Chapter 2

Physical Layer

Digital Communication

Digital communication is made from two words **digital** and **communication**. Digital refers to the discrete time-varying signal. Communication refers to the exchange of information between two or more sources. Digital refers to the discrete time-varying signal. Communication refers to the exchange of information between two or more sources. Digital communication refers to the exchange of digital information between the sender and receiver using different devices and methods.

The data transmission using analog methods for long-distance communication suffers from distortion, delays, interferences, and other losses. To overcome these problems, the digitization and sampling of signals using different techniques help in making the transmission process more **efficient, clear,** and **accurate**.

Digital communication is a popular technology used today in electronics. It allows us to access **video conferencing, digital meetings, online education**, etc. The data can travel upto long distances within a second with the help of the internet and other modes of digital communication. It not only saves money but also saves time and effort. It has also raised the standard of an individual's social, political, and economic life.

What is Communication?

Communication refers to the exchange of information using a specific medium, such as **vacuum, space, wireless medium, wired medium**, etc. Good communication always transmits information with reduced attenuation and noise. The received signal is the same as the transmitted signal with clear information. Communication is a **two-way** process of sharing information. In digital terms, communication refers to the exchange of digital information from the transmitter to the receiver.

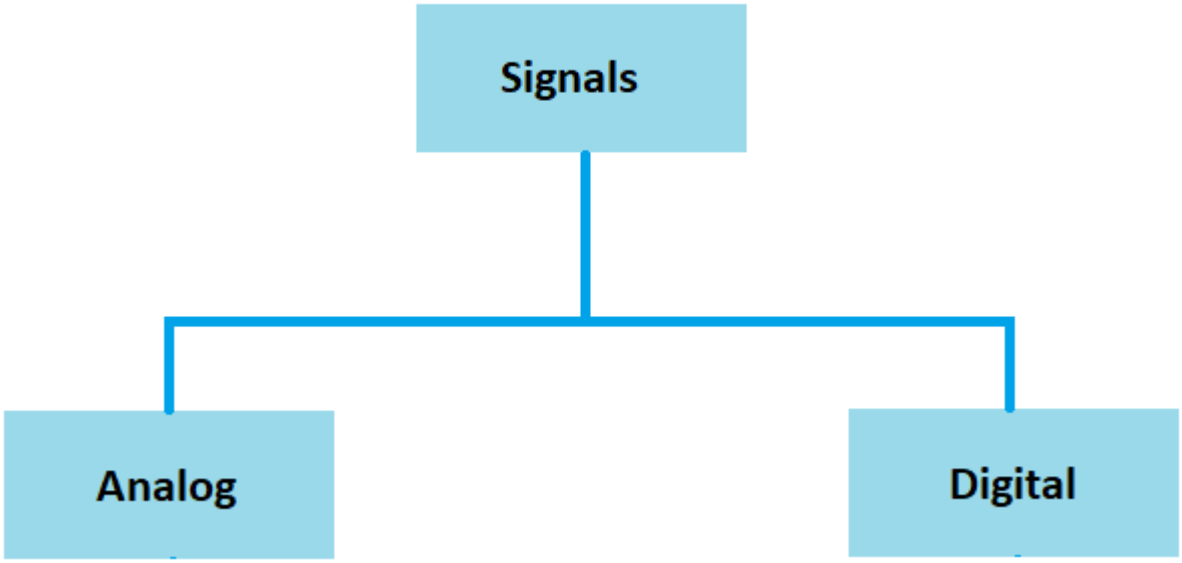
The components of a communication system are the **transmitter, communication channel,** and **receiver**. The transmitter transmits the data to the communication channel, which further sends it to the receiver. Various devices are used in cascade or parallel with the transmitters and receivers for different purposes, such as **modulation, demodulation,**

noise removal, sampling, etc. The devices include modulators, filters, amplifiers, encoders, and decoders.

Signals

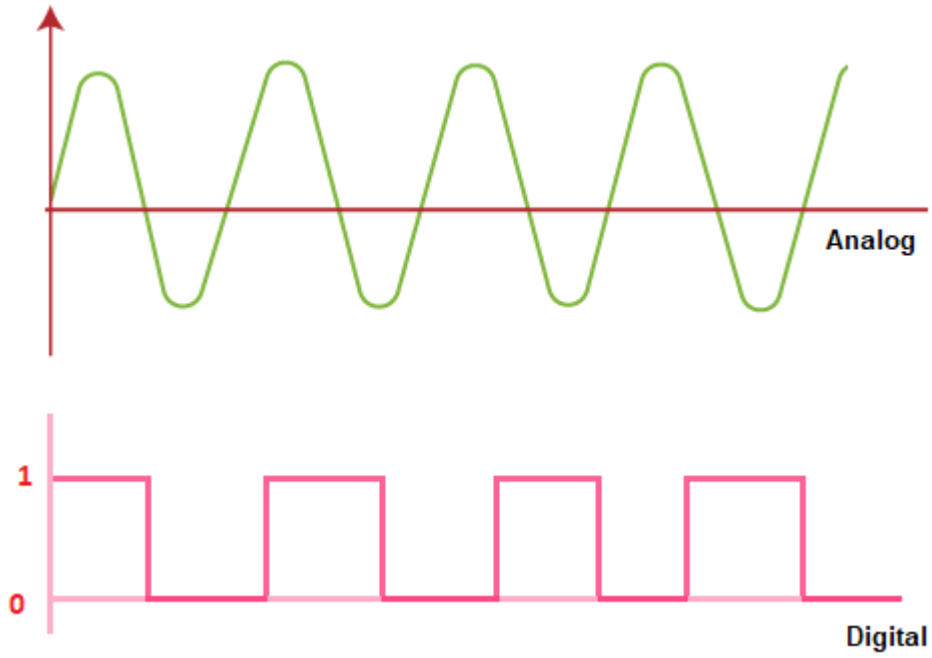
A signal is an electromagnetic wave that carries information from one place to another, using a specific propagation medium, such as **air, vacuum, water**, and **solid**. In electronics, the signal is defined as a **current, voltage,** or **wave** carrying information. It can travel short distances or long distances depending on the requirements. The speed of a signal wave is equal to the speed of light.

The signals are categorized as analog signal and digital signals.



Analog refers to the data transmission in continuous form, while digital refers to the data transmission in the discrete form. It is also known as the transmission in the form of bits, **0 (LOW)** and **1 (HIGH).**

The waveforms of the analog and digital signal are shown below:



The noise in analog signals is high as compared to digital signal. It is due to the thresholding and high bandwidth of the digital signals. Hence, electronic noise affects analog signals more than digital signals. Filters are generally used in analog communication at transmitting and receiving ends to remove the noise.

Digital Signal

We can represent various physical quantities using digital signals, such as voltage and current. A signal represented in the form of **discrete values** is known as digital signal. It is transmitted in the form of **bits**. Only two bits (0 and 1) work in different combinations. A digital signal can take only one value at a time from the set of finite possible values.

Digital signal is nothing but the representation of the analog data in the discrete form.

Advantages of Digital Communication

The advantages of digital communication are as follows:

- It is fast, more accurate, and more reliable than analog communication.
- The data with the help of digital communication can be quickly transmitted upto long distances.
- The detection and correction of errors is easy.
- It allows easy removal of noise, cross-talk, or any interference in the signal.

- It is inexpensive due to advanced technologies and compact size.
- The transmission speed of signal is high.
- It facilitates video and audio conferencing, allowing quick meetings and discussion with several people. It saves time and effort.

Disadvantages of Digital Communication

The disadvantages of digital communication are as follows:

- **High power consumption**
  It consumes high power due to the requirement of greater number of components, higher bandwidth, and high transmission speed.
- **High transmission bandwidth**
  Digital communication requires high transmission bandwidth to transmit the signals at high speed.
- **High power loss**
  The power loss in digital communication is higher than analog communication due to the high processing speed and hardware components.

Nyquist Theorem

The Nyquist theorem essentially tells us how often we need to sample a signal to accurately capture and reproduce it. If you sample too slowly, you miss important details, leading to distortions known as aliasing.

Key Points:

1. **Sampling Rate**: To accurately capture a signal, you need to sample it at least twice the frequency of its highest component. This minimum rate is called the Nyquist rate.
2. **Bandwidth**: In terms of data transmission, the bandwidth is the range of frequencies within which the signal operates.

Example:

Imagine you're recording a piece of music. The highest note (frequency) you want to capture is 10 kHz (10,000 Hz).

According to the Nyquist theorem, you need to sample this music at least twice the highest frequency to capture it accurately.

So, the **Nyquist rate** for your music is:

Nyquist rate=2×10,000 Hz=20,000 Hz\text{Nyquist rate} = 2 \times 10,000 \text{ Hz} = 20,000 \text{ Hz}Nyquist rate=2×10,000 Hz=20,000 Hz

This means you need to take 20,000 samples per second to accurately capture all the details of your music.

In Computer Networks:

Now, let's apply this to a simple computer network example. Suppose you're transmitting a signal over a network, and the signal has a maximum frequency of 5 kHz.

1. **Calculate the Nyquist rate**: To avoid distortion, you should sample at least at twice the highest frequency.

   Nyquist rate=2×5,000 Hz=10,000 Hz\text{Nyquist rate} = 2 \times 5,000 \text{ Hz} = 10,000 \text{ Hz}Nyquist rate=2×5,000 Hz=10,000 Hz

2. **Bandwidth**: The bandwidth of your channel should be able to support this sampling rate. So, you need a channel with a bandwidth of at least 10 kHz to accurately transmit the signal.

Practical Scenario:

Think about how internet speeds work. When you're streaming a video, the video data is broken down into small pieces and sent over the network. If the network's bandwidth is too low (sampling rate too low), you won't get a clear picture; it will be pixelated or have lag. But if the network's bandwidth is high enough (sampling rate meets or exceeds the Nyquist rate), the video will stream smoothly and clearly.

Physical Layer

- The lowest layer of the OSI reference model is the physical layer. It is responsible for the actual physical connection between the devices.
- The physical layer contains information in the form of **bits.** It is responsible for transmitting individual bits from one node to the next.
- When receiving data, this layer will get the signal received and convert it into 0s and 1s and send them to the Data Link layer, which will put the frame back together.

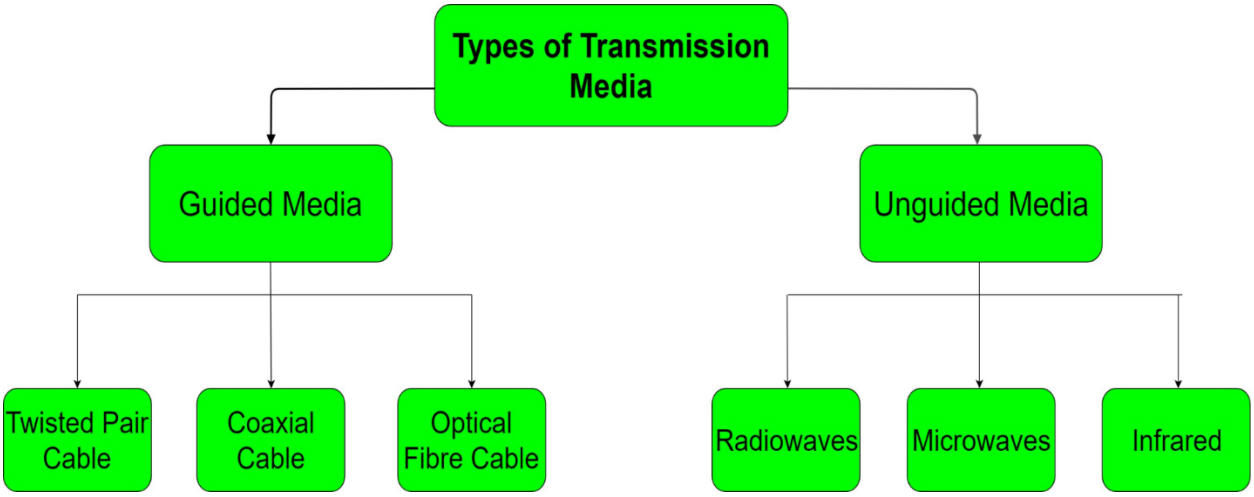
The functions of the physical layer are:

- **Bit synchronization:** The physical layer provides the synchronization of the bits by providing a clock. This clock controls both sender and receiver thus providing synchronization at bit level.
- **Bit rate control:** The Physical layer also defines the transmission rate i.e. the number of bits sent per second.
- **Physical topologies:** Physical layer specifies the way in which the different, devices/nodes are arranged in a network i.e. bus, star or mesh topology.
- **Transmission mode:** Physical layer also defines the way in which the data flows between the two connected devices. The various transmission modes possible are: Simplex, half-duplex and full-duplex.

Transmission Media

- Media are what the message is transmitted over. In other words, communication channel is also called as medium.
- Different media have different properties and use in different environment.
- The purpose of the Physical layer is transport a raw bit stream from one computer to another.

Classification of Transmission Media



Wired Media

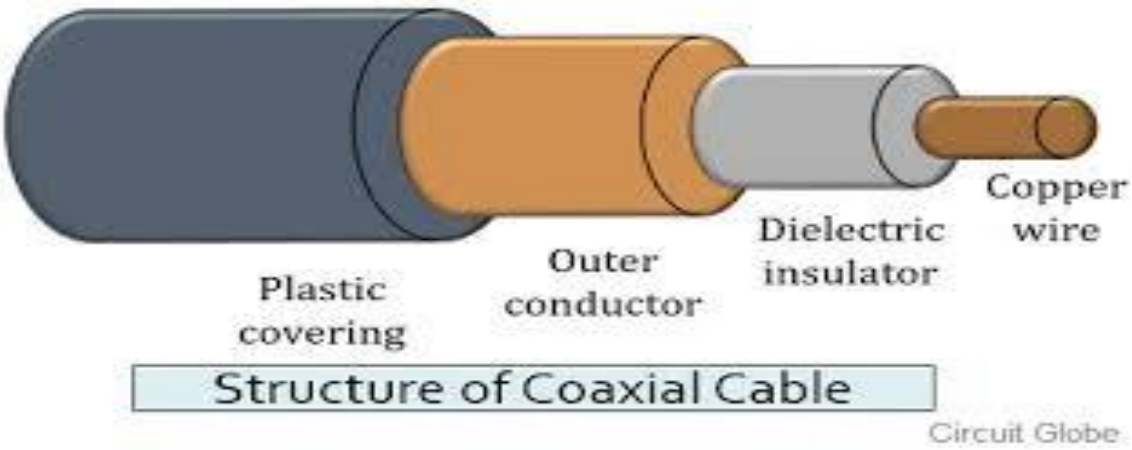
- The signal energy is contained and guided with solid Medium.
- Wired media used for point to point communication.

Types of wired media

- Co-axial cable
- Twisted pair
- Optical Fiber cable

Co-axial Cable

- Coaxial cable is a group of wrapped and insulated wire line.
- They transmit data at higher rates.
- The conductor is made of copper wire surrounded by PVC insulation. This insulation is encased in an outer conductor of metal foil, which is enclosed in a PVC insulation sheath. Also, it is completely covered by a plastic cover.



Advantages of Coaxial Cable

- Coaxial cable is used in cable television.
- It offers much higher bandwidth.
- It is preferred for long distance telephone lines as well.
- Provides better shield when compared with Twisted Pair cable.
- It offers data transmission without any distortion.
- Expect quite higher noise immunity from coaxial cable.

Disadvantages of Coaxial Cable

- Costlier than Twisted pair cable
- BNC connectors are required for connection.

Types of Co-Axial Cable

Baseband Coaxial Cable

- LAN generally uses Baseband Coaxial cable. It is the 50-ohm coaxial cable used for digital transmission. The cable comes with a power of transmitting a single signal at quite high speed. It transmits a single signal at a time.

Broadband Coaxial Cable

- This cable transmits many simultaneous signals and that too using different frequency. It covers more area than the Baseband coaxial cable and can run nearly 100km.

Applications of Coaxial Cable

- Analog telephone network
- Cable TV

- Digital telephone network
- Traditional LAN Network

Twisted Pair cable

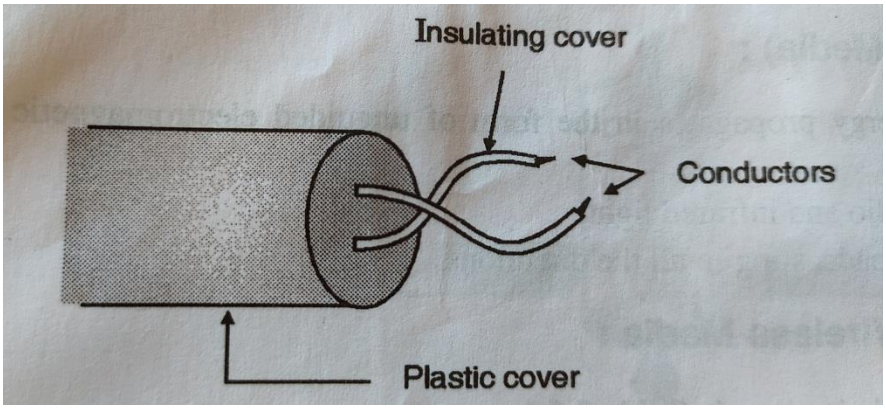
- This is commonly use medium and it is cheaper than co-acial cable.
- It is made up of two insulated copper wires, typically, twisted around each other in a continuous spiral.
- The purpose of twisting the wires is to reduce electrical interference (or noise) from similar pairs close by.

Types of Twisted pair cable.

- Unshielded twisted pair
- Shielded twisted pair

Unshielded twisted pair cable

- UTP is the type of twisted pair cable. It stands for Unshielded twisted pair.
- Both Data and voice both are transmitted through UTP because its frequency range is suitable.
- In UTP grounding cable is not necessary also in UTP much more maintenance is not needed therefore it is cost effective.



Advantages of Unshielded Twisted Pair Cable

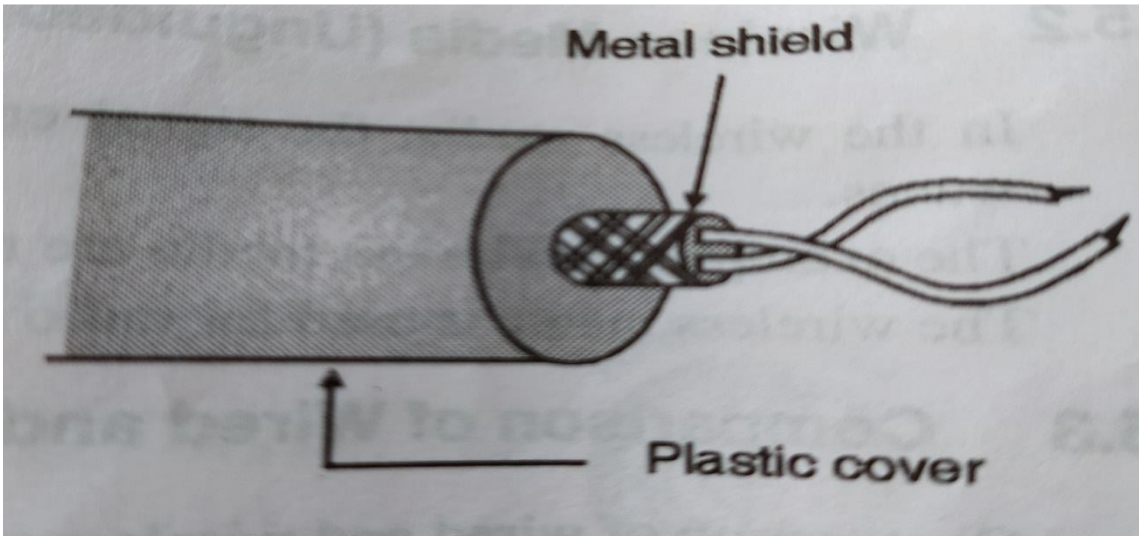
- Installation is easy
- Flexible
- Cheap
- It has high speed capacity,
- 100-meter limit
- Higher grades of UTP are used in LAN technologies like Ethernet.

Disadvantages of Unshielded Twisted Pair Cable

- Bandwidth is low when compared with Coaxial Cable
- Provides less protection from interference.

Shielded twisted pair cable

- STP is also the type of twisted pair which stands for Shielded twisted pair. In STP grounding cable is required but in UTP grounding cable is not required.
- In Shielded Twisted Pair (STP) much more maintenance is needed therefore it is costlier than Unshielded Twisted Pair (UTP).



Advantages of Shielded Twisted Pair Cable

- Easy to install
- Performance is adequate
- Can be used for Analog or Digital transmission
- Increases the signaling rate

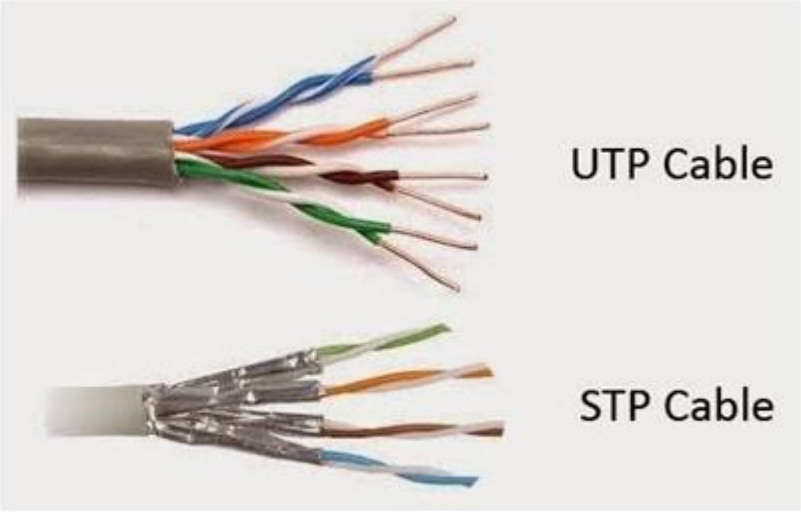
- Higher capacity than unshielded twisted pair
- Eliminates crosstalk

Disadvantages of Shielded Twisted Pair Cable

- Difficult to manufacture
- Heavy
- It is the most expensive wire from UTP cables.
- It requires more maintenance to reduce the loss of data signals.
- There is no segment improvement in length despite its thick and heavier connection.
- It is used only as a grounded wire.

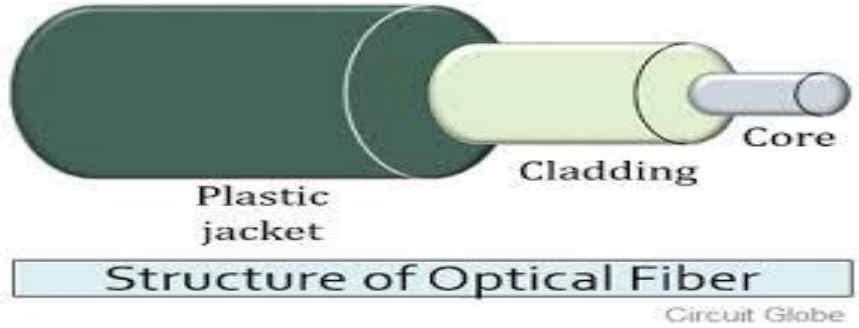
Application of Twisted pair cable

- LAN
- Conventional telephone line



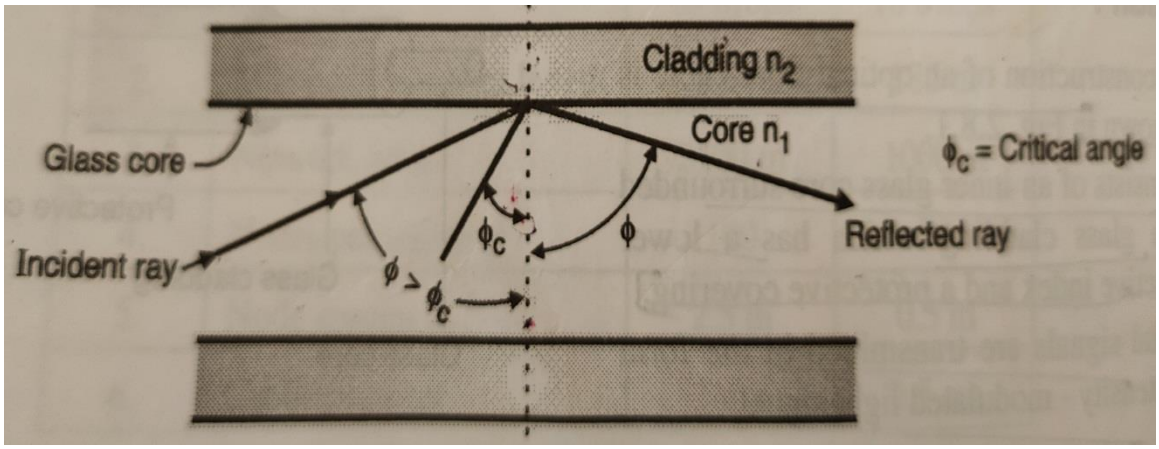
Optical Fiber cable

- It consists of an inner glass core surrounded by a glass cladding which has lower refractive index and protective covering.
- Digital signals are transmitted in form of intensity modulated light signals.
- Light is launched into a fiber at end using light source like LED and detected by other side using photo detector.



Principal of propagation

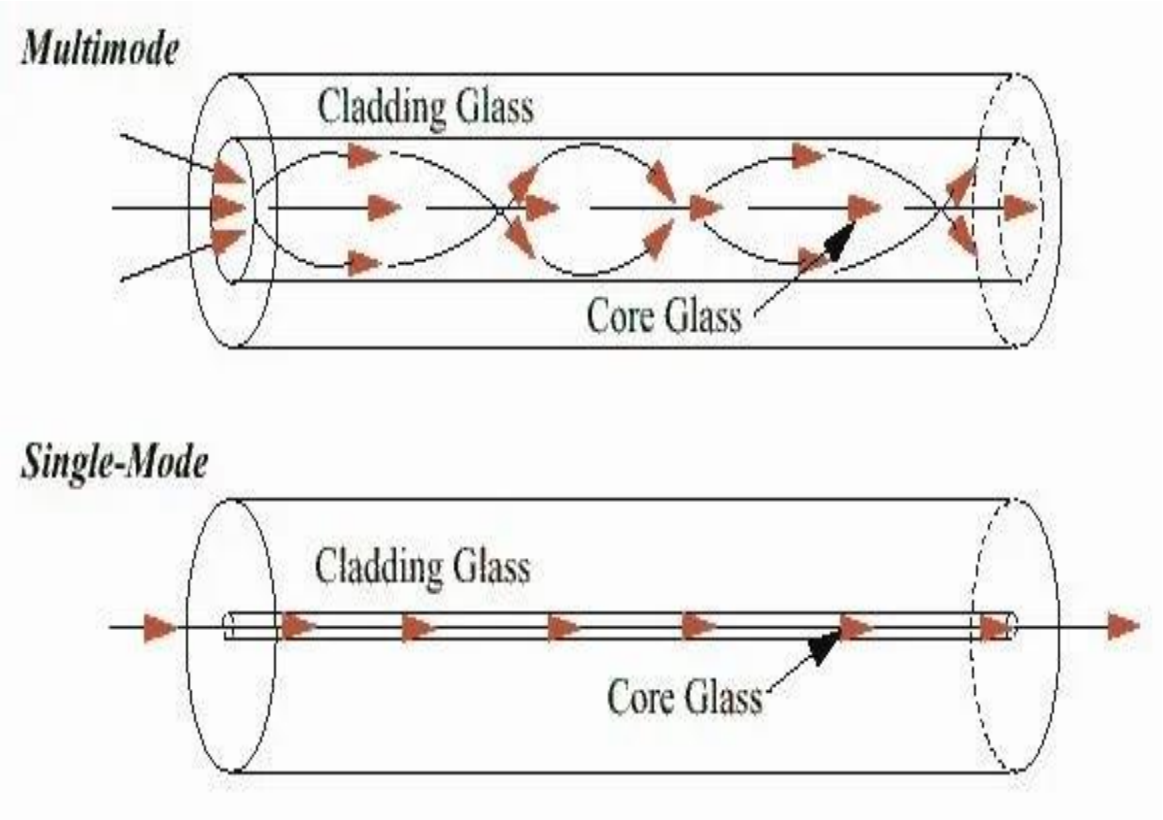
- The angle of incidence i.e. Ø is greater than the critical angle Øc therefore the incident light ray will be reflated within the core totally.
- If the incident light makes an angle which is less than critical angle Øc then it's get refracted.



Modes of propagation

- Single Mode

- Multimode



Advantages of Optical Fiber cable

- Small size and light weight
- Easy available
- No electromagnetic interference
- Large bandwidth
- No crosstalk

Disadvantages of Optical Fiber cable

- Cost is high
- Sophisticated plants are required for manufacturing.
- Joining the cables is difficult job.

Applications of Optical Fiber cable

- LAN

- Telephone Network
- Cable television
- Defense/Government
- Medical

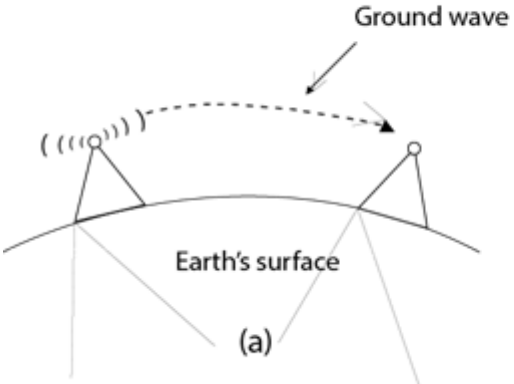
Unguided Transmission

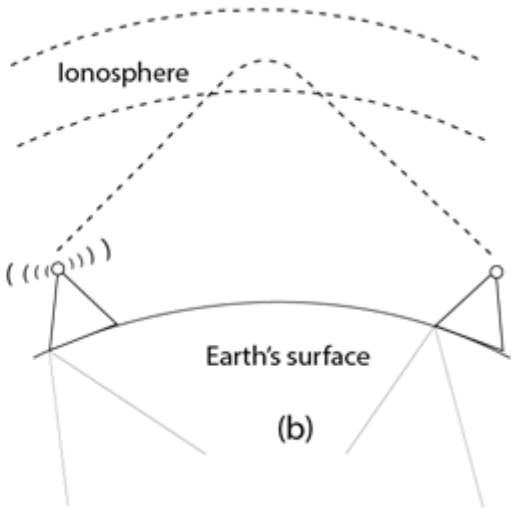
- An unguided transmission transmits the electromagnetic waves without using any physical medium. Therefore, it is also known as **wireless transmission**.
- In unguided media, air is the media through which the electromagnetic energy can flow easily.

Unguided transmission is broadly classified into three categories:

Radio waves

- Radio waves are the electromagnetic waves that are transmitted in all the directions of free space.
- Radio waves are omnidirectional, i.e., the signals are propagated in all the directions.
- The range in frequencies of radio waves is from 3Khz to 1 kHz.
- In the case of radio waves, the sending and receiving antenna are not aligned, i.e., the wave sent by the sending antenna can be received by any receiving antenna.
- An example of the radio wave is **FM radio**.





Applications of Radio waves:

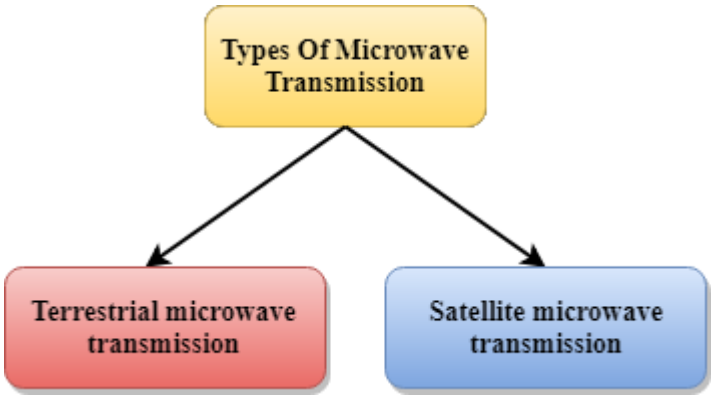
- A Radio wave is useful for multicasting when there is one sender and many receivers.
- An FM radio, television, cordless phones are examples of a radio wave.

Advantages of Radio transmission:

- Radio transmission is mainly used for wide area networks and mobile cellular phones.
- Radio waves cover a large area, and they can penetrate the walls.
- Radio transmission provides a higher transmission rate.

Microwaves

Microwaves are of two types:



- Terrestrial microwave
- Satellite microwave communication.

Terrestrial Microwave Transmission

- Terrestrial Microwave transmission is a technology that transmits the focused beam of a radio signal from one ground-based microwave transmission antenna to another.
- Microwaves are the electromagnetic waves having the frequency in the range from 1GHz to 1000 GHz.

- Microwaves are unidirectional as the sending and receiving antenna is to be aligned, i.e., the waves sent by the sending antenna are narrowly focused.
- In this case, antennas are mounted on the towers to send a beam to another antenna which is km away.
- It works on the line of sight transmission, i.e., the antennas mounted on the towers are the direct sight of each other.

Characteristics of Microwave:

- **Frequency range:** The frequency range of terrestrial microwave is from 4-6 GHz to 21-23 GHz.
- **Bandwidth:** It supports the bandwidth from 1 to 10 Mbps.
- **Short distance:** It is inexpensive for short distance.
- **Long distance:** It is expensive as it requires a higher tower for a longer distance.
- **Attenuation:** Attenuation means loss of signal. It is affected by environmental conditions and antenna size.

Advantages Of Microwave:

- Microwave transmission is cheaper than using cables.
- It is free from land acquisition as it does not require any land for the installation of cables.
- Microwave transmission provides an easy communication in terrains as the installation of cable in terrain is quite a difficult task.
- Communication over oceans can be achieved by using microwave transmission.

Disadvantages of Microwave transmission:

- **Eavesdropping:** An eavesdropping creates insecure communication. Any malicious user can catch the signal in the air by using its own antenna.
- **Out of phase signal:** A signal can be moved out of phase by using microwave transmission.
- **Susceptible to weather condition:** A microwave transmission is susceptible to weather condition. This means that any environmental change such as rain; wind can distort the signal.

- **Bandwidth limited:** Allocation of bandwidth is limited in the case of microwave transmission.

Satellite Microwave Communication

- A satellite is a physical object that revolves around the earth at a known height.
- Satellite communication is more reliable nowadays as it offers more flexibility than cable and fibre optic systems.
- We can communicate with any point on the globe by using satellite communication.

How Does Satellite work?

The satellite accepts the signal that is transmitted from the earth station, and it amplifies the signal. The amplified signal is retransmitted to another earth station.

Advantages of Satellite Microwave Communication:

- The coverage area of a satellite microwave is more than the terrestrial microwave.
- The transmission cost of the satellite is independent of the distance from the centre of the coverage area.
- Satellite communication is used in mobile and wireless communication applications.
- It is easy to install.
- It is used in a wide variety of applications such as weather forecasting, radio/TV signal broadcasting, mobile communication, etc.

Disadvantages of Satellite Microwave Communication:

- Satellite designing and development requires more time and higher cost.
- The Satellite needs to be monitored and controlled on regular periods so that it remains in orbit.
- The life of the satellite is about 12-15 years. Due to this reason, another launch of the satellite has to be planned before it becomes non-functional.