Unit-1 Data and Signals

Unit I:

Data and Signals Analog and Digital Data, Analog and Digital Signals, Periodic and Non periodic, Periodic Analog signals, Time and Frequency Domains, Composite Signals, Bandwidth, Digital Signals, Bit Rate, Digital Signal as a Composite Analog Signal, Transmission of Digital and Analog Signals, Transmission Impairment, Attenuation, Distortion, Noise, Data rate limits, Noiseless channel: Nyquist bit rate, Noisy Channel: Shannon Capacity, Simplified Communication & Data Communication models. Data Flow-Simplex, Half Duplex, Full Duplex.

When we communicate,we are sharing information.This sharing can be local or remote. Between individuals,local communication usually occurs face to face, while remote communication takes place over distance.

Data Communications are the exchange of data between two devices via some form of transmission media such as a cable, wire or it can be air or vacuum also. For occurrence of data communication, communicating devices must be a part of a communication system made up of a combination of hardware or software devices and programs.

The effectiveness of a data communication system depends on four fundamental characteristics:

- **Delivery-** The system must deliver data to the correct destination. Data must be received by the intended device or user and only by the device or user.

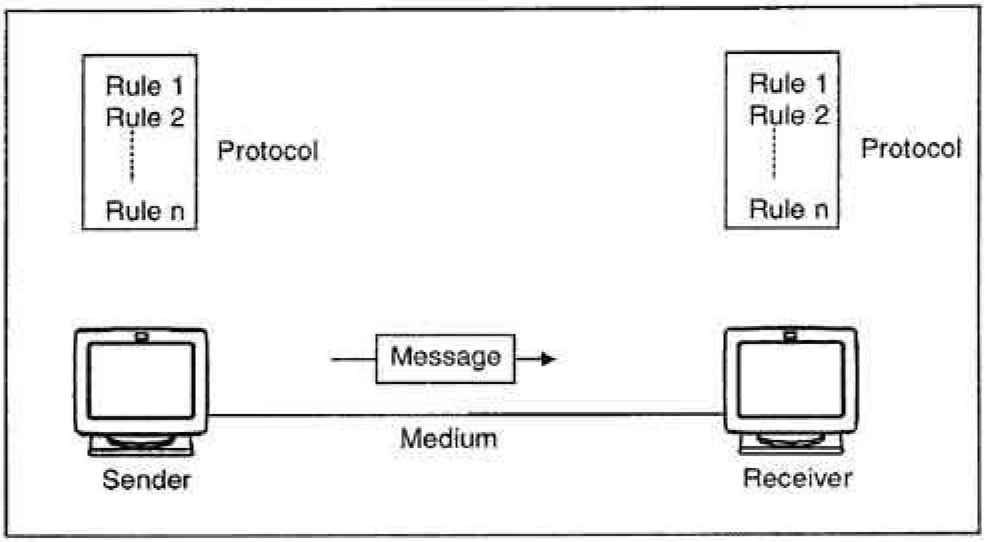
- **Accuracy-**The system must deliver the data accurately.Data that has been altered in transmission and left uncorrected are unusable.

- **Timeliness-** The system must deliver data in a timely manner.Data delivered late is useless.In case of video and audio,timely delivery means delivering data as they produced, in the same order they are produced and without significant delay.This kind of delivery is called real-time transmission.

- **Jitter-** Jitter refers to the variation in the packet arrival time.It is the uneven delay in the delivery of audio or video packets.

Components of a data communication system

A data communication system has five components.



1.Message- The message is the information (data) to be communicated.Popular form of information include text, numbers, pictures,audio and video.

2. Sender- The sender is the device that sends the message.It can be a computer, workstation, telephone, video camera and so on.

3. Receiver- The receiver is the device that receives the message. It can be a computer, workstation, television and so on.

4. Transmission medium- The transmission medium is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted pair wire,coaxial cable,fibre optic cable and radio waves.

5. Protocol- A protocol is a set of rules that govern data communication. It represents an agreement between the communication devices. Without a protocol, two devices may be connected but not communicating.

DATA FLOW

Communication between two devices can be **simplex, half-duplex, or full duplex.**

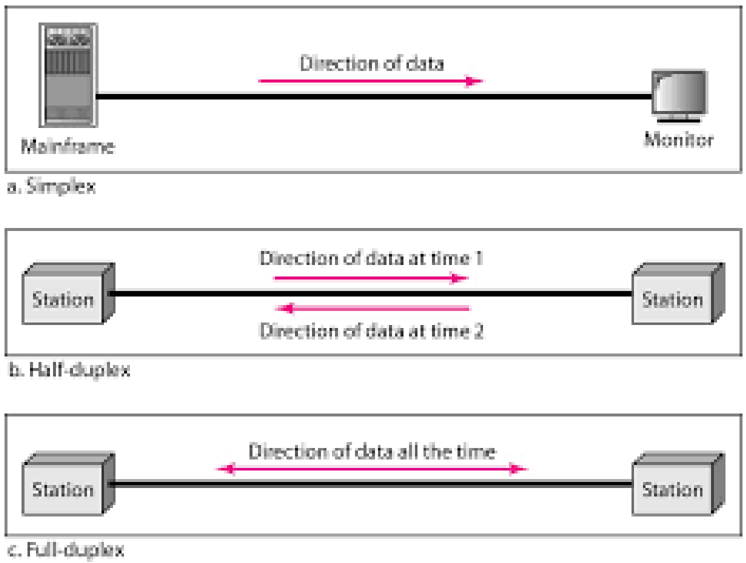
Simplex
In simplex mode, the communication is unidirectional,as on a one- way street. Only one of the two devices on link can be transmitted; the other can only receive. Eg: keyboard and traditional monitors ,The keyboard can only introduce input; the monitor can only accept output.The simplex mode can use the entire be capacity of the channel to send data in one direction.

Half-duplex

In half-duplex mode, each station can both transmit and receive, but not at the same time. When one device is sending, the other can only receive and vice versa. The entire capacity of the channel can be utilized for each direction.E.g. Walkie-Talkie

Full-duplex

In full- duplex mode,both stations can transmit and receive simultaneously. One common example of full duplex communication is the telephone network. When two people are communicating by a telephone line, both can talk and listen at the same time.



<u>ANALOG AND DIGITAL</u>

Both data and signals that represent them can be either analog or digital in form.

Analog and Digital Data

Data can be analog or digital

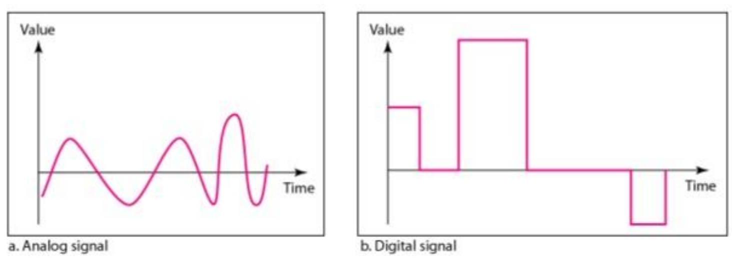
Analog data: The term analog data refers to <u>information that is continuous</u>. Analog data,such as the sounds made by a human voice,takes on continuous values. When someone speaks,an analog wave is created in the air.This can be captured by a microphone and converted to an analog signal or sampled and converted to a digital signal.

Digital data: The digital data refers to <u>information that has discrete states</u>. Digital data takes on discrete values. For example, data are stored in computer memory in the form of 0s and 1s.They can be converted to a digital signal or modulated into analog signals for transmission across a medium.

Analog and Digital Signals

Like the data they represent,Signals can be either in analog or digital.
Analog signal: An analog signal has infinitely many levels of intensity over a period of time. As we move from value A to B , it passes through and includes an infinite number of values along its path.
Digital signal: A digital signal can have only a limited number of defined values. Although each value can be any number, it is often as simple as 1 and 0.

Figure 3.1 *Comparison of analog and digital signals*



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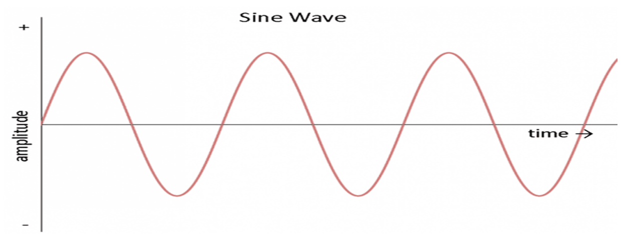
Periodic and Nonperiodic
Both analog and digital signals can take one of two forms: periodic or nonperiodic (aperiodic).
A periodic signal completes a pattern within a measurable time frame , called a period and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a cycle.
A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.
Both analog and digital signals can be periodic or nonperiodic.

PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as **simple or composite**. A simple periodic analog signal , a sine wave,cannot be decomposed into simpler signals. A composite periodic analog signal is composed of multiple sine waves.

Sine Wave

The sine wave is the most fundamental form of a periodic analog signal. When we visualize it as a simple oscillating curve, it's changes over the course of a cycle are smooth and consistent, a continuous, rolling flow.

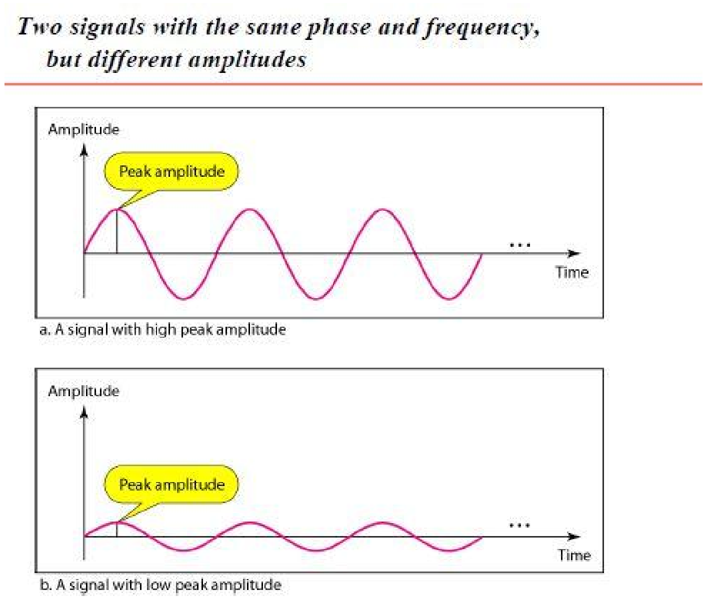


A sine wave can be represented by three parameters

- **Peak amplitude**
- **Frequency**
- **Phase**

Peak Amplitude

The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries. For electric signal, peak amplitude is normally measured in volts.



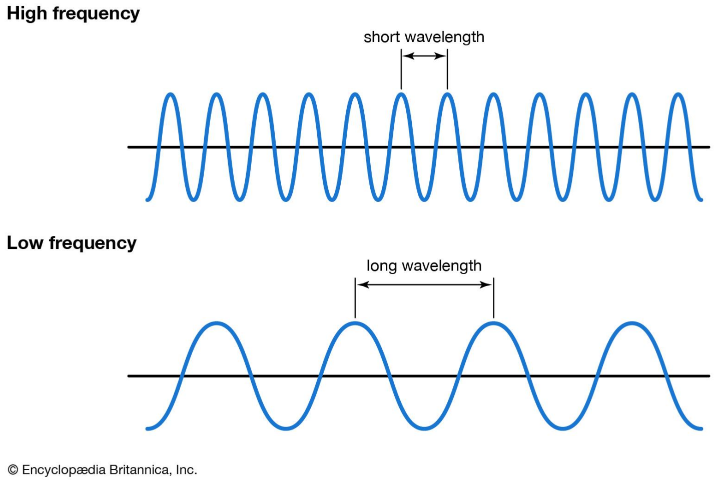
a. A signal with high peak amplitude

b. A signal with low peak amplitude

Period and Frequency

Period (T) refers to the amount of time, in seconds, a signal needs to complete 1 cycle. Frequency (f) refers to the number of periods in 1s. Period is the inverse of frequency.

$$f = 1/T \quad \text{and} \quad T = 1/f$$



Phase

The term phase or phase shift, describes the position of the waveform relative to time 0. If we think of the wave as something that can be shifted backward or forward along the time axis. The phase describes the amount of that shift. It indicates the status of the first cycle.

Wavelength

Wavelength is another characteristic of a signal traveling through a transmission medium. Wavelength binds or frequency of simple sine waves to the propagation speed of the medium.

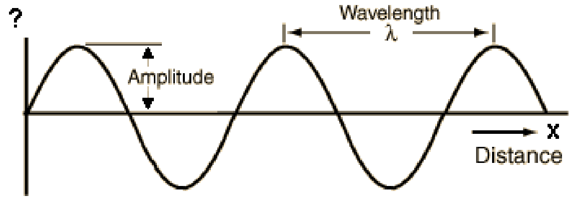
A wave cycle consists of one complete wave—starting at the zero point, going up to a wave crest, going back down to a wave trough, and back to the zero point again. The wavelength of a wave is the distance between any two corresponding points on adjacent waves. It is easiest to visualize the wavelength of a wave as the distance from one wave crest to the next. In an equation, wavelength is represented by the Greek letter lambda (λ).

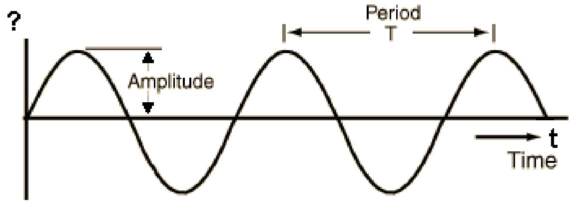
While the frequency of a signal is independent of the medium the wavelength depends on both the frequency and the medium. In data communication, we often use wavelength to describe the transmission of light in an optical fiber.

Wavelength can be calculated, if we represent wavelength by λ , propagation speed by c (speed of light) and frequency by f

Wavelength = (propagation speed)x period
= Propagation speed / frequency

ie, $\lambda = c/f$

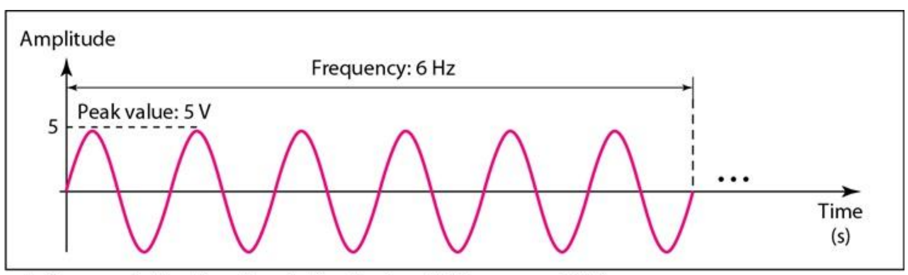




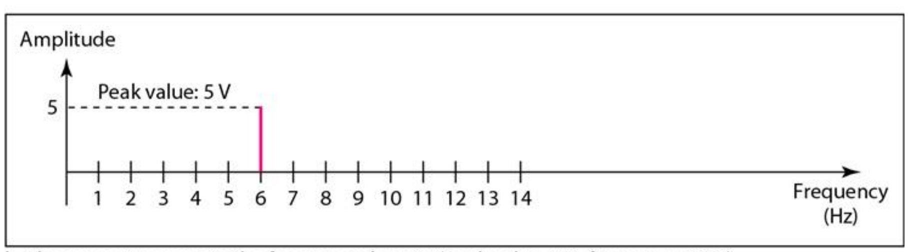
Propagation speed is the speed at which a signal moves through a medium.
Propagation time is the time required for a signal or wave to travel from one point of a transmission medium to another.

Time and Frequency Domain

A sine wave is comprehensively defined by its amplitude, frequency and phase. We have been showing a sine wave by using a **time - domain plot. T**he time - domain plot shows changes in signal amplitude with respect to time (it is an amplitude versus time plot). Phase is not explicitly shown on a time - domain plot.
To show the relationship between amplitude and frequency,we can use **frequency-domain plots**. A frequency - domain plot is concerned with only the peak value and the frequency. Changes of amplitude during one period are not shown.



a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)

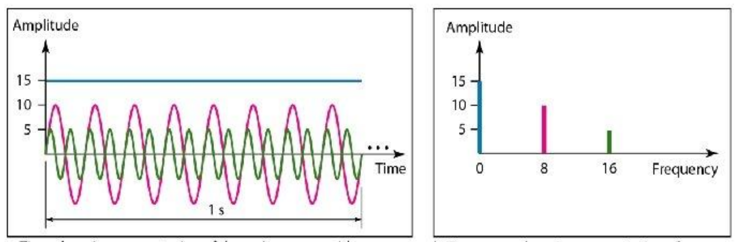


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

It is obvious that the frequency domain is easy to plot and convey the information that one can find in a time domain plot. The advantage of the frequency domain is that we can immediately see the value of the frequency and peak amplitude**.**

A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Figure 3.8 *The time domain and frequency domain of three sine waves*



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

b. Frequency-domain representation of the same three signals

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Composite Signals

Simple sine waves have many applications in daily life. We can send a single sine wave to carry electric energy from one place to another. We can use a single sine wave to send an alarm to a security center when a bulgar opens a door or window in the house.

A single frequency sine wave is not useful in data communication; we need to send a composite signal, a signal made of many simple sine waves.

According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitude and phases.

Figure 3.9 *A composite periodic signal with frequency f*

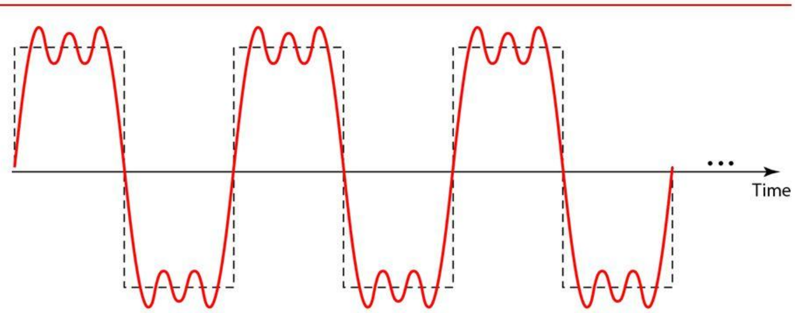

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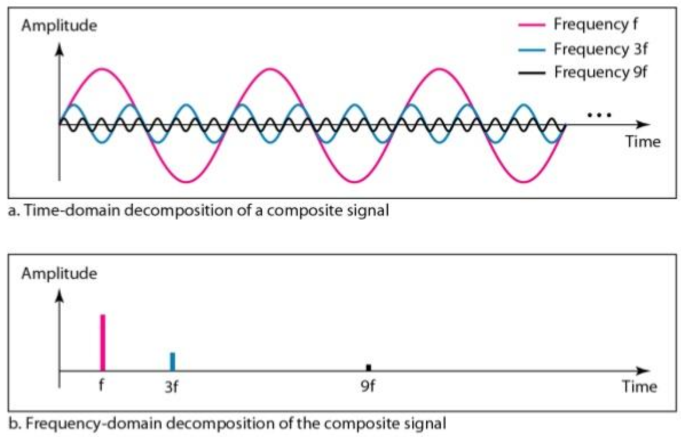
Figure 3.10 *Decomposition of a composite periodic signal in the time and frequency domains*



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A composite signal can be periodic or non periodic. A periodic composite signal can be decomposed into a series of simple sine waves with discrete frequencies (frequencies that have an integer values 1,2,3 and so on). A non periodic composite signal can be decomposed into a combination of an infinite number of simple sine waves with continuous frequencies, frequencies that have real values.

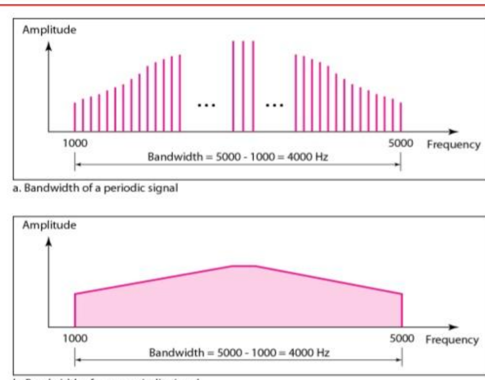
Bandwidth

The range of frequencies contained in a composite signal is its bandwidth. The bandwidth is normally a difference between two numbers.

Eg: if a composite signal contains frequencies between 1000 and 5000, it's bandwidth is 5000 - 1000 = 4000.

The bandwidth of a composite signal is the difference between the highest and lowest frequencies contained in the signal.

Figure 3.12 *The bandwidth of periodic and nonperiodic composite signals*



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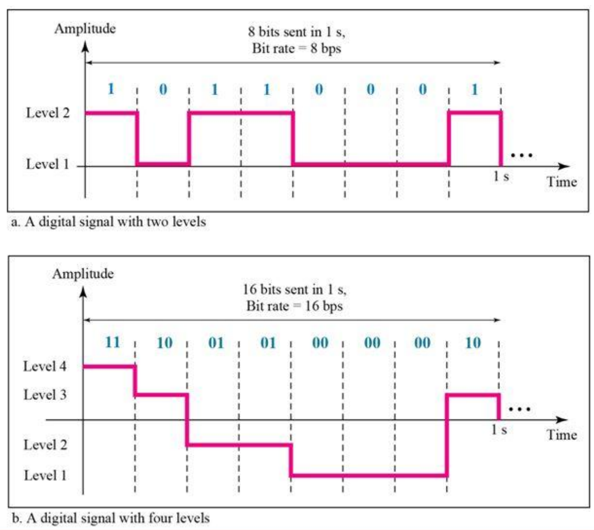
DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a digital signal. Eg: 1 can be encoded as positive voltage and 0 as negative voltage. A digital signal can have more than two levels. We can send more than one bit for each level.
Figure shows two signals, one with two levels and the other with four.

Figure 3.16 *Two digital signals: one with two signal levels and the other with four signal levels*



3.1

In general, if a signal has *L* levels, each level needs $\log_2 L$ bits.
Eg: $\log_2 4 = 2$ bits

? A digital signal has 8 levels.How many bits are needed per level.

Ans: Number of bits per level = $\log_2 8 = 3$ bits

Bit Rate
Most digital signals are nonperiodic and thus period and frequency are not appropriate characters.
Bit rate is used to describe digital signals. The bit rate is the number of bits sent in 1s, expressed in bits per second (bps).

Bit Length

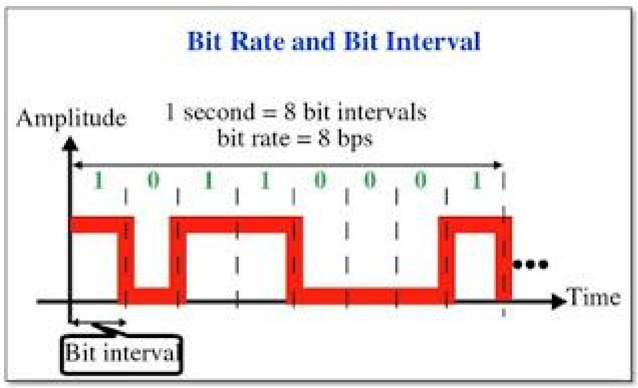
Like the concept of wavelength for an analog signal, bit length is used to describe the digital signal.

The bit length is the distance one bit occupies on the transmission medium.

Bit length = propagation speed x bit duration

Bit Interval

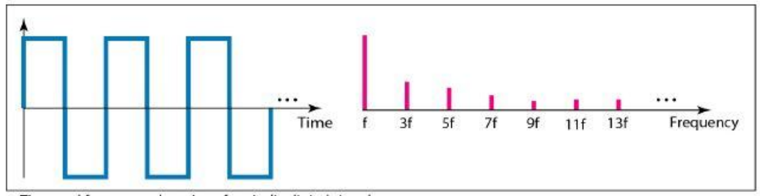
Data can be represented by a digital signal. The bit interval is the time required to send one single bit. This means that the bit rate is number of bits sent in one second, usually expressed in bits per seconds (bps)



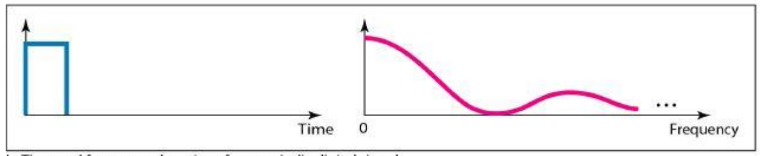
Digital Signal as Composite Analog Signal

A digital signal is a composite analog signal with an infinite bandwidth. A digital signal, in the time domain, comprises connected vertical and horizontal line segments. A vertical line in the time domain means a frequency of infinity (sudden change in time); a horizontal line in the time domain means a frequency of zero(no change in time). Going from a frequency of zero to a frequency of infinity implies all frequencies in between are part of the domain.

If the digital signal is periodic, which is rare in data communications, the decomposed signal has a frequency domain representation with an infinite bandwidth and discrete frequencies. If the digital signal is nonperiodic, the decomposed signal still has an infinite bandwidth, but frequencies are continuous**.**



a. Time and frequency domains of periodic digital signal



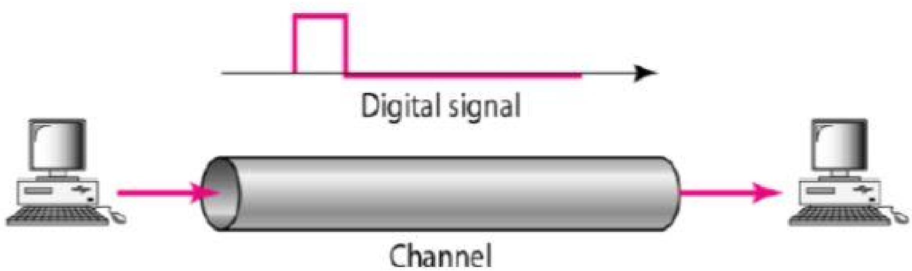
b. Time and frequency domains of nonperiodic digital signal

A digital signal is a composite analog signal with an infinite bandwidth.

Transmission of Digital Signal

A digital signal, periodic or nonperiodic, is a composite analog signal with frequencies between zero and infinity. How can we send a digital signal from point A to point B? We can transmit a digital signal by using one of two approaches:. Baseband transmission or Broadband transmission.

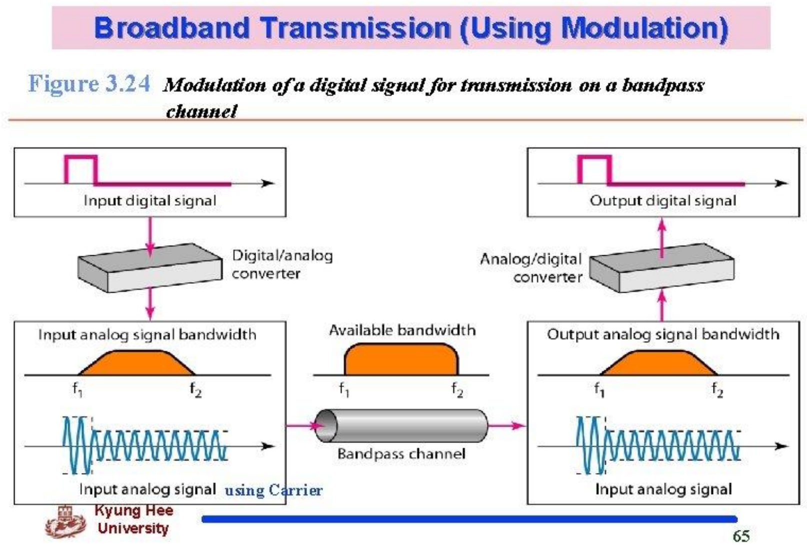
Baseband Transmission: Baseband transmission means sending a digital signal over a channel without changing the digital signal to analog signal.



Baseband transmission requires **a low pass channel,** a channel with a bandwidth that starts from zero. This is the case if we have a dedicated medium with a bandwidth constituting only one channel. Eg: the entire bandwidth of a cable connecting two computers is one single channel. Another example is we may connect several computers to a bus, but not allow more than two stations to communicate at a time.

A low pass channel with infinite bandwidth is ideal, but we cannot have such a channel in real life.

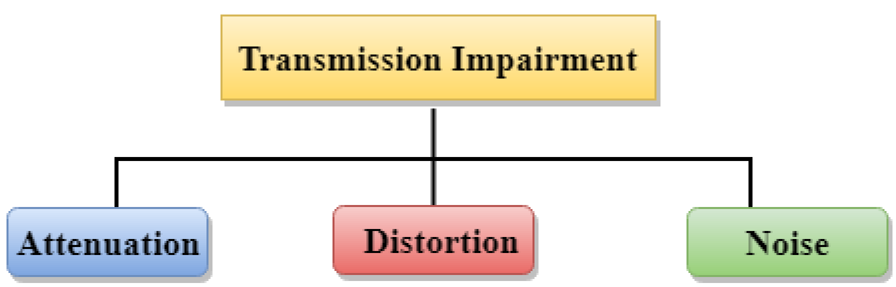
Broadband Transmission: Baseband transmission or modulation means changing the digital signal to an analog signal for transmission. Modulation allows us to use a bandpass channel, a channel with a bandwidth that does not start from zero.



In the figure, a digital signal is converted to composite analog signal. We have used a single-frequency analog signal (carrier), the amplitude of the carrier has been changed to look like the digital signal. At the receiver, the received analog signal is converted to digital, and the result is a replica of what has been sent.
<u>If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.</u>

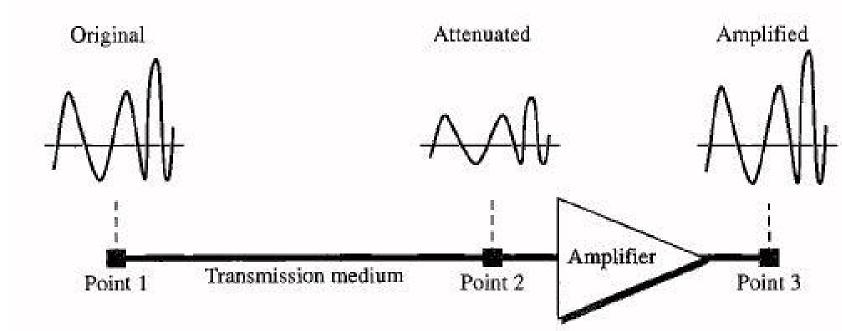
<u>TRANSMISSION IMPAIRMENT</u>

Signals travel through transmission media, which are not perfect.The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. Three cause of impairment are:



Attenuation

Attenuation means loss of energy. When a signal, simple or composite signal, travels through a medium, it loses some of its energy in overcoming resistance of the medium. To compensate for this loss amplifiers are used to amplify the signal.



To show that a signal has lost or gained strength engineers use of the decibel.

The **decibel (dB)** measures the relative strength of two signals or one signal at two different points.The decibel is negative if a signal is attenuated and positive if a signal is amplified.

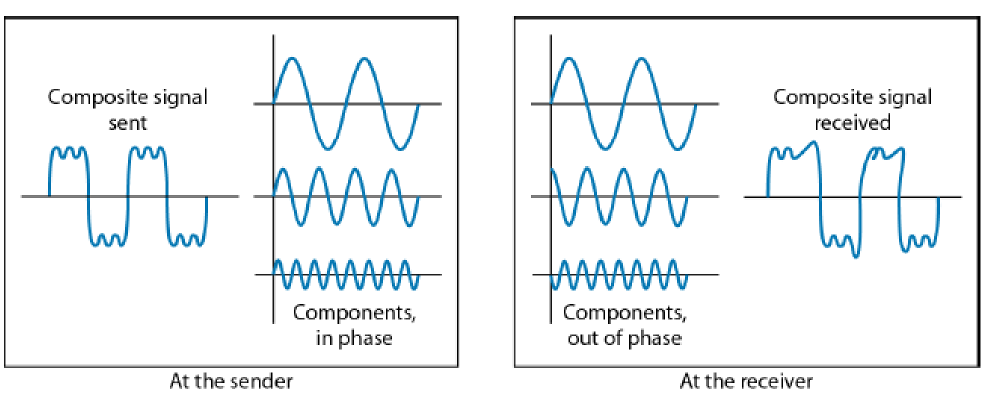
$$\mathbf{dB = 10 \log_{10} P_2/P_1}$$

$\mathbf{P_1}$ and $\mathbf{P_2}$ are the power of a signal at points 1&2 respectively.

?

Distortion

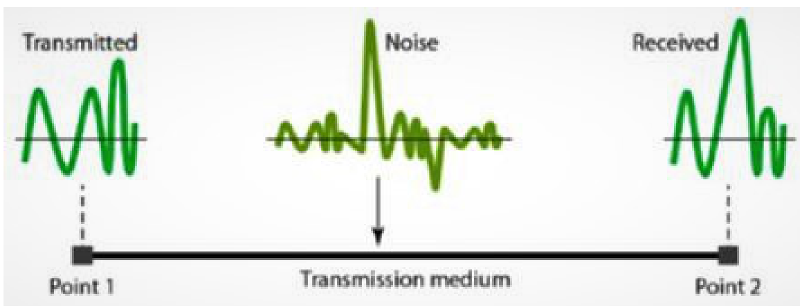
Distortion means that the signal changes its form or shape. It can occur in a composite signal made of different frequencies. Each signal component has its own propagation speed through a medium and its own delay in arriving at the final destination. Signal components at the receiver have phases different from what they had at the sender. The shape of the composite signal is therefore not the same.



Noise

The random or unwanted signal that mixes up with the original signal is called noise. There are several types of noise such as induced noise, crosstalk noise, thermal noise and impulse noise which may corrupt the signal.

Induced noise: It comes from sources such as motors and appliances.These devices act as sending antenna and transmission medium act as receiving antenna.
Thermal noise: It is the movement of electrons in wire which creates an extra signal.
Crosstalk: is when one wire affects the other wire.
Impulse noise: It is a signal with high energy that comes from lightning or power lines



To know the ratio of the signal power to the noise power,
The Signal- to-Noise-Ratio (SNR) is defined as,

$$\mathbf{SNR} = \frac{\textbf{Average signal power}}{\textbf{Average noise power}}$$

SNR is the ratio of what is wanted (signal) to what is not wanted(noise). A high SNR means the signal is less corrupted by noise. A low SNR means the signal is more corrupted by noise.
SNR is the ratio of two powers, it is defined in decibel units SNR_{dB},

$$SNR_{dB} = 10 \log_{10} SNR$$

?The power of a signal is 10mW and the power of the noise is 1μw. What are the values of SNR &SNR_{dB}. *(10mW= 10000μW)*

Ans:SNR=10000/1=10000

$SNR_{dB} = 10 \log_{10}(10000)$

$= 10 \log_{10} 10^4 = 40$

? The value of SNR and SNR dB for a noiseless channel.

Ans: SNR= Signal power/0 =∞

SNR_{dB}= 10 $\log_{10}$ 0 = ∞

DATA RATE LIMITS

In data communication we consider how fast we can send data in bits per second over a channel.

Data rate depends on three factors,

- The bandwidth available
- The level of the of the signal
- The quality of the channel

Two theoretical formulas were developed to calculate the data rate.

- ★ Nyquist for noiseless channel
- ★ Shannon for noisy channel

Noiseless Channel: Nyquist Bit Rate

The noiseless channel, the Nyquist bit rate formula, defines the theoretical maximum bit rate.

$$\textbf{Bit Rate} = 2 \times \textbf{bandwidth} \times \log_2 L$$

Bandwidth is the bandwidth of the channel.

L is the number of signal levels used to represent data.

bit rate is the bit rate in bits per second.

Noisy Channel: Shannon Capacity

We cannot have a noiseless channel,the channel is always noisy. In 1944 Claude Shannon introduced a formula called Shannon Capacity, to determine the theoretical highest data rate for a noisy channel.

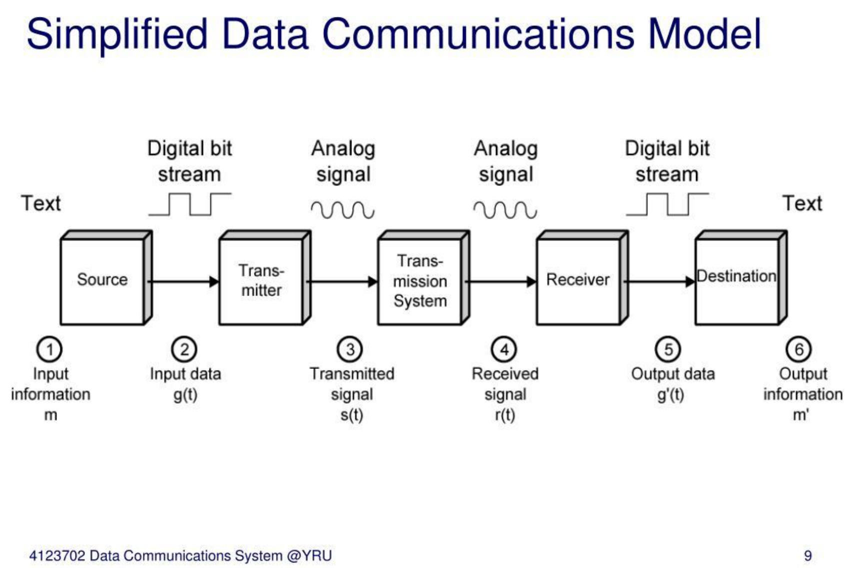
$$\textbf{Capacity} = \textbf{bandwidth} \times \log_2(1+SNR)$$

Bandwidth is the bandwidth of the channel.

SNR is the Signal-to-Noise-Ratio.

Capacity is the capacity of the channel in bits per second.

SIMPLIFIED DATA COMMUNICATION MODEL



<u>Source</u>- it is a device that generates the data to be transmitted.

<u>Transmitter</u>- it transforms and encodes in the way that it can be transmitted.

<u>Transmission System</u>- it is a single transmission line or a complex network connecting source and destination.

<u>Receiver</u>- it accepts signals from the transmission system and converts it into a form that can be handled by the destination device.

<u>Destination</u>- it takes the incoming data from the receiver.