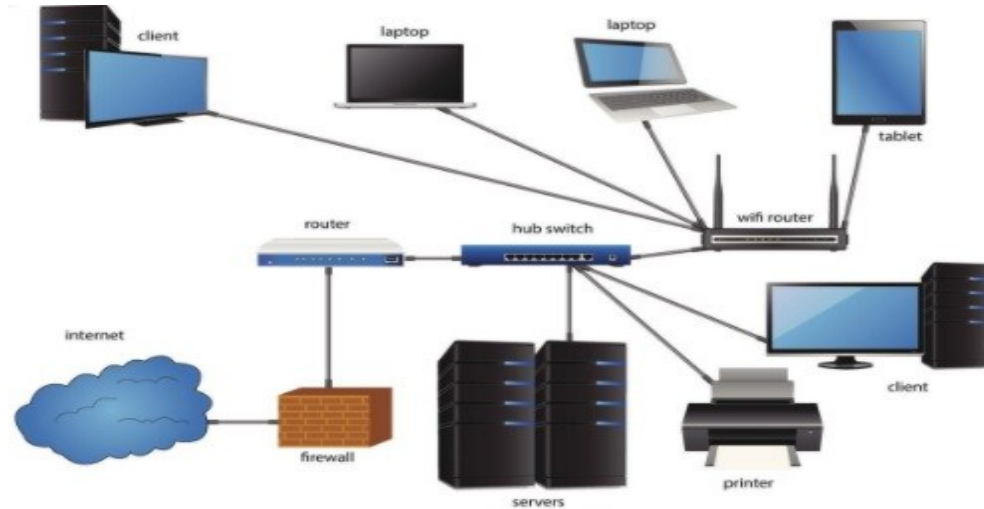


COMPUTER NETWORKS



Instructor: Mr. B. V. Sathish Kumar, Assistant Professor
Department of Electronics and Communication Engineering

Syllabus

UNIT – II

Physical Layer – Fourier Analysis – Bandwidth Limited Signals – The Maximum Data Rate of a Channel – Guided Transmission Media, Digital Modulation and Multiplexing: Frequency Division Multiplexing, Time Division Multiplexing, Code Division Multiplexing Data Link Layer Design Issues, Error Detection and Correction, Elementary Data Link Protocols, Sliding Window Protocols

UNIT-II

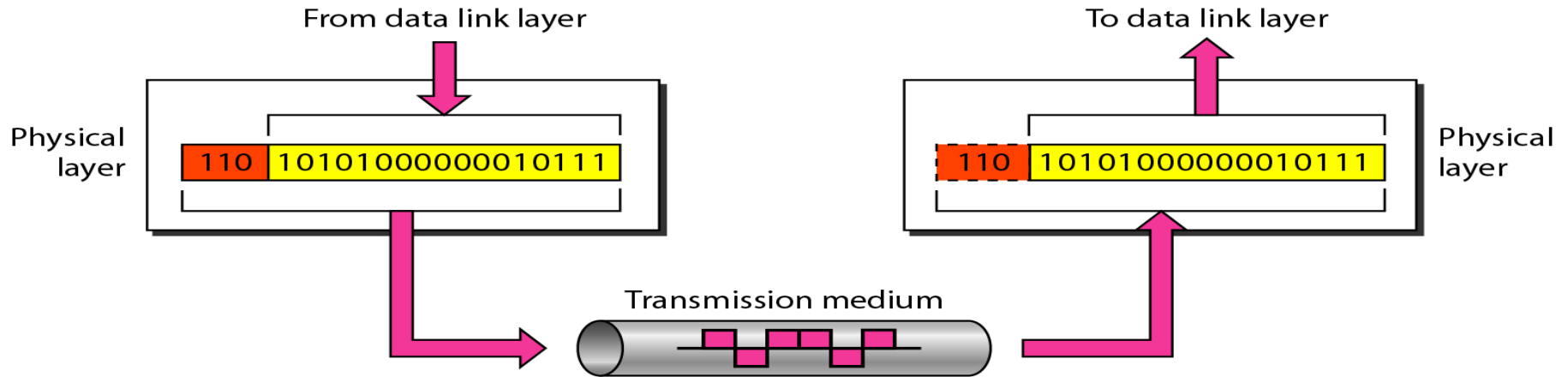
Physical Layer

Functions of physical layer

Transport data using electrical, mechanical or procedural interfaces

- **Signalling**-Transmission of bits in the suitable form over different types of physical media i.e. Light, Voltage or EM waves
- **Data encoding** – Base Band, Band pass transmission
- **Multiplexing** – Allows information from different sources on the same transmission medium without interference

Figure 2.1 *Physical layer*



Theoretical Basis for Data Communication

- Fourier analysis
- Bandwidth-limited signals
- Maximum data rate of a channel

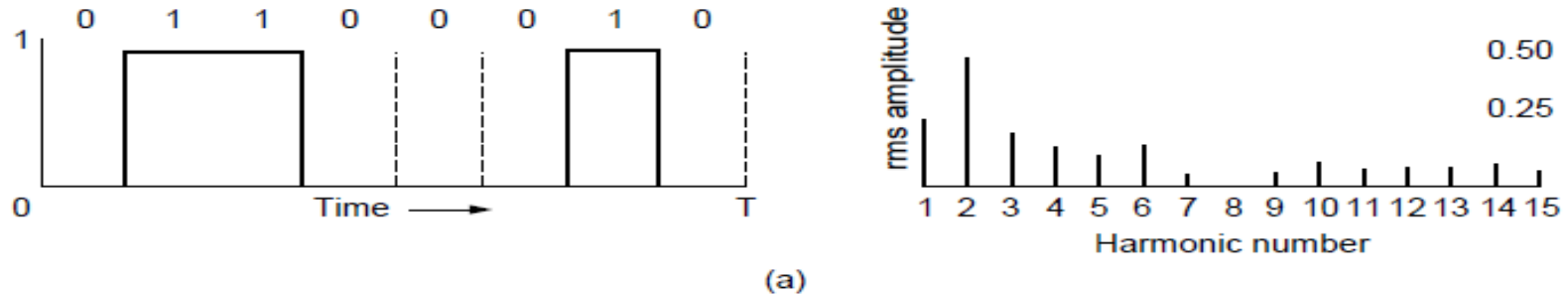
Fourier Analysis

- We model the behavior of variation of voltage or current with mathematical functions

- $$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

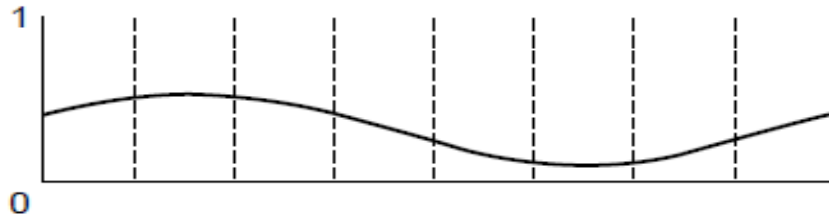
$$a_n = \frac{2}{T} \int_0^T g(t) \sin(2\pi nft) dt \quad b_n = \frac{2}{T} \int_0^T g(t) \cos(2\pi nft) dt \quad c = \frac{2}{T} \int_0^T g(t) dt$$

Bandwidth-Limited Signals

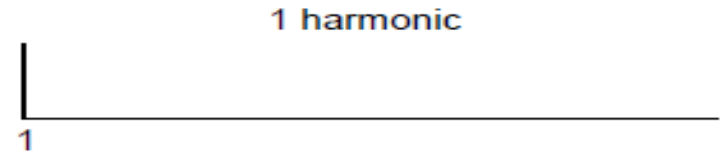


A binary signal and its root-mean-square Fourier amplitudes.

Contd..

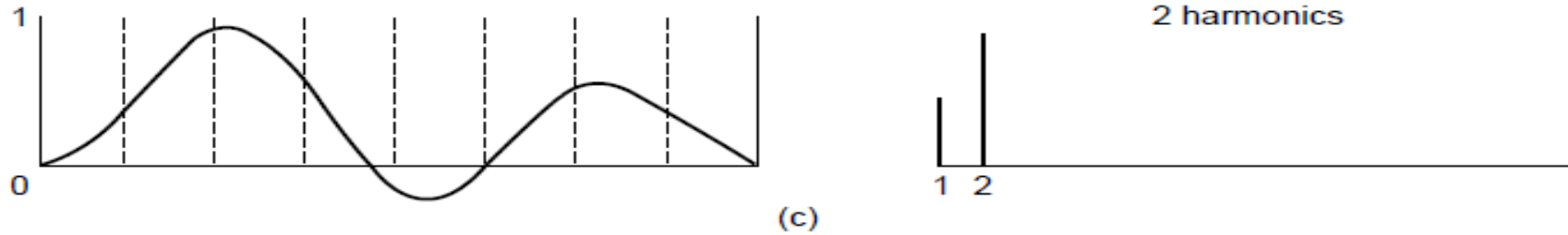


(b)



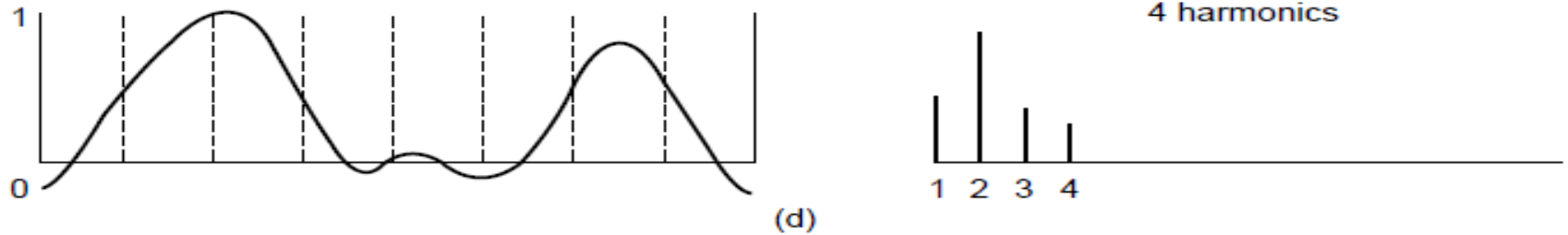
(b)-(e) Successive approximations to the original signal.

Contd..



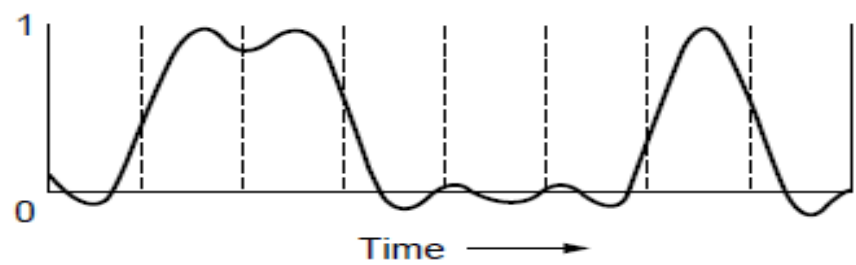
(b)-(e) Successive approximations to the original signal.

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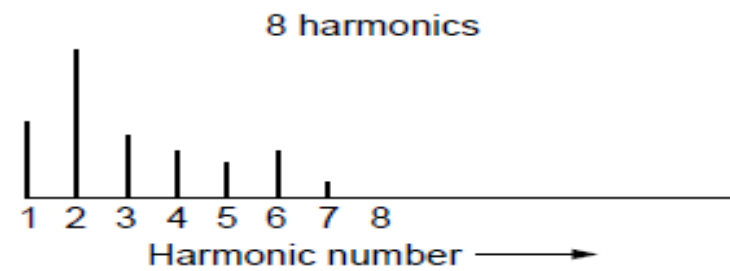


(b)-(e) Successive approximations to the original signal.

Contd..



(e)



(b)-(e) Successive approximations to the original signal.

The Maximum Data Rate of a Channel

- Nyquist's theorem (For Noiseless channel)

$$\text{maximum data rate} = 2 B \log_2 V \text{ bits / sec}$$

- Shannon's formula for capacity of a noisy channel

$$\text{maximum number of bits / sec} = B \log_2 (1 + S / N)$$

Transmission Media

Figure 2.2 *Transmission medium and physical layer*

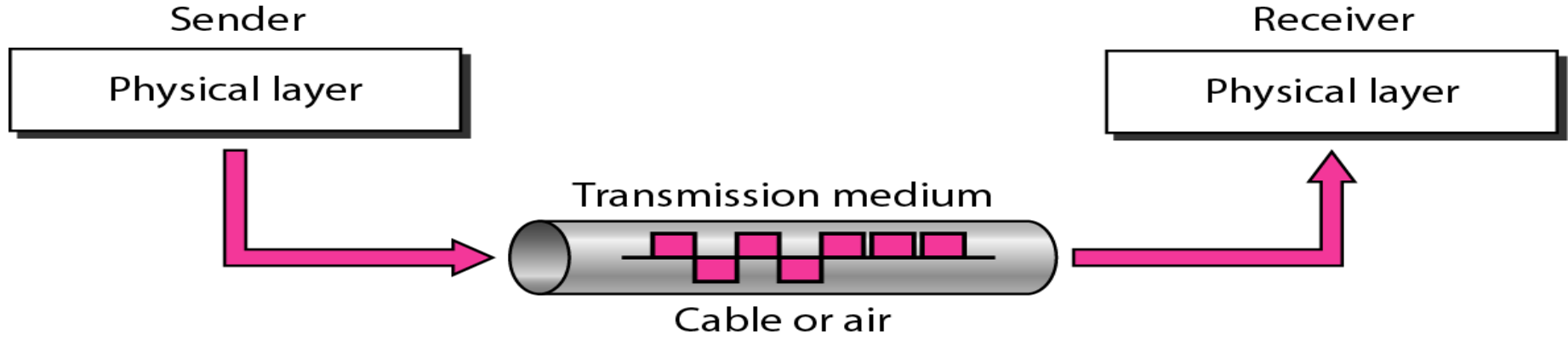
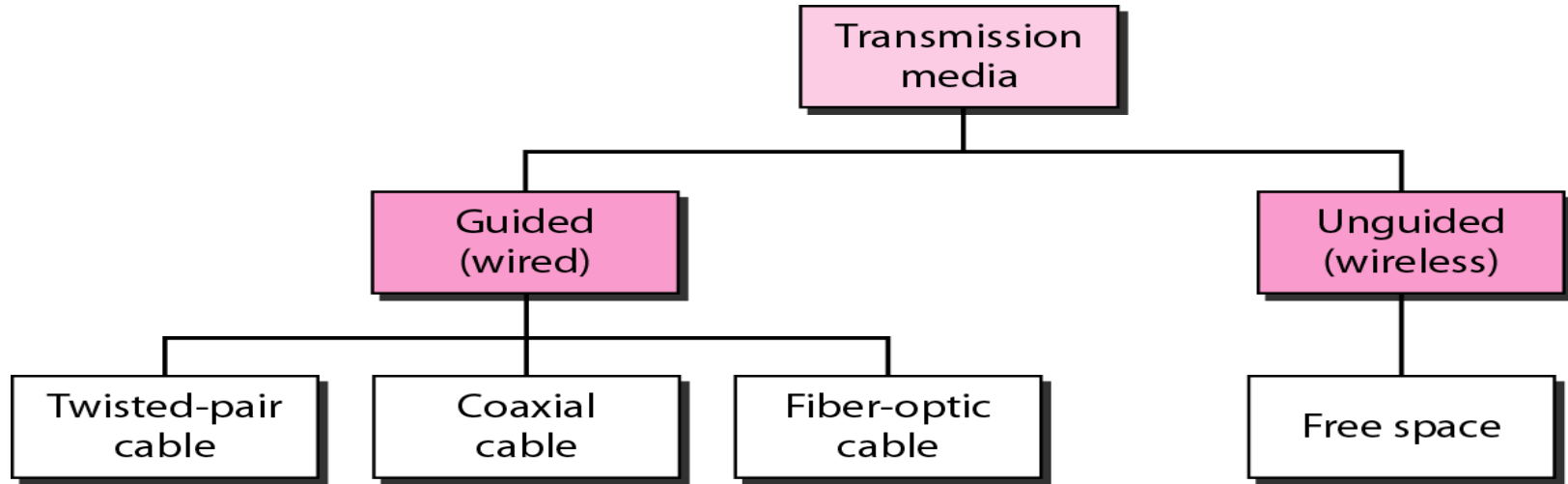


Figure 2.3 *Classes of transmission media*



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.

Topics discussed in this section:

1. Twisted-Pair Cable
2. Coaxial Cable
3. Fiber-Optic Cable

Figure 2.4 *Twisted-pair cable*

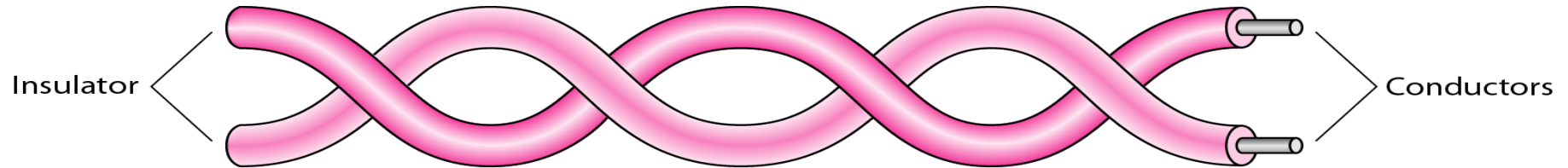
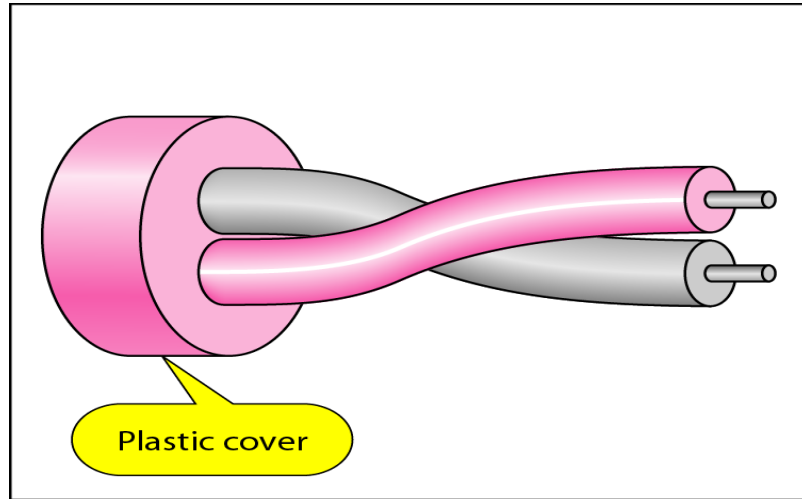
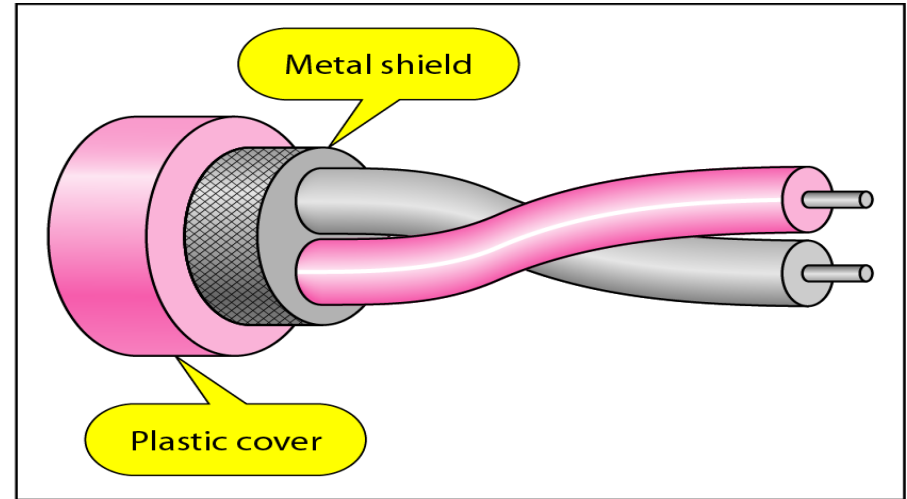


Figure 2.5 *UTP and STP cables*



a. UTP

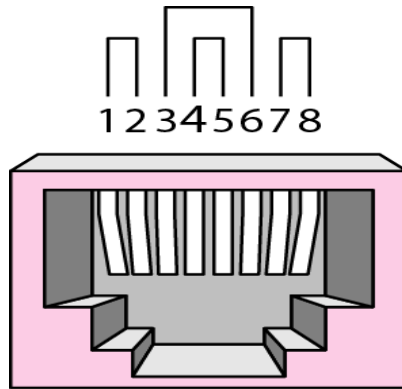


b. STP

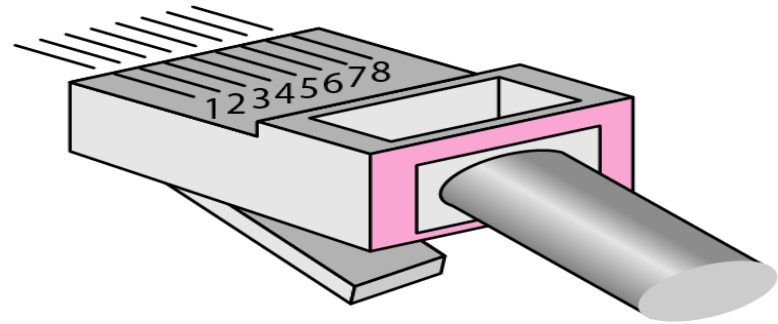
Table 2.1 *Categories of unshielded twisted-pair cables*

<i>Category</i>	<i>Specification</i>	<i>Data Rate (Mbps)</i>	<i>Use</i>
1	Unshielded twisted-pair used in telephone	< 0.1	Telephone
2	Unshielded twisted-pair originally used in T-lines	2	T-1 lines
3	Improved CAT 2 used in LANs	10	LANs
4	Improved CAT 3 used in Token Ring networks	20	LANs
5	Cable wire is normally 24 AWG with a jacket and outside sheath	100	LANs
5E	An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference	125	LANs
6	A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate.	200	LANs
7	Sometimes called SSTP (shielded screen twisted-pair). Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate.	600	LANs

Figure 2.6 *UTP connector*



RJ-45 Female



RJ-45 Male

RJ- Registered Jack

Figure 2.7 *UTP performance*

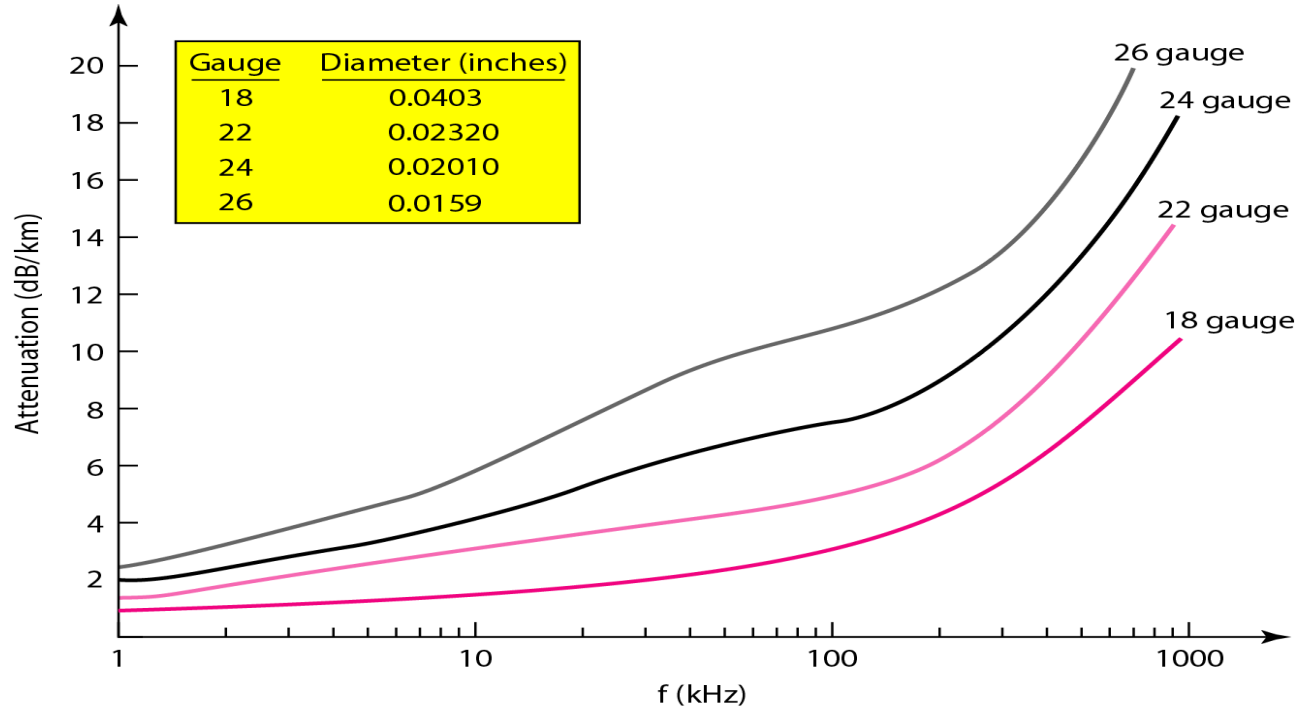


Figure 2.8 *Coaxial cable*

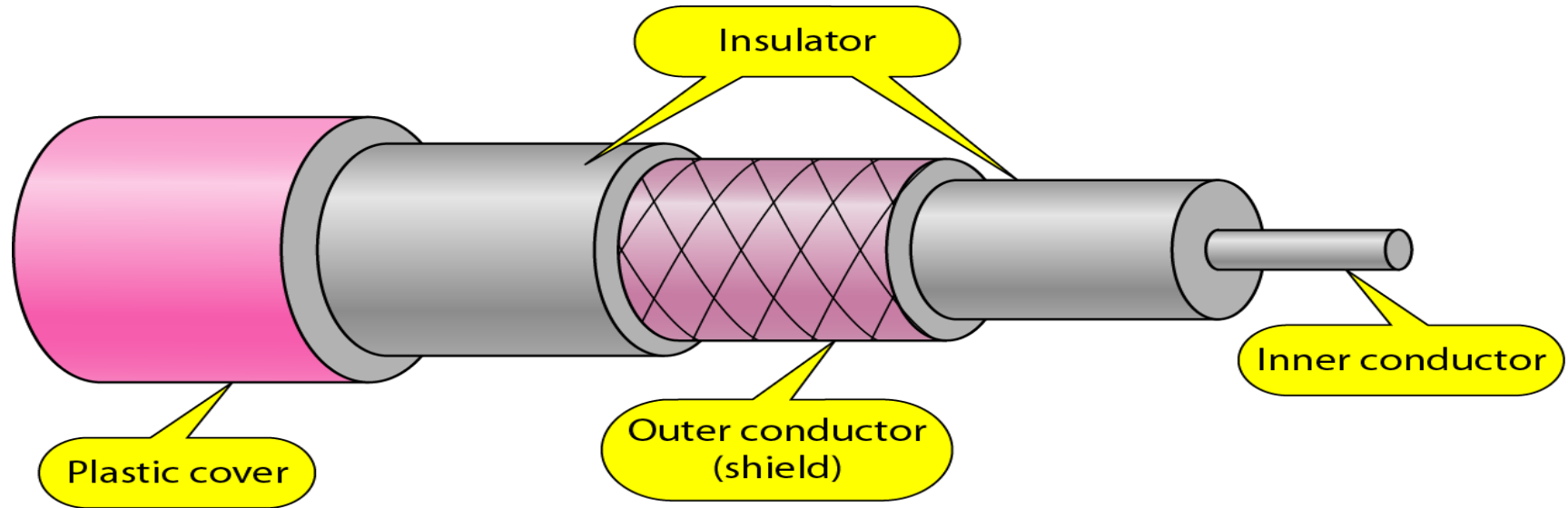
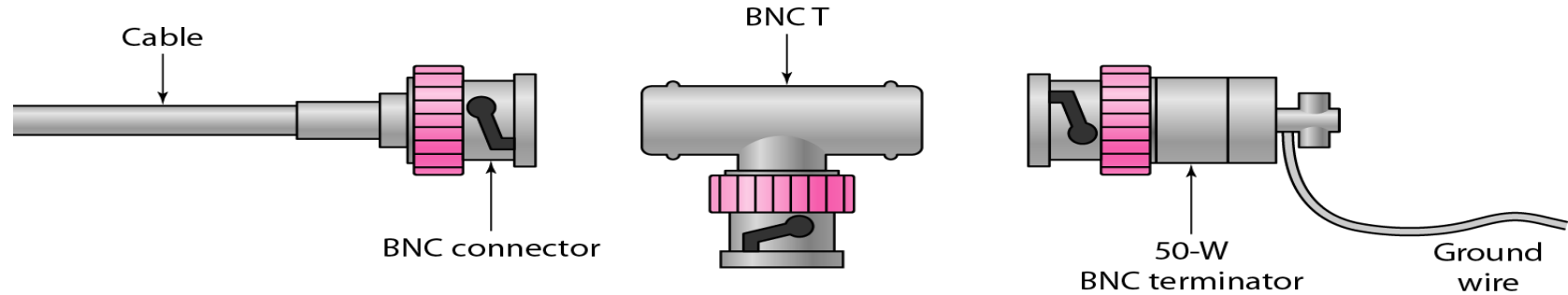


Table 2.2 *Categories of coaxial cables*

<i>Category</i>	<i>Impedance</i>	<i>Use</i>
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

RG- Radio Guide

Figure 2.9 *BNC connectors*



Bayonet Neill–Concealman

Figure 2.10 *Coaxial cable performance*

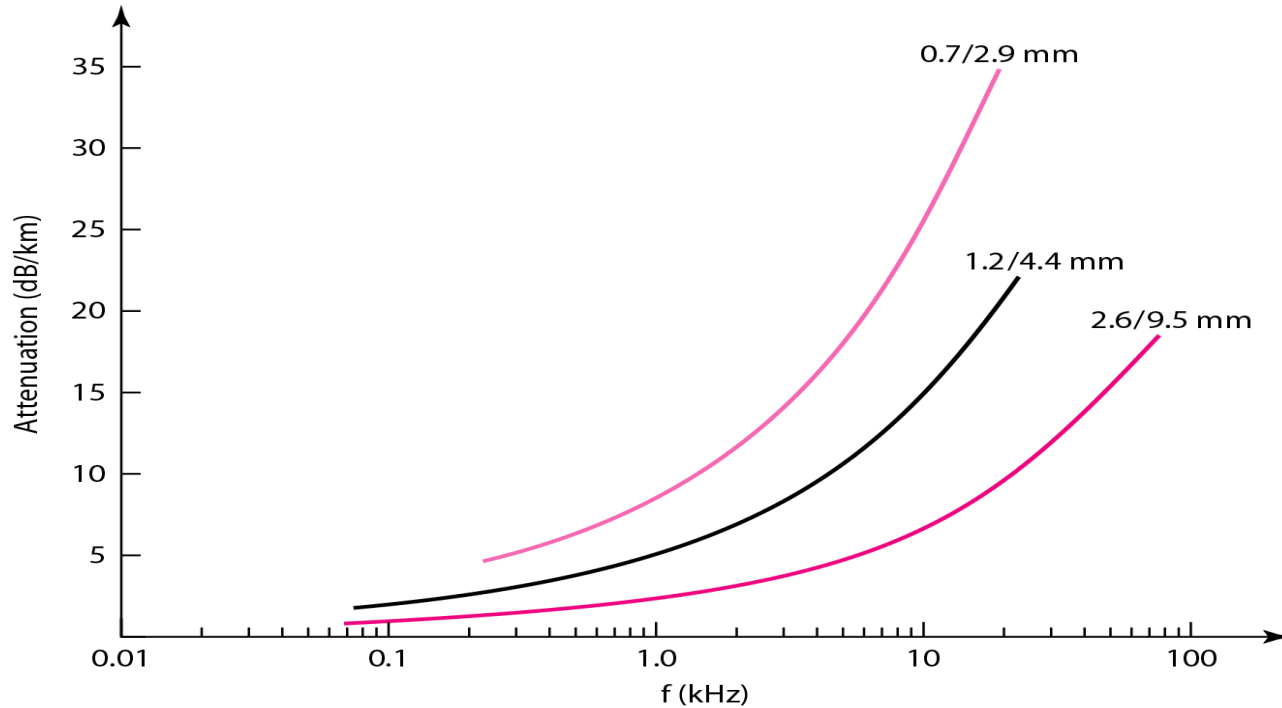


Figure 2.11 Fiber optics: *Bending of light ray*

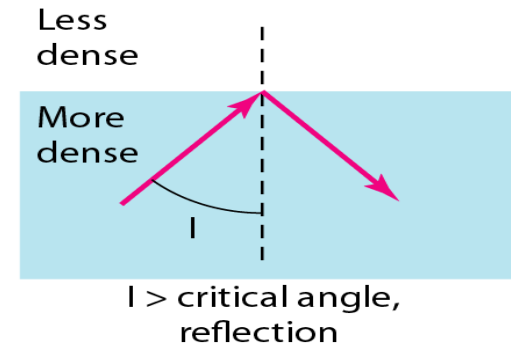
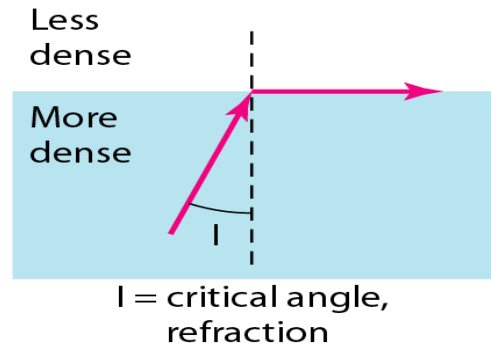
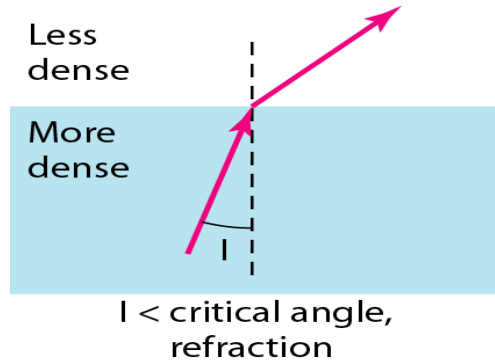


Figure 2.12 *Optical fiber*

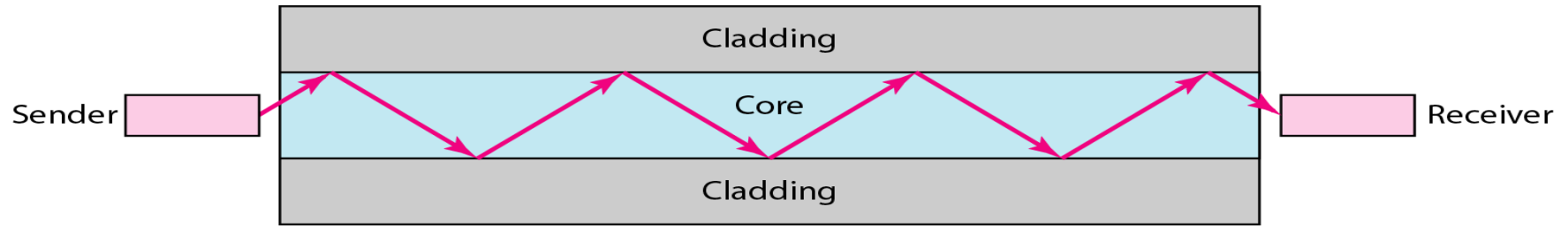


Figure 2.13 *Propagation modes*

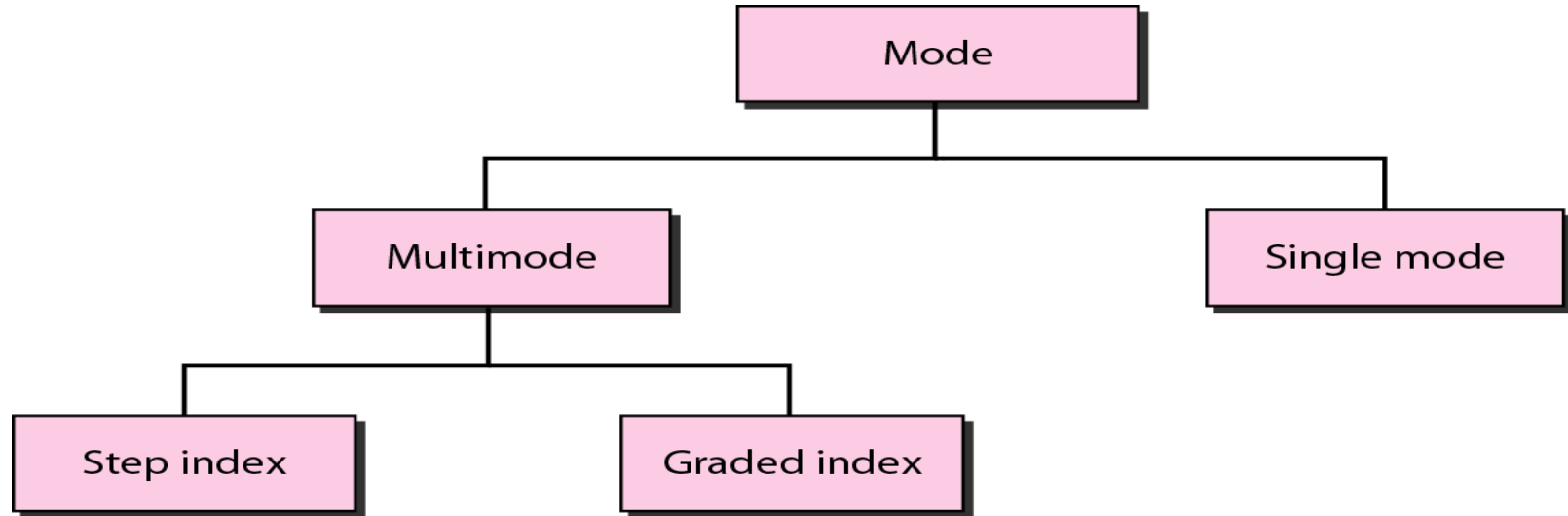


Figure 2.14 *Modes*

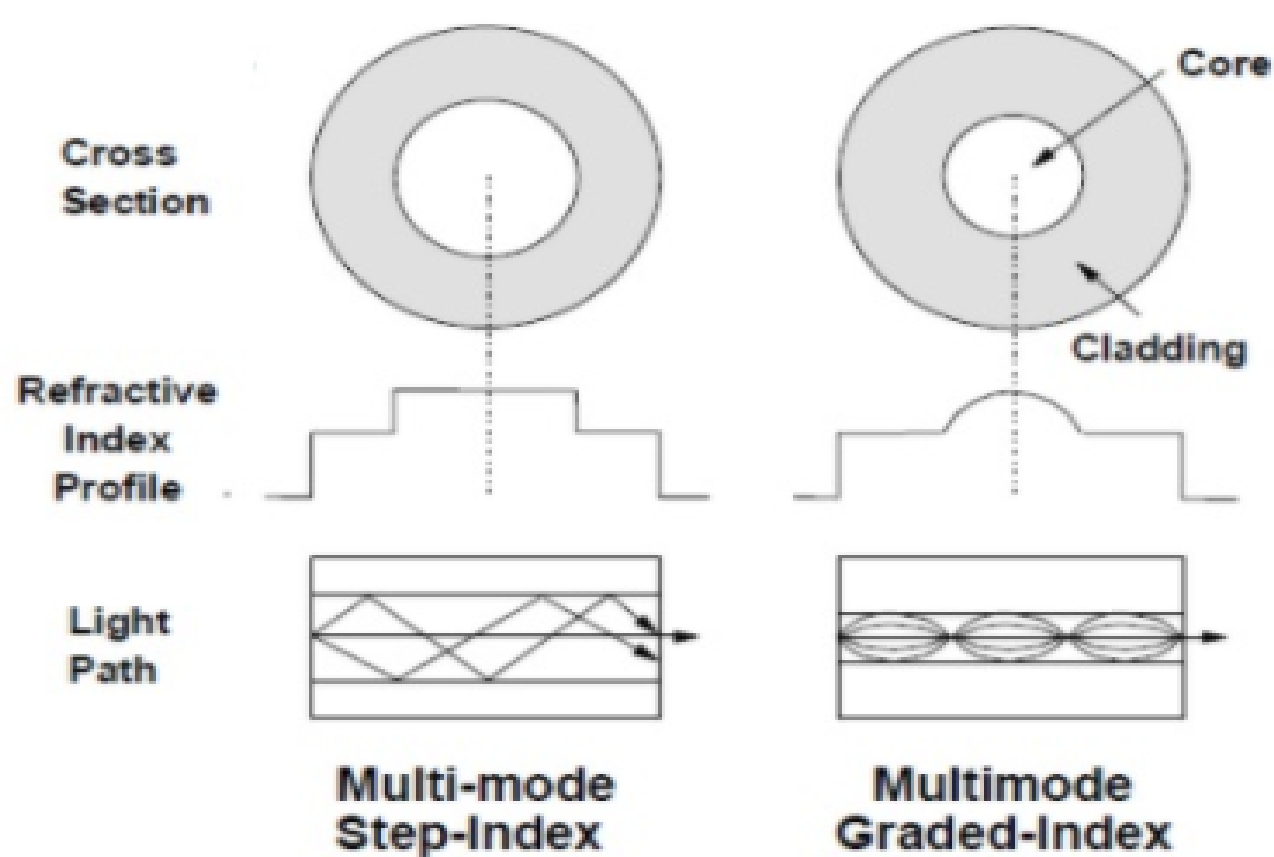
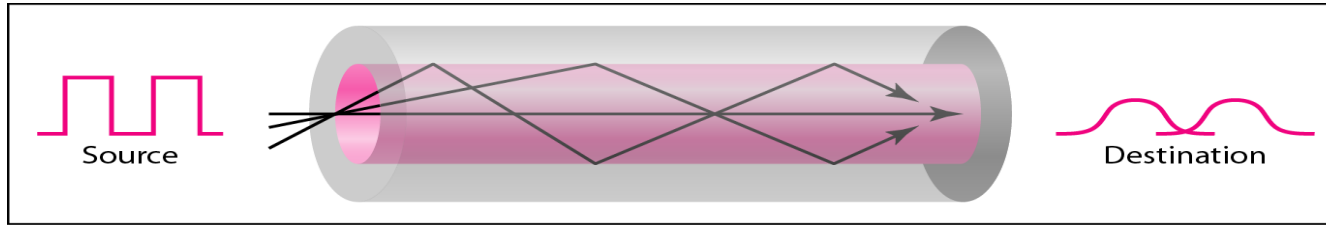
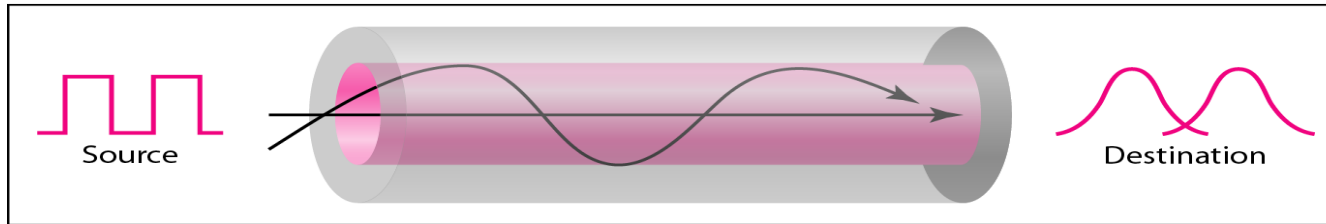


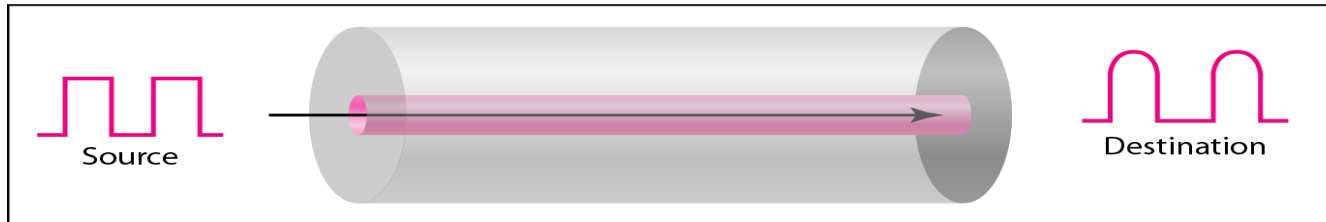
Figure 2.15 Modes



a. Multimode, step index



b. Multimode, graded index



c. Single mode

Table 2.3 *Fiber types*

<i>Type</i>	<i>Core (μm)</i>	<i>Cladding (μm)</i>	<i>Mode</i>
50/125	50.0	125	Multimode, graded index
62.5/125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode

Figure 2.16 *Fiber construction*

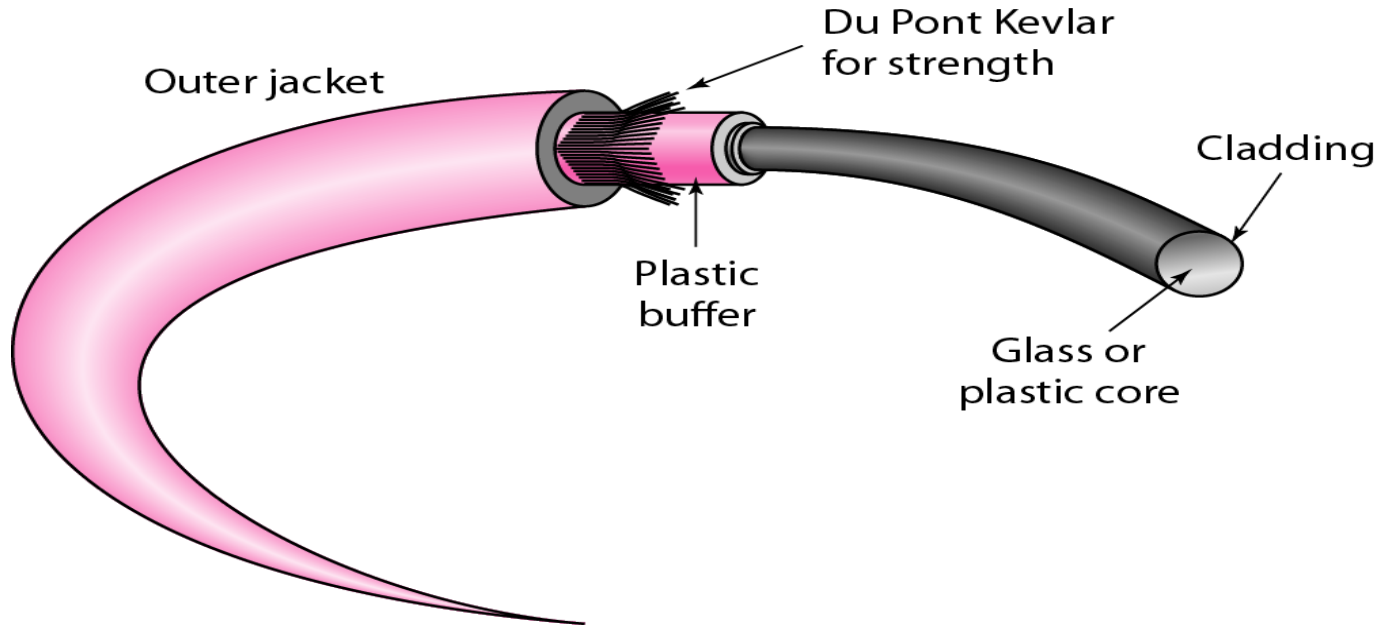
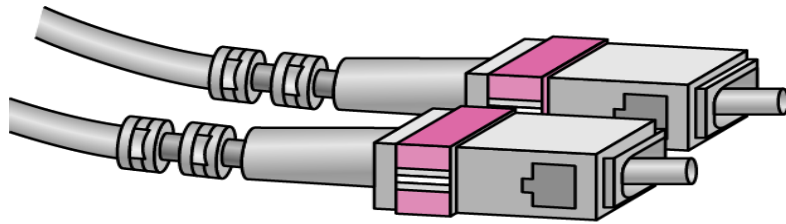
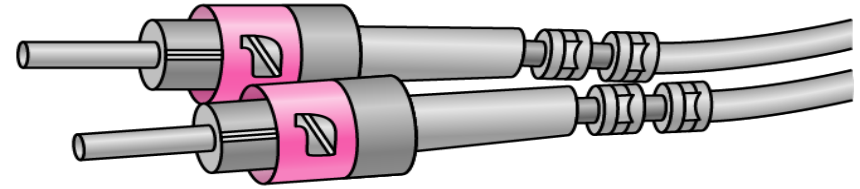


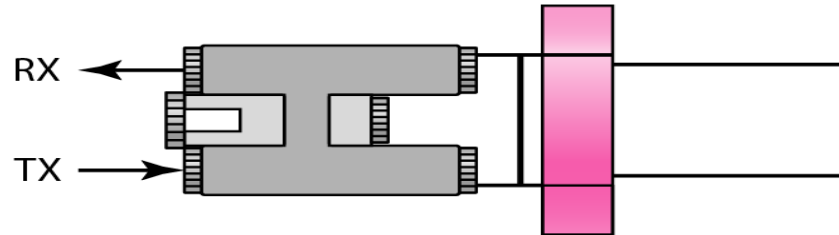
Figure 2.17 *Fiber-optic cable connectors*



SC connector

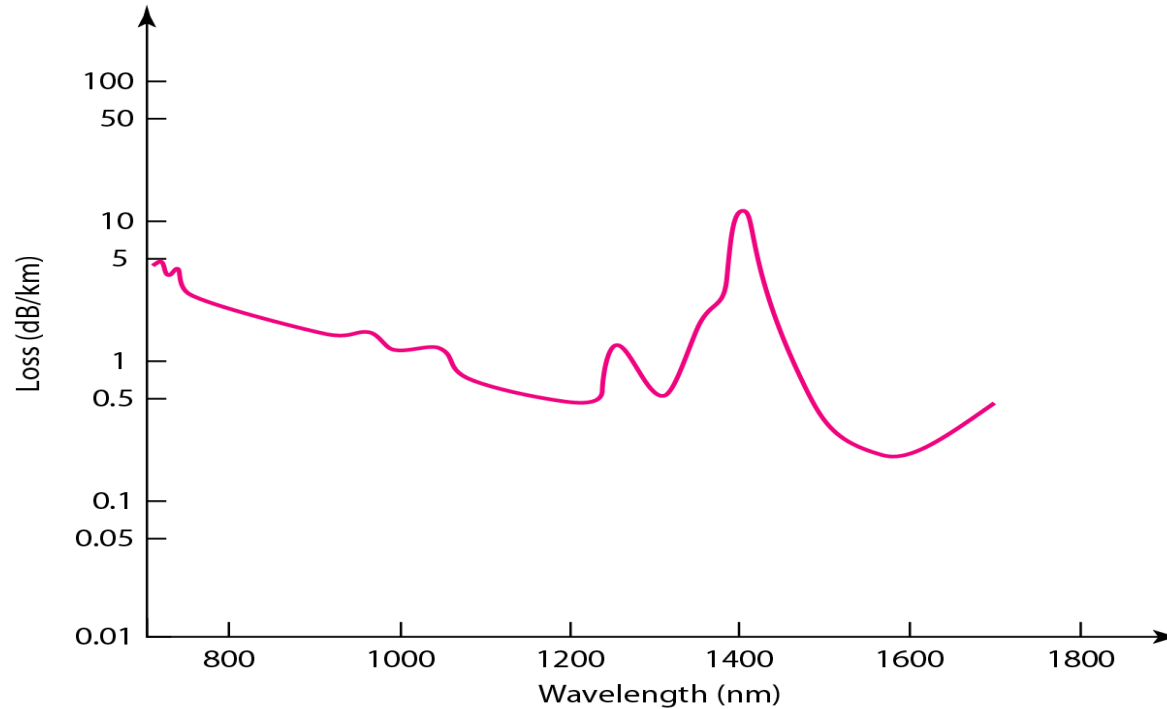


ST connector



MT-RJ connector

Figure 2.18 *Optical fiber performance*



Differences

Characteristics	UTP	STP	Coaxial Cables	Fiber Optic Cables
Bandwidth	10 Mbps - 100 Mbps	10 Mbps - 100 Mbps	10 Mbps	100 Mbps - 1 Gbps
Maximum cable segment	100 meters	100 meters	200 - 500 meters	2 k.m. - 100 k.m.
Interference rating	Poor	Better than UTP	Better than Twisted Pair Cable	Very good as compared to any other cable
Installation cost	Cheap	Costly than UTP	Costlier than twisted pair wires	Costliest to install
Bend radius	360 degrees / feet	360 degrees / feet	360 degrees / feet or 30 degrees / feet	30 degrees / feet
Security	Low	Low	Low	High

Coaxial Cable



- transmission of signals happens in the electrical form over the inner conductor of the cable
- higher noise immunity than twisted-pair cable
- moderate cost
- moderately high bandwidth
- low attenuation
- easy to install
- get disturbed by external magnetic field

Twisted-Pair Cable



- transmission of signals happens in the electrical form over the metallic conducting wires
- low noise immunity
- cheapest
- low bandwidth
- very high attenuation
- easy to install
- get disturbed by external magnetic field

Fiber-Optic Cable



- signal transmission happens in optical forms over a glass fiber
- highest noise immunity
- expensive
- very high bandwidth
- very low attenuation
- difficult to install
- not affected by the external magnetic field
- most efficient
- glass fiber

UNGUIDED MEDIA: WIRELESS

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

Topics discussed in this section:

1. Radio Waves
2. Microwaves
3. Infrared

Figure 2.19 *Electromagnetic spectrum for wireless communication*

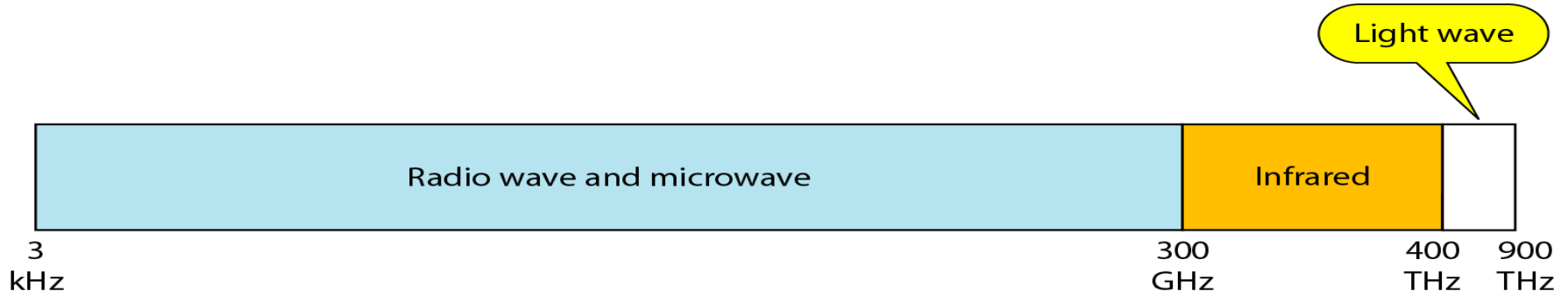


Figure 2.20 Propagation methods

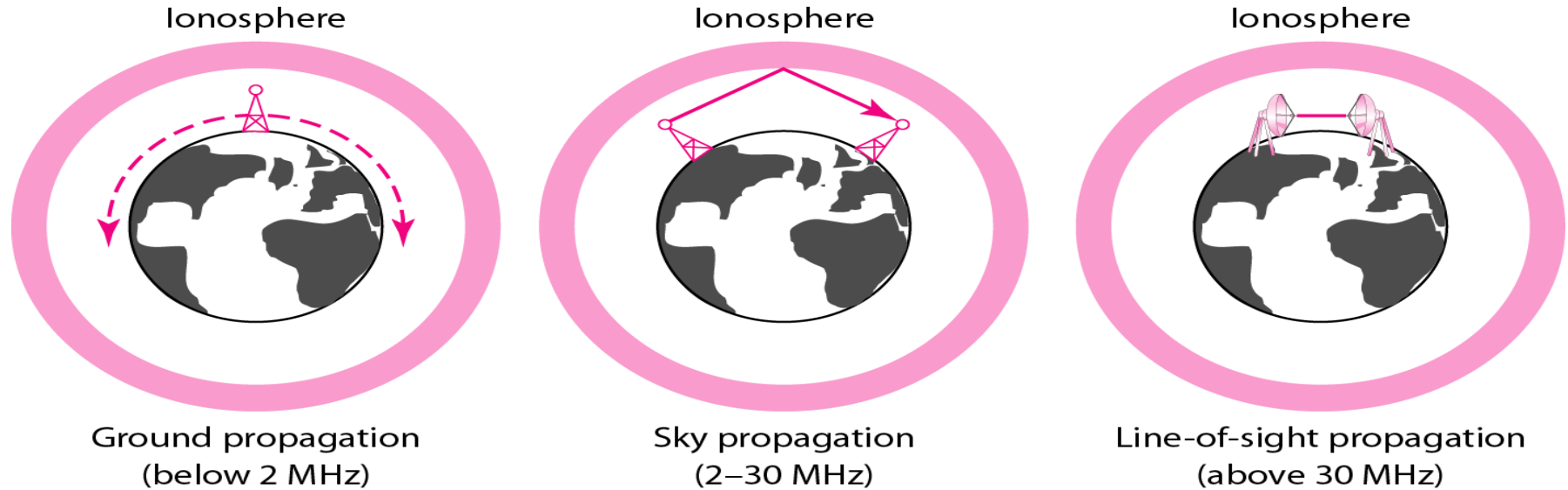
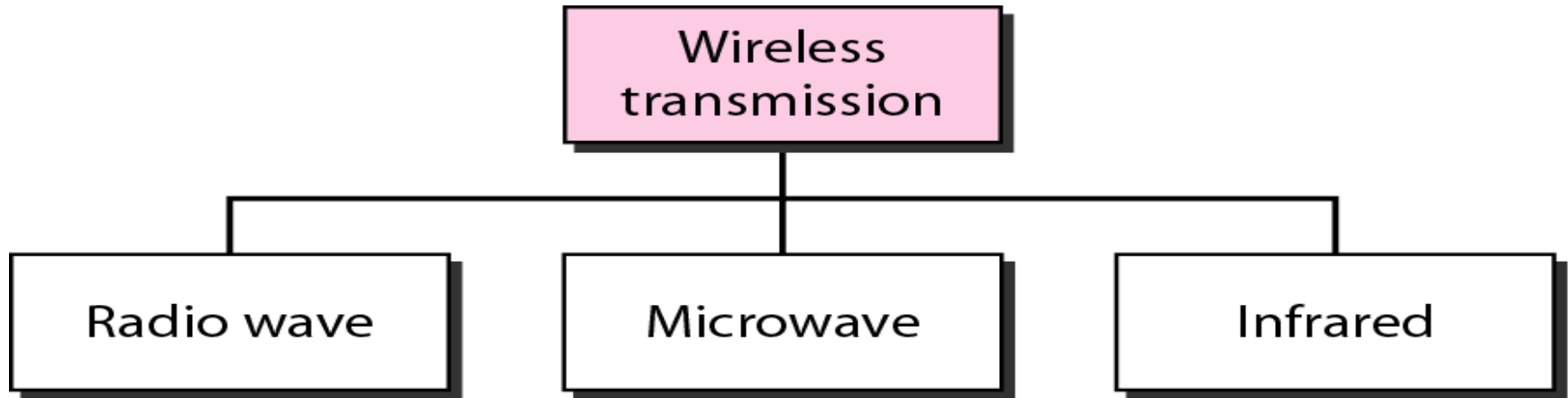


Table 2.4 *Bands*

<i>Band</i>	<i>Range</i>	<i>Propagation</i>	<i>Application</i>
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

Figure 2.21 *Wireless transmission waves*

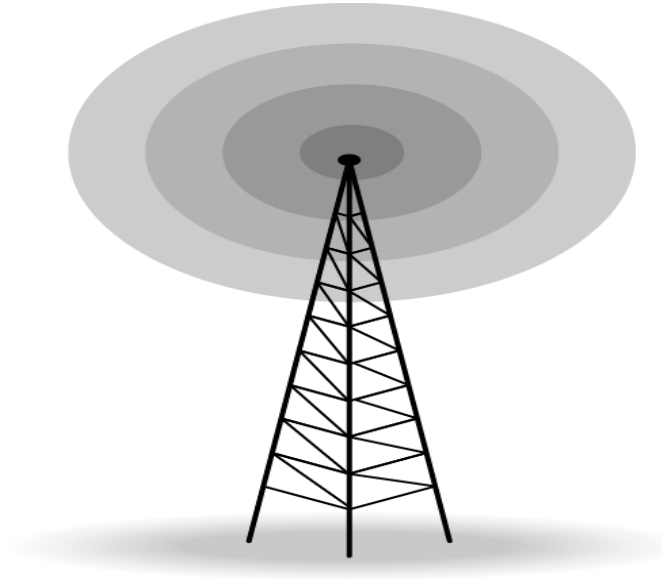


Note

Radio waves are used for multicast communications, such as radio and television, and paging systems. They can penetrate through walls.

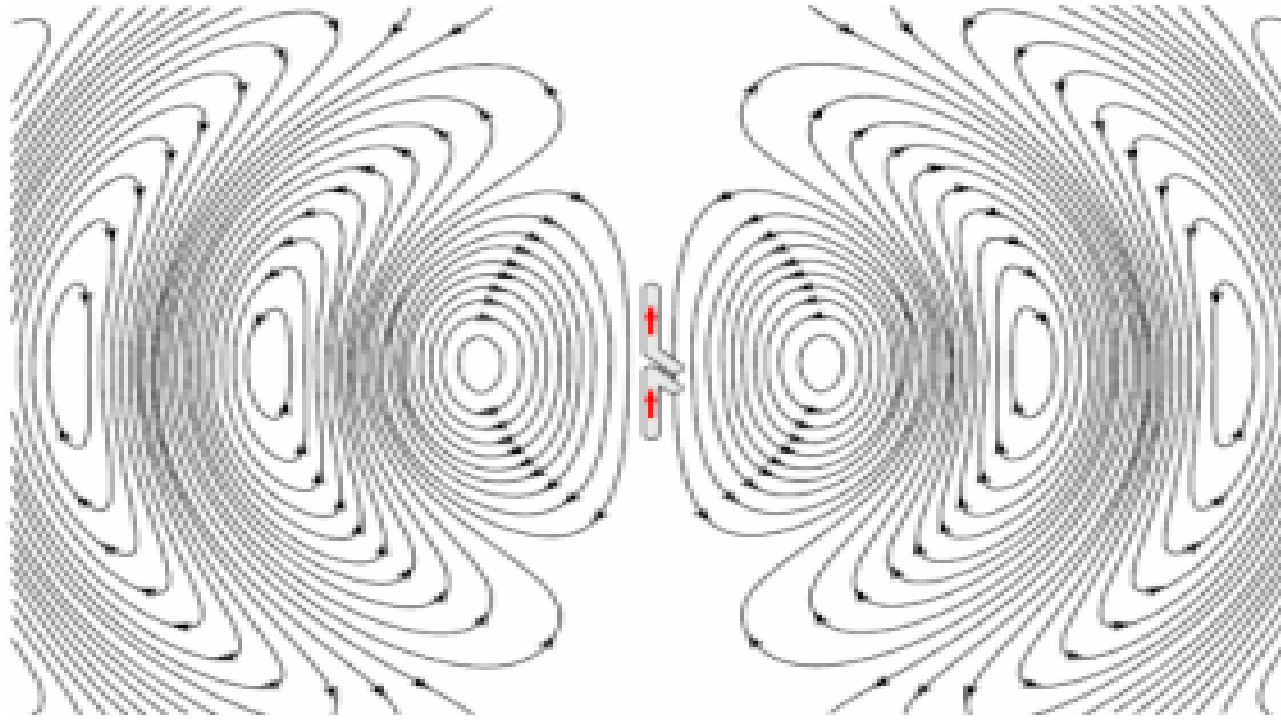
Highly regulated. Use omni directional antennas

Figure 2.22 *Omnidirectional antenna*



Transmitting/receiving signals in all directions horizontally

Figure 2.23 *Radiation pattern of Omnidirectional antenna*

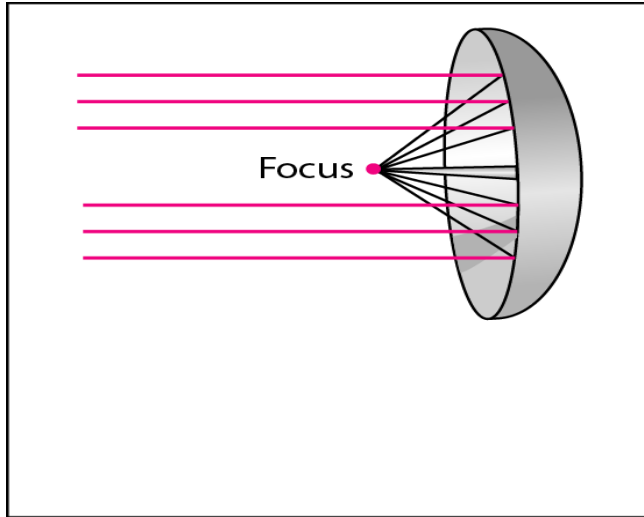


Note

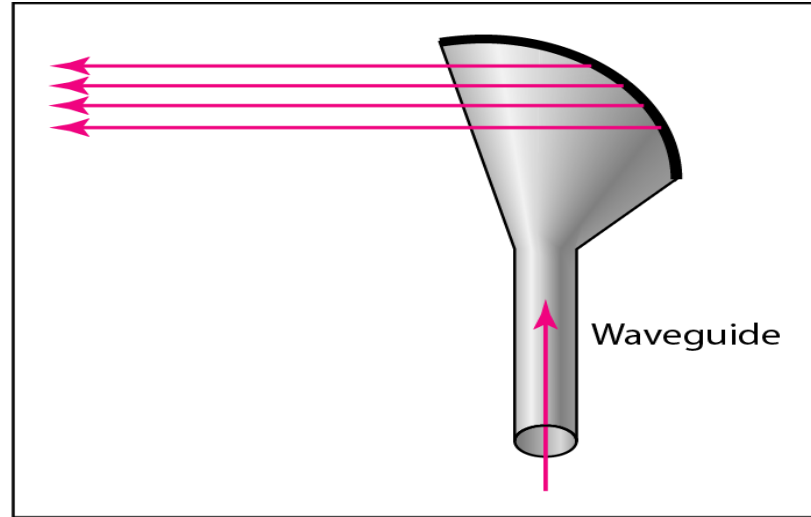
Microwaves are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.

Higher frequency ranges cannot penetrate walls.
Use directional antennas - point to point line of sight communications.

Figure 2.24 *Unidirectional antennas*

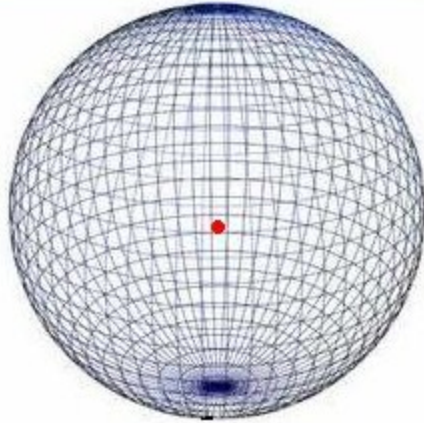


a. Dish antenna

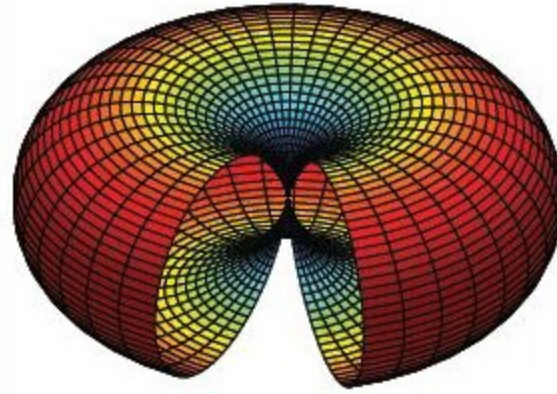


b. Horn antenna

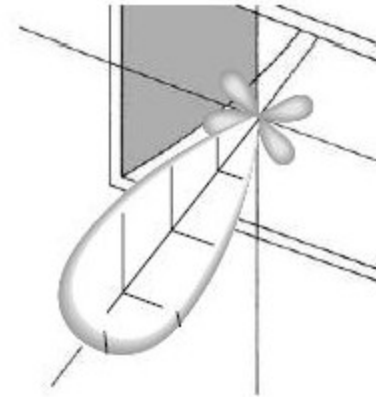
Figure 2.25 *Directional Antenna Pattern*



Isotropic



Omni-directional

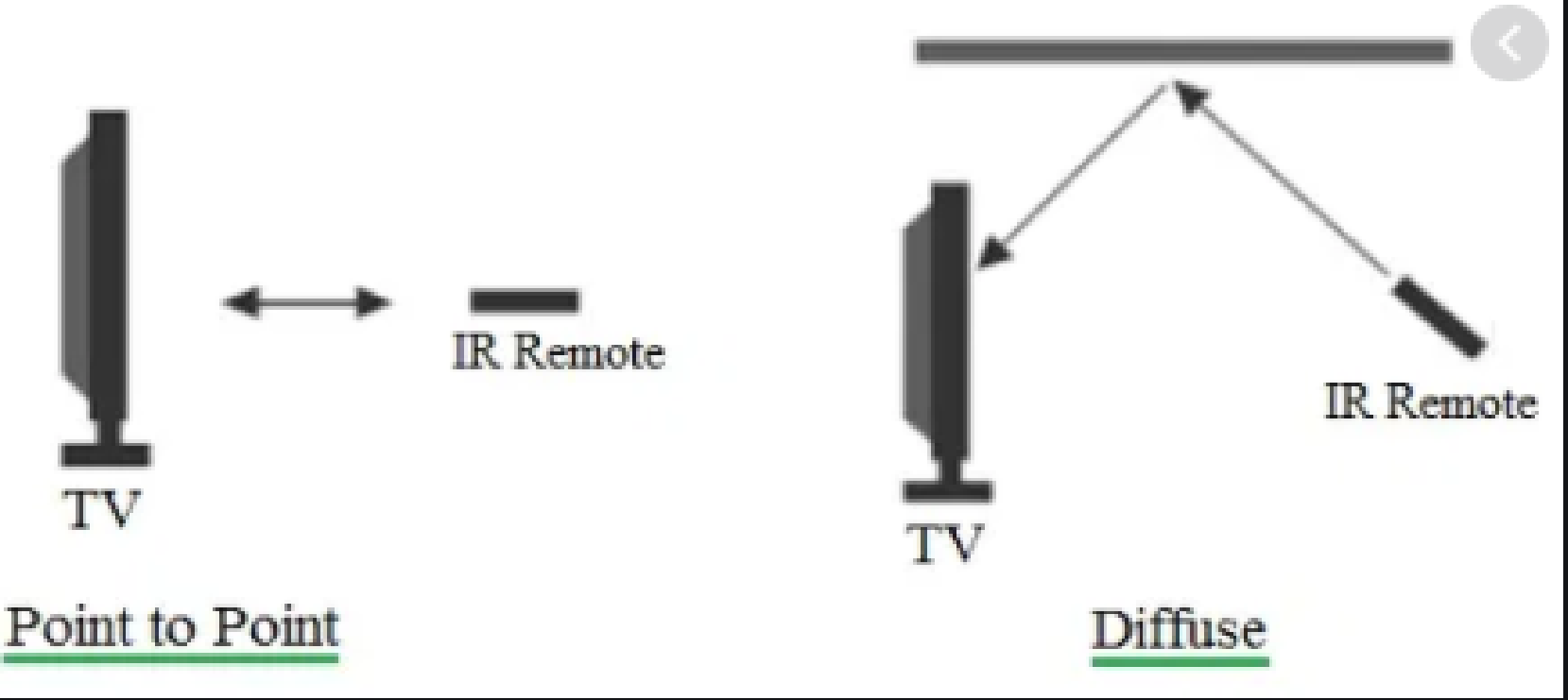


directional

Infrared Transmission

- Infrared waves lies in between visible light spectrum and microwaves. It has wavelength of 700 nm to 1 mm and frequency ranges from 300 GHz to 430 THz.
- Infrared waves are used for very short range communication purposes such as television and it's remote.
- Infrared travels in a straight line so they are directional by nature.
- Because of high frequency range, Infrared do not cross wall like obstacles.

Contd..



Note

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

Wireless Channels

- Are subject to a lot more errors than guided media channels.
- Interference is one cause for errors, can be circumvented with high SNR.
- The higher the SNR the less capacity is available for transmission due to the broadcast nature of the channel.
- Channel also subject to fading and no coverage holes.

Wireless Vs. Wired Communication

Wireless Networks ↕	Fixed Networks ↕
1) No physical configuration is required.	1) Physical configuration is required.
2) Data loss rate is high.	2) Since a perfect link is established, data loss rate is very low.
3) Low data transmission rate which results in less speed.	3) High rate of data transmission and hence high speed.
4) More delays.	4) Less delays.
5) Low on security.	5) Highly secured.

Digital Modulation and Multiplexing

- Baseband Transmission
- Pass band Transmission
- Frequency Division Multiplexing
- Time Division Multiplexing
- Code Division Multiplexing

Baseband Transmission

- Wires and wireless channels carry **analog signals** such as continuously varying voltage, light intensity, or sound intensity.
- To send digital information, we must plan analog signals to represent bits. The process of converting between bits and signals that represent them is called **digital modulation**.

Contd..

- Schemes that directly convert bits into a signal results in **baseband transmission**, in which the signal occupies frequencies from **zero up to a maximum** that depends on the signaling rate.

Baseband Transmission or Line Coding

(a) Bit stream

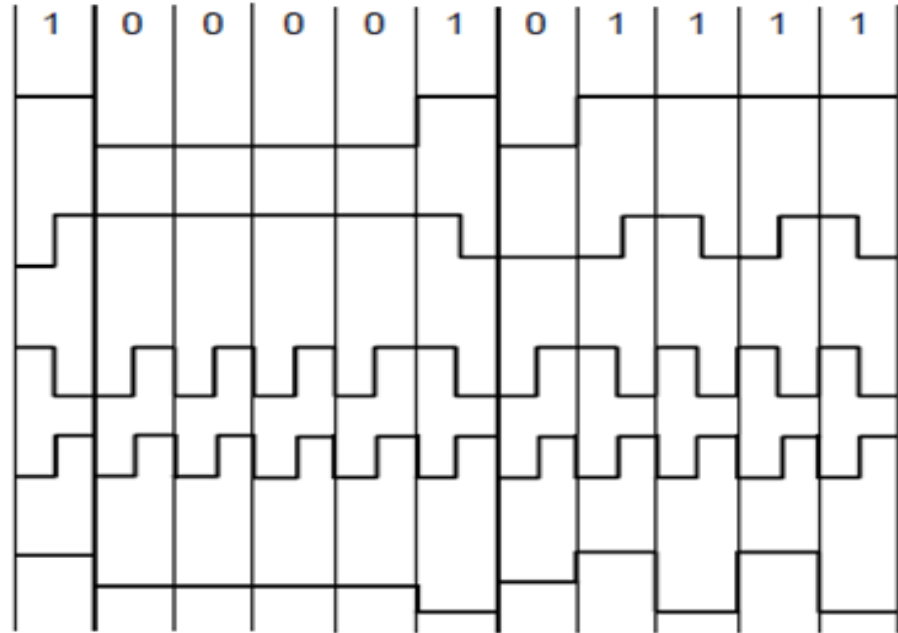
(b) Non-Return to Zero (NRZ)

(c) NRZ Invert (NRZI)

(d) Manchester

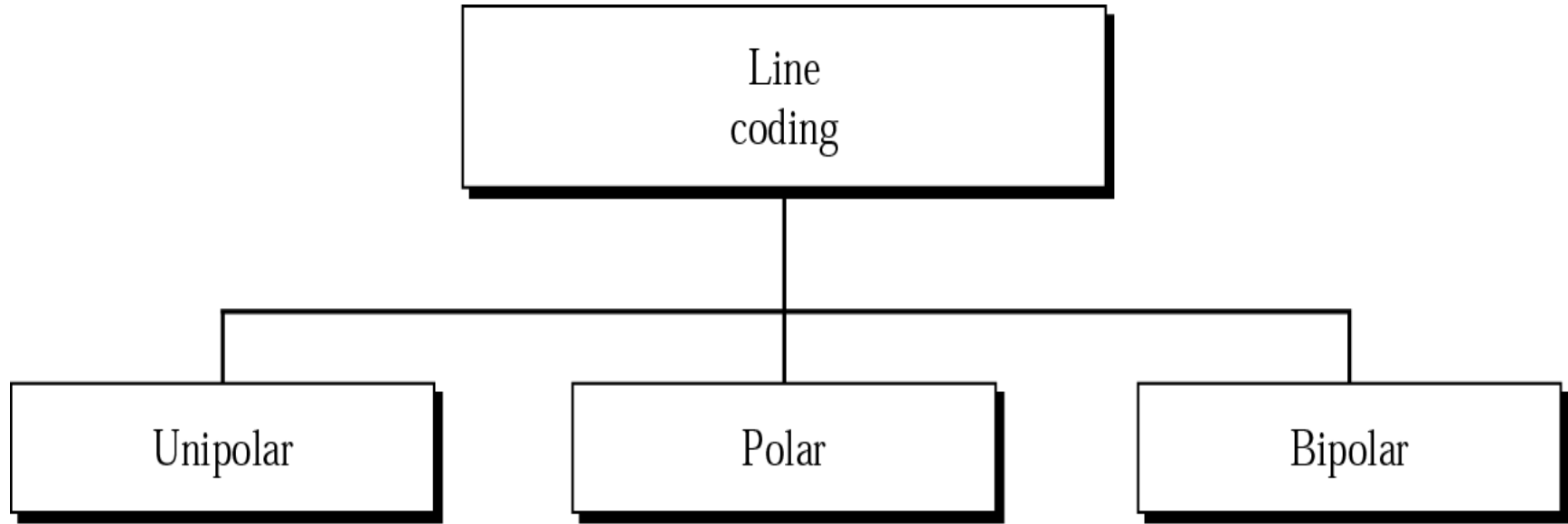
(Clock that is XORed with bits)

(e) Bipolar encoding
(also Alternate Mark
Inversion, AMI)



Line codes: (a) Bits, (b) NRZ, (c) NRZI, (d) Manchester, (e) Bipolar or AMI.

Types of Line Coding



Unipolar Signaling

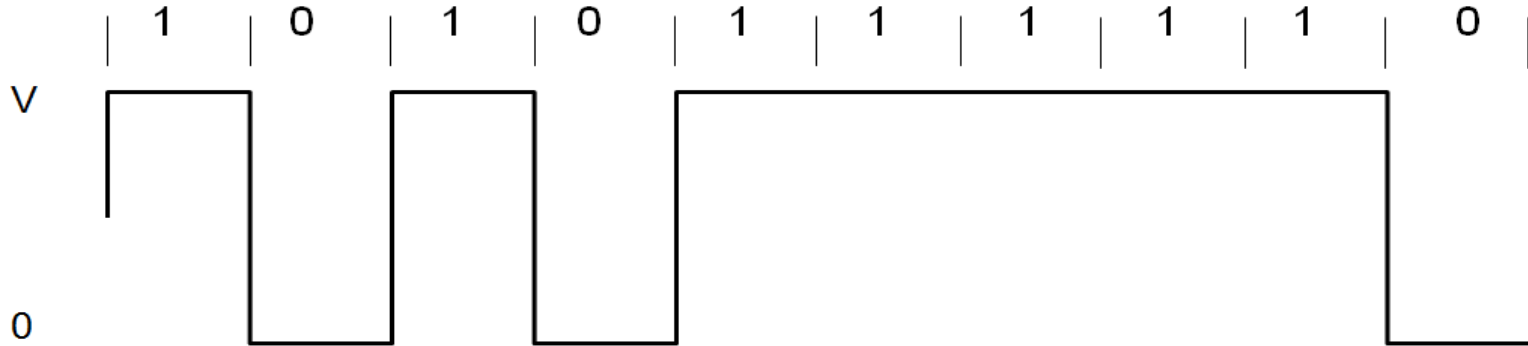
- On-Off keying ie OOK
- Pulse 0: Absence of pulse
- Pulse1 : Presence of pulse

There are two common variations of unipolar signalling:

1. Non-Return to Zero (NRZ)
2. Return to Zero (RZ)

Unipolar Non-Return to Zero (NRZ)

- Duration of the MARK pulse (T) is equal to the duration (T_o) of the symbol slot.



Advantages:

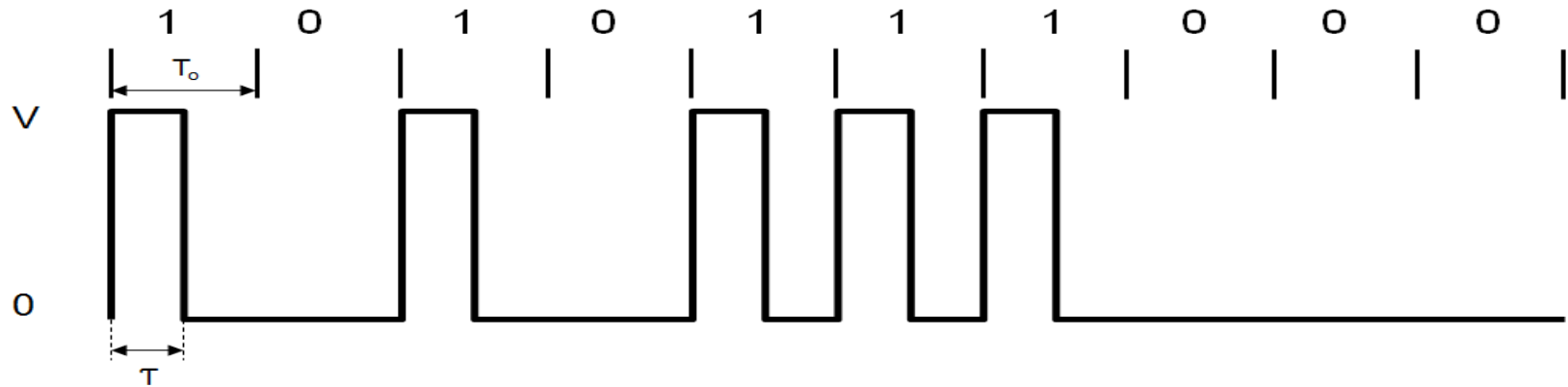
- Simplicity in implementation
- Doesn't require a lot of bandwidth for transmission.

Disadvantages:

- Presence of DC level (indicated by spectral line at 0 Hz).
- Contains low frequency components. Causes "Signal Droop"
- Does not have any error correction capability.
- Does not possess any clocking component for ease of synchronization

Unipolar Return to Zero (RZ)

- MARK pulse (T) is **less** than the duration (T_o) of the symbol slot.
- Fills only the first half of the time slot, returning to zero for the second half.



Advantages:

- Simplicity in implementation.
- Presence of a spectral line at symbol rate which can be used as symbol timing clock signal.

Disadvantages:

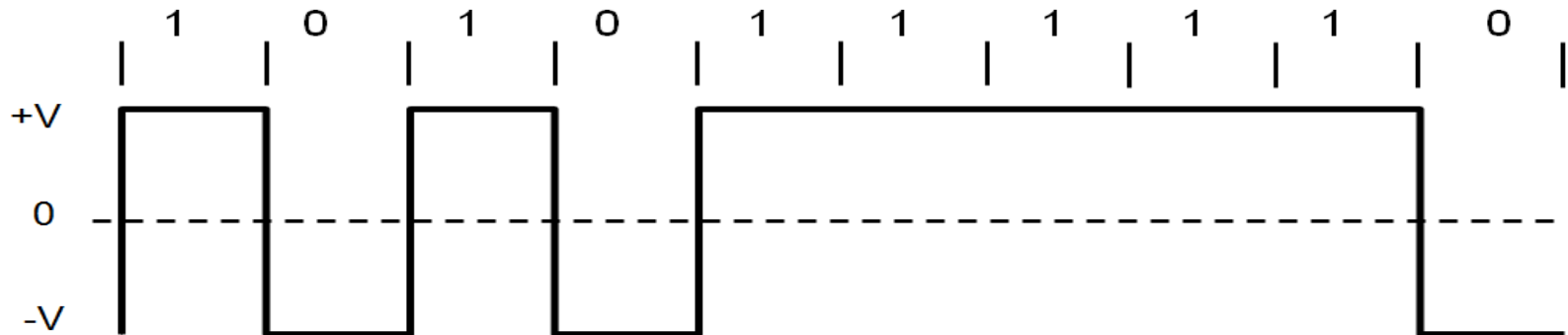
- Presence of DC level (indicated by spectral line at 0 Hz).
- Continuous part is non-zero at 0 Hz. Causes “Signal Droop”.
- Does not have any error correction capability.
- Occupies twice as much bandwidth as Unipolar NRZ.
- Is not Transparent

Polar Signalling

- Polar RZ
- Polar NRZ

Polar NRZ:

- A binary 1 is represented by a pulse $g_1(t)$
- A binary 0 by the opposite (or antipodal) pulse $g_0(t) = -g_1(t)$.



Advantages:

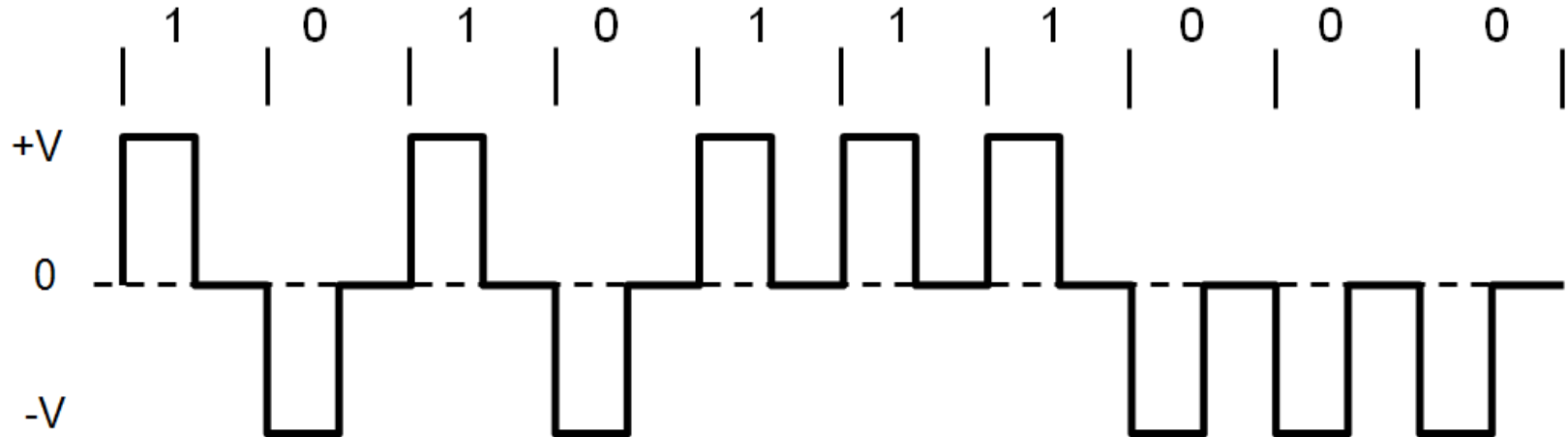
- Simplicity in implementation.
- No DC component.

Disadvantages:

- Continuous part is non-zero at 0 Hz. Causes “Signal Droop”.
- Does not have any error correction capability.
- Does not possess any clocking component for ease of synchronisation.
- Is not transparent.

Polar RZ

- A binary 1: A pulse $g_1(t)$
- A binary 0: The opposite (or antipodal) pulse $g_0(t) = -g_1(t)$.
- Fills only the first half of the time slot, returning to zero for the second half.



Advantages:

- Simplicity in implementation.
- No DC component.

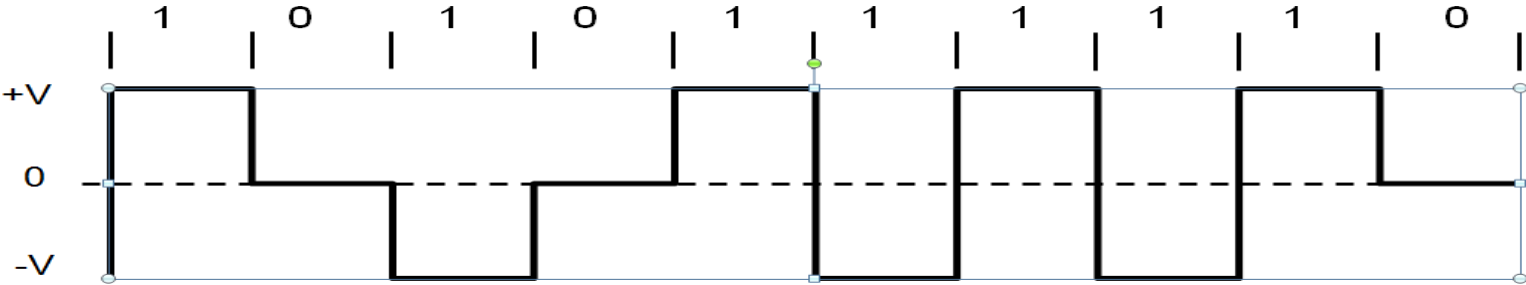
Disadvantages:

- Continuous part is non-zero at 0 Hz. Causes “Signal Droop”.
- Does not have any error correction capability.
- Occupies twice as much bandwidth as Polar NRZ.

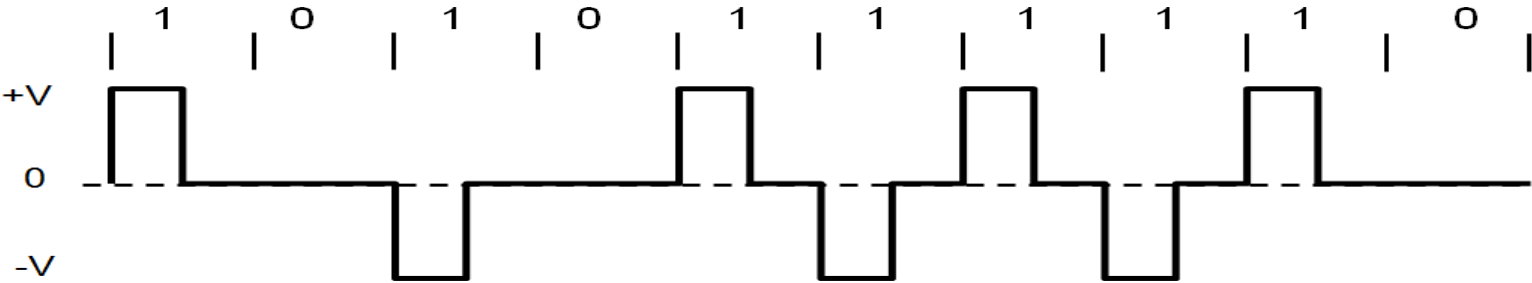
Bipolar Signalling

- Alternate mark inversion (AMI)
- Uses three voltage levels ($+V$, 0 , $-V$)
- 0 : Absence of a pulse
- 1 : Alternating voltage levels of $+V$ and $-V$

Bipolar NRZ:



Bipolar RZ:



Advantages:

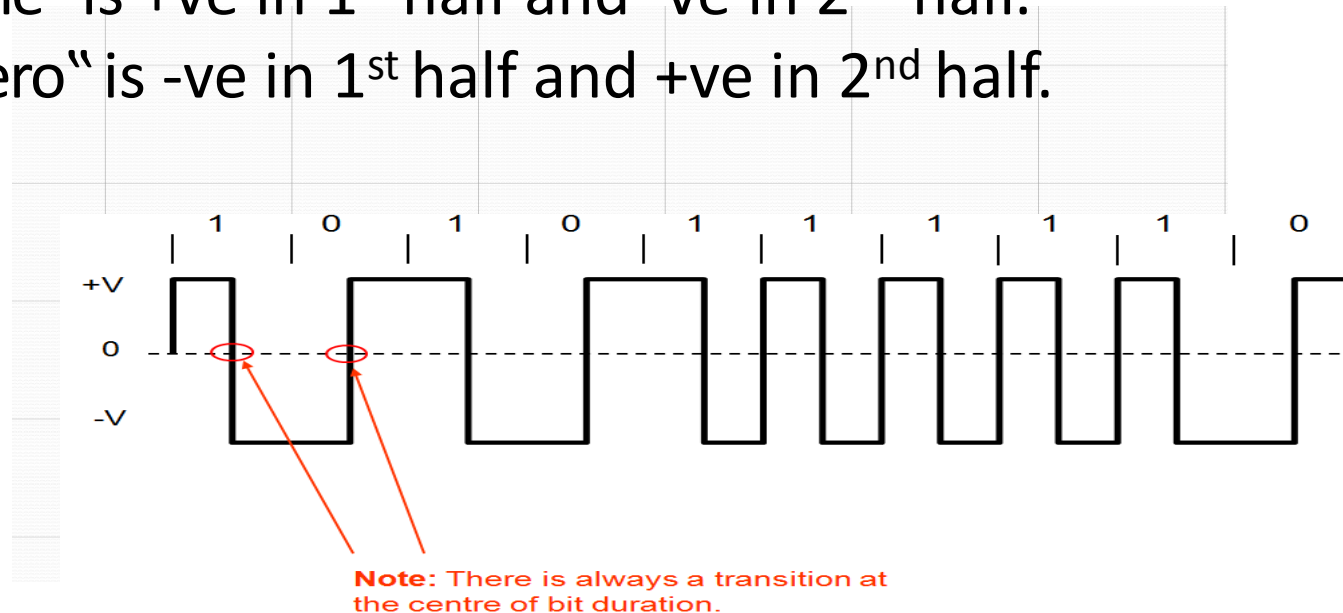
- No DC component.
- Occupies less bandwidth than unipolar and polar NRZ schemes.
- Does not suffer from signal droop (suitable for transmission over AC coupled lines).
- Possesses single error detection capability.

Disadvantages:

- Does not possess any clocking component for ease of synchronisation.
- Is not Transparent.

Manchester Signalling

- The duration of the bit is divided into two halves
- A One" is +ve in 1st half and -ve in 2nd half.
- A Zero" is -ve in 1st half and +ve in 2nd half.



Advantages:

- No DC component.
- Does not suffer from signal droop (suitable for transmission over AC coupled lines).
- Easy to synchronise.
- Is Transparent.

Disadvantages:

- Because of the greater number of transitions it occupies a significantly large bandwidth.
- Does not have error detection capability.

Comparison of Line Codes

Sr. No.	Parameters	Polar RZ	Polar NRZ	AMI	Manchester
1	Transmission of DC component	YES	YES	NO	NO
2	Signaling Rate	$1/T_b$	$1/T_b$	$1/T_b$	$1/T_b$
3	Noise Immunity	LOW	LOW	HIGH	HIGH
4	Synchronizing Capability	Poor	Poor	Very Good	Very Good
5	Bandwidth Required	$1/T_b$	$1/2T_b$	$1/2T_b$	$1/T_b$
6	Crosstalk	HIGH	HIGH	LOW	LOW

Clock Recovery

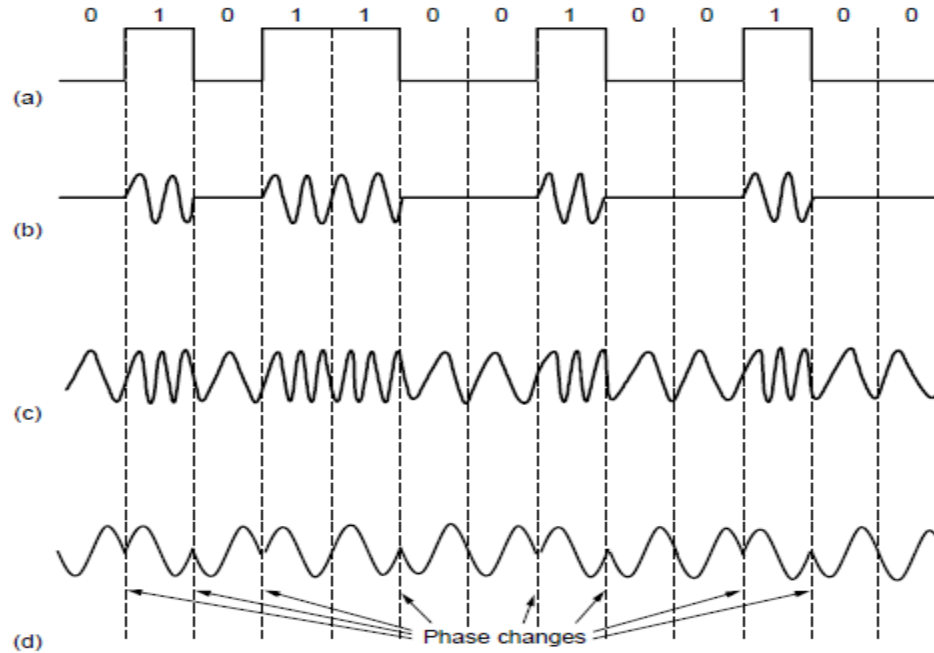
Data (4B)	Codeword (5B)	Data (4B)	Codeword (5B)
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

4B/5B mapping.

Passband Transmission

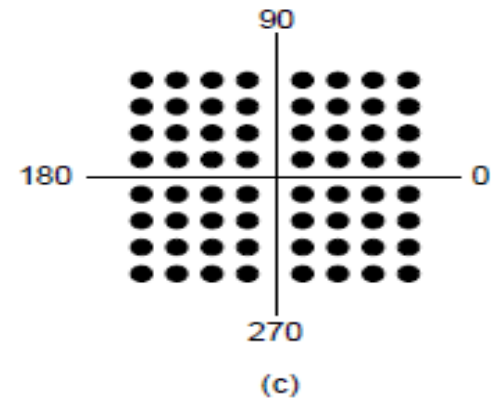
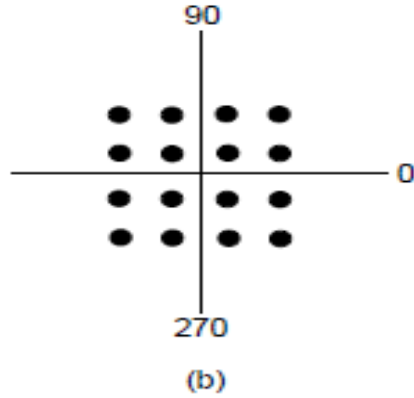
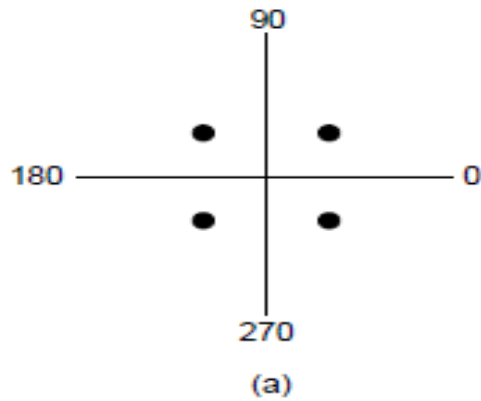
- Schemes that regulate the amplitude, phase, or frequency of a carrier signal to convey bits results in **pass band transmission**, in which the signal occupies a band of frequencies around the frequency of the carrier signal.
- We can modulate the amplitude, frequency, or phase of the carrier signal according to the digital data named as ASK,FSK,PSK respectively.

Contd..



- (a) A binary signal. (b) Amplitude shift keying.
(c) Frequency shift keying. (d) Phase shift keying.

Contd..



(a) QPSK. (b) QAM-16. (c) QAM-64.

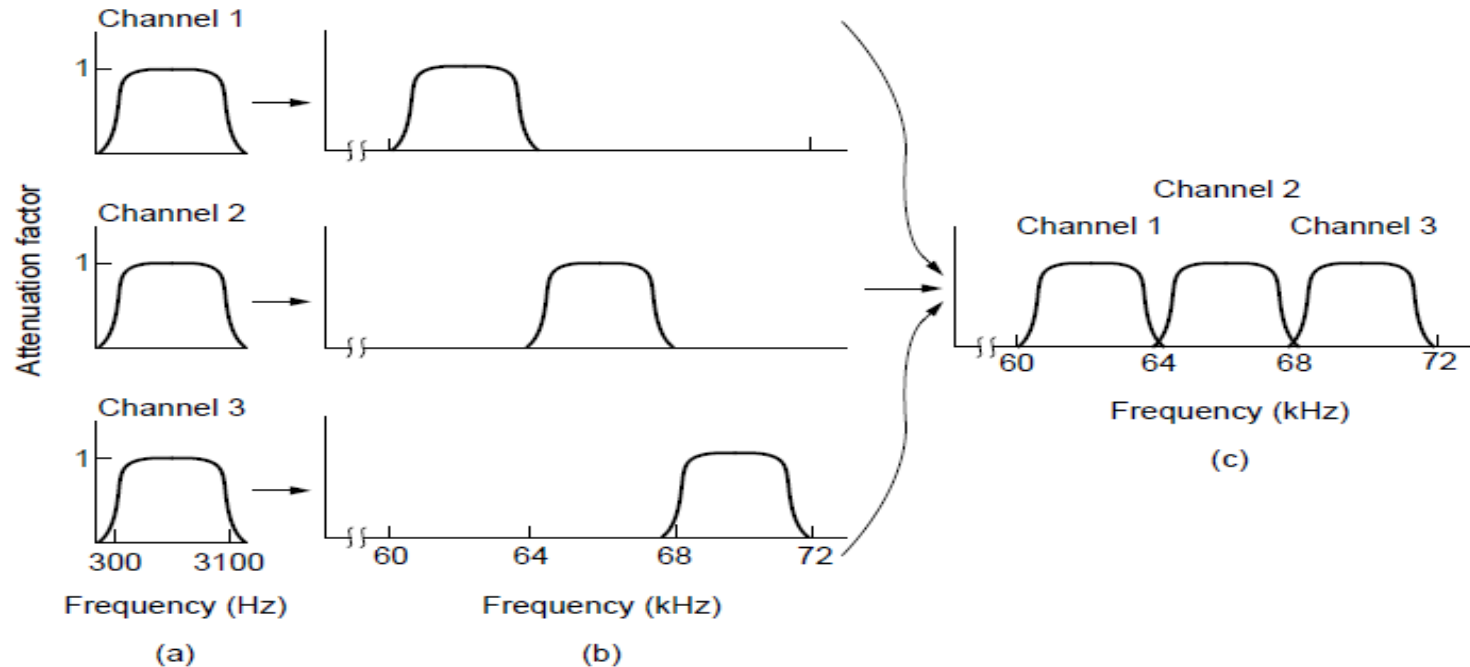
Multiplexing

- Channels are often shared by multiple signals. After all, it is much more convenient to use a single wire to carry several signals than to install a wire for every signal. This kind of sharing is called **multiplexing**.
- It can be accomplished in several different ways. We will present methods for time, frequency, and code division multiplexing.

Multiplexing techniques

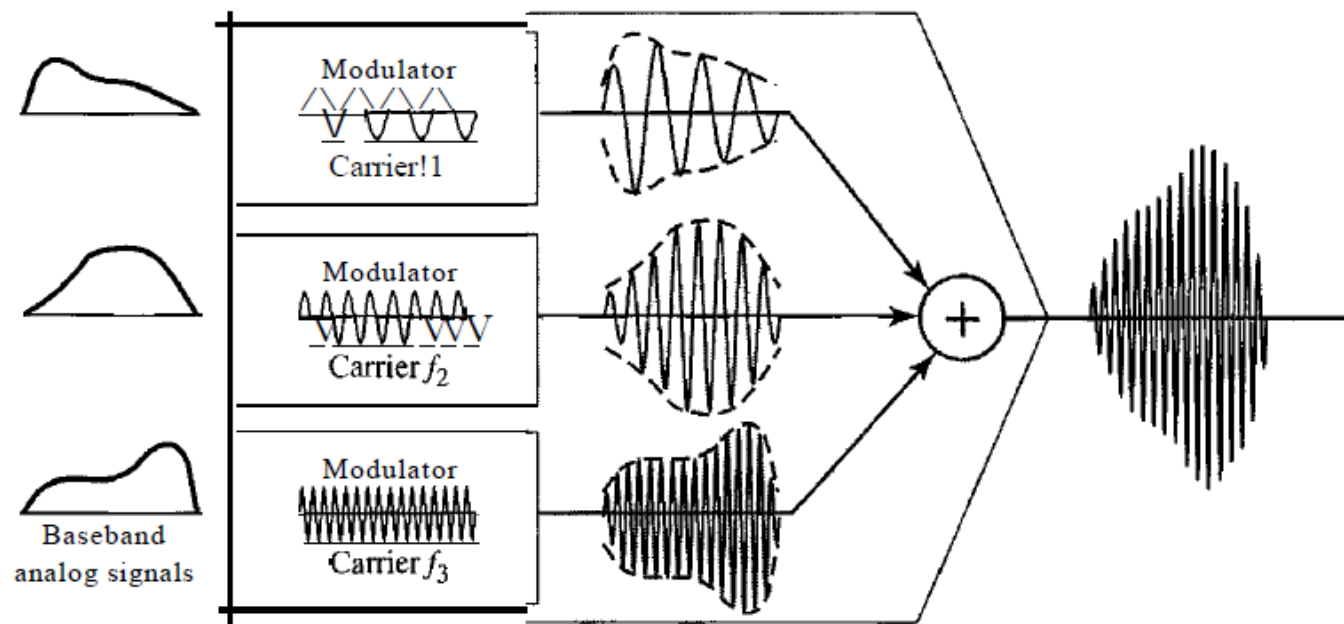
- Frequency division multiplexing
- Wavelength division multiplexing
- Time division multiplexing
- Code division multiplexing

Frequency Division Multiplexing

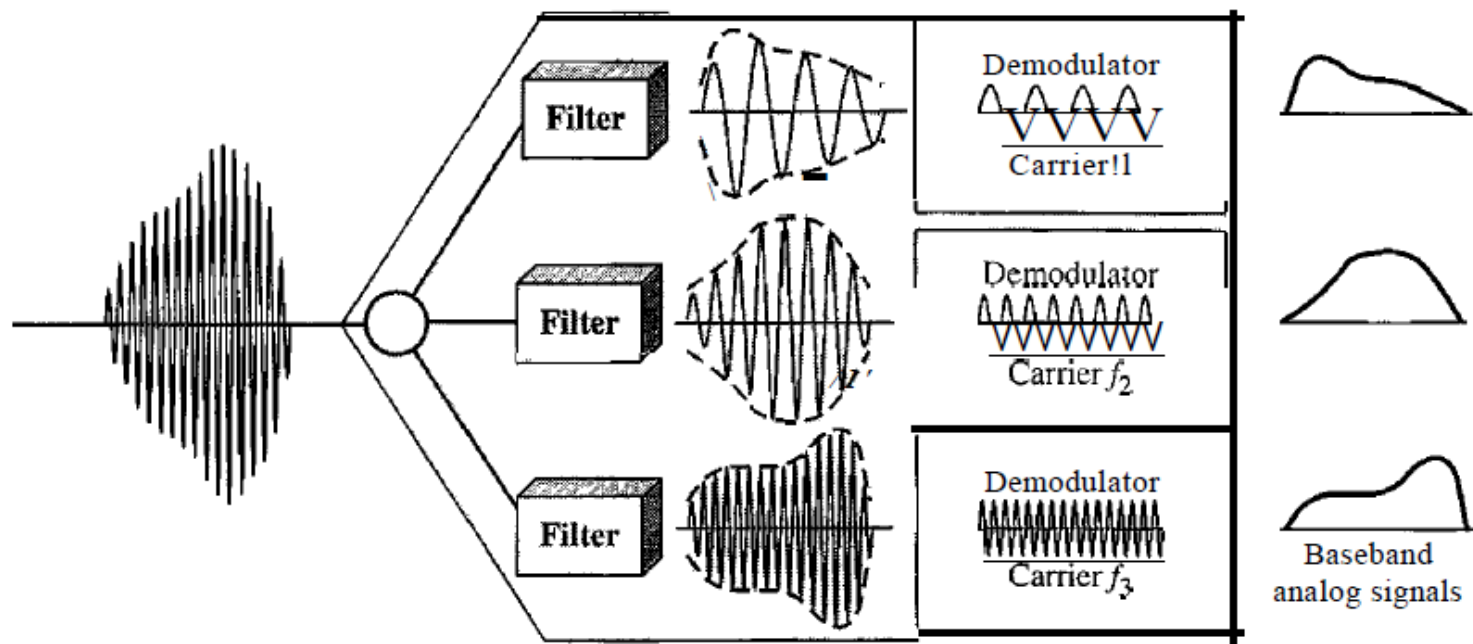


Frequency division multiplexing. (a) The original bandwidths. (b) The bandwidths raised in frequency. (c) The multiplexed channel.

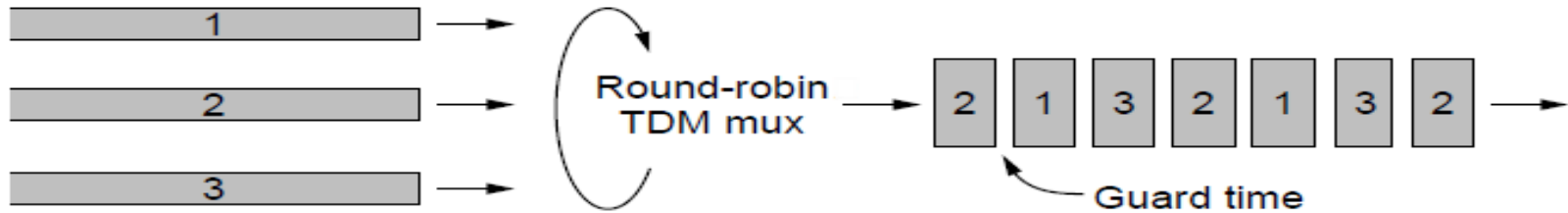
FDM process



FDM demultiplexing example



Time Division Multiplexing



Time Division Multiplexing (TDM).

Code Division Multiplexing

- CDM allows each station to transmit over the entire frequency spectrum all the time.
- Multiple simultaneous transmissions are separated using coding theory.

Walsh codes(orthogonal)

$$\mathbf{S} \bullet \mathbf{T} \equiv \frac{1}{m} \sum_{i=1}^m S_i T_i = 0$$

$$\mathbf{S} \bullet \mathbf{S} = \frac{1}{m} \sum_{i=1}^m S_i S_i = \frac{1}{m} \sum_{i=1}^m S_i^2 = \frac{1}{m} \sum_{i=1}^m (\pm 1)^2 = 1$$

$$\mathbf{S} \bullet \bar{\mathbf{S}} = -1.$$

Contd..

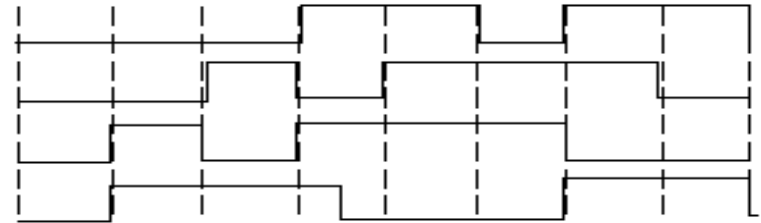
$A = (-1 -1 -1 +1 +1 -1 +1 +1)$

$B = (-1 -1 +1 -1 +1 +1 +1 -1)$

$C = (-1 +1 -1 +1 +1 +1 -1 -1)$

$D = (-1 +1 -1 -1 -1 -1 +1 -1)$

(a)



(b)

(a) Chip sequences for four stations.

(b) Signals the sequences represent

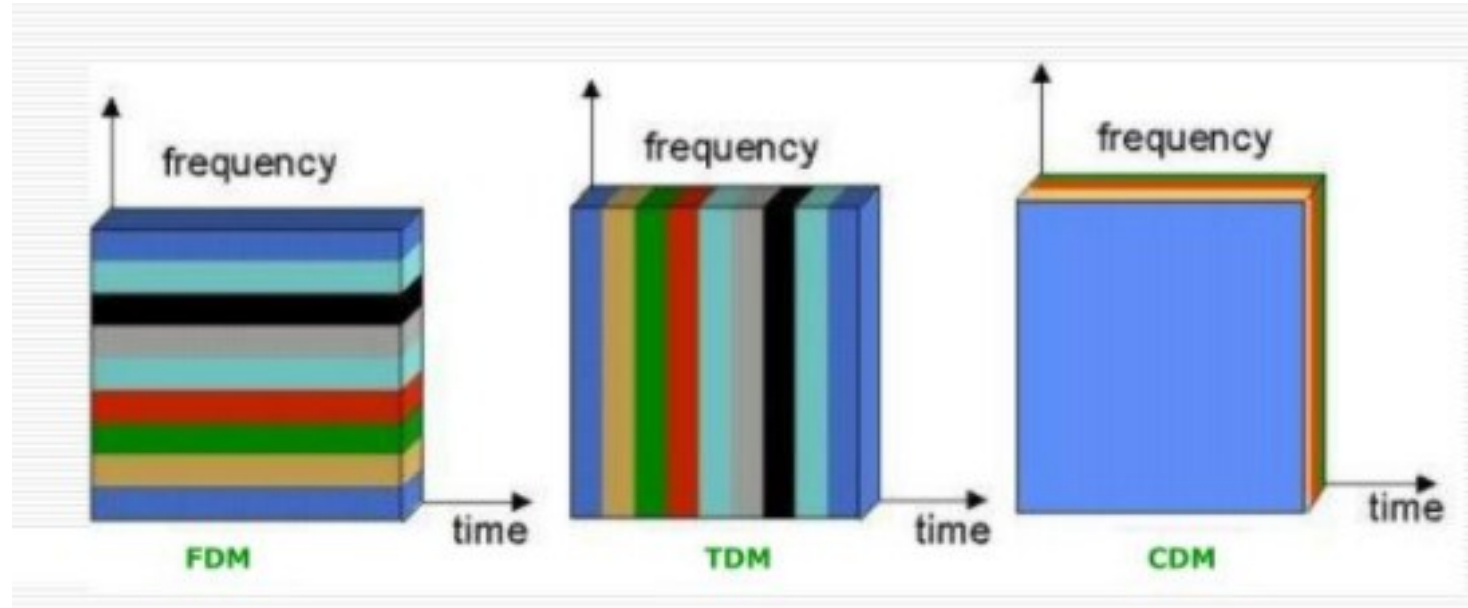
$S_1 = C$	$= (-1 +1 -1 +1 +1 +1 -1 -1)$	$S_1 \bullet C = [1+1-1+1+1+1-1-1]/8 = 1$
$S_2 = B + \overline{C}$	$= (-2 \ 0 \ 0 \ 0 +2 +2 \ 0 -2)$	$S_2 \bullet C = [2+0+0+0+2+2+0+2]/8 = 1$
$S_3 = A + \overline{B}$	$= (0 \ 0 -2 +2 \ 0 -2 \ 0 +2)$	$S_3 \bullet C = [0+0+2+2+0-2+0-2]/8 = 0$
$S_4 = A + \overline{B} + C$	$= (-1 +1 -3 +3 +1 -1 -1 +1)$	$S_4 \bullet C = [1+1+3+3+1-1+1-1]/8 = 1$
$S_5 = A + B + \overline{C} + D$	$= (-4 \ 0 -2 \ 0 +2 \ 0 +2 -2)$	$S_5 \bullet C = [4+0+2+0+2+0-2+2]/8 = 1$
$S_6 = A + B + \overline{C} + D$	$= (-2 -2 \ 0 -2 \ 0 -2 +4 \ 0)$	$S_6 \bullet C = [2-2+0-2+0-2-4+0]/8 = -1$

(c)
(d)

(a) Six examples of transmissions.

(b) Recovery of station C's

FDM Vs. TDM Vs. CDM



Switching

- A network is a set of connected devices. Whenever we have multiple devices, we have the problem of **how to connect them to make one-to-one** communication possible.
- One solution is to make a point-to-point connection between each pair of devices (a mesh topology) or between a central device and every other device (a star topology).
- These methods, however, are **impractical and wasteful** when applied to **very large networks**.

Contd..

- The number and length of the links require too much infrastructure to be cost- efficient, and the majority of those links would be idle most of the time.
- A better solution is switching. A switched network consists of a series of interlinked nodes, called switches.
- Switches are devices capable of **creating temporary connections** between two or more devices linked to the switch.
- In a switched network, some of these nodes are connected to the end systems and others are used only for routing.

Structure of a Cross bar switch

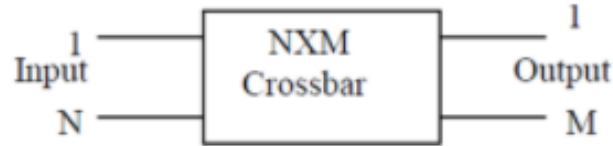
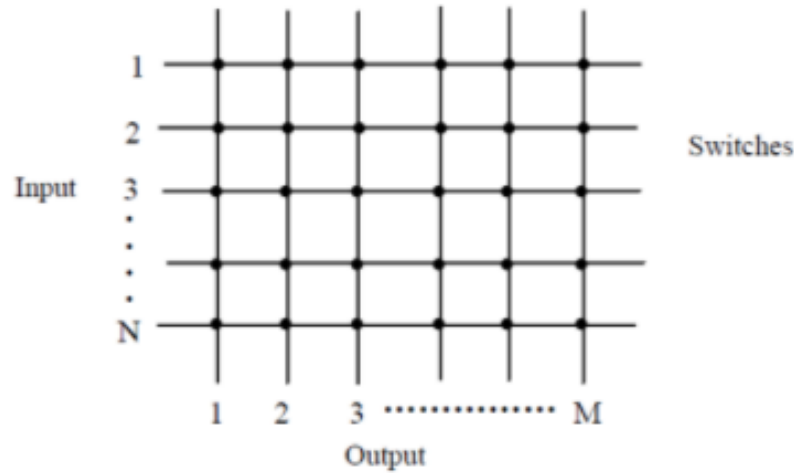
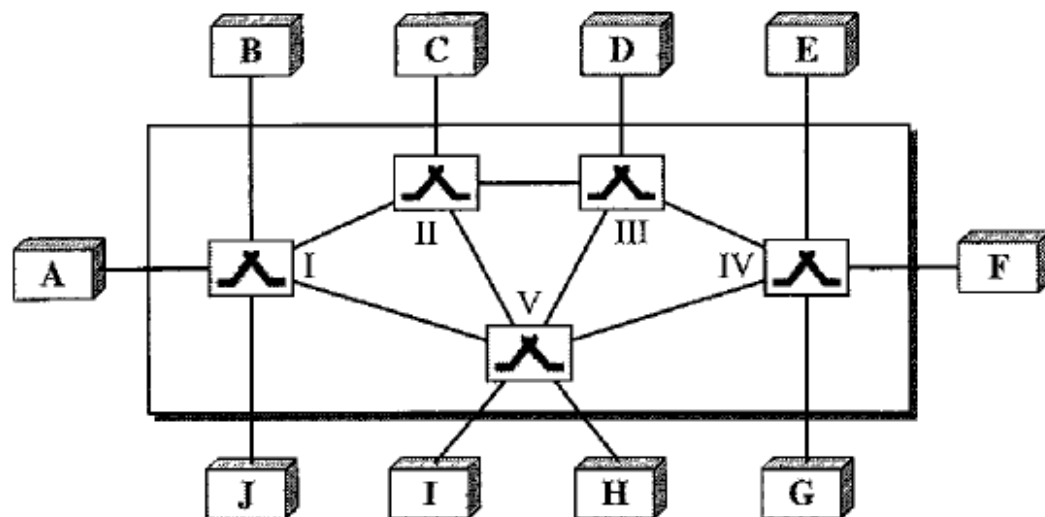


Figure: 3(a)

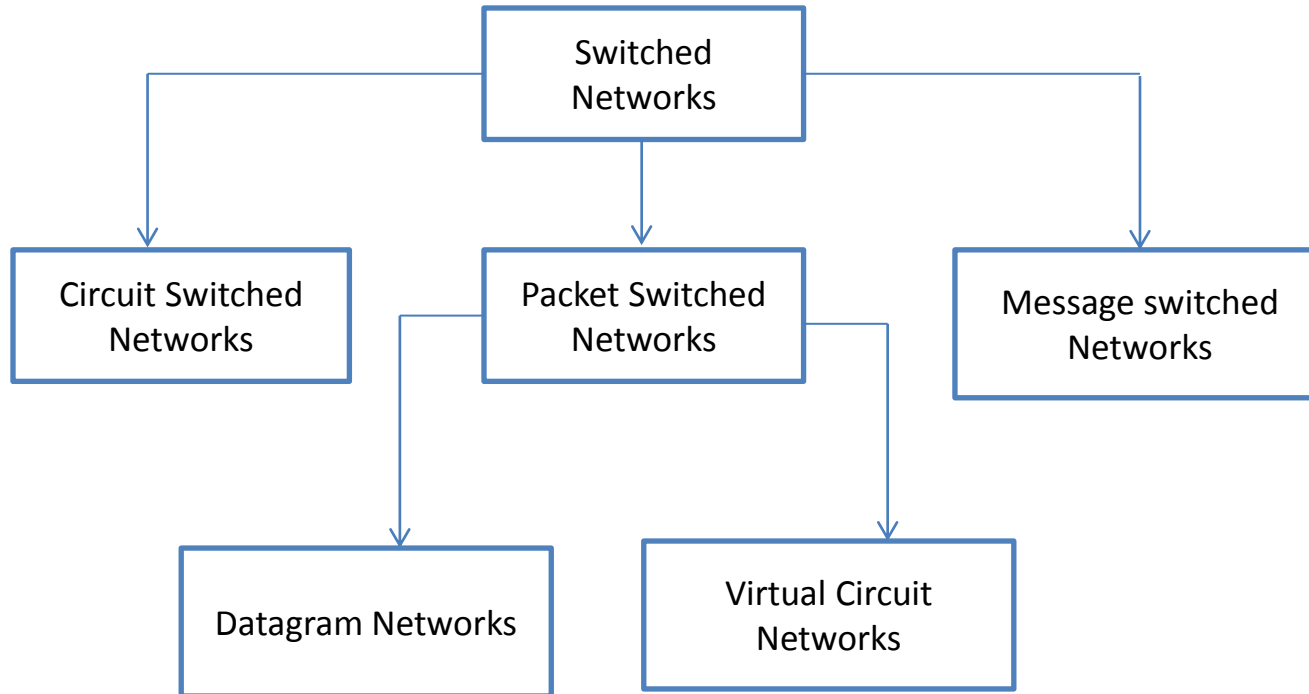


Crossbar Network

Switched network



Classification



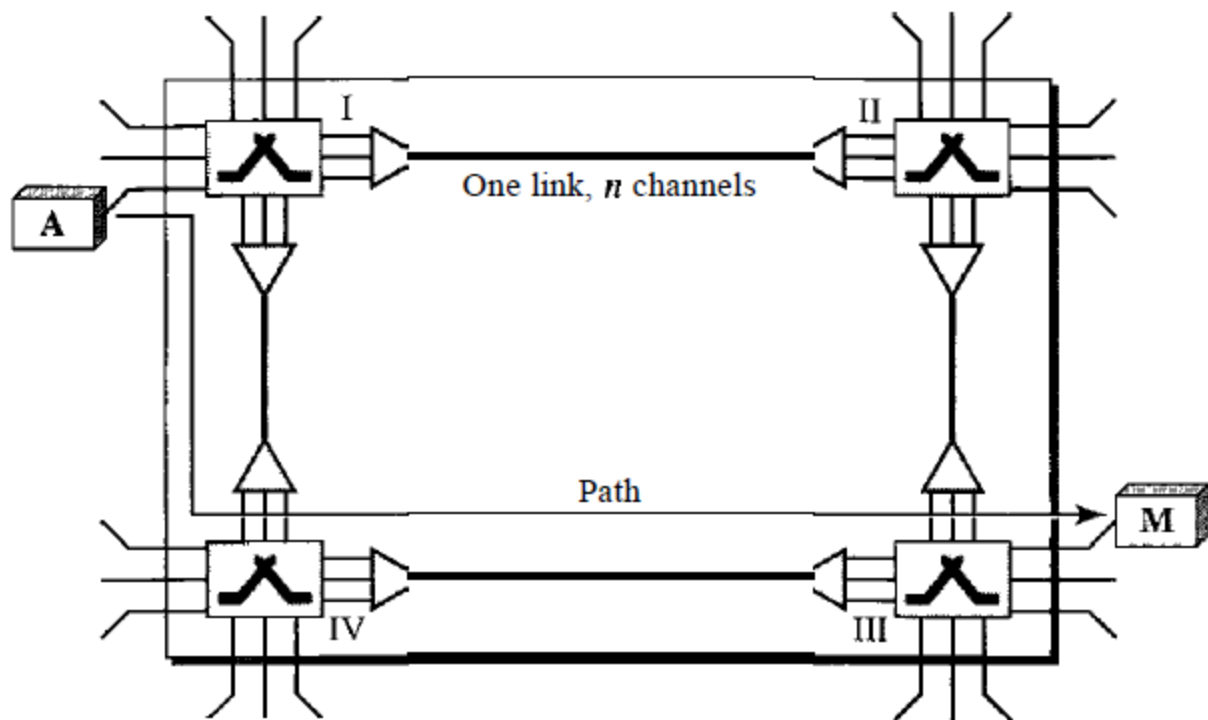
Circuit Switching

- A circuit-switched network consists of a set of switches connected by physical links.
- A connection between two stations is a dedicated path made of one or more links.
- However, each connection uses only one dedicated channel on each link. Each link is normally divided into n channels by using FDM or TDM
- Circuit Switching is done at **the physical layer**

Contd..

- THREE PHASES:
 - (i) Connection Establishment Phase
 - (ii) Data transfer
 - (iii) Connection release

A trivial circuit-switched network



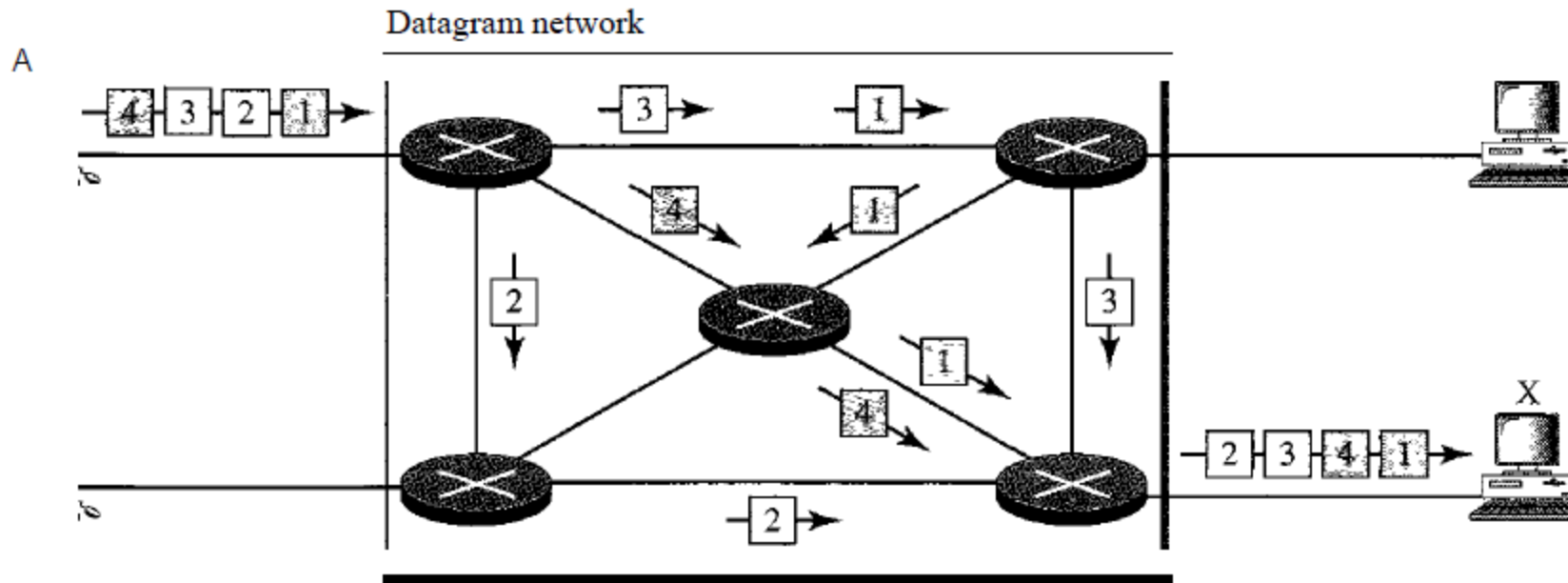
Packet Switching

- If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size.
- The size of the packet is determined by the network and the governing protocol.
- In a packet-switched network, there is no resource reservation; resources are allocated on demand.

Datagram network

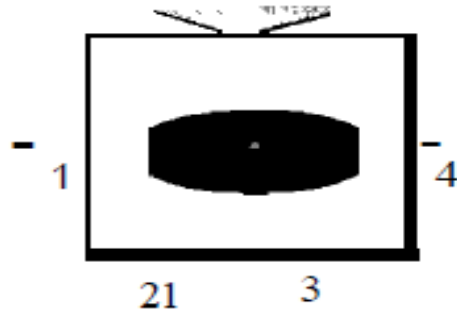
- In a datagram network, each packet is treated independently of all others.
- Packets in this approach are referred to as **datagrams**.
- Datagram switching is normally done at **the network layer**.
- In this type of network, each switch (or packet switch) has a routing table which is based on the destination address. The routing tables are dynamic and are updated periodically.
- The destination addresses and the corresponding forwarding output ports are recorded in the tables.

A datagram network with four switches (routers)



Routing table in datagram network

Destination address	Output port
1232	1
4150	2
.	.
9130	3



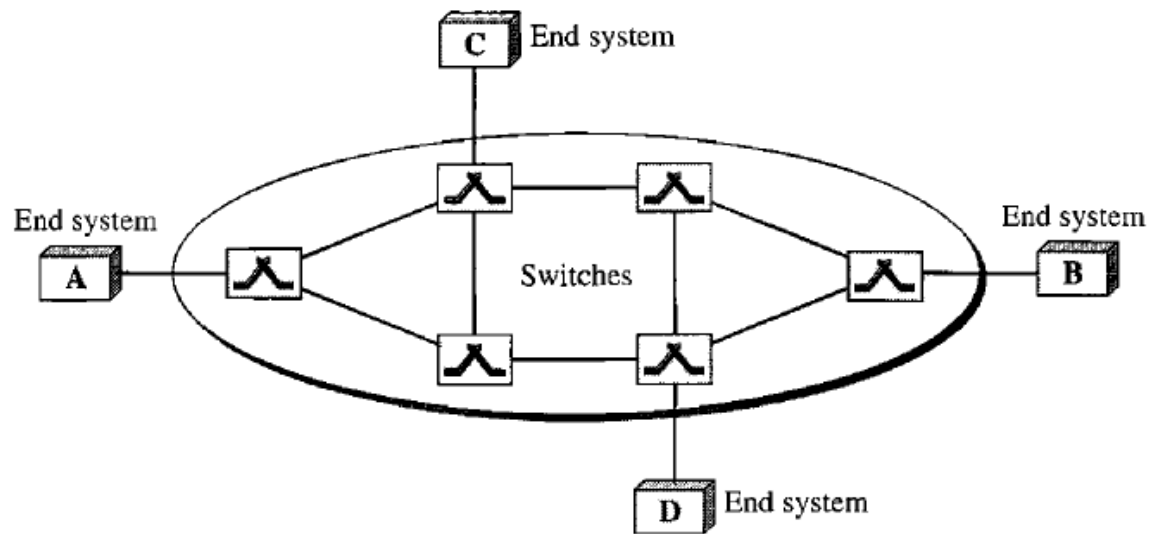
Virtual Circuit switching

- A virtual-circuit network is a cross between a circuit-switched network and a datagram network.
- It has some characteristics of both.
 - (i) As in a circuit-switched network, there are setup and teardown phases in addition to the data transfer phase.
 - (ii) Resources can be allocated during the setup phase, as in a circuit-switched network, or on demand, as in a datagram network.

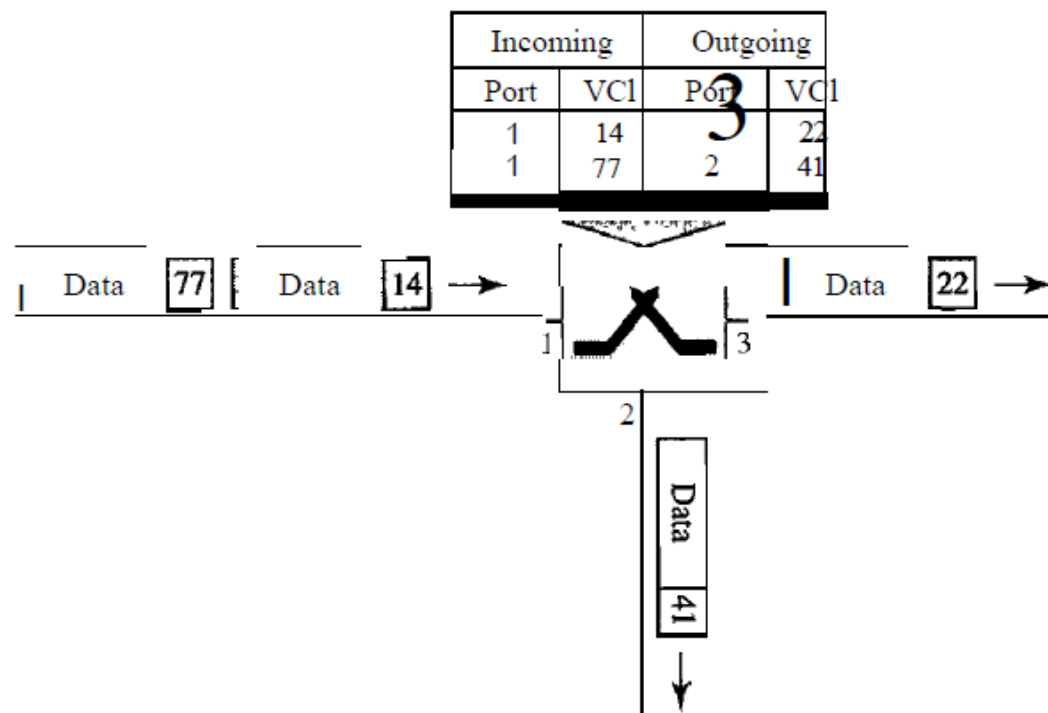
Contd..

- (iii) As in a datagram network, data are packetized and each packet carries an address in the header.
- (iv) As in a circuit-switched network, all packets follow the same path established during the connection.
- (v) A virtual-circuit network is normally implemented in the data link layer.

Virtual-circuit network



Switch and tables in a virtual-circuit network



Parameter	Circuit Switching	Packet Switching
Call setup	Required	Not required
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Bandwidth available	Fixed	Dynamic
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Charging	Per Minute	Per Packet

Queries ?