ANALOG AND DIGITAL

Analog Data: The term **analog data** refers to information that is continuous; For example, an analog clock that has hour, minute, and second hands gives information in a continuous form; the movements of the hands are continuous.

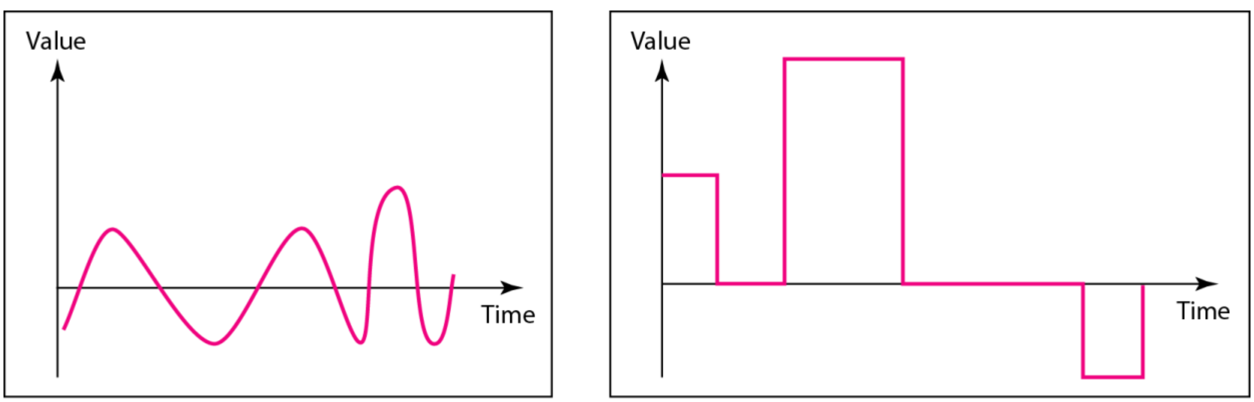
- Analog data, such as the sounds made by a human voice, take on continuous values. When someone speaks, an analog wave is created in the air. This can be captured by a microphone and converted to an analog signal or sampled and converted to a digital signal.

Digital Data: Digital data refers to information that has discrete states. For example, a digital clock that reports the hours and the minutes will change suddenly from 8:05 to 8:06. Digital data takes on discrete values.

- For example, data are stored in computer memory in the form of Os and 1s. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.

Analog and Digital Signals: Like the data they represent, signals can be either analog or digital.

- An ***analog signal*** has infinitely many levels of intensity over a period of time. As the wave moves from value *A* to value *B*, it passes through and includes an infinite number of values along its path.
- A ***digital signal***, on the other hand, can have only a limited number of defined values. Although each value can be any number, it is often as simple as 1 and 0. The simplest way to show signals is by plotting them on a pair of perpendicular axes. The vertical axis represents the value or strength of a signal. The horizontal axis represents time.
- Figure below illustrates an analog signal and a digital signal. The curve representing the analog signal passes through an infinite number of points. The vertical lines of the digital signal, however, demonstrate the sudden jump that the signal makes from value to value.



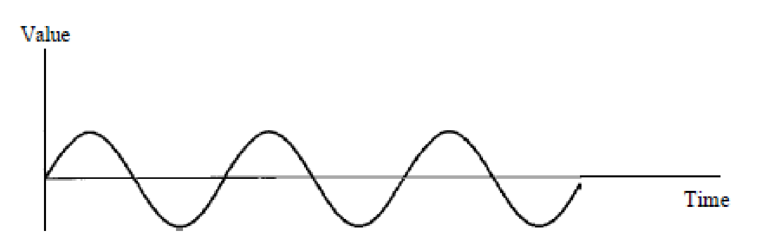
a. Analog signal b. Digital signal

Periodic and Nonperiodic Signals: 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.

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

Sine Wave : The sine wave is the most fundamental form of a periodic analog signal. When we visualize it as a simple oscillating curve, its change over the course of a cycle is smooth and consistent, a continuous, rolling flow. Figure below shows a sine wave. Each cycle consists of a single arc above the time axis followed by a single arc below it.

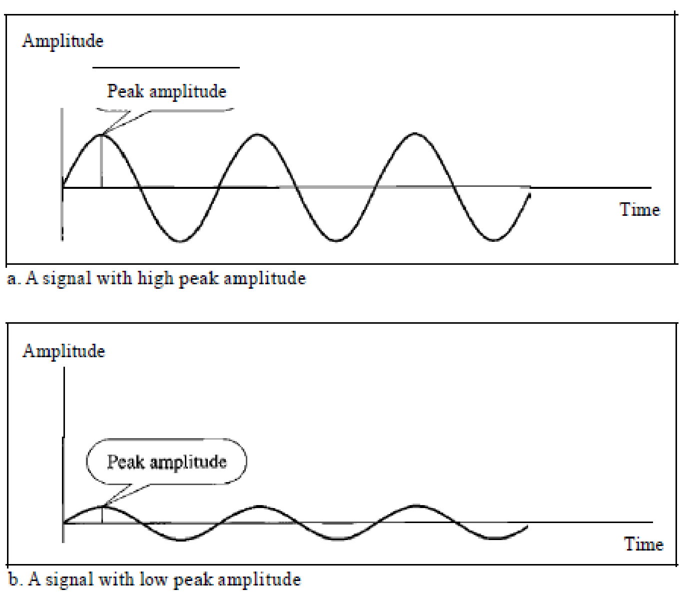
A sine wave



Characteristics of Signals:

1. *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 below shows two signals and their peak amplitudes.

Two signals with the same phase and frequency, but different amplitudes



a. A signal with high peak amplitude

b. A signal with low peak amplitude

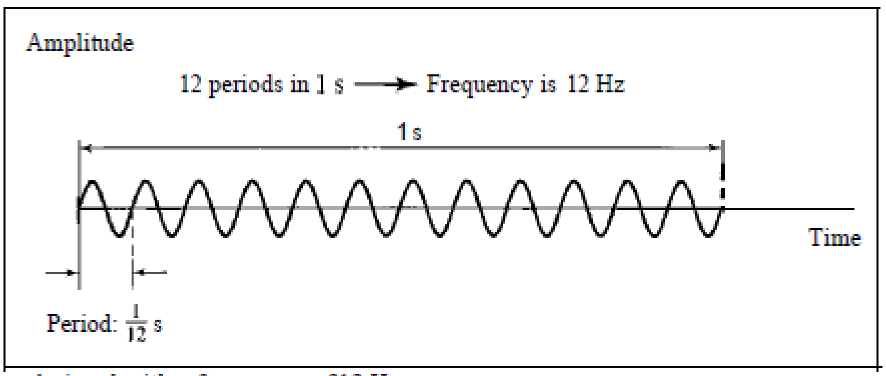
2. Period and Frequency

- ***Period*** refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- ***Frequency*** refers to the number of periods in I s. Note that 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.

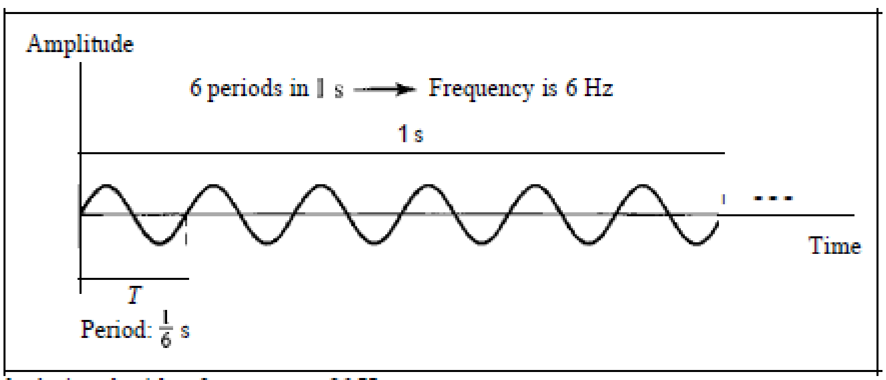
$$f=1/T \text{ and } T=1/f$$

- Period is formally expressed in seconds. Frequency is formally expressed in Hertz (Hz), which is cycle per second.

Two signals with the same amplitude and phase, but different frequencies



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

3. *Phase*

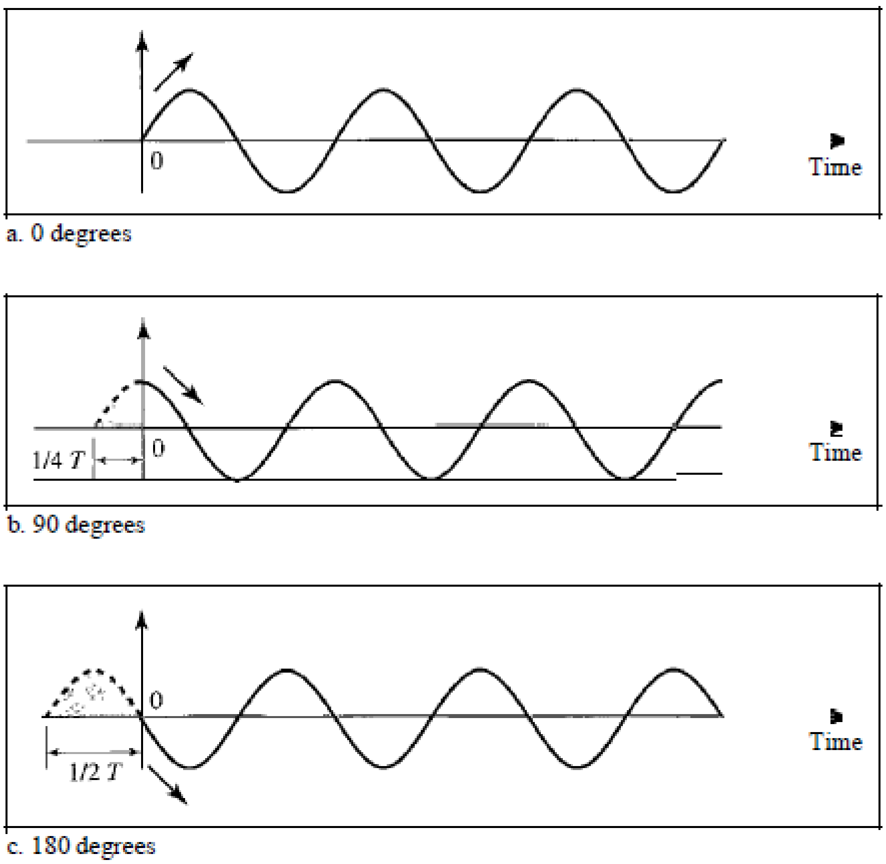
- The term phase describes the position of the waveform relative to time 0. If we think of the wave as something that can be shifted backward or forward along the time axis, phase describes the amount of that shift.
- It indicates the status of the first cycle. Phase is measured in degrees or radians

  360° = 2π rad;

  Hence, 1° is $2\pi/360$ rad, and 1 rad is $360/(2\pi)$.

- A phase shift of 360° corresponds to a shift of a complete period; a phase shift of 180° corresponds to a shift of one-half of a period; and a phase shift of 90° corresponds to a shift of one-quarter of a period.

Three sine waves with the same amplitude andfrequency, but differentphases



I. A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitude is increasing.
II. A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing.
III. A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.

4. *Wavelength*h

- Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium. While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium.
- Wavelength is a property of any type of signal. In data communications, we often use wavelength to describe the transmission of light in an optical fiber.

- 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. The wavelength is normally measured in micrometers (microns) instead of meters.

- However, since period and frequency are related to each other, if we represent wavelength by λ, propagation speed by c (speed of light), and frequency by *f*, we get

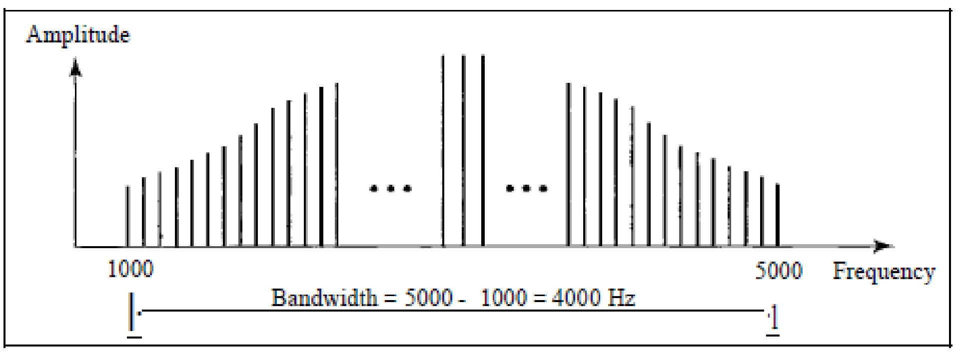
Wavelength=Propagation speed * Period = propagation speed/frequency $\lambda = c/f$

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

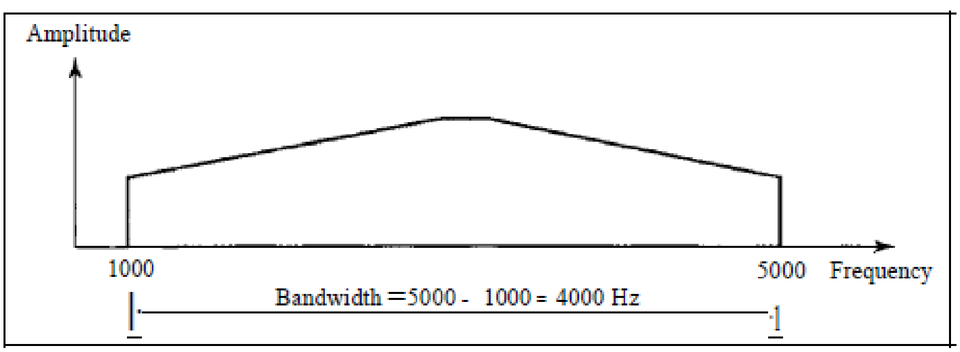
$BW = f_H - f_L$ Where f_H= highest frequency and f_L=lowest frequency

For example, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 - 1000, or 4000.

Figure 3.12 *The bandwidth ofperiodic and nonperiodic composite signals*



a. Bandwidth of a periodic signal



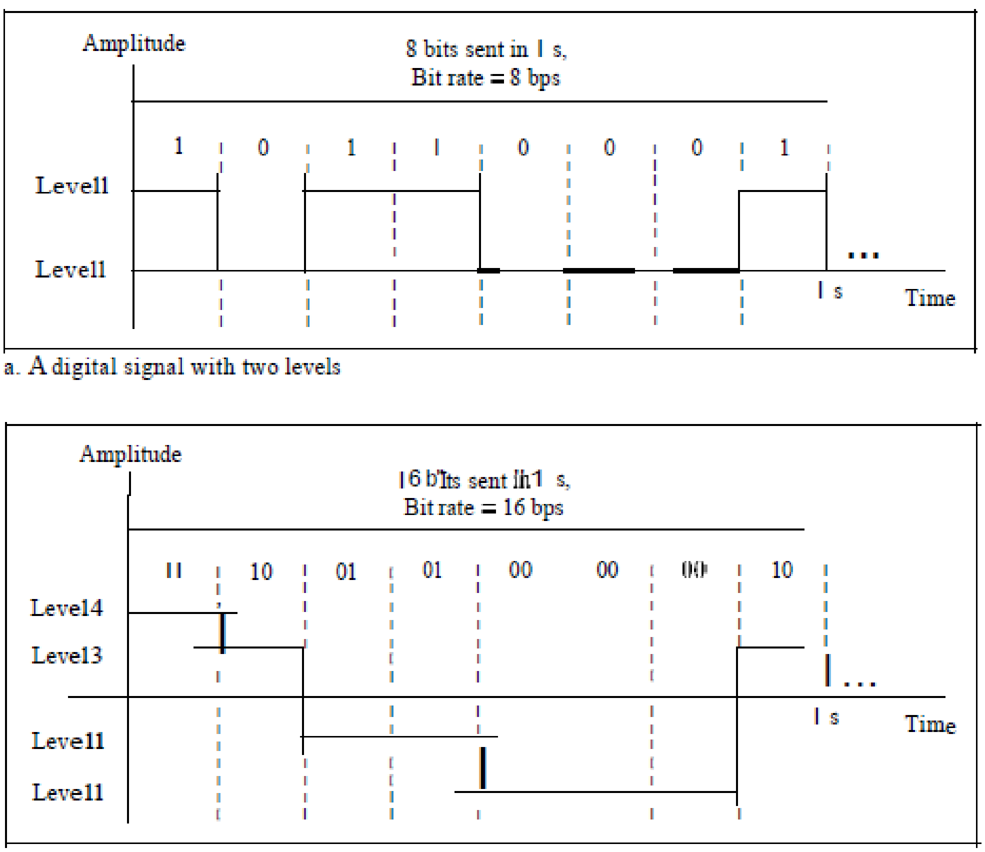
b. Bandwidth of a nonperiodic signal

Figure 3.12 shows the concept of bandwidth. The figure depicts two composite signals, one periodic and the other nonperiodic. The bandwidth of the periodic signal contains all integer frequencies between 1000 and 5000 (1000, 100 I, 1002, ...). The bandwidth of the nonperiodic signals has the same range, but the frequencies are continuous.

DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level. Figure 3.16 shows two signals, one with two levels and the other with four.

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



a. A digital signal with two levels

b. A digital signal with four levels

We send 1 bit per level in part a of the figure and 2 bits per level in part b of the figure. In general, if a signal has L levels, each level needs $\log_2 L$ bits.

Bit Rate :

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

Bit length:
It can be defined as the distance one bit occupies on the transmission medium.

Bit length= propagation speed * bit duration

Transmission Impairment

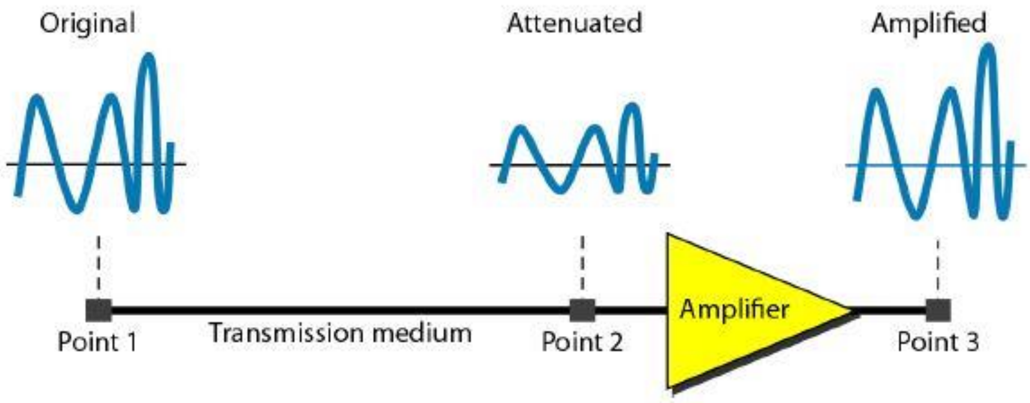
Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received.

Three causes of impairment are :

1. **Attenuation**
2. **Distortion**
3. **Noise**.

<u>Attenuation</u>

- Attenuation means a loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium. That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifiers are used to amplify the signal.



- **Decibel**
  To show that a signal has lost or gained strength, engineers use the unit of the decibel. The decibel (dB) measures the relative strengths of two signals or one signal at two different points.

- ***Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.***

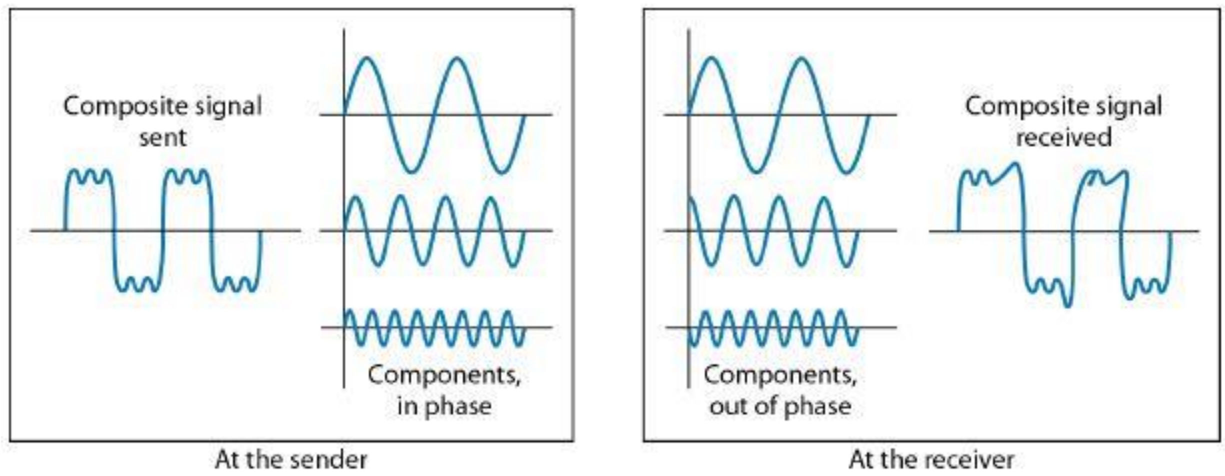
$$\mathbf{dB = 10\ log_{10}\ P2/P1}$$

Where Variables *PI* and *P2* are the powers of a signal at points 1 and 2, respectively.

- **Example:**
  Suppose a signal travels through a transmission medium and its power is reduced to one half. Find the attenuation (loss of power).
  Solution:
  $dB=10\ \log_{10} (P/2P)= -3\ dB$
- **Example:**
  A signal travels through an amplifier, and its power is increased 10 times Find the amplification (gain of power).
  Solution:
  $dB=10\ \log_{10} (10P/P)= 10\ dB$

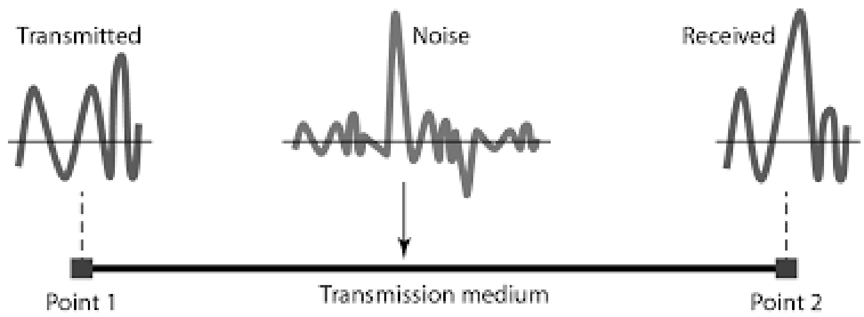
<u>Distortion</u>

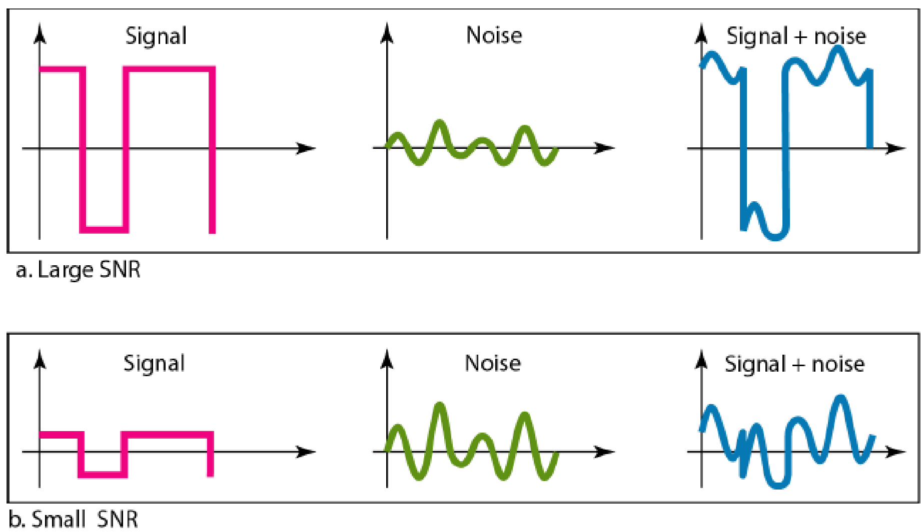
- **Distortion** means that the signal changes its form or shape.
- Distortion can occur in a composite signal made of different frequencies. Each signal component has its own propagation speed (see the next section) through a medium and, therefore, its own delay in arriving at the final destination. Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.
- In other words, signal components at the receiver have phases different from what they had at the sender. The shape of the composite signal is therefore not the same.



<u>Noise</u>

Noise is another cause of impairment. Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.





- Thermal noise is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter.
- Induced noise comes from sources such as motors and appliances.
- Crosstalk is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.
- Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.

Signal-to-Noise Ratio (SNR)

- The signal-to-noise ratio is defined as

$$\boxed{\textbf{SNR= Average Signal power / Average Noise Power}}$$

- SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise).
- A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise. Because SNR is the ratio of two powers, it is often described in decibel units, SNR dB, defined as

$$\boxed{\mathbf{SNR_{dB} = 10 \times \log_{10} SNR}}$$

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

Solution: The values of SNR and SNR_{dB} can be calculated as follows:
SNR = 10^-2 / 10^-6 = 10, 000
SNR_{dB} =10 $\log_{10} 10^{\wedge 4}$ = 10 × 4 = 40

Data Rate Limits

A very important consideration in data communications is how fast we can send data, in bits per second over a channel. Data rate depends on three factors:

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

Two theoretical formulas were developed to calculate the data rate: one by ***Nyquist for a noiseless channel, another by Shannon for a noisy channel.***

Noiseless Channel: Nyquist Bit Rate

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

$$\boxed{\textbf{BitRate = 2 x bandwidth x } \log_2 L}$$

- In this formula, bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data, and Bit Rate is the bit rate in bits per second.

- **Example:**
  Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as,
  BitRate =2 x 3000 x $\log_2 2$ =6000 bps

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy. In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel:

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

- In this formula, bandwidth is the bandwidth of the channel, SNR is the signal-to-noise ratio, and capacity is the capacity of the channel in bits per second.
- Note that in the Shannon formula there is no indication of the signal level, which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel. In other words, the formula defines a characteristic of the channel, not the method of transmission.

➢ **Example:**

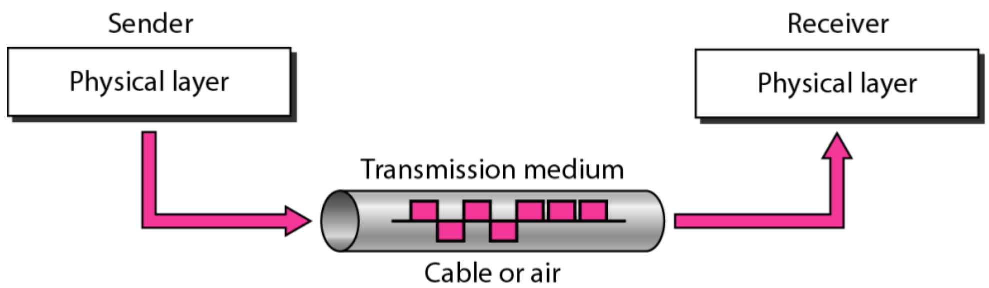
Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

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

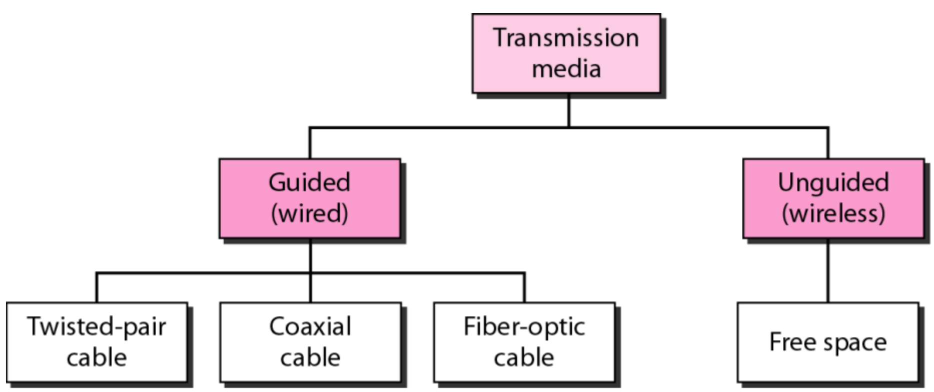
This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

TRANSMISSION MEDIA

A transmission **medium** can be broadly defined as anything that can carry information from a source to a destination.



In telecommunications, 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. Below Figure shows this taxonomy.

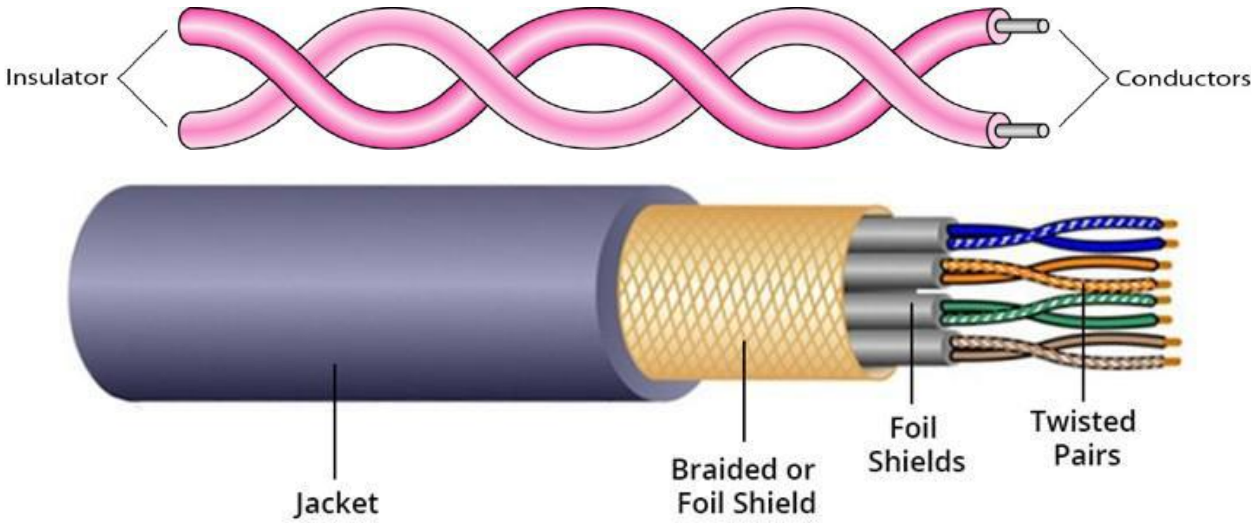


Guided Media

- 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.

1. Twisted-Pair Cable

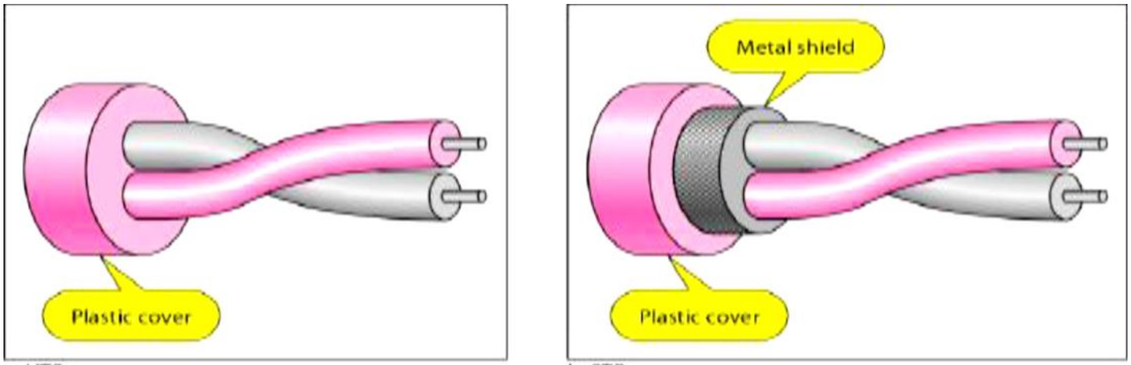
A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in below figure.



- One of the wires is used to carry signals to the receiver, and the other is used only as a 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 (e,g., one is closer and the other is farther). 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. The unwanted signals are mostly canceled out. From the above discussion, it is clear that the number of twists per unit of length (e.g., inch) has some effect on the quality of the cable.
- The most common UTP connector is RJ45 (RJ stands for registered jack)

Unshielded Versus Shielded Twisted-Pair Cable

- The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP).
- STP cable has a metal foil or braided mesh covering that encases each pair of insulated conductors. Although metal casing improves the quality of cable by preventing the penetration of noise or crosstalk, it is bulkier and more expensive.



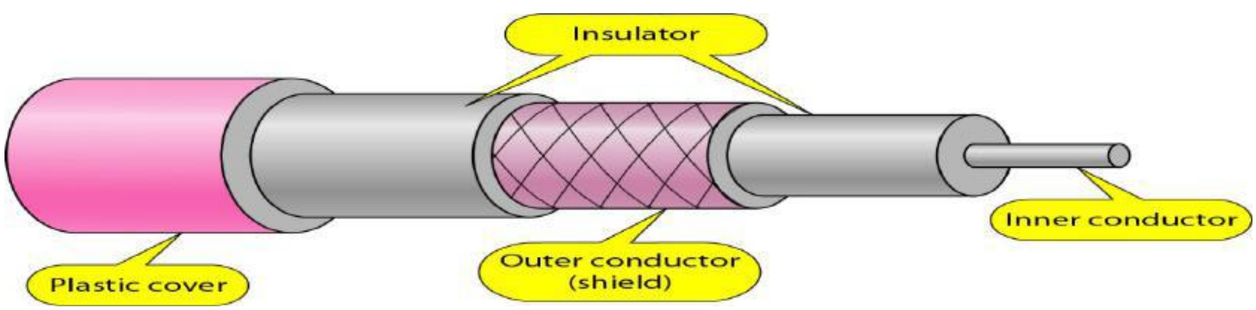
a. UTP b. STP

Applications

- Twisted-pair cables are used in telephone lines to provide voice and data channels.
- Local-area networks, such as l0Base-T and l00Base-T, also use twisted-pair cables.

2. Coaxial Cable

Coaxial cable (or *coax)* carries signals of higher frequency ranges than those in twisted pair cable, in part because the two media are constructed quite differently. Instead of having two wires, 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. The outer metallic wrapping serves both as a shield against noise and as the second conductor, which completes the circuit. This outer conductor is also enclosed in an insulating sheath, and the whole cable is protected by a plastic cover.



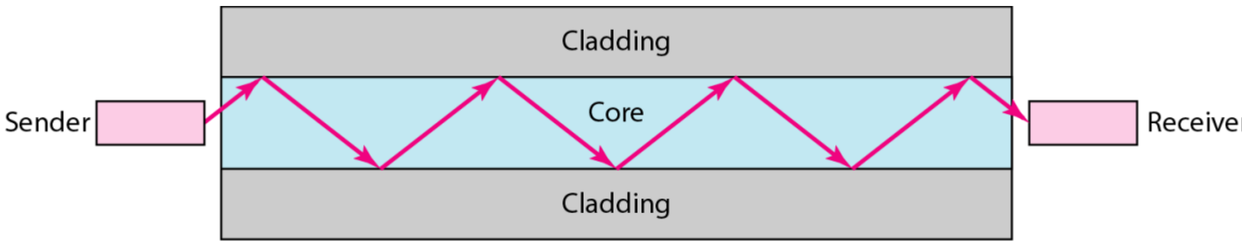
The most common type of connector used today is the Bayone-Neill-Concelman (BNC) connector.

Applications

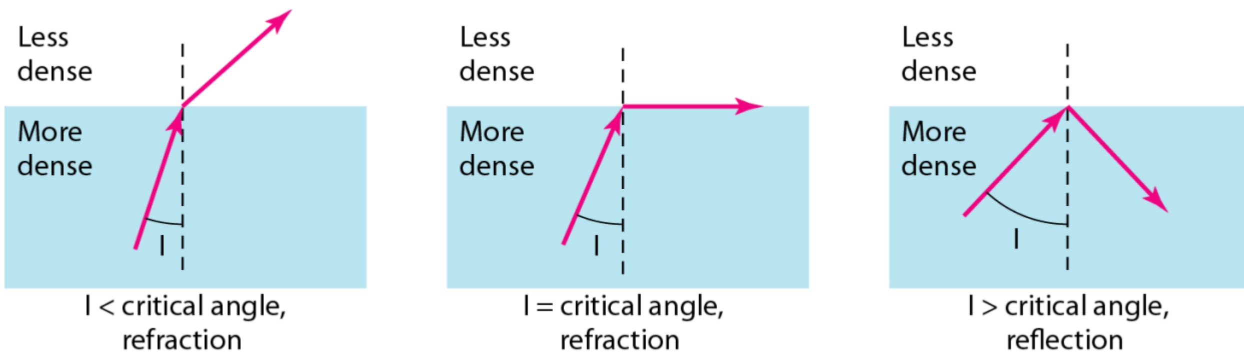
- Coaxial cable was widely used in analog telephone networks,digital telephone networks
- Cable TV networks also use coaxial cables.
- Another common application of coaxial cable is in traditional Ethernet LANs

3. Fiber-Optic Cable

- A fiber-optic cable is made of glass or plastic and transmits signals in the form of light. Light travels in a straight line as long as it is moving through a single uniform substance.
- 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.
- If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction.

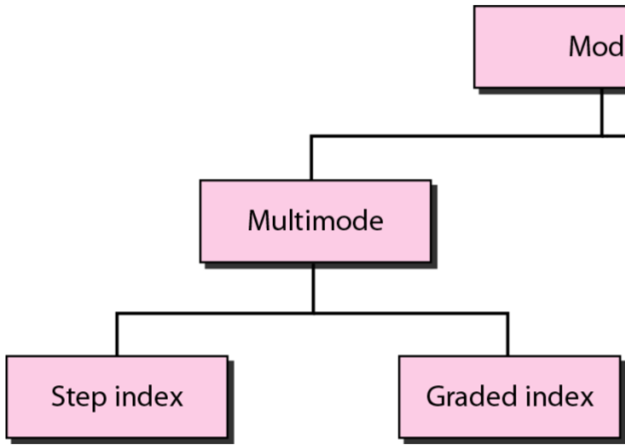


Bending of light ray



- 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 equal to the critical angle, the light bends along the interface. If the angle is greater than the critical angle, the ray reflects (makes a turn) and travels again in the denser substance. Note that the critical angle is a property of the substance, and its value differs from one substance to another.
- 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



Multimode:

- It is so named because multiple beams from a light source move through the core in different paths. How these beams move within the cable depends on the structure of the core, as shown in Figure

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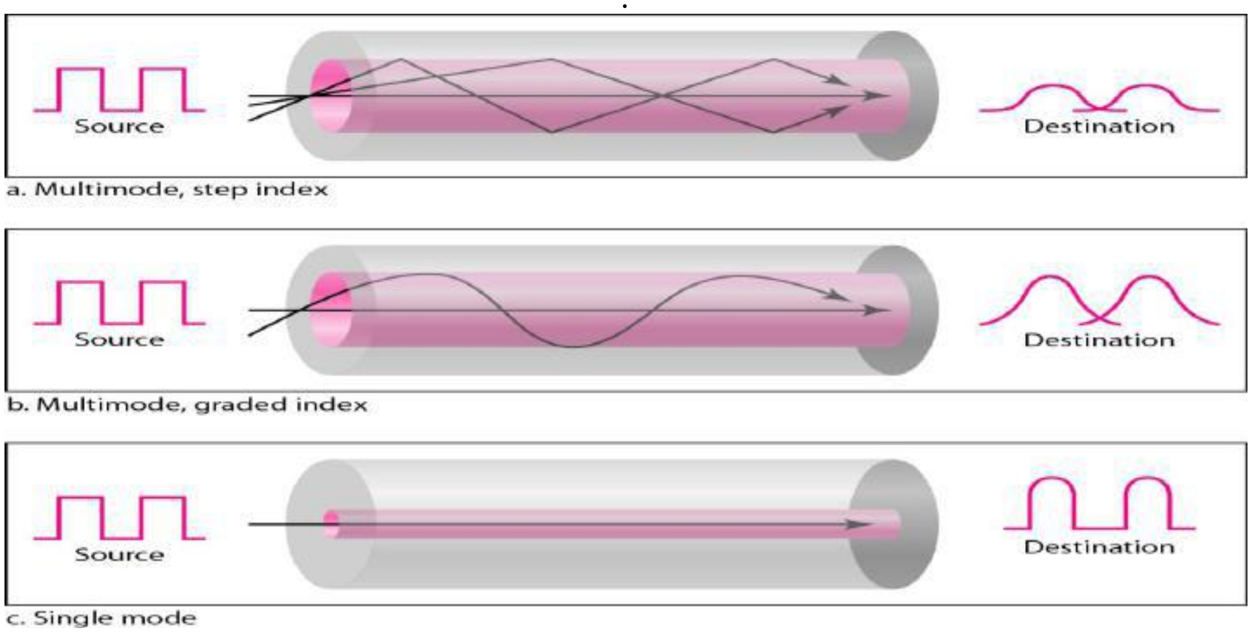


- In ***multimode step-index fiber***, the density of the core remains constant from the center to the edges. A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding. . All the light waves in step-index propagates in different speed inside the core. Hence there will be variation in delay. Consequently there will be significant change in phase shift. Therefore in step-index the distortion of the signal through the cable is more. The term *step index* refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fiber.

- In ***multimode graded-index fiber***, the density is maximum at the center of the core and the density decreases gradually from the center to the edge of the core. So all the light waves propagates moreover in similar speed inside the core. Hence the variation in delay is minimum. Consequently the phase shift changes is minimum, therefore this decreases the distortion of the signal through the cable.

Single-Mode:

- The diameter of core in single mode is very less than the diameter of core in multi-mode. The density of core in single-mode is uniform or constant throughout the core and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal. The light waves inside the core moves in straight line or horizontally parallel to the interface of core and cladding.

Connector: The **subscriber channel** (SC) **connector,** The **straight-tip** (ST) **connector**

Applications

- Fiber-optic cable is often found in backbone networks because its wide bandwidth is cost-effective..
- Some cable TV companies use a combination of optical fiber and coaxial cable, thus creating a hybrid network.
- Local-area networks such as 100Base-FX network (Fast Ethernet) and 1000Base-X also use fiber-optic cable

Advantages and Disadvantages of Optical Fiber

Advantages

Fiber-optic cable has several advantages over metallic cable (twisted pair or coaxial).

1. Higher bandwidth.
2. Less signal attenuation. Fiber-optic transmission distance is significantly greater than that of other guided media. A signal can run for 50 km without requiring regeneration. We need repeaters every 5 km for coaxial or twisted pair cable.
3. Immunity to electromagnetic interference. Electromagnetic noise cannot affect fiber-optic cables.
4. Resistance to corrosive materials. Glass is more resistant to corrosive materials than copper.
5. Light weight. Fiber-optic cables are much lighter than copper cables.
6. Greater immunity to tapping. Fiber-optic cables are more immune to tapping than copper cables. Copper cables create antenna effects that can easily be tapped.

Disadvantages

There are some disadvantages in the use of optical fiber.

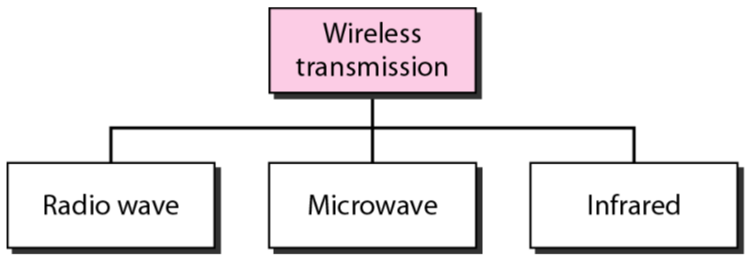
1. Installation and maintenance
2. Unidirectional light propagation. Propagation of light is unidirectional. If we need bidirectional communication, two fibers are needed.

3. Cost. The cable and the interfaces are relatively more expensive than those of other guided media. If the demand for bandwidth is not high, often the use of optical fiber cannot be justified.

Unguided Media: Wireless

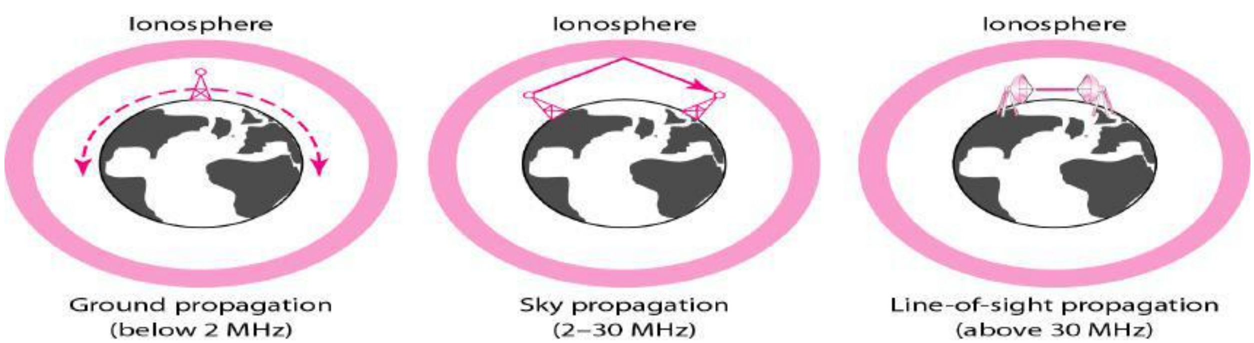
Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication. It is of 3 types:

- Radio Waves
- Microwaves
- Infrared



Unguided signals can travel from the source to destination in several ways:

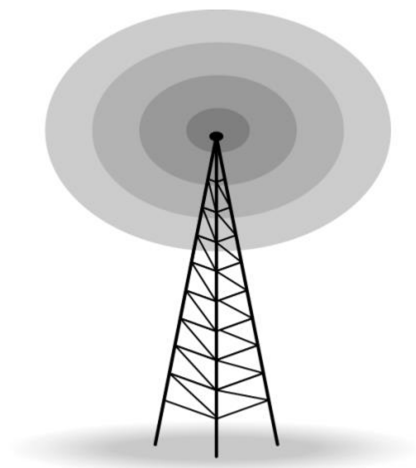
- ground propagation
- sky propagation
- line-of-sight propagation



- In **ground propagation**, radio waves travel through the lowest portion of the atmosphere, following the curvature of the earth.
- In **sky propagation**, higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere where particles exist as ions) where they are reflected back to earth.
- In **line-or-sight propagation**, very high-frequency signals are transmitted in straight lines directly from sending antenna to receiving antenna.

1. Radio Waves

- Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves. Radio waves are omni directional. 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 sends waves that can be received by any receiving antenna.
- The omnidirectional property has a disadvantage, too. The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the same frequency or band.
- *Omni directional Antenna*
  Radio waves use omnidirectional antennas that send out signals in all directions. Based on the wavelength, strength, and the purpose of transmission, we can have several types of antennas. Figure shows an omnidirectional antenna.

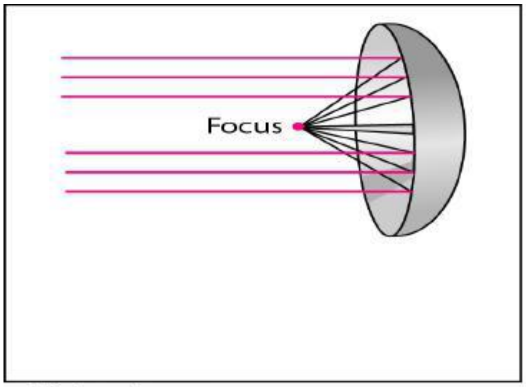


Applications

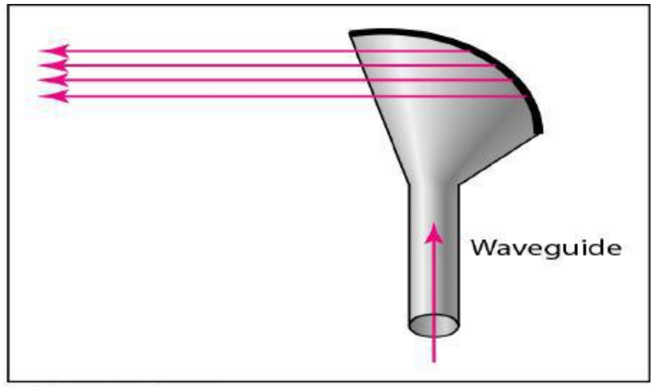
The Omni directional characteristics of radio waves make them useful for multicasting, in which there is one sender but many receivers. AM and FM radio, television, maritime radio, cordless phones, and paging are examples of multicasting.

2. Microwaves

- Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves. Microwaves are unidirectional. 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
- *Unidirectional Antenna*
  Microwaves need unidirectional antennas that send out signals in one direction. Two types of antennas are used for microwave communications: the parabolic dish and the horn antenna.



a. Dish antenna



b. Horn antenna

Applications:

Microwaves are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.

3. Infrared

- Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mm to 770nm), can be used for short-range communication. Infrared waves, having high frequencies, cannot penetrate walls. This advantageous 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 our infrared remote control, we do not interfere with the use of the remote by our neighbors. Infrared signals useless for long-range communication. In addition, we cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.
- Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation.