Unit- 1
Fundamentals of Data Communication

Definition, components in data communication - message, sender, receiver, communication channels, set of rules (protocol), data representation, data flow.

* **Data Communication :**
Communication means sharing ~~of~~ or exchanging information. Communication can be local or remote. Communication can be of two types
1. Communication among living things
2. Data Communication

When we talk about human communication then local communication usually occurs face-to face communication.
Remote communication takes place over distance. Humans use telecommunication for remote communication. Tele means far. So telecommunication includes telephony, telegraphy & television.
Communication channel for face-to-face communation is air ~~wh~~ and for telecommunication is cable.

Data communication: It is exchange of data between two devices such as computers, laptops, mobile phones sensor nodes etc via transmission medium. For data communication to happen communication system is required. Communication system is made up of a combination of hardware and software.

Data Communication system has four characterist

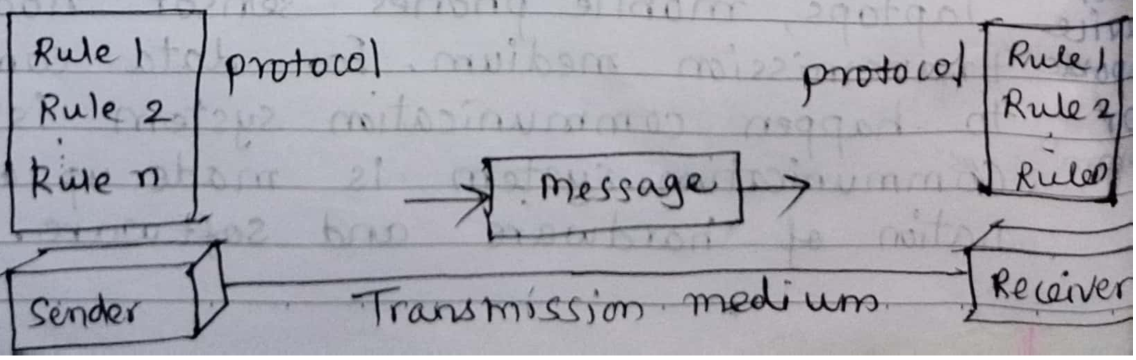
1. Delivery: The ~~data~~ system must deliver dat to the correct destination.
The data must be received by the only intend device.

2. Accuracy: The system must deliver data accura The data transmitted by the sender should n be ~~alterned~~ altered in the way.

3. Timeliness: The system must deliver data on time. It data is not received on time then data becomes useless in many application.
In real-time applications that involves transmission of audio and video, timeliness means delivering data as they are produced, delive in the same order of production and witho significant delay.

4. Jitter: Jitter means variation in the pack arrival time. Eg. If the video packets are sent every 30 ms, then some packets arrive with 30-ms delay and some with 40-ms delay. This variation in arrival of packets is called jitter and it results in uneven quality in the video.

Components in data communication system:
A data communication system has five components as shown in the fig 1.



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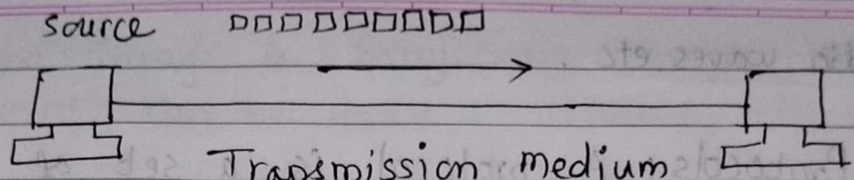


Fig.1a Data Communication

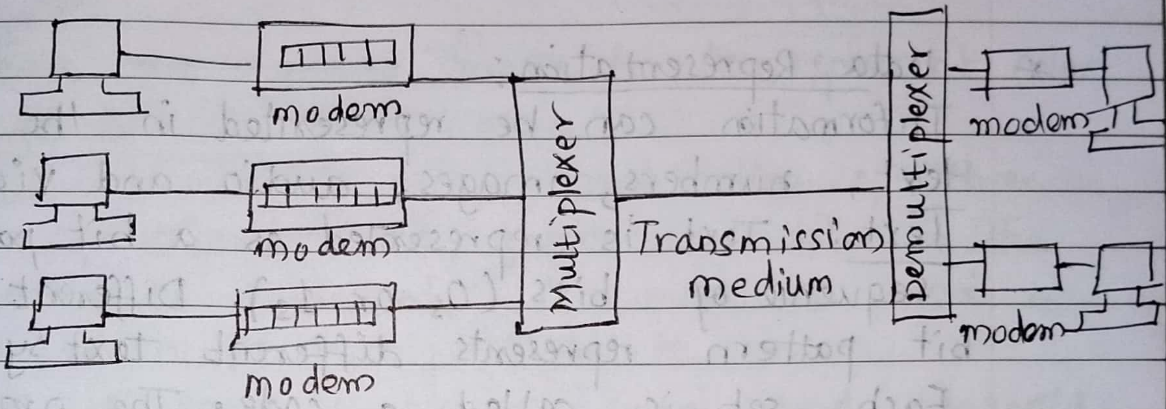


Fig.1b, Real-time data communication systems.

1. Message: message is the information (data) to be communicated in the form of text, numbers, pictures, audio and video.

2. Sender: The sender is the device that sends the data message. Eg. computer, workstation, telephone handset, video camera and so on.

3. Receiver: Receiver is the device that receives the message. Eg. Computer, laptop, mobile, workstation, telephone handset, video, audio etc.

4. Transmission medium: It is a physical path by which a msg travels from sender to receiver. Eg. Twisted pair cable, fiber optics cable,

radio waves etc.

5. Protocols: A protocol is a set of rules that govern data communications. without protocols devices can be connected but can not be made to communicate.

* Data Representation:
Information can be represented in the form of text, numbers, images, audio and video.
Text: Text is represented as a bit pattern, a sequence of bits (0s or 1s). Different set of bit pattern represents different text symbols. Each set is called a code. The process of representing symbols is called coding. Eg. ASCII, EBCDIC, UNICODE etc.

Numbers: Numbers are also represented by bi patterns. Numbering systems such as binary, deci ,octal etc are available.

Images: Images are also represented by bit patterns. An Image is represented as a matrix of pixels (picture elements). Each pixel is a smal dot. The size of the pixel depends on the resolution.
First an image is divided into pixels, each pixel is assigned a bit pattern. The size and the valu of the pattern depend on the image. Eg. If a image is made up of only black and white dots (eg. a chessboard), a ~~one~~ 1-bit pattern is enough to represent a pixel.

If the image is Gray-scale image, then 2-bit patterns can be used.

00 - to represent Black pixel
01 - to represent dark gray pixel,
10 - to represent light gray pixel
11 - to represent a white pixel.

There are many methods to represent color images. Eg: RGB, YCM etc.

RGB is made of a combination of three primary colors: red, green and blue. The intensity of each color is measured and a bit pattern is assigned to it.

YCM is made of yellow, cyan and magenta.

Audio: Audio is different from text, image or number. Audio is continuous not discrete.

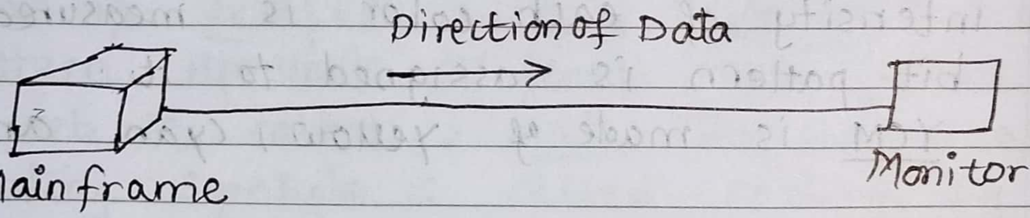
It refers to recording or broadcasting of sound or music.

Video: video refers to the recording or broadcasting of a picture or movie. Video can be a continuous entity (eg. shooting by a TV camera) or can be combination of images, each a discrete entity, arranged to convey idea of motion.

* **Data flow**: How exactly the data is transmitted between sender and receiver is called data flow.

Data flow can be of two types: Simplex, half-duplex or full-duplex.

Simplex mode: Simplex mode is like one way road where vehicle can ~~either~~ only go from one place to another but can't come.
In Simplex mode, communication is unidirectional as shown in the following figure.

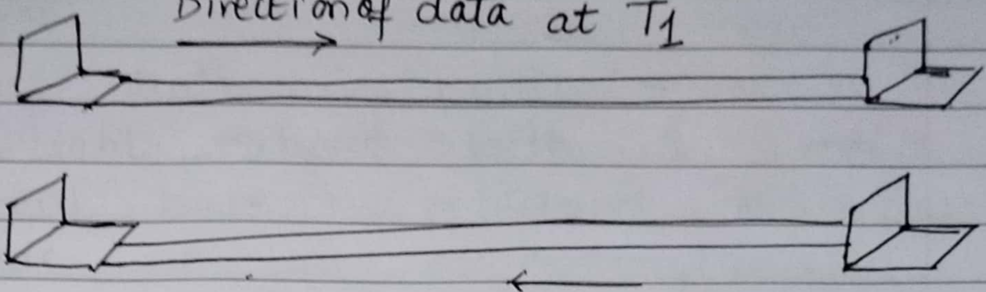


a. Simplex

In this figure, only ~~fro~~ mainframe computer can transmit data to the monitor. Monitor remains in receive mode.
Eg. keyboard and monitor. keyboard can only send keystrokes (input). Monitor can only display output.
In Simplex mode, entire capacity of channel is used to send data.

Half-Duplex: In half-duplex mode, each station can both transmit and receive but not at the same time. When one device transmits, the other device can only receive and vice versa.

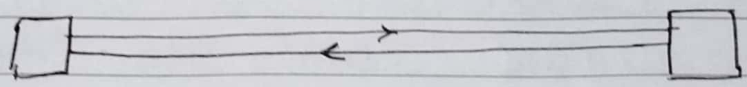
Direction of data at T_1



Direction of data at T_2

Eg. Telephone, mobile phone, Radio (fm Radio mirchi)
So the entire capacity of the channel is taken over by whichever of the two devices is transmitting at the time. In case, data to be transmitted is less then channel capacity gets wasted.

Full-duplex: In this mode, both devices can transmit and receive simultaneously.



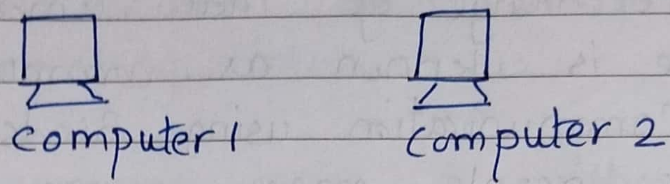
Direction of Data

Fig. Full-duplex communication.

It is like a two-way street with traffic flowing in both directions at the same time. So the capacity of the channel is shared by both the signals (going and coming). The channel is divided into two separate channels one for ~~g~~ sending and one for receiving.

Data Communication : sharing of Informati among two electronic devices through trans mission medium.

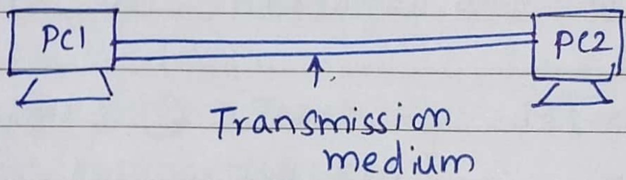
~~For two~~



Two computers just kept near to each othe can not communicate.

For communication, two computers need to be connected with each other.

Computers can be connected using transmission medium like cable. or using wireless ~~com~~ trans. mission medium.



* Can these computers now communicate with each other? Not yet

For ~~devi~~ any two devices to communicate, it has some requirement. It has hardware requirement and software requirement.

Hardware requirement :

1. Transmission medium → Data sent by one computer passes through transmission medium.

2. Transmission medium ~~वर~~ computer ला connect करण्यासाठी slot लागतो. तो slot NIC provide करते.

NIC is network Interface card. It is fitted into the computer that has slot to connect transmission medium. It also has transceiver device for wireless communication. NIC enables computer to transmit ~~d~~ and receive data.

NIC is hardware device. Hardware runs due to software. So NIC ~~ø~~ needs network driver to enable transmission and ~~tr~~ reception of data.

Eg. Printer.

Can it work? No it needs printer driver.

3. Communicating two devices is it sufficient?

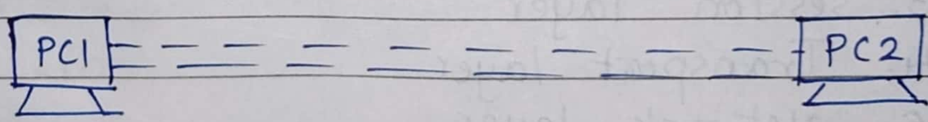
No

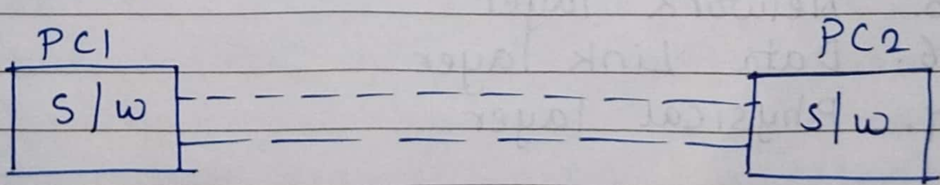
There can two devices, 10 devices, 100 devices, 1000 devices or many more devices that wants ~~m~~ to communicate.

Hence third requirement is switching devices: Bridge, Hub, Switch, Router, Gateway.

4. Software requirement:

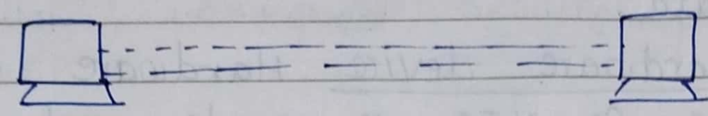
1. Protocols.



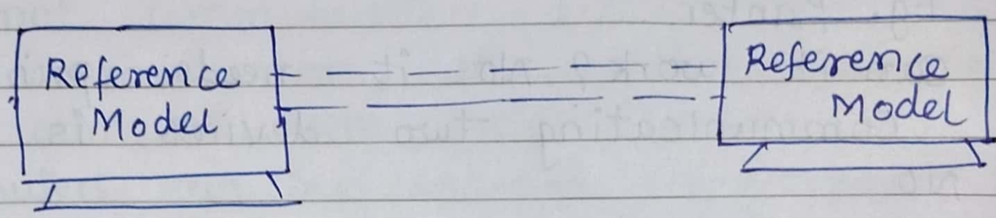


Now computers can communicate with each other.

Let us see s/w requirement in detail. The only s/w requirement is the protocols. Protocols are all packed in reference model.



Reference model is the layered architecture.



Reference models are of two types:

1. OSI reference model
2. TCP/IP reference model.

OSI reference model:

Reference model is a layered architecture
OSI reference model has 7 layers.

1. Application layer
2. Presentation layer
3. session layer
4. Transport layer
5. Network layer
6. Data Link layer
7. Physical layer.

~~When~~ Data communication takes place as shown in the following figure.

[P2]

Router comes into picture where two computers are located far from each other. When ~~two~~ a group of computers connected – Hub and switch are required. Eg Lab When two Labs are required to connected, two switches are required. When a computer is connected with internet, a router is required.

What happens when we send an email? what is the process?
When we search something on Google? What is the process?
When we write a message, Application layer.

Presentation layer
Session layer, Transport layer, Network layer, Data Link Layer, Physical layer?
Digital to analog signal coversion, Analog to digital signal conversion, → (Modulation/Demodulation), which transmission media to use?, what voltage is used to represent 0, what voltage is used to represent 1 bit. Data representation? how is the data flow? Physical layer is ~~connected wit~~ the lowest layer of the TCP/IP reference model.
It is directly connected with transmission

Unit-2 : Data and Signals

When a computer sends data, ~~that it comes to physical layer~~ it is in the form of 0_s to 1_s. It is known as digital data. When ~~bit~~ bits are put on the transmission medium, it needs to represented ~~in~~ using voltages. So 0_s & 1_s and also voltages are ~~known as~~ represented using waves known as signals.

Data represented using voltages in the form ~~of~~ waveform is called as analog signal. Hence when data is transmitted from computer to transmission medium, it is converted from digital to analog signal and when data is received, it is converted from analog to digital signal.

Analog data refers to the information that is continuous. Eg. Analog clock has Hour, minute, hand. Digital data refers to the information that has discrete states. Eg. Digital clock. Suddenly changes from 8:05 to 8:06.

Eg. Sounds made by human voice, take on continuous values. When we speak an analog wave is created in the air. This can be capture by a microphone and converted to an analog signal.

Digital data Eg. data stored in the computer memory in the form of 0_s and 1_s. They can be converted into digital signal. and modulated into an analog signal for transmission across a medium.

Analog and Digital Signals:

Signals can be either analog or digital.

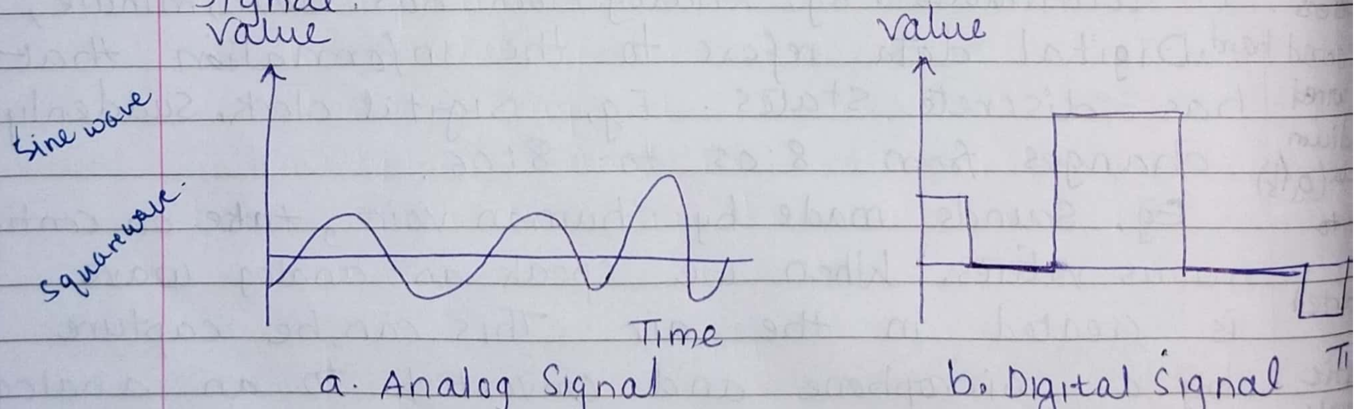
An analog signal has infinitely many levels of intensity over a period of time. As the wave moves from value A to value B, it passes through and includes an infinite number of values along its path.

A digital signal has only a limited number of defined values. Although each value can be any number, it is often 1 and 0.

Representation of signal:

Signal is plotted on a pair of perpendicular axes. vertical axis represents the value or strength of a signal. The horizontal axis represents time.

Following figure represents analog and digital signal.



a. Analog Signal

b. Digital Signal

The curved lines in figure a show continuous values. The figure b shows the sudden jump from one value to another.

Periodic and Nonperiodic:

Analog and ~~po~~ digital signal can be of two types:

1. Periodic
2. Nonperiodic

A periodic signal completes a pattern within a measurable time frame, called a period and repeats the pattern over subsequent identical periods. Completion of one full pattern is called a cycle.

A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.

In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

Periodic Analog Signals:

Periodic Analog signals can be classified as simple or composite.

Simple periodic Analog Signal: These signals can not be decomposed into simpler signals

Composite periodic Analog Signal: These signals is composed of multiple sine waves

Sine wave:

Sine wave is the most fundamental form of a periodic analog signal. It is smooth, consistent and it has a continuous and rolling flow. Each cycle consists of a single arc above the time axis ~~a~~ followed by a single arc below it.

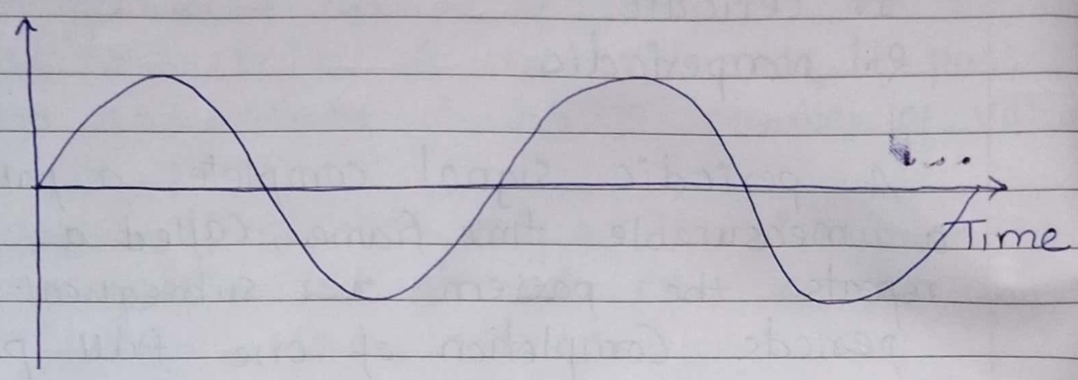
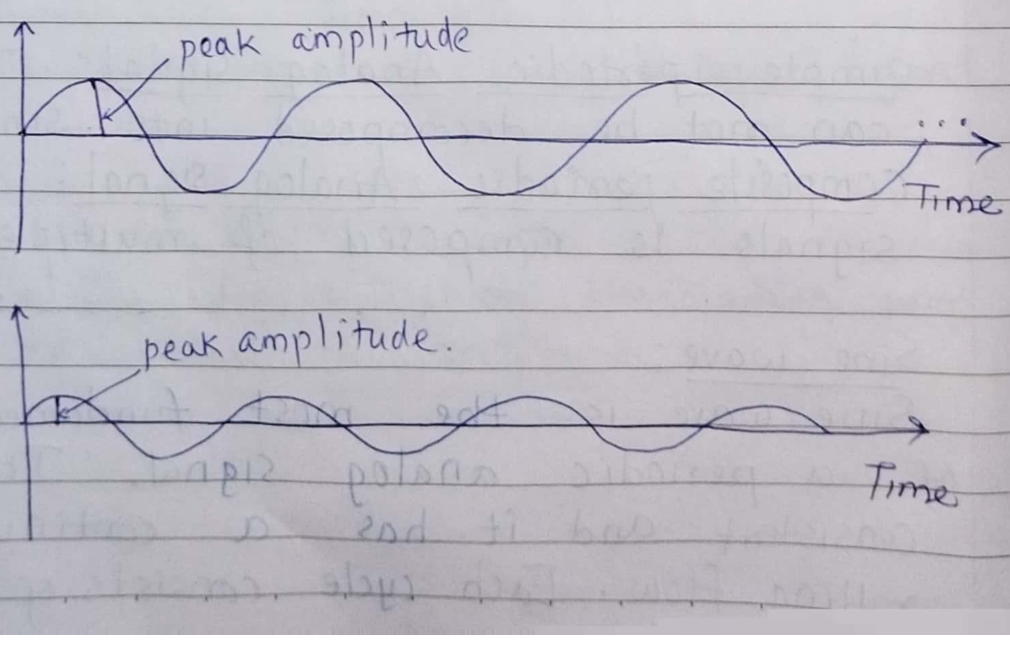


Fig. Sine Wave

A sine wave is represented by three paramete the peak amplitude, the frequency and the pha

Peak amplitude: Peak amplitude of a signal is the absolute value of its highest intensity, proportiona to the energy it carries. Peak amplitude is generally measured in volts. Following fig shows the two signals with same phase and frequency.



Period :

Period is the amount of time in seconds a Signal needs to complete 1 cycle.

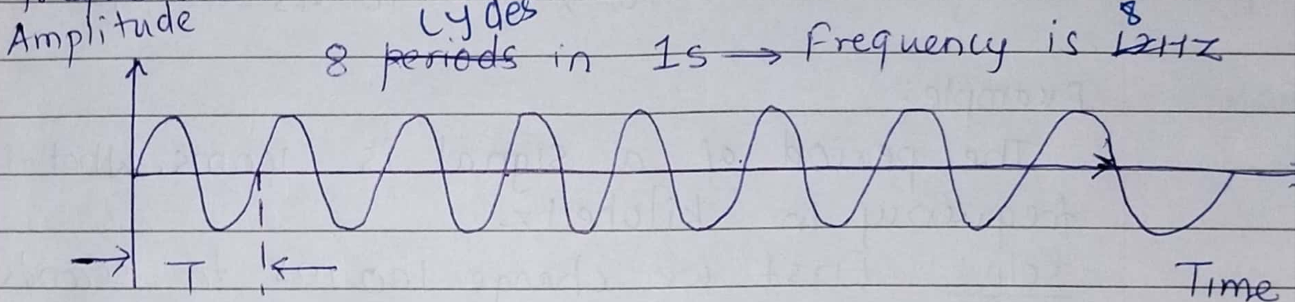
Frequency : refers to the number of periods in 1s. Number of cycles in 1 second.

Period and frequency are inverse of ~~period~~ each other.

$\therefore f = \frac{1}{T}$ and $T = \frac{1}{f}$

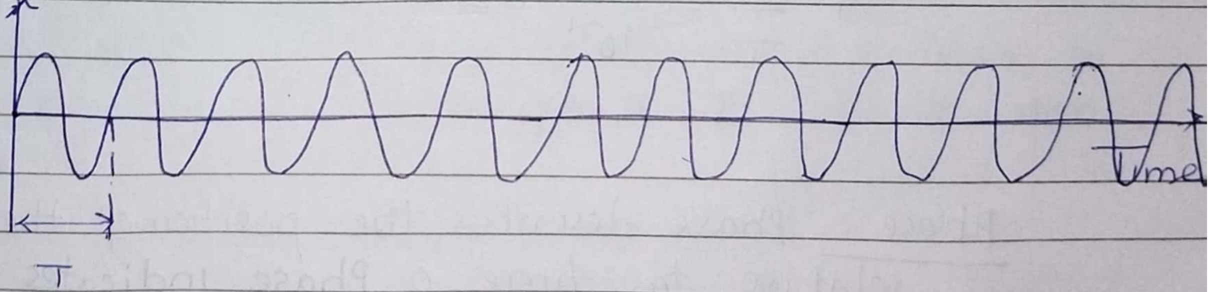
Following figure shows two signals and their frequencies.

8 ~~periods~~ cycles in 1s → Frequency is ~~12Hz~~ 8



Period : $\frac{1}{128}$ s

Fig. A signal with a frequency of 8 Hz.



period $\frac{1}{4}$ s

Fig. A signal with a frequency of 4 HZ

If a signal does not change at all, its frequency is zero. If a signal changes instantaneously

infinite.

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Example:

The power we use at home has a frequency of 60 Hz (50 Hz in Europe). The period of this sine wave can be

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166 s = 0.0166 \times 10^{3} ms = 16.6 ms$$

Example:

Express a period of 100 ms in microsecond

$$100 ms = 100 \times 10^{-3} s = 100 \times 10^{-3} \times 10^{6} \mu s$$
$$= 10^{2} \times 10^{-3} \times 10^{6} \mu s = 10^{5} \mu s$$

Example:

The period of a signal is 100ms. What is its frequency in kilohertz.

soln: First we change 100 ms to seconds and then calculate the frequency from the period ($1 HZ = 10^{-3} KHZ$)

$$100 ms = 100 \times 10^{-3} s = 10^{-1} s$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} HZ = 10 HZ = 10 \times 10^{-3} KHZ = 10^{-2} KHZ$$

Phase: Phase describes the position of the waveform relative to time 0. Phase indicates the status of the first cycle. Wave can be thought of as shifting backward or forward along the time axis. Phase describes amount of that shift.

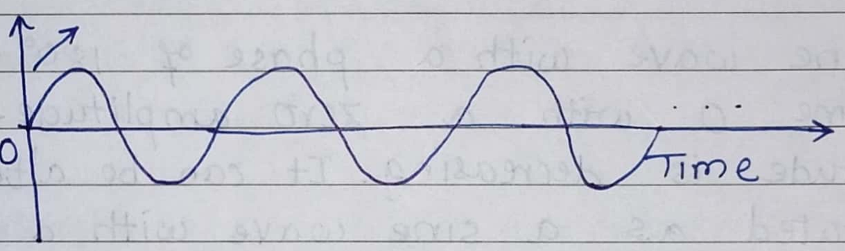
Unit of phase is degrees or radians

[360^{0} is 2π rad]

$\therefore$ ~~1° rad~~ $\quad 1^\circ = \dfrac{2\pi \text{ rad}}{360}$

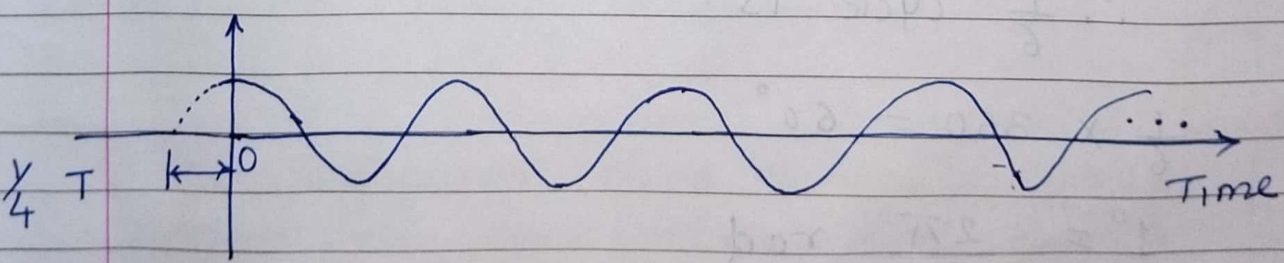
and $\quad 1 \text{ rad} = \dfrac{360}{(2\pi)}$

A phase shift of 360° corresponds to a shift of a complete period.
A phase shift of 180° corresponds to a shift of one-half of a period
A phase shift of 90° corresponds to a shift of one-quarter of a period.
Following figure shows these three ~~se~~ scenari



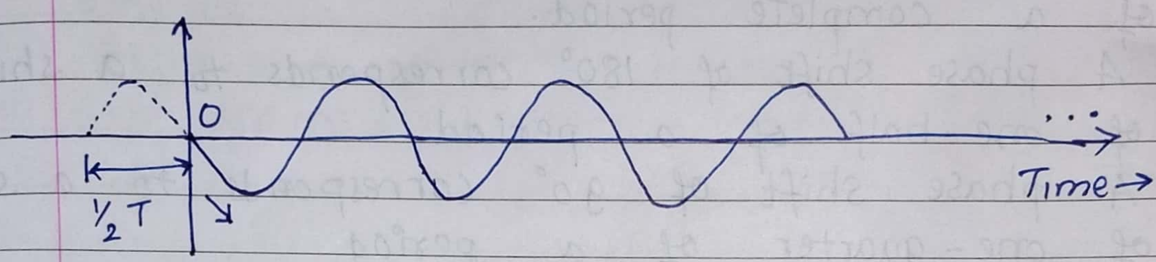
a. 0 degrees

A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitu is increasing. It can be alternatively said as A sine wave with a phase of 0° is not shifted.



b. 90 degrees

A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing. It can be alternatively said as A sine wave with a phase of 90° is shifted left by $\frac{1}{4}$ cycle. However, the signal really doesn't exist before time 0.



c. 180 degrees

A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing. It can be alternatively stated as a sine wave with a phase of 180° is shifted to left by $\frac{1}{2}$ cycle. However, the signal does not really exist before time 0.

Example 1: A sine wave is offset $\frac{1}{6}$ cycle with respect to time 0. What is its phase in degrees and radians?

Soln: 1 complete cycle is 360°.

$\therefore \frac{1}{6}$ cycle is

$$\frac{1}{6} \times 360 = 60^\circ$$

$$1^\circ = \frac{2\pi}{360} \text{ rad}$$

$$\therefore 60^\circ = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

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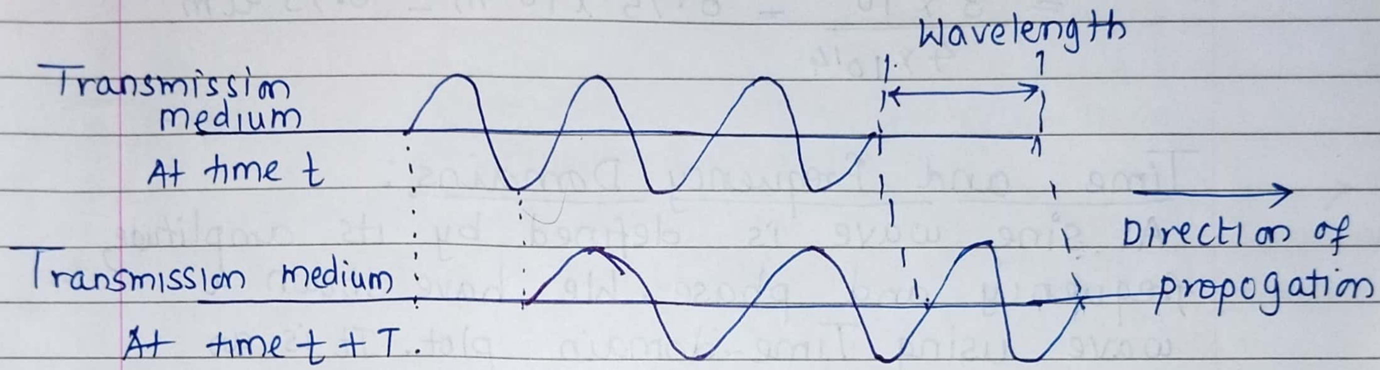
Wavelength :

Wavelength is characteristic of a signal travelling through a transmission medium. Wavelength is the distance a signal travels in one period.

Frequency of a signal is independent of the medium but wavelength of a signal depends on both the frequency and the medium.



Wavelength of a signal can be calculated if the propogation speed (the speed at which the signal travels) and period of the signal is given.

$\therefore$ Wavelength = (propogation speed) x period

$$= \frac{\text{propogation speed}}{\text{frequency}}$$

$$\therefore \lambda = \frac{c}{f}$$

The propogation speed of electromagnetic signals depends on the medium and on the frequency of the signal. Eg. The propogation speed of light in vaccum is 3×10^8 m/s, the speed is lower in air and even lower in cable.

Unit of Wavelength is micrometers (microns).

Example: 1. Find wavelength of red light

In air where frequency $= 4 \times 10^{14}$.

$$\lambda = \frac{c}{f} = \frac{\text{Propogation speed}}{\text{frequency}}$$

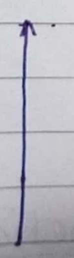
$$= \frac{3 \times 10^{8}}{4 \times 10^{14}} = 0.75 \times 10^{-6} m = 0.75 \mu m.$$

Time and Frequency Domains:

A sine wave is defined by its amplitude, frequency and phase. We have shown a wave using Time-domain plot. It is an amplitude-versus-time plot. This plot shows changes in signal amplitude with respect to time.

We can even use a frequency-domain plot to show the relationship between amplitude and frequency. This plot is concerned with only the peak value and the frequency.

Following fig. shows both time-domain and frequency-domain plots of a sine wave.



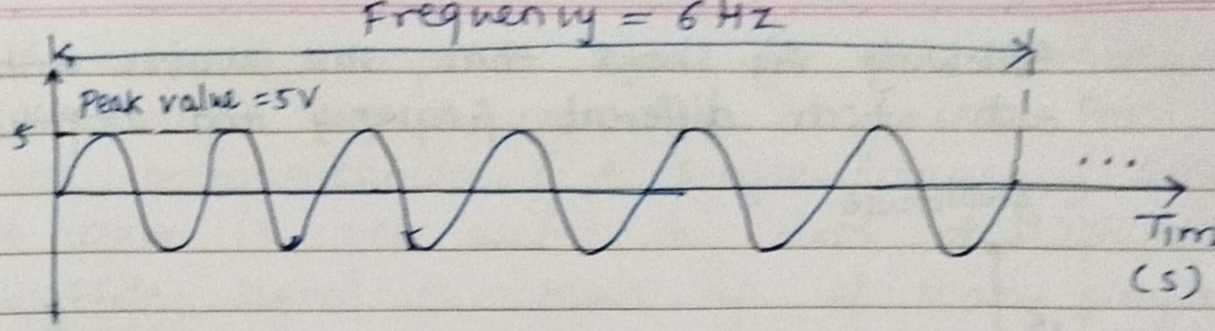


Fig. A Sine wave in the time domain
(Peak value : 5V, frequency : 6Hz)

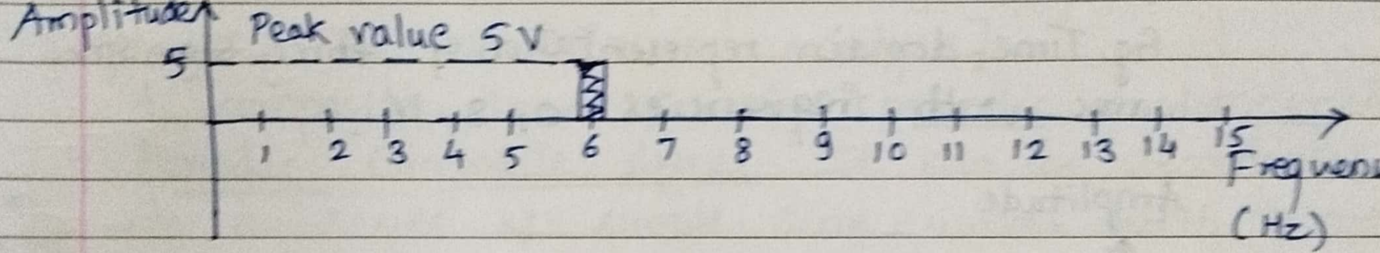


Fig b. The same sign in the frequency domain
(peak Value ; 5V, frequency : 6Hz)

$ Time-domain and frequency domain conveys the same information. The advantages of the frequency domain is that ① we can Immediately see the values of the frequency and peak amplitude. The complete sine wave is represented by one spike. The position of the spike shows the frequency and its height shows the peak amplitude.

② Frequency domain is more compact and useful when we are dealing with more than one sign wave.

following fig. shows three sine waves ~~with~~ each which different frequency and amplitude.

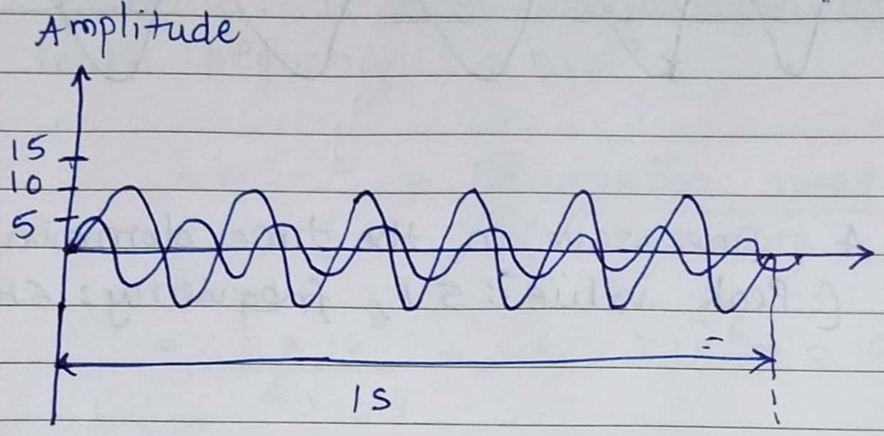


fig. Time-domain representation of three ~~sign~~ sine waves with frequencies 0, 8, 16.

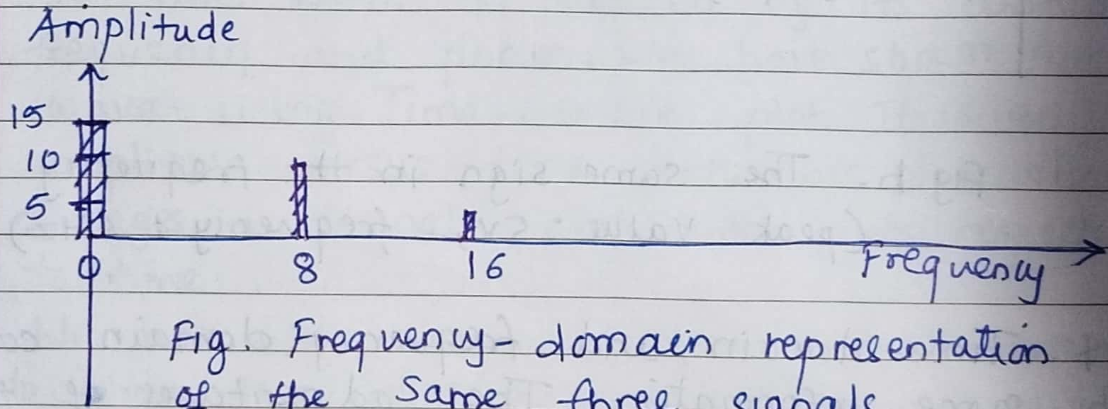


Fig. Frequency-domain representation of the same three signals.

Composite Signals :

Applications of simple sine wave :

1. Single sine wave can be sent to carry electric energy from one place to another.

Eg. The power company sends a single sine wave with a frequency of 60 Hz to distribute electric energy to houses and businesses.

2. A single sine wave can be ~~sent~~ used to send an alarm to a security center when a burglar opens a door or window in the house.

We need a composite signal for data communication. Simple signal can not be used for data communication. [A single-frequency sine A wave is not useful in data communication. Composite signal is made up of many simple sine waves.

In the early 1900s, the French mathematician Jean-Baptiste Fourier showed that any composite signal is actually a combination of simple sine waves with different frequencies, amplitudes and phases.[This is Fourier analysis].

A composite signal can be periodic or nonperiodic.

Periodic Composite signal: It can be decomposed into a series of simple sine waves with discrete frequencies (frequencies that have integer values 1, 2, 3 and so on)

Nonperiodic composite signal: It can be decomposed into a combination of an Infinite number of simple sine waves with continuous frequencies (frequencies that have real values.)

Fig. shows a periodic composite signal with freq. f. It is very difficult to manually decompose this signal into a series of simple sine waves. There are hardware and software tools that decompose the composite signal.

The amplitude of the sine wave with frequency f is almost the same as the peak amplitude of the composite signal. The amplitude of sine wave with frequency 3f is one-third of that of the first and the amplitude of sine wave with frequency 9f is one-ninth of the first. The frequency f is same as the frequency of the composite signal. It is called the fundamental frequency

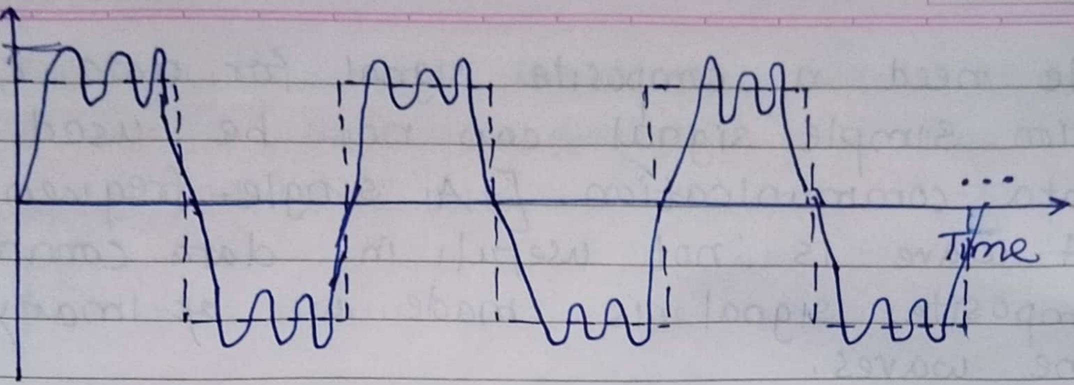


Fig. A periodic composite signal

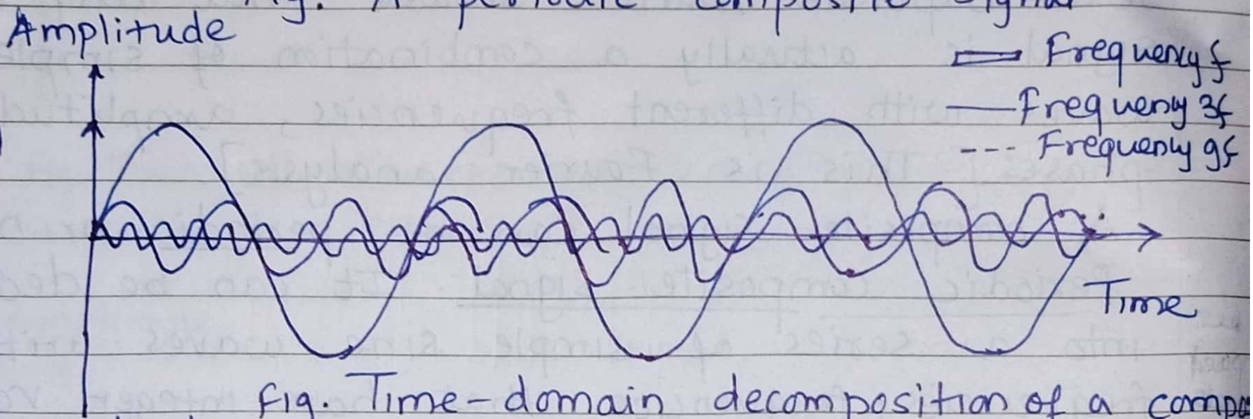


Fig. Time-domain decomposition of a composite signal

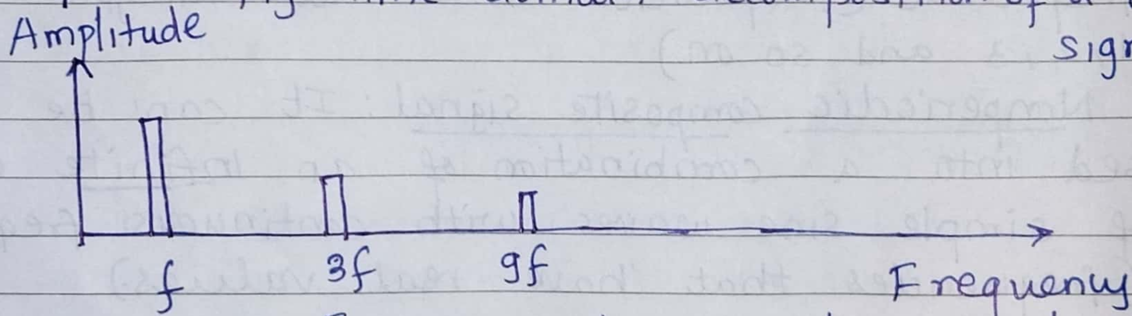


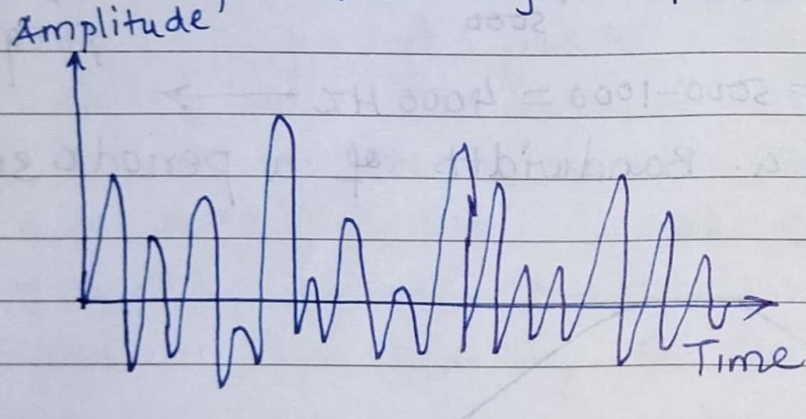
Fig. Frequency-domain decomposition of the Composite signal.

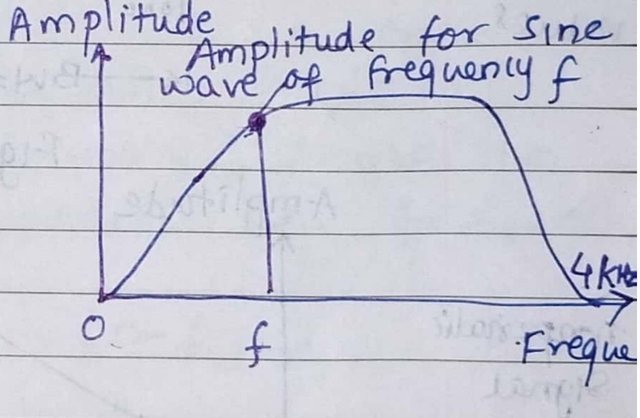
or first harmonic. The sine wave with frequency 3f has a frequency of 3 times the fundamental frequency. It is the third harmonic. The third sine wave with frequency 9f has a frequency of 9 times the fundamental frequency. It is called ninth harmonic.

Following figure shows a nonperiodic composite signal. It can be the signal

created by a microphone or a telephone set when a word or two is pronounced.
Eg. The composite signal can not be periodic bcaz that implies that we are repeating the same word or words with exactly the same tone.

In a time-domain representation of this composite signal, there are infinite number of simple sine frequencies. Although the number of frequencies in a human voice is infinite, the range is limited. A normal human being can create a continuous range of frequencies between 0 and 4 KHz. The frequency decomposition of the signal yields a continuous curve.





a. Time domains   b. Frequency domain

There are an infinite no. of frequencies between 0.0 and 4000.0 (real values). To find the amplitude related to frequency f, we draw a vertical line at f to intersect the envelope curve. The height of the vertical line is the amplitude of the corresponding frequency

Bandwidth: The range of frequencies containe in a composite signal is its bandwidth. The bandwidth is the difference between highest frequency and lowest frequency.

Eg. If a composite signal contains frequencie between 1000 and 5000, its bandwidth is 5000 − 1000 = 4000.

Figure shows the bandwidth of periodic and nonperiodic composite signals.

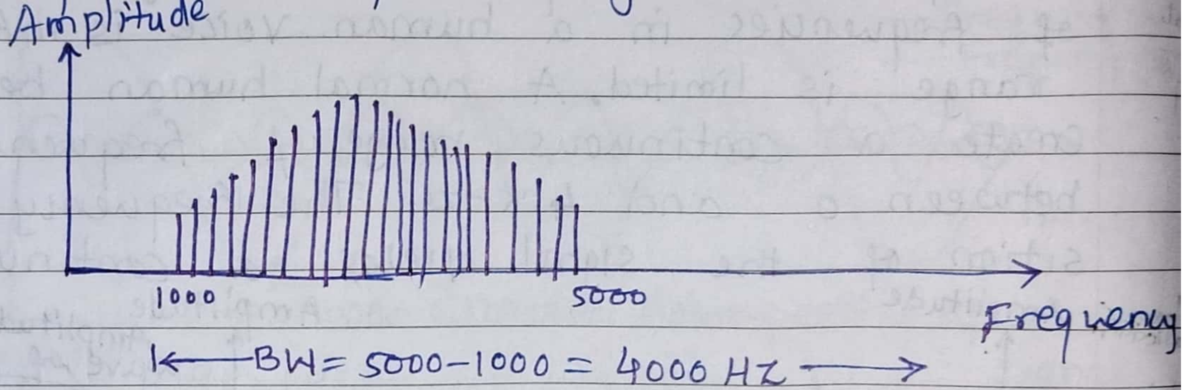


Fig a. Bandwidth of a periodic signal.

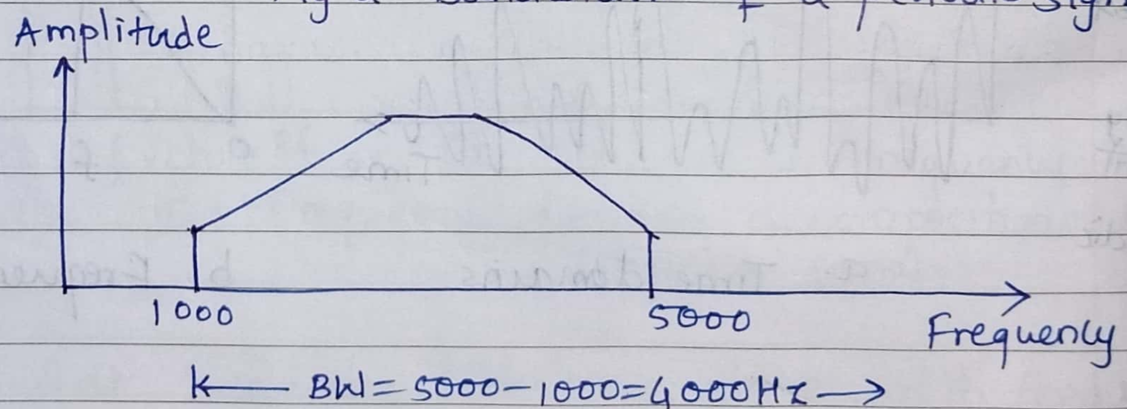


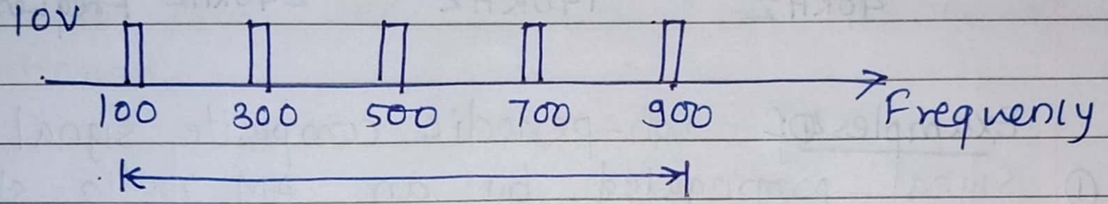
Fig b. Bandwidth of a non-periodic sign

Fig. shows two composite signals, one periodic and one non-periodic. BW of periodic signal contains all integer frequencies between 1000 and 5000 (1000, 1001, 1002, ---). The BW of non-periodic signals has the same range but the frequencies are continuous 1000, 1000.1, 1000.2, 1000.3, - - - -.

Example 1: If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700 and 900 Hz. What is the bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Soln:

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

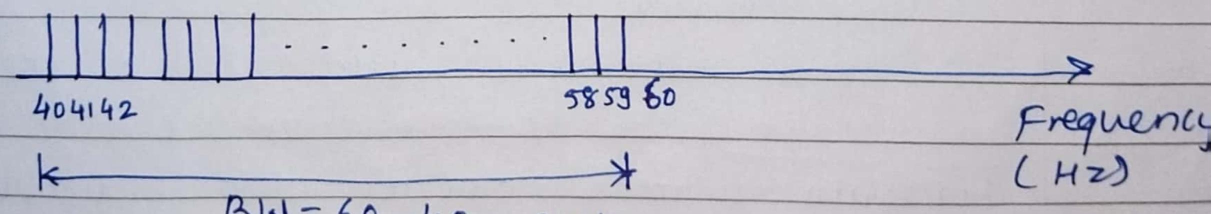


Bandwidth = 900 − 100 = 800 HZ

Example 2: A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

Soln: $B = f_h - f_l \Rightarrow 20 = 60 - f_l$

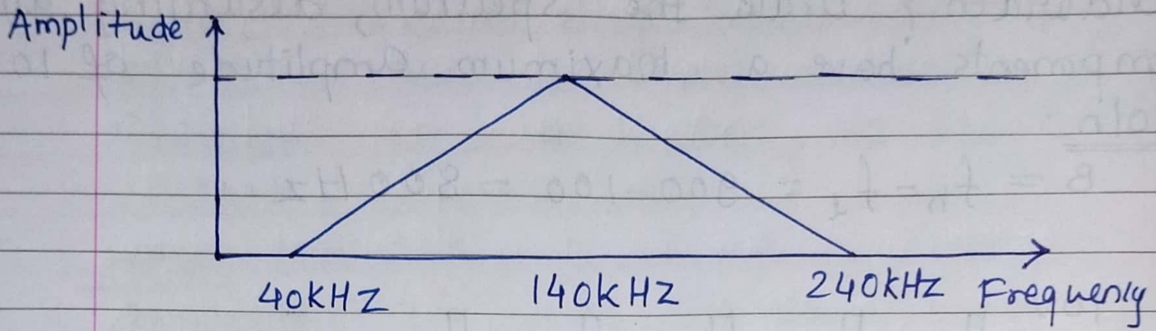
$$f_l = 60 - 20 = 40 \text{ HZ}$$



BW = 60 − 40 = 20 HZ

Example 3: A non-periodic composite signal has a bandwidth of ~~240~~ 200 KHZ, with a middle frequency of 140 KHZ and peak amplitude of 20V. The two extreme frequencies have an amplitude of Q. Draw the frequency domain of the signal

Soln: The lowest frequency must be 40 KHz and the highest at 240 KHz.



Examples of non-periodic composite signal is the

① Signal propogated by an AM radio station. In US, each AM radio station is assigned a 10-KHz bandwidth. The total BW dedidated to AM radio ranges from 530 to 1700 KHz.

② Signal propogated by an FM radio station. In US, each FM radio station is assigned a 200-KHZ bandwidth. The total BW dedicated to FM radio ranges from 88 to 108 MHz.

③ Signal received by an old-fashioned analog black and white TV.

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Unit 2
Data and Signals

Analog and Digital Data :

Data can be analog or digital. Analog data refers to the information that is continuous.
Eg. An analog clock that has hour, minute and second hands gives information in a continuous form. The movement of the hands is continuous.

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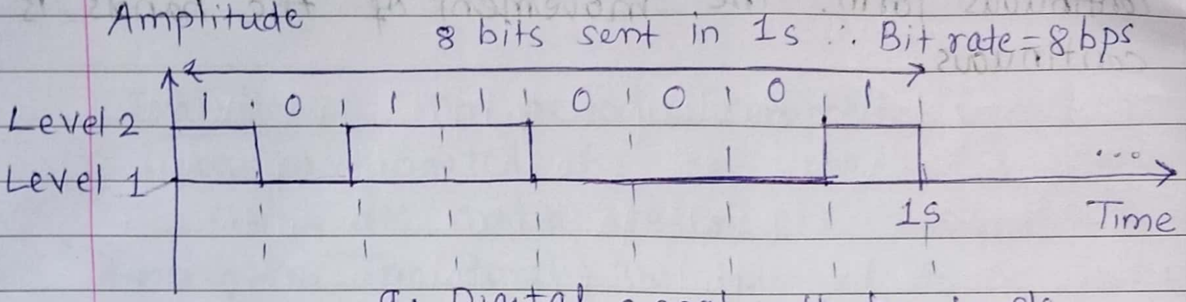
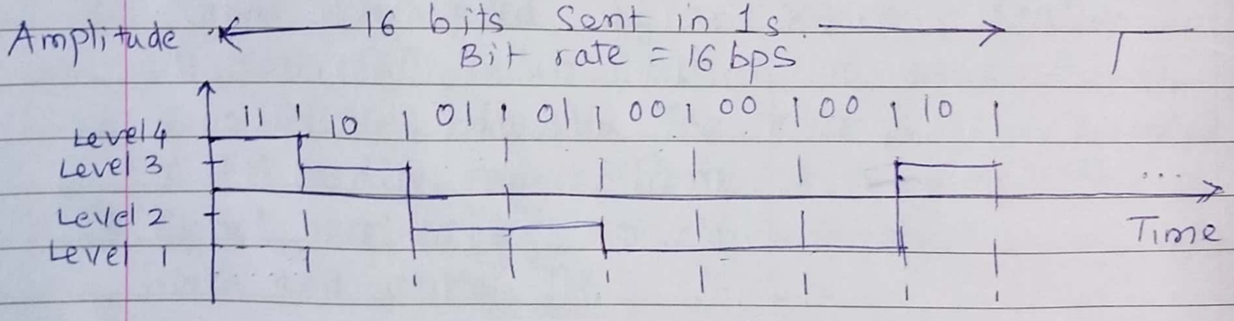
Digital Signals: Information is represented by both analog and digital signals. Eg. 1 can be encoded as a positive voltage and 0 as zero voltage. A digital signal can have more than two levels. For this we can use more bits for each level.

Following figure shows two digital signals one with two levels and the other with four.



a. Digital signal with two levels



b. Digital signal with four levels

In fig a, we have used 1 bit per level, while in fig b, we have used 2 bits per level.
Formula to find no. of bits required for L levels is

$\log_2 L$ bits.

∴ for four levels, we need $\log_2 4 = 2$ bits in figure b.

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Example: Find no. of bits required to send a Signal of ~~three~~ 8 levels.

soln: No. of bits per level = $\log_2 8 = 3$.

Example:

A digital signal has 9 Levels. How many bits are needed per level.

soln: No. of bits per level = $\log_2 9 = 3.17$ bits

This answer is not realistic. The no. of bits sent per level needs to be an integer as well as a power of 2.

Bit rate:

Most digital signals are nonperiodic and hence period and frequency are not appropriate characteristics. Instead, bit rate is used to describe digital signals.

The bit rate is the number of bits sent in 1s. Unit of bit rate is bits per second.

Example: To download text documents at the rate of 100 pages per second, find the required bit rate of the channel.

soln:

A page is an average of 24 lines. Each line has on an average 80 characters.

If we assume that one character requires 8 bits, the bit rate is

$100 \times 24 \times 80 \times 8 = 1{,}536{,}000$ bps $= 1.536$ Mbps

Example:

A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequenly (two samples per Hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Soln:

Bit rate = $2 \times 4000 \times 8 = 64{,}000$ bps $= 64$ kbps.

Example 3:

What is the bit rate for high definition TV (HDTV)?

Soln:

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16:9 (in contrast to 4:3 for regular TV), which means the screen is wider.

There are 1920 by 1080 pixels per screen and the screen is renewed 30 times per second. 24 bits represents one color pixel.

$\therefore$ Bit rate $= 1920 \times 1080 \times 30 \times 24$
$= 1{,}492{,}992{,}000$
$= 1.5$ Gbps

The TV stations reduce this rate to 20 to 40 Mbps through compression.

Bit Length: It is something simillar to wavelength for analog signal. It is the distance one bit occupies on the transmission medium.

Bit length = propogation speed × bit duration.

Digital signal as a composite Analog Signal:

According to fourier analysis, a digital signal, periodic or nonperiodic, is a composite analog signal with frequencies between zero and infinity. Data communication uses non-periodic digital signals.

We will now see, how a digital signal can be sent from point A to point B?

There are two different approaches:

1) Baseband Transmission 2) Broadband Transmission

Baseband Transmission: (Low-pass channel)

Baseband Transmission means sending a digital signal over a channel without converting the digital signal to an analog signal. Following figure shows the baseband transmission.

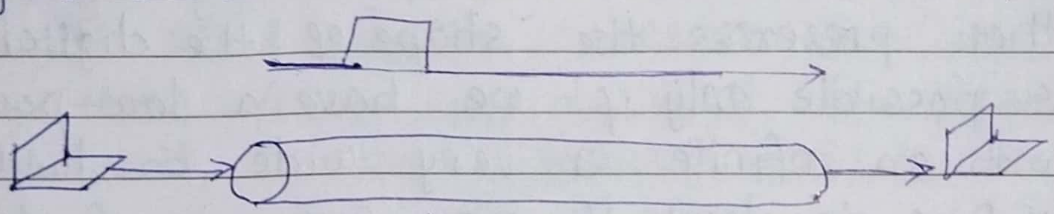


Fig. Baseband Transmission.

Baseband Transmission requires a low-pass channel(a channel that starts from zero.). This case can be when a dedicated medium with a bandwidth constituting only one channel that is entire BW of a cable connecting two computers is one single channel.

Eg. Many computers are connected to a channel but only two computers can communicate at a time.

Following figure shows BW of two Low pass Channels.

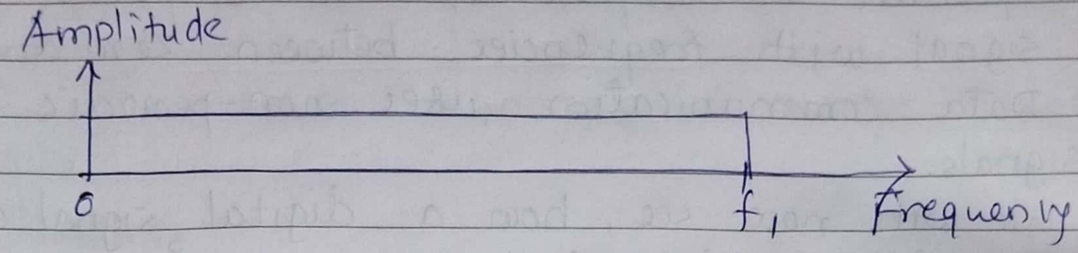


Fig. a Low pass channel, wide BW.

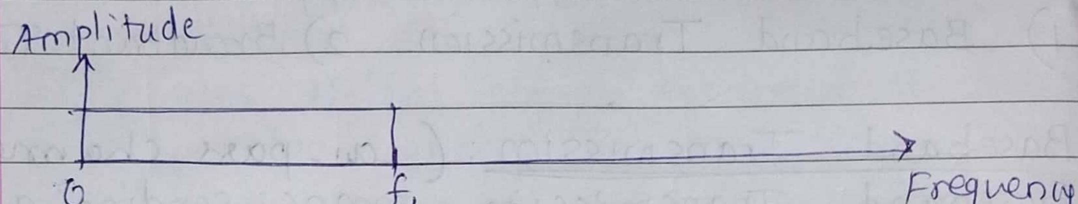


Fig b, Low pass Channel, narrow BW

Case1: Low-pass channel with wide Bandwidth
Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.
LAN Bus topology is an example of dedicated channel between two computers.

<u>Case 2</u>: Low-pass channel with limited BW
In this type of channel, we approximate the digital signal with an analog signal. The level of approximation depends on the available BW.

In baseband transmission, the required BW is proportional to the bit rate; if we need to send bits faster, we need more BW.
A ~~better~~ approximation can be achieved using first and third harmonic.
A better approximation can be achieved by using

first, third and fifth harmonics.

Example:
What is the required BW of a low-pass channel if we need to send 1 Mbps by using base-band transmission?

Soln:
Bit rate = 1 mbps.

① The minimum bandwidth is $B = \text{bit rate}/2$
$= 500\text{ kHz}$.

∴ we need a low-pass channel with frequencies between 0 and 500 kHz.

② The better result can be achieved by using the first and the third harmonics with the required bandwidth $B = 3 \times 500\text{ kHz}$
$= 1.5\text{ MHz}$

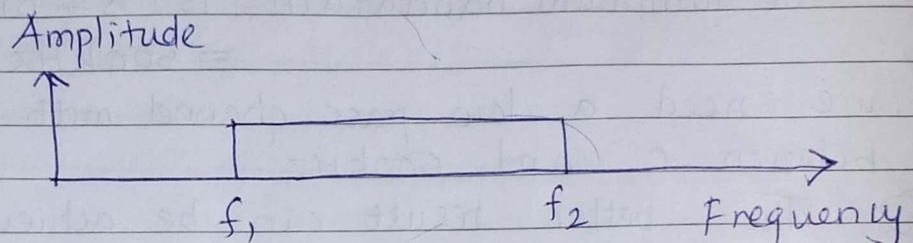
③ A still better result can be achieved by using first, third and ~~the~~ fifth harmonic with $B = 5 \times 500\text{ kHz} = 2.5\text{ MHz}$

Example: We have a low-pass channel with bandwidth 100 kHz. What is the max. bit rate of this channel?

Soln: Maximum bit rate can be achieved if we use the first harmonic. The bit rate is 2 times the available BW or 200 kbps.

Broadband Transmission: or modulation means changing the digital signal to an analog signal for transmission. Modulation allows us to use a baseband channel. It is a channel with bandwidth that doesnot start from zero. This type of channel is more available than a low-pass channel.

Following figure shows a bandpass channel.



Bandpass channel

A low-pass channel can be considered a bandpass channel with the lower frequency starting at zero.

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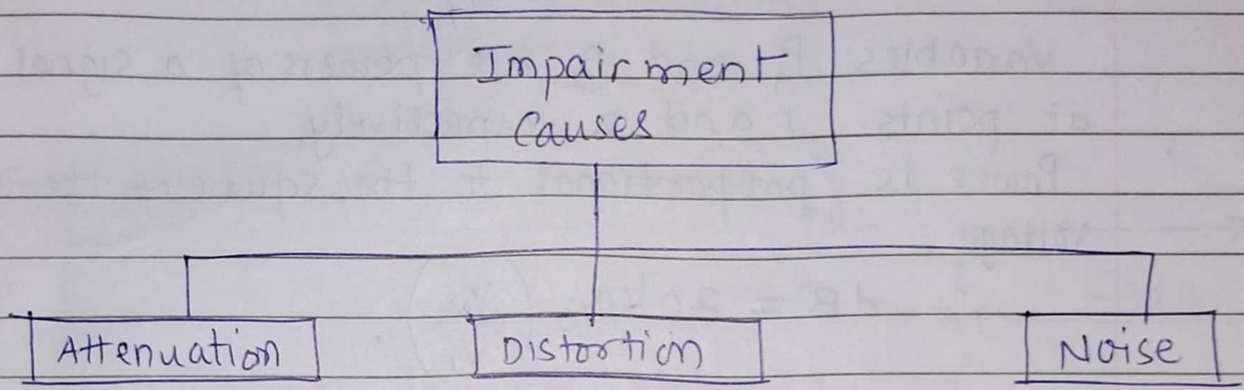
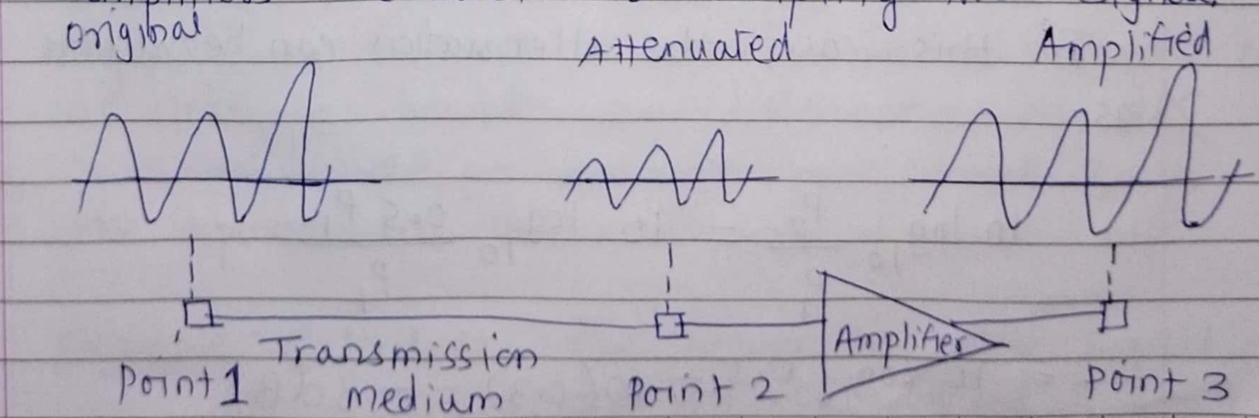
Transmission Impairment

Signal travels through transmission media.
~~It~~ Transmission media is not perfect and causes impairment to signal. The signal being sent and being received will be different because of impairments. There are three causes of impairment.

1. Attenuation
2. Distortion
3. Noise.



Attenuation: Attenuation means the signal becomes weak as it looses energy in overcoming the resistance of the medium. Some of the electrical energy in the signal is converted to heat that's why a wire carrying electric signal gets warm.
Signal becomes weak means amplitude of the signal is reduced. So to compensate this loss, amplifiers are used to amplify the signal.



Decibel: Decibel is the unit to measure strength of the signal whether signal has lost or gained strength.
The Decibel (DB) measures the relative strengths of two signals or one signal at two different points. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

Variables P_1 and P_2 are powers of a signal at points 1 and 2 respectively.
Power is proportional to the square of the voltage.

$$\therefore \; dB = 20 \log_{10} \left(\frac{V_2}{V_1}\right).$$

Here we express dB in terms of power.

Example 1: Suppose a signal travels through a transmission medium and its power is reduced to ½. Calculate the attenuation.
Soln: Power is reduced to ½

$$\therefore \; P_2 = \frac{1}{2} P_1 .$$

In this case, the attenuation can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1}$$

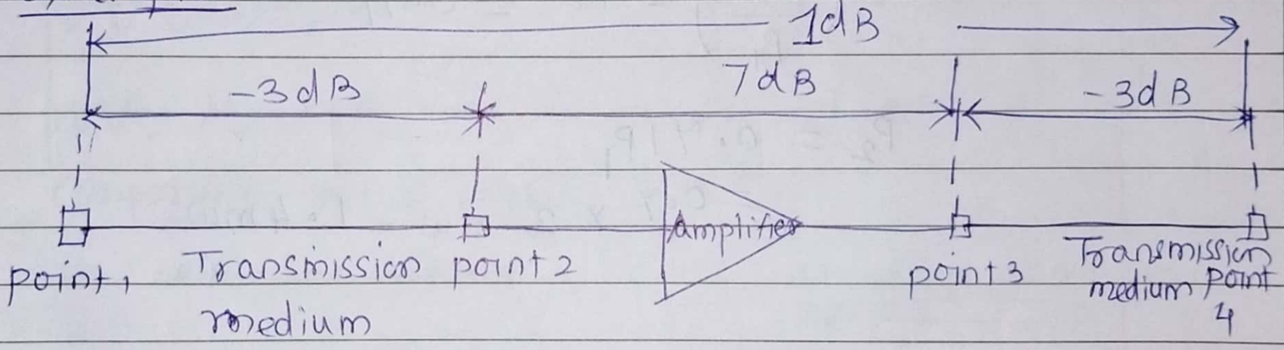
$$= 10 \log_{10} 0.5 = 10(-0.3) = -3 dB.$$

A loss of 3dB (−3dB) is equivalent to losing one-half the power.

Example 2: A signal travels through an amplifier and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10 P_1}{P_1} = 10 \log_{10} 10 = 10(1) = 10\,dB$$

Example 3:



The signal has gained in power.

Decibel can add and substract the values.

~~for~~ Sometimes the decibel is used to measure signal power in miliwatts. It is referred to as dB_m and is calculated as dB_m.

$dB_m = 10 \log_{10} P_m$ where P_m is the power in miliwatts.

Example: Calculate the power in the signal as

$dB_m = 10 \log_{10} \rightarrow dB_m = -30 \rightarrow \log_{10} P_m = -3$

Faulty Data → second +,
faulty search → PAN card no ↵
enter ↵ white color button ↵
Data will be fetched & Information to get ready.

$P_m = 10^{-3}$ mW.

Example:

The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5km?

Soln: The loss in the cable in decibels is

$5 \times (-0.3) = -1.5$ dB.

We can calculate the power as

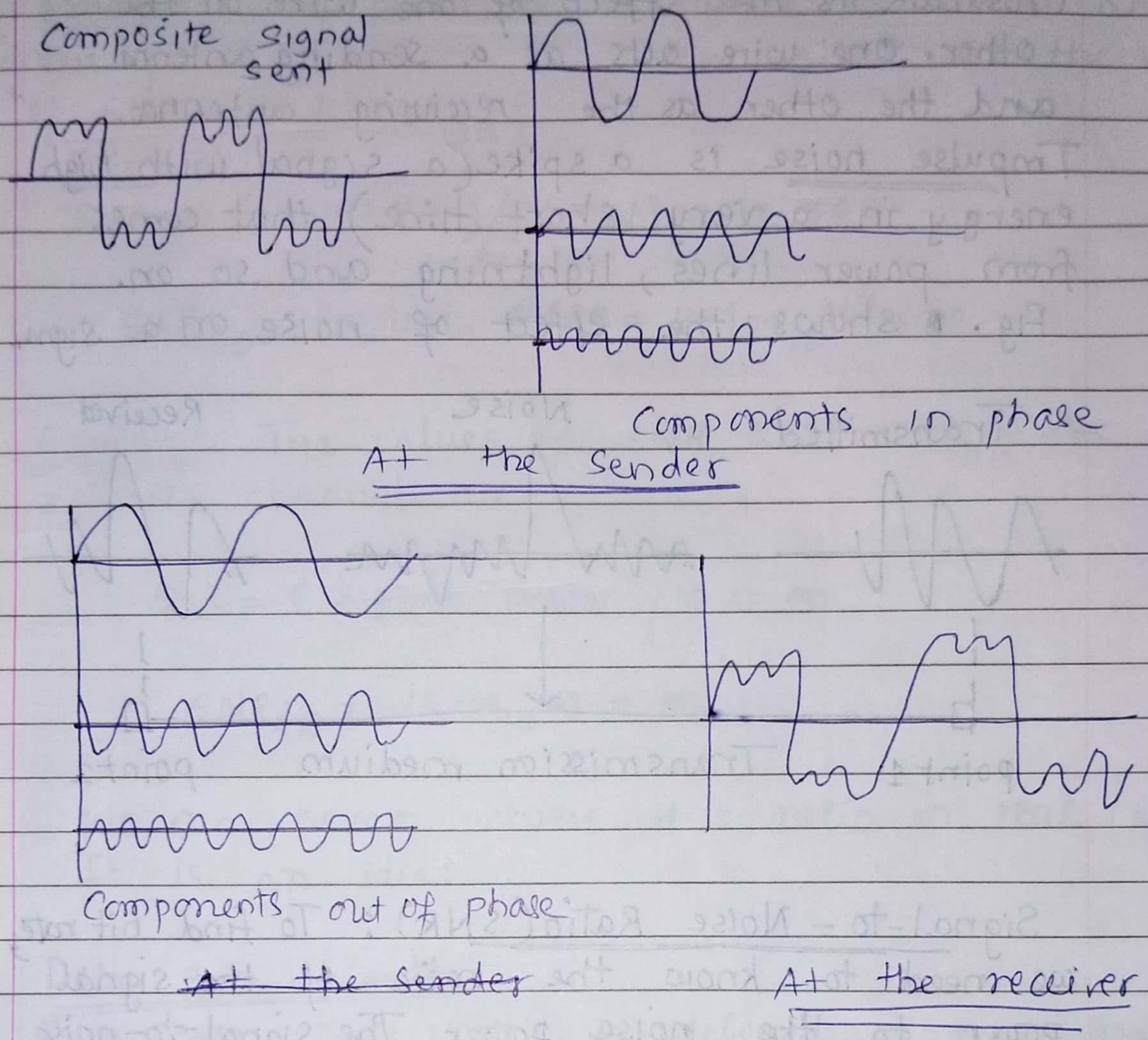
$$dB = 10 \log_{10}(P_2/P_1) = -1.5$$

$$= \left(\frac{P_2}{P_1}\right) = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1$$

$$= 0.7 \times 2 \text{ mw} = 1.4 \text{ mw}.$$

Distortion: Distortion means the signal changes its form or shape. Distortion occurs in composite signal made of different frequencies. Each signal component has its own propogation speed through a medium and so delay in arriving at the final destination. The difference in delay creates a difference in phase. Signal components at the receiver have phases different from what they had at the sender. Therefore, the shape of the received signal is not the same.



Noise: It is another cause of impairment.
There are several types of noise :
1. Thermal noise 2. Induced noise 3. crosstalk
4. Impulse noise

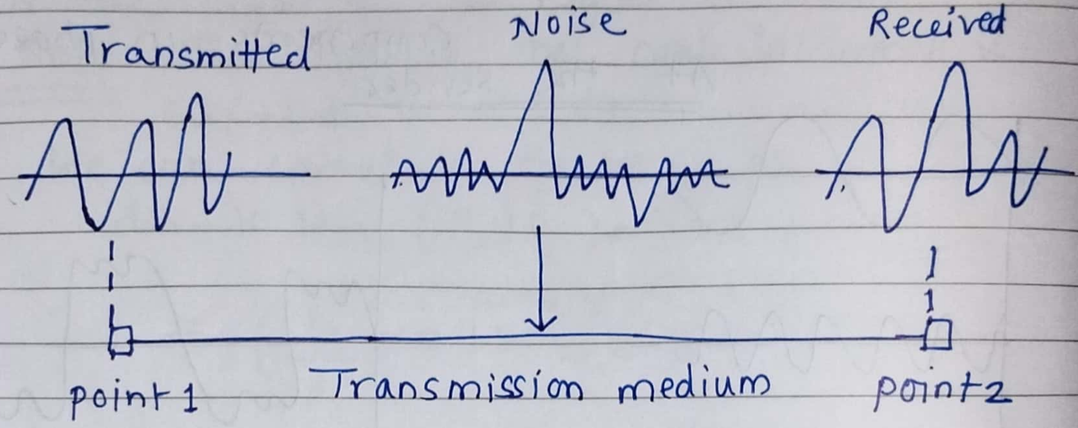
Thermal noise is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter.

Induced noise comes from sources such as motors and appliances. These devices act as a sending antenna and the transmission medium acts as the receiving antenna.

Crosstalk is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.

Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning and so on.

Fig. shows the effect of noise on a signal.



Signal-to-Noise Ratio (SNR): To find bit rate, we need to know the ratio of the signal power to the noise power. The signal-to-noise ratio is defined as

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

SNR is actually 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.

Unit of SNR is decibel.

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

Example: The power of a signal is 10 mW and the power of noise is 1 μW. What are the values of SNR and SNR_{dB}?

Soln:

$$SNR = (10{,}000\,\mu W)/(1\,\mu W) = 10{,}000$$

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

Example: The values of SNR and SNR_{dB} for a noiseless channel are

$$SNR = (\text{signal power})/0 = \infty$$

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

We can never achieve this ratio in real life. It is an ideal.

Data Rate Limits:

Data rate: Data rate is defined as how many bits can be transmitted in one second. Data rate depends on three factors:

1. The bandwidth available
2. The level of the signals we use
3. The quality of the channel (the level of noise)

We can calculate the data rate for noisy channel and noiseless channel.

1. Data rate for noiseless chanel can be find by using Nyquist formula
2. Data rate for noisy channel can be found by using Shannon.

1. Noiseless Channel : Nyquist Bit Rate

For noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

Here, bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data, ~~bit rate~~ BitRate is the bit rate in bits per second.

Increasing the levels of a signal may reduce the reliability of the system.

Example: Does the Nyquist theorem bit rate agree with the intuitive bit rate described in baseband transmission.

Yes Nyquist formula ~~is~~ can be applied to baseband transmission and modulation. It can be applied when we have two or more levels of signals.

Example: Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. Find max bit rate.

Soln:

$$\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Example: consider the same noiseless channel transmitting a signal with four signal levels (for each level we send 2 bits). Find max bit rate

Soln:

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}.$$

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Example: We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Soln: using Nyquist formula,

$$\text{Bit Rate} = 2 \times \text{Bandwidth} \times \log_2 L$$

$$265000 = 2 \times 20000 \times \log_2 L$$

$$\log_2 L = 6625$$

$$L = 2^{6625}$$

$$= 98.7 \text{ levels.}$$

The result is not power of 2 hence we need to either increase or decrease the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, bit rate is 240 kbps.

Noisy channel : Shannon Capacity :

In reality, channel can not be noiseless. The channel is always noisy. In 1944, Claude Shannon introduced a formula, called the Shannon capacity to determine the theoretical highest data rate for a noisy channel. Channel's capacity

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

Capacity is measured in bits per second.

Example: calculate the capacity for the extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. {The noise is so strong that the signal is faint}

Soln: $C = B \log_2(1 + SNR) = B \log_2(1+0) = B \log_2 1 = B \times 0 = B$

Example: ~~We can e~~ Calculate the channel capacity of a telephone line having a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162.

Soln:

$$C = B \log_2(1+SNR)$$
$$= 3000 \log_2(1+3162)$$
$$= 3000 \times 11.62 = 34,860 \text{ bps.}$$

This means that the highest bit rate for the telephone line is 34,860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the SNR.

Example: Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity

Soln:

$$SNR_{dB} = 10 \log_{10} SNR$$
$$\cancel{10}$$
$$SNR = 10^{SNR_{dB}/10}$$

$$SNR = 10^{36/10} = 10^{3.6} = 3681.$$

$$C = B \log_2(1+SNR) = 2\times10^6 \times \log_2 3982$$
$$= 24 \text{ Mbps.}$$

Example:

Using Both limits: In practice, we need to use both methods to find the limits and signal levels.

Example: We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the approxiate bit rate and signal level ?

Soln: First find capacity (bit rate) using Shannon formula

$$C = B \log_2 (1 + SNR)$$
$$= 10^6 \log_2 (1+63) = 10^6 \log_2 64 = 6 \text{ Mbps}.$$

The shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower 4 Mbps for example.

Use Nyquist formula to find no. of signal levels.

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L$$
$$L = 4.$$

The shannon capacity gives us the upper limit, the Nyquist formula tells us how many signal levels we need.

Performance:

We need to understand what are the different performance measures that will measure how the network is performing.

Bandwidth: Bandwidth is the capacity of the channel. It can be measured in hertz and in bits per second.

Bandwidth in Hertz: Bandwidth in Hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass. Eg. We can say the Bandwidth of a subscriber telephone line is 4 kHz.

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Bandwidth in Bits per second: It refers to the number of bits per second that a channel can transmit. Eg. BW of a fast Ethernet network is a maximum of 100 Mbps. This means that this network can send 100 Mbps late use

Throughput: It refers to the ~~data~~ number of bits received by the receiver. Though the bandwidth of the channel is more, the throughput can be less depending on the congestion on the road.

Example: A network with bandwidth of 10 Mbps can pass only an average of 12000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Soln:

$$\text{Throughput} = (12000 \times 10000)/60 = 2\text{ Mbps}$$

The throughput is almost $1/5$ of the bandwidth in this case.

Latency (Delay):

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

Latency is made of four components: propogation time, transmission time, queuing time and processing delay.

Latency = propogation time + transmission time + queuing time + processing delay

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Propogation time: It is the time required for a bit to travel from the source to the destination.

$$\text{Propogation time} = \frac{\text{Distance}}{(\text{propogation speed})}$$

The propogation speed of electromagnetic signal depends on the medium and on the frequency of the signal. Eg. In a vacuum, light is propogated with a speed of 3×10^8 m/s. It is lower is air and much lower in a cable.

Example: What is the propogation time if the distance between the two points is 12000 km? Assume the propogation speed to be 2.4×10^8 m/s in cable.

Soln:

propogation time $= (12000 \times 10000) / (2.4 \times 2^8) = 50$ ms.

Transmission Time: It is time required to send an entire message (the last bit of the message) out of the device on to the transmission medium.

Transmission Time $=$ (Message size) / Bandwidth.

First bit takes time equal to propogation speed.

Example: What are the propogation time and the transmission time for 2.5 kB (kilobyte) message if the BW of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12000 km and the light travels at 2.4×10^8 m/s.

Propogation time = $(12000 \times 1000) / (2.4 \times 10^8)$
$= 50$ m/s

Transmission time $= (2500 \times 8) / 10^9 = 0.020$ ms

Example: What are the propogation time and the transmission time for a 5-MB message if the bandwidth of the network is 1 Mbps. Assume the distance between the sender and the receiver is ~~20000~~ 12000 km and light travels at 2.4×10^8 m/s.

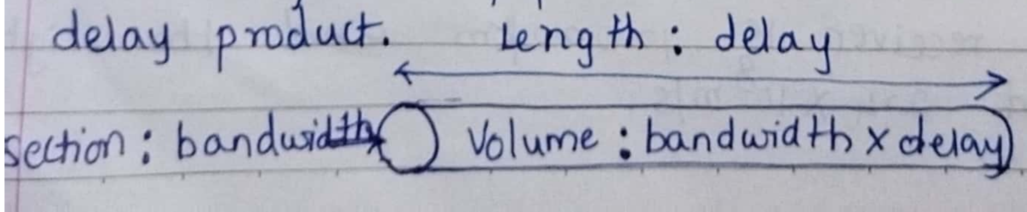
Soln:

Propogation time $= (12000 \times 1000) / (2.4 \times 10^8)$
$= 50$ ms

Transmission time $= (5,000,000 \times 8) / 10^6 = 40$ sec

Queuing Time: It is the time spent by the message in the queue of each intermediate node before processing. The queueing time is not fixed. It depends on the load present in the network.

Bandwidth-Delay product:
Bandwidth and Delay are two performance metrics of a link. In data communication, the Bandwidth-Delay product is very important. We can think about the link between two points as a pipe. The cross section of the pipe represents the bandwidth and the length of the pipe represents the delay. We can say the volume of the pipe defines the bandwidth-delay product.



Jitter : Jitter is the metric related to delay. Jitter is the difference between delay encountered by the different packets of data.