Mechatronics

UNIT –III

Data Acquisition system

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Syllabus

Data Acquisition & Microcontroller System

- Interfacing of Sensors / Actuators to DAQ system, Bit width, Sampling theorem, Sampling Frequency, Aliasing, Sample and hold circuit,
- ADC (Successive Approximation),
- DAC (R-2R),
- Current and Voltage Amplifier.

PC-based Data Acquisition System Overview

- In the last few years, industrial PC I/O interface products have become increasingly reliable, accurate and affordable. PC-based data acquisition and control systems are widely used in industrial and laboratory applications like monitoring, control, data acquisition and automated testing
- Selecting and building a DA&C (Data Acquisition and Control) system that actually does what you want it to do requires some knowledge of electrical and computer engineering.
    - Transducers and actuators
    - Signal conditioning
    - Data acquisition and control hardware
    - Computer systems software

Analog vs. Digital signal

Property	Analog	Digital
Representation	Continuous voltage or current	Binary Number
Precision	Infinite range of values	Limited by the number's length
Resistance to Degradation	Weak	Tolerant to signal degradation
Processing	Limited	Powerful
Storage	Impossible	Possible

Analog to Digital Conversion

- Most physical signals are analog.
- Analog signals are captured by sensors or transducers.
- Examples: temperature, sound, pressure, …
- Need to convert to digital signals to facilitate processing by the microcontroller.
- The device that does this is analog-to-digital converter (ADC).

Data Acquisition System

- A data acquisition system consists of many components that are integrated to:

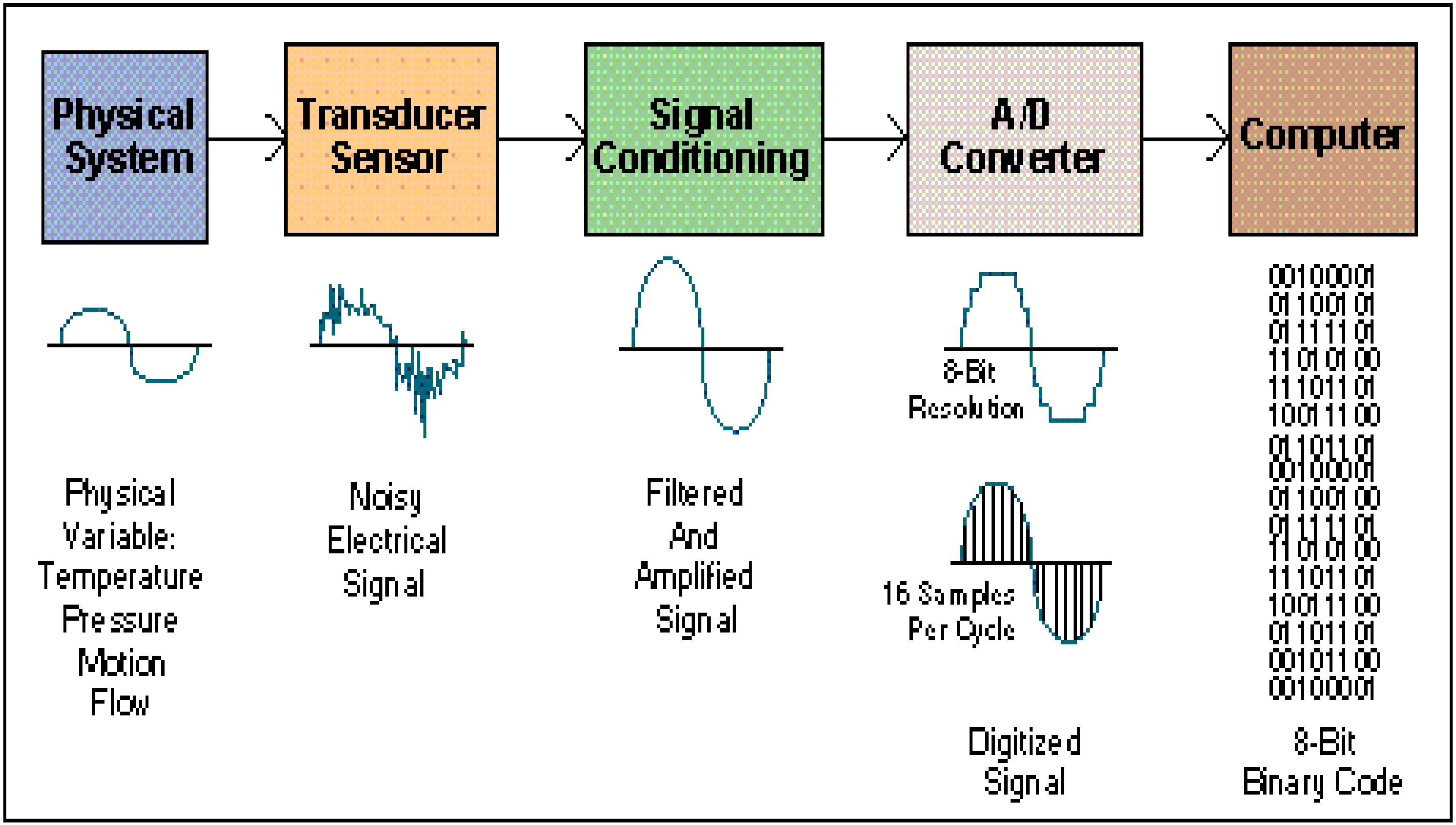
  1)Sense physical variables (use of transducers)

  2)Condition the electrical signal to make it readable by an A/D board

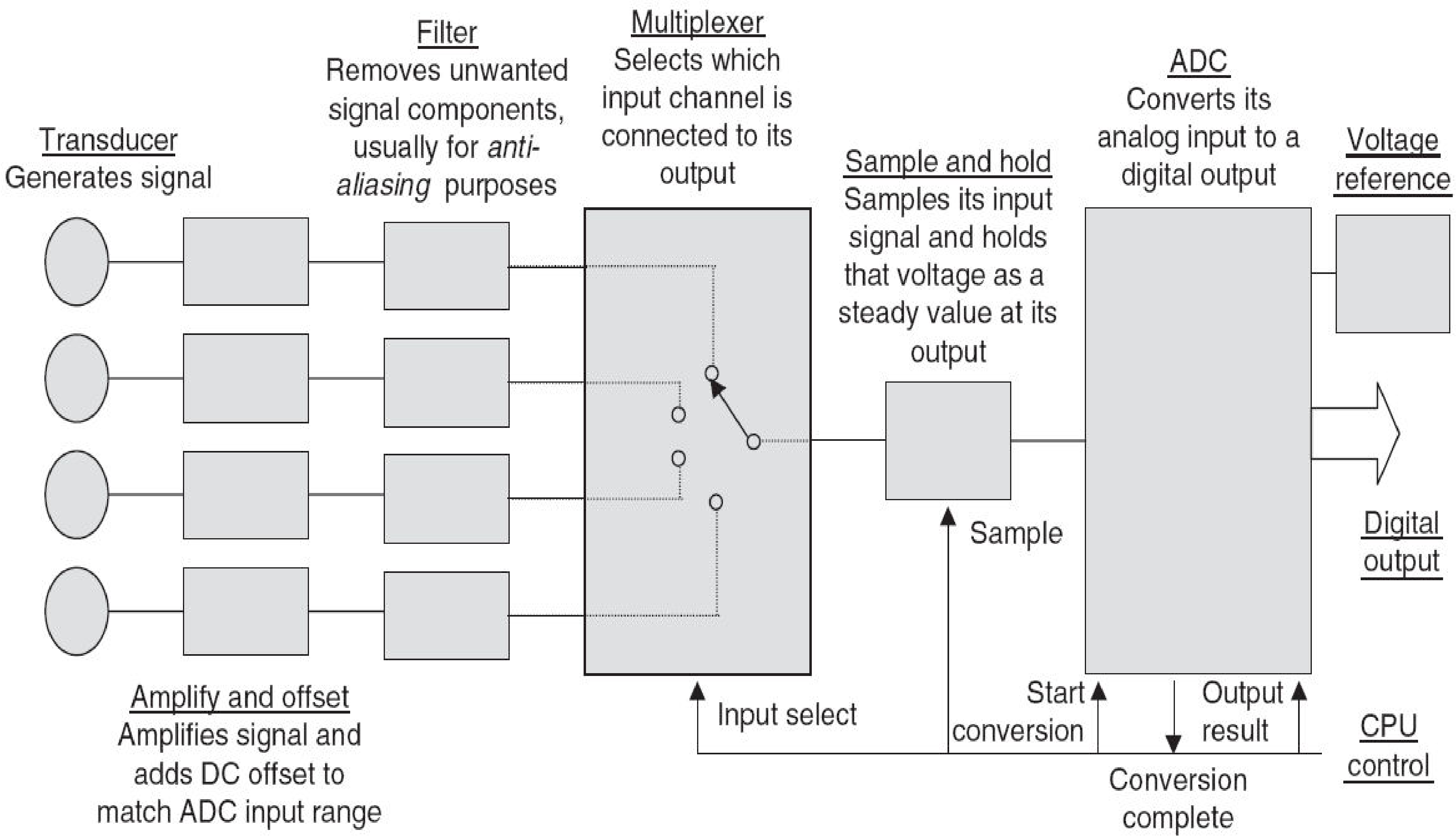
  3)Convert the signal into a digital format acceptable by a computer.

  4)Process, analyze, store, and display the acquired data with the help of software

Data Acquisition System Block Diagram

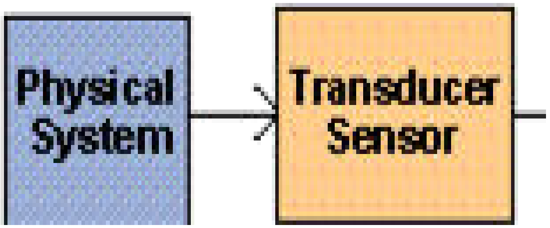


Elements of a data acquisition system



Elements of a data acquisition system

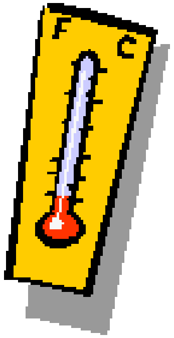
1. **Transducers**: physical to electrical signal
2. **Amplify and offset circuits**
   – The input voltage should traverse as much of its input range as possible
   – Voltage level shifting may also be required
3. **Filter**: get rid of unwanted signal components
4. **Multiplexer**: select one of multiple inputs
5. **Sampler**: the conversion rate must be at least twice the highest signal frequency (Nyquist sampling criterion)
6. **ADC**



Transducers

Sense physical phenomena and translate it into electric signal.

- Temperature
- Pressure
- Light
- Force



- Displacement
- Level
- Electric signals
- ON/OFF switch

Transducers and Actuators

- A transducer converts temperature, pressure, level, length, position, etc. into voltage, current, frequency, pulses or other signals.

- An actuator is a device that activates process control equipment by using pneumatic, hydraulic or electrical power. For example, a valve actuator opens and closes a valve to control fluid rate.

Signal Conditioning

- Signal conditioning circuits improve the quality of signals generated by transducers before they are converted into digital signals by the PC's data-acquisition hardware.

- Examples of signal conditioning are signal scaling, amplification, linearization, cold-junction compensation, filtering, attenuation, excitation, common-mode rejection, and so on.

Signal Conditioning

- One of the most common signal conditioning functions is amplification.
- For maximum resolution, the voltage range of the input signals should be approximately equal to the maximum input range of the A/D converter. Amplification expands the range of the transducer signals so that they match the input range of the A/D converter. For example, a x10 amplifier maps transducer signals which range from 0 to 1 V into the range 0 to 10 V before they go into the A/D converter.

Signal Conditioning

Electrical signals are conditioned so they can be used by an analog input board. The following features may be available:

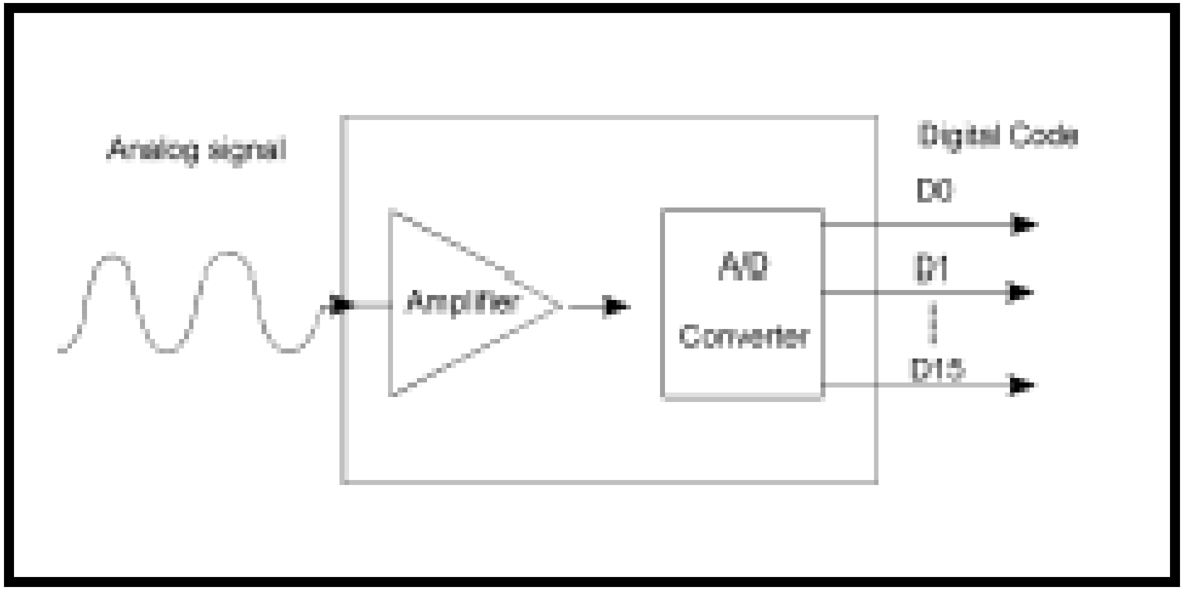
- Amplification
- Isolation
- Filtering
- Linearization

Data Acquisition

- Data acquisition and control hardware generally performs one or more of the following functions:
  - analog input,
  - analog output,
  - digital input,
  - digital output and
  - counter/timer functions.

Analog Inputs (A/D)

- Analog to digital (A/D) conversion changes analog voltage or current levels into digital information. The conversion is necessary to enable the computer to process or store the signals.



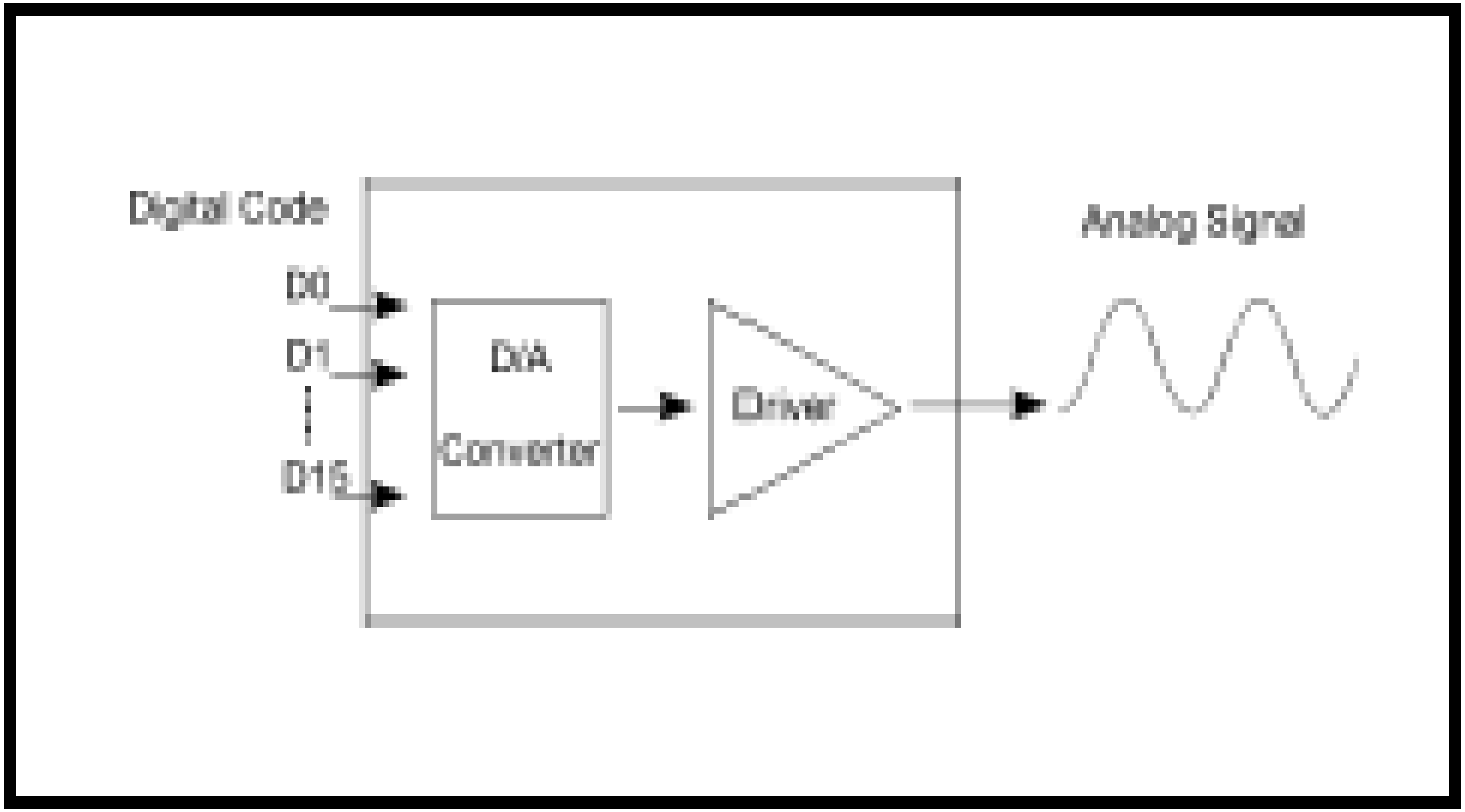
Analog Inputs (A/D)

- The most significant criteria when selecting A/D hardware are:
  1. Number of input channels
  2. Single-ended or differential input signals
  3. Sampling rate (in samples per second)
  4. Resolution (usually measured in bits of resolution)
  5. Input range (specified in full-scale volts)
  6. Noise and nonlinearity

Analog Outputs (D/A)

- The opposite of analog to digital conversion is digital to analog (D/A) conversion. This operation converts digital information into analog voltage or current. D/A devices allow the computer to control real-world events.
- Analog output signals may directly control process equipment. The process can give feedback in the form of analog input signals. This is referred to as a closed loop control system with PID control.
- Analog outputs can also be used to generate waveforms. In this case, the device behaves as a function generator.

Analog Outputs (D/A)



Data Acquisition Software

- It can be the most critical factor in obtaining reliable, high performance operation.
- Transforms the PC and DAQ hardware into a complete DAQ, analysis, and display system.
- Different alternatives:
  - Programmable software.
  - Data acquisition software packages.

Programmable Software

- Involves the use of a programming language, such as:
  - C++, visual C++
  - BASIC, Visual Basic + Add-on tools (such as VisuaLab with VTX)
  - Fortran
  - Pascal
- Advantage: flexibility
- Disadvantages: complexity and steep learning curve

Objective of DAQ System

- DAS must acquire the necessary data, at correct speed and at correct time.
- It must monitor the complete plant operation to maintain on line and safe operations.
- It must be able to collect, summarise and store data for diagnosis of operation and record purpose.
- It must be flexible and capable of being expanded for future requirements.
- It must be able to compute unit performance indices using on-line, real time data.
- It must be reliable, easy to operate and must be user friendly.

Merits/Advantages

- Reduced data redundancy
- Reduced updating errors and increased consistency
- Greater data integrity and independence from applications programs
- Improved data access to users through use of host and query languages
- Improved data security
- Reduced data entry, storage, and retrieval costs
- Facilitated development of new applications program

Demerits/Disadvantages

- Database systems are complex, difficult, and time-consuming to design
- Substantial hardware and software start-up costs
- Damage to database affects virtually all applications programs
- Extensive conversion costs in moving form a file-based system to a database system
- Initial training required for all programmers and users

Configuration of DAS

Configuration of DAS :

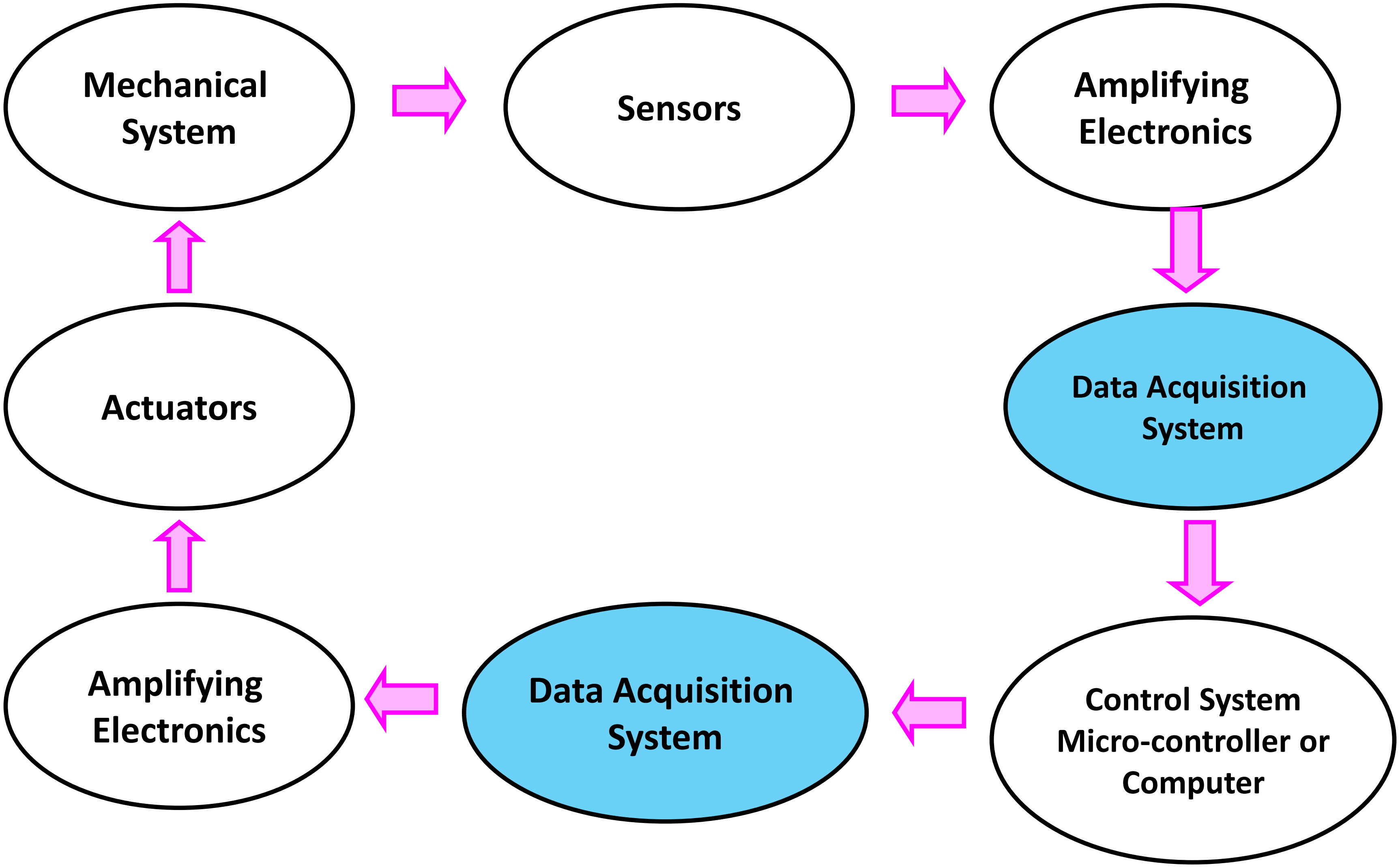
The important factors that decide the configuration and the sub-systems of a data acquisition system are as follows :

(*i*) The number of channels to the monitored.
(*ii*) Sampling rate per channel.
(*iii*) Signal conditioning requirement of each channel.
(*iv*) Resolution and accuracy.
(*v*) Cost.

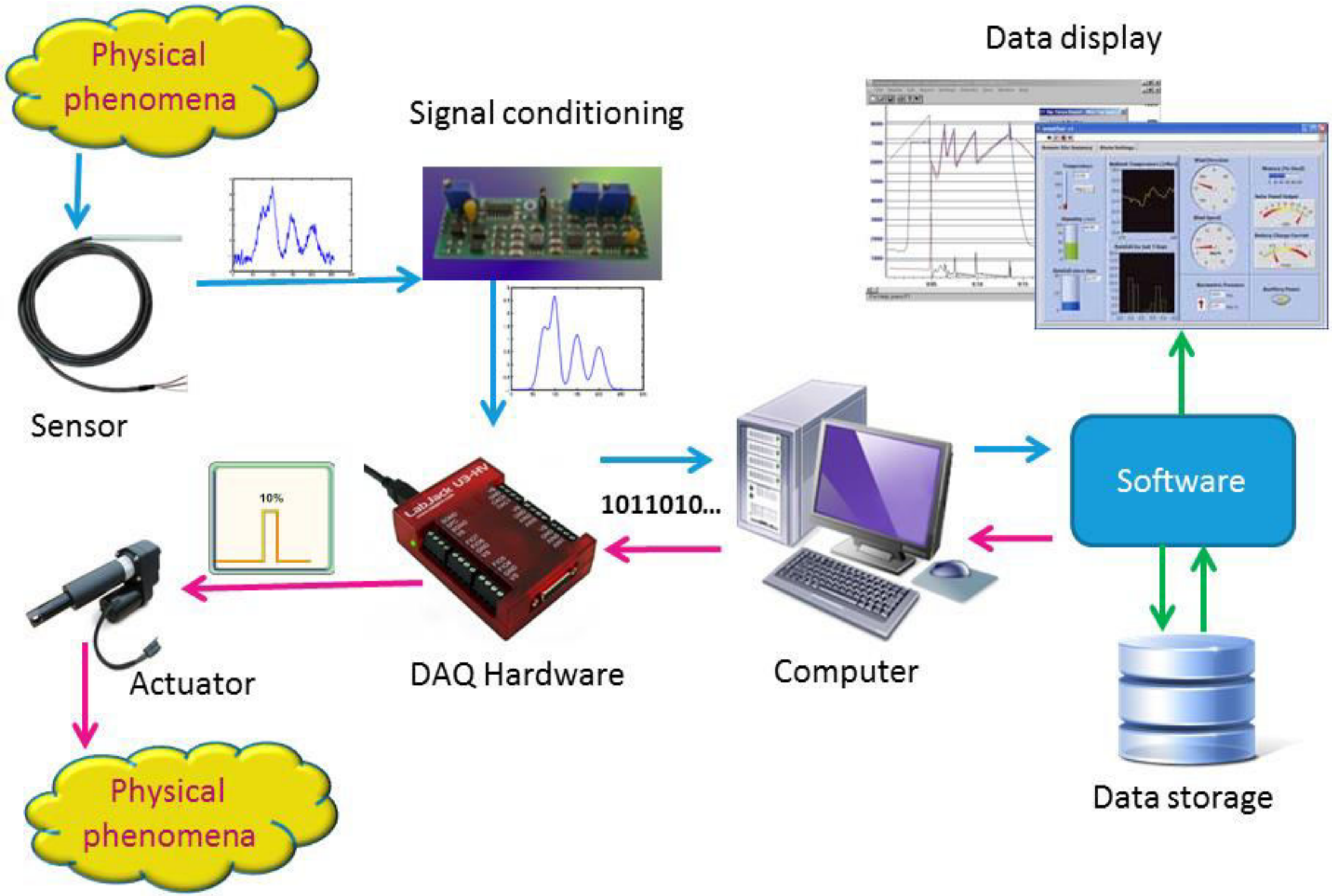
The various general configurations include :

1. *Signal channel possibilities :*
   (*i*) Direct conversion.
   (*ii*) Pre-amplification and direct conversion.
   (*iii*) Sample and hold, and conversion.
   (*iv*) Pre-amplification, sample and hold, and conversion.
   (*v*) Pre-amplification, signal conditioning, and any of the above.
2. *Multi-channel possibilities :*
   (*i*) Multiplexing the outputs of single channel converters.
   (*ii*) Multiplexing the outputs of sample-hold circuits.
   (*iii*) Multiplexing the inputs of the sample-hold circuits.
   (*iv*) Multiplexing low level data.
3. *Noise-reduction options :*
   (*i*) Filtering.
   (*ii*) Integrating converters and digital processing.

Interfacing of Sensor / Actuator to DAQ



Interfacing of Sensor / Actuator to DAQ



Bit width

- When analog signal is converted to digital, it is represented in the digital form by a series of binary number, each of which represents the signal value in the point of time
- Definition:-

  The number of binary digits or bits in each word is known as the bit width
- A bit is the smallest unit of information possible on a digital computer.
- It represents a zero or a one(0 or 1)

- In computer everything is 0 or 1. It is easy to represent and process information in that way. One bit can be 0 or 1 that is where the number 2 is coming from as you have two options.
- If you have 2 bits you have 4 options (00,01,10,11). The number of bits is risen always by multiplications of 2 so you have1, 2, 4, 8, 16, 32, 64, 128, ...
- Two bits allows you to have 4 different combinations: [0, 0], [0, 1], [1, 0] and [1, 1]. Three bits allows $2^3 = 8$ different combinations, four bits allows $2^4 = 16$ combinations, and so on.
- A 32-bit wide bus is a collection of 32 individual wires, giving you 32 bits of data, which have up to $2^{32} =$ 4,294,967,296 different combinations.

Sampling and Sampling theorem

- In signal processing, sampling is the reduction of a continuous signal to a discrete signal.
- A common example is the conversion of a sound wave (a continuous signal) to a sequence of samples (a discrete-time signal).
- A sample is a value or set of values at a point in time and/or space.
- The number of samples per second is called the sampling rate or sampling frequency.

Sampling and Nyquist Sampling theorem

- During sampling process, a continuous-time signal is converted into discrete -time signals by taking samples of continuous-time signal at discrete time intervals.
- Sampling theorem gives the criteria for minimum number of samples that should be taken.
- Sampling theorem:-"Sampling frequency must be twice of the highest frequency"

$$f_s=2W$$

f_s=sampling frequency
w=higher frequency content
2w also known as Nyquist rate

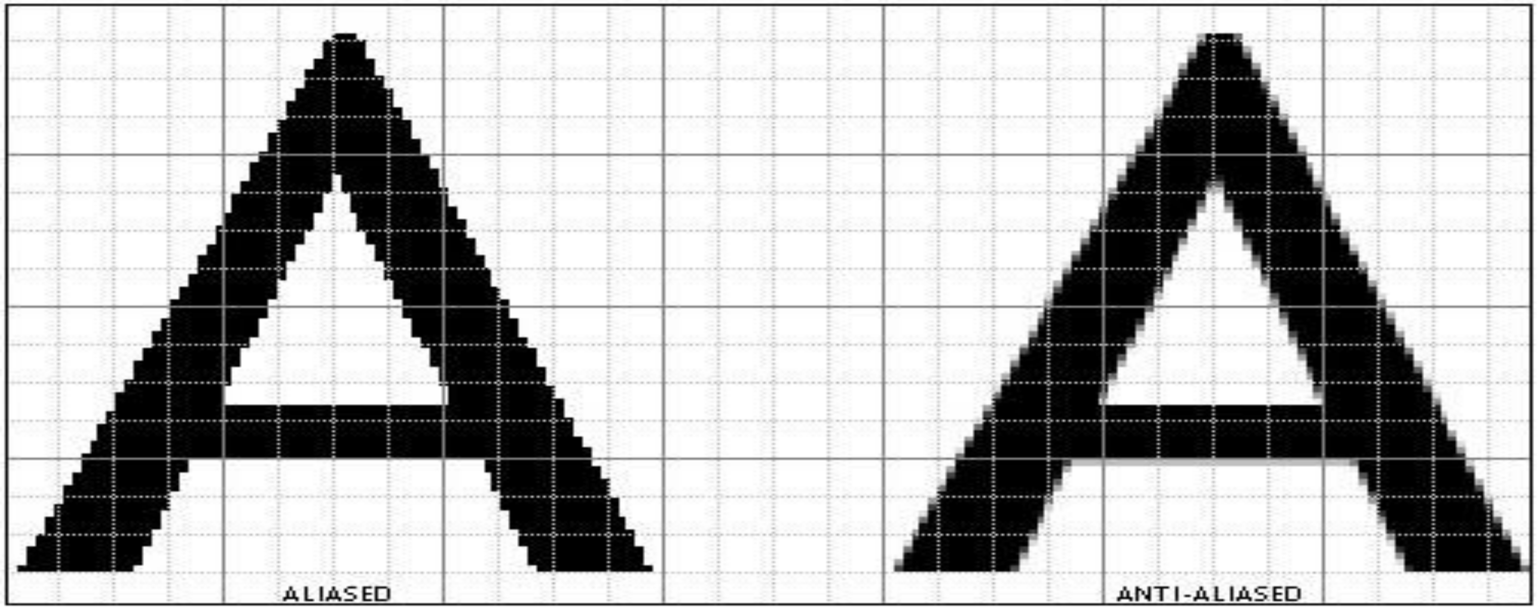
- Nyquist rate is defined as the minimum sampling rate for the perfect reconstruction of the continuous time signals from samples.
- Nyquist rate=2*highest frequency component

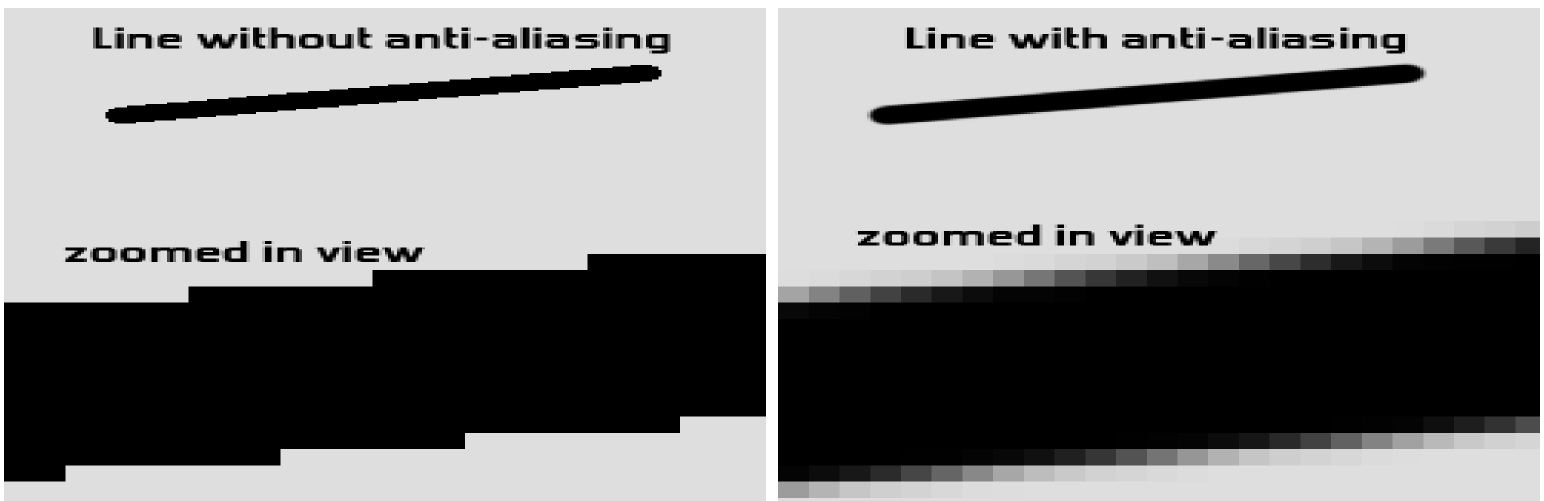
  =2*W
- So sampling rate must be greater than or equal to nyquist rate

Aliasing

- Aliasing is a signal processing term. Aliasing occurs when a system is measured at an insufficient sampling rate.
- Imagine a disk (or paper plate) with a dot near the edge. If the disk began rotating at one revolution per minute, you could observe the angular velocity by looking at it. Now close your eyes.
- If you open your eyes every 15 seconds and observe the dot, you can still measure direction of rotation and speed. Every 30 seconds and it becomes difficult to determine the rotation of the plate (this is the NYQUIST FREQUENCY). Look every 75 seconds and the plate appears to be rotating opposite to its true rotation.
- This is aliasing. The same thing happens when a digital measurement device does not sample a signal often enough.

- Aliasing occurs when you sample a signal (anything which repeats a cycle over time) too slowly (at a frequency comparable to or smaller than the signal being measured), and obtain an incorrect frequency and/or amplitude as a result.
- Aliasing is generally avoided by applying low pass filters- anti-aliasing filters to the analog signal before sampling.





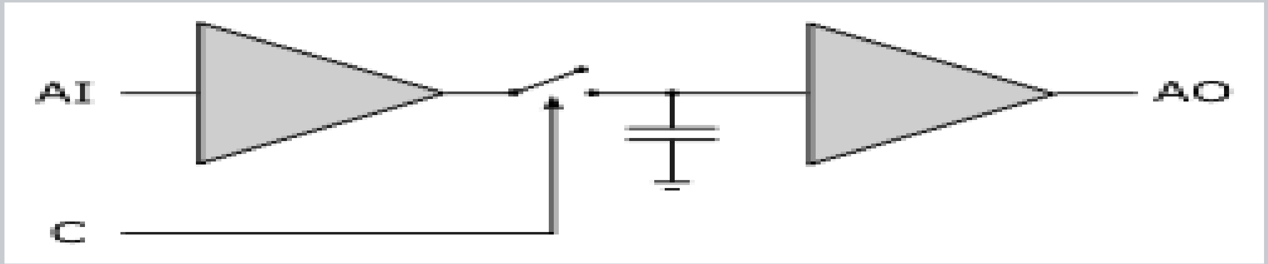
Anti-aliasing makes lines look smooth. When zoomed in, you can see that anti-aliasing works by adding grey pixels at the borders. If those grey pixels are lost on an SD TV, there is no anti-aliasing anymore and graphics loose smoothness.

Anti aliasing

- In digital signal processing, **spatial anti-aliasing** is the technique of minimizing the distortion artefacts known as aliasing when representing a high-resolution image at a lower resolution. Anti-aliasing is used in digital photography, computer graphics, digital audio, and many other applications.
- Anti-aliasing means removing signal components that have a higher frequency than is able to be properly resolved by the recording (or sampling) device. This removal is done before (re)sampling at a lower resolution.

Sample and hold circuit

- In electronics, a **sample and hold** (S/H, also "follow-and-hold") circuit is an analog device that **samples** (captures, grabs) the voltage of a continuously varying analog signal and holds (locks, freezes) its value at a constant level for a specified minimum period of time
- They are typically used in analog-to-digital converters to eliminate variations in input signal that can corrupt the conversion process
- A typical sample and hold circuit stores electric charge in a capacitor and contains at least one switching device such as a FET (field effect transistor) switch and normally one operational amplifier



A simplified sample and hold circuit diagram. AI is an analog input, AO — an analog output, C — a control signal.

- To sample the input signal the switch connects the capacitor to the output of a buffer amplifier. The buffer amplifier charges or discharges the capacitor so that the voltage across the capacitor is practically equal, or proportional to, input voltage.
- In hold mode the switch disconnects the capacitor from the buffer. The capacitor is invariably discharged by its own leakage currents and useful load currents, which makes the circuit inherently volatile, but the loss of voltage (*voltage drop*) within a specified hold time remains within an acceptable error margin.

Analog Signals

Analog signals – directly measurable quantities in terms of some other quantity

Examples:

- Thermometer – mercury height rises as temperature rises
- Car Speedometer – Needle moves farther right as you accelerate
- Stereo – Volume increases as you turn the knob.

Digital Signals

Digital Signals – have only two states. For digital computers, we refer to binary states, 0 and 1. "1" can be on, "0" can be off.

Examples:

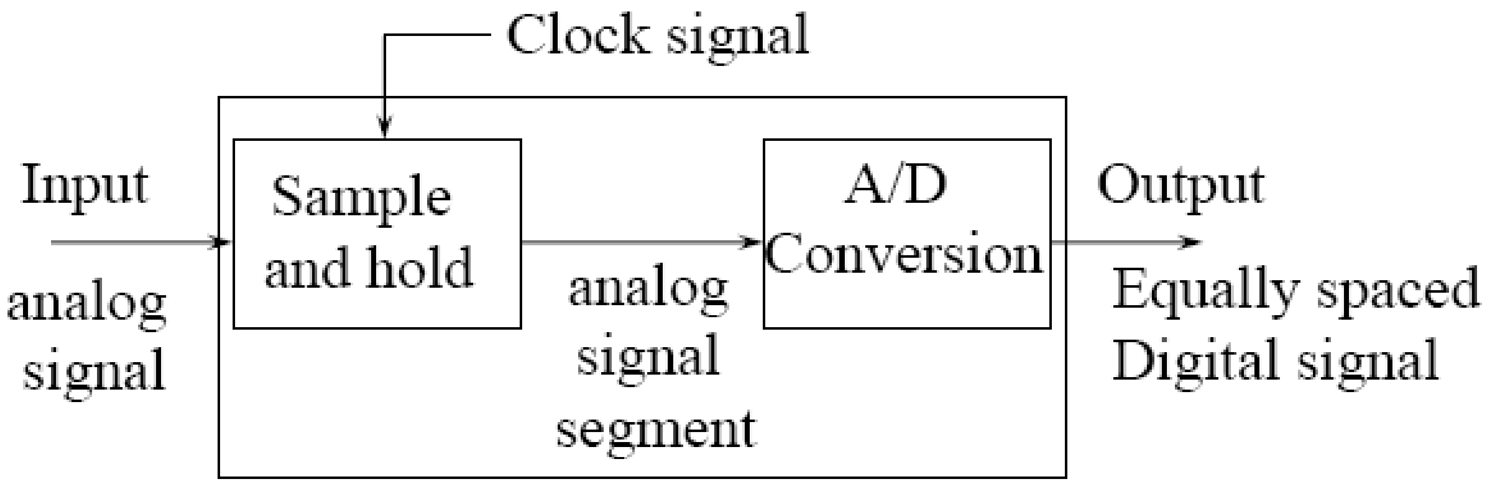
- Light switch can be either on or off
- Door to a room is either open or closed

Examples of A/D Applications

- Microphones - take your voice varying pressure waves in the air and convert them into varying electrical signals
- Strain Gages - determines the amount of strain (change in dimensions) when a stress is applied
- Thermocouple – temperature measuring device converts thermal energy to electric energy
- Voltmeters
- Digital Multimeters

Just what does an A/D converter DO?

- Converts analog signals into binary words.



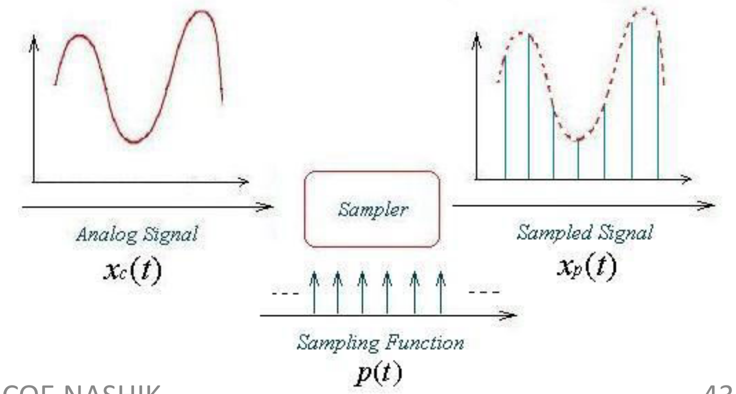
ADC

- Generally signals are analog in nature (eg:speech,weather signals).
- To process the analog signal by digital means, it is essential to convert them to discrete-time signal , and then convert them to a sequence of numbers.
- The process of converting an analog to digital signal is 'Analog-to-Digital Conversion'.
- The ADC involves three steps which are:

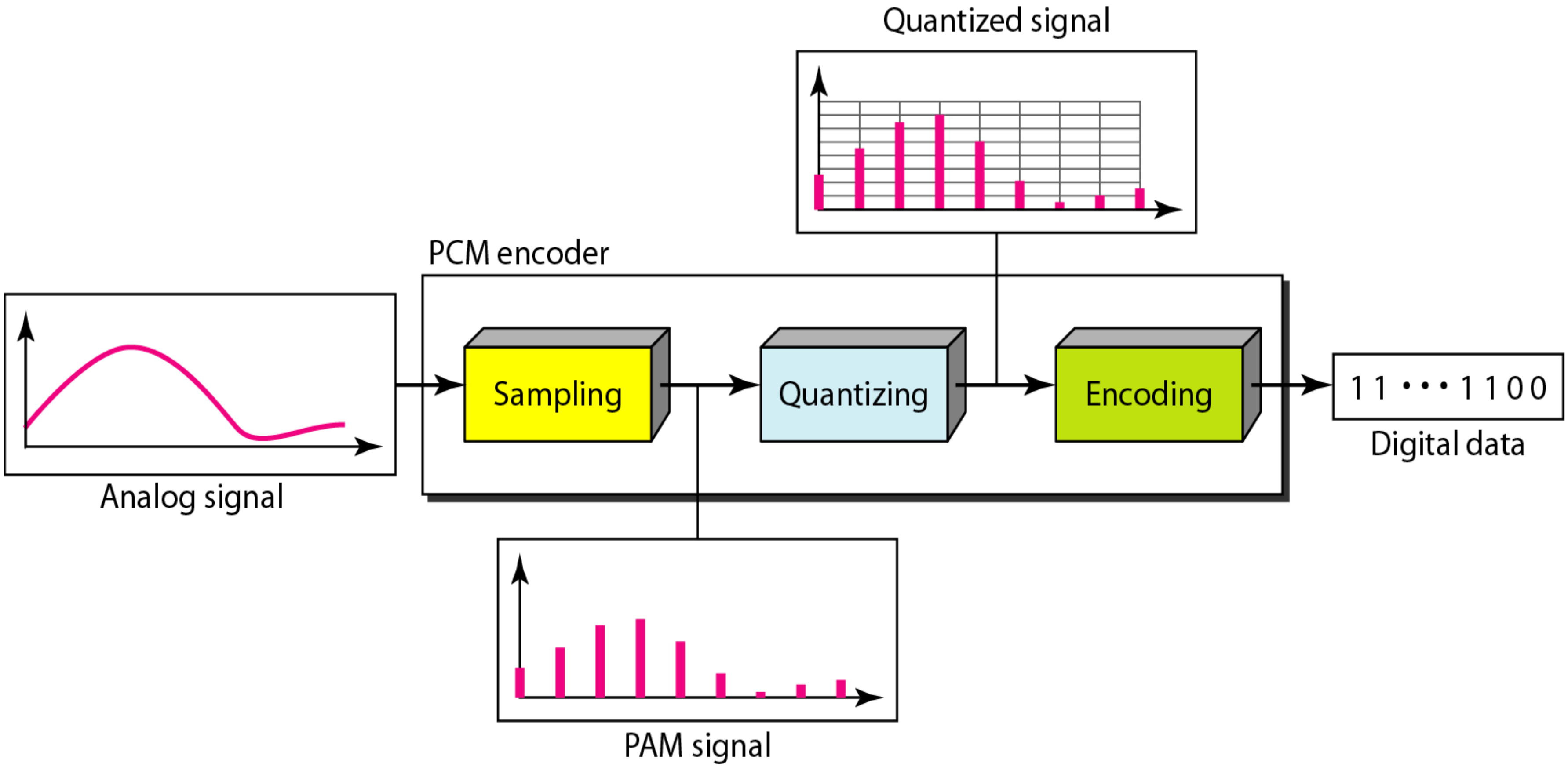
1)Sampling

2)Quantization

3)coding



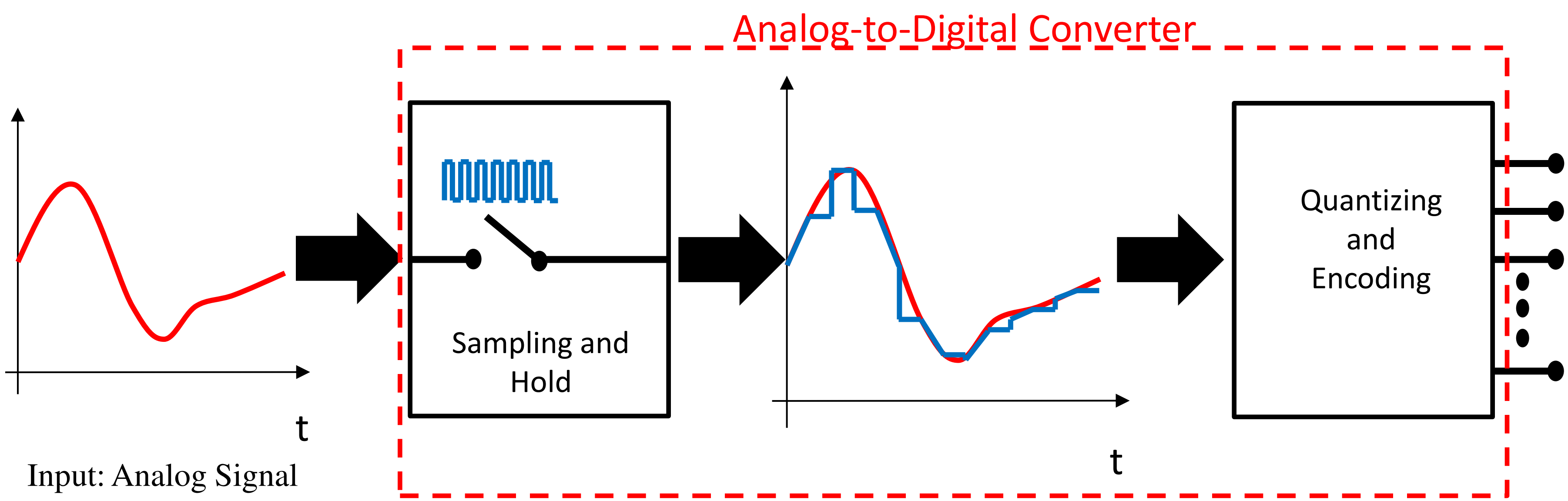
ADC Conversion Process



ADC Conversion Process

Two main steps of process

1. Sampling and Holding
2. Quantization and Encoding



- Quantizing - breaking down analog value in a set of finite states
- Encoding - assigning a digital word or number to each state and matching it to the input signal
- The analog quantization size (or resolution) Q is defined as the full scale range of the ADC divided by the number of output states:

➢ Quantisation

$$Q = \frac{V_{\max} - V_{\min}}{2^n}$$

where

- (Vmax – Vmin) is range of the ADC
- n is bit of ADC

A/D Converter Types

- Converters
  - Flash ADC
  - Delta-Sigma ADC
  - Dual Slope (integrating) ADC
  - **Successive Approximation ADC**

Successive Approximation ADC

- A **successive approximation ADC** is a type of analog-to-digital converter that converts a continuous analog waveform into a discrete digital representation via a binary search through all possible quantization levels before finally converging upon a digital output for each conversion.

- **Elements:-**

  DAC = Digital to Analog Converter

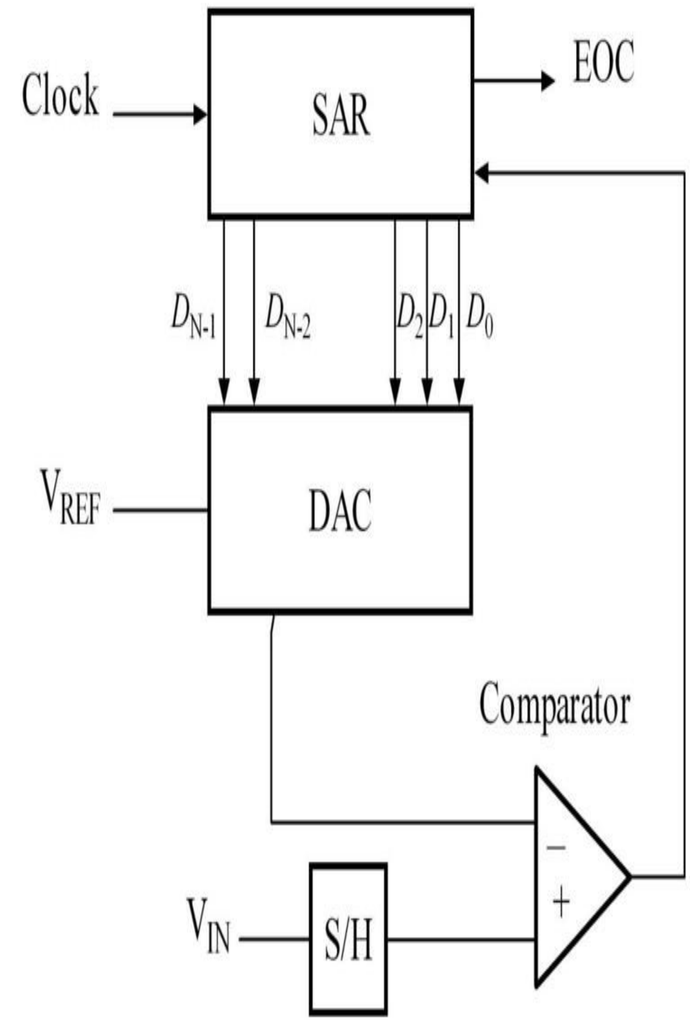
  EOC = End of Conversion

  SAR = Successive Approximation Register

  S/H = Sample and Hold Circuit

  V_{in} = Input Voltage Comparator

  V_{ref} = Reference Voltage



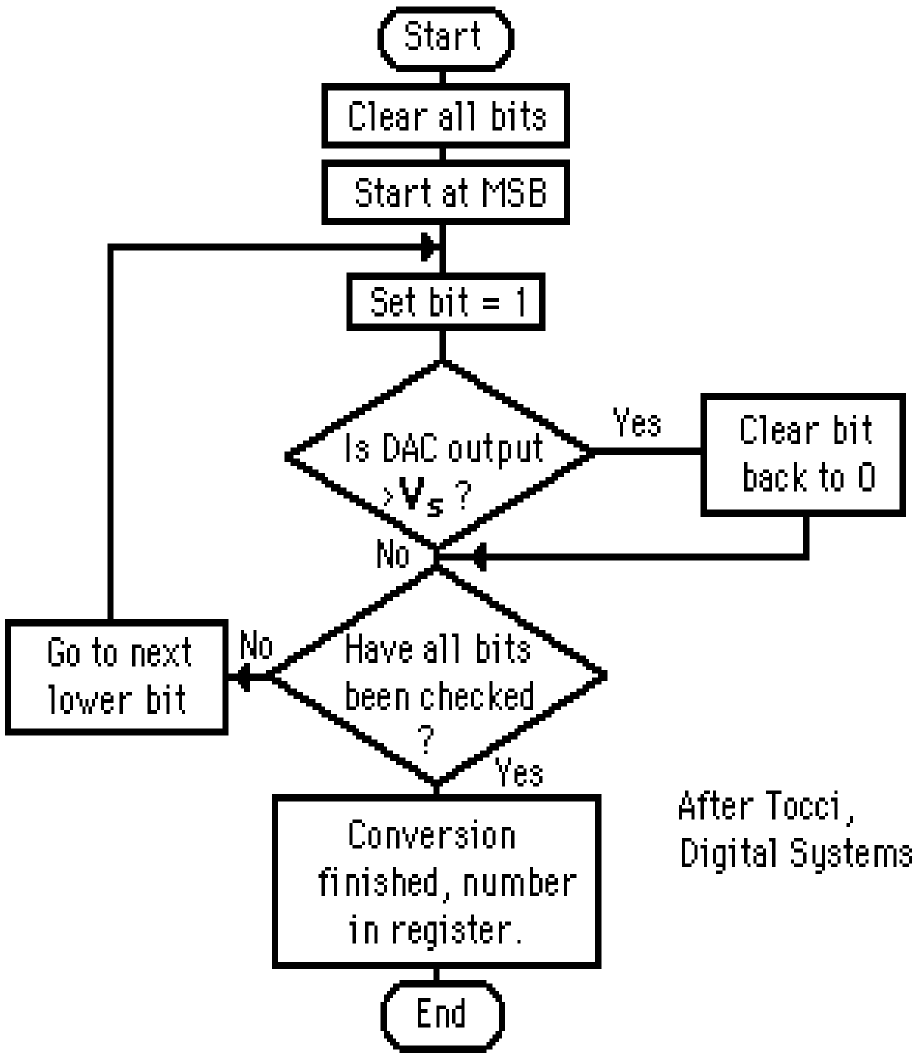
- The successive approximation analog-to-digital converter circuit typically consists of four chief subcircuits:

1) A sample and hold circuit to acquire the input voltage(V_{in}).
2) An analog voltage comparator that compares V_{in} to the output of the internal DAC and outputs the result of the comparison to the successive approximation register (SAR).
3) A successive approximation register subcircuit designed to supply an approximate digital code of V_{in} to the internal DAC.
4) An internal reference DAC that, for comparison with V_{REF}, supplies the comparator with an analog voltage equal to the digital code output of the SAR_{in}.

SAR Types ADC

- The SAR is initialized so that the MSB is equal to a 1.
- This code is fed into the DAC, which then supplies the analog equivalent of this digital code into the comparator circuit for comparison with the sampled input voltage.
- If this analog voltage exceeds V_{in} the comparator causes the SAR to reset this bit; otherwise, the bit is left a 1.
- Then the next bit is set to 1 and the same test is done, continuing this until every bit in the SAR has been tested.
- The resulting code is the digital approximation of the sampled input voltage

SAR Types ADC



After Tocci, Digital Systems

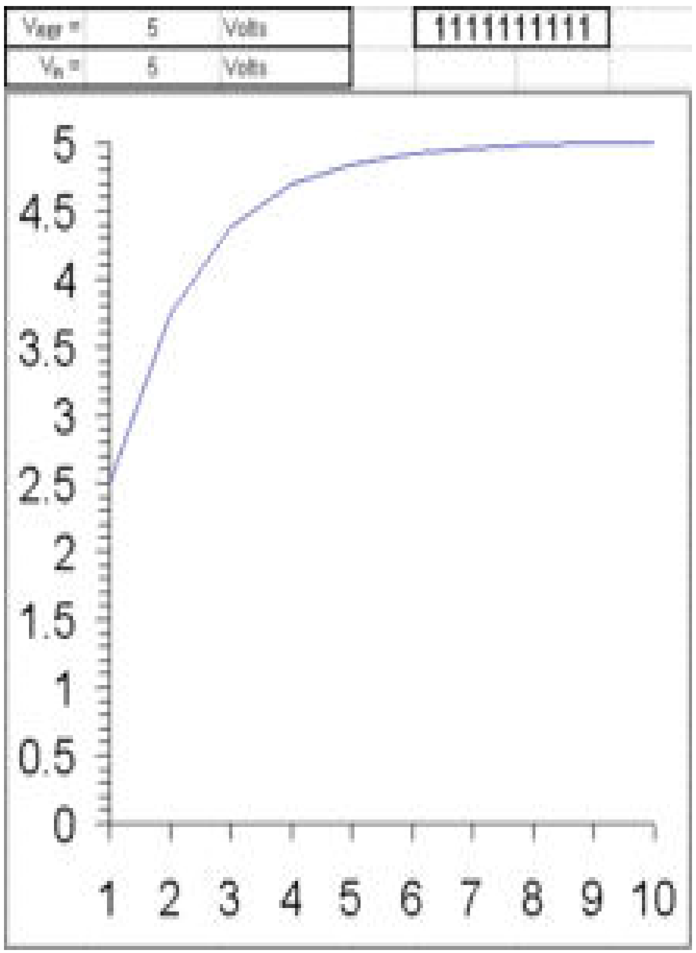
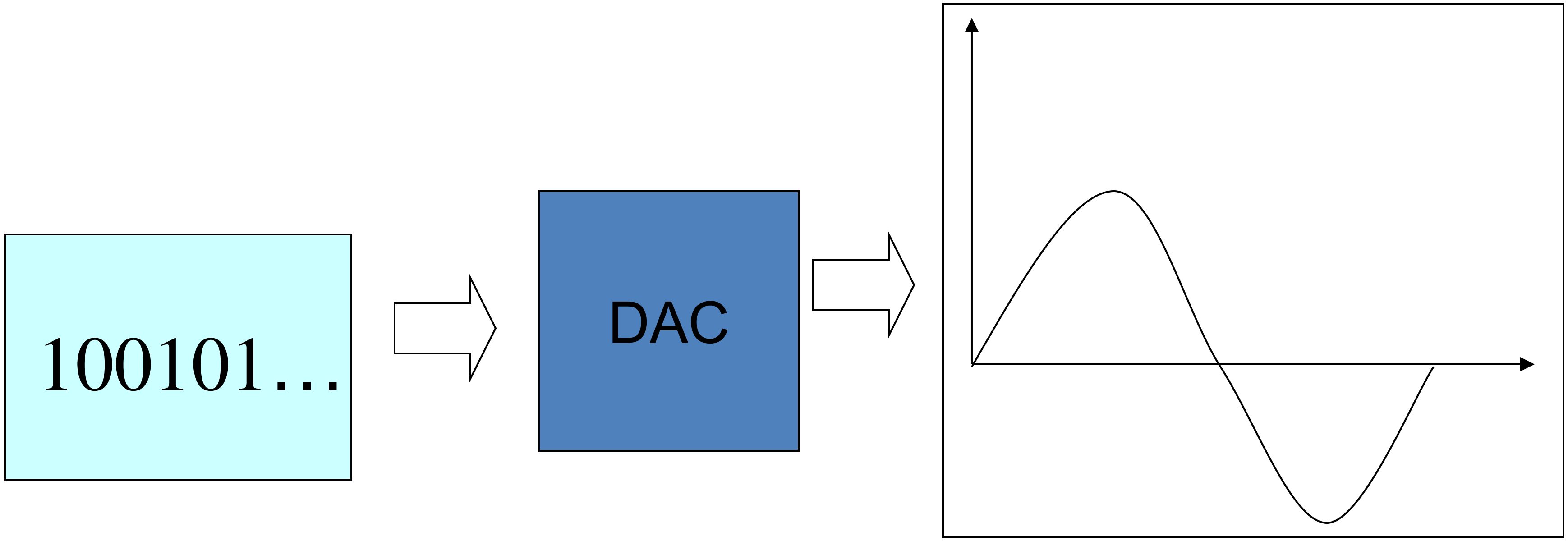


Fig: ADC using successive approximation

- **Advantages of Successive Approximation ADC**
- Speed is high compared to counter type ADC.
- Good ratio of speed to power.
- Compact design compared to Flash Type and it is inexpensive.
- **Disadvantages:**
- Cost is high because of SAR
- Complexity in design.
- **Applications**
- The SAR ADC will used widely data acquisition techniques at the sampling rates higher than 10KHz

Digital to analog converter(DAC)

- A digital to analog converter (DAC) converts a digital signal to an analog voltage or current output.
- In this the digital data in the form of 1's and 0's are used to control the switches which are placed in a analog circuit with reference voltage, based on this switch condition (ON/OFF) and position (MSB or LSB) the output analog amplitude is calculated.



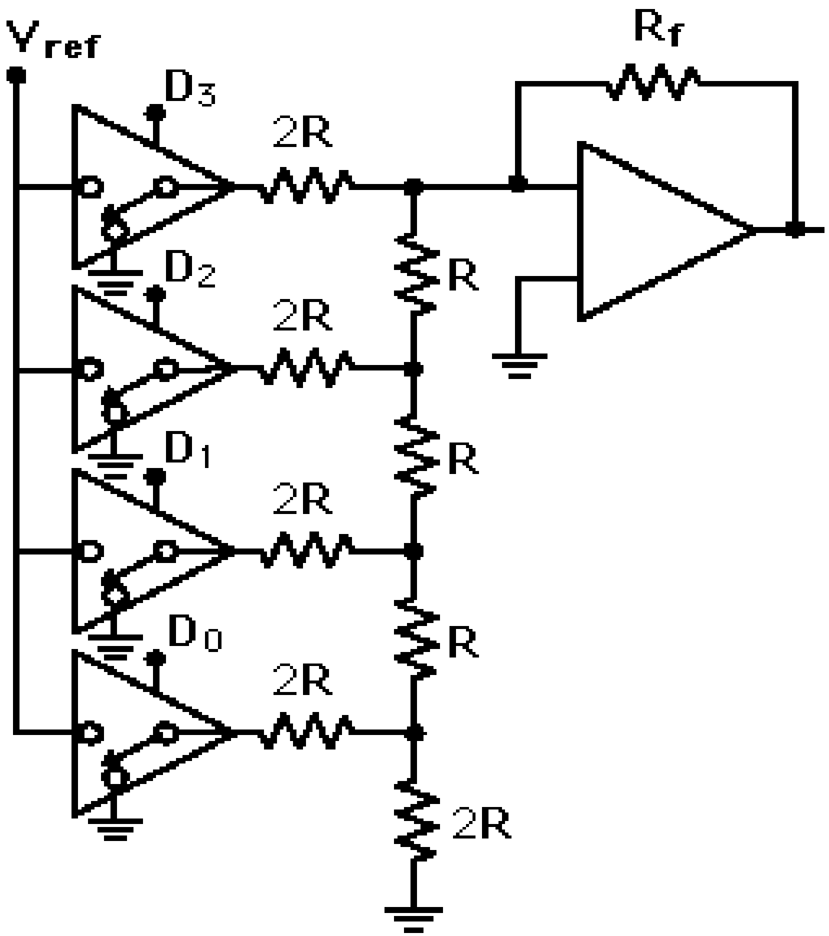
- The DAC fundamentally converts finite-precision numbers (usually fixed-point binary numbers) into a continuously varying physical quantity, usually an analogue electrical voltage.

- **Types of DAC'S**
- Many types of DACs available.
- Usually switches, resistors, and op-amps used to implement conversion
- Two Types:
  - Binary Weighted Resistor
  - **R-2R Ladder**

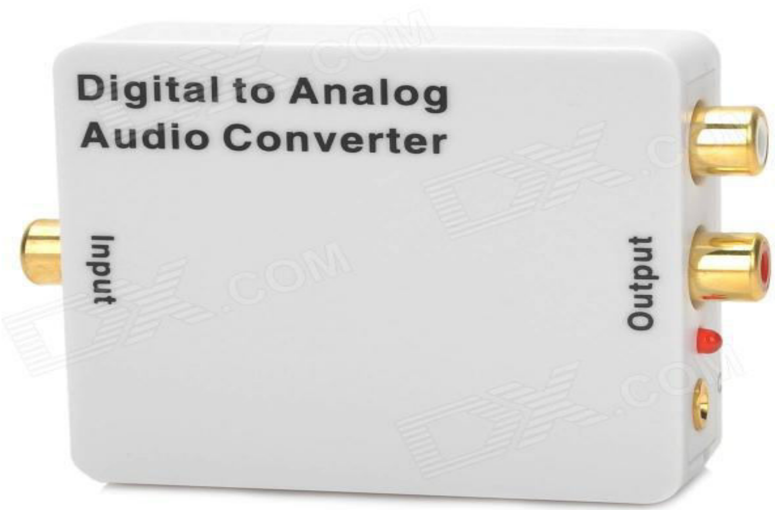
Applications

- DACs are commonly used in music players to convert digital data streams into analog audio signals.
- They are also used in televisions and mobile phones to convert digital video data into analog video signals which connect to the screen drivers to display monochrome or color images.
- These two applications use DACs at opposite ends of the speed/resolution trade-off. The audio DAC is a low speed high resolution type while the video DAC is a high speed low to medium resolution type.
- Discrete DACs would typically be extremely high speed low resolution power hungry types, as used in military radar systems. Very high speed test equipment, especially sampling oscilloscopes, may also use discrete DACs.

R-2R Ladder type DAC



$$V_{out} = \frac{R_f}{R} V_{ref} \left[\frac{D_0}{16} + \frac{D_1}{8} + \frac{D_2}{4} + \frac{D_3}{2} \right]$$



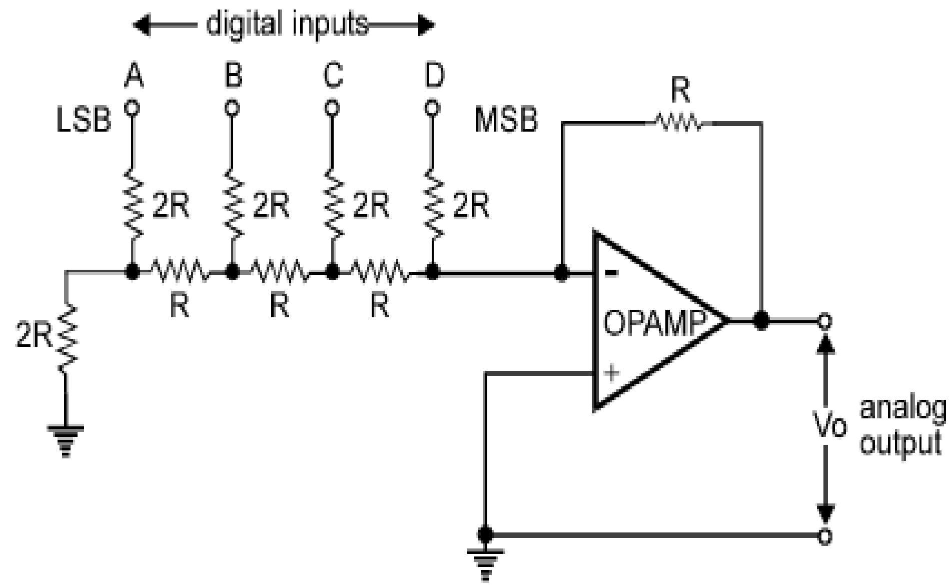
4 Bit Digital-Analog Converter using R-2R Approach

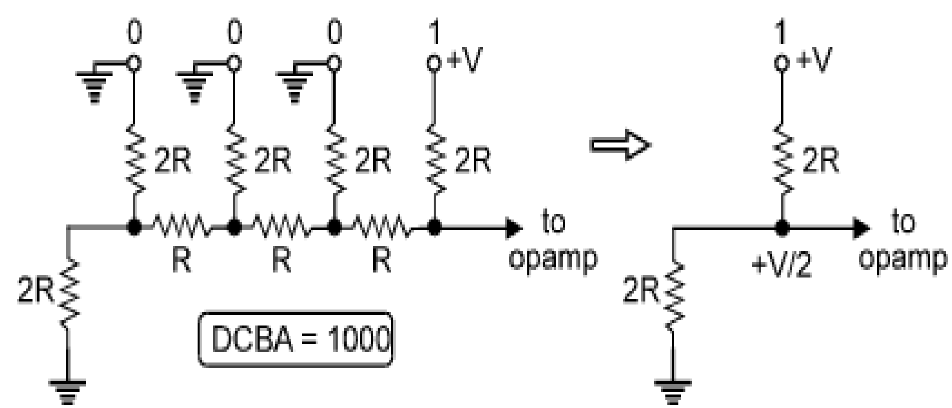
R-2R Ladder type DAC

- The disadvantage of the binary weighted register is the availability and manufacturing of exact values of the resistances.
- it is modern type of resistor network. It has only two values of resistors the R and 2R. These values repeat throughout in the circuit.
- The Opamp Is Used At Output For Scaling The Output Voltage.

R-2R Ladder type DAC

- Now consider the circuit, without op amp. Suppose the digital input is DCBA = 1000. Then the circuit is reduced to a small circuit Its output is given by





$$output = \left(\frac{2R}{2R+2R}\right) x (+V) = \frac{V}{2}$$

Example

An 8-bit DAC has a V_{ref} of 10 V. The binary input is 10011011. Find the analog output voltage.

10011011

$$= 1 \times 2^7 + 0 \times 2^6 + 0 \times 2^5 + 1 \times 2^4 + 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$$

$$= 128 + 0 + 0 + 16 + 8 + 0 + 2 + 1$$

$$= 155$$

we can calculate the analog output voltage:

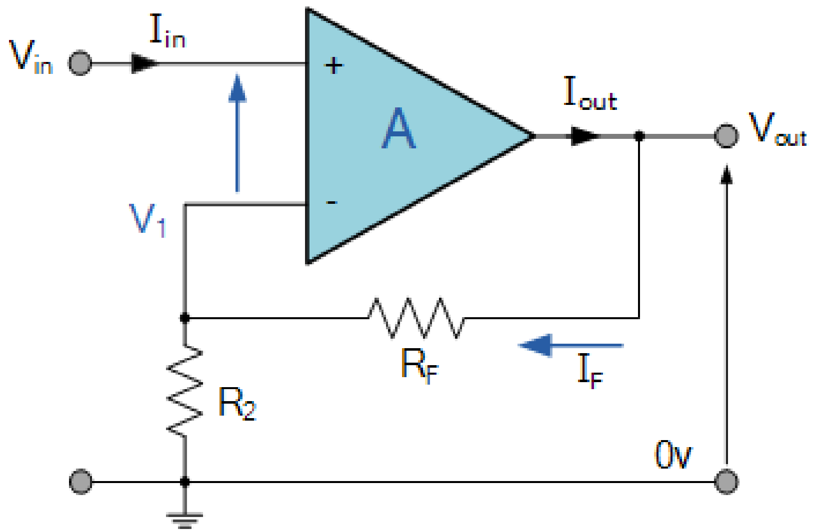
$$V_{out} = \frac{input \times V_{ref}}{256} = \frac{155 \times 10V}{256} = 6.05\ V$$

6.05 V is the voltage we would expect on the analog output pin.

Calculate output voltage for 11111111 and justify ?

Voltage Amplifier

- A non-inverting type voltage amplifier
- Amplifies output voltage
- Voltage input is applied to non-inverting terminal
- Gain is positive and greater than unity
- Consists of feedback resistor, R_f, to give stable, self-correcting and un-saturated output



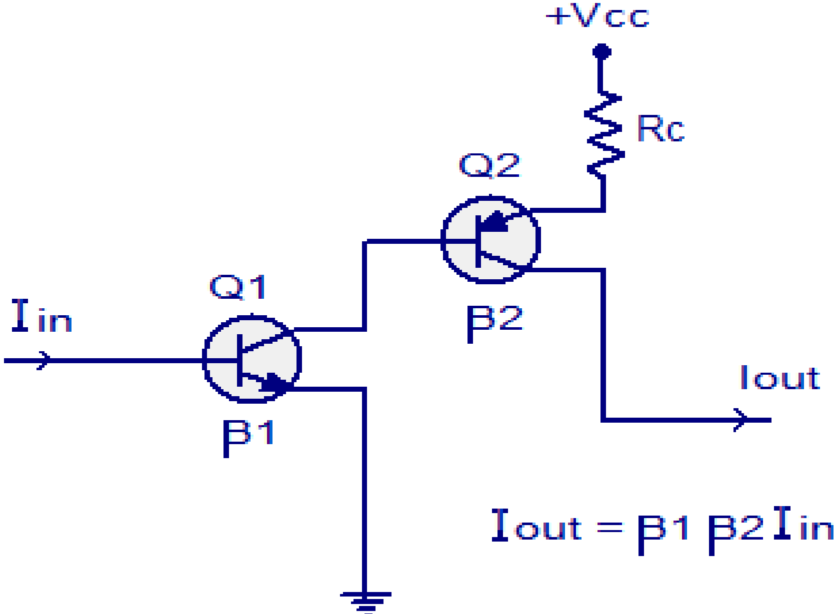
$$V_{out} = V_{in}\left(1 + \frac{R_f}{R_2}\right)$$

Voltage Amplifier

- A voltage amplifier in simplest form is any circuit that puts out a higher voltage than the input voltage.
- When you are forced to work with a set amount of voltage, these amplifiers are commonly used to increase the voltage and thus the amount of power coming out of a circuit.
- This is useful for reading and adapting small signals such as boosting an audio signal before sending it on its way to speakers.

Current Amplifier

- Amplifies current in a step by step process
- Realized using multiple transistors
- β is the gain of the transistor= collector current / base current = I_C/I_B
- Output current is the product of input current and the gain, β



Current Amplifier

- A current amplifier circuit is a circuit which amplifies the input current by a fixed factor and feeds it to the succeeding circuit.
- A current amplifier can be realized using transistors. The schematic of a current amplifier circuit using transistors is shown in the figure.
- Two transistors are used in this circuit. $\beta 1$ and $\beta 2$ are the current gains of transistors Q1 and Q2 respectively. Iin is the input current, Iout is the output current and+Vcc is the transistor T2's collector voltage
- The equation for the output current is

$$Iout = \beta 1\ \beta 2\ Iin .$$