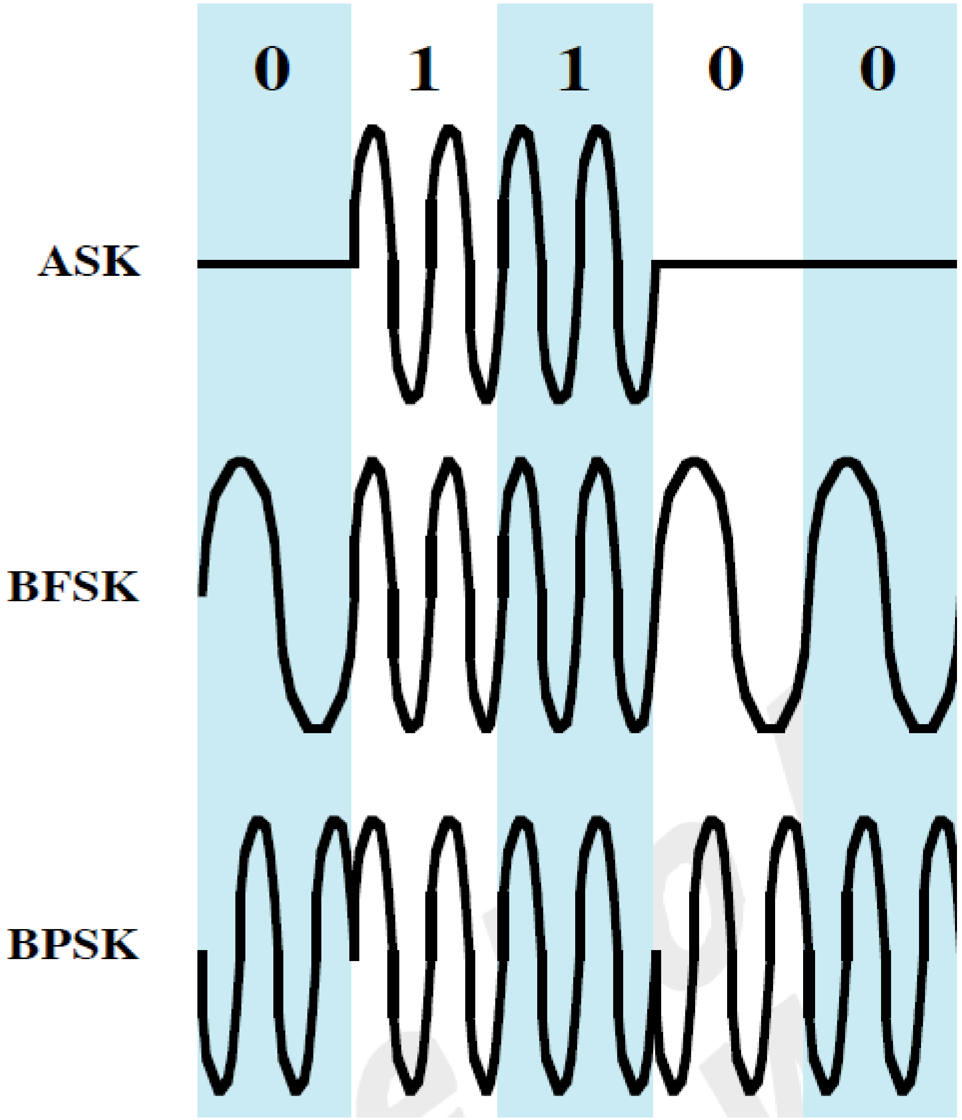
Wireless Transmission

Tutorials /Example questions

- Given the bit pattern 01100, encode this data using ASK, BFSK, and BPSK.


0
1
1
0
0
ASK
BFSK
BPSK

Example

- An NRZ-L signal is passed through a filter with r=0.5 and then modulated onto a carrier. The data rate is 2400 bps. Evaluate the bandwidth for ASK and FSK.

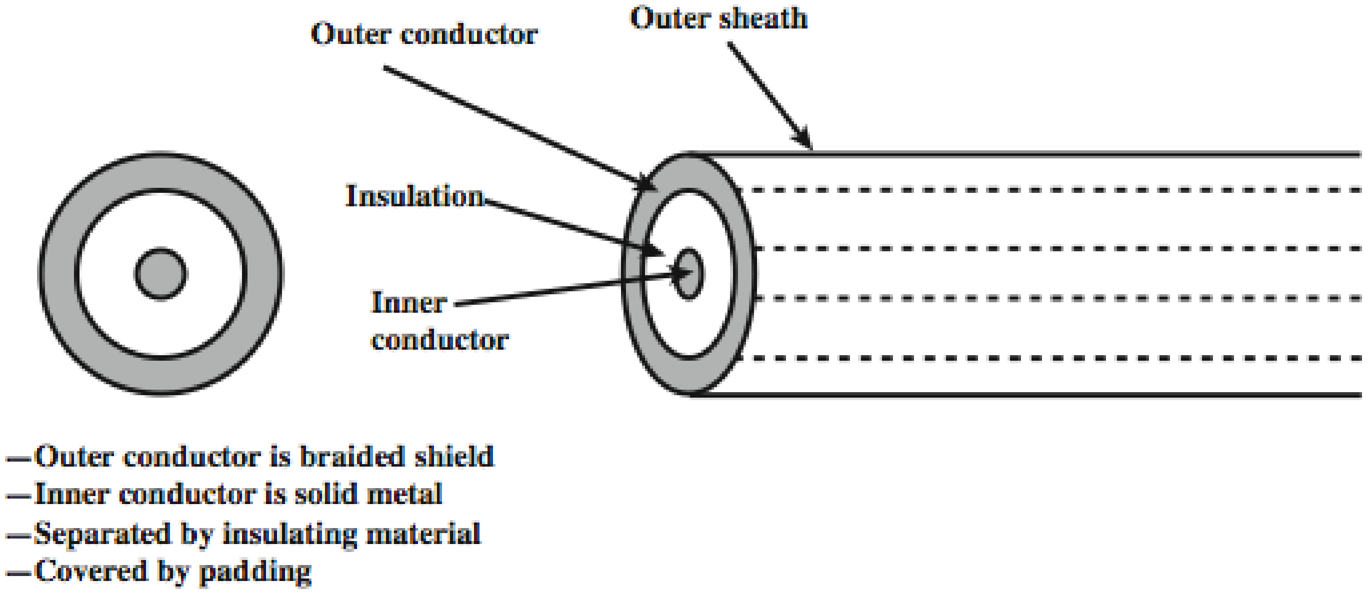
- For ASK, BT = (1 + r)R = (1.5)2400 = 3600 Hz
- For FSK,
- BT = (1 + r)R
- = (1.5)2400 = 8600 Hz

Example

- Assume that a telephone line channel is equalized to allow bandpass data transmission over a frequency range of 600 to 3000 Hz. The available bandwidth is 2400 Hz. For r=1 evaluate the required bandwidth for 2400 bps QPSK and 4800-bps, eight level multilevel signaling. Is the bandwidth adequate?

- For multilevel signaling $BT = [(1 + r)/\log_2 M]R$
- For 2400 bps QPSK,
  - $\log_2 M = \log_2 4 = 2$
  - $BT = (2/2)2400 = 2400$ Hz, which just fits the available bandwidth
- For 8-level 4800 bps signaling,
  - $\log_2 M = \log_2 8 = 3$
  - $BT = (2/3)(4800) = 3200$ Hz, which exceeds the available bandwidth

Coaxial Cable

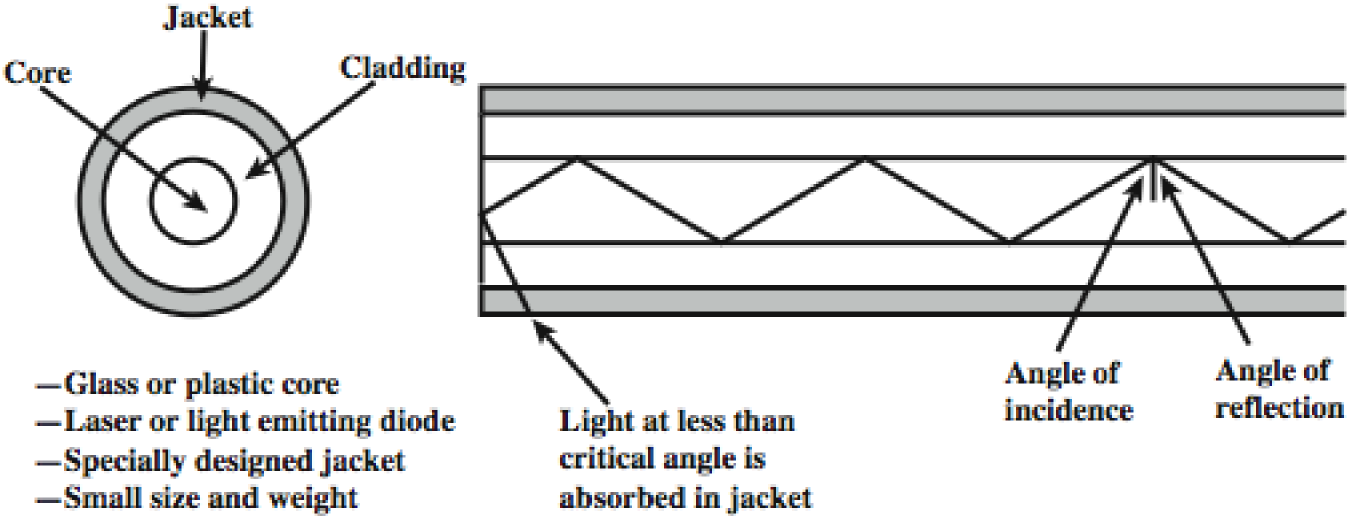


(b) Coaxial cable

Coaxial Cable - Transmission Characteristics

- superior frequency characteristics to TP
- performance limited by attenuation & noise
- analog signals
  - amplifiers every few km
  - closer if higher frequency
  - up to 500MHz
- digital signals
  - repeater every 1km
  - closer for higher data rates

Optical Fiber



(c) Optical fiber

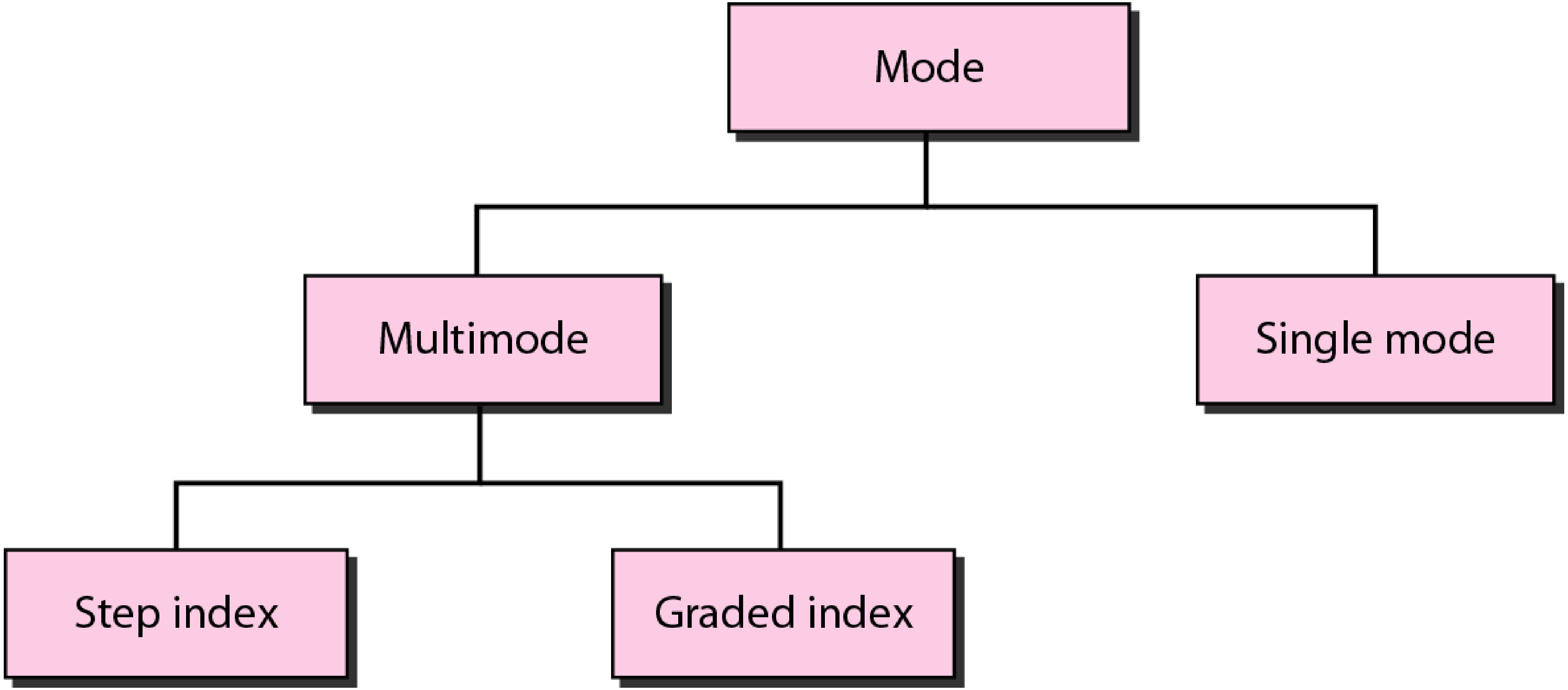
Optical Fiber - Benefits

- greater capacity
  - data rates of hundreds of Gbps
- smaller size & weight
- lower attenuation
- electromagnetic isolation
- greater repeater spacing
  - 10s of km at least

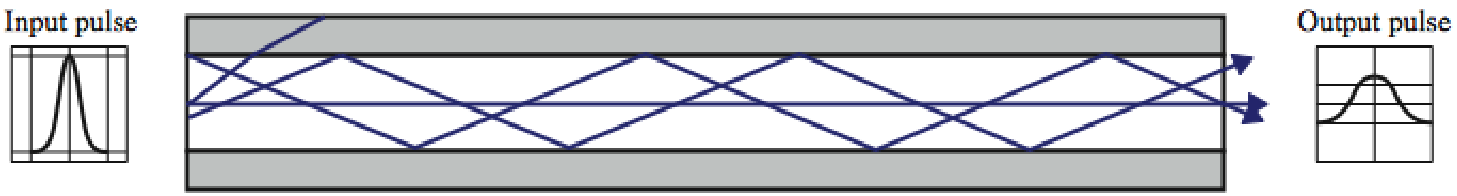
Optical Fiber - Transmission Characteristics

- uses total internal reflection to transmit light
- 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

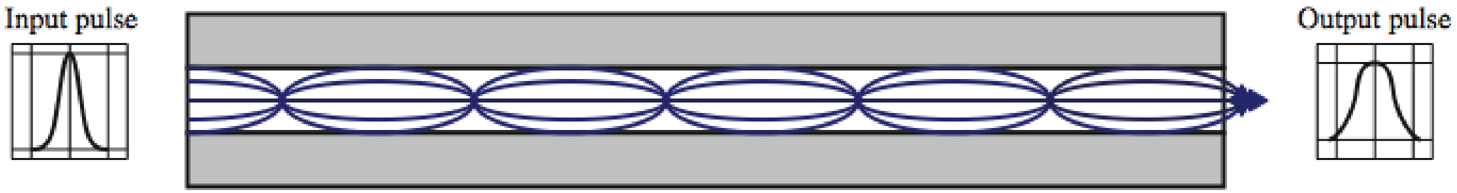
Propagation modes



Optical Fiber Transmission Modes

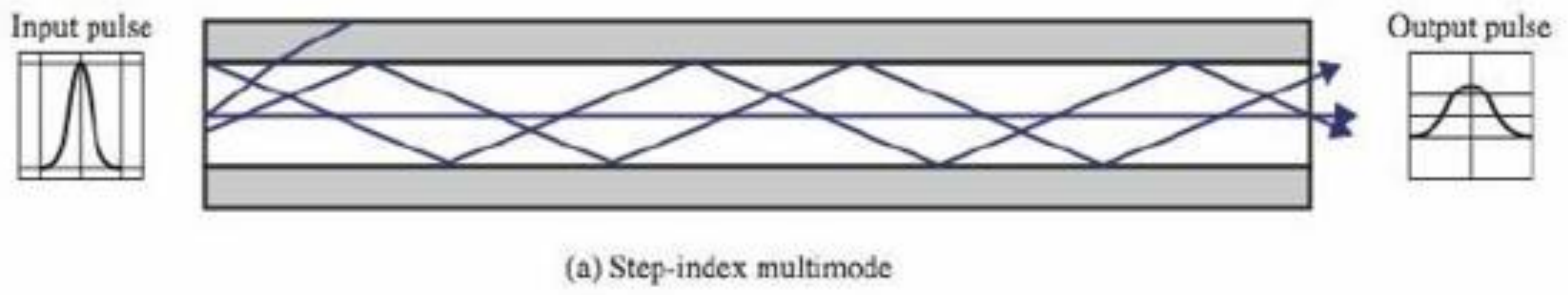


(a) Step-index multimode

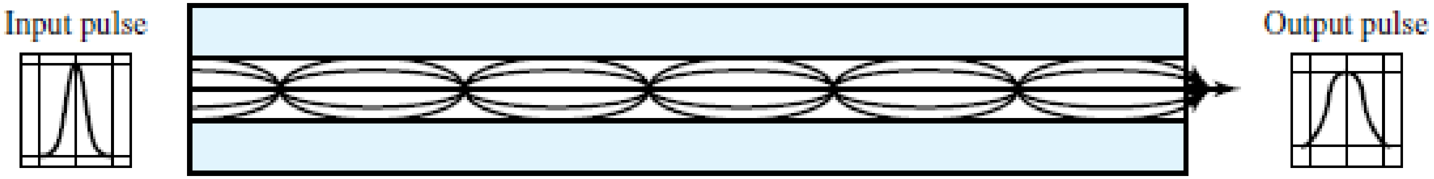


(b) Graded-index multimode

(c) Single mode



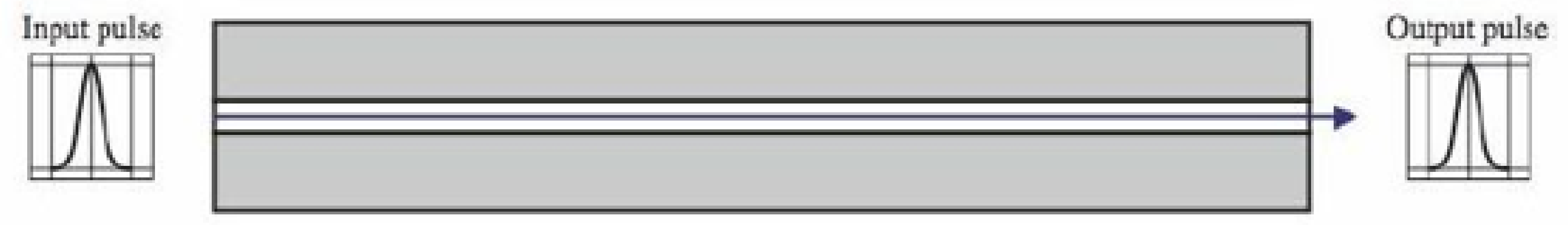
- Light from a source enters the cylindrical glass or plastic core.
- Rays at shallow angles are reflected and propagated along the fiber; other rays are absorbed by the surrounding material
- Multiple propagation path exists each with a different path length and hence time to traverse the fiber.
- Signals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

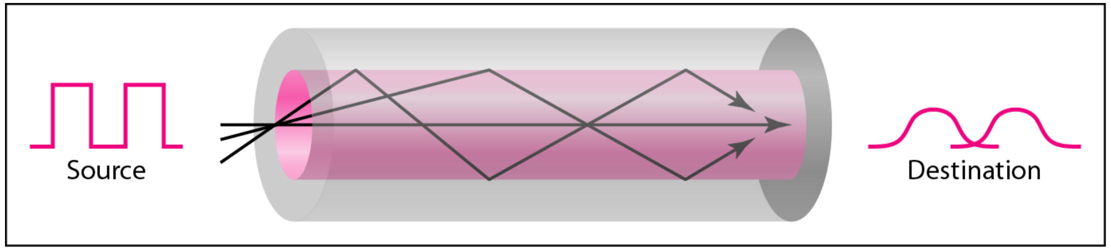
- The shortened path and higher speed allows light at the periphery to arrive at a receiver at about the same time as the straight rays in the core axis.



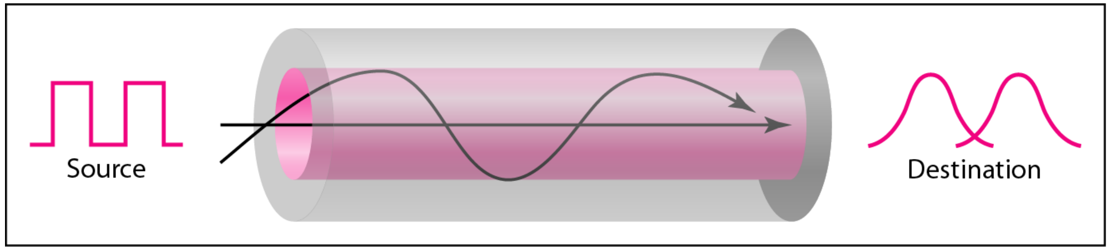
(c) Single mode

- 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.

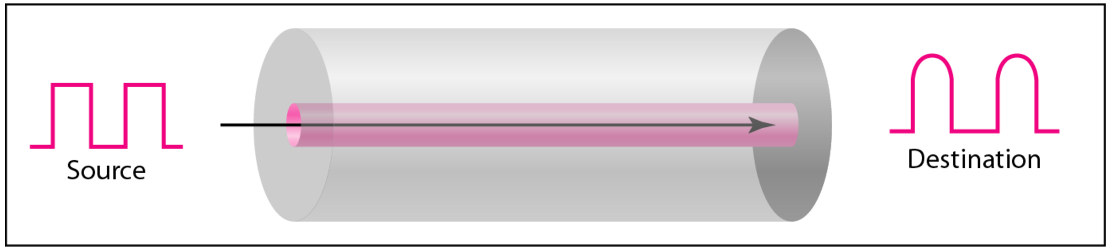
Optical Fiber Transmission Modes



a. Multimode, step index



b. Multimode, graded index



c. Single mode

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

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

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

3 general range of frequencies

- Microwave frequency 1GHz to 40GHz - Microwaves
- Radio frequency 30MHz to 1 GHz - Radiowaves
- Infrared frequency $3x10^{11}$ to $2x10^{12}$ Hz - Infrared

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

Radiation Pattern

- Power radiated in all directions
- Not same performance in all directions
- An isotropic antenna is a (theoretical) point in space
  - Radiates in all directions equally
  - With A spherical radiation pattern

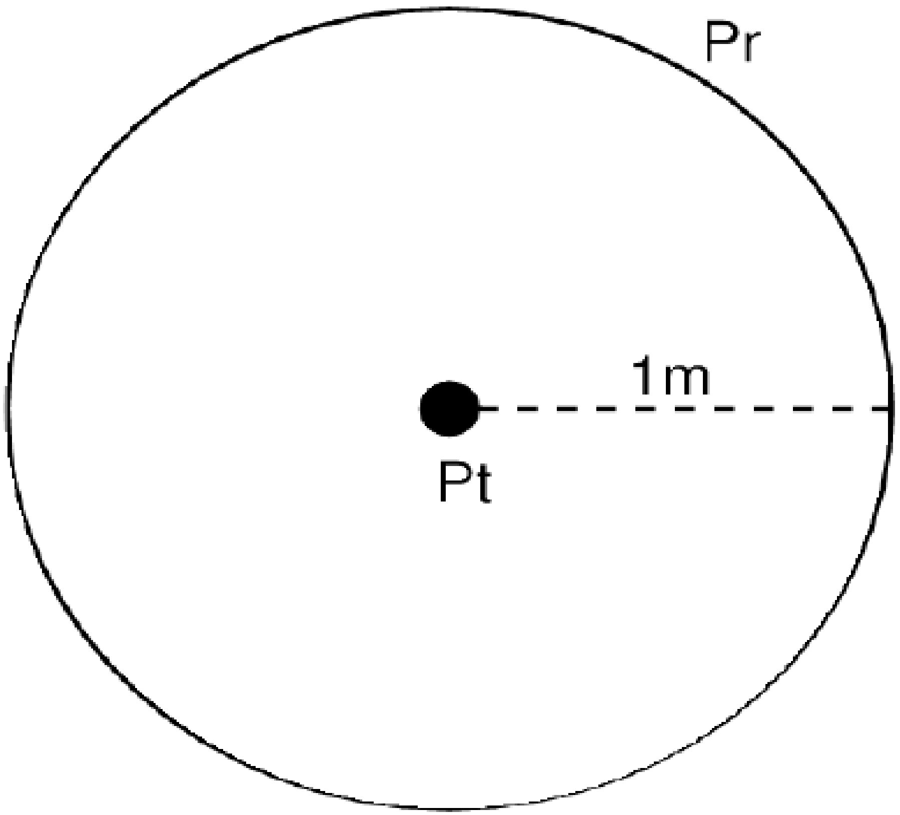
Antenna Types

Direction and propagation of a wave depends on antenna shape

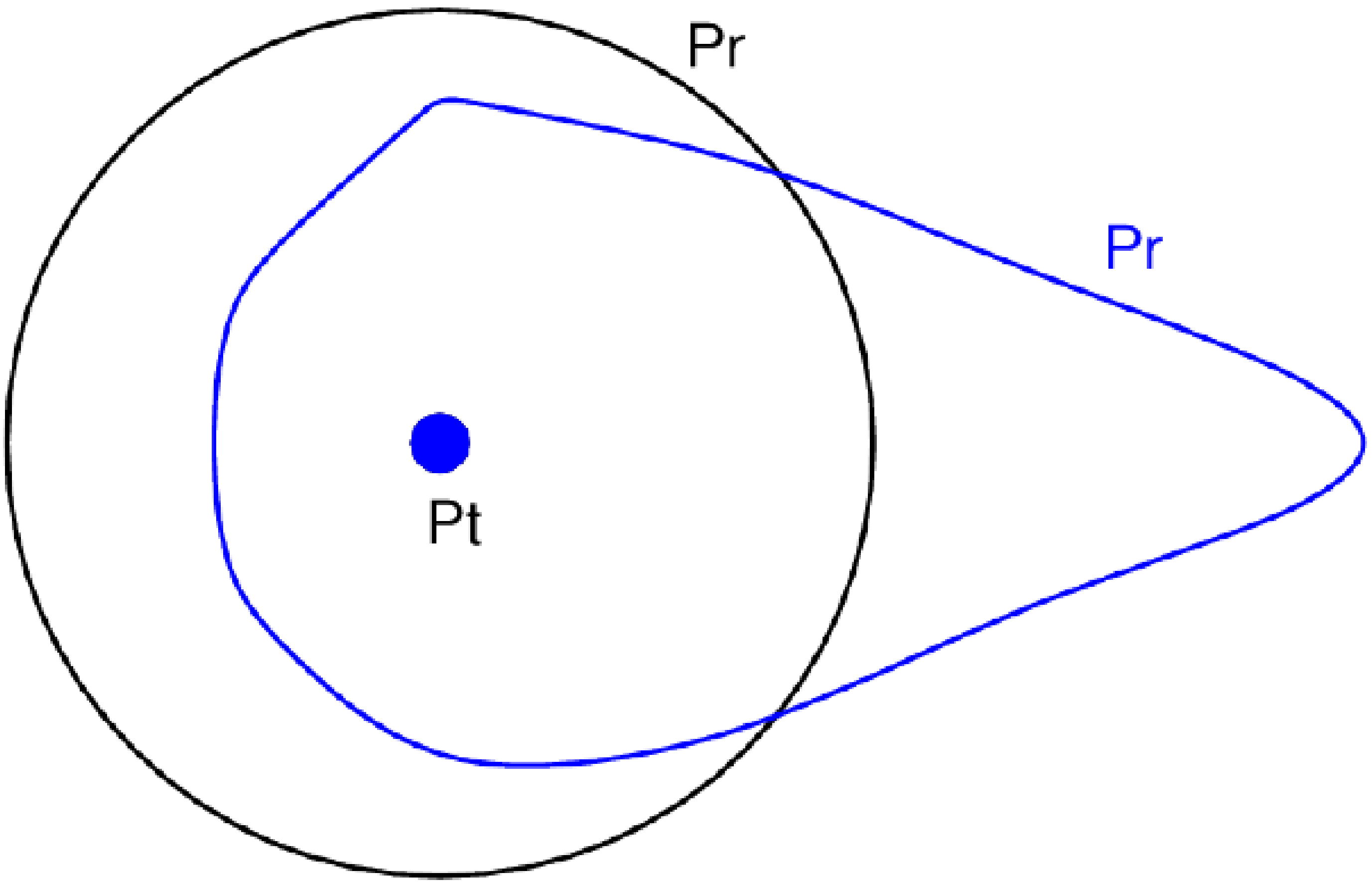
- **Isotropic antenna:** Power propagates in all directions equally (spherical pattern, ideal)
- **Omni-directional antenna:** Power propagates in all directions on one plane (donut)
- **Directional antenna:** Power concentrated in particular direction
- Power output in particular direction compared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

Wireless

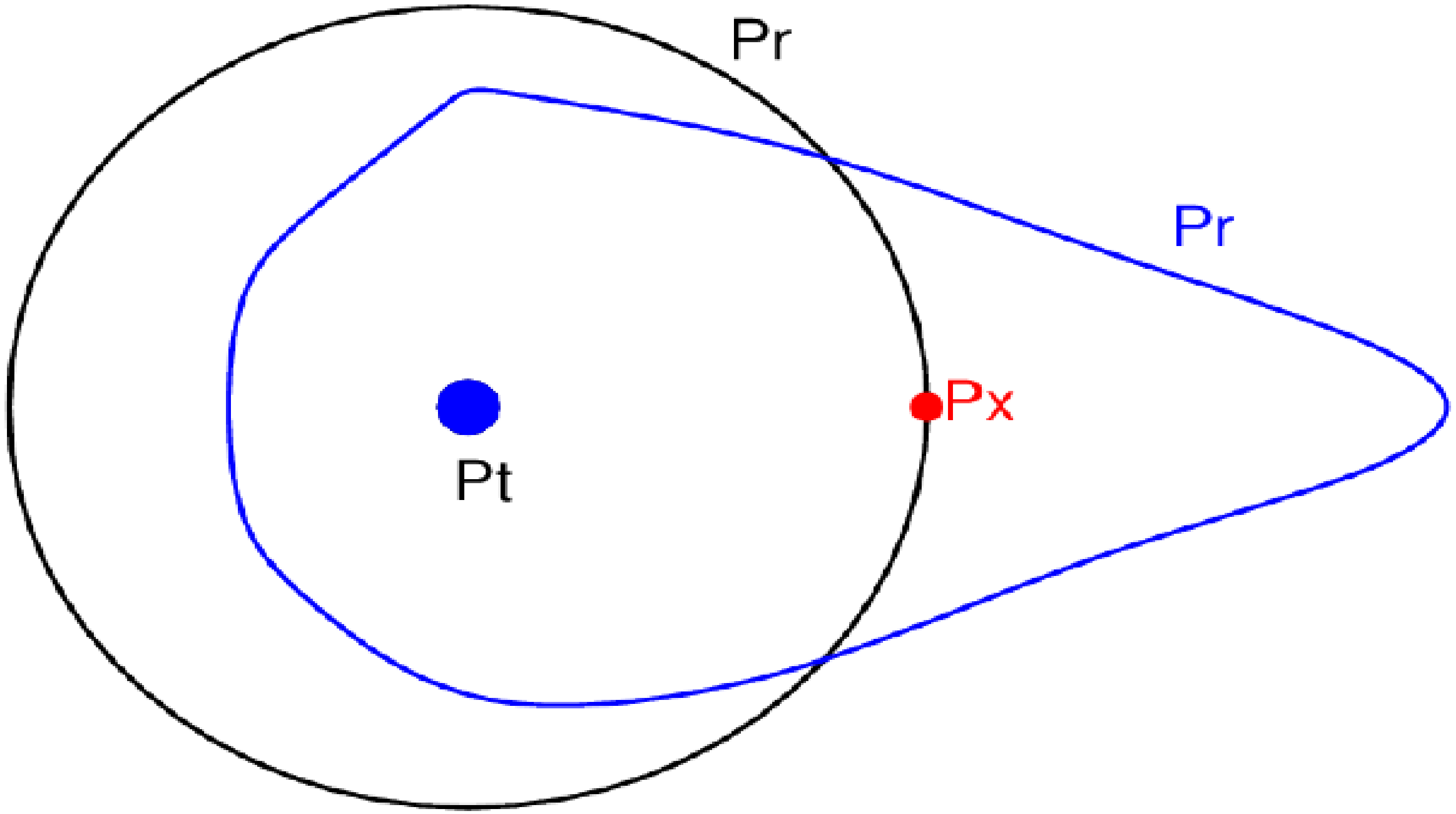
Isotropic antenna. Transmit with power Pt. Power received at all points 1m away is Pr



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



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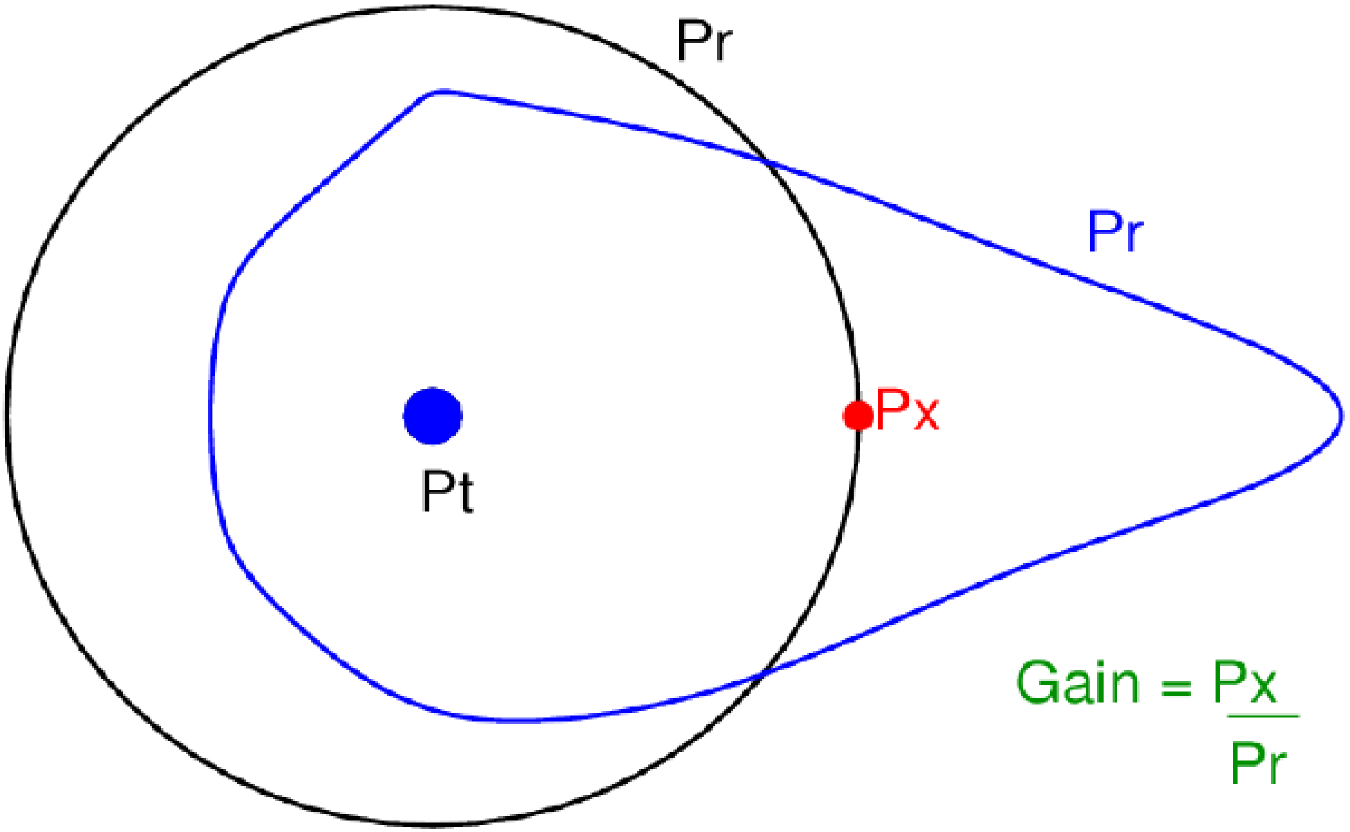
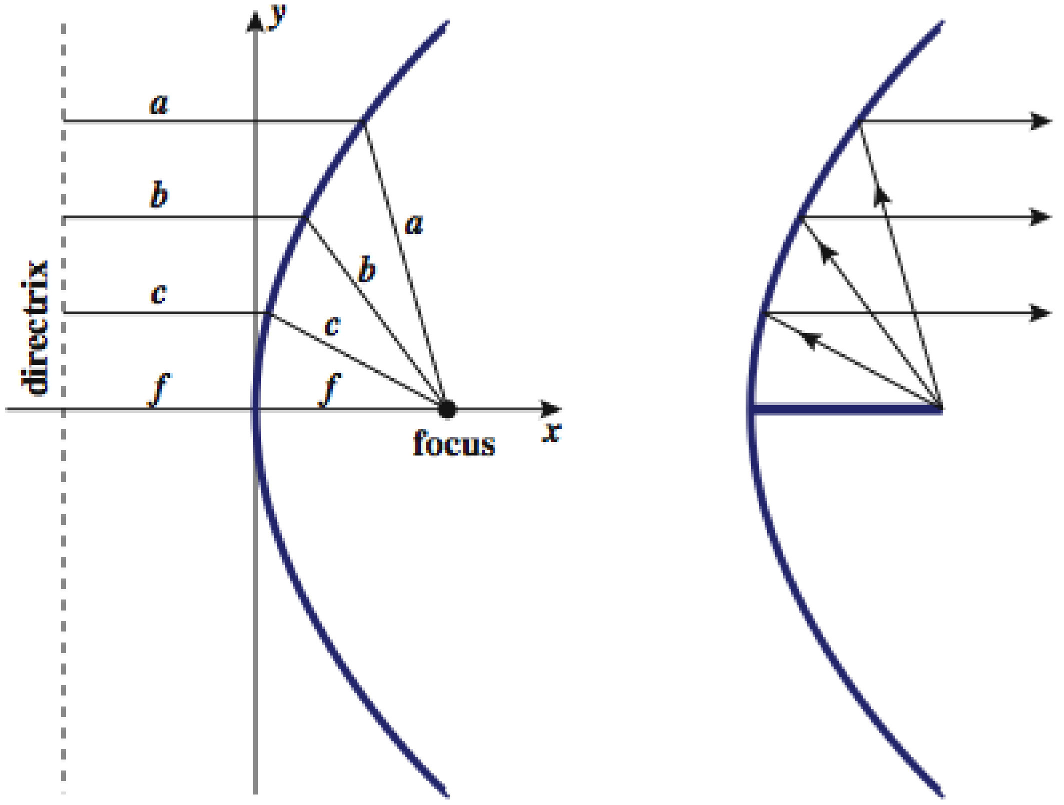
The gain of the blue directional antenna is the ratio between power received 1m away
From directional antenna (Px) and power received 1m away from isotropic antenna (Pr)

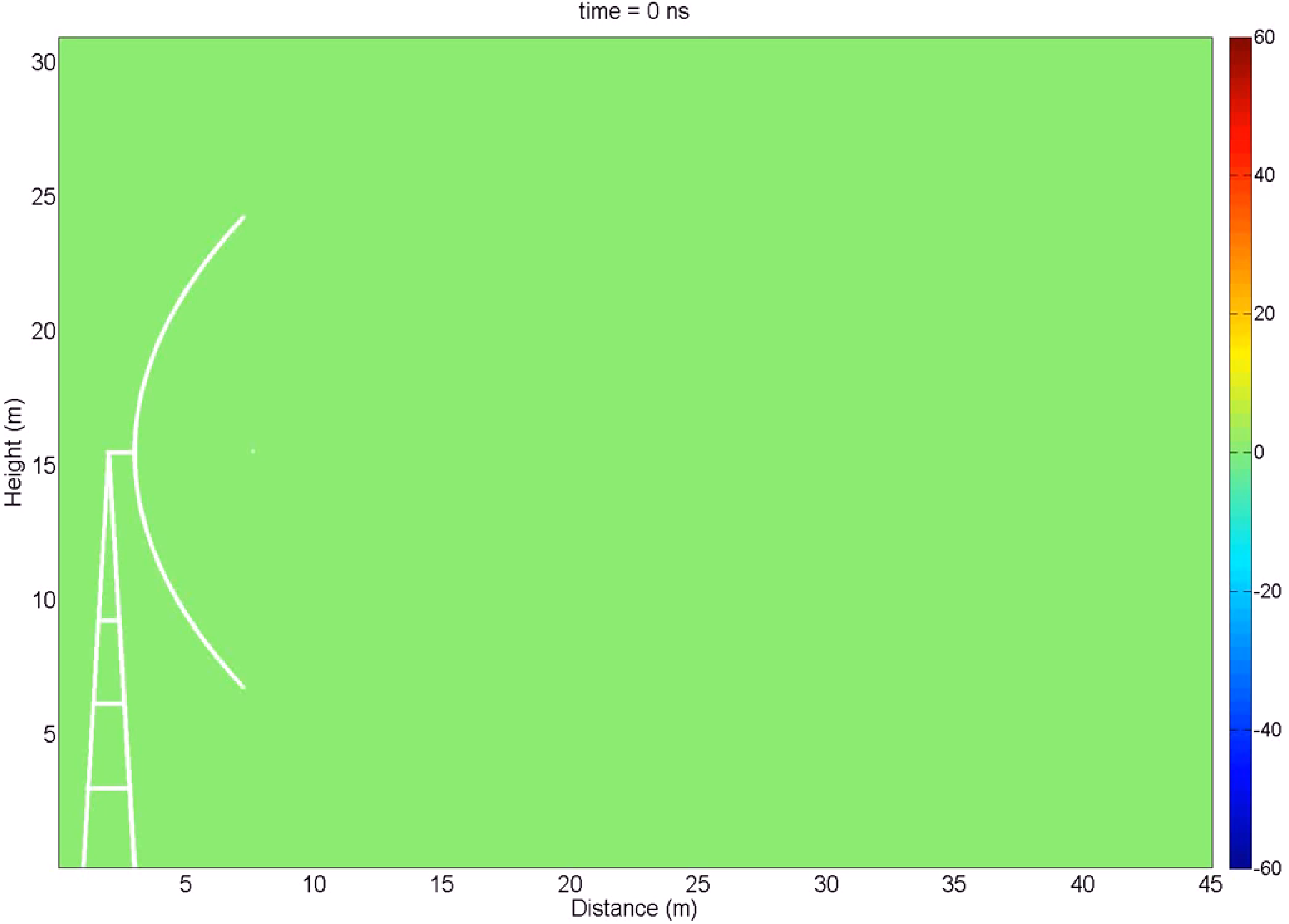


Parabolic Reflective Antenna



(a) Parabola

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


time = 0 ns
Height (m)
Distance (m)
30
25
20
15
10
5
5
10
15
20
25
30
35
40
45
60
40
20
0
-20
-40
-60

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
- The antenna gain is related to the effective area of an antenna:
- Gain in db: G=10 log(P2/P1)

  where P2: radiated power from reference antenna

  P1: radiated power from directional antenna

Antenna Gain and Effective Area Relationship

- A concept related to that of antenna gain is the effective area of an antenna.
- The effective area of an antenna is related to the physical size of the antenna and to its shape.
- The relationship between antenna gain and effective area is

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

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

G = antenna gain
A_e = effective area
f = carrier frequency
c = speed of light ($\approx 3 \times 10^8$ m/s)
λ = carrier wavelength

- The effective area of an ideal isotropic antenna is $\lambda^2/4\pi$ with 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

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

$$G_{dB} = 45.46 \text{ dB}$$

Antenna Gain Problem

Consider a directional antenna that has a gain of 6 dB over a reference antenna and that radiates 700 W. How much power must the reference antenna radiate to provide the same signal power in the preferred direction? To solve, we have

$$G_{db} = 10 \log (P_2 / \ P_1)$$

6 = 10 log(P2 /700)

P2/700 = 10^(0.6) = 3.98

P2 = 2786W

(1) Broadcast Radio

First one is radio wave [radio frequency range]

- range 30 MHz to 1 GHz
- Omnidirectional [means it propagates in all directions from the antenna]
- antenna is the center point the wave is propagating in all possible directions
- The typical applications of broadcast radio communication are FM radio, television

Broadcast Radio

- Physical Description: The principal difference between broadcast radio and microwave is that the former is omnidirectional and the latter is directional.

Terrestrial Microwave

- Used for long haul telecommunications
- And short point-to-point links
- Requires fewer repeaters but line of sight
- 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(rainfall)

Applications

- ✓ Used for long-distance telephone service
- ✓ Parabolic dish transmitter, mounted high
- ✓ Used for both voice and TV transmission
- ✓ Used by common carriers as well as private networks

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

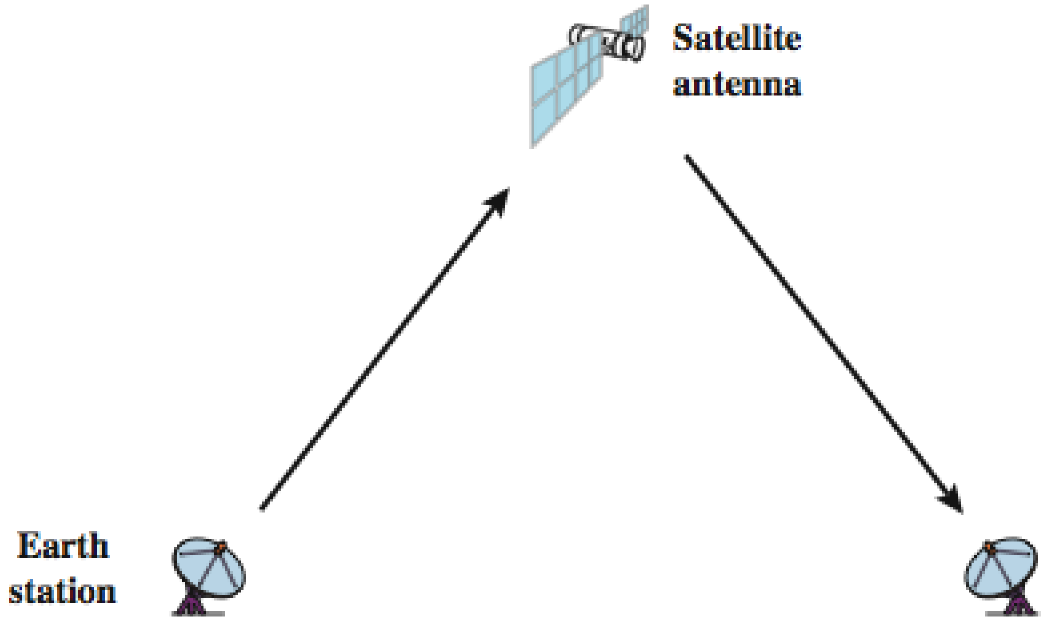
$$L = 10 \log\left(\frac{4\pi d}{\lambda}\right)^2 \text{ dB}$$

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

Satellite Microwave

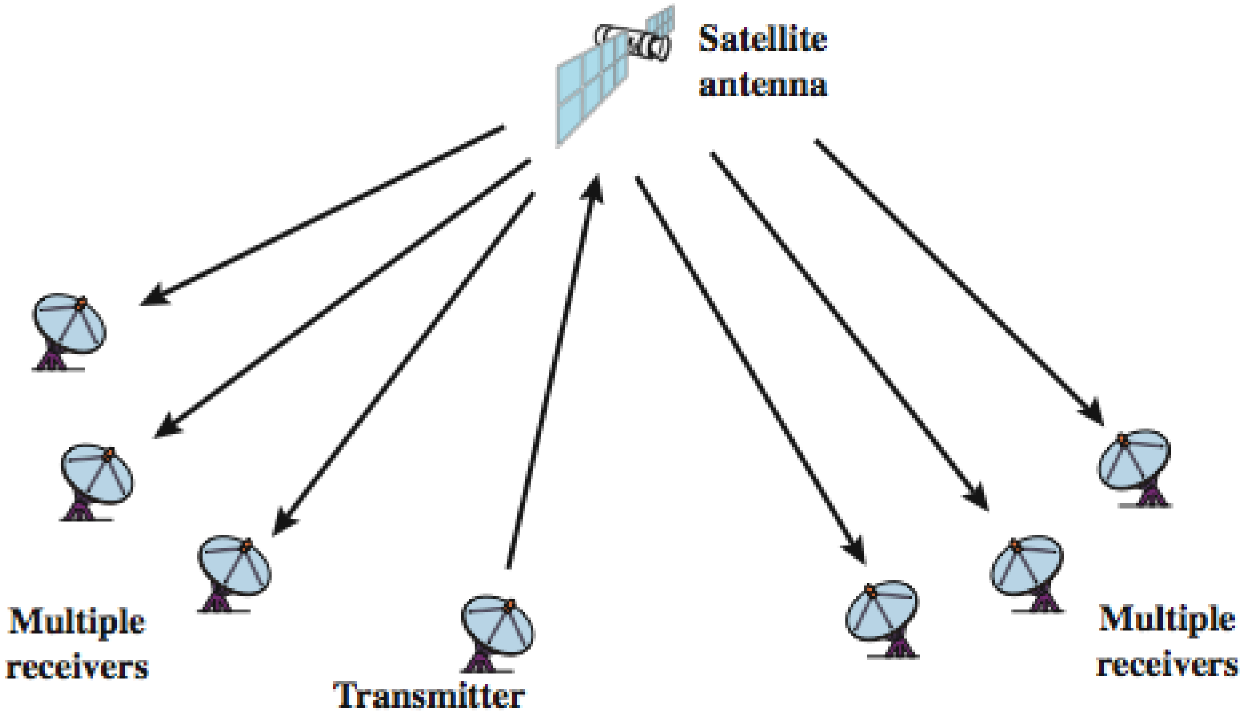
- satellite is relay station.(To link two or more ground-based microwave transmitter called as earth stations.)
- receives on one frequency, amplifies or repeats signal and transmits on another frequency
  - eg. uplink 5.925-6.425 GHz & downlink 3.7-4.2 GHz
- typically requires geo-stationary orbit
  - height of 35,784km
  - spaced at least 3-4° apart(to minimize interference from other satellites)
- 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

INFRARED

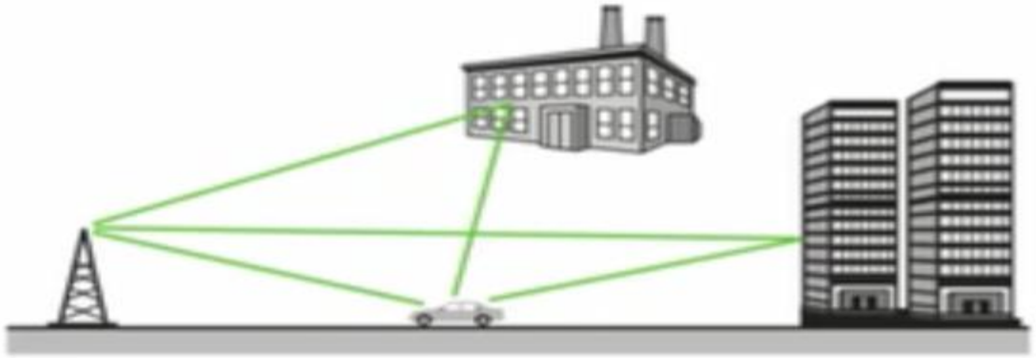
- Infrared communications is achieved using transmitters / receivers (transceivers) that modulate noncoherent infrared light.
- Transceivers within the line of sight of each other either directly or through reflection.
- Blocked by walls
- Typical use
  - TV remote control

WIRELESS PROPAGATION

A signal radiated from an antenna travels along one of three routes:

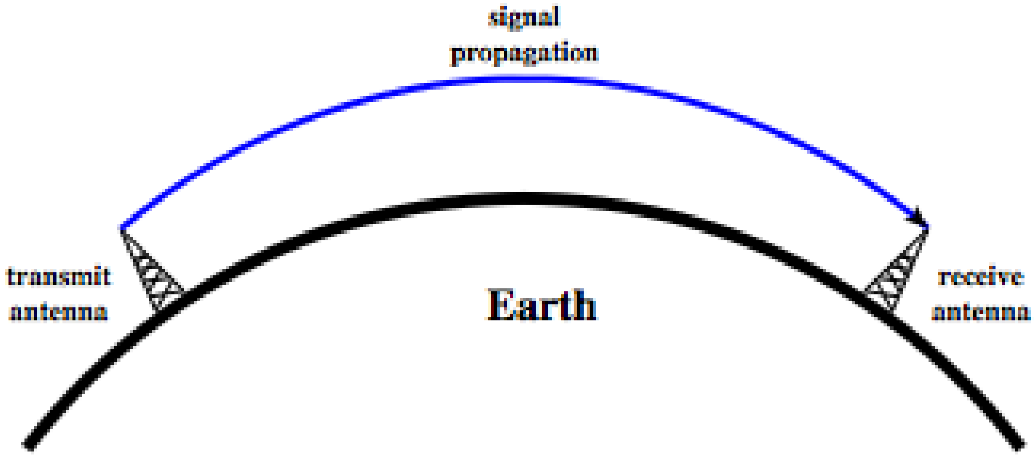
- ground wave,
- sky wave,
- line of sight (LOS).

(a) Microwave line of sight



(b) Mobile radio

Wireless Propagation Ground Wave



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

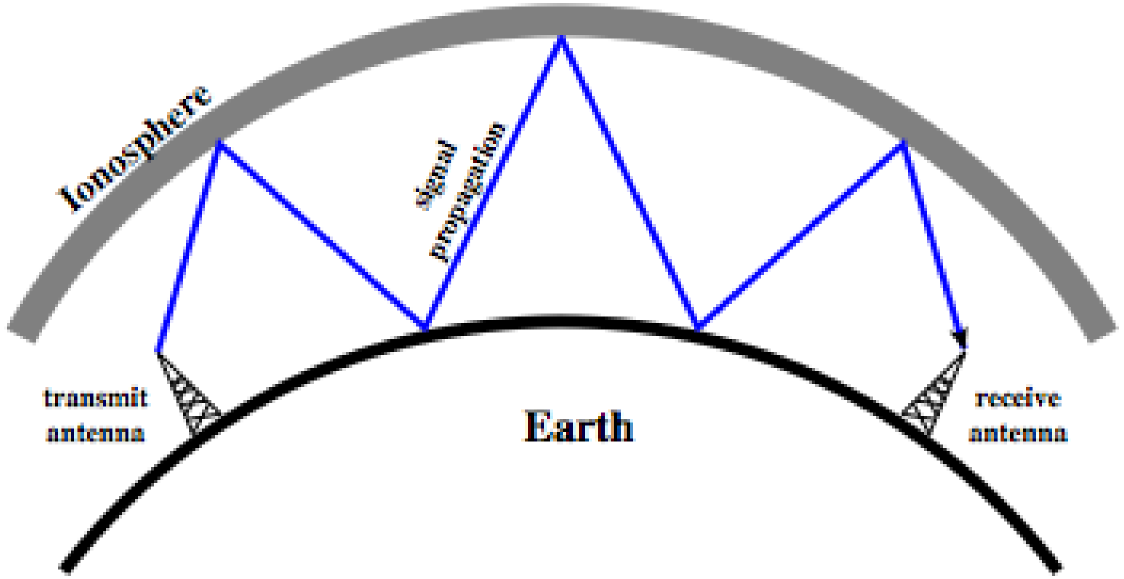
- More or less follows the contour of the earth and can propagate considerable distances.
- This effect is found in frequencies up to 2 MHz.
- Factors=>to follow the earth's curvature=>

i. electromagnetic wave induces a current in the earth's surface, causing the wavefront to tilt downward and hence follow the earth's curvature

ii. Diffraction : In presence of obstacles.

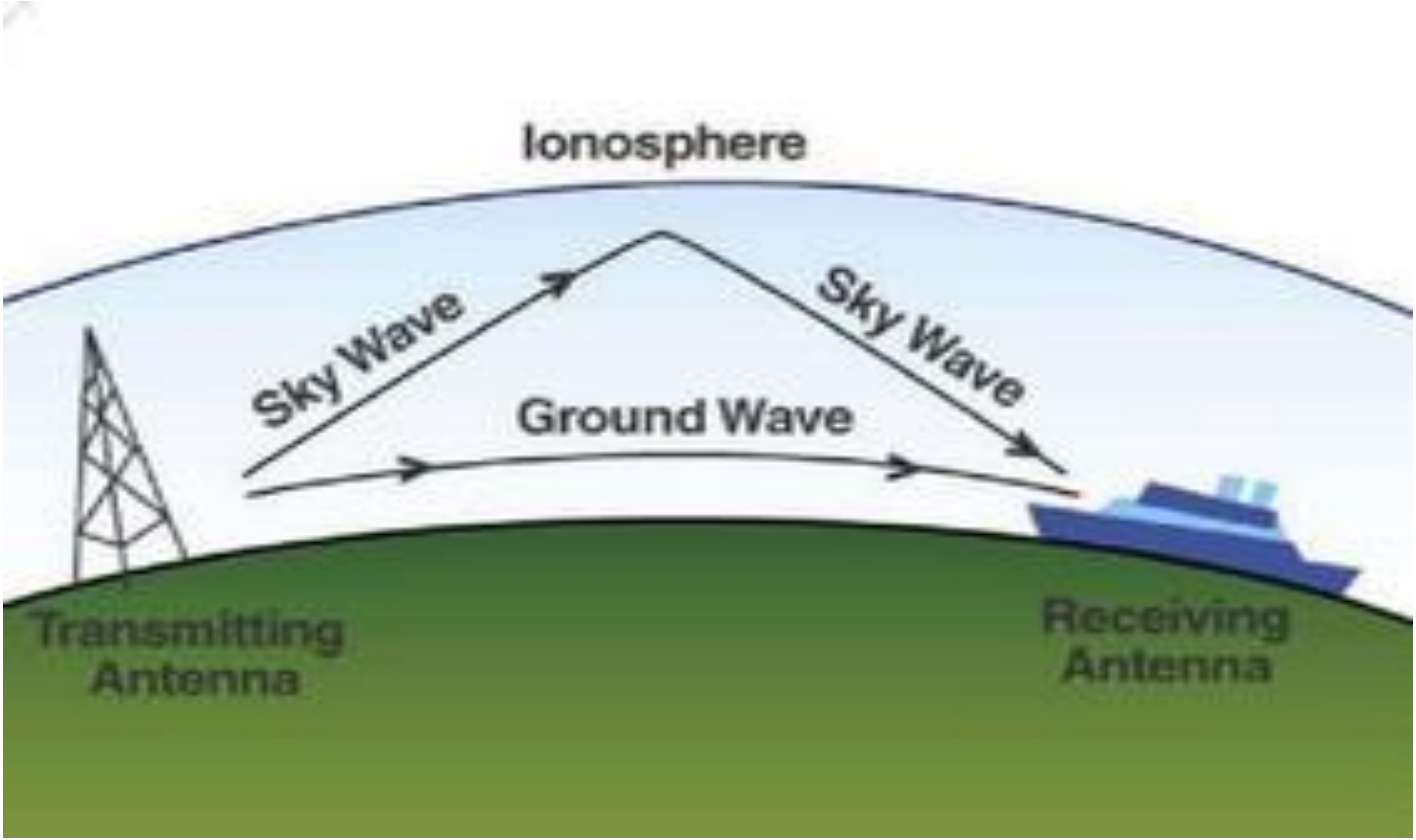
- Advantage:
  - Tendency to bend around the corners or obstructions during propagation .
  - Not affected by atmospheric conditions.

Wireless Propagation
Sky Wave

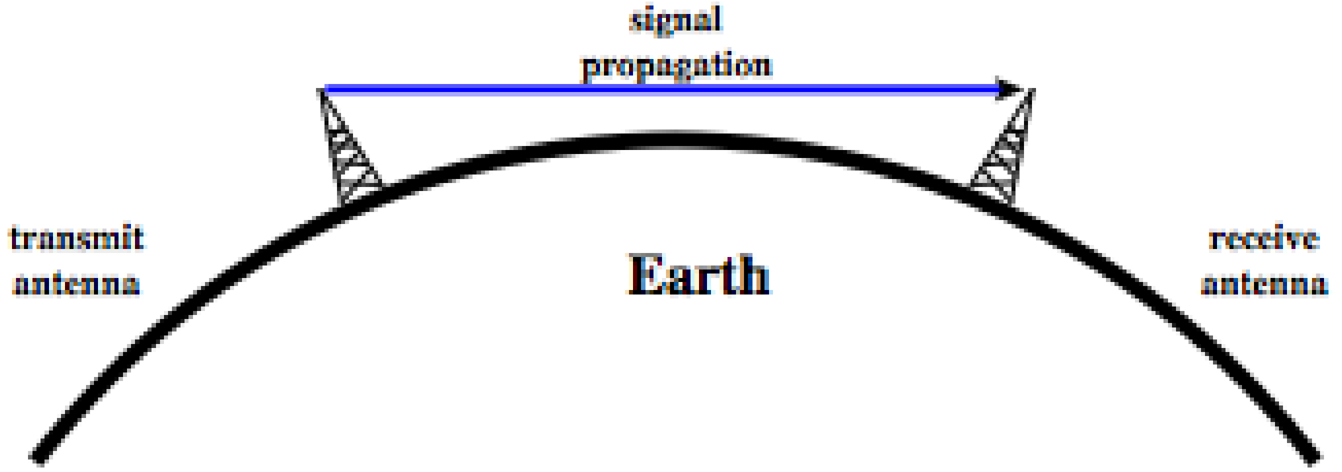


(b) Sky-wave propagation (2 to 30 MHz)

A signal from an earth-based antenna is reflected from the ionized layer of the upper atmosphere (ionosphere) back down to earth.
A sky wave signal can travel through a number of hops, bouncing back and forth between the ionosphere and the earth's surface.
Eg: International broadcasts such as BBC and Voice of America.


Ionosphere
Sky Wave
Sky Wave
Ground Wave
Transmitting Antenna
Receiving Antenna

Wireless Propagation
Line of Sight(space wave propagation)



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

Refraction

- velocity of electromagnetic wave is a function of density of material
  ~3 x 10^8 m/s in vacuum, less in anything else
- speed changes as move between media
- Index of refraction (refractive index)
  - varies with wavelength
- have gradual bending if medium density varies
  - density of atmosphere decreases with height
  - results in bending towards earth

Optical and Radio Line of Sight

- With no intervening obstacles, the optical line of sight can be expressed as $$d = 3.57\sqrt{h}$$

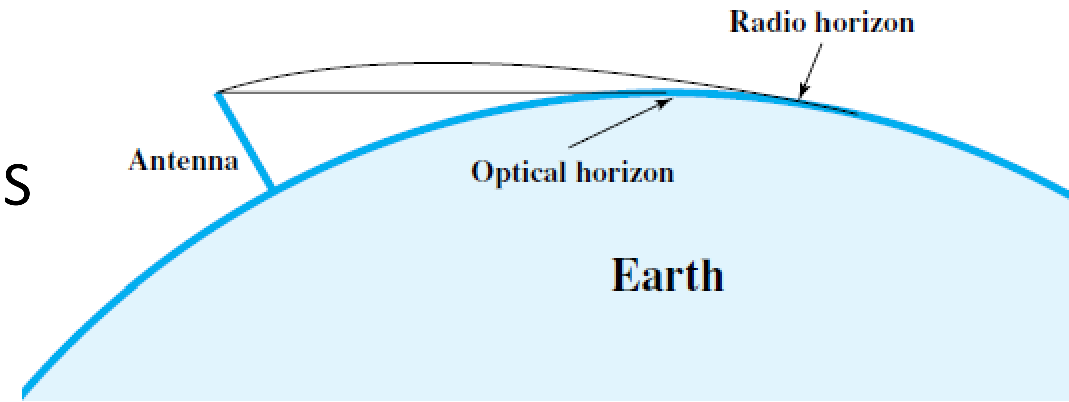
  d is the distance between an antenna and the horizon in kilometers.

  h is the antenna height in meters.

- The effective, or radio, line of sight to the horizon is expressed as

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

K is an adjustment factor to account for the refraction.(K=4/3)



- The maximum distance between two antennas for LOS

Propagation $$3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$$

- where h1 and h2 are the heights of the two antennas.

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

$$d = 3.57\sqrt{Kh} = 3.57\sqrt{133} = 41 \text{ km}$$

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

$$41 = 3.57\left(\sqrt{Kh_1} + \sqrt{13.3}\right)$$

$$\sqrt{Kh_1} = \frac{41}{3.57} - \sqrt{13.3} = 7.84$$

$$h_1 = 7.84^2/1.33 = 46.2 \text{ m}$$

Line of Sight Transmission: Impairments specific to wireless

- Free space loss
  - loss of signal with distance-form of attenuation
- Atmospheric Absorption
  - from water vapour and oxygen absorption
- Multipath interference
  - multiple interfering signals from reflections.
  - Signal strength-Depends on the differences in the path lengths of reflected/direct waves
- Refraction
  - weather conditions may lead to variations in speed with height
  - bending signal away from receiver=> fraction or no part of signals reaches

Free space loss is the ratio of the radiated power to the power received by the antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2} \qquad \text{----- } 4.2$$

P_t = signal power at the transmitting antenna

P_r = signal power at the receiving antenna

λ = carrier wavelength

d = propagation distance between antennas

c = speed of light (3×10^8 m/s)

where *d* and λ are in the same units

$$L_{dB} = 10 \log \frac{P_t}{P_r} = 20 \log\left(\frac{4\pi d}{\lambda}\right) = -20 \log(\lambda) + 20 \log(d) + 21.98 \text{ dB}$$
$$= 20 \log\left(\frac{4\pi f d}{c}\right) = 20 \log(f) + 20 \log(d) - 147.56 \text{ dB} \qquad \textbf{(4.3)}$$

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

where

G_t = gain of the transmitting antenna
G_r = gain of the receiving antenna
A_t = effective area of the transmitting antenna
A_r = effective area of the receiving antenna

The third fraction is derived from the second fraction using the relationship between antenna gain and effective area defined in Equation (4.1). We can recast the loss equation as

$$L_{dB} = 20 \log(\lambda) + 20 \log(d) - 10 \log(A_t A_r)$$
$$= -20 \log(f) + 20 \log(d) - 10 \log(A_t A_r) + 169.54 \text{ dB} \qquad \textbf{(4.4)}$$

Thus, for the same antenna dimensions and separation, the longer the carrier wavelength (lower the carrier frequency f), the higher is the free space path loss. It is interesting to compare Equations (4.3) and (4.4). Equation (4.3) indicates that as the frequency increases, the free space loss also increases, which would suggest that at higher frequencies, losses become more burdensome. However, Equation (4.4) shows that we can easily compensate for this increased loss with antenna gains. In

Multipath interference

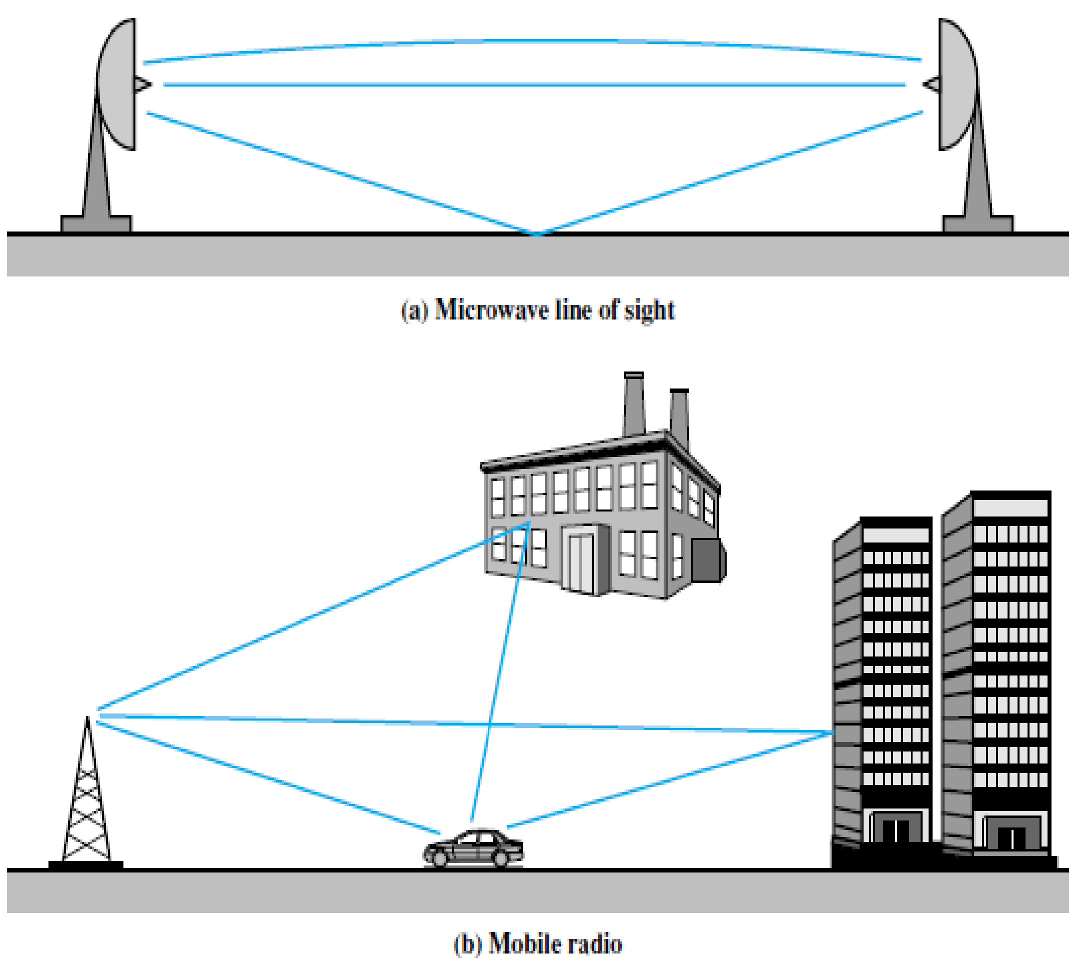
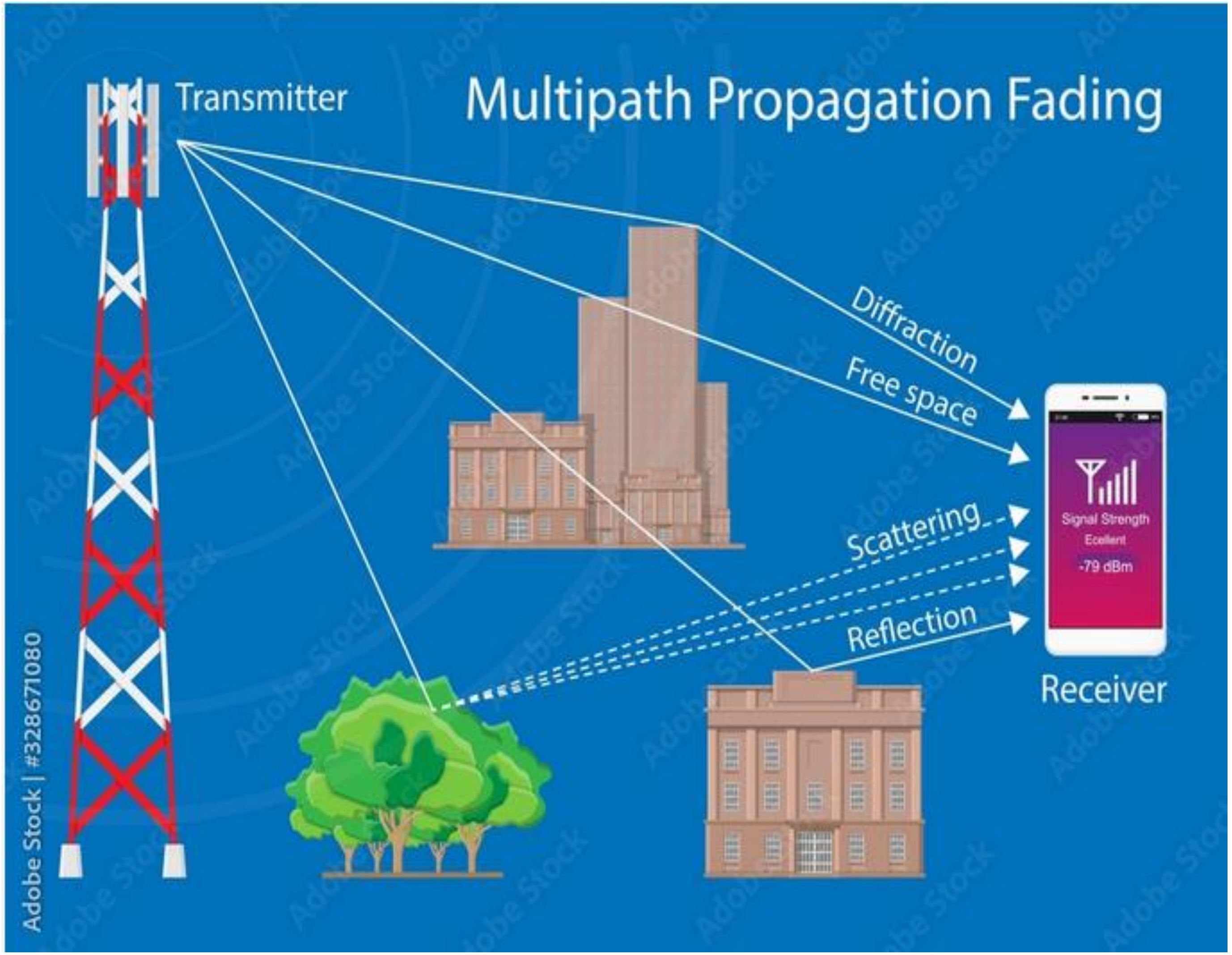


Figure 4.11 Examples of Multipath Interference



RANGE OF WAVE PROPAGATION

Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	Ground wave
Infra low	ILF	300 Hz - 3 kHz	
Very low	VLF	3 kHz - 30 kHz	
Low	LF	30 kHz - 300 kHz	
Medium	MF	300 kHz - 3 MHz	Ground/Sky wave
High	HF	3 MHz - 30 MHz	Sky wave
Very high	VHF	30 MHz - 300 MHz	Space wave
Ultra high	UHF	300 MHz - 3 GHz	
Super high	SHF	3 GHz - 30 GHz	
Extremely high	EHF	30 GHz - 300 GHz	
Tremendously high	THF	300 GHz - 3000 GHz	

Tutorials

- Show that doubling the transmission frequency or doubling the distance between transmitting antenna and receiving antenna attenuates the power received by 6 dB.

- From Equation 4.2, the ratio of transmitted power to received power is
- $Pt/Pr = (4\pi d/\lambda)^2$ ----------- 1
- If we double the frequency, we halve λ, or if we double the distance, we double d,
- so the new ratio for either of these events is:
- $Pt/Pr_2 = (8\pi d/\lambda)^2$ -------- 2
- Therefore:
- $10 \log (Pr/Pr_2) = 10 \log (2^2) = 6$ dB (Equ 2/1)

5 Example

A microwave transmitter has an output of 0.1 W at 2 GHz. Assume that this transmitter is used in a microwave communication system where the transmitting and receiving antennas are parabolas, each 1.2 m in diameter.

a. What is the gain of each antenna in decibels?

b. Taking into account antenna gain, what is the effective radiated power of the transmitted signal?

c. If the receiving antenna is located 24 km from the transmitting antenna over a free space path, find the available signal power out of the receiving antenna in dBm units.

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

a

- $G = 7A/\lambda^2 = 7Af^2/c^2$
- $= (7 \times \pi \times (0.6)^2 \times (2\times10^9)^2]/(3 \times 10^8)^2$
- $= 351.85$
- $G_{dB} = 25.46$ dB(transmitting and receiving antennas)

b

- 0.1 W x 351.85 = 35.185 W

C

- Use $L_{dB} = 20 \log(4\pi) + 20 \log(d) + 20 \log(f) - 20 \log(c) - 10 \log(G_r) - 10 \log(G_t)$
- $L_{dB} = 21.98 + 87.6 + 186.02 - 169.54 - 25.46 - 25.46 = 75.14$ dB
- The transmitter power, in dBm is

  $10 \log(100) = 20.(0.1W)$
- The available received signal power is

  $20 - 75.14 = -55.14$ dBm

6 Example

- Determine the height of an antenna for a TV station that must be able to reach customers up to 80 km away.

- For radio line of sight, we use $d = 3.57(\mathrm{K}h)^{1/2}$, with $K = 4/3$, we have
- $80^2 = (3.57)^2 \times 1.33 \times h$.
- Solving for h, we get h = 378 m.