# Chapter Three

# Signals & Encoding
# Transmission Media

***((PHYSICAL LAYER))***

## 3.1- Signals

*Information* can be in the form of data, voice, and picture, and so on. Generally, the information usable to a person or application is not in a form that can he transmitted over a network. For example, you cannot roll up a photograph, insert it into a wire, and transmit it across town. You can transmit however, an encoded description of the photograph. Instead of sending the actual photograph, you can use an ***encoder*** to create a stream of 1's and 0's that tells the receiving device how to reconstruct the image of the photograph. But even 1's and 0's cannot be sent as such across network links. They must be further converted into a form that transmission media can accept. Transmission media work by conducting energy along a physical path.

A major concern of the physical layer is moving information in the form of electromagnetic *signals* across a transmission medium by turning the data stream of 1's and 0's into energy in the form of electromagnetic signals.

## 3.2- Analogue and Digital

Both *data* and the *signals* that represent them can take either *analogue or digital* form. Analogue refers to something that is *continuous*, while digital refers to something that is *discrete*.

Both analogue and digital signals can be of two forms: *periodic and aperiodic* (nonperiodic).

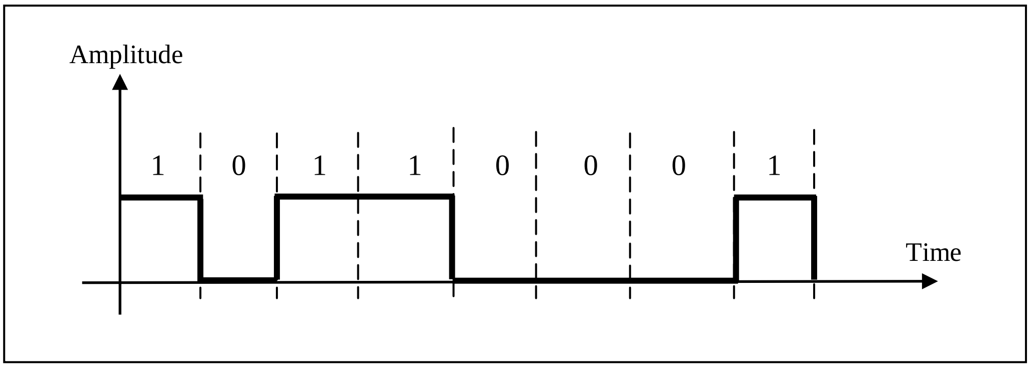
### 3.2.1- Analogue Signals

The sine wave is the most fundamental form of a periodic analogue signal as Visualized as simple oscillating curve, its change over the course of a cycle is smooth and consistent, Sine waves can be fully described by three

characteristics: *amplitude, period or frequency, and phase.*
*Amplitude refers to* the height of the signal.
*Period is the* amount of time it takes a signal to complete one cycle; *frequency is the* number of cycles per second. Frequency and period are inverses of each other: ***f = 1/T*** and ***T= I / f***.
*Phase describes* the position of the waveform relative to time zero.

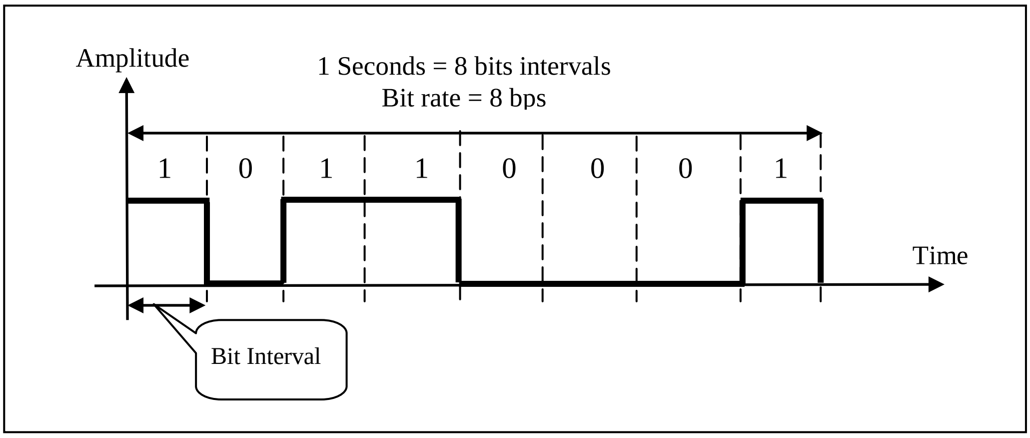
## 3.2.2- Digital Signals

In addition to being represented by an analog signal, data can also be represented by digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as a zero voltage. The three characteristics of periodic analog signals (amplitude, period, and phase) can be redefined for a periodic digital signal.




### Bit-Interval and Bit-Rate

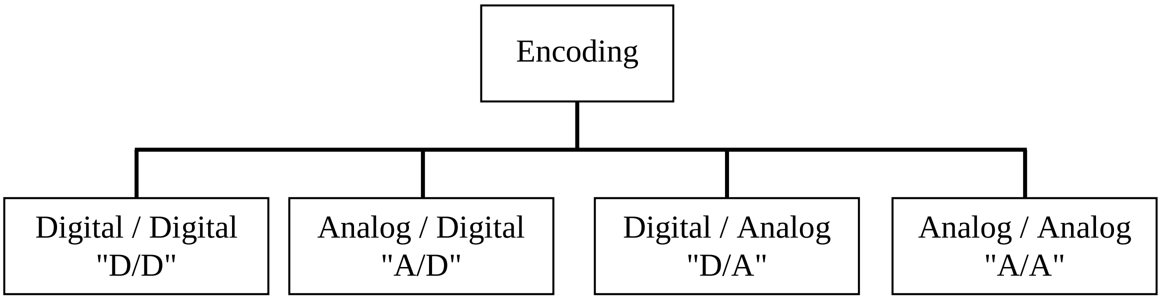
Most digital signals are aperiodic and thus period or frequency is not appropriate. Two new terms, ***bit intervals (***instead of period) and ***bit rate*** (instead of frequency) are used to describe digital signals. The bit interval is the time required to send one single bit. The bit rate is the number of bit intervals per second. This means that the bit rate is the number of bits sent in one second, usually expressed in bps (bits per second).



## 3.3- Encoding

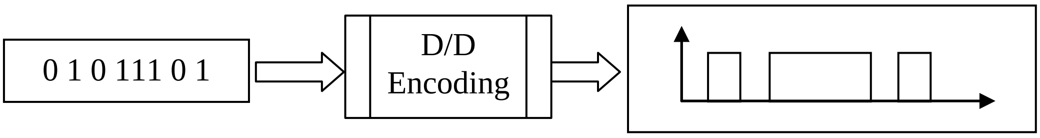
*Information* must be ***encoded*** into *signals* before it can be transported across communication media. Information is encoded depends on its original format and on the format used by the communication hardware.

A simple signal by itself dose not carry information any more than a straight line conveys words. The signal must be manipulated so that it contains identifiable changes that are recognizable to the sender and receiver as representing the information intended. Information can be of two types, digital or analog, and signals can be of two types, also digital or analog. Therefore, *four* types of encoding are possible as shown in the figure below.

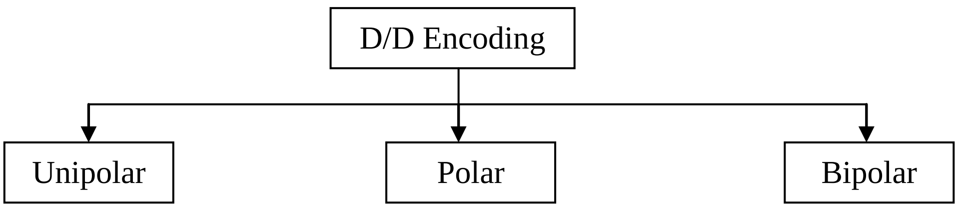



### 3.3.1- Digital-to-Digital Encoding

Digital-to-digital encoding is the representation of digital information by a digital signal. For example, in transmitting data from the computer to the printer, both the original data and the transmitted data are digital. The binary 1's and 0's generated by a computer are translated into a sequence of voltage pulses that can propagate over a wire as shown in following figure;

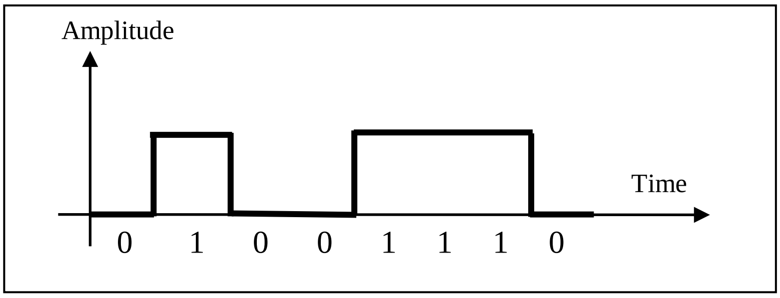



D/D encoding can be categorized into three main types as shown below:



## (a)- Unipolar

Is a very simple and primitive. One voltage level stands for binary 0, and another level stands for binary 1. The polarity of a pulse refers to whether it is positive or negative. Only one of the two states is encoded, usually the 1. The other state (the 0) is represented by zero voltage or an idle line.




## Disadvantages of Unipolar

### 1- DC Component (Direct Current)

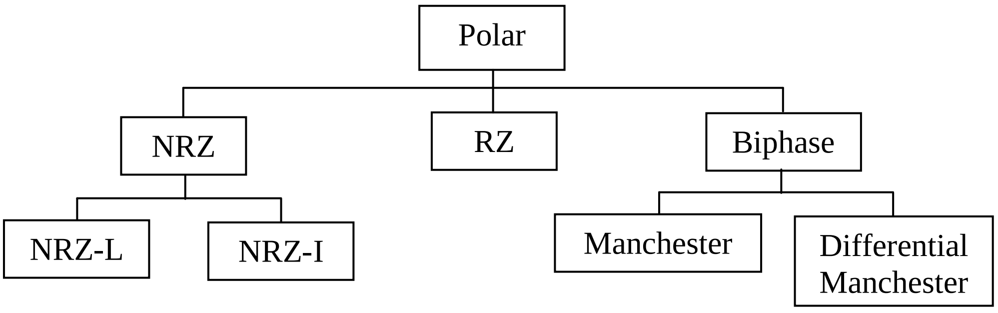
The average amplitude of the unipolar signal is non-zero that is it is a component with zero frequency. This makes it unable to travel through microwaves or transformers.

### 2- Synchronization

When the signal is unvarying, the receiver can not determine the beginning and ending of each bit. Therefore a Synchronization problem can occur wherever the data stream includes a long uninterrupted series of 1's or 0's.

## (b)- Polar

Uses two voltage levels, one positive and one negative of amplitudes this reduces the average level on the line and eliminates the DC component problem of unipolar. The most popular polar encoding types are shown in figure below:



## Types of Polar

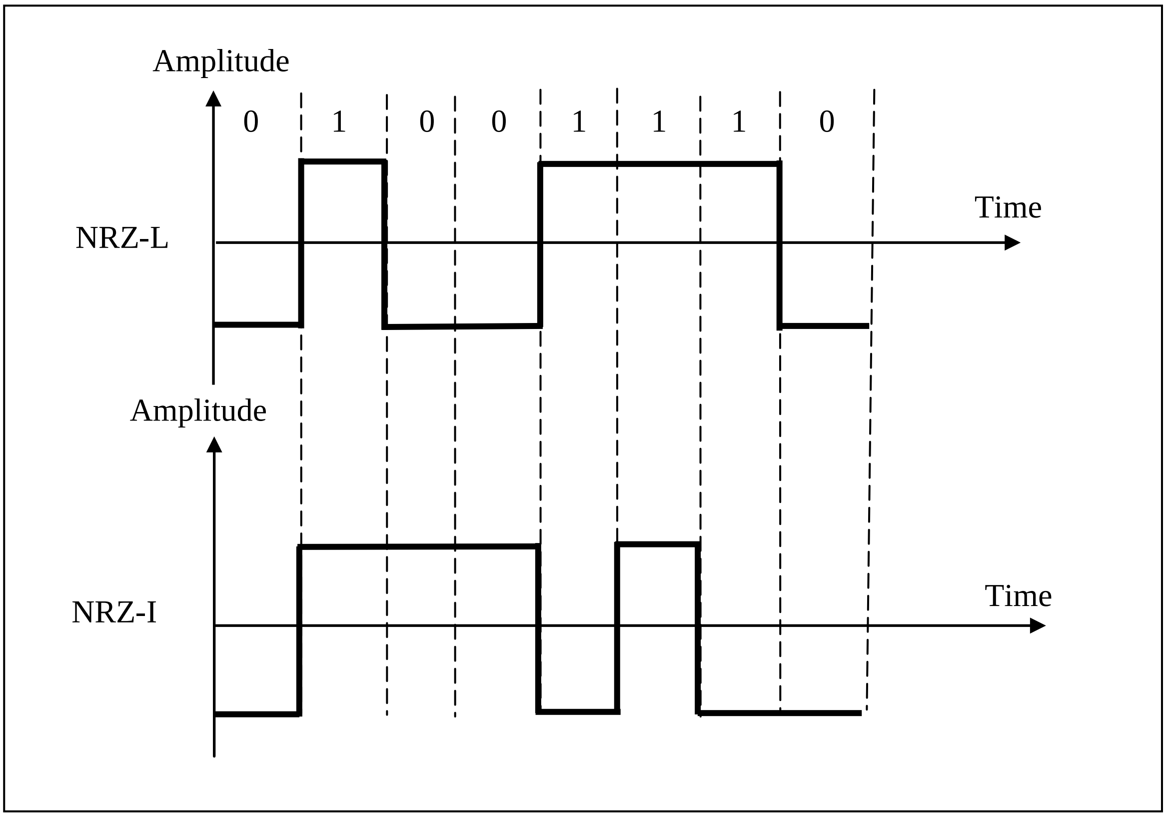
### I- Non-Return to Zero (NRZ)

In NRZ, the level of the signal is always either positive or negative. If the line is idle it means no transmission is occurring at all. The two most popular methods of NRZ are:

- **NRZ-L**
  The level of the signal is dependent upon the state of the bit (0 negative, 1 positive).

- **NRZ-I**
  The signal is inverted if a 1 is encountered (0 no change, 1 invert).

The *advantage* of NRZ-I over NRZ-L is that because the signal changes every time a 1 bit is encountered; it provides some synchronization. A string of 0's can still cause a problem of synchronization.

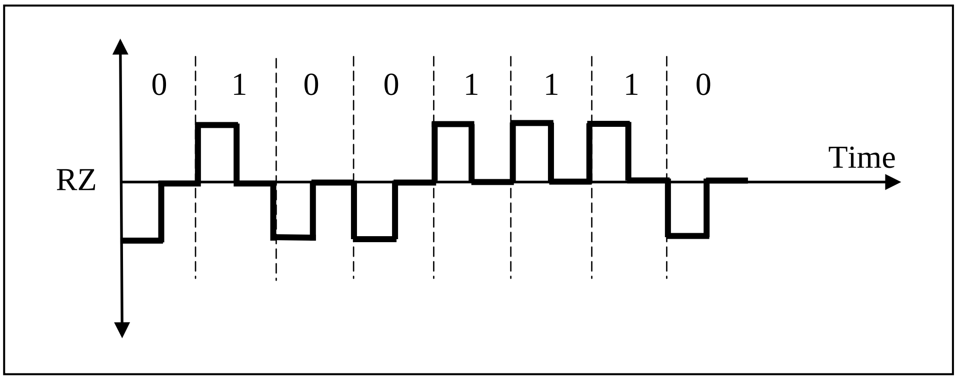



 Dr. Eng. M. S. Mahmoud

**II- Return to Zero (RZ)**

The RZ encoding uses three values: positive, negative, and zero to assure synchronization for both 0's and 1's. In RZ, the signal change not between bits but during each bit.

.



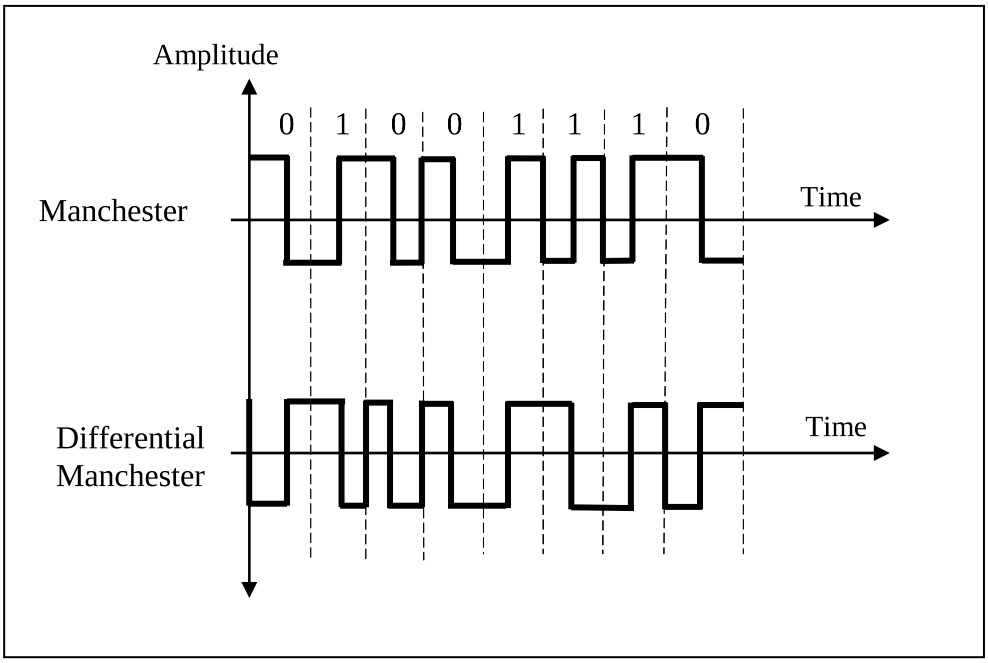

The main *disadvantage* of RZ encoding is that it requires two signal changes to encode one bit and therefore requires more bandwidth.

**III- Biphase**

Biphase is the best existing solution for the synchronization problem. The signal changes at the middle of the bit interval but dose not return to zero. Instead, it continues to the opposite pole. As in RZ these mid interval transitions allow for synchronization. There are two main types of biphase encoding, these are:

- **Manchester Biphase**
  Uses the inversion at the middle of each bit interval for both synchronization and bit representation. A *negative to positive* transition represents binary **1** and *positive to negative* transition represent binary **0**. By using a single transition for a dual purpose, Manchester achieves the same level of synchronization as RZ but with only two levels of amplitude.

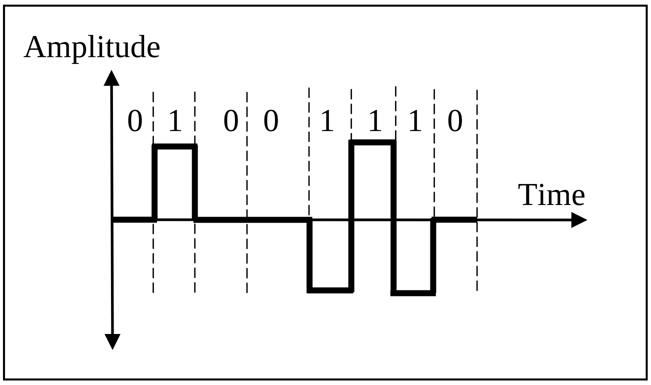
- **Differential Manchester Biphase**
  The inversion at the middle of the bit interval is used for synchronization, but the present or absence of an additional transition at the beginning of the interval is used to identify the bit. A *transition* means binary **0** and *no transition* means binary **1**. Differential Manchester requires two signal changes to represent binary 0 and only one to represent binary 1.




**(c)- <u>Bipolar</u>**

Bipolar encoding uses three voltage level (positive, negative, and zero). The zero level is to represent binary 0. Positive and negative voltages represent alternating 1's. If the first 1 bit is represented by the positive amplitude, the second will be represented by the negative amplitude, the third by positive, and so on. This alternation occurs even when the 1 bit are not consecutive.

Three types of bipolar encoding are in popular use: AMI, B8ZS, and H0B3.
The AMI is the simplest type of bipolar. In AMI, zero voltage represents binary 0. Binary 1's are represented by alternative positive and negative voltages as shown below.

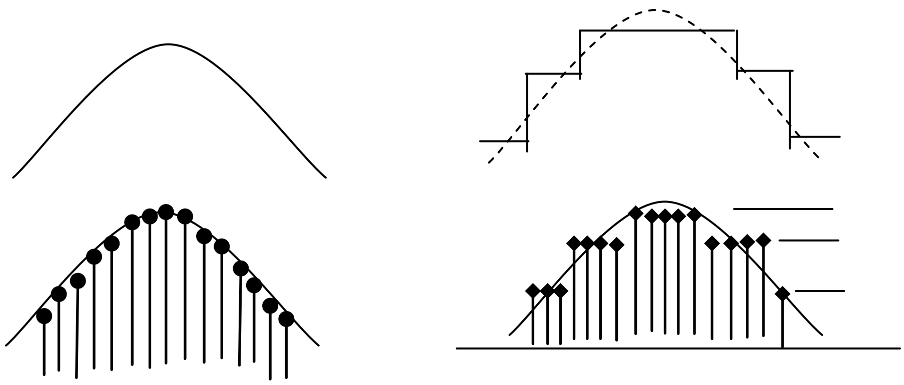


The other bipolar types have been developed to solve the problem of synchronizing sequential 0's.

## 3.3.2- **Analog-to-Digital Encoding**

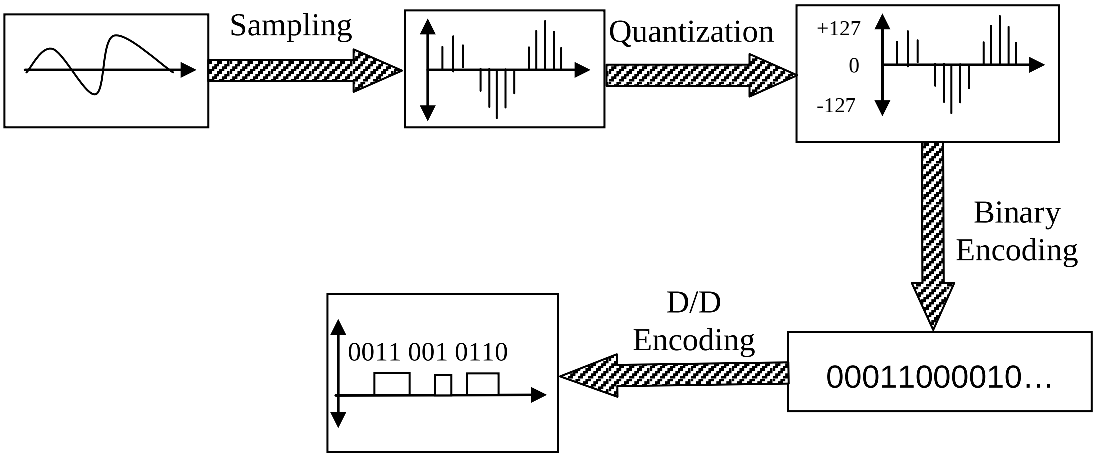
Analog information (images, speech, movies, etc.) are physically represented as analog signals. That is, a time-continuous and amplitude-continuous which need a potentially infinite number of values. Manipulating any analog information using a computer need to convert its analog representation which is not suitable to be stored in a digital device into a digital signal which more suitable to be manipulated by digital devices .

The figure below illustrates how analog signal enter the digital world by means of time discretization (Sampling) and amplitude discretization (Quantization).



**Sampling** **Quantization**

The entire process of A/D encoding illustrated in figure below:



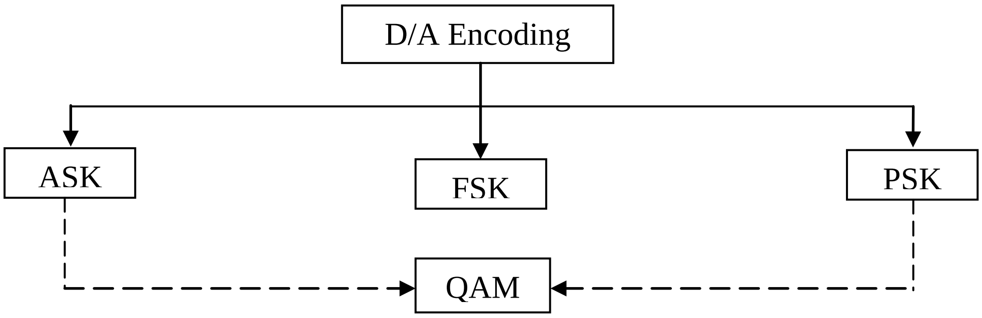
### 3.3.3- Digital-to-Analog Encoding

D/A encoding is the representation of digital information by an analog signal. Since digital communication still uses physical channels digital information must to be encoded on an analog signal that has been manipulated to look like two distinct values that correspond to binary 1 and binary 0.

Since wave is the electrical signal mostly generated by the physical devices and most of our communication system rely on it. It can be defined by three characteristics; *Amplitude, Frequency*, and *Phase*. When we vary any one of these characteristics, we create another version of that wave. So, by changing one aspect of a simple electrical signal (making the binary 1, a binary 0 or the vice versa) back and forth, we can use it to represent digital data.

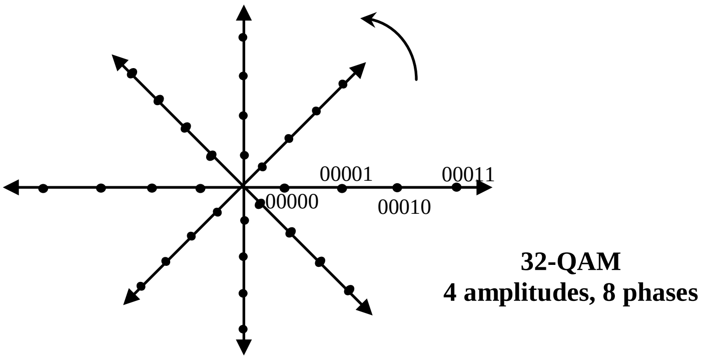
Any of the above three characteristics can be altered in this way giving us at least three mechanisms for encoding digital data in to analog signal ; *Amplitude Shift Keying* **(ASK)** *, Frequency Shift Keying* **(FSK)** *, and Phase Shift Keying* **(PSK)**. In addition to the *Quadrature Amplitude Modulation* (**QAM)** which is the most efficient of these options.

In analog transmission the sending device produces a *high-frequency* signal that acts as a basis for information signal. This base signal is called the *carrier signal* or carrier frequency. The receiving device is tuned to the frequency of the carrier signal. Digital information is then encoded onto the carrier signal by modifying one or more of its characteristics. This kind of modification is called MODULATION or SHIFTKEYING




Combining ASK and PSK gives an ***x*** variations in phase and ***y*** variations in amplitude. Producing x times ***y*** possible variations and corresponding number of bits per duration. A basic feature of QAM is that; *the number of amplitude shifts is fewer than the number of phase shift;* because amplitude changes are sensitive to noise.

Four amplitudes and eight phases (32-QAM), is the OSI recommendation.




***Bit-rate and Baud-rate***

*Bit rate* is the number of bits transmitted during one second. While *Baud rate (signaling rate)* refers to the number of signal units per second that are required to represent those bits, that is, the number of times per second the amplitude, frequency or phase of the transmission signal changes. Bit rate equal the baud rate times the number of bits represents by each signal unit. The baud rate equals the bit rate divided by the number of bits represented by each signal shift.

**Example:** Compute the bit rate for a 1000 baud 16-QAM signal

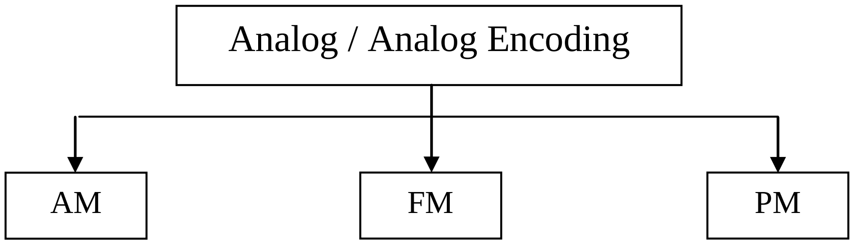
**Solution:**

16-QAM means that there is 4 bits per signal

$1000 \times 4 = 4000$ bps.

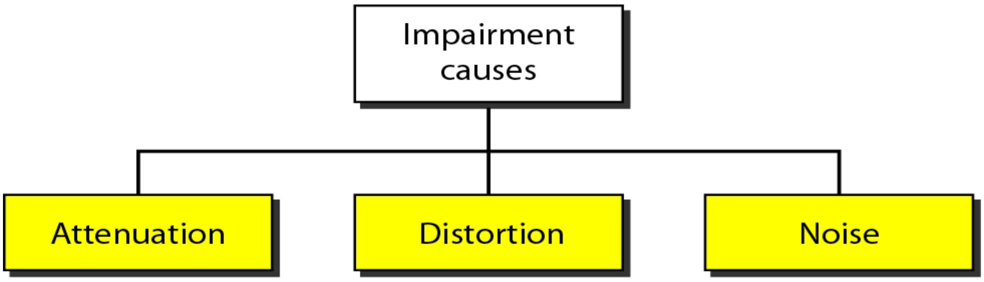
## 3.3.4- Analog-to-Analog Encoding

Analog-to-Analog encoding is the representation of analog information by an analog signal. Like *baseband modulation* (ASK, FSK, or PSK); *broadband modulation* is the operation of transmitting a signal using another signal called the *carrier* by changing one of the basic features of the carrier (amplitude, frequency, or phase); as shown in figure below:



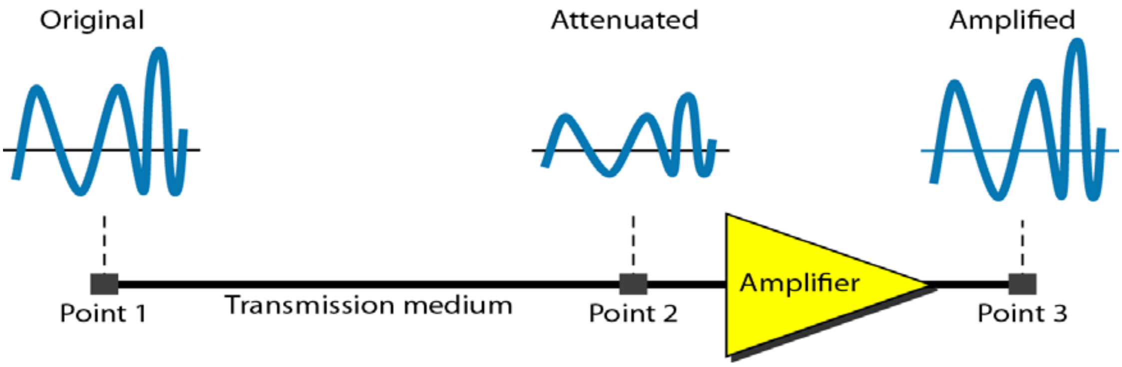
## 3.4- TRANSMISSION IMPAIRMENT

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 ***attenuation***, ***distortion***, and ***noise***




***Attenuation***

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.




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.

$$\mathbf{dB = 10\ Log_{10}\ (P_2 / P_1)}$$

**Example:**

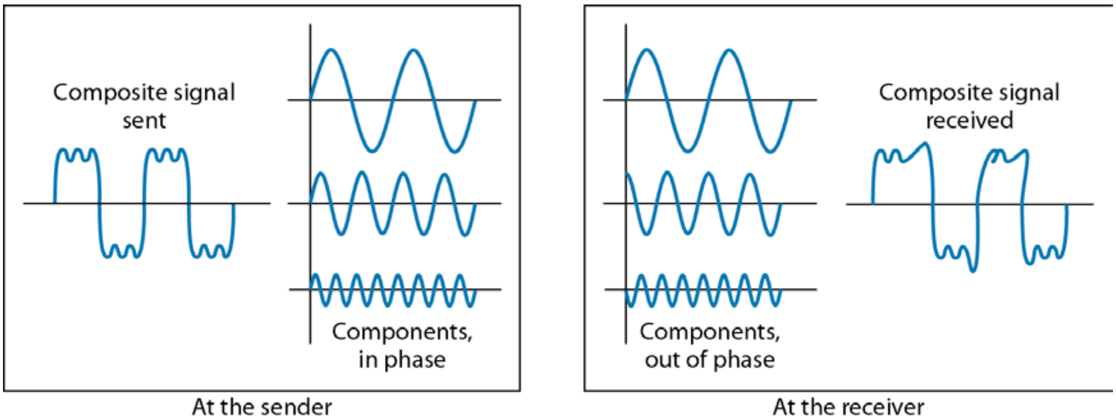
Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as follows:

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

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

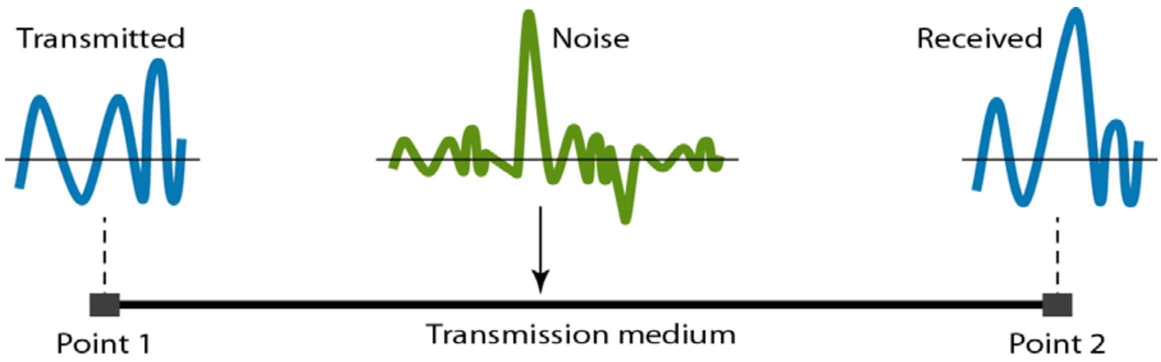
***Distortion***

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.



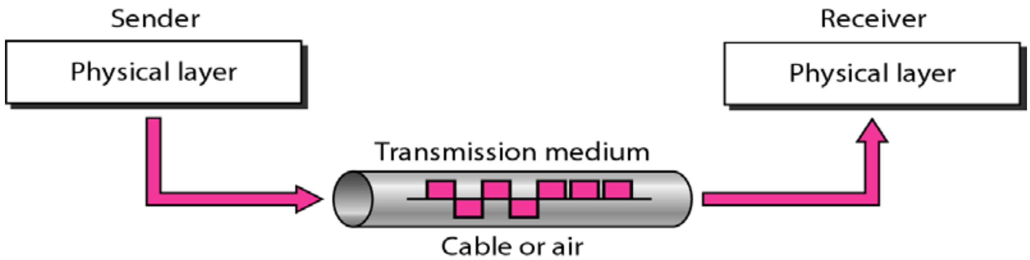

***Noise***

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. These devices act as a sending antenna, and the transmission medium acts as the receiving antenna. Crosstalk is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna. Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.




## 3.5- Transmission Media

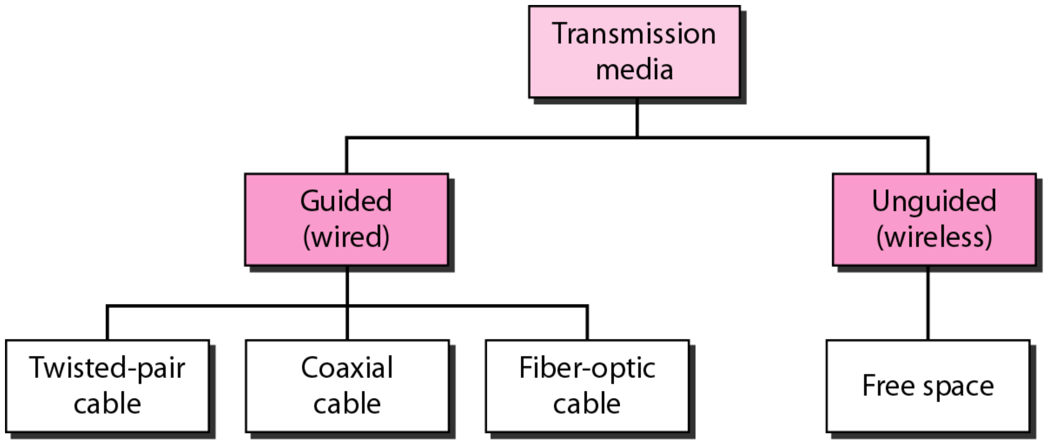
We discussed many issues related to the physical layer in the previous sections. Now we will discuss transmission media. Transmission media are actually located below the physical layer and are directly controlled by the physical layer. You could say that transmission media belong to layer zero.




A transmission medium can be broadly defined as anything that can carry information from a source to a destination. In data communications the definition of the information and the transmission medium is more specific. 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.

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, as illustrated in the figure shown below.

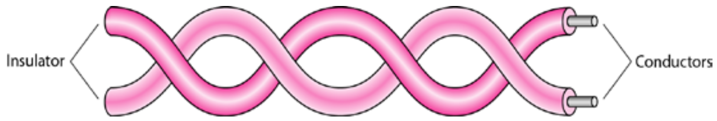


## 3.5.1- GUIDED MEDIA

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.

### *Twisted Pair*

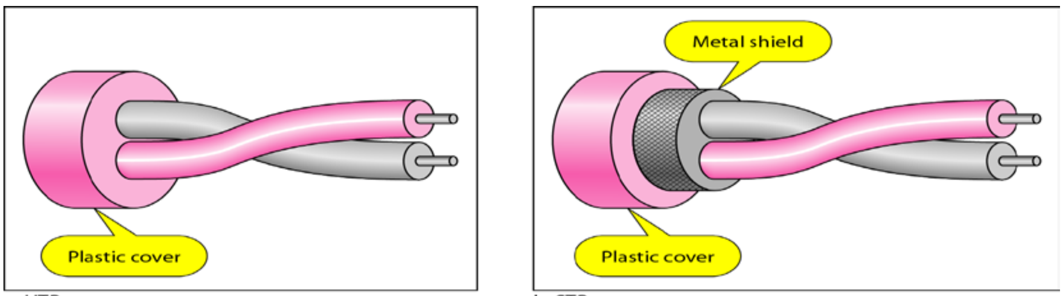
A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together, as shown in Figure below.




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. 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.

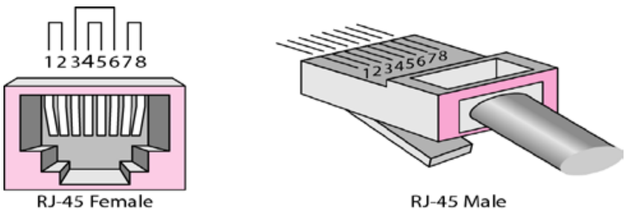
### *Unshielded Versus Shielded Twisted-Pair Cable*

The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP). IBM has also produced a version of twisted-pair cable for its use called shielded twisted-pair (STP). 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.



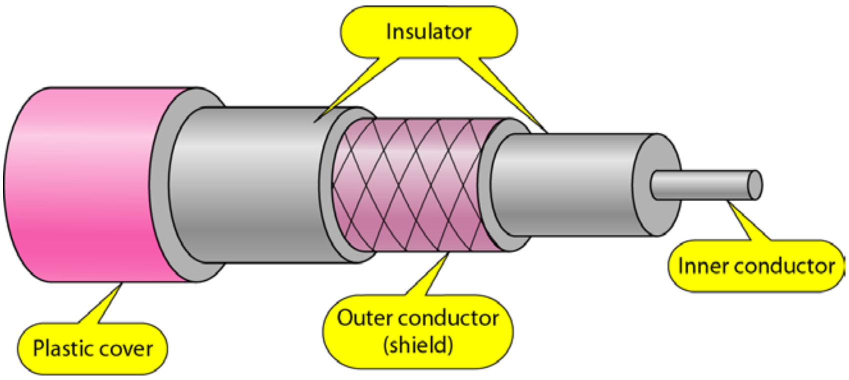

a. UTP b. STP

The most common UTP connector is RJ45 (RJ stands for registered jack), as shown below. The RJ45 is a keyed connector, meaning the connector can be inserted in only one way.

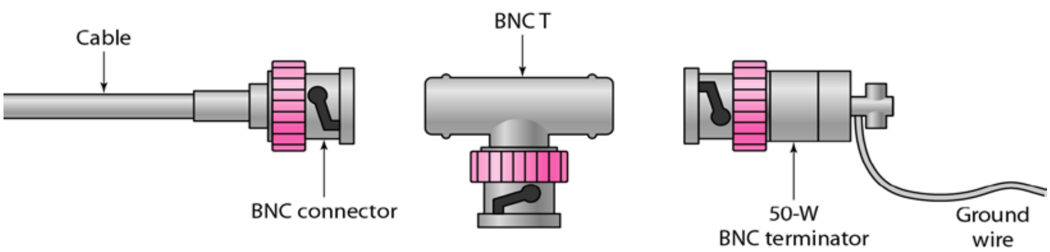



## ***Coaxial Cable***

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 as shown in figure below.

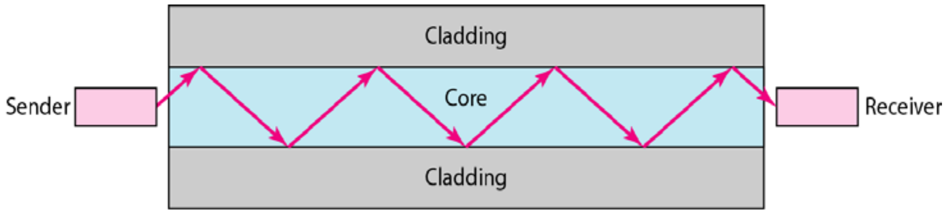



To connect coaxial cable to devices, we need coaxial connectors. The most common type of connector used today is the Bayone-Neill-Concelman (BNC), connector. The figure shown below illustrate the three popular types of these connectors: the BNC connector, the BNC T connector, and the BNC terminator.

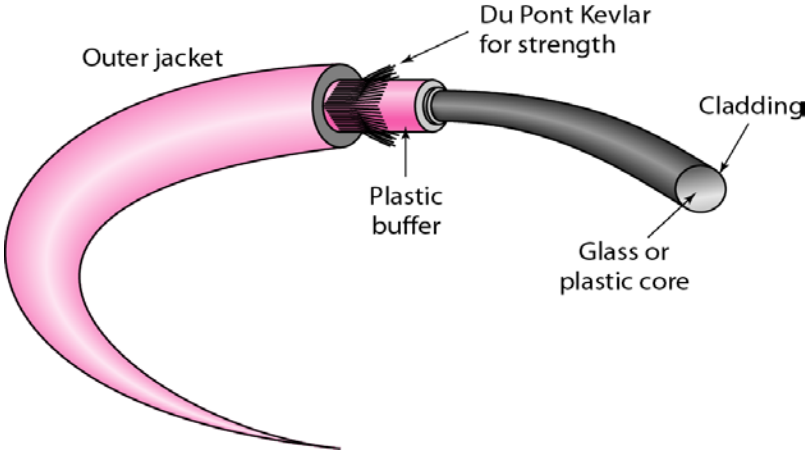


### ***Fiber-Optic Cable***

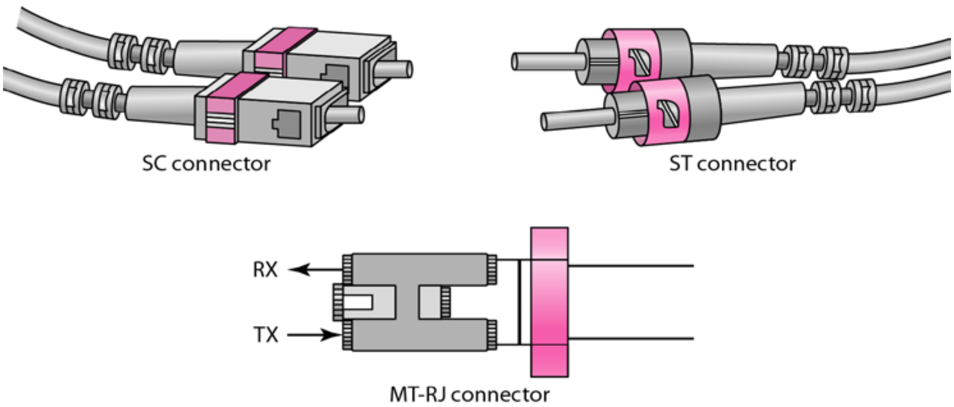
A fiber-optic cable is made of glass or plastic and transmits signals in the form of light. Optical fibers use reflection to guide light through a channel. A glass or plastic core is surrounded by a cladding of less dense glass or plastic. The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it, as shown in figure below.




Current technology supports two modes (multimode and single mode) for propagating light along optical channels, each requiring fiber with different physical characteristics.




There are three types of connectors for fiber-optic cables, as shown in Figure below.




## Advantages and Disadvantages of Optical Fiber

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

- **Higher bandwidth**: Fiber-optic cable can support dramatically higher bandwidths (and hence data rates) than either twisted-pair or coaxial cable.
- **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.
- **Immunity to electromagnetic interference**: Electromagnetic noise cannot affect fiber-optic cables.
- **Resistance to corrosive materials**: Glass is more resistant to corrosive materials than copper.
- **Light weight**: Fiber-optic cables are much lighter than copper cables.
- **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.

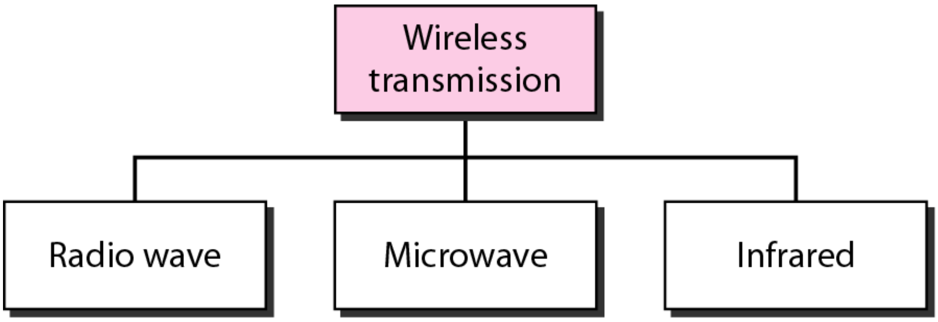
Disadvantages There are some disadvantages in the use of optical fiber.

- **Installation and maintenance:** Fiber-optic cable is a relatively new technology. Its installation and maintenance require expertise that is not yet available everywhere.
- **Unidirectional light propagation:** Propagation of light is unidirectional. If we need bidirectional communication, two fibers are needed.
- **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.

## 3.4.2- UNGUIDED MEDIA: WIRELESS

Unguided media 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.

We can divide wireless transmission into three broad groups: ***radio waves,*** **microwaves**, and ***infrared waves.***

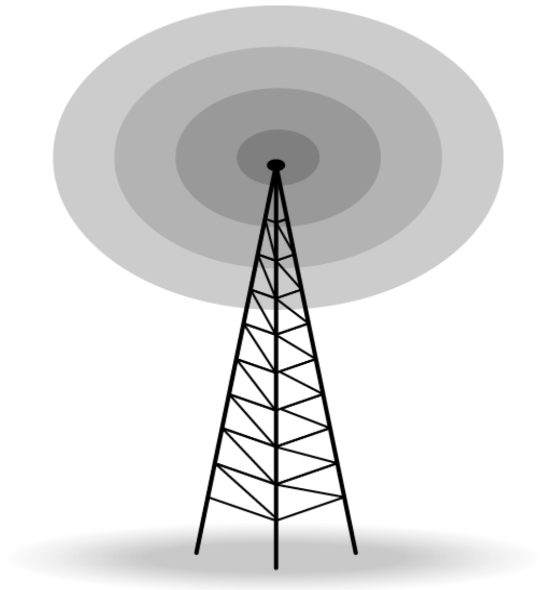



***<u>Radio Waves</u>***

Although there is no clear-cut demarcation between radio waves and microwaves, electromagnetic waves ranging in frequencies between **<u>3 kHz and 1 GHz</u>** are normally called radio waves; waves ranging in frequencies between 1 and 300 GHz are called microwaves.

However, the behavior of the waves, rather than the frequencies, is a better criterion for classification. Radio waves, for the most part, are ***Omni-directional***. When an antenna transmits radio waves, they are <u>propagated in all directions</u>. 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 Omni-directional 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.

(*Radio waves are used for multicast communications, such as radio and television, and paging systems*).

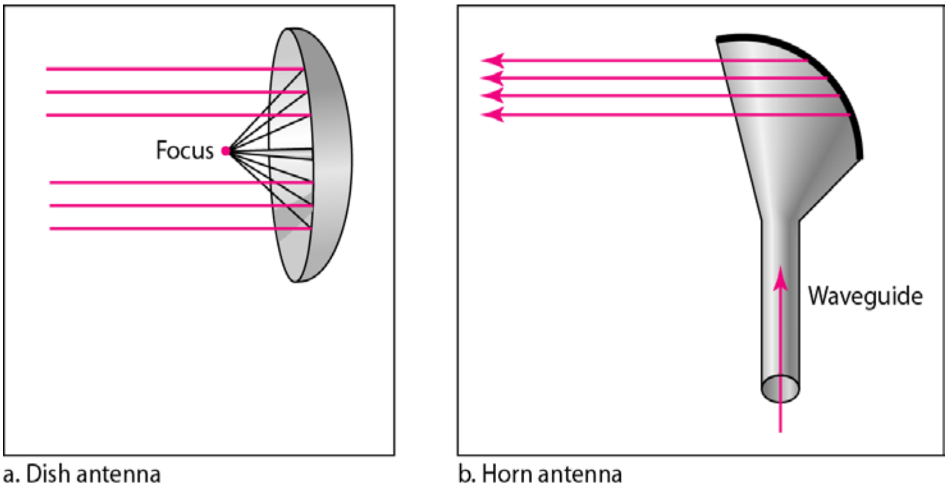


***Microwaves***

Electromagnetic waves having frequencies between **1 GHz and 300 GHz** are called microwaves.

Microwaves are ***unidirectional***. When an antenna transmits microwave waves, they can be narrowly focused. This means that 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.

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




***Infrared***

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 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. However, this same characteristic makes infrared signals useless for long-range communication.

(*Infrared signals can be used for short-range communication in a closed area using line-of-sight propagation*).