INTRODUCTION TO DATA COMMUNICATION AND NETWORKING

DATA COMMUNICATION

***Data communication* is the exchange of data between two devices via some form of transmission medium such as a wire /cable. It also includes wireless transmission.**

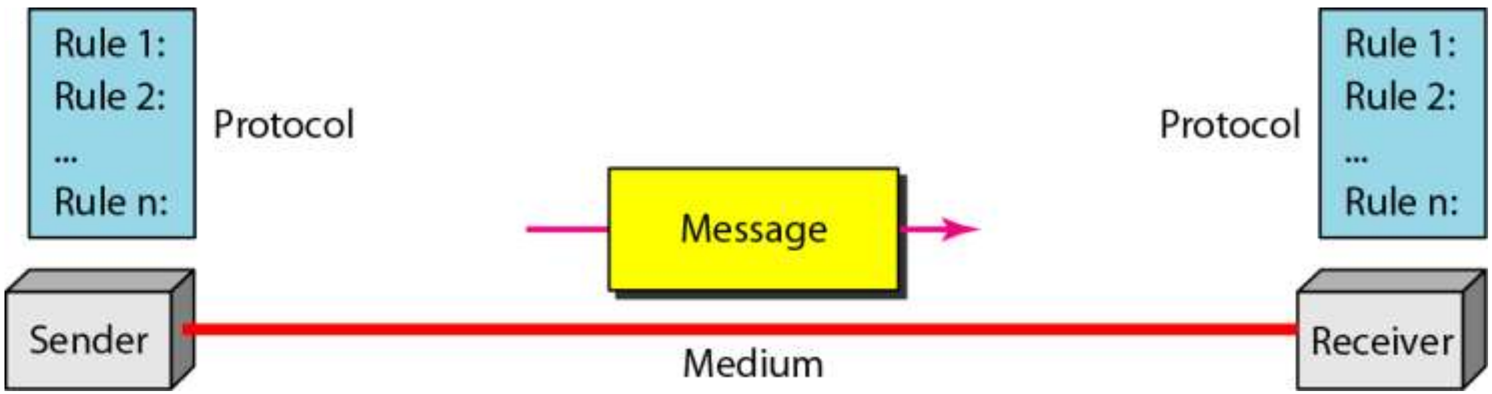


Figure 1.1 ***Components of a data communication system***

1-2 NETWORKS

A network is a set of devices (often referred to as nodes) connected by communication links. A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network. A link can be a cable, air, optical fiber, or any medium which can transport a signal carrying information.

Introduction to Networks

- A computer network consists of two or more computing devices connected to each other to share resources and information.

- The network becomes a powerful tool when computers communicate and share resources with other computers on the same network or entirely distinct networks.

Classification by Network Geography

Local area network (LAN):

- A LAN covers a relatively small area such as a classroom, school, or a single building.

- LANs are inexpensive to install and also provide higher speeds.

Classification by Network Geography

Metropolitan area network (MAN):

- A MAN spans the distance of a typical metropolitan city.
- The cost of installation and operation is higher.
- MANs use high-speed connections such as fiber optics to achieve higher speeds.

Classification by Network Geography

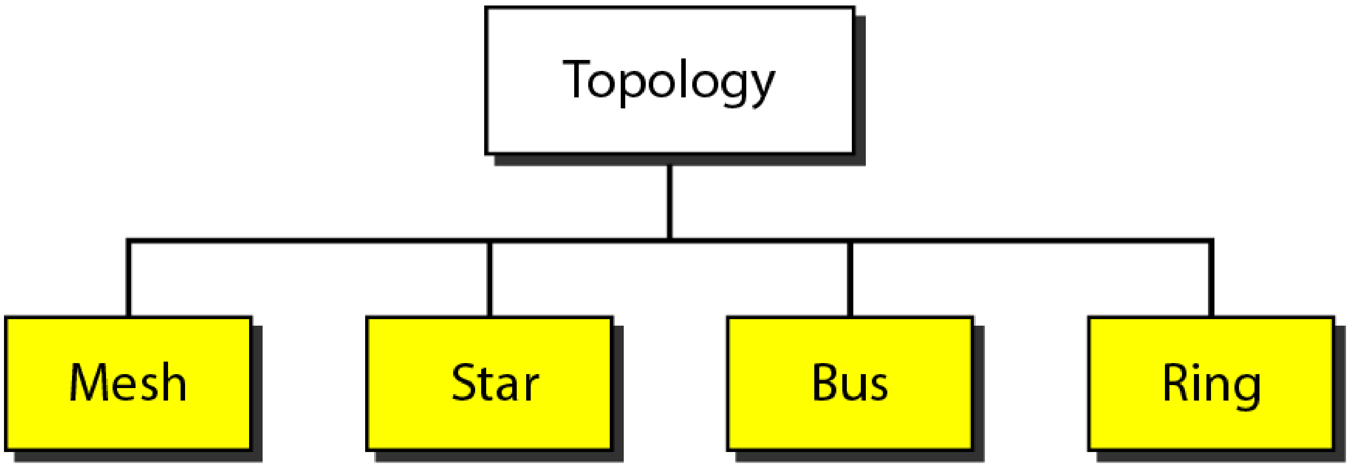
Wide area network (WAN):

- WANs span a larger area than a single city.
- These use long distance telecommunication networks for connection, thereby increasing the cost.
- The Internet is a good example of a WAN.

Topology

- The physical topology of a network refers to the configuration of cables, computers and other peripherals.
- The main types of network topologies are:
  - Bus
  - Star
  - Ring
  - mesh
  - Tree or Hybrid

Categories of topology



International Standards Organization Open Systems Interconnect (OSI) Reference Model

2-2 THE OSI MODEL

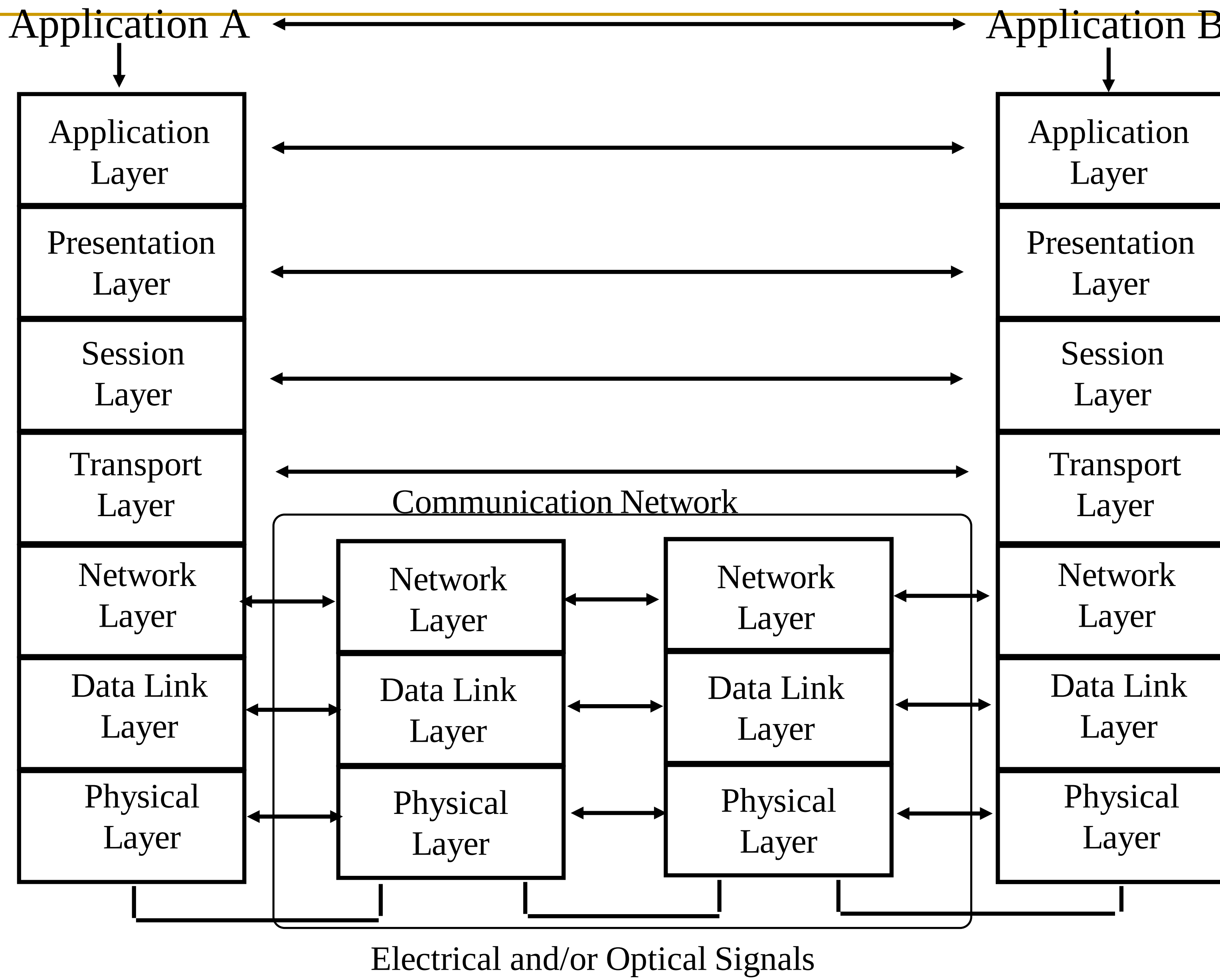
Established in 1947, the International Standards Organization (ISO) is a multinational body dedicated to worldwide agreement on international standards. An ISO standard that covers all aspects of network communications is the Open Systems Interconnection (OSI) model. It was first introduced in the late 1970s.

The OSI Model

- An ISO (International standard Organization) standard that covers all aspects of network communications is the **Open System Interconnection (OSI) model**.
- An open system is a model that allows any two different systems to communicate regardless of their underlying architecture (hardware or software).
- The OSI model is not a protocol; it is model for understanding and designing a network architecture that is flexible, robust and interoperable.

- The OSI model is a layered framework for the design of network systems that allows for communication across all types of computer systems.
- The OSI model is built of seven ordered layers:

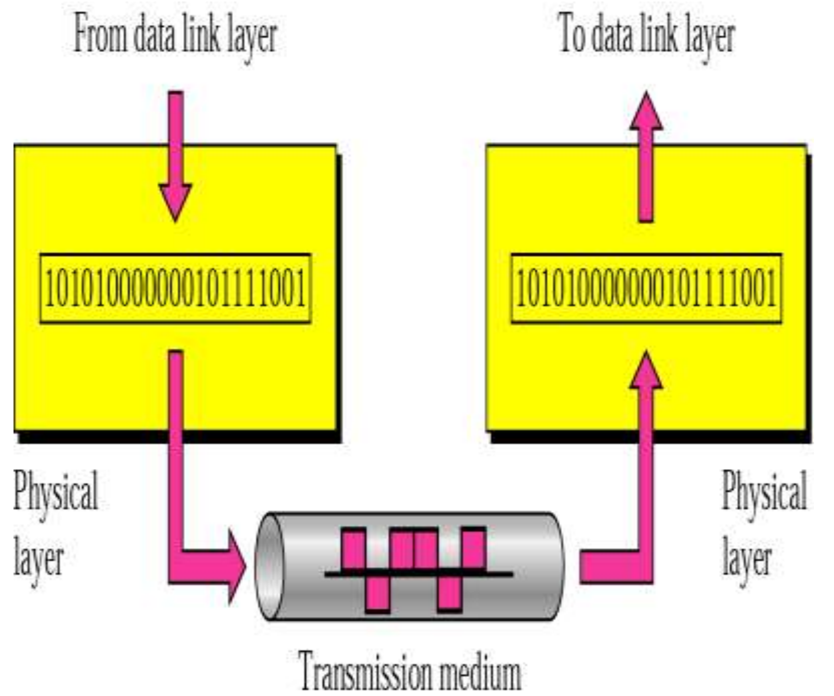
1. (layer 1) physical layer
2. (layer 2) data link
3. (layer 3) network layer
4. (layer 4) transport layer
5. (layer 5) session layer
6. (layer 6) presentation layer
7. (layer 7) application layer



Application A
Application B
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer
Application Layer
Presentation Layer
Session Layer
Transport Layer
Network Layer
Data Link Layer
Physical Layer
Communication Network
Network Layer
Data Link Layer
Physical Layer
Network Layer
Data Link Layer
Physical Layer
Electrical and/or Optical Signals

Physical Layer

- The physical layer coordinates the functions required to transmit a bit stream over a physical medium. It also defines the procedures and functions that physical devices and interfaces have to perform for transmission occur.



The physical layer is responsible for transmitting individual bits from one node to the next.

Physical layer

The physical layer is concerned with the following:

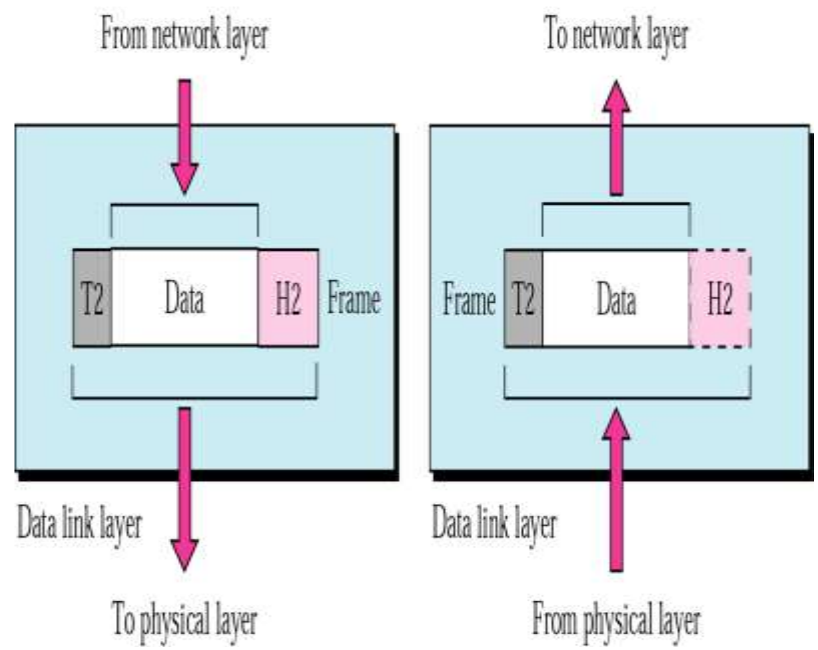
- Physical characteristics of interfaces and media: The physical layer defines the characteristics of the interface between devices and the transmission media, including its type.
- Representation of the bits: the physical layer data consist of a stream of bits without any interpretation. To be transmitted, bits must be encoded into signals –electrical or optical-. The physical layer defines the type of **encoding**.
- Data rate: The physical layer defines the transmission rate, the number of bits sent each second.

Physical Layer

- <u>Line configuration:</u> the physical layer is concerned with the connection of devices to the medium.
- <u>Physical topology</u>
- <u>Transmission Mode</u>

Data Link Layer

- The data link layer transforms the physical layer, a raw transmission facility, to a reliable link and is responsible for node-to-node delivery. It makes the physical layer appear error free to the upper layer (network layer).



The data link layer is responsible for transmitting frames from one node to the next.

Functions of the data link layer:

- Framing. The data link layer divides the stream of bits received from the network layer into data units called **frames**.

- Physical addressing. If frames are to be distributed to different systems on the network, the data link layer adds a header to the frame to define the physical address of the sender (source address) and/or receiver (destination address) of the frame.

- If the frame is intended for a system outside the sender's network, the receiver address is the address of the device that connects one network to the next.

- <u>Flow Control</u>. If the rate at which the data are absorbed by the receiver is less than the rate produced in the sender, the data link layer imposes a flow control mechanism to prevent overwhelming the receiver.
- <u>Error control</u>. The data link layer adds reliability to the physical layer by adding mechanisms to detect and retransmit damaged or lost frames. Error control is normally achieved through a trailer to the end of the frame.
- <u>Access Control</u>. When two or more devices are connected to the same link, data link layer protocols are necessary to determine which device has control over the link at any time.

Network Layer

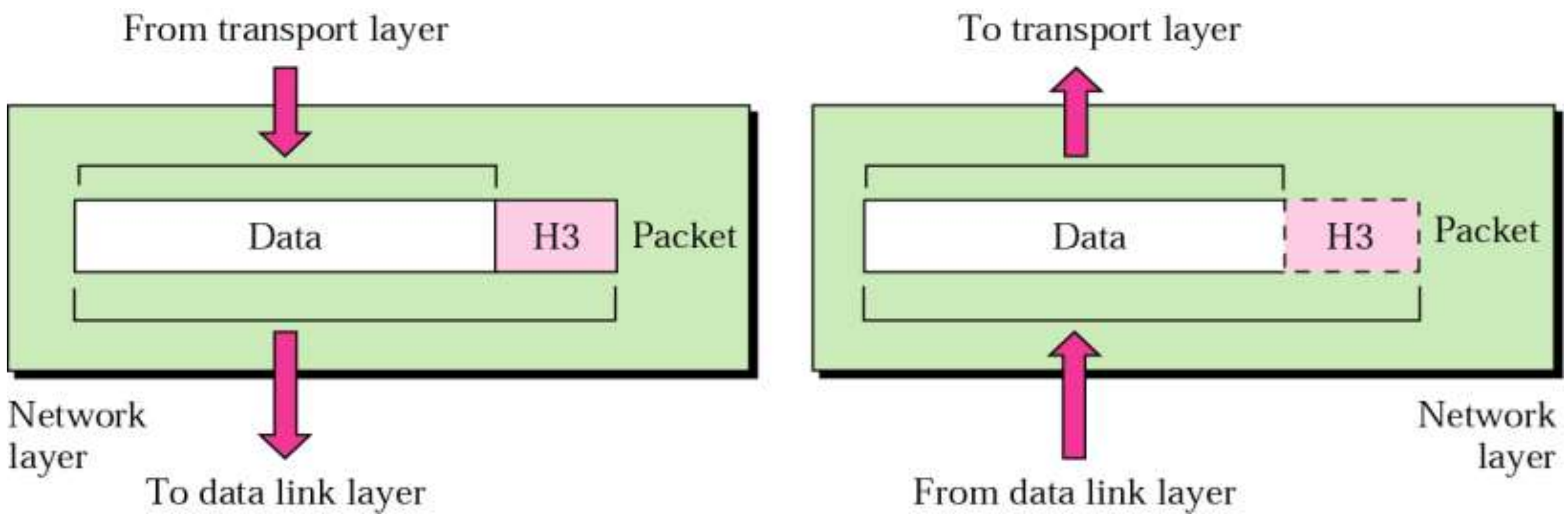
- The Network layer is responsible for the source-to-destination delivery of a packet possible across multiple networks.

- If two systems are connected to the same link, there is usually no need for a network layer. However, if the two systems are attached to different networks, there is often a need for the network layer to accomplish source-to-destination delivery.

Network Layer

Functions:

- Logical addressing.
- Routing



The network layer is responsible for the delivery of packets from the original source to the final destination.

- <u>Logical addressing</u>. The physical addressing implemented by the data link layer handles the addressing problem locally.
- The network layer adds a header to the packet coming from the upper layer, among other things, includes the <u>logical address</u> of the sender and receiver.
- Routing. When independent networks or links are connected together to create an **internetwork** (a network of networks) or a large network, the connecting devices (called routers or gateways) route or switch the packets to their final destination.

Transport Layer

- The transport layer is responsible for process-to-process delivery of the entire message.
- The network layer oversees host-to-destination delivery of individual packets, it does not recognize any relationship between those packets.
- The transport layer ensures that the whole message arrives intact and in order, overseeing both error control and flow control at the process-to-process level.

Functions of the transport layer

- Port addressing:computer often run several processes (running programs) at the same time. Process-to-process delivery means delivery from a specific process on one computer to a specific process on the other.
- The transport layer header include a type of address called port address.
- The network layer gets each packet to the correct computer; the transport layer gets the entire message to the correct process on that computer.

Functions of the transport layer

- **Segmentation and reassembly**: a message is divided into transmittable segments, each having a sequence number. These numbers enable the transport layer to reassemble the message correctly upon arrival at the destination.
- **Connection control**: The transport layer can be either connectionless or connection-oriented.
- A connectionless transport layer treats each segment as an independent packet and delivers it to the transport layer at the destination machine.
- A connection-oriented transport layer makes a connection with the transport layer at the destination machine first before delivering the packets. After all the data are transferred, the connection is terminated.

Functions of the transport layer

- **Flow control**: the transport layer performs a flow control end to end. The data link layer performs flow control across a single link.

- **Error control**: the transport layer performs error control end to end. The data link layer performs control across a single link.

- The **session layer** is the network dialog controller. It was designed to establish, maintain, and synchronize the interaction between communicating devices.

- The **presentation layer** was designed to handle the syntax and semantics of the information exchanged between the two systems. It was designed for data translation, encryption, decryption, and compression.

- The **application layer** enables the user to access the network. It provides user interfaces and support for services such electronic email, remote file access, www, and so on.

Figure 2.15 *Summary of layers*

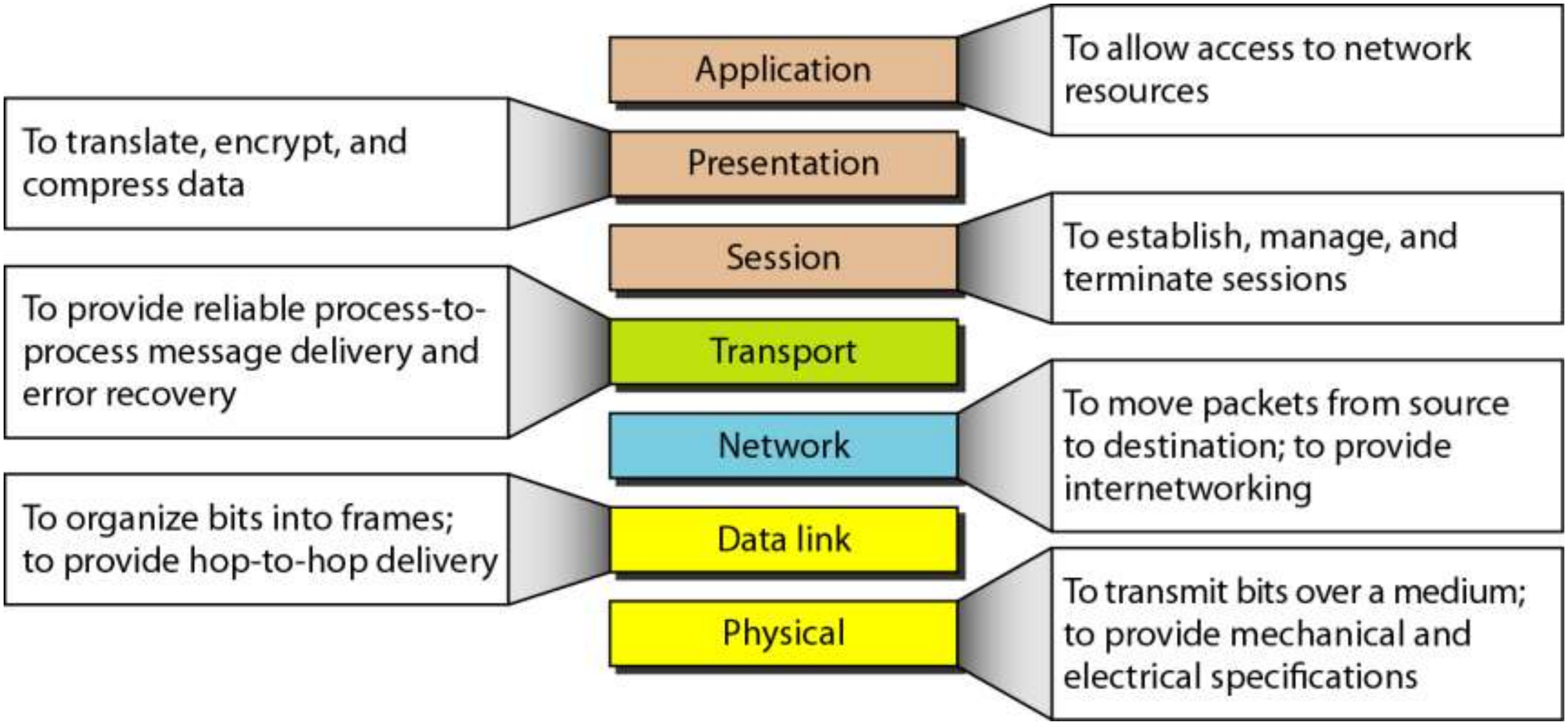
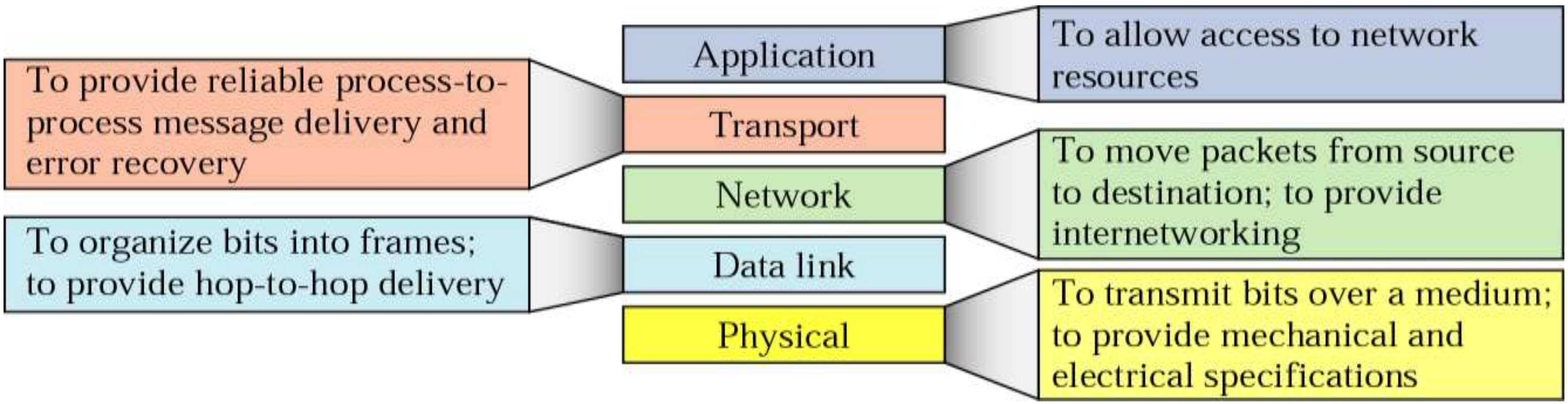


Figure 2.16 *TCP/IP model*



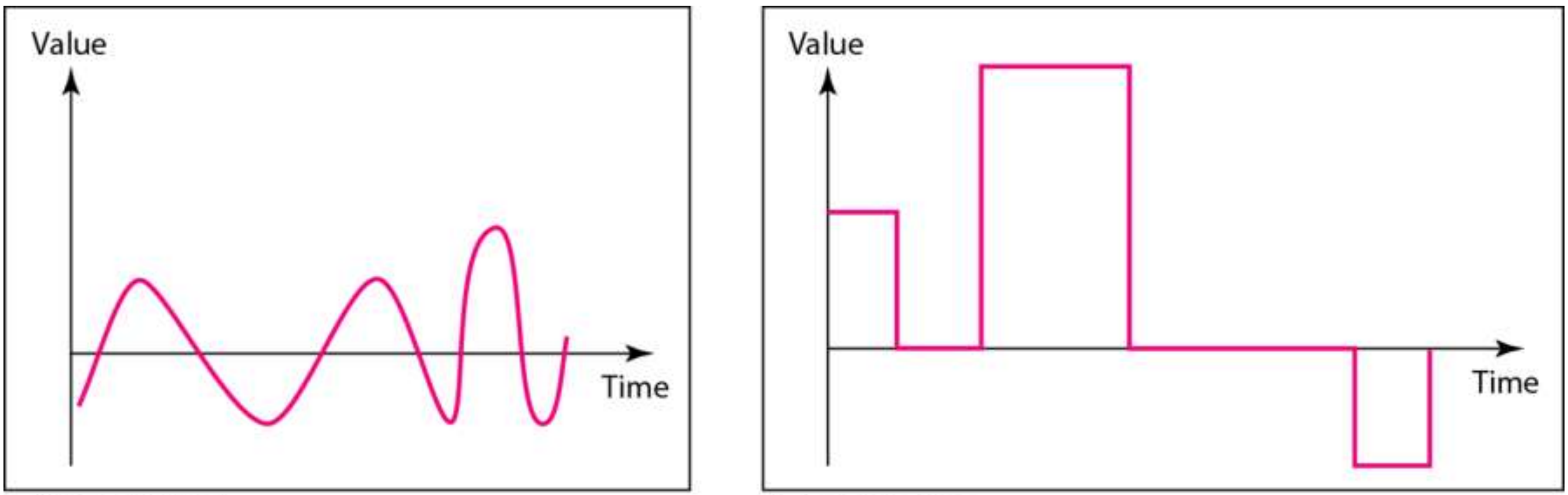
Data and Signals

To be transmitted, data must be transformed to electromagnetic signals.

Data can be analog or digital.
Analog data are continuous and take continuous values.
Digital data have discrete states and take discrete values.

Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.

Figure 3.1 *Comparison of analog and digital signals*



a. Analog signal b. Digital signal

Frequency and period are the inverse of each other.

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

Frequency is the rate of change with respect to time.

Change in a short span of time means high frequency.

Change over a long span of time means low frequency.

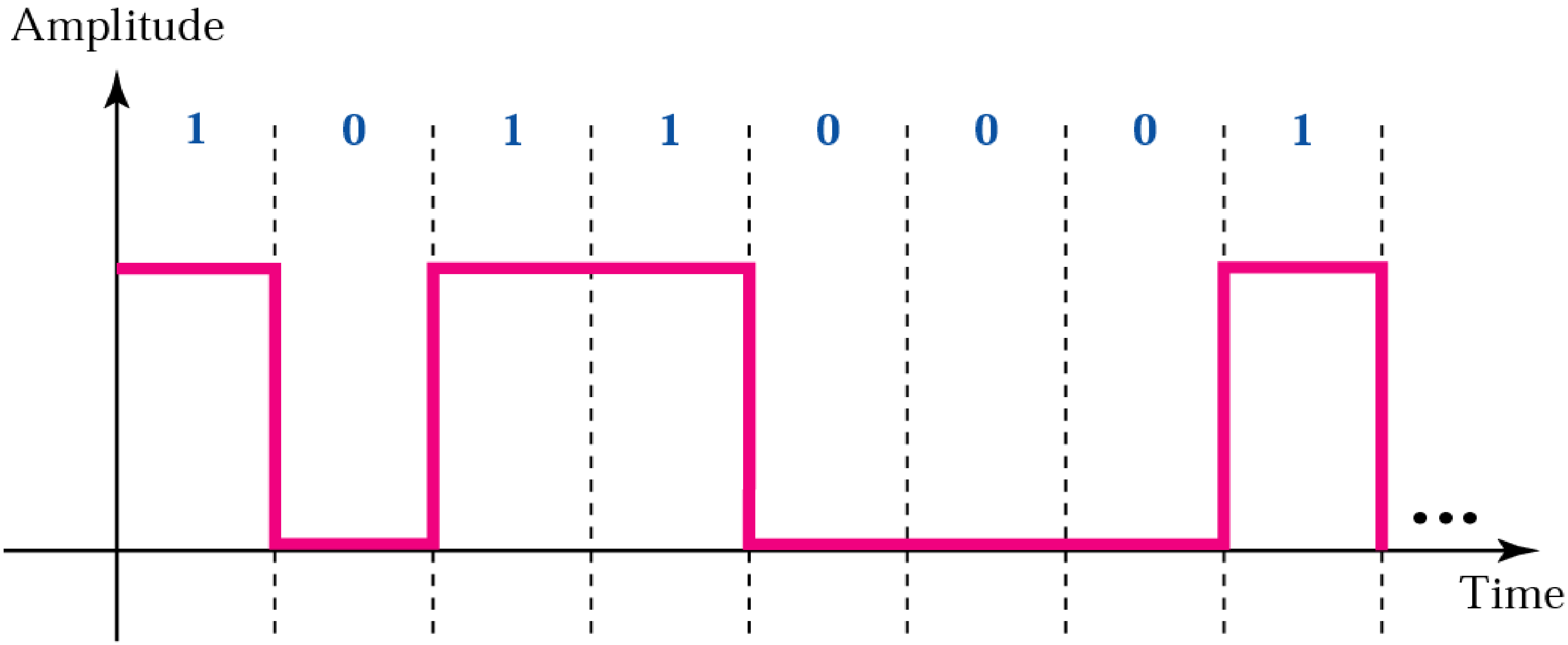
If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

Phase describes the position of the waveform relative to time 0.

3-3 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.

Digital Signals

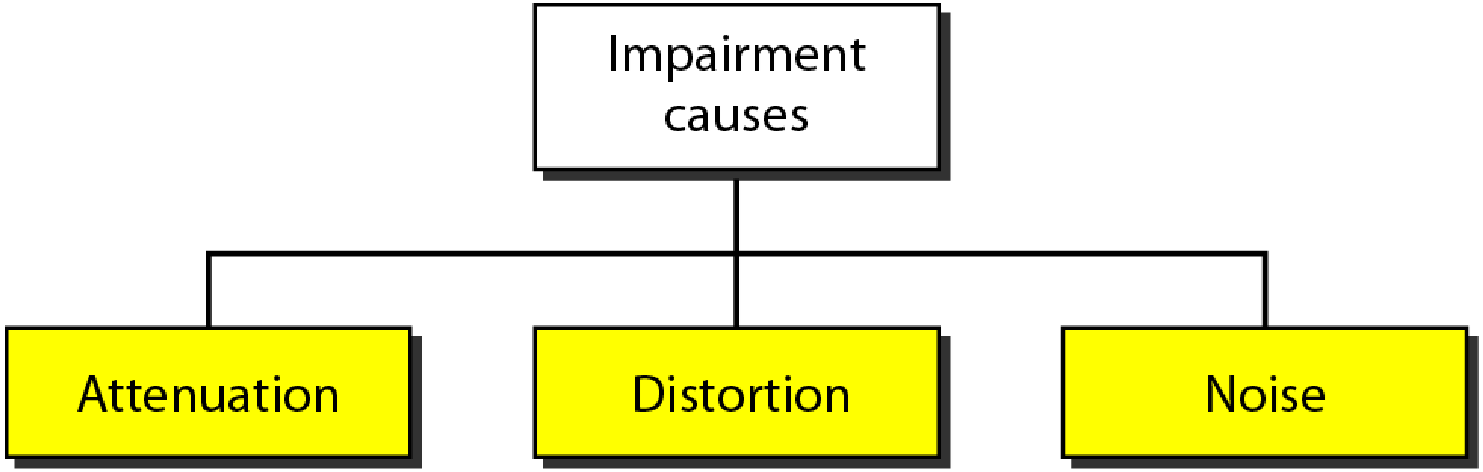


3-4 TRANSMISSION IMPAIRMENT

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
- Distortion
- Noise

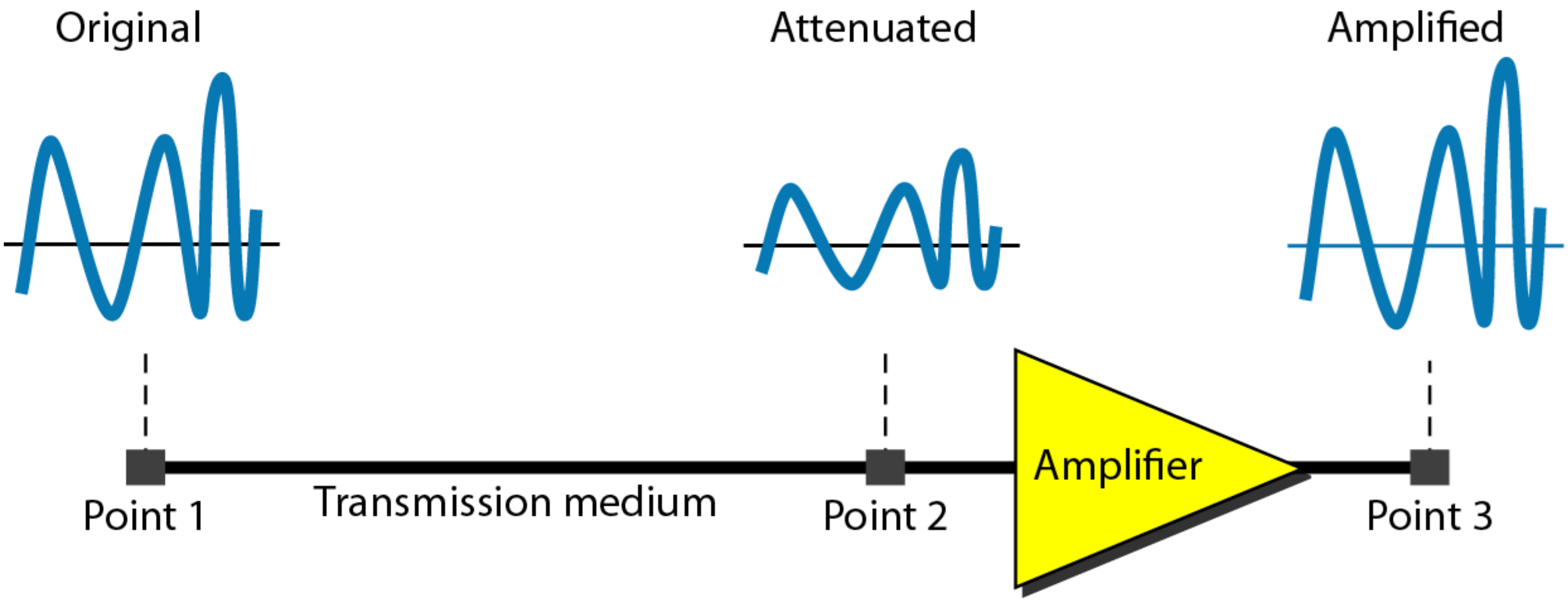
Figure 3.25 *Causes of impairment*



Attenuation

- Means loss of energy -> weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.

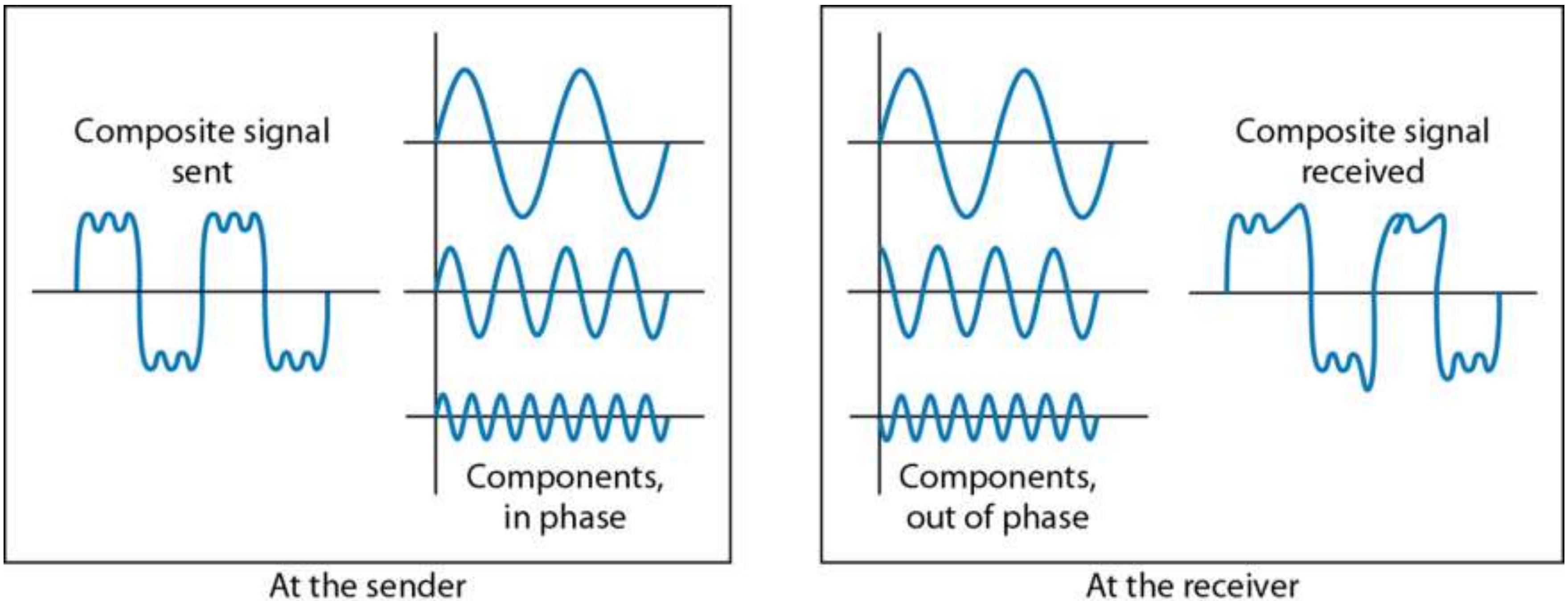
Figure 3.26
Attenuation



Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.

Figure 3.28
Distortion

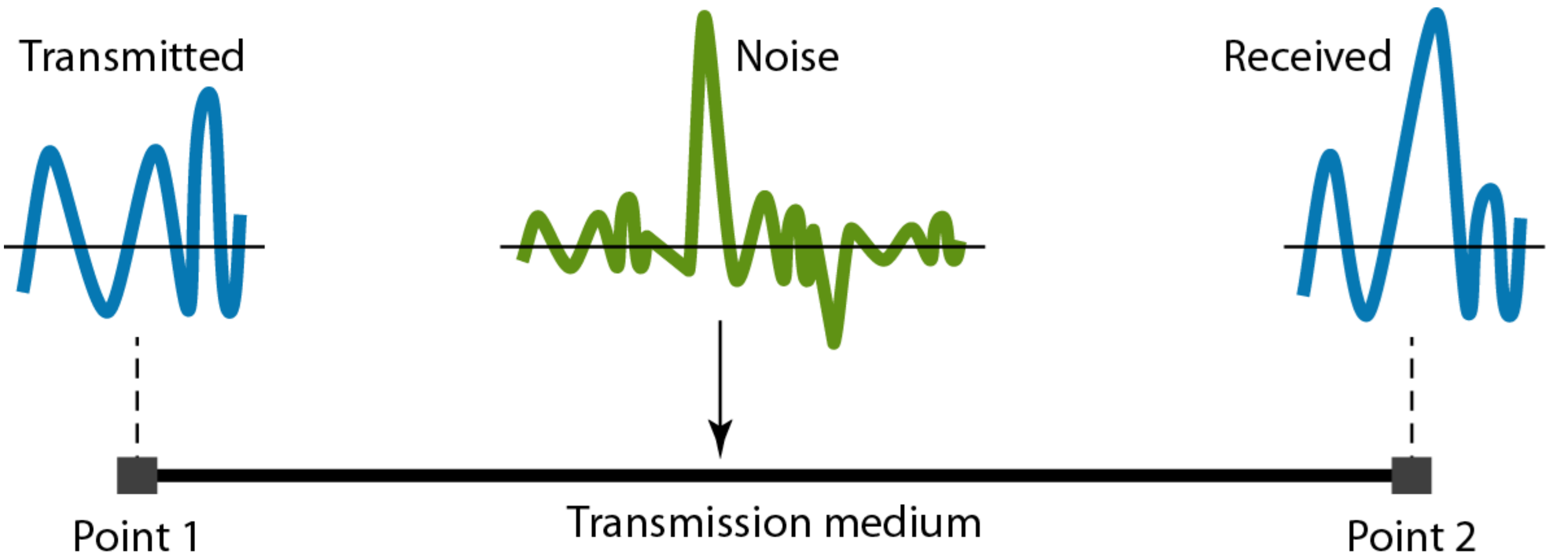


Noise

- There are different types of noise
  - Thermal - random noise of electrons in the wire creates an extra signal
  - Induced - from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
  - Crosstalk - same as above but between two wires.
  - Impulse - Spikes that result from power lines, lighning, etc.

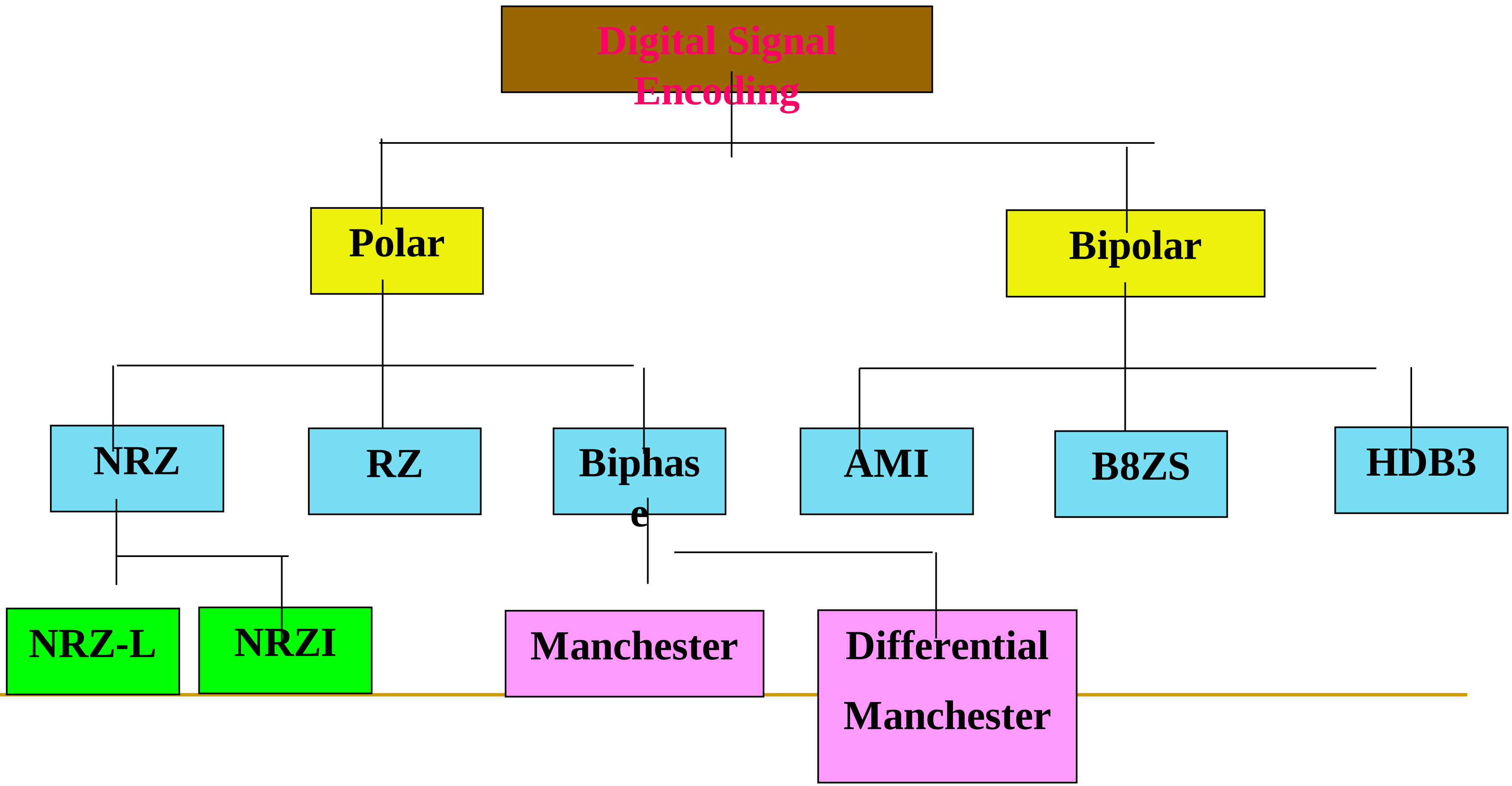
Figure 3.29

Noise



Data Encoding

Digital Data, Digital Signals



Non Return to zero (NRZ):

- The most common and easiest way to transmit digital signals is to use two different voltage levels for the two binary digits.
- Usually a negative voltage is used to represent one binary value and a positive voltage to represent the other.
- The data is encoded as the presence or absence of a signal transition at the beginning of the bit time.
- As shown in the figure below, in NRZ encoding, the signal level remains same throughout the bit-period.
- There are two encoding schemes in NRZ: NRZ-L and NRZ-I, as shown in Fig.

The **advantages** of NRZ coding are:

- Detecting a transition in presence of noise is more reliable than to compare a value to a threshold.
- NRZ codes are easy to engineer and it makes efficient use of bandwidth.
- The spectrum of the NRZ-L and NRZ-I signals are shown in Fig. It may be noted that most of the energy is concentrated between 0 and half the bit rate.
- The main limitations are the presence of a dc component and the lack of synchronization capability.
- When there is long sequence of 0’s or 1’s, the receiving side will fail to regenerate the clock and synchronization between the transmitter and receiver clocks will fail.

Figure 4.5 ***Unipolar NRZ scheme***

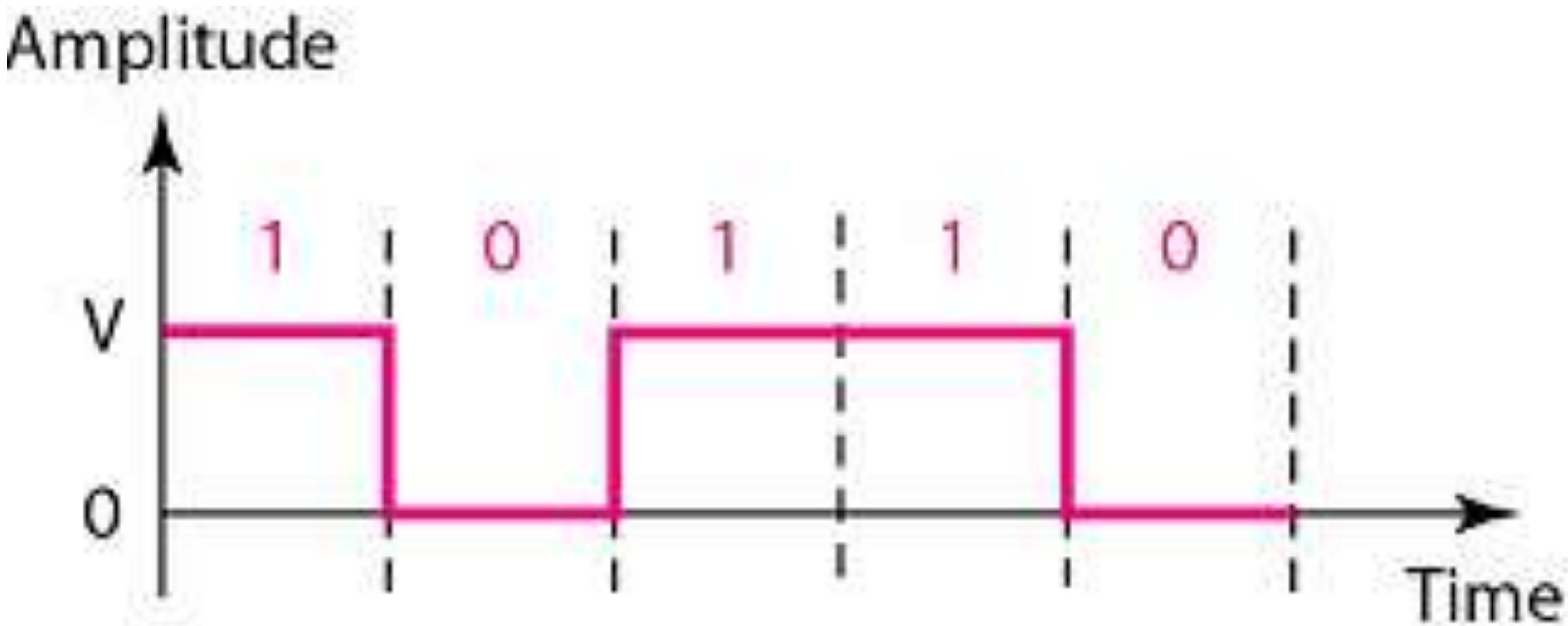
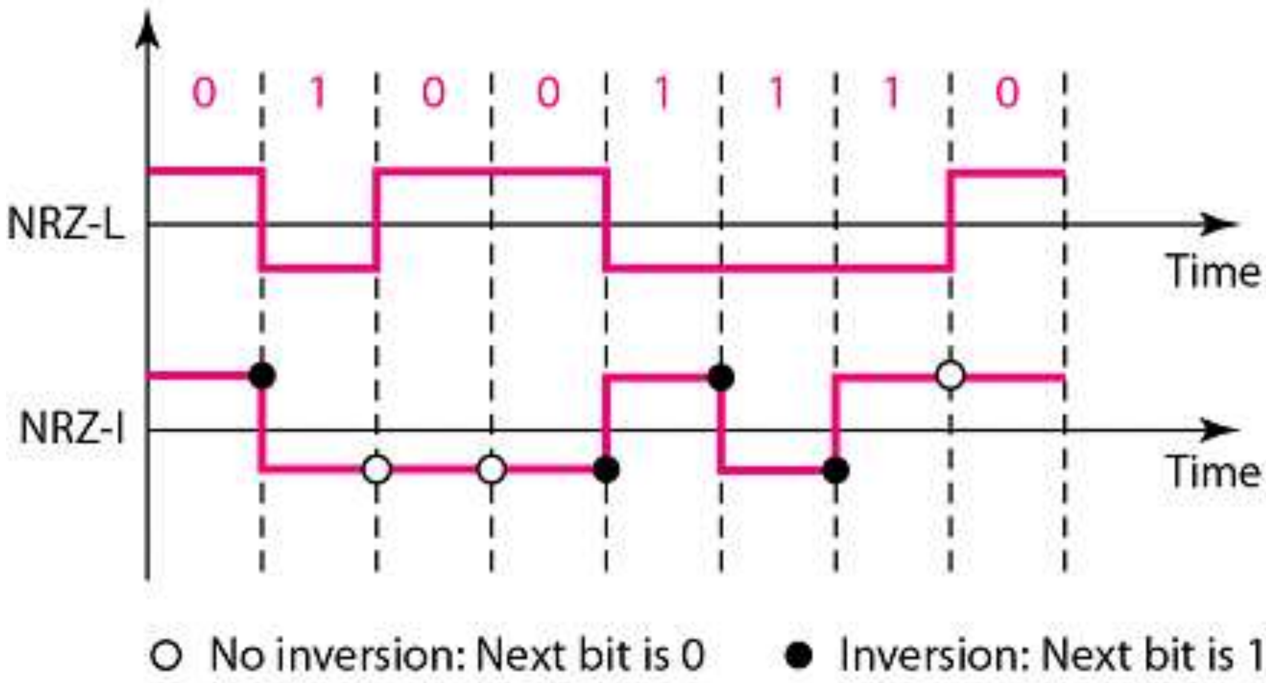


Figure 4.6 *Polar NRZ-L and NRZ-I schemes*



In NRZ-L the level of the voltage determines the value of the bit.
In NRZ-I the inversion or the lack of inversion determines the value of the bit.

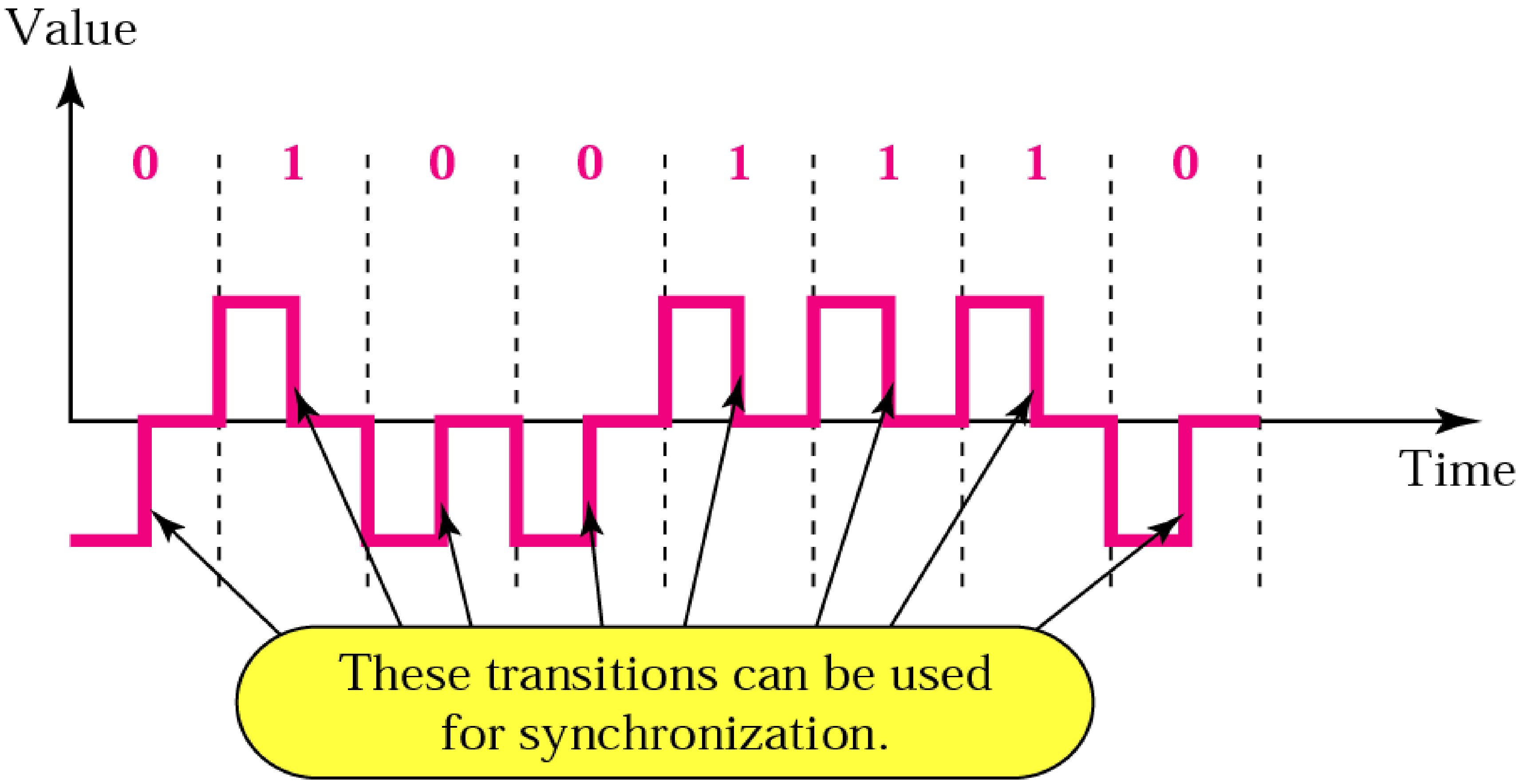
- NRZ-Level, the level of the voltage determines the value of the bit

- NRZ-Invert, the change or lack of change in the level of the voltage determines the value of the bit. If there is no change, the bit is 0, if there is a change, the bit is 1.

- If there is a long sequence of 0s or 1s in NRZ-L, the average signal power becomes skewed. The receiver might have difficulty discerning the bit value.
- IN NRZ-I this problem occurs only for a long sequence of 0s.

- The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized. The receiver does not know when one bit has ended and the next bit is starting.
- One solution is the RZ (return-to-zero) scheme, which uses three voltage levels.

RZ Encoding



Value
0
1
0
0
1
1
1
0
Time
These transitions can be used for synchronization.

Return to Zero RZ: To ensure synchronization, there must be a signal transition in each bit as shown in Fig. 2.4.9. Key characteristics of the RZ coding are:

- Three levels
- Good synchronization
- Main limitation is the increase in bandwidth

- The main disadvantage of RZ encoding is that it requires two signal changes to encode a bit and therefore occupies greater bandwidth.

RZ Encoding

A good encoded digital signal must contain a provision for synchronization.

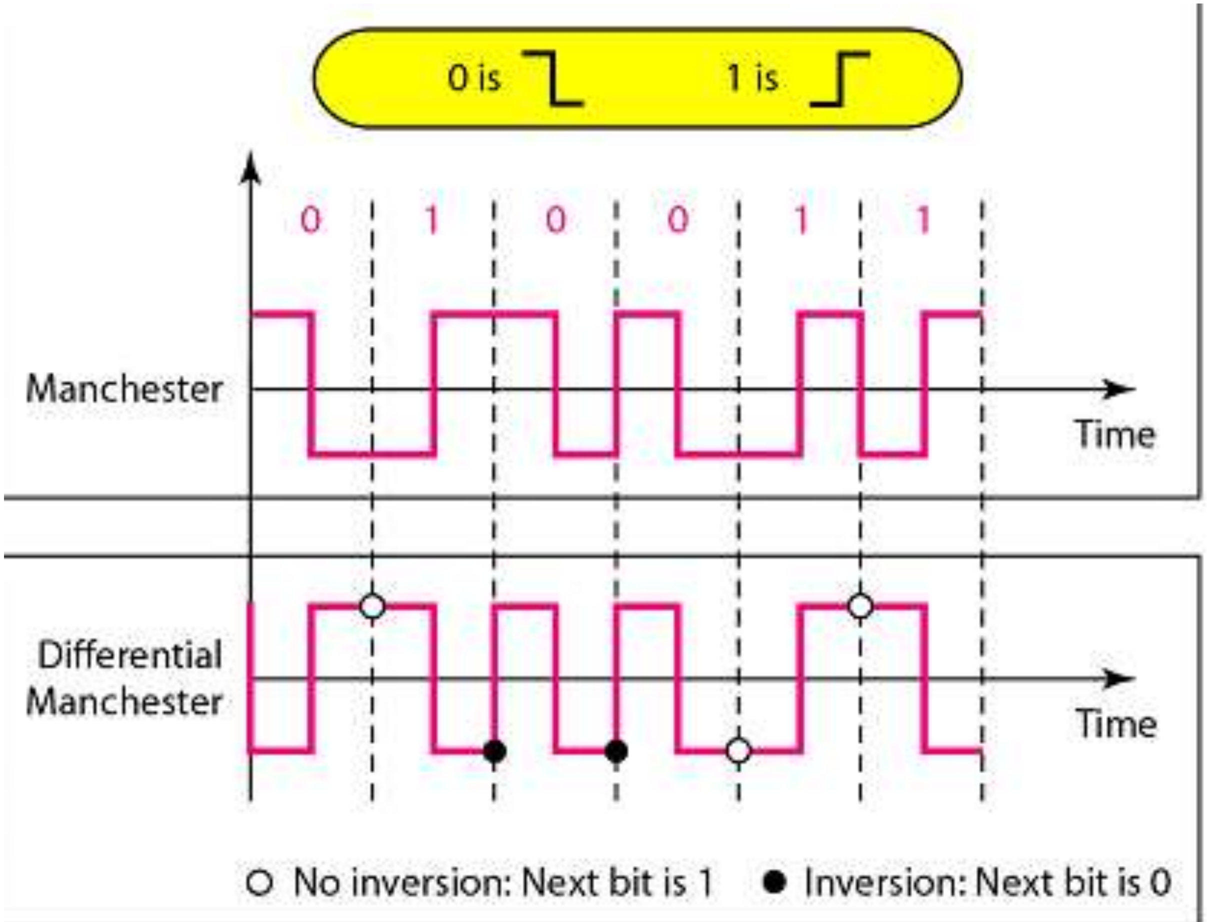
Manchaster

Biphase:

- To overcome the limitations of NRZ encoding, biphase encoding techniques can be adopted.
- *Manchester* and *differential Manchester Coding* are the two common Biphase techniques in use, as shown in Fig. .
- In Manchester coding the mid-bit transition serves as a clocking mechanism and also as data.

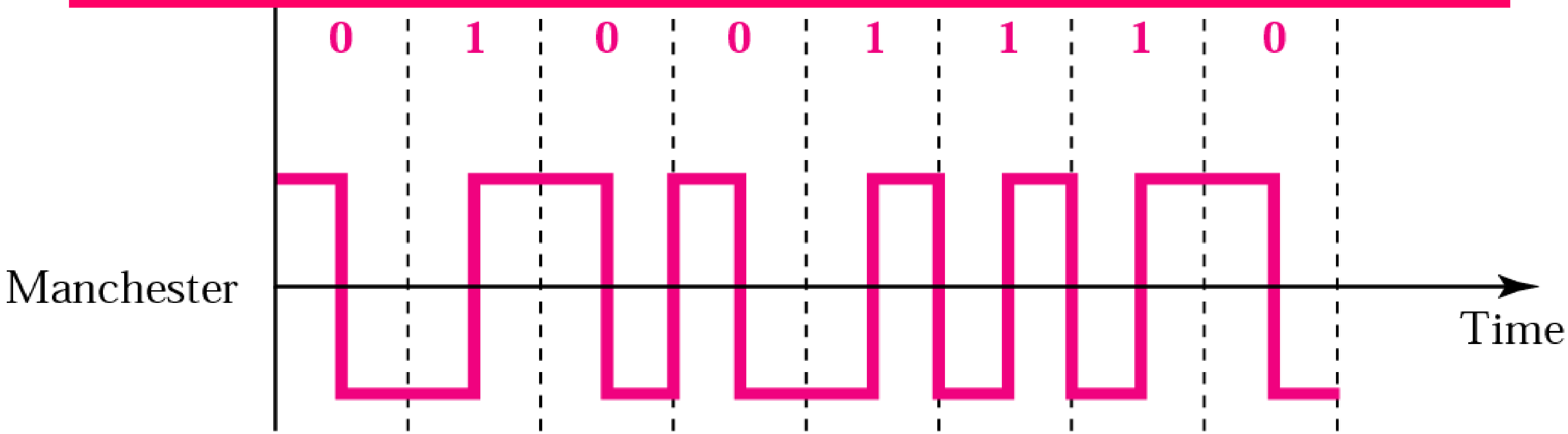
- In the standard Manchester coding there is a transition at the middle of each bit period.
- A binary 1 corresponds to a *low-to-high transition* and a binary 0 to a *high-to-low transition* in the middle.

Figure 4.8 *Polar biphase: Manchester and differential Manchester schemes*



In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.

In Manchester encoding, the transition at the middle of the bit is used for both synchronization and bit representation.



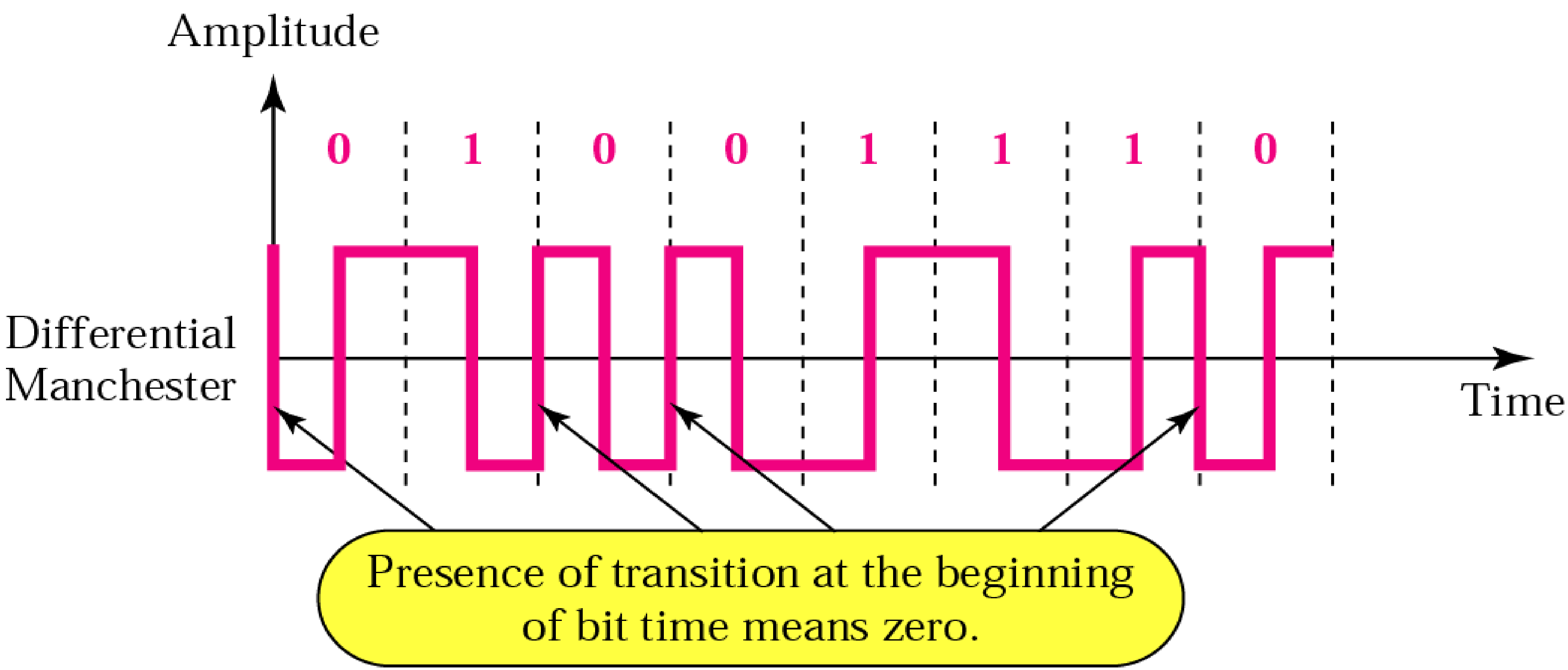
- **In Differential Manchester**, inversion in the middle of each bit is used for synchronization.
- The encoding of a 0 is represented by the presence of a transition both at the beginning and at the middle and 1 is represented by a transition only in the middle of the bit period.

Key characteristics are:

- Two levels
- No DC component
- Good synchronization
- Higher bandwidth due to doubling of bit rate with respect to data rate

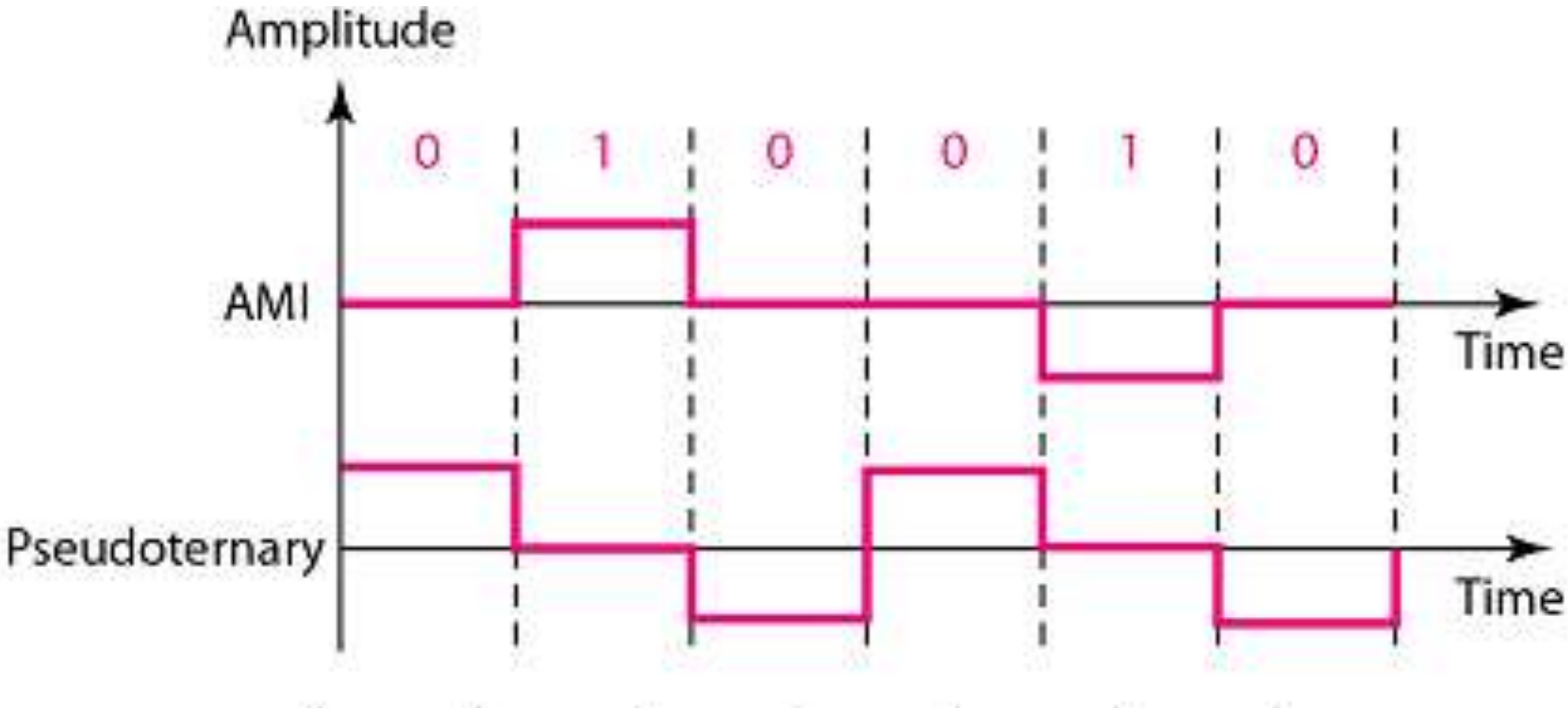
- The bandwidth required for biphase techniques are greater than that of NRZ techniques, but due to the predictable transition during each bit time, the receiver can synchronize properly on that transition.
- Biphase encoded signals have no DC components as shown in Fig..
- A Manchester code is now very popular and has been specified for the IEEE 802.3 standard for base band coaxial cables and twisted pair CSMA/CD bus LANs.

In differential Manchester encoding, the transition at the middle of the bit is used only for synchronization.
The bit representation is defined by the inversion or noninversion at the beginning of the bit.

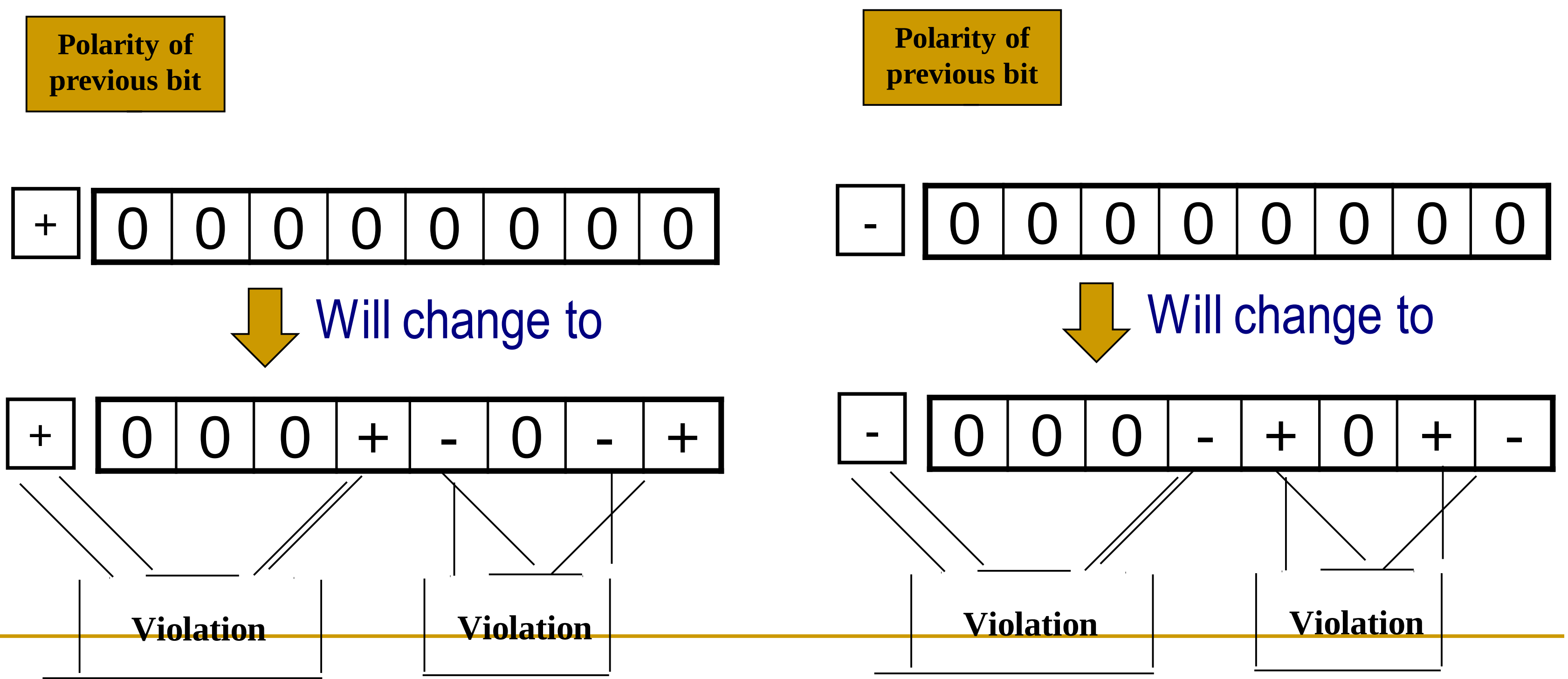


In bipolar encoding, we use three levels: positive, zero, and negative.

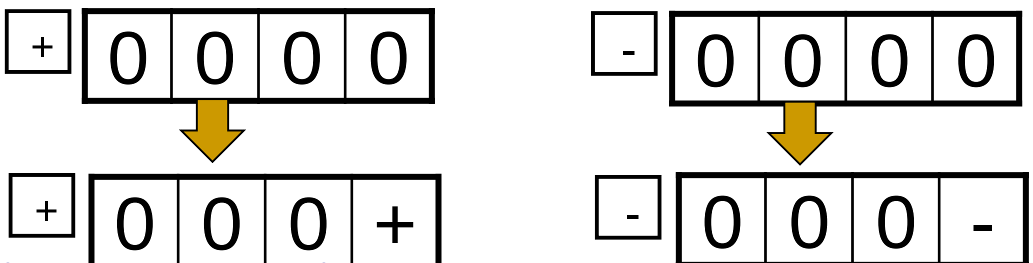
Bipolar schemes: AMI (alternate mark inversion) and pseudoternary



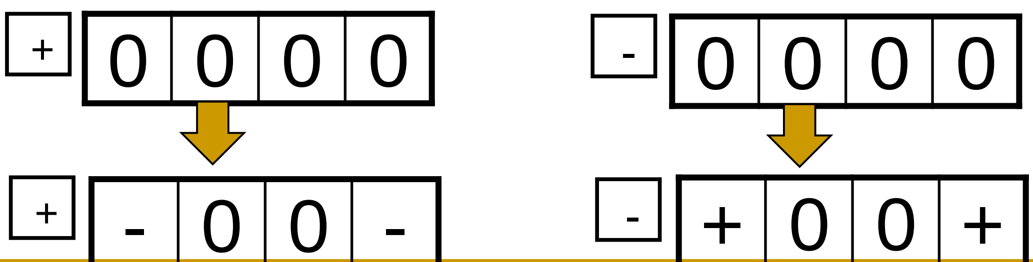
- **Bipolar with 8-zeros substitution (B8ZS):**
- **The coding scheme is based on a bipolar-AMI. The encoding is updated with the following rules:**



HDB3(High Density Bipolar Order 3 Encoding)



If the number of 1a since the last substitution is odd



If the number of 1a since the last substitution is even

4-2 ANALOG-TO-DIGITAL CONVERSION

A digital signal is superior to an analog signal. The tendency today is to change an analog signal to digital data.

Pulse Code Modulation (PCM)
Delta Modulation (DM)

Pulse Code Modulation involves the following three basic steps as shown in Fig. :

- Sampling – PAM
- Quantization
- Line coding

Analog to PCM Digital code

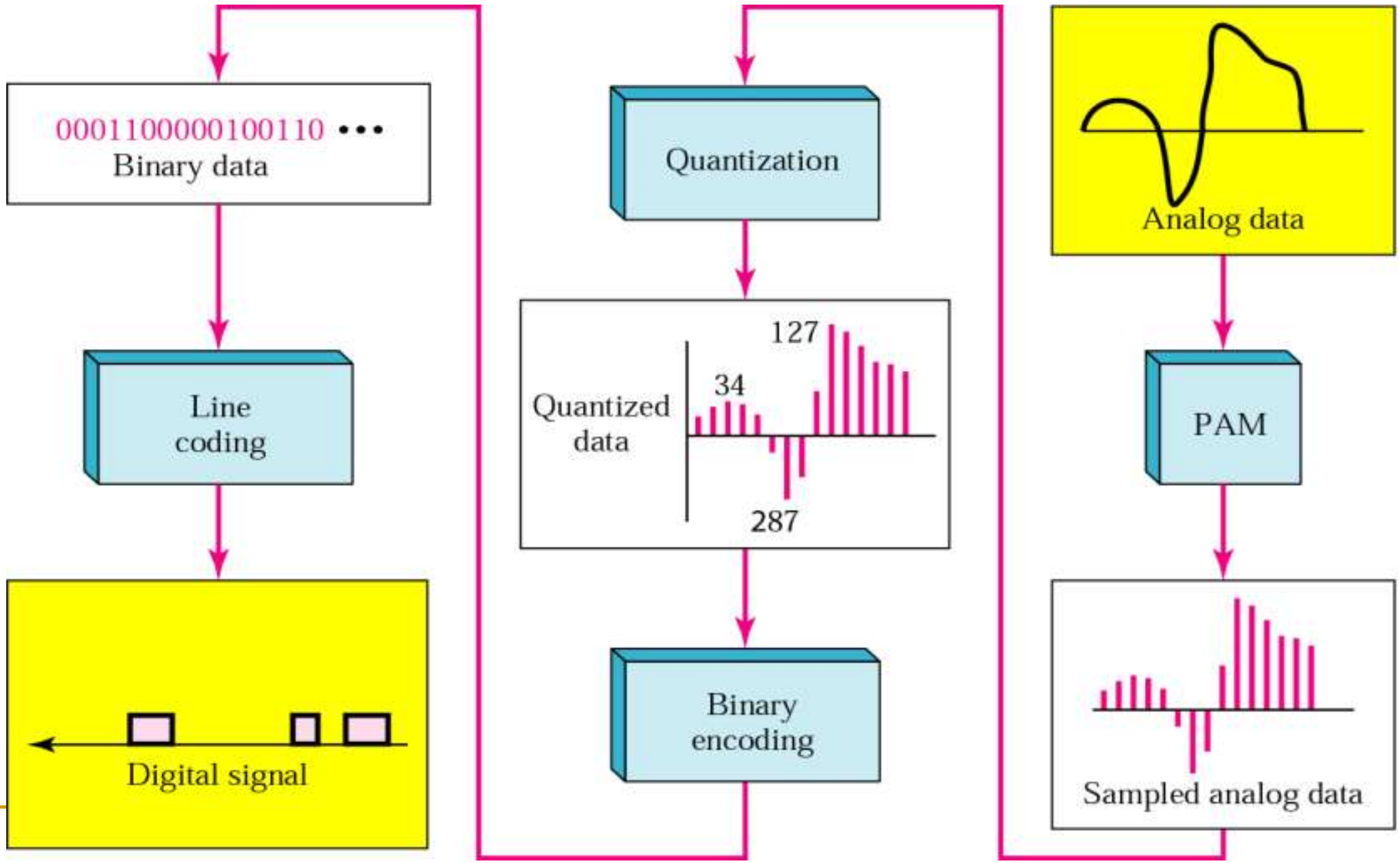
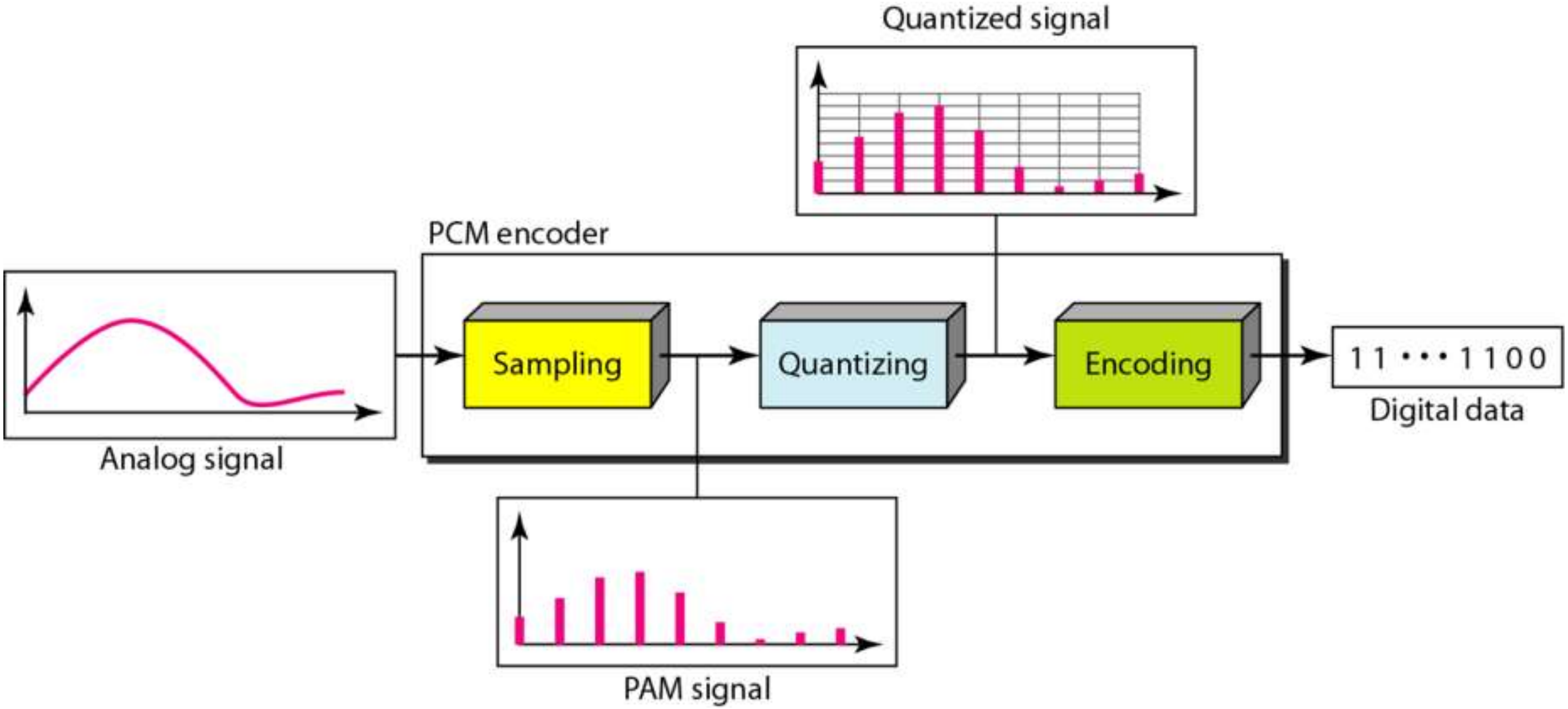
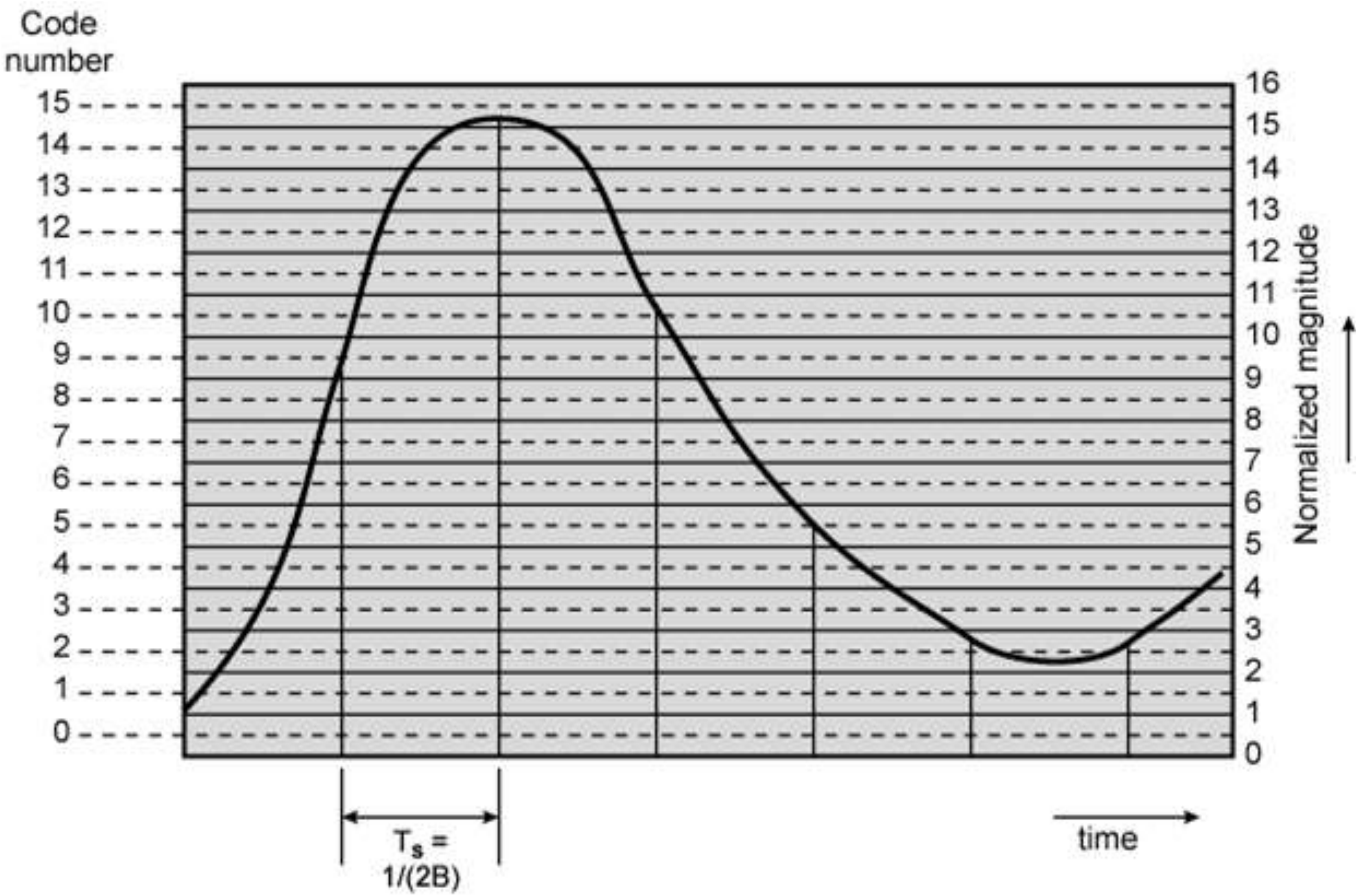


Figure 4.21 *Components of PCM encoder*



PCM Example

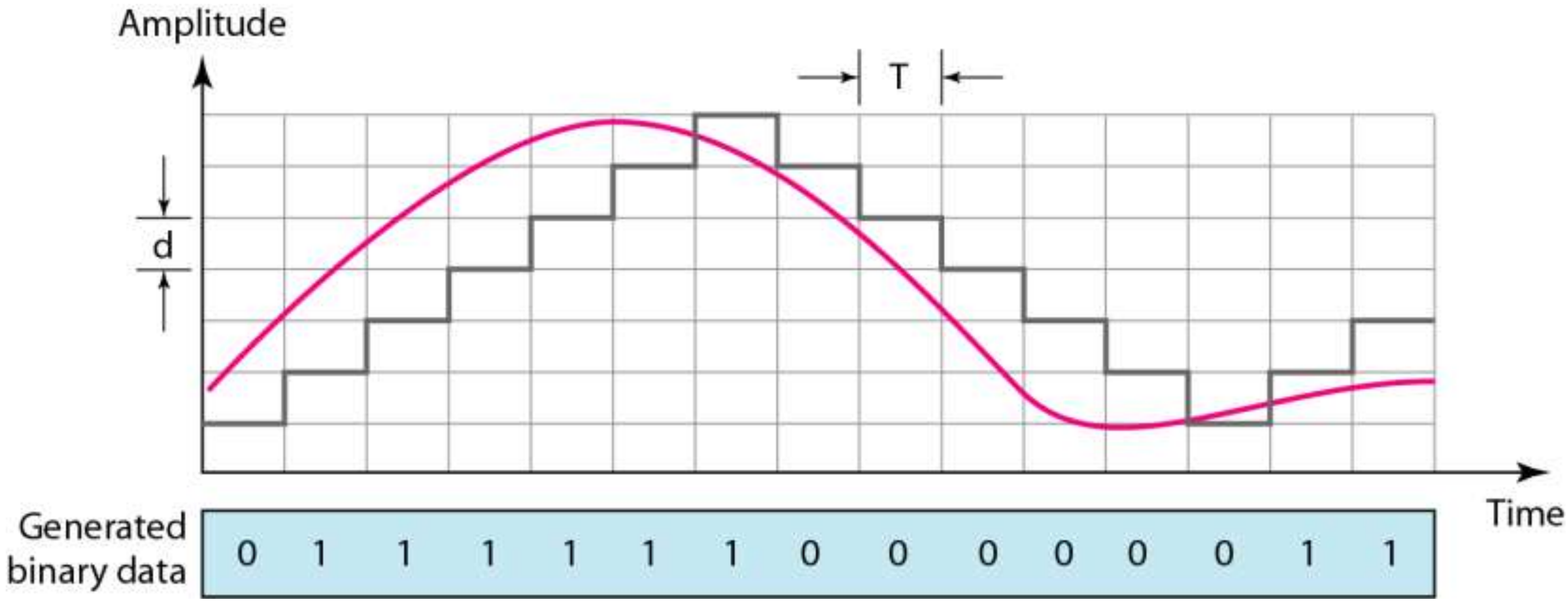


PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Delta Modulation

- Analog input is approximated by a staircase function
- Move up or down one level (δ) at each sample interval
- Binary behavior
  - Function moves up or down at each sample interval

Figure 4.28 *The process of delta modulation*



5-1 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.

Figure 5.1 *Digital-to-analog conversion*

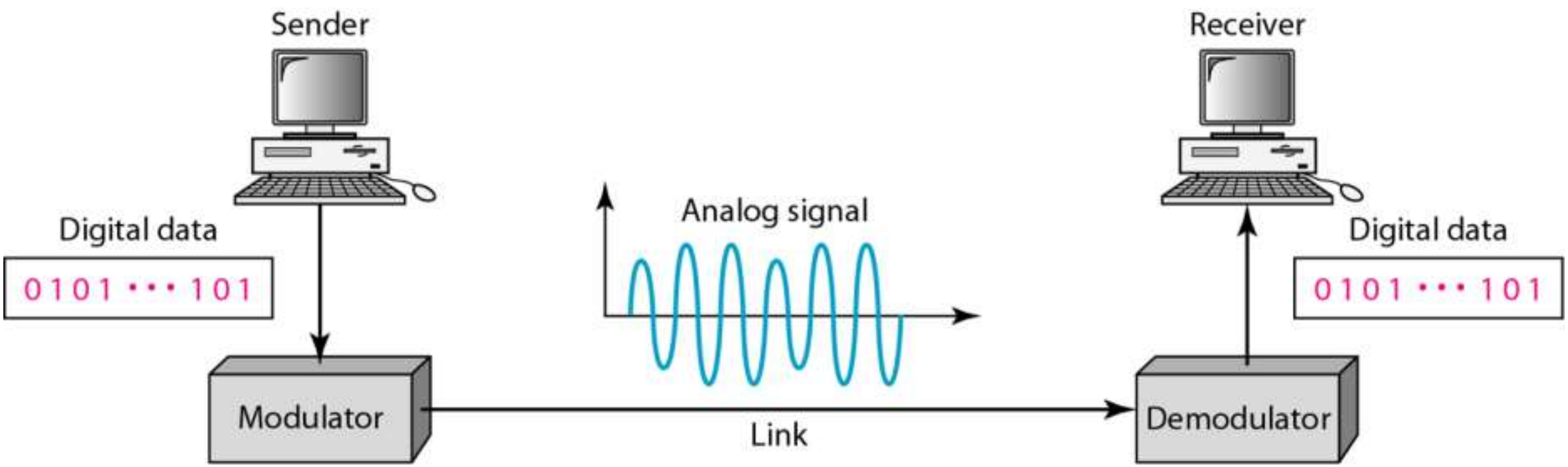


Figure 5.2 *Types of digital-to-analog conversion*

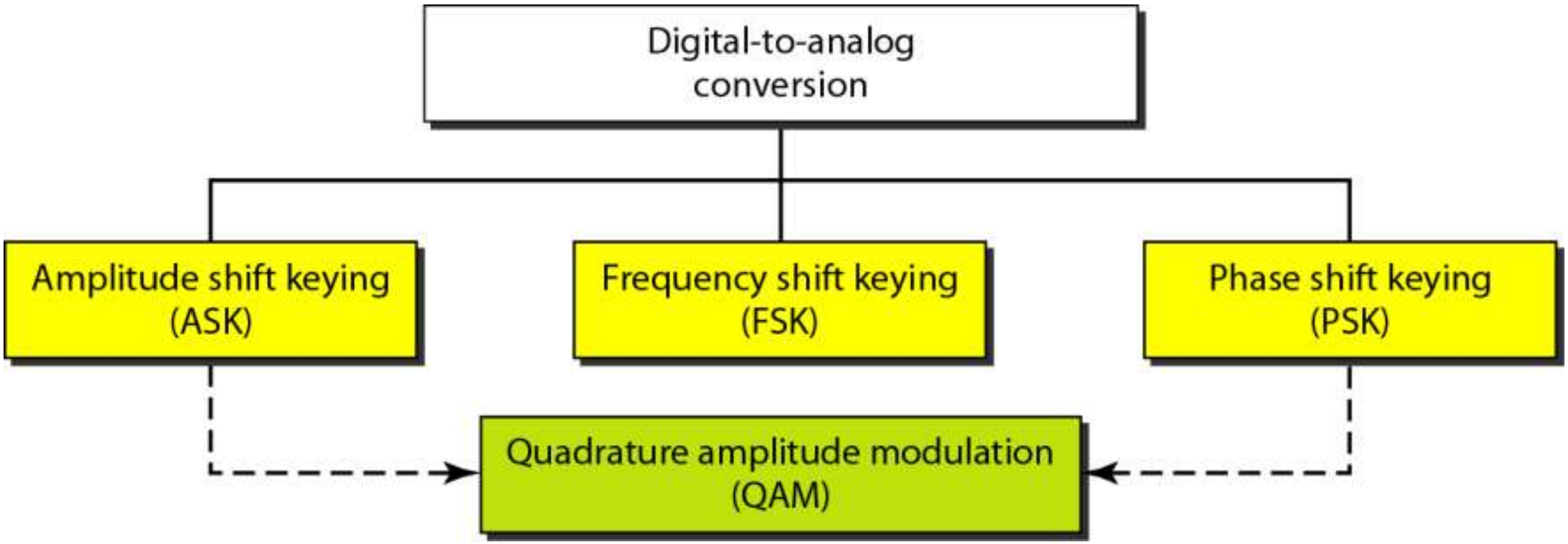


Figure 5.3 ***Binary amplitude shift keying***

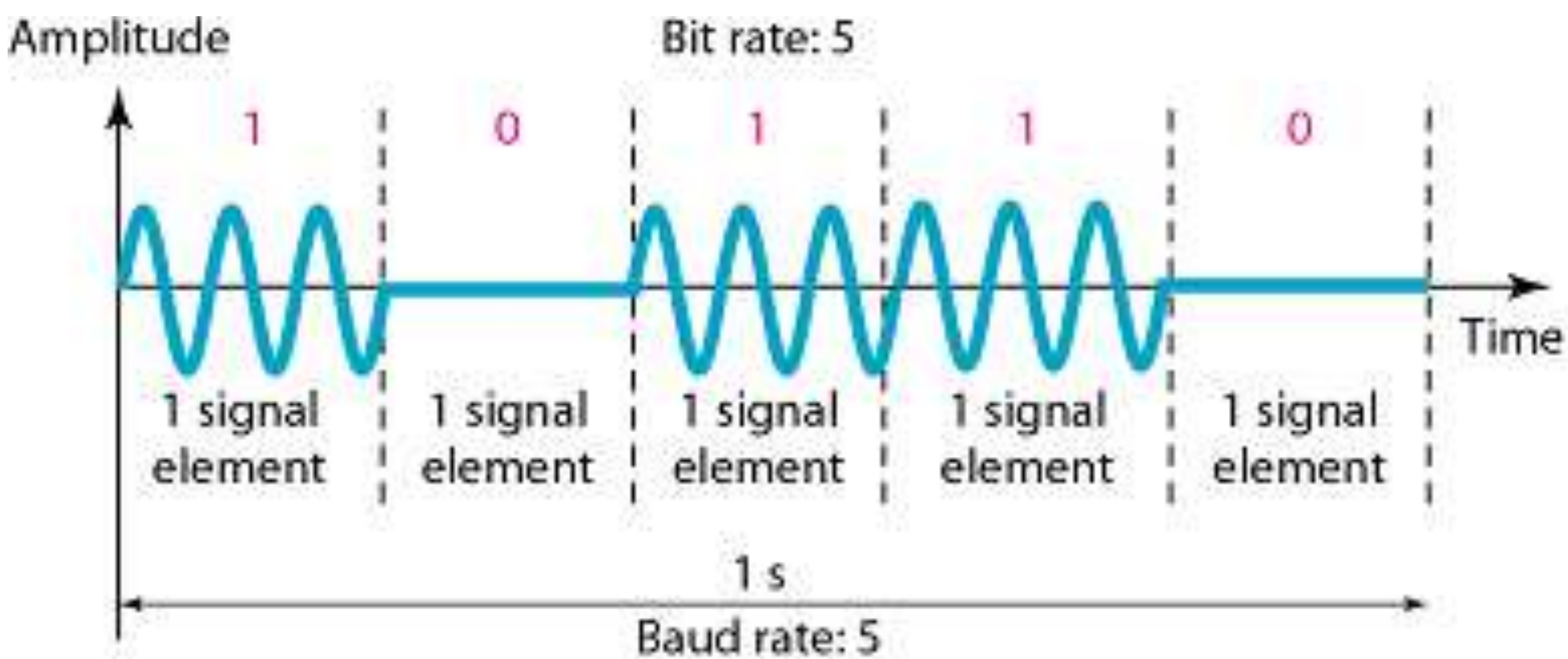


Figure 5.6 ***Binary frequency shift keying***

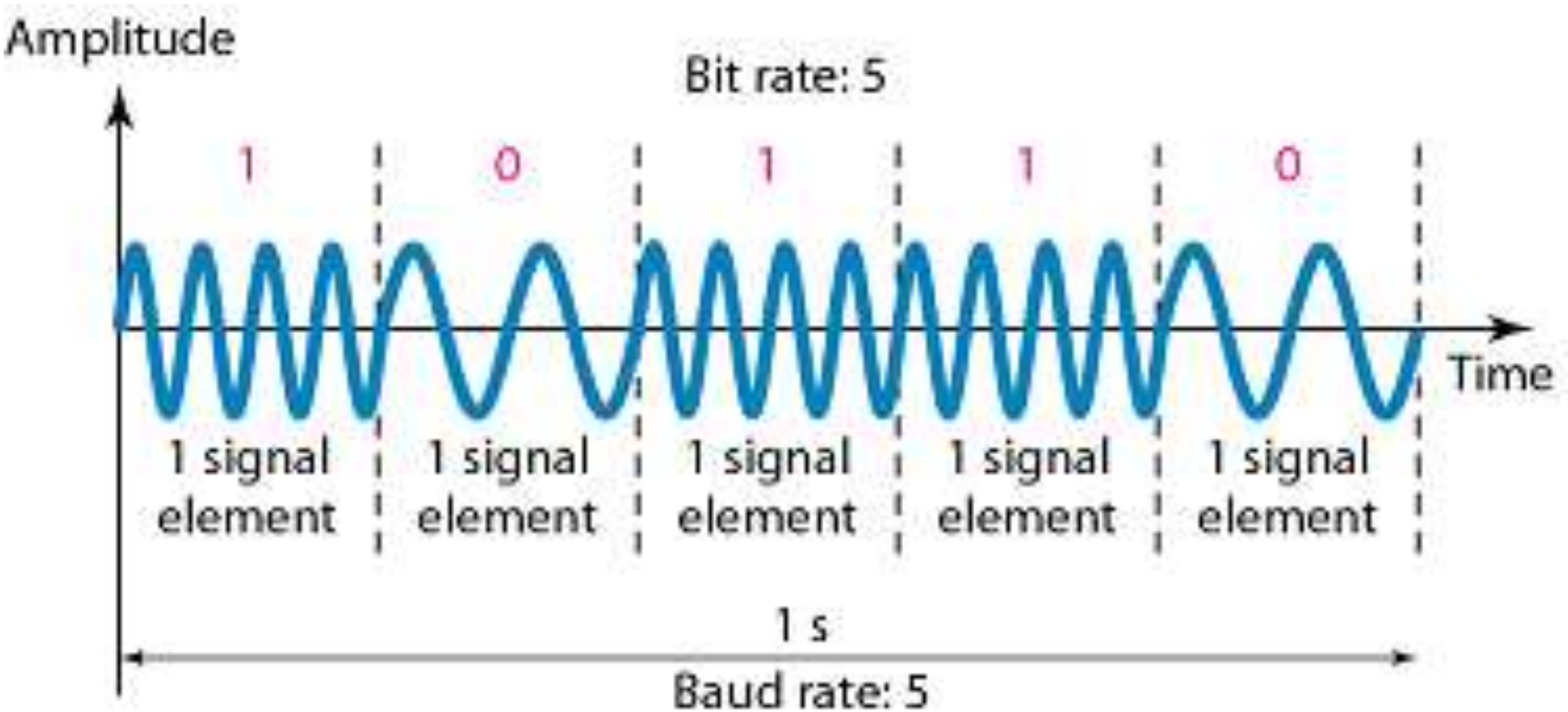
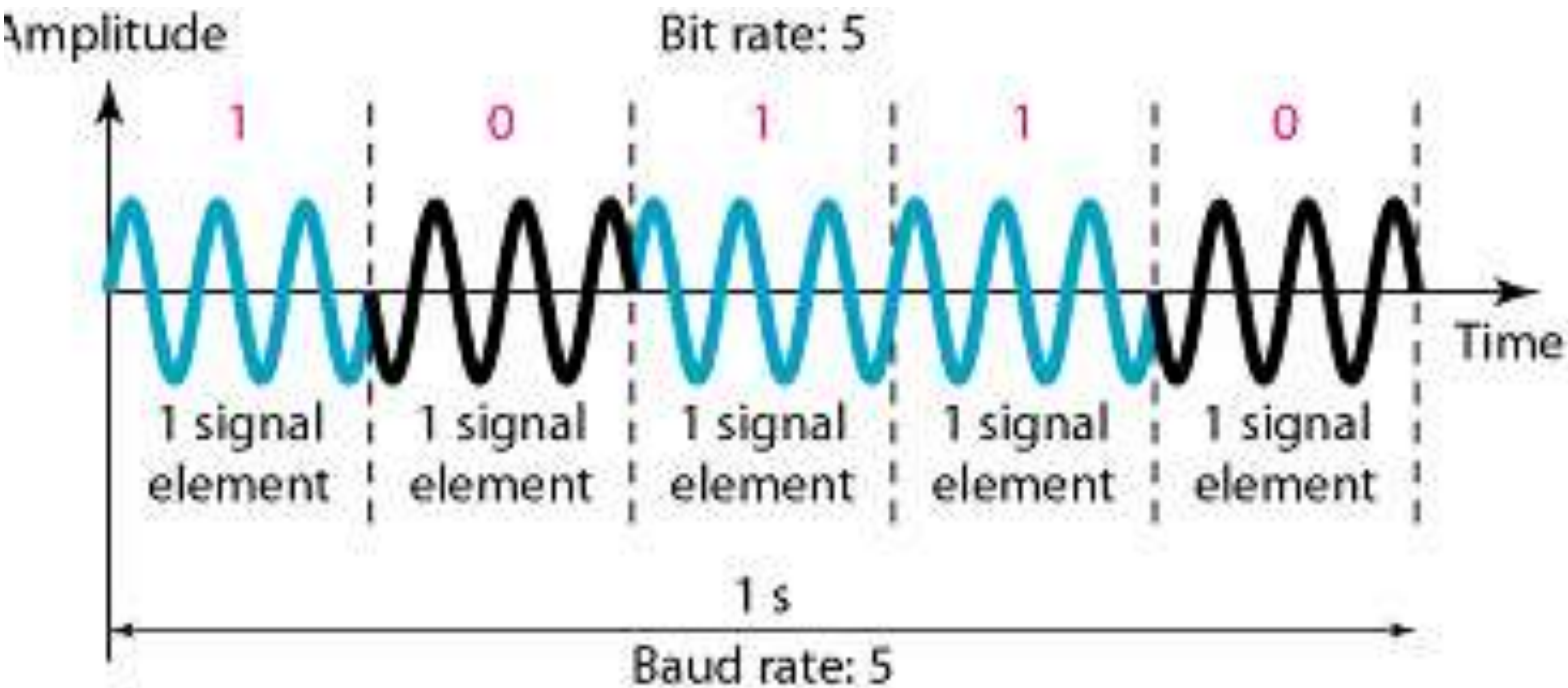


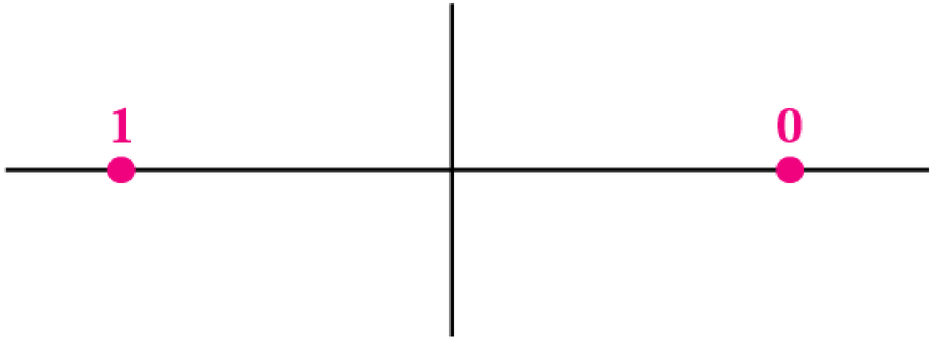
Figure 5.9 ***Binary phase shift keying***



PSK Constellation

Bit	Phase
0	0
1	180

Bits

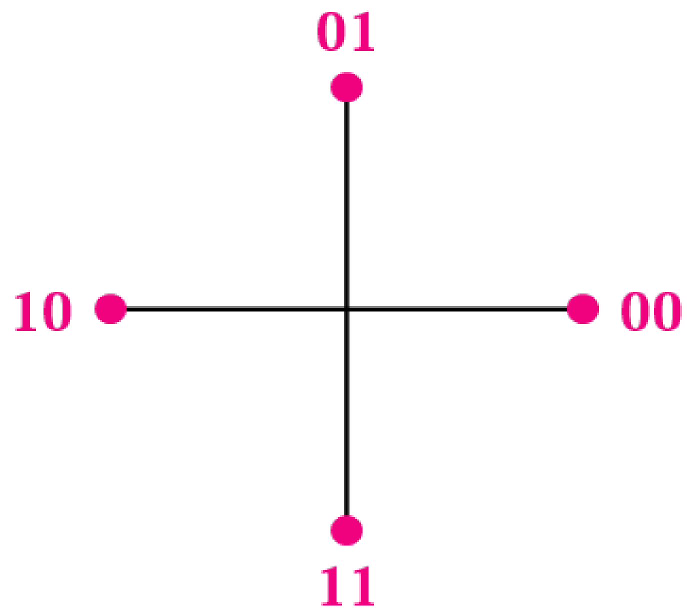


Constellation diagram

4-PSK

Dibit	Phase
00	0
01	90
10	180
11	270

Dibit
(2 bits)

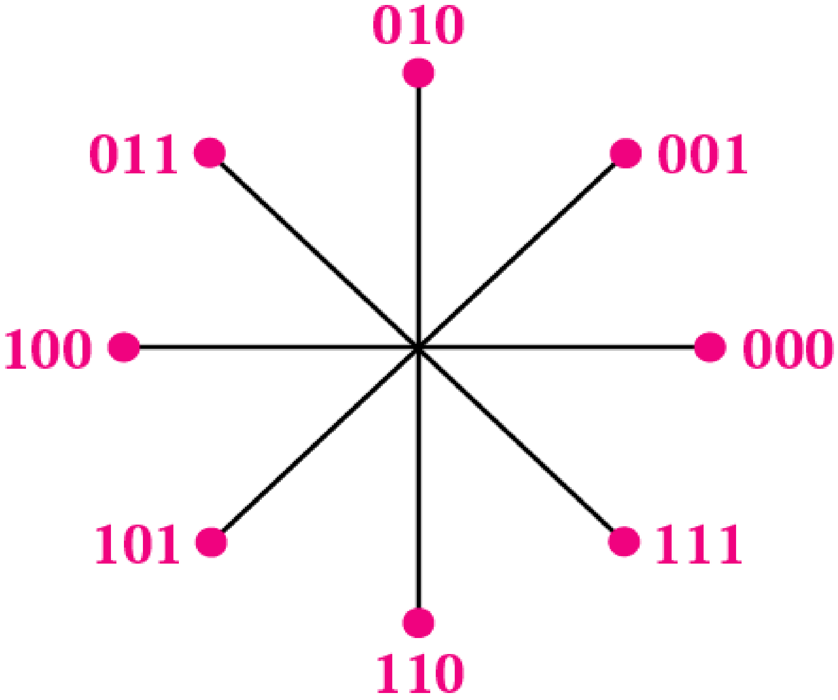


Constellation diagram

8-PSK

Tribit	Phase
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

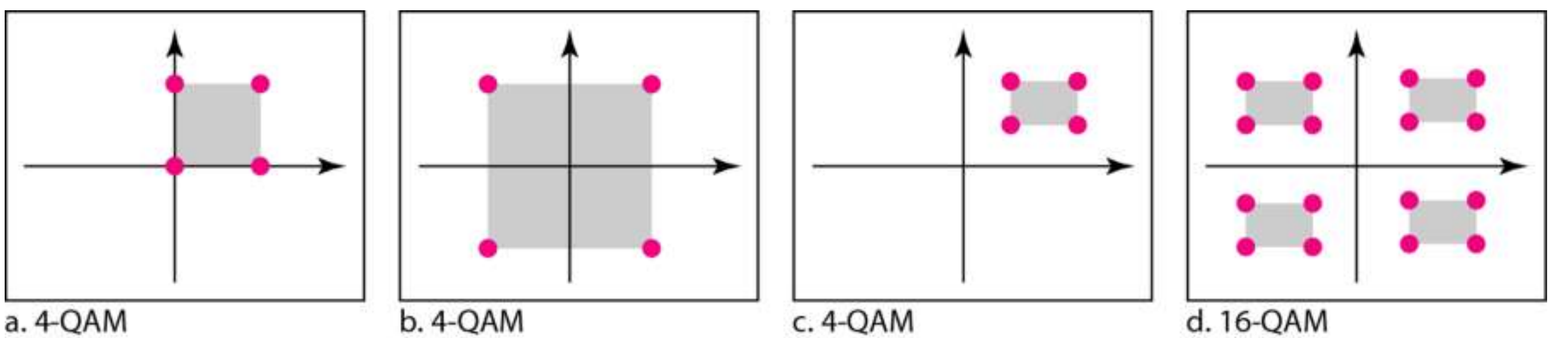
Tribits
(3 bits)

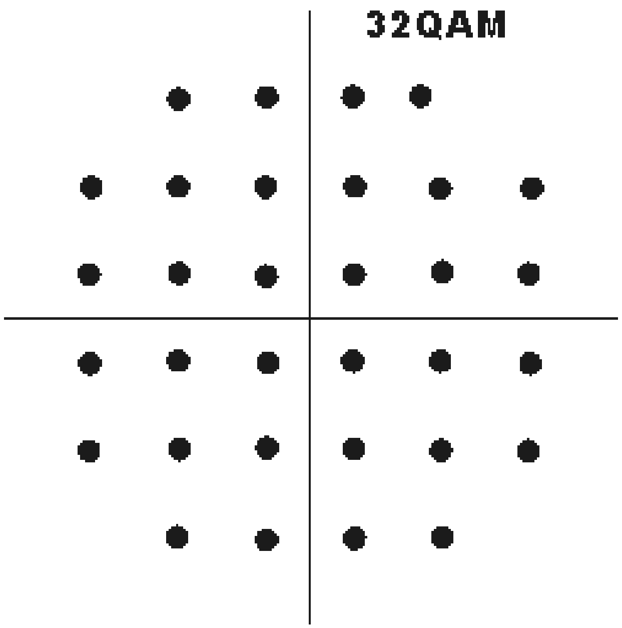


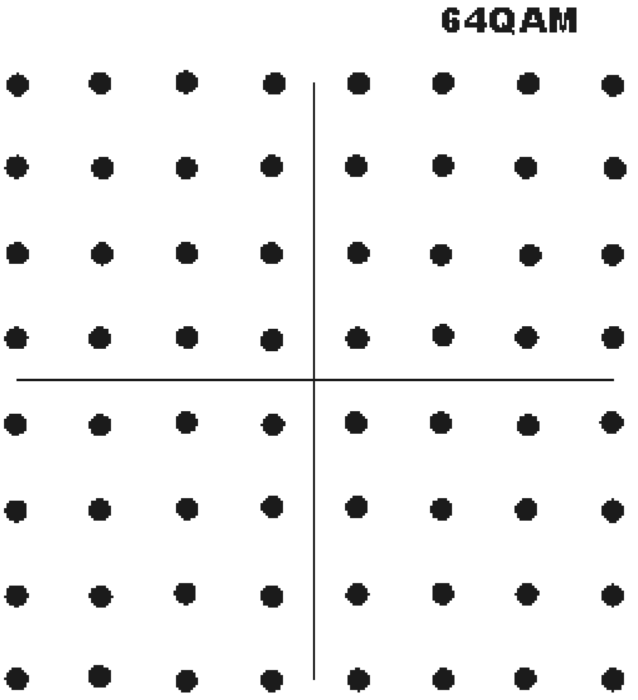
Constellation diagram

Quadrature amplitude modulation is a combination of ASK and PSK.

Figure 5.14 *Constellation diagrams for some QAMs*




32QAM


64QAM

5-2 ANALOG AND DIGITAL

Analog-to-analog conversion is the representation of analog information by an analog signal.

Amplitude Modulation
Frequency Modulation
Phase Modulation

Basic analog communications system

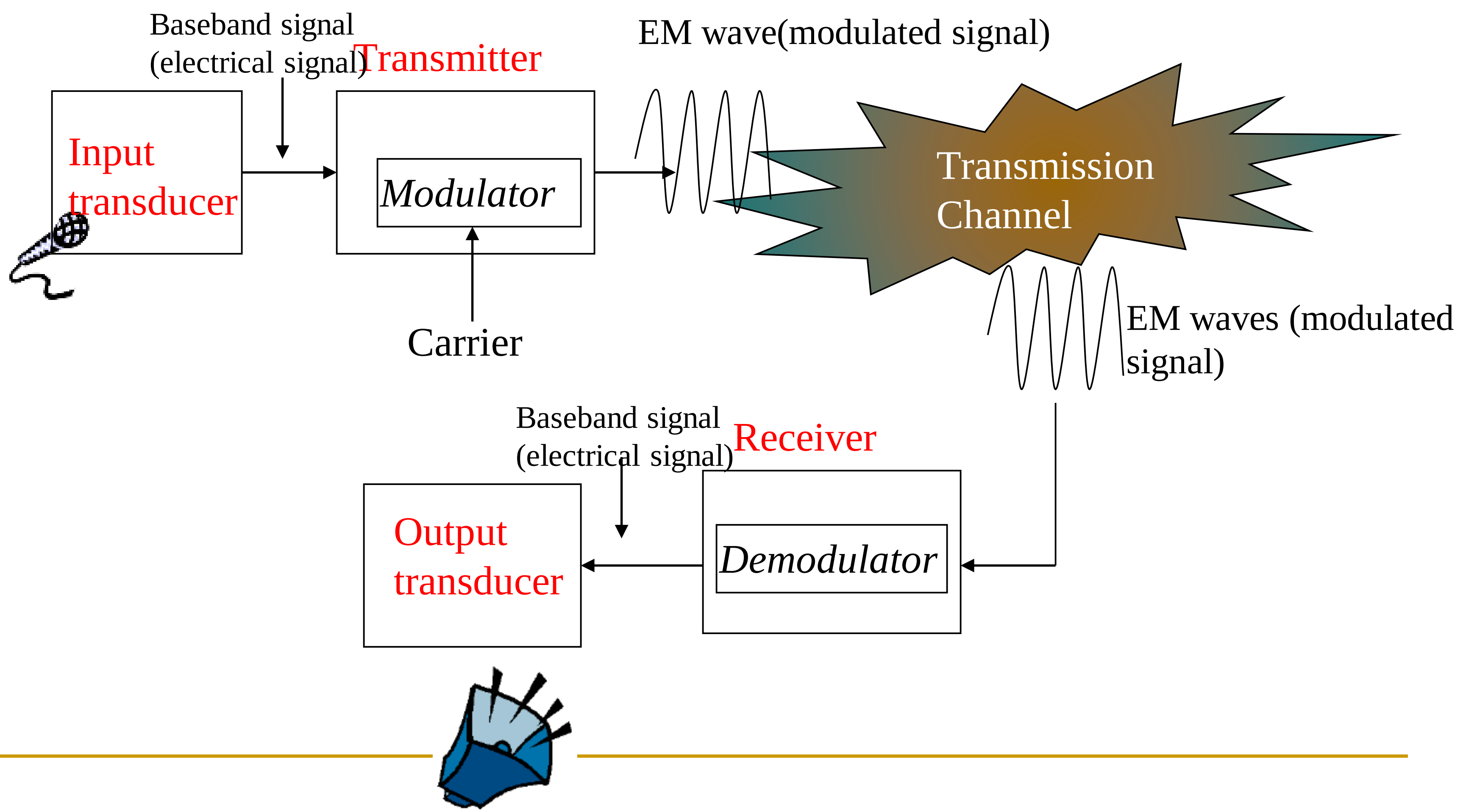


Figure 5.15 *Types of analog-to-analog modulation*

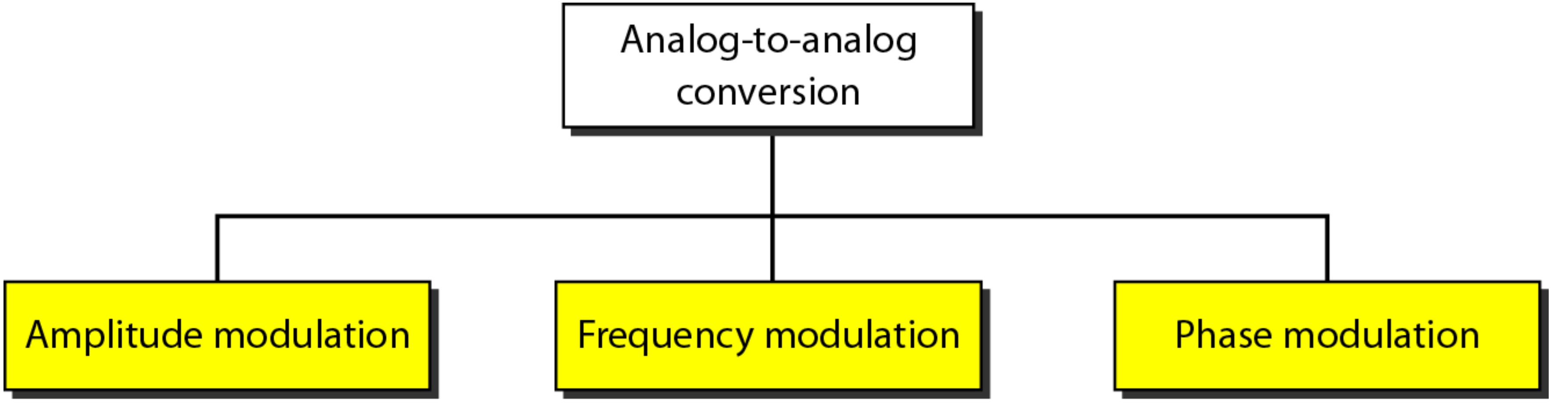


Figure 5.16 *Amplitude modulation*

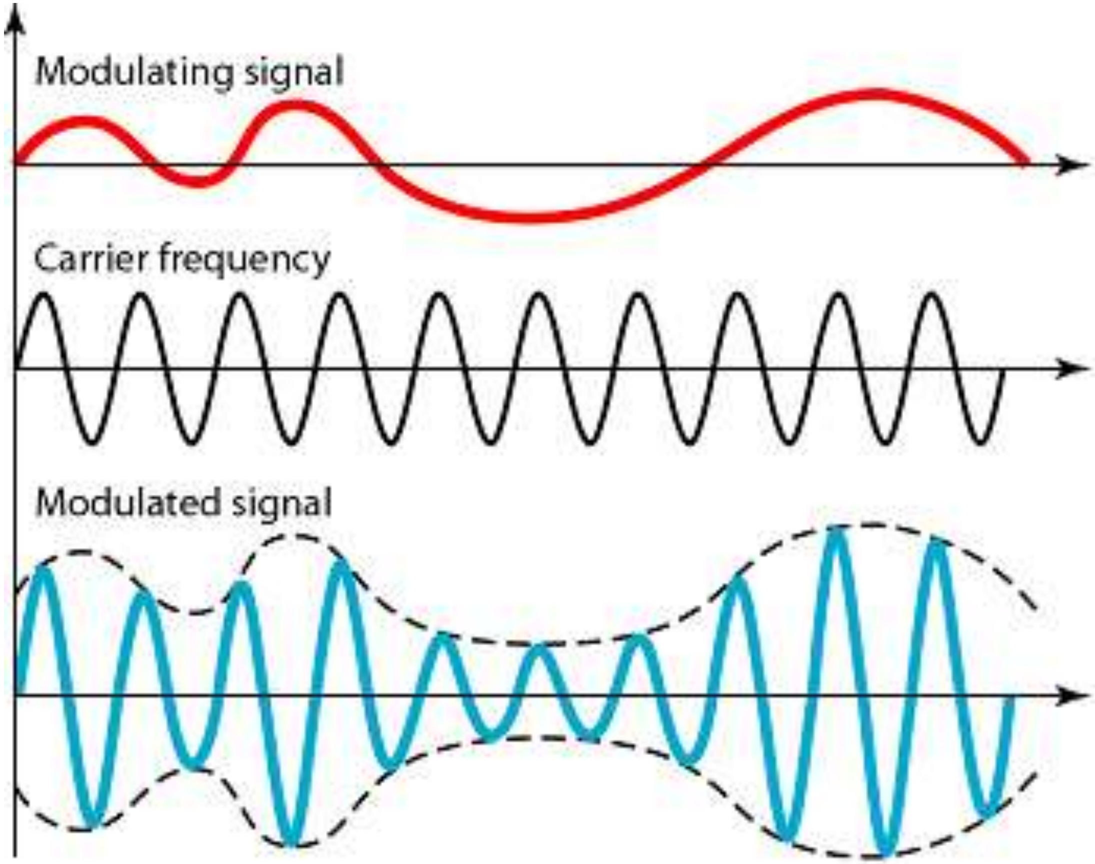


Figure 5.18 ***Frequency modulation***

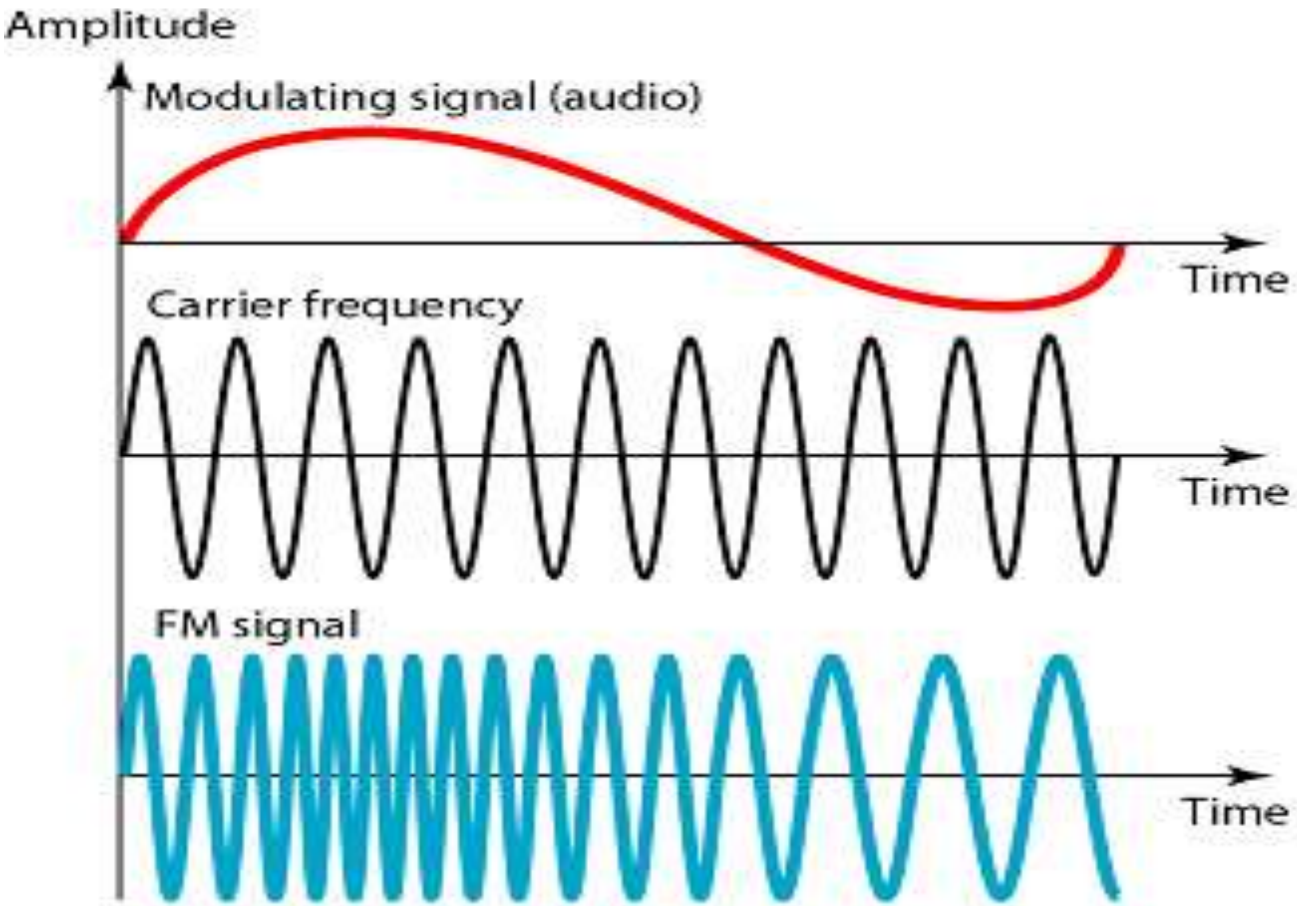
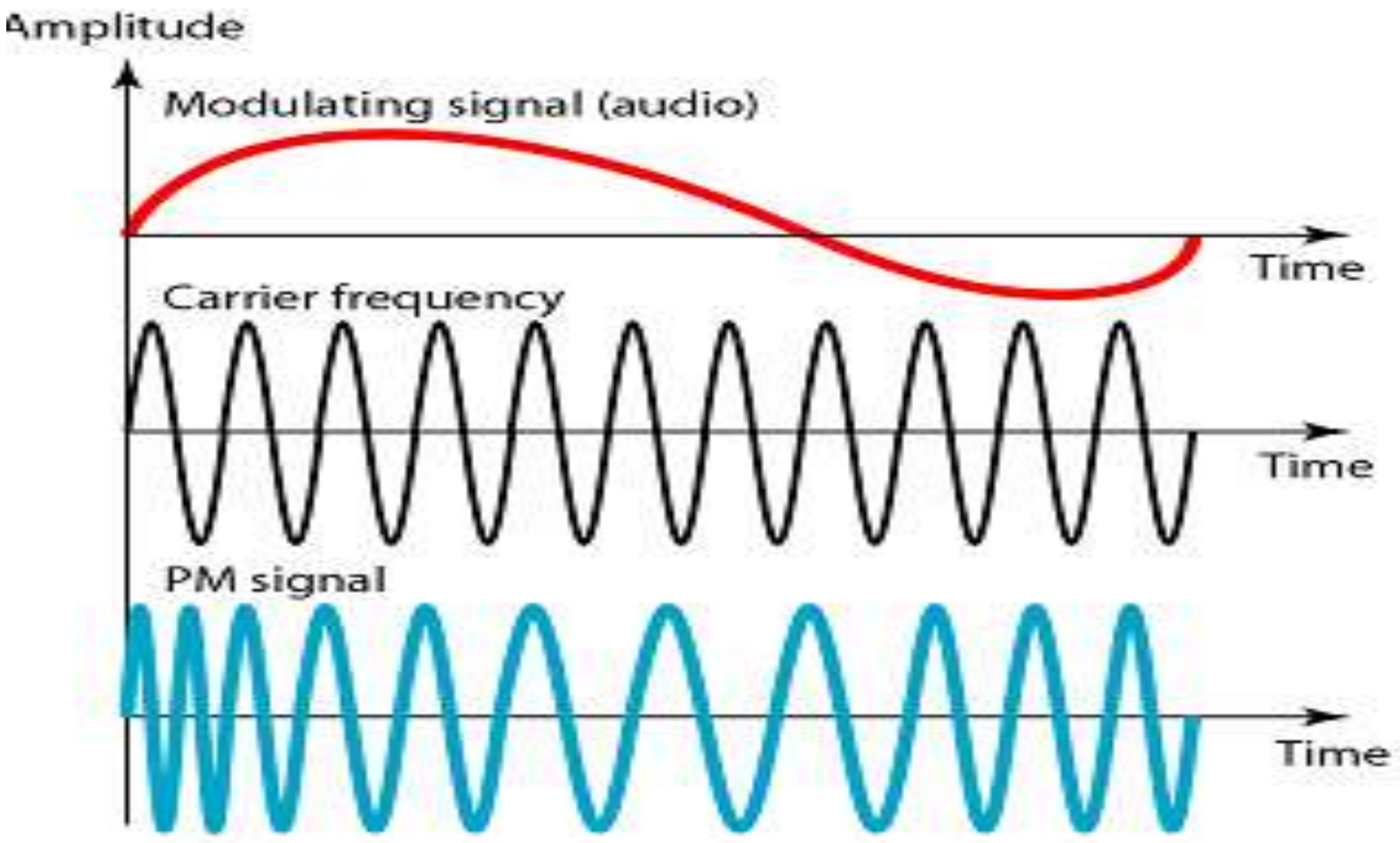
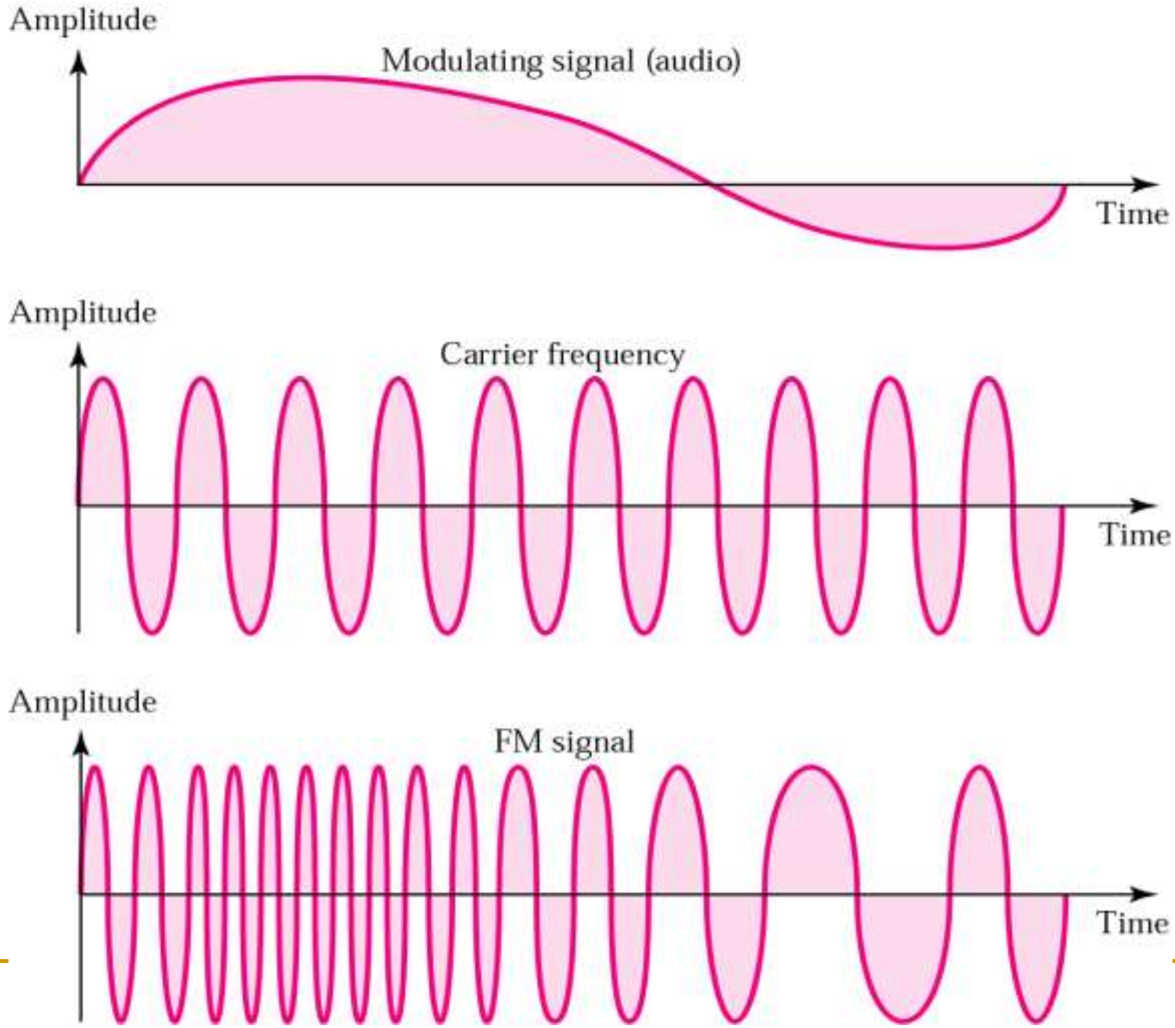


Figure 5.20 ***Phase modulation***



Frequency Modulation



6-1 MULTIPLEXING

Whenever the bandwidth of a medium linking two devices is greater than the bandwidth needs of the devices, the link can be shared. Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic.

Frequency-Division Multiplexing
Wavelength-Division Multiplexing
Synchronous Time-Division Multiplexing
Statistical Time-Division Multiplexing

Figure 6.1 *Dividing a link into channels*

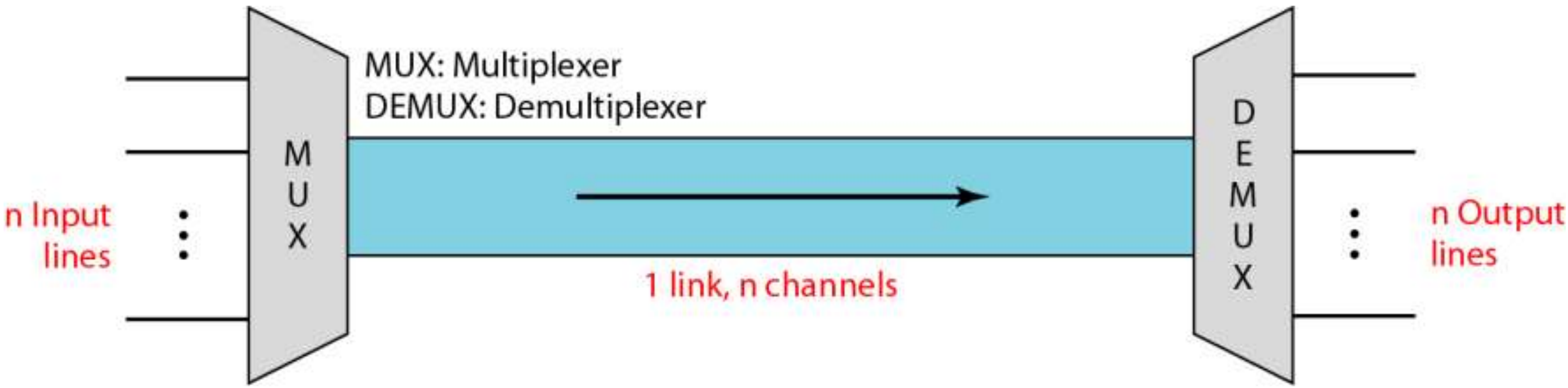


Figure 6.2 *Categories of multiplexing*

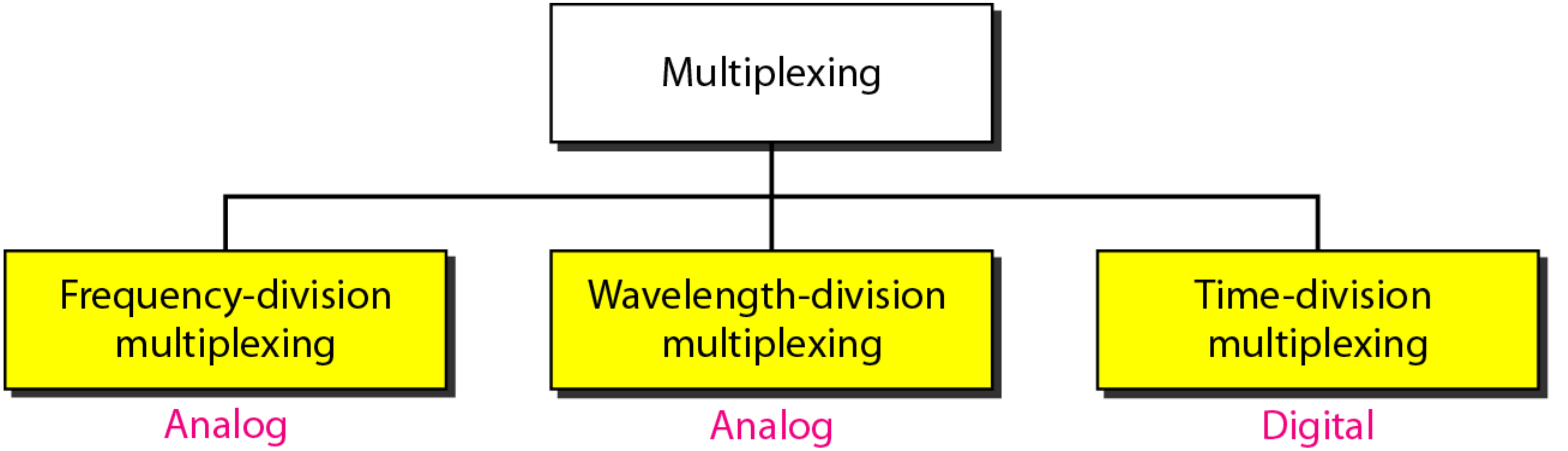


Figure 6.3 *Frequency-division multiplexing*

FDM is an analog multiplexing technique that combines analog signals.

Figure 6.4 *FDM process*

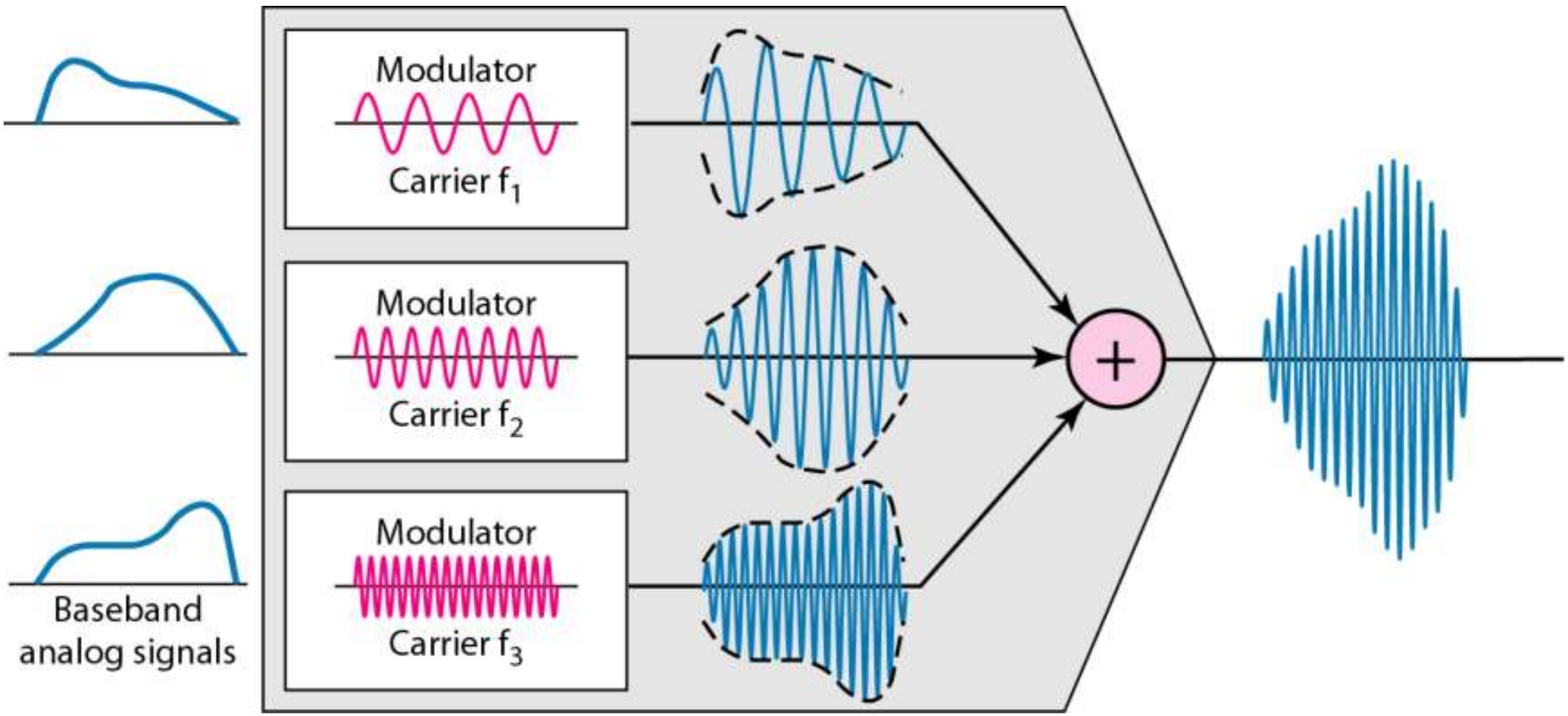


Figure 6.5 *FDM demultiplexing example*

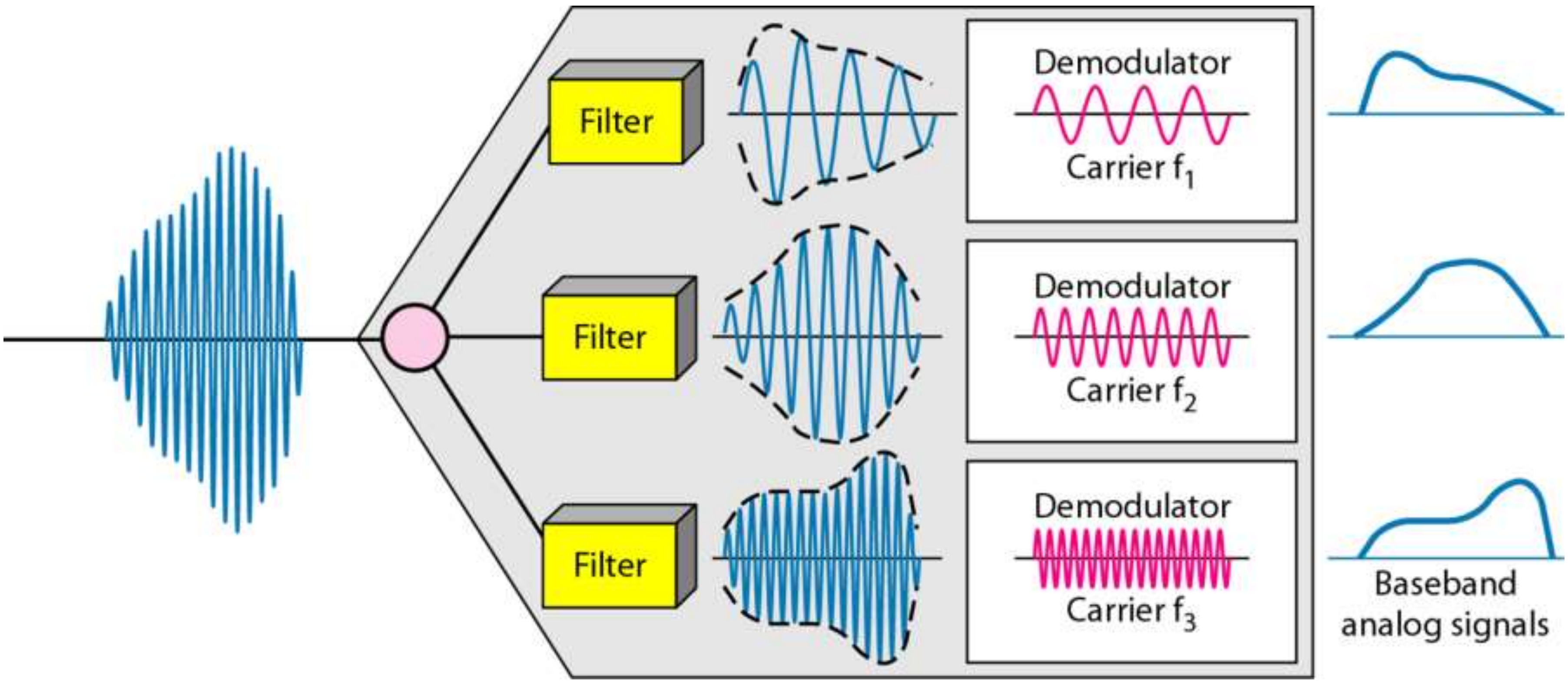
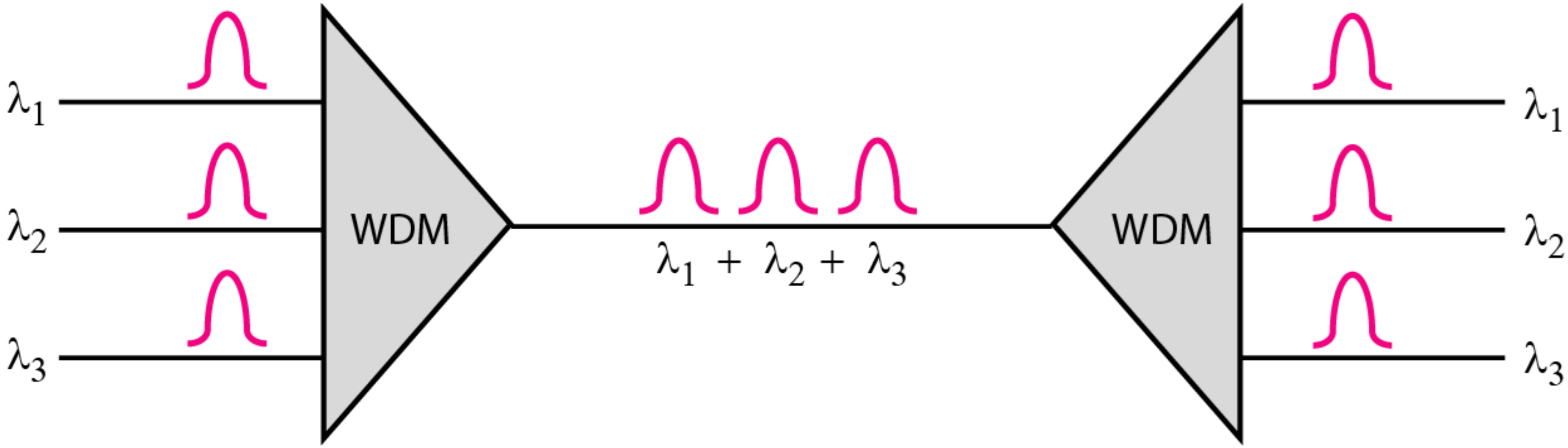


Figure 6.10 *Wavelength-division multiplexing*



WDM is an analog multiplexing technique to combine optical signals.

Figure 6.11 *Prisms in wavelength-division multiplexing and demultiplexing*

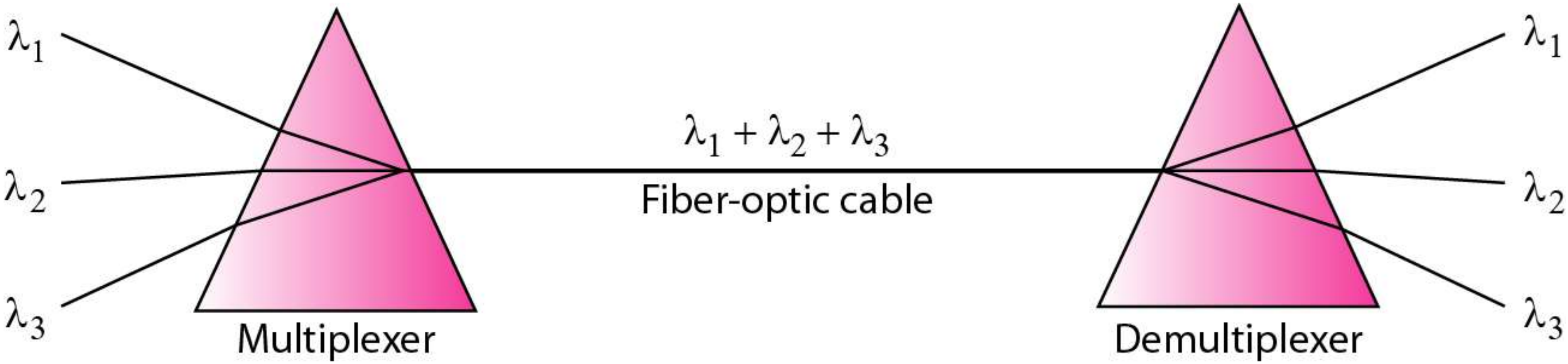
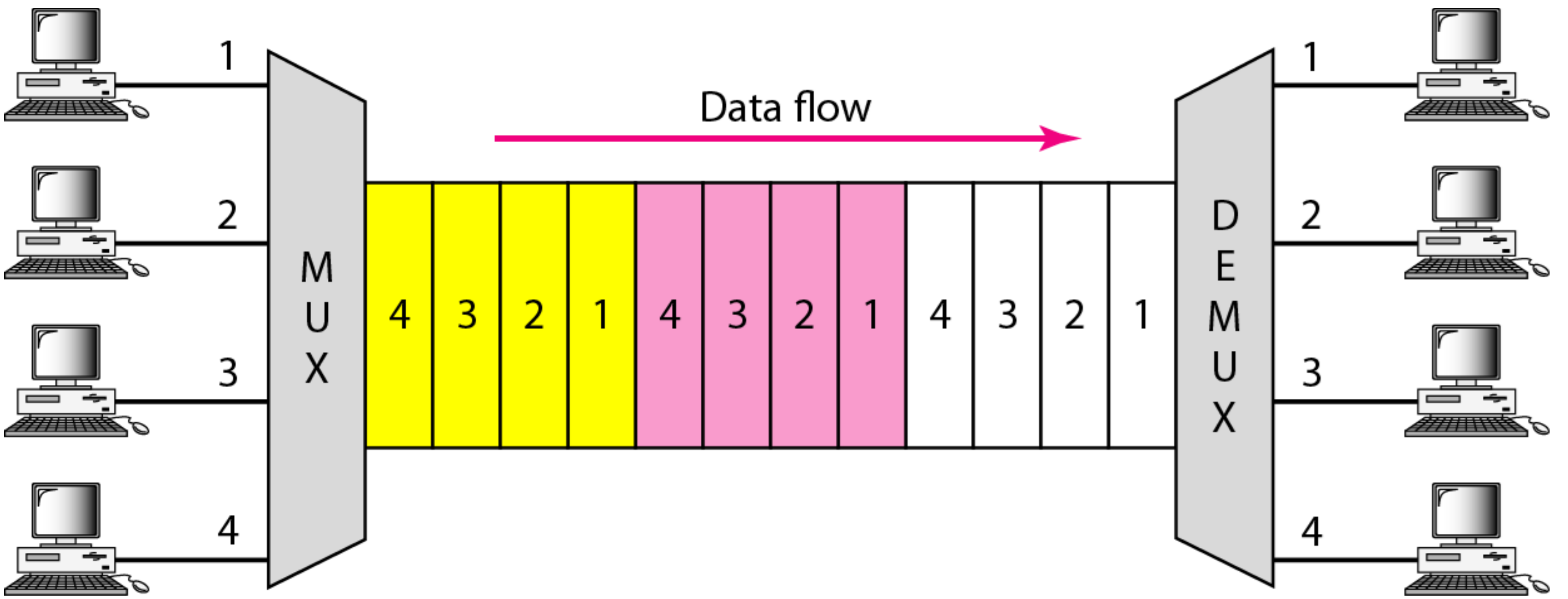


Figure 6.12 *TDM*



TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

Figure 6.13 *Synchronous time-division multiplexing*

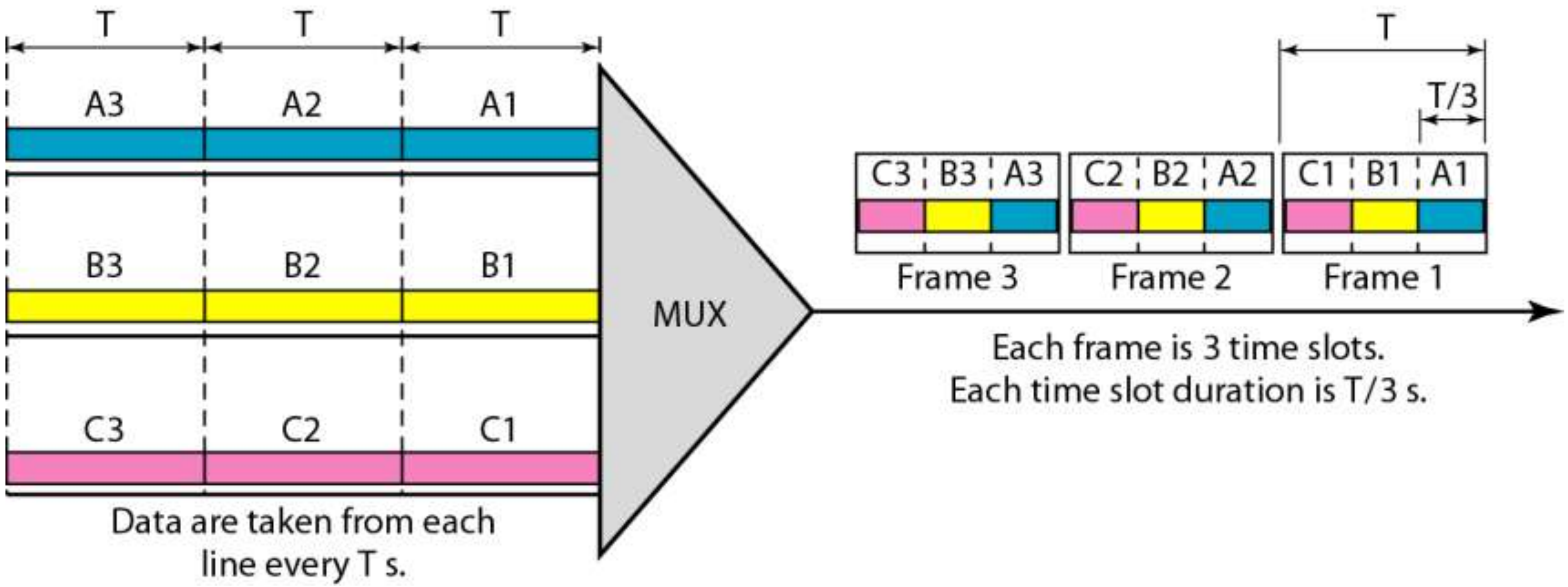


Figure 6.18 *Empty slots*

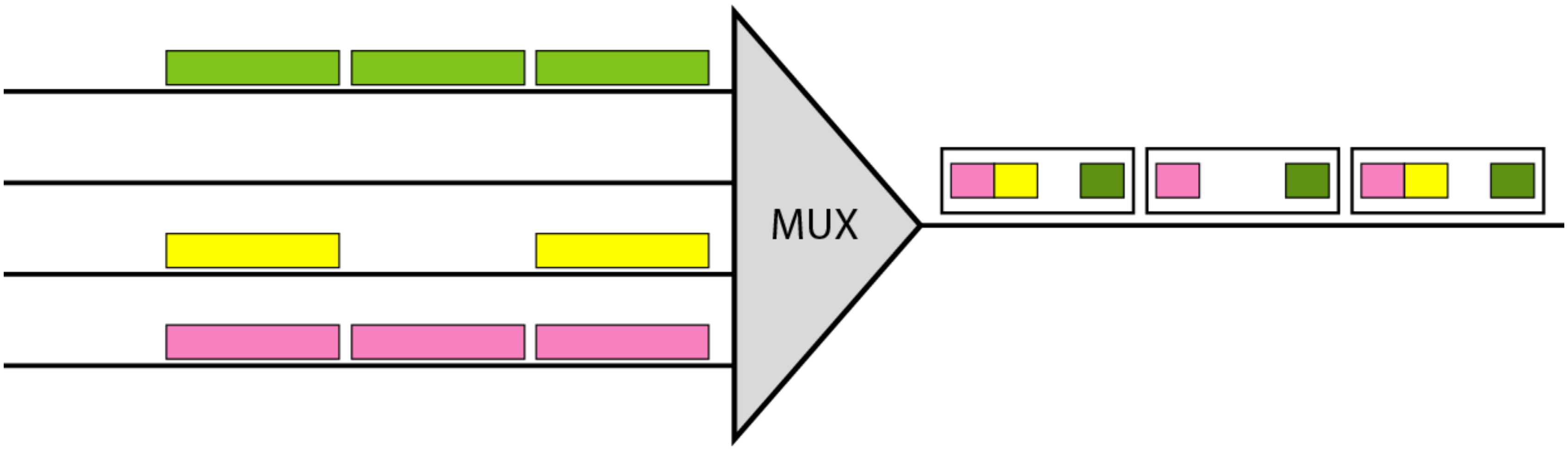
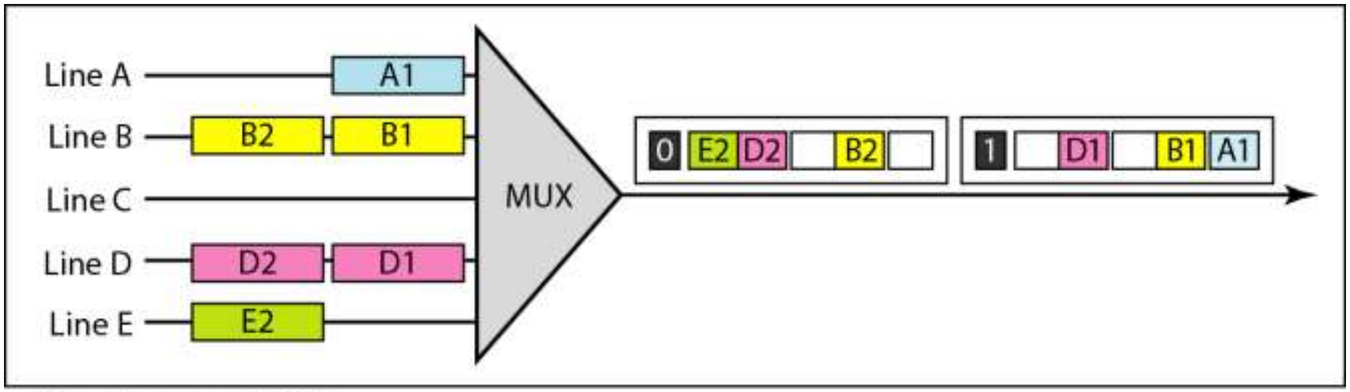
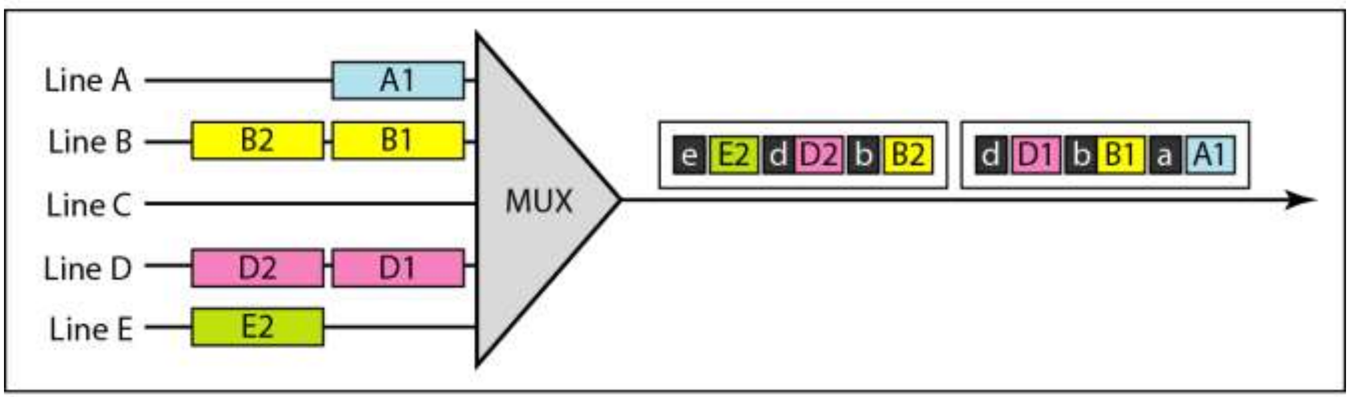


Figure 6.26 *TDM slot comparison*



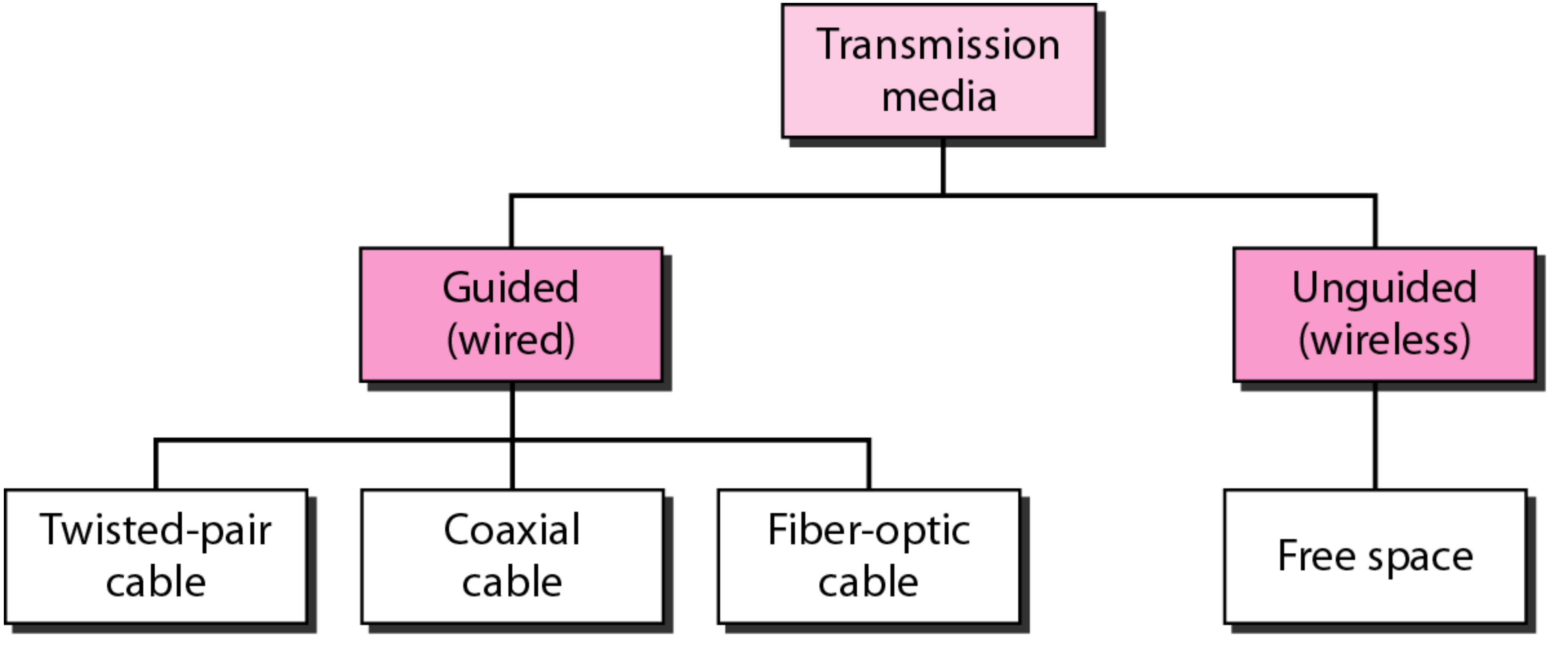
a. Synchronous TDM



b. Statistical TDM

Transmission Media

Figure 7.2 *Classes of transmission media*



7-1 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.

Twisted Pair

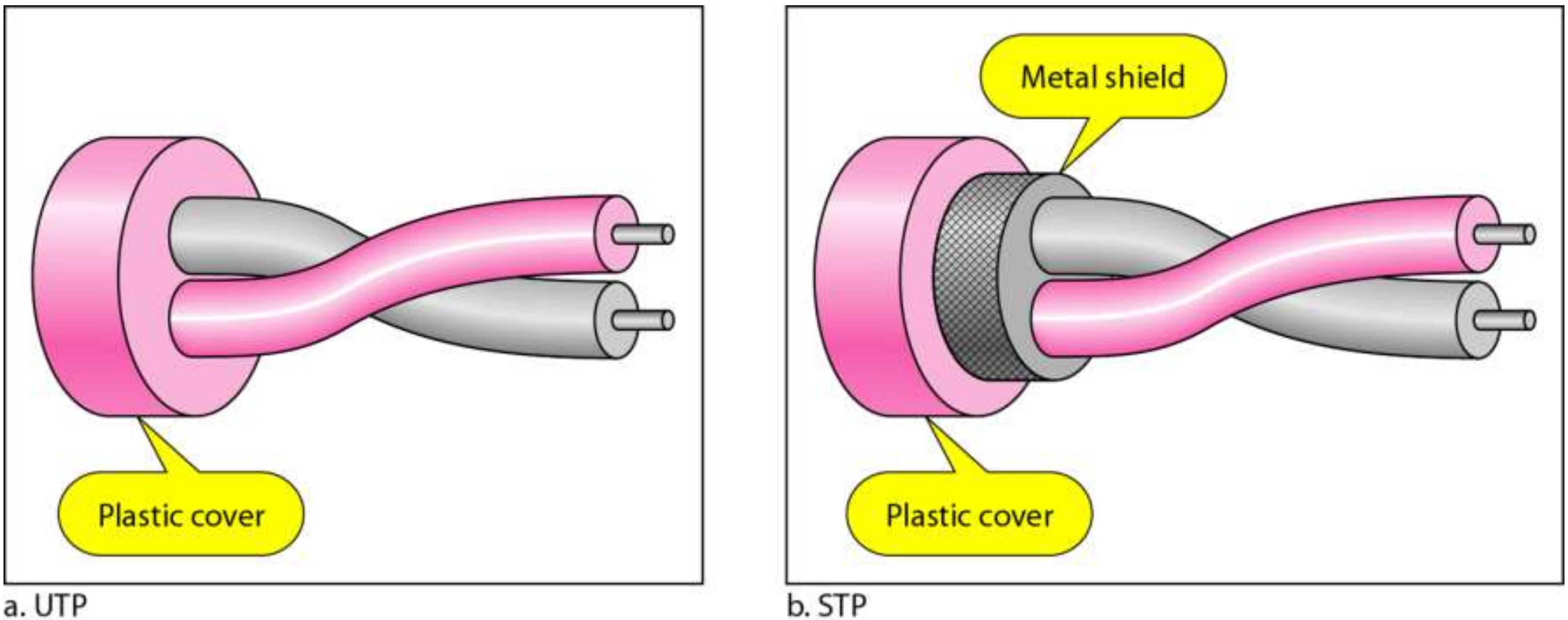
a) Two insulated wires arranged in a spiral pattern.
b) Copper or steel wires are coated with plastic.
c) The signal is transmitted through one wire and a ground reference is transmitted in the other wire.
d) Typically twisted pair is installed in building telephone wiring.
e) Local loop connection to central telephone exchange is twisted pair.

Twisted Pair

Limited in distance, bandwidth and data rate due to problems with attenuation, interference and noise.

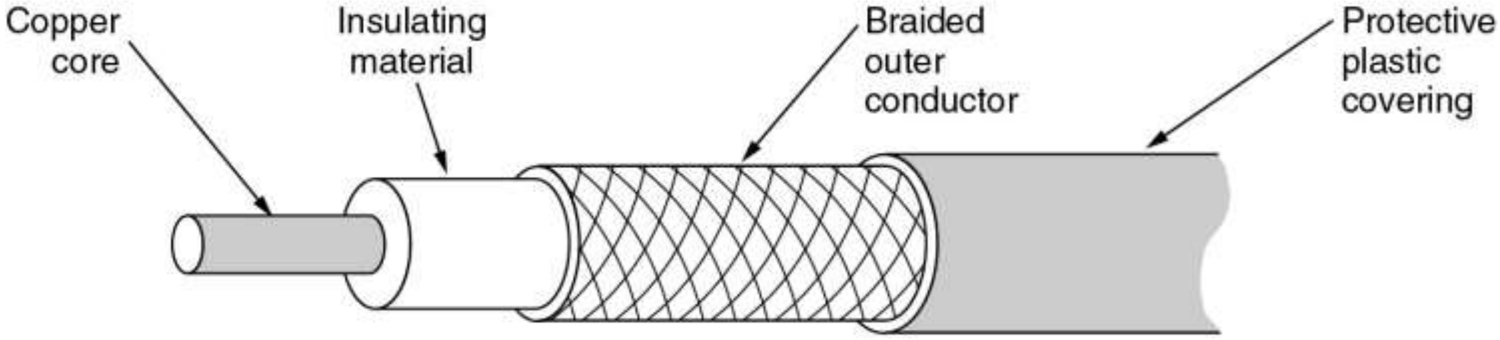
- **Issue: *cross-talk* due to interference from other signals.**
- **“shielding” wire (shielded twisted pair (STP)) with metallic braid or sheathing reduces interference.**
- **“twisting” reduces low-frequency interference and crosstalk.**

Figure 7.4 *UTP and STP cables*



Coaxial Cable

A coaxial cable.



- Coaxial cable carries signals of higher frequency ranges than those in twisted pair cable, in part because the two media are constructed 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.

- 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.

BASEBAND

Uses digital signaling

Bi-directional transmission

No frequency-division multiplexing

Signal travels over short distances - (attenuation becomes evident after 1 km of medium, after which repeaters can be used to retransmit the signal)

Used primarily on bus Uses Manchester or differential Manchester encoding

BROADBAND

uses analog signaling

Unidirectional transmission

Frequency-division multiplexing is possible - Separate channels can support separate and independent data traffic)

Signal can travel over long distances before being attenuated

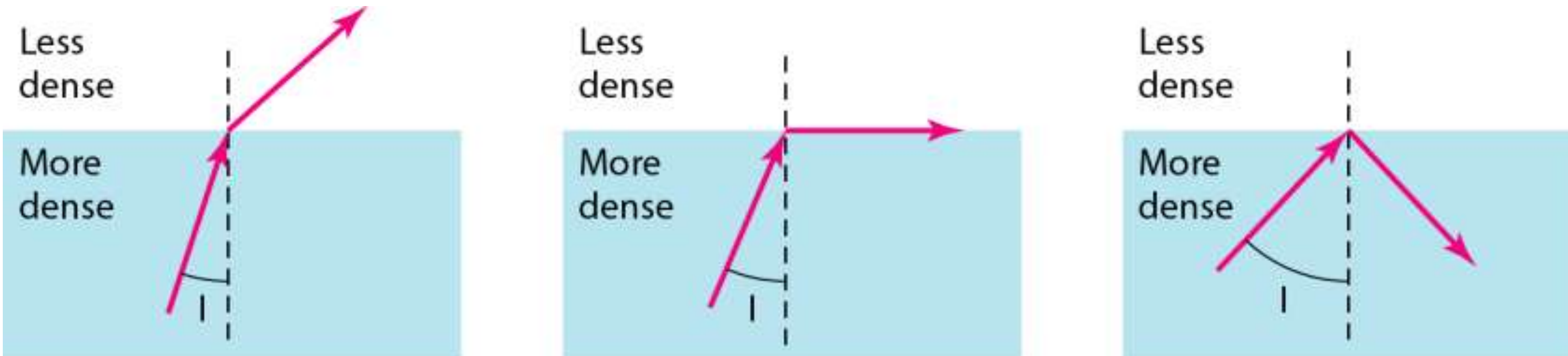
Good for both bus and tree topologies

No digital encoding

Optical Fiber

- Optical fiber :: a thin flexible medium capable of conducting optical rays. Optical fiber consists of a very fine cylinder of glass (core) surrounded by concentric layers of glass (cladding).
- a signal-encoded beam of light (a fluctuating beam) is transmitted by <u>total internal reflection</u>.
- Total internal reflection occurs in the core because it has a higher optical density (index of refraction) than the cladding.
- Attenuation in the fiber can be kept low by controlling the impurities in the glass.

Figure 7.10 Fiber optics: *Bending of light ray*



I < critical angle, refraction

I = critical angle, refraction

I > critical angle, reflection

Optical Fiber

- If the angle of incidence I (the angle the ray makes with the line perpendicular to the interface between the two substance) is less that 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 surface.

- If the angle I greater than the critical angle, the ray reflects (makes a turn) and travels again in the denser substance.

- Note that the critical angle is property of the substance, and its value differs from one substance to another.

Optical Fiber

- Optical fibers use reflection to guide light through a channel.
- A glass or plastic 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 of the cladding instead of being refracted into it.

Figure 7.11 *Optical fiber*

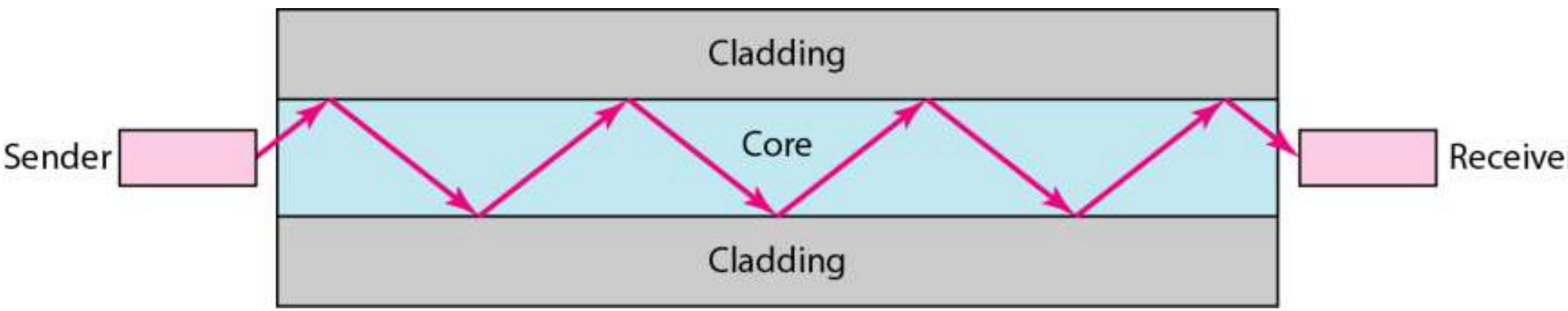
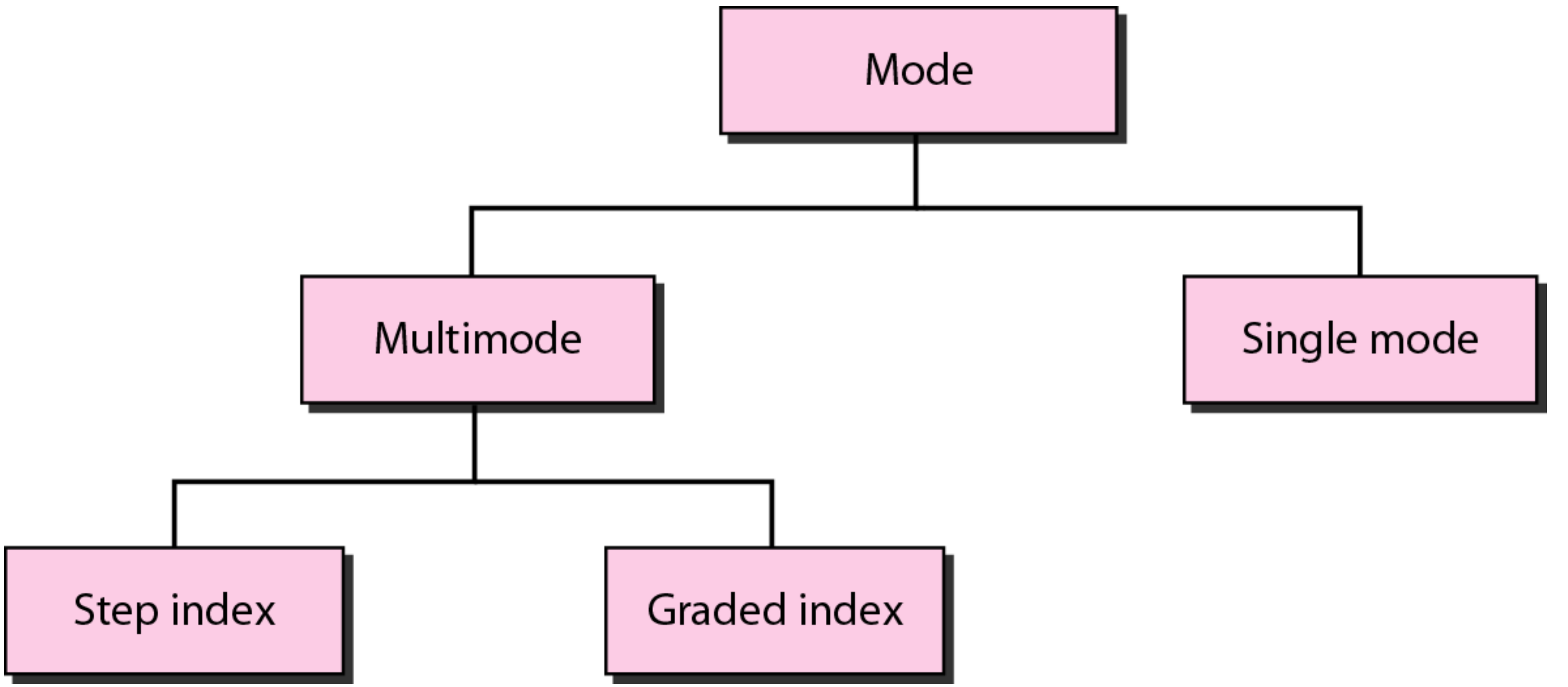


Figure 7.12 *Propagation modes*



Optical Fiber

- Multimode is so named because multiple beams from a light source move through the core in different paths.
- 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.
- At the interface, there is an abrupt change due to a lower density, this alters the angle of the beam’s motion.
- 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.

Optical Fiber

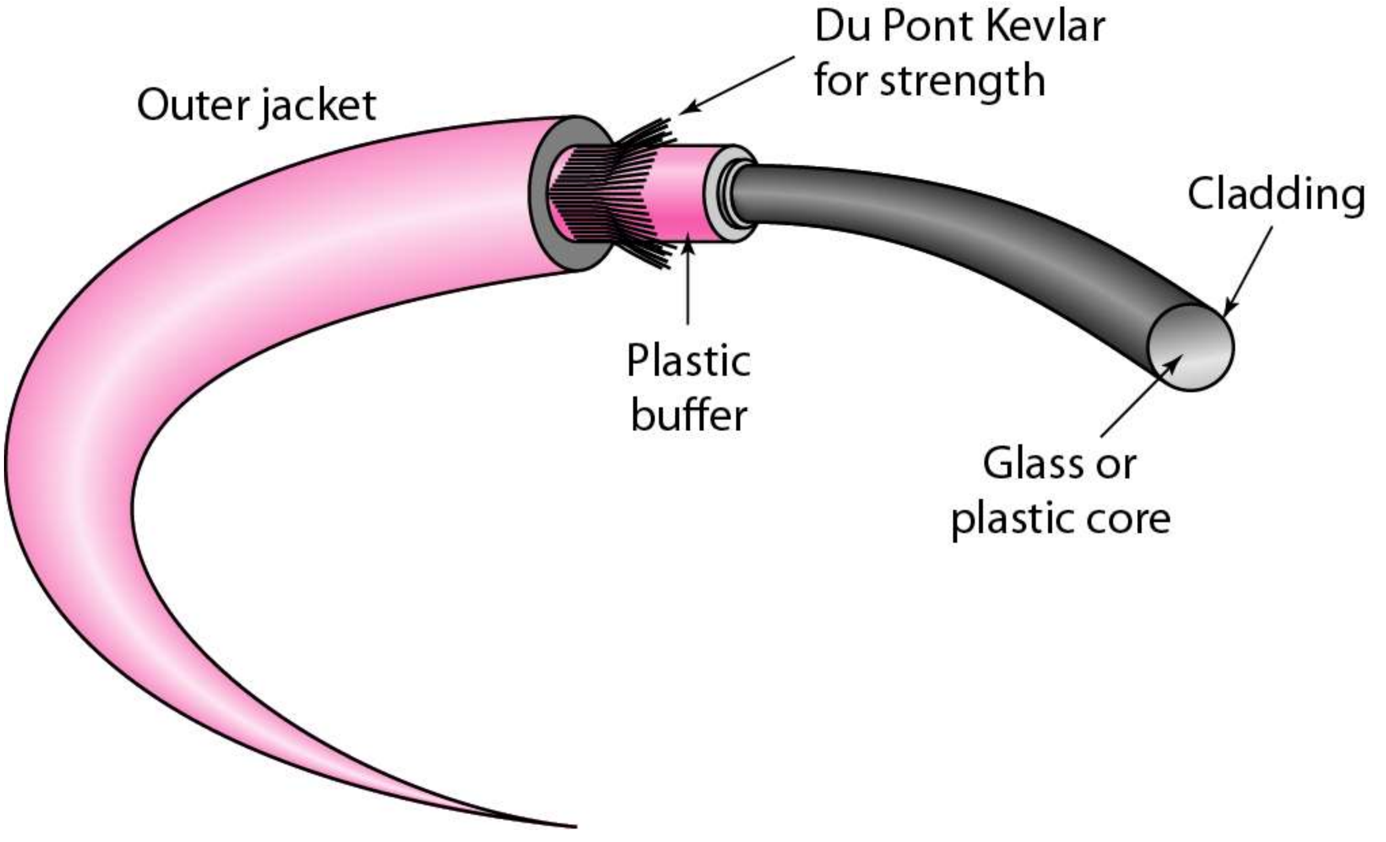
- Multimode step index fibers are similar to the single mode step index fibers except the center core is much larger with multimode configuration.

- With this large core diameter there are many paths through which light can travel.

- This type of fiber has a large light to fiber aperture and allows more light to enter the fiber.

- The light rays that strike the core/cladding interface at an angle greater than the critical angle are propagated down the core in a zigzag fashion.

Figure 7.14 *Fiber construction*



UNGUIDED MEDIA: WIRELESS

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

Radio Waves
Microwaves
Infrared

Unguided Media: Wireless

Unguided transmission is used when running a physical cable (either fiber or copper) between two end points is not possible.

For example, running wires between buildings is probably not legal if the building is separated by a public street.

Infrared signals typically used for short distances (across the street or within same room),

Microwave signals commonly used for longer distances (10's of km). Sender and receiver use some sort of dish antenna

Figure 7.17 *Electromagnetic spectrum for wireless communication*

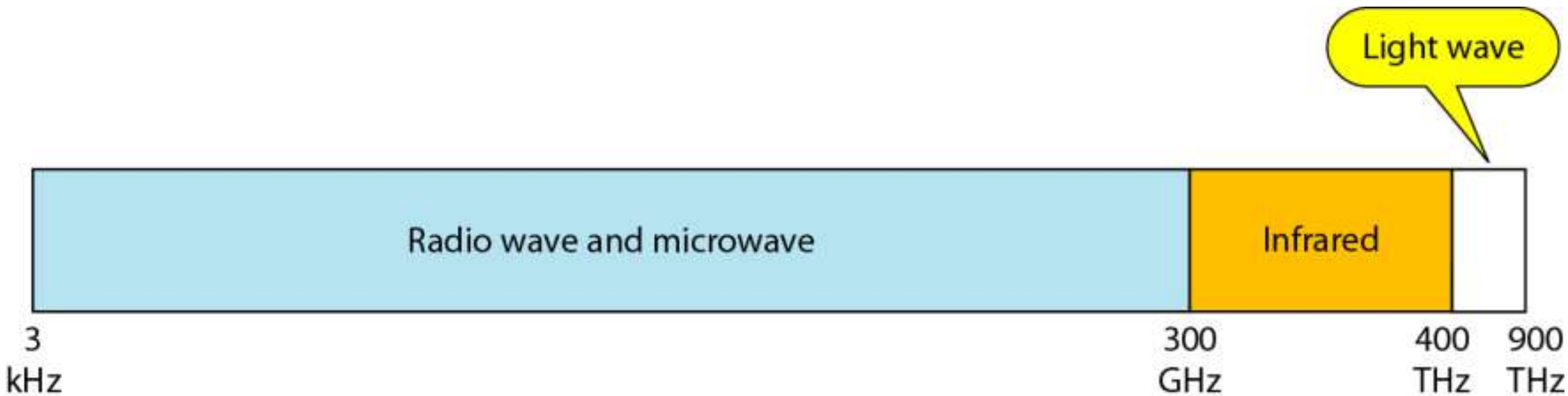
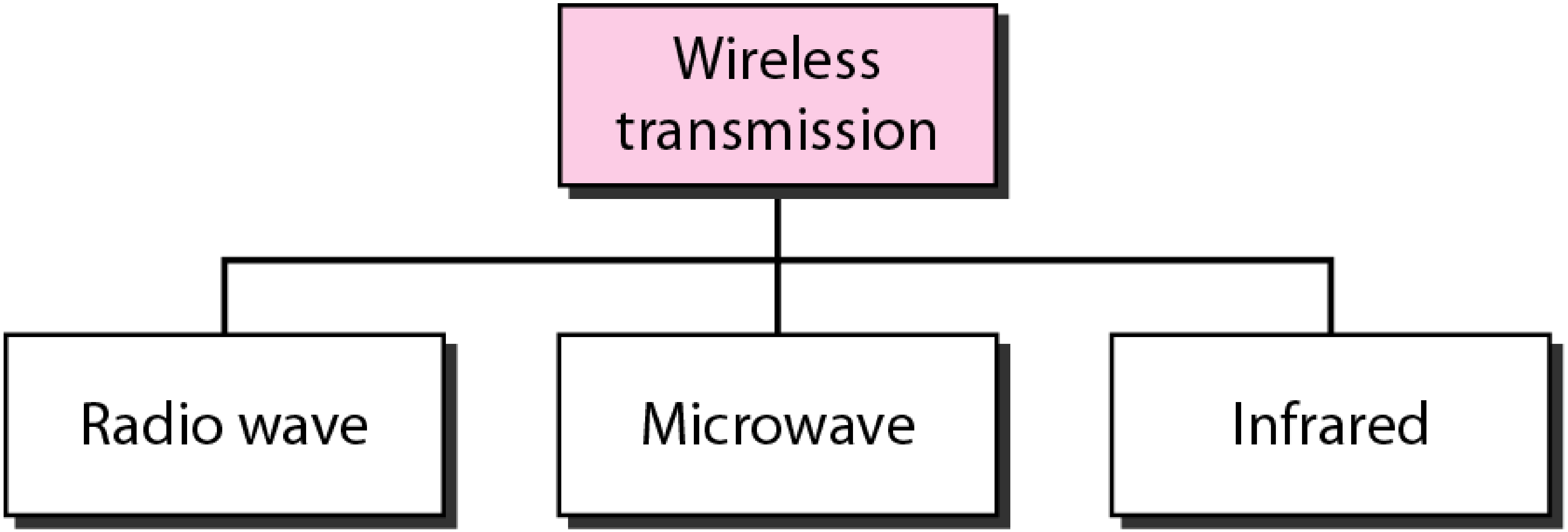


Figure 7.19 *Wireless transmission waves*



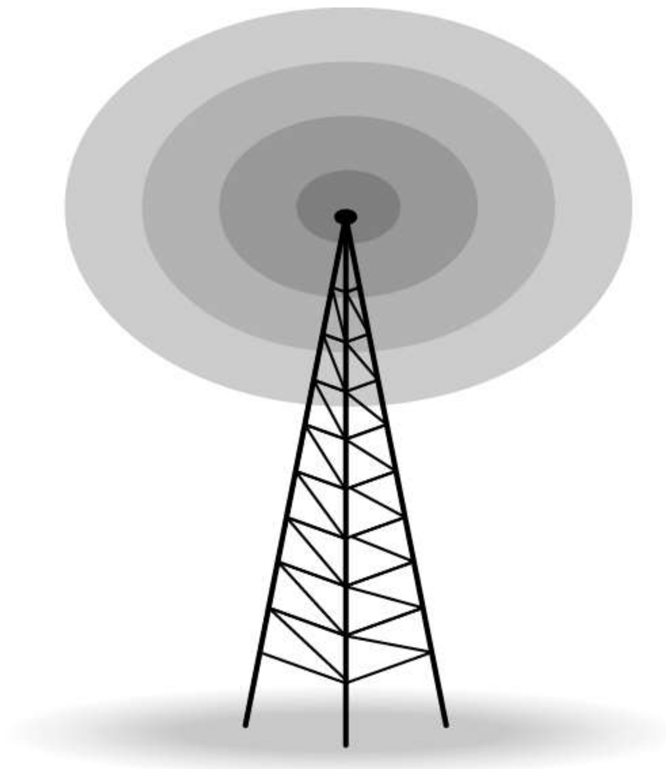
RADIO WAVE

- Ranges in frequencies between 3 Khz and 1 Ghz.
- Radio waves use omnidirectional antenna.
- When an antenna transmits radio waves, they are propagated in all directions.
- This means that the sending and receiving antenna do not have to be aligned.
- A sending antenna send waves that can be received by any receiving antenna.
- It has a disadvantage , that radio waves transmitted by one antennas are susceptible to interference by another antenna that may send signals using the same frequency or band.

RADIO WAVE

- Omni directional antenna of radio waves make them useful for multicasting, in which there is one sender but many receivers
- AM, FM, Television, Cordless Phone and paging

Figure 7.20 *Omnidirectional antenna*



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

Microwave

- Electromagnetic waves having frequencies between 1 and 300 GHz are called micro-waves.
- It uses uni-directional antenna
- When an antenna transmits microwave waves, they can be narrowly focused.
- This means that the sending and receiving antennas need to be aligned.
- It has an advantage, a pair of antennas can be aligned without interfering with another pair of aligned antennas.

Microwave

- Unidirectional antenna can be parabolic dish antenna and the horn
- A parabolic antenna is based on the geometry of a parabola : Every line parallel to the line of symmetry reflects off the curve at angles such that all the lines intersect in a common point called the focus.
- The parabolic dish works as a funnel, catching a wide range of waves and directing them to a common point.
- In this way, more of the signal is recovered than would be possible with a single-point receiver.

Infrared

- Unguided
- Used for remote controls
- Highly directional, cheap and easy to build
- Line of sight
- Do not pass through solid object
- + so less interference (u cant control your neighbors TV, VCR, audio systems)
- + No govt license requred

Communication Satellites

- Geostationary Satellites
- Medium-Earth Orbit Satellites
- Low-Earth Orbit Satellites
- VSAT

Satellite Networks

Microwave frequencies, which travel in straight lines, are commonly used for wideband communication.

The curvature of the earth results in obstruction of the signal between two *earth stations* and the signal also gets attenuated with the distance it traverses.

To overcome both the problems, it is necessary to use a *repeater*, which can receive a signal from one earth station, amplify it, and retransmit it to another earth station.

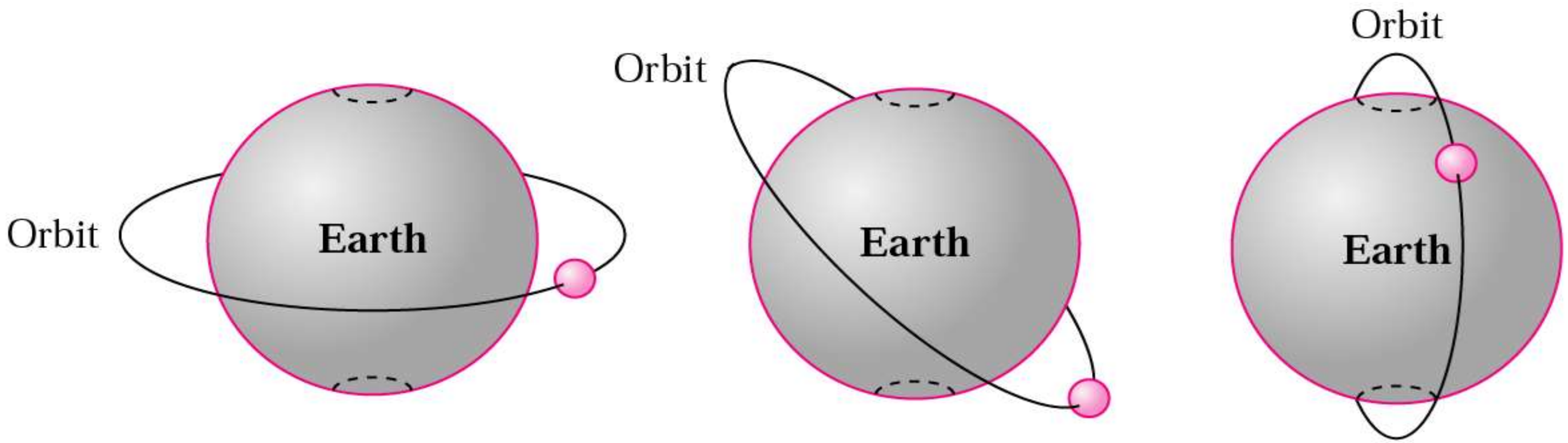
Larger the height of a repeater from the surface of the earth, longer is the distance of line-of-sight communication.

Satellite Networks

Satellite networks were originally developed to provide long-distance telephone service.

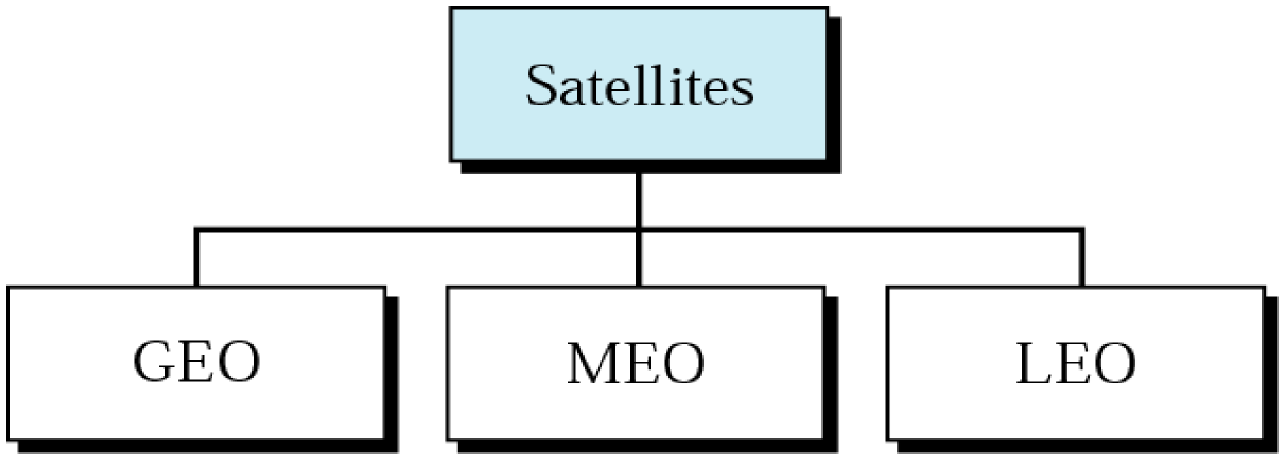
So, for communication over long distances, satellites are a natural choice for use as *repeaters in the sky*. In this lesson, we shall discuss different aspects of satellite networks.

Satellite Networks



a. Equatorial-orbit satellite   b. Inclined-orbit satellite   c. Polar-orbit satellite

Satellite Networks



Satellite Networks

The satellites can be categorized into three different types , based on the location of the orbit.

These orbits are chosen such that the satellites are not destroyed by the high-energy charged particles present in the two *Van Allen belts*, as shown in Fig..

The Low Earth Orbit (LEO) is below the lower Van Allen belt in the altitude of 500 to 2000 Km. T

he Medium Earth Orbit (MEO) is in between the lower Van Allen belt and upper Van Allen belt in the altitude of 5000 to 15000 Km.

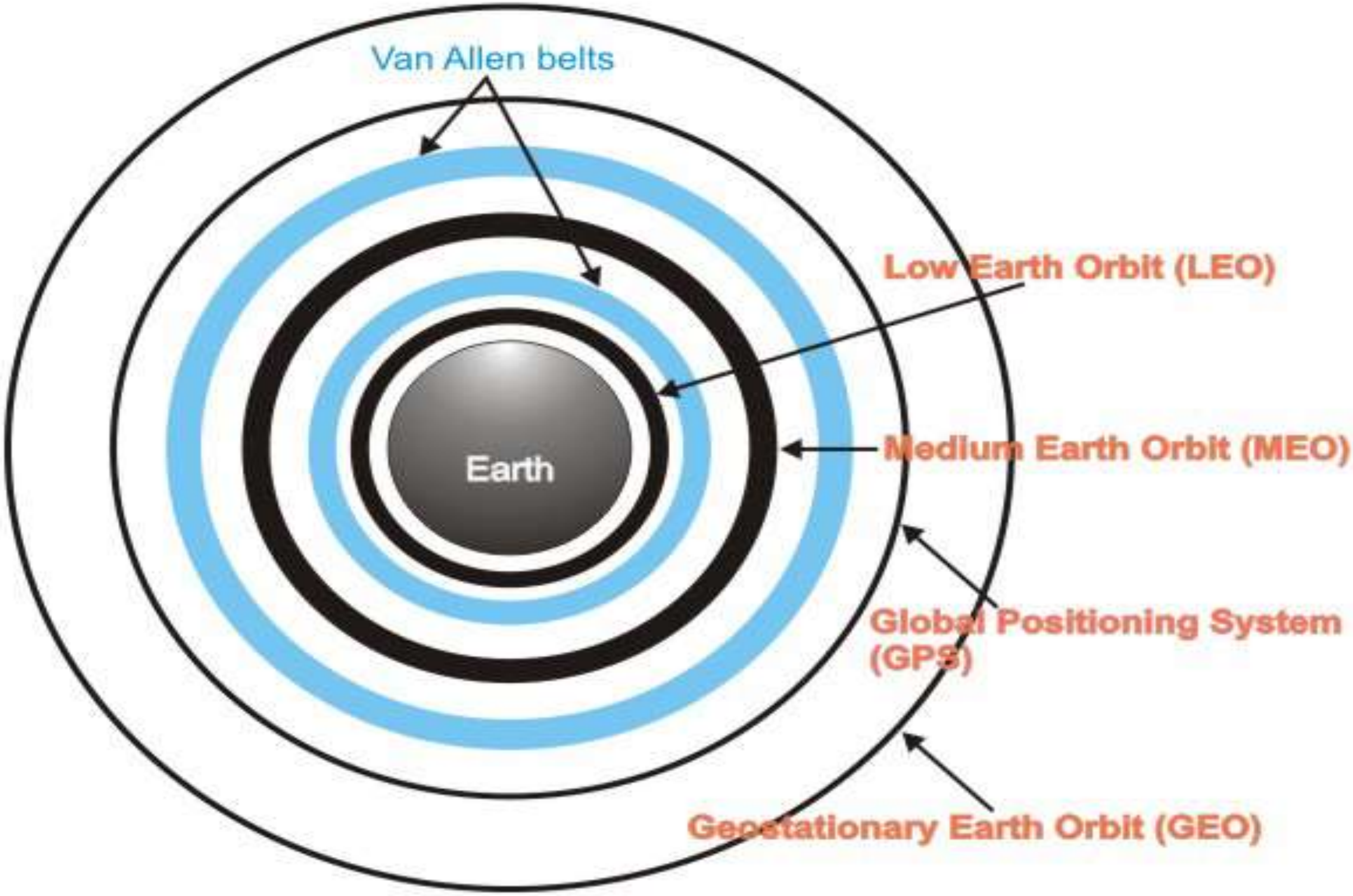
Satellite Networks

The Medium Earth Orbit (MEO) is in between the lower Van Allen belt and upper Van Allen belt in the altitude of 5000 to 15000 Km.

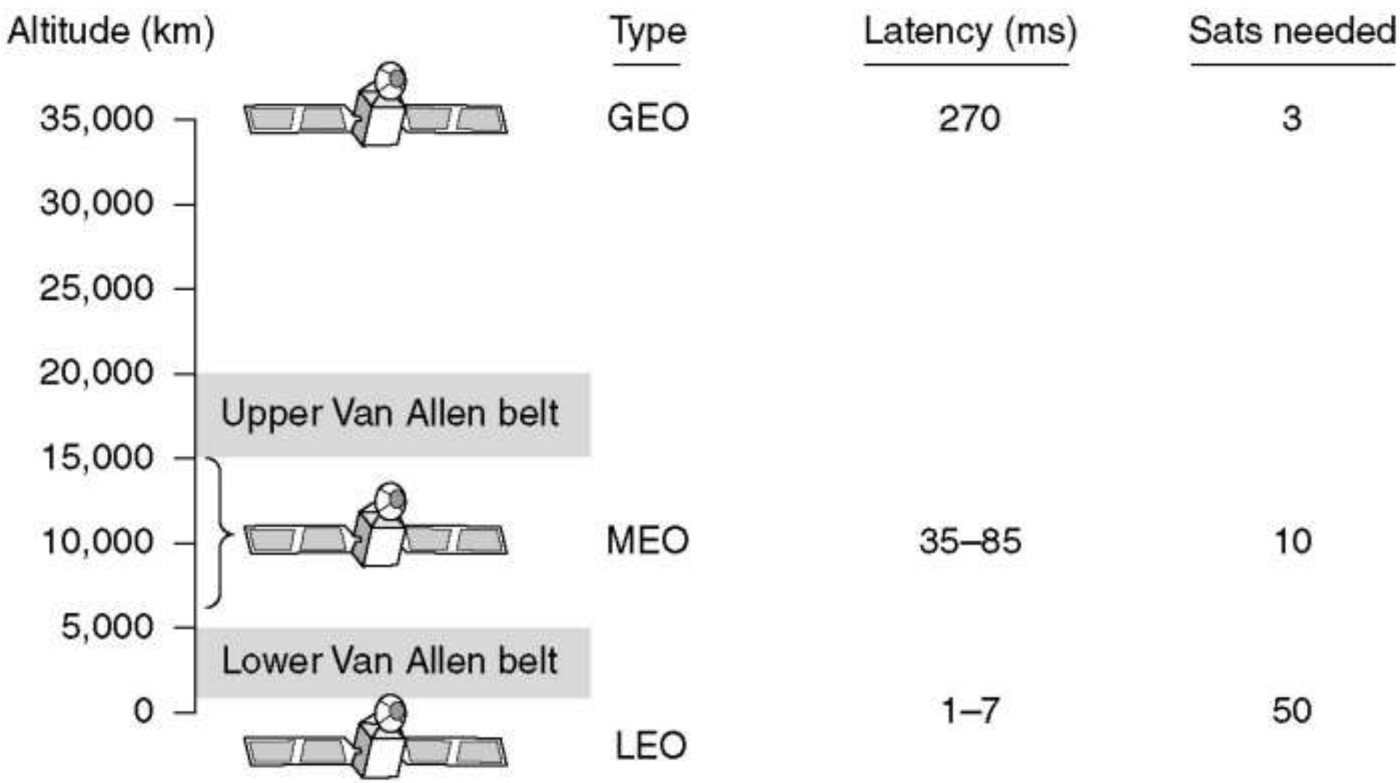
Above the upper Van Allen belt is the Geostationary Earth Orbit (GEO) at the altitude of about 36,000 Km.

Below the Geostationary Earth Orbit and above the upper Van Allen belt is Global Positioning System (GPS) satellites at the altitude of 20,000 Km.

Satellite Networks



Communication Satellites



Communication satellites and some of their properties, including altitude above the earth, round-trip delay time and number of satellites needed for global coverage.

Low-Earth Orbit Satellites

- Rapid motion
- Large number are needed to make a system
- Close to earth so ground stations need less power
- Round trip delay is less

Medium-Earth Orbit Satellites

- Take 6 hrs to encircle the earth so they must be tracked
- Smaller footprint as they are lower than geo sats
- Require less powerful transmitters
- The 24 global positioning satellites orbiting at 18000km

Medium Earth Orbit Satellites

MEO satellites are positioned between two Van Allen Belts at an height of about 10,000 Km with a rotation period of 6 hours. One important example of the MEO satellites is the Global Positioning System (GPS)

GPS

The Global Positioning System (GPS) is a satellite-based navigation system. It comprises a network of 24 satellites at an altitude of 20,000 Km (Period 12 Hrs) and an inclination of 55° as shown in Fig.

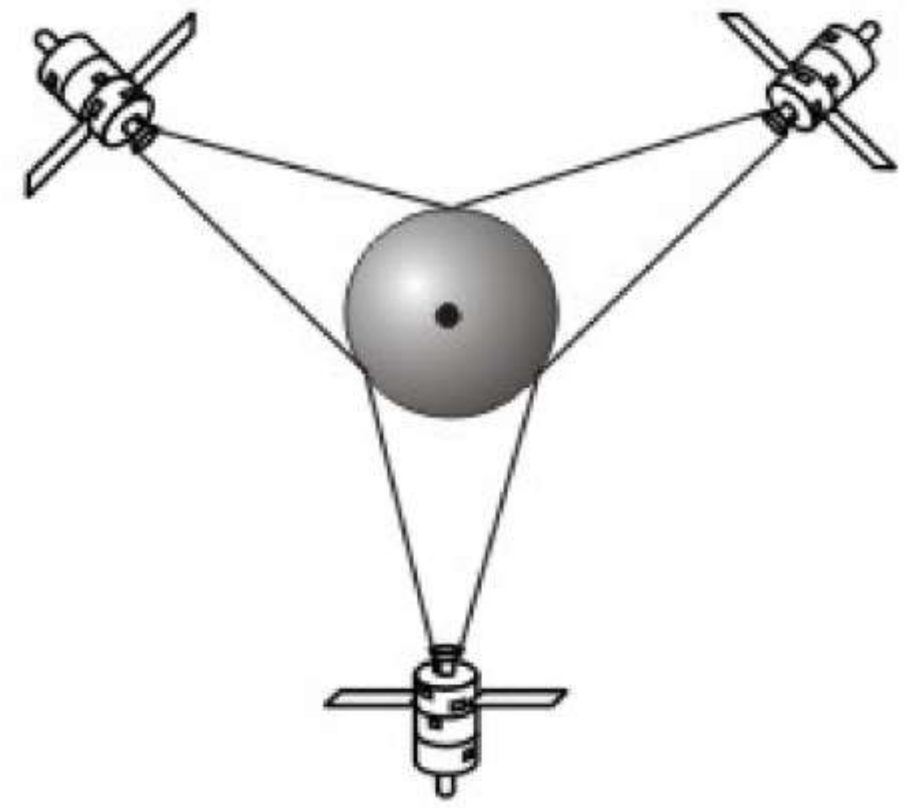
Although it was originally intended for military applications and deployed by the Department of Defence, the system is available for civilian use since 1980.

It allows land, sea and airborne users to measure their position, velocity and time.

It works in any weather conditions, 24 hrs a day.
Positioning is accurate to within 15 meters.
It is used for land and sea navigation using the principle of triangulation as shown in Fig. .
It requires that at any time at least 4 satellites to be visible from any point of earth. A GPS receiver can find out the location on a map.

Figure shows a GPS receiver is shown in the caption’s cabin of a ship. GPS was widely used in Persian Gulf war.

Satellite Networks



Three satellites providing full global coverage i GEO system Version

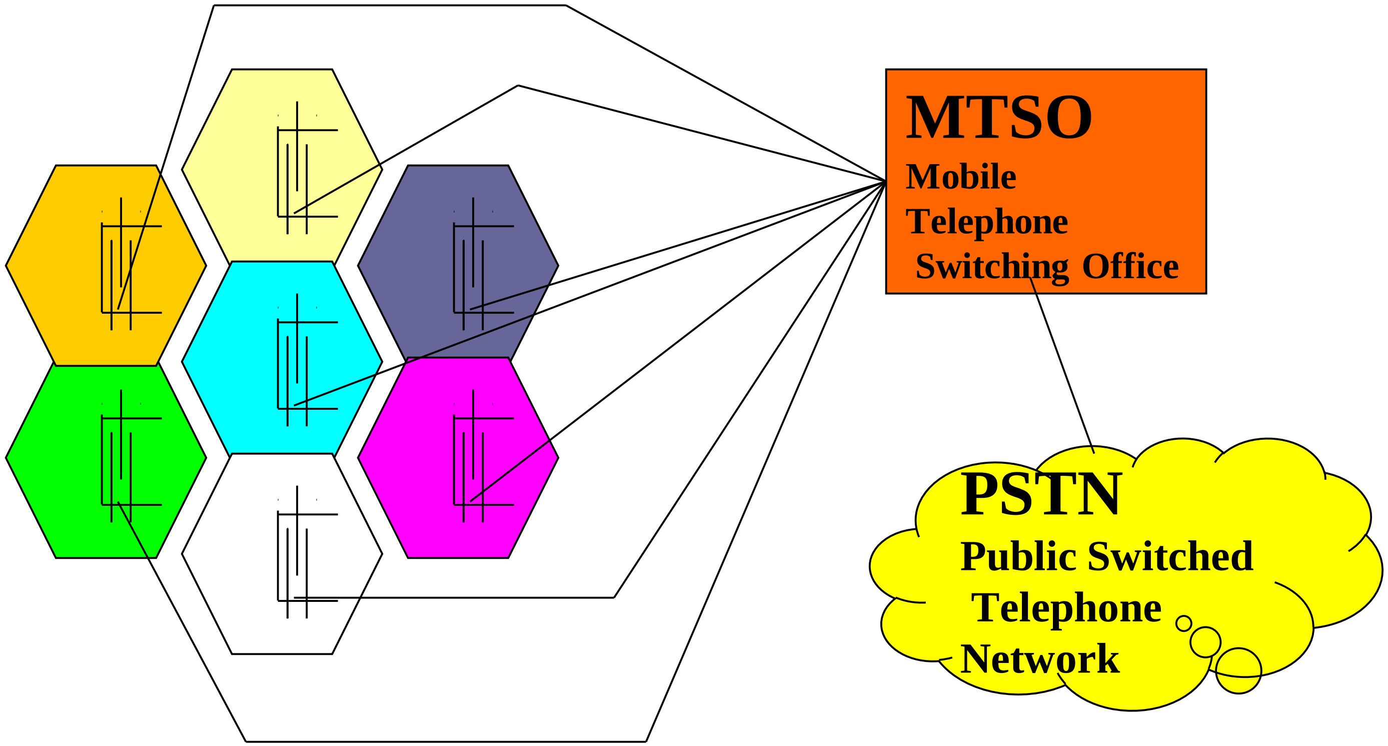
Geostationary satellites

- 2 degree seperation required so 360/2 = 180 satellites can be placed in the equatorial plane of the earth
- Transponders can use different frequencies and polarizations to increase the available bandwidth
- Station keeping
- Footprint (the area covered by the satellite signal)
- Wide beam
- Spot beam (multiple transponders)

The Mobile Telephone System

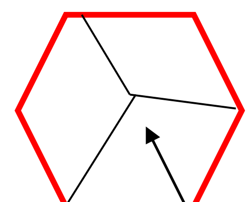
How cellular telephone systems work

a) **The area (a city, or a part of town) is divided into a number of cells (typically 2 to 10 miles in size, but can be smaller for more crowded areas) and a base station is positioned within each cell**
b) **If a user (mobile phone) is within a particular cell, the call is handled by the corresponding base station within that cell**
c) **The base station transmits the signal to the mobile switching center (MTSO) which switches the signal to another base station, or to a Public Switched Telephone Network (PSTN), depending on the destination of the call: whether another mobile unit or a regular telephone**
d) **As a user moves from one cell to another, the call is "handed over" to the base station of the other cell-This is called *hand-off***
e) **The handover is (hopefully) transparent to the user**



MTSO
Mobile
Telephone
Switching Office
PSTN
Public Switched
Telephone
Network

- The mobile unit and the base station in a cell communicate at a certain frequency
- The signal from the mobile unit arrives at the antenna of the base station and is converted into an electrical signal



Advanced Mobile Phone System

***Base station* – At the center of each cell is a base station to which all phones in the cell transmit**

Consists of a computer and transmitter/receiver connected to an antenna

Connected to Mobile Telephone Switching Office (MTSO), or Mobile Switching Center (MSC)

At any time, mobile phone is logically in one cell and under control of that cell's base station

***Handoff* – The process of breaking a connection with the base station in one cell and reestablishing a connection with the base station in another cell**

When mobile phone leaves a cell, its base station notices the phone signal fading and asks surrounding base stations how much power they're getting from the mobile

Base station then transfers ownership to the base station getting the strongest signal

Mobile is informed of its new base station and switches to a new channel

Advanced Mobile Phone System

- Uses FDM
  - 832 transmission channels, 30kHz wide
  - 832 receive channels, 30kHz wide
- The 832 channels are divided into four categories
  - Control (base station to mobile) to manage the system
    - 21 channels
  - Paging (base station to mobile) to alert users of calls for them
  - Access (bidirectional) for call setup and channel assignment
  - Data (bidirectional) for voice, fax, or data
- Each mobile phone has a 32-bit serial number, and a 10-digit phone number, in its PROM

Advanced Mobile Phone System

- Steps in Call Management
  - When switched on, **mobile phone** scans list of 21 control channels to find most powerful signal from which it learns the numbers of the paging channel and access channel
  - **Mobile phone** then sends its serial number and phone number on the **access channel**
  - When the **base station** hears this, it tells the MTSO
  - **MTSO** records the new customer and informs the phone's home MTSO of the customer's location
  - Mobile re-registers every 15 minutes

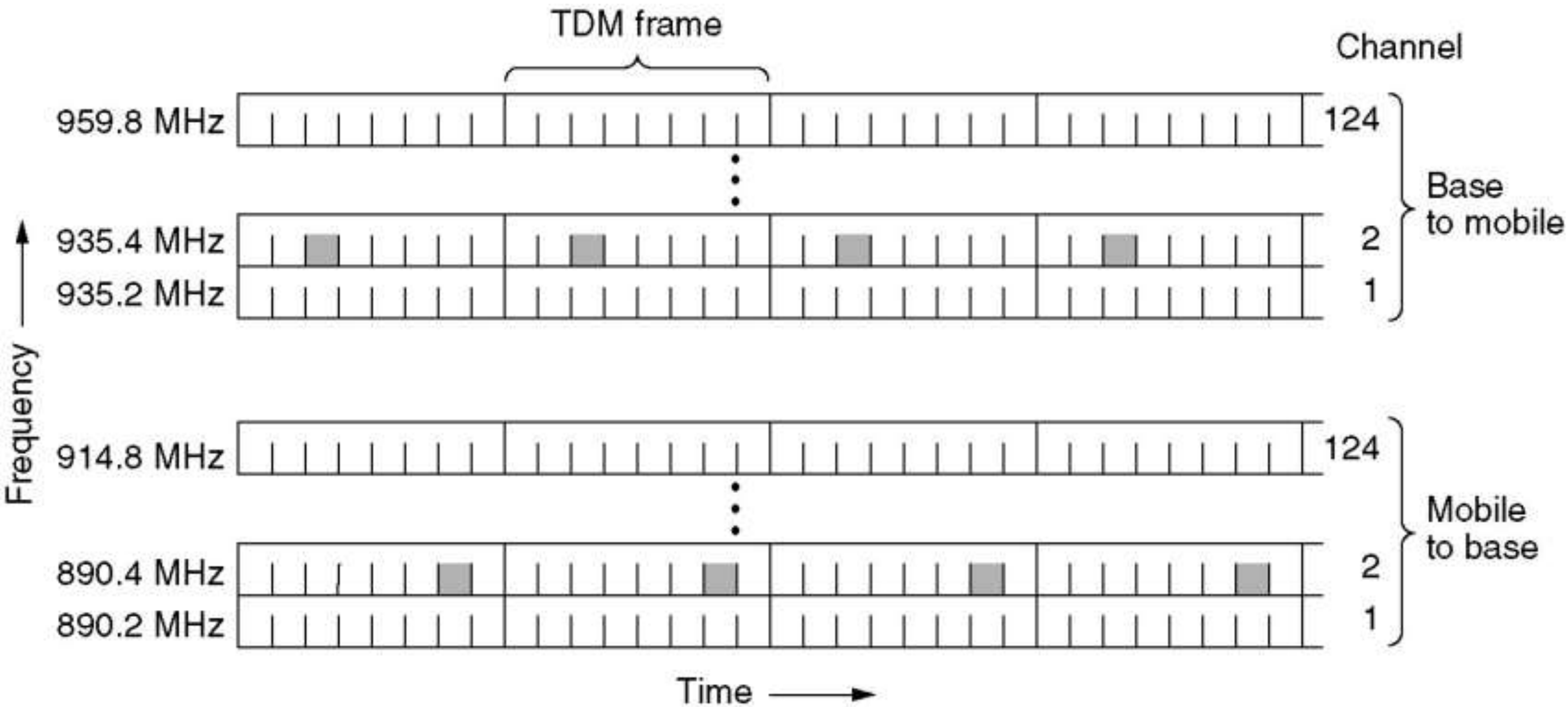
Advanced Mobile Phone System

- Steps in Making a Call
  - User switches on mobile phone, enters number to be called on keypad, hits SEND button
  - **Mobile phone** sends phone number to be called and its own id on the **access channel**
  - When the **base station** gets the request, it informs the MTSO
  - **MTSO** looks for an idle channel for the call and sends channel number back on **control channel**
  - **Mobile phone** switches to selected **voice channel** and waits for called party to pick up the phone

Advanced Mobile Phone System

- Steps in Receiving a Call
  - **Idle phone** continuously listens to **paging channel** to detect messages for them
  - When a call is placed to a mobile phone, **MTSO** is informed which in turn informs mobile's **base station**
  - **Base station** sends on **paging channel**
  - **Mobile phone** responds on **control channel**
  - **Base station** tells mobile phone which channel to switch to
  - **Mobile phone** switches to that channel and phone starts ringing

GSM
Global System for Mobile Communications



GSM uses 124 frequency channels, each of which uses an eight-slot TDM system

Code Division Multiple Access (CDMA)

- Works completely differently from TDM and FDM
  - Each station transmits over entire frequency spectrum all the time
  - Each station is assigned a unique m-bit code, called a *chip sequence*
    - To transmit a 1, the station sends its chip sequence
    - To transmit a 0, it sends the one's complement of its chip sequence
  - Chip sequences for twp different stations are orthogonal, i.e., the inner (dot) product of their chip sequences is 0
  - If two or more stations transmit simultaneously, their chip sequences are added component-wise
  - To determine the bit that a station transmitted, receiver
    - Must know chip sequence of transmitter
    - Computes normalized inner (dot) product of received chip sequence and chip sequence of transmitter

CDMA – Code Division Multiple Access

A: 0 0 0 1 1 0 1 1
B: 0 0 1 0 1 1 1 0
C: 0 1 0 1 1 1 0 0
D: 0 1 0 0 0 0 1 0

(a)

A: (−1 −1 −1 +1 +1 −1 +1 +1)
B: (−1 −1 +1 −1 +1 +1 +1 −1)
C: (−1 +1 −1 +1 +1 +1 −1 −1)
D: (−1 +1 −1 −1 −1 −1 +1 −1)

(b)

Six examples:

– – 1 –	**C**	$S_1 = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$
– 1 1 –	**B + C**	$S_2 = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2)$
1 0 – –	**A +** $\bar{\mathbf{B}}$	$S_3 = (\ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2)$
1 0 1 –	**A +** $\bar{\mathbf{B}}$ **+ C**	$S_4 = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$
1 1 1 1	**A + B + C + D**	$S_5 = (-4\ \ 0\ -2\ \ 0\ +2\ \ 0\ +2\ -2)$
1 1 0 1	**A + B +** $\bar{\mathbf{C}}$ **+ D**	$S_6 = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)$

(c)

$S_1 \bullet C = (1 +1 +1 +1 +1 +1 +1 +1)/8 = 1$
$S_2 \bullet C = (2 +0 +0 +0 +2 +2 +0 +2)/8 = 1$
$S_3 \bullet C = (0 +0 +2 +2 +0 -2 +0 -2)/8 = 0$
$S_4 \bullet C = (1 +1 +3 +3 +1 -1 +1 -1)/8 = 1$
$S_5 \bullet C = (4 +0 +2 +0 +2 +0 -2 +2)/8 = 1$
$S_6 \bullet C = (2 -2 +0 -2 +0 -2 -4 +0)/8 = -1$

(d)

(a) Binary chip sequences for four stations
(b) Bipolar chip sequences
(c) Six examples of transmissions
(d) Recovery of station C's signal