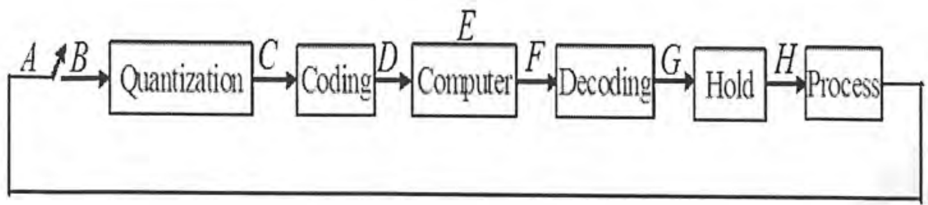
## 1.8 Types of Signals in Computer Control System(CCS)

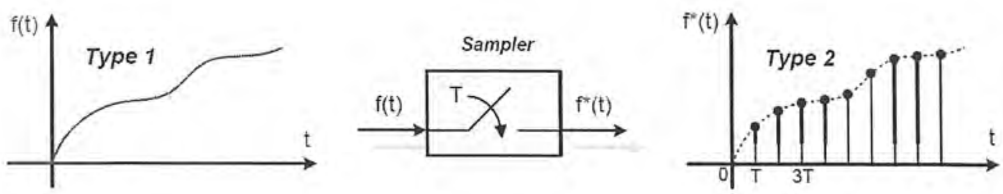



- Analog signal (continuous in time and magnitude, such as signal A, H);
- Digital signal (discrete in time and binary coding in magnitude, such as signal C, D, F, G);
- Sampled signal (discrete in time and continuous in magnitude, such as signal B)

## 1.9 Elements of I/O Interfaces

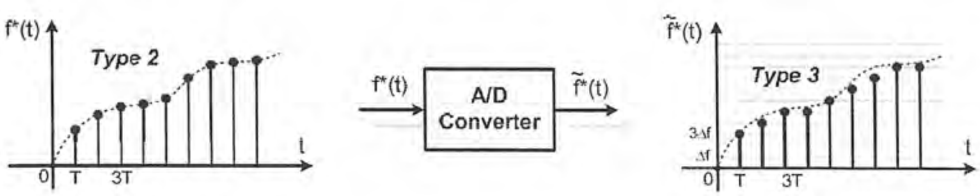
I. Sampler
II. Analog-to-Digital (A/D) Converter
III. Latch
IV. Digital-to-Analog (D/A) Converter

# I) Sampler



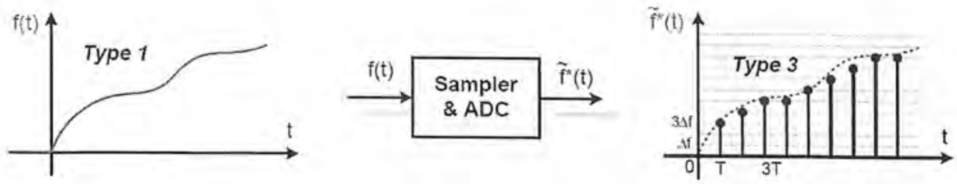

- Samples a continuous-time signal at sampling instances.
- Converts effectively an analog signal (Type 1) into a discrete-time one (Type 2).

# II) A/D Converter




- It converts a voltage level into a corresponding (binary) number representation at a particular instant of time.

# Input Interface




- In practice, sampler & ADC are considered to be a single unit:
  - Input to the unit is an analog voltage varying in time,
  - Output is binary number sequence with finite "word" length.

## Analog to Digital Conversion: Sampling

An input signal is converted from continuous-varying physical value (e.g. pressure in air, or frequency or wavelength of light), by some electro-mechanical device into a continuously varying electrical signal. This signal has a range of amplitude, and a range of frequencies that can present. This continuously varying electrical signal may then be converted to a sequence of digital values, called samples, by some analog to digital conversion circuit.

- There are two factors which determine the accuracy with which the digital sequence of values captures the original continuous signal: the maximum rate at which we sample, and the number of bits used in each sample. This latter value is known as the quantization level

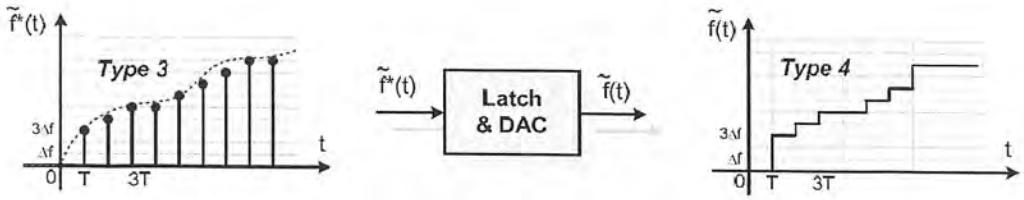
# III) Latch

- Latch holds a binary number during one sampling period.
- It is an integrated circuit which holds the input (N-bit digital) signal throughout one sampling period.
  - The output of the device remains the same during this period.

# IV) D/A Converter

- Converts an N-bit digital signal into a corresponding voltage level:
  - Complementary operation of A/D converter.
- Important properties:
  - Output Voltage Range:
    - 5V unipolar, 5V bipolar, 10V unipolar, 10V bipolar
  - Resolution (and Accuracy)
  - Conversion Time

# Output Interface




- Latch and D/A converter (DAC) are rolled into a single unit (output interface).
- Output interface oftentimes referred to as "Sample and Hold" (S/H) Unit.

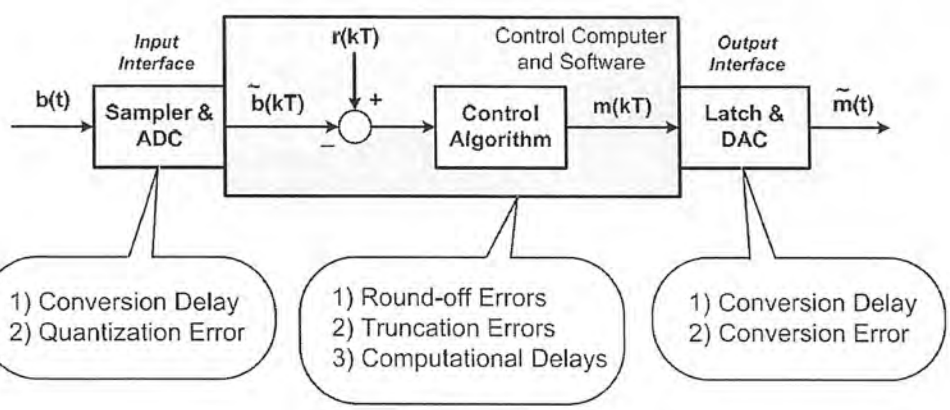
## Zero-Order Hold

- The Zero-Order Hold block samples and holds its input for the specified sample period.
- The block accepts one input and generates one output, both of which can be scalar or vector. If the input is a vector, all elements of the vector are held for the same sample period.
- This device provides a mechanism for discretizing one or more signals in time, or resampling the signal at a different rate.
- The sample rate of the Zero-Order Hold must be set to that of the slower block. For slow-to-fast transitions, use the unit delay block.

# Why Use Digital Control ?

- Often Cheaper
- Usually Smaller/lighter
- Usually needs Less power
- Often More precise
- Can Re-program
- Can use same component (with different programming) ➔ Generallity

## 1.10 Errors in Digital Control Systems



# Chapter 2

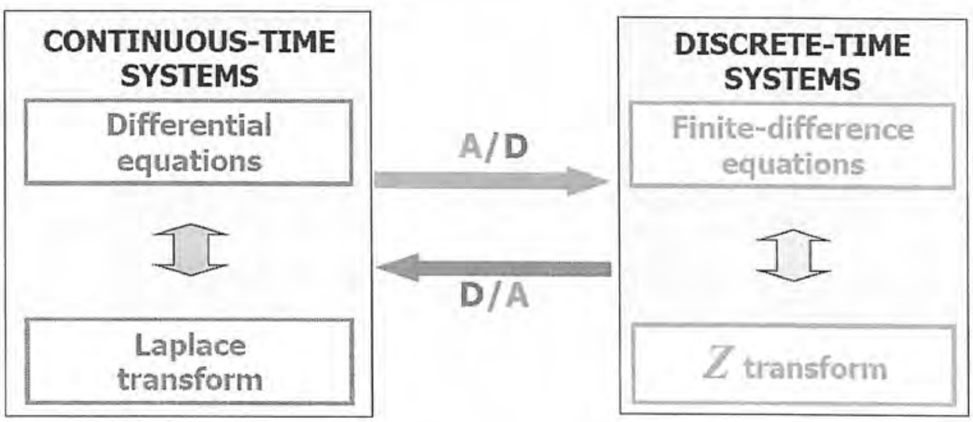
## 2-1 Modeling Issues

- Discrete-time:
  - *Constant Coefficient Difference Equations* (CCDEs) are used to model the systems.
  - No information on discrete variables is available between sampling instances.
  - Magnitudes of digital signals are quantized.
- Continuous-time:
  - *Ordinary Differential Equations* (ODEs) are used.
  - Time and every physical quantity are continuous.
  - Magnitudes are usually not quantized.

### Description of sampled data systems

$3\ddot{y}(t)+2\dot{y}(t)+y(t)=5\dot{x}(t)+x(t)$

$2y_{k-2}+5y_{k-1}+y_k=x_k$




$3s^2Y(s)+2sY(s)+Y(s)=5sX(s)+X(s)$

$$G(s)=\frac{Y(s)}{X(s)}=\frac{5s+1}{3s^2+2s+1}$$

$2z^{-2}Y(z)+5z^{-1}Y(z)+Y(z)=X(z)$

$$G(z)=\frac{Y(z)}{X(z)}=\frac{1}{2z^{-2}+5z^{-1}+1}$$

# Constant Coefficient Difference Equations

All relationships in discrete-time domain can be expressed in terms of finite difference equations:

$$y(k) = -\sum_{i=1}^{N} a_i y(k-i) + \sum_{j=0}^{M} b_j x(k-j) \quad (N \geq M)$$

For convenience, let us define a *unit delay operator* $q^{-1}$:

$$y(k-1) = q^{-1}y(k) \qquad\qquad y(k+1) = q\ y(k)$$
$$y(k-2) = q^{-2}y(k) \qquad \text{OR} \qquad y(k+2) = q^{2}y(k)$$
$$\vdots \qquad\qquad\qquad\qquad \vdots$$
$$y(k-N) = q^{-N}y(k) \qquad\qquad y(k+N) = q^{N}y(k)$$

In digital control literature, this operator $q^{-1}$ is also known as *backward time-shift operator*.

Let :-

In our literature $q^{-1} = z^{-1}$

Hence, the CCDE becomes

$$y(k) = -\sum_{i=1}^{N} a_i q^{-i} y(k) + \sum_{j=0}^{M} b_j q^{-j} x(k)$$

The relationship between input x(k) and the output y(k) boils down to the ratio of two polynomials $A(q^{-1})$ and $B(q^{-1})$:

$$\frac{y(k)}{x(k)} = \frac{b_0 + b_1 q^{-1} + \ldots + b_M q^{-M}}{1 + a_1 q^{-1} + \ldots + a_N q^{-N}} = \frac{B(q^{-1})}{A(q^{-1})}$$

where $a_1, .., a_N, b_0, b_1, \ldots, b_N \in \Re$ (Real numbers).