Omdurman Islamic University

Faculty of Engineering

Electrical & Electronic Engineering
(4th year)

Signal Processing and Systems

Lecturer
FAWAZ FATHI

Module 1

Introduction to signals and systems

Course Description (Part 1)

- Module 1: Introduction to signals and systems.
- Module 2: Continuous-Time (CT) Signals and Systems
- Module 3: Continuous-Time Linear Time-Invariant (LTI) Systems
- Module 4: Continuous-Time Fourier Series (CTFS)
- Module 5: Continuous-Time Fourier Transform (CTFT)
- Module 6: Laplace Transform (LT)

Course Description (Part2)

- Module 1: Introduction to Digital signal Processing.
- Module 2: Analogue to Digital conversion, Sampling, Quantization
- Module 3-1: Digital signal and systems .
- Module 3-2: LTI systems described by difference equations.
- Module 4-1: Discrete Time Fourier Transform.
- Module 4-2: Fast Fourier Transforms (FFT).

Course Description (Part2)

- Module 5: Z Transform
- Module 6: Basic Filtering Types
- Module 7: FIR Filters design, implementation.
- Module 8: IIR Filters design, implementation.

Part 1

Introduction to signals and systems

Introduction

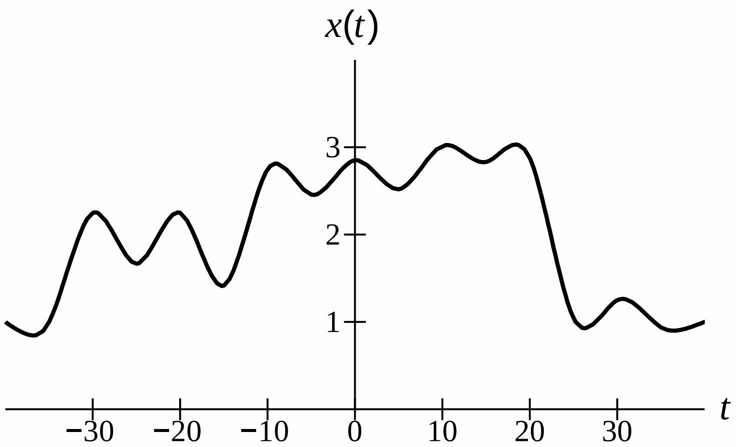
Signals

- A signal is a function of one or more variables that conveys information about some (usually physical) phenomenon.
- For a function f, in the expression $f(t_1, t_2, \ldots, t_n)$, each of the $\{t_k\}$ is called an independent variable, while the function value itself is referred to as a dependent variable.
- Some examples of signals include:
  - a voltage or current in an electronic circuit
  - the position, velocity, or acceleration of an object
  - a force or torque in a mechanical system
  - a flow rate of a liquid or gas in a chemical process
  - a digital image, digital video, or digital audio
  - a stock market index

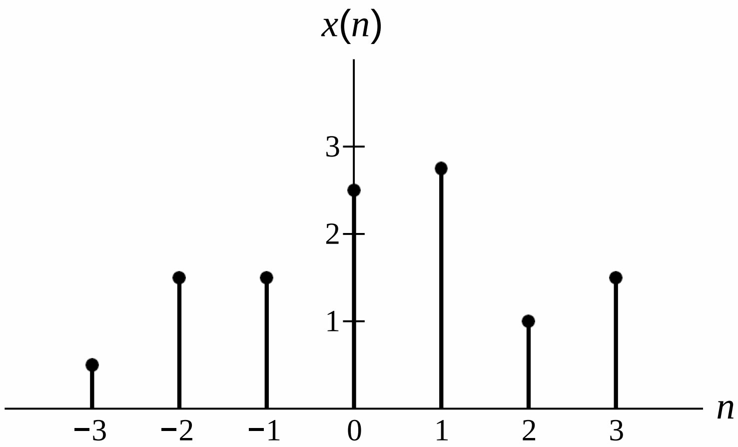
Classification of Signals

- Number of independent variables (i.e., dimensionality):
  - A signal with *one* independent variable is said to be one dimensional (e.g., audio).
  - A signal with *more than one* independent variable is said to be multi-dimensional (e.g., image).
- Continuous or discrete independent variables:
  - A signal with *continuous* independent variables is said to be continuous time (CT) (e.g., voltage waveform).
  - A signal with *discrete* independent variables is said to be discrete time (DT) (e.g., stock market index).
- Continuous or discrete dependent variable:
  - A signal with a *continuous* dependent variable is said to be continuous valued (e.g., voltage waveform).
  - A signal with a *discrete* dependent variable is said to be discrete valued (e.g., digital image).
- A *continuous-valued CT* signal is said to be analog (e.g., voltage waveform).
- A *discrete-valued DT* signal is said to be digital (e.g., digital audio).

Graphical Representation of Signals

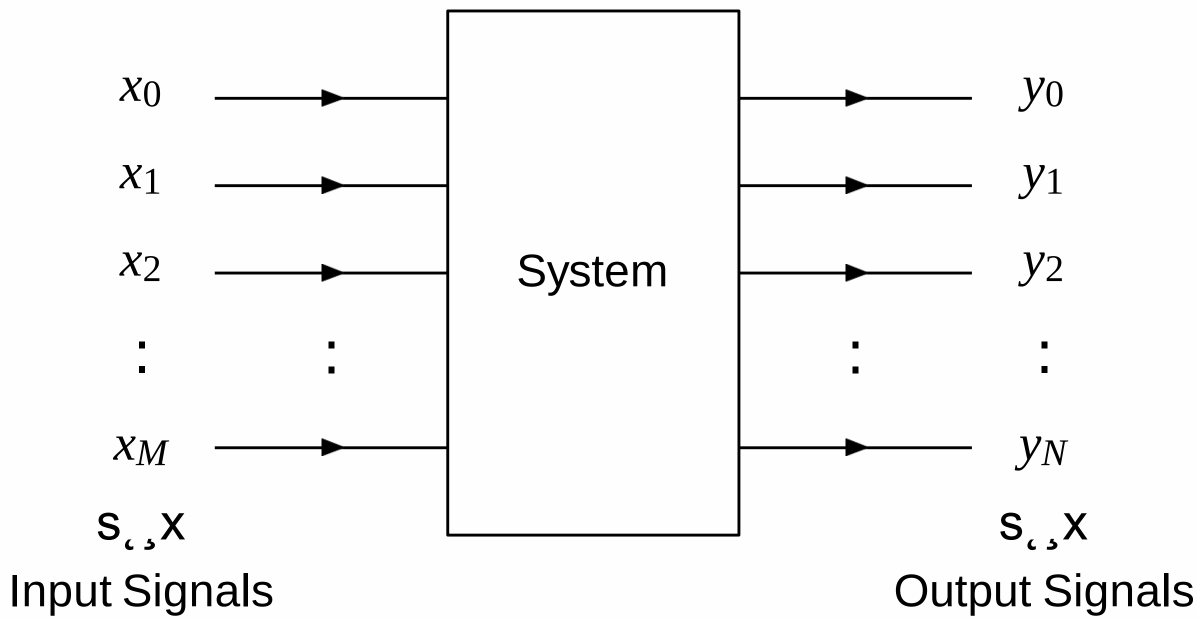


Continuous-Time (CT) Signal



Discrete-Time (DT) Signal

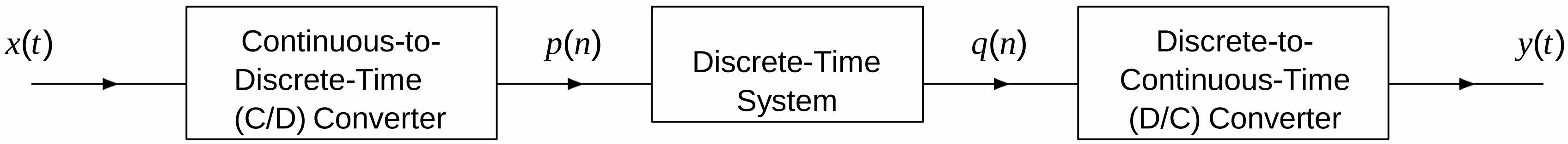
- A system is an entity that processes one or more input signals in order to produce one or more output signals.



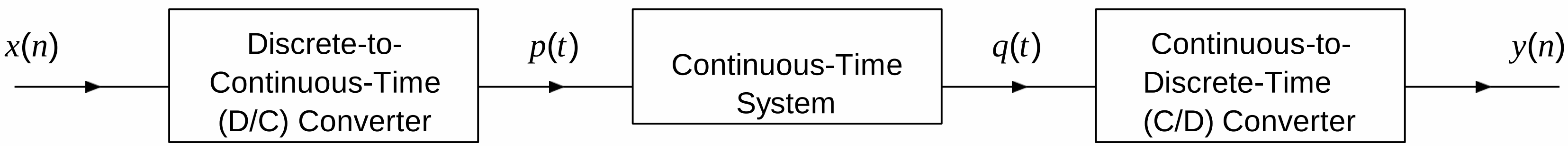
Classification of Systems

- Number of inputs:
  - A system with *one* input is said to be single input (SI).
  - A system with *more than one* input is said to be multiple input (MI).
- Number of outputs:
  - A system with *one* output is said to be single output (SO).
  - A system with *more than one* output is said to be multiple output (MO).
- Types of signals processed:
  - A system can be classified in terms of the *types of signals* that it processes.
  - Consequently, terms such as the following (which describe signals) can also be used to describe systems:
    - one-dimensional and multi-dimensional,
    - continuous-time (CT) and discrete-time (DT), and
    - analog and digital.
  - For example, a continuous-time (CT) system processes CT signals and a discrete-time (DT) system processes DT signals.

Signal Processing Systems

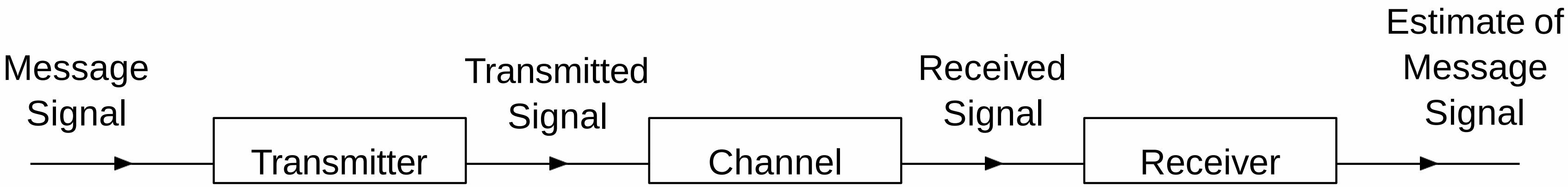


Processing a Continuous-Time Signal With a Discrete-Time System

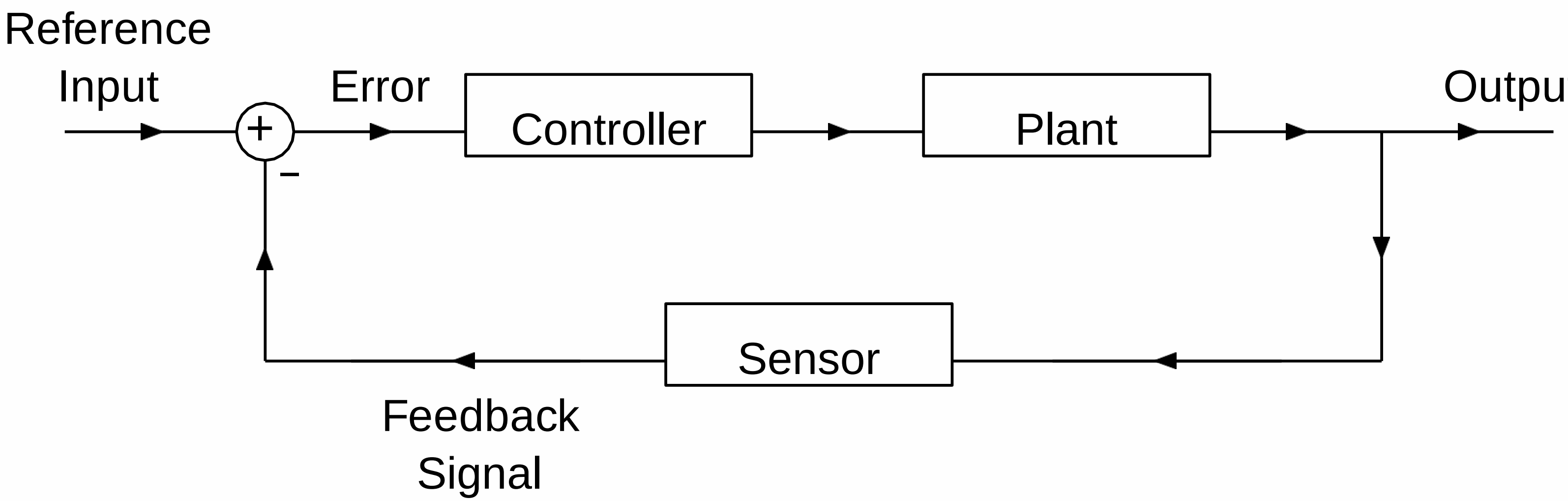


Processing a Discrete-Time Signal With a Continuous-Time System

Communication Systems



General Structure of a Communication System



General Structure of a Feedback Control System

Why Study Signals and Systems?

- Engineers build systems that process/manipulate signals.
- We need a formal mathematical framework for the study of such systems.
- Such a framework is necessary in order to ensure that a system will meet the required specifications (e.g., performance and safety).
- If a system fails to meet the required specifications or fails to work altogether, negative consequences usually ensue.
- When a system fails to operate as expected, the consequences can sometimes be catastrophic.

Section 1.1

Signals

Signals

- Earlier, we were introduced to CT and DT signals.
- A CT signal is called a function.
- A DT signal is called a sequence.
- Although, strictly speaking, a sequence is a special case of a function (where the domain of the function is the integers), we will use the term function exclusively to mean a function that is not a sequence.
- The nth element of a sequence x is denoted as either $x(n)$ or x_n.

Notation: Functions Versus Function Values

- Strictly speaking, an expression like "$f(t)$" means the *value* of the function f evaluated at the point t.
- Unfortunately, engineers often use an expression like "$f(t)$" to refer to the *function* f (rather than the value of f evaluated at the point t), and this sloppy notation can lead to problems (e.g., ambiguity) in some situations.
- In contexts where sloppy notation may lead to problems, one should be careful to clearly distinguish between a function and its value.
- Example (meaning of notation):
  - Let f and g denote real-valued functions of a real variable.
  - Let t denote an arbitrary real number.
  - Let $\mathcal{H}$ denote a system operator (which maps a function to a function).
  - The quantity $f+g$ is a *function*, namely, the function formed by adding the functions f and g.
  - The quantity $f(t)+g(t)$ is a *number*, namely, the sum of: the value of the function f evaluated at t; and the value of the function g evaluated at t.
  - The quantity $\mathcal{H}x$ is a *function*, namely, the output produced by the system represented by $\mathcal{H}$ when the input to the system is the function x.
  - The quantity $\mathcal{H}x(t)$ is a *number*, namely, the value of the function $\mathcal{H}x$ evaluated at t.

Section
1.2

Properties of Signals

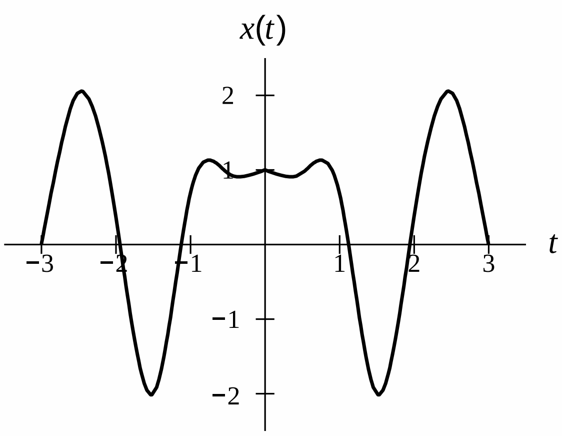
- A function x is said to be even if it satisfies

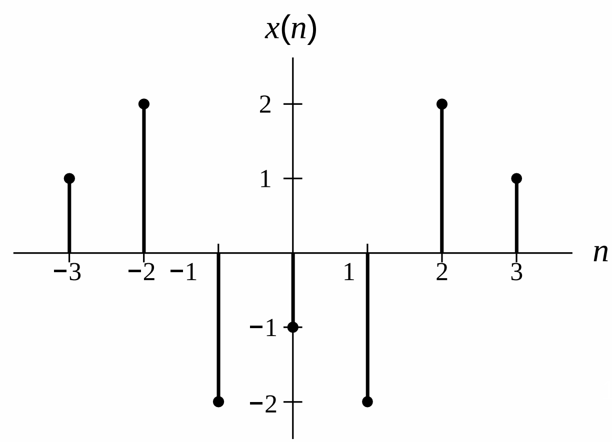
$$x(t) = x(-t) \qquad \text{for all } t.$$

- A sequence x is said to be even if it satisfies

$$x(n) = x(-n) \qquad \text{for all } n.$$

- Geometrically, the graph of an even signal is *symmetric* about the origin.
- Some examples of even signals are shown below.





Odd Signals

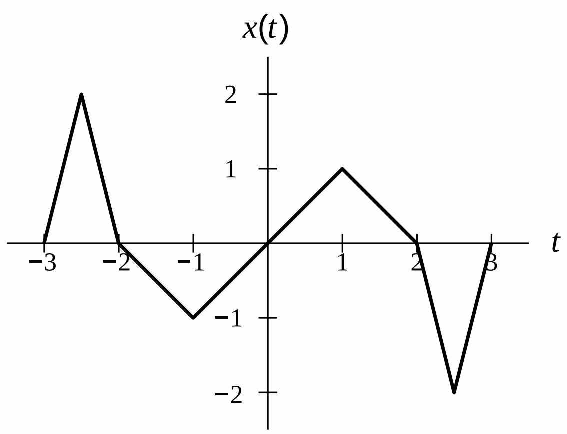
- A function x is said to be odd if it satisfies

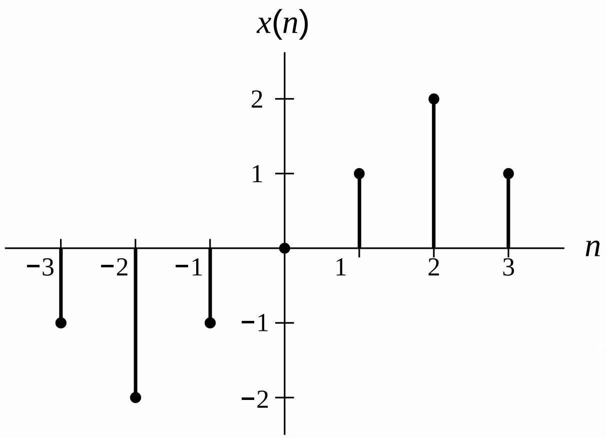
$$x(t) = -x(-t) \qquad \text{for all } t.$$

- A sequence x is said to be odd if it satisfies

$$x(n) = -x(-n) \qquad \text{for all } n.$$

- Geometrically, the graph of an odd signal is *antisymmetric* about the origin.
- An odd signal x must be such that $x(0) = 0$.
- Some examples of odd signals are shown below.





Periodic Signals

- A function x is said to be periodic with period T (or T-periodic) if, for some strictly-positive real constant T, the following condition holds:

$$x(t) = x(t+T) \qquad \text{for all } t.$$

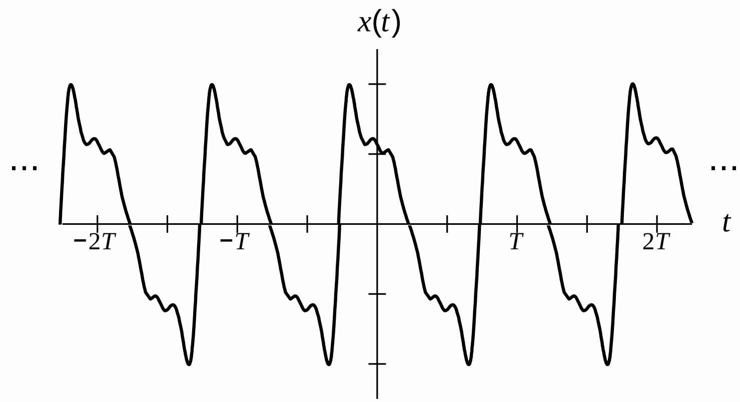
- A T-periodic function x is said to have frequency $\frac{1}{T}$ and angular frequency $\frac{2\pi}{T}$.
- A sequence x is said to be periodic with period N (or N-periodic) if, for some strictly-positive integer constant N, the following condition holds:

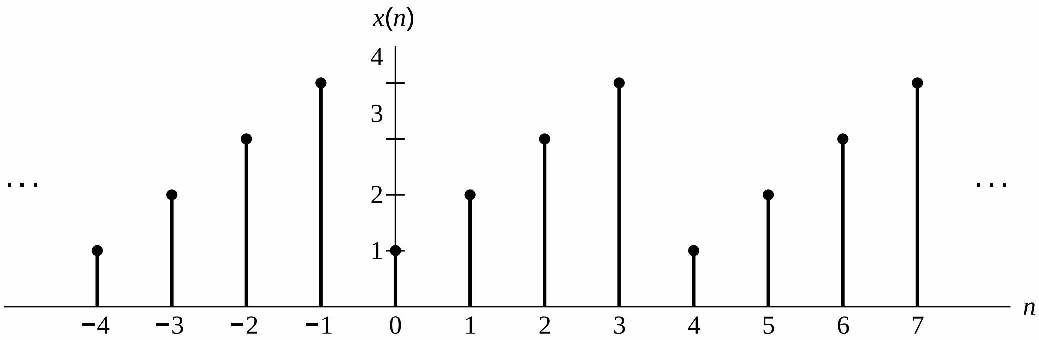
$$x(n) = x(n+N) \qquad \text{for all } n.$$

- An N-periodic sequence x is said to have frequency $\frac{1}{N}$ and angular frequency $\frac{2\pi}{N}$.
- A function/sequence that is not periodic is said to be aperiodic.

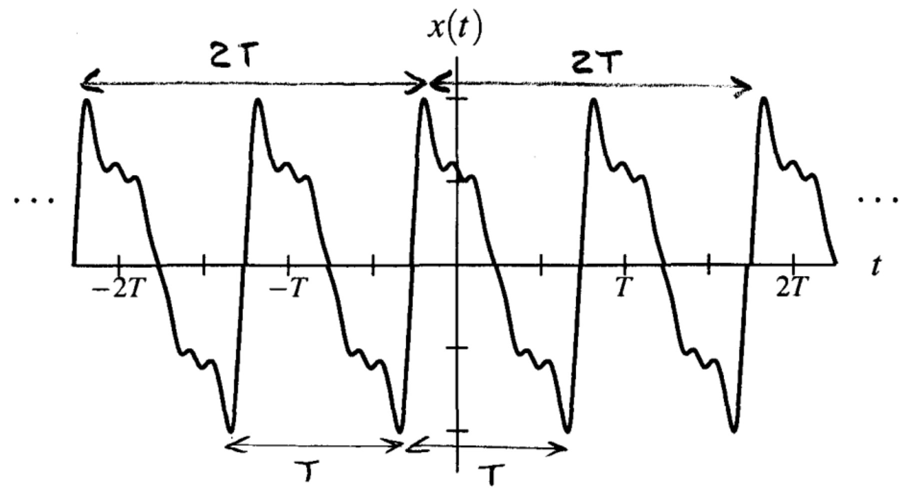
Periodic Signals (Continued 1)

- Some examples of periodic signals are shown below.





- The period of a periodic signal is *not unique*. That is, a signal that is periodic with period T is also periodic with period kT, for every (strictly) positive integer k.



- The smallest period with which a signal is periodic is called the fundamental period and its corresponding frequency is called the fundamental frequency.