# Transmission Media

## CHAPTER 4 – William Stallings

# TYPES OF TRANSMISSION MEDIA

- Guided transmission media
- Unguided (Wireless)transmission media

- **Guided media (physical path)**

→Twisted pair, coaxial cable, and optical fiber.

→Electromagnetic waves are guided over the solid medium.

- **Unguided (antenna for transmitting)**

→ Air, vacuum, or water.

→Techniques commonly used for information communications include broadcast radio, terrestrial microwave, and satellite.

What are the key concerns for the design of data transmission systems?

**High data rates over long distance**

**Bandwidth**

**Transmission impairments**

**Interference**

# GUIDED TRANSMISSION MEDIA

- Twisted Pair
- Coaxial cable
- Optical Fiber

# TWISTED PAIR

- A twisted pair consists of two insulated copper wires arranged in a regular spiral pattern.

  Twisting tends to decrease cross talk.

  Neighbouring pairs will have different twist length to reduce cross talk.
- Twist length: 5 to 15cm

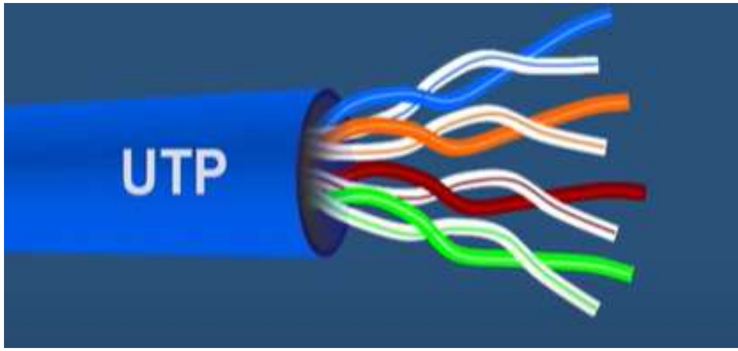

—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building during construction

# TWISTED PAIR - TRANSMISSION CHARACTERISTICS

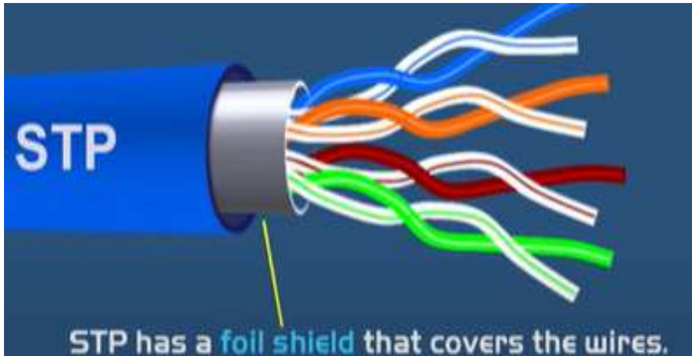
- Analog
  - Needs amplifiers every 5km to 6km
- Digital
  - Needs a repeater every 2-3km
- Limited in distance
- Limited in bandwidth (1MHz)
- Limited in data rate
- For long distance- limited data rate (100Mbps- 1 Gbps)
- For short distance data rate(10Gbps)
- Less expensive

# VARIETIES OF TWISTED PAIRS

- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheapest
  - Easiest to install
  - Suffers from external EM interference from nearby twisted pair. (No electromagnetic shielding)
  - Commonly used for local area networks.




- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - Better performance at higher data rates.
  - More expensive
  - Harder to handle (thick, heavy)



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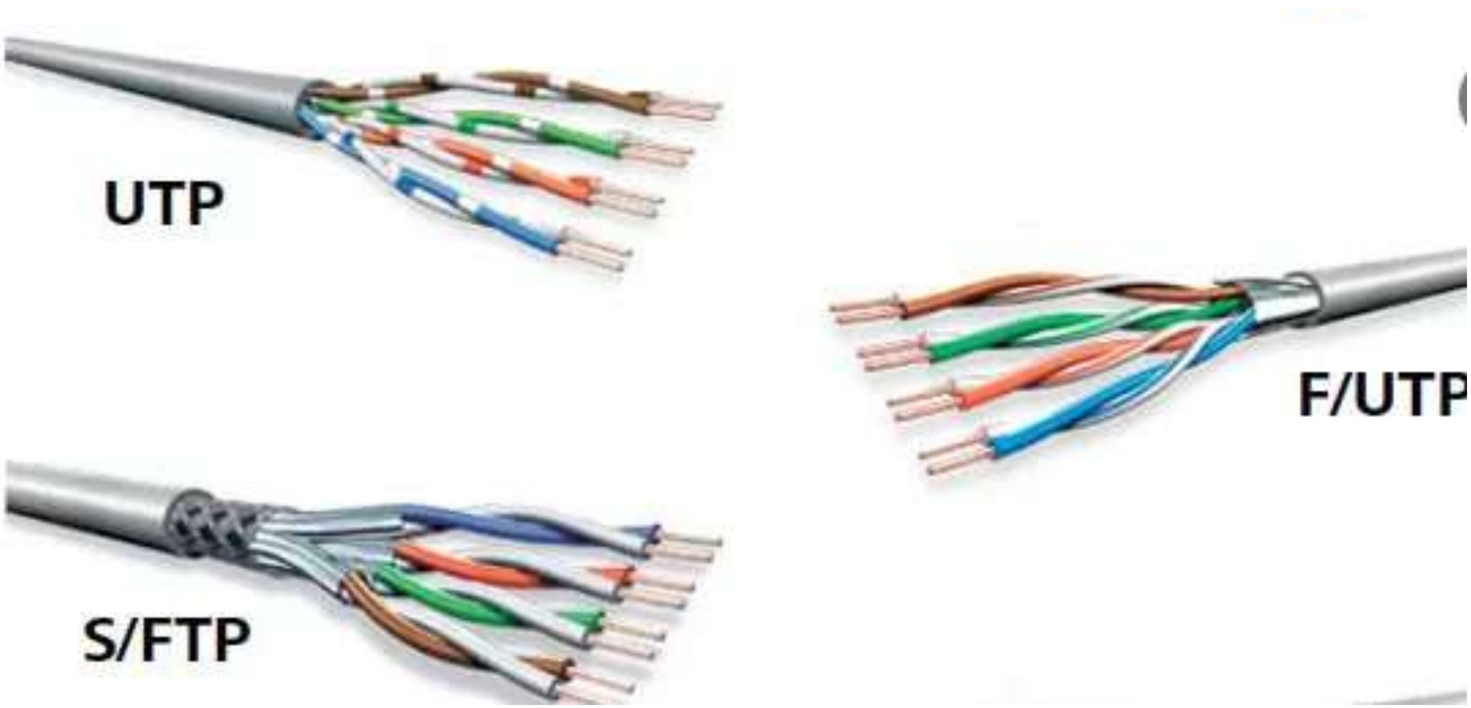
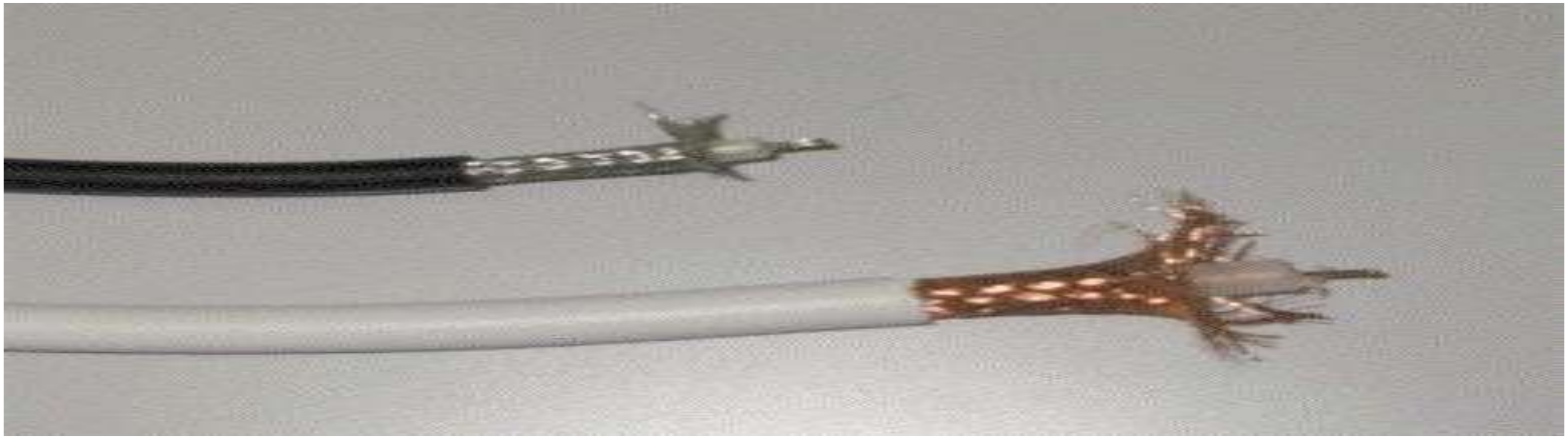
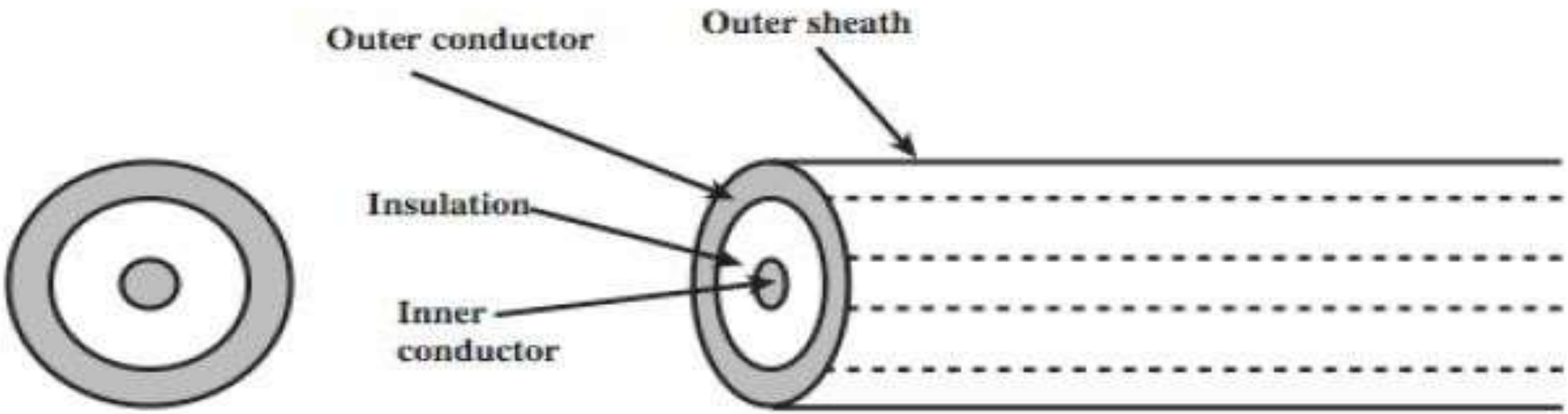


# COAXIAL CABLE





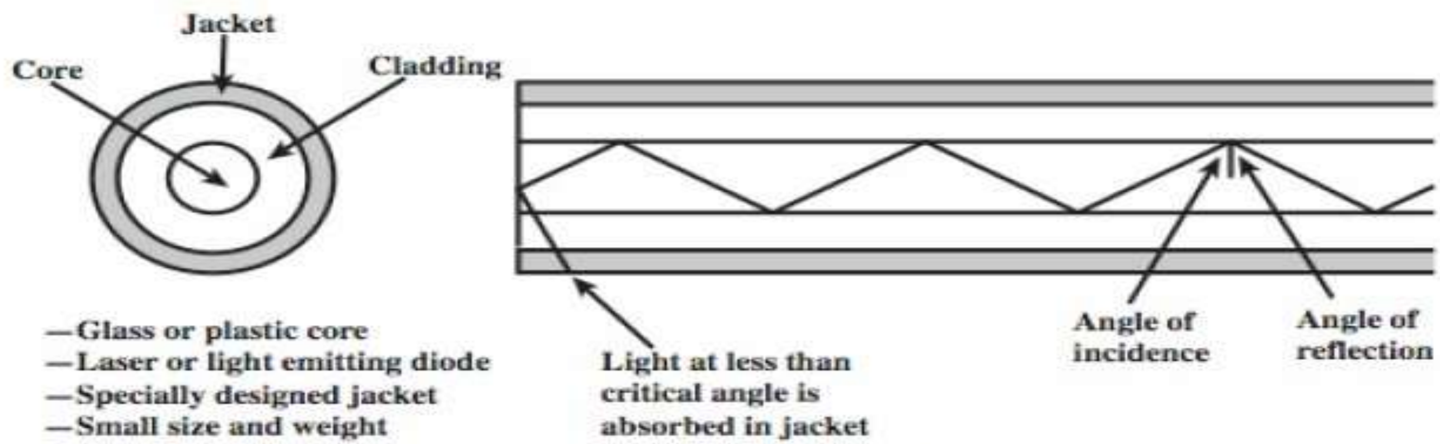

—Outer conductor is braided shield
—Inner conductor is solid metal
—Separated by insulating material
—Covered by padding

- Consists of two conductors but is constructed differently to TP to permit it to operate over a wider range of frequencies.
- It consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor.
- The inner conductor is held in place by either regularly spaced insulating rings or a solid dielectric material.
- The outer conductor is covered with a jacket or shield.
- A single coaxial cable has a diameter of from 1 to 2.5 cm.

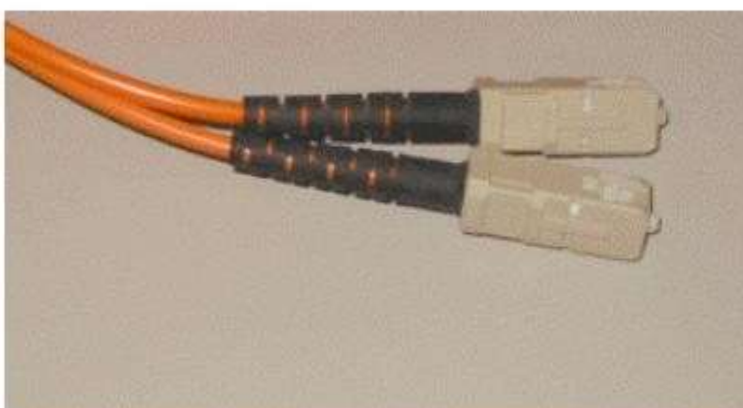
# COAXIAL CABLE - TRANSMISSION CHARACTERISTICS

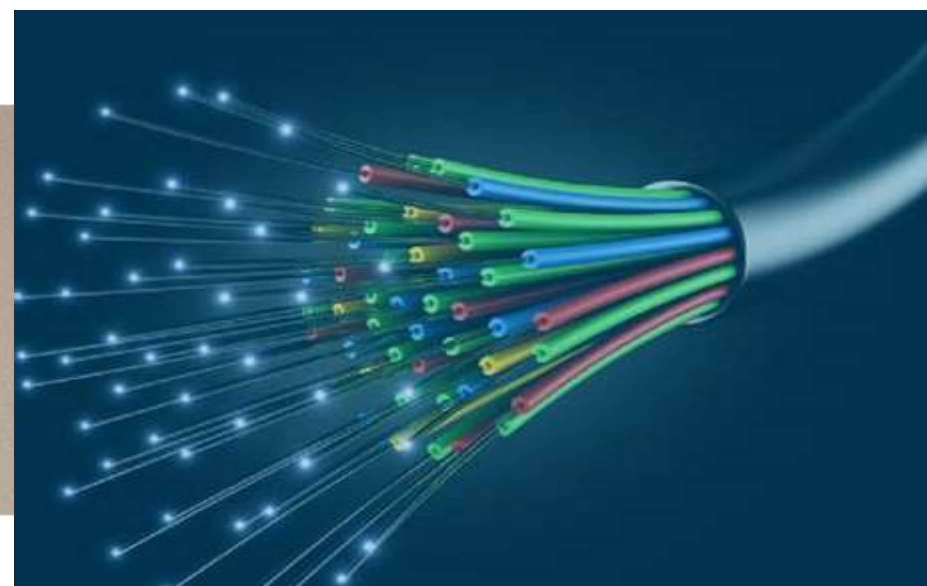
- It can be used effectively at higher frequencies and data rates.
- Less susceptible to interference and crosstalk when compared to TP
- Performance limited by attenuation & noise
  - Analog signals
    - amplifiers every few km
  - Digital signals
    - repeater every 1 km

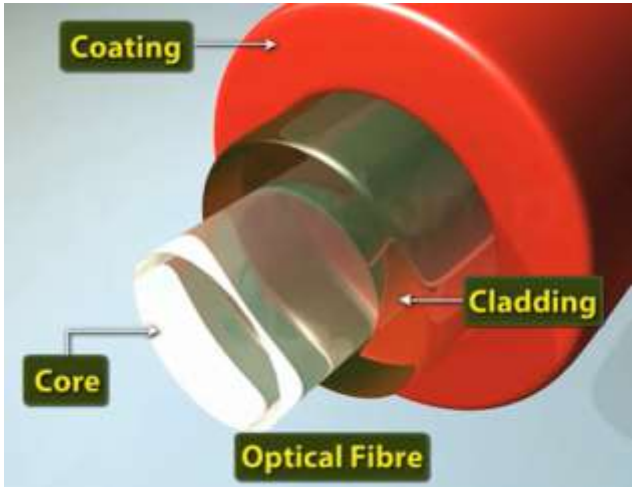
# OPTICAL FIBER

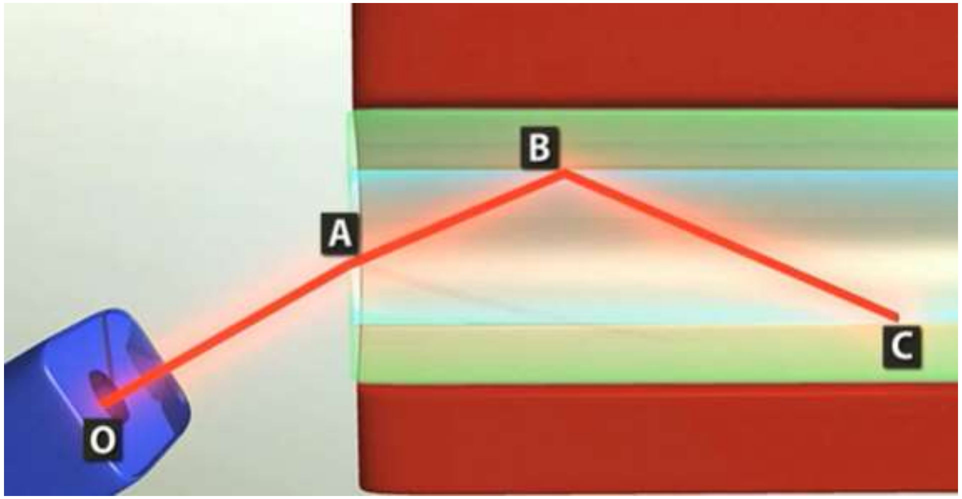



(c) Optical fiber






Coating
Cladding
Core
Optical Fibre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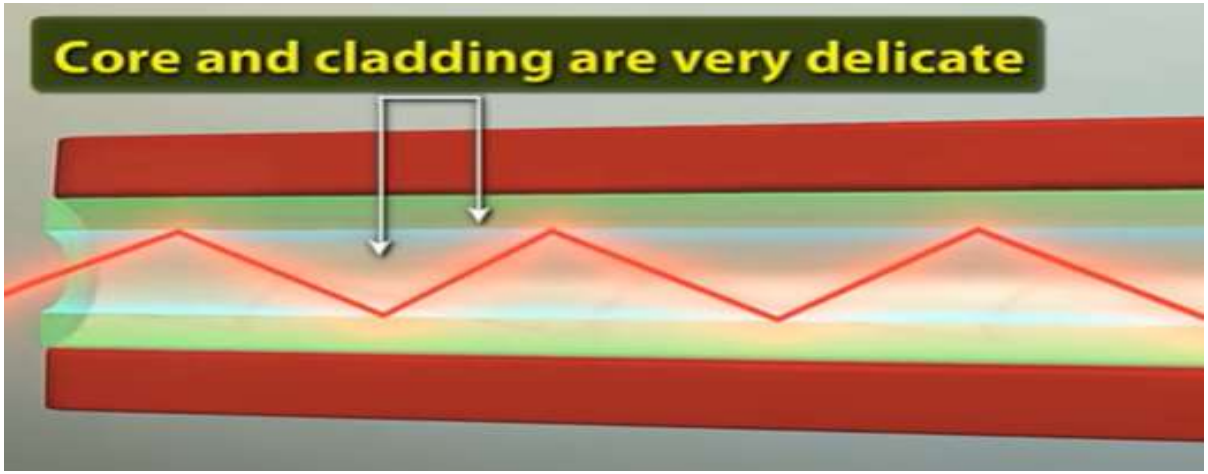

Core and cladding are very delicate

- An optical fiber cable has a cylindrical shape and consists of three concentric sections: the core, the cladding, and the jacket

- The **core** is the innermost section and consists of one or more very thin strands, or fibers, made of glass or plastic.

- Each fiber is surrounded by its own **cladding**, a glass or plastic coating that has optical properties different from those of the core .

- The interface between the core and cladding acts as a reflector to confine light that would otherwise escape the core. The outermost layer, surrounding one or a bundle of cladded fibers, is the **jacket**.

- The jacket is composed of plastic and other material layered to protect against moisture, crushing, and other environmental dangers.

# OPTICAL FIBER - BENEFITS

- Bandwidth of 370THz
- Greater capacity
    - Data rates of hundreds of Gbps
- Smaller size & weight
- Lower attenuation
- Greater repeater spacing: 10s of km.
- Electromagnetic isolation: Not affected by external electromagnetic interference

# OPTICAL FIBER - TRANSMISSION CHARACTERISTICS

- Optical fiber transmits a signal-encoded beam of light by means of **total internal reflection**.

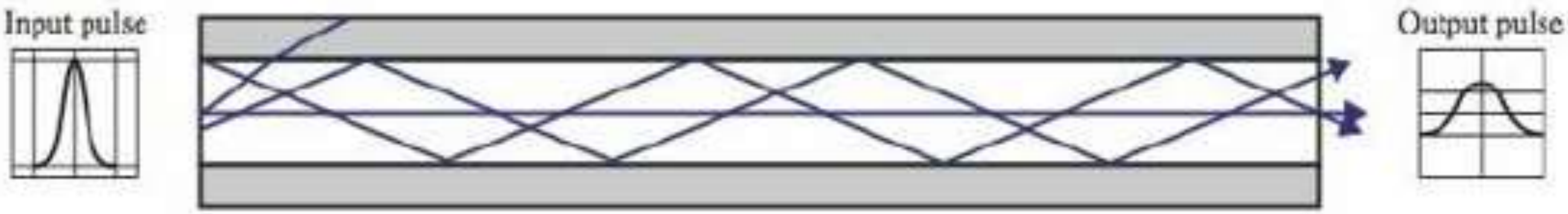
- Total internal reflection can occur in any transparent medium that has a higher index of refraction than the surrounding medium.

- Act as wave guide for 1014 to 1015 Hz
- Can use several different light sources
  - Light Emitting Diode (LED)
    - cheaper, wider operating temp range, lasts longer
  - Injection Laser Diode (ILD)
    - more efficient, has greater data rate

(c) Single mode

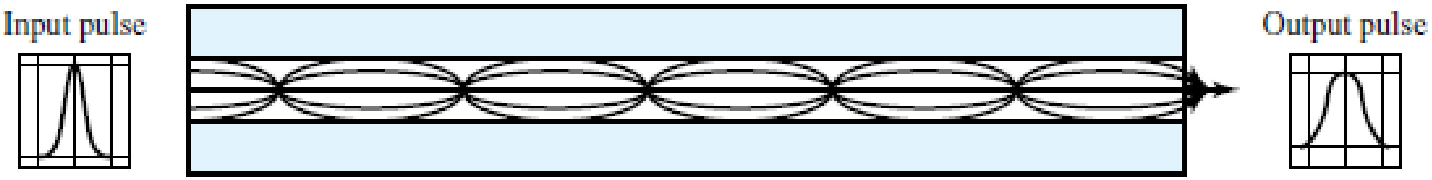
- When the fiber core radius is reduced, fewer angles will reflect.
- By reducing the radius of the core to the order of a wavelength, only a single angle or mode can pass.
- Used for long-distance applications, including telephone and cable television.

# OPTICAL FIBER TRANSMISSION MODES



(a) Step-index multimode

- Light from a source enters the cylindrical glass or plastic core.
- Rays at shallow angles are reflected and propagated along the fiber; other rays are absorbed by the surrounding material
- Multiple propagation path exists each with a different path length and hence time to traverse the fiber.
- Signals will spread out and limits the rate at which it is received.

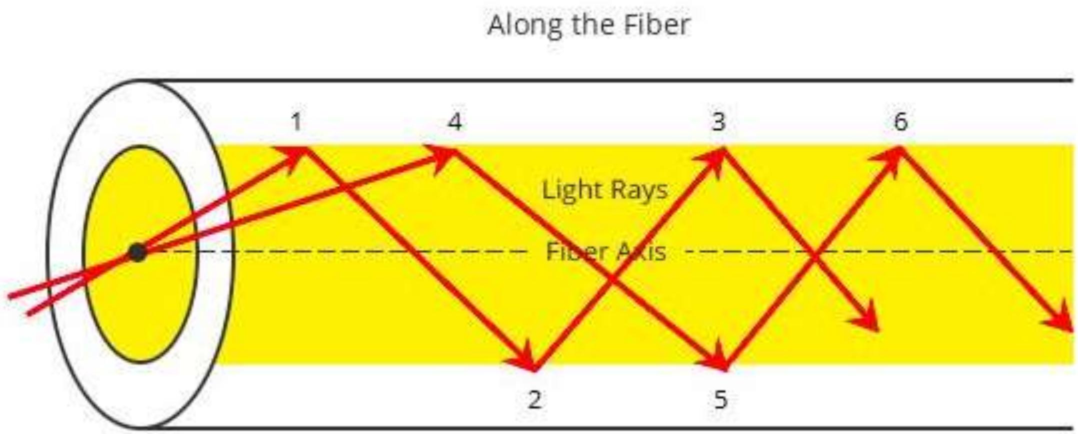


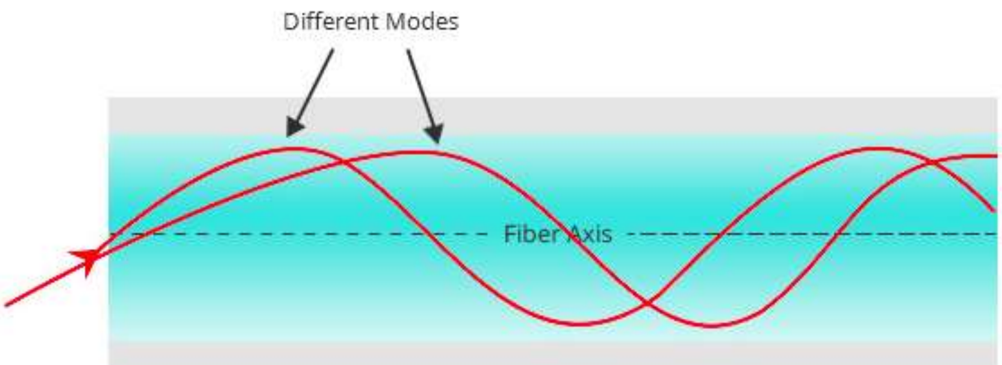
(b) Graded-index multimode

- The higher refractive index (discussed subsequently) at the center makes the light rays moving down the axis advance more slowly than those near the cladding.
- Rather than zig-zagging off the cladding, light in the core curves helically because of the graded index, reducing its travel distance.

- The shortened path and higher speed allows light at the periphery to arrive at a receiver at about the same time as the straight rays in the core axis.

# Step Index VS Graded Index




Graded-Index Multimode Fiber

# Comparison of Guided Media

**Electrical Cables**

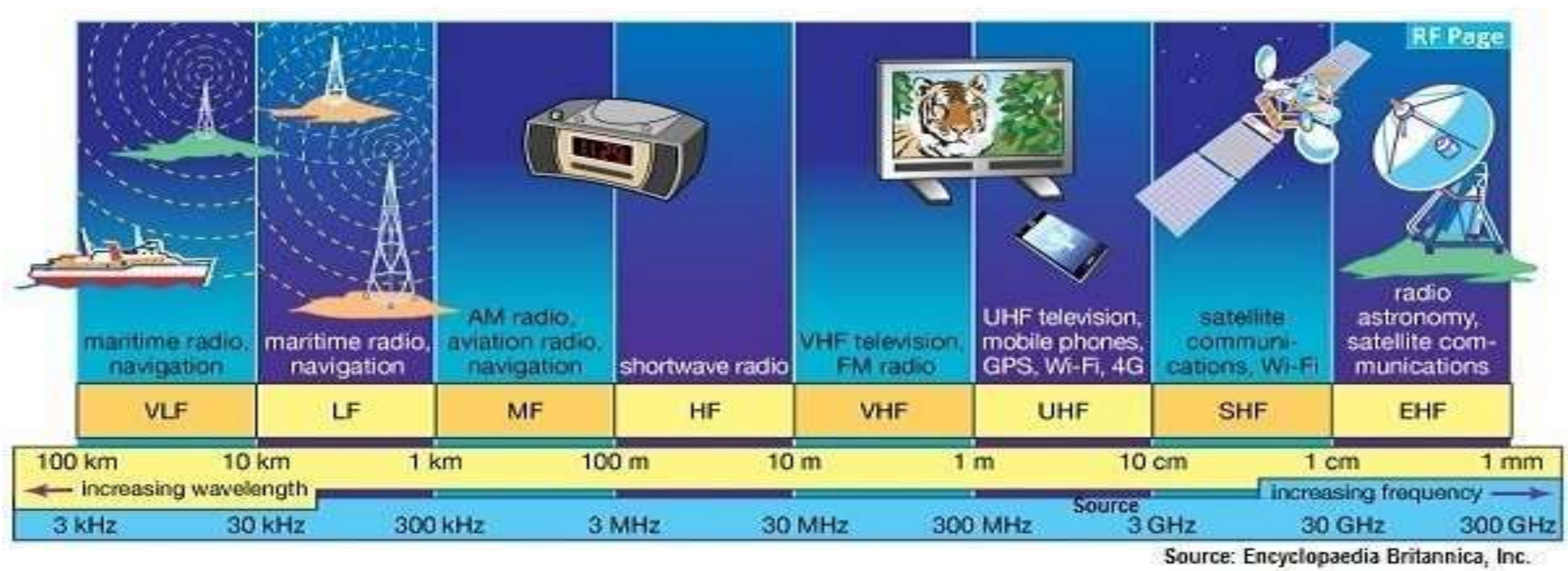
- Moderate data rates: 1Gb/s
- Maximum distance: 2km (twisted pair); 10km (coaxial)
- Cheapest for low data rates
- UTP: easy to install, susceptible to interference
- STP, Coaxial Cable: rigid, protection against interference

**Optical Cables**

- Very high data rates: 100Gb/s
- Maximum distance: 40km
- Expensive equipment, but cost effective for high data rates, Difficult to install

# Wireless transmission
# 3 general range of frequencies

- Microwave frequency 1GHz to 40GHz
  - Highly directional-satellite communication, tower to tower communication
- Radio frequency 30MHz to 1 GHz
- Infrared frequency $3x10^{11}$ to $2x10^{12}$ Hz
  - Within confined room(TV remote)



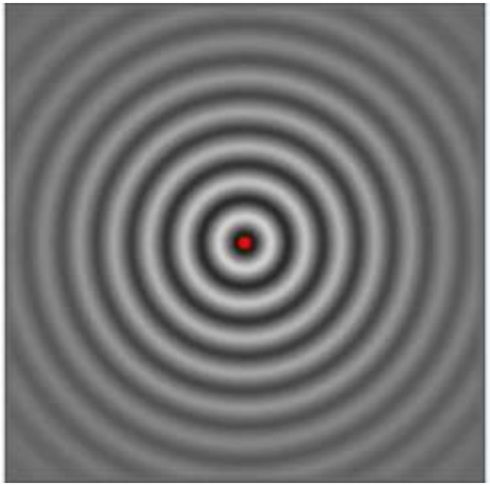
# Antennas

- electrical conductor used to radiate or collect electromagnetic energy
- transmission antenna
  - radio frequency energy from transmitter
  - converted to electromagnetic energy by antenna
  - radiated into surrounding environment
- reception antenna
  - converted to radio frequency electrical energy
  - fed to receiver
- same antenna is often used for both purposes

Direction and propagation of a wave depends on antenna shape

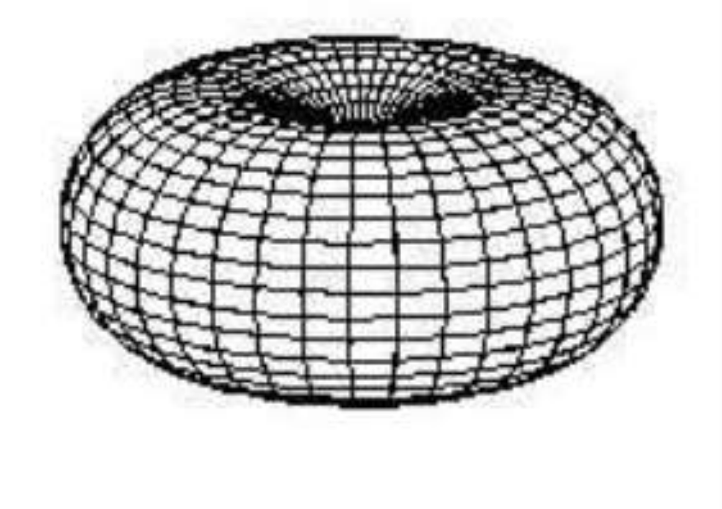
- **Isotropic antenna:** power propagates in all directions equally (spherical pattern, ideal)
  - **Omni-directional antenna:** power propagates in all directions on one plane
- **Directional antenna:** power concentrated in particular direction
- Power output in particular direction compared to power produced by isotropic antenna is antenna gain [dB]

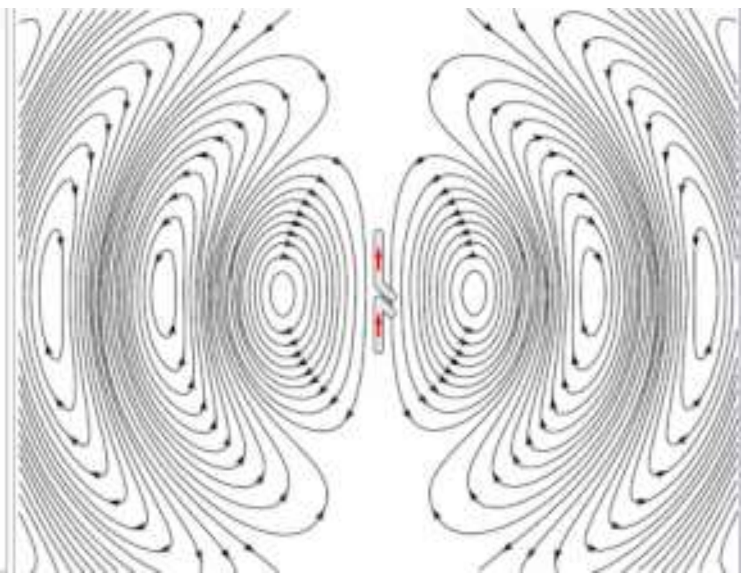
**Isotropic antenna**



An antenna will radiate power in all directions but, typically, does not perform equally well in all directions.

# Omni-directional antenna

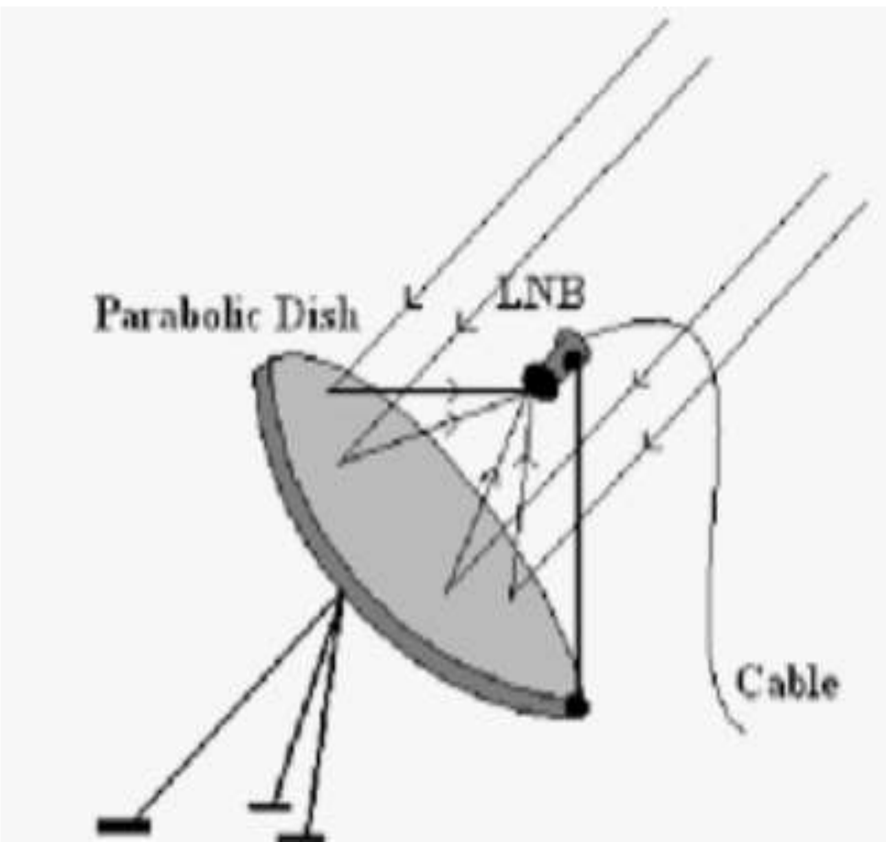




Example of omnidirectional antenna; a whip antenna on a walkie-talkie

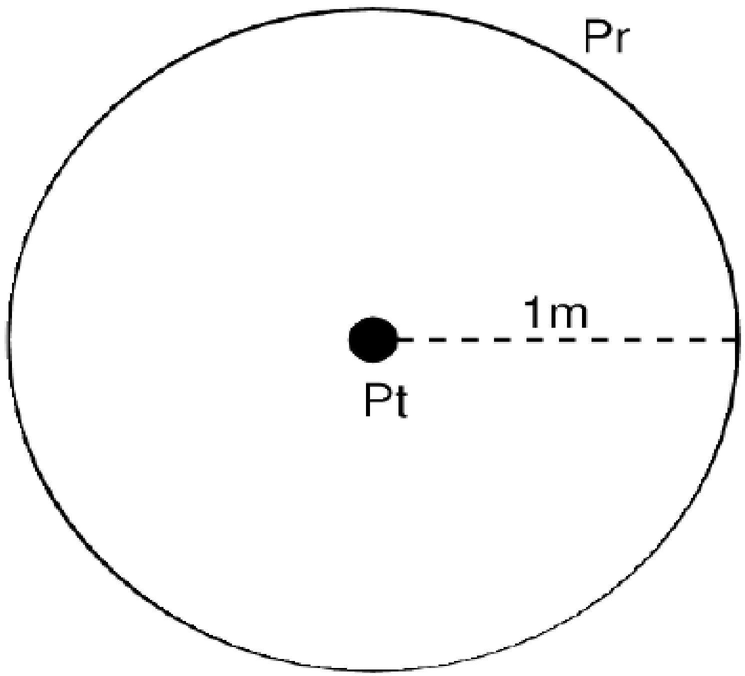
**Parabolic Reflective Antenna**

- Used in terrestrial microwave and satellite applications.

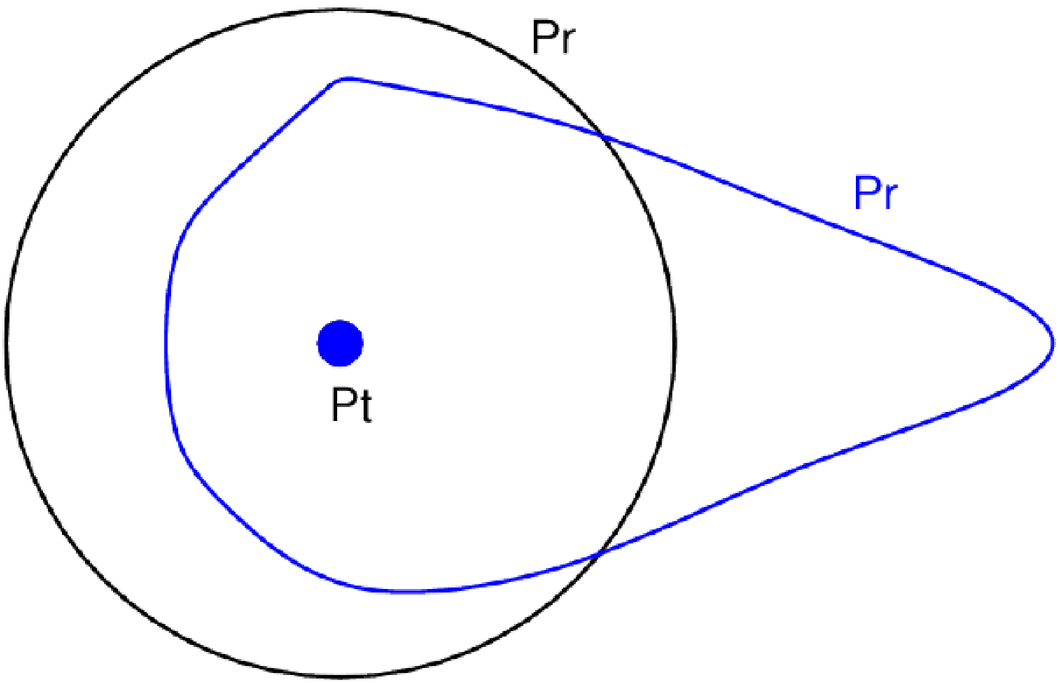



# Wireless

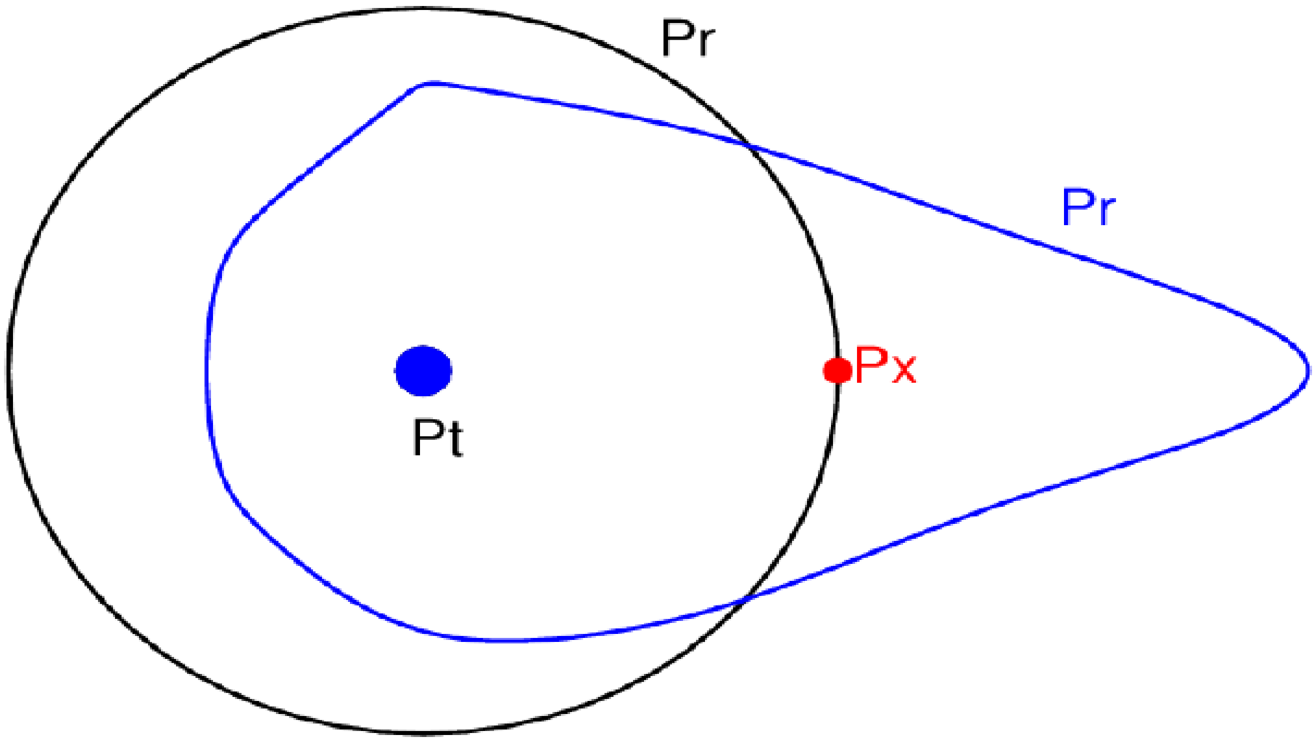
Isotropic antenna. Transmit with power Pt. Power received at all points 1m away is Pr



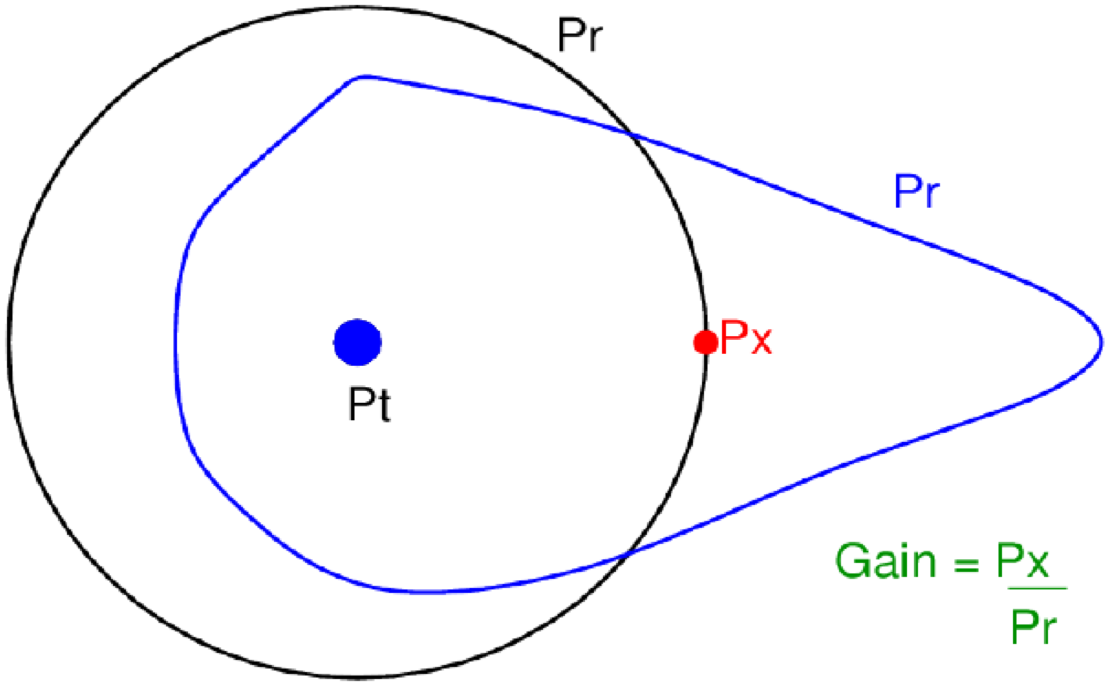
Directional antenna. Transmit with power Pt. Power received at all points on blue line is Pr (the same power level as 1m away from isotropic)

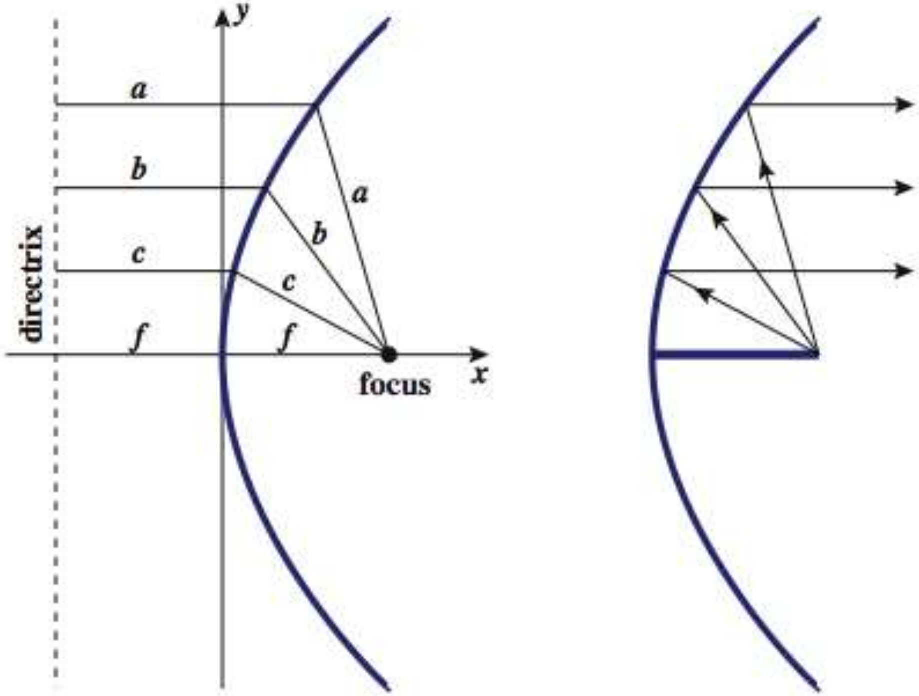


At the red point (1m away from directional antenna), power received is Px.
Px is greater than Pr



The gain of the blue directional antenna is the ratio between power received 1m away From directional antenna (Px) and power received 1m away from isotropic antenna (Pr)






(a) Parabola

(b) Cross-section of parabolic antenna showing reflective property

# Antenna Gain

- measure of directionality of antenna
- power output in particular direction verses that produced by an isotropic antenna
- measured in decibels (dB)
- effective area relates to size and shape
  - related to gain

- **effective area** of an antenna
- The effective area of an antenna is related to the physical size of the antenna and to its shape.

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

$G$ = antenna gain

$A_e$ = effective area

$f$ = carrier frequency

c = speed of light ($\approx 3 \times 10^8$ m/s)

$\lambda$ = carrier wavelength

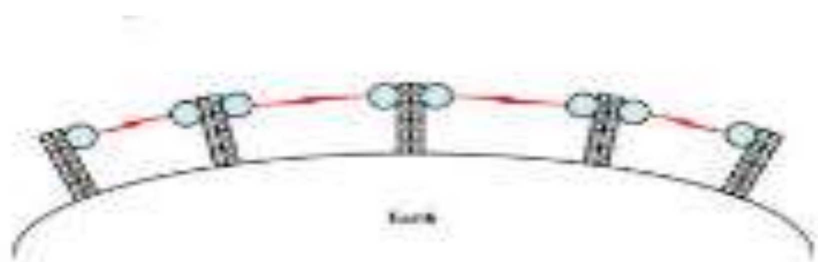
- The effective area of an ideal isotropic antenna is with $\lambda^2/4\pi$ a power gain of 1;
- The effective area of a parabolic antenna with a face area of *A* is 0.56*A*, with a power gain of $7A/\lambda^2$.

**EXAMPLE 4.2** For a parabolic reflective antenna with a diameter of 2 m, operating at 12 GHz, what is the effective area and the antenna gain? We have an area of $A = \pi r^2 = \pi$ and an effective area of $A_e = 0.56\pi$. The wavelength is $\lambda = c/f = (3 \times 10^8)/(12 \times 10^9) = 0.025$ m. Then

$$G = (7A)/\lambda^2 = (7 \times \pi)/(0.025)^2 = 35{,}186$$
$$G_{dB} = 45.46 \text{ dB}$$

# Terrestrial Microwave

- Used for long haul telecommunications and short point-to-point links
- Requires fewer repeaters but must be LOS
- Use a parabolic dish to focus a narrow beam onto a receiver antenna
- 1-40GHz frequencies
- Higher frequencies give higher data rates
- main source of loss is attenuation + interference



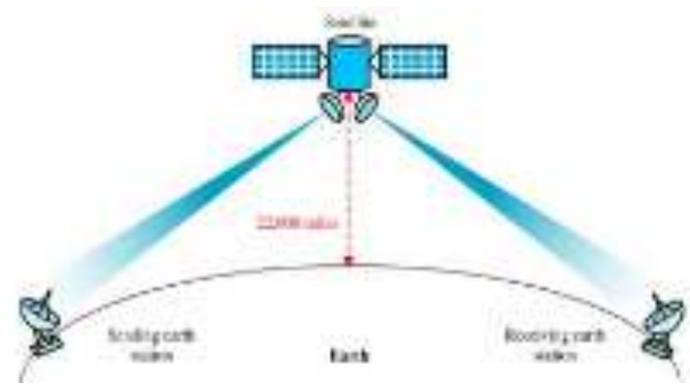
- As with any transmission system, a main source of loss is attenuation. For microwave (and radio frequencies), the loss can be expressed as

$$L = 10 \log\left(\frac{4\pi d}{\lambda}\right)^2 \text{ dB}$$

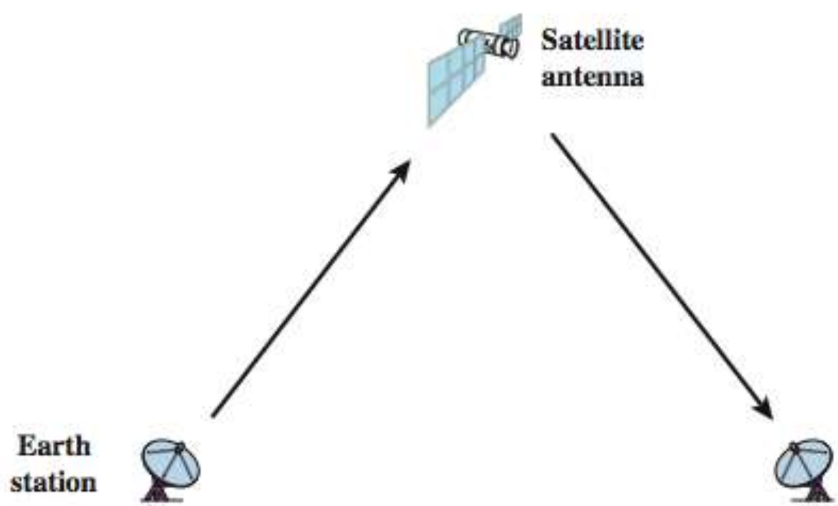
- where *d* is the distance and λ is the wavelength, in the same units

# Satellite Microwave

- satellite is relay station:
- earth /ground stations → satellite → earth /ground stations
- receives on one frequency band (uplink),), amplifies or repeats signal and transmits on another frequency (downlink)
  - eg. uplink 5.925-6.425 GHz & downlink 3.7-4.2 GHz
- **transponder channels**(**transponders**): The subsystem, which provides the connecting link between transmitting and receiving antennas of a satellite.
- used for communications, navigation, map-making, astronomical observations, scientific experimentation, and monitoring of the Earth's environment
- typically requires geo-stationary orbit
  - height of 35,784km
  - spaced at least 3-4° apart
- typical uses
  - television
  - long distance telephone
  - private business networks
  - global positioning

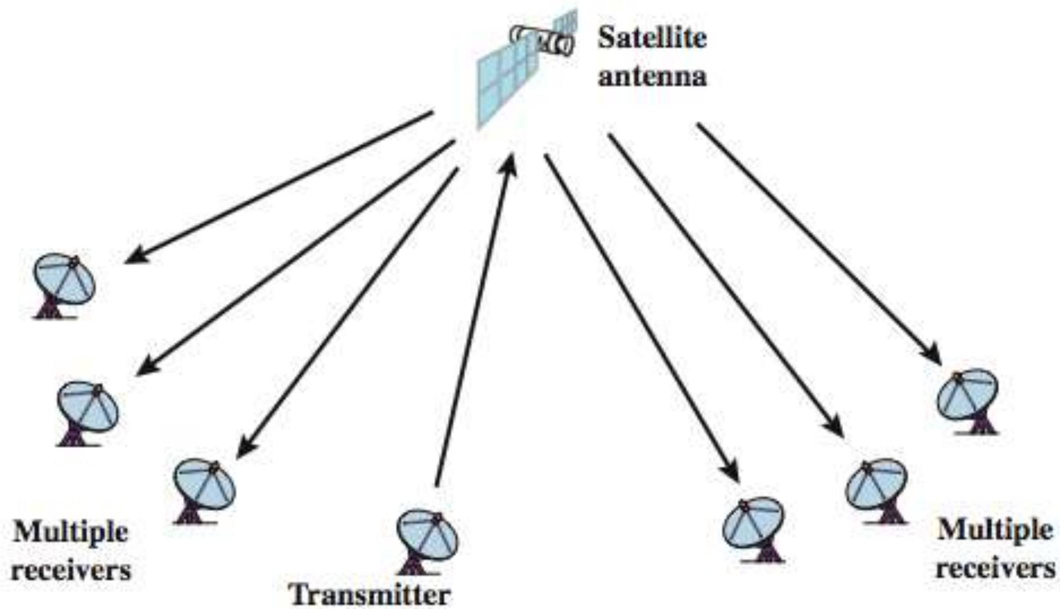


# Satellite Point to Point Link



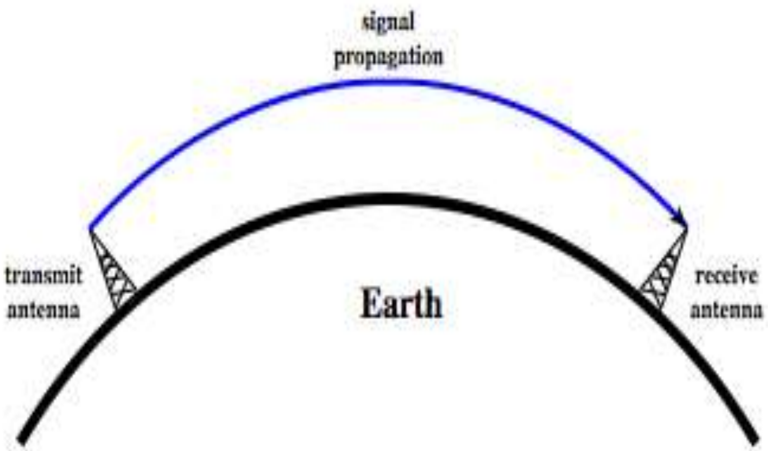

(a) Point-to-point link

# Satellite Broadcast Link

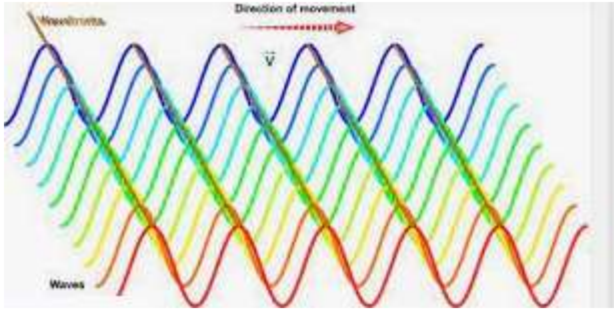



(b) Broadcast link

# Wireless Propagation
# Ground Wave

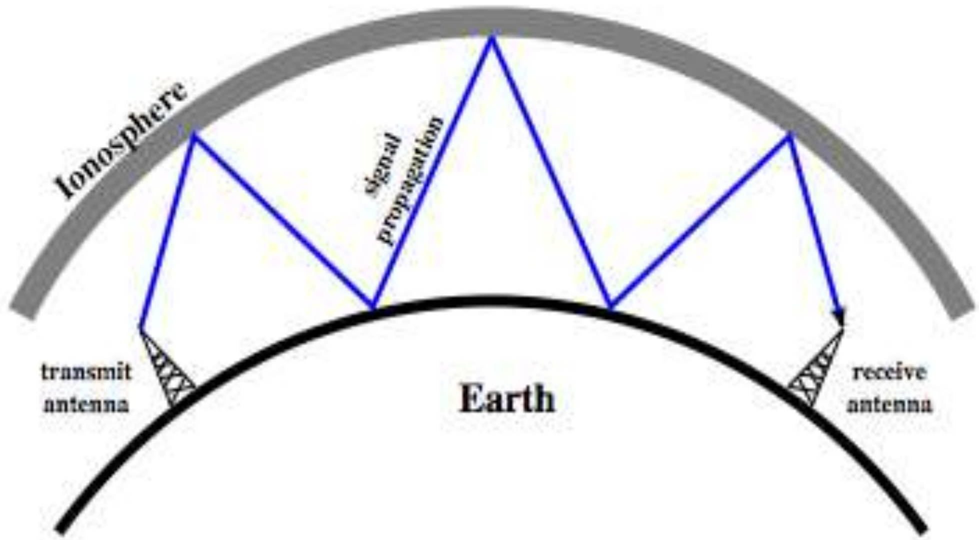



(a) Ground-wave propagation (below 2 MHz)



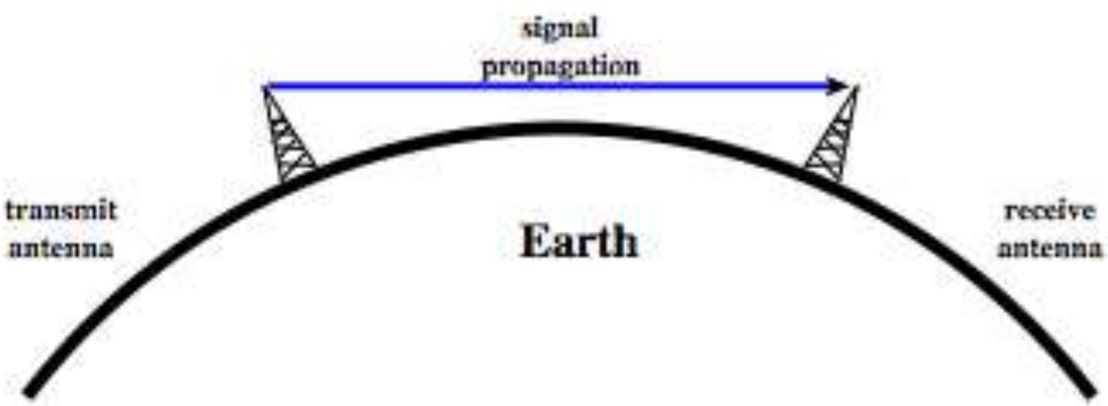

- electromagnetic wave induces a current in the earth’s surface, the result of which is to slow the wavefront near the earth, causing the wavefront to tilt downward and hence follow the earth’s curvature
- scattered by the atmosphere in such a way that they do not penetrate the upper atmosphere(diffraction)
- Eg: AM radio

# Wireless Propagation
Sky Wave




(b) Sky-wave propagation (2 to 30 MHz)

# Wireless Propagation
# Line of Sight




(c) Line-of-sight (LOS) propagation (above 30 MHz)

# Line of Sight Transmission

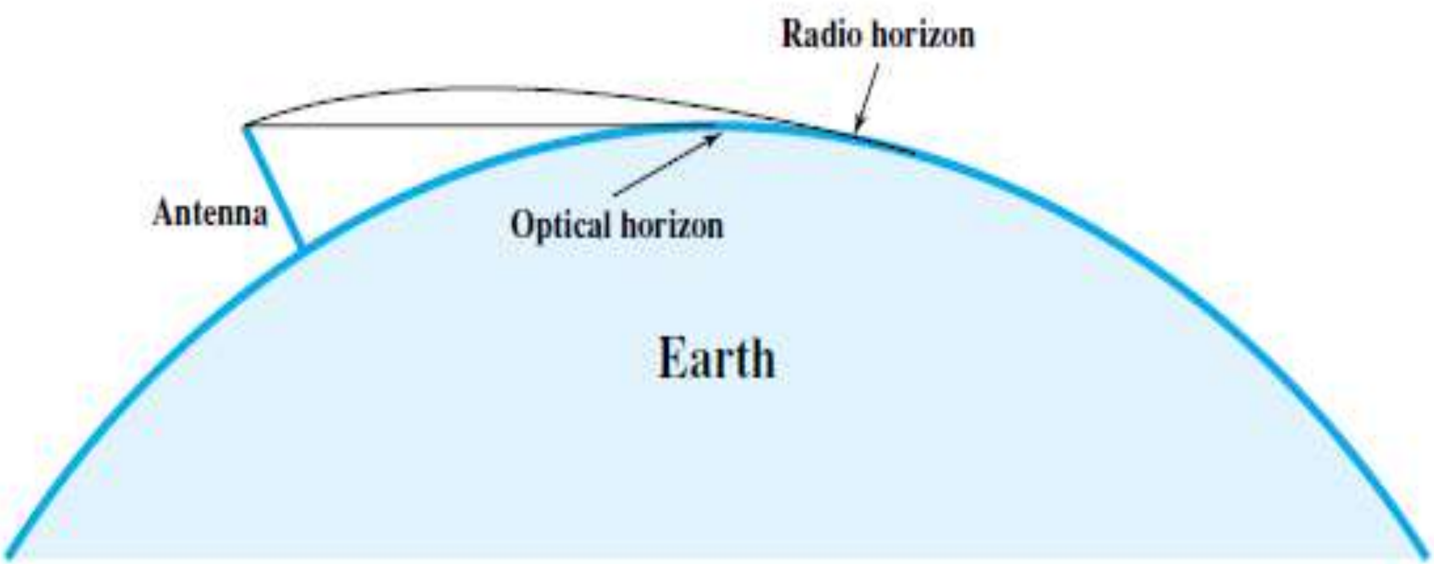



Figure 4.9 Optical and Radio Horizons

$$d = 3.57\sqrt{Kh}$$

$$K = 4/3.$$

$$d = 3.57\sqrt{h}$$

- The maximum distance between two antennas for LOS transmission if one antenna is 100 m high and the other is at ground level is____?

- Now suppose that the receiving antenna is 10 m high. To achieve the same distance, how high must the transmitting antenna be?

# Transmission impairments specific to wireless line-of-sight transmission

- **Free Space Loss:** transmitted signal attenuates over distance because the signal is being spread over a larger and larger area(free space loss)
- radiated power $P_t$ , to the power $P_r$ received by the antenna

$$\frac{P_t}{P_r} \quad \text{OR} \quad 10 \log \frac{P_t}{P_r} \quad \text{dB}$$

$$L_{dB} = 10 \log \frac{P_t}{P_r}$$

For the ideal isotropic antenna, free space loss is $\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$

$$L_{dB} = 10 \log \frac{P_t}{P_r} = 20 \log\left(\frac{4\pi d}{\lambda}\right) = -20 \log(\lambda) + 20 \log(d) + 21.98 \text{ dB}$$

$$= 20 \log\left(\frac{4\pi f d}{c}\right) = 20 \log(f) + 20 \log(d) - 147.56 \text{ dB}$$

For other antennas, we must take into account the gain of the antenna, which yields the following free space loss equation:

$$\frac{P_t}{P_r} = \frac{(4\pi)^2(d)^2}{G_r G_t \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}$$

$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

$$\begin{aligned} L_{\mathrm{dB}} &= 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r) \\ &= -20\log(f) + 20\log(d) - 10\log(A_t A_r) + 169.54\ \mathrm{dB} \end{aligned}$$

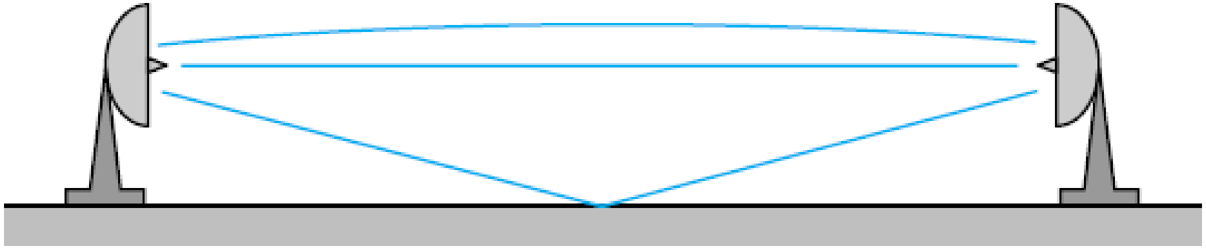
- Determine the isotropic free space loss at 4 GHz for the shortest path to a synchronous satellite from earth (35,863 km). At 4 GHz, the wavelength is $(3 \times 10^8)/(4 \times 10^9) = 0.075$ m.

- Now consider the antenna gain of both the satellite- and ground-based antennas. Typical values are 44 dB and 48 dB, respectively. Find the free space loss.

- Now assume a transmit power of 250 W at the earth station. What is the power received at the satellite antenna?

# Other wireless transmission impairments

- **Atmospheric Absorption**
- **Multipath**
- **Refraction**


(a) Microwave line of sight

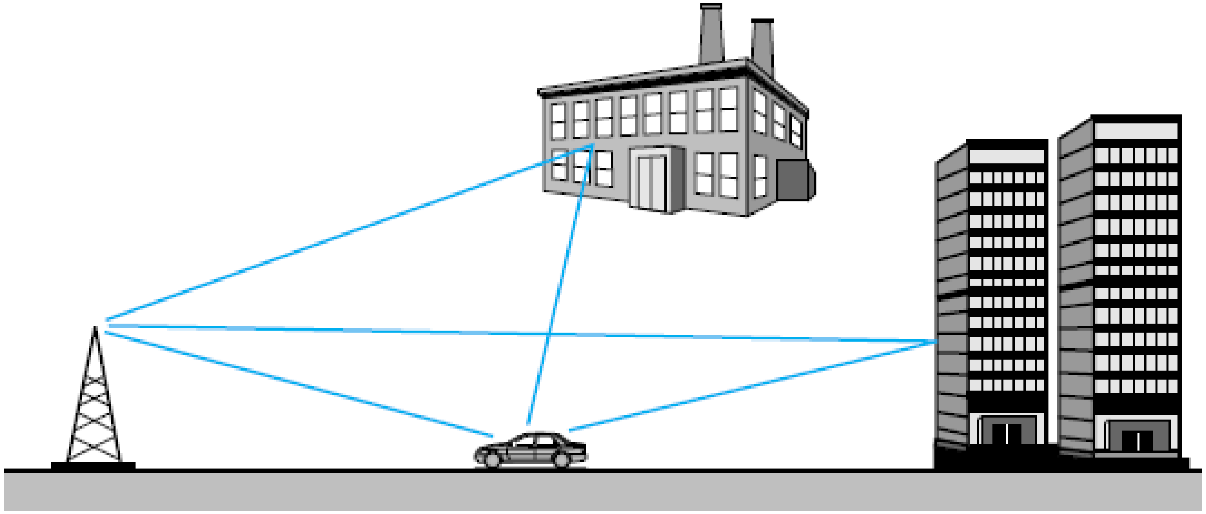

(b) Mobile radio

Figure 4.11 Examples of Multipath Interference