Computer Networks

Transmission Media

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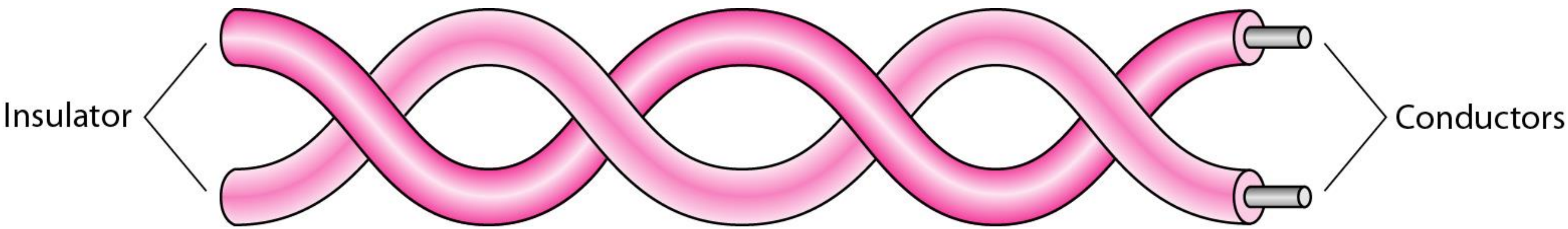
Transmission Medium

- Guided medium:
  - Twisted pair, coaxial cable, optical fiber
  - Twisted pair and coaxial cable: Use metallic (copper) conductors that accept and transport signals in the form of electric current
  - Optical fiber is a cable that accepts and transports signals in the form of light
- Unguided medium:
  - Air, water, vacuum

Twisted pair cable

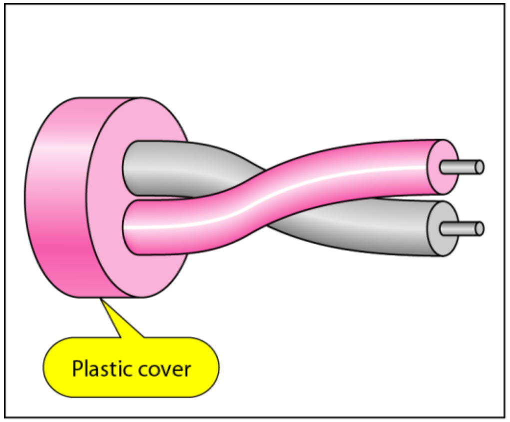
- Twisted pair cable:
  - A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together
  - One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference
  - The receiver uses the difference between the two
  - Twisting makes it probable that both wires are equally affected by external influences (noise or crosstalk)



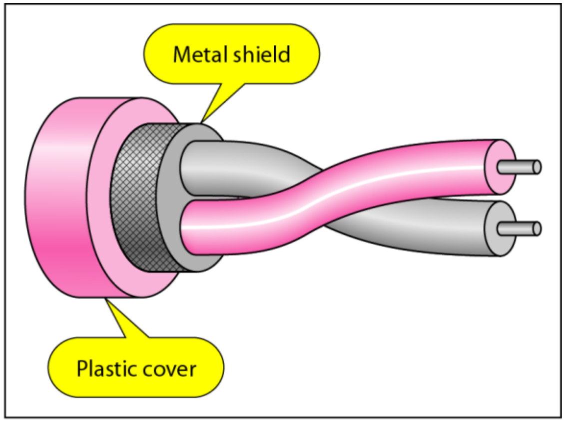
Twisted pair cable

- Twisted pair cable:
  - Unshielded Twisted pair
    - ordinary telephone wire
    - cheapest
    - easiest to install
    - suffers from external electromagnetic interference
  - Shielded Twisted pair:
    - Has a metal foil or braided mesh covering that encases each pair of insulated conductors
    - Improves the quality of cable by preventing the penetration of noise or crosstalk
    - Bulkier and more expensive

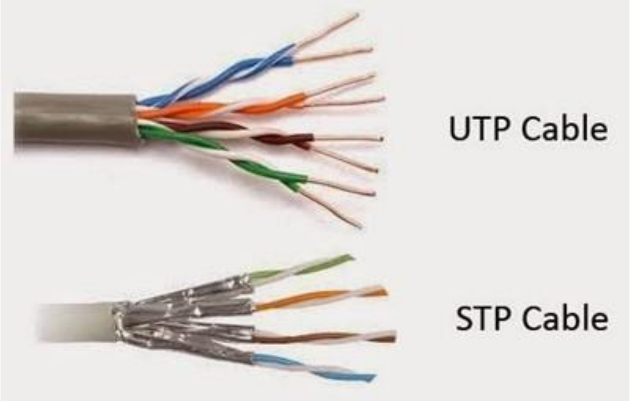
  - Used in telephone lines and LANs



a. UTP



b. STP



Src: https://medium.com/@bilby_yang/comparison-between-utp-and-stp-27f7ac1d61aa

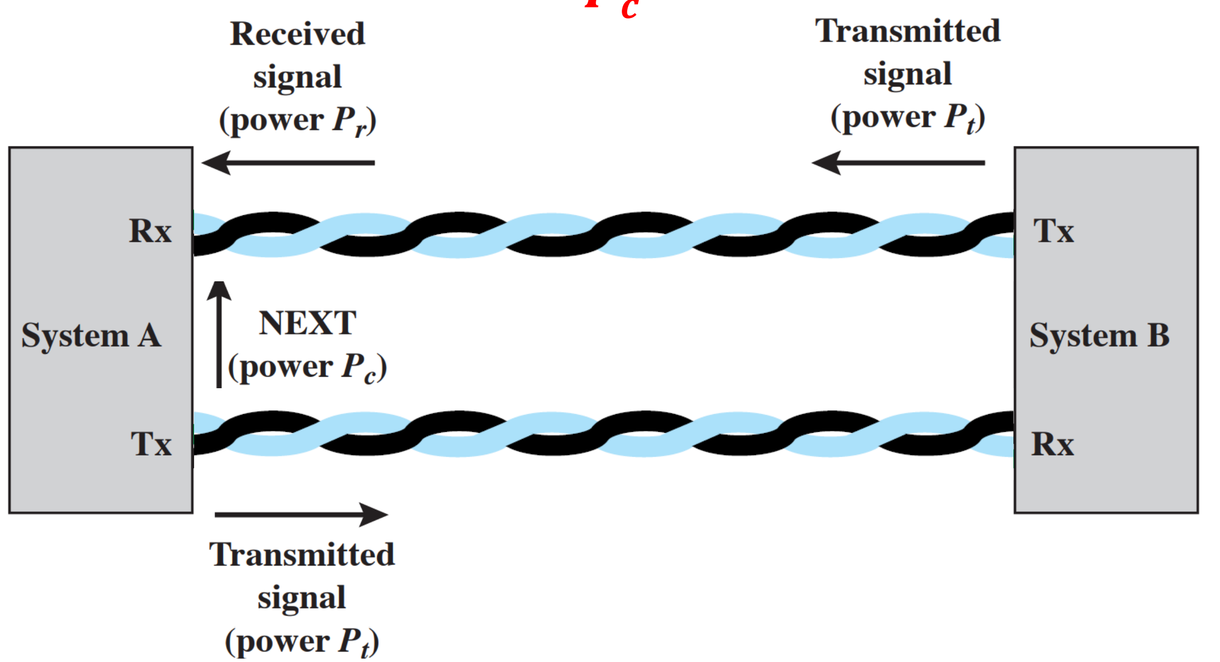
Twisted pair cable

- Insertion Loss: Amount of attenuation across the link

$$A_{dB} = 10\log_{10}\frac{P_t}{P_r}$$

- Near-end Crosstalk (NEXT) Loss: Coupling of the signal from one pair of conductors to another pair

$$NEXT_{dB} = 10\log_{10}\frac{P_t}{P_c}$$



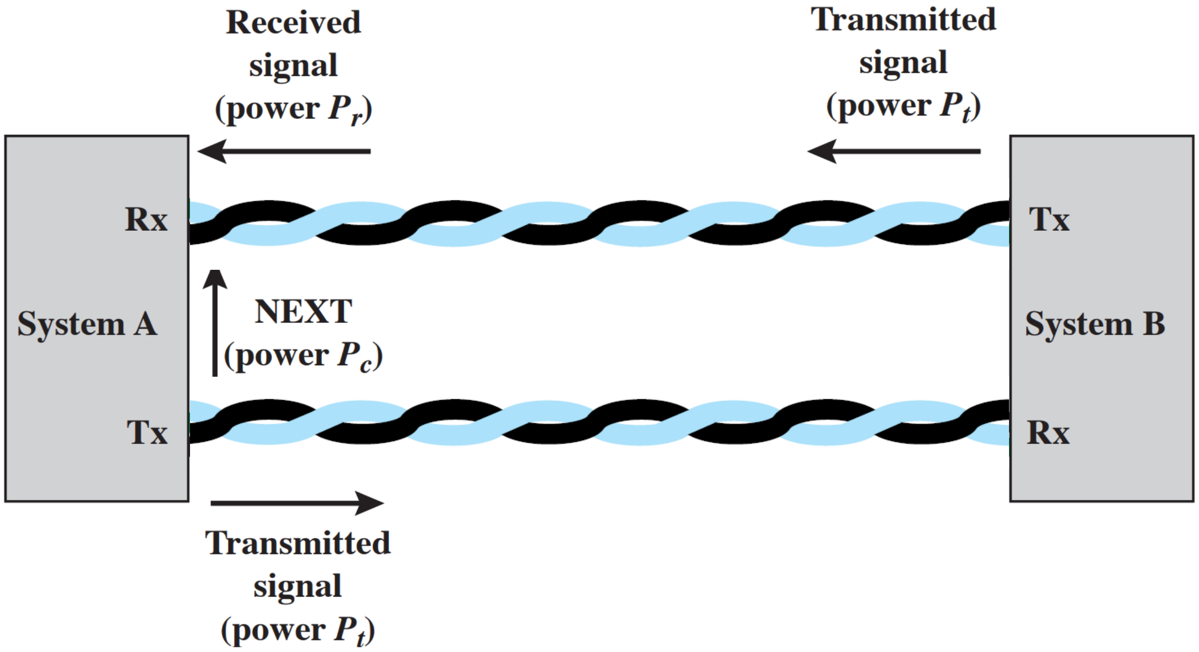
Twisted pair cable

- Attenuation-to-crosstalk ratio (ACR): How much larger the received signal strength is compared to the crosstalk on the same pair

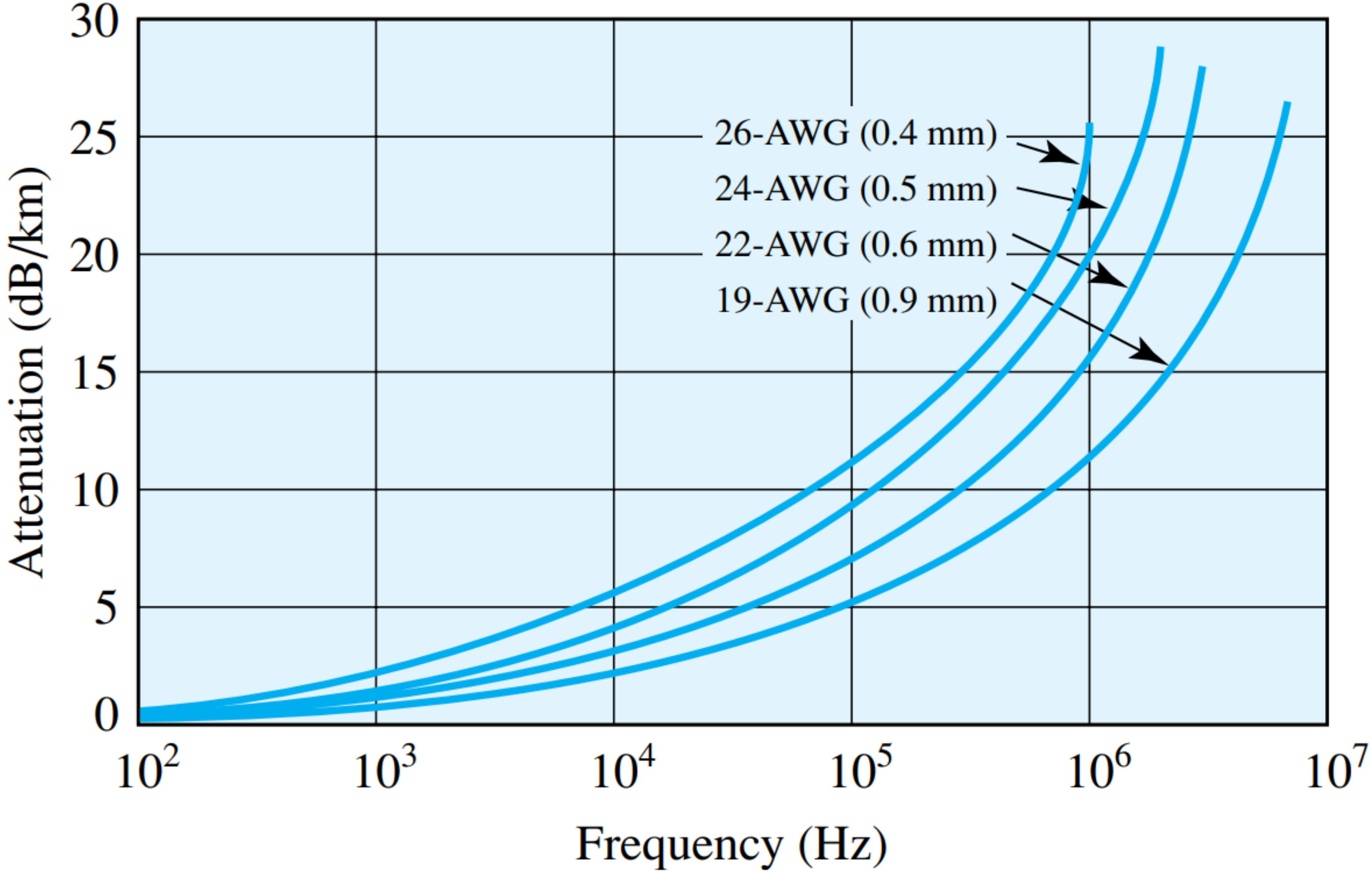
$$ACR_{dB} = NEXT_{dB} - A_{dB}$$

- A positive ACR is desired for successful operation, i.e.

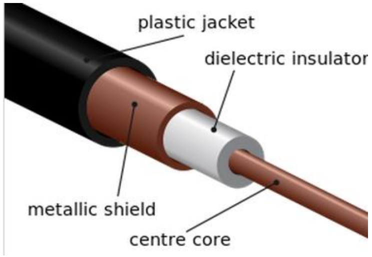
$$NEXT_{dB} > A_{dB} \rightarrow P_r > P_c$$



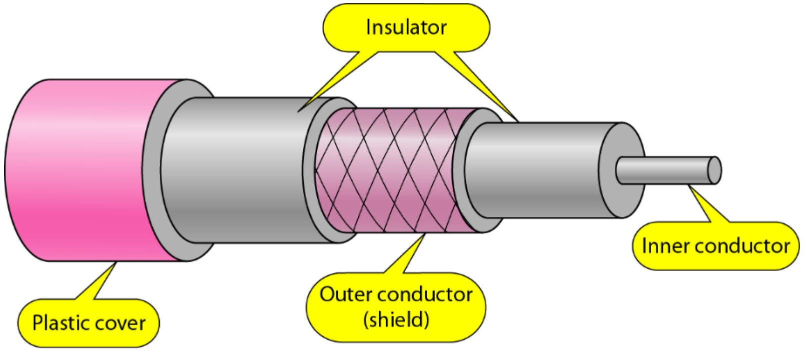
Twisted Pair Cable Performance

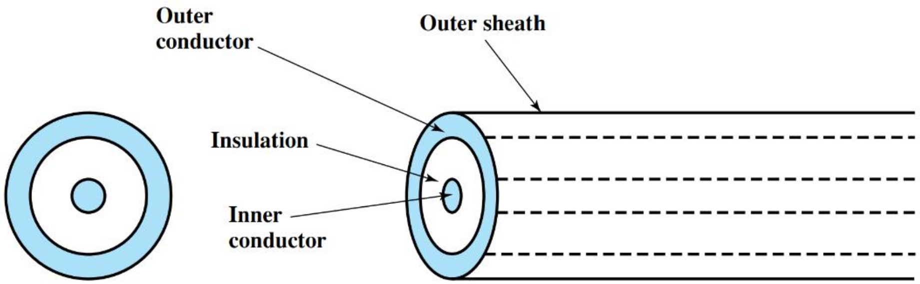


Coaxial Cable

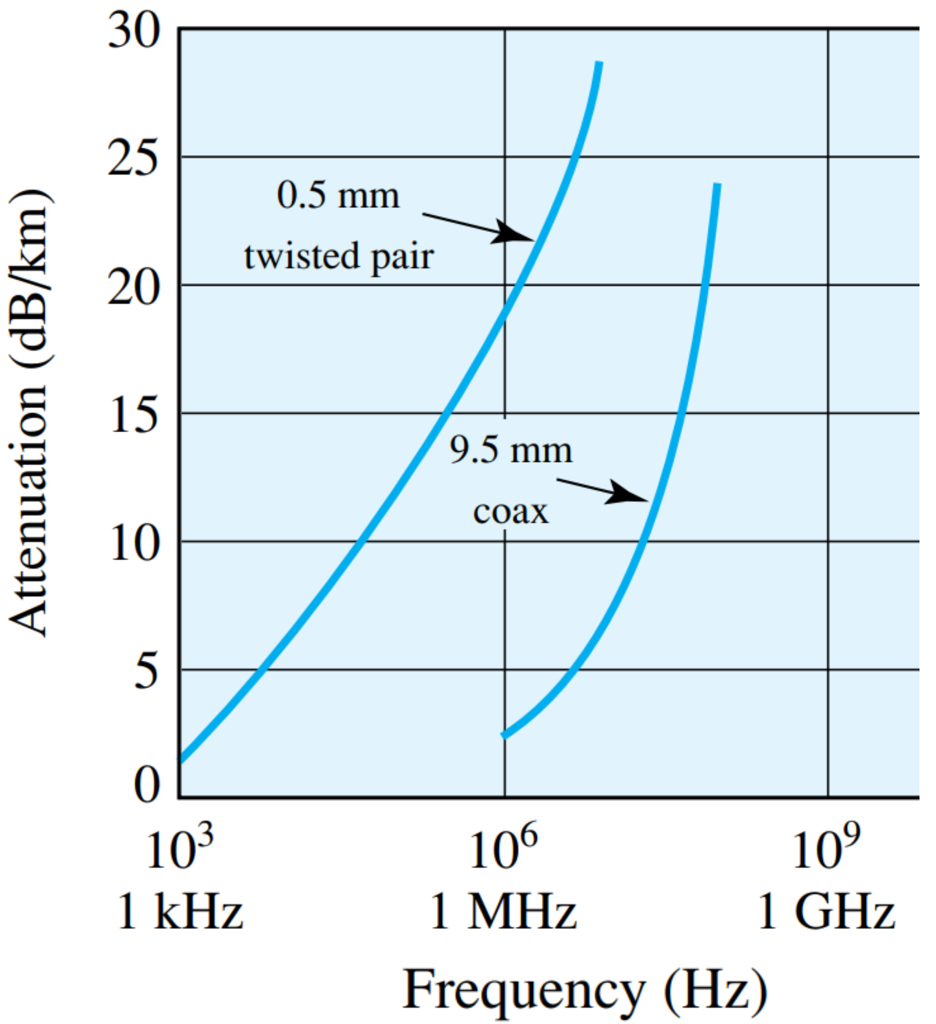


- Coaxial cable can be used over longer distances
- Supports more stations on a shared line than twisted pair
- Consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor
- Used for TV distribution, long distance telephone transmission and LANs



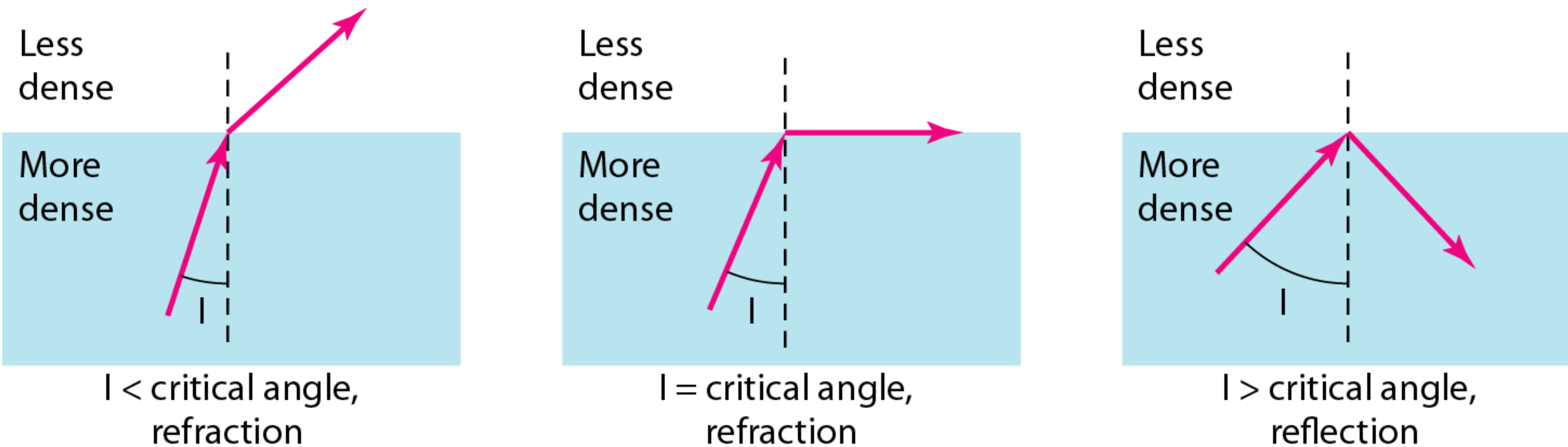


Coaxial Cable Performance



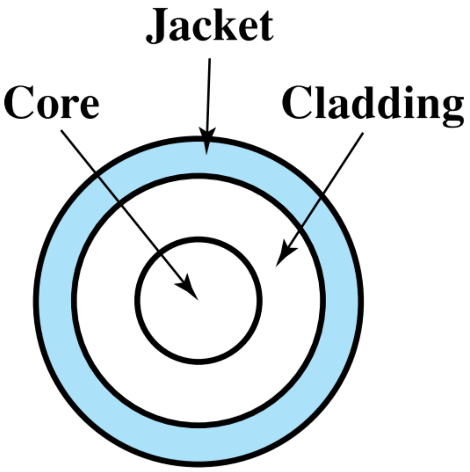
Optical Fiber

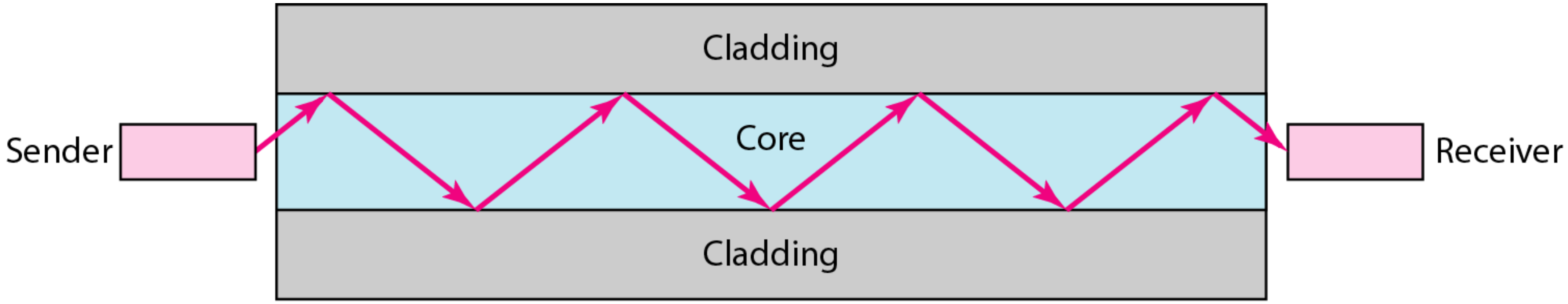
- Uses total internal reflection to transmit light
  - When waves are refracted from a dense medium to a lighter medium the angle of refraction is greater than the angle of incidence
  - As the angle of incidence approaches a certain threshold (called the critical angle), the angle of refraction approaches 90° → the refracted ray becomes parallel to the boundary surface
  - As the angle of incidence increases beyond the critical angle, the conditions of refraction can no longer be satisfied, so there is no refracted ray, and the partial reflection becomes total



Optical Fiber

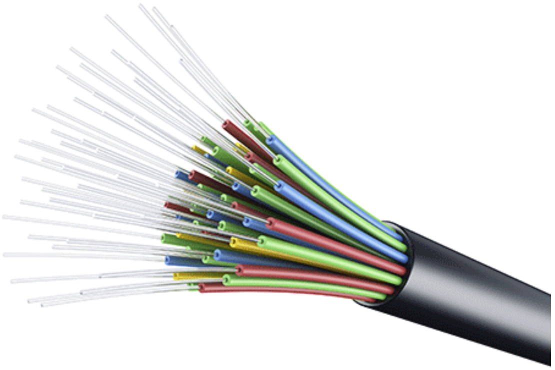
- Optical fiber is a thin flexible medium capable of guiding an optical ray
- Various glasses and plastics can be used to make optical fibers
- Has a cylindrical shape with three sections
  - Core, cladding, jacket



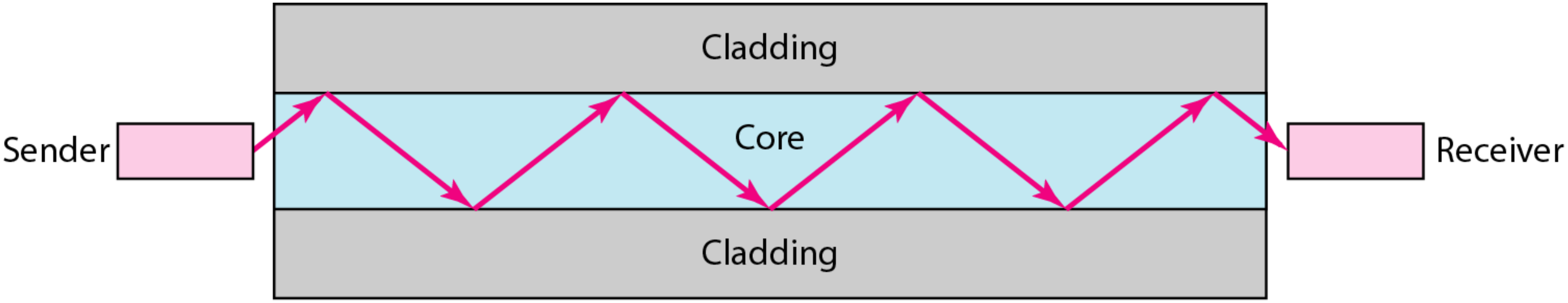


Optical Fiber

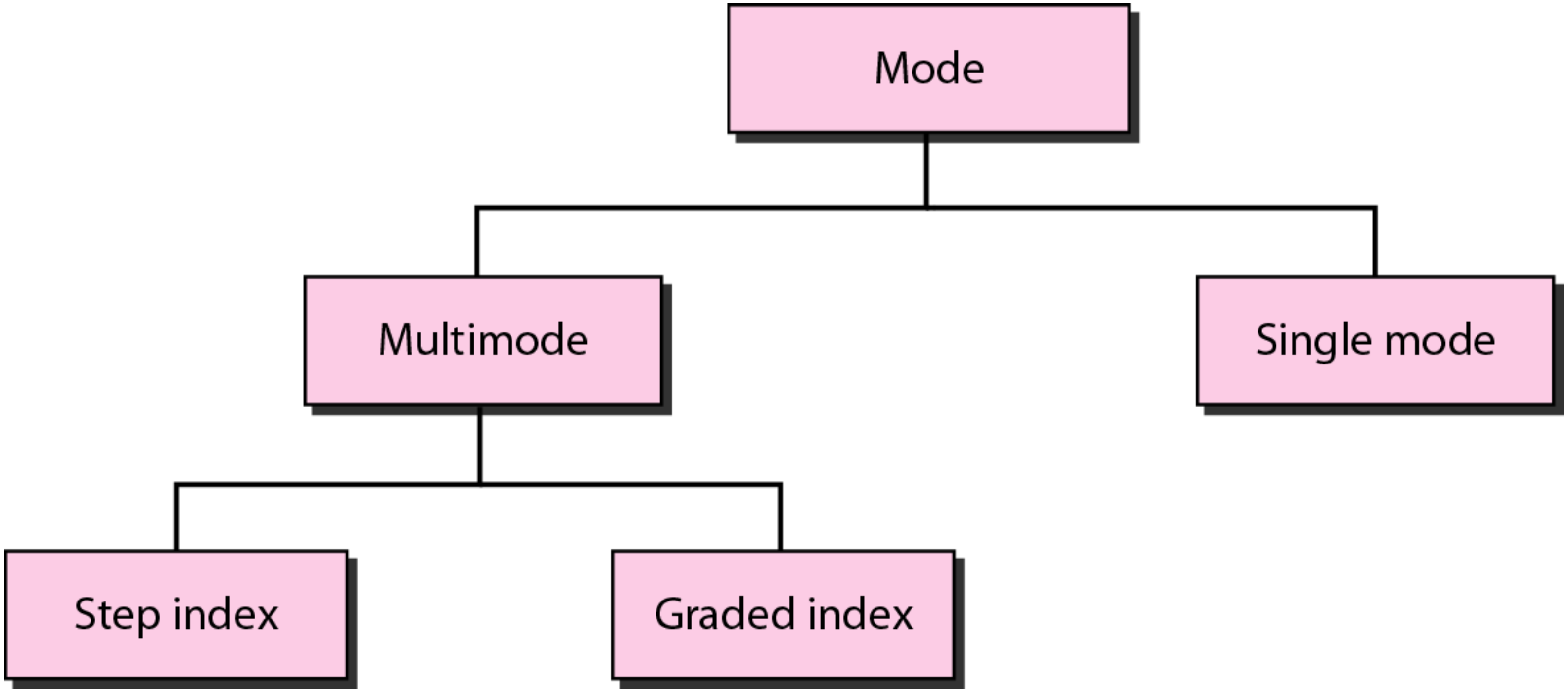
- Light sources used:
  - Light Emitting Diode (LED)
  - Cheaper, operates over a greater temperature range, lasts longer



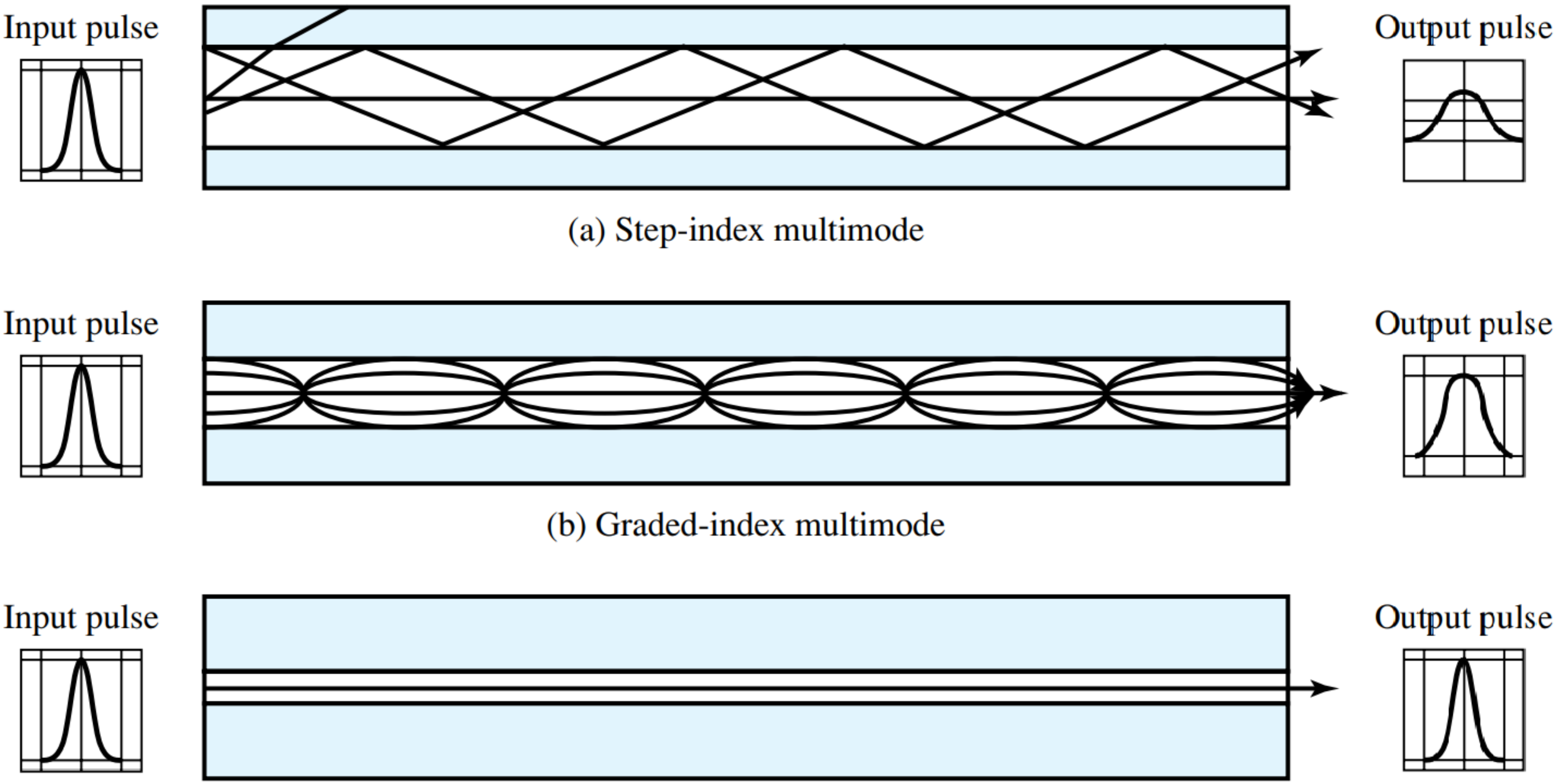
- Injection Laser Diode (ILD)
  - More efficient, has greater data rates



Optical Fiber



Optical Fiber Transmission Modes

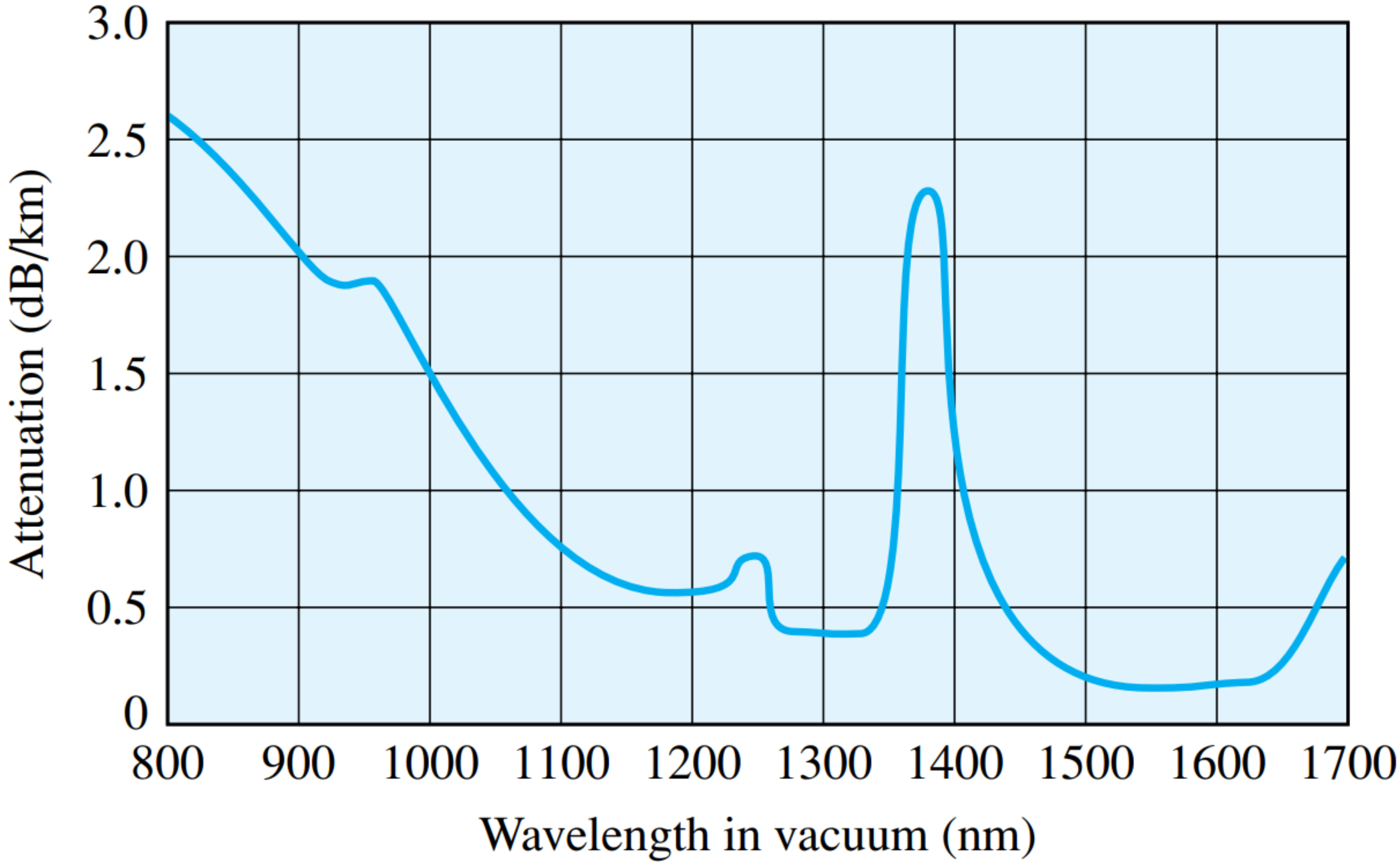


(a) Step-index multimode

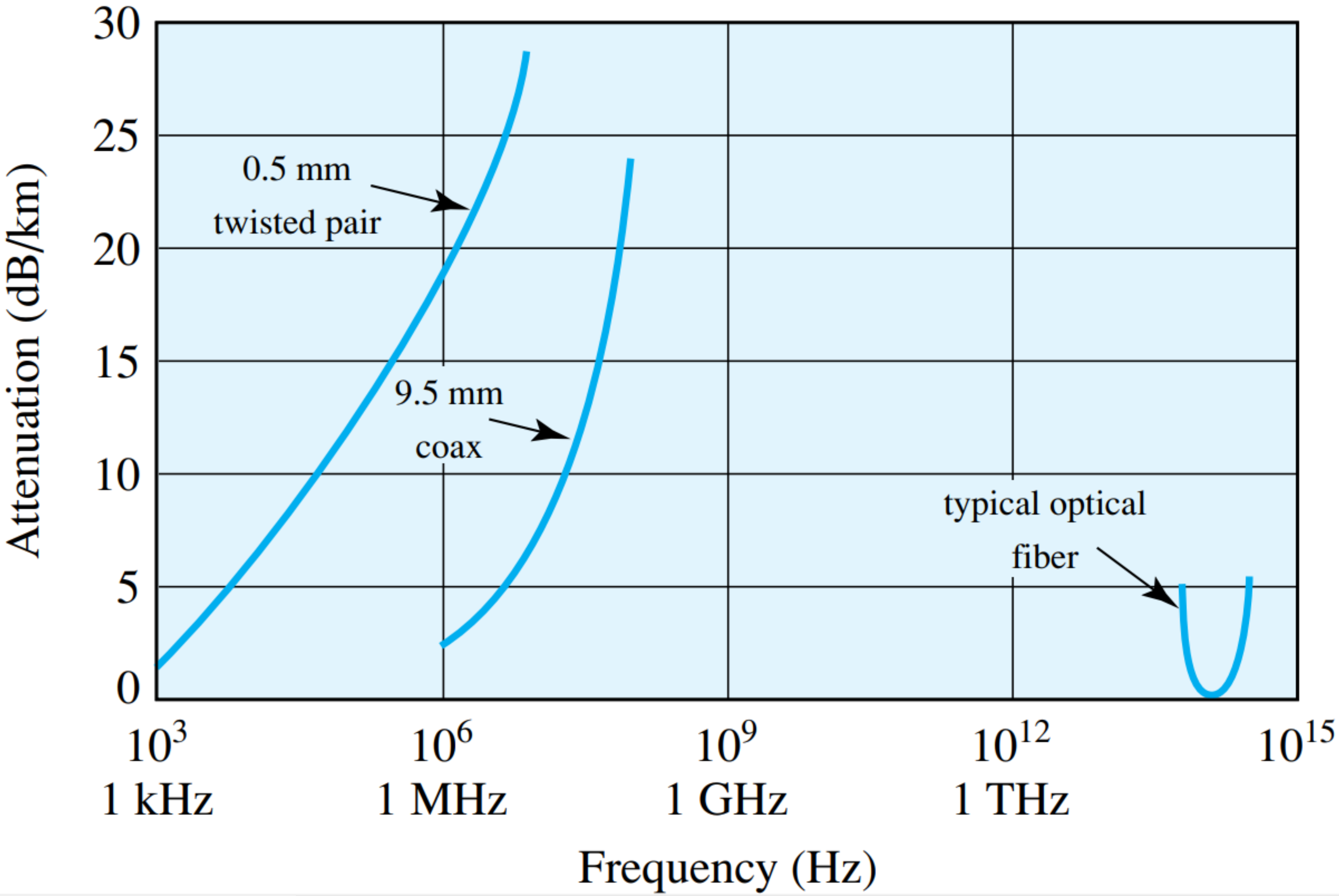
(b) Graded-index multimode

(c) Single mode

Optical Fiber Performance



Attenuation Comparison



Optical Fiber - Benefits

- Greater capacity
  - Data rates of 100 Gbps+ (as compared to 1 Gps with electrical cables)
- Smaller size and lighter weight
  - Considerably thinner than coaxial or twisted pair cable
  - Reduces structural support requirements
- Lower attenuation
  - Maximum distance is 40 km → as compared to 2 km (twisted pair) and 10 km (coaxial cable)
- Electromagnetic isolation
  - Not vulnerable to interference, impulse noise, or crosstalk
  - High degree of security from eavesdropping
- Greater repeater spacing
  - Lower cost and fewer sources of error

Wireless Transmission

- Common wireless systems for communications:
  - Radio:
    - 3kHz to 300GHz
    - Suitable for omnidirectional applications
    - IEEE 802.11 WiFi or wireless LAN
  - Microwave:
    - 2GHz to 40GHz
    - Highly directional beams are possible → suitable for point to point communication
    - Satellite transmission, television transmission
  - Infrared:
    - 3×10^{11} to 2×10^{14} Hz
    - Local point-to-point and multipoint applications within confined areas → such as a single room
    - In-home communications, TV remote

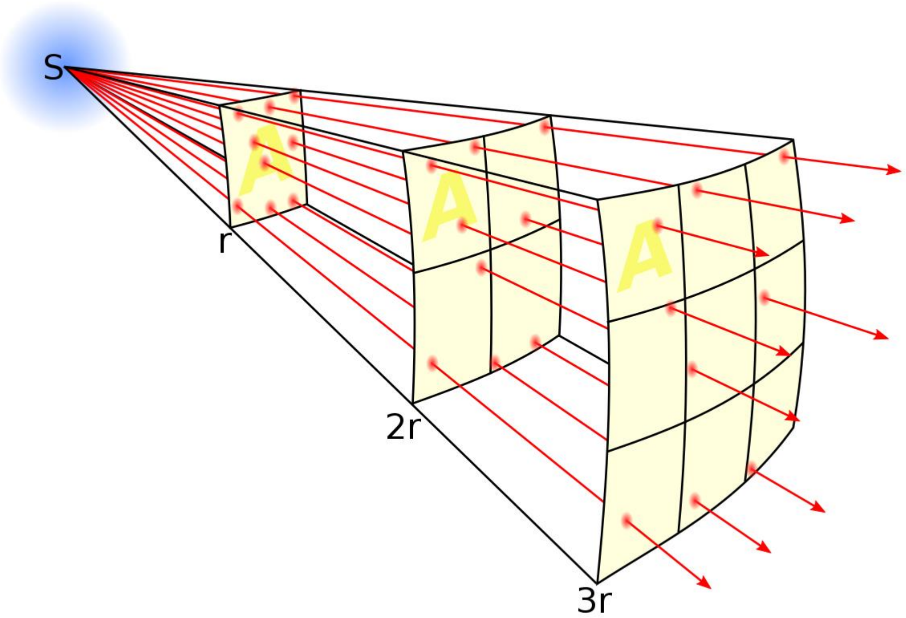
Antennas

- Electrical conductors used to radiate or collect electromagnetic energy
- Transmission antenna: Radio-frequency electrical energy → converted to electromagnetic energy → radiated into the surrounding
- Reception antenna: Electromagnetic energy → converted to radio-frequency electrical energy → fed to the receiver

Antennas

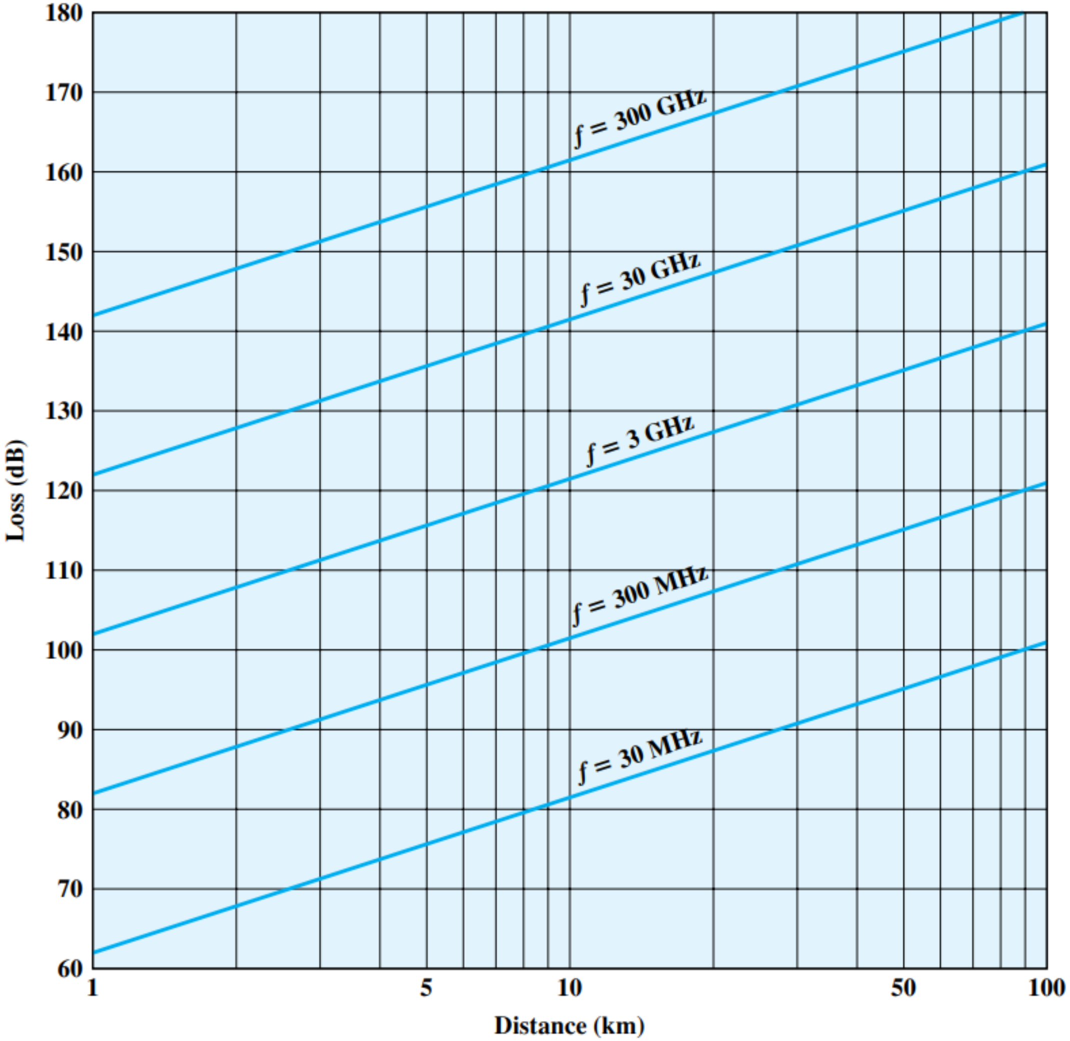
- Isotropic antenna:
  - A point in space that radiates power in all directions equally with a spherical radiation pattern

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



Src: https://en.wikipedia.org/wiki/Free-space_path_loss

Line of Sight Impairments

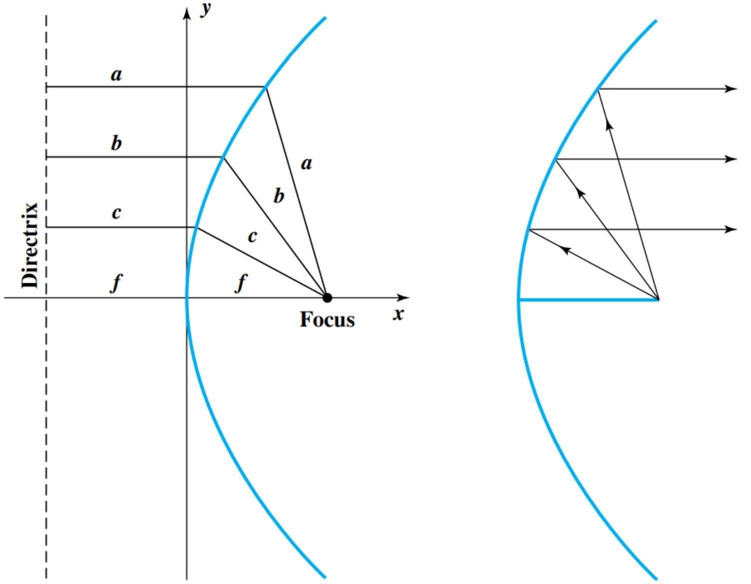


Antennas

- **Omni-directional antenna:** power propagates in all directions in a plane

- **Parabolic Reflective antenna:**

  Directional antenna

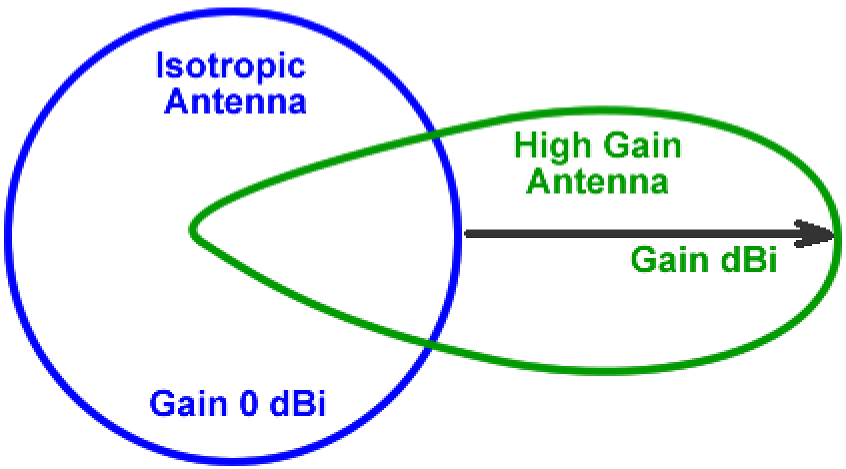


(a) Parabola

(b) Cross section of parabolic antenna showing reflective property

Antenna Gain

- Antenna gain:
  - Measure of directionality
  - Defined as the power output in a particular direction, compared to that produced in any direction by a perfect isotropic antenna (dBi)
  - http://www.cisco.com/en/US/prod/collateral/wireless/ps7183/ps469/product_data_sheet09186a008008883b.html



Src: https://www.ahsystems.com/articles/Understanding-antenna-gain-beamwidth-directivity.php

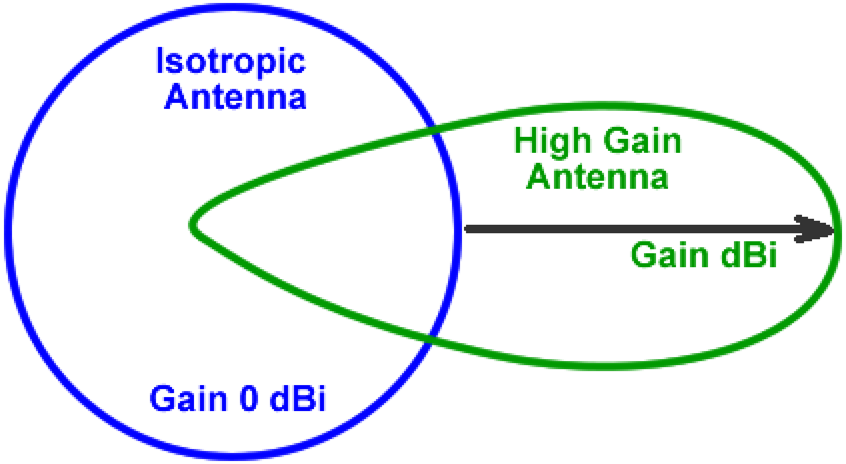
Radiated power of isotropic antenna

$$G_{dB} = 10log_{10}\frac{P_2}{P_1}$$

Radiated power of directional antenna

Antenna Gain

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



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Radiated power of isotropic antenna

$$G_{dB} = 10log_{10}\frac{P_2}{P_1}$$

Radiated power of directional antenna

Antenna Gain

- Antenna gain:
  - Relates to the effective area of the antenna
  - Effective area of an antenna is related to its physical size and its shape
  - Effective area of an ideal isotropic antenna is $\frac{\lambda^2}{4\pi}$, with a power gain = 1
  - Effective area of an parabolic antenna with a face area of A is 0.56A, with a power gain of $\frac{7A}{\lambda^2}$

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

Antenna Gain

- For a parabolic reflective antenna with a diameter of 2 m, operating at 12 GHz, what is the effective area and the antenna gain?

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

Antenna Gain

- Antenna gain:

$$\frac{P_t}{P_r} = \frac{1}{G_t G_r}\left(\frac{4\pi d}{\lambda}\right)^2 = \frac{1}{G_t G_r}\left(\frac{4\pi f d}{c}\right)^2$$

- Assume that a ground station is transmitting a signal of 250 W to a satellite at 4 GHz (earth to satellite distance is 35863 km). The antenna gains are 44 dB and 48 dB. What is the received power?

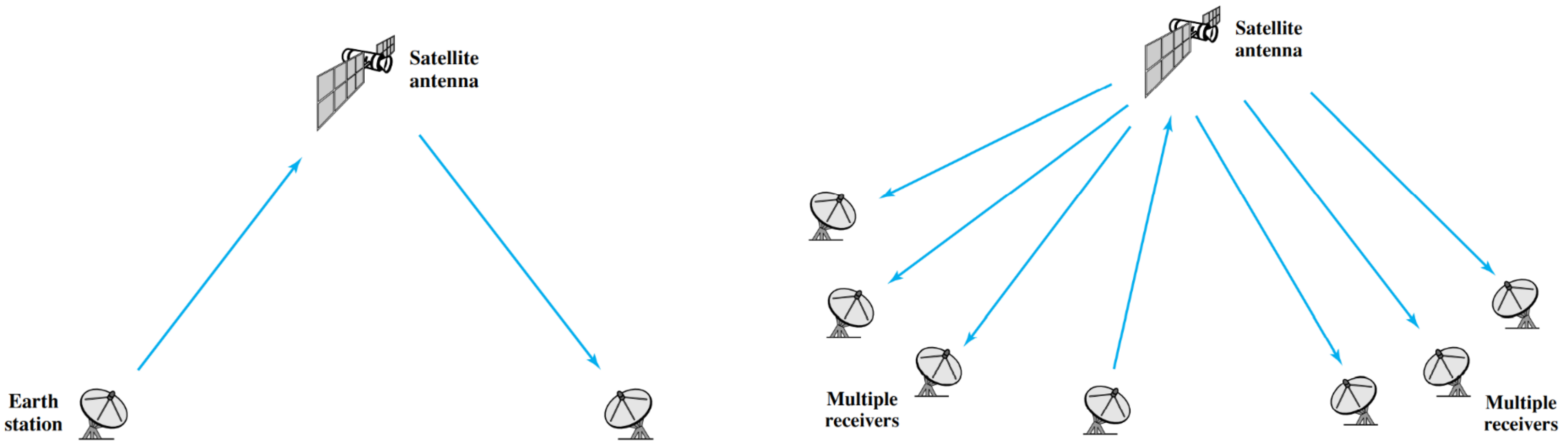
Microwave

- Terrestrial Microwave:
  - Requires line-of-sight
  - Most common type is a parabolic dish with an antenna focusing a narrow beam onto a receiving antenna
  - Located at substantial heights above ground to extend range and transmit over obstacles
  - Uses a series of microwave relay towers with point-to-point microwave links to achieve long distance
  - Used for both voice and TV transmission, cellular systems
  - Main source of loss is attenuation caused mostly by distance, rainfall and interference
  - 1-40GHz frequencies, with higher frequencies having higher data rates

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

Microwave

- Satellite Microwave:
  - Used to link two or more ground stations
  - Receives on one frequency, amplifies or repeats signal and transmits on another frequency
  - Frequency bands are called transponder channels
  - Requires geo-stationary orbit
    - Rotation match occurs at a height of 35,863km at the equator
    - Need to be spaced at least 3° - 4° apart to avoid interfering with each other
  - Uses: television distribution, Global Positioning System (GPS)

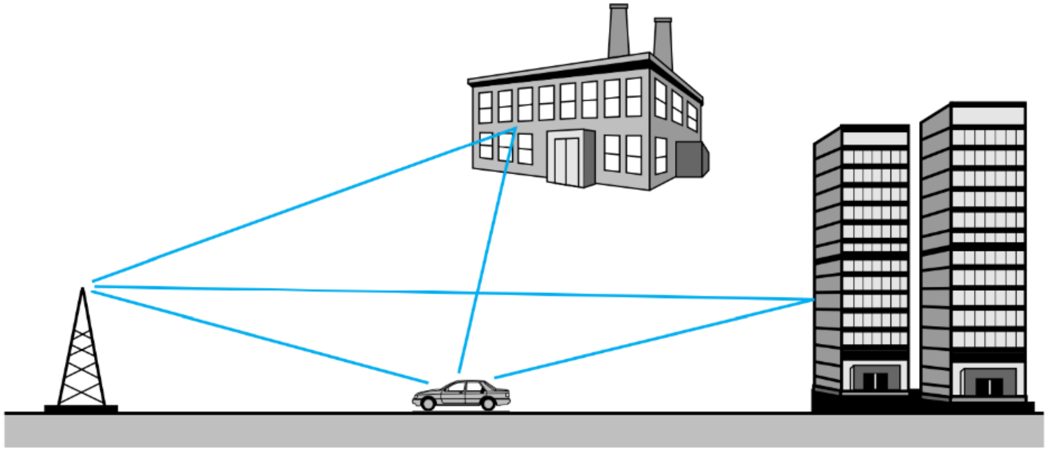


(a) Point-to-point link

(b) Broadcast link

Radio

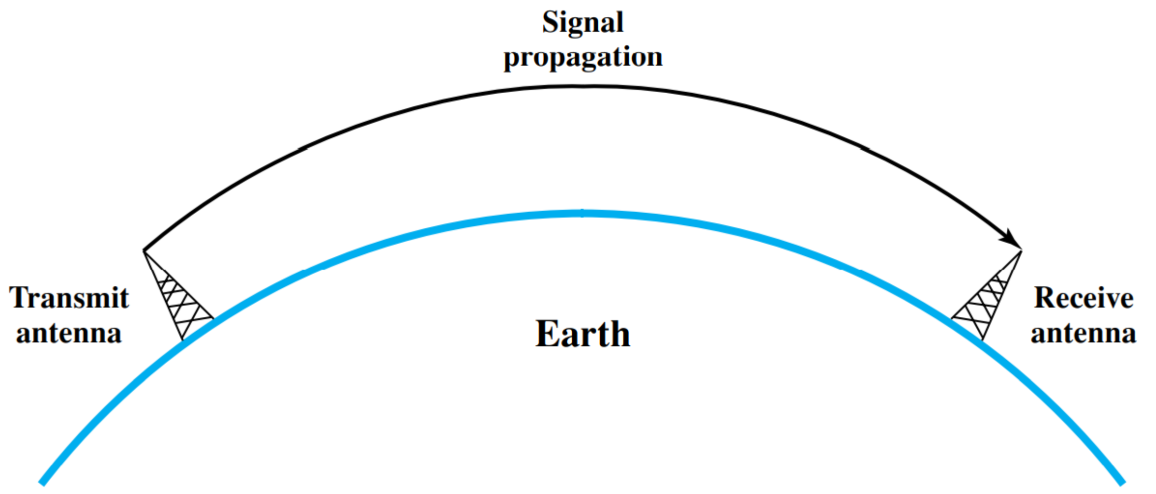
- Radio is the term used to encompass frequencies in the range of 3kHz to 300GHz
- Broadcast radio (30MHz - 1GHz) covers
  - FM radio
  - UHF and VHF television
  - data networking applications
- Omnidirectional
- Suffers from multipath interference
  - reflections from land, water, man-made objects



Infrared

- Achieved using transceivers that modulate noncoherent infrared light
- Transceivers must be within line of sight of each other directly or via reflection
- Does not penetrate walls
- No licenses required
- No frequency allocation issues
- Uses: TV remote control

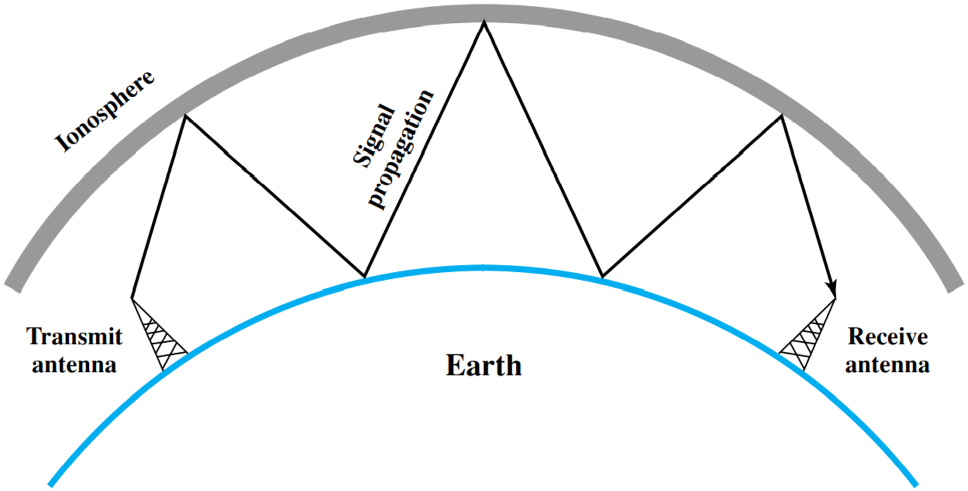
Wireless Propagation - Ground Wave



(a) Ground wave propagation (below 2 MHz)

- Ground wave propagation follows the contour of the earth and can propagate distances well over the visible horizon
- This effect is found in frequencies up to 2MHz
- Example: AM radio

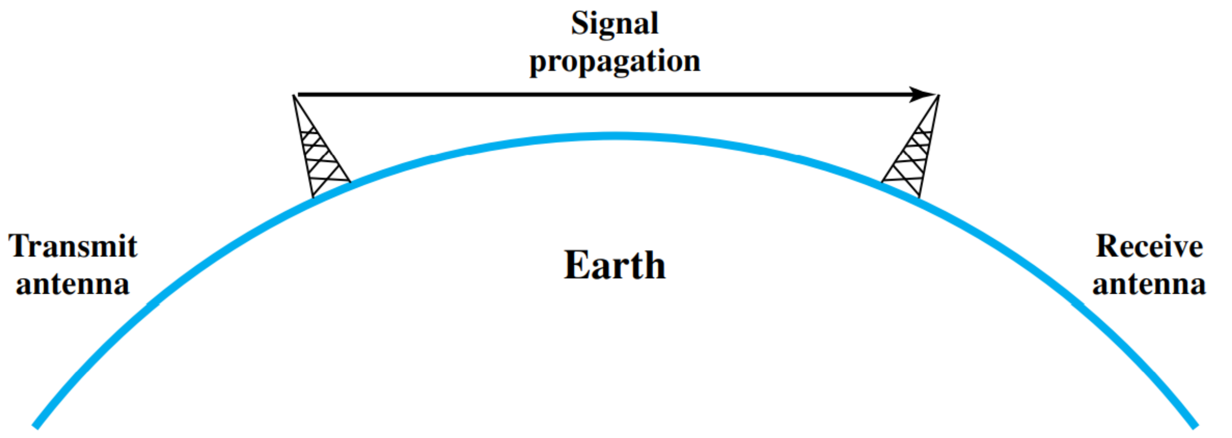
Wireless Propagation - Sky Wave



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

- Sky wave propagation is used for amateur radio, CB radio, and international broadcasts such as BBC
- A signal from an earth based antenna is reflected from the ionized layer of the upper atmosphere back down to earth
- Sky wave signals can travel through a number of hops, bouncing back and for the between the ionosphere and the earth's surface

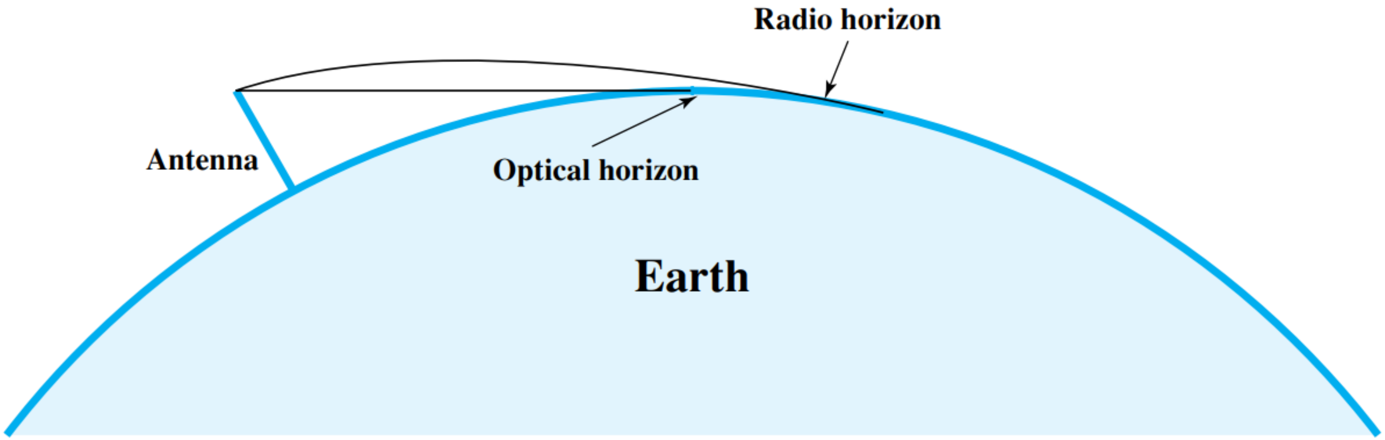
Wireless Propagation - Line of Sight



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

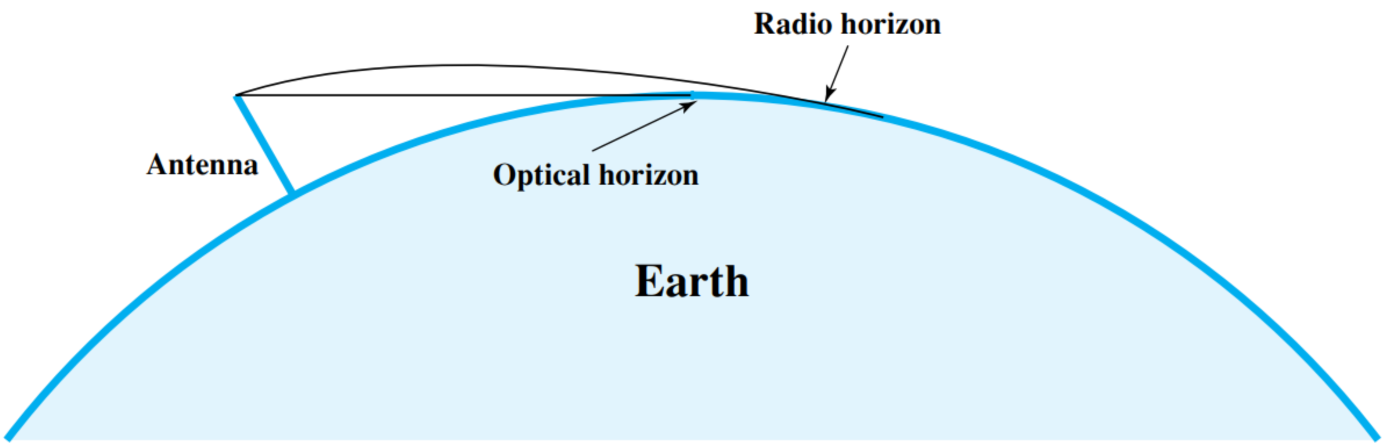
- Ground and sky wave propagation modes do not operate above 30 MHz communication must be by line of sight

Radio Horizon vs Optical Horizon

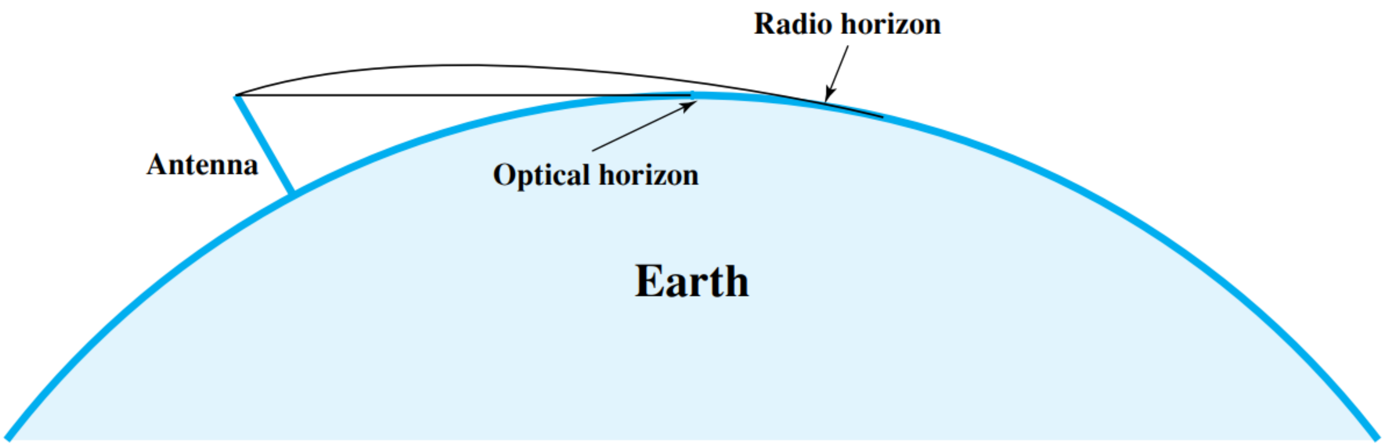


- Optical LOS refers to the straight-line propagation of light waves
- Radio LOS refers to the propagation of radio waves bent by the curvature of the earth

Radio Horizon vs Optical Horizon



Radio Horizon vs Optical Horizon

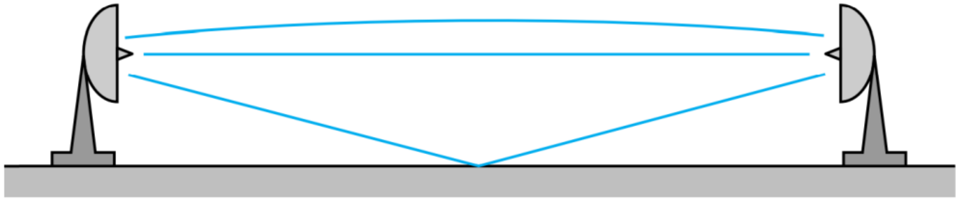


Radio Horizon vs Optical Horizon

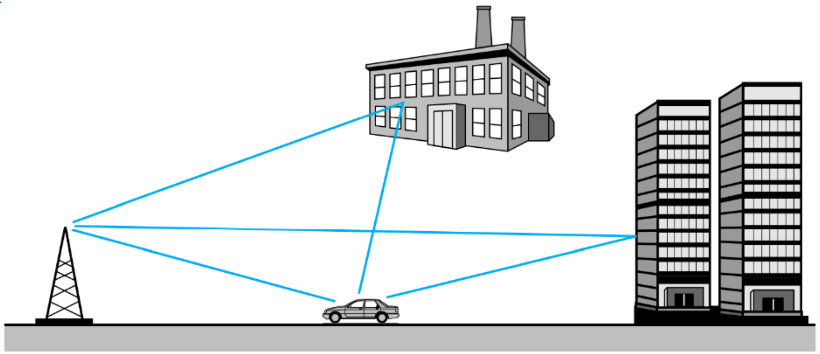
- The maximum distance between two antennas for LOS transmis sion if one antenna is 100 m high and the other is at ground level is

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

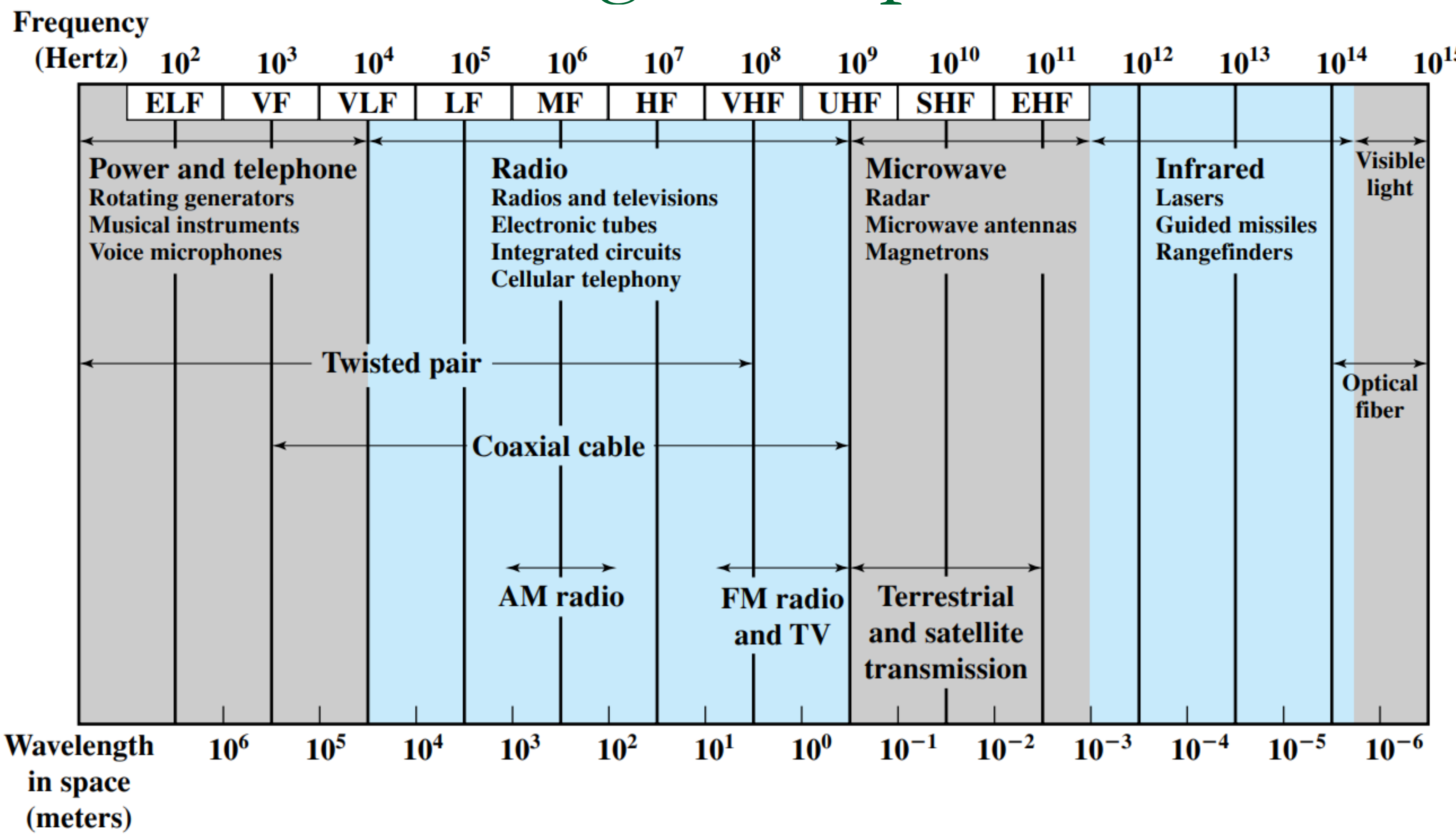
Line of Sight Impairments



- Free space loss
  - Loss of signal with distance
- Atmospheric loss
  - From water vapor and oxygen absorption
- Multipath
  - Multiple interfering signals from reflections
- Refraction
  - Bending signal away from receiver



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 = Ultra high frequency
SHF = Super high frequency
EHF = Extremely high frequency

THANK YOU

QUESTIONS???