

DIGITAL SYSTEMS

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D/A and A/D CONVERTER

- Digital-to-analogue (D/A) and analogue-to-digital (A/D) converters constitute an essential link when digital devices interface with analogue devices, and vice versa.
- They are important building blocks of any digital system, including both communication and non-communication systems.

D/A and A/D CONVERTER

- A D/A converter takes digital data at its input and converts them into analogue voltage or current that is proportional to the weighted sum of digital inputs.
- A D/A converter is important not only because it is needed at the output of most digital systems, where it converts a digital signal into an analogue voltage or current so that it can be fed to a chart recorder, for instance, for measurement purposes, or a servo motor in a control application.
- It is also important because it forms an indispensable part of the majority of A/D converter types.

D/A and A/D CONVERTER

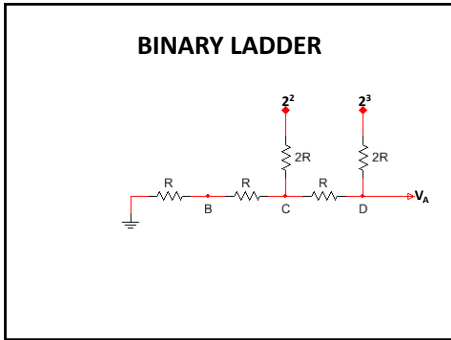
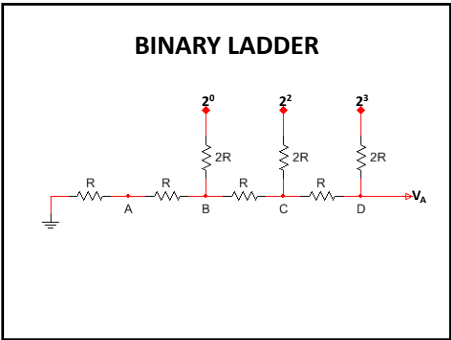
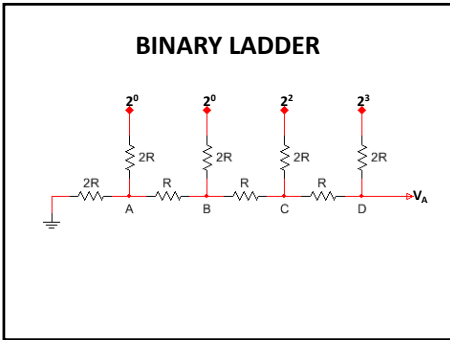
- An A/D converter takes at its input an analogue voltage and after a certain amount of time produces a digital output code representing the analogue input.
- When it comes to transmitting analogue data, it forms an essential interface with a digital communication system where the analogue signal to be transmitted is digitized at the sending end with an A/D converter.
- It is invariably used in all digital read-out test and measuring equipment. Whether it is a digital multimeter or a digital storage oscilloscope or even a pH meter, an A/D converter is an important and essential component of all of them.

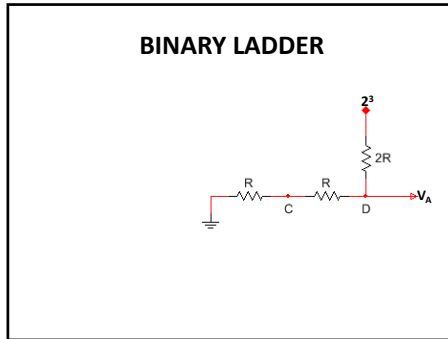
DIGITAL SYSTEMS

DIGITAL TO ANALOG CONVERTER

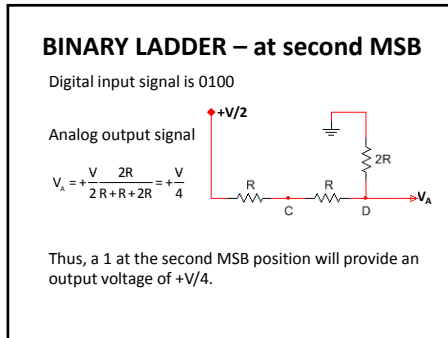
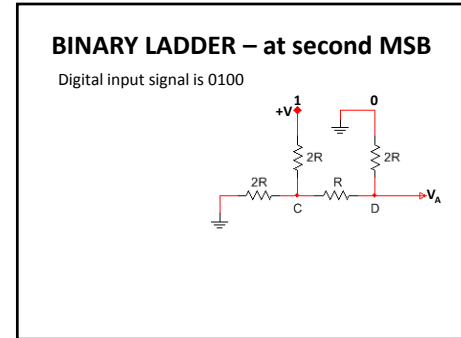
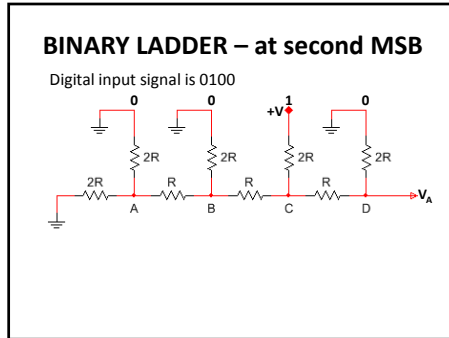
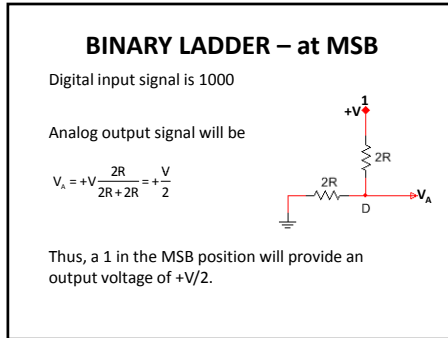
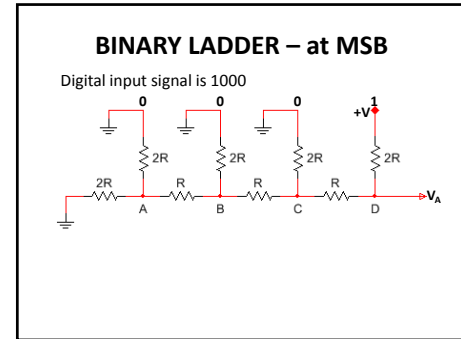
BINARY LADDER

- The **Binary ladder** is a resistive network whose output voltage is a properly weighted sum of the digital inputs.
- Such a ladder is constructed of resistors that have only two values (R and $2R$).
- The left end of the ladder is terminated in a resistance of $2R$.
- The right end of the ladder (the output) is open-circuited.
- Let us now examine the resistive property of 4-bit binary ladder, assuming that all the digital inputs are at ground.





- ### BINARY LADDER
- We can conclude that the total resistance looking from any node back toward the terminating resistor or out toward the digital input is 2R.
 - This is true regardless of whether the digital inputs are at ground or +V.
 - We can use the resistance characteristics of the ladder to determine the output voltages for the various digital inputs.



BINARY LADDER

Bit Position	Binary Weight	Output Voltage
MSB	1/2	V/2
2 nd MSB	1/4	V/4
3 rd MSB	1/8	V/8
4 th MSB	1/16	V/16
..
..
..
N th MSB	1/2 ^N	V/2 ^N

- ### BINARY LADDER
- The total output voltage due to the combination of input digital levels can be found by simply taking sum of the output levels caused by each digital input
- $$V_A = \frac{V}{2} + \frac{V}{4} + \frac{V}{8} + \frac{V}{16} + \dots + \frac{V}{2^N}$$
- where N is the total number of bits at the input.

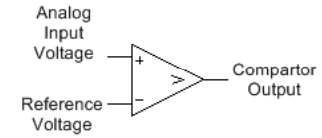
A/D CONVERTER

- A number of different methods have been developed, such as
- Simultaneous Method (Comparator /Flash/Instant Method)
 - Counter Method
 - Continuous Counter Method
 - Single slope or Double Slope Ramp Method
 - Successive Approximation Method.

SIMULTANEOUS A/D CONVERSION

- The simultaneous method of A/D conversion is based on using a number of comparators. The number of comparators needed for n-bit A/D conversion is $2^n - 1$.
- The analogue signal to be digitized serves as one of the inputs to each of the comparators.
- The second input for each of the comparators is a reference input, different for each comparator.
- The reference voltages to be used for comparators are in general $V/2^n, 2V/2^n, 3V/2^n, 4V/2^n$ and so on. Here, V is the maximum amplitude of the analogue signal that the A/D converter can digitize, and n is the number of bits in the digitized output.

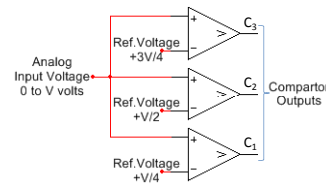
COMPARATOR



SIMULTANEOUS A/D CONVERSION

- In two-bit A/D converter, the reference voltages for the three comparators will be $V/4, V/2$ and $3V/4$.
- There are four voltage ranges that can be detected by this converter. Four ranges can be effectively differentiated by two digital bits.
- The three comparator outputs can then be fed into a coding network to provide two bits which are equivalent to the input analog voltage.
- The bits of the coding network can then be entered into a FF register for storage.

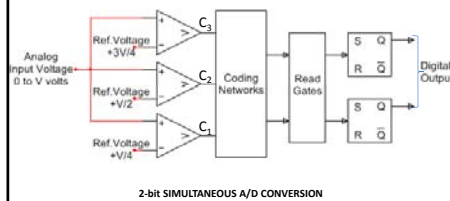
SIMULTANEOUS A/D CONVERSION



SIMULTANEOUS A/D CONVERSION

INPUT VOLTAGE	COMPARATOR OUTPUT		
	C ₃	C ₂	C ₁
0 to +V/4	L	L	L
+V/4 to +V/2	H	L	L
+V/2 to +3V/4	H	H	L
+3V/4 to V	H	H	H

SIMULTANEOUS A/D CONVERSION



3-bit SIMULTANEOUS A/D CONVERSION

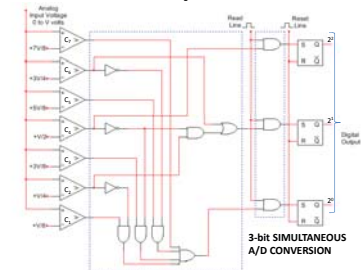
- In general, $2^n - 1$ comparators are required to define 2^n ranges and to convert to a digital signal having n bits.
- It is necessary to have seven comparators to convert the 3-bit digital input signal.
- If we wanted a three-bit output, the reference voltages would have been $V/8, V/4, 3V/8, V/2, 5V/8, 3V/4$ and $7V/8$.
- The encoding matrix must accept seven input level and encode them into 3-bit numbers. They are

$$2^2 = C_6$$

$$2^1 = C_5 \bar{C}_4 + C_6$$

$$2^0 = C_4 \bar{C}_3 + C_5 \bar{C}_4 + C_6 \bar{C}_6 + C_7$$

SIMULTANEOUS A/D CONVERSION



3-bit SIMULTANEOUS A/D CONVERSION

INPUT VOLTAGE	COMPARATOR OUTPUT							BINARY OUTPUT		
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	C ₇	2 ²	2 ¹	2 ⁰
0 to +V/8	L	L	L	L	L	L	L	0	0	0
+V/8 to +V/4	H	L	L	L	L	L	L	0	0	1
+V/4 to +3V/8	H	H	L	L	L	L	L	0	1	0
+3V/8 to +V/2	H	H	H	L	L	L	L	0	1	1
+V/2 to +5V/8	H	H	H	H	L	L	L	1	0	0
+5V/8 to +3V/4	H	H	H	H	H	L	L	1	0	1
+3V/4 to +7V/8	H	H	H	H	H	H	L	1	1	0
+7V/8 to +V	H	H	H	H	H	H	H	1	1	1

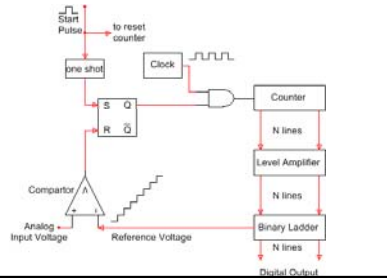
SIMULTANEOUS A/D CONVERSION

- The construction of a simultaneous A/D converter is quite straightforward and relatively easy to understand.
- However, as the number of bits in the desired digital signal increases, the number of comparators required to perform A/D conversion increases very rapidly.
- It may not be feasible to use this approach once the number of bits exceeds six or so.
- The greatest advantage of this technique lies in its capability to execute extremely fast analogue-to-digital conversion.

COUNTER TYPE A/D CONVERTER

- It is possible to construct higher-resolution A/D converters with a single comparator by using a variable reference voltage.
- Conversion would be complete when this variable reference voltage becomes equal to the input voltage.
- One such A/D converter is the *counter-type A/D converter*.
- The counter-type A/D converter provides a very good method for digitizing to a high resolution.
- This method is much simpler than the simultaneous method for higher-resolution A/D converters.

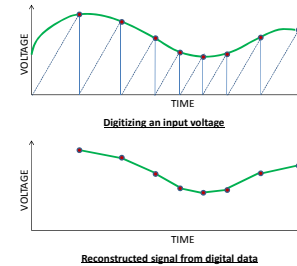
COUNTER TYPE A/D CONVERTER



COUNTER TYPE A/D CONVERTER

- To begin with, the counter is reset to all 0s.
- When a convert signal appears on the start line, the input gate is enabled and the clock pulses are applied to the clock input of the counter.
- The counter advances through its normal binary count sequence.
- The counter output feeds a D/A converter and the staircase waveform generated at the output of the D/A converter forms one of the inputs of the comparator.
- The other input to the comparator is the analogue input signal.

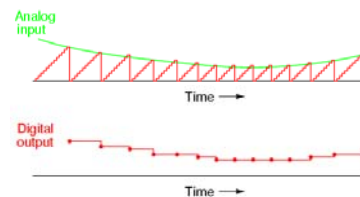
COUNTER TYPE A/D CONVERTER



COUNTER TYPE A/D CONVERTER

- Whenever the D/A converter output exceeds the analogue input voltage, the comparator changes state.
- The gate is disabled and the counter stops.
- The counter output at that instant of time is then the required digital output corresponding to the analogue input signal.

COUNTER TYPE A/D CONVERTER



COUNTER TYPE A/D CONVERTER

- In the counter-type A/D converter described above, the counter is reset to zero at the start of each new conversion.
- The D/A converter output staircase waveform always begins at zero and increases in steps until it reaches a point where the analogue output of the D/A converter exceeds the analogue input to be digitized.
- As a result, the counter-type A/D converter of the type discussed above is slow.

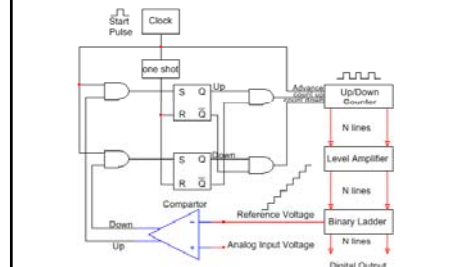
COUNTER TYPE A/D CONVERTER

- The drawback with this converter is that the required conversion time is longer.
- Since the counter always begins from the all 0s position and counts through its normal binary sequence, it may require as many as 2^n counts before conversion is complete.
- The average conversion time can be taken to be $2^n/2 = 2^{n-1}$ counts. One clock cycle gives one count.
- Thus, the resolution can be improved only at the cost of a longer conversion time.
- This makes the counter-type A/D converter unsuitable for digitizing rapidly changing analogue signals.

CONTINUOUS TYPE A/D CONVERTER

- The *Continuous-type A/D converter*, also called the *tracking type* or *delta-encoded A/D converter*, is a modified form of counter-type converter that to some extent overcomes the shortcoming of the latter.
- In the modified arrangement, the counter, which is primarily an UP counter, is replaced with an UP/DOWN counter.
- It counts in upward sequence whenever the D/A converter output analogue voltage is less than the analogue input voltage, and it counts in the downward sequence whenever the D/A converter output analogue voltage is greater than the analogue input voltage.

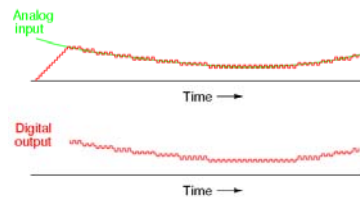
CONTINUOUS TYPE A/D CONVERTER



CONTINUOUS TYPE A/D CONVERTER

- In this type of converter, whenever a new conversion is to begin, the counter is not reset to zero; in fact it begins counting either up or down from its last value, depending upon the comparator output.
- The D/A converter output staircase waveform contains both positive-going and negative-going staircase signals that track the input analogue signal.

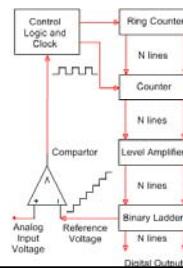
CONTINUOUS TYPE A/D CONVERTER



SUCCESSIVE APPROXIMATION A/D CONVERTER

- The development of A/D converters has progressed in a quest to reduce the conversion time.
- The *successive approximation type A/D converter* aims at approximating the analogue signal to be digitized by trying only one bit at a time.
- The process of A/D conversion by this technique can be illustrated with the help of an example.
- Let us take a four-bit successive approximation type A/D converter.

SUCCESSIVE APPROXIMATION A/D CONVERTER

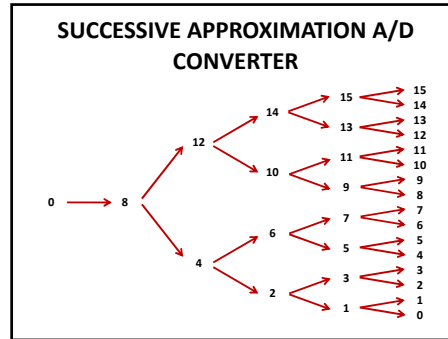
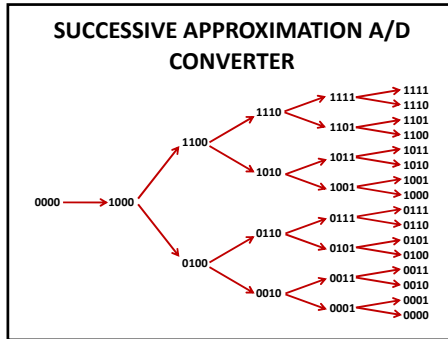


SUCCESSIVE APPROXIMATION A/D CONVERTER

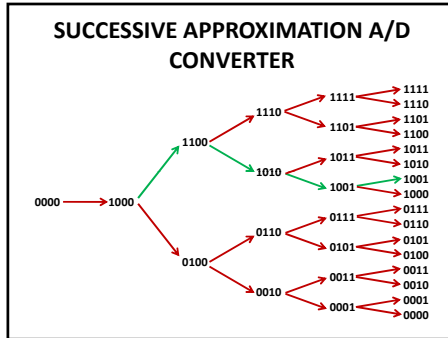
- Last slide shows a block schematic representation of a successive approximation type A/D converter.
- Only one flip-flop (in the counter) is operated upon at one time, a ring counter, which is nothing but a circulating register (a serial shift register with the outputs Q and Q' of the last flip-flop connected to the J and K inputs respectively of the first flip-flop), is used to do the job.

SUCCESSIVE APPROXIMATION A/D CONVERTER

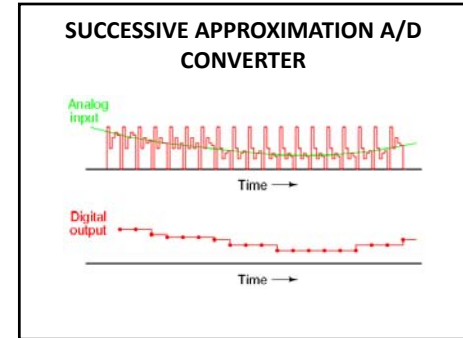
- Initially, the counter is reset to all 0s. The conversion process begins with the MSB being set by the start pulse. That is, the flip-flop representing the MSB is set.
- The counter output is converted into equivalent analog signal and then compared with the analog signal to be digitized.
- A decision is then taken as to whether the MSB is to be left in (i.e. the flip-flop representing the MSB is to remain set) or whether it is to be taken out (i.e. the flip-flop is to be reset) when the first clock pulse sets the second MSB.
- Once the second MSB is set, again a comparison is made and a decision taken as to whether or not the second MSB is to remain set when the subsequent clock pulse sets the third MSB. The process continues until we go down to the LSB.



- ### SUCCESSIVE APPROXIMATION A/D CONVERTER
- Note that, every time we make a comparison, we tend to narrow down the difference between the analogue signal to be digitized and the analogue signal representing the counter count.
 - Refer to the operational diagram. It is clear from the diagram that, to reach any count from 0000 to 1111, the converter requires four clock cycles.
 - In general, the number of clock cycles required for each conversion will be n for an n-bit A/D converter of this type.
 - The green lines show the sequence in which the counter arrives at the desired count, assuming that 1001 is the desired count.



- ### SUCCESSIVE APPROXIMATION A/D CONVERTER
- This type of A/D converter is much faster than the counter-type A/D converter previously discussed. In an n-bit converter, the counter-type A/D converter on average would require 2^{n-1} clock cycles for each conversion, whereas a successive approximation type converter requires only n clock cycles.
 - That is, an eight-bit A/D converter of this type operating on a 1 MHz clock has a conversion time of 8 μ-sec.



- ### SUCCESSIVE APPROXIMATION A/D CONVERTER
- Advantages of Successive Approximation ADC**
- Speed is high compared to counter type ADC.
 - Good ratio of speed to power.
 - Compact design compared to Simultaneous Type
 - It is inexpensive.
- Disadvantages of Successive Approximation ADC**
- Complexity in design.
- Applications**
- The S A ADC will used widely data acquisition techniques at the sampling rates higher than 10KHz

Digital Systems

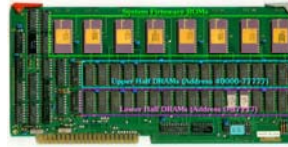
MEMORY

- ## MEMORY
- Memory is required to store:
1. data
 2. application programs
 3. operating system

MEMORY

Can be broadly classified as:
Random Access Memory (RAM)
or
Read Only Memory (ROM)

MEMORY



Random Access Memory (RAM)



RANDOM ACCESS MEMORY

- Can be written to or read from.
 - Read/Write memory
- Reading from RAM is non-destructive.
- Access time to read from any memory location is the same.
 - As compared to serial access memory.
- Volatile
 - Information is lost when power is removed.

RANDOM ACCESS MEMORY

- RAM is a read/write memory where the data can be read from or written into any of the memory locations regardless of the order in which they are arranged. Therefore, all the memory locations in a RAM can be accessed at the same speed.
- RAM is used to store data, program instructions and the results of any intermediate calculations during the execution of a program.
- Also, the same data can be read any number of times and different data can be written into the same memory location, with every fresh data item overwriting the existing one.
- It is typically used for short-term data storage as it cannot retain data when the power is turned off.

RANDOM ACCESS MEMORY

- RAM is available in the form of ICs as well as in the form of plug-in modules.
- The plug-in modules are small circuit boards containing memory ICs and having input and output lines connected to an edge connector.
- They are available as single in-line memory modules (SIMMs) and dual in-line memory modules (DIMMs).
- More than one memory IC (or chip) can be used to build the RAM for larger systems.

RANDOM ACCESS MEMORY

- The capacity or size of a RAM is measured in bytes.
- RAM chips are available in the memory capacities ranging from 2 kB to as much as 32 MB.
- 1 kB of memory equals $2^{10} = 1024$ bytes and 1 MB of memory equals 2^{20} bytes.
- The terms 'kilo' (k) and 'mega' (M) have been used, as 2^{10} and 2^{20} are approximately equal to 1000 and 1,000,000 respectively.
- As an illustration, a microcomputer with a 64 kB of RAM has $64 \times 2^{10} = 2^6 \times 2^{10} = 2^{16} = 65,536$ bytes of memory.
- The two categories of RAM are static RAM (SRAM) and dynamic RAM (DRAM).

RANDOM ACCESS MEMORY

- Static Random Access Memory (SRAM)
 - Based on the Flip-Flop
 - Requires a large number of transistors
 - Fast
- Dynamic Random Access Memory (DRAM)
 - Uses a single transistor to store charge
 - Requires very few transistors
 - Must be periodically refreshed
 - Slow(er)

RANDOM ACCESS MEMORY

RAM Applications

- One of the major applications of RAM is its use in cache memories. It is also used as main memory to store temporary data and instructions in a computer.

READ ONLY MEMORY (ROM)



READ ONLY MEMORY

- Can only be read from.
- Memory is written (or “programmed”) once
- Reading from ROM is non-destructive.
- Access time to read from any memory location is the same.
 - As compared to serial access memory.
- Non-Volatile
 - Information is retained even after power is removed.

READ ONLY MEMORY

- In the case of ROM, instructions can be written into the memory only once at the manufacturer’s premises.
- These instructions can, however, be read from a ROM as many times as desired.
- Once it is written, a ROM cannot be written into again.
- The contents of a ROM can thus be accessed by a CPU but cannot be changed by it.
- The instructions stored on a ROM vary with the type of application for which it is made.
- The ROM for a general-purpose microcomputer, for instance, would contain system programs such as those designed to handle operating system instructions.

READ ONLY MEMORY

- In the case of some special types of ROM, it is possible for users to have their own instructions stored on the ROM as per their requirements.
- Such ROM chips are called PROMs (Programmable Read Only Memory). PROM contents, once programmed, cannot be changed.
- But then there are some special types of PROMs whose contents can be erased and then reprogrammed. These are known as EPROMs (Erasable Programmable Read Only Memory). They are of two type.
- Ultraviolet-erasable programmable ROMs (UV EPROMs) and Electrically erasable programmable ROMs (EEPROMs).

READ ONLY MEMORY

- Programmable Read Only Memory (PROM)
 - Can be “programmed”
- Erasable PROM (EPROM)
 - Can be “programmed” and erased
- Electrically Erasable PROM (EEPROM)
 - Can be erased using an electrical signal
- UV Erasable PROM (UVEPROM)
 - Can be erased using Ultraviolet light

READ ONLY MEMORY

- ROM is a nonvolatile memory that is used for permanent or semi-permanent storage of data. The contents of ROM are retained even after the power is turned off.

READ ONLY MEMORY

Applications of ROMs

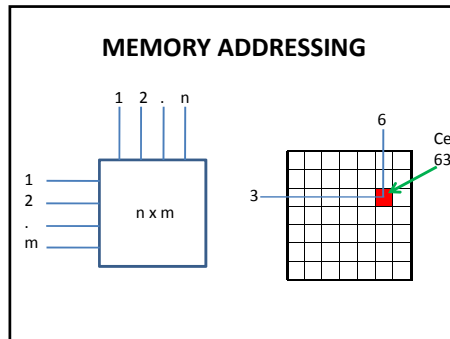
- Some of the common application areas include firmware, bootstrap memory, look-up tables, function generators and auxiliary memory.
- The ROM chips is use in the storage of data and program codes that must be made available to microprocessor-based systems such as microcomputers on power-up.
- This component of the software is referred to as firmware as it comes embedded in the hardware with the machine.
- Consumer products such as CD players, microwave ovens, washing machines, etc., have embedded microcontrollers that have a microprocessor to control and monitor the operation according to the information stored on the ROM.

MEMORY ADDRESSING



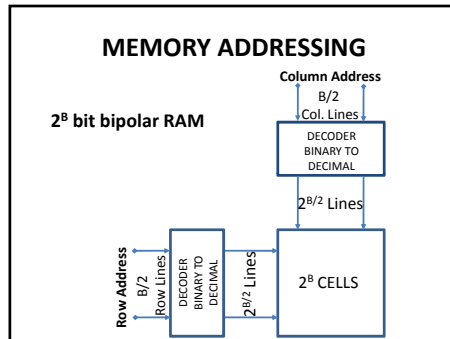
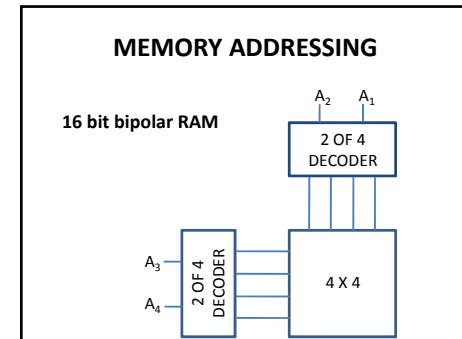
MEMORY ADDRESSING

- Memories are generally arranged by placing cells in the rectangular arrangement of rows and columns.
- Addressing is the process of selecting one of the cells in the memory to be written into or to be read from.
- If there are m rows and n columns, then there will be a total of $n \times m$ cells in the memory.
- If row 3 is activated and column 6 is activated, the cell at the intersection of this row and column is selected. This cell is then called 63.
- This is defined as the “address” of the cell.



Random Access Memory

- Address
 - Location in memory of the binary information
 - Must be decoded to select the appropriate location and read/write the associated data
 - B-bit address → 2^B memory cell locations
- Data
 - Binary information of interest
 - Stored in a specific location in the memory
 - Typically organized into words
 - Each word has n bits



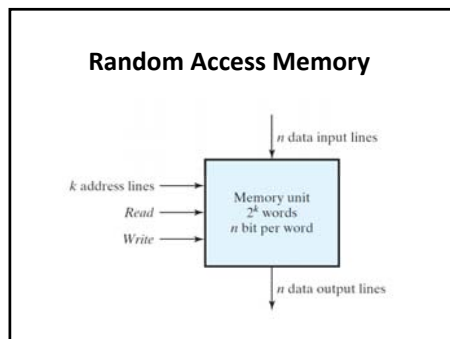
Random Access Memory

Memory address		Memory content
Binary	Decimal	
000000000	0	1011010101011101
000000001	1	1010101110001001
000000010	2	0000110101000110
...
111111101	1021	1001110100010100
111111110	1022	0000110100011110
111111111	1023	1101111000100101

Note: A 10-bit address provides 1024 locations. The 'address' label points to the binary column, and the 'data' label points to the memory content column.

Random Access Memory

- Read
 - Indicates that the memory is to be read
- Write
 - Indicates that the memory is to be written



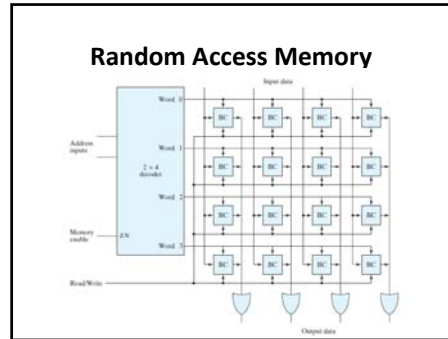
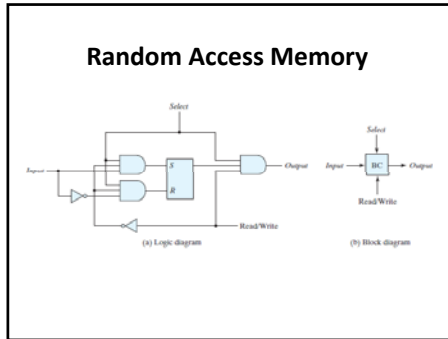
Random Access Memory

- Rather than use the *Read* and *Write* signals, most commercially available RAM chips use Enable and Read/Write'
- Enable
 - Used to enable the selected RAM chip
 - Alternative of "chip select"
- Read/Write'
 - RAM is read when Read/Write' = 1
 - RAM is written when Read/Write' = 0

Random Access Memory

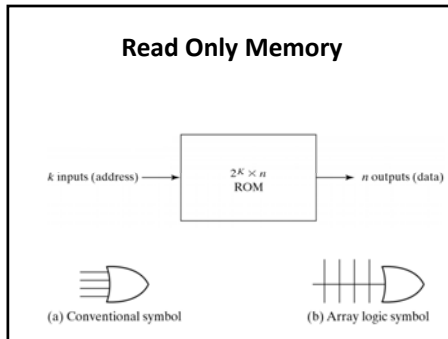
Table 7.1
Control Inputs to Memory Chip

Memory Enable	Read/Write'	Memory Operation
0	X	None
1	0	Write to selected word
1	1	Read from selected word



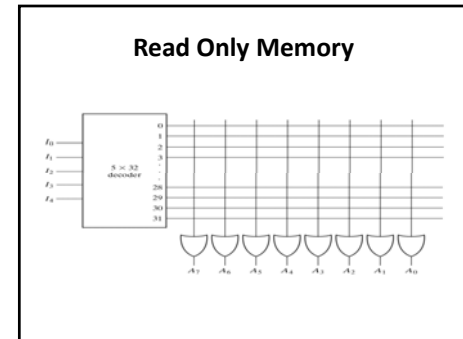
Read Only Memory

- Device that allows permanent storage of information.
- Device has k input (address) lines and n output (data) lines.
- No Data Input, No read/Write control.
- We can store $2^k \times n$ bits of information inside the device.
- The address lines specify a memory location and the data outputs at any time represents the value stored at the memory location specified on the address lines.



Read Only Memory

- Uses an address decoder such that the k address lines selects one word of the 2^k words of data stored in the ROM.
- Each of the $2^k \times n$ bits inside of the ROM are programmable via opening and/or closing switches.
- Can implement multi-input/multi-output logic functions inside of ROM.
- Data outputs are the logic functions and the address lines are the logic function inputs.



Read Only Memory

ROM Internal Logic 8x32.

- 5x32 decoder & 8 OR gates.
- Each output of the decoder is connected to one of the inputs in each or gate.
- Total connection = $32 \times 8 = 256$ connections and these connections are programmable.
- The binary content to be stored in the ROM is specified by a truth table.

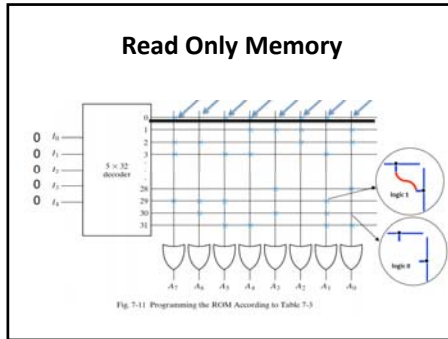
Read Only Memory

- We can create a ROM Table to store the logic functions.
- When an input (or address) is presented, the value stored in the specified memory location appears at the data outputs.
- Each data output represents the correct value for its logic function.

Read Only Memory

Table 7-3 ROM Truth Table (Partial)

Inputs				Outputs								
I ₄	I ₃	I ₂	I ₁	I ₀	A ₇	A ₆	A ₅	A ₄	A ₃	A ₂	A ₁	A ₀
0	0	0	0	0	1	0	1	1	0	1	1	0
0	0	0	0	1	0	0	0	1	1	1	0	1
0	0	0	1	0	1	1	0	0	0	1	0	1
0	0	0	1	1	1	0	1	1	0	0	1	0
:	:	:	:	:	:	:	:	:	:	:	:	:
1	1	1	0	0	0	0	0	1	0	0	0	1
1	1	1	0	1	1	1	1	0	0	0	1	0
1	1	1	1	0	0	1	0	0	1	0	1	0
1	1	1	1	1	0	0	1	1	0	0	1	1



DIGITAL SYSTEMS
ENDS

