3-5 DATA RATE LIMITS

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

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

Topics discussed in this section:

Noiseless Channel: Nyquist Bit Rate
Noisy Channel: Shannon Capacity
Using Both Limits

3-5 DATA RATE LIMITS

Noiseless Channel: Nyquist Bit Rate
-Theorotical maximum bit rate

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

L=number of signal levels used to represent data

Note

Increasing the levels of a signal may reduce the reliability of the system.

Example 3.34

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}}$$

Example 3.35

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}}$$

3-5 DATA RATE LIMITS

Noisy Channel: Shannon Capacity

Theoretical data rate for a nosiy channel

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

Example 3.37

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

$$\boxed{C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0}$$

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

Example 3.38

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Using both levels

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, we use the Shannon formula to find the upper limit.

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

Example 3.41 (continued)

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$\boxed{4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \quad \Rightarrow \quad L = 4}$$

Note

The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

3-6 PERFORMANCE

One important issue in networking is the performance of the network—how good is it? In this section, we introduce terms that we need for future.

Topics discussed in this section:

Bandwidth
Throughput
Latency (Delay)
Bandwidth-Delay Product

Note

In networking, we use the term bandwidth in two contexts.

- The first, bandwidth in hertz, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.

- The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link.

Latency

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source. We can say that latency is made of four components: **propagation time, transmission time, queuing time** and **processing delay.**

$$\textbf{Latency} = \textbf{propagation time} + \textbf{transmission time} + \textbf{queuing time} + \textbf{processing delay}$$

Propagation Time

Propagation time measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

$$\textbf{Propagation time} = \frac{\textbf{Distance}}{\textbf{Propagation speed}}$$

Example 3.45

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 × 108 m/s in cable.

Solution

We can calculate the propagation time as

$$\boxed{\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^{8}} = 50 \text{ ms}}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

Transmission Terminology (1)

- Data transmission occurs between transmitter and receiver over some transmission medium.
- Transmission media may be classified as guided or unguided.
- In both cases, communication is in the form of electromagnetic waves.

Guided media

- waves are guided along a physical path
- examples of guided media are twisted pair, coaxial cable, and optical fiber.

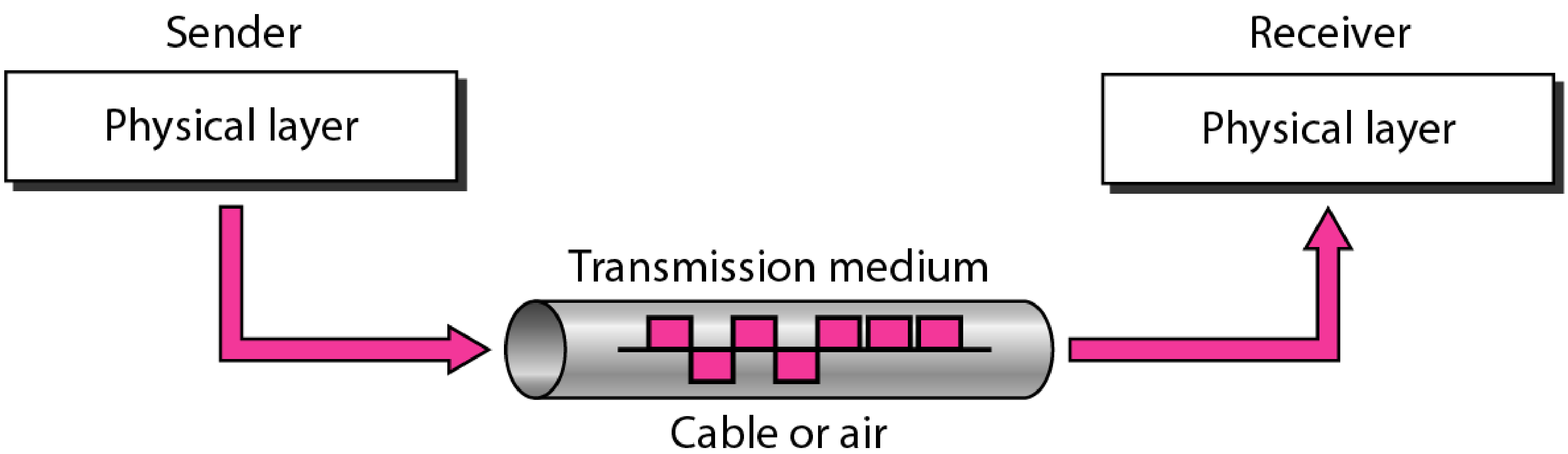
Unguided media, also called **wireless**

- provide a means for transmitting electromagnetic waves but do not guide them
- examples are propagation through air, vacuum, and seawater.

Transmission media

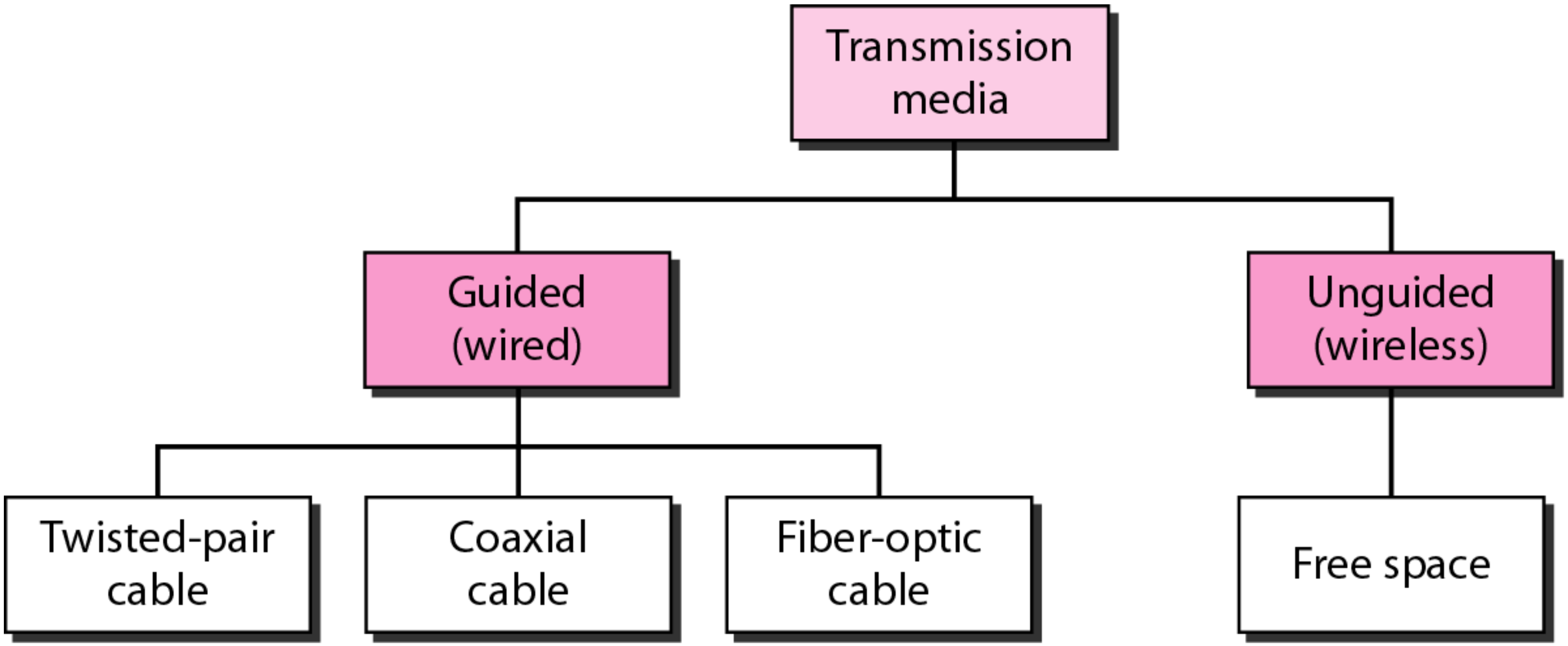
- Located below physical layer and directly controlled by the physical layer
- Computers and telecommunication devices use signal to transfer data
- which is transmitted in the form of electromagnetic energy with the help of transmission media

Figure 1 *Transmission medium and physical layer*



Electromagnetic energy, a combination of electric and magnetic fields vibrating in relation to each other, includes power, radio waves, infrared light, visible light, ultraviolet light, and X, gamma, and cosmic rays. Each of these constitutes a portion of the **electromagnetic spectrum.** Not all portions of the spectrum are currently usable for telecommunications, however. The media to harness those that are usable are also limited to a few types.

Figure 2 *Classes of transmission media*



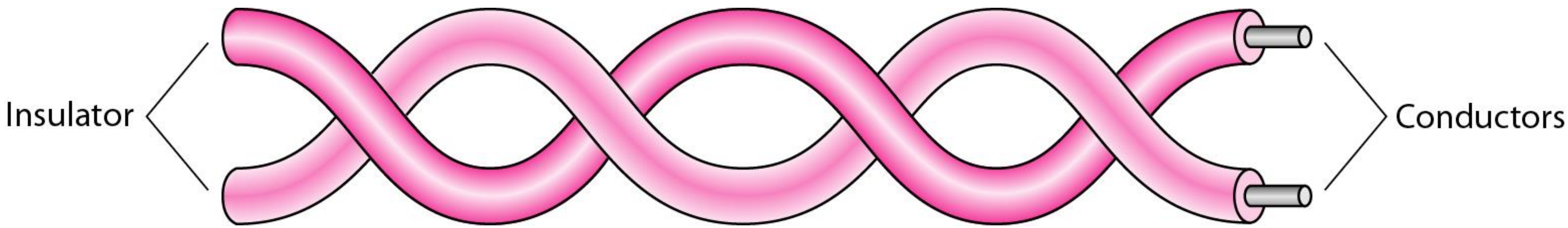
7-1 GUIDED MEDIA

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

Topics discussed in this section:

Twisted-Pair Cable : Signal transmitted in the form of electric current
Coaxial Cable: same as TPC
Fiber-Optic Cable: Light

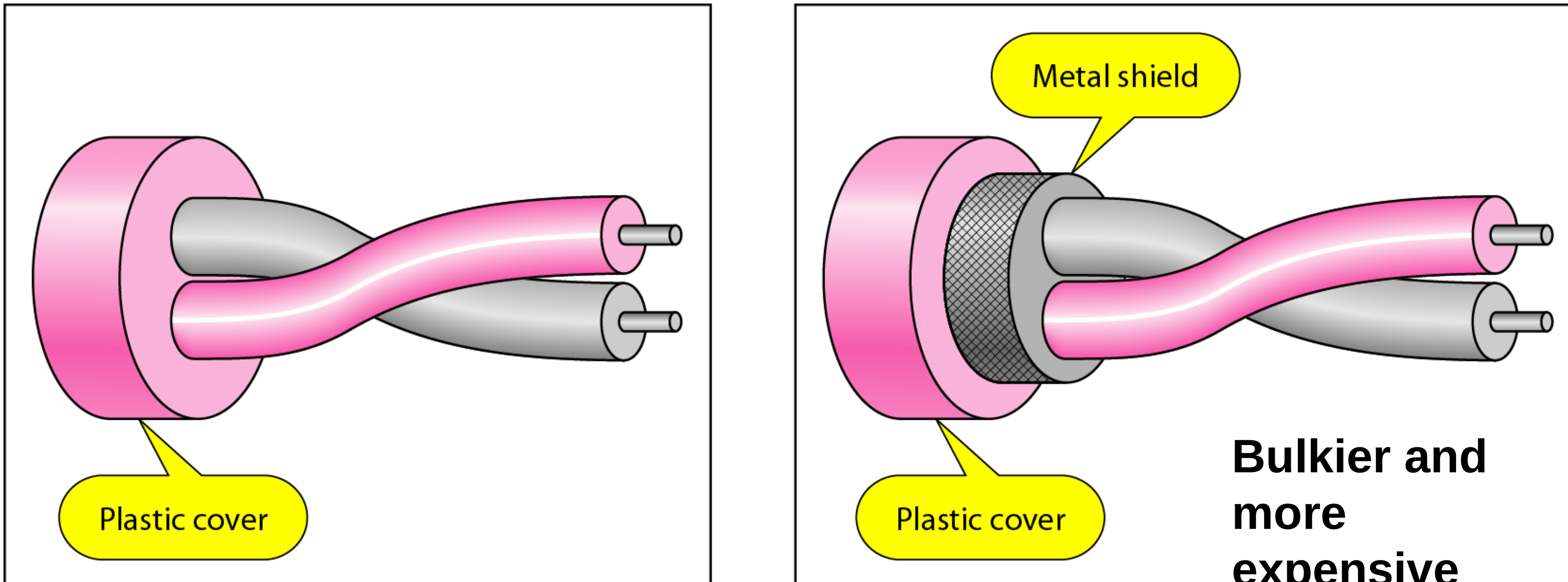
Figure 3 ***Twisted-pair cable***



Twisted-pair cable

- Consists of two conductors, each with its own plastic insulation twisted together.
- One is used to carry signal other is used as ground reference.
- Receiver uses the difference between the two.
- Noise may affect both wires
- Number of twists per length has effect on the quality of wire.

Figure 4 Two types: *UTP and STP cables*



a. UTP b. STP

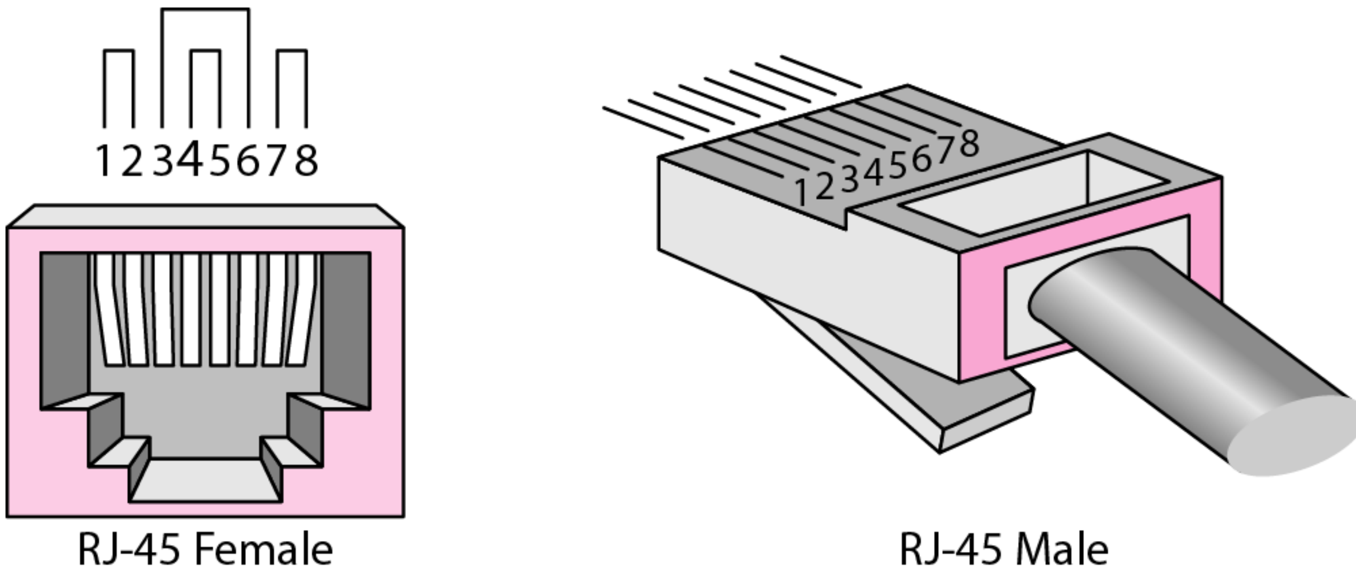
Bulkier and more expensive

Electronic Industries association

Table 7.1 *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 5 *UTP connector*

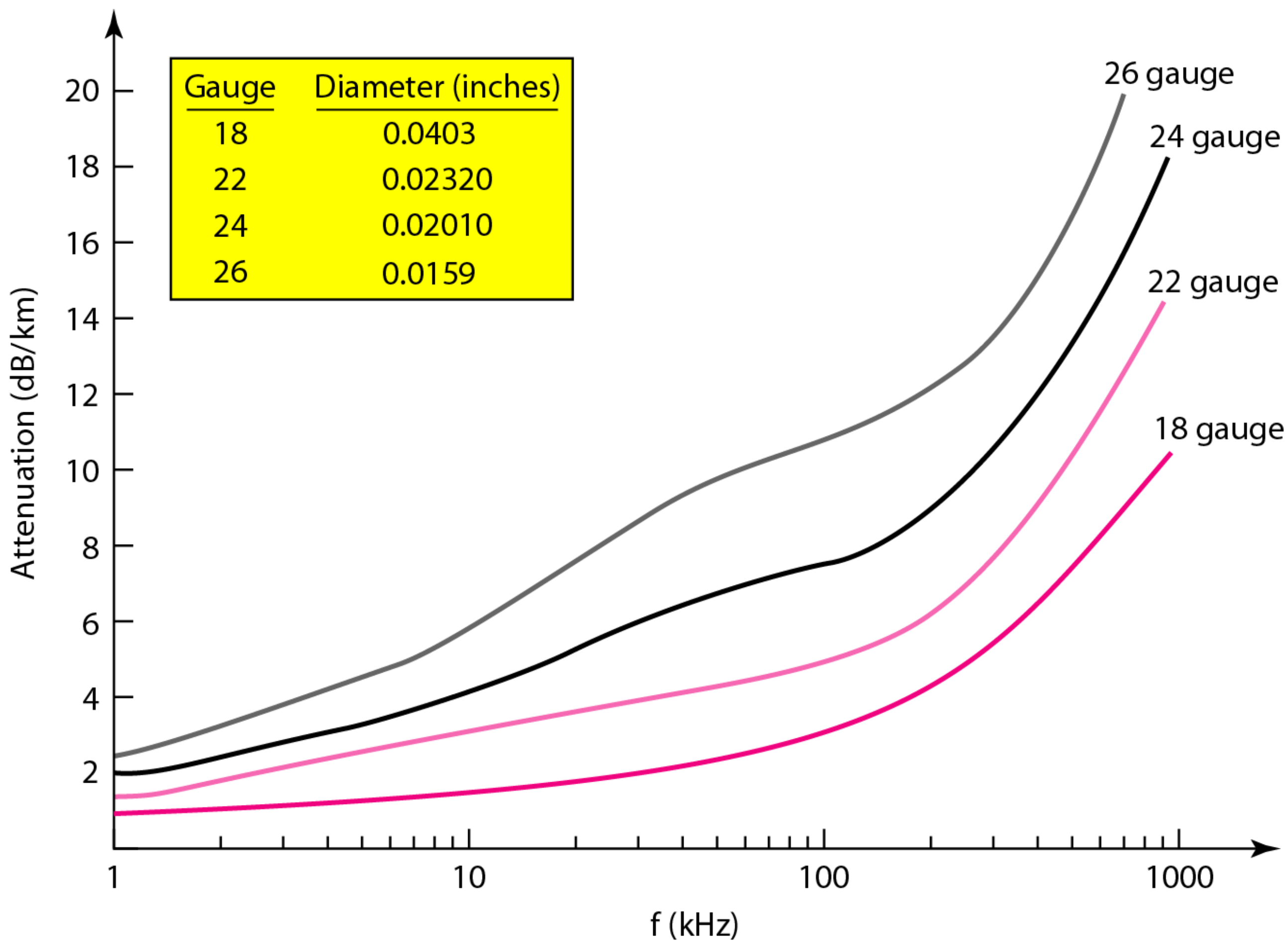


RJ: Registered Jack

Keyed connector

Figure 6 *UTP performance*

Gauge: measure of thickness of wire



Attenuation versus frequency and distance

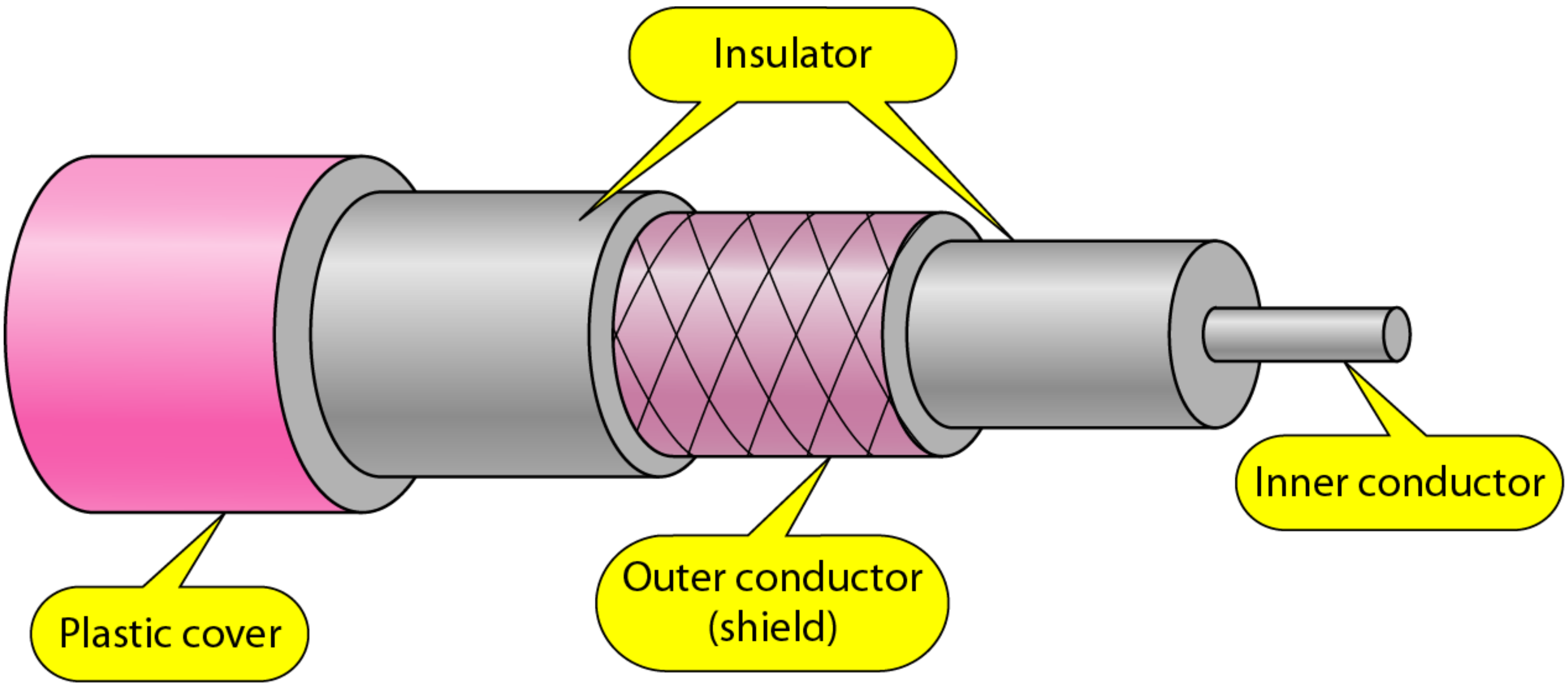
TP Applications

- Used in telephones to provide voice and data channel.
- DSL lines: Unshielded twisted pair cables
- Local area networks: 10Base-T ,100Base-T

Coaxial cable

- Carries signals of higher frequencies as compared to TP cables.
- A central core conductor enclosed in a insulating sheath enclosed in a outer conductor of metal foil which is also enclosed in an insulating sheath.

Figure 7 *Coaxial cable*



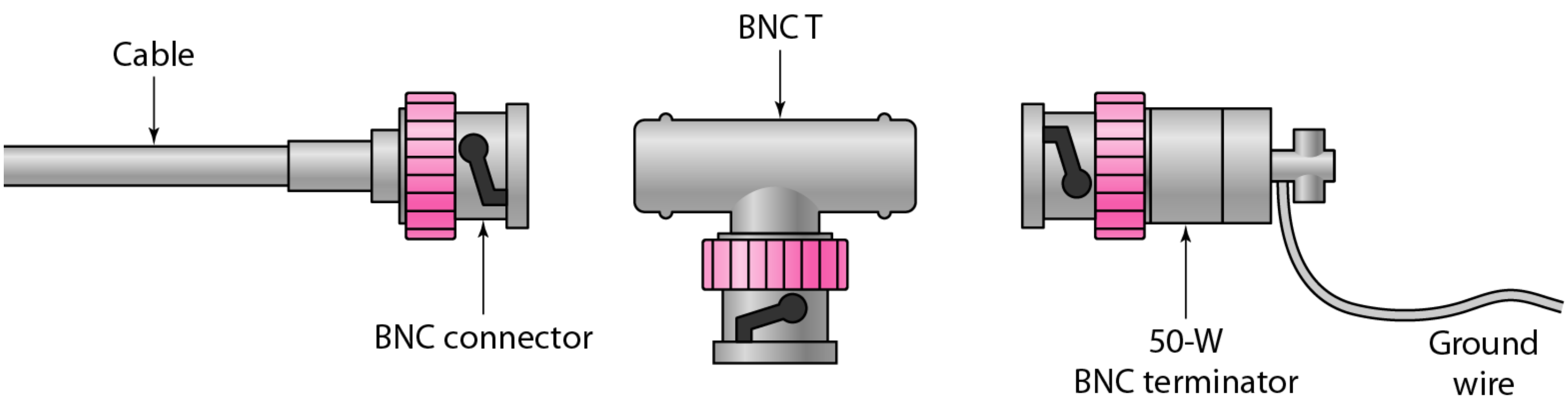
RG Rating : Radio Government ratings

Table 7.2 ***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

Figure 8 ***BNC connectors three types***

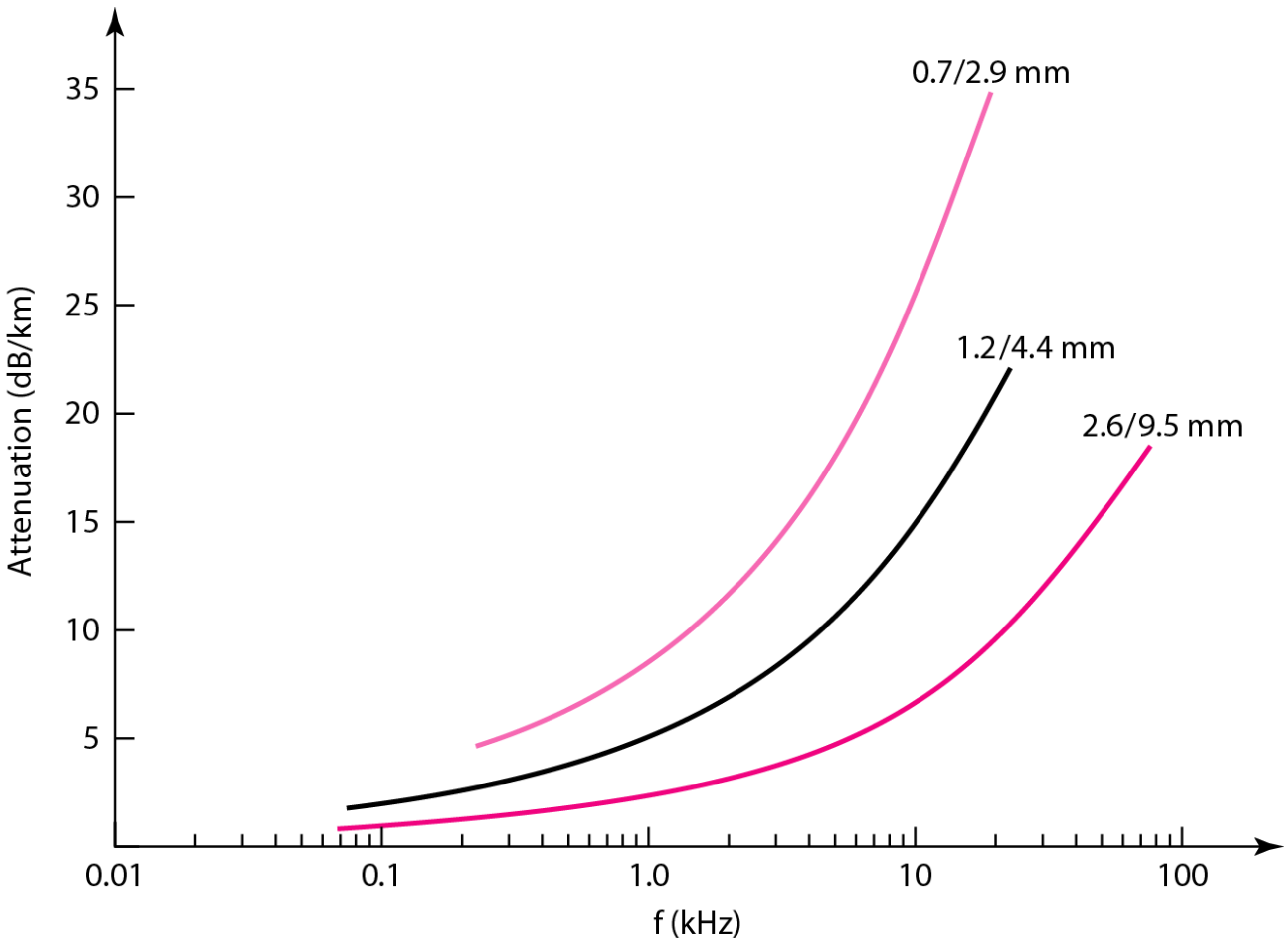
Bayone-Neill-Concelman (BNC)



prevent the reflection of the signal.

Figure 9 *Coaxial cable performance*

Both bandwidth and attenuation is higher



Coaxial cable applications

- Analog telephone networks
- Hybrid networks
- Traditional ethernet LAN

Fiber optic cable

- Made of glass or plastic
- Transmits signal in the form of light

Figure 10 *Bending of light ray*

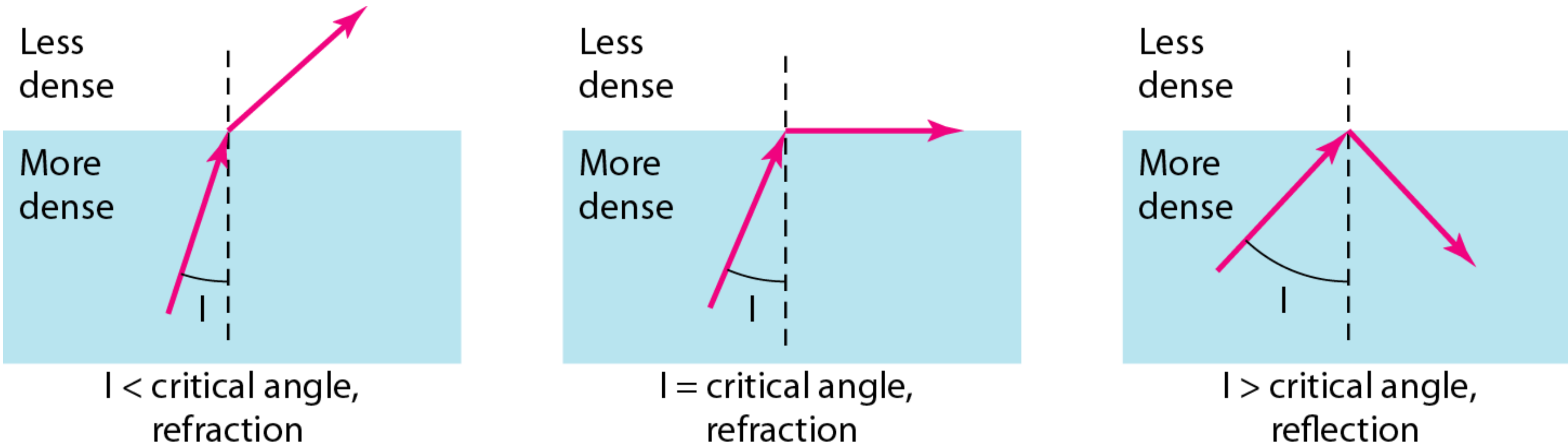


Figure 11 *Optical fiber*

made of glass or plastic and transmits signals in the form of light.

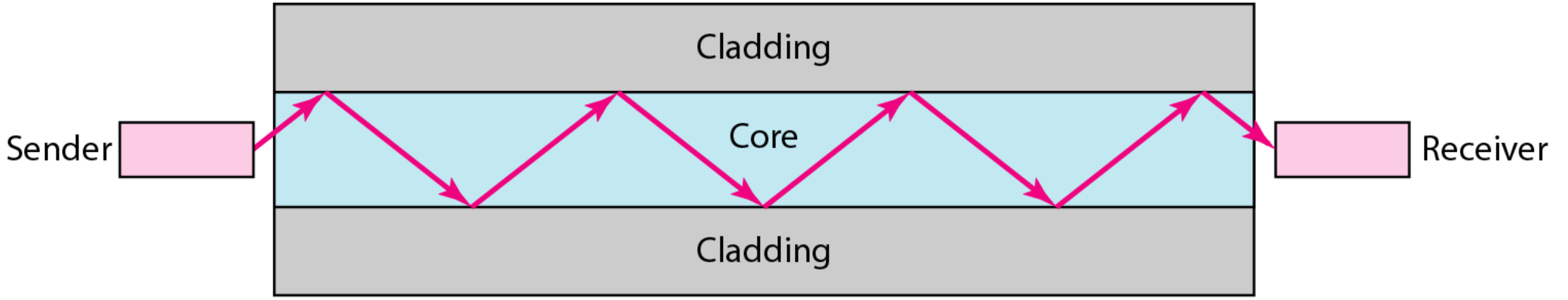
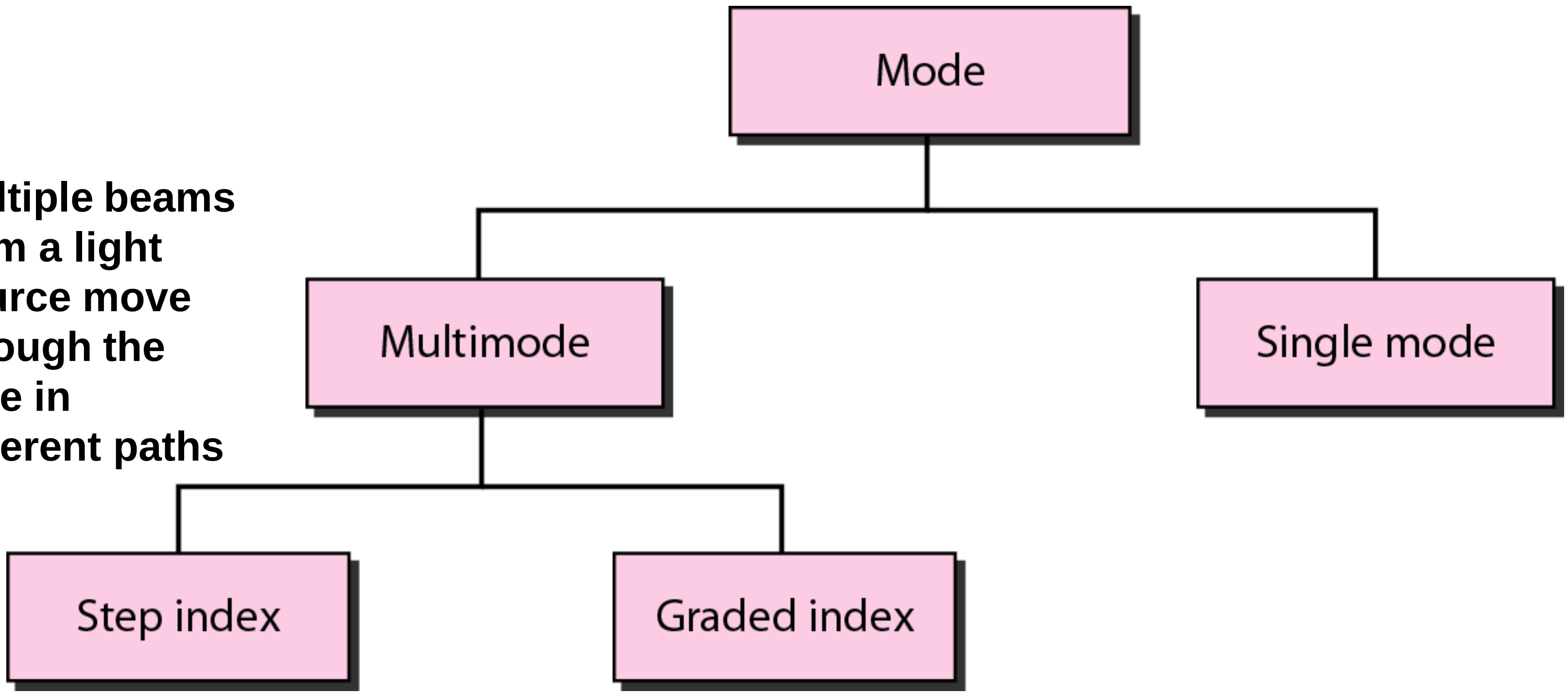


Figure 12 *Propagation modes along optical channels*

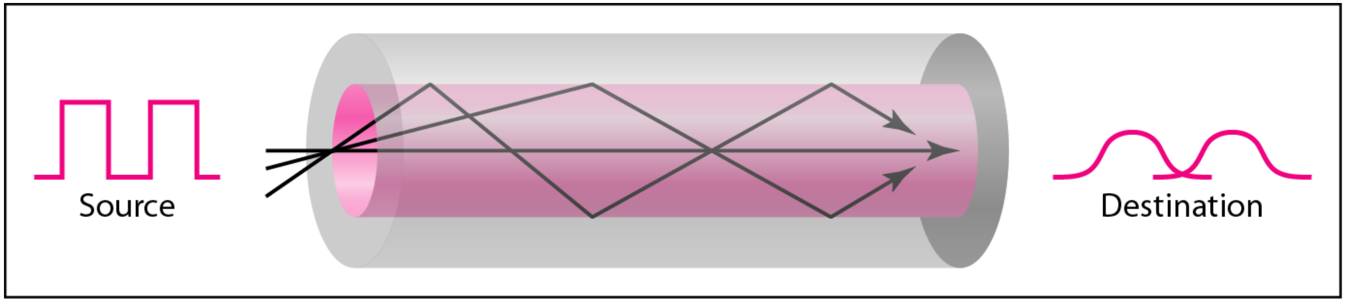
Multiple beams from a light source move through the core in different paths



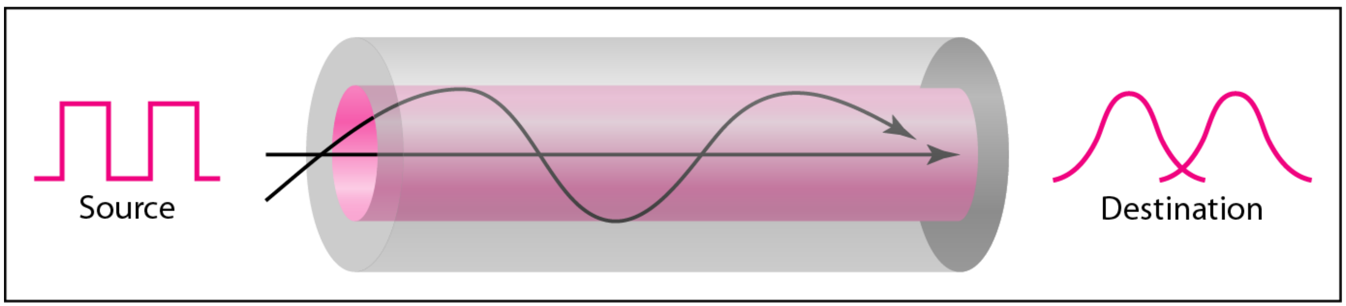
Density of cores remains constant from core to edges

Density of cores highest at the centre and lowest at the edges

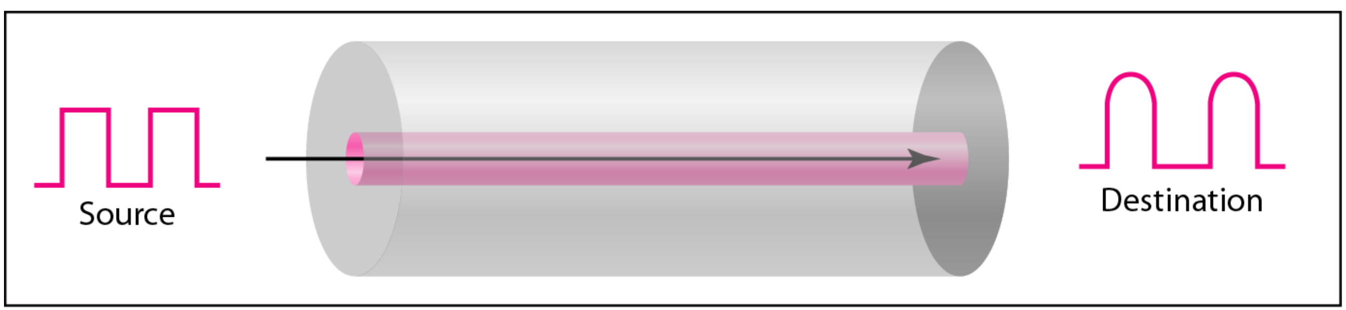
Figure 13 *Modes*



a. Multimode, step index



b. Multimode, graded index



c. Single mode

Table 7.3 ***Fiber types***

Type	*Core* (μ*m*)	*Cladding* (μ*m*)	*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

Defined by ratio of the diameter of their core to the diameter of their cladding

Figure 14 ***Fiber construction***

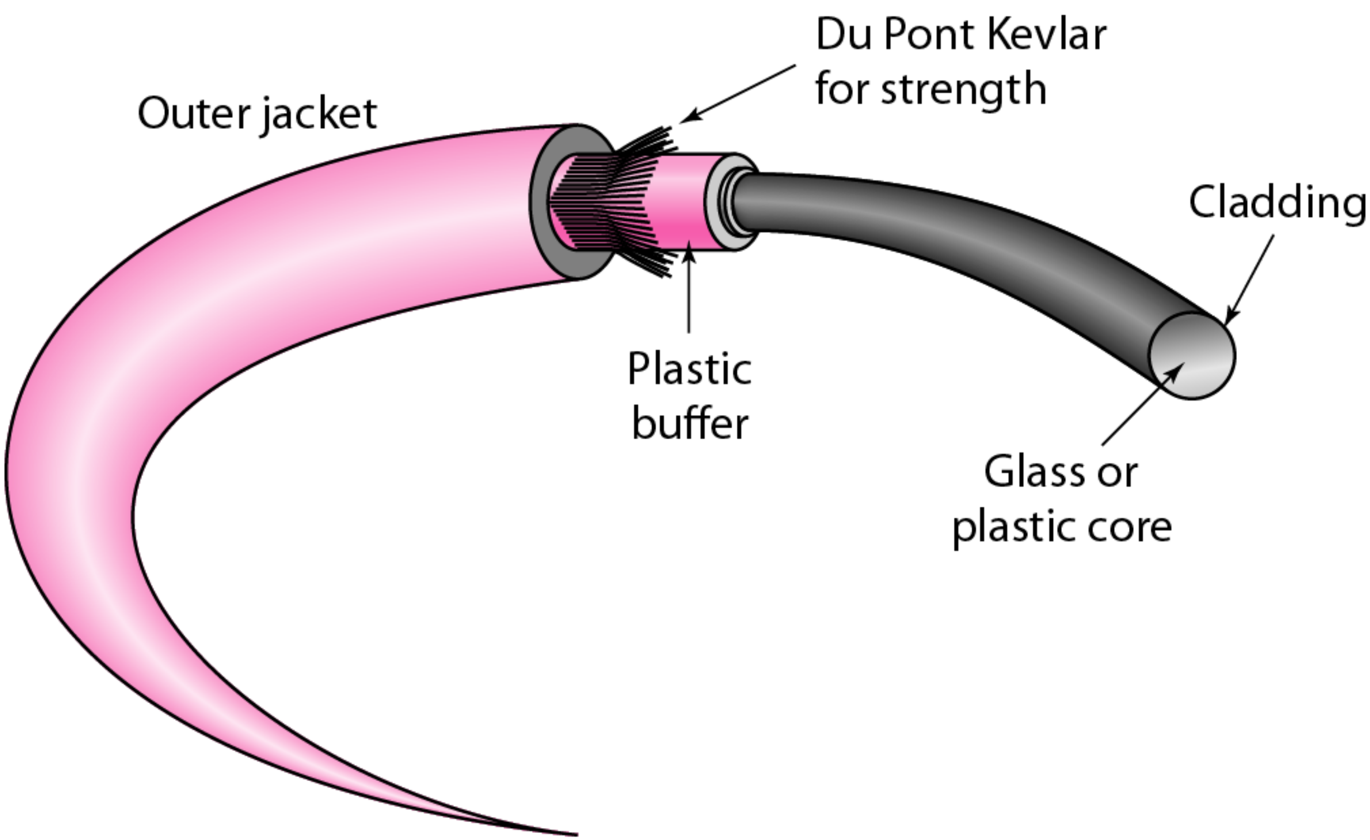
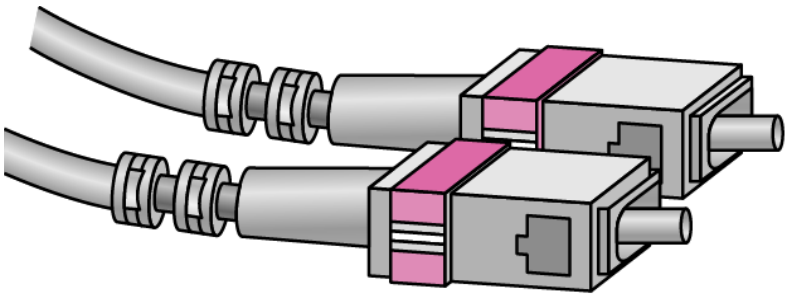


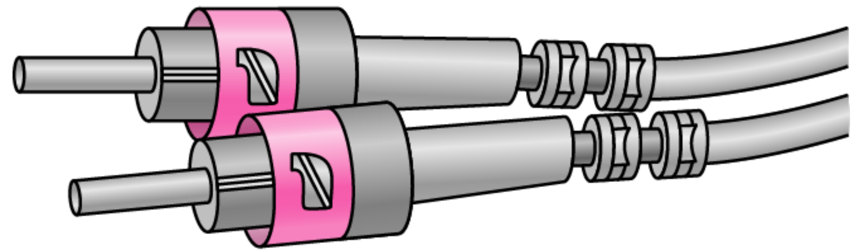
Figure 15 *Fiber-optic cable connectors*



SC connector

subscriber channel (SC) connector

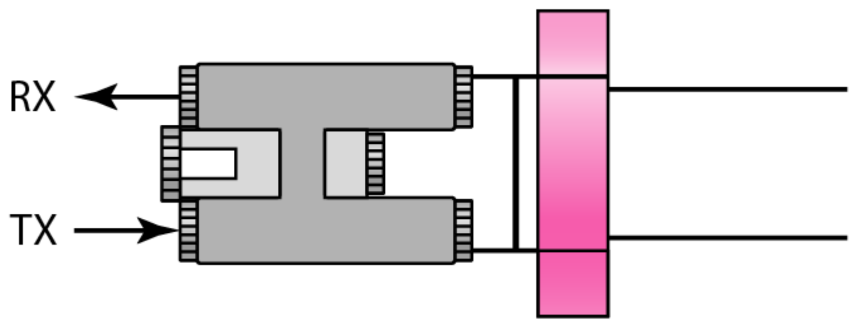
Cable TV



ST connector

straight-tip (ST) connector

Internet devices



MT-RJ connector

Advantages and disadvantages of optical fibre

- Higher bandwidth
- Less signal attenuation
- Immunity to electromagnetic interference
- Resistance to corrosive material
- Light weight
- Greater immunity to tapping

- Installation and maintenance
- Unidirectional light propagation
- cost

7-2 UNGUIDED MEDIA: WIRELESS

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

Topics discussed in this section:

Radio Waves
Microwaves
Infrared

Figure 17 *Electromagnetic spectrum for wireless communication*

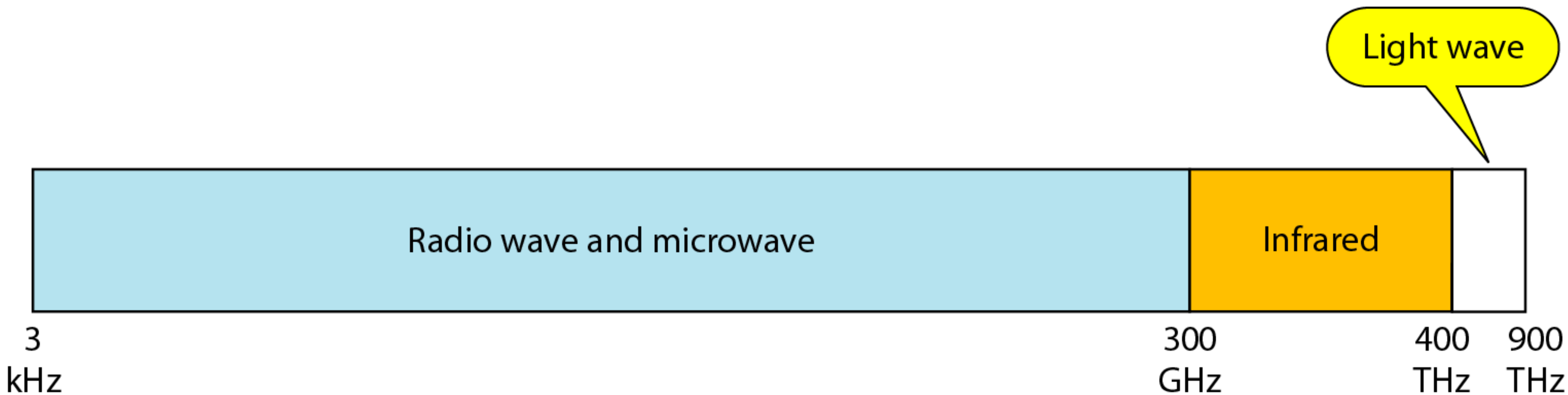
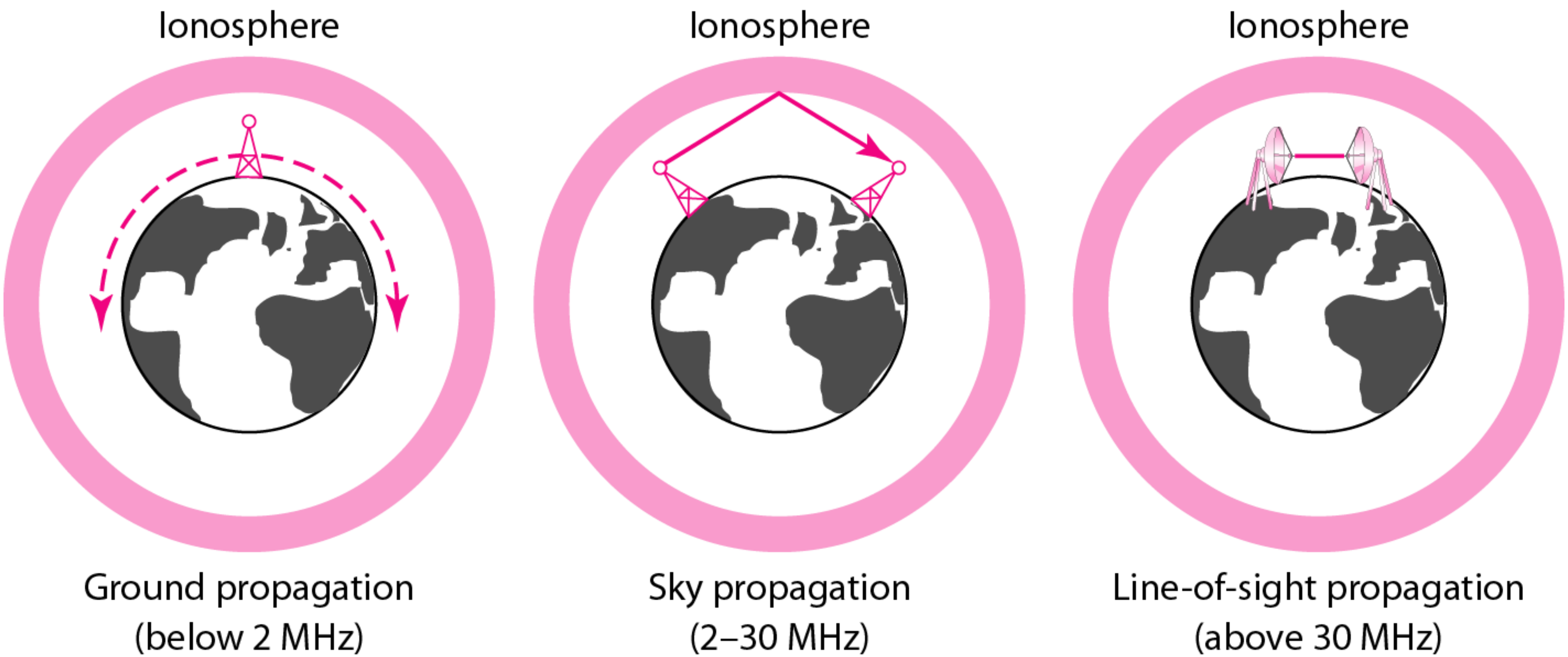


Figure 18 ***Propagation methods***



(below 2 MHz) (2–30 MHz) (above 30 MHz)

Distance depends on amount of power in the signal

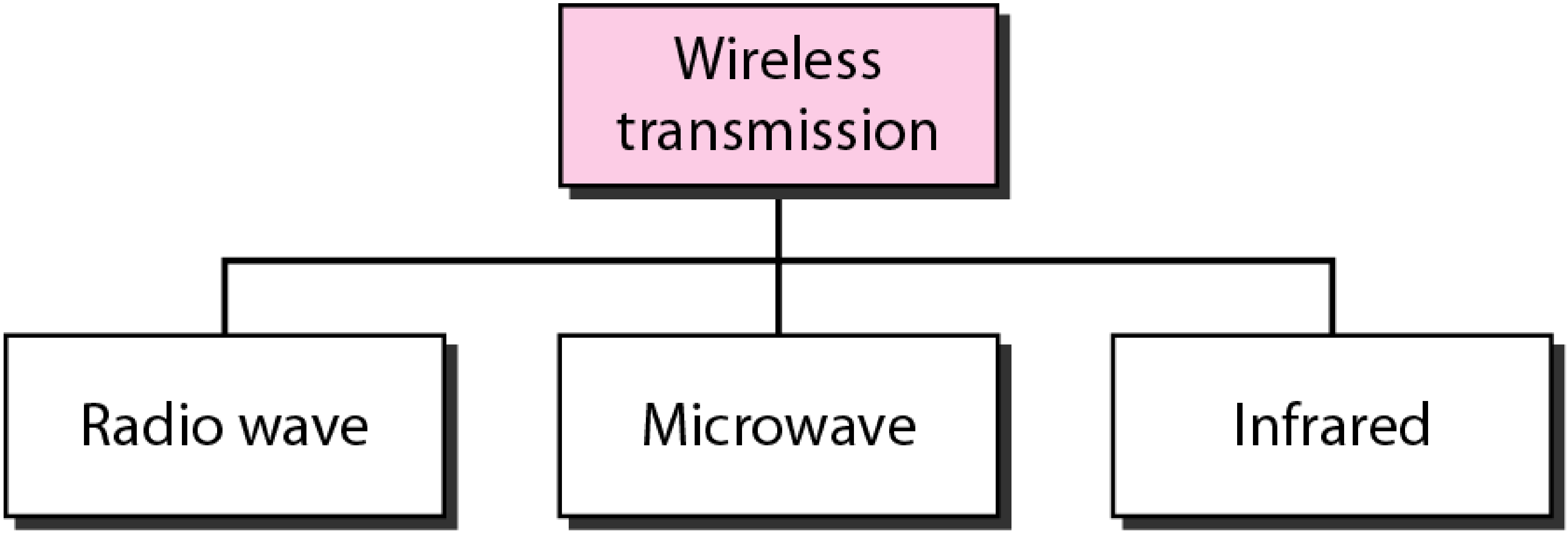
Table 7.4 *Bands*

The section of the electromagnetic spectrum defined as radio waves and microwaves is divided into eight ranges, called *bands*, each regulated by government authorities. These bands are rated from *very low frequency* (VLF) to *extremely high frequency* (EHF). Table 7.4 lists these bands, their ranges, propagation methods, and some applications.

Table 7.4 *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 19 *Wireless transmission waves*



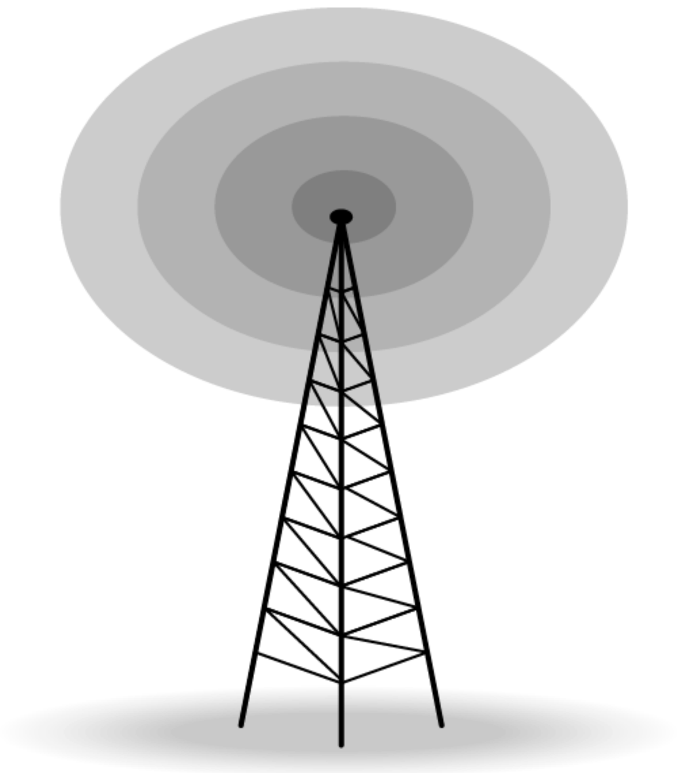
electromagnetic waves

Range	Waves	property
3 kHz and 1 GHz	Radio waves	Omni - directional
1 and 300 GHz	Micro waves	Uni-directional

Radio waves

- Omni directional
- Sky mode: travel long distance: AM radio
- Low and medium frequency can penetrate walls
- Band is relatively narrow leading to low data rate for digital communications
- Useful for multicasting applications like paging, radio, television etc.

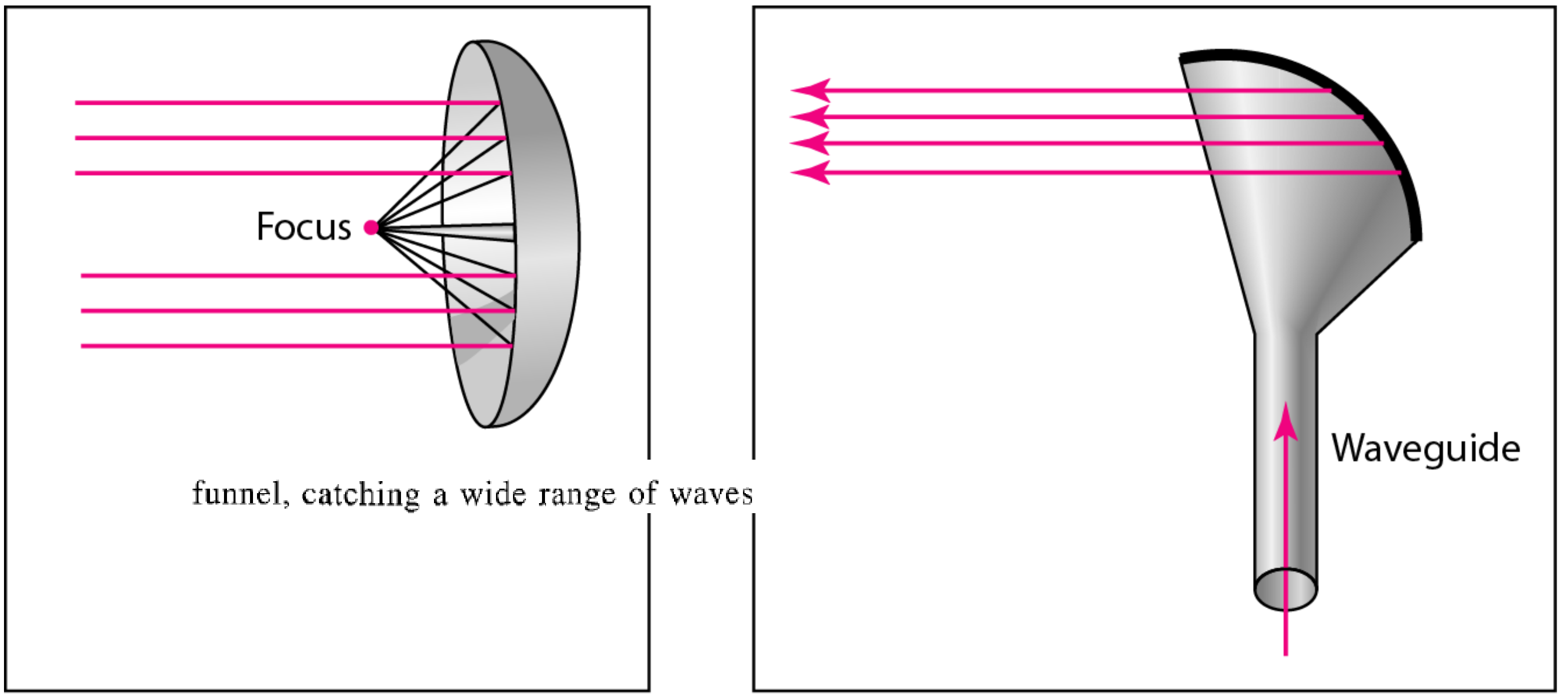
Figure 20 *Omnidirectional antenna*



Microwaves

- **Unidirectional and narrowly focussed**
- **Line-of-sight propagation**
- **Repeaters often needed in long distance communication**
- **Very high frequency microwaves cannot penetrate walls**
- **Higher data rate possible due to wider band**

Figure 21 *Unidirectional antennas*



a. Dish antenna

b. Horn antenna

Note

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

Note

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

ι 300 GHz to 400 THz

Cannot penetrate walls

Reference:Chapter 7

Transmission Media