Transmission Media

Introduction

- Physical path between transmitter and receiver in a data communication system.

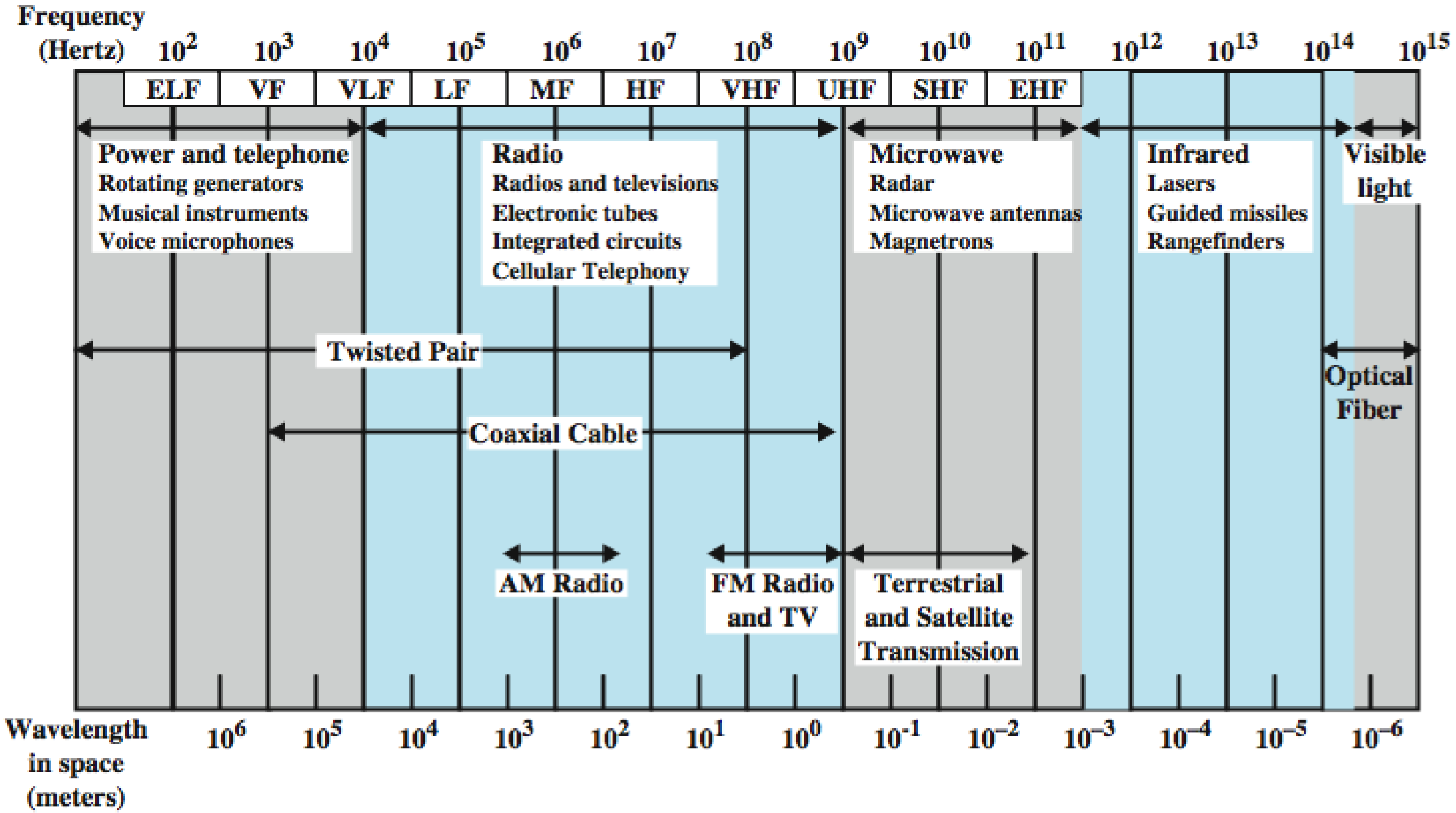
Overview

- Guided - wire / optical fibre
- Unguided - wireless
- Characteristics and quality determined by medium and signal
  - in unguided media - bandwidth produced by the antenna is more important
  - in guided media - medium is more important
- key concerns are data rate and distance

Design Factors

- Key concerns are data rate and distance: maximise both
- Design factors:
  - Bandwidth
  - Transmission impairments
  - Interference
  - Number of receivers

Electromagnetic Spectrum



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Transmission Characteristics of Guided Media

	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 µs/km	2 km
Twisted pairs (multi-pair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 µs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 µs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 µs/km	40 km

Twisted Pair

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

(a) Twisted pair

Twisted Pair

- A twisted pair consist of two insulated copper wires arranged in a regular spiral pattern.
- Typically, a number of pair are bundled together into cable by wrapping them in a tough protective sheath.

Why twisting?

- Twisting decreases cross talk interference between adjacent pairs in a cable.
- Tighter twisting provide much better performance, but also increases the cost.

Twisted Pair - Transmission Characteristics

- Analog
  - needs amplifiers every 5km to 6km
- Digital
  - can use either analog or digital signals
  - needs a repeater every 2-3km
- limited distance
- limited bandwidth (1MHz)
- limited data rate
- susceptible to interference and noise

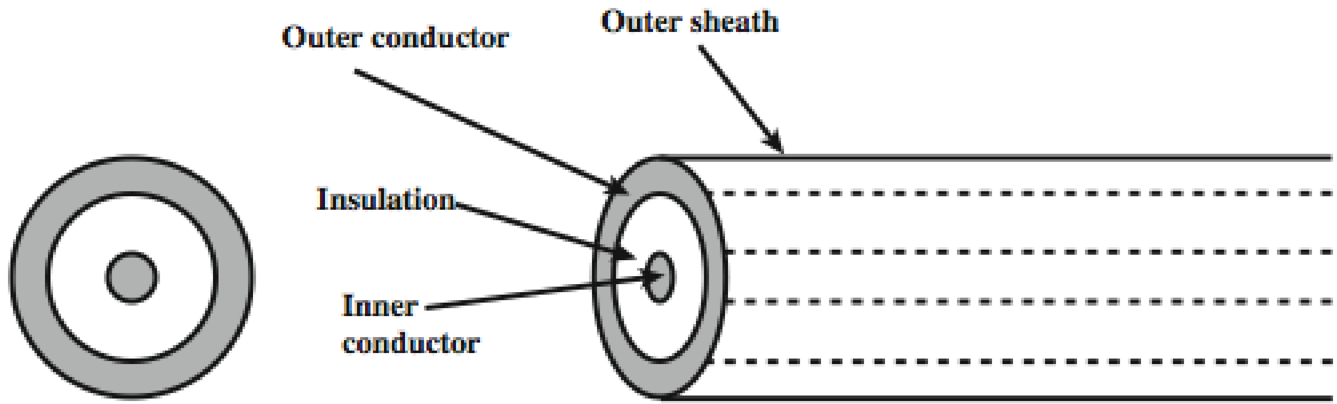
Unshielded vs Shielded TP

- Unshielded Twisted Pair (UTP)
  - ordinary telephone wire
  - cheapest
  - easiest to install
  - suffers from external EM interference
- Shielded Twisted Pair (STP)
  - metal braid or sheathing that reduces interference
  - more expensive
  - harder to handle (thick, heavy)
- The twist length typically varies from 5 to 15 cm.
- The wires in a pair have thicknesses of from 0.4 to 0.9 mm.

Near End Crosstalk

- Coupling of signal from one pair to another.
- Occurs when transmit signal entering the link couples back to receiving pair. ie. near transmitted signal is picked up by near receiving pair

Coaxial Cable



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

(b) Coaxial cable

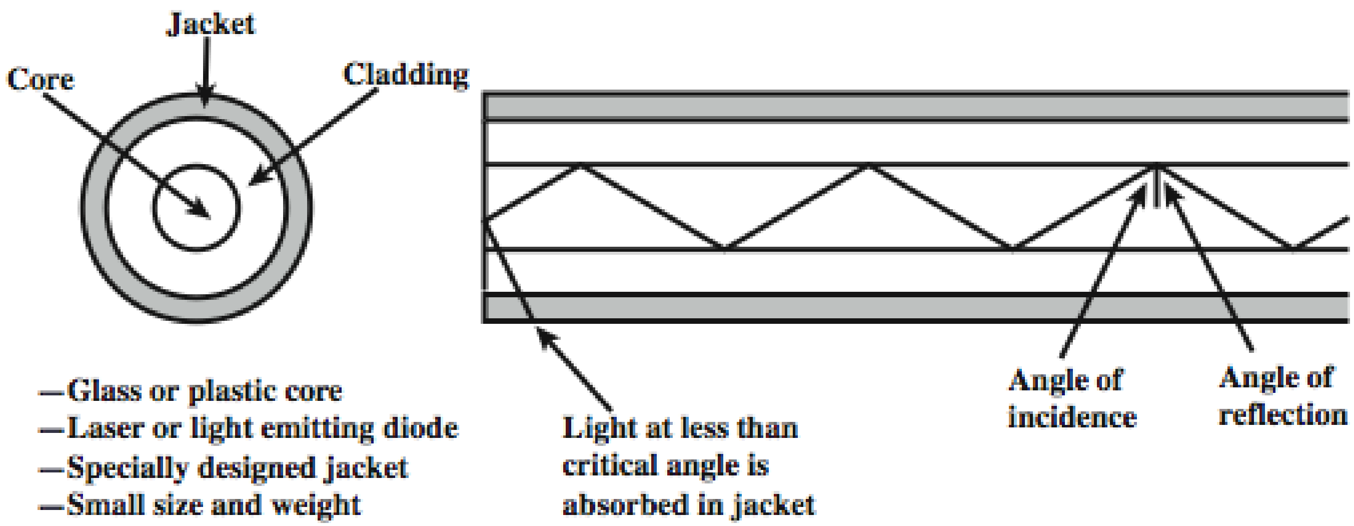
Coaxial Cable

- Due to shielding, coaxial cable are much less susceptible to interference or cross talk than twisted pair.

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

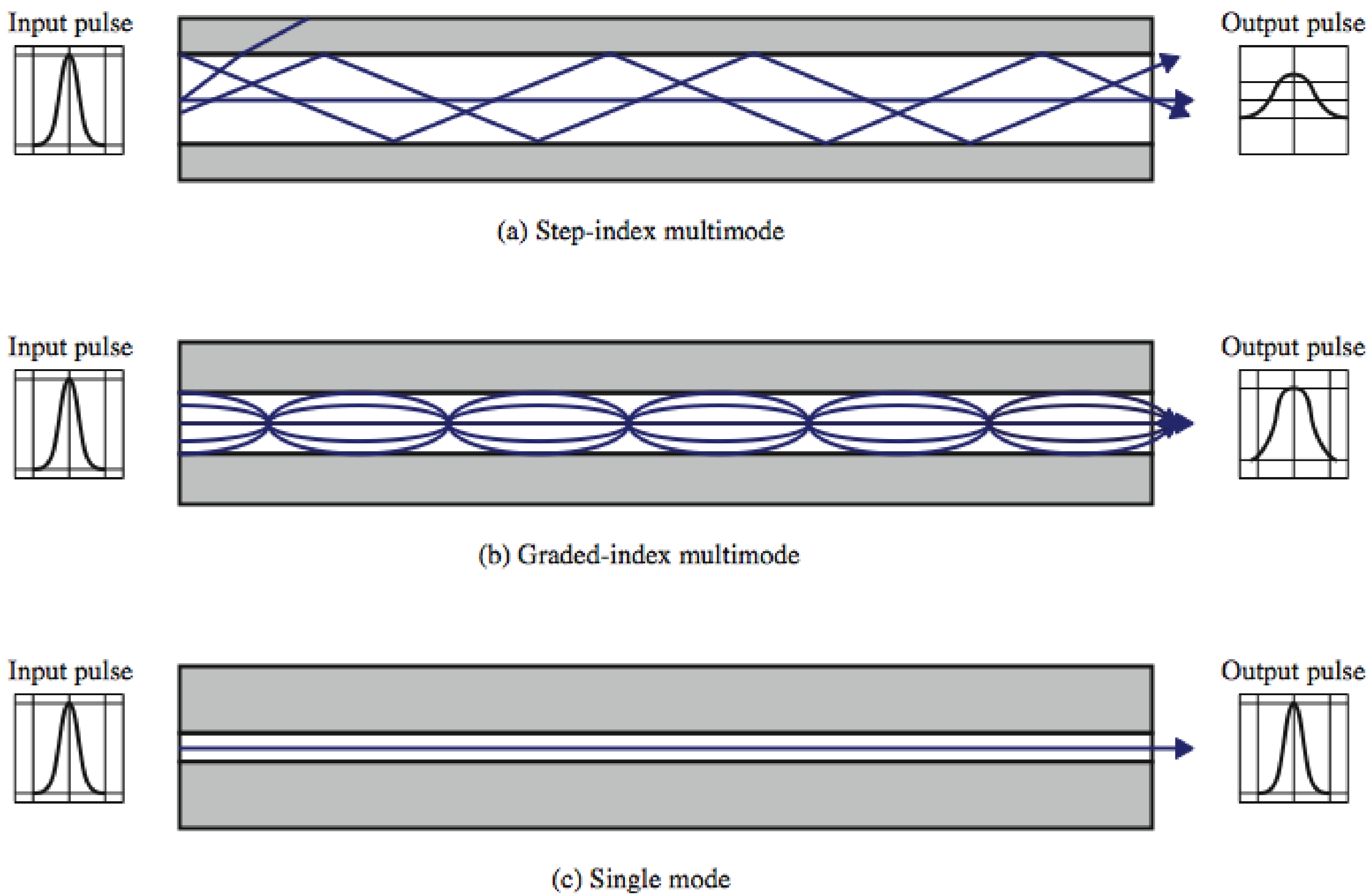
Optical Fiber - Benefits

- 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

Optical Fiber Transmission Modes



Optical Fiber Transmission Modes

- Multimode: Refers to the variety of angles that will reflect. Multiple propagation path exists, signal element spread out in time, and hence limit the data rate.
- Single mode: When the fiber core radius is reduced, fewer angle will reflect. By reducing the core to the order of the wavelength only a single angle or mode can pass.
- Multimode graded index: By varying the refractive index of the core, rays may be focused more efficiently then multimode.

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

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

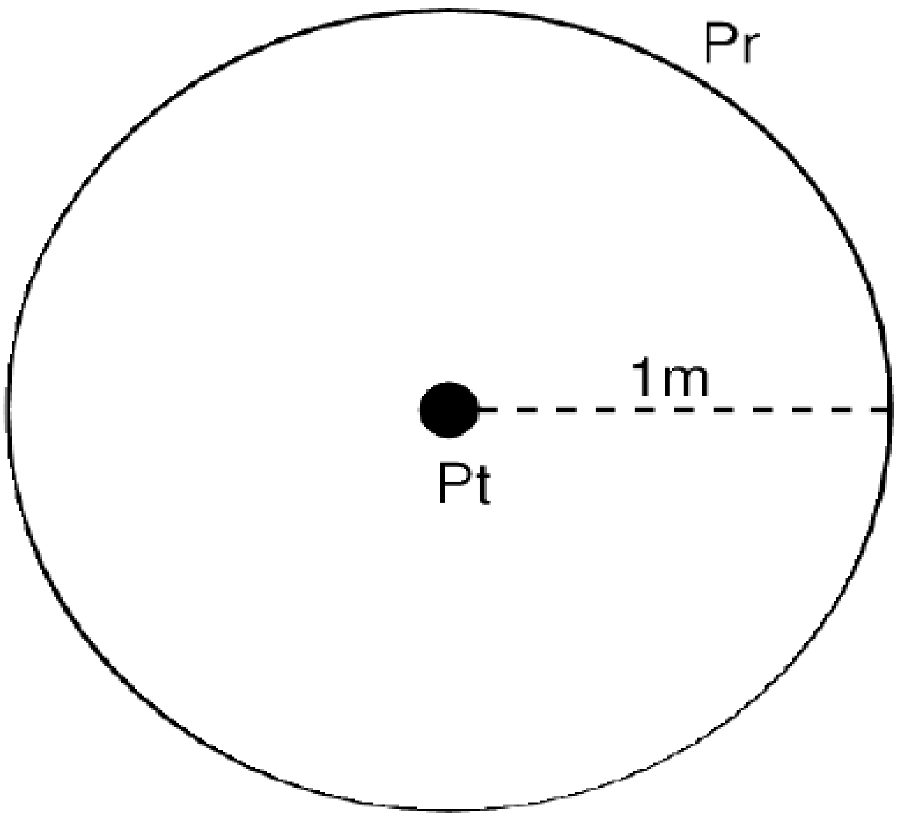
- Power radiated in all directions
- But not same performance in all directions
- An isotropic antenna is a (theoretical) point in space
  - radiates in all directions equally
  - with a spherical radiation pattern

Direction and propagation of a wave depends on antenna shape

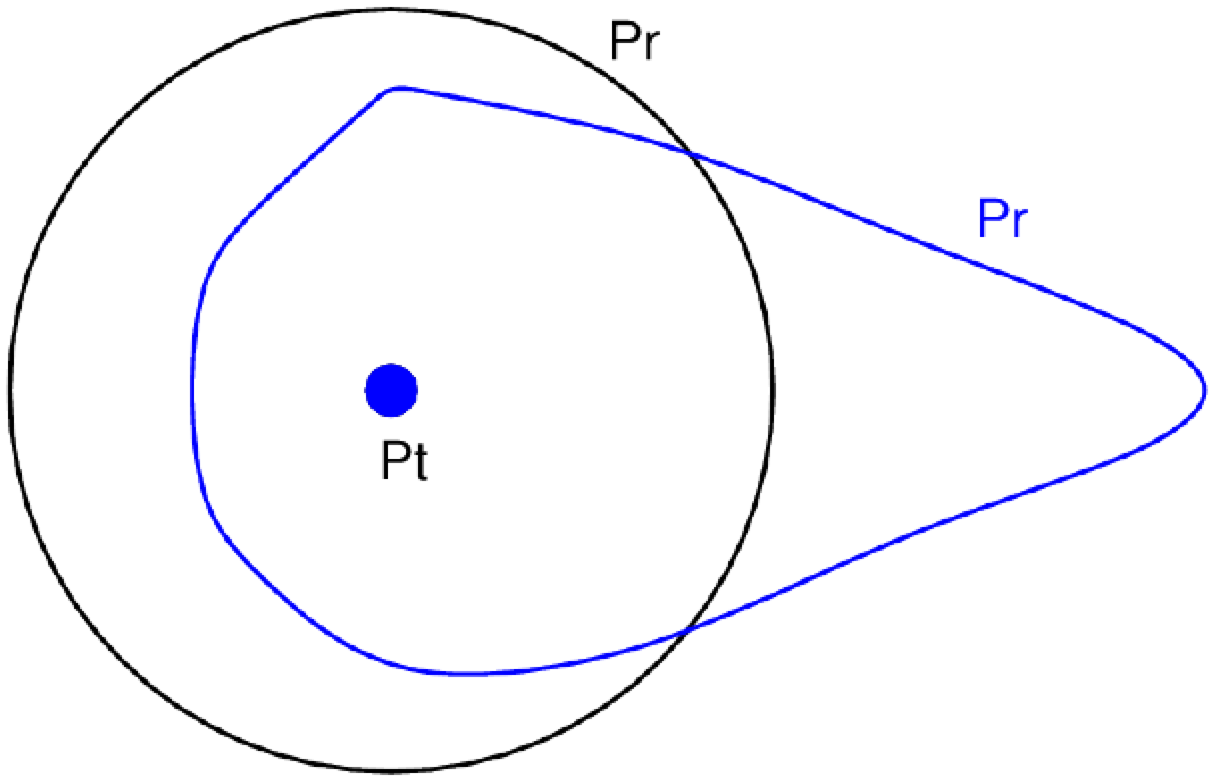
- **Isotropic antenna:** power propagates in all directions equally (spherical pattern, ideal)
- **Omni-directional antenna:** power propagates in all directions on one plane (donut)
- **Directional antenna:** power concentrated in particular direction
- Power output in particular direction compared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

Wireless

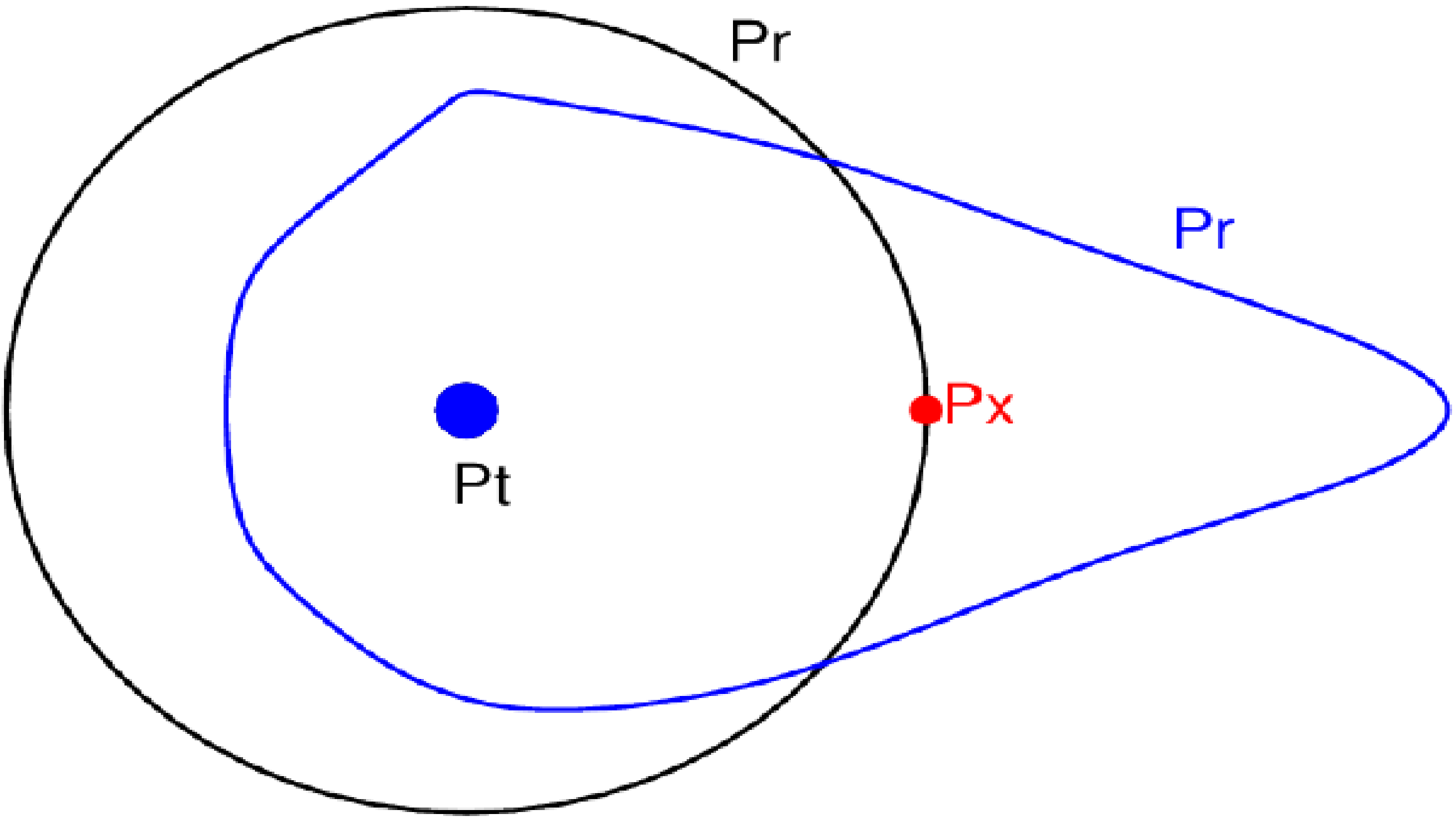
Isotropic antenna. Transmit with power Pt. Power received at all points 1m away is Pr



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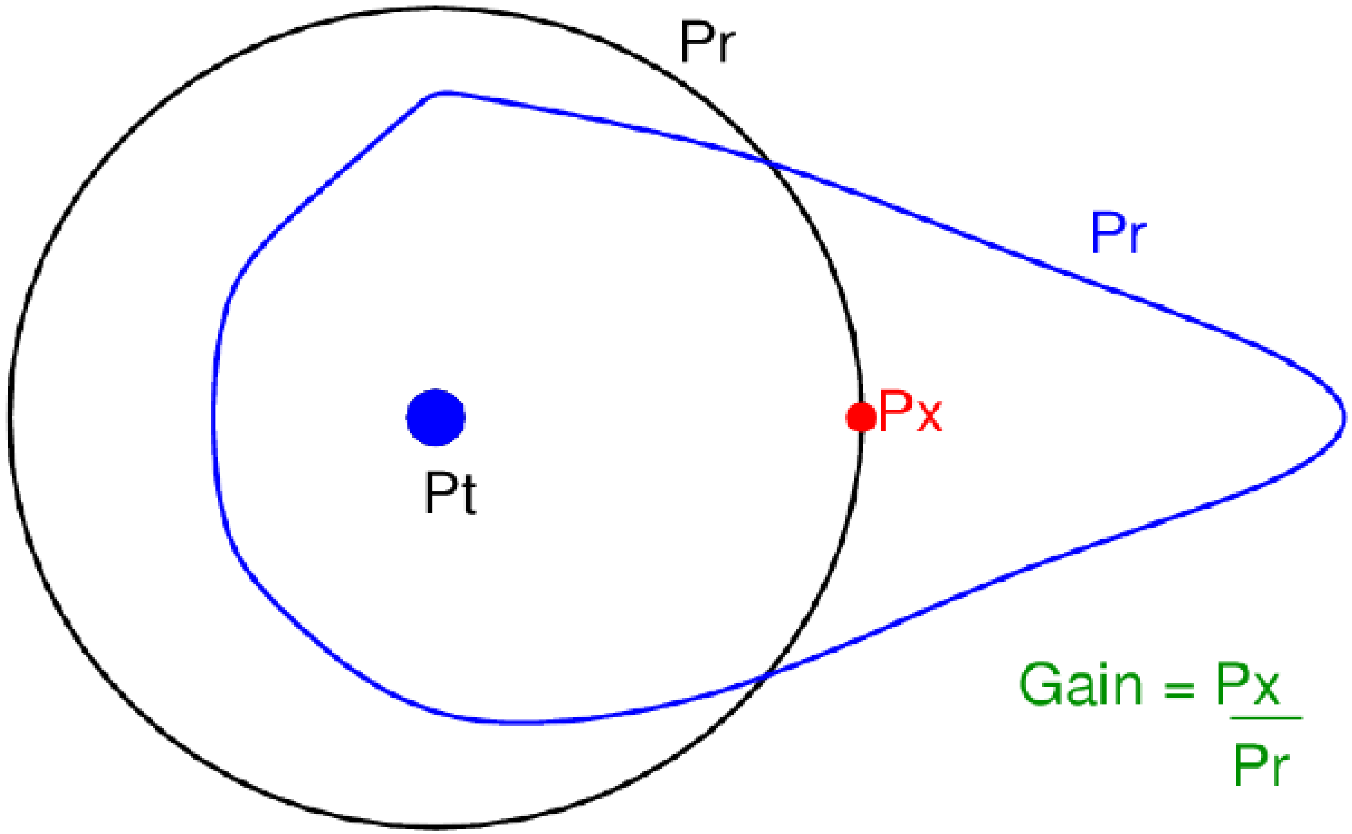
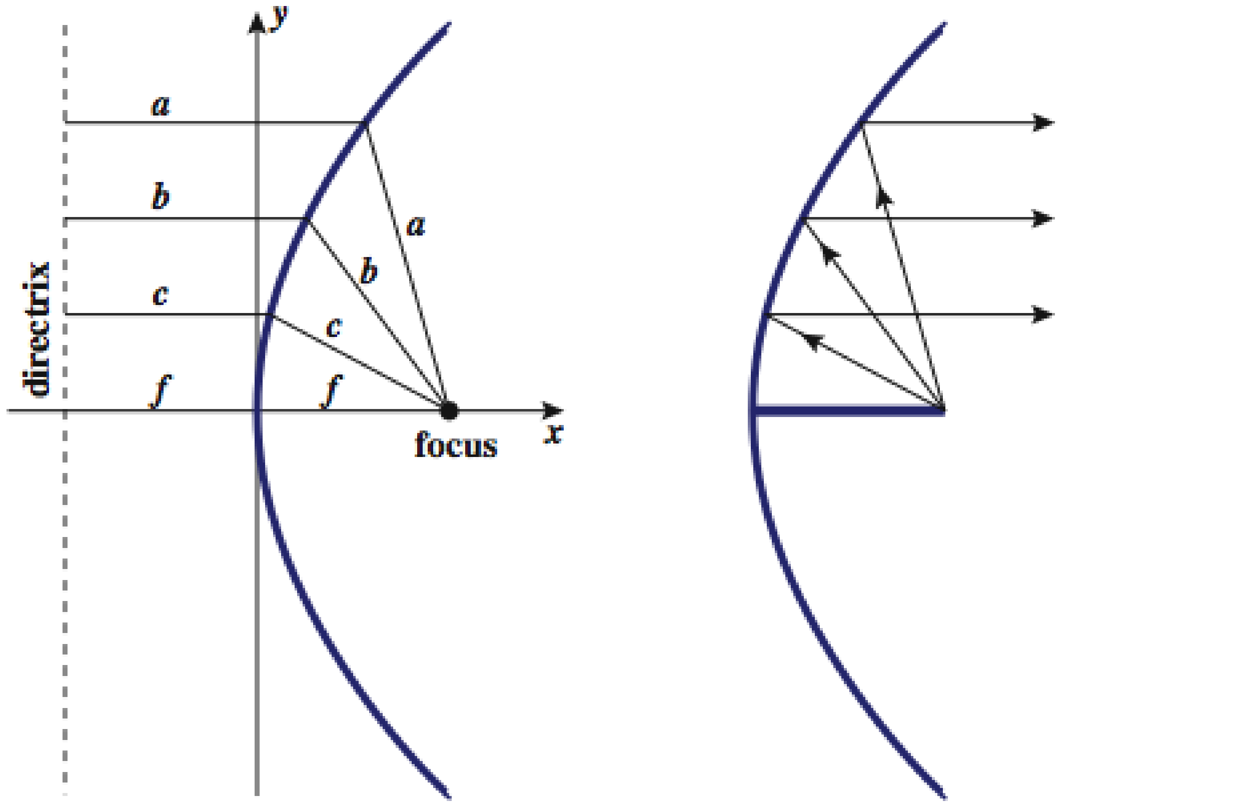
The gain of the blue directional antenna is the ratio between power received 1m away
From directional antenna (Px) and power received 1m away from isotropic antenna (Pr)



Parabolic Reflective Antenna



(a) Parabola

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

Example

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

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

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

G = antenna gain

A_e = effective area

f = carrier frequency

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

λ = carrier wavelength

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 also interference

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

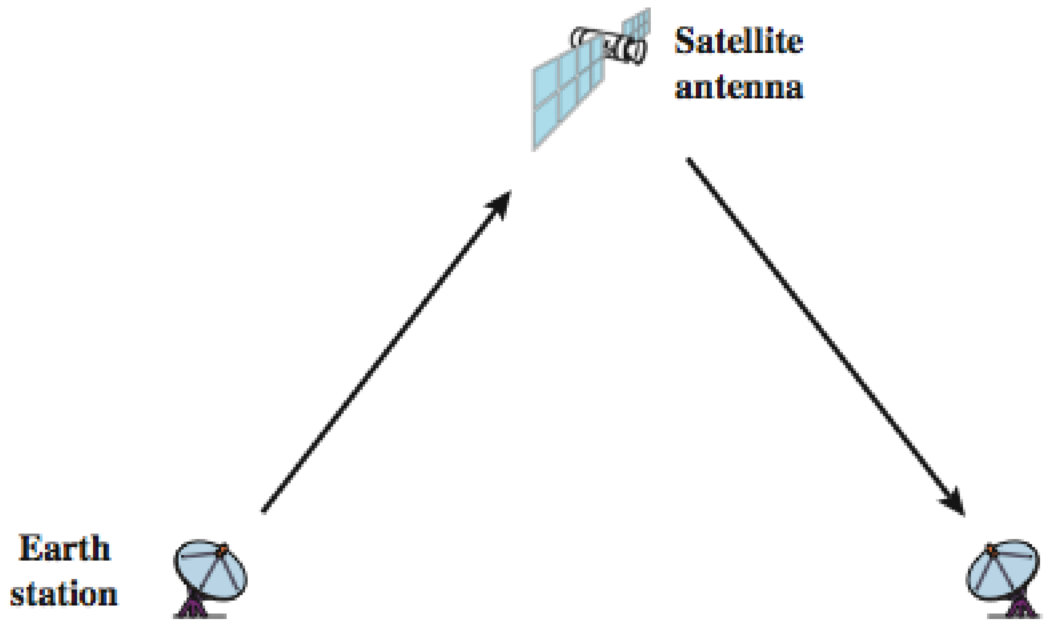
$$L = 10 \log\left(\frac{4\pi d}{\lambda}\right)^2 \text{ dB}$$

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

Satellite Microwave

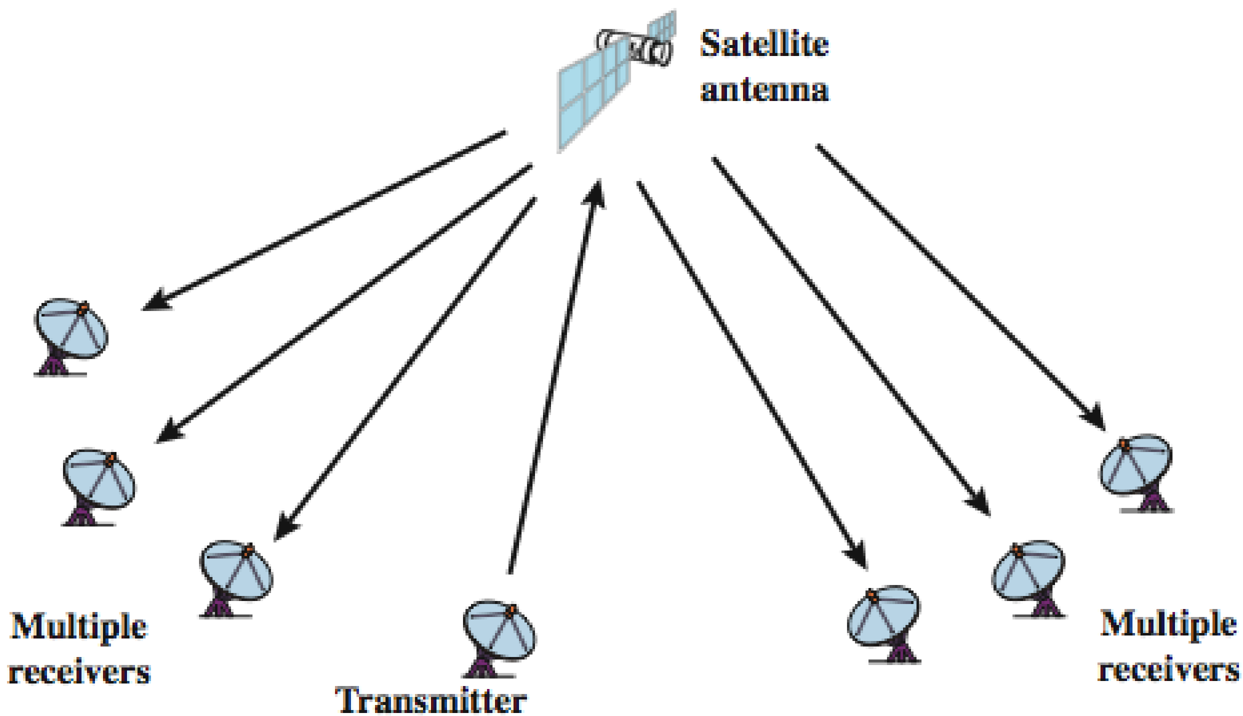
- Satellite is relay station
- Receives on one frequency, amplifies or repeats signal and transmits on another frequency
  - eg. uplink 5.925-6.425 GHz & downlink 3.7-4.2 GHz
- Typically requires geo-stationary orbit
  - height of 35,784km
  - spaced at least 3-4° apart
- Typical uses
  - television
  - long distance telephone
  - private business networks
  - global positioning

Satellite Point to Point Link



(a) Point-to-point link

Satellite Broadcast Link

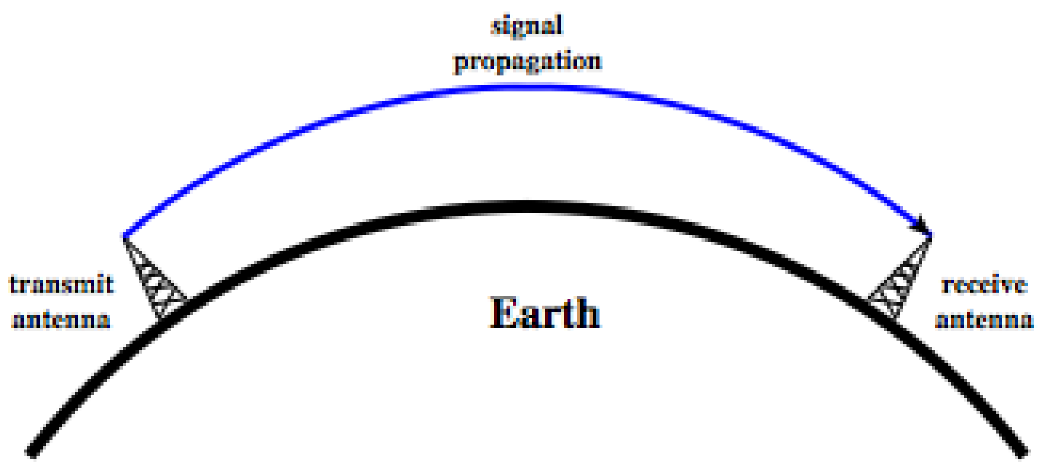


(b) Broadcast link

Application

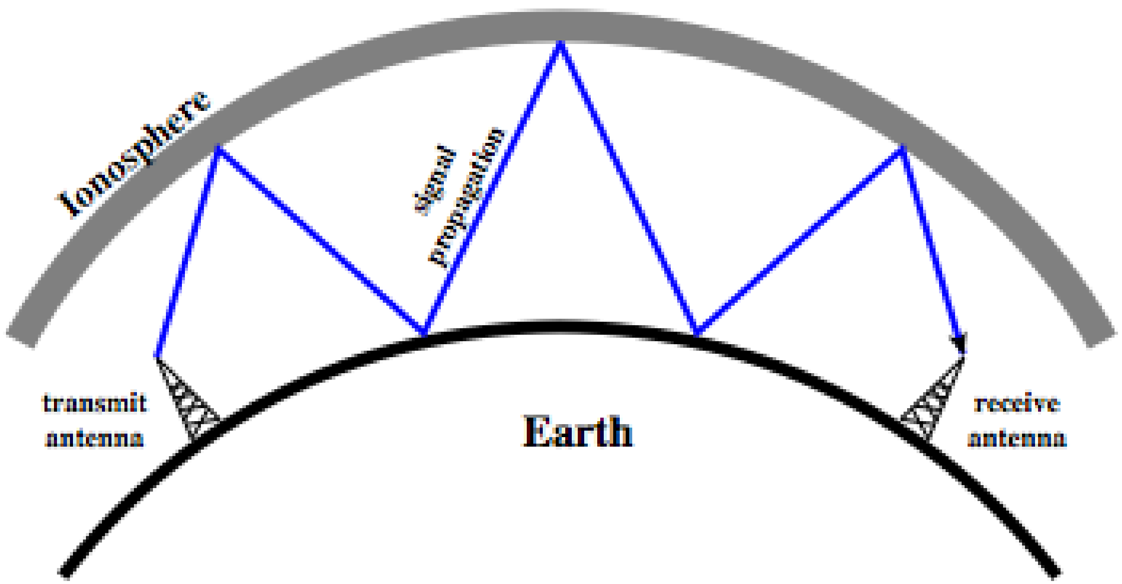
- Television distribution
- Long distance telephone transmission
- GPS
- Private business network

Wireless Propagation Ground Wave



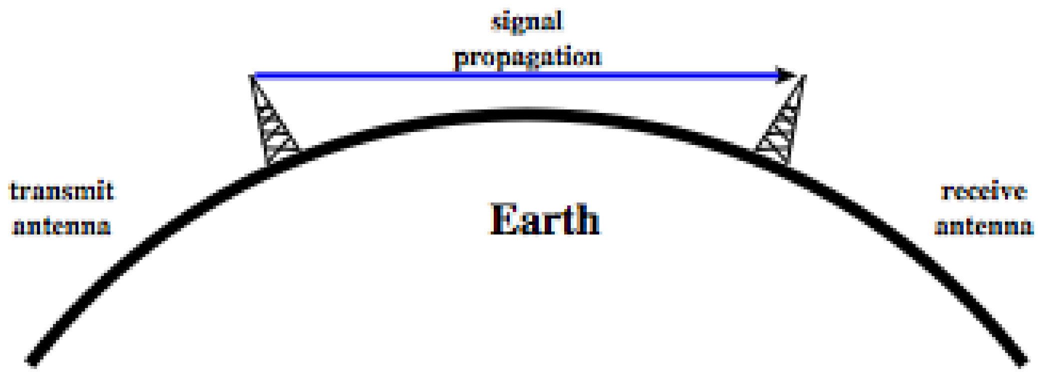
(a) Ground-wave propagation (below 2 MHz)

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)

Broadcast Radio

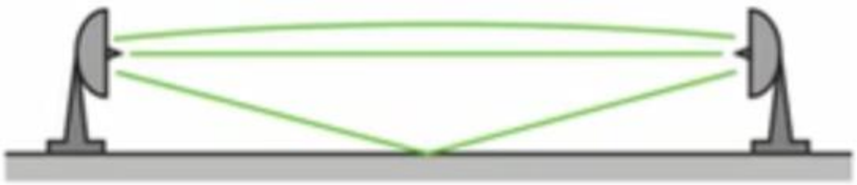
- Radio is 3kHz to 300GHz
- Use broadcast radio, 30MHz - 1GHz, for FM radio.
- It is omnidirectional
- It still need line of sight
- Suffers from multipath interference
  - reflections from land, water, other objects

Infrared

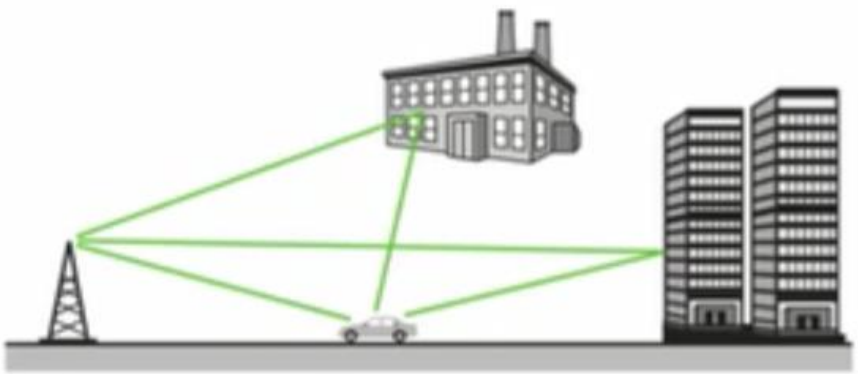
- Modulate noncoherent infrared light
- Line of sight (or reflection)
- Blocked by walls
- No licenses required
- Typical uses
  - TV remote control

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
- They have gradual bending if medium density varies
  - density of atmosphere decreases with height
  - results in bending towards earth



(a) Microwave line of sight



(b) Mobile radio

Line of Sight Transmission

- Free space loss
  - loss of signal with distance
- Atmospheric Absorption
  - from water vapour and oxygen absorption
- Multipath
  - multiple interfering signals from reflections
- Refraction
  - bending signal away from receiver

free space loss is

- 4.2

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

where

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 (e.g., meters).

This can be recast as[3]

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

Figure 4.10 illustrates the free space loss equation.

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

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

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

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

1 Example

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

- Hint:$P_t/P_r = (4\pi d/\lambda)^2$

- From Equation 4.2, the ratio of transmitted power to received power is
- $Pt/Pr = (4\pi d/\lambda)^2$
- 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:
- $Pt/Pr_2 = (8\pi d/\lambda)^2$
- Therefore:
- $10 \log (Pr/Pr_2) = 10 \log (2^2) = 6$ dB

2 Example

The audio power of the human voice is concentrated at about 300 Hz. Antennas of the appropriate size for this frequency are impracticably large, so that to send voice by radio the voice signal must be used to modulate a higher (carrier) frequency for which the natural antenna size is smaller.

a. What is the length of an antenna half the wavelength long for sending radio at 300 Hz?

b. An alternative is to use a modulation scheme, for transmitting the voice signal by modulating a carrier frequency, so that the bandwidth of the signal is a narrow band centered on the carrier frequency. Suppose we would like a half-wave antenna to have a length of 1 meter. What carrier frequency would we use?

Hint: $\lambda f = c$

- **a.** Using $\lambda f = c$, we have $\lambda = (3 \times 10^8$ m/sec)/(300 Hz) = 1,000 km, so that
  $\lambda/2 = 500$ km.
- **b.** The carrier frequency corresponding to
  $\lambda/2 = 1$ m is given by:
- $f = c/\lambda = (3 \times 10^8$ m/sec)/(2 m) = 150 MHz.

3 Example

- You are communicating between two satellites. The transmission obeys the free space law. The signal is too weak. Your vendor offers you two options. The vendor can use a higher frequency that is twice the current frequency or can double the effective area of both of the antennas. Which will offer you more received power or will both offer the same improvement, all other factors remaining equal? How much improvement in the received power do you obtain from the best option?

- The received signal is, essentially, the same
- The received power will increase by a factor of 4

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

4 Example

Suppose a transmitter produces 50 W of power.

a. Express the transmit power in units of dBm and dBW.

b. If the transmitter's power is applied to a unity gain antenna with a 900-MHz carrier frequency, what is the received power in dBm at a free space distance of 100 m?

c. Repeat (b) for a distance of 10 km.

d. Repeat (c) but assume a receiver antenna gain of 2.

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

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

a

- PowerdBW = 10 log (PowerW) = 10 log (50) = 17 dBW
- PowerdBm = 10 log (PowermW) = 10 log (50,000) = 47 dBm

b

- $L_{dB} = 20 \log(900 \times 10^6) + 20 \log(100) - 147.56 = 120 + 59.08 + 40 - 147.56 = 71.52$
- Therefore, received power in dBm = 47 – 71.52 = –24.52 dBm

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

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

c

- L_{dB} = 120 + 59.08 +80 – 147.56 =111.52;
- $P_{r,dBm}$ = 47 – 111.52 = –64.52 dBm

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

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

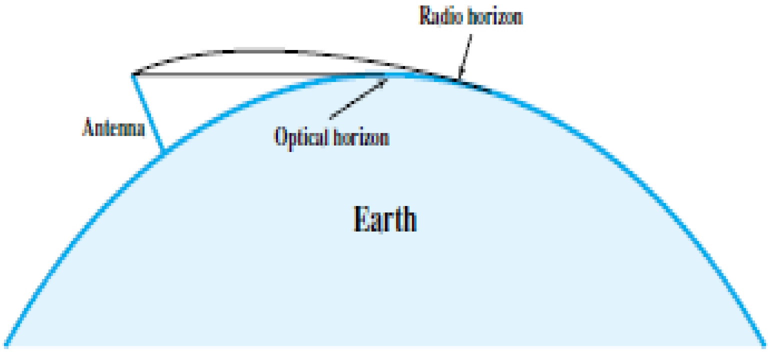
d

- The antenna gain results in an increase of 3 dB, so that $P_{r,dBm} = -61.52$ dBm

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

where d is the distance between an antenna and the horizon in kilometers and h is the antenna height in meters. The effective, or radio, line of sight to the horizon is

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



where K is an adjustment factor to account for the refraction. A good rule of thumb is $K = 4/3$. Thus, the maximum distance between two antennas for LOS propagation is $3.57\left(\sqrt{Kh_1} + \sqrt{Kh_2}\right)$, where h_1 and h_2 are the heights of the two antennas.

5 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 $d = 3.57(\ Kh\ )^{1/2}$, with $K = 4/3$, we have
- $80^2 = (3.57)^2 \times 1.33 \times h$.
- Solving for h, we get h = 378 m.

6 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 $LdB = 20 \log (4\pi) + 20 \log (d) + 20 \log (f) - 20 \log (c) - 10 \log(Gr) - 10 \log (Gt)$
- $LdB = 21.98 + 87.6 + 186.02 - 169.54 - 25.46 - 25.46 = 75.14$ 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