Introduction

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Communication:

- Communication is simply the basic process of exchanging the information from one place to another.
- Communication is the process of establishing connection or Link between two points for information exchange.
- a communication is a collecting of individual telecommunication networks, transmission systems, relay stations, tributary stations and terminal equipment usually capable of interconnection and interoperation to form an integrated whole.

data - the raw function or figure is called data i.e (25°c)
Information - the processed data is called information ie (25°C today)
message - the transfer of information is called message.

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Classification of Electronic Communication System:

The electronic communication system may be classified into various categories as shown in figure:

(Electronic Communication System)

- # Unidirectional / Bidirectional Communication
  - Simplex
  - Half duplex
  - Full duplex
- # Nature of Information Signal
  - analog
  - digital
- # techniques of transmission
  - Baseband (unmodulated)
  - Passband (modulated)

#Unidirectional / Bidirectional Communication:

(1) Simplex :

- In these system, information is communicated in only one direction.
- For example (a) the radio or TV broadcasting system can only transmit, they cannot receive.

(b) the telemetry system transmits information about the physical status of the satellite such as its position of temperature.

(2) Half duplex :

- these system are bidirectional, i.e. they can transmit as well as receive but not simultaneously. At a time, these systems can either transmit or receive.

For example, a trans receiver, walky talky set, the radio communication such as those used in citizen band and amateur radio are half duplex system.

- the direction of communication alternates.

(3) Full duplex:

- these are truely bidirectional systems as they allow the communication to take place in both the directions simultaneously.
- these system can transmit as well as receive at all time.

For example: the telephone system, mobile communication.

Nature of Information signal

(1) Analog communication →

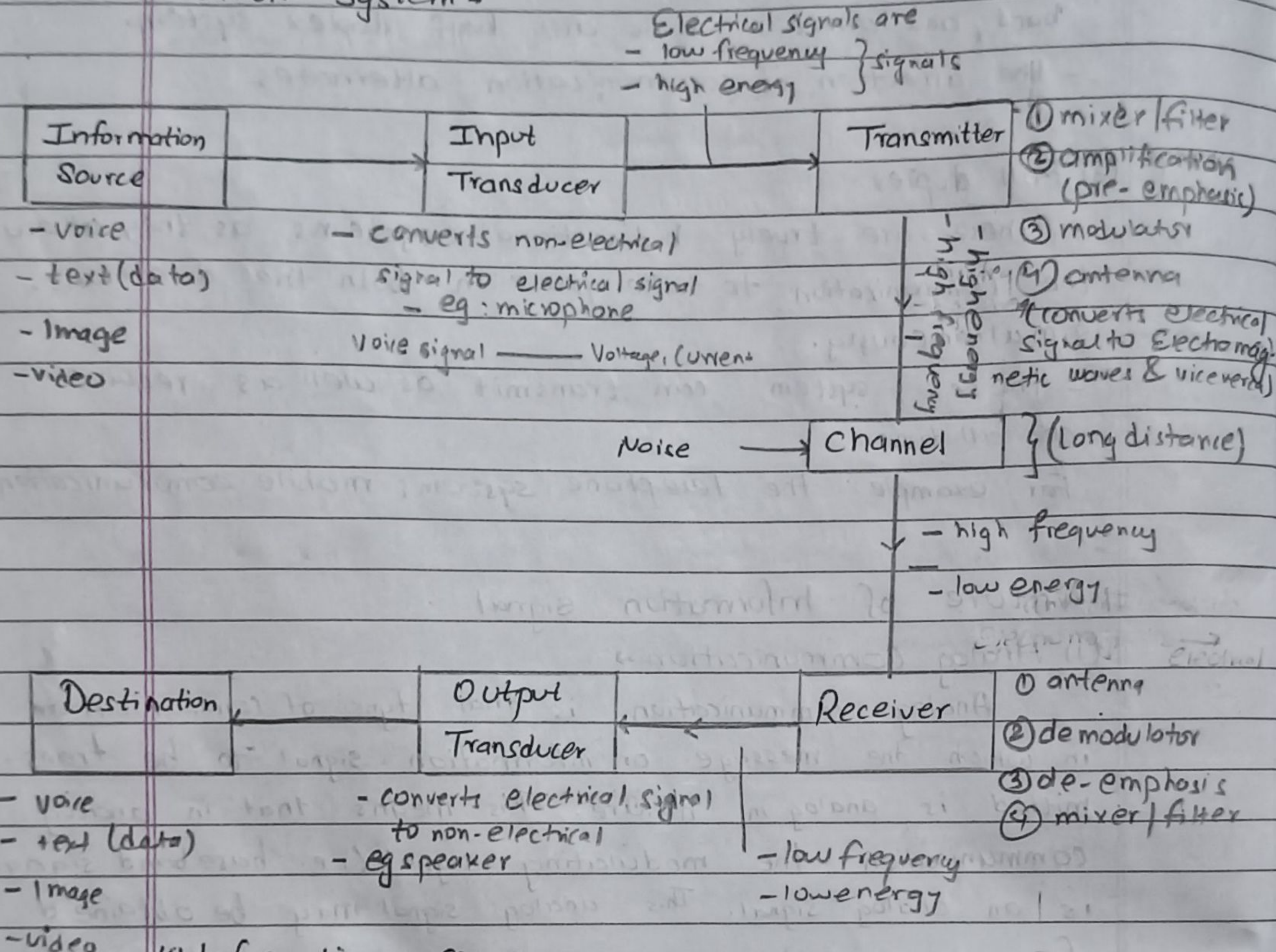
Analog communication is that type of communication in which the message or information signal to be transmitted is analog in nature. This means that in analog communication the modulating signal (i.e. baseband signal) is an analog signal. This analog signal may be obtained from source such as image, speech, video, text, etc.

Applications of communication

One way: (1) FM Broad casting (2) TV Broad casting (3) AM Broad casting (4) Cable (5) Remote control (6) Pager (transmits one way voice)

two way: (1) mobile communication (2) telephony (3) data communication (4) Amateur Radio (Ham Radio) (5) Citizen Band (CB) (6) Radar (7) SONAR (Sound navigation and Ranging) (8) Walkie Talkie

⇒ Block diagram / Components / Elements of analog communication system →



(1) Information source -

We know that a communication system serves to communicate to message or information. This message or information originates in the information source. In general, there can be various message in the form of words, groups of words, code, symbols, sound signal, etc.

- However out of these messages only the desired message is selected and conveyed or communicated.
- In short, we can say that the function of information source is to produce required message which has to be transmitted.

(2) Input transducer-

- A transducer is a device which converts one form of energy into another form.
- The message from the information source may or may-not be electrical in nature. In a case when the message produced by the information source is not electrical in nature, an input transducer is used to convert it into a time-varying electrical signal.
- Example: In case of radio broadcasting, a microphone converts the information or message which is in the form of sound waves into corresponding electrical signal.

(3) Transmitter-

- The function of the transmitter is to process the electrical signal from different aspects.
- Example: in long-distance radio communication or broadcast, signal amplification is necessary before modulation. Modulation is the main function of the transmitter.

- In modulation, the message signal is superimposed upon the high-frequency carrier signal.
- Inside the transmitter, signal processing such as restriction of range of audio frequencies, amplification and modulator are achieved. All these processings of the message signal are done just to ease the transmission of the signal through the channel. (Pre-emphasis is done to amplify the frequency of signal)

(4) Channel →

- The term channel means the medium through which the message travels from the transmitter to the receiver.
- In other words, we can say that the function of the channel is to provide connection between the transmitter and receiver. Noise is added to channel which reduces the signal quality.

Communication Channel

- Guided (wireline) (physical cable)
  - Twisted pair
  - Co-axial cable
  - Wave guide
  - Fiber-optics (optical fiber)
- Un Guided (wireless) (air, vacuum)
  - Microwave
  - Satellite
  - Radio Broadcasting (AM, FM, TV).

Note, channel may be P2P and Broadcast.

Communication Channel

- point to point
  - optical fiber
  - Twisted pair
  - Waveguide
  - Microwave
  - Satellite
- Broadcast
  - AM
  - FM
  - Mobile
  - TV
  - PM

(5) Receiver -

- The main function of the receiver is to reproduce the message signal in electrical form from the distorted received signal. This reproduction of the original signal is accomplished by a process known as the demodulation or detection. Demodulation is reverse process of modulation carried out in transmitter.

(6) Output Transducer -

It is used to convert the electrical signal into non-electrical signal. Example: Electrical signal to sound signal, image, video, etc.

(7) destination -

Destination is the final stage which is used to convert an electrical message signal into its original form. For example

example: in radio broadcasting, the destination is a loud speaker which works as a transducer i.e. it converts the electrical signal in the form of original sound signal.

⇒ Advantages of analog communication:

(1) Transmitter and receiver are simple.
(2) low bandwidth requirement.
(3) Frequency division multiplexing can be used.

⇒ Drawbacks of analog communication:

(i) Noise affects the signal quality.
i.e. it is not possible to separate noise and signal.
(ii) Repeaters cannot be used between transmitter and receivers.
(iii) Coding is not possible.
(iv) It is not suitable for the transmission of secret information. (encryption)

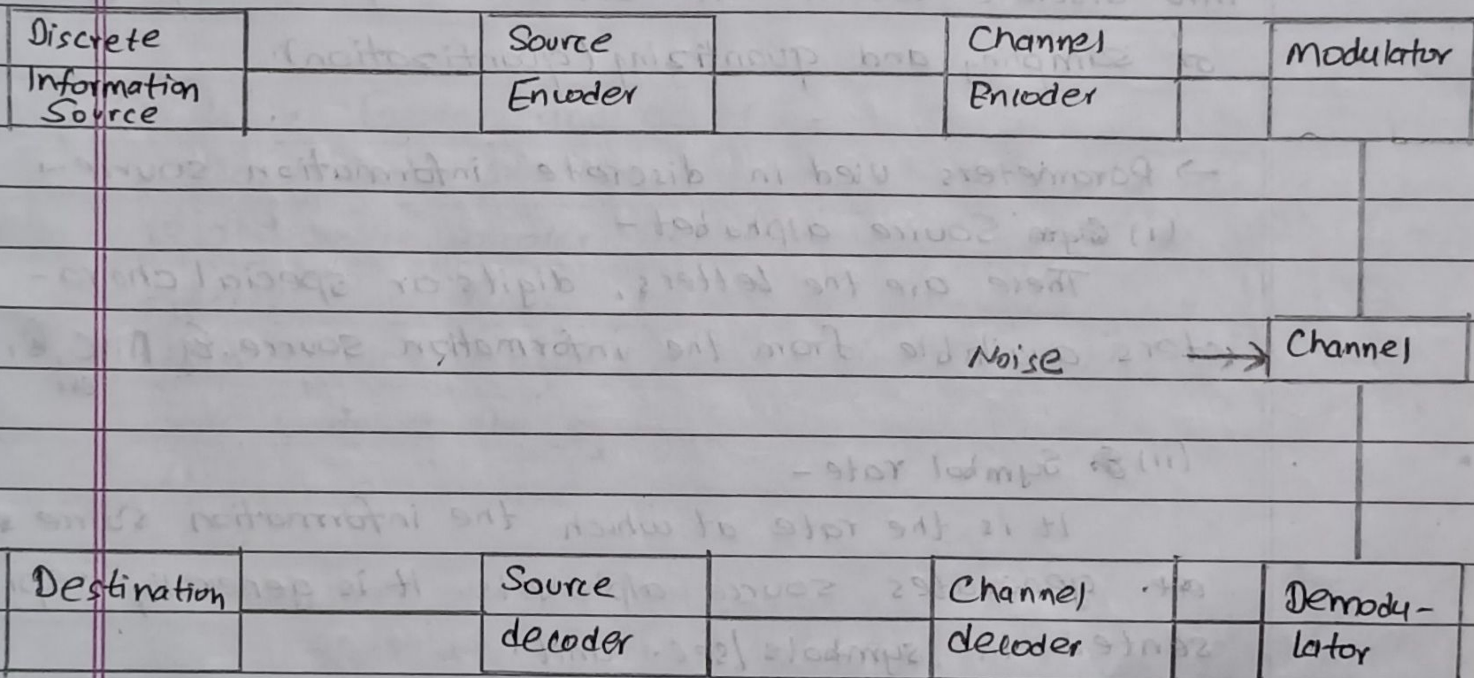
⇒ Applications

(1) FM Broadcasting
(2) TV Broadcasting
(3) AM Broadcasting

(2) Digital Communication:

In digital communication, the message signal to be transmitted is digital in nature. This means that digital communication involves the transmission of information in digital form.

Block diagram / Components / Elements of Digital Communication system →



(1) Discrete Information Source -

- Information source may be classified into two categories based upon the nature of their output i.e analog information sources and discrete information sources.

- In case of analog communication, the information source is analog. Analog information sources, such as microphone actuated by speech, emit one or more continuous amplitude signals.

=> In case of digital communication, the information source produces a message signal which is not continuously varying with time. Rather the message signal is intermittent with respect to computer consists of a sequence of discrete symbols or letters.

=> An analog information source may be transformed into discrete information source through the process of sampling and quantizing (quantization).

→ Parameters used in discrete information source→

(i) ~~Sym~~ Source alphabet -

These are the letters, digits or special characters available from the information source. Eg: A, C, @, etc.

(ii) Symbol rate -

It is the rate at which the information source ~~source~~ ~~at~~ generates source alphabets. It is generally represented in symbols/sec. unit.

(iii) Entropy →

the average information content per symbol is called Entropy. It is represented by H. It's unit is bits/symbol.

(iv) Information rate -

The maximum rate of transmission of error less data and can be obtained by multiplication of symbol Rate and Entropy is called information rate.

It is represented by R. It's unit is bits/second.

i.e.

Information Rate(R) = Symbol Rate * Entropy

Bits/sec. = Symbols/sec * Bits/Symbol

= Bits/sec.

(2) Source Encoder and decoder -

The symbols produced by the information source are given to the source encoder. these symbols cannot be transmitted directly. Each binary '1' and '0' is known as a bit. The group of bits is called a codeword. The source encoder assigns codewords to the symbols. For each distinct symbol, there is an unique code word.

(i) Block size and code word:

- Block size describes the maximum number of distinct codewords which can be represented by a source encoder. This depends on the number of bits in the code word. As an example, the block size of 8 bits source encoder will be 2^8. i.e. 256 code words.

i.e. $2^2 \rightarrow$ (2 encoder) $\Rightarrow$ $\underbrace{\text{4 codeword}}_{\text{block size}}$, i.e. 4 symbols

$2^4 \rightarrow$ (4 encoder) $\Rightarrow$ $\underbrace{\text{16 codeword}}_{\text{block size}}$, i.e. 16 symbols

$2^8 \rightarrow$ (8 encoder) $\Rightarrow$ $\underbrace{\text{256 codeword}}_{\text{block size}}$ i.e. 256 symbols

⇑

code word length = 4 or 16, or 256 bits

block size length = 4 or 16 or 256 bits

Code word length / block size length is the number of bits to represent each codeword or block size.

(ii) Average data rate -

- Average data rate is the output bits per second from the source encoder. In fact, the source encoder assigns multiple number of bits to each input symbol. Hence, the data rate is generally higher than the symbol rate.

Data rate = Symbol rate * Codelength

= 10 * 8

= 80 bits/sec.

For code length 1,

data rate → symbol rate * codelength

= 10 * 1 = 10 bits/sec.

$\boxed{\text{data rate = Symbol rate}}$

However, due to practical limitations, designing such type of source encoder is quite difficult. Thus, the average data rate is higher than the information rate and hence symbol rate also.

Efficiency of the Encoder:

$$\eta \Rightarrow \frac{\text{minimum source Information rate}}{\text{Actual output data rate of source encoder}}$$

In last, it may be noted that at the receiver end, some sort of decoder is used to perform the reverse operation to that of source encoder. It converts the binary output of the channel decoder into a symbol sequence. Some decoders also use memory to store codewords. the decoders and the encoders can be synchronous or asynchronous.

(3) Channel Encoder and decoder →

After converting the message or information signal in the form of binary sequence by the source encoder, the signal is transmitted through the channel. The communication channel adds noise and interference to the signal being transmitted. Hence errors are introduced inthe binary sequence received at the receiver end.

Therefore, the errors are also introduced in the symbols generated from these binary code words. Thus, Channel coding is done to avoid these types of errors. In fact, the channel encoder adds some redundant binary bits to the input sequence. Also, these redundant bits are always added with some properly defined logic.

→ Source Encoder → output o/p of source encoder → Channel Encoder (add even parity) → o/p of channel encoder.

(Output of source encoder) b3	b2	b1	(added bit, (for even parity)) b0	output of a channel encoder b3	b2	b1	b0
1	0	0	1	1	0	0	1
0	1	0	1	0	1	0	1
0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1

A channel encoder must have the following parameters.

(i) coding method used and coding rate depends upon the redundant bits added by the channel encoder.

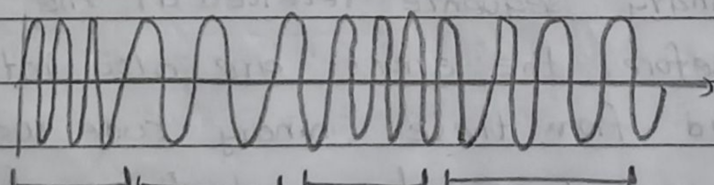
coding efficiency (η) = $\frac{\text{data rate input}}{\text{data rate output}}$, of encoder

(ii) Error control capabilities (Error free).

(iii) Feasibility of encoder and decoder.

(4) Digital modulator and demodulator:-

- Here, if the modulating signal is digital (i.e. binary code word). then digital modulation techniques are used. In digital modulation carrier signal is always continuous sinusoidal wave of high frequency. In fact, the digital modulation map the input binary sequency of 1's and 0's to the analog signal waveform.



1   0   1   0

$S_2(t)$ $S_1(t)$ $S_2(t)$ $S_1(t)$.

- $S_1(t)$ is low frequency compared to $S_2(t)$.
- if one bit at a time transmitted, then digital modulator signal is $S_1(t)$ to transmit binary 0 & $S_2(t)$ to transmit binary 1.

Example, ASK, PSK, FSK, QPSK, GMSK, etc.

(5) destination - destination where message is reached from source decoder and finally obtained the binary sequence number.

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Advantages of digital communication-

(1) Digital communication system are simple, flexiable and cheaper, because of advancement in IC technology.

(2) Digital communication has increased immunity to noise and interference.

(3) Multiplexing can be used in digital communication (voice, video, picture, text) can be transmitted by the common channel.

(4) Data Encryption is possible.

(5) Channel Coding is possible.

(6) Information rate, transmission rate and speed are higher.

(7) Error correction ability.

(8) Digital data can be compressed and therefore possible to pass over higher bandwidth.

Disadvantages:

(1) High cost of increased channel bandwidth.

(2) the bit rates of digital systems are high. Therefore, they require a larger channel bandwidth as compared to analog system. (Gbps to 100 Gbps)

(3) Digital modulation needs synchronization in case of Synchronization modulation.

(4) System complexity is increased.

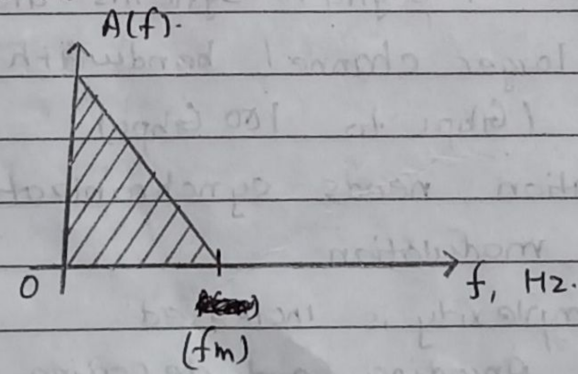
(5) Additional encoding and decoding circuits are required to transmit and receive.

Applications of digital Communication:
(1) mobile communication
(2) data communication
(3) satellite communication
(4) optical fiber communication.

Techniques of transmission →
(1) Baseband Signal / Transmission -

The information or the input signal to a communicated system can be analog i.e. sound, picture or it can be digital eg. the computer data. The electrical equivalent of this original information signal is known as the base band signal.

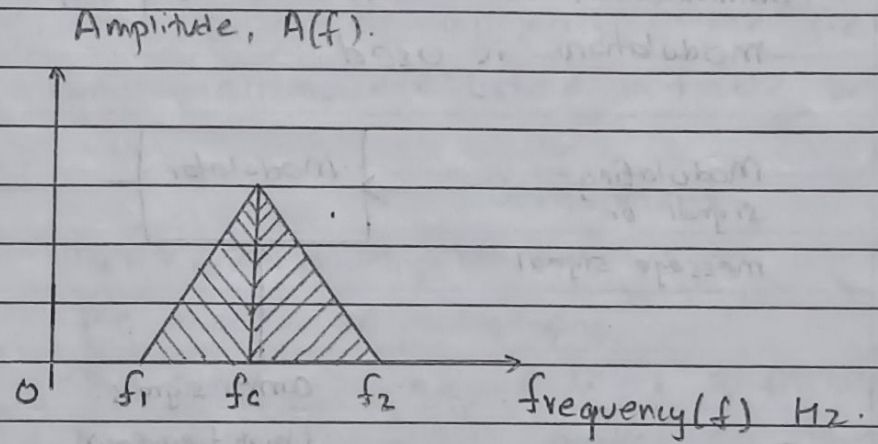
In other words, we can define a baseband signal as that one which is not modulated. All the voice, data, picture are called base band signal.



(a) the frequency spectrum of a baseband signal. (starts from 0 to fm Hz).

(2) Pass band signal / transmission:

- It may be defined as a signal which has a non-zero lowest frequency in its spectrum. This means that the frequency spectrum of a passband signal extends from f_1 to f_2 Hz. The modulated signal is called as the bandpass signal.
- It is obtained by shifting the baseband signal in frequency domain.



(b) spectrum of a pass band signal.

Note;

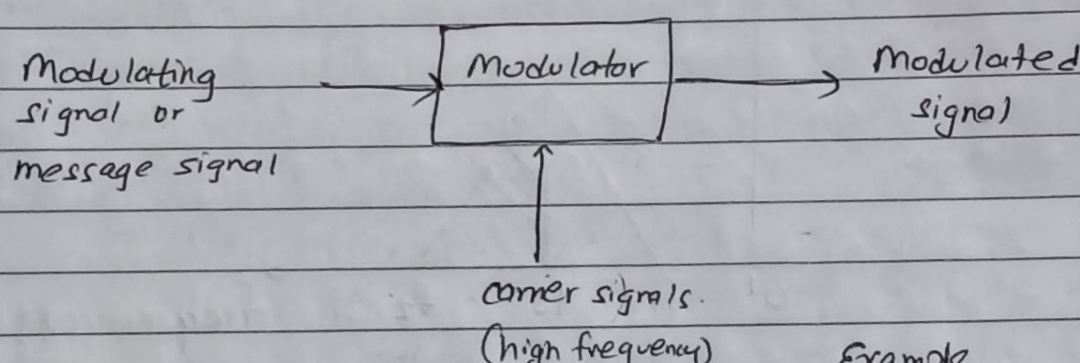
In some systems, called the baseband transmission systems, the base band signals (original information signals) are directly transmitted.

example Sound signal $\xrightarrow{\text{Converted}}$ Electrical signal

Computer signal $\xrightarrow{\text{converted}}$ Electrical signal.

Limitation of Baseband transmission:

- The baseband transmission cannot be used with certain mediums. Example it cannot be used for the radio transmission where the medium is free space.
- This is because the voice signal (in the electrical form) cannot travel long distance in air. It gets suppressed after a short distance. Therefore, for the radio communication of baseband signals, a technique called modulation is used.



Example
0 to 20 KHz audio.
0 to 55 MHz video

Example
550 KHz - 1050 KHz for AM.
88 MHz - 108 MHz for FM.

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Historical Perspective →

(The Evolution of Modern Electronic Communication)

The electronic communication has undergone through a chain of dramatic development even since the first electronic communication invented by Morse in 1838. However, it may be noted that this development became possible due to the parallel development in the field of electronic devices, circuits, etc. To provide historical perspective, the important developments in the field of electronic communication are listed in table below.

Year	Development
1800-1837	Preliminary developments
1838	The invention of telegraphy
1845	The Kirchoff's circuit laws enunciated
1864	Maxwell's equations predict electromagnetic radiation.
1876	The invention of telephony
1887	The invention of wireless telegraphy
1904	Communication Electronics
1920	Transmission Theory
1923	Invention of television
1927	Federal communications. commission established
1931	Teletypewriter service initiated
1934	H.S. Black develops the negative-feedback amplifier
1936	Armstrong's paper states the case for FM radio.

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1937	Pulse code modulation
1938	Radar and microwave communication
1948	Information theory and coding
1950	Time-division multiplexing applied to telephony
1953	Colour T.V. standards established in United States
1956	First trans oceanic states telephone cable (36 voice channels)
1958	Long-distance data transmission system developed for military purposes.
1960	Maiman demonstrated the first Laser
1961	Integrated circuits go into commercial production.
1962	Satellite communication begins with Telestar I
1962-1966	High speed digital communication.
1963	Solid-state microwave oscillators
1964	Full electronic telephone switching system goes into service.
1965	Mariner IV transmits pictures from Mars to earth.
1966-1975	Wideband communication systems
1979	Intercity optical links
1988	Under sea fiber optical link.

Signals in communication system →

- A signal as referred to in communication systems, signal processing and electrical engineering is a function that ~~"conveys~~ "conveys information about the behaviour or attributes of some phenomenon
  - the representation of physical phenomenon (electrical, mechanical, optical, etc.). is called signals.
  - In other words, a signal is defined as any physical quantity that varies with time, space or any other dependent or independent variable.

physical quantity: quantity that can be measured.
(length, mass, pressure, heart rate; etc.)

unknown quantity: quantity that cannot be measured.
(color, taste).

- Note;
  - the independent variable can be continuous or discrete
  - A signal can either be real valued or complex valued.
  - A signal carries information or set of information.

Example: Electronic signal - speech
Mechanical - Earthquake
Biological - Blood pressure, Heartrate
Finance - stock market

speech - 1 dimensional
pictures - two "
videodata - three "
Volume data - four " over time

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Mathematically,

It is a function of one or more independent variables.

Example 1. $x_1(t) = 5t$ → signal varies linearly with time 't'.

2. $x_2(t) = 20t^2 + 10t$ → signal varies quadratically with time 't'.

3. $I(x,y) = 3x^2 + 2xy + 10y^2$ → Signal varies with two independent variables x & y → Image signal

Here, t is independent variable,

$x(t)$ (the value of x of t) in dependent variable

(a) Analog signal →

- A signal whose function is continuous instants of time is called continuous time signals, for continuous-time signal, the amplitude between two time instants is defined and the independent variable is time t.

- It is not uniformly spaced and hence connected

- It is denoted by $x(t)$.

- the schematic diagram of continuous-time signal is shown in figure below:

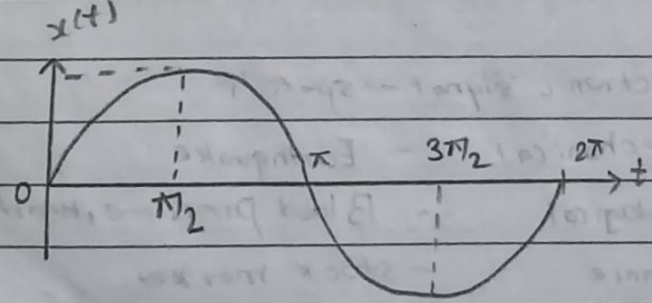


Fig: continuous time signal.

: Note

- A continuous-time signal can be obtained through the input easily.

- Continuous-time signal between two successive sample is defined.

- the independent variable is time 't'.

(2) Digital Signal →

- A signal whose function is discrete instants of time is called discrete-time signals, for discrete-time signal, the amplitude between two time instants is not defined and the independent variable is time n.

- It is uniformly spaced and hence not connected.
- It is denoted by $x[n]$.

- The schematic diagram of discrete-time signal is shown in figure below:

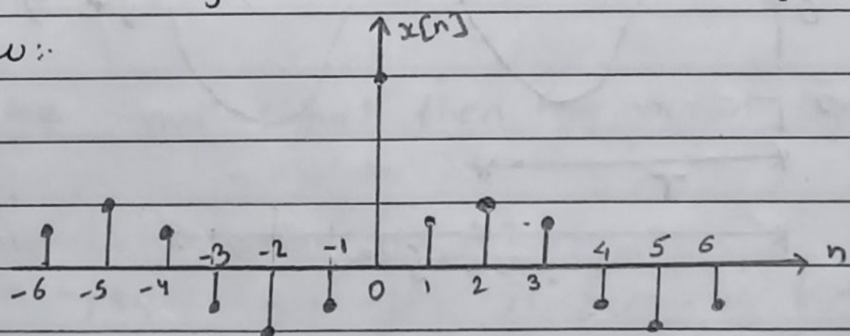


Figure: discrete-time signal

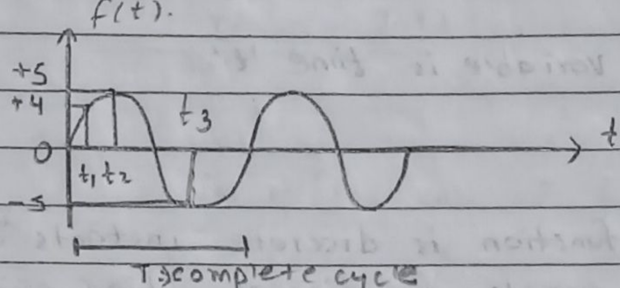
- Note

- A discrete-time signal can be obtained from a continuous time Signal by sampling it at a uniform rate. $[x[n]] = n[nT], n = 0, \pm 1, \pm 2, \ldots]$
- Discrete-time signal between two successive sample is not defined.

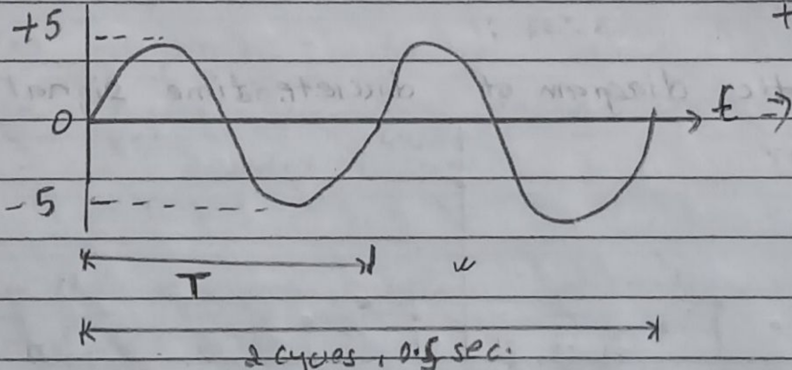
Narayani - the independent variable is time n.

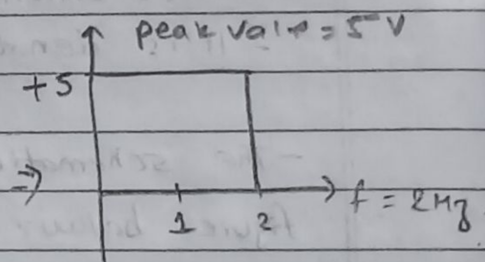
~~[illegible]~~ Time and frequency domain Representation of signal:

- The time domain representation shows changes in amplitude with respect to time.
- So, it is basically an amplitude vs time plot.



- In frequency domain representation, only two things are important. peak amplitude and frequency.
- so, it is an amplitude vs frequency plot.





Frequency	time
1 cycle = 1 Hz.	→ 1 cycle ⇒ $1/f = 1/1 = 1$ sec.
2 cycle = 2 Hz	→ 2 cycle ⇒ $1/f = 1/2 = 0.5$ sec.

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Hilbert Transformation -

- the transformation that adds $-90°$ phase shift to all the positive frequency of input signal and $+90°$ phase shift to all the negative frequency of input signal is called Hilbert Transformation.
- Hilbert transformer is an Ideal device such that the amplitude response of Hilbert transform is constant over entire frequency range of interest i.e. 1
- the phase response lies between $-\pi/2$ to $+\pi/2$.

Laplace, Fourier, Z-transform

- the schematic diagram of Hilbert Transformation is shown in figure below →

changes time to another time.

$$x(t) \longrightarrow \boxed{\text{Hilbert Transformer}} \longrightarrow \hat{x}(t)$$

Fig: Hilbert Transformation

- If $x(t)$ is the input signal then the output signal is denoted by $\hat{x}(t)$

• the frequency response of HT is,

$$H(F) = -j\,\text{sgn}(f) = \begin{cases} -j & \text{if } f>0 \quad t<0 \\ +j & \text{if } f<0 \quad t>0 \\ 0 & \text{if } f=0 \quad t=\infty \end{cases}$$

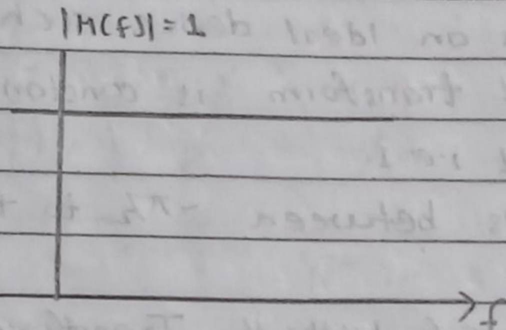
• the amplitude response of HT is,

$$|H(f)| = |-j\,\text{sgn}(f)| = |j\,\text{sgn}(f)|$$
$$= 1$$

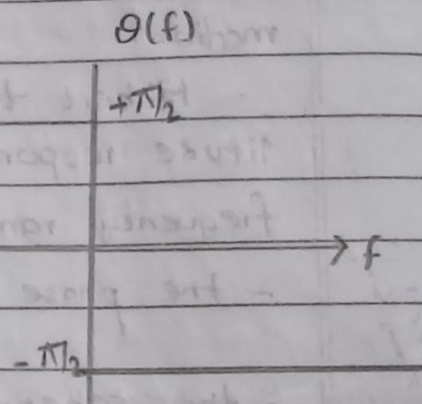
• the phase response of HT is,

$$\theta(f) = \angle H(f) = \begin{cases} -\pi/2 & \text{if } f>0,\ t<0 \\ +\pi/2 & \text{if } f<0,\ t>0 \\ 0 & \text{if } f=0,\ t=\infty \end{cases}$$

i.e.



(a) amplitude response



(b) phase response

→ properties of Hilbert Transform (HT) →

1. the energy content of i/p signal $x(t)$ and output signal $\hat{x}(t)$ are same.
2. $x(t)$ and $\hat{x}(t)$ are orthogonal and therefore ~~cross section~~ cross-correlation between them is zero.
   (same auto correlation function)
3. If $\hat{x}(t)$ is a Hilbert Transform of $x(t)$, the Hilbert transform of $\hat{x}(t)$ is $-x(t)$.
4. If $c(t)$ is a carrier signal and $m(t)$ is a lowpass signal, then HT of product of $m(t)$ and $c(t)$ is equal to the product of $\hat{m}(t)$ and $\hat{c}(t)$
5. the application of Hilbert Transform is for generation of single sideband wave. Also used ECG signal analysis.

→ Application of Hilbert Transform →

1. designing minimum phase type filters.
2. generation of SSB signals.
3. representation of band pass signals.

- the impulse response of HT is,

$h(t) = 1/\pi t$

Hence, the convolution of this response with a signal $x(t)$ applied to the input of Hilbert Transform resulting output $\hat{x}(t)$ is given as,

$$\hat{x}(t) = x(t) * h(t).$$

$$\hat{x}(t) = x(t) * \frac{1}{\pi t}$$

$$\therefore \hat{x}(t) = \frac{1}{\pi} \int_{-\infty}^{\infty} \frac{x(\tau)}{(t-\tau)} d\tau.$$

∴ Hence, $\hat{x}(t)$ is the Hilbert Transform of $x(t)$.

- the inverse of Hilbert transform defining $x(t)$ in terms of $\hat{x}(t)$ is given as,

$$x(t) = -\frac{1}{\pi} \int_{-\infty}^{\infty} \frac{\hat{x}(\tau)}{(t-\tau)} d\tau.$$

∴ Hence, $x(t)$ is the Inverse Hilbert Transform of $\hat{x}(t)$.

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Distortionless Transmission →

- A transmission of signal through a system is said to be distortionless, if output signal waveform is an exact replica of input signal. However, a constant change in magnitude (amplitude) and constant time delay in output are not distortion.

- the schematic diagram of distortionless transmission is shown in figure below →

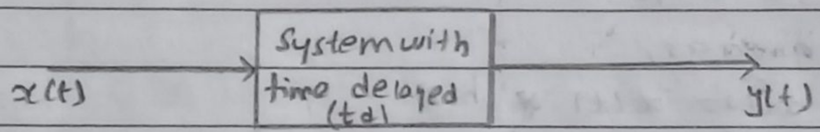

Fig: distortionless transmission.

$$y(t) = Kx(t - t_d).$$

where, K = amplitude factor.

- Mathematically,

$y(t) = Kx(t - t_d)$

Taking Fourier transform,

$Y(j\omega) = K(j\omega) \cdot e^{-j\omega t_d}$.

$Y(j\omega) = H(j\omega) * (j\omega)$

where, $H(j\omega) = K \cdot e^{-j\omega t_d}$

So, amplification response $|H(j\omega)| = K$.

and phase response $\theta(j\omega) = -\omega t_d$.

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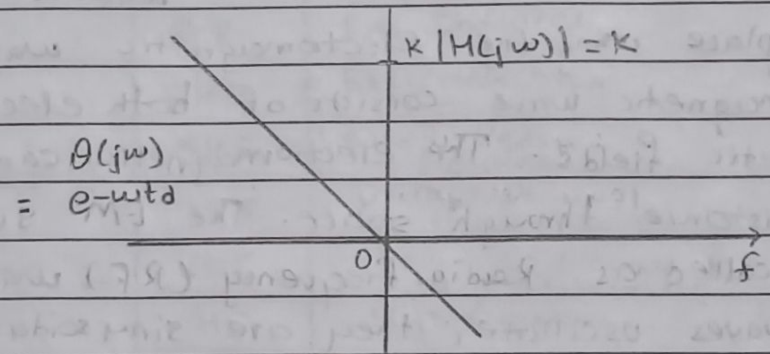
- $H(j\omega) = K$, shows that magnitude response must be constant over entire frequency range of signal for distortionless transmission.
- $\theta(j\omega) = -\omega t_d$ shows that phase response must be linearly proportion to time delay introduced by the system.

i.e.



- In practice no system has infinite bandwidth. therefore, distortion less condition are never met.

Note;

there are two types of distortion system i.e.

(1) Amplitude distortion →

It occurs when $|H(j\omega)|$ is not constant within the frequency range.

(2) Phase distortion →

It occurs when $\theta(j\omega)$ is not linearly changing with time and frequency component in i/p are subjected to differen delays.

The Electromagnetic (EM) spectrum →

→ The electromagnetic spectrum is the range of frequencies (the spectrum) of electromagnetic radiation and their respective wavelengths and photon energies.

⇒ As a matter fact, the information signal should be first converted into an electromagnetic signal before transmission because the wireless transmission takes place using the electromagnetic waves. The electromagnetic wave consists of both electric and magnetic fields. The electromagnetic can travel a long distance through space. The EM signals are also called as Radio frequency (RF) waves. The EM waves oscillate, they are sinusoidal and their frequency is measured in Hz. The frequency of EM ~~waves~~ signal can be very low or it can be extremely high. This entire range of frequencies of EM waves is called as Electromagnetic spectrum.

– Radio waves, Microwaves & satellite, Infrared ~~or~~ & Visible and Ionizing radiation (X-ray, UV ray, γ-rays) are the types of Electromagnetic spectrum.

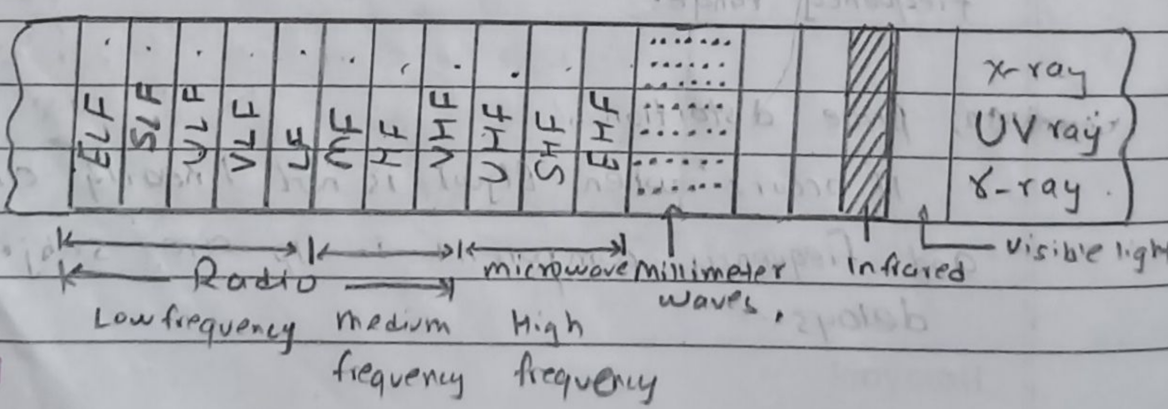


Fig:: EM spectrum

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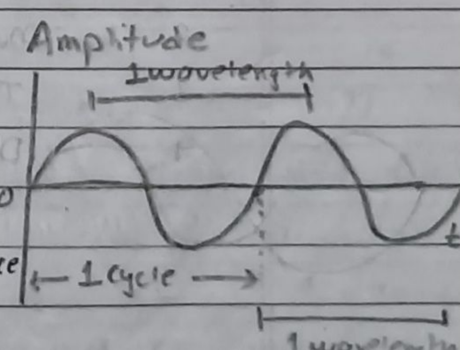
	γ	Gamma rays	300 EHz to above
Ionizing	HX	Hard X-rays	30 EHz - 300 EHz
radiation	SX	Soft X-rays	300 PHz - 30 EHz
	EUX	Extreme ultra violet	300 PHz - 3000 PHz
	NUV	Near ultra violet, visible	300 THz - 30 PHz
Visible	NIR	Near Infrared	30 THz - 300 THz
Infrared	MIR	Mid Infrared	3 THz - 30 THz
	FIR	Far Infrared	300 GHz - 3 THz
	EHF	Extremely high frequency	30 GHz - 300 GHz
Microwaves	SHF	Super High frequency	3 GHz - 30 GHz
	UHF	Ultra high frequency	300 MHz - 3 GHz
~~Radio waves~~	VHF	Very high frequency	30 MHz - 300 MHz
	HF	High frequency	3 MHz - 30 MHz
	MF	Medium frequency	300 kHz - 3 MHz
	LF	Low frequency	30 kHz - 300 kHz
Radio waves	VLF	Very Low frequency	3 kHz - 30 kHz
	ULF	Ultra low frequency	300 Hz - 3 kHz
	SLF	Super low frequency	30 Hz - 300 Hz
	ELF	Extremely low frequency	3 Hz - 30 Hz

Frequency and wavelength →

→ Basically, frequency is defined as the number of cycles of a waveform per second. It is expressed in Hertz (Hz). , 1 KHz = 1000 Hz.



→ Basically, wavelength (λ) is defined as the distance between two points of similar cycle of a periodic wave.

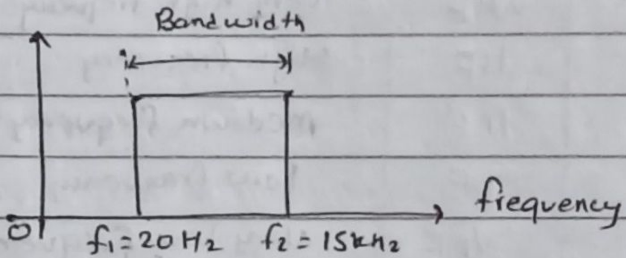
$$V = f\lambda \quad \text{or,} \quad \lambda = \frac{V}{f} = \frac{\text{Speed of light}}{\text{frequency}} = \frac{3\times10^8 \text{ m/s}}{f}$$

Hence, wavelength is inversely proportion to frequency.

Concept of Bandwidth →

- Bandwidth may be defined as the portion of the electro-magnetic spectrum occupied by a signal.
- We may also define the bandwidth as the frequency range over which an information signal is transmitted. ~~Bandwidth~~
- Bandwidth is the difference between the upper and lower frequency limits of the signal.
- We ~~know~~ already know different types of passband signals such as voice signal, music signal, TV signal, etc. Each of these signals will have its own frequency range. This frequency range of a signal is known as its bandwidth.

Example,



$$Bw = f_2 - f_1 = 15 * 1000 - 20 = 14980\,Hz.$$

also, $Bw = \left(\text{Upper frequency} - \text{lower frequency}\right)$

S.No.	Type of the signal	Range of frequency in Hz	Bandwidth in Hz
1	Voice signal (speech) for telephony	300 - 3400	3,100
2	Music signal	20 - 15000	14980
3	TV signals (picture)	0 - 5 MHz	5 MHz
4	Digital data	300 - 3400	3100

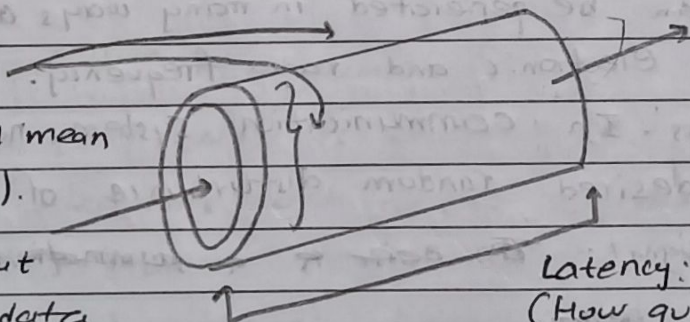
- Bandwidth (speed) Vs Latency Vs Throughput.
  (Digital Communication)

• Bandwidth - This is about the volume of data that can be transferred over a network. The standard measurement for data transfer speed is mega bits per second (Mbps).

• Throughput - While bandwidth tells you how much data could theoretically be transferred across the network, throughput indicates how much data was actually transferred from a source at any given time.

• Latency - This measures the time it takes for data to get to its destination across the network. It is commonly measured as a round trip delay. Latency is usually measured in milliseconds (ms).

Bandwidth: measures capacity (bigger pipe would mean higher bandwidth).



Throughput measures data transmitted and received during a specific time period. (throughput is the water running through the pipe).

Latency: measures data speed. (How quickly does the water in the pipe reach its destination?)

Example - If you need 5 mbps data of 20-mbps Bandwidth you will get easily.
- If you need 25mbps for 20mbps Bandwidth ; you will get 20mb for 1st one second and 5 mb for next one second so, the latency will be higher.

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Noise, distortion and interference →

These term are the limitations of communication system →

(1) Due to noise, we have to increased the channel bandwidth which are more costly.

(2) Due to distortion, the exact wave of signal is not obtained in the destination.

3. Due to interference, the signal cannot be distinguished.

[A] Noise →

- In electronics, noise is an unwanted disturbance in an electrical signal.
- Noise generated by electronic devices varies greatly as it is produced by several different effects.
- Noise is a random fluctuation in an electrical signal a characteristic of all electronic circuit. Noise comes in many forms. It can be generated in many ways and noise can affect electronic and radio frequency. RF circuits and systems. In communication system, noise is an error or undesired random disturbance of a useful information signal. ~~The noise is a summation of unwanted or disturbing energy~~
- Practically, we cannot avoid the existence of unwanted signal together with the modulated signal transmitted by transmitter. This unwanted signal is called noise.
- For example, Signal to noise Ratio (SNR), signal-to-interference ratio (SIR), and signal to noise plus interference ratio, (SNIR) measures.

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Types of Noise

Noise

- Internal
  - Thermal or Johnson Noise (white)
  - Shot Noise
  - Partition Noise
  - Low frequency / Flicker
  - High frequency / transit,
  - Generation - Recombination noise
  - Popcorn / Burst noise
  - avalanche noise
- External
  - Manmade noise
    - Industrial noise
  - Natural noise
    - atmospheric noise (Earth)
    - terrestial and extra-terrestial noise (beyond earth)

Internal noise →

The noise which is generated, within the system itself is called internal noise.

(a) Thermal / Johnson / white Noise →

The noise which is produced due to random movement of free electrons with in the conductive path of the material is called thermal noise. As the temperature increases (↑es), internel kinetic energy electron increases KE electron (↑es), means the energy of the electron increases (↑es), thus randomness increases.

① Experimentally result by (Johnson) and theoretical studies (by Nyquist) give the mean square voltage as,

$$v_n^2 = 4RKTB \quad —(1)$$

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② Current generator equivalent,

$$I_n^2 = 4GKTB \quad \text{---(2)}$$

G = Conductance = $1/R$.

Hence, the average thermal noise power is given as,

$$P_n = KTB \text{ Watts}$$

where, K = Boltzmann Constant (1.38×10^{-23} J/K).
T = Temperature in kelvin
B = BW of noise spectrum (Hz).

Power of spectral density (Psd) = KT (watt/Hz).
(white- Gaussian noise).

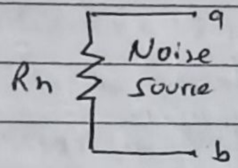

Fig: Noise source ckt

=

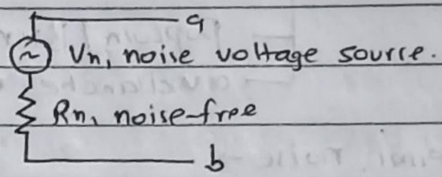

Fig: Thevenin equ. ckt.

(b) Shot noise →

The noise of which the anode current noise in vacuum tube resulting from random fluctuation of electrons emission from the cathode is called shot noise. It is due to variation in number of electrons crossing the potential barrier.

The mean square shot noise current for a diode is given as,

$$I_n^2 = 2(I + 2I_0)\,q\,B \text{ amperes}^2$$

where, I = direct current across the junction
I_0 = Reverse saturation current
q = electronic charge = 1.6×10^{-19} C.
B = effective noise bandwidth in Hz.

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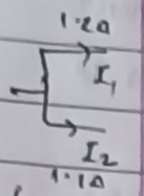
(c) Partition Noise →

Partition Noise is generated when the current gets divided between two or more paths. It is generated due to the random fluctuations in the division. Therefore, the partition noise in a transistor will be higher than that in a diode. The devices like gallium arsenide FET draw almost zero gate bias current and therefore, keeping the partition noise to its minimum value.



transistor > diode

(d) Low frequency or Flicker Noise →

The flicker noise will appear at frequencies below a few Kilohertz. It is sometimes called as 1/f noise. In the semiconductor devices, the flicker noise is generated due to the fluctuations in the carrier density. These fluctuations in the carrier density will cause the fluctuations in the conductivity of the material. This will produce a fluctuation voltage drop when a direct current flows through a device. This fluctuating voltage is called as flicker noise voltage. The mean square value of flicker noise voltage is proportional to the square of direct current flowing through the device.

voltage ↓
low freq. ↓

(e) High frequency or Transit Time Noise →

If the time taken by an electron to travel from the emitter to the collector of a transistor becomes comparable to the period of the signal which is being amplified then the transit time effect takes place. This effect is observed

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at very high frequencies. Due to transit time effect some of the carriers may diffuse back to the emitter. This gives rise to an input admittance, the conductance component of which increases with frequency. The minute currents induced in the input of the device by the random fluctuations in the output current, will create random noise at high frequencies. Once this noise appears, it goes on increasing with frequency at a rate of 6dB per octave.

$Y = \frac{1}{2}$

~~Resistance~~ decreases ~~increase~~

(f) Generation - recombination noise →

The ~~noise~~ fluctuations of the charge carriers' number produce fluctuations of the resistance and consequently, of current and/or voltage if a nonzero mean current is passing through the specimen. This noise is called generation-recombination noise (G-R) noise.

(g) Burst / popcorn Noise →

Burst noise is a type of electronic noise that occurs in semiconductor. It is also called impulse noise, bi-stable noise or random telegraph signal (RTS) noise. It consists of sudden step like transistors between 2 or more levels, as high as several hundred millivolts at random and unpredictable times. Each shif in offset voltage or current last for several milliseconds, and interval between pulse tend to be in audio range, leading to the term popcorn noise for the popping or crackling sounds it produces in audio circuits. (the noise that appear due to dc current fluctuation or heavy voltage updown).

(h) Avalanche noise →

Avalanche noise is a noise of a reverse biased emitter-base junction of a bipolar silicon transistor is a low frequency spectra. It appears that 1/f noise is not directly related to the direct current flowing at avalanche breakdown condition.

External Noise →

The noise which is generated externally to the communication system is called external noise.

(a) man made noise →

The noise that are generated by the industry, machines, plants and heavy equipment, semiconductor defects is called man-made noise.

(i) Industrial noise →

Between 1 to 600 MHz, the intensity noise made by humans easily outstrips that created by any other source to the receiver.

- Sources such as: aircraft, electronic motors, machines, automobile plants, heavy equipment.
- Nature of ~~individual~~ industrial noise is so variable that ~~it~~ it is difficult to analyze.

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(b) Natural Noise →

The Noise that are generated by atmosphere, celestial body such as gamma-ray, X-ray, cosmic rays, (terrestial and extra terrestial) is called Natural Noise.

(i) Atmospheric Noise →

- caused by lightning discharges, in thunderstorms and other natural electric disturbances occuring in the atmosphere.
- consists of spurious radio signal with components distributed over a wide range of frequencies.
- Became less severe at frequencies above 30MHz because,
  - Higher frequencies are limited to line of sight propagation.
  - Nature of mechanism generating this noise is such that very little of it is created in the VHF range and above.

(ii) Extra terrestial Noise →

SOLAR Noise →

- Normal condition, there is a constant noise radiation from the sun, simply because large body at a very high frequency.
- Radiates over a very broad frequency spectrum.

COSMIC Noise →

- star radiates RF noise in the same manner of sun.
- The noise received is called thermal noise and distributed fairly uniformly over the entire sky.

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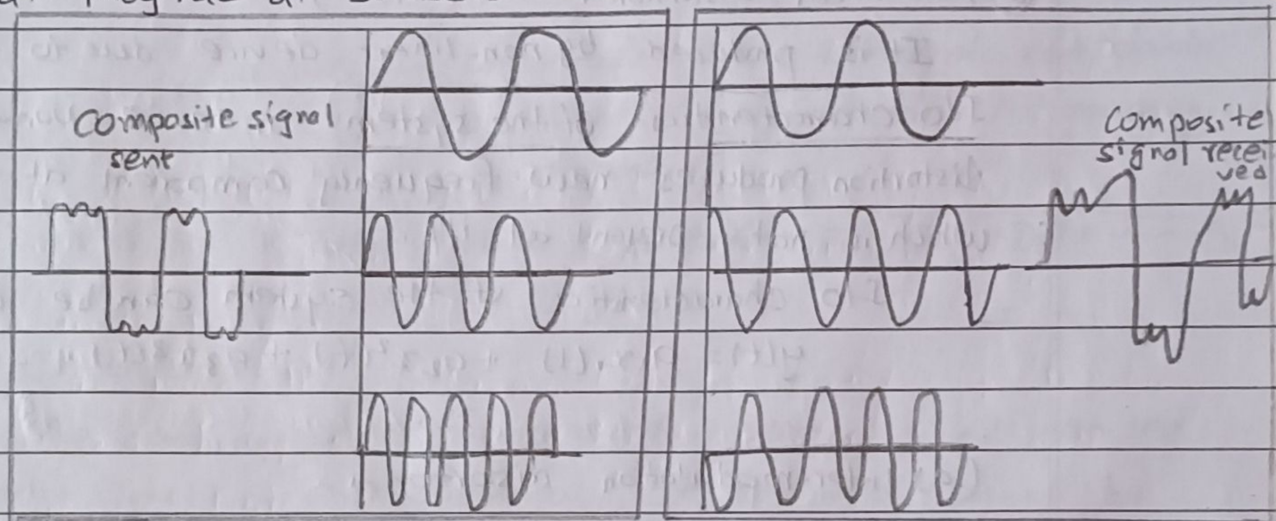
[B] Distortion →

- The unwanted change in the output waveform of any device in comparision to the input waveform is called distortion.
- This is generally seen in composite signals made up with different frequencies. Each frequency composit have its own propagation speed travelling through a medium. And thats why it delay in arriving at the final destination. Every component arrive at different time which leads to distortion.
- Therefore, they have different phases at receiver end from what they had at senders end.



At the sender, Components, in phase — Components, out of phase — At the receiver,

- Distortion may be corrected or reduced with the help of equalizers.

① Linear distortion → (RLC) (Mathematically. Interpretation)

It is produced by linear device due to non-uniform frequency and phase responses. It results in amplitude scaling

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and phase shift of input signal. For digital transmission, the phase distortion is more critical than amplitude distortion. A linear device is distortionless if magnitude response, transfer function/ impulse response is constand and the phase is lineorly proportional to frequency for $f \leq f_{max}$.

i.e. $y(t) = K_1 A_1 \cos(\omega_1 t + \theta_1) + K_2 A_2 \cos(\omega_2 t + \theta_2) \rightarrow$ Linear distortion

$y(t) = K \cdot A_1 \cos(\omega_1 t + \theta_1) + K A_2 \cos(\omega_2 t + \theta_2) \rightarrow$ distortionless system.

(2) Non-linear distortion → (diode)

It is produced by non-linear device due to non-linear I/o characteristics of the system or device. Non-linear distortion produces new frequency component at the o/p which is not present at i/p.

I/o characteristics of the system can be approximated as,

$$y(t) = a_1 x_1(t) + a_2 x^2(t) + a_3 x^3(t) + \text{-----}$$

(a) Inter-modulation distortion →

This is the special case of non-linear distortion. When two signal x_1 and x_2 having different frequency band width pass through the non-linear device, the o/p may contain a part from x_1 and x_2 component like x_1^2, x_2^2, $x_1(t)$, $x_2(t)$, etc. Spectral dispersion cause interference with other signals which is a serious problem in FDm. Because of spectral dispersion original spectrum may overlap and called as crosstalk or intermodulation distortion.

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(b) Harmonic distortion →

The distortion in which there is presence of higher harmonics at the output of any non-linear device. The generation of harmonics of fundamental frequency of input signal is due to non-linearity of the device. Generation of harmonics of fundamental frequency of i/p signal due to non-linearity of device is evaluated in terms of harmonic distortion.

i.e. % of nth harmonic distortion = % A_n

$$= \frac{|A_n|}{|A_1|} \times 100\%$$

where, A_n = amplitude of nth harmonic component.
A_1 = amplitude of fundamental frequency component.

∴ Total harmonic distortion $= \sqrt{D_2^2 + D_3^2 + \cdots D_n^2}$.

[C] Interference →

The combination of information bearing signal with the similar signal or the combination of received signal by other extra neous magnetic signals, similar to desired signal is called interference. Interference may be defined as the non-uniform distribution of the contamination of received signal by unwanted signals. It may due to the man made as well as natural disturbances. Magnetic interference is usually, from various broad casting and communication system. ISI (Inter Symbol Interference) is a special case of interference in the digital communication system where the interference is occured with in the system itself.

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Shannon - Hartley Channel Capacity Theorem :

In Shannon-Hartley Channel Capicity theorem, "The channel capacity is defined as the maximum rate at which information may be transmitted without error through the channel."

"maximum amount of information, or data capacity, which can be sent over any channel or medium."

"What this says is that higher the signal-to-noise (SNR) ratio and more the channel Bandwidth, the higher the possible data rate."

$\log_2 x$
$\log_{10} x$
base 2 - binary 0 & 1
base 10 - decimal 0,1,2,...,9

i.e.

$$C = B \log_2 (1 + SNR) \quad (\text{bit/second})$$

where, B = Channel Bandwidth
SNR = Received signal to Noise Ratio.

i.e. S/N for a given channel of Bandwidth B & required level of noise SNR, the maximum speed of data transmission (channel capacity is limited) is possible.

Signal to Noise Ratio →

(i) In the communication systems, the comparison of signal power with the noise power at the same point is important, to ensure that the noise at that point is not excessively large. It is defined as the ratio of signal power to the noise power at the same time.

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There fore,

$$\frac{S}{N} = \frac{P_s}{P_n}$$

where, P_s = Signal Power } at the same point.
P_n = Noise power

(ii) The signal to noise ratio is normally expressed in dB and the typical values of S/N ratio range from about 10dB to 90dB. Higher the value of S/N ratio better the system performance in presence of noise.

$$S/N(dB) = 10\log_{10}(P_s/P_n)$$

(iii) The powers can be expressed interms of signal and noise voltages as under:

$$P_s = \frac{V_s^2}{R} \text{ and } P_n = \frac{V_n^2}{R}$$

where, V_s = signal voltage and V_n = Noise voltage.

Hence, $$\frac{S}{N} = \frac{V_s^2/R}{V_n^2/R} = \left(\frac{V_s}{V_n}\right)^2$$

The signal to noise ratio in dB is given by,

$$(S/N)_{dB} = 10\log_{10}[V_s/V_n]^2$$

$$(S/N)_{dB} = 20\log \log_{10}(V_s/V_n).$$

(iv) All the possible efforts are made to keep the signal to noise ratio has high as possible, under all the operating conditions.

(v) Although the signal to noise ratio is a fundamental characteristics of a communication systems it is often difficult to measure. In practice instead of measuring S/N, another ratio called (S+N)/N is measured.

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SINAD →

This is another variation of signal to noise ratio. SINAD stands for signal noise and distortion and it is defined as,

$$SINAD = \frac{S+N+D}{N+D}$$

where, S = Signal, N = Noise and D = Distortion.

SINAD is generally used in the specification of FM receiver.

Noise Factor (F) and Noise Figure (F_{dB}) →

→ The noise factor (F) of an amplifier or any network is defined in terms of the signal to noise ratio at the input and the output of the system. It is defined as,

$$F = \frac{S/N \text{ ratio at the input}}{S/N \text{ ratio at the output}}$$

$$F = \frac{P_{si}}{P_{ni}} \times \frac{P_{no}}{P_{so}}$$

where, P_{si} and P_{ni} = Signal and noise power at the input.

and P_{so} and P_{no} = Signal and noise power at the output.

→ Sometimes, the noise factor is expressed in decibels. When noise factor is expressed in decibels, it is known as noise figure.

Noise figure ⇒ $F_{dB} = 10\log_{10}F$.

$$\Rightarrow 10\log_{10}\left[\frac{S/N \text{ at the input}}{S/N \text{ at the output}}\right] = 10\log_{10}(S/N)_i - 10\log_{10}(S/N)_o$$

$$= (S/N)_i \, dB - (S/N)_o \, dB$$

The ideal value of noise figure is 0 dB.

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Noise Temperoture,

The concept of noise factor or noise figure is not always the most convenient way of measuring noise. Another way to represent the noise by means of the equivalent noise temperature.

Equivalent noise temperature of a system is defined as the temperature at which the noisy resistor has to be maintained so that by connecting this resistor to the input of a noiseless version of the system, it will produce the same amount power at the system output as that produced by the actual system.

Equivalent Noise Temperature Teq at Amplifier Input.

The noise at the input of the amplifier input is given by :

$$P_a = (F-1)\,K T_o B \quad \text{--- (i)}$$

This is the noise contributed by the amplifier. This noise power can be alternatively represented by some fictitious temperature Teq such that

$$K T_{eq} B = (F-1)\,K T_o B \quad \text{--- (ii)}$$

Thus the equivalent Noise temperature of the amplifier is given as,

$$\boxed{T_{eq} = (F-1)\,T_o} \quad \text{--- (iii)}$$

(G) for, Power gain of Lossy n/w $= 1/L$

also, $$\boxed{F = 1 + \frac{T_{eq}}{T_o}} \quad \text{--- (iv)}$$

& $$\boxed{T_{eq} = (L-1).T}$$

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(1) Noiseless channel: Nyquist Bit Rate →

$$\boxed{\text{Bit Rate} = 2 * \text{Bandwidth} * \log_2(L)}\ \text{bits/sec.}$$

L = no. of levels.

(2) Noisly channel Shannon ~~ca~~ Capacity.

$$\boxed{C = B \log_2 (1 + SNR)}$$

→ Implication of Shannon Hartley Channel Capacity theorem →

(1) Indicates the upper limit of data transmission for reliable communication.

(2) Trade-off between Bandwidth (B) and signal to Noise Ratio (SNR) for given channel capacity (C) as they are exchangeable. Here, channel capacity can be increased either increase of BW or signal power.

(3) Bandwidth compression →

Shannon Channel Capacity theorem indicate that it is possible to transmit signal with highest frequency 'f_{max}' through a channel having BW less than f_{max}.

(P_{SAf} = Watt / Hertz)

Theoretical limitation of shannon's channel capacity theorem →

(i) The noise in channel tends to zero, $SNR \to \infty$, subsequently, $C \to \infty$. it means that noiseless channel has infinite bandwidth. This kind of channel is called ideal channel.

(ii) This is true even if the bandwidth B is infinite. The noise signal is a white noise with a uniform power density spectrum over the entire frequency range. Therefore, as the bandwidth B is increased, N also increases and hence the channel capacity remains finite even if $B = \infty$.

If $\eta/2$ is the power density, then we have,

$$N = \eta B \quad —(1)$$

i.e. Power spectrum density function of white Noise can be calculated as,

$$P_N = \int_{-B}^{B} S_{WN}(f)\,df$$

$$= \int_{-B}^{B} \frac{\eta}{2}\,df$$

power density (watt/Hz)

Noise power → Watt

Hence,

$$\therefore N = B\eta \quad —(11)$$

Also,

$$C = B \log_2\left(1 + \frac{S}{\eta B}\right)$$

and

$$\lim_{B \to \infty} C = \frac{S}{\eta} \cdot \frac{\eta B}{S} \log_2\left(1 + \frac{S}{\eta B}\right)$$

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The above limit may be found with the help of following standard expressions:

$$\lim_{x \to 0} \frac{1}{x} \log_2(1+x) = \log_2 e = 1.44$$

, use L'Hospital Rule, (0/0 form)

$$\lim_{x \to 0} \frac{1}{(x+1)\ln 2}$$

$$\Rightarrow \frac{1}{\ln 2} \Rightarrow \log_2 e \to 1.44$$

$\to \log_e 2$ Ans.

Therefore, we have,

$$\lim_{B \to \infty} C = \frac{S}{\eta} \log_2 e = 1.44 \frac{S}{\eta}$$

$$\therefore \boxed{C = 1.44 \frac{S}{\eta}}$$

** The improvement in the signal-to-noise ratio in wideband FM & PCM can be properly understood.

Fundamental Limitation of communication systems are Noise, Bandwidth & Equipment limitation →

Every communication system has limited bandwidth that limits the signal speed. Noise imposes a second limitation on information transmission as it can also cause signal distortion. It is unavoidable. At any temperature above absolute zero, thermal energy causes microscopic particles to exhibit random motion. The random motion of charged particles, such as electron, generates random currents or voltage called thermal noise. Thermal noise exists in every communication system.

Due to various reasons, every communication system supports transmission at certain limited frequency bands only. Bandwidth of a channel is the range of frequencies that it can transmit with reasonable fidelity. So, the increase in bandwidth means the increase in number of frequencies, so, the transmission speed also increases. SNR is defined as the ratio of signal power to noise power. As we have no control on noise, increasing the signal power, we are able to increase SNR. That means reducing the signal effect.

$$C = B \log_2 (1 + SNR) \text{ bits/sec.}$$

But, we cannot increase the signal power and channel bandwidth ultimately. Because they are exchange able, which describes that increase in bandwidth causes decreases in signal power & vice versa. Similarly, equipment like receiver, encoder, transmitter, and other devices used for communication have its own ~~to~~ noise, frequency & limitations. Hence, noise, BW, and equipment limitations are limitation of communication system.

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Bandwidth, signal power & SNR are exchangeability.
Bandwidth Importance with the helpof Shannon - Hartley law :.
Shannon's Channel Capacity theorem is,

$$C = B \log_2\left(1+\frac{S}{N}\right) \text{ bits/s.}$$

where, C = channel capacity.
B = Channel Bandwidth in Hz.
S = Signal power.
N = Noise power.

- The channel capacity C increases as the available bandwidth increases and as the signal to noise ratio increase (improves).
- This expression applies to information in any format & to both analog & data communications, but its application is most common in data communication.
- As the Bandwidth Increases, the capacity should increase proportionately, But this doesnot happen, because increasing the Bandwidth, B also increases the noise power.

$N = \eta B$,

$$C = B \log_2(1+S/N)$$

$$= B \log_2\left(1+\frac{S}{\eta B}\right)$$

$$= \frac{S}{\eta} \cdot \frac{\eta B}{S} \cdot \log_2\left(1+\frac{S}{\eta B}\right).$$

$$\therefore C = S/\eta \, \log_2\left(1+S/\eta B\right)^{\eta B/S}$$

- A SNR of zero dB means that noise power equals the signal power. It is not possible to transmit at rate higher than 'C'. reliability by any means.

$\boxed{(S/N)_{dB} = 10\log\left(\frac{S}{N}\right)}$

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(Q) A receiver produces a noise power of 100mW when no signal is present at its input. The receiver output power is equal to 3W with the signal applied as its input. Calculate the (S+N)/N ratio as a power ratio and in dB.

Solution,

Signal output power (P_s) = 3W

Noise output power (P_n) = 100mW = 0.1W

(S+N)/N = ?

we have,

$\frac{(S+N)}{N} \Rightarrow (3+0.1)/(0.1) = 31$

In dB, $\frac{(S+N)}{N}$ (dB) = $10\log_{10} 31 = 14.91$ dB.

(Q) The signal power and noise power measured at the input of an amplifier are 150 μW and 1.5μW respectively. If the signal power at the output 1.5W and noise power is 40mW, calculate the amplifier noise factor & noise figure.

soln:

$P_{si} = 150\mu W$, $P_{ni} = 1.5\mu W$, $P_{so} = 1.5W$, $P_{no} = 40mW$.

(i) Noise factor = $\frac{P_{si}}{P_{ni}} \times \frac{P_{no}}{P_{so}} = \frac{150\times10^{-6}}{1.5\times10^{-6}} * \frac{40\times10^{-3}}{1.5}$

$= 2.666$ Ans.

(ii) Noise figure = $10\log_{10}$(Noise factor)

$= 10\log_{10}(2.667)$

$= 4.26$ Ans

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Also, ($C = 0.332 * \text{Bandwidth} * \text{SNR in dB}$)

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(8) Calculate the maximum bit rate for a channel having Bandwidth of 3.1KHz and the SNR of 40dB. Also, Calculate the number of levels required to transmit at the maximum bit rate.

Solution,

Channel Capacity $(C) = ?$

Bandwidth $= 3.1 KHz = 3.1 \times 10^3 Hz$.

$(SNR)_{dB} = 40dB$.

No. of levels $(L) = ?$

We have,

$C = B \log_2 (1 + SNR)$.

$= B \log_2 (1 + 10000)$

$= 3.1 \times 10^3 \log_2 (10001)$

$= 41.19$ Kbps.

Also,

$(SNR)_{dB} = 10 \log_{10} (S/N)$.

$40 = 10 \log_{10} (S/N)$

or, $\log_{10} (S/N) = 4$

or, $S/N = 10^4$

$= 10000$

Now,

Number of level Required $(L) = ?$

we have,

Using Noiseless Nyquist ~~Rate~~, formula,

$C = 2 * Bw * \log_2 (L)$

$1000 * 41.19 = 2 * 3.1 * 1000 * \log_2 (L)$.

or, $\log_2 (L) = 6.64$

or $L = 2^{6.64}$ (2.26 is bits/baud).

$\therefore L = 99.73 \simeq 100$

Hence, No. of levels required.

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(Q) A system has bandwidth of 44 KHz and signal to noise ratio of 28 dB at input to receiver, calculate.

(i) Information carrying capacity.

(ii) Capacity of channel if its Bandwidth is double and transmitted signal power remains constant:

Solution,

Bandwidth (B.W.) = 44 KHz

Signal to noise ratio (SNR) = 28 dB.

We know,

(i) Carrying capacity (C) = $B \log_2(1+SNR)$.

Here,

$SNR \text{ in dB} = 28dB = 10\log_{10}(SNR)$

or, $SNR = 10^{2.8} = 10^{28/10}$

or $SNR = 630.957$.

$C = B\log_2(1+SNR)$

$= 44 \times 10^3 \log_2(1+630.957)$

$= 409362.033$ bps

$= 0.4094$ Mbps

(ii) Bandwidth is doubled (B) = $2 \times 44 = 88$ KHz,

Since, power transmitted remains constant,

$C = B\log_2(1+SNR)$

$= 88 \times 10^3 \times \log_2\left(1+\frac{630.957}{2}\right)$

(BW doubled then Noise will be doubled)

$= 730924.8071$ bps

$= 0.7309$ Mbps.

i.e. $\left(\frac{S}{N}\right) \Rightarrow \left(\frac{S}{\eta B}\right) \rightarrow \left(\frac{S}{\eta 2.B}\right) = \left(\frac{S}{N.2}\right)$

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(AWGN ⇒ additive white Gaussian Noise)
awgn

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(Q) State channel capacity theorem. Given an AWGN channel with 4 KHz bandwidth, the noise power spectrum density of 10^{-12} W/Hz. The signal power required at the receiver is 0.1 mW. Calculate the capacity of the channel.

Solution,

(see formula)

Noise power spectrum density (η) = 10^{-12} W/Hz × 2

Bandwidth (B) = 4 KHz = 4000 Hz.

Signal power transmit ($\bar{P}$) = 0.1 mW

= 0.0001 W

Capacity of channel (C) = ?

we have,

$$C_{awgn} = B \log_2\left(1 + \frac{\bar{P}}{\eta B}\right) \text{ bits/sec.}$$

$$= 4000 \times \log_2\left(1 + \frac{0.0001}{2 \times 10^{-12} \times 4000}\right)$$

= 54438.562 bps

= 54.44 Kbps.

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(Q) The initial SNR measured at the transmitter was 20dB. In order to combat the channel conditions, the signal power was doubled prior to transmission. What is the new SNR at the transmitter?

Solution,

$SNR = 20dB.$

If power signal is doubled ⇒ new SNR ⇒ ?

We have,

$$SNR = 10\log_{10}\left(\frac{S_p}{N_p}\right).$$

$$20dB = 10\log_{10}\left(\frac{S_p}{N_p}\right).$$

$$\log_{10}\left(\frac{S_p}{N_p}\right) = 2 \Rightarrow \left(\frac{S_p}{N_p}\right) = 10^2 = 100.$$

$$\left(S_p/N_p\right) = 100 \text{ and, } S_p = 100N_p.$$

Let SNR' denote the new SNR. We know,

~~New SNR is~~, New signal power is doubled,

i.e. $S_p' = 2S_p$.

$$SNR' = 10\log_{10}\left(\frac{S_p'}{N_p}\right)$$

$$= 10\log_{10}\left(\frac{2S_p}{N_p}\right)$$

$$= 10\log_{10}\left(\frac{2\cdot 100\cdot \cancel{N_p}}{\cancel{N_p}}\right)$$

$$= 10\log_{10}200$$

$$= 23dB.$$

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∴ Therefore, the new SNR is 23dB.

Cha. Communication Channel | Transmission media →

- The term Channel means the media through which the message travels from the transmitter to the receiver.
- In other words, we can say that the function of the channel is to provide connection between the transmitter and receiver. Noise is added to channel which reduces the signal quality.
- transmission media is a material substance (solid, liquid, gas or plasma) that can propagate energy wave.

- In absence of material medium in vacuum may also constitute a transmission medium for EM waves such as electrical / light and RF / microwave.
- For the propagation of EM wave material substance is not required.

- Factors of channel.
  1. Transmission Rate
  2. Cost
  3. Ease of Installation
  4. Resistance to environment condition
  5. distances

Channel

- Guided (Physical connection)
  - twisted pair cable
  - Co-axial
  - Wave guide
  - Optical fiber
- Unguided (wireless) (air vacuum)
  - Microwave
  - Satellite
  - Radio frequency broadcasting

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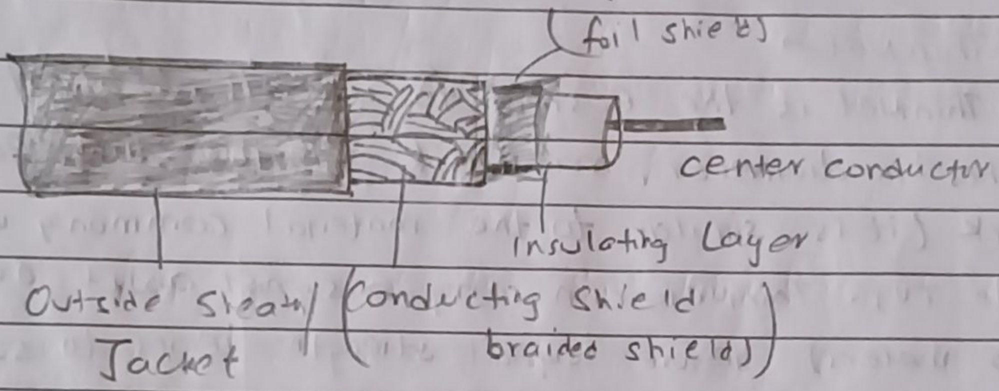
Guided (wire line) →

- Guided media is a medium that sends signals through a solid physical path.
- Guided media help wired transmission.

(1) Coaxial cable –

Transmission signals in electrical form over the metallic conductor.



Coaxial cable is made of two ~~characters~~ conductors that share the same axis; the centre is a copper wire that is insulated by a plastic coating and then wrapped with an outer conductor (usually a wire braid). This outer conductor around the insulation serves as electrical shielding for the signal being carried by the inner conductor. A tough insulating plastic tube outside the outer conductor provides physical and electrical protection. At one time, coaxial cable was the most widely used network cabling. However, with improvements and the ~~lowest~~ lower cost of twisted-pair cables, it had lost its popularity.

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There are two types of coaxial cable.

(1) Thick Net →

Thick-net is about 0.38 inches in diameter. This makes it a better conductor, and it can carry a signal about ~~500 meters~~ 1640 feet (500 meters) before signal strength begins to suffer. The disadvantage of ThickNet version is also known as standard Ethernet cable.

(2) Thin Net →

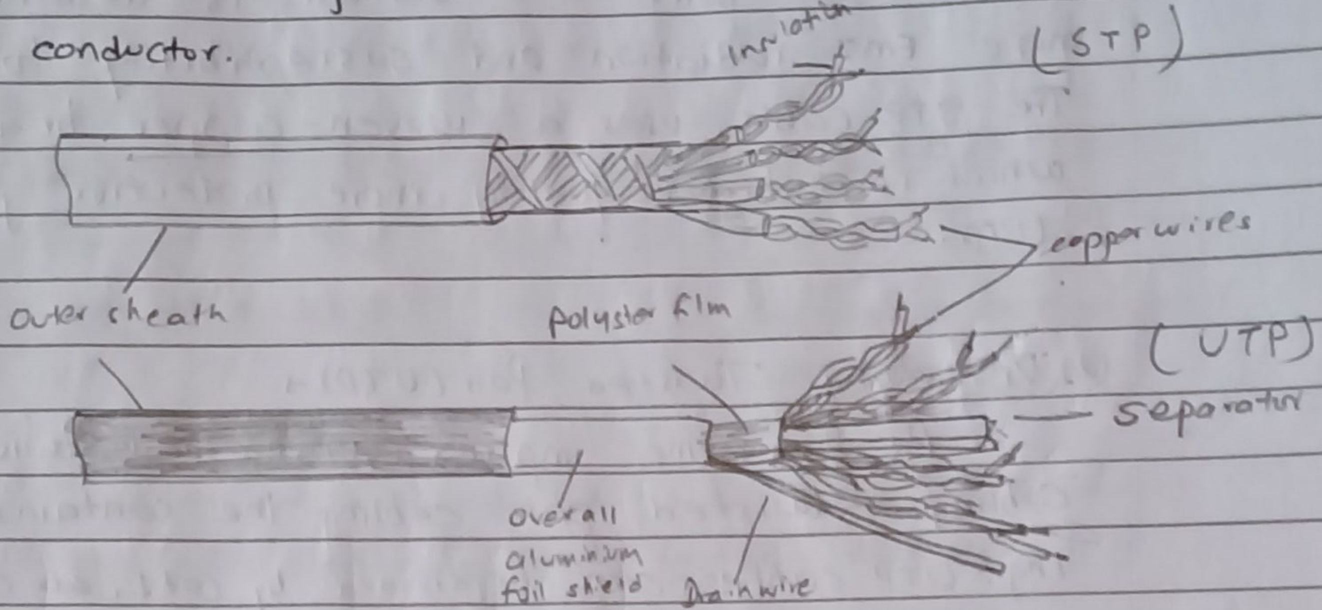
ThinNet is the easiest to use. It is about 0.25 inches in diameter, making it flexible and easy to work (it is similar to the material commonly used for cable TV). ThinNet can carry a signal about 605 feet (185 meters) before signal strength begins to suffer.

Name	Description	Type	Segment	Speed
10Bas 2	Thin Net	Coaxial	185 meters	10Mbps
10 Base 5	ThickNet	Coaxial	500 meters	10 Mbps

Co-axial cable can only be used with a BNC (bayonet - Neill - Concelman) Connector.

(2) Twisted Pair →

Transmission signal is in electrical form over the metallic conductor.



Twisted-pair cable consists of two insulated strands of copper wire twisted around each other to form a pair. One or more twisted pairs are used in a twisted-pair cable. The purpose of twisting the wires is to eliminate electrical interference from other wires and outside sources such as motors. Twisting the wires cancels any electrical noise from the adjacent pair. The more twisted per linear foot, the greater the effect.

There are two types of twisted pair cable
(1) Shielded Twisted Pair (STP) →

The only difference between STP and UTP is that STP

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has a foil or wire braid wrapped around the individual wires of the pairs. The shielding is designed to minimize EMI radiation and susceptibility to crosstalk. The STP cable uses a woven-copper braided jacket, which is a higher-quality, more protective jacket than UTP.

(2) Unshielded Twisted Pair (UTP) →

As the name implies, "unshielded twisted pair" (UTP) cabling is twisted pair cabling the contains no shielding. UTP cables can be divided by Cat 1, Cat 2, ... and so on.

Name	Description	Type	Segment	Speed
10BaseT	UTP	Twisted-pair	0.5 to 100 m	10 Mbps
100BaseT	STP	Twisted-pair	0.5 to 100m	100 Mbps

Twisted-pair cable has several advantages over the other types of cable (coaxial and fiber optic):

It is readily available, easy to install, and inexpensive. Among its disadvantages are its sensitivity to electromagnetic interference (EMI), its susceptibility to eavesdropping, its lack of support for communication at distances of greater than 100 feet, and its requirement of a hub (multiple network connection point) if it is to be used with more than two computers.

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Twisted pair cables use RJ45 connector.

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(3) Fiber optic Cable →

Transmission signal is in the form of light over the glass fiber.

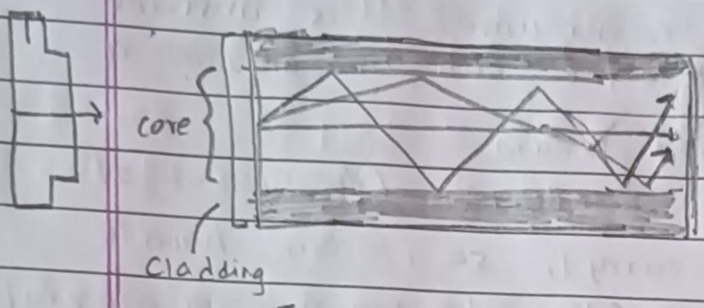

Figure: Step Index (multimode)

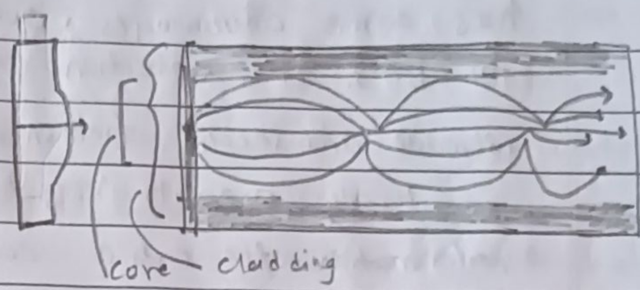

Fig: gradual Index (multimode).

Multimode 50/125 μm core/cladding diameter

Single mode : 9/125 μm core/cladding diameter

Fiber optic cable is made of light-conducting glass or plastic fibers. It can carry data signals in the form of modulated pulse of light. The plastic core cables are easier to install but do not carry signals as far as glass-core cables. Multiple fiber core can be bundled in the centre of the protective tubing.

There are two types of fiber optics :-

(1) Step Index.
  (i) Step Index monomode
  (ii) Step Index multimode

(2) Gradual Index.

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When both material and installation costs are taken into account, fiber optic cable can ~~prove~~ prove to be no more expensive than twisted-pair or coaxial cable. Fiber has some advantages over copper wire. It is immune to EMI and detection outside the cable and provides a reliable and secure transmission media.

It also supports very high bandwidths (the amount of information the cable can carry), so it can handle thousands of times more data than twisted-pair or coaxial cable. Cable length can run from 0.25 to 2.0 km ~~(LAN)~~ (on local area network), depending on the fiberoptic cable & network it can be more distance.

Connector : LC - Lucent connector.
: FC - Fer-rule connector.
: SC - Square/standard connector.
: ST - Straight Tip

(4) wave guide →
- uses to Guide EM wave.
- In microwave ~~and~~, satellite ~~or~~ and Radio we ~~used~~ need to connect ~~Antenna to transmitter ODU~~ (antenna and outdoor trx frequency unit), in such ~~an~~ time we use wave guide.
- It is of two types (1) Rectangular.
(2) Circular.

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Comparision betn Guided media:-

Twisted pair cable	Coaxial cable	Optical fiber cable
- tx signal is in electrical form over the metallic conductor.	- transmission signal is in electrical form over the metallic conductor.	- transmission signal is in light form over the glass fiber.
- carries data & power.	- carries data and power	- carries data only
- lowest data rate	- moderately data rate	- high data rate
- effected due to external magnetic field.	- affected due to external magnetic field	- no affected
- noise immunity is low.	- noise immunity is high.	- no noise immunity.
- short ckt (chances).	- short circuit	- no short circuit.
- signal power loss	- signal power loss	- signal power doesnot loss
- Economical	- Economical but higher cost than twisted pair.	- more expensive among all.
- Easy Installation & maintainance	- Easy	- difficult to Install & maintainance.
Types:		
(a) Unshielded	(a) thicknet	(a) Step Index
10 to 1000 Mbps (f → 0, to 1 MHz)	- 0.38" dia.	(1) Step Index monomode
N/w Impedence = 100 Ω	10base5 - 10 Mbps upto 500 m	(2) Step Index multimode
telephone " - 600 Ω long - 100 m, dia - 0.11"	(b) thin net	(b) Gradual Index
(b) Shielded (10 to 100 Mbps)	- 0.25" dia.	(1) Gradual Index
(Impedance - 150 Ω, short - 10 m)	10base2 - 10 Mbps upto 185 m	multimode.
- telephony & Ethernet	- cable TV	
- RJ45 connector.	- BNC connector	- LC, FC, SC Connector.

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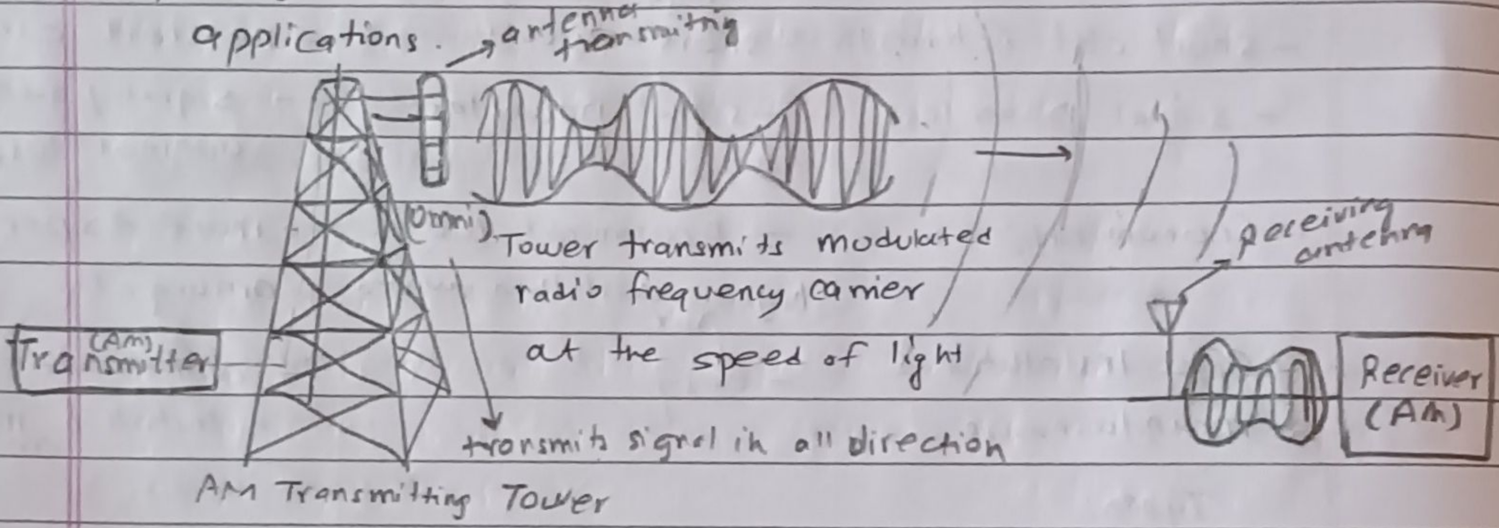
UnGuided Media →

- UnGuided media is a medium that sends signals through a space, i.e. on air.
- Unguided transmission media help wireless transmission.

(1) Radio waves -

- the Radio frequency in EM spectrum vary from 3Hz - 300MHz frequency which is equivalent to the wavelength of 100 Mm to 1m.
- omni-directional in nature. So, use omni directional for tx & Rx.
- Uses AM & FM broadcasting, television, cordless phone pagging and wide variety of other multi casting applications.



- specification -

RF range, 3Hz - 300MHz.

- uses
1. FM Broadcasting
2. AM Broadcasting
3. TV Broadcasting.

- characterestics:

advantages

(1) High frequency / long-distance communication

(2) Space & ground wave communication

(3) Can reduce cost.

disadvantages

1. Effects on propagation model.

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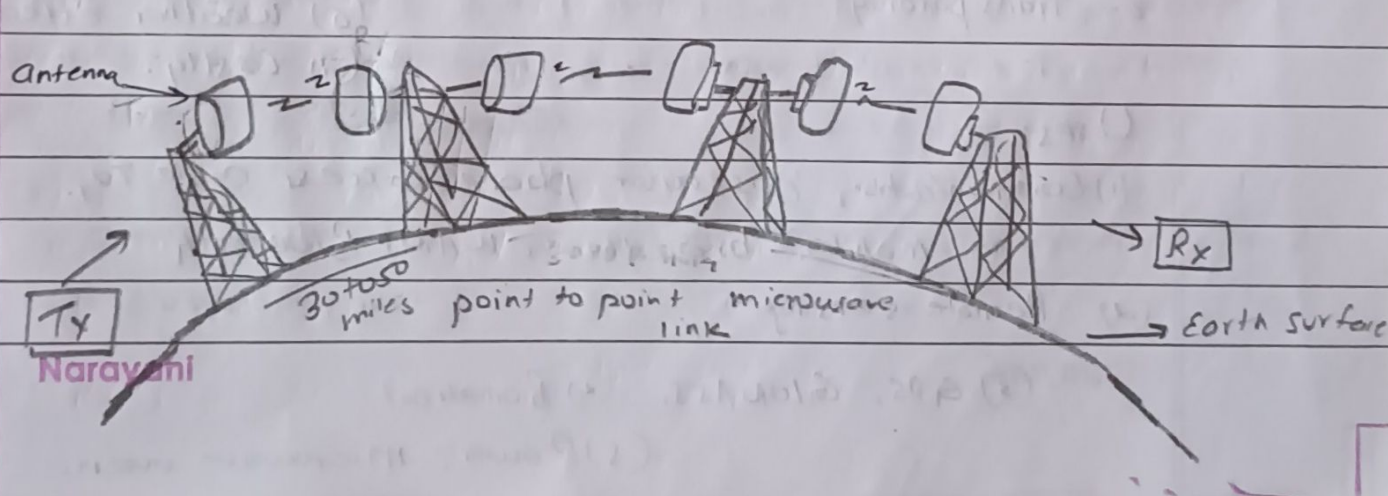
Microwave →

- Microwave transmission is the transmission of information by electromagnetic waves with wavelengths in the microwave frequency range of 300MHz - 300GHz (1m - 1mm wavelength) of the electromagnetic spectrum.
- Microwave signals are normaly limited to the line of sight, so long-distance transmission using these signals requires a series of repeaters forming a microwave relay network.
- The requirement of a L-O-S (line of sight) limits the ~~spe~~ separation between stations to the visual horizon, about 30 to 50 miles (48 to 80 km).

For long distances, the receiving ~~antenna~~ station could function as a relay, retransmitting the received information to another station along its journey.

- Information can be sent from one point to another.



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At transmitter side,

(a) a modulator which turns the Incoming Information signal into a high frequency electrical signal on a wire.

(b) an antenna, which turns the high-frequency electrical signal into a EM wave sent through the atmosphere.

At receiver side,

(a) a receiver antenna which pick up the incoming EM wave and turns it back into the high frequency electrical signal.

(b) a demodulator, which returns the higher frequency electrical signal back to the Information signal.

Advantages:-

1. High BW is avaiable in microwave
2. Improved gain and direction properties
3. Reduction in antenna physical size
4. Low power requirement
5. Higher degree of Reliability,
6. Transparancy.

Disadvantages

(1) L-O-S propagation
(2) EM interference
(3) adverse fading Effect.
(4) Hazard of EM.
(5) Super posing of two signals.
(6) Weather effect
(7) Costly.

Uses:.

(1) Communication, cellular phone, access cable TV, mobile broadband, WAN, Bluetooth

(2) Remote sensing

Narayani (3) GPS, GLONASS, (4) Biomedical

(5) Power: microwave oven.

Satellite →

- A satellite communication is an artificial satellite that relays and amplifies radio telecommunication signal via a transponder and it creates a communication channel between a source transmitter and a destination receiver at different locations on earth.

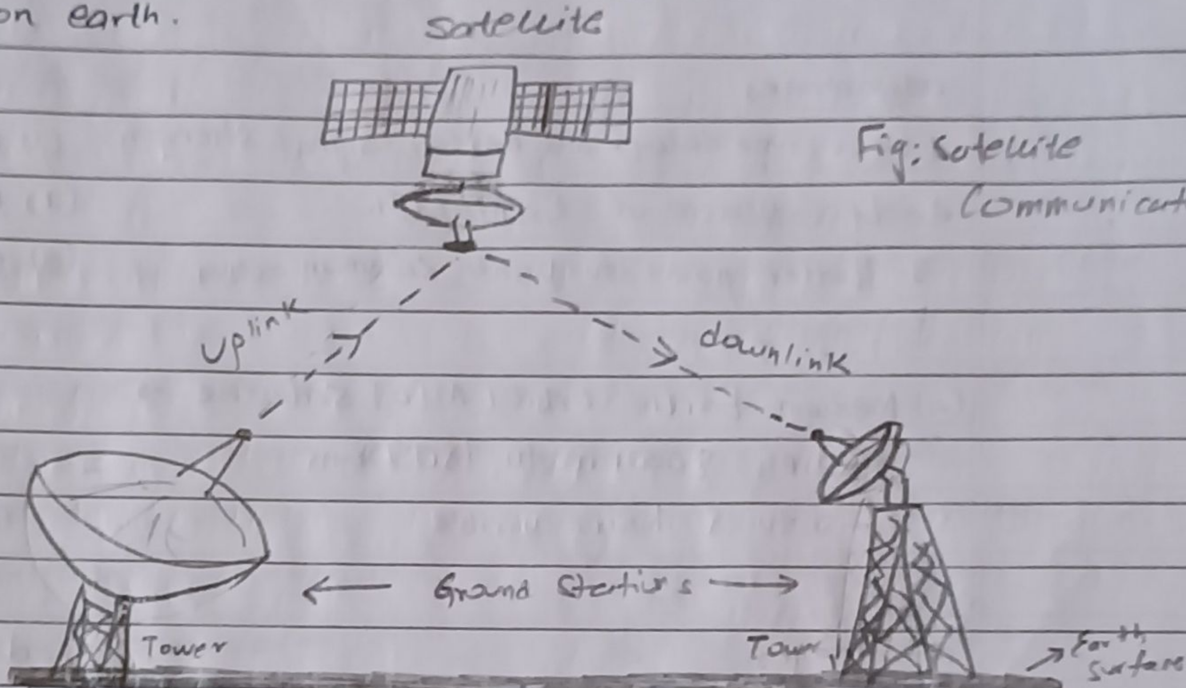

Fig: Satellite Communication

- A satellite communication consists of Ground station for transmitting and Receiving signals and communication satellite in the space. A satellite is simply a repeater. It consists of radio equipments / active elements such as transmitter, receiver, antenna, signal processor, amplifier, transponder (a set of elements) and power is given by solar photo voltaic module.

- Some how satellite is not necessary to transmit RF and microwave signal.

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Types of satellite

(1) low-Earth-orbit (LEO) satellite →

- close to the earth 500km to 1500Km
- doesn't stay in fixed position
- Visible 15 to 20 minute in each pass

advantages	disadvantages
1. Less time delay and better signal strength	(1) more N/w
2. Less waste of Bandwidth.	(2) more account of dopler shift
3. Better point to point communication	(3) atmospheric effect.

(2) Medium Earth orbit (MEO) satellite →

- lies 8000Km to 18000Km
- 2 to 8 hours visible

advantages	disadvantages
(1) Less network	(1) more time delay & bad signal strength
(2) Less account of doppler shift	(2) more waste of BW
(3) less atmospheric effect	(3) worse point-to-point comn.

(3) Geostationary Earth orbit (GEO) satellite →

- far from earth and fixed at a point 35786 Km ~~abo~~ along the equator.
- same speed as earth rotates
- remain same position relative to earth.

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Characterestics
altitude → 35786
period - 2hr, 56min, 4.09sec.
Orbital Inclination : 0°.
velocity - 3.075 km/sec.
Subsatellite point : on equator.
coverage : 42.5% (3-sat a part 120°).

advantage
(1) No network required.
(2) Less doppler shift.
(3) Less atmospheric effect.
(4) simple Ground stationary tracking.
(5) No handover problem.
(6) Long distance communication.
(7) Low cost per added side.

disadvantage
(1) much more time delay (bad signal strength)
(2) much more waste of BW
(3) Free space loss
(4) No polar coverage
(5) Signal attenuation
(6) weather condition
(7) Echo.

(4) Molniya Orbit satellite / Highly Elliptical Earth Orbit (HEO) satellite →
- Russia.
- fixed 8-hours relative to earth.
- 3 molniya - 1 Geo.
- near polar region.

(5) High altitude platforms (HAPs) Satellite →
- newest idea in satcom
- above 20km

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- small coverage area
- strong signal.
- lots of n/w but cheaper.

<u>application of satellite</u>

- FM, Radio & TV Broadcasting
- Data collection
- RS & mapping
- weather
- meterological data collection
- FSS. NASA
- MSS, - BSS, etc.
- file transfer, E-mail, Internet
- Navigation, spy, and millitary
- TTC&M
- GPS & GLONASS
- disaster monitoring
- news gathering
- sat to sat comm
- telemediction.
- telephone ~~[illegible]~~
- Aeromobile, landmobile, maritime communication
- video confrerencing