# COMPUTER NETWORKS


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**Department of Electronics and Communication Engineering**

# Syllabus

**UNIT – I**

**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

# UNIT-I

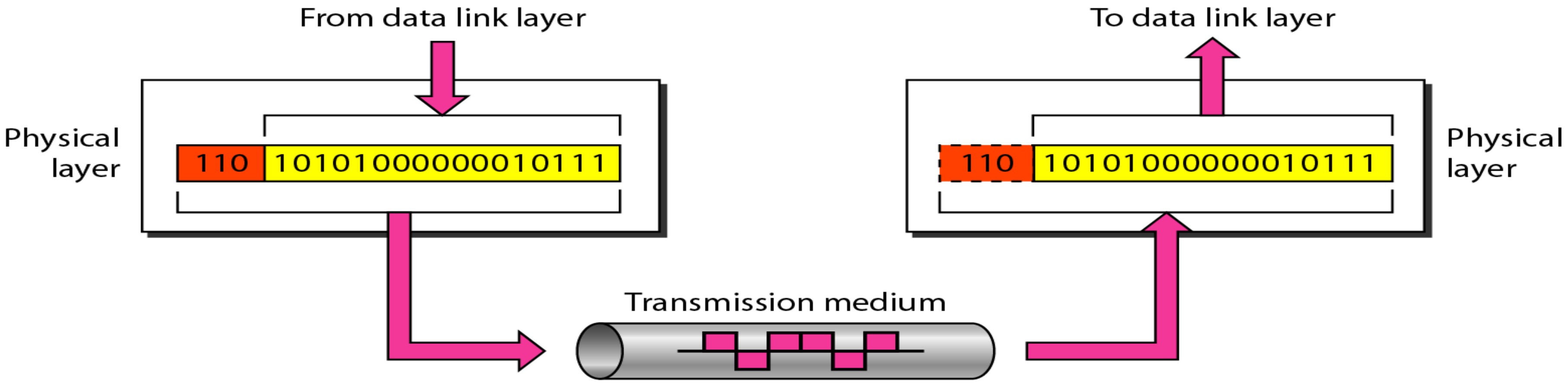
# Physical Layer

# 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

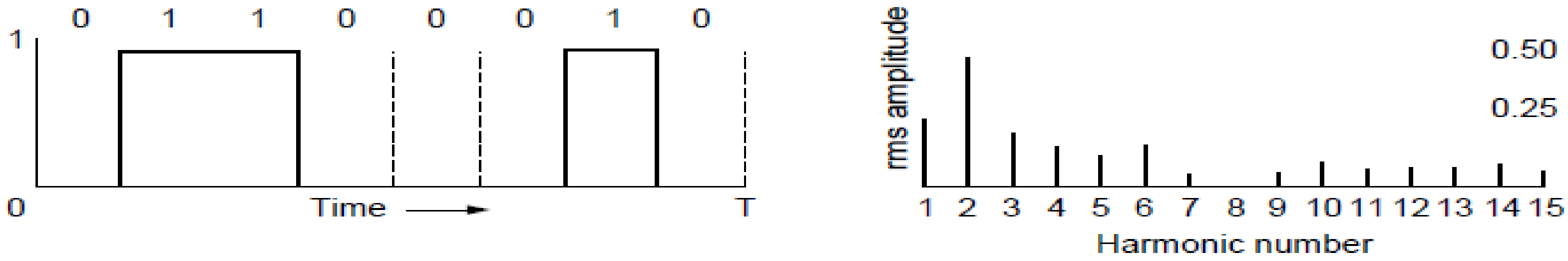
# Fourier Analysis

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

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

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

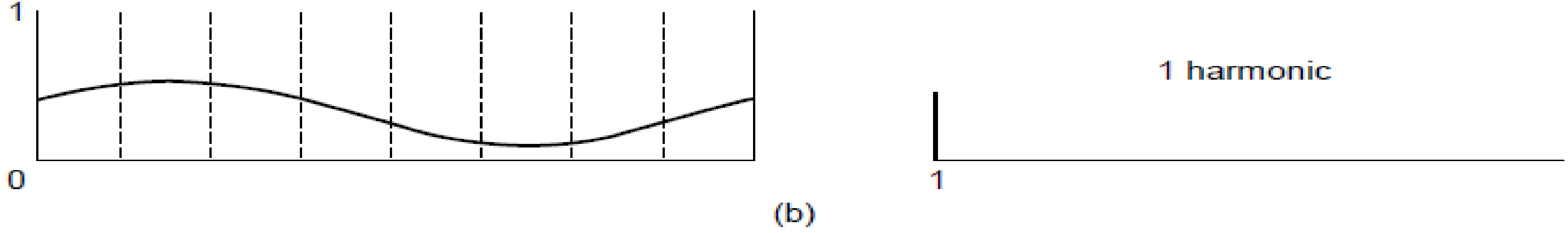
# Bandwidth-Limited Signals




(a)

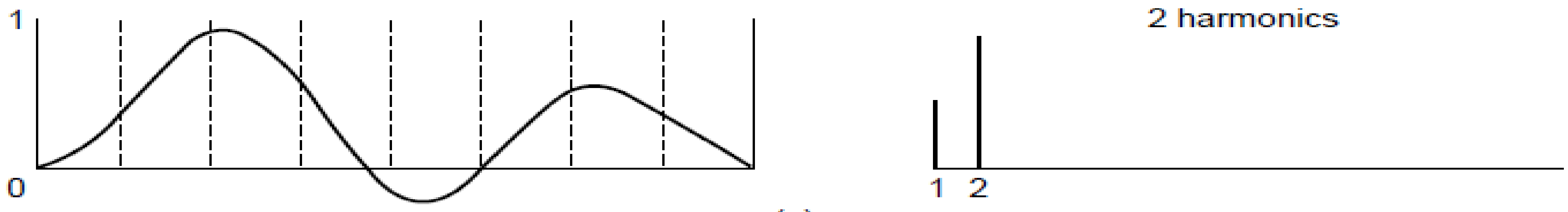
A binary signal and its root-mean-square Fourier amplitudes.

# Contd..




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

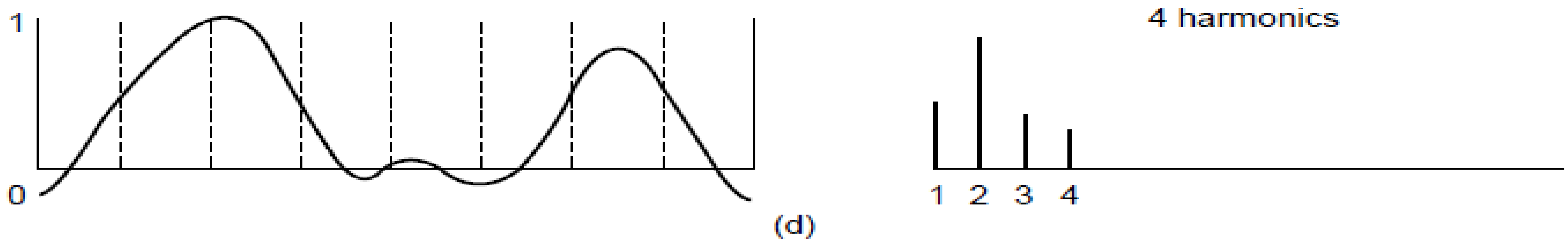
# Contd..



(c)

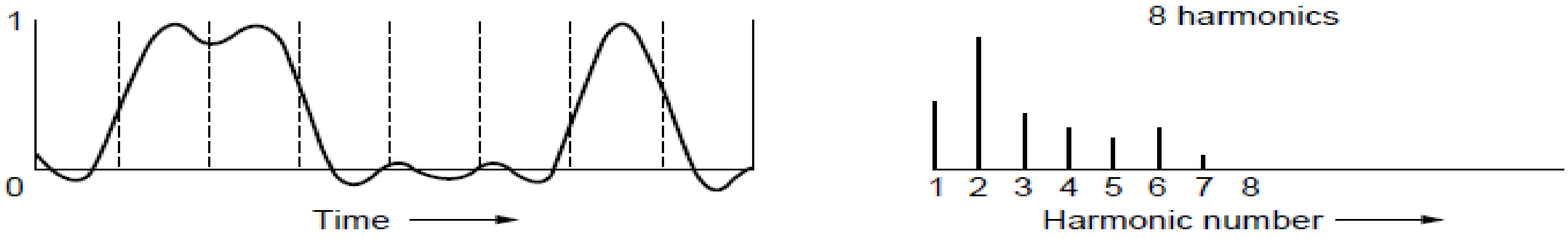
(b)-(e) Successive approximations to the original signal.

# Contd..




(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)

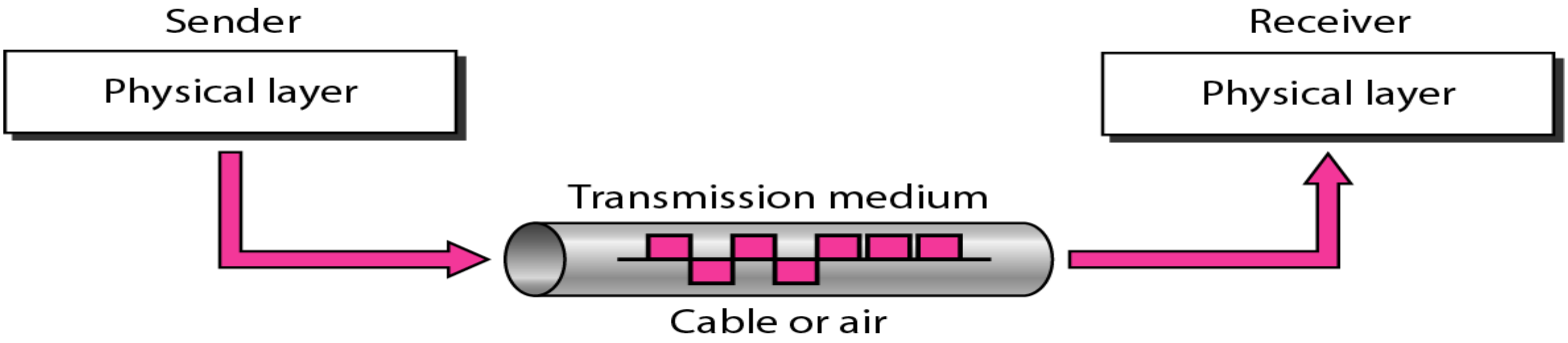
$$\text{maximum data rate} = 2\,B \log_2 V \text{ bits / sec}$$

- Shannon's formula for capacity of a noisy channel

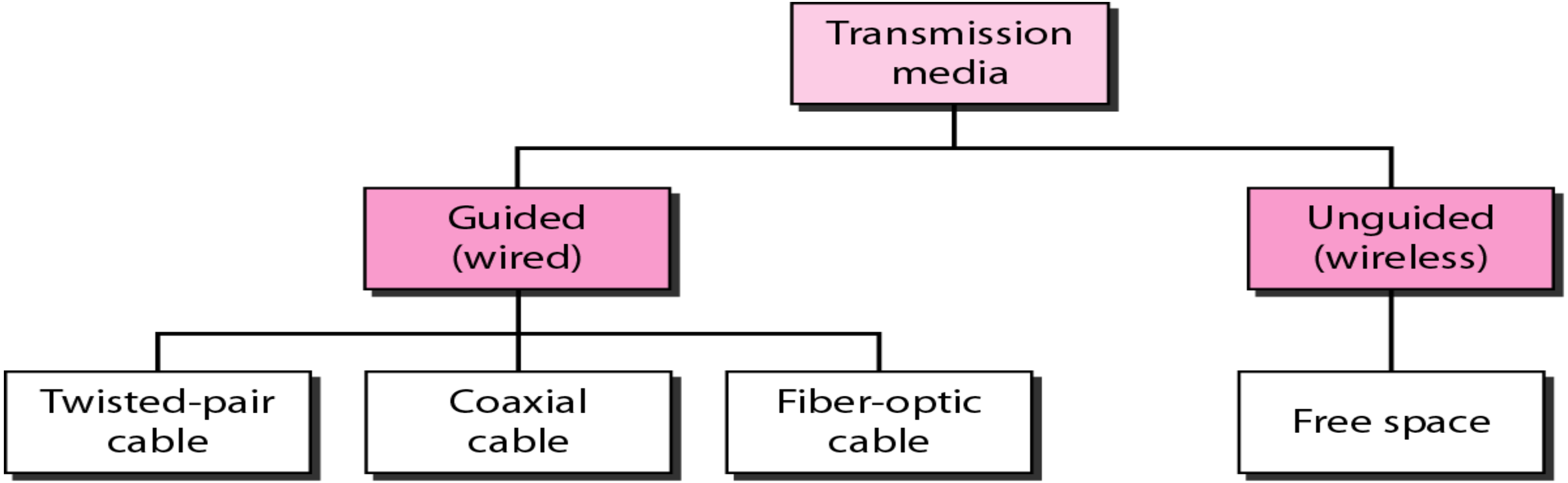
$$\text{maximum number of bits / sec} = B \log_2 (1 + S / N)$$

# Transmission Media

# Figure 2.2 *Transmission medium and physical layer*



# Figure 2.3 *Classes of transmission media*



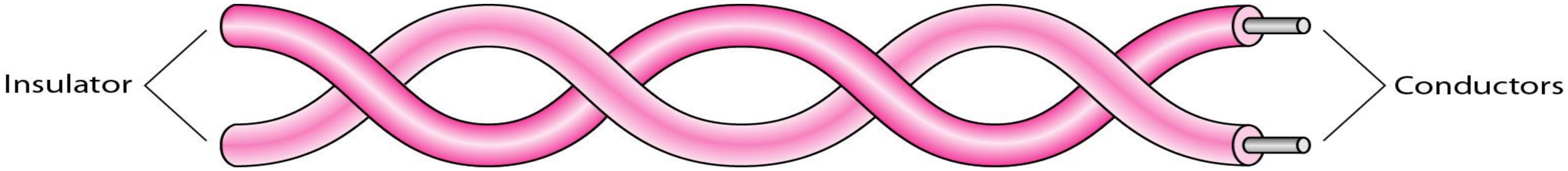
# GUIDED MEDIA

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.

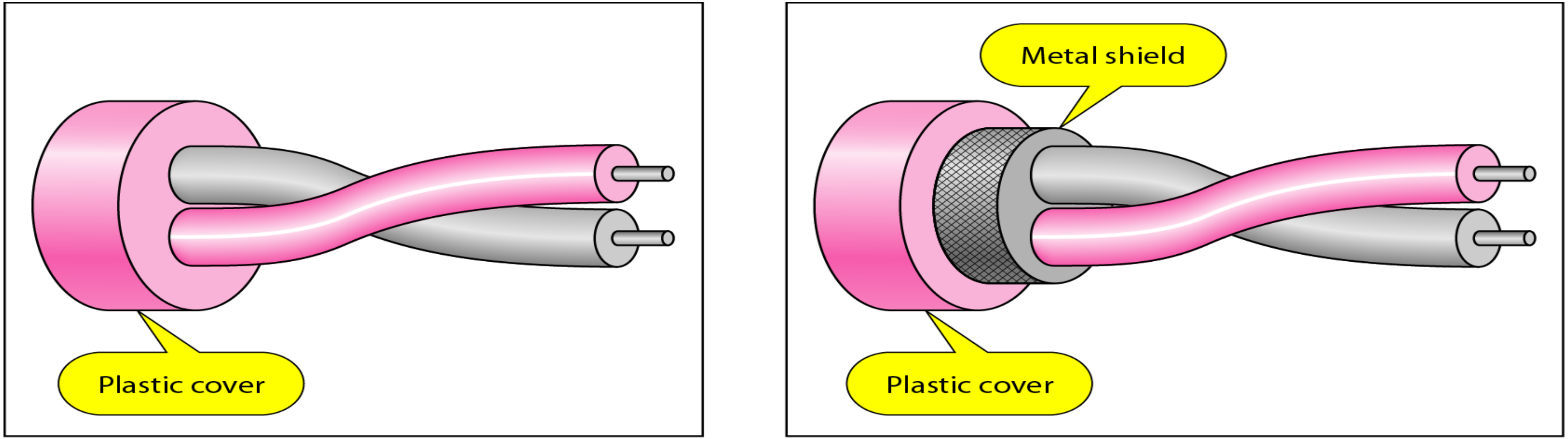
*Topics discussed in this section:*

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

## Figure 2.4 *Twisted-pair cable*



# Figure 2.5 *UTP and STP cables*

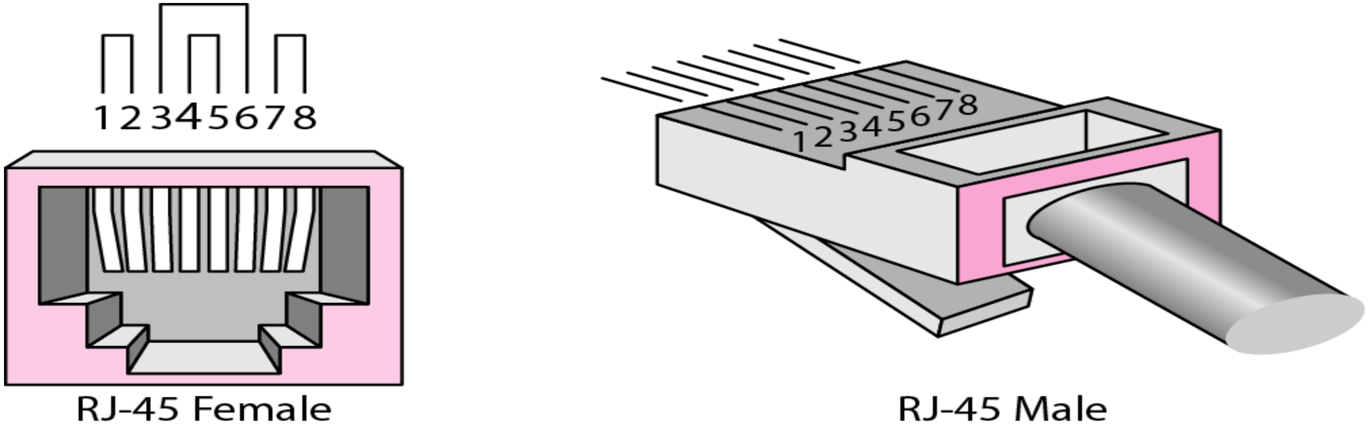



a. UTP b. STP

# Table 2.1 *Categories of unshielded twisted-pair cables*

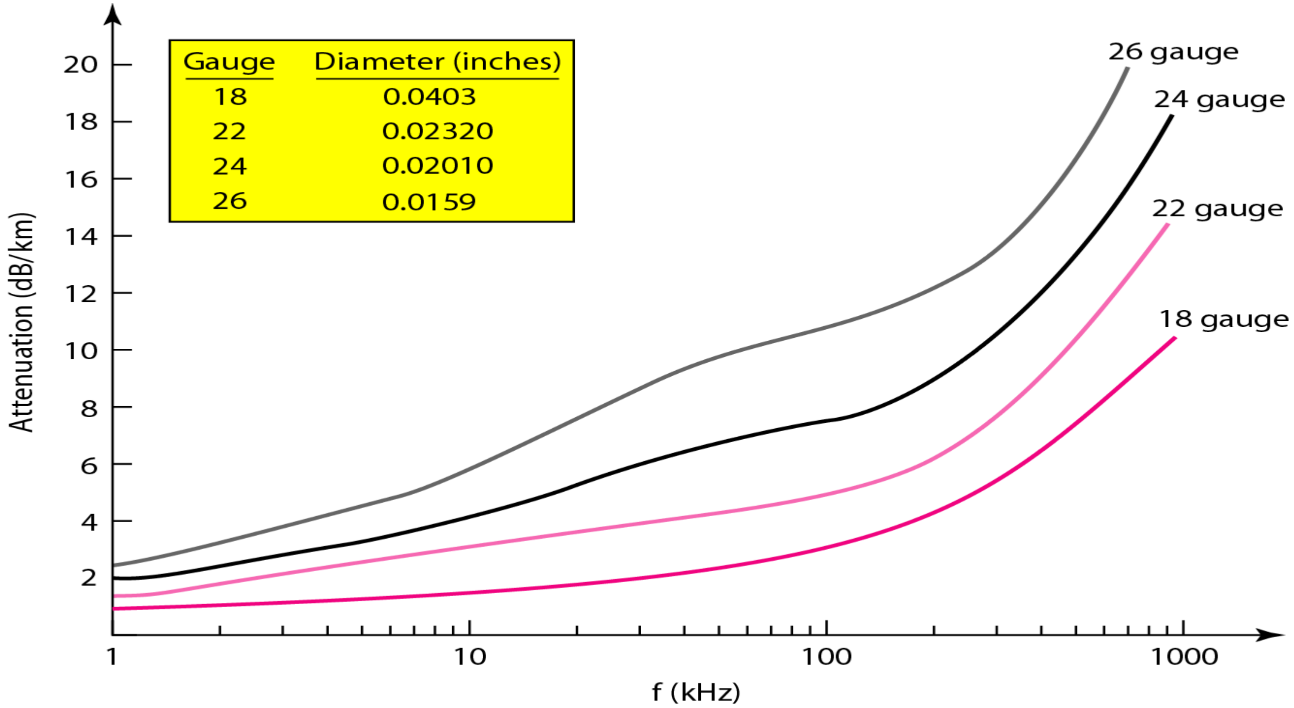
| *Category* | *Specification* | *Data Rate (Mbps)* | *Use* |
|---|---|---|---|
| 1 | Unshielded twisted-pair used in telephone | < 0.1 | Telephone |
| 2 | Unshielded twisted-pair originally used in T-lines | 2 | T-1 lines |
| 3 | Improved CAT 2 used in LANs | 10 | LANs |
| 4 | Improved CAT 3 used in 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*

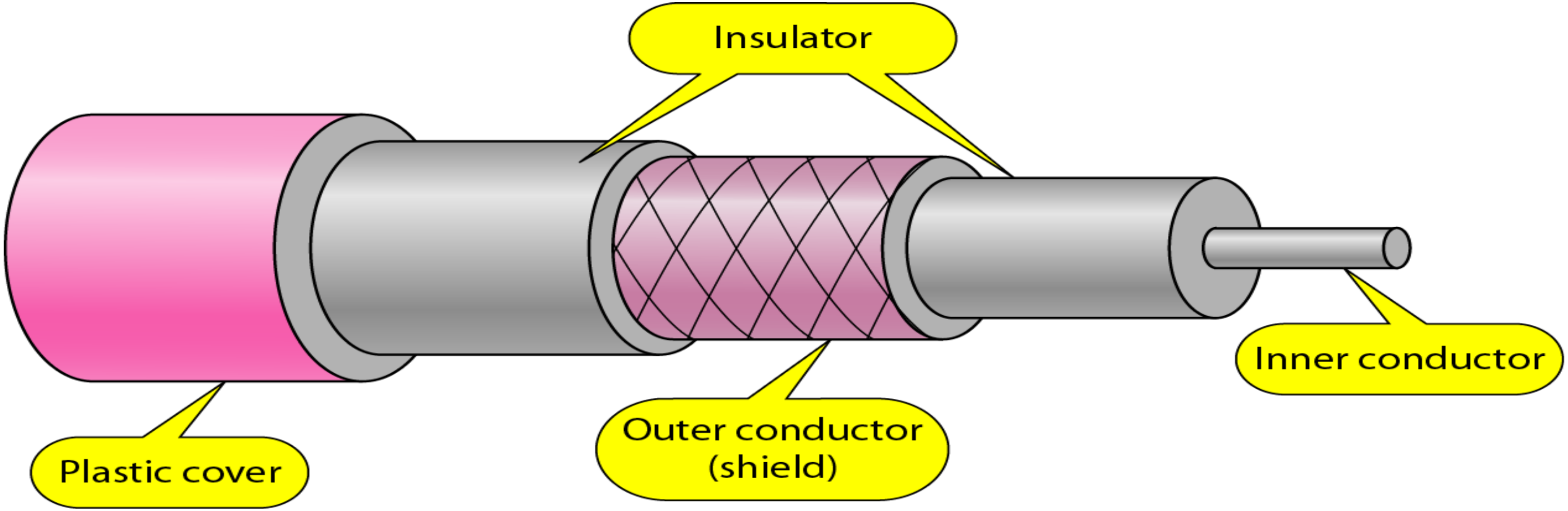



RJ- Registered Jack

# Figure 2.7 *UTP performance*



# Figure 2.8 *Coaxial cable*

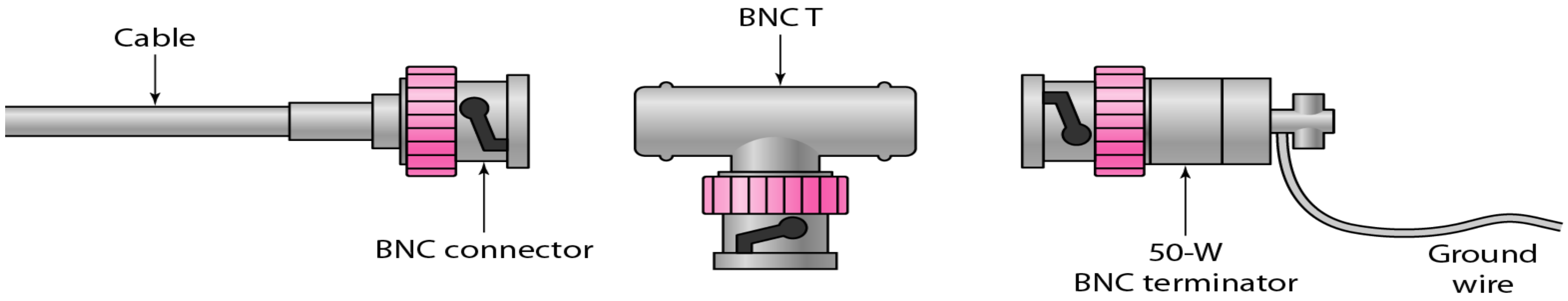


# Table 2.2 *Categories of coaxial cables*

| *Category* | *Impedance* | *Use* |
|---|---|---|
| RG-59 | 75 Ω | Cable TV |
| RG-58 | 50 Ω | Thin Ethernet |
| RG-11 | 50 Ω | Thick Ethernet |

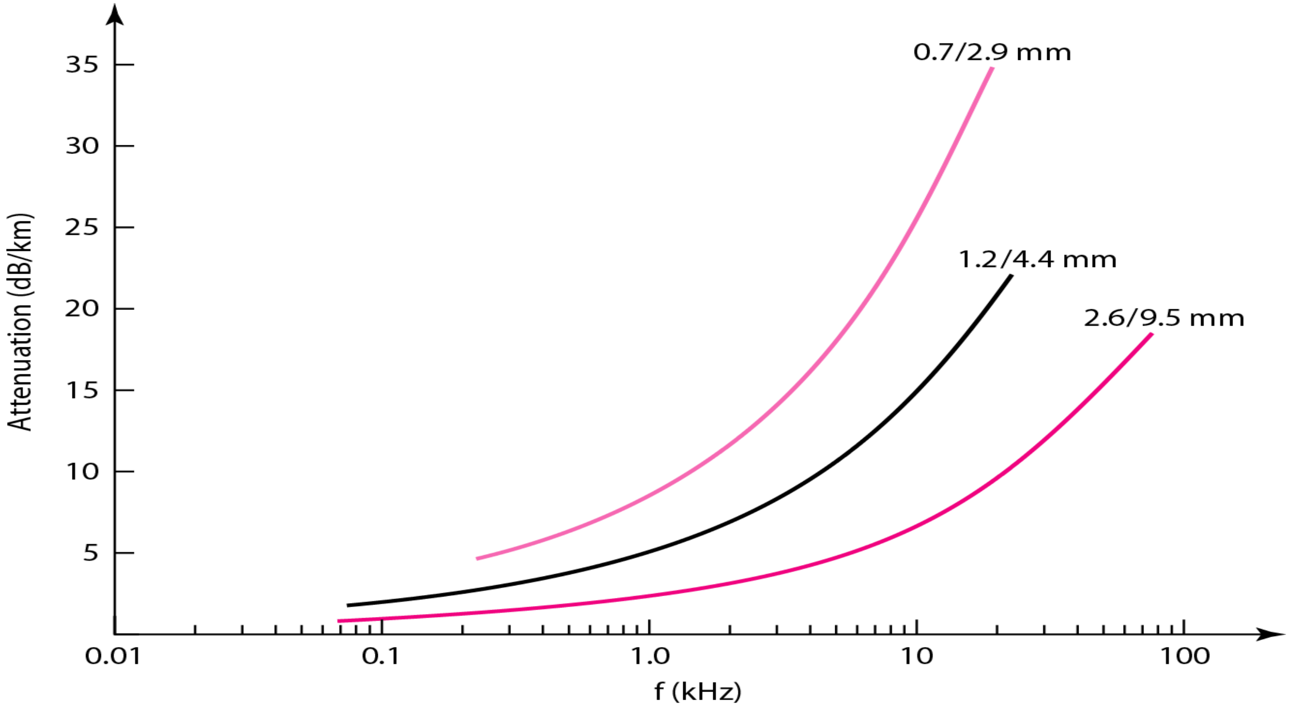
RG- Radio Guide

## Figure 2.9 *BNC connectors*

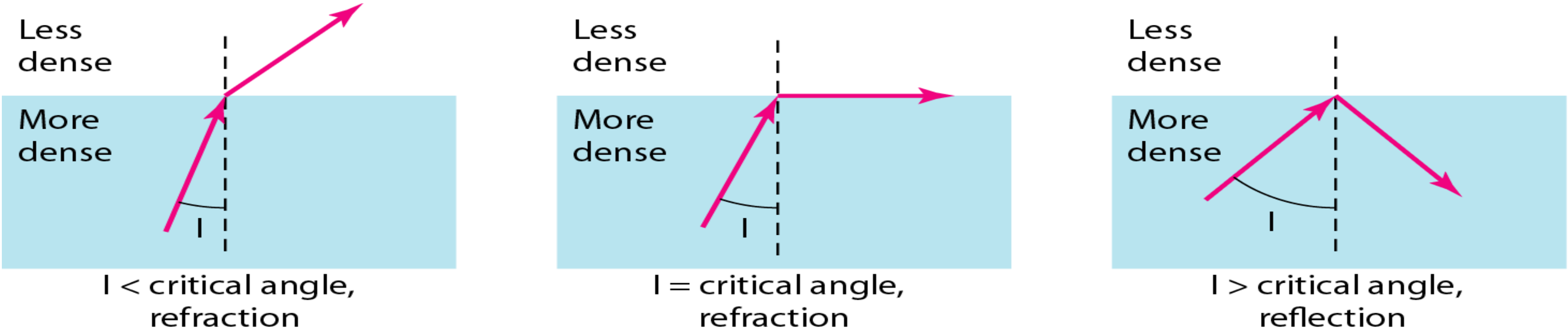



Bayonet Neill–Concealman

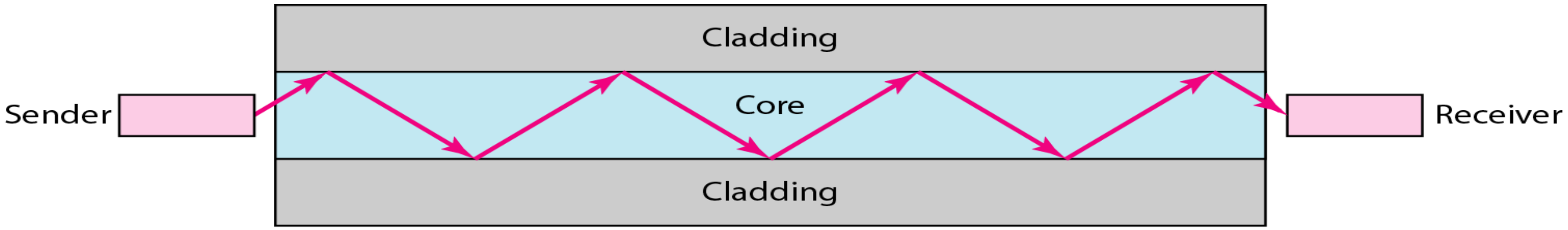
# Figure 2.10 *Coaxial cable performance*



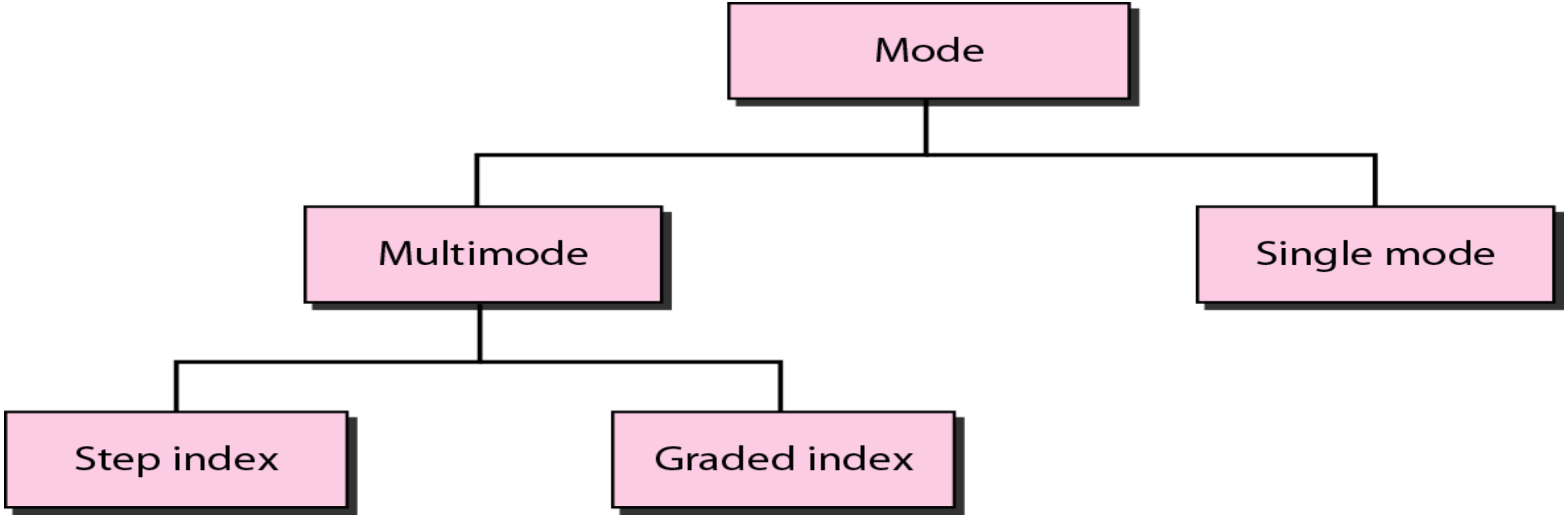
# Figure 2.11 Fiber optics: *Bending of light ray*



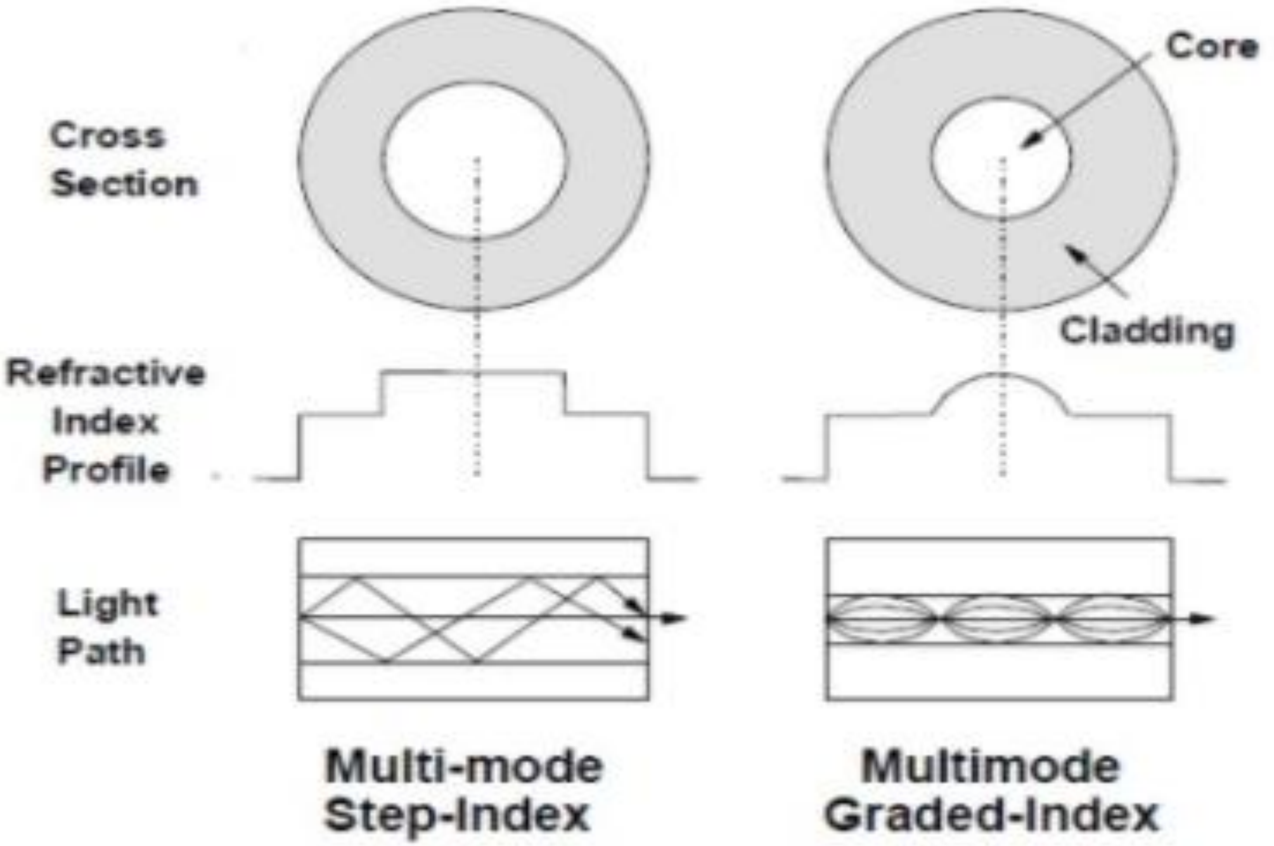
# Figure 2.12 *Optical fiber*



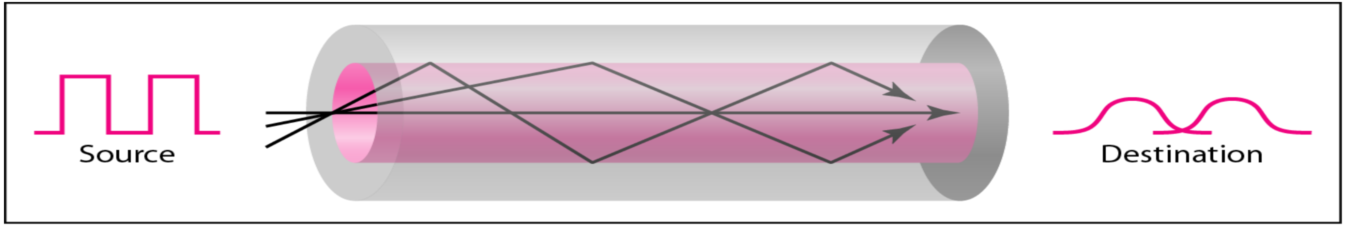
# Figure 2.13 *Propagation modes*



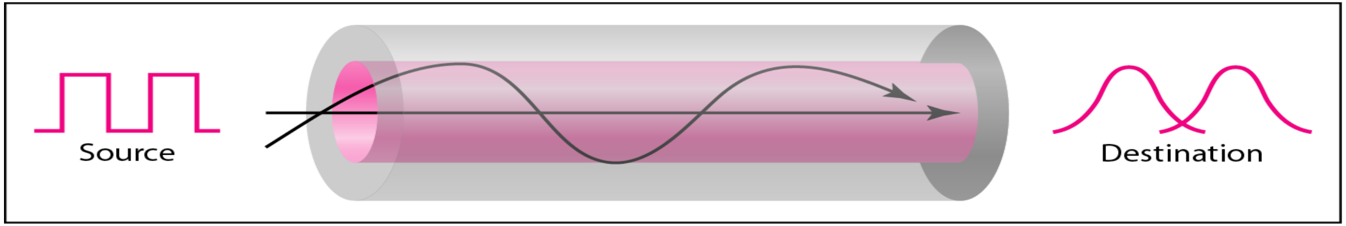
# Figure 2.14 *Modes*



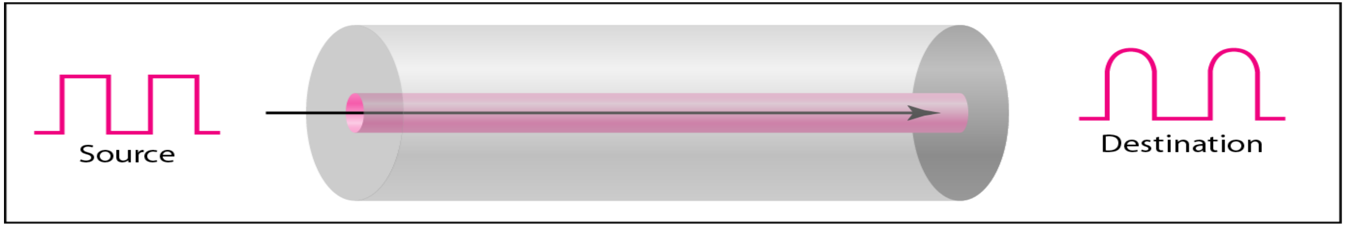
# Figure 2.15 *Modes*



a. Multimode, step index



b. Multimode, graded index

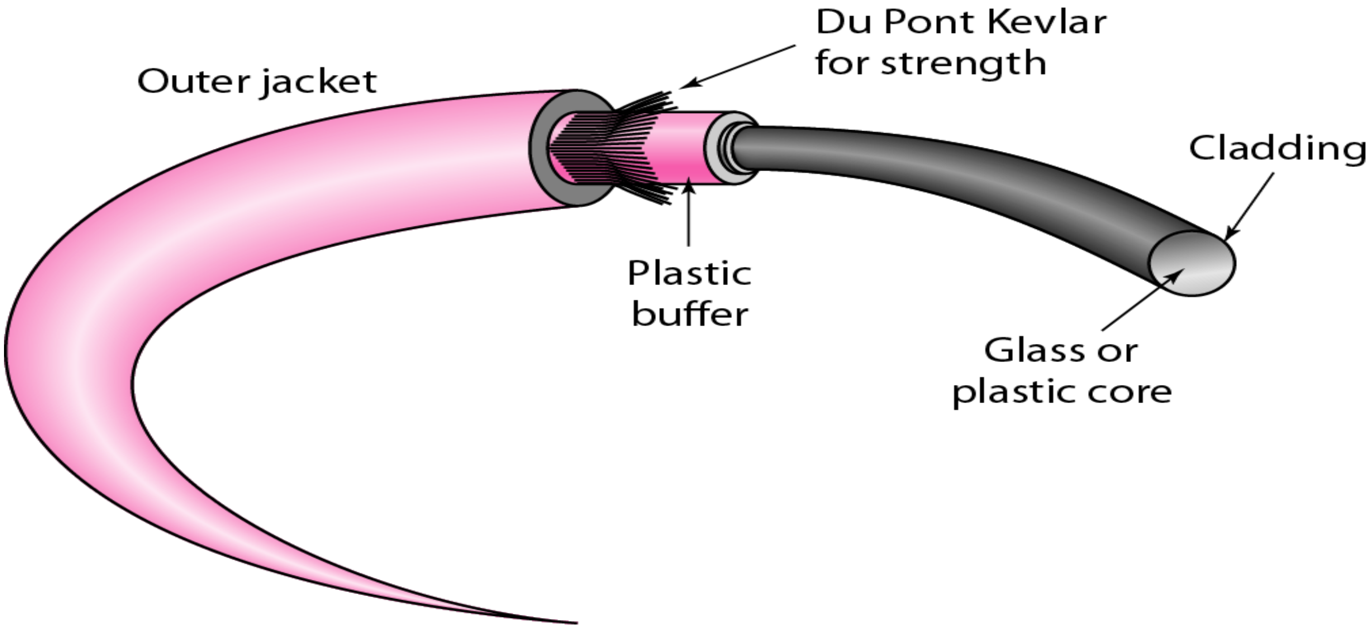


c. Single mode

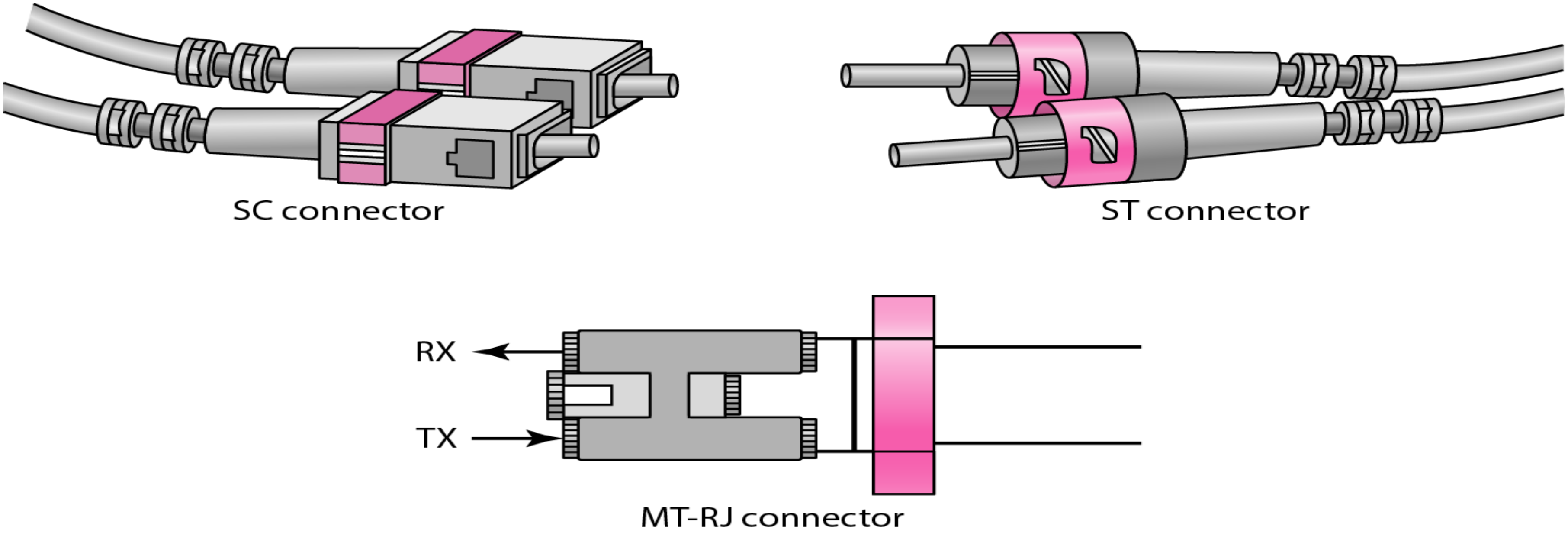
# Table 2.3 *Fiber types*

| *Type* | *Core (μm)* | *Cladding (μm)* | *Mode* |
|---|---|---|---|
| 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 |

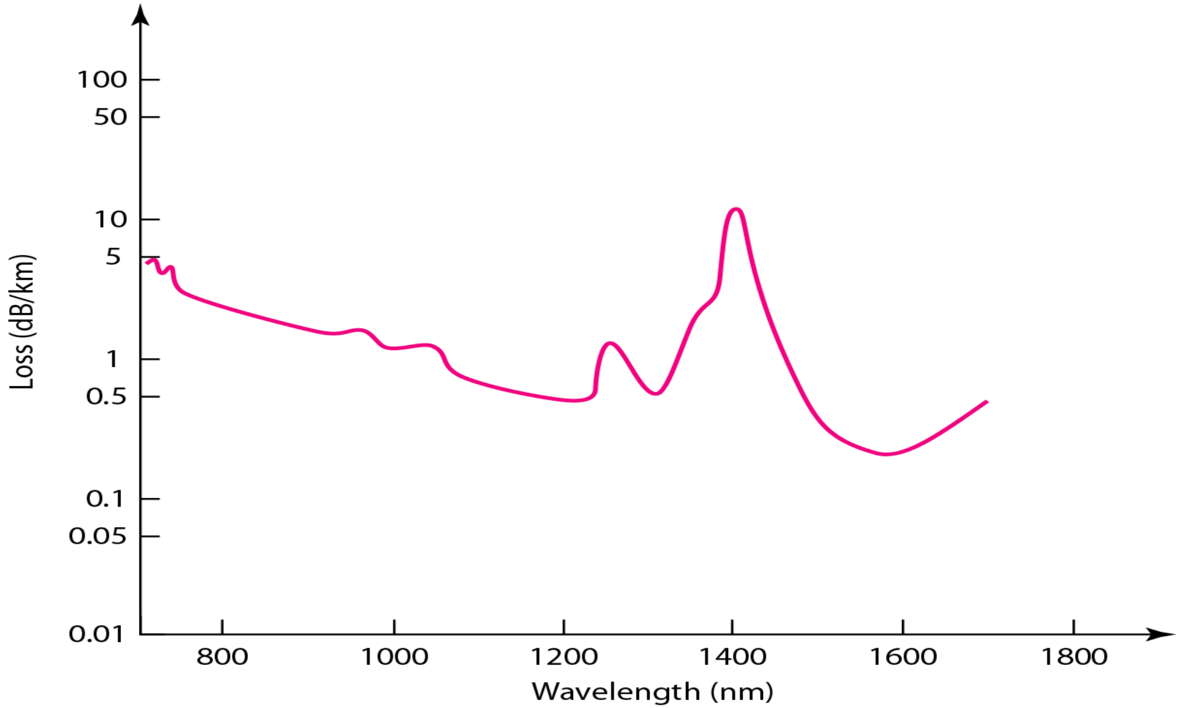
# Figure 2.16 *Fiber construction*



# Figure 2.17 *Fiber-optic cable connectors*

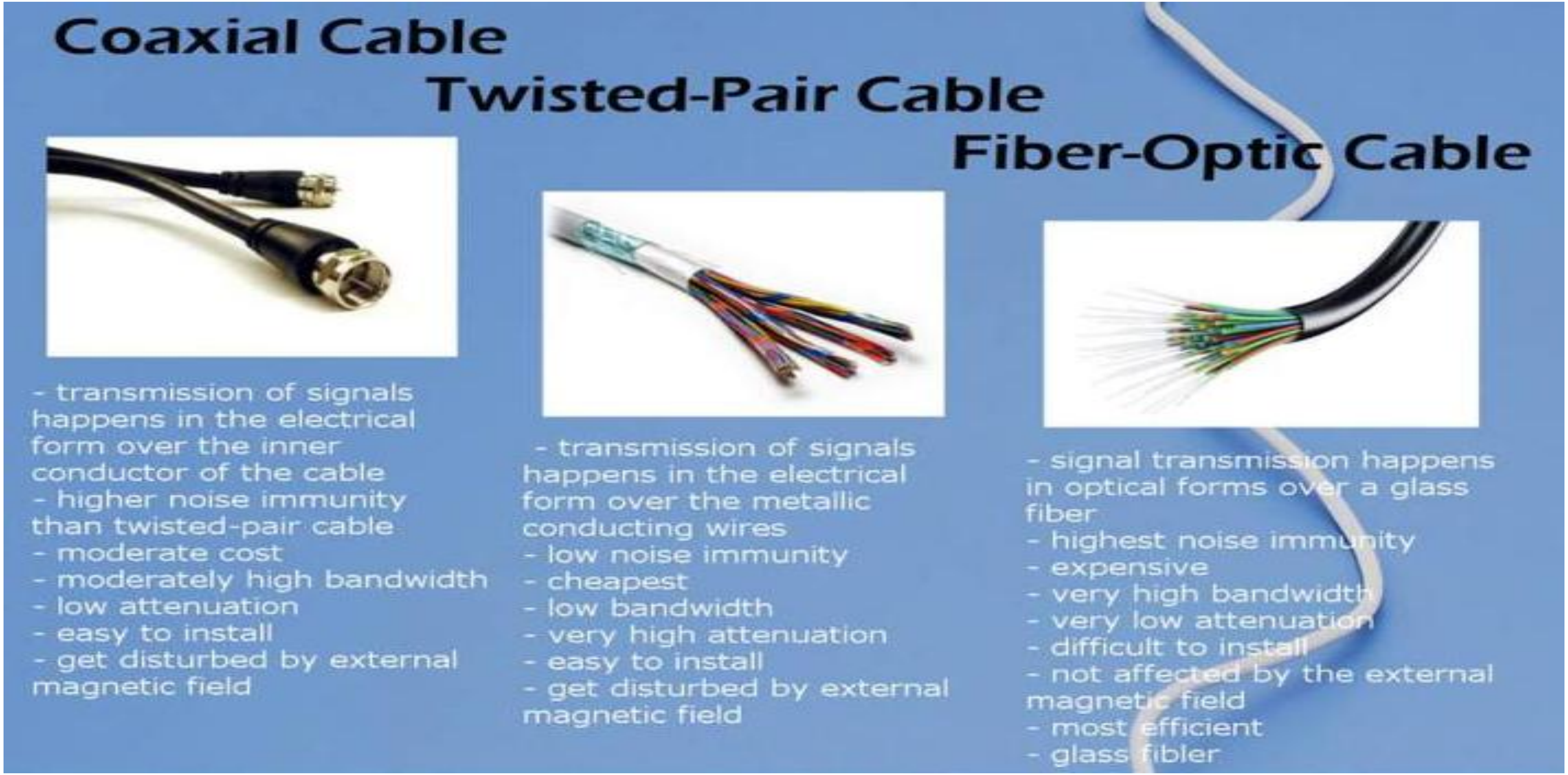


# Figure 2.18 *Optical fiber performance*



# 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
Twisted-Pair Cable
Fiber-Optic 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
- 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
- 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 fibler

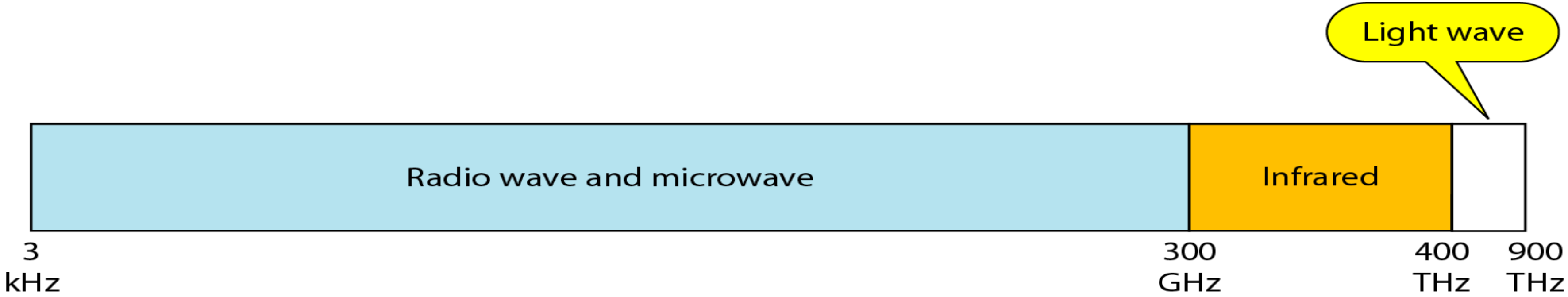
# UNGUIDED MEDIA: WIRELESS

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

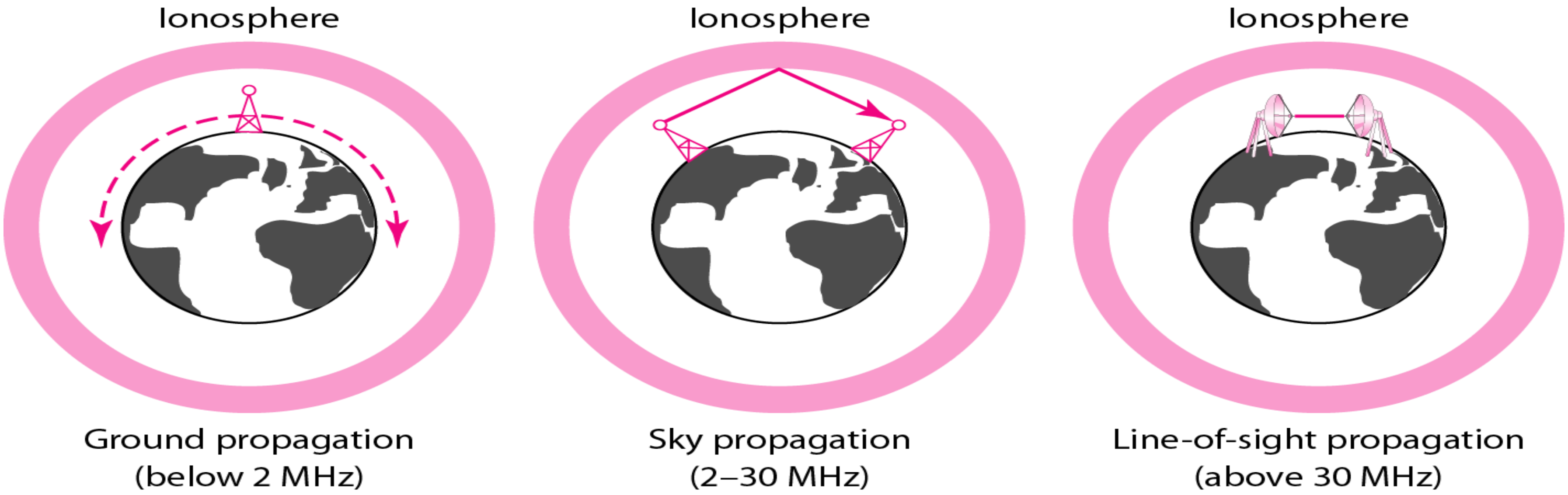
*Topics discussed in this section:*

1. Radio Waves
2. Microwaves
3. Infrared

# Figure 2.19 *Electromagnetic spectrum for wireless communication*



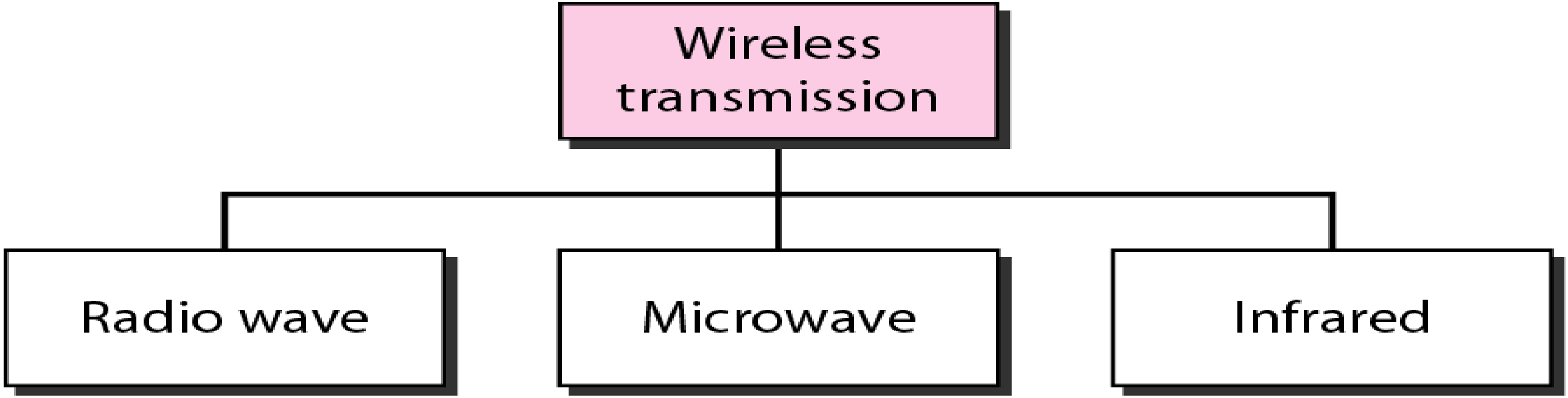
# Figure 2.20 *Propagation methods*



# Table 2.4 *Bands*

| *Band* | *Range* | *Propagation* | *Application* |
|---|---|---|---|
| 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*



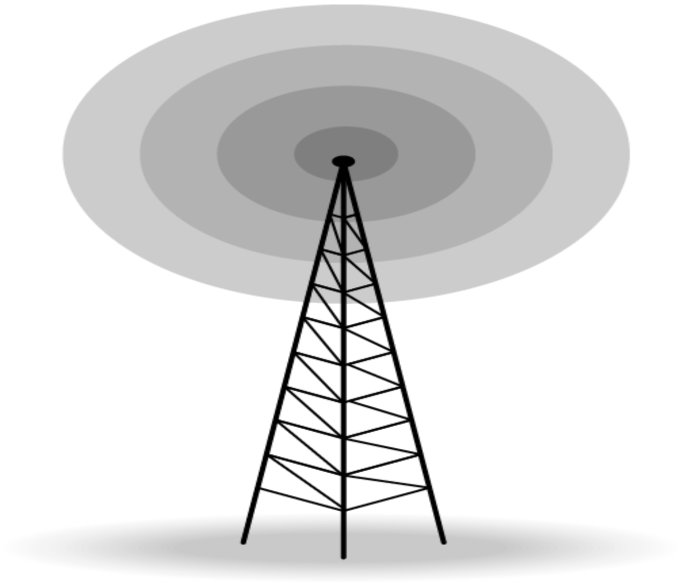
## Note

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

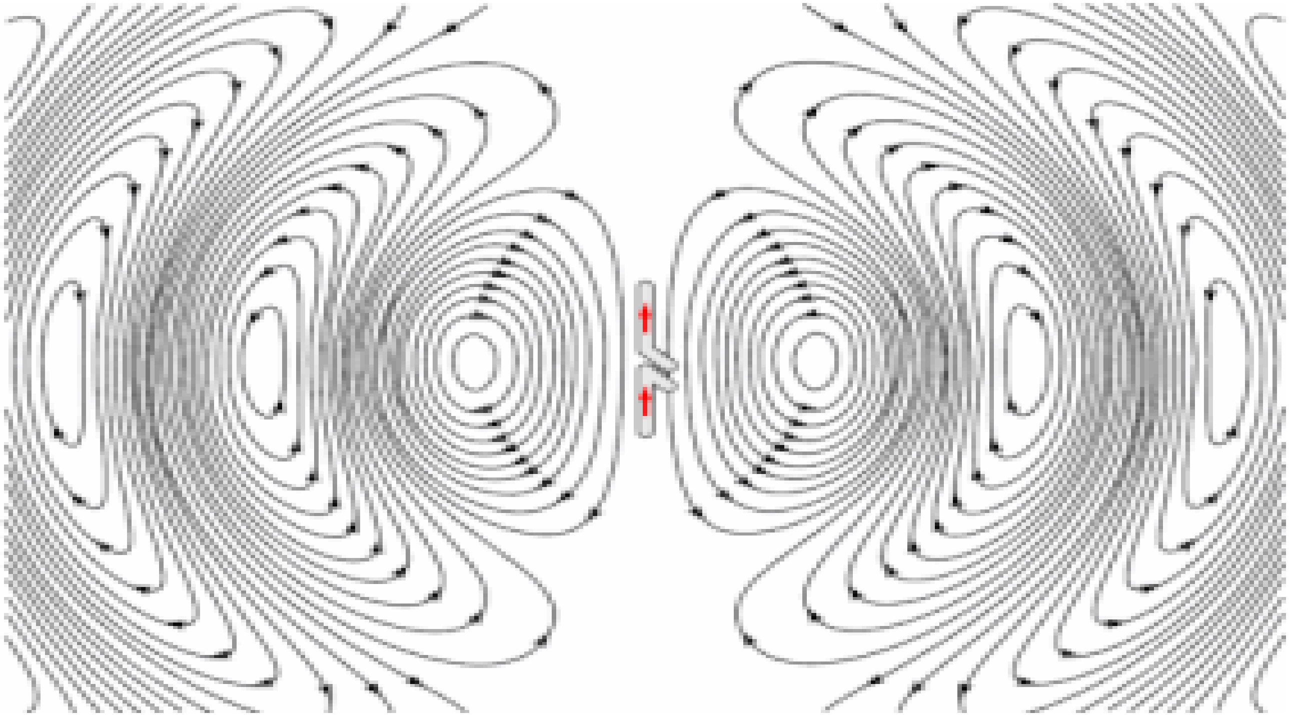
VVIT

# Figure 2.22 *Omni directional antenna*



Transmitting/receiving signals in all directions horizontally

## Figure 2.23 *Radiation pattern of Omnidirectional antenna*



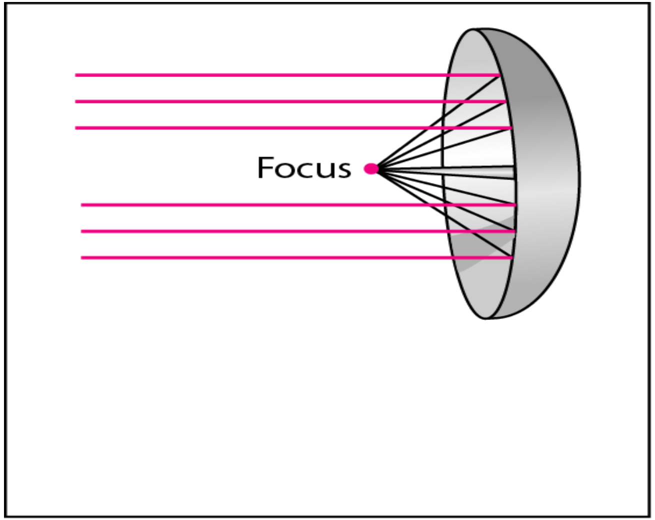
## Note

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

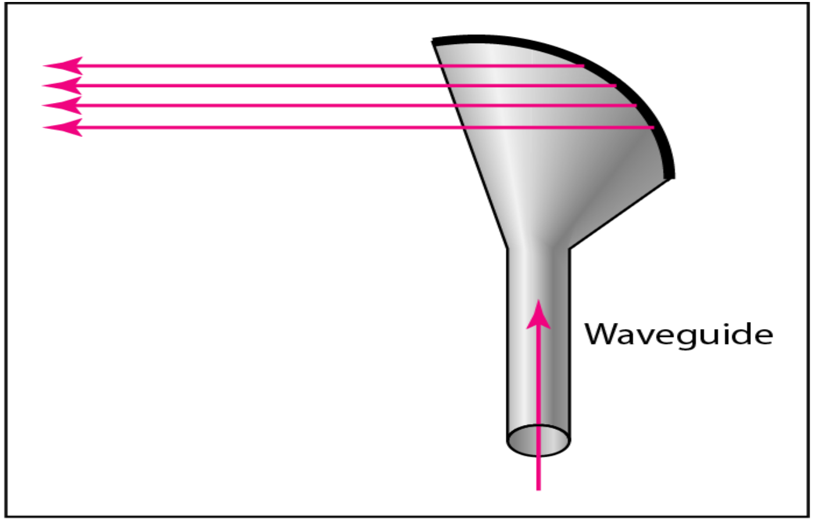
Higher frequency ranges cannot penetrate walls.

Use directional antennas - point to point line of sight communications.

# Figure 2.24 *Unidirectional antennas*




a. Dish antenna

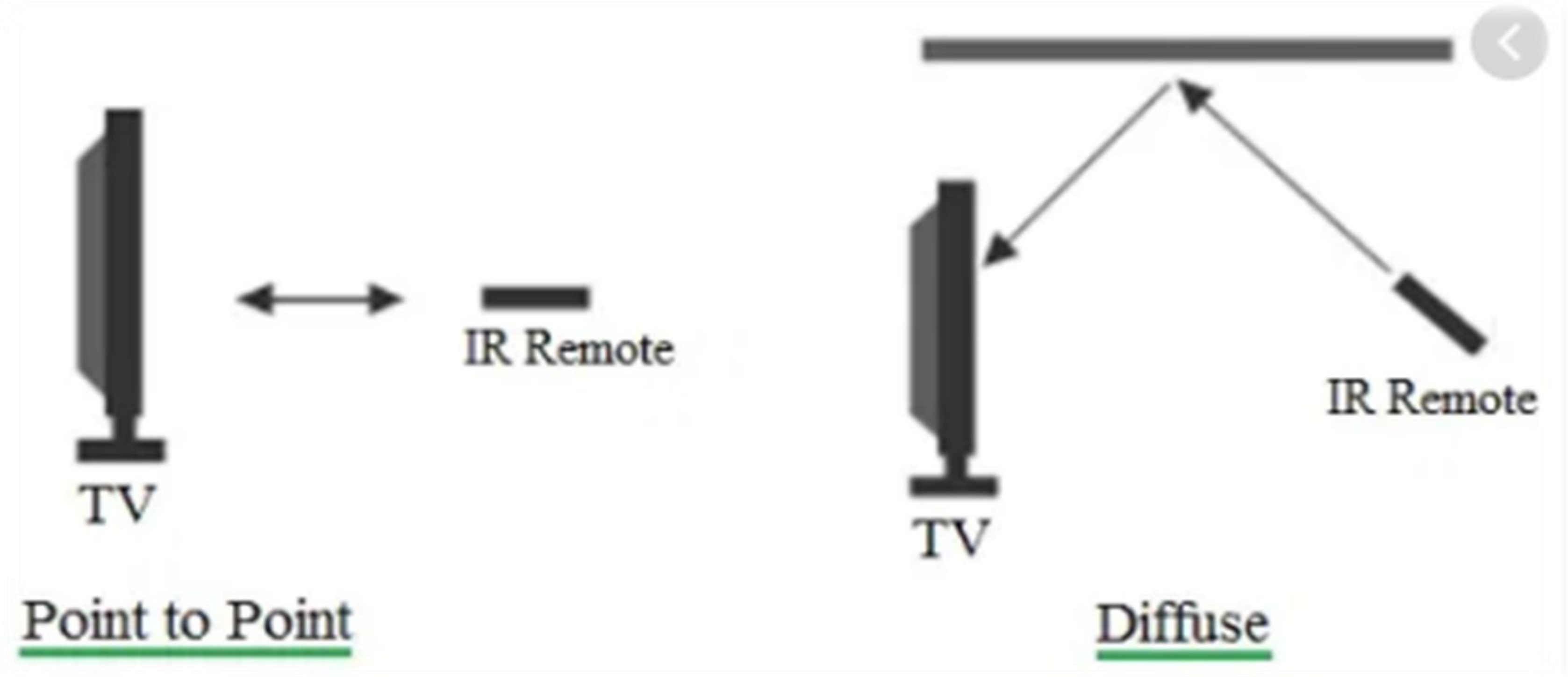



b. Horn antenna

# 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 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 ad 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

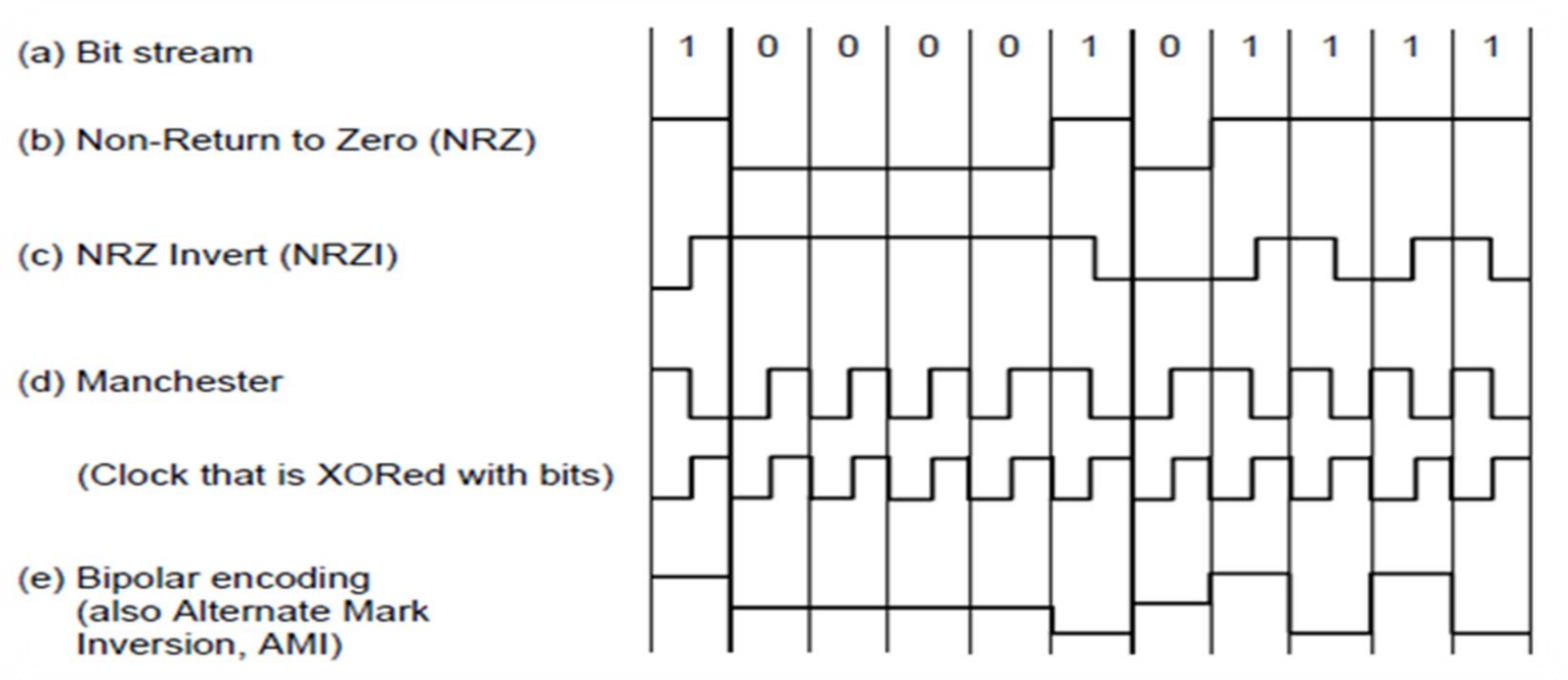
# Baseband Transmission

- 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..

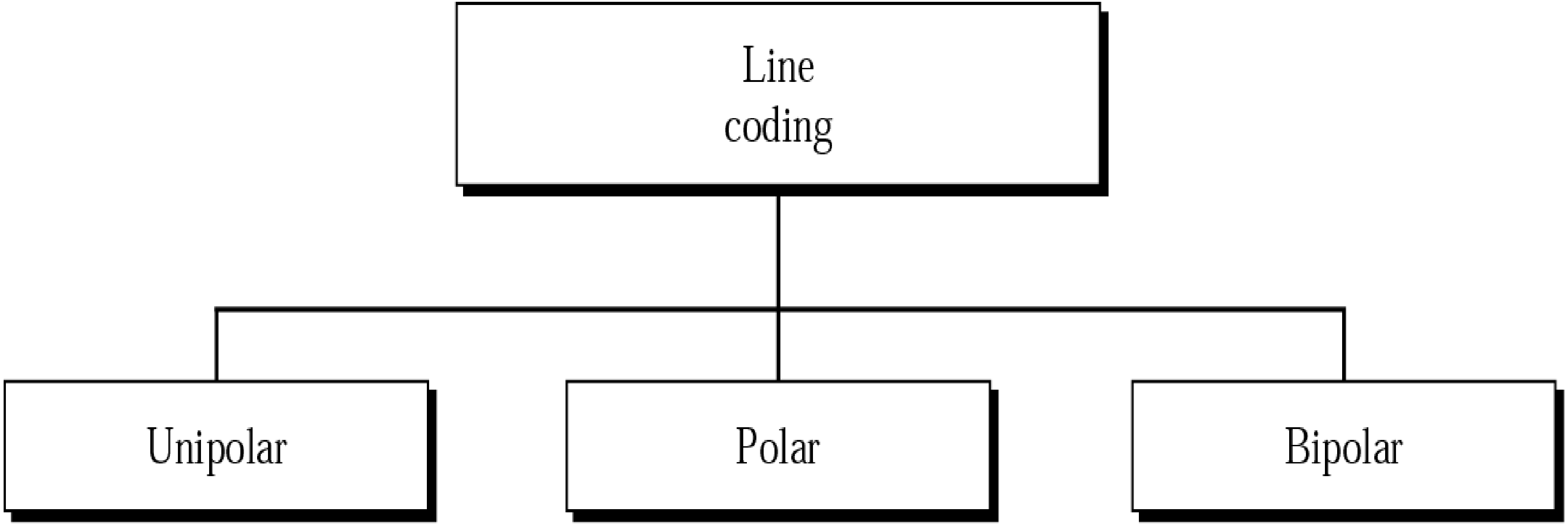
- Schemes that directly convert bits into a signal results in **baseband transmission**, in which the signal occupies frequencies from **zero up to a maximum** that depends on the signaling rate.

# Baseband Transmission or Line Coding




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

# Types of Line Coding



# Unipolar Signaling

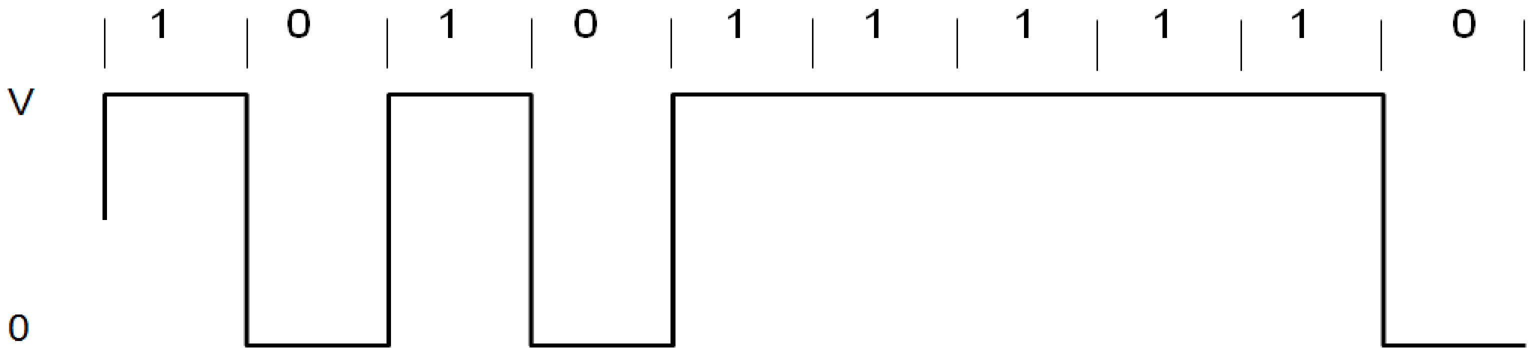
- On-Off keying ie OOK
- Pulse 0: Absence of pulse
- Pulse1 : Presence of pulse

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:**

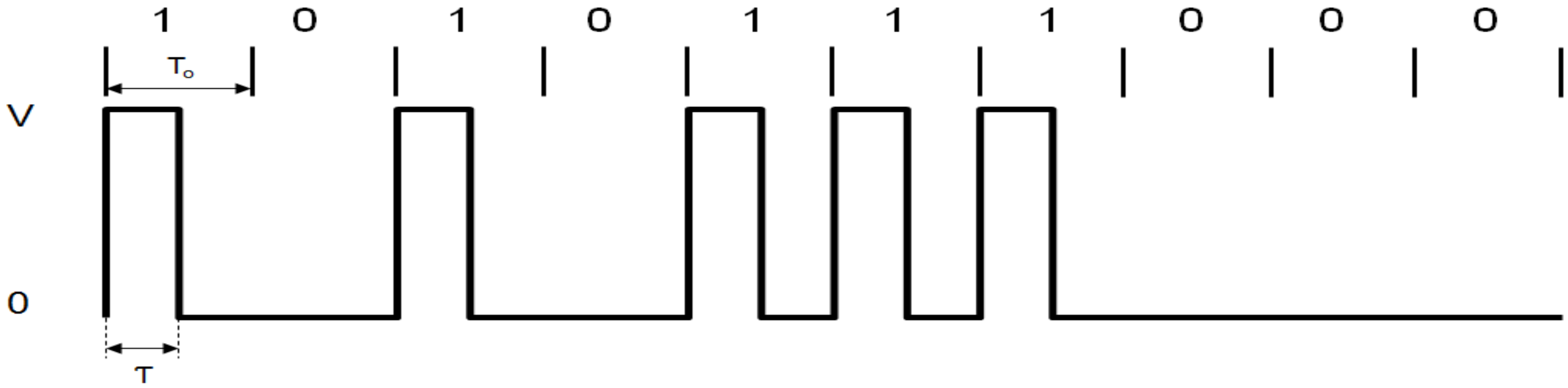
- Simplicity in implementation
- Doesn‟t require a lot of bandwidth for transmission.

**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 posses 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:**

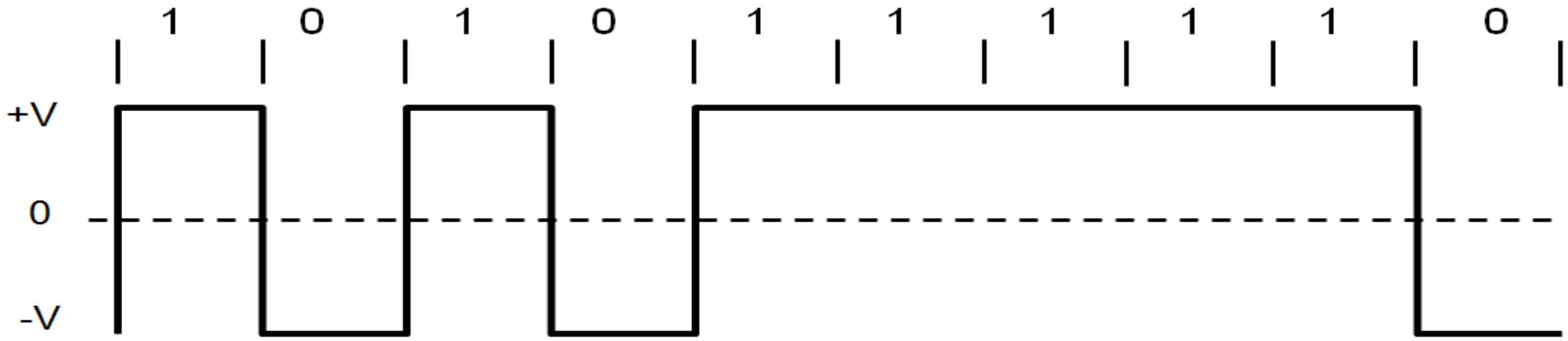
- Presence of DC level (indicated by spectral line at 0 Hz).
- Continuous part is non-zero at 0 Hz. Causes “Signal Droop”.
- Does not have any error correction capability.
- Occupies twice as much bandwidth as Unipolar NRZ.
- Is not Transparent

# 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:**

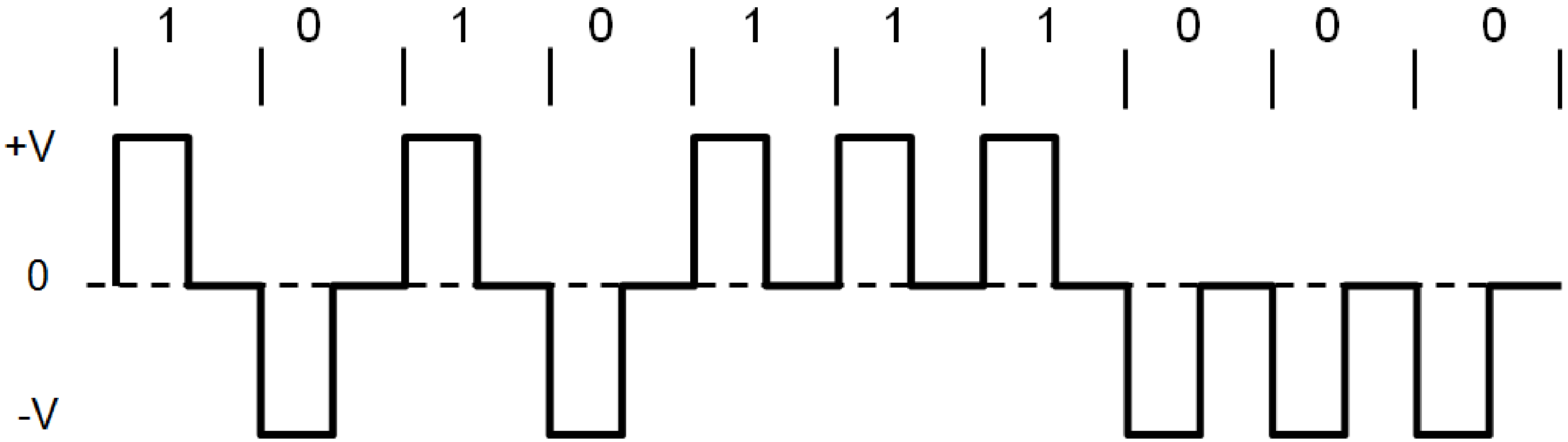
- Simplicity in implementation.
- No DC component.

**Disadvantages:**

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

# Polar RZ

- A binary 1: Apulse $g_1(t)$
- 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.

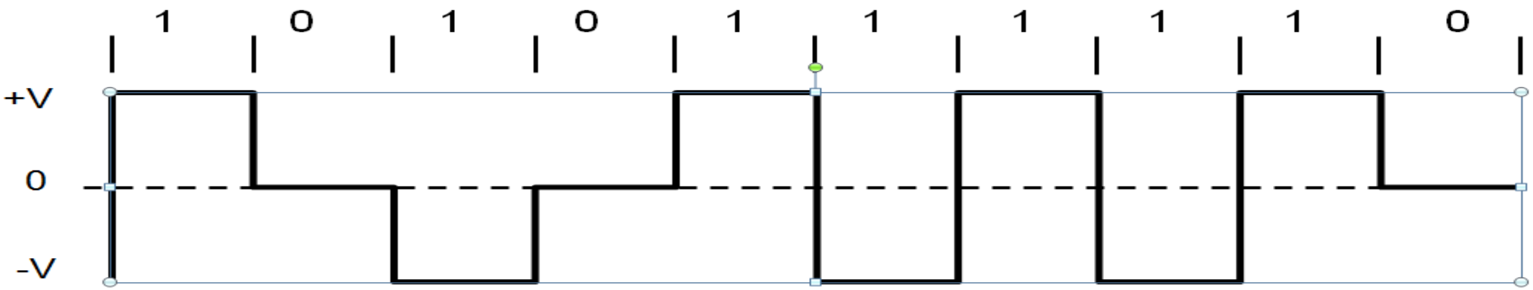
**Disadvantages:**

- 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.

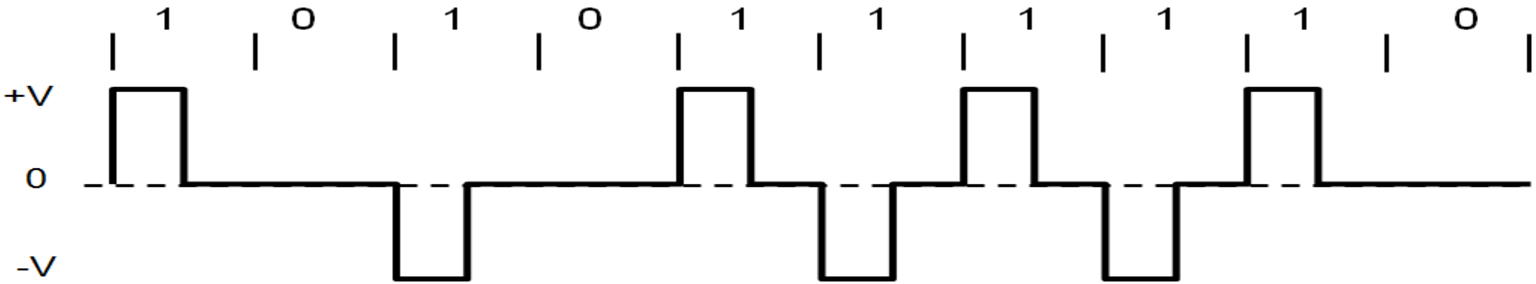
# Bipolar Signalling

- 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:**

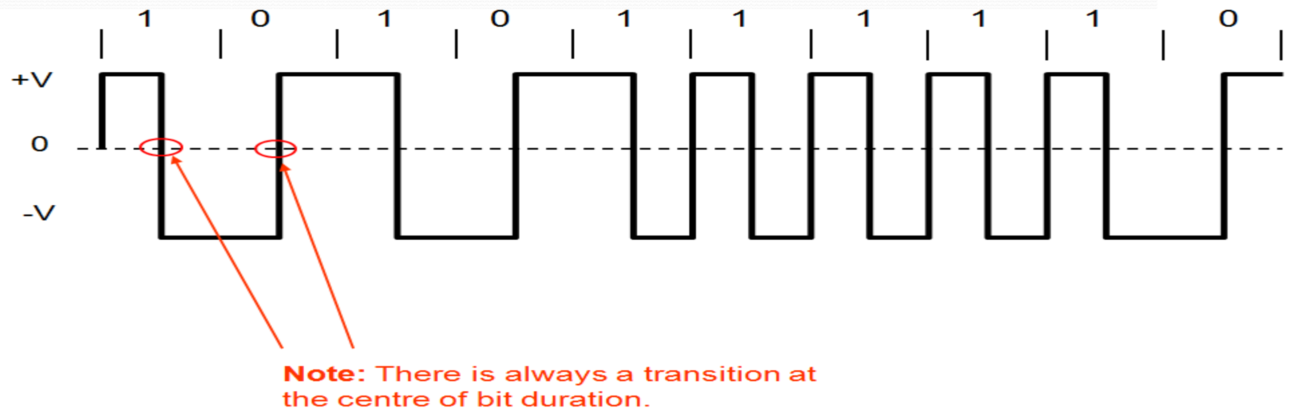
- No DC component.
- Occupies less bandwidth than unipolar and polar NRZ schemes.
- Does not suffer from signal droop (suitable for transmission over AC coupled lines).
- Possesses single error detection capability.

**Disadvantages:**

- Does not posses 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 1$^{st}$ half and -ve in 2$^{nd}$ half.
- A  Zero‟ is -ve in 1$^{st}$ half and +ve in 2$^{nd}$ 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

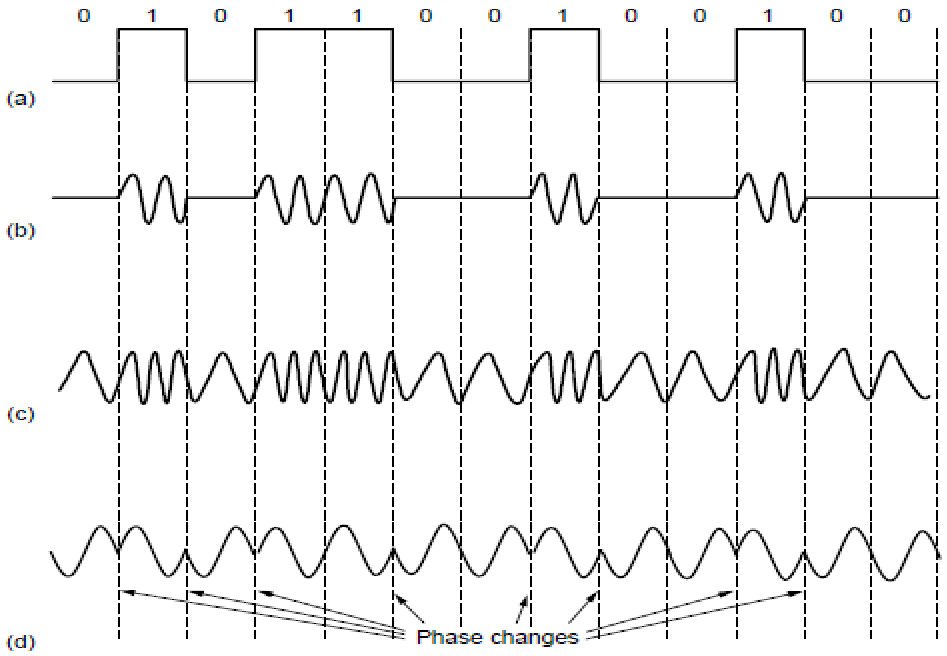
| Sr. No. | Parameters | Polar RZ | Polar NRZ | AMI | Manchester |
|---|---|---|---|---|---|
| 1 | Transmission of DC component | YES | YES | NO | NO |
| 2 | Signaling Rate | 1/Tb | 1/Tb | 1/Tb | 1/Tb |
| 3 | Noise Immunity | LOW | LOW | HIGH | HIGH |
| 4 | Synchronizing Capability | Poor | Poor | Very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

# Pass band 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.

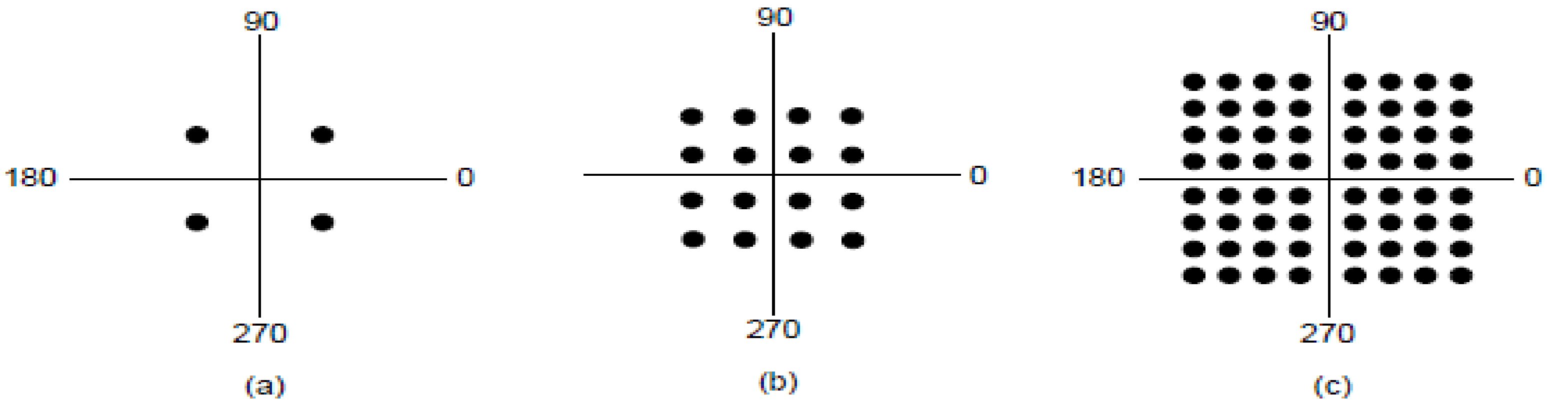
- We can modulate the amplitude, frequency, or phase of the carrier signal according to the digital data named as ASK,FSK,PSK respectively.

# 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

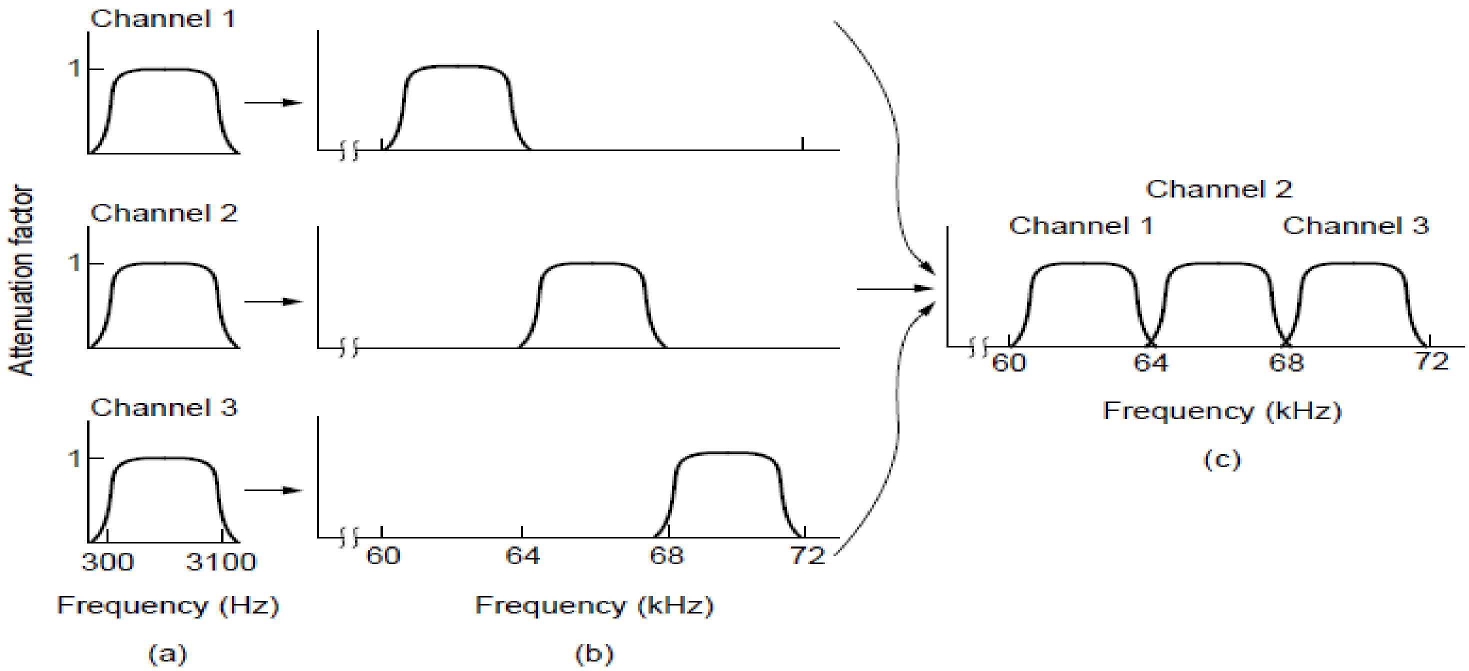
- Channels are often shared by multiple signals. After all, it is much more convenient to use a single wire to carry several signals than to install a wire for every signal. This kind of sharing is called **multiplexing**.

- It can be accomplished in several different ways. We will present methods for time, frequency, and code division multiplexing.

# Multiplexing techniques

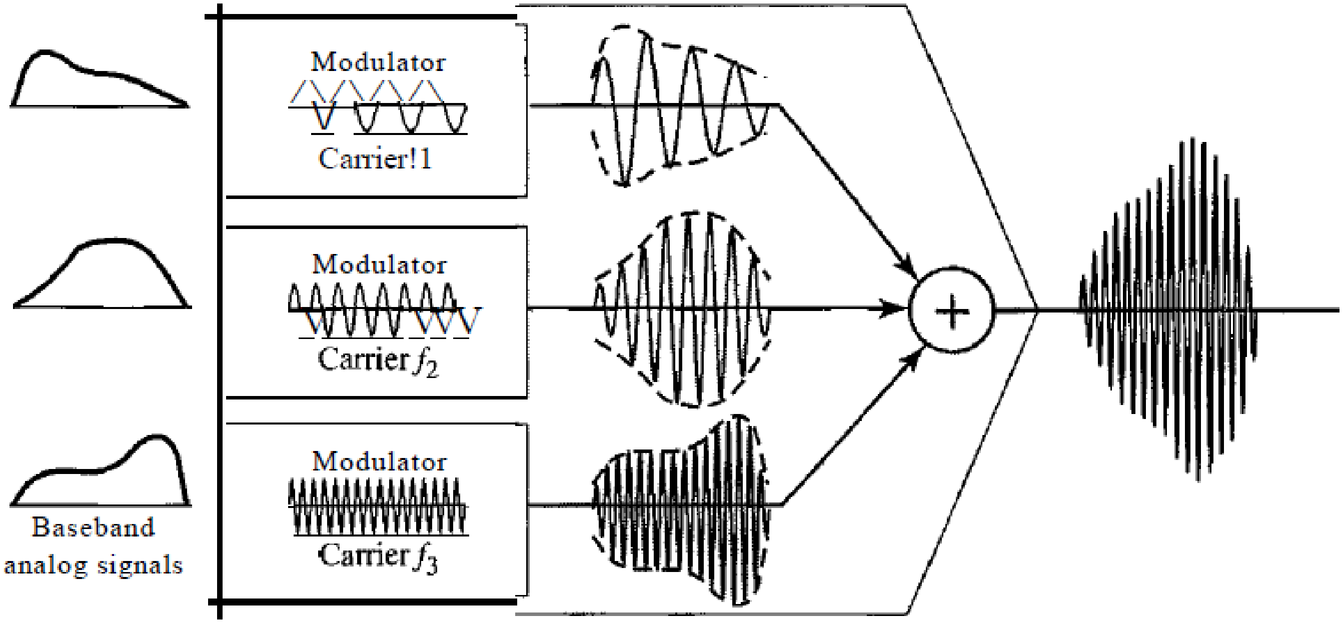
- Frequency division multiplexing
- Wavelength division multiplexing
- Time division multiplexing
- Code division multiplexing

# Frequency Division Multiplexing



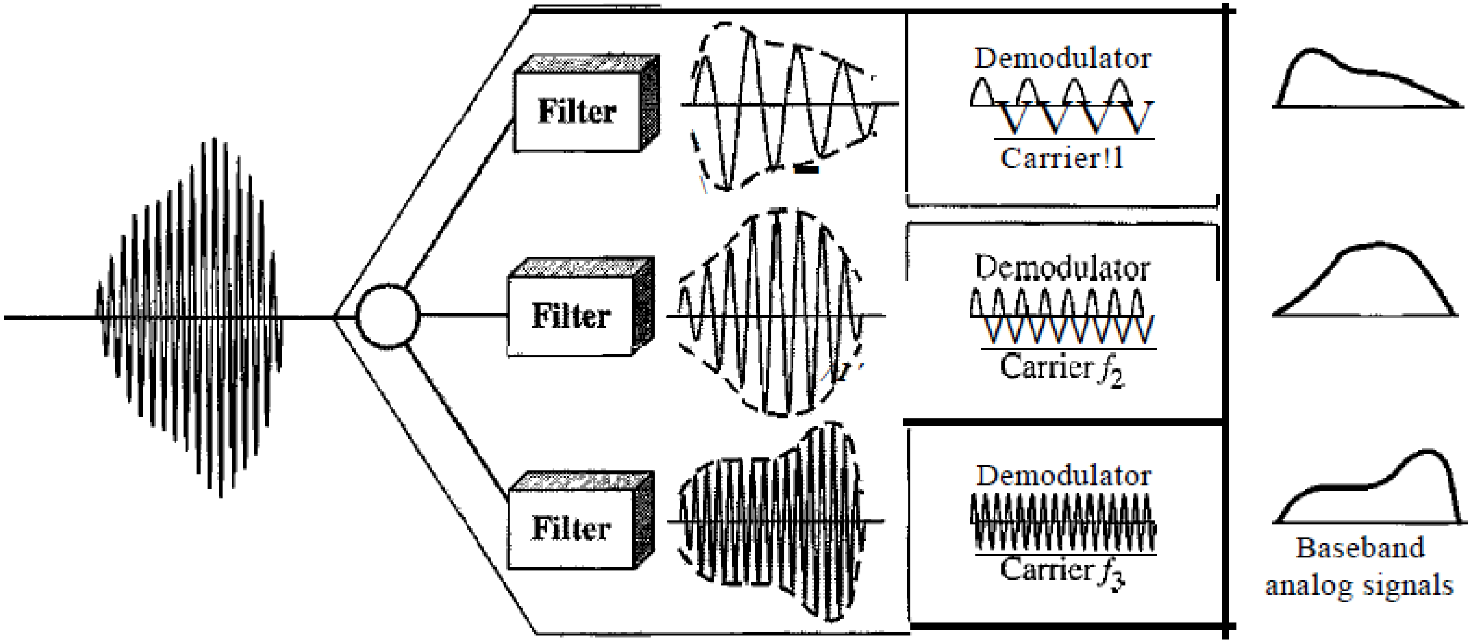

Frequency division multiplexing. (a) The original bandwidths.
(b) The bandwidths raised in frequency. (c) The multiplexed channel.

*FDM process*

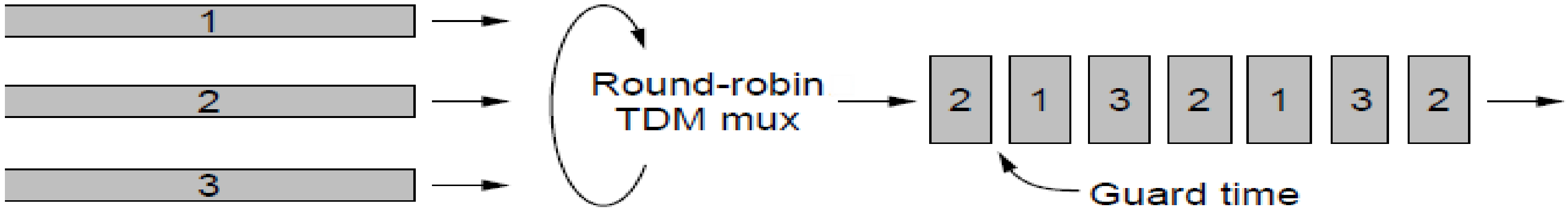


Modulator
Carrier!1
Modulator
Carrier $f_2$
Modulator
Carrier $f_3$
Baseband
analog signals
+

*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.

# Contd..

Walsh codes(orthogonal)

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

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

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

# Contd..

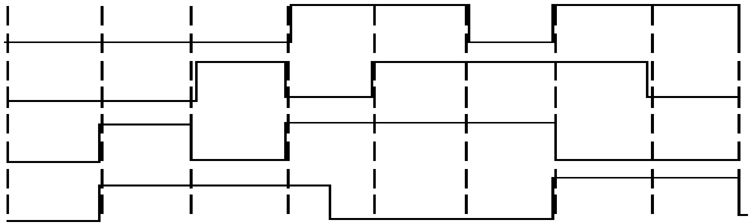
A = (−1 −1 −1 +1 +1 −1 +1 +1)

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

# Contd..

$$
\begin{aligned}
S_1 &= C &&= (-1\ {+1}\ {-1}\ {+1}\ {+1}\ {+1}\ {-1}\ {-1}) \\
S_2 &= B+C &&= (-2\ \ 0\ \ 0\ \ 0\ {+2}\ {+2}\ \ 0\ {-2}) \\
S_3 &= A+\overline{B} &&= (\ 0\ \ 0\ {-2}\ {+2}\ \ 0\ {-2}\ \ 0\ {+2}) \\
S_4 &= A+\overline{B}+C &&= (-1\ {+1}\ {-3}\ {+3}\ {+1}\ {-1}\ {-1}\ {+1}) \\
S_5 &= A+B+C+D &&= (-4\ \ 0\ {-2}\ \ 0\ {+2}\ \ 0\ {+2}\ {-2}) \\
S_6 &= A+B+\overline{C}+D &&= (-2\ {-2}\ \ 0\ {-2}\ \ 0\ {-2}\ {+4}\ \ 0)
\end{aligned}
$$

(c)

$$
\begin{aligned}
S_1 \bullet C &= [1+1-1+1+1+1-1-1]/8 = 1 \\
S_2 \bullet C &= [2+0+0+0+2+2+0+2]/8 = 1 \\
S_3 \bullet C &= [0+0+2+2+0-2+0-2]/8 = 0 \\
S_4 \bullet C &= [1+1+3+3+1-1+1-1]/8 = 1 \\
S_5 \bullet C &= [4+0+2+0+2+0-2+2]/8 = 1 \\
S_6 \bullet C &= [2-2+0-2+0-2-4+0]/8 = -1
\end{aligned}
$$

(d)

(a) Six examples of transmissions.

(b) Recovery of station C's

# FDM Vs. TDM Vs. CDM