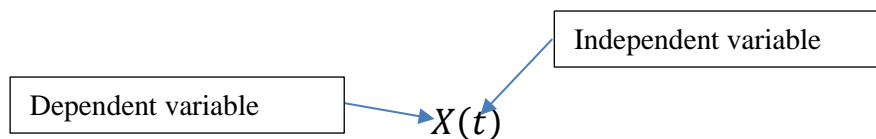


## 1.1 SIGNALS AND CLASSIFICATION OF SIGNALS

Signals are represented mathematically as functions of one or more independent variables. It mainly focuses attention on signals involving a single independent variable.



For convenience, this will generally refer to the independent variable as time. It is defined as physical quantities that carry information and changes with respect to time.

Ex: voice, television picture, telegraph.

### CLASSIFICATION OF SIGNALS

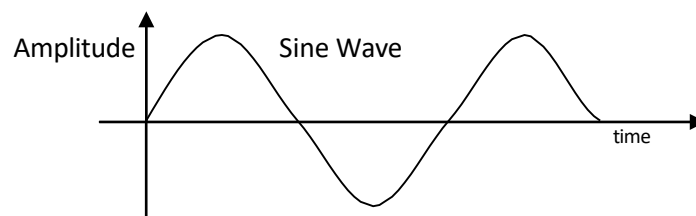
Signal classification is the process of organizing signals into different categories based on their characteristics such as time behavior, amplitude type, periodicity, predictability, energy/power, causality, and symmetry.

Classification Type	Categories	Description
1. Time Domain	Continuous-Time, Discrete-Time	Whether the signal is defined at all times or only specific instances
2. Amplitude Domain	Analog, Digital	Whether amplitude values are continuous or discrete
3. Periodicity	Periodic, Aperiodic	Whether the signal repeats over time
4. Determinism	Deterministic, Random (Stochastic)	Whether the signal can be predicted exactly
5. Energy/Power	Energy Signal, Power Signal	Based on how much energy or average power the signal contains
6. Causality	Causal, Non-Causal	Whether the signal exists only from a reference time forward
7. Symmetry	Even, Odd	Whether the signal is symmetric or anti-symmetric around the origin

## CONTINUOUS TIME AND DISCRETE TIME SIGNAL

### Continuous time signal:

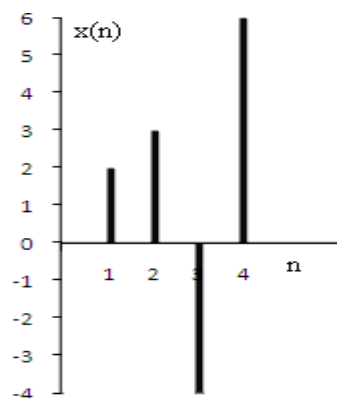
A signal that is defined for every instant of time is known as continuous time signal. Continuous time signals are continuous in amplitude and continuous in time. It is denoted by  $x(t)$  and shown in Figure 1.2.1



**Figure 1.2.1 Continuous time signal**

### Discrete time signal:

A signal that is defined for discrete instants of time is known as discrete time signal. Discrete time signals are continuous in amplitude and discrete in time. It is also obtained by sampling a continuous time signal. It is denoted by  $x(n)$  and shown in Figure 1.2.2



**Figure 1.2.2 Discrete time signal**

**EVEN (SYMMETRIC) AND ODD (ANTI-SYMMETRIC) SIGNAL****Continuous domain:****Even signal:**

A signal that exhibits symmetry with respect to  $t=0$  is called even signal

Even signal satisfies the condition  $x(t) = x(-t)$

**Odd signal:**

A signal that exhibits anti-symmetry with respect to  $t=0$  is called odd signal

Odd signal satisfies the condition  $x(t) = -x(-t)$

Even part  $x_e(t)$  and Odd part  $x_o(t)$  of continuous time signal  $x(t)$ :

Even component of  $x(t)$  is  $x_e(t) = \frac{1}{2}[x(t) + x(-t)]$

Odd component of  $x(t)$  is  $x_o(t) = \frac{1}{2}[x(t) - x(-t)]$

**Discrete domain:****Even signal:**

A signal that exhibits symmetry with respect to  $n=0$  is called even signal

Even signal satisfies the condition  $x(n) = x(-n)$ .

**Odd signal:**

A signal that exhibits anti-symmetry with respect to  $n=0$  is called odd signal

Odd signal satisfies the condition  $x(n) = -x(-n)$ .

Even part  $x_e(n)$  and Odd part  $x_o(n)$  of discrete time signal  $x(n)$ :

Even component of  $x(n)$  is  $x_e(n) = \frac{1}{2}[x(n) + x(-n)]$

Odd component of  $x(n)$  is  $x_o(n) = \frac{1}{2}[x(n) - x(-n)]$

## PERIODIC AND APERIODIC SIGNAL

### Periodic signal:

A signal is said to be periodic if it repeats again and again over a certain period of time.

### Aperiodic signal:

A signal that does not repeat at a definite interval of time is called an aperiodic signal.

### Continuous domain:

A Continuous time signal is said to be periodic if it satisfies the condition

$$x(t) = x(t + T) \text{ where } T \text{ is fundamental time period}$$

If the above condition is not satisfied, then the signal is said to be aperiodic

Fundamental time period

$$T = 2\pi/\Omega$$

where  $\Omega$  is fundamental angular frequency in rad/sec

### Discrete domain:

A Discrete time signal is said to be periodic if it satisfies the condition

$$x(n) = x(n + N) \text{ where } N \text{ is fundamental time period}$$

If the above condition is not satisfied, then the signal is said to be aperiodic

Fundamental time period

$$N = 2\pi m/\omega$$

where  $\omega$  is fundamental angular frequency in rad/sec,

$m$  is smallest positive integer that makes  $N$  as positive integer.

## ENERGY AND POWER SIGNAL

### Energy signal:

The signal which has finite energy and zero average power is called an energy signal. The non-periodic signals like exponential signals will have constant energy and so non-periodic signals are energy signals.

i.e., For energy signal,  $0 < E < \infty$  and  $P = 0$

For Continuous time signals,

$$\text{Energy } E = \lim_{T \rightarrow \infty} \int_{-T}^T |x(t)|^2 dt$$

For Discrete time signals,

$$\text{Energy } E = \lim_{N \rightarrow \infty} \sum_{n=-N}^N |x(n)|^2$$

### Power signal:

The signal which has finite average power and infinite energy is called power signal. The periodic signals like sinusoidal complex exponential signals will have constant power and so periodic signals are power signals.

i.e., For power signal,  $0 < P < \infty$  and  $E = \infty$  For

Continuous time signals,

$$\text{Average power } P = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T |x(t)|^2 dt$$

For Discrete time signals,

$$\text{Average power } P = \lim_{N \rightarrow \infty} \frac{1}{2N+1} \sum_{n=-N}^N |x(n)|^2$$

## DETERMINISTIC AND RANDOM SIGNALS

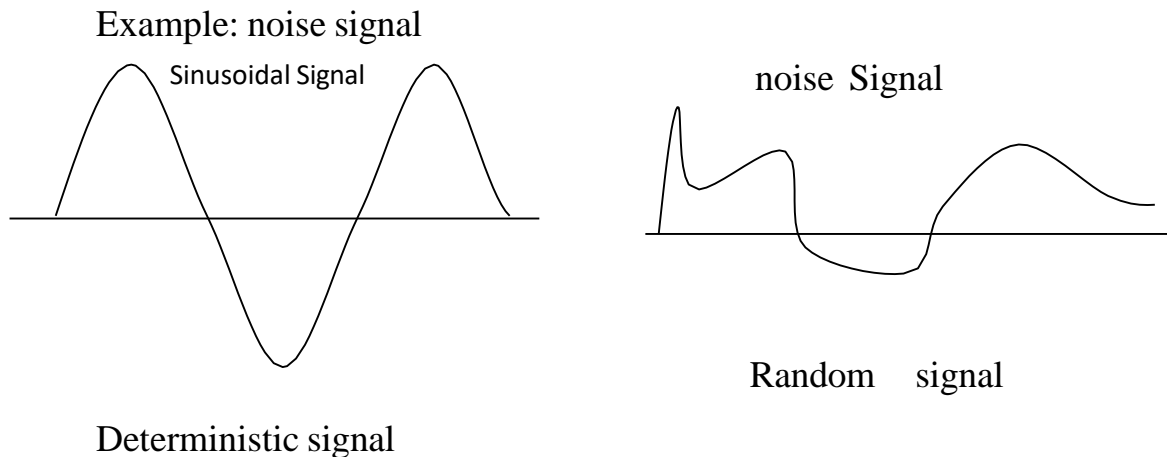
### Deterministic signal:

A signal is said to be deterministic if there is no uncertainty over the signal at any instant of time i.e., its instantaneous value can be predicted. It can be represented by mathematical equation.

Example: sinusoidal signal

### Random signal (non-deterministic signal):

A signal is said to be random if there is uncertainty over the signal at any instant of time i.e., its instantaneous value cannot be predicted. It cannot be represented by mathematical equation.



## CAUSAL AND NON-CAUSAL SIGNAL

### Continuous domain:

#### Causal signal:

A signal is said to be causal if it is defined for  $t \geq 0$ .

$$i. e., x(t) = 0 \text{ for } t < 0$$

#### Non-causal signal:

A signal is said to be non-causal, if it is defined for  $t < 0$  or for both  $t < 0$  and  $t \geq 0$

$$i. e., x(t) \neq 0 \text{ for } t < 0$$

When a non-causal signal is defined only for  $t < 0$ , it is called as anti-causal signal

### Discrete domain:

#### Causal signal:

A signal is said to be causal, if it is defined for  $n \geq 0$ .

$$i. e., x(n) = 0 \text{ for } n < 0$$

#### Non-causal signal:

A signal is said to be non-causal, if it is defined, for  $n < 0$  or for both  $n < 0$  and  $n \geq 0$

$$i. e., x(n) \neq 0 \text{ for } n < 0$$

When a non-causal signal is defined only for  $n < 0$ , it is called as anti-causal signal.