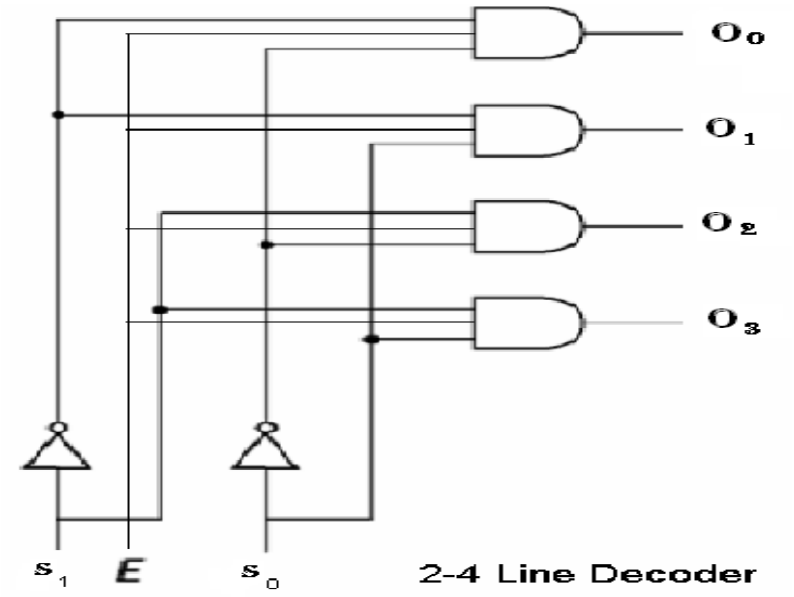
- A combinational circuit that converts binary information from the ***n*** coded inputs to a maximum of 2n unique outputs
  - ***n***-to-***m*** line decoder = ***n x m*** decoder i.e., ***n*** inputs, ***m*** outputs
- Selectors / Enable (active high or active low)

The truth table of 2-to-4 Decoder



(b)

S_1	S_0	E	O_0	O_1	O_2	O_3
X	X	0	0	0	0	0
0	0	1	1	0	0	0
0	1	1	0	1	0	0
1	0	1	0	0	1	0
1	1	1	0	0	0	1



Encoders

- Perform the inverse operation of a decoder
  - 2^n (or less) input lines and n output lines

Multiplexer (MUX)

A multiplexer can use addressing bits to select one of several input bits to be the output.

- A selector chooses a single data input and passes it to the MUX output
- It has one output selected at a time.

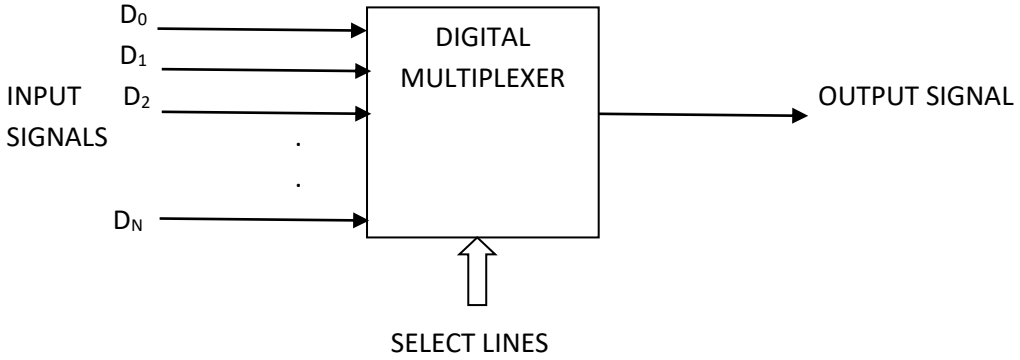
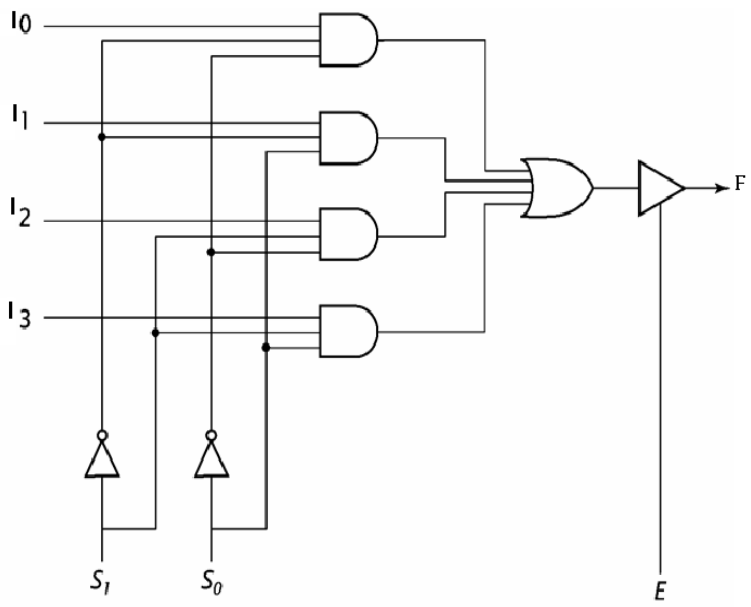


FIG: DIGITAL MULTIPLEXER

- 4 to 1 line multiplexer

  2 selection lines s_0 and s_1
  - Consists of:
    - Inputs (multiple) $= 2^n$
    - Output (single)
    - Selectors (# depends on # of inputs) = n
    - Enable (active high or active low)



Function Table for 4-to-1-Line Multiplexer

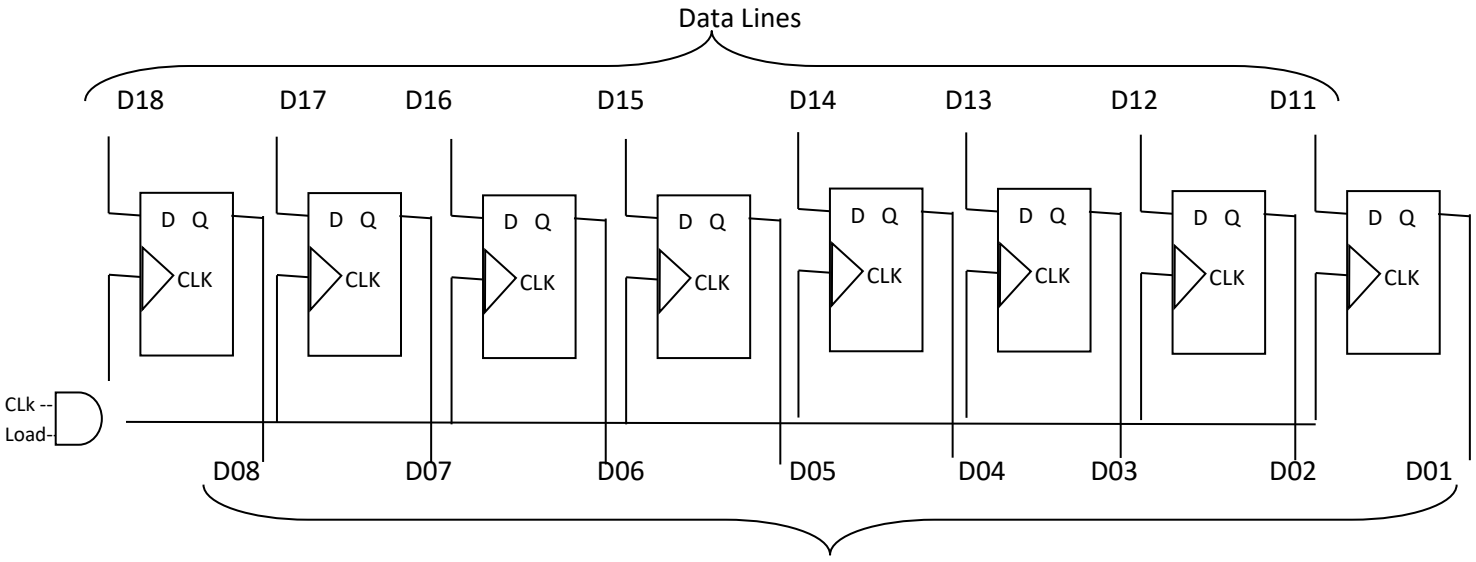
Select		Output
S_1	S_0	Y
0	0	I_0
0	1	I_1
1	0	I_2
1	1	I_3

Registers

- A group of flip-flops with each flip-flop capable of storing one bit of information
- An n-bit register has a group of n flip-flops and is capable of storing any binary information of n bits
- The simplest register consists only of flip-flops, with no external gate :

Parallel Registers:

A parallel register consists of a set of 1-bit memories that can be read or written simultaneously. It is used to store data.
The 8 bit register of figure illustrates the operation of a parallel register using D flip flops. A control signal, labelled load, controls writing into the register from signal lines, D11 through D18. These lines might be the output of multiplexers, so that data from a variety of sources can be loaded into the register.

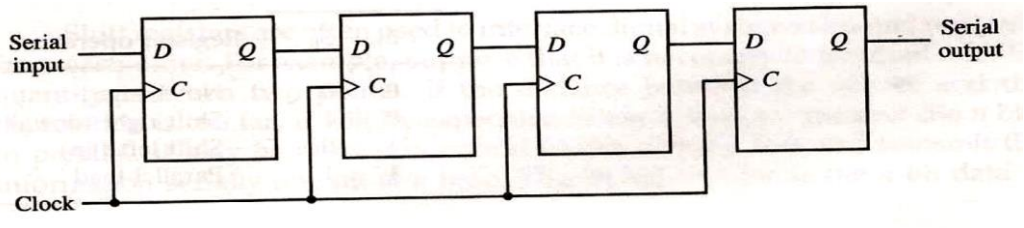


--8-bit Parallel Register--

Shift Registers

- A register capable of shifting its binary information in one or both directions
- The logical configuration of a shift register consists of a chain of flip-flops in cascade
- The simplest possible shift register uses only flip-flops

- The serial input determines what goes into the leftmost position during the shift
- The serial output is taken from the output of the rightmost flip-flop



4- bit shift register

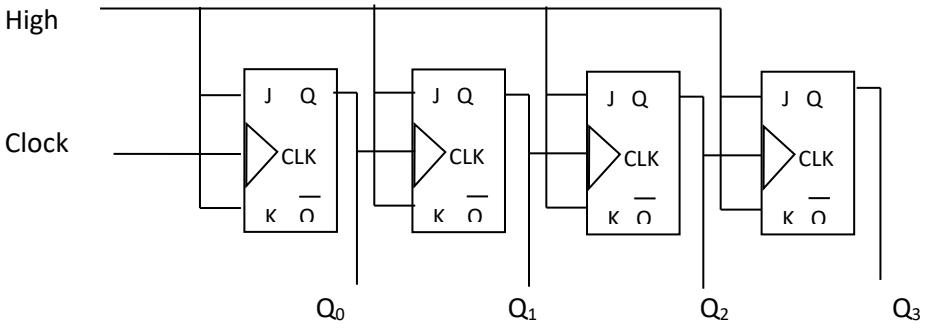
Counter

- Used for counting the number of occurrences of an event and ***useful for generating timing signals to control the sequence of operations*** in digital computers
- An n-bit binary counter is a register of n flip-flop(count from 0 to 2n -1)

Counters can be designated as asynchronous or synchronous, depending on the way in which they operate. Asynchronous counters are relatively slow because the output of one flip flop triggers a change in the status of the next flip flop.
In synchronous counter, all of the flip flops change state at the same time. This type is much faster, it is the kind used in CPUs.

Ripple Counter:

An asynchronous counter is also referred to as a ripple counter, because the change that occurs to increment the counter starts at one end and ripples through to the other end.

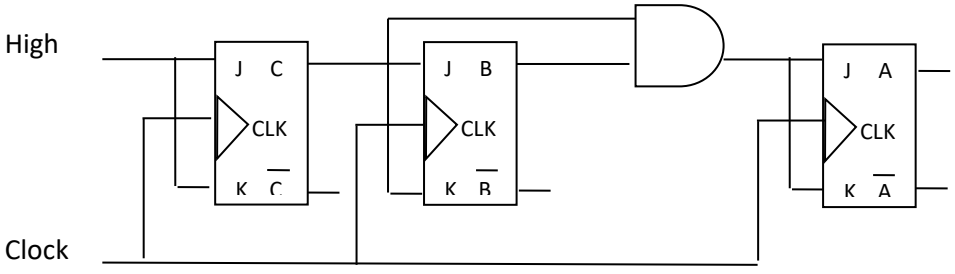


---Sequential Circuit----

In the illustrated implementation, the counter is incremented with each clock pulse. The J and K inputs to each flip flop are held at a constant 1. This means that, when there is a clock pulse, the output at Q will be inverted (1 to 0; 0 to 1).

Note that the change in state is shown as occurring with the falling edge of the clock pulse; this is known as an edge-triggered flip flop. If one looks at patterns of output for this counter, it can be seen that it cycles through 0000, 0001, ...1110,1111,0000 and so on.

Synchronous counters: the ripple counter has the disadvantage of the delay involved in changing value. To overcome this disadvantage, CPUs make use of synchronous counters, in which all of the flip-flops of the counter change at the same time.



--Design of a Synchronous counter--

For a 3 bit counter, three flip flops will be needed. Let us use JK flipflops. Label the uncomplemented output of the three flip flops A, B,C respectively, with C representing the lease significant bit.

Memory Unit

A collection of storage cells together with associated circuits needed to transfer information in and out of storage. The memory stores binary information in groups of bits called ***words***

Word: A group of binary information that is processed in one simultaneous operation
Byte : A group of eight bits (nibble : four bits)
The number of address line = k
Address(Identification number) : 0, 1, 2, 3, … up to 2^k -1
The selection of specific word inside memory : k bit binary address

 1 Kilo= 2^{10}, 1 Mega= 2^{20}, 1 Giga= 2^{30}
 16 bit address line : 2^{16}= 64 K

Solid State Memory(IC Memory)

 RAM(Volatile Memory) and ROM(Non-volatile Memory)

Random Access Memory

 The memory cells can be accessed for information transfer from any desired random location
 Communication between a memory and its environment is achieved through ***data input and output lines, address selection lines,*** and ***control lines*** :
 The two operations that a random-access memory can perform are the ***write*** and ***read*** operations

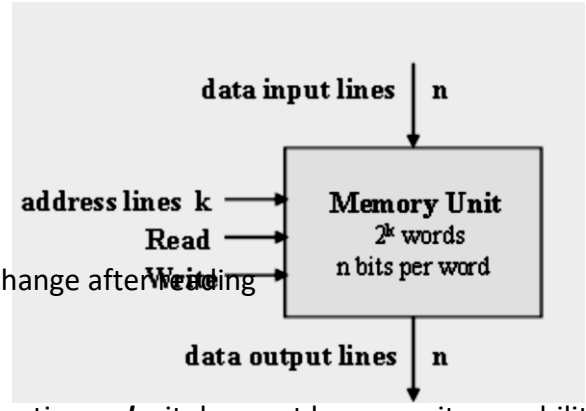
Memory Write

1) Apply the binary address
2) Apply the data bits
3) Activate the write input

Memory Read

1) Apply the binary address
2) Activate the read input

» The content of the selected word does not change after reading

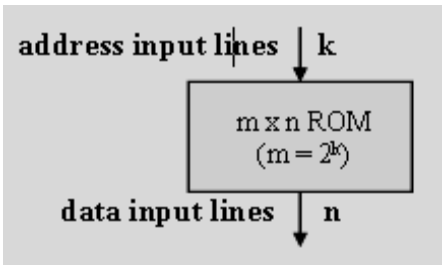


Read-Only Memory

- A memory unit that performs the read operation ***only***; it does not have a write capability.
- ROM comes with special internal electronic ***fuses*** that can be "***programmed***" for a specific configuration.

m x n ROM :

 k address input lines to select one of 2k = *m words* of memory, and n output lines(n bits word).



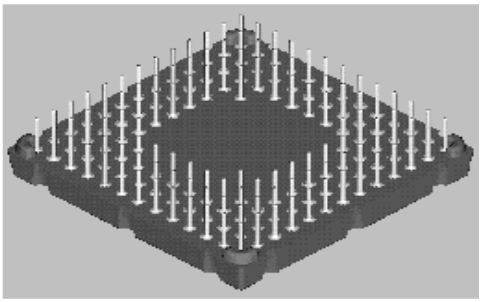
- ROM is classified as a ***combinational circuit***, because the outputs are a function of only the present inputs(address lines).
  - There is no need for providing storage capabilities as in a RAM.
- ROM is also employed in the design of ***control units*** for digital computers.
  - A Control Unit that utilizes a ROM to store binary control information is called a ***micro-programmed control.***

Types of ROMs

 UVEPROM(Chip level erase), EEPROM(Byte level erase), Flash ROM(Page or block level erase), OTPROM, Mask ROM.

DIGITAL COMPONENTS

Integrated Circuits(IC)



- Digital circuits are constructed with Integrated Circuits
- An Integrated Circuits is a small silicon semiconductor crystal, called chip
- The various gates are interconnected inside the chip to form the required circuit
- The chip is mounted in a ceramic or plastic container, and connections are welded by thin gold wires to external pins to form the integrated circuits
- The number of pins may range from 14 in a small IC package to 100 or more in a larger package
- Each IC has a numeric designation printed on the surface of the package for identification

Abbreviation	Name	Number of Gates
SSI	Small-Scale Integration	1 to 10
MSI	Medium-Scale Integration	10 to 100
LSI	Large-Scale Integration	100 to 100,000
VLSI	Very-Large-Scale Integration	more than 100,000

- *SSI, MSI, LSI: They perform small tasks such as addition of few bits. small memories, small processors*
- *VLSI Tasks: - Large memory - Complex microprocessors, CPUs*