AL FURAT AL AWSAT TECHNICAL UNIVERSITY

NAJAF COLLEGE OF TECHNOLOGY

DEPARTMENT OF TECHNICAL COMMUNICATIONS ENGINEERING

DIGITAL SIGNAL PROCESSING

3rd YEAR

Academic Responsible

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Basic Concepts of Digital Signal Processing

Digital signal processing (DSP) technology and its advancements have dramatically impacted our modern society everywhere. Without DSP, we would not have digital/Internet audio or video; digital recording; CD, DVD, and MP3 players; digital cameras; digital and cellular telephones; digital satellite and TV; or wire and wireless networks. Medical instruments would be less efficient or unable to provide useful information for precise diagnoses if there were no digital electrocardiography (ECG) analyzers or digital x-rays and medical image systems. We would also live in many less efficient ways, since we would not be equipped with voice recognition systems, speech synthesis systems, and image and video editing systems. Without DSP, scientists, engineers, and technologists would have no powerful tools to analyze and visualize data and perform their design, and so on.

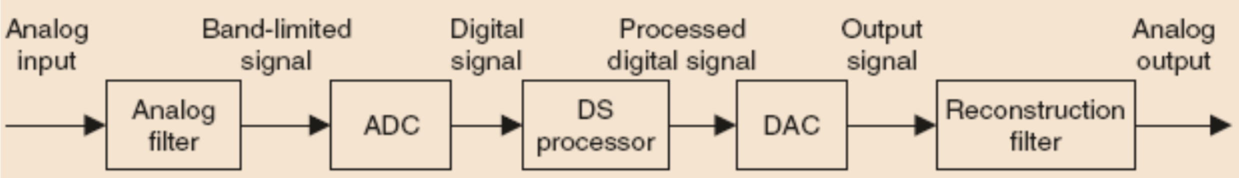


FIGURE 1.1 **A digital signal processing scheme.**

The concept of DSP is illustrated by the simplified block diagram in Fig. (1.1), which consists of an analog filter, an analog-to-digital conversion (ADC) unit, a digital signal (DS) processor, a digital-to-analog conversion (DAC) unit, and a reconstruction (anti-image) filter.

As shown in the diagram, the analog input signal, which is continuous in time and amplitude, is generally encountered in our real life. Examples of such analog signals include current, voltage, temperature, pressure, and light intensity.

Usually a transducer (sensor) is used to convert the non-electrical signal to the analog electrical signal (voltage). This analog signal is fed to an analog filter, which is applied to limit the frequency range of analog signals prior to the sampling process. The purpose of filtering is to significantly attenuate aliasing distortion. The band-limited signal at the output of the analog filter is then sampled and converted via the ADC unit into the digital signal, which is discrete both in time and in amplitude.

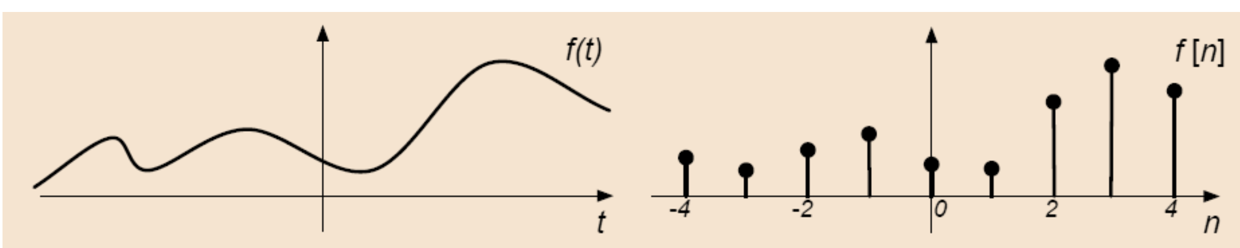
The DS processor then accepts the digital signal and processes the digital data according to DSP rules such as lowpass, highpass, and bandpass digital filtering, or other algorithms for different applications. Notice that the DS processor unit is a special type of digital computer and can be a general-purpose digital computer, a microprocessor, or an advanced microcontroller; furthermore, DSP rules can be implemented using software in general.

With the DS processor and corresponding software, a processed digital output signal is generated. This signal behaves in a manner according to the specific algorithm used.

The DAC unit converts the processed digital signal to an analog output signal. The signal is continuous in time and discrete in amplitude (usually a sample-and-hold signal). The final block in Fig (1.1) is designated as a function to smooth the DAC output voltage levels back to the analog signal via a reconstruction (anti-image) filter for real-world applications.

Continuous and Discrete Time Signals

- Most of the signals we will talk about are functions of time.
- There are many ways to classify signals. This class is organized according to whether the signals are continuous in time, or discrete.
- A continuous-time signal has values for all points in time in some (possibly infinite) interval.
- A discrete time signal has values for only discrete points in time.
- Signals can also be a function of space (images) or of space and time (video), and may be continuous or discrete in each dimension.



What is a signal?

The concept of signal refers to the time, space or other types of variations in the physical state of an object, phenomenon, entity etc. The quantification of this state is used to represent, store or transmit a message. The course is not about the message but about the properties of the signal.

Examples and mathematical representation

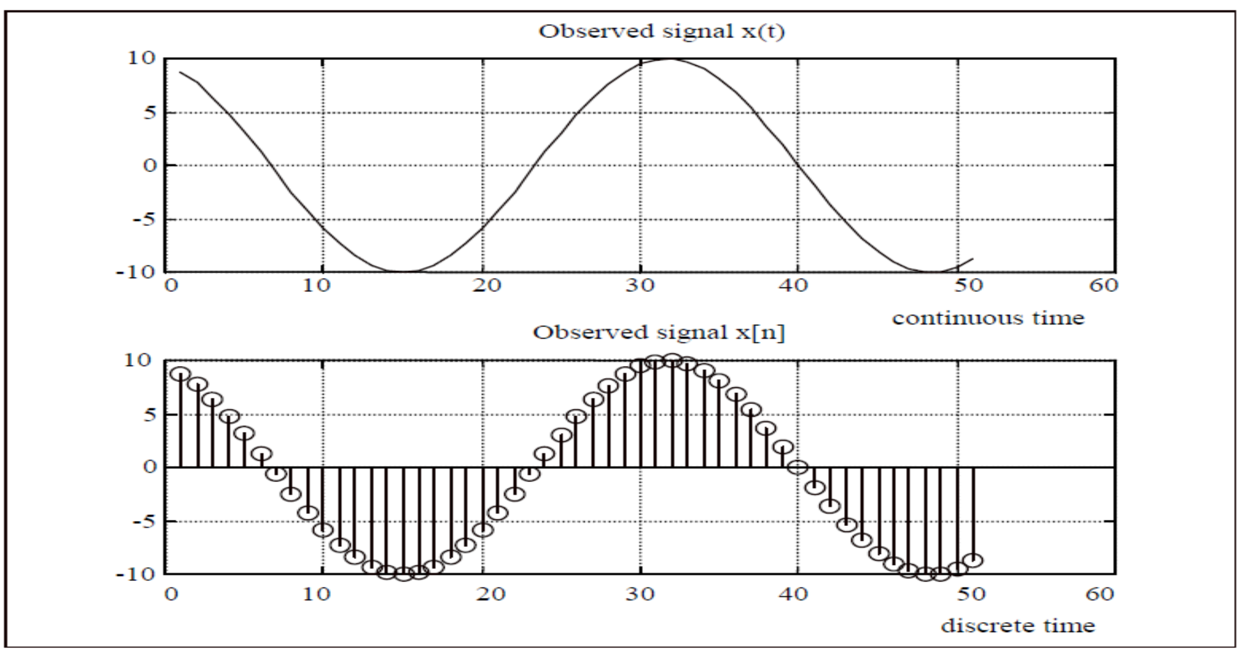
Signals are met in diverse fields, such as:

Elec. Eng.	e.g. voltages/currents in a circuit
	speech signals
	image signals
Physics	e.g. radiation
Mech. Eng.	e.g. vibration studies
Astronomy	e.g. (2-D) pulsars, distant stars
Biomedicine	e.g. EEG, ECG, retinoscopy, MRI

Signals are represented mathematically as functions of one or more independent variables. In this course we focus our attention on signals involving a single independent variable. For convenience, we will usually refer to this variable as time.

We will be considering two basic types of signals.

- Continuous-time signals. In this case the independent variable is continuous, i.e., these signals are defined for a continuum of values of the independent variable.
- Discrete-time signals. In this case the independent variable takes a discrete set of values,



i.e., these signals are defined only at discrete times.

In the figure above you can see a continuous and a discrete sine wave described by the following equations, respectively.

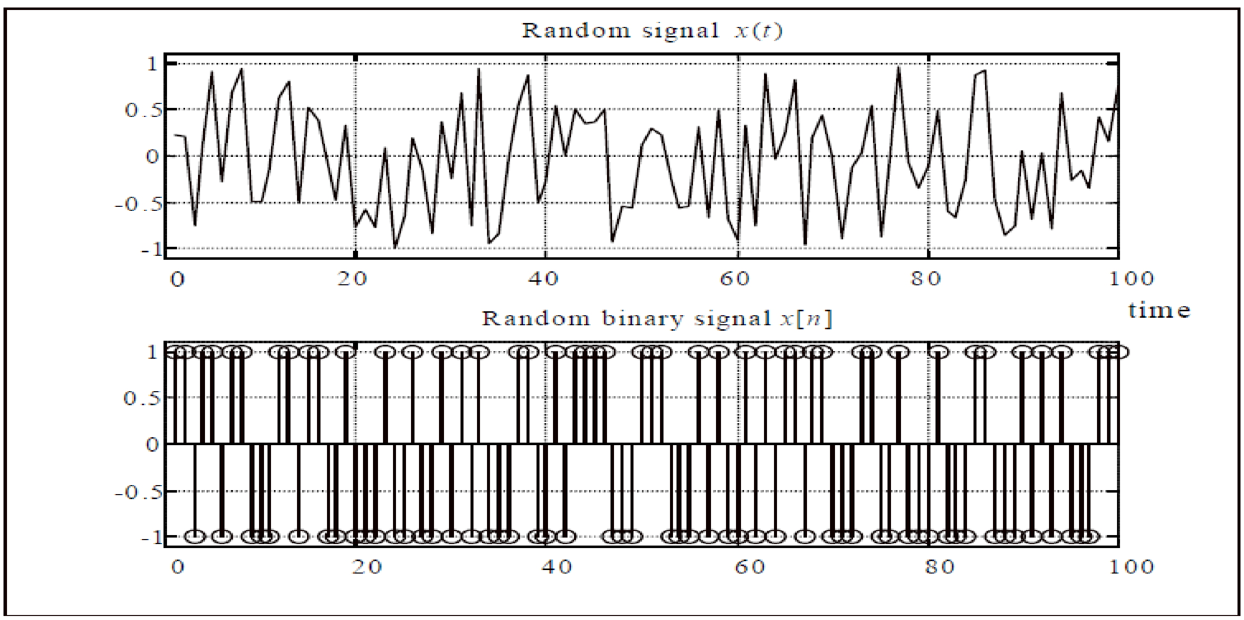
- Continuous case: $x(t) = A\cos(\omega_0 t + \varphi)$
- Discrete case: $x[n] = A\cos(\theta_0 n + \psi)$

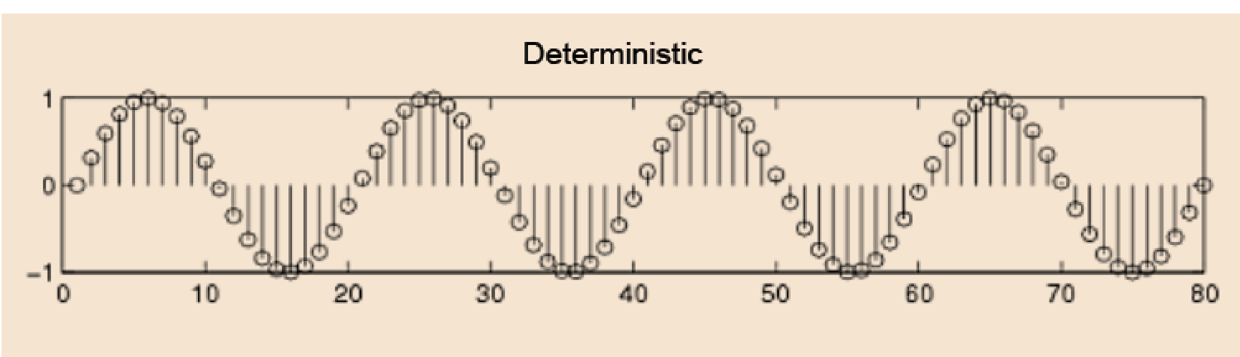
Fundamental classes of signals

1- Deterministic and random signals

The following classification can be made in real life signals.

- If the value of a signal at some specific time is determined exactly by its model then we have a deterministic signal.
- If the value of the signal cannot be determined but only some statistical properties of it, e.g., probability of occurrence of a certain value at some specific time, then we have a random or stochastic signal.

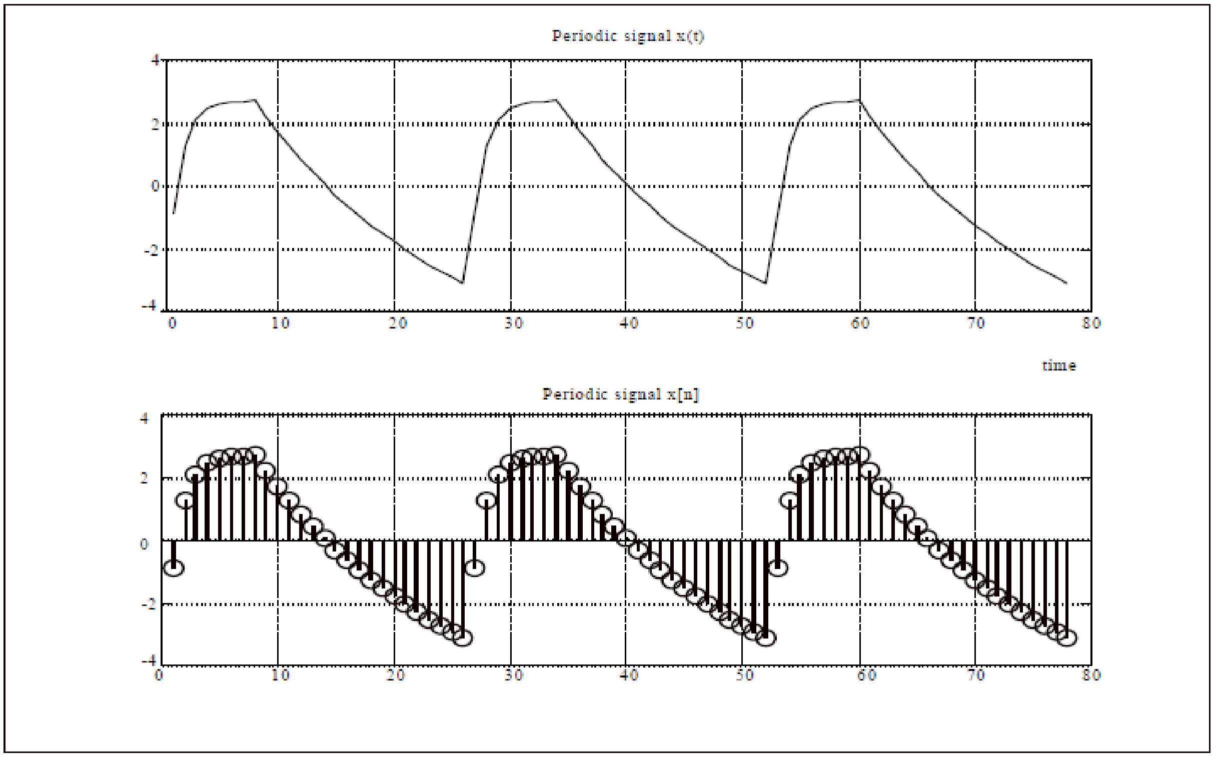


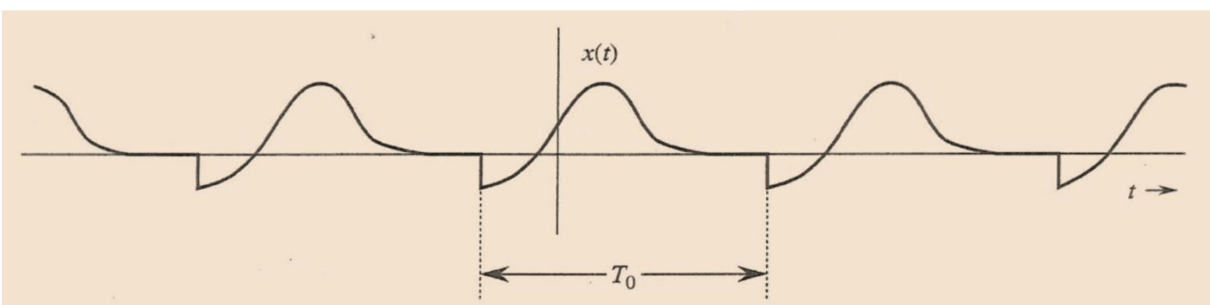


2- Periodic and non-periodic signals

The following classification can be made.

- For a continuous signal, if we can find a number T_0 such that $x(t + T_0) = x(t)$ for all t, then the signal is periodic. In the case of a discrete signal we have $x[n + N_0] = x[n]$ for all n.
- If there are no such numbers T_0 or N_0 the signal is non-periodic.

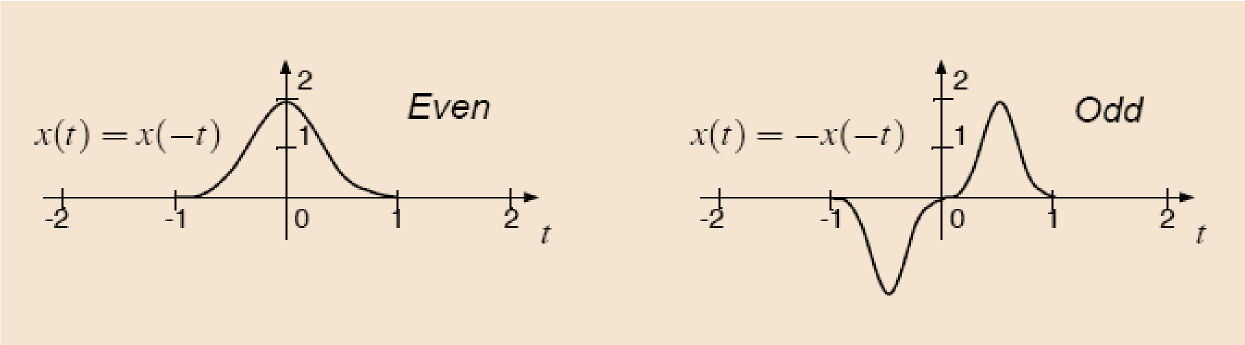




3- Even and odd signals

The following states can be made

- For a continuous signal, if ***x(-t) = x(t)*** for all **t**, then the signal is even. In the case of a discrete signal we have ***x[-n] = x[n]*** for all **n**.
- For a continuous signal, if ***x(t) = -x(-t)*** for all **t**, then the signal is odd. In the case of a discrete signal we have ***x[n] = -x[-n]*** for all **n** . An odd signal is 0 at t = 0 or n = 0, since $x(0) = -x(0) \Rightarrow x(0) = 0$.



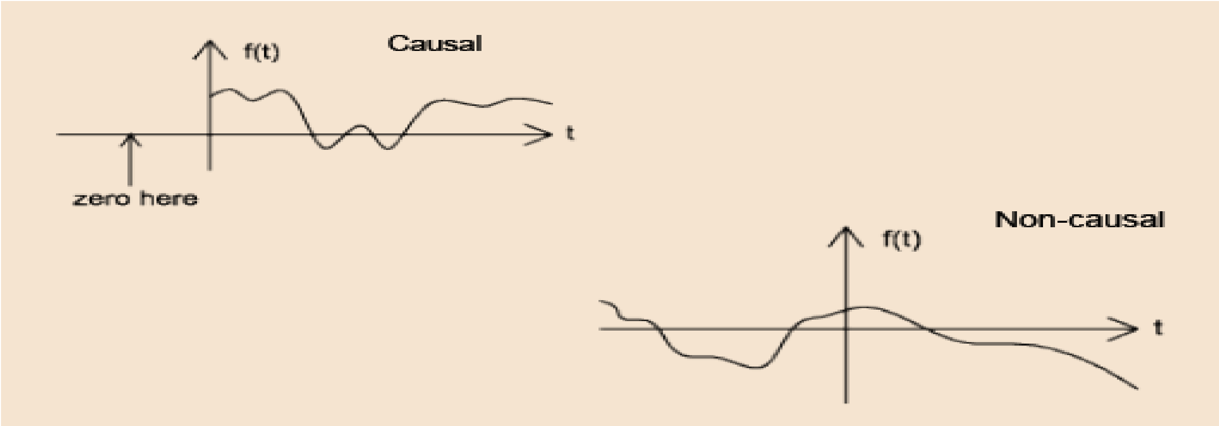
Any signal can be broken into a sum of two signals, one of which is even and one of which is odd. This is because

$$x(t) = x(t) + \frac{1}{2}x(-t) - \frac{1}{2}x(-t) = \frac{1}{2}x(t) + \frac{1}{2}x(t) + \frac{1}{2}x(-t) - \frac{1}{2}x(-t) =$$
$$= \frac{1}{2}x(t) + \frac{1}{2}x(-t) + \frac{1}{2}x(t) - \frac{1}{2}x(-t) = \frac{1}{2}[x(t) + x(-t)] + \frac{1}{2}[x(t) - x(-t)]$$

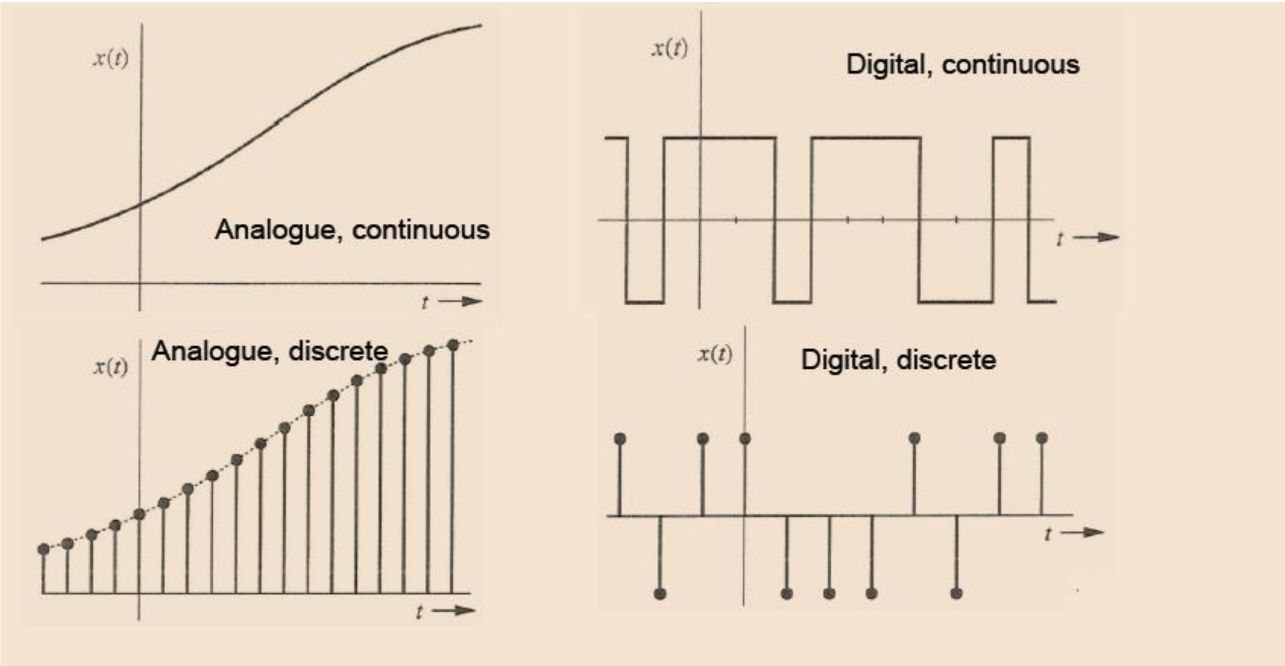
where $\frac{1}{2}[x(t) + x(-t)]$ is even signal **(why?)** and $\frac{1}{2}[x(t) - x(-t)]$ is odd signal **(why?)**.

4- Causal and Non-Causal Signals

If **x(t) = 0**, for **t <** $\mathbf{t_0}$ or for discrete signals **x[n] = 0**, for **n <** $\mathbf{n_0}$ then we have causal signals. The starting point $\mathbf{t_0}$ or $\mathbf{n_0}$ is very often taken to be the origin.



5- Analogue and Digital Signals



6- Energy and Power Signals

We will use abroad definition of power and energy that applies to any signal x(t) or x[n]

***Signal Energy**

$$E = \int_{t0}^{t1} |x(t)|^2 dt \qquad \text{and in discrete time} \quad E = \sum_{n=n0}^{n1} |x(t)|^2$$

***Signal Power**

$$P = \frac{1}{t1-t0}\int_{t0}^{t1} |x(t)|^2 dt \qquad \text{and in discrete time} \quad P = \frac{1}{n1-n0+1}\sum_{n=n0}^{n1} |x(t)|^2$$

We will encounter many types of signals; some of them have infinite average power, energy or both. There are a few rules that can help to determine whether a signal is power or energy signal:

- A signal is called energy signal if $E < \infty$.
- A signal is called power signal if $0 < P < \infty$.
- A signal can be an energy signal, a power signal or neither type.
- An energy signal has zero power. $E < \infty$; $P = 0$
- A power signal has infinite energy. $P < \infty$; $E = \infty$

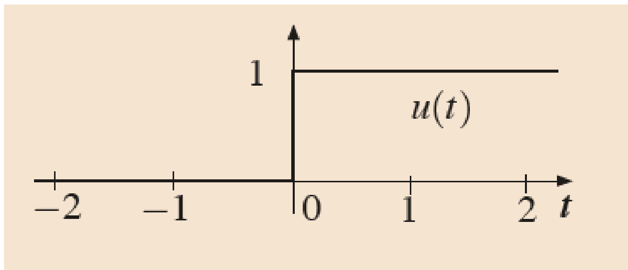
Special signal models

1- The unit step function *u(t)*

This is defined as $$u(t) = \begin{cases} 0 & t < 0 \\ 1 & t \geq 0 \end{cases}$$

In discrete time the equivalent function is defined as

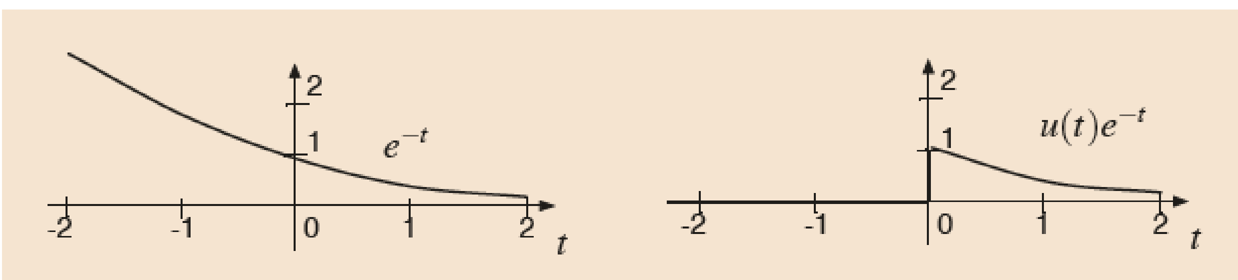
$$u[n] = \begin{cases} 0 & n < 0 \\ 1 & n \geq 0 \end{cases}$$



The unit step is used for extracting part of another signal. For example,

$$x(t) = \begin{cases} e^{-t} & t \geq 0 \\ 0 & t < 0 \end{cases}$$

Can be written as x(t) = u(t) e^{-t}



2- The delta function or unit impulse function *δ(t)*

This is a signal that is everywhere equal to zero except at the origin. This is defined as

$$\delta(t) = \begin{cases} 0 & t \neq 0 \\ +\infty & t = 0 \end{cases}$$

It is conveniently defined as assigning the value x(τ) to the signal x(t) at the instant t =τ through the integral

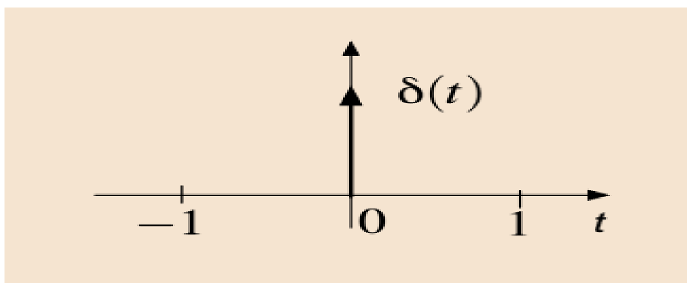
$$\int_{-\infty}^{+\infty} x(t)\delta(t-\tau)dt = \int_{-\infty}^{+\infty} x(t+\tau)\delta(t)dt = x(\tau)$$

In discrete time the equivalent function is defined as

$$\delta[n] = \begin{cases} 0 & n \neq 0 \\ 1 & n = 0 \end{cases}$$

and the following relationships hold.

$$\sum_{n=-\infty}^{n=+\infty} x[n]\delta[n-k] = \sum_{n=-\infty}^{n=+\infty} x[n+k]\delta[n] = x[k]$$



3- Unit Ramp

The unit ramp is defined as

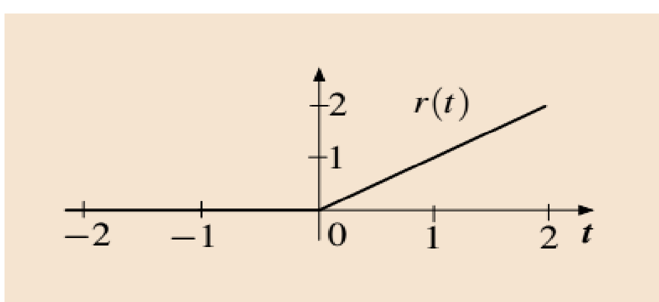
$$r(t) = \begin{cases} t & t \geq 0 \\ 0 & t < 0 \end{cases}$$

In discrete time the equivalent function is defined as

$$r[n] = \begin{cases} n & n \geq 0 \\ 0 & n < 0 \end{cases}$$

The unit ramp is the integral of the unit step,

$$r(t) = \int_{-\infty}^{t} u(\tau)d\tau$$

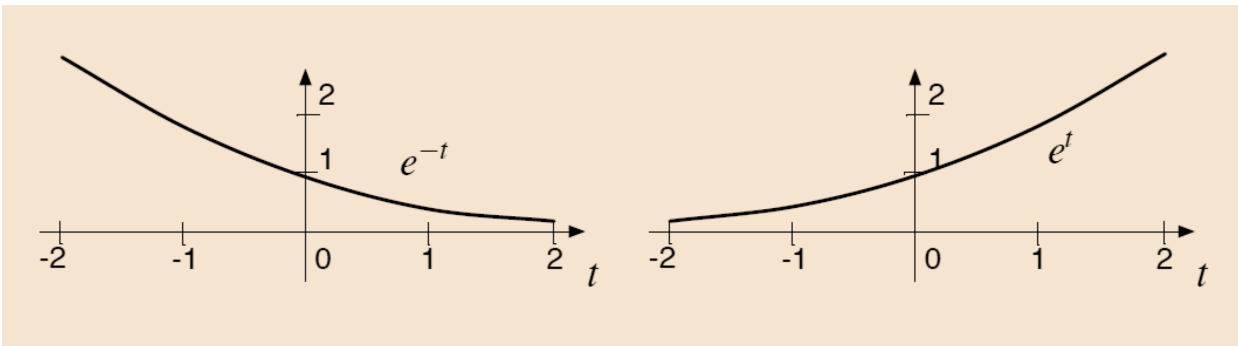


4- Exponential Signal

An exponential signal is given by

$$x(t) = e^{\sigma t}$$

- If $\sigma < 0$ this is exponential decay.
- If $\sigma > 0$ this is exponential growth.



Elementary transformations of the independent variable

In this section we focus on a class of elementary signal transformations that involve simple modifications of the independent variable, i.e., the time axis. These transformations allow us to introduce several basic properties of signals and systems. We consider the following.

1- **Time shift**: Starting from the signal **x(t)** in continuous time, time shift refers to the operation that gives us either the signal $\mathbf{x(t - t_0)}$, $\mathbf{t_0 > 0}$ that is a delayed version of **x(t)** or the signal $\mathbf{x(t + t_0)}$ that is an advanced version of **x(t)** . For discrete time signals we would have $\mathbf{x[n]}$, $\mathbf{x[n - n_0]}$, $\mathbf{x\,[n + n_0]}$ respectively.

2- **Time reversal**: Starting from the signal **x(t)** in continuous time, time reversal refers to the operation that gives us the signal **x(-t)**, that is a reflection of **x(t)** about **t = 0**. For discrete time signals we would have **x[n]** and **x[-n]** respectively.

3- **Time scaling:** Starting from the signal **x(t)** in continuous time, time scaling refers to the operation that gives us the signal **x(α**t) that is

(i) Linearly stressed if $|\alpha|$ <**1** ,
(ii) Linearly compressed if $|\alpha|$ > **1** and also
(iii) Reversed in time if $|\alpha|$ < **0**. For discrete time signals we would have **x[n]** and **x[αn]** respectively.