UNIT II DATA COMMUNICATION

Signal characteristics – Data transmission – Physical links and transmission media – Signal encoding techniques - Channel access techniques – TDM – FDM-CDM

Data Communication

- The word data refers to information presented in whatever form is agreed upon by the parties creating and using the data
- Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable.

SIGNAL CHARACTERISTICS

- Signal is an electromagnetic or light wave that represents data.
- Signals are used to transfer data from one device to another through a communication medium.
- A **signal** is any time-varying or spatial-varying quantity.
- In a *communication system*, a *transmitter* encodes a *message* into a signal, which is carried to a *receiver* by the communications *channel*.
- The signal is composed of two basic parts -- baseband signal (information) and the carrier signal -- which are mixed with each other through the process of modulation.
- Both data and the signals that represent them can be either **analog or digital** in form
- **Analog and Digital Data**
  - Data can be analog or digital.
  - Analog data are continuous and take continuous values
    - Ex: the sounds made by a human voice, take on continuous values
  - Digital data have discrete states and take discrete values.
    - Ex:data are stored in computer memory in the form of 0s and 1s

Forms of signals

Different forms of communication signals are as follows:

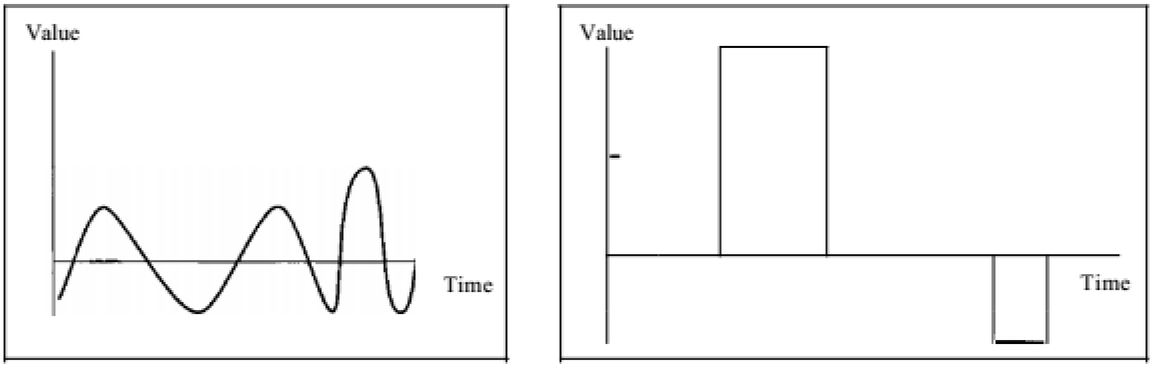
1. Digital signals
2. Analog signals

Digital Signals

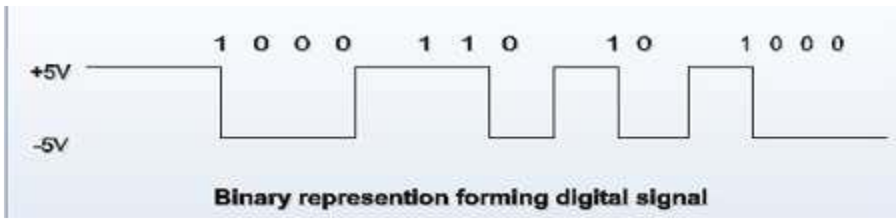
- Digital signal is a sequence of voltage represented in binary form.
- A digital signal can have only a limited number of defined discrete values often as simple as 1 and 0
- The digital signals are in the form of electrical pulses of ON and OFF
- For Example 1 can be encoded as a positive voltage and a 0 as zero voltage

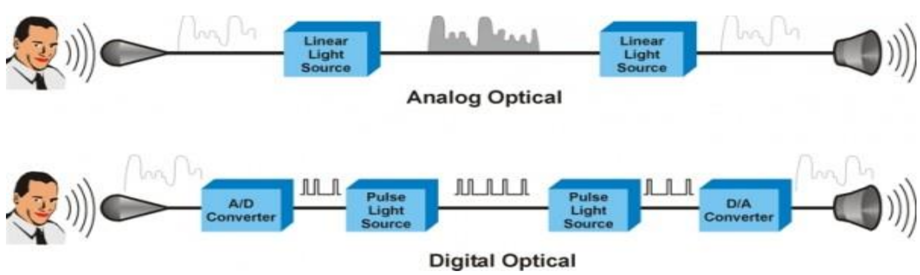
Analog Signals

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



a. Analog signal b. Digital signal





Periodic and Nonperiodic Signals

- Both analog and digital signals can take one of two forms: periodic or nonperiodic(aperiodic)
- A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a cycle.
- A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.
- In data communications, we commonly use periodic analog signals (because they need less bandwidth, and nonperiodic digital signals (because they can represent variation in data)

Composite Signals

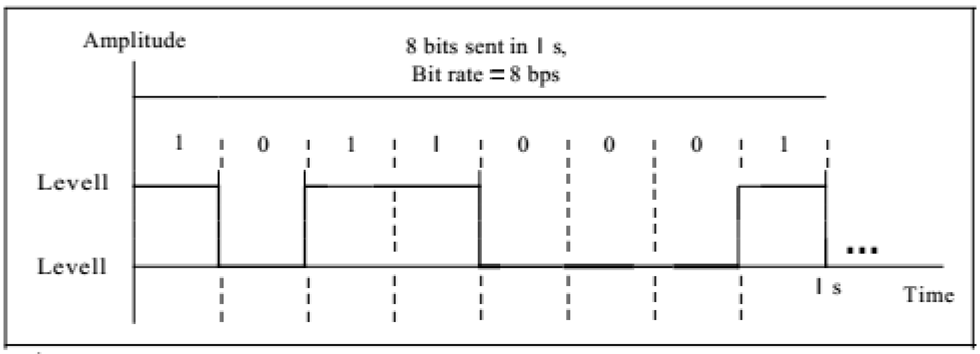
- Any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies; if the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

Characteristics of Digital Signals

Bit rate

- The bit rate is the number of bits sent in 1s, expressed in bits per second (bps).
- Figure below shows the bit rate
- Other units used to express bit rate are Kbps, Mbps and Gbps.
  - 1 kilobit per second (Kbps) = 1,000 bits per second
  - 1 Megabit per second (Mbps) = 1,000,000 bits per second
  - 1 Gigabit per second (Gbps) = 1,000,000,000 bits per second



Example:

Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}$$

Bit Length

- The bit length is the distance one bit occupies on the transmission medium (similar to wavelength for an analog signal)

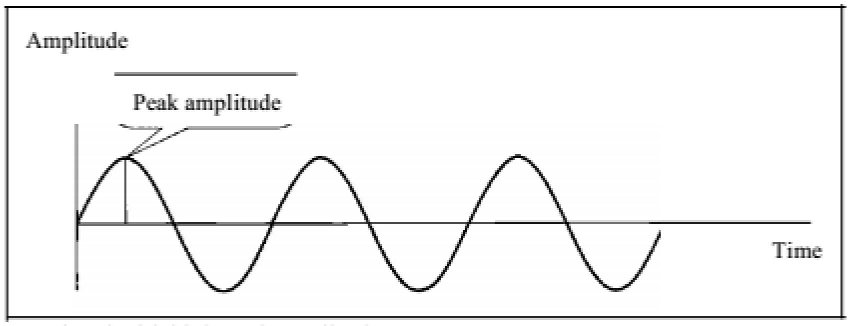
$$\text{Bit length} = \text{propagation speed} \times \text{bit duration}$$

Characteristics of Analog Signals

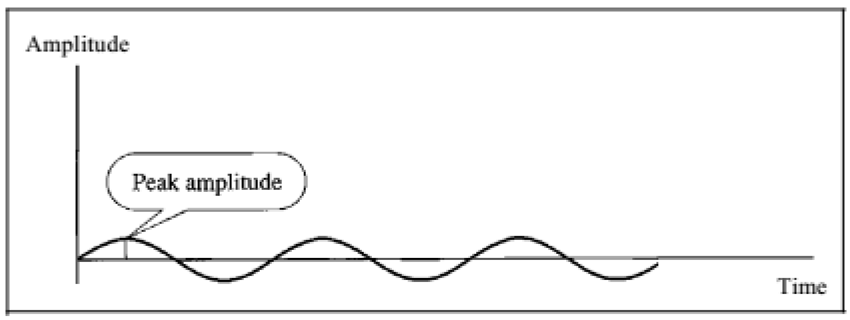
Peak Amplitude

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

- Figure shows two signals and their peak amplitudes.
- Example: The voltage of battery is a constant; this constant value can be considered a sine wave, For example, the peak value of an AA battery is normally 1.5 V.



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Period and Frequency

- Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- Frequency refers to the number of periods in one second.
- Period and frequency are just one characteristic defined in two ways.
- Period is the inverse of frequency, and frequency is the inverse of period, as the following formulas show.

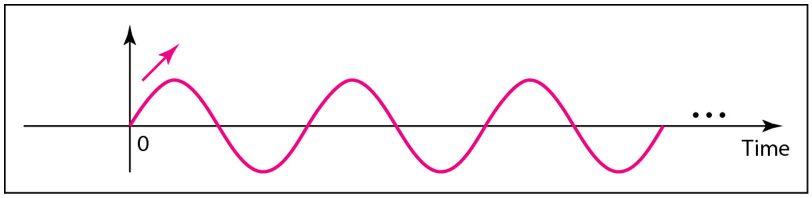
$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

- Period is formally expressed in seconds.
- Frequency is formally expressed in Hertz (Hz), which is cycle per second
- If a signal does not change at all, its frequency is zero.
- If a signal changes instantaneously, its frequency is infinite.

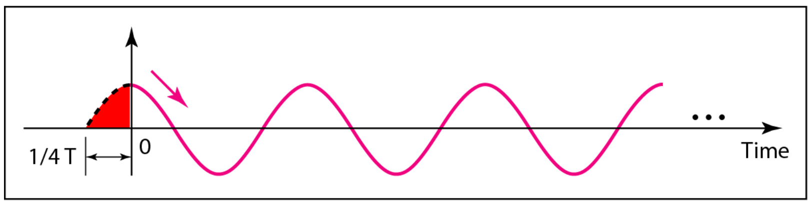
Phase

- The term phase describes the position of the waveform relative to time 0
- Phase is measured in degrees or radians [360° is **2n** rad; 1° is **2n/360** rad, and 1 rad is **360/(2n)]**

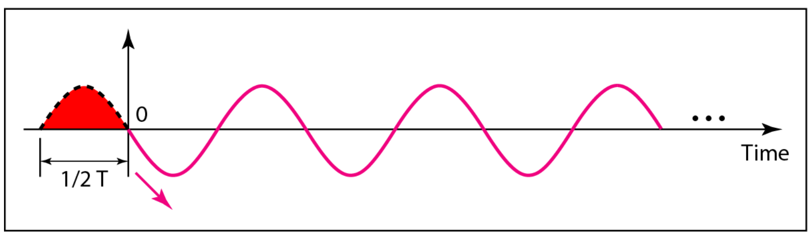
- A phase shift of 360° corresponds to a shift of a complete period; a phase shift of 180° corresponds to a shift of one-half of a period; and a phase shift of 90° corresponds to a shift of one-quarter of a period
- Figure shows three sine waves with the same amplitude & frequency, but different phases



a. 0 degrees



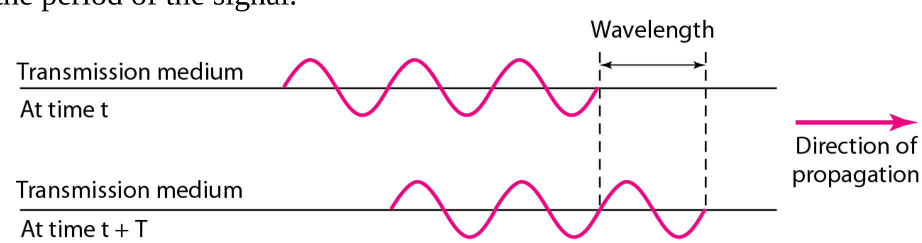
b. 90 degrees



c. 180 degrees

Wavelength

- Wavelength is another characteristic of a signal traveling through a transmission medium.
- Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium
- The frequency of a signal is independent of the medium whereas the wavelength depends on both the frequency and the medium.
- The wavelength is the distance a simple signal can travel in one period.
- Wavelength can be calculated if one is given the propagation speed (the speed of light) and the period of the signal.

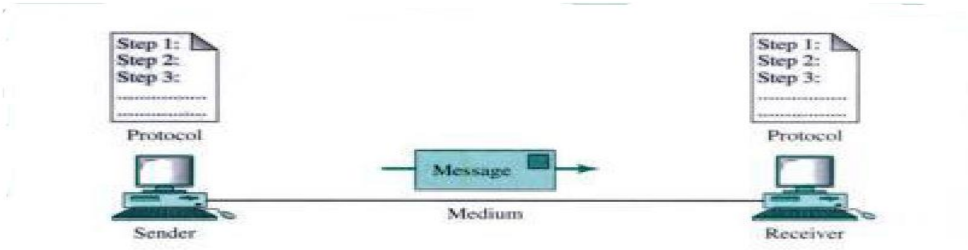


- We represent wavelength by λ, propagation speed by c (speed of light), and frequency by f , we get

$$\textbf{Wavelength} = \textbf{propagation speed} \times \textbf{period} = \frac{\textbf{propagation speed}}{\textbf{frequency}} \qquad \lambda = \frac{c}{f}$$

Data Communications is the exchange of data between two devices via some form of transmission media such as a wire cable.

The term Data Communication can generally be defined as the movement of encoded information by means of electrical transmission systems from one computer or device to other computer or device through communication channels (such as cables, wireless media etc.



Component of Data Communication

There are five components in data communication.

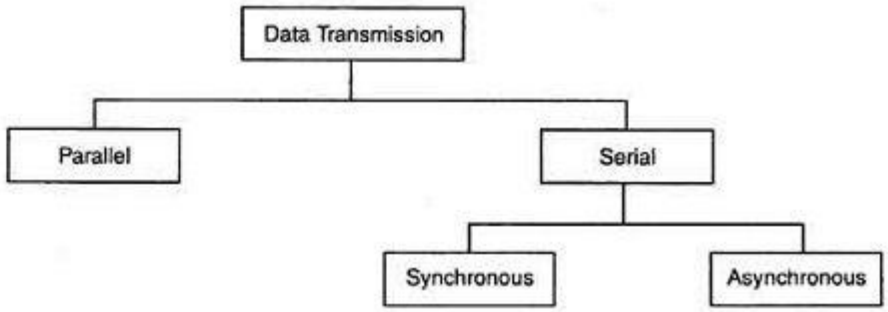
- **Message:** The message is the information (data) to be communicated. It can consist of text, number, pictures, sound, video or any combination of these.
- **Sender:** The sender is the device that sends the data. It can be computer, workstation, telephone, video camera and so on.
- **Receiver:** The receiver is the device that receives the data. It can be computer, workstation, telephone, television and so on.
- **Transmission medium:** The Communication channel is the physical path by which a data travels from sender to receiver. It can be a twisted – pair wire, coaxial cable, fiber optic cable, or microwave etc.
- **Protocol:** A protocol is a set of rules that govern data communications. It represents an agreement between the communicating devices.

DATA TRANSMISSION

Data Transmission

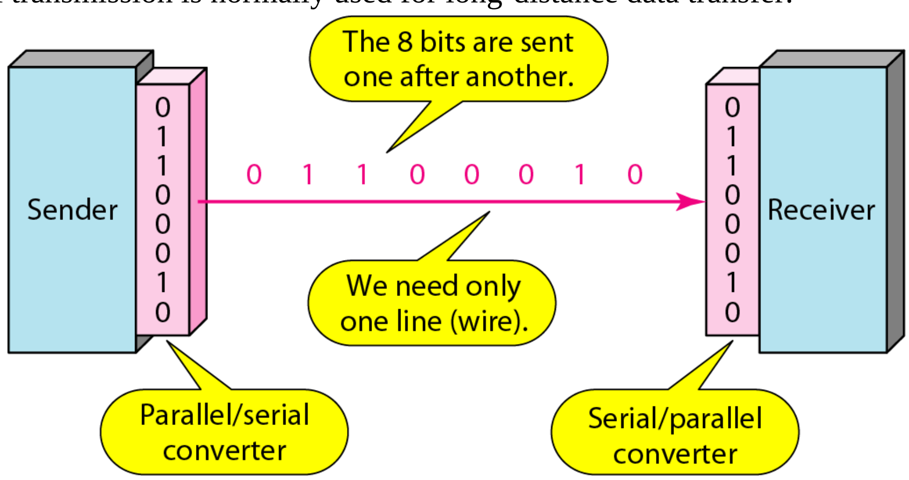
- Data transmission refers to the movement of data in form of bits between two or more digital devices.

Types of Data Transmission



Serial Transmission

- Data is transmitted as a single bit at a time using a fixed time interval for each bit. This mode of transmission is known as bit-serial transmission
- When data is sent or received using serial data transmission, the data bits are organized in a specific order, since they can only be sent one after another.
- The order of the data bits is important as it dictates how the transmission is organized when it is received.
- It requires only one communication line rather than n lines to transmit data from sender to receiver
- It is viewed as a reliable data transmission method because a data bit is only sent if the previous data bit has already been received.
- Serial transmission is normally used for long-distance data transfer.

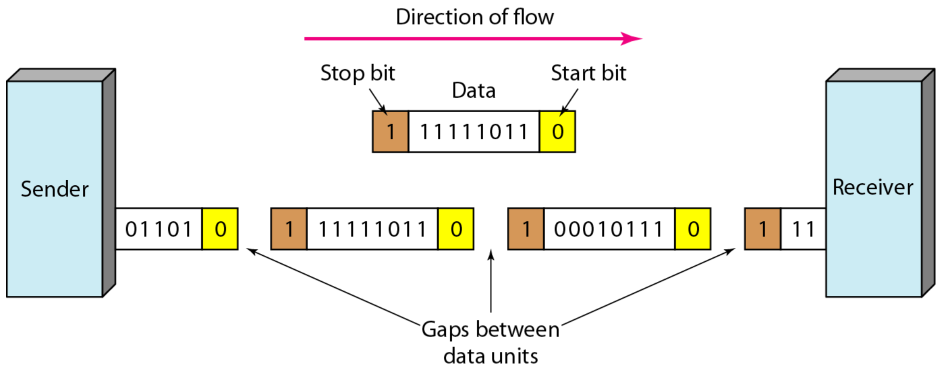


Example of Serial Data Transmission

Serial transmission has two classifications: asynchronous and synchronous

Asynchronous Serial Transmission

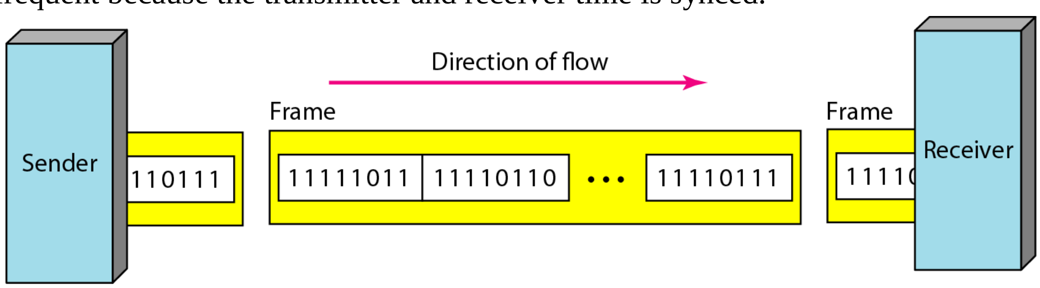
- Data bits can be sent at any point in time.
- Stop bits and start bits are used between data bytes to synchronize the transmitter and receiver and to ensure that the data is transmitted correctly.



- The time between sending and receiving data bits is not constant, so gaps are used to provide time between transmissions.
- There is idle time between the transmissions of different data bytes. This idle time is known as Gap
- Advantage:
  - No synchronization is required between the transmitter and receiver devices.
  - It is also a more cost effective method.
  - It is possible to transmit signals from sources having different bit rates
- A disadvantage is that data transmission can be slower

Synchronous Serial Transmission

- Data bits are transmitted as a continuous stream in time with a master clock.
- The data transmitter and receiver both operate using a synchronized clock frequency; therefore, start bits, stop bits, and gaps are not used.
- This means that data moves faster as there are no extra bits and timing errors are less frequent because the transmitter and receiver time is synced.

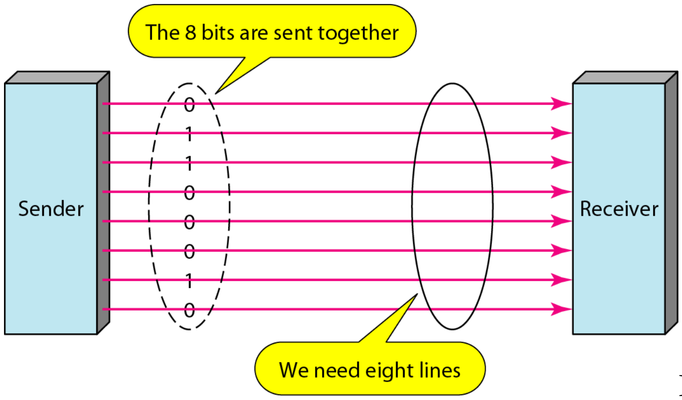


- Data accuracy is highly dependent on timing being synced correctly between devices.
- In comparison with asynchronous serial transmission, this method is usually more expensive.

Parallel Transmission

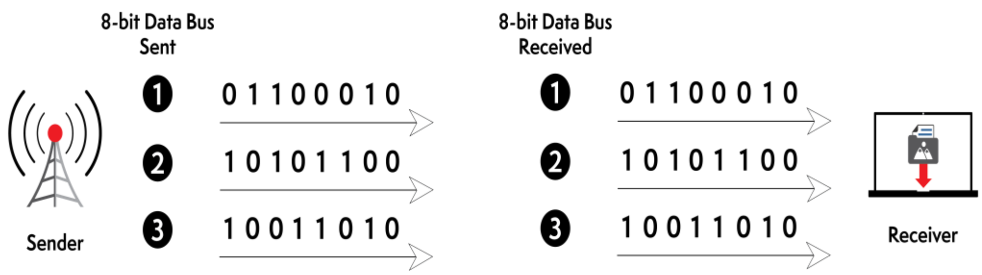
- When data is sent using parallel data transmission, multiple data bits are transmitted over multiple channels at the same time. This means that data can be sent much faster than using serial transmission methods.

- In parallel transmission, all the bits of data are transmitted simultaneously on separate communication lines.
- In order to transmit n bits, n wires or lines are used. Thus each bit has its own line

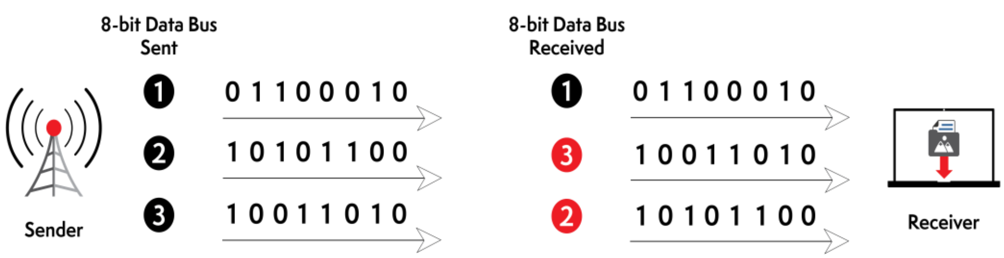


Example of Parallel Data Transmission

- Given that multiple bits are sent over multiple channels at the same time, the order in which a bit string is received can depend on various conditions, such as proximity to the data source, user location, and bandwidth availability.
- Parallel transmission is used when:
  - a large amount of data is being sent;
  - the data being sent is time-sensitive;
  - the data needs to be sent quickly.
- Two examples of parallel interfaces can be seen below.
  - In the first parallel interface, the data is sent and received in the correct order.
  - In the second parallel interface, the data is sent in the correct order, but some bits were received faster than others.



Example of Parallel Transmission – Data Received Correctly



Example of Parallel Transmission – Data Received Incorrectly

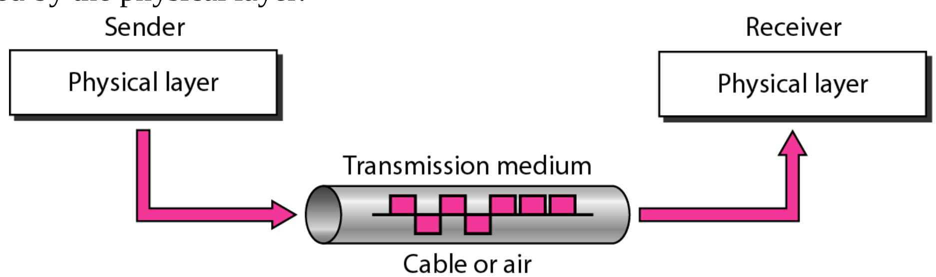
Advantages and Disadvantages of Using Parallel Data Transmission

- It is speedy way of transmitting data as multiple bits are transmitted simultaneously with a single clock pulse.
- Although parallel transmission can transfer data faster, it requires more transmission channels than serial transmission.This means that data bits can be out of sync, depending on transfer distance and how fast each bit loads.

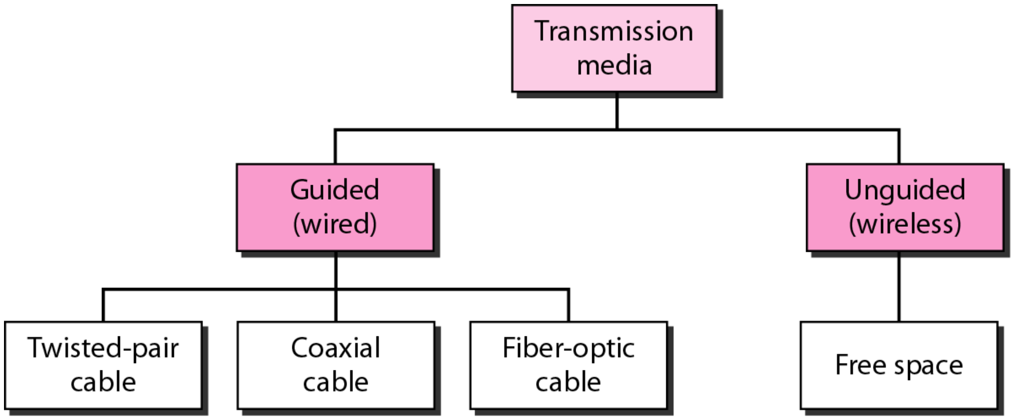
PHYSICAL LINKS AND TRANSMISSION MEDIA

Transmission Medium:

- A transmission medium can be broadly defined as anything that can carry information from a source to a destination.
- For example, the transmission medium for two people having a dinner conversation is the air.
- The transmission medium is usually free space, metallic cable, or fiber-optic cable.
- The information is usually a signal that is the result of a conversion of data from another form
- Transmission media are actually located below the physical layer and are directly controlled by the physical layer.



- Transmission media can be divided into two broad categories: guided and unguided.
- Guided media include twisted-pair cable, coaxial cable, and fiber-optic cable.
- Unguided medium is free space.



Factors to be considered while selecting a Transmission Medium

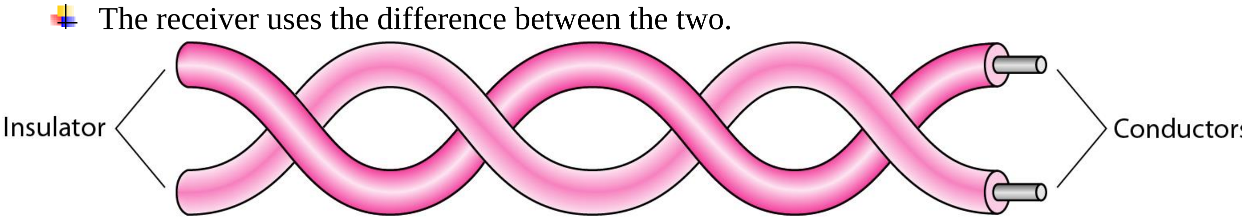
1. Transmission Rate
2. Cost and Ease of Installation
3. Resistance to Environmental Conditions
4. Distances

Bounded or Guided Transmission Media

- Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.
- A signal traveling along any of these media is directed and contained by the physical limits of the medium.
- Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current.
- Optical fiber is a cable that accepts and transports signals in the form of light.

Twisted Pair Cable

- A twisted pair consists of two conductors(normally copper), each with its own plastic insulation, twisted together.
- One of these wires is used to carry signals to the receiver, and the other is used only as ground reference.
- The receiver uses the difference between the two.

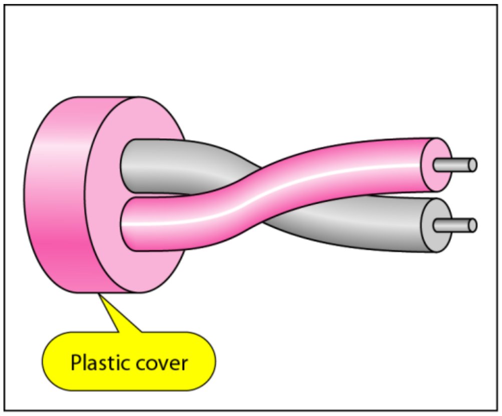


- In addition to the signal sent by the sender on one of the wires, interference(noise) and crosstalk may affect both wires and create unwanted signals.

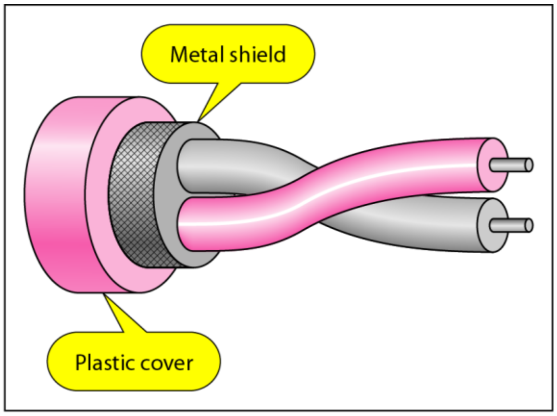
- If the two wires are parallel, the effect of these unwanted signals is not the same in both wires because they are at different locations relative to the noise or crosstalk sources. This results in a difference at the receiver.
- By twisting the pairs, a balance is maintained. For example, suppose in one twist, one wire is closer to the noise source and the other is farther; in the next twist, the reverse is true.
- Twisting makes it probable that both wires are equally affected by external influences (noise or crosstalk). This means that the receiver, which calculates the difference between the two, receives no unwanted signals.
- **Twisted Pair is of two types:**
    - **Unshielded Twisted Pair (UTP)**
    - **Shielded Twisted Pair (STP)**

Unshielded Twisted Pair Cable

- It is the most common type of telecommunication when compared with Shielded Twisted Pair Cable which consists of two conductors usually copper, each with its own colour plastic insulator.
- Identification is the reason behind coloured plastic insulation.
- UTP cables consist of 2 or 4 pairs of twisted cable.
- Cable with 2 pair use **RJ-11** connector and 4 pair cable use **RJ-45** connector.
- **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.
- It consists of two insulating copper wires (1mm thick).
- The wires are twisted together in a helical form to reduce electrical interference from similar pair.



a. UTP



b. STP

- **Disadvantages of Unshielded Twisted Pair Cable**
  - Bandwidth is low when compared with Coaxial Cable
  - Provides less protection from interference.

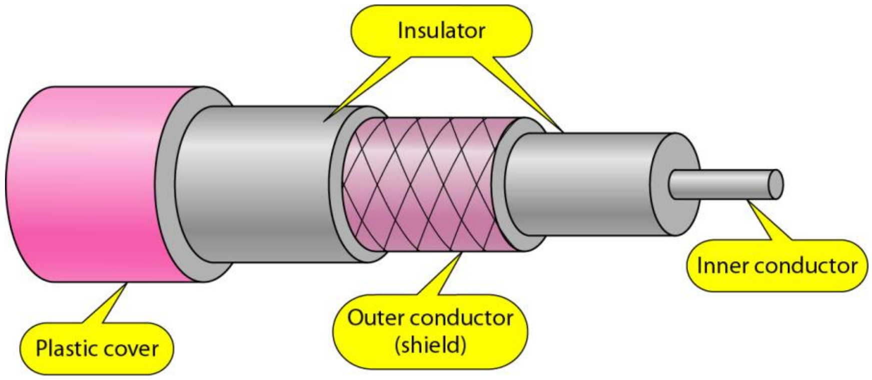
Shielded Twisted Pair Cable

- It has a metal foil or braided-mesh covering which encases each pair of insulated conductors.
- Electromagnetic noise penetration is prevented by metal casing
- Shielding also eliminates crosstalk
- It has same attenuation as unshielded twisted pair.
- It is faster the unshielded and coaxial cable.
- It is more expensive than coaxial and unshielded twisted pair.
- **Advantages of Shielded Twisted Pair Cable**
  - Easy to install
  - Performance is adequate
  - Can be used for Analog or Digital transmission
  - Increases the signalling rate
  - Higher capacity than unshielded twisted pair & Eliminates crosstalk
- **Disadvantages of Shielded Twisted Pair Cable**
  - Difficult to manufacture
  - Heavy
- **Performance of Shielded Twisted Pair Cable**
  - One way to measure the performance of twisted-pair cable is to compare attenuation versus frequency and distance. A twisted-pair cable can pass a wide range of frequencies.
  - With increasing frequency, the attenuation, measured in decibels per kilometre (dB/km), sharply increases with frequencies above 100kHz.
- **Applications of Shielded Twisted Pair Cable**
  - In telephone lines to provide voice and data channels. The DSL lines that are used by the telephone companies to provide high-data-rate connections also use the high-bandwidth capability of unshielded twisted-pair cables.
  - Local Area Network, such as 10Base-T and 100Base-T, also use twisted-pair cables.

Coaxial Cable

- Coaxial cable (or **coax)** carries signals of higher frequency ranges than those in twisted pair cable
- Coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two.

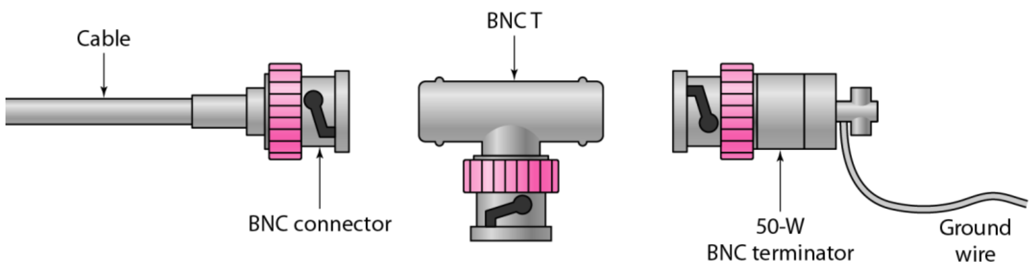
- Outer metallic wrapping is used as a shield against noise and as the second conductor which completes the circuit.
- The outer conductor is also encased in an insulating sheath.
- The outermost part is the plastic cover which protects the whole cable.



- The most common coaxial standards
    - 50-Ohm RG-7 or RG-11 : used with thick Ethernet.
    - 50-Ohm RG-58 : used with thin Ethernet
    - 75-Ohm RG-59 : used with cable television
    - 93-Ohm RG-62 : used with ARCNET.

Coaxial Cable Connectors

- To connect coaxial cable to devices, we need coaxial connectors.
- The most common type of connector used today is the Bayonet Neill-Concelman (BNC) connector.
- The below figure shows 3 popular types of these connectors: the BNC Connector, the BNC T connector and the BNC terminator.

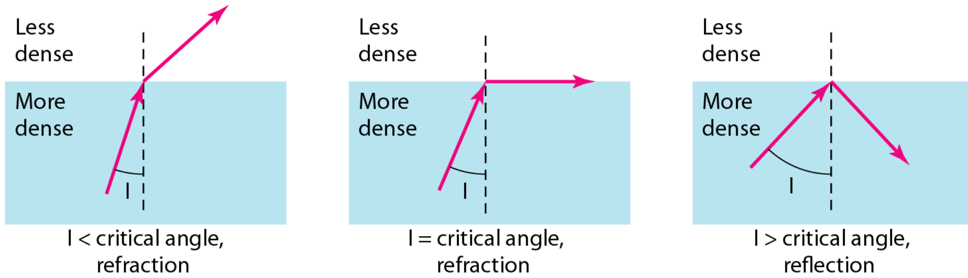


- The BNC connector is used to connect the end of the cable to the device, such as a TV set.
- The BNC T connector is used in Ethernet networks to branch out to a connection to a computer or other device.
- The BNC terminator is used at the end of the cable to prevent the reflection of the signal.
- **There are two types of Coaxial cables:**
    - **BaseBand**
        - This is a 50 ohm (Ω) coaxial cable which is used for digital transmission.
        - It is mostly used for LAN's.

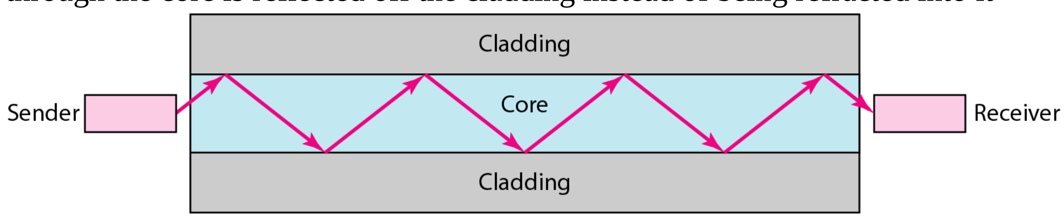
        - Baseband transmits a single signal at a time with very high speed. The major drawback is that it needs amplification after every 1000 feet.
    - **BroadBand**
        - This uses analog transmission on standard cable television cabling.
        - It transmits several simultaneous signal using different frequencies.
        - It covers large area when compared with Baseband Coaxial Cable.
- **Advantages of Coaxial Cable**
    - Bandwidth is high
    - Used in long distance telephone lines.
    - Transmits digital signals at a very high rate of 10Mbps.
    - Much higher noise immunity
    - Data transmission without distortion.
    - The can span to longer distance at higher speeds as they have better shielding when compared to twisted pair cable
- **Disadvantages of Coaxial Cable**
    - Single cable failure can fail the entire network.
    - Difficult to install and expensive when compared with twisted pair.
    - If the shield is imperfect, it can lead to grounded loop.
- **Applications of Coaxial Cable**
    - Coaxial cable was widely used in analog telephone networks, where a single coaxial network could carry 10,000 voice signals.
    - Cable TV networks also use coaxial cables
    - In traditional Ethernet LANs. Because of it high bandwidth, and consequence high data rate, coaxial cable was chosen for digital transmission in early Ethernet LANs.

Fiber Optic Cable

- A fibre-optic cable is made of glass or plastic and transmits signals in the form of light.
- **Nature of light**.
    - Light travels in a straight line as long as it is mobbing through a single uniform substance.
    - If ray of light travelling through one substance suddenly enters another substance (of a different density), the ray changes direction.
    - The below figure shows how a ray of light changes direction when going from a more dense to a less dense substance.

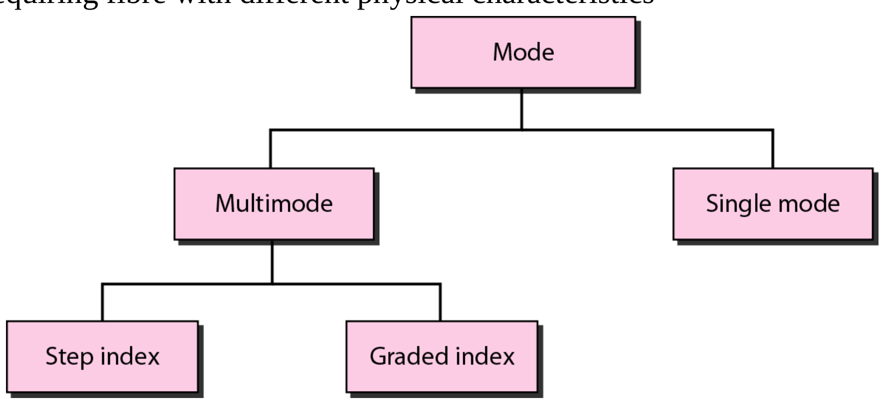


- **Bending of a light ray**
- As the figure shows:
  - If the **angle of incidence I** (the angle the ray makes with the line perpendicular to the interface between the two substances) is **less** than the **critical angle**, the ray **refracts** and moves closer to the surface.
  - If the angle of incidence is **greater** than the critical angle, the ray **reflects** (makes a turn) and travels again in the denser substance.
  - If the angle of incidence is **equal** to the critical angle, the ray refracts and **moves parallel** to the surface as shown.
- Optical fibers use reflection to guide light through a channel.
- A glass or plastic core is surrounded by a cladding of less dense glass or plastic.
- The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it



Propagation Modes of Fiber Optic Cable

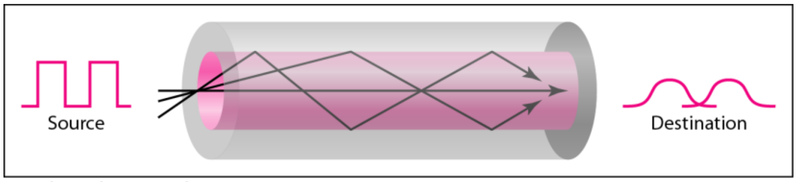
- Two modes(Multimode and Single mode) for propagating light along optical channels, each requiring fibre with different physical characteristics



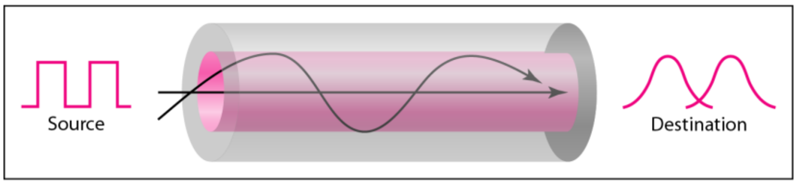
- Multimode can be implemented in two forms: **Step-index** and **Graded-index**.

Multimode Propagation Mode

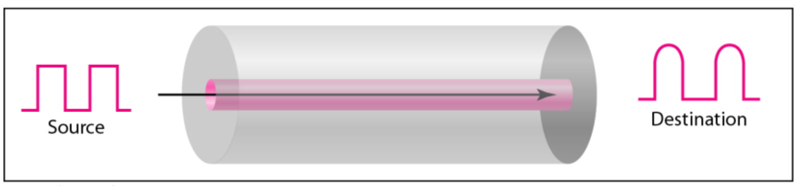
- In multimode multiple beams from a light source move through the core in different paths.
- These beams move within the cable depends on the structure of the core as shown in the below figure.



a. Multimode, step index



b. Multimode, graded index

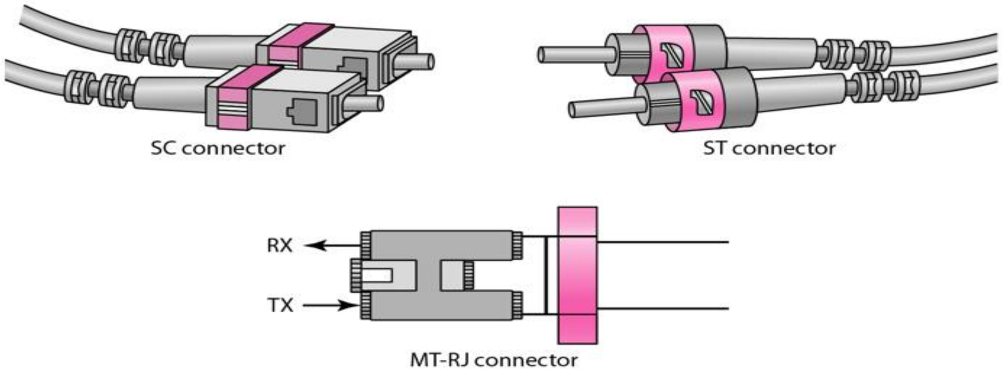


c. Single mode

- In **multimode step-index fibre**, the density of the core remains constant from the centre to the edges. A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding. The term step-index refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fibre.
- In **multimode graded-index fibre**, this distortion gets decreases through the cable. The index of refraction is related to the density. A graded-index fibre, therefore, is one with varying densities. Density is highest at the centre of the core and decreases gradually to its lowest at the edge.
- **In Single mode** it uses step-index fibre and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal. The single-mode fibre itself is manufactured with a much smaller diameter than that of multimode fibre, and with substantially lower density.

Fibre Optic Cable Connectors

- There are three types of connectors for fibre-optic cables, as shown in the figure below.



- The Subscriber Channel(SC) connector is used for cable TV. It uses push/pull locking system.
- The Straight-Tip(ST) connector is used for connecting cable to the networking devices.
- MT-RJ is a connector that is the same size as RJ45.

Advantages of Fibre Optic Cable

- Fibre optic has several advantages over metallic cable:
- Higher bandwidth
- Less signal attenuation
- Immunity to electromagnetic interference
- Resistance to corrosive materials
- Light weight
- Greater immunity to tapping

Disadvantages of Fibre Optic Cable

- Installation and maintenance
- Unidirectional light propagation
- High Cost

Performance of Fibre Optic Cable

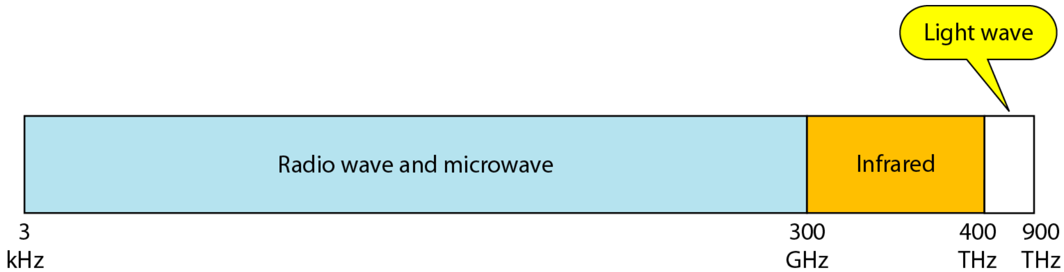
- Attenuation is flatter than in the case of twisted-pair cable and coaxial cable. Fewer(actually one tenth as many) repeaters are needed when we use the fibre-optic cable.

Applications of Fibre Optic Cable

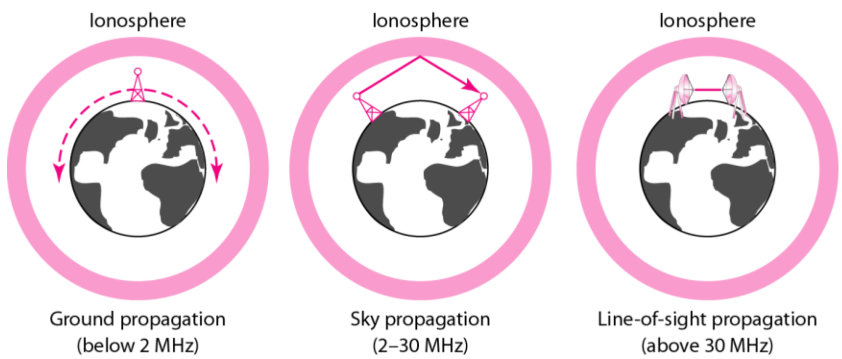
- Often found in backbone networks because its wide bandwidth is cost-effective.
- Some cable TV companies use a combination of optical fibre and coaxial cable thus creating a hybrid network.
- Local-area Networks such as 100Base-FX network and 1000Base-X also use fibre-optic cable.

UnBounded or UnGuided Transmission Media

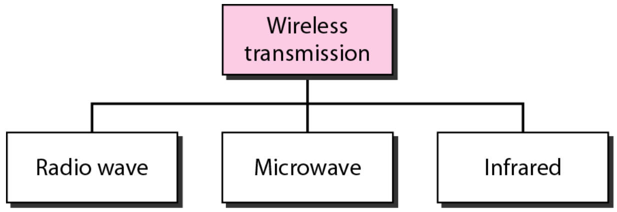
- Unguided medium transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication.
- Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.
- The below figure shows the part of the electromagnetic spectrum, ranging from 3 kHz to 900 THz, used for wireless communication.



- Unguided signals can travel from the source to the destination in several ways: **Ground propagation**, **Sky propagation** and **Line-of-sight propagation** as shown in below figure.



- **Propagation Modes**
  - **Ground Propagation:** In this, radio waves travel through the lowest portion of the atmosphere, hugging the Earth. These low-frequency signals emanate in all directions from the transmitting antenna and follow the curvature of the planet.
  - **Sky Propagation:** In this, higher-frequency radio waves radiate upward into the ionosphere where they are reflected back to Earth. This type of transmission allows for greater distances with lower output power.
  - **Line-of-sight Propagation:** in this type, very high-frequency signals are transmitted in straight lines directly from antenna to antenna.
- We can divide wireless transmission into three broad groups:
  - Radio waves
  - Micro waves
  - Infrared waves



Radio Waves

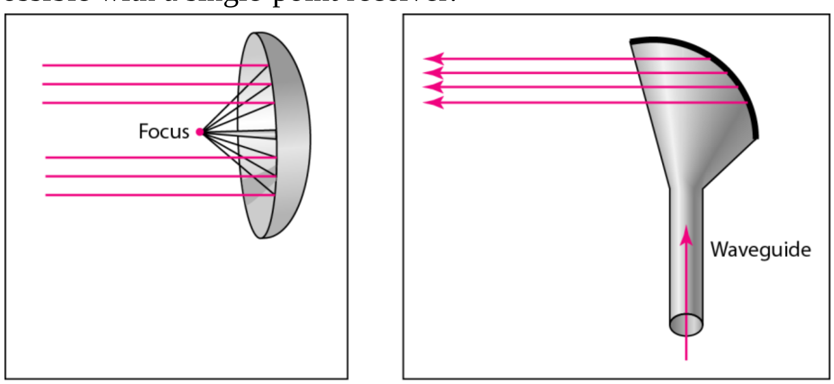
- Electromagnetic waves ranging in frequencies between 3 KHz and 1 GHz are normally called radio waves.
- Radio waves are omnidirectional.
- When an antenna transmits radio waves, they are propagated in all directions. This means that the sending and receiving antennas do not have to be aligned.
- A sending antenna send waves that can be received by any receiving antenna.
- The omnidirectional property has disadvantage
    - The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signal suing the same frequency or band.
- Radio waves, particularly with those of low and medium frequencies, can penetrate walls. This characteristic can be both an advantage and a disadvantage. It is an advantage because, an AM radio can receive signals inside a building. It is a disadvantage because we cannot isolate a communication to just inside or outside a building.
- **Omnidirectional Antenna for Radio Waves**
    - Radio waves use omnidirectional antennas that send out signals in all directions.

- **Applications of Radio Waves**
    - The omnidirectional characteristics of radio waves make them useful for multicasting in which there is one sender but many receivers.
    - AM and FM radio, television, maritime radio, cordless phones, and paging are examples of multicasting.

Micro Waves

- Electromagnetic waves having frequencies between 1 and 300 GHz are called micro waves.
- Micro waves are unidirectional.
- When an antenna transmits microwaves, they can be narrowly focused -the sending and receiving antennas need to be aligned.
- The unidirectional property has an obvious advantage.

- A pair of antennas can be aligned without interfering with another pair of aligned antennas.
- Characteristics of microwaves propagation:
    - Microwave propagation is line-of-sight. Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall.
    - Very high-frequency microwaves cannot penetrate walls. This characteristic can be a disadvantage if receivers are inside the buildings.
    - The microwave band is relatively wide, almost 299 GHz. Therefore, wider sub-bands can be assigned and a high date rate is possible.
    - Use of certain portions of the band requires permission from authorities.
- **Unidirectional Antenna for Micro Waves**
    - Microwaves need unidirectional antennas that send out signals in one direction.
    - Two types of antennas are used for microwave communications: **Parabolic Dish** and **Horn**.
    - A parabolic antenna works as a funnel, catching a wide range of waves and directing them to a common point. More of the signal is recovered than would be possible with a single-point receiver.



a. Dish antenna b. Horn antenna

    - A horn antenna looks like a gigantic scoop. Outgoing transmissions are broadcast up through the stem and deflected outward in a series of narrow parallel beams by the curved head. Received transmissions are collected by the scooped shape of the horn and are deflected down into the stem.
- **Applications of Micro Waves**
    - Microwaves, due to their unidirectional properties, are very useful when unicast(one-to-one) communication is needed between the sender and the receiver. They are used in cellular phones, satellite networks and wireless LANs.
- **Types of Microwave Transmission :**
    - Terrestrial Microwave
        - Example telephone systems

        - For increasing the distance served by terrestrial microwave, repeaters can be installed with each antenna .The signal received by an antenna can be converted into transmittable form and relayed to next antenna
    - Satellite Microwave
        - This is a microwave relay station which is placed in outer space. The satellites are used
- **Advantages of Microwave Transmission**
    - Used for long distance telephone communication
    - Carries 1000's of voice channels at the same time
- **Disadvantages of Microwave Transmission**
    - It is very costly

Infrared Waves

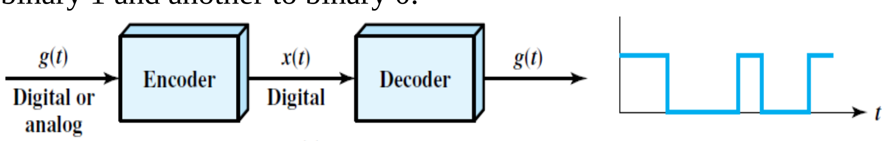
- Infrared waves, with frequencies from 300 GHz to 400 THz, can be used for short-range communication.
- Infrared waves, having high frequencies, cannot penetrate walls. This characteristic prevents interference between one system and another, a short-range communication system in one room cannot be affected by another system in the next room.
- When we use infrared remote control, we do not interfere with the use of the remote by our neighbours. This characteristic makes infrared signals useless for long-range communication
- We cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.
- **Applications of Infrared Waves**
    - Can be used to transmit digital data with a very high data rate.
    - These signals are used for communication between devices such as keyboards, mouse, PCs and printers.
    - Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.

SIGNAL ENCODING TECHNIQUES

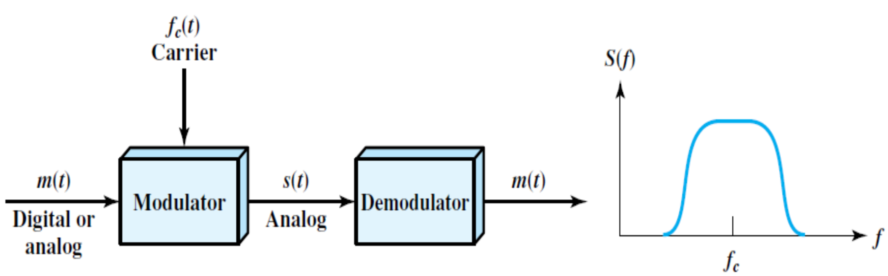
- **Encoding** is the process of converting the data or a given sequence of characters, symbols, alphabets etc., into a specified format, for the secured transmission of data.
- **Decoding** is the reverse process of encoding which is to extract the information from the converted format.
- **Data Encoding**
    - Encoding is the process of using various patterns of voltage or current levels to represent **1s** and **0s** of the digital signals on the transmission link.
- **Encoding Techniques**
    - The data encoding technique is divided into the following types, depending upon the type of data conversion.

- **Analog data to Analog signals**
  - The modulation techniques such as Amplitude Modulation, Frequency Modulation and Phase Modulation of analog signals, fall under this category.
  - Analog data are modulated by a carrier frequency to produce an analog signal in different frequency band, which can be utilized on an analog transmission system.
- **Analog data to Digital signals**
  - This process can be termed as digitization, which is done by Pulse Code Modulation (PCM). In digital modulation sampling and quantization are the important factors.
  - Delta Modulation gives a better output than PCM.
  - Analog data such as voice and video are often digitized to be able to use the digital transmission facilities.
- **Digital data to Analog signals**
  - The modulation techniques such as Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), Phase Shift Keying (PSK), etc., fall under this category.
  - A modem converts digital data to analog signals so that it can be transmitted over analog line
- **Digital data to Digital signals**
  - The conversion involves three techniques: line coding, block coding, and scrambling.
  - Line coding is always needed, block coding and scrambling may or may not be needed.
  - The common types of line encoding are Unipolar, Polar, Bipolar

- The simplest form digital encoding of digital signals is to assign one voltage level to binary 1 and another to binary 0.



(a) Encoding onto a digital signal

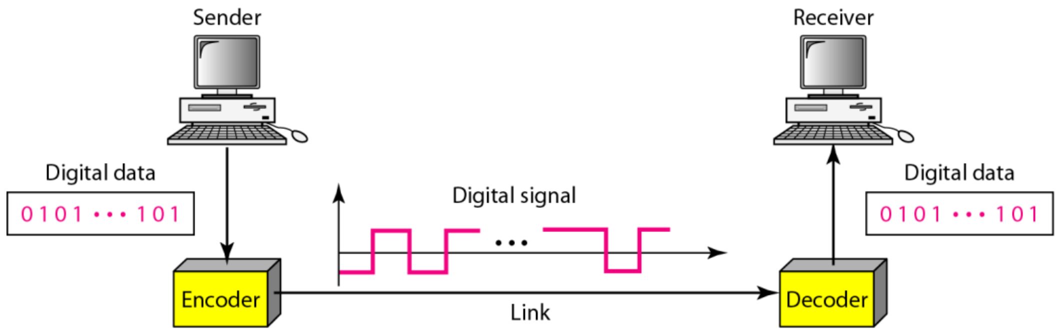


(b) Modulation onto an analog signal

Digital-To-Digital Conversion

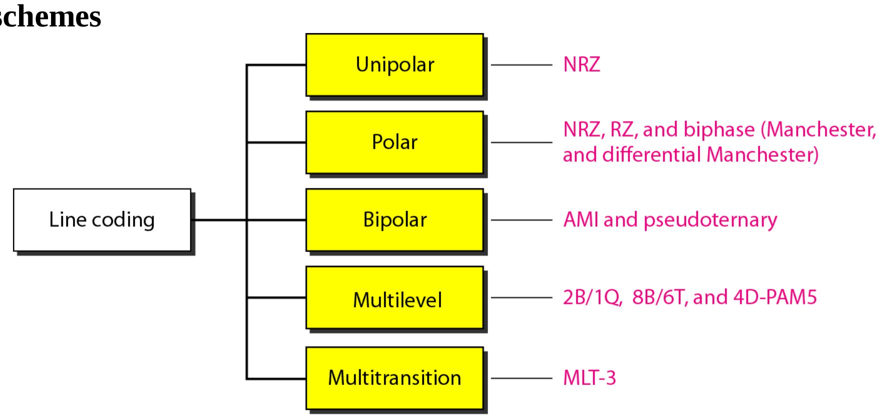
Line Coding

- Converting a string of 1's and 0's (digital data) into a sequence of signals that denote the 1's and 0's.
- For example a high voltage level (+V) could represent a "1" and a low voltage level (0 or -V) could represent a "0".



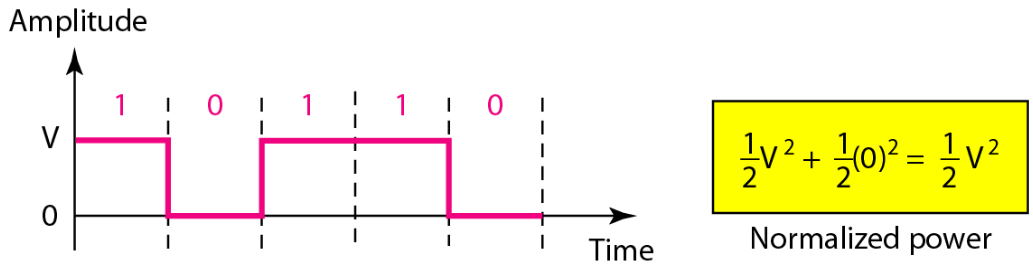
- Data Rate Versus Signal Rate
- The data rate defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps).
- The signal rate is the number of signal elements sent in Is. The unit is the baud.

Line coding schemes



Unipolar

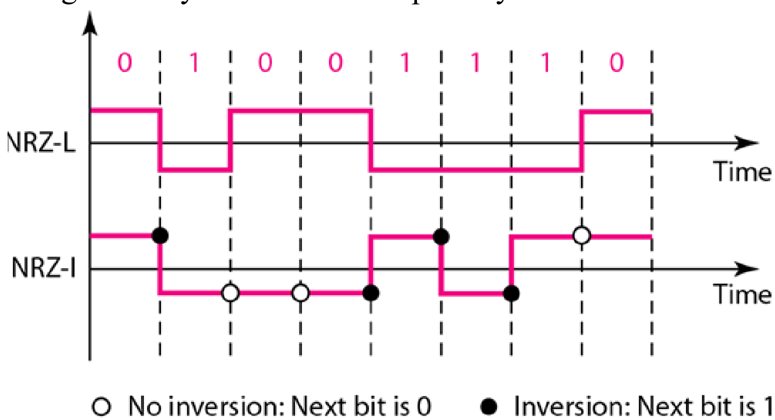
- All signal levels are on one side of the time axis - either above or below
- NRZ - Non Return to Zero scheme is an example of this code.
- Scheme is prone to baseline wandering and DC components.
- It has no synchronization or any error detection.
- It is simple but costly in power consumption.
- **Non Return to Zero (NRZ)**
  - The positive voltage defines bit 1 and the zero voltage defines bit 0.
  - It is called NRZ because the signal does not return to zero at the middle of the bit.
  - The end or start of a bit will not be indicated and it will maintain the same voltage state, if the value of the previous bit and the value of the present bit are same.



Polar

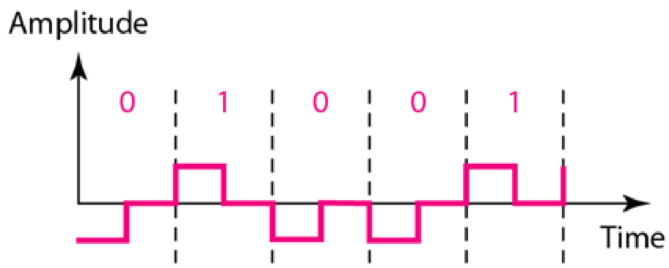
Polar-NRZ

- The voltages are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages. E.g. +V for 1 and -V for 0.
- There are two versions:
- **NZR - Level (NRZ-L)** - positive voltage for one symbol and negative for the other
  - There is a change in the polarity of the signal, only when the incoming signal changes from 1 to 0 or from 0 to 1
- **NRZ - Inversion (NRZ-I)** - the change or lack of change in polarity determines the value of a symbol. E.g. a "1" symbol inverts the polarity a "0" does not.



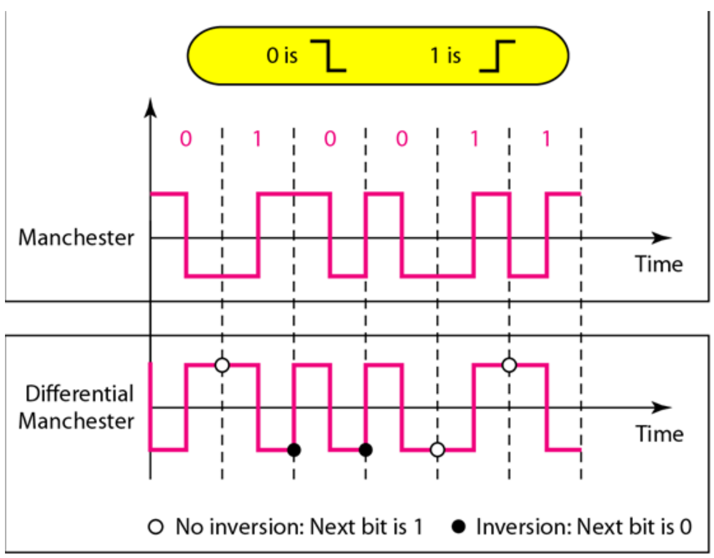
Polar - RZ

- The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.
- Each symbol has a transition in the middle. Either from high to zero or from low to zero.
- This scheme has more signal transitions (two per symbol) and therefore requires a wider bandwidth.
- No DC components or baseline wandering.
- Self synchronization - transition indicates symbol value.
- More complex as it uses three voltage level. It has no error detection capability.



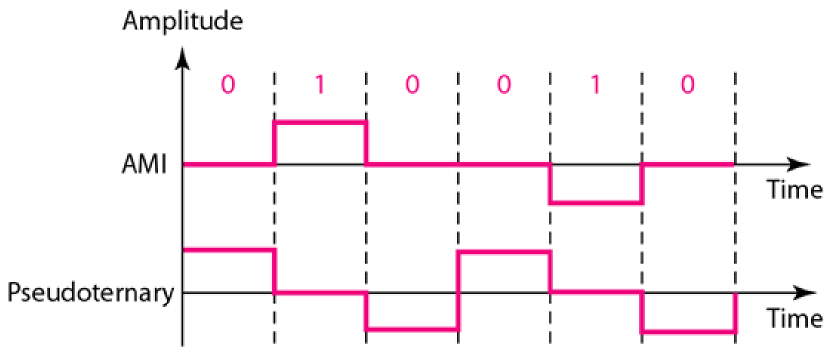
Polar - Biphase: Manchester and Differential Manchester

- **Manchester coding** consists of combining the NRZ-L and RZ schemes.
  - Every symbol has a level transition in the middle: from high to low or low to high. Uses only two voltage levels.
- **Differential Manchester** coding consists of combining the NRZ-I and RZ schemes.
  - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value.
  - One symbol causes a level change the other does not.



Bipolar - AMI and Pseudoternary

- Code uses 3 voltage levels: - +, 0, -, to represent the symbols
- Voltage level for one symbol is at "0" and the other alternates between + & -.
- Bipolar Alternate Mark Inversion (AMI) - the "0" symbol is represented by zero voltage and the "1" symbol alternates between +V and -V.
- Pseudoternary is the reverse of AMI.



Multilevel Schemes

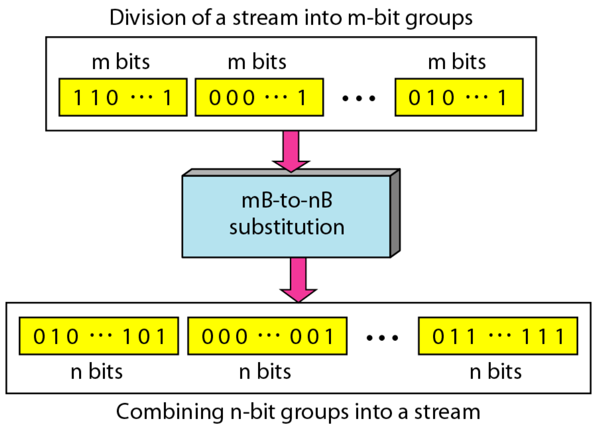
- In these schemes we increase the number of data bits per symbol thereby increasing the bit rate.
- Since we are dealing with binary data we only have 2 types of data element a 1 or a 0.
- We can combine the 2 data elements into a pattern of "m" elements to create "2^m" symbols.
- If we have L signal levels, we can use "n" signal elements to create L^n signal elements.
- **2B1Q**
  - Use the notation mBnL, where m is the length of the binary pattern, B represents binary data, n represents the length of the signal pattern and L the number of levels.
  - L = B binary, L = T for 3 ternary, L = Q for 4 quaternary.
  - 2B1Q-two binary, one quaternary (2BIQ), uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal.

Multiline Transmission: MLT-3

- The multiline transmission, three level (MLT-3) scheme uses three levels (+V, 0, & - V) and three transition rules to move between the levels.
  - If the next bit is 0, there is no transition.
  - If the next bit is 1 and the current level is not 0, the next level is 0.
  - If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.

Block Coding

- Redundancy is needed to ensure synchronization and to provide some kind of inherent error detecting.
- Block coding can give this redundancy and improve the performance of line coding.
- Block coding is normally referred to as mB/nB coding; it replaces each m-bit group with an n-bit group.



Scrambling

- Scrambling is a technique used to create a sequence of bits that has the required code for transmission - self clocking, no low frequencies, no wide bandwidth.
- It is implemented at the same time as encoding, the bit stream is created on the fly.
- It replaces 'unfriendly' runs of bits with a violation code that is easy to recognize and removes the unfriendly codes.

Table 5.2 Definition of Digital Signal Encoding Formats

Nonreturn to Zero-Level (NRZ-L)
0 = high level
1 = low level

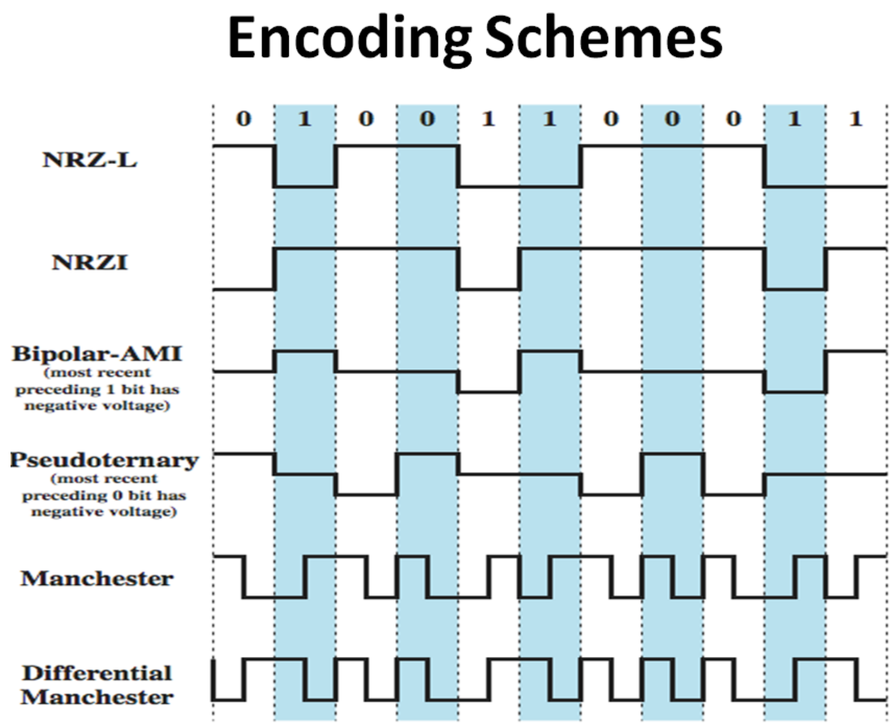
Nonreturn to Zero Inverted (NRZI)
0 = no transition at beginning of interval (one bit time)
1 = transition at beginning of interval

Bipolar-AMI
0 = no line signal
1 = positive or negative level, alternating for successive ones

Pseudoternary
0 = positive or negative level, alternating for successive zeros
1 = no line signal

Manchester
0 = transition from high to low in middle of interval
1 = transition from low to high in middle of interval

Differential Manchester
Always a transition in middle of interval
0 = transition at beginning of interval

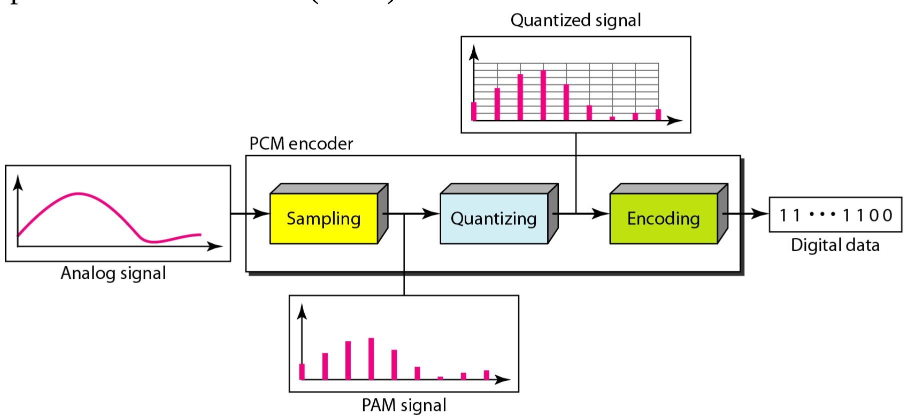


Analog to Digital Conversion

- The process of converting an analog signal to digital data is called digitization
- Two techniques to change an analog signal to digital data
    - pulse code modulation
    - delta modulation

Pulse code modulation (PCM)

- The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM)

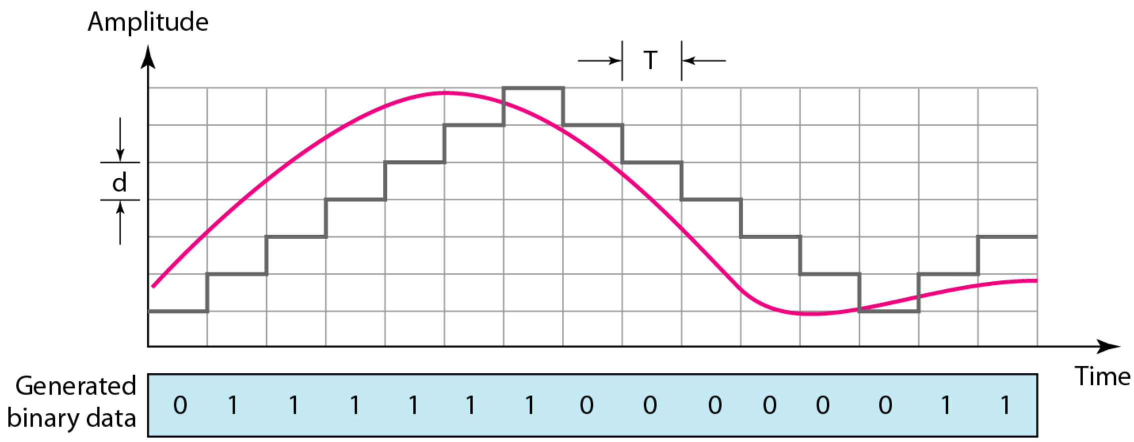


1. The analog signal is sampled.
2. The sampled signal is quantized.
3. The quantized values are encoded as streams of bits.

- PCM consists of three steps to digitize an analog signal:
  - Sampling
    - Analog signal is sampled every T_S secs.
    - T_s is referred to as the sampling interval.
    - $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
    - The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values
  - Quantization
    - Quantization is representing the sampled values of the amplitude by a finite set of levels, which means converting a continuous-amplitude sample into a discrete-time signal.
  - Binary encoding
    - The last step in PCM is encoding.
    - After each sample is quantized and the number of bits per sample is decided, each sample can be changed to an binary-bit code word.
    - A quantization code of 2 is encoded as 010; 5 is encoded as 101; and so on. The number of bits for each sample is determined from the number of quantization levels

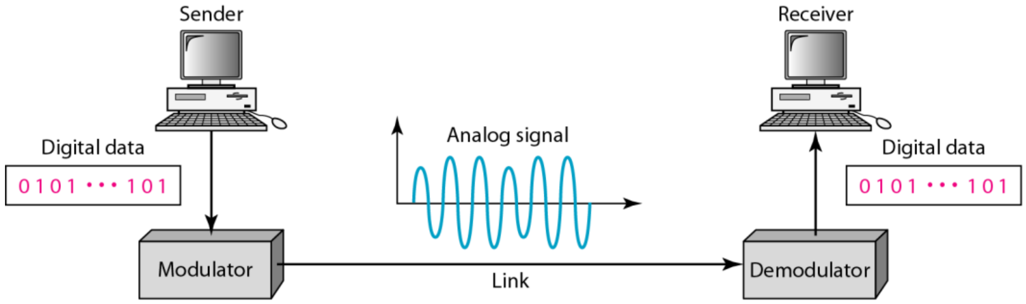
Delta modulation

- PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample.
- There are no code words here; bits are sent one after another.

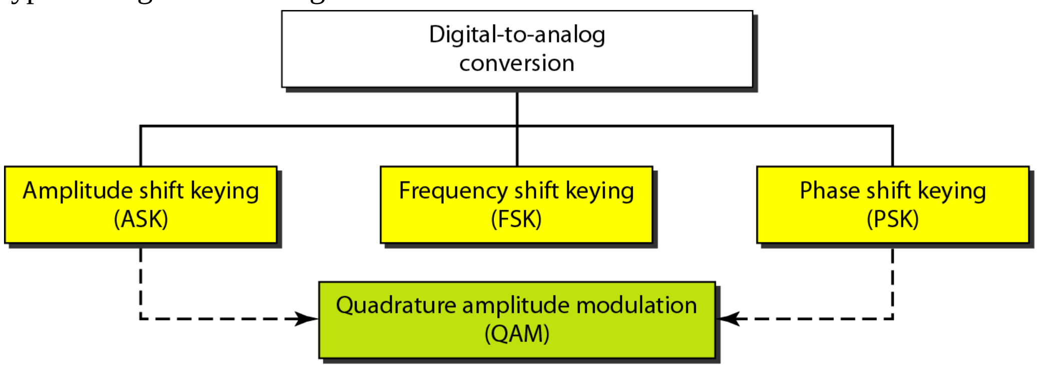


Digital to Analog Conversion

- **Digital-to-analog conversion** is the process of changing one of the characteristics of an analog signal based on the information in digital data.

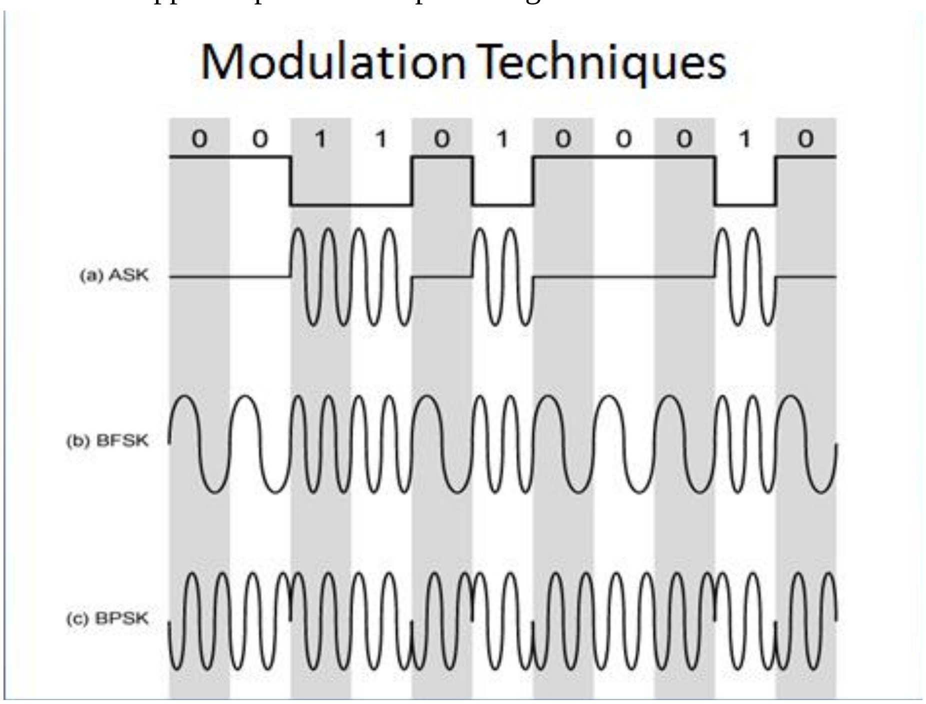


- A sine wave is defined by three characteristics: amplitude, frequency, and phase.
- When we vary anyone of these characteristics, we create a different version of that wave.
- By changing one characteristic of a simple electric signal, we can use it to represent digital data.
- Types of digital-to-analog conversion



- Carrier Signal
  - In analog transmission, the sending device produces a high-frequency signal that acts as a base for the information signal. This base signal is called the carrier signal or carrier frequency.
  - Digital information then changes the carrier signal by modifying one or more of its characteristics (amplitude, frequency, or phase)-Shift key
- **Amplitude Shift Key (ASK):**
  - ASK is implemented by changing the amplitude of a carrier signal to reflect amplitude levels in the digital signal.
  - The two binary values are represented by two different amplitudes of the carrier frequency.
  - Commonly, one of the amplitudes is zero; that is, the 1 binary digit is represented by the presence, at constant amplitude, of the carrier, the 0 binary digit by the absence of the carrier.
  - Used for very high speed over optical fiber.

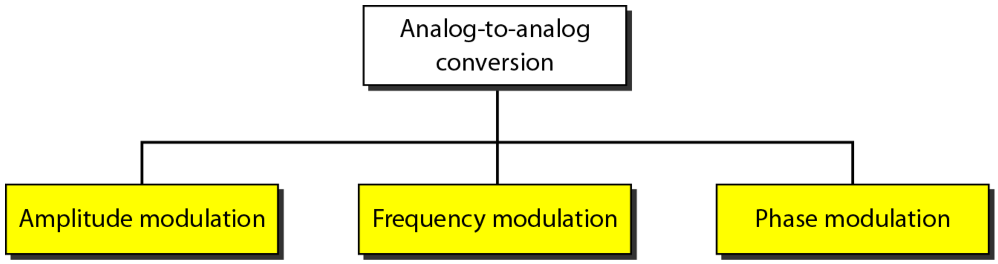
- **Frequency Shift Key (FSK):**
  - The digital data stream changes the frequency of the carrier signal, f_c.
  - For example, a “1” could be represented by $f_1=f_c+\Delta f$, and a “0” could be represented by $f_2=f_c-\Delta f$.
  - Have two types: Binary FSK, and Multiple FSK.
  - In BFSK, the two binary values are represented by two different frequencies near the carrier frequency.
    - BFSK is less susceptible to error than ASK, and used for high frequency radio and higher frequency on LANs using coaxial cables.
  - In MFSK, more than two frequencies are used.
    - In this case each signaling element represents more than one bit.
    - MFSK is more bandwidth efficient and more porn to errors.
- **Phase Shift Key (PSK):**
  - The phase of the carrier signal is shifted to represent data.
  - It has two types: Binary PSK and Differential PSK.
  - In BPSK, two phases to represent the two binary digits.
  - In DPSK, a binary 0 is represented by sending a signal burst of the same phase as the previous signal burst sent, and a binary 1 is represented by sending a signal burst of opposite phase to the preceding one.



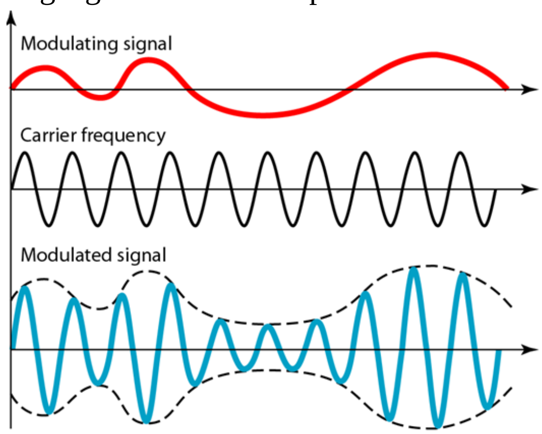
- **Quadrature Amplitude Modulation**
  - Using two carriers, one in-phase and the other quadrature, with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM).
  - Quadrature amplitude modulation is a combination of ASK and PSK

Analog to Analog Conversion

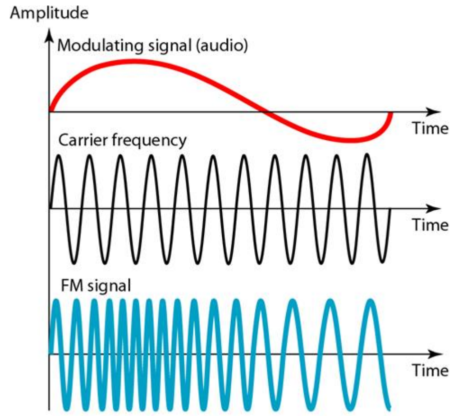
- Analog-to-analog conversion, or analog modulation, is the representation of analog information by an analog signal.
- Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us
- Types of analog-to-analog modulation



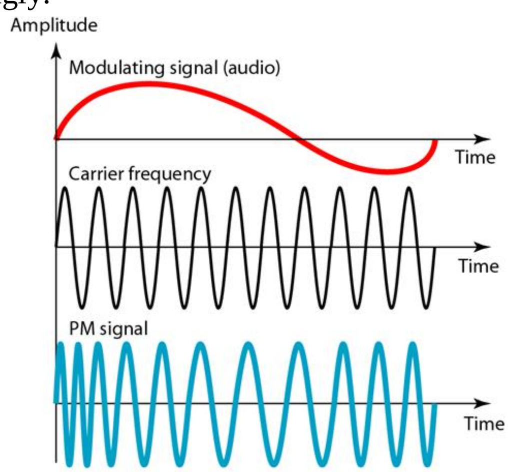
- **Amplitude Modulation**
    - In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal.
    - The frequency and phase of the carrier remain the same; only the amplitude changes to follow variations in the information.
    - The modulating signal is the envelope of the carrier.



- **Frequency Modulation**
    - In FM transmission, the frequency of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.
    - The peak amplitude and phase of the carrier signal remain constant, but as the amplitude of the information signal changes, the frequency of the carrier changes correspondingly.



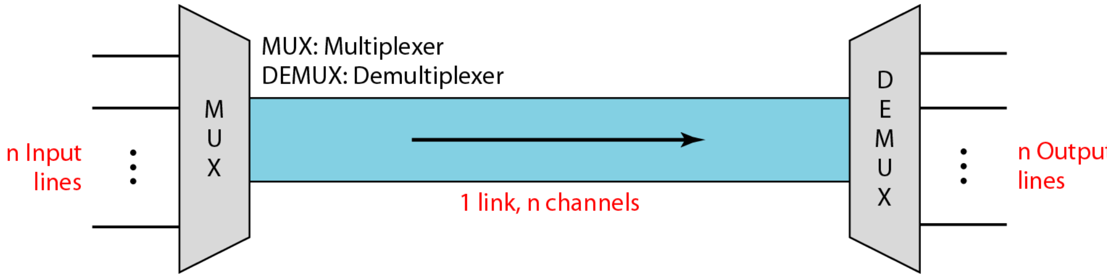
- **Phase Modulation**
    - In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.
    - The peak amplitude and frequency of the carrier signal remain constant, but as the amplitude of the information signal changes, the phase of the carrier changes correspondingly.



CHANNEL ACCESS TECHNIQUES

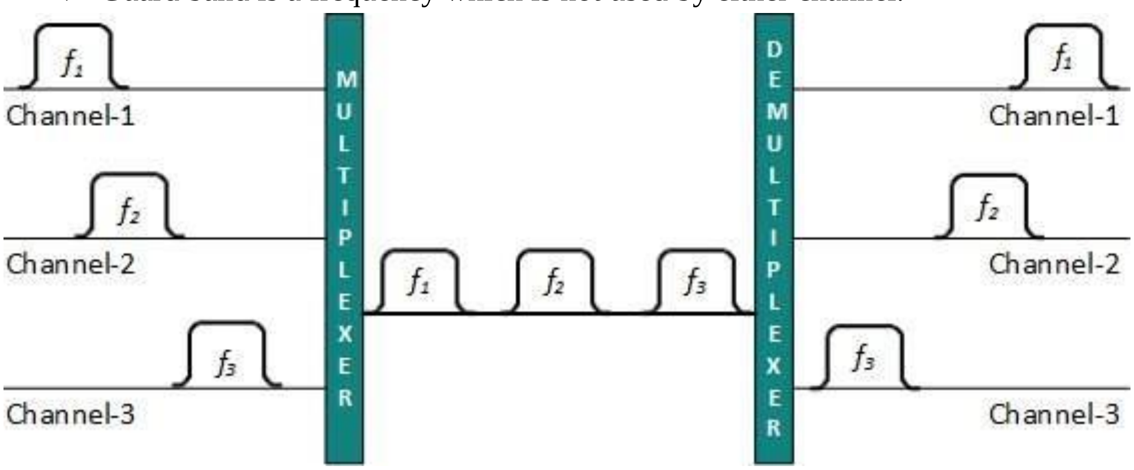
- Multiplexing is a technique by which different analog and digital streams of transmission can be simultaneously processed over a shared link.
- Multiplexing divides the high capacity medium into low capacity logical medium which is then shared by different streams.
- Communication is possible over the air (radio frequency), using a physical media (cable), and light (optical fiber). All mediums are capable of multiplexing.
- When multiple senders try to send over a single medium, a device called Multiplexer divides the physical channel and allocates one to each.

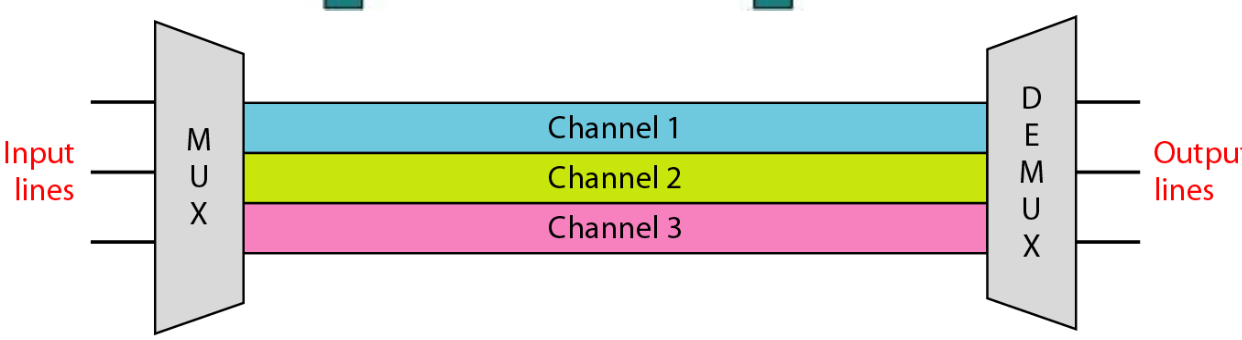
- On the other end of communication, a De-multiplexer receives data from a single medium, identifies each, and sends to different receivers.



Frequency Division Multiplexing

- When the carrier is frequency, FDM is used. FDM is an analog technology.
- FDM achieves the combining of several signals into one medium by sending signals in several distinct frequency ranges over a single medium
- Each user can use the channel frequency independently and has exclusive access of it.
- All channels are divided in such a way that they do not overlap with each other.
- Channels are separated by guard bands.
- Guard band is a frequency which is not used by either channel.



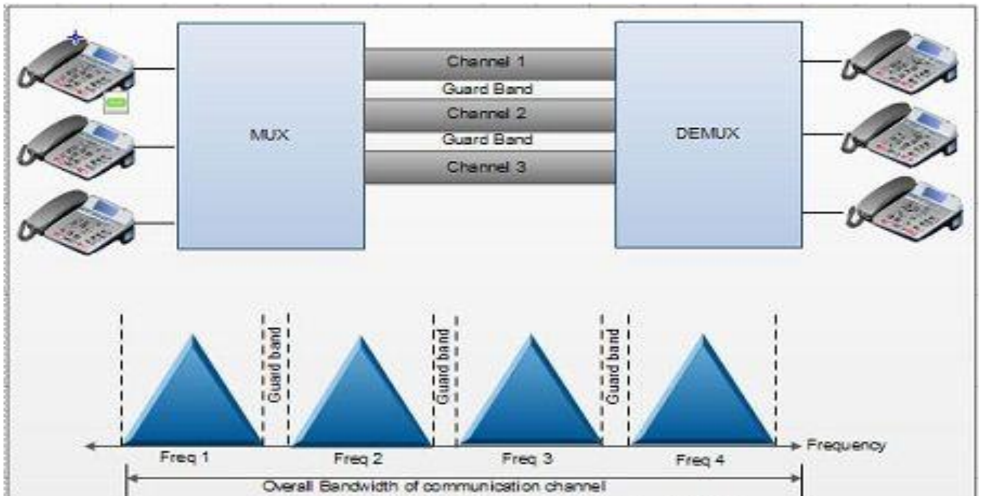


Example:

1. Radio broad casting (AM and FM) provides multiple signals or stations of different frequencies with the inter channel separation to prevent interference.

2. Cable TV or Television transmission relay center transmits all channels simultaneously and at the receiving end the TV "tunes in" to select a particular channel for watch.

- FDM requires that the bandwidth of a link should be greater than the combined bandwidths of the various signals to be transmitted. Thus each signal having different frequency forms a particular logical channel on the link and follows this channel only.
- These channels are then separated by the strips of unused bandwidth called guard bands.
- Guard bands prevent the signals from overlapping as shown in Fig.

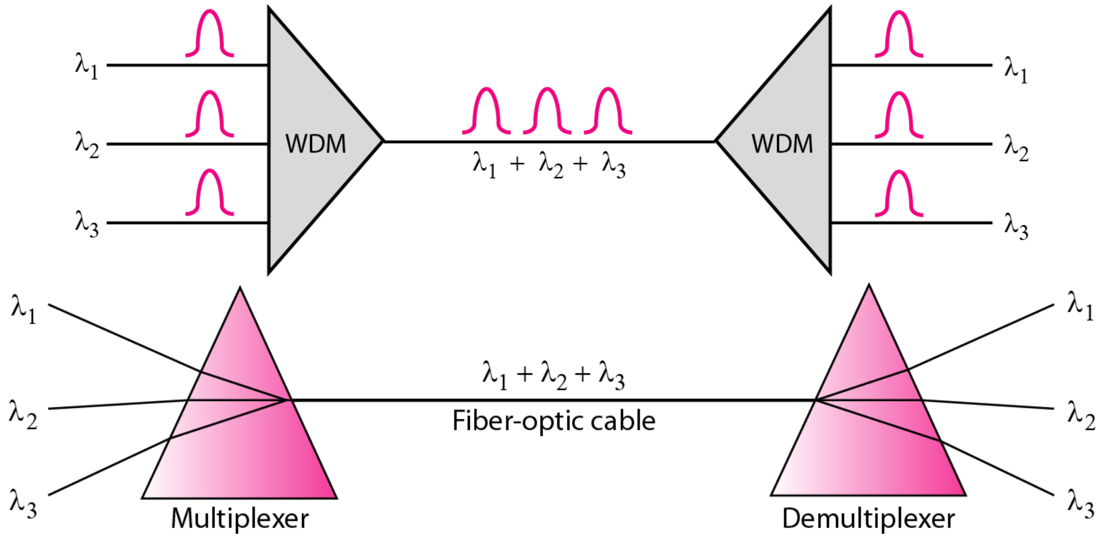


Frequency Division Multiplexing FDM

- **Advantages of FDM:**
  - A large number of signals (channels) can be transmitted simultaneously.
  - FDM does not need synchronization between its transmitter and receiver for proper operation.
  - Demodulation of FDM is easy.
  - Due to slow narrow band fading only a single channel gets affected.
- **Disadvantages of FDM:**
  - The communication channel must have a very large bandwidth.
  - Intermodulation distortion takes place.
  - Large number of modulators and filters are required.
  - FDM suffers from the problem of crosstalk.
  - All the FDM channels get affected due to wideband fading.
- **Applications of FDM**
  - FDM is used for FM & AM radio broadcasting. Each AM and FM radio station uses a different carrier frequency. In AM broadcasting, these frequencies use a special band from 530 to 1700 KHz. All these signals/frequencies are multiplexed and are transmitted in air. A receiver receives all these signals but tunes only one which is required. Similarly FM broadcasting uses a bandwidth of 88 to 108 MHz
  - FDM is used in television broadcasting.
  - First generation cellular telephone also uses FDM.

Wavelength-division multiplexing (WDM)

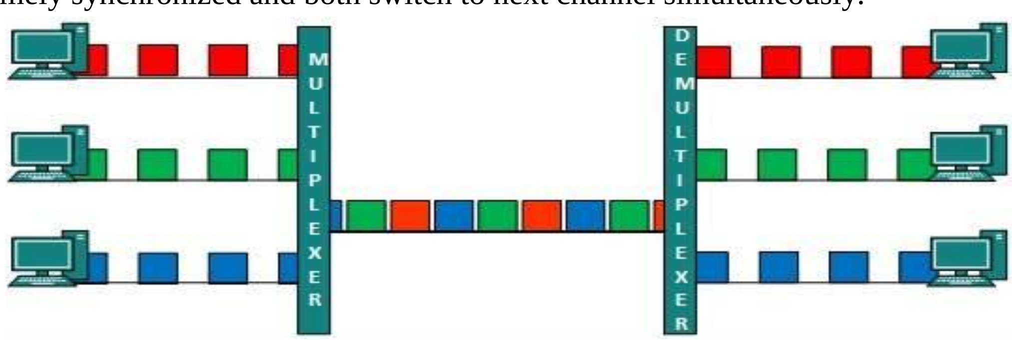
- WDM is conceptually the same as FDM, except that the multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels
- WDM is an analog multiplexing technique to combine optical signals.
- Very narrow bands of light(colors) from different sources are combined to make a wider bandof light.
- At the receiver, the signals are separated by the demultiplexer.

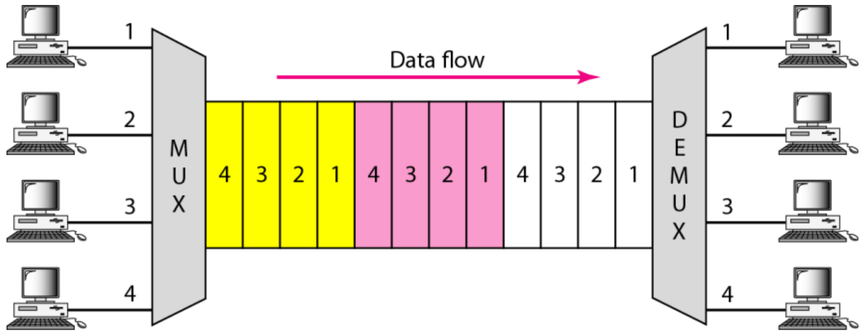


Prisms in wavelength-division multiplexing and demultiplexing

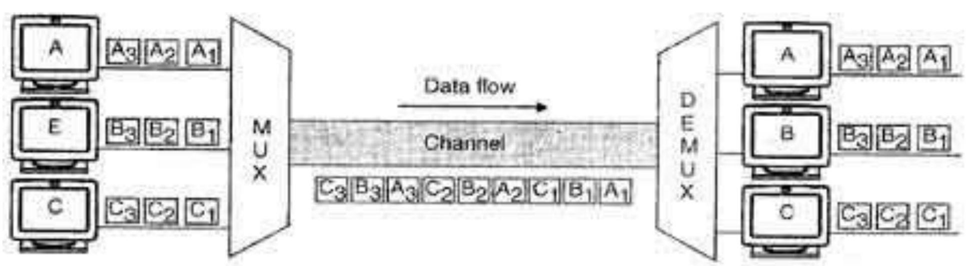
Time Division Multiplexing

- TDM is applied primarily on digital signals
- TDM is a digital multiplexing technique for combining several low-rate digital channels into one high-rate one.
- In TDM the shared channel is divided among its user by means of time slot.
- Each user can transmit data within the provided time slot only.
- Digital signals are divided in frames, equivalent to time slot i.e. frame of an optimal size which can be transmitted in given time slot.
- TDM works in synchronized mode. Both ends, i.e. Multiplexer and De-multiplexer are timely synchronized and both switch to next channel simultaneously.





- When channel A transmits its frame at one end, the De-multiplexer provides media to channel A on the other end.
- As soon as the channel A's time slot expires, this side switches to channel B.
- On the other end, the De-multiplexer works in a synchronized manner and provides media to channel B. Signals from different channels travel the path in interleaved manner.
- Each user is allotted a particular a time interval called time slot or time slice during which the data is transmitted by that user. Thus each sending device takes control of entire bandwidth of the channel for fixed amount of time.
- In TDM the data rate capacity of the transmission medium should be greater than the data rate required by sending or receiving devices.



Time Division Multiplexing (TDM)

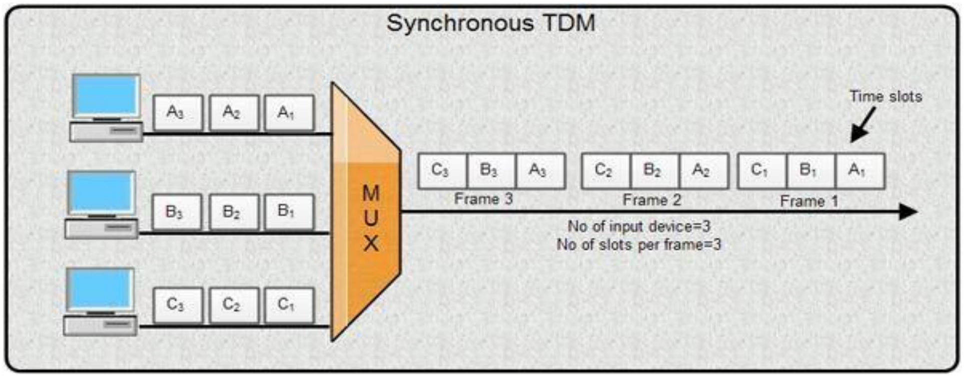
Types of TDM

1. Synchronous TDM
2. Asynchronous TDM

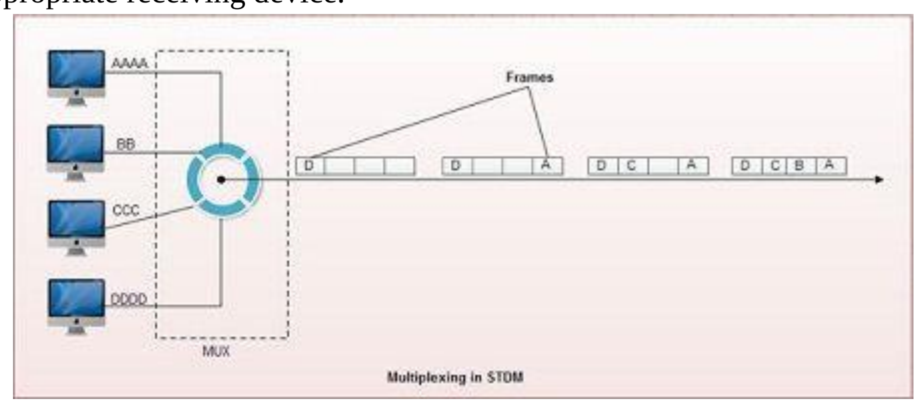
Synchronous TDM (STDM)

- In synchronous TDM, each device is given same **time slot** to transmit the data over the link, irrespective of the fact that the device has any data to transmit or not. Hence the name Synchronous TDM. Synchronous TDM requires that the total speed of various input lines should not exceed the capacity of path.
- Each device places its data onto the link when its **time slot** arrives *i.e.* each device is given the possession of line turn by turn.
- If any device does not have data to send then its time slot remains empty.

- The various time slots are organized into **frames** and each frame consists of one or more time slots dedicated to each sending device.
- If there are *n* sending devices, there will be *n* slots in frame *i.e.* one slot for each device.



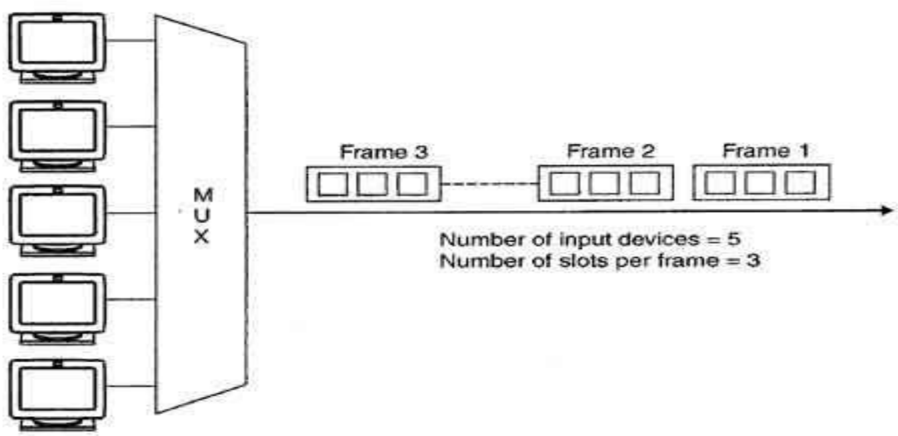
- As show in fig, there are 3 input devices, so there are 3 slots in each frame.
- **Multiplexing Process in STDM**
    - In STDM every device is given the opportunity to transmit a specific amount of data onto the link.
    - Each device gets its turn in fixed order and for fixed amount of time. This process is known as interleaving.
    - The operation of STDM is similar to that of a fast interleaved switch. The switch opens in front of a device; the device gets a chance to place the data onto the link.
    - Interleaving may be done on the basis of a hit, a byte or by any other data unit.
    - In STDM, the interleaved units are of same size *i.e.* if one device sends a byte, other will also send a byte and so on.
    - As shown in the fig. interleaving is done by a character (one byte). Each frame consists of four slots as there are four input devices. The slots of some devices go empty if they do not have any data to send.
    - At the receiver, demultiplexer decomposes each frame by extracting each character in turn. As a character is removed from frame, it is passed to the appropriate receiving device.



- **Disadvantages of Synchronous TDM**
  - The channel capacity cannot be fully utilized. Some of the slots go empty in certain frames.
  - The capacity of single communication line that is used to carry the various transmission should be greater than the total speed of input lines.

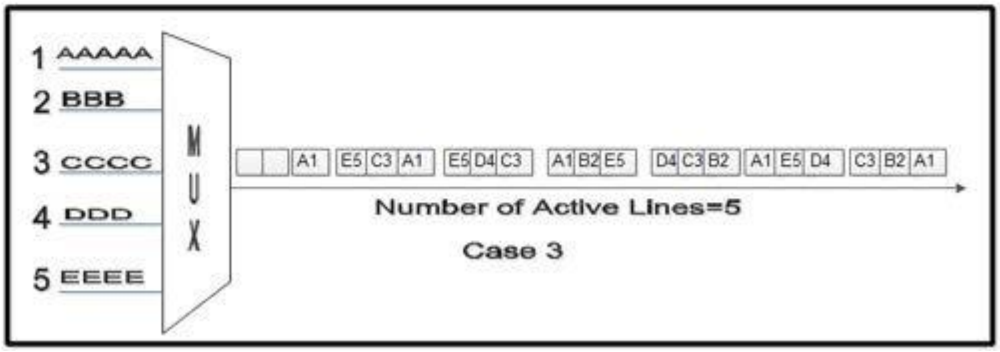
Asynchronous TDM

- It is also known as statistical time division multiplexing.
- Asynchronous TDM is called so because is this type of multiplexing, time slots are not fixed *i.e.* the slots are flexible.
- The total speed of input lines can be greater than the capacity of the path.
- In synchronous TDM, if we have *n* input lines then there are *n* slots in one frame. But in asynchronous it is not so.
- In asynchronous TDM, if we have *n* input lines then the frame contains not more than *m* slots, with *m* less than *n (m < n).*
- In asynchronous TDM, the number of time slots in a frame is based on a statistical analysis of number of input lines.



Asynchronous TDM

- In this system slots are not predefined, the slots are allocated to any of the device that has data to send.
- The multiplexer scans the various input lines, accepts the data from the lines that have data to send, fills the frame and then sends the frame across the link.
- If there are not enough data to fill all the slots in a frame, then the frames are transmitted partially filled.
- Asynchronous Time Division Multiplexing is depicted in fig. Here we have five input lines and three slots per frame.
- The distribution of various slots in the frames is not symmetrical.
- In statistical TDM, a slot needs to carry data as well as the address of the destination.

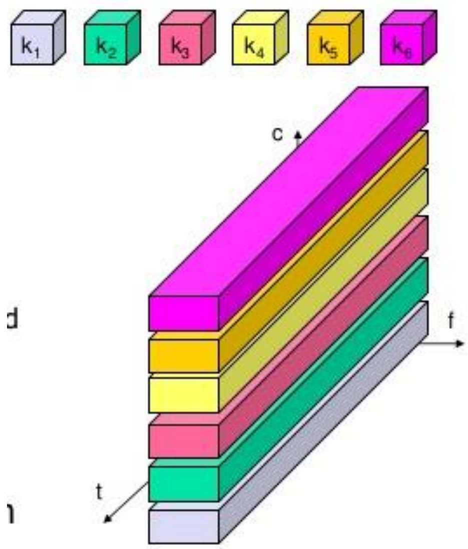


- **Advantages of TDM :**
  - Full available channel bandwidth can be utilized for each channel.
  - lntermodulation distortion is absent.
  - TDM circuitry is not very complex.
  - The problem of crosstalk is not severe.
- **Disadvantages of TDM :**
  - Synchronization is essential for proper operation.
  - Due to slow narrowband fading, all the TDM channels may get wiped out.

Code Division Multiplexing

- Multiple data signals can be transmitted over a single frequency by using Code Division Multiplexing.
- FDM divides the frequency in smaller channels but CDM allows its users to full bandwidth and transmit signals all the time using a unique code.
- CDM uses orthogonal codes to spread signals.
- Each station is assigned with a unique code, called chip. Signals travel with these codes independently, inside the whole bandwidth. The receiver knows in advance the chip code signal it has to receive.
- CDM is widely used in so-called second-generation (2G) and third-generation 3G wireless communications. The technology is used in ultra-high-frequency (UHF) cellular telephone systems in the 800-MHz and 1.9-GHz bands. This is a combination of analog-to-digital conversion and spread spectrum technology.
- CDM may be defined as a form of multiplexing where the transmitter encodes the signal using a pseudo-random sequence.
- CDM involves the original digital signal with a spreading code. This spreading has the effect of spreading the spectrum of the signal greatly and reducing the power over anyone part of the spectrum.
- On the other hand, the receiver knows about the code generated and transmitted by the transmitter and therefore, can decode the received signal.

- Each different random sequence corresponds to a different communication channel from multiple stations.
- Each sender is assigned a unique binary code C_i
    - that is known as a chip sequence
    - chip sequences are selected to be orthogonal vectors
    - (i.e., the dot product of any two chip sequences is zero)
- At any point in time, each sender has a value to transmit, V_i
    - The senders each multiply C_i x V_i and transmit the results
- The senders transmit at the same time
    - and the values are added together
- To extract value V_i, a receiver multiplies the sum by C_i



- A single bit may be transmitted by modulating a series of signal elements at different frequencies in some particular order. These numbers of different frequencies per bit are called as the chip rate.
- If one or more bits are transmitted at the same frequency, it is called as frequency hopping. This will happen only when the chip rate is less than one because chip rate is the ratio of frequency and bit. At the receiving side, receiver decodes a 0 or a 1 bit by checking these frequencies in the correct order.
- Disadvantage
    - Each user's transmitted bandwidth is enlarged than the digital data rate of the source. The result is an occupied bandwidth approximately equal to the coded rate.
    - The transmitter and receiver require a complex electronics circuitry.

Other Methods

A unique and widely used method of multiple access is carrier sense multiple access with collision detection (CSMA-CD). This is the classical access method used in Ethernet local-area networks (LANs). It allows multiple users of the network to access the single cable for transmission. All network nodes listen continuously. When they want to send data, they listen first and then transmit if no other signals are on the line. For instance, the transmission will be one packet or frame. Then the process repeats. If two or more transmissions occur simultaneously, a collision occurs. The network interface circuitry can detect a collision, and then the nodes will wait a random time before retransmitting.

A variation of this method is called carrier sense multiple access with collision avoidance (CSMA-CA). This method is similar to CSMA-CD. However, a special scheduling algorithm is used to determine the appropriate time to transmit over the shared channel. While the CSMA-CD technique is most used in wired networks, CSMA-CA is the preferred method in wireless networks.