Chapter One

- Introduction to digital control

Introduction to Digital control

Continuous time signal

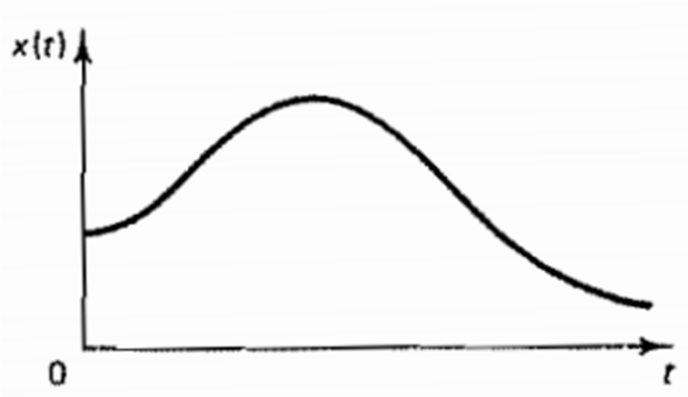
- A signal is called continuous time if it is defined at every time t.
- A controller is continuous time if it takes a continuous time signal and outputs a continuous time signal.

Discrete Time signal

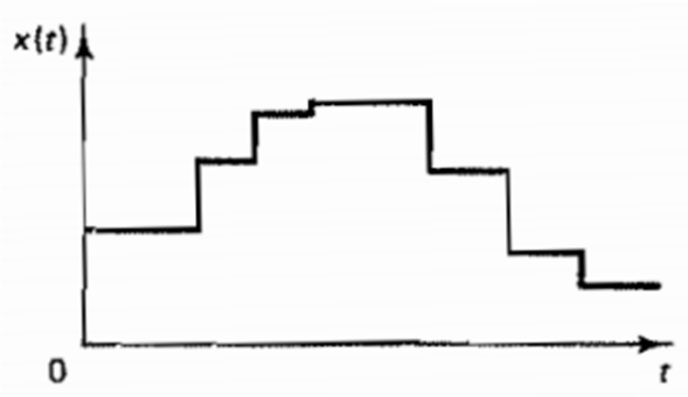
- A signal is called discrete time if it is only defined for particular points in time
- A discrete time controller takes discrete time input signal and produces discrete time output signal.
- Sampling and quantization are methods of changing analog signal in to discrete signal.

Discrete Time signal

- **Sampling Time - the time interval samples are taken**
- **Discrete Signals – signals that has values at regular intervals of sample.**

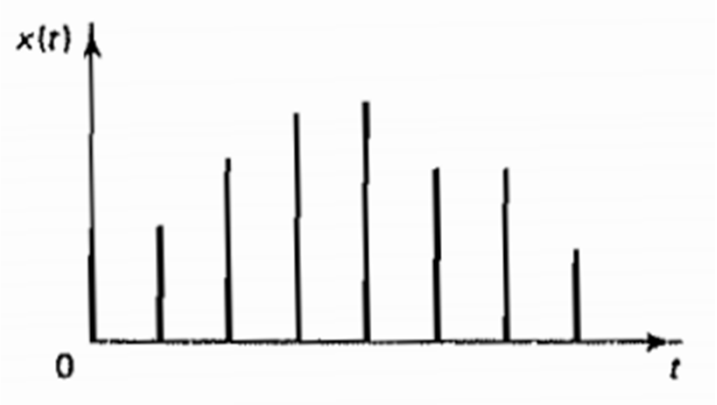


Analog signal

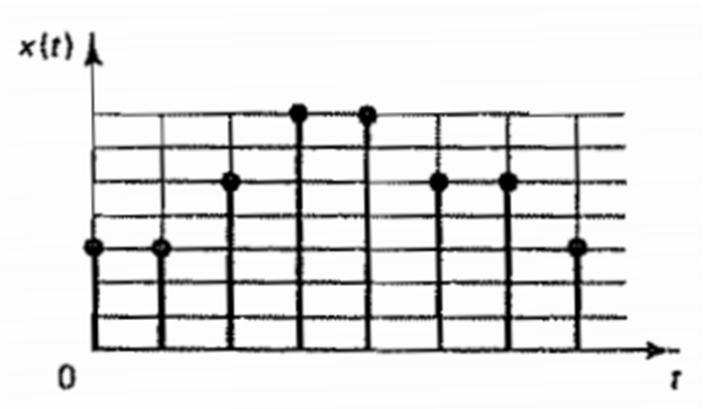


Amplitude quantized
Analog signal

Discrete Time signal



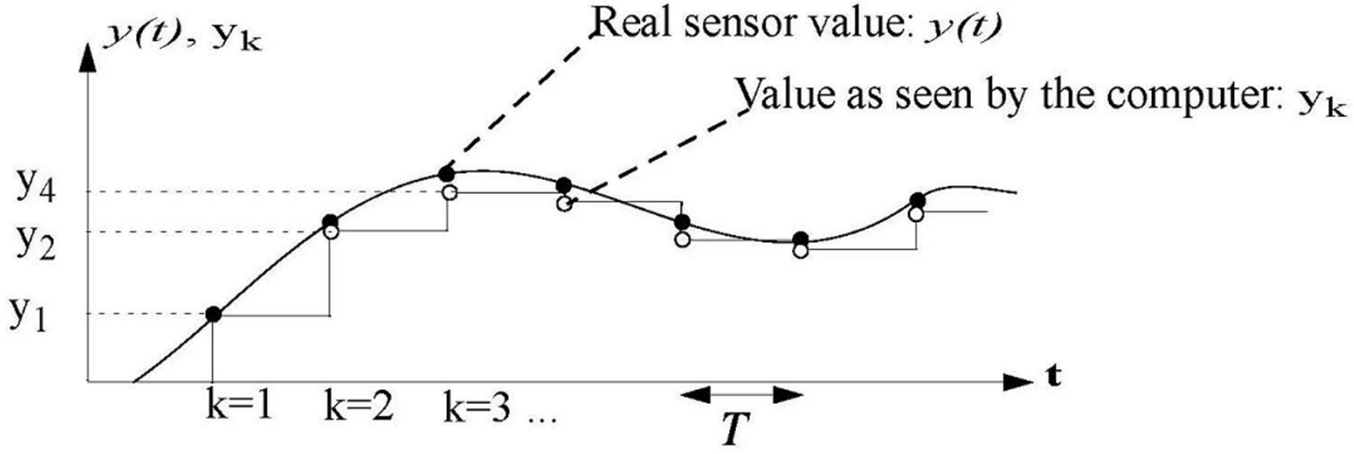
Sampled Data signal



Digital signal

Discrete Time signal

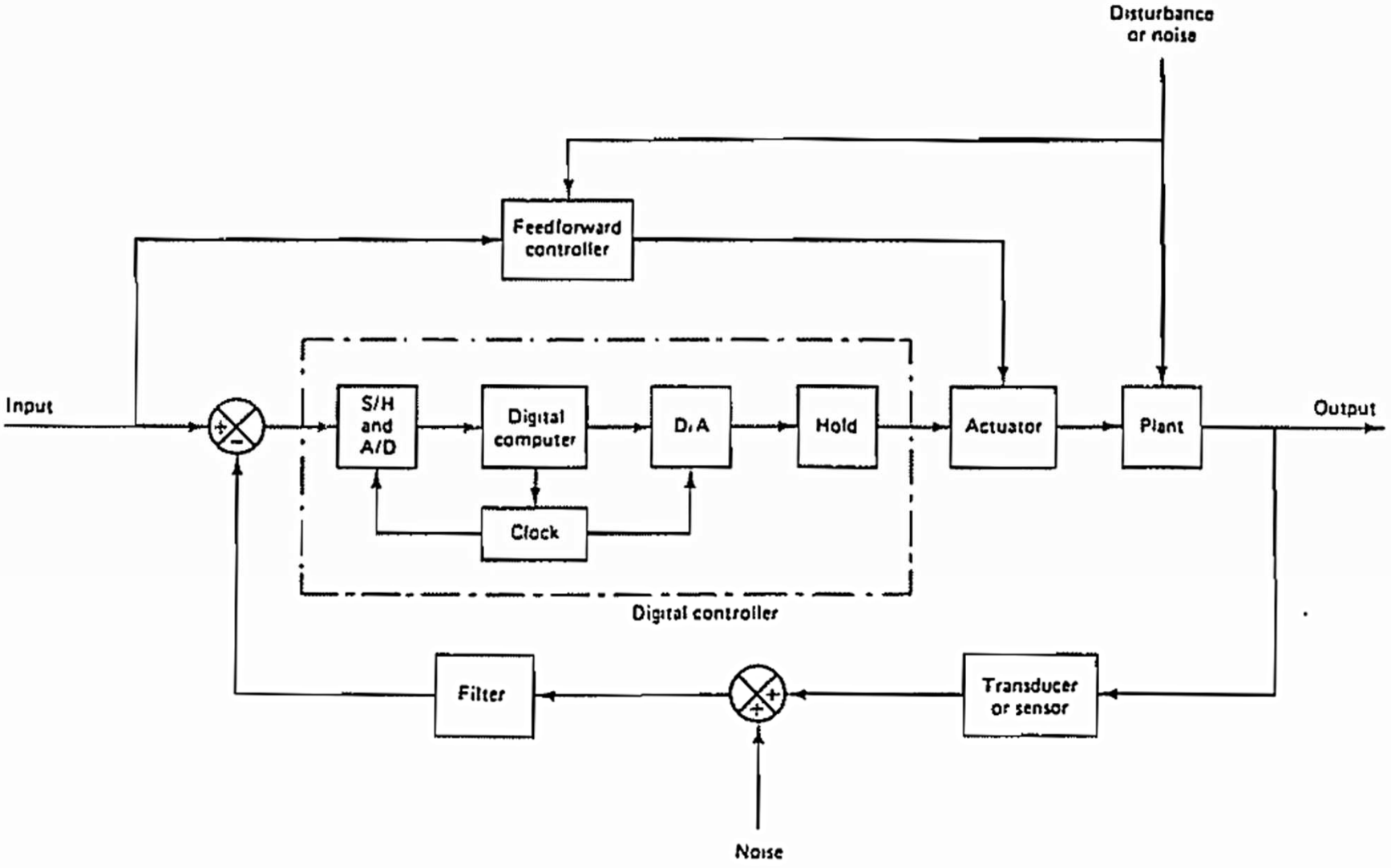
- **In Discrete time control systems one or more variables can change only at discrete instant of time. This instants are denoted by KT or t_K where K=0, 1, 2, …, this intervals of time represent the time at which measurements are read or the memory of digital controller is accessed.**



Sampling Process

- Sampling is a process of sampling a sequence of values from continuous time signal to create discrete time signal.
- The sampling process is followed by quantization in order to generate digital signal, where analog amplitude is replaced by digital amplitude, so that digital signal can be processed by digital computer.

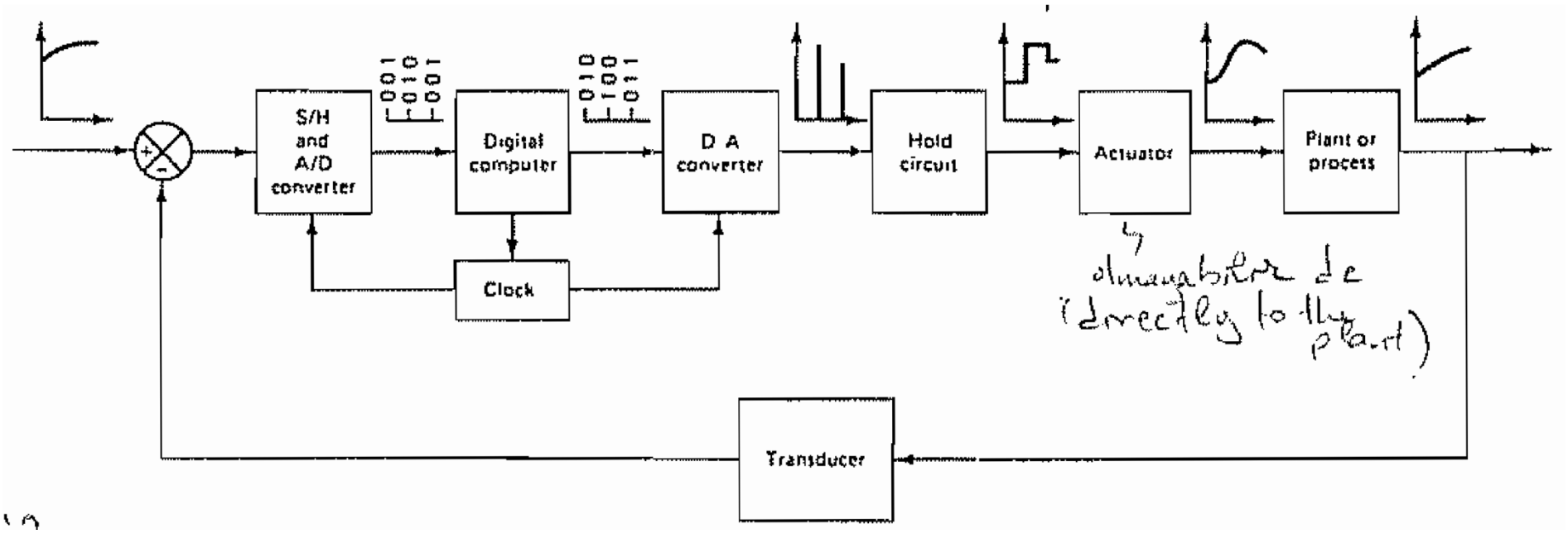
Digital control system



Digital control system

- The output of the plant is a continuous time signal. The error signal is converted in to digital form by the sample and hold circuit and analog to digital converter. The conversion is done at the sampling time. The digital computer processes the sequence of number by means of an algorithm and produces new sequence of number.

Digital control system



Digital control system

- At every sampling instant the digital signal must be converted in to the actual controlling analog signal.
- The digital to analog converter and the hold circuit convert the sequence of numerical output from the computer in to a piecewise continuous time signal.
- The real time clock of the computer synchronize all events.
- The output of the hold circuit which is a continuous time signal fed to the plant either directly or through actuator to control its dynamics.
- Data hold: the process of converting discrete time signal in to continuous time signal.

Important Terms in Digital Control

- **Sample and Hold: a circuit that receives an analog input signal and holds this signal at a constant value for a specified period of time.**
- **Analog to digital converter (A/D): a circuit that converts the output of the sample and hold circuit analog signal to a digital signal.**
- **Transducer/ Sensor: a device that converts an input signal in to an output signal of another form.**

Quantization

- The main parts of A/D converter are
  - Sampler
  - Amplitude quantizer
  - Encoder
- The process of representing a continuous or analog signal by a finite number of discrete state is called Amplitude quantization.
- Encoding is a process of assigning a digital word or code to each discrete state.
- Encoding uses binary number 0 an 1.
- N number of 1 and 0 can represent 2^N states.

Quantization level

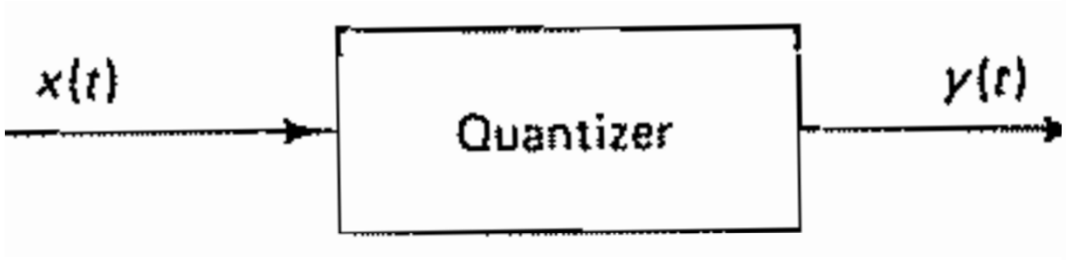
- Quantization level is the range between two adjacent decision points.

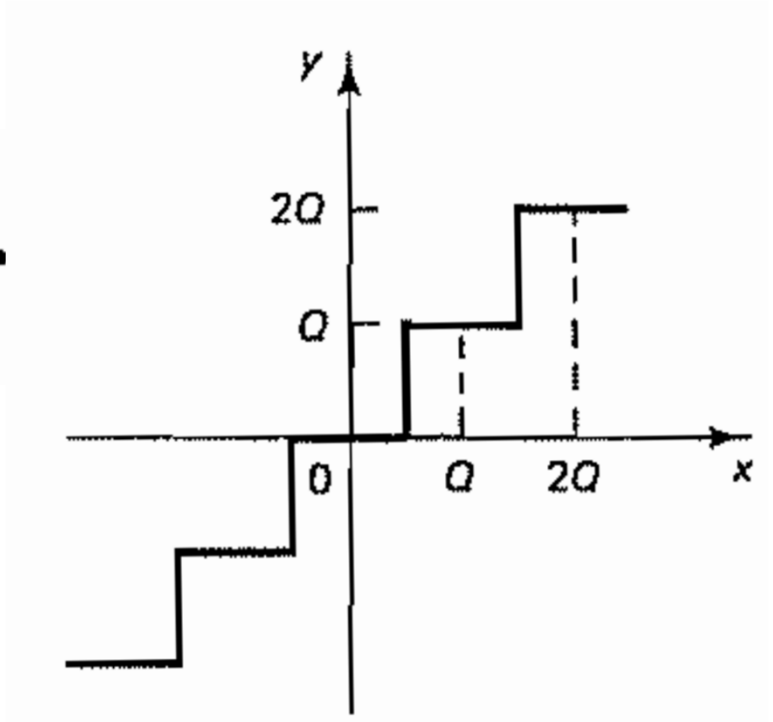
$$Q = \frac{FSR}{2^N}$$

FSR: full scale range

Quantization error

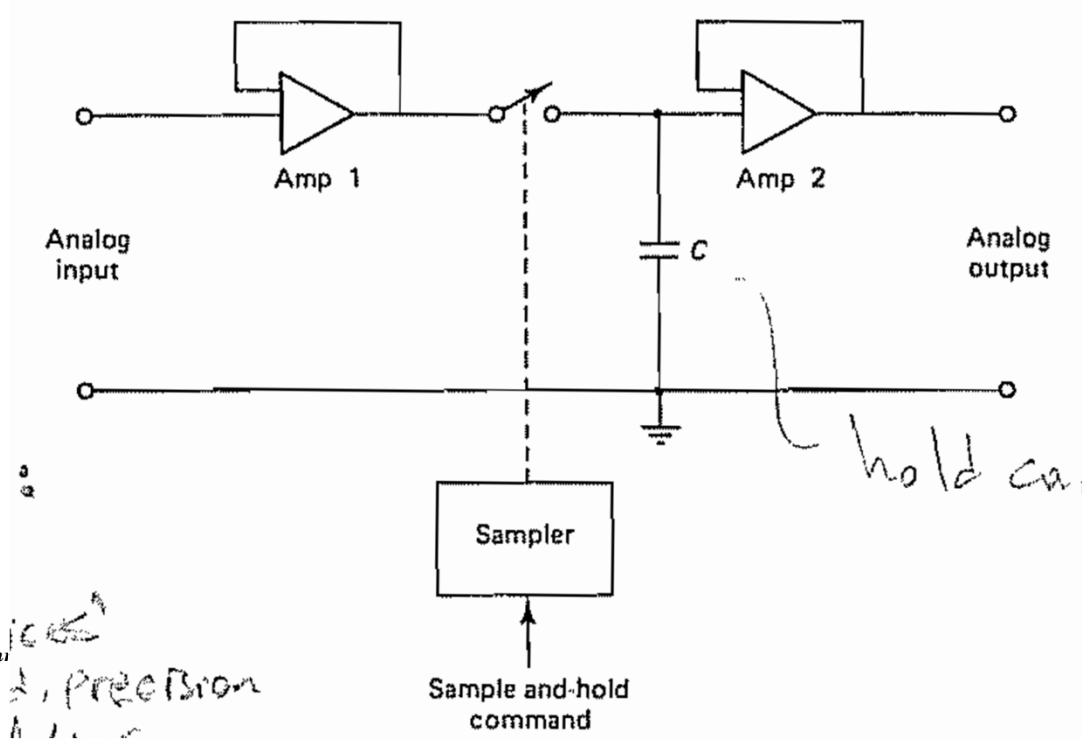
- Any A/D converter has error ranges between 0 and $\pm {}^{1}/_{2}\, Q$
- Quantization error depends on quantization level.





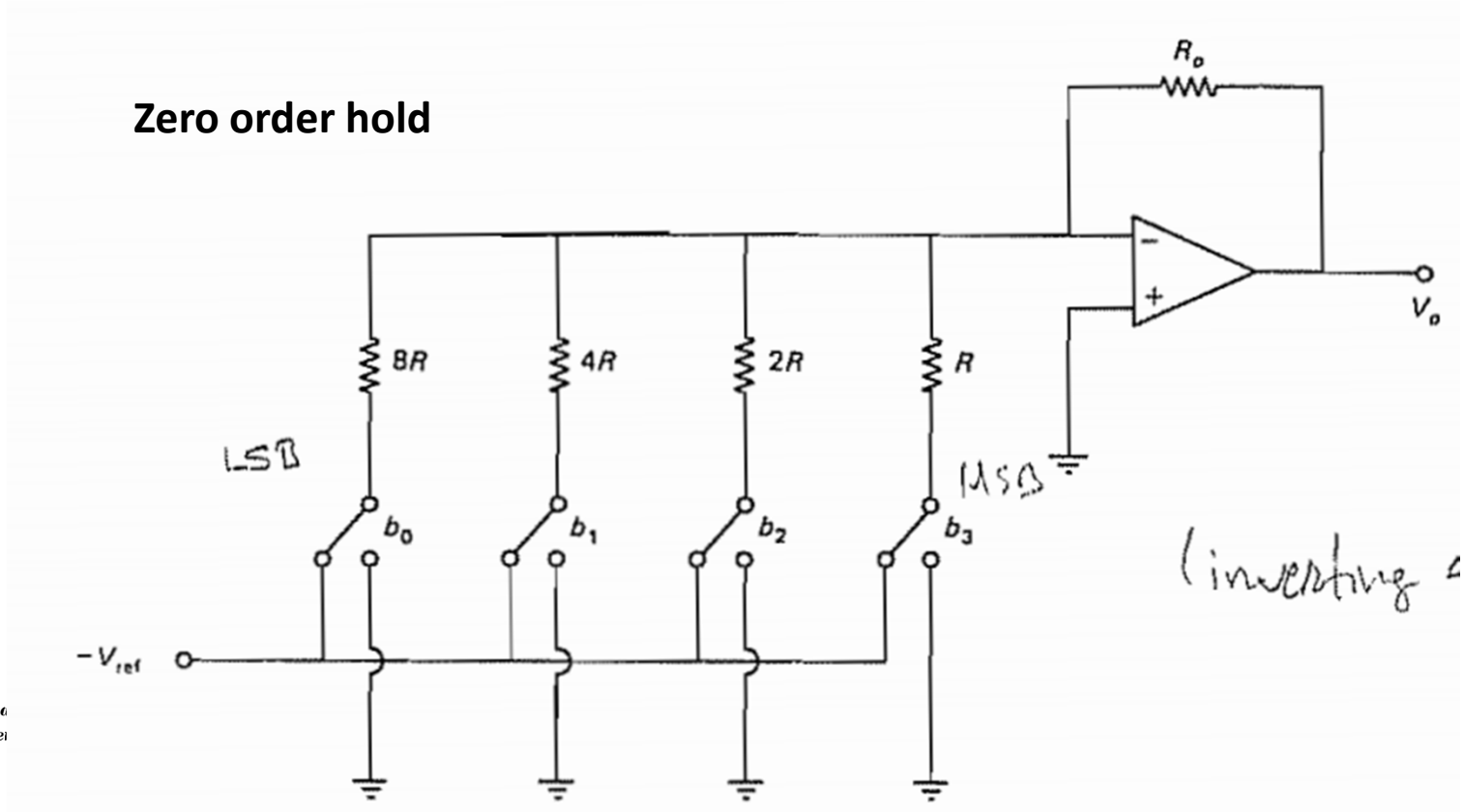
Sample and Hold (S/H)

- A sampler in a digital system converts an analog signal into a train of amplitude modulated pulses.
- The hold circuit holds the value of the sampled pulse signal over a specified period of time.



Digital to Analog converter

- At the output of the digital controller the digital signal must be converted to an analog signal by the process called digital to analog conversion.

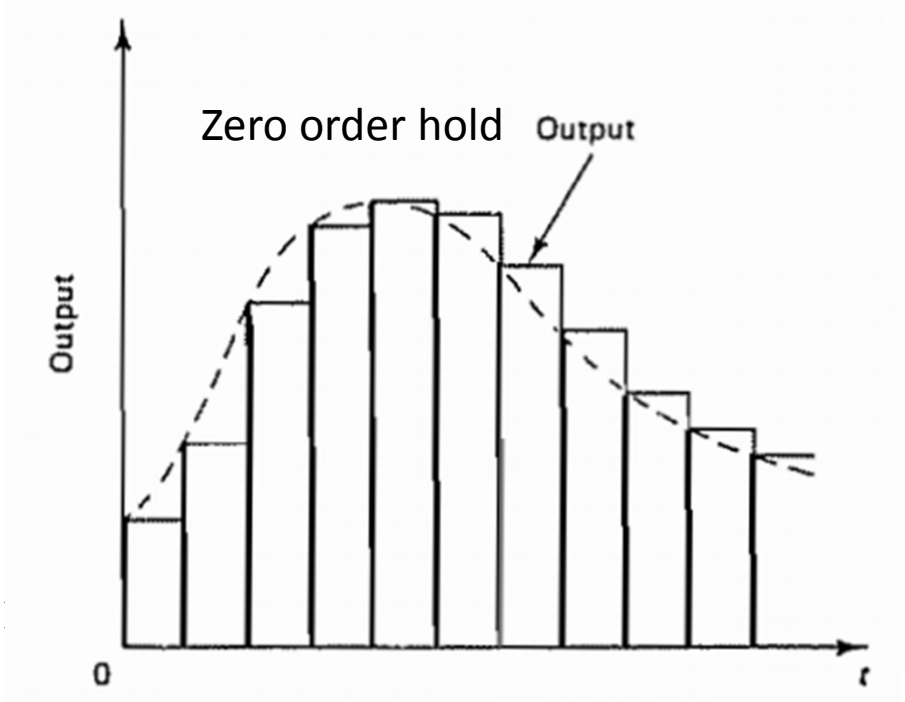


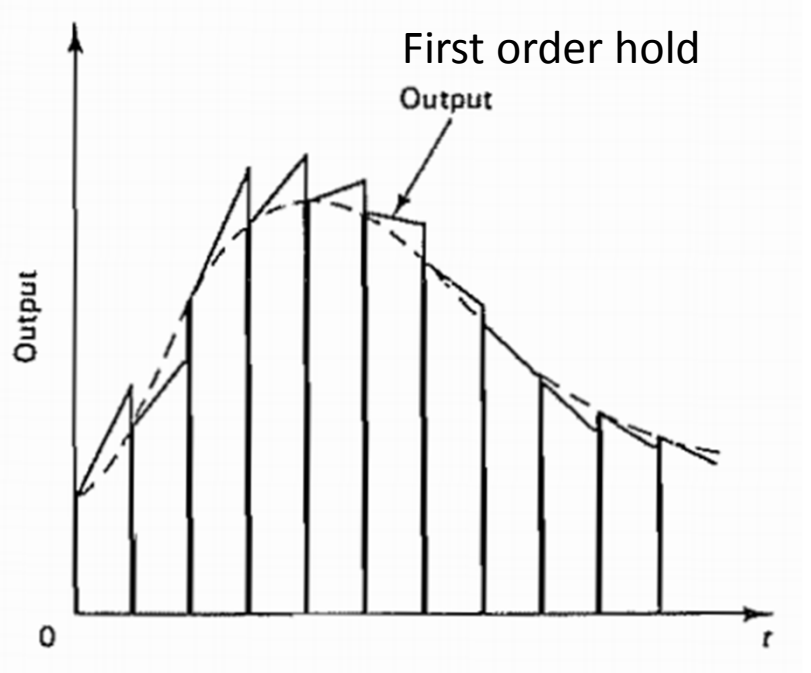
Digital to Analog converter

- The D/A converter generates the analog output voltage corresponding to the given digital voltage.

$$V_o = \frac{R_o}{R}\left(b_3 + \frac{b_2}{2} + \frac{b_1}{4} + \frac{b_0}{8}\right)V_{ref}$$

4 bit D/A converter : $b_3 b_2 b_1 b_0$, $b_i = 0 \; or \; 1$



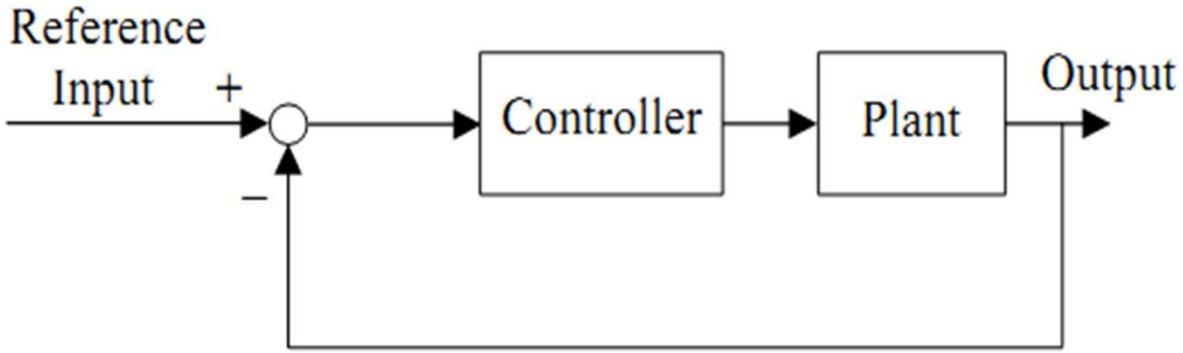


What is Digital controller?

- Digital controller is a controller that uses digital system (e.g. microcontrollers) to control a given plant.
- Controllers are required
  - ❑ To ensure satisfactory transients and steady-state behavior.
  - ❑ To guarantee satisfactory performance in the presence of disturbance and model uncertainty, most controllers in use today employ some form of negative feedback.

What is Digital controller?

A sensor is needed to measure the controlled variables and compare its behavior to a reference signal. Control action is based on an error signal defined as the difference between the reference and the actual values.



Cont.…

- The process of holding the actual value close to the reference value is referred as Regulation. A system that has good regulation in the presence of disturbance signals is said to have good disturbance rejection. A system that has good regulation regardless of plant parameters change is said to have low sensitivity to these parameters. A system that has both good disturbance rejection and low sensitivity is called Robust.

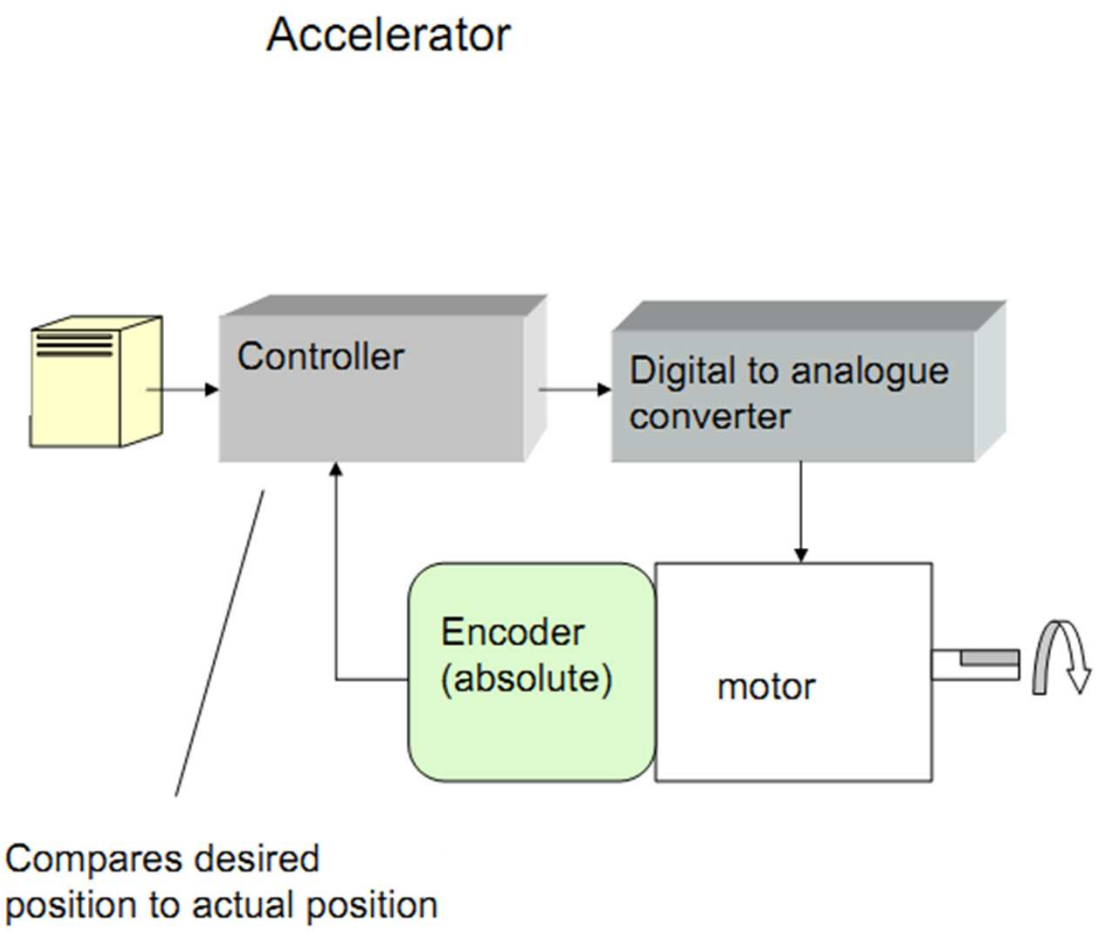
Why digital control

- **Accuracy- digital systems are accurate as compared with analog systems since digital systems can avoid noise.**
- **Implementation errors - the processing of analog signals is performed using components such as resisters and capacitors with actual values that vary significantly from the nominal design values. The errors that result from digital representation and arithmetic are negligible.**

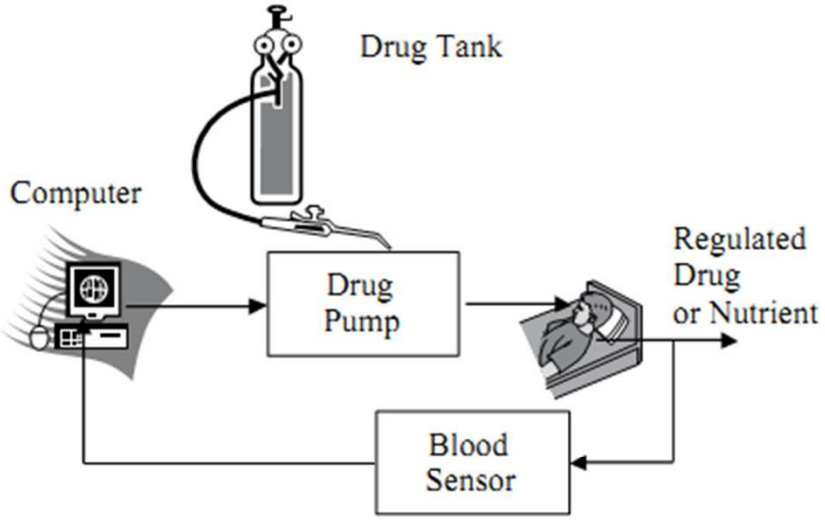
Why digital control

- **Flexibility - An analog controller is difficult to modify. A digital controller is implemented in firmware or software and its modification is possible without a complete replacement of original controller.**
- **Speed – computation speed of micro-computers/embedded system increases significantly.**
- **Cost- cost of micro-computers/embedded system decreases.**

Digital mechanical control system



Drug regulation system



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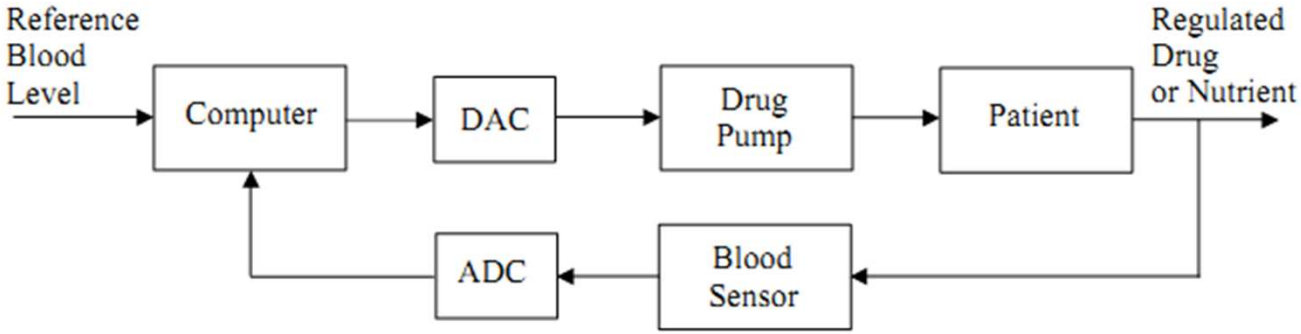
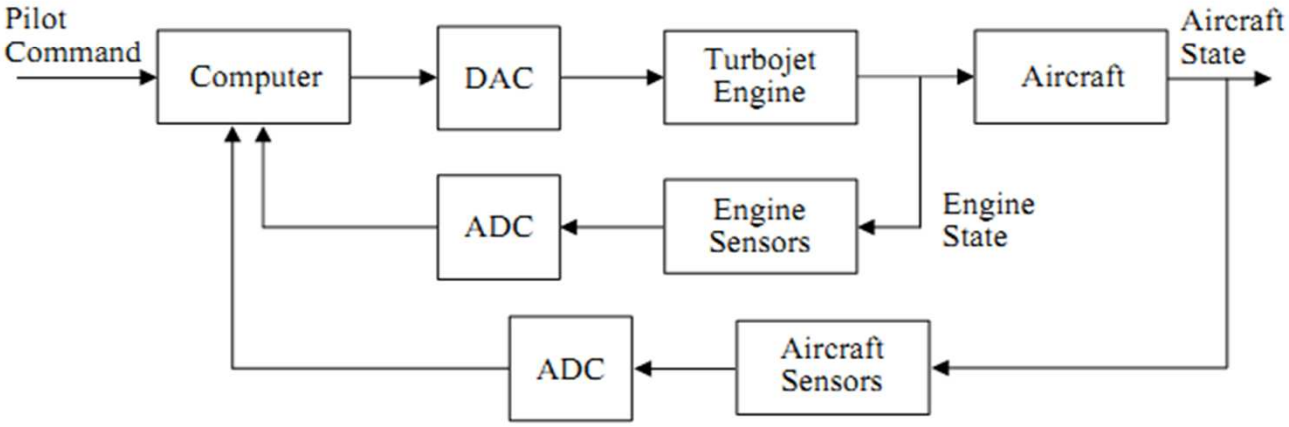


Simplified Turbo jet engine controller

(a)



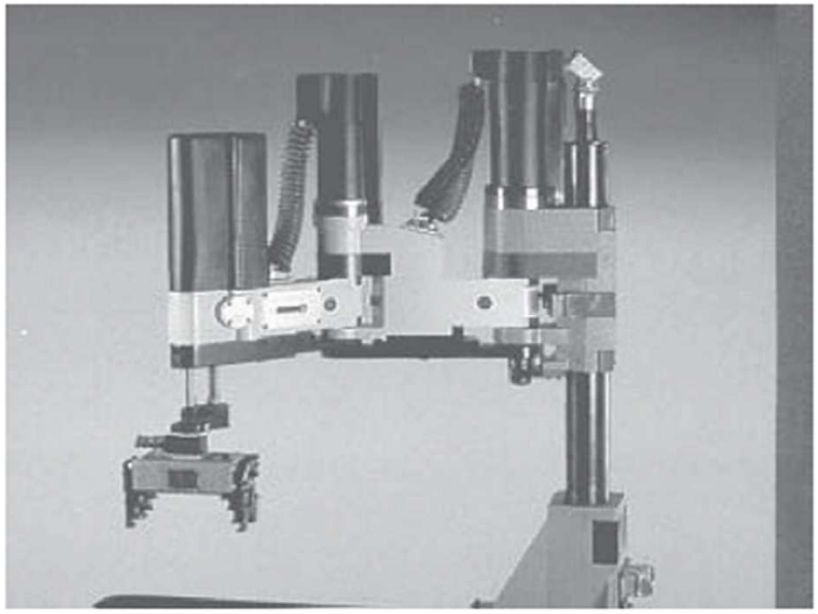
- **The control requires feedback of the engine state**

❑**Speed, temperature and pressure.**

- **Air craft state**

❑**Speed and direction**

Robotic manipulator control system



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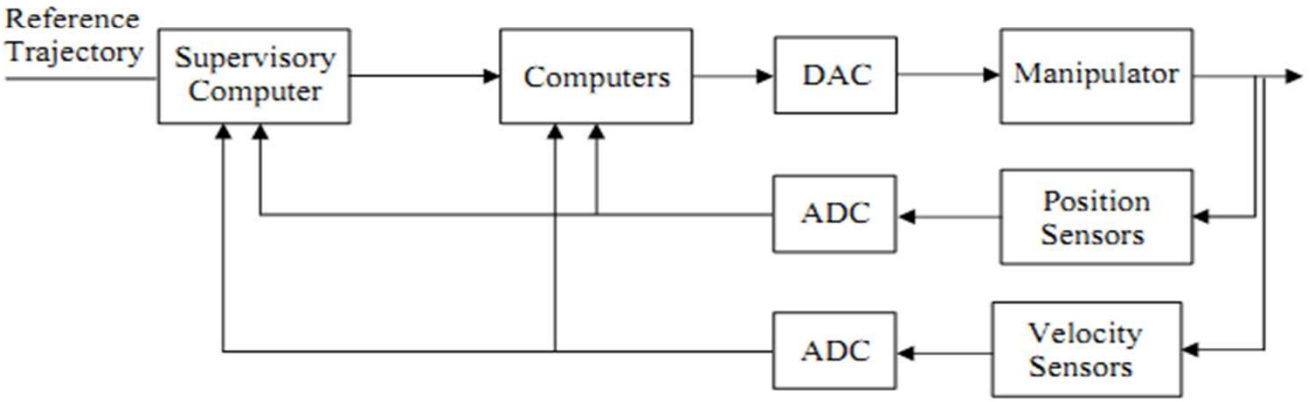

Digital PID temperature controller