Digital Communications
Lecture 2

LECTURE SLIDES BY
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2022

Referances

- Data and Computer Communications-10th Ed William Stallings
- Data Communications and Networking Behrouz Forouzan
- McGraw Hill - Communication Systems – 4th Ed Carlson
- Introduction to Analog and Digital communications_2nd Ed Simon Haykin & Michael Moher

Classification of signals …

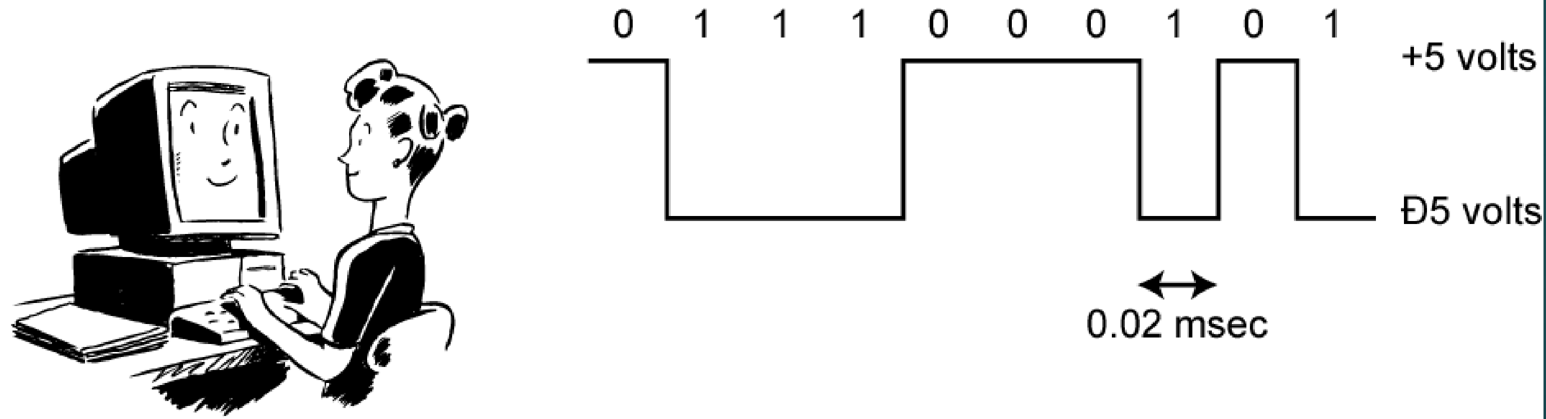
- Analog and digital Signals
- Continuous time and discrete time signals
- Periodic and non-periodic signals
- Odd and even signals
- Deterministic and random signals
- Energy and Power signals

Digital Data

Digital or Binary data, as generated by terminals, computers, and other data processing equipment and then converted into digital voltage pulses for transmission.

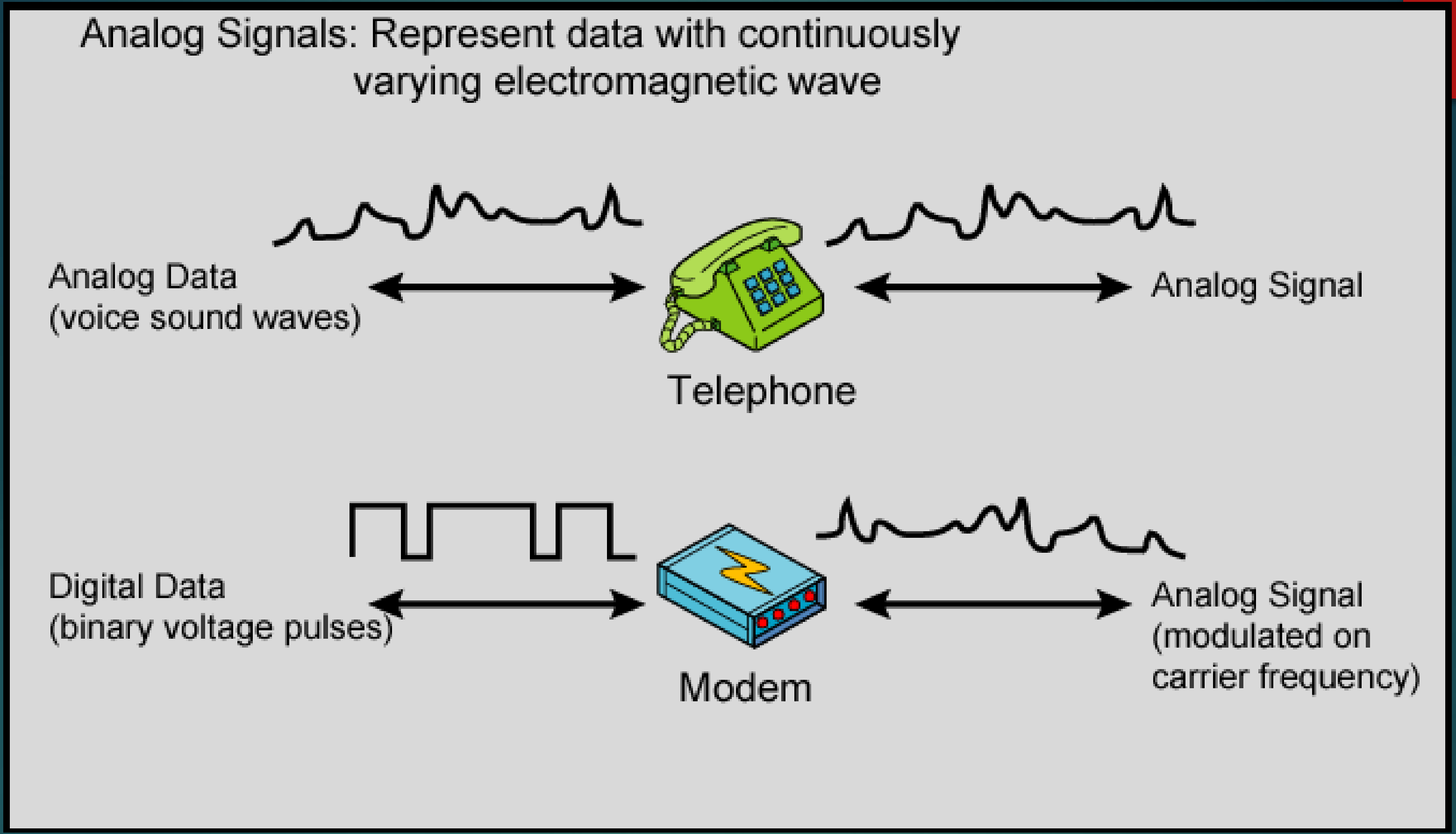
A commonly used signal for such data uses two constant (dc) voltage levels: one level for binary 1 and one level for binary 0.

- bandwidth depends on data rate



User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Ð5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

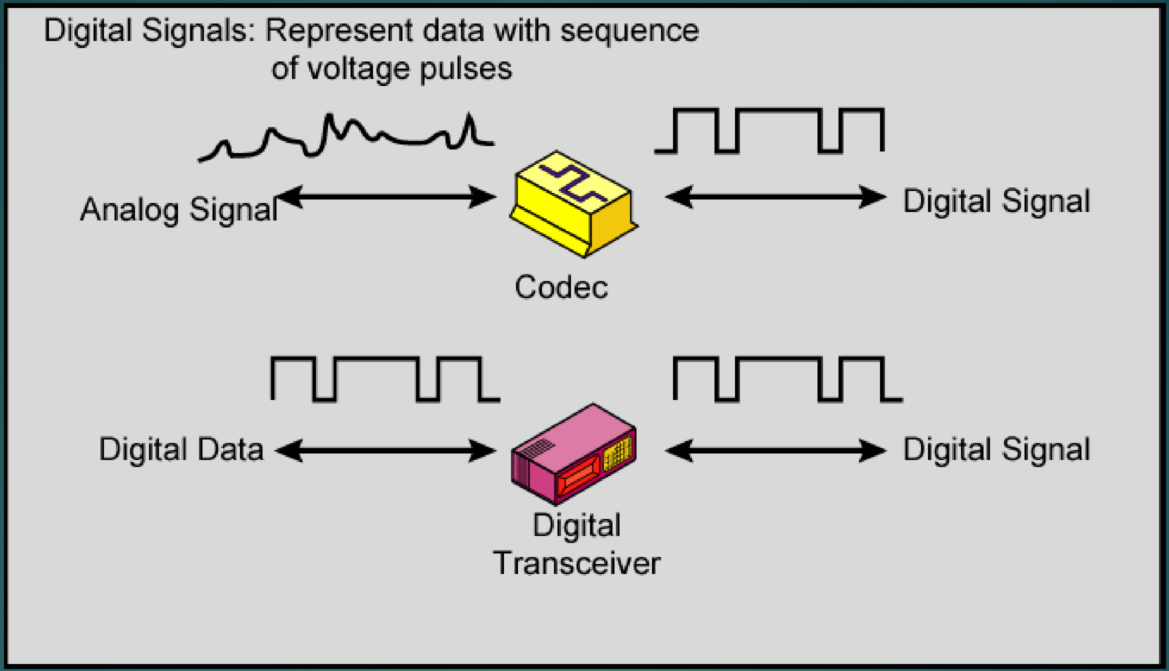
Analog Signals



Analog signals can be used to transmit :

- Analog data represented by an electromagnetic signal occupying the same spectrum,
- digital data using a modem (modulator/demodulator) to modulate the digital data on some carrier frequency.

Digital Signals



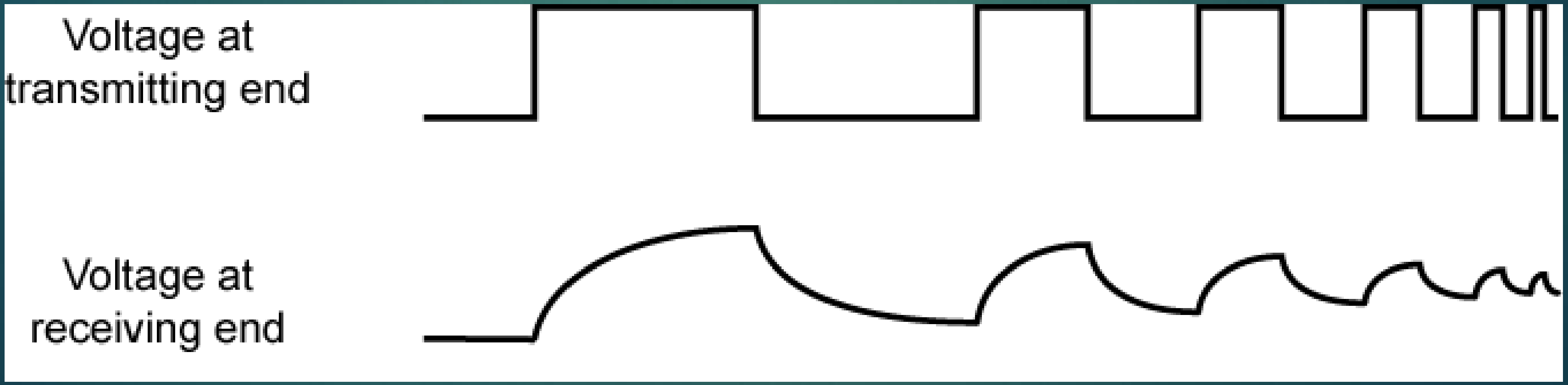
- A **digital signal** is a sequence of voltage pulses that may be transmitted over a wire medium;

- **Digital signals** can be used to transmit both analog signals and digital data.

  - Analog data be can converted to digital using a codec (coder-decoder), which takes an analog signal that directly represents the voice data and approximates that signal by a bit stream. At the receiving end, the bit stream is used to reconstruct the analog data.
  - Digital data can be directly represented by digital signals.

Advantages & Disadvantages of Digital Signals

- cheaper
- less susceptible to noise
- Greater attenuation
- digital now is the preferred choice



Classification of signals …

Signals As Functions of Time

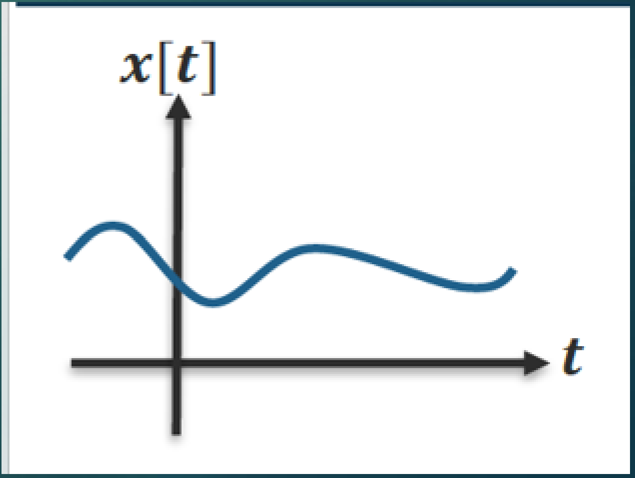
Continuous time and discrete time signals

- **Continuous-time signal:** if the signal is specified for every value in time , then it is known as Continuous-time signal **X(t)**
- Main example is the **Analog signal,**
- Example : Atmospheric Pressure
- Continuous-time signals are functions of a real argument

  $x(t)$ where time, t, can take any real value

  $x(t)$ may be 0 for a given range of values of t

- Continuous--time signals are represented with **t**



Classification of signals …

Signals As Functions of Time

Continuous time and discrete time signals

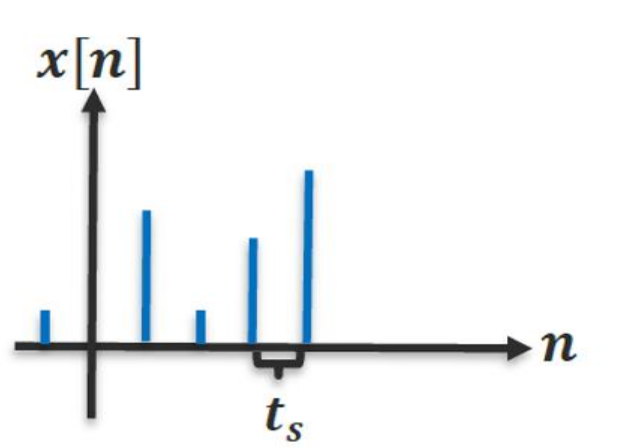
- **Discrete-time signal :** if the signal is specified only for the discrete time instance , then it is called Discrete-time signal X(n)
- Main example is the **Digital signal (either 0 or 1)**
- Discrete-time signals are functions of an argument that takes values from a discrete set

  $x[n]$ where $n \in \{...-3,-2,-1,0,1,2,3...\}$

  Integer time index, e.g. *n,* for discrete-time systems

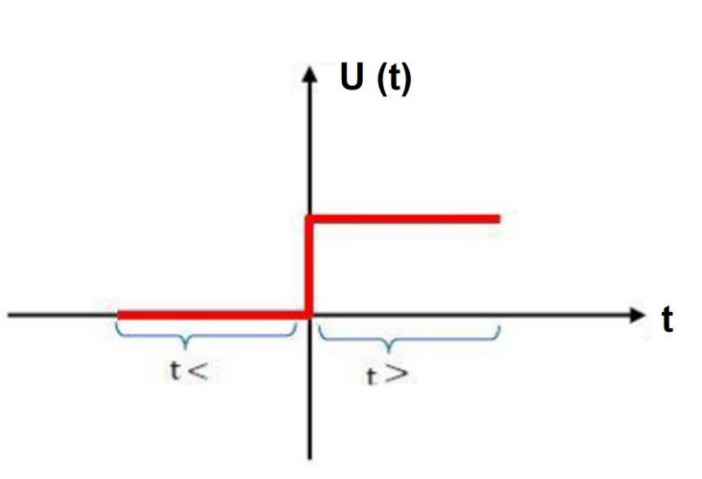
- Discrete-time signals are represented with **n**

ts = Sampling period



Basic Continuous-time signal Functions…

1- The Unit Step Function (Heaviside Unit Function) U(t)



$$u(t) = \begin{cases} 1 \, ; t \geq 0 \\ 0 \, ; t < 0 \end{cases}$$

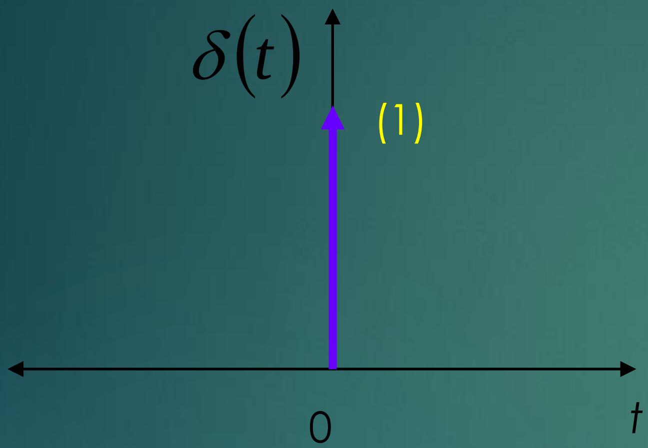
When **t** is greater or equals to Zero , **u(t)** value equals to 1

Other wise **u(t)** equal to Zero

Can be a good example of current switch

Basic Continuous-time signal Functions…

2- The Unit Impulse Function (Dirac Delta Function) $\delta(t)$



$$\delta(t) = \begin{cases} 0 \; ; t \neq 0 \\ 1 \; ; t = 0 \end{cases}$$

- When **t** equals to Zero , $\delta(t)$ value equals to 1
- Dirac Function is usually plotted as arrow at origin and Undefined amplitude at origin
  - Denote area at origin as (area)
  - Height of arrow is irrelevant
  - Direction of arrow indicates sign of area

Basic Continuous-time signal Functions…

Relationship between unit impulse and unit step

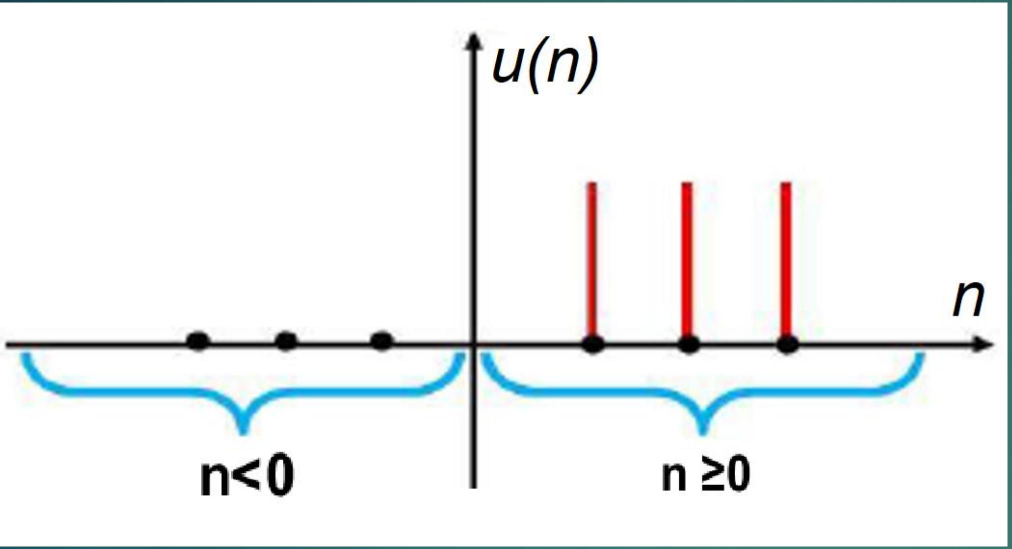
- What happens at the origin for u(t)?
  - $u(0^-) = 0$ and $u(0^+) = 1$,
  - but $u(0)$ can take any value
- Common values for $u(0)$ are 0, ½, and 1
- $u(0) = ½$ is used in impulse invariance filter design:

$$\int_{-\infty}^{t} \delta(\tau)\,d\tau = \begin{cases} 0 & t < 0 \\ ? & t = 0 \\ 1 & t > 0 \end{cases} \Longleftrightarrow \frac{du}{dt} = \delta(t)$$

$$= u(t)$$

Basic Discrete-time signal Functions…

1- Discrete Unit Step Sequence U(n)



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

- When **n** is greater or equals to Zero , **u(n)** value equals to 1

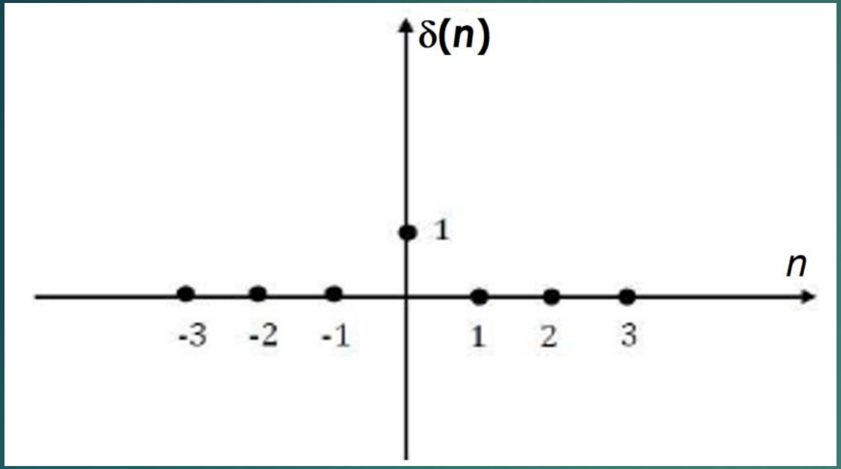
Other wise **u(n)** equal to Zero

- **U(n)** is a Power signal : the average P for u(n)= 0.5 watt which is finite

so $0 < P\,U(n) < \infty$

Basic Discrete-time signal Functions…

2- Discrete Unit Impulse Sequence $\delta(n)$



$$\delta(n) = \begin{cases} 0 \; ; \; n \neq 0 \\ 1 \; ; \; n = 0 \end{cases}$$

- Only When n equals to Zero , $\delta(n)$ value equals to 1

Other wise $\delta(n)$ value equals to 0

- $\delta(n)$ is an Even signal : $\delta(n) = \delta(-n)$
- $\delta(n)$ is an Energy signal : E for $\delta(n)$ is finite so $0 < E\,\delta(n) < \infty$

Classification of signals …

Deterministic and random signals

Deterministic Signal:

- A signal whose physical description is known completely either in mathematical form or graphical form is known as the **Deterministic Signal**
- No uncertainty with respect to the signal value at any time.
- The Signal which its values are completely specified for any giving time **<u>within a range of known values.</u>**
- Example: Human Body temperature: between 36 to 40 degree)

Random signal:

- A Signal which is known only in terms of probabilistic description is known as **Random signal** (like noise Signals)
- Some degree of uncertainty in signal values before it actually occurs. (**<u>Range of values is unKnown</u>**)
- **Examples:**
  - Thermal noise in electronic circuits due to the random movement of electrons
  - Reflection of radio waves from different layers of ionosphere

Classification of signals …

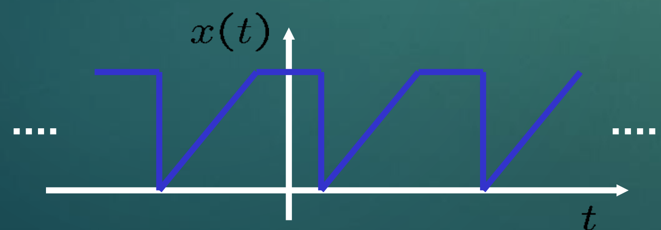
Periodic and non-periodic signals

- If the Signal Repeats itself after finite time T then it is called **Periodic signal**
  - For Continuous time signals: $X(t) = X(t + T)$, where : T is time period of the signal

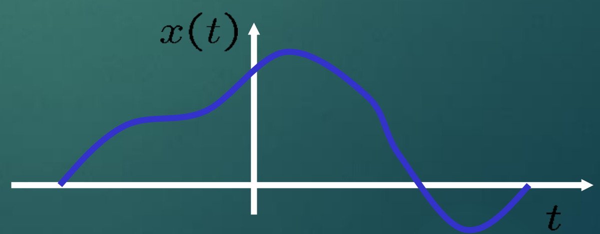
  This means that signal value at time stamp (t + T) equals to signal value at time stamp (t)

  - For discrete time signals : $X(n) = X(n + N)$, where : N is number of Samples

- If the Signal doesn't repeat its pattern with time, it is called **Aperiodic signal**



Periodic signal

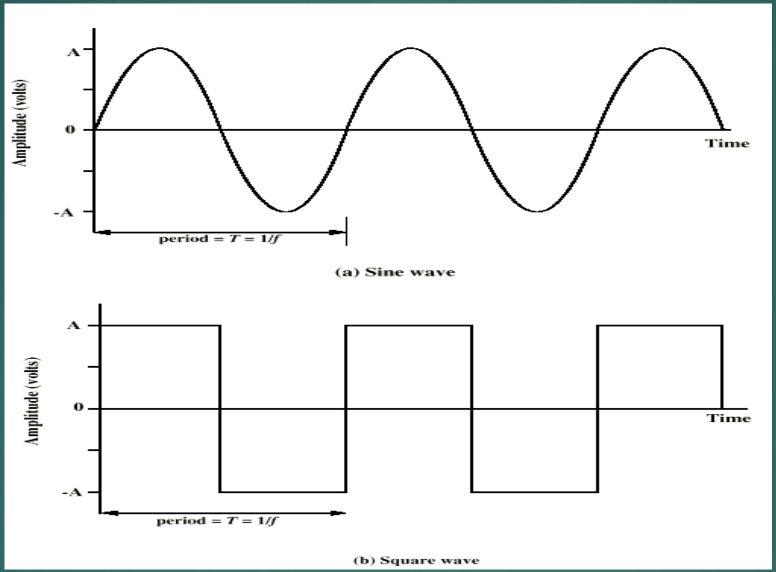


A non-periodic signal (Aperiodic)

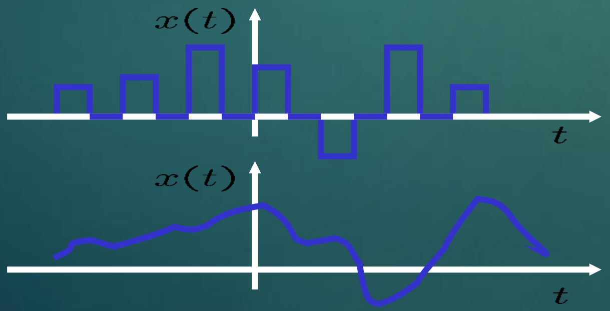
Classification of signals …

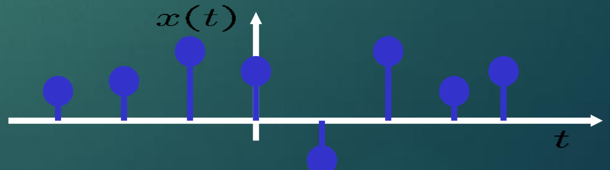
Periodic and non-periodic signals

- Examples of Periodic signals



- Examples of Aperiodic signals





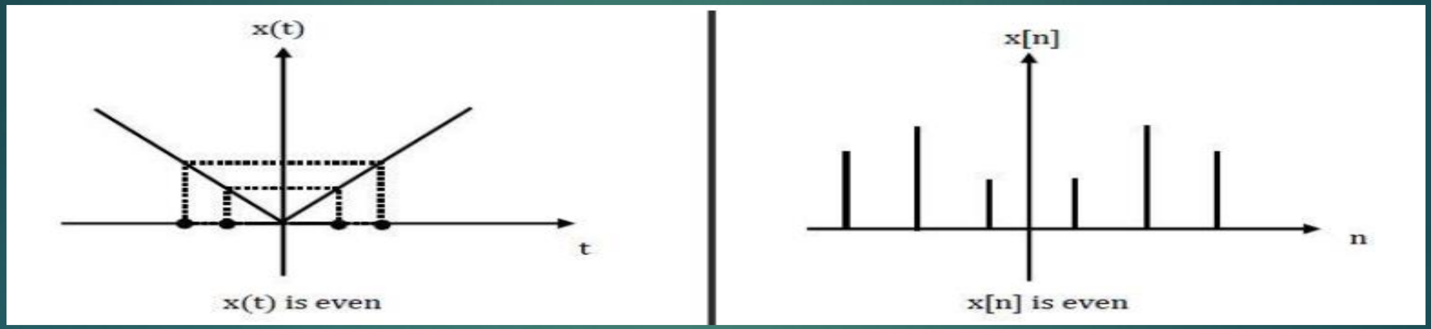
A discrete signal

Classification of signals …

Odd and Even signals

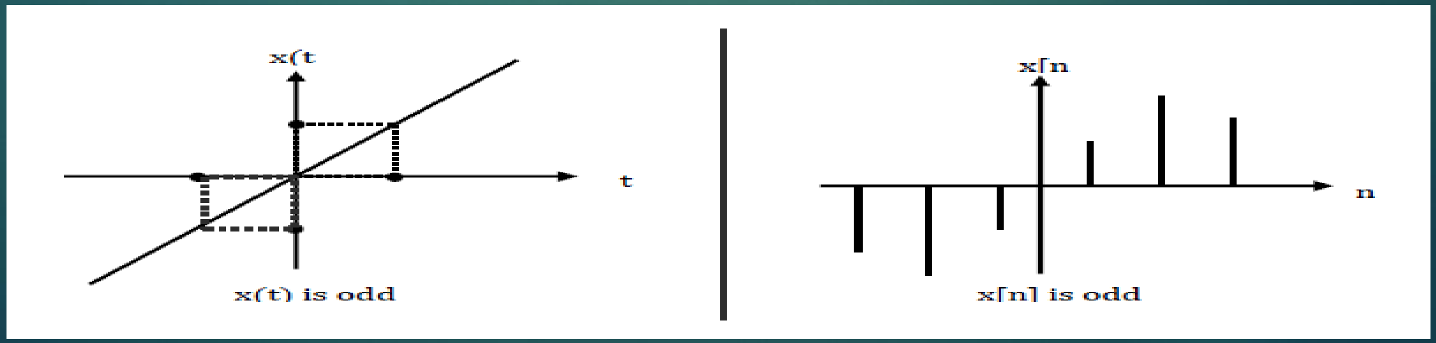
- **Even Signal :** Symmetrical to axis Y

X(t) is even if X(-t) = X(t)   and   X(n) is even if X(-n) = X(n)



- **Odd Signal :** Symmetrical to Zero

X(t) is Odd if X(-t) = -X(t)   and   X(n) is Odd if X(-n) = -X(n)



Classification of signals …

Energy and power signals

- Power is the Amount of Energy transferred per unit Time:

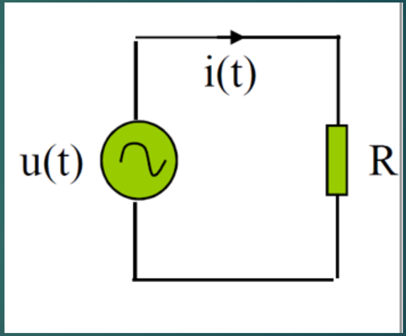
Energy = Power X time

  - Power P is measured in Watt
  - Energy E is measured in Joule

- Example: Power and Energy of a resistor :

$$p(t) = u(t)i(t) = i^2(t)/R$$

$$E = \int_{t_1}^{t_2} \frac{1}{R} i^2(t)dt$$



- Whenever we are talking about any type of signal :We need to measure the strength of the signal (which is reflected by energy and Power)

Classification of signals …

Energy and power signals

- A signal is called as **Energy signal** if, and only if, it has nonzero but **Finite Energy** for all time: (so P = 0)

$$E_x = \int_{-\infty}^{+\infty} x^2(t)\, dt$$

$$\boxed{(0 < E_x < \infty)}$$

- A signal is called as **Power signal** if, and only if, it has nonzero but **Finite Power** for all time: (so E = ∞)

$$P_x = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} x^2(t)\, dt$$

$$\boxed{(0 < P_x < \infty)}$$

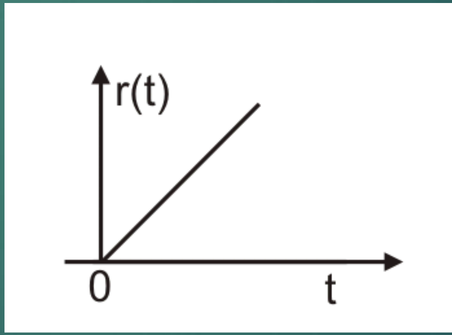
Classification of signals …

Energy and power signals

General Rules:

- Periodic and random signals are power signals.
- Signals that are both deterministic and non-periodic are energy signals.
- Energy Signals : **Pulses** while Power Signals : **Periodic**
- Some signals are neither Energy or Power signals :

Example: Ramp signal

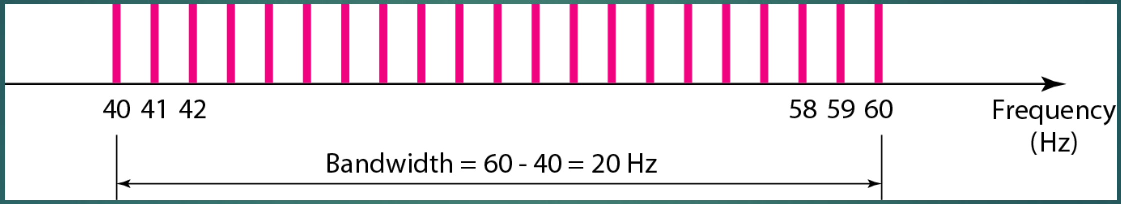


Question: Why All Sine wave are Power Signals?

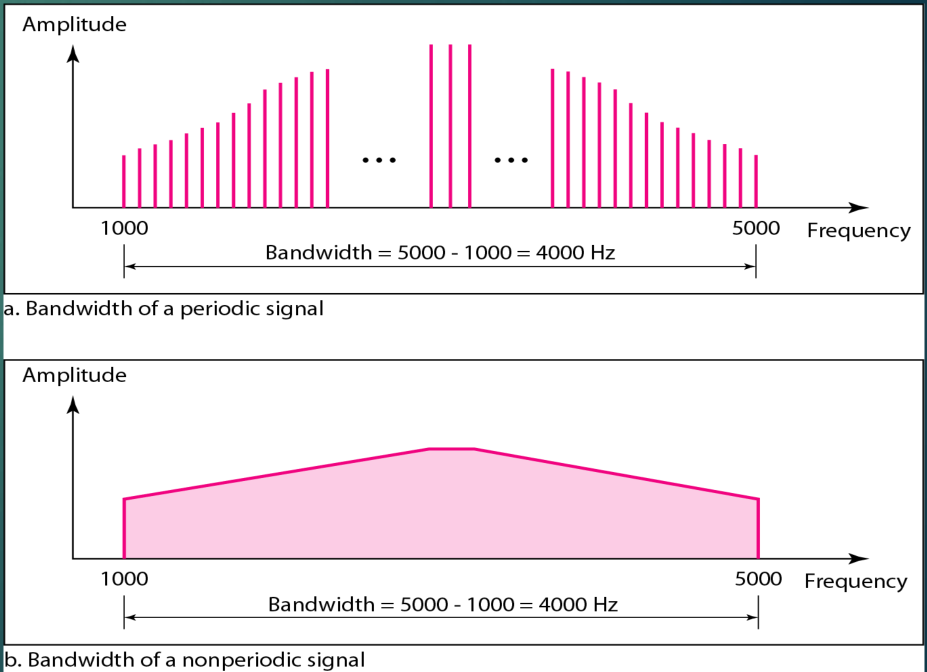
The average values of sine wave = 0 (because the Average value is the integral with respect to time , i.e. the positive part of signal cancels out the negative Part)

Definitions

Bandwidth is the width of the range (or band) of frequencies that a signal uses on a given transmission medium.
Bandwidth is expressed in terms of the difference between the highest-frequency and the lowest-frequency of a signal component.
Since the frequency of a signal is measured in hertz (Hz) (which is the number of cycles of change per second). A given bandwidth is the difference in hertz between the highest frequency and the lowest frequency that it uses.



A typical voice signal has a bandwidth of approximately three kilohertz (3 kHz); an analog television (TV) broadcast video signal has a bandwidth of six mega hertz (6 MHz).
Below is The bandwidth of periodic and nonperiodic composite signals



a. Bandwidth of a periodic signal

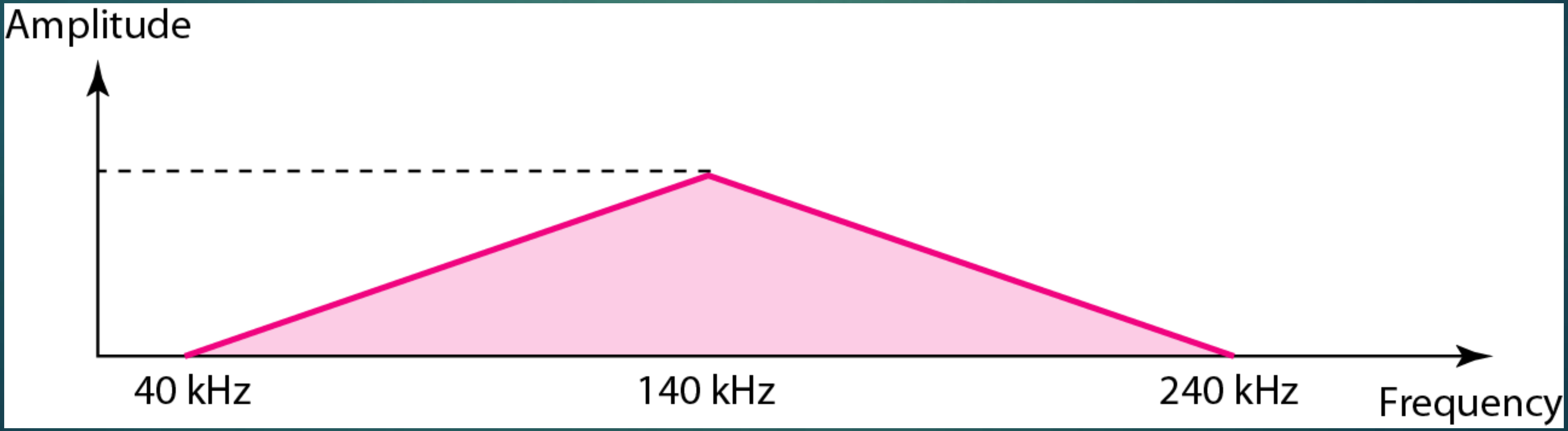
b. Bandwidth of a nonperiodic signal

Example on Bandwidth

A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.



Definitions

Channel Capacity :

The maximum rate at which data can be transmitted over a given communication channel, under given conditions, is referred to as the **channel capacity**. There are four concepts here that we are trying to relate to one another.

- **Data rate**, in bits per second (bps), at which data can be communicated
- **Bandwidth,** as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or Hertz
- **Noise,** average level of noise over the communications path
- **Error rate,** at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted

- All transmission channels are of **limited bandwidth**, which arise from the physical properties of the transmission medium.

- It's important to make as efficient use as possible of a given bandwidth.
For example: for digital data we need to get as high a data rate as possible at a particular limit of error rate for a given bandwidth. The main constraint on achieving this efficiency is noise.

Definitions

Noise & Reliable Communications

- All physical systems have noise (thermal noise)
  - Electrons always vibrate (at non-zero temperature)
  - Motion of electrons induces noise

- Presence of noise limits accuracy of measurement of received signal amplitude
- Errors occur if signal separation is comparable to noise level
- Bit Error Rate (BER) increases with decreasing signal-to-noise ratio
- Noise places a limit on how many amplitude levels can be used for pulse transmission

Signal to Noise Ratio (SNR)

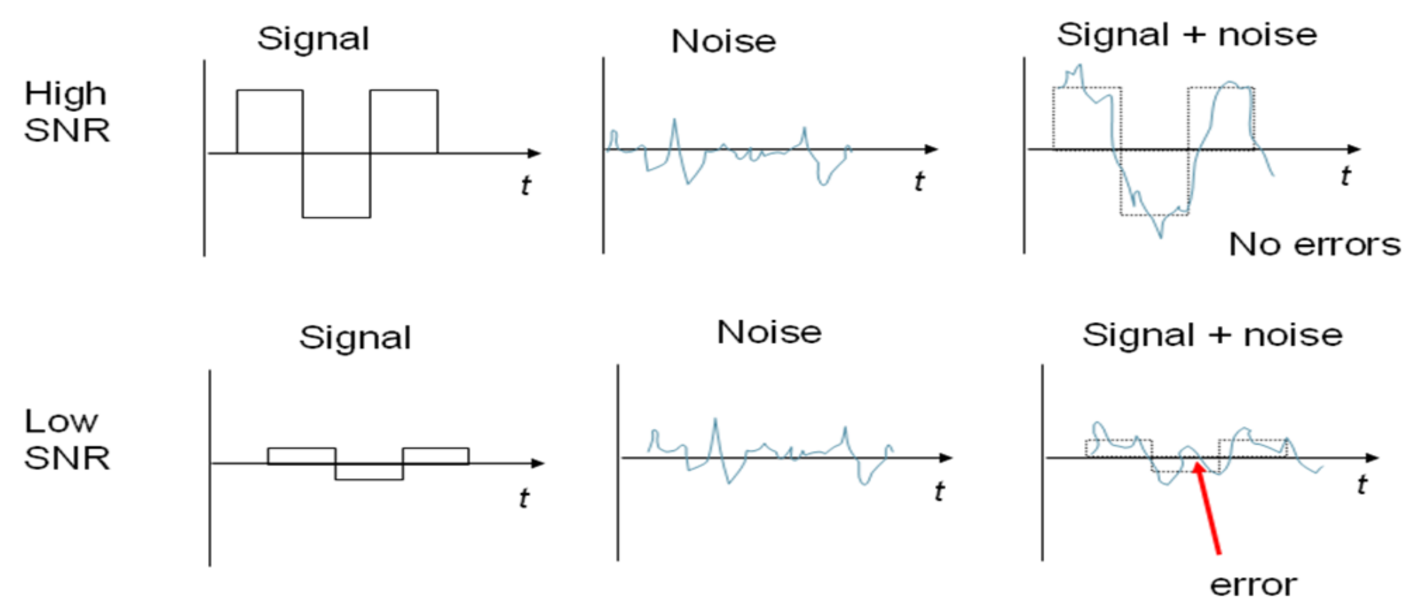
- Amount of thermal noise measured by signal-to-noise ratio (SNR).
- SNR = S/N, where S is signal power and N is noise power.
- SNR usually given in decibels (dB).
- SNR in dB is = 10 log 10 S/N.

Example :
If S/N is 10, SNR is 10dB;
If S/N is 100, SNR is 20dB.

Definitions

Signal to Noise Ratio (SNR)

A high SNR will mean a high-quality signal and a low number of required intermediate repeaters



$$SNR = \frac{\text{Average signal power}}{\text{Average noise power}}$$

$$SNR\ (dB) = 10 \log_{10} SNR$$

Example on SNR

1

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNRdB ?

Solution

The values of SNR and SNR in dB can be calculated as follows:

$$\mathrm{SNR} = \frac{10{,}000\ \mu\mathrm{W}}{1\ \mathrm{mW}} = 10{,}000$$

$$\mathrm{SNR_{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

2

The values of SNR and SNR in dB for **a noiseless channel** are

$$\mathrm{SNR} = \frac{\text{signal power}}{0} = \infty$$

$$\mathrm{SNR_{dB}} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal

Primary Resources and operational Requirements In communications

- The Two primary Communication resources are:
  - **Transmitter Power**
  - **Channel bandwidth**

- The Performance of the system is also affected by the noise

- Signal to noise (SNR = S/N):
  - **a Joint effect of the Received signal power (Sr) and noise power (Nr)**
  - **can be considered as the system Sensitivity threshold**
- The design of a communication system is a tradeoff between SNR and channel Bandwidth.
- To improve the Performance of a system :We either increase SNR or increase Channel bandwidth :
  - If there is limitation on Bandwidth, we Can increase the SNR (easier)
  - If there is a limitation on SNR (for example: sometimes increasing the SNR means increasing the signal power and this might not be recommended due to design limitation and interference issues) so we increase the bandwidth (more **difficult and costly**)