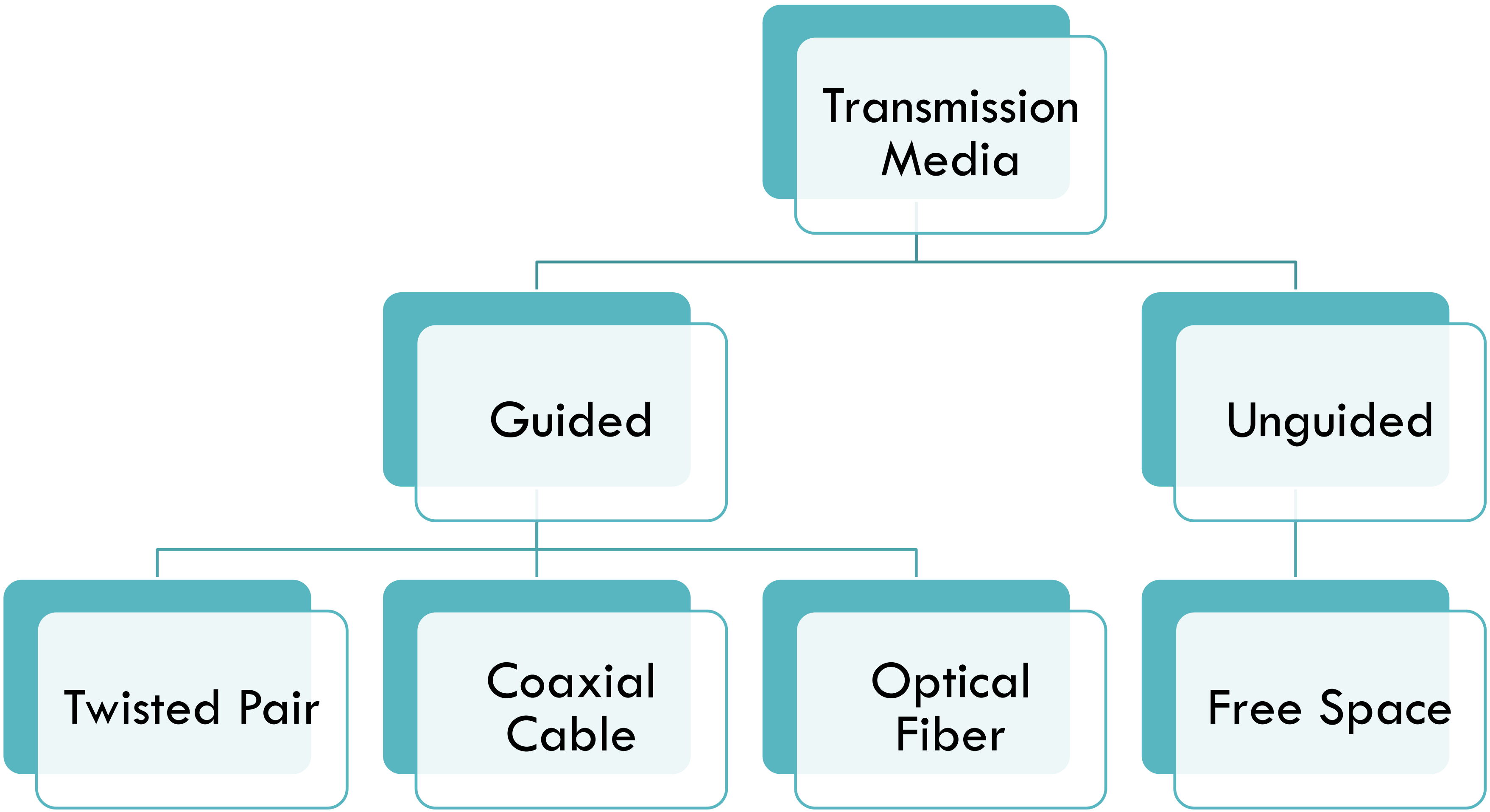
Computer Networks 1

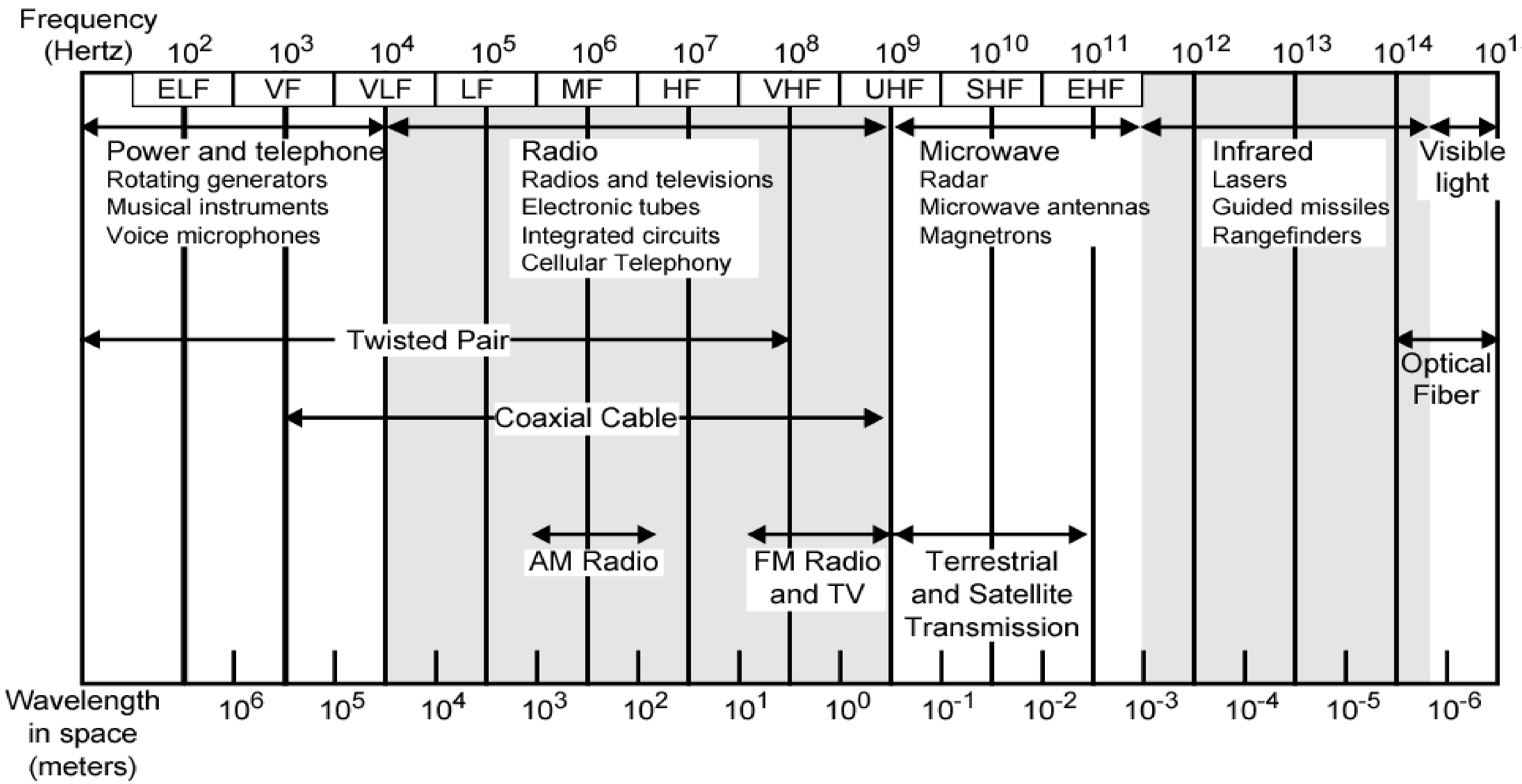
TRANSMISSION MEDIA

Fatemeh Rezaei

TRANSMISSION MEDIA



ELECTROMAGNETIC SPECTRUM FOR TELECOMMUNICATION



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

KEY CONCERNS IN DESIGN OF DATA TRANSMISSION SYSTEMS

OUTLINE

Guided Media

- Twisted Pair
- Coaxial Cable
- Optical Fiber

Unguided Media

OUTLINE

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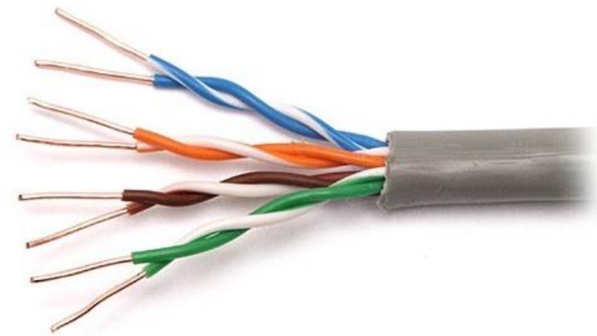
- Twisted Pair
- Coaxial Cable
- Optical Fiber

Unguided Media

TWISTED PAIR (TP)

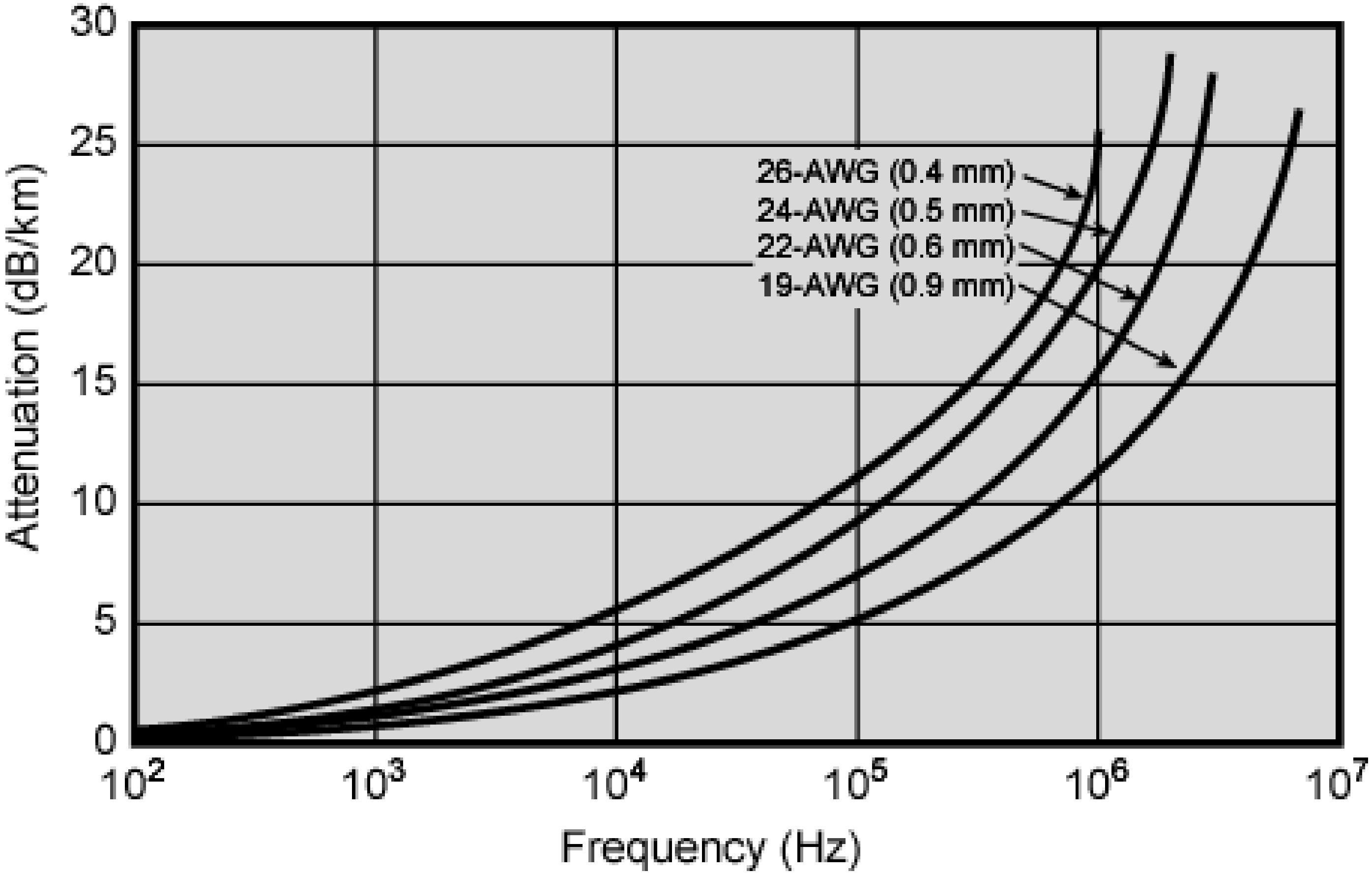


Applications

- Telephone Network
- Communications within Buildings
- Analog and Digital Signals

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

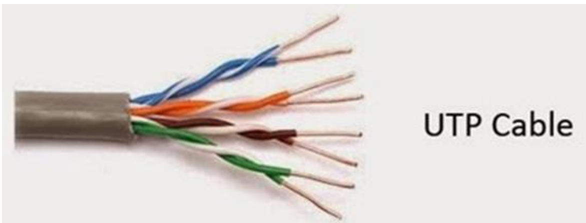
ATTENUATION IN TWISTED PAIR



TWISTED PAIR TRANSMISSION CHARACTERISTICS

- Analog Transmission
  - For analog signals only
  - Amplifiers every 5km to 6km
  - Bandwidth up to 1 MHz
- Digital Transmission
  - For either analog or digital signals
  - Repeaters every 2km or 3km
  - Data rates up to few Mbps
    - 1Gbps: very short distance

TWISTED PAIR TYPES



Unshielded Twisted Pair (UTP)

- Cheapest
- Easiest to install
- External EM interference
- Ordinary telephone wire

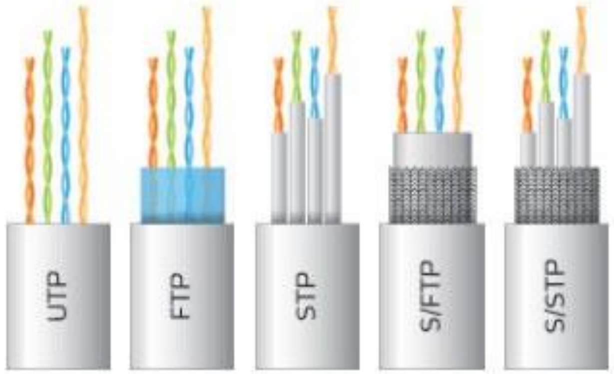
Shielded Twisted Pair (STP)

- More expensive
- Harder to handle (thicker, heavier)
- Reduce interference
- Reduce attenuation at high frequencies
- Increased data rates (BW)
- Increased distances covered

TWISTED PAIR CATEGORIES AND CLASSES

	Category 3 Class C	Category 5 Class D	Category 5E	Category 6 Class E	Category 7 Class F
Bandwidth	16 MHz	100 MHz	100 MHz	200 MHz	600 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	UTP/FTP	SSTP
Link Cost (Cat 5 = 1)	0.7	1	1.2	1.5	2.2

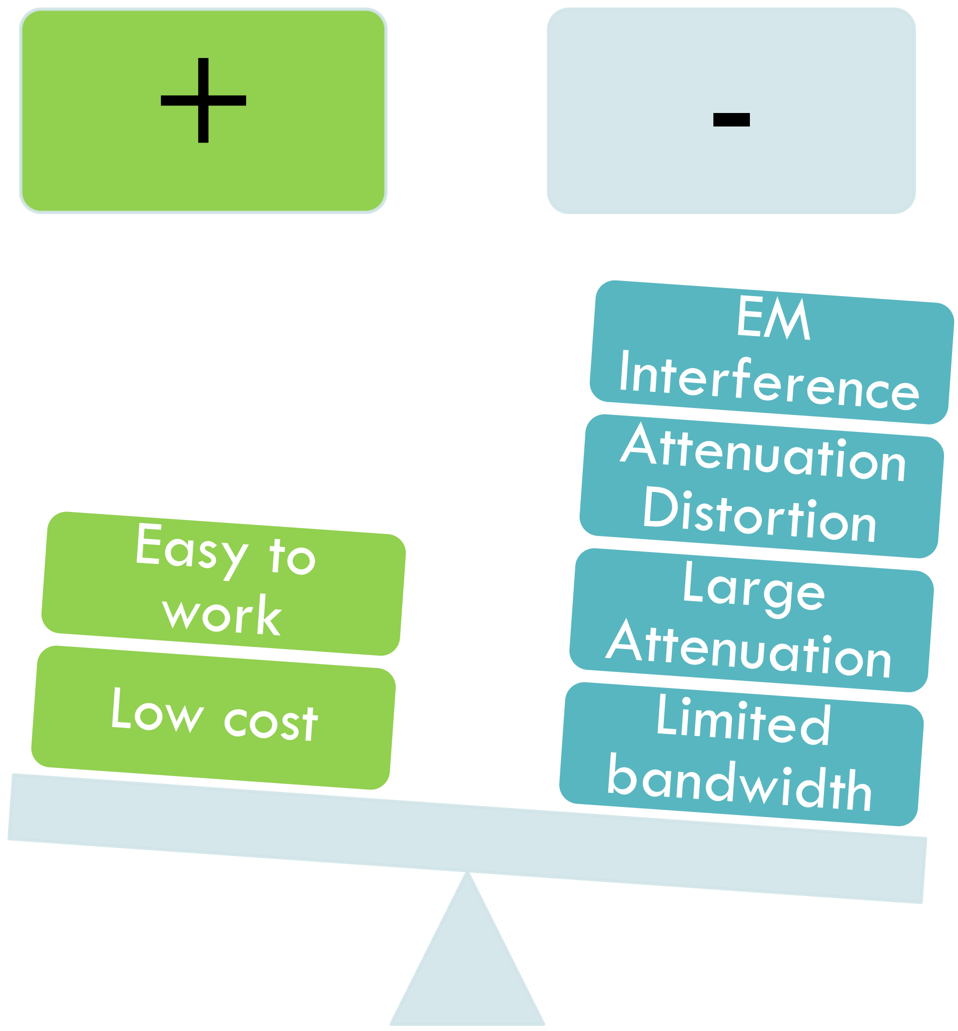
UTP = Unshielded twisted pair
FTP = Foil twisted pair
SSTP = Shielded screen twisted pair



SHIELDED AND UNSHIELDED TWISTED PAIRS

	Attenuation (dB per 100 m)			Near-End Crosstalk (dB)		
Frequency (MHz)	Category 3 UTP	Category 5 UTP	150-ohm STP	Category 3 UTP	Category 5 UTP	150-ohm STP
1	2.6	2.0	1.1	41	62	58
4	5.6	4.1	2.2	32	53	58
16	13.1	8.2	4.4	23	44	50.4
25	—	10.4	6.2	—	41	47.5
100	—	22.0	12.3	—	32	38.5
300	—	—	21.4	—	—	31.3

TWISTED PAIR CHARACTERISTICS



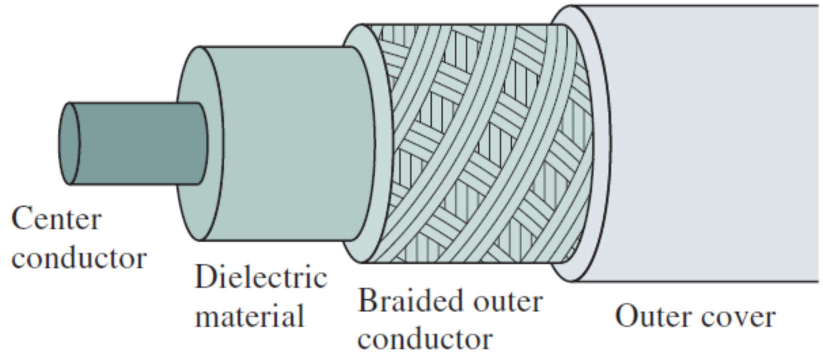
OUTLINE

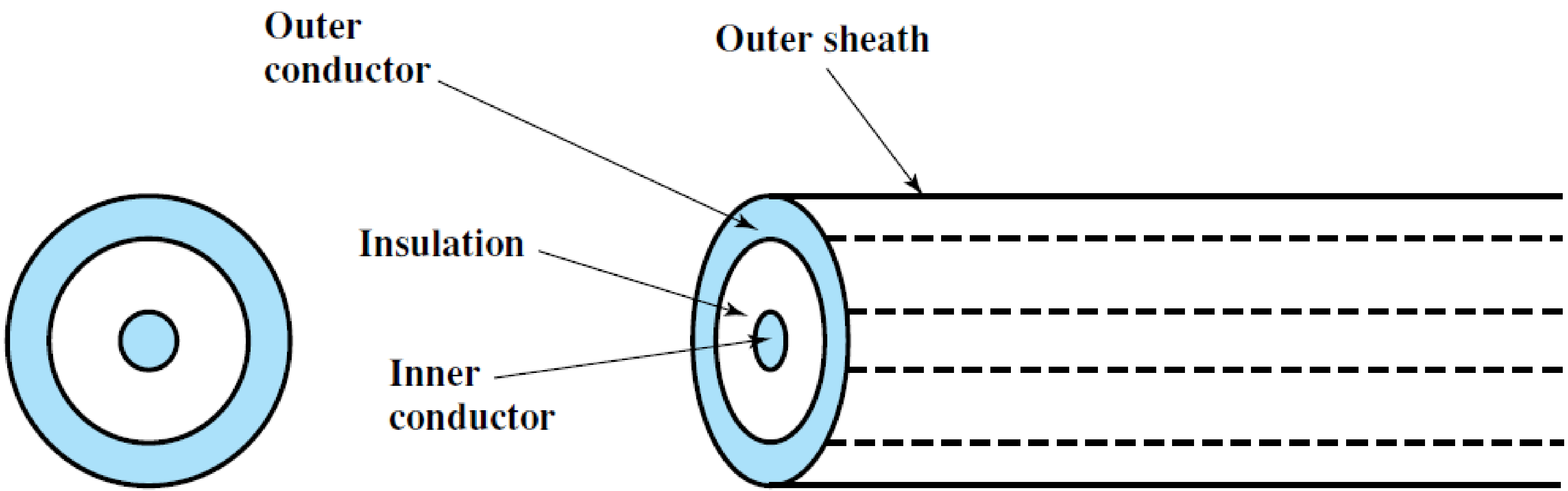
Guided Media

- Twisted Pair
- Coaxial Cable
- Optical Fiber

Unguided Media

COAXIAL CABLE



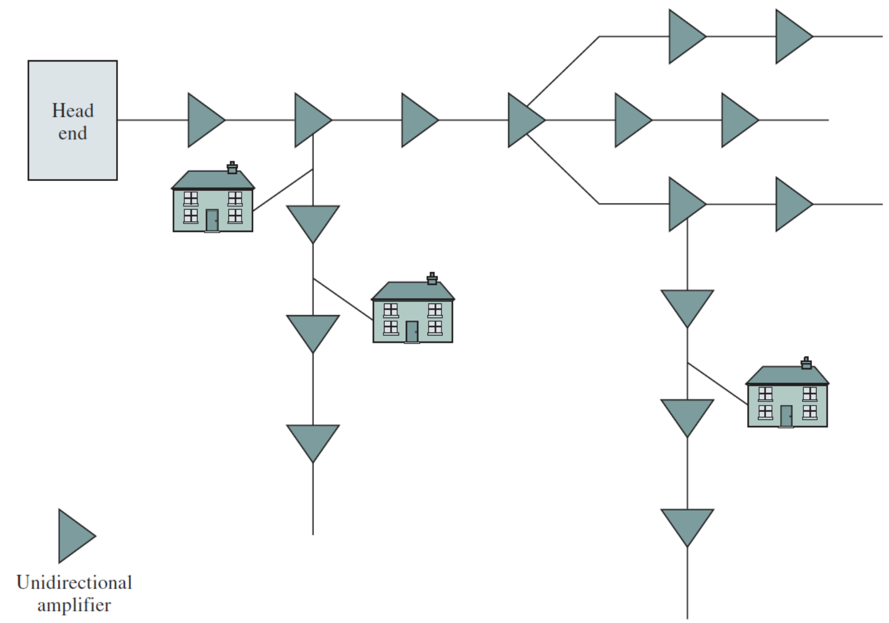


—Outer conductor is braided shield
—Inner conductor is solid metal
—Separated by insulating material
—Covered by padding

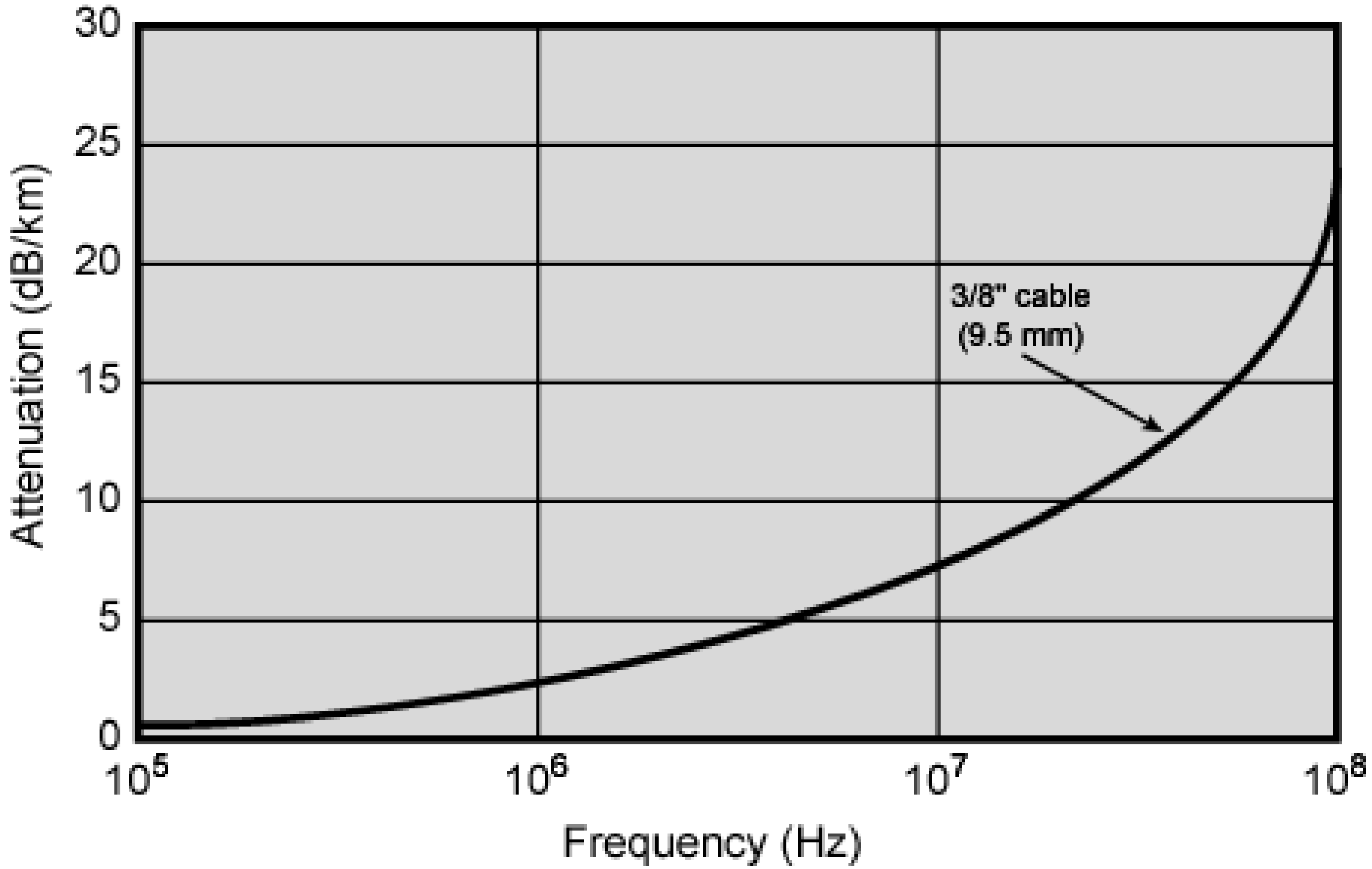
Diameter: 1 to 2.5 cm

APPLICATION: CABLE TV SYSTEMS

- Television distribution
- Long-distance telephone transmission
- Short-run computer system links
- Local area networks



ATTENUATION IN COAXIAL CABLE



COAXIAL CABLE CHARACTERISTICS

- Extended frequency range
  - Up to 500 MHz
- Reduced EM interference and crosstalk
  - Enclosed concentric construction
  - EM fields terminate within cable
- Remaining limitations
  - Attenuation
  - Thermal and inter modulation noise (FDM)

COAXIAL CABLE TRANSMISSION CHARACTERISTICS

- Analog Transmission
  - Amplifiers every few kms
  - Closer amplifier spacing for higher operating frequencies

- Digital Transmission
  - Repeater every 1km
  - Closer repeater spacing for higher data rates

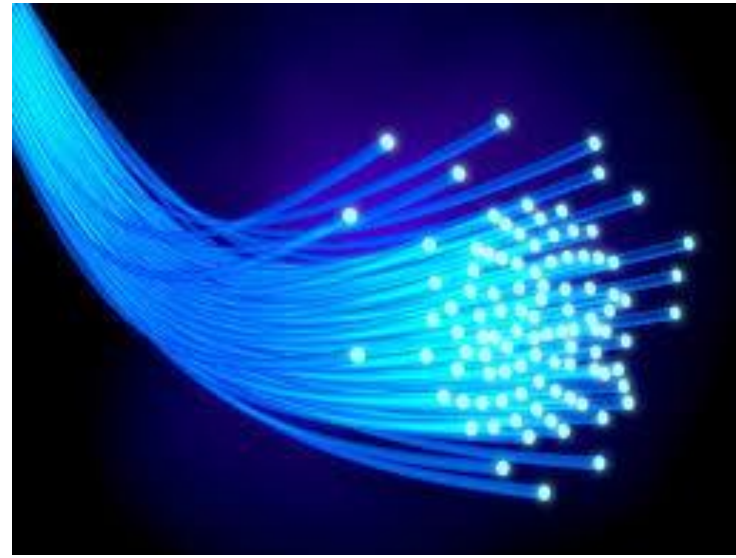
OUTLINE

Guided Media

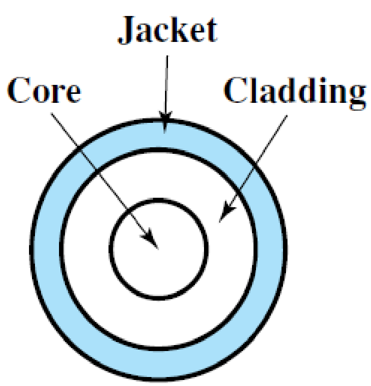
- Twisted Pair
- Coaxial Cable
- Optical Fiber

Unguided Media

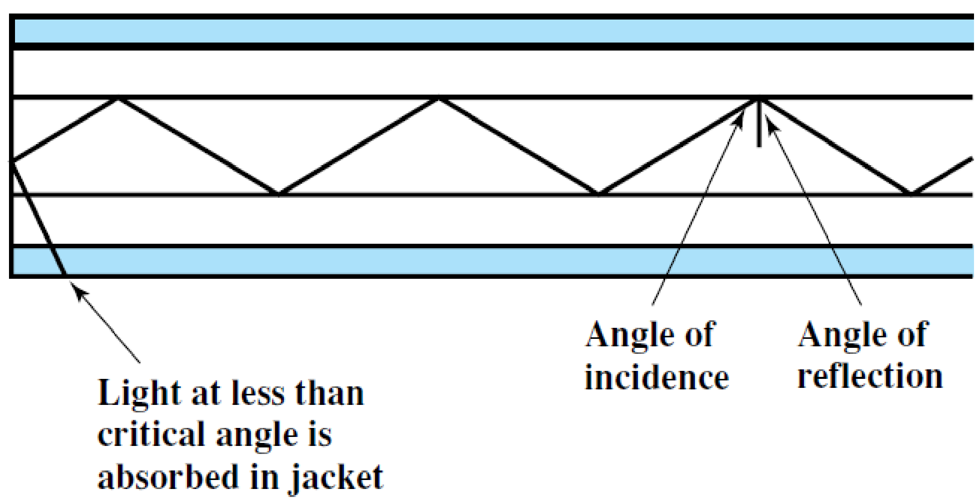
OPTICAL FIBER



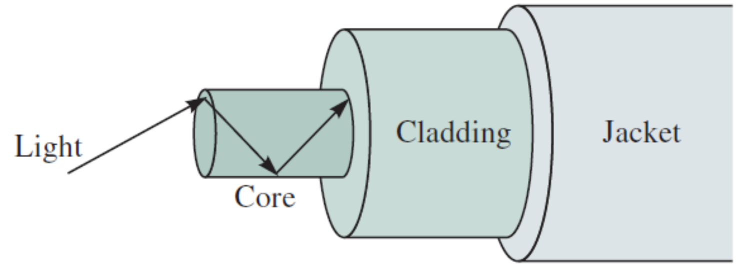
Diameter: 2 to 125 μm



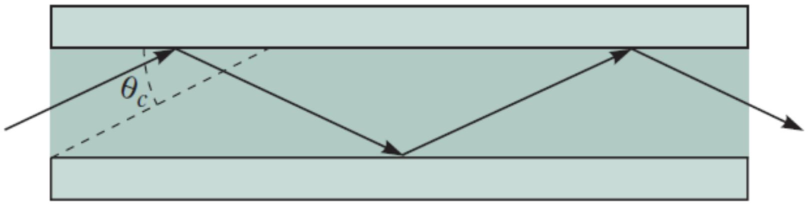
—Glass or plastic core
—Laser or light emitting diode
—Specially designed jacket
—Small size and weight



OPTICAL FIBER PARTS



- Core
  - Narrow cylindrical strand of glass/plastic
    - Refractive index n_1

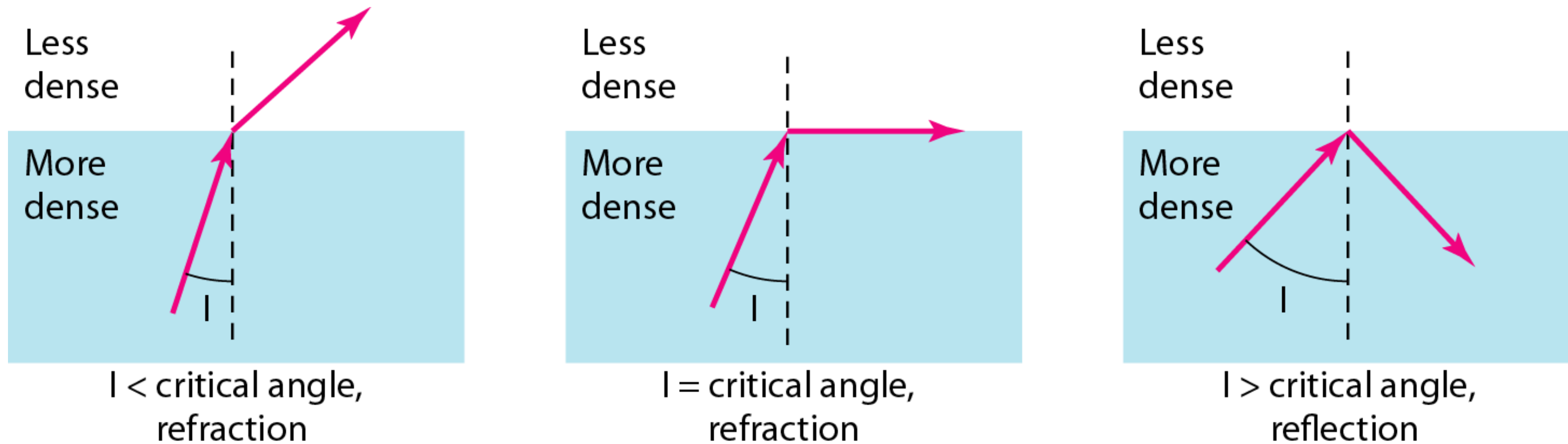


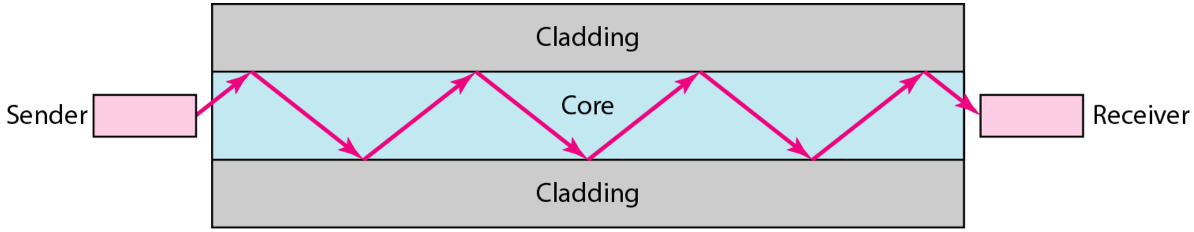
- Cladding
  - Tube surrounding each core
  - Refractive index n_2
- Protective outer jacket
  - Protecting against moisture, abrasion, crushing

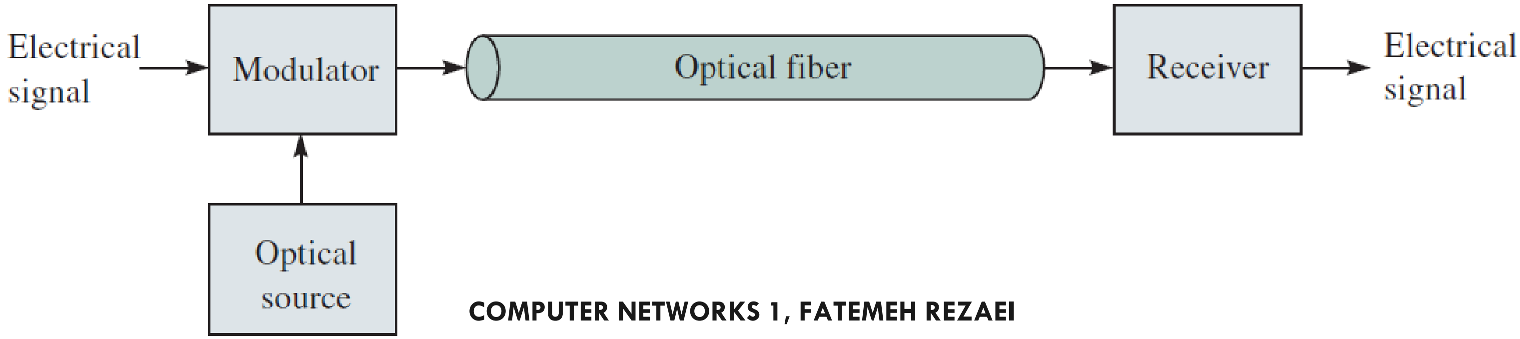
✓ To keep the light beam trapped inside

$$\mathbf{n_1 > n_2}$$

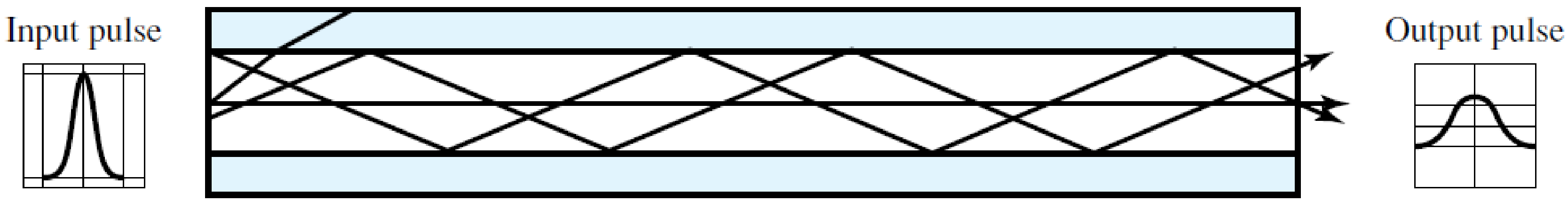
OPTICAL FIBER TRANSMISSION



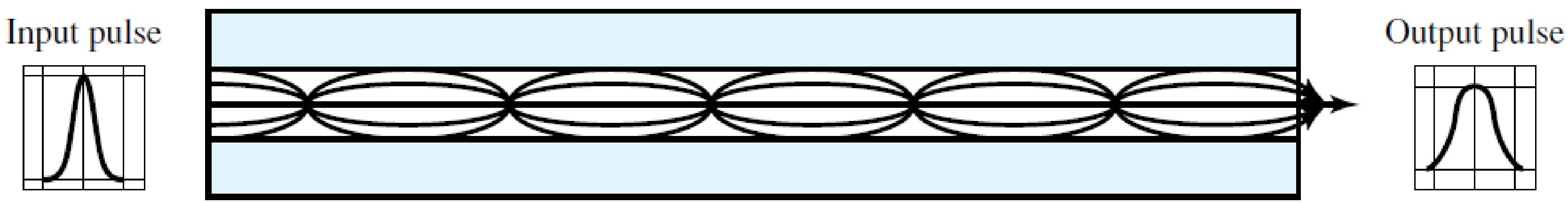




OPTICAL FIBER - TRANSMISSION MODES



(a) Step-index multimode

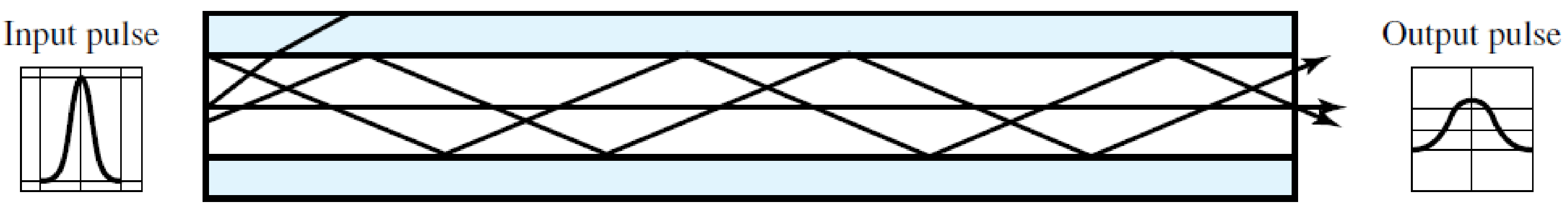


(b) Graded-index multimode

(c) Single mode

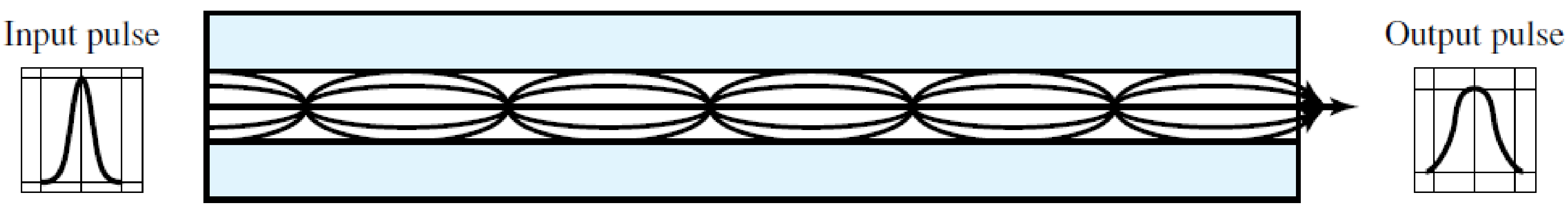
STEP- INDEX MULTIMODE TRANSMISSION

- Indexed multimode
  - Multiple propagation paths exist
    - Each with a different path length
    - Different time to traverse the fiber
  - Causing signal elements (light pulses) to spread out in time
    - Limiting the rate at which data can be accurately received
- Step- index
  - Variety of angles that will reflect



GRADED- INDEX MULTIMODE TRANSMISSION

- Changing the index of refraction of the core
- Higher refractive index at the center
  - Traveling more slowly than those near the cladding
- Not zig-zagging off the cladding, but curves helically
- Shortened path and higher speed
  - Almost similar time to traverse the fiber
- Often used in LANs



SINGLE MODE TRANSMISSION

- There is a single transmission path
- Distortion found in multimode cannot occur
- No spread out in time
- High data rates
- Very long distances

DISPERSION

- Propagation through multiple reflections at different angles of incidence

- Spread of received light pulse in time (dispersion)
  - Causes inter-symbol interference → bit errors
  - Limits usable data rate and transmission distance

DISPERSION

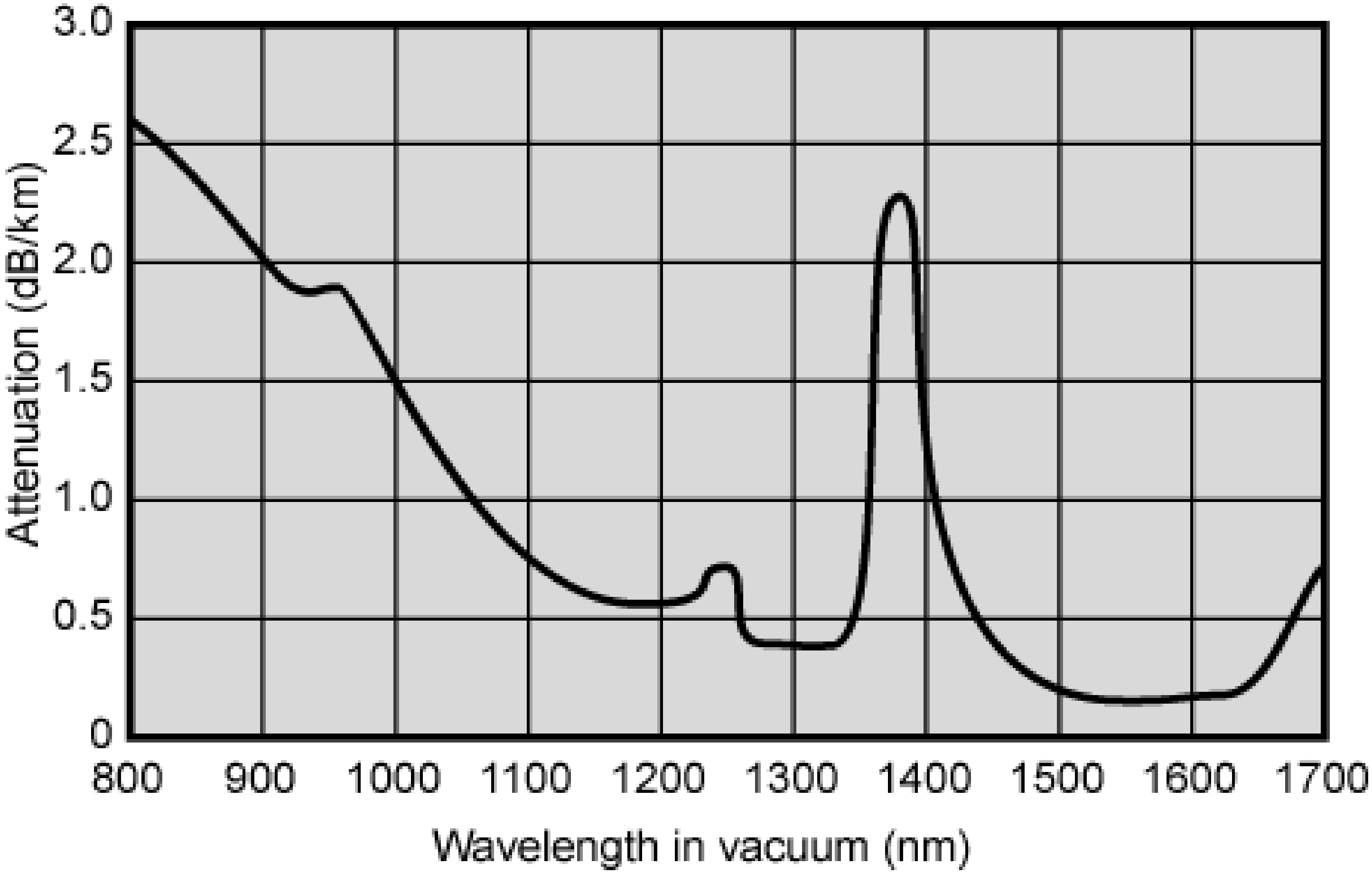
Increasing with

- Larger distance
- Thicker fibers with step index
- Less focused sources

Can be reduced by

- Limiting the distance
- Thinner fibers
- Highly focused light source
- Single mode fibers
- Graded-index multimode thicker fibers
  - The lower cost solution

ATTENUATION IN OPTICAL FIBER



FIBER TRANSMISSION WINDOWS

Wavelength (in vacuum) Range (nm)	Frequency Range (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	192 to 185	L	Single mode	WDM

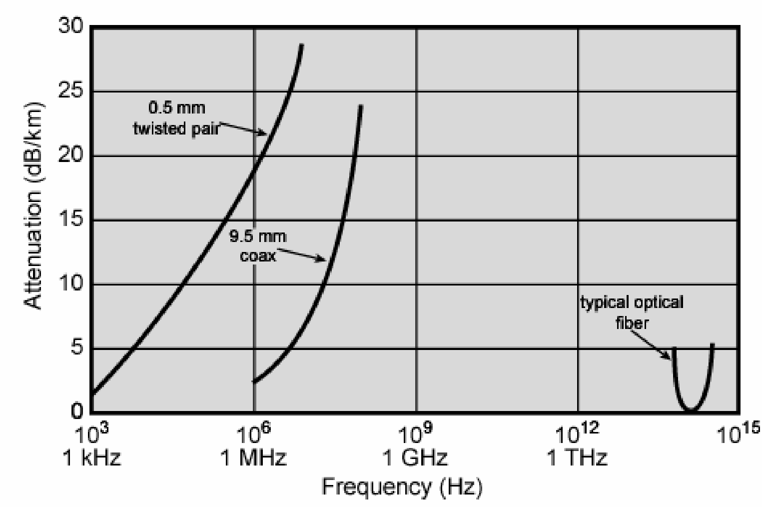
OPTICAL FIBER - BENEFITS

- Greater capacity
  - Fiber: 100's of Gbps over 10's of Kms
  - Coaxial Cable: 100's of Mbps over 1's of Kms
  - Twisted pair: 100's of Mbps over 10's of ms
- Lower/more uniform attenuation
  - An order of magnitude lower
  - Constant over a larger range of frequencies

OPTICAL FIBER - BENEFITS

- Electromagnetic isolation
  - Not affected by external EM fields
    - No interference, impulse noise, crosstalk
  - Does not radiate
    - Not a source of interference
    - Difficult to tap (data security)
- Smaller size and weight
  - An order of magnitude thinner for same capacity

TRANSMISSION CHARACTERISTICS OF GUIDED MEDIA



	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 μs/km	2 km
Twisted pairs (multipair 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

THz = TeraHertz = 10^{12} Hz

OUTLINE

Guided Media

- Twisted Pair
- Coaxial Cable
- Optical Fiber

Unguided Media

WIRELESS TRANSMISSION

- Introduction
- Antennas
- Terrestrial Microwave
- Satellite Microwave
- Broadcast Radio
- Infrared
- Wireless Propagation

WIRELESS TRANSMISSION

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WIRELESS TRANSMISSION

Transmission medium

- Free-space

Transmission/Reception

- By means of an antenna

WIRELESS TRANSMISSION WAVES

Radio wave 30 MHz to 1 GHz

- Multicast/broadcast communications
- Radio and television

Microwave 1 GHz to 40 GHz

- Unicast communication
- Cellular telephones
- Satellite networks
- Wireless LANs

Infrared 300 GHz to 200 THz

- Short-range communication
- Line-of-sight propagation

WIRELESS TRANSMISSION

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ANTENNAS

- Electrical conductor or system of conductors used for radiating or collecting electromagnetic energy
- Transmission
  - Radio frequency electrical energy from transmitter
  - Converted into electromagnetic energy
  - Radiated into surrounding space
- Reception
  - Electromagnetic energy impinging on antenna
  - Converted to radio frequency electrical energy

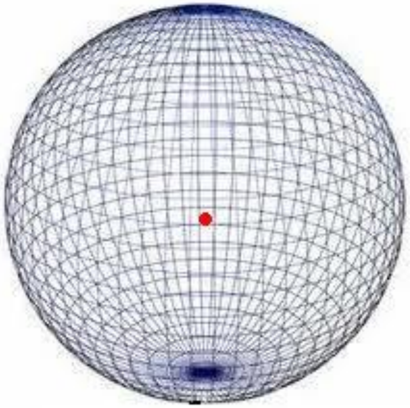
RADIATION PATTERNS

- Power transmitted in all directions but usually not with the same efficiency

- Radiation pattern
  - Graphical representation of radiation properties of an antenna
  - As a function of space coordinates

- Reception pattern
  - Receiving antenna’s equivalent to radiation pattern

ISOTROPIC ANTENNA

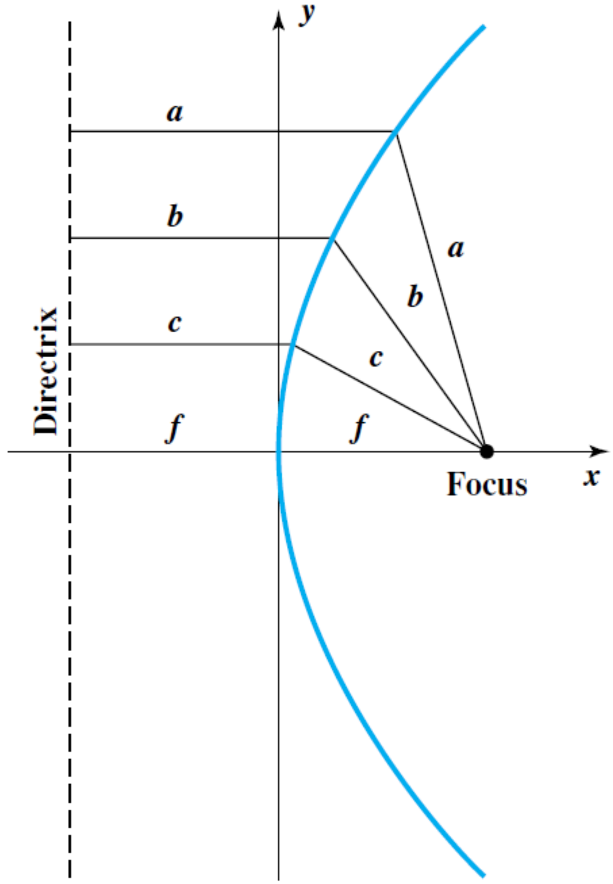


- An idealized antenna
- A point in space
- Radiating power in all directions equally
- Also called omnidirectional antenna
- Spherical radiation pattern

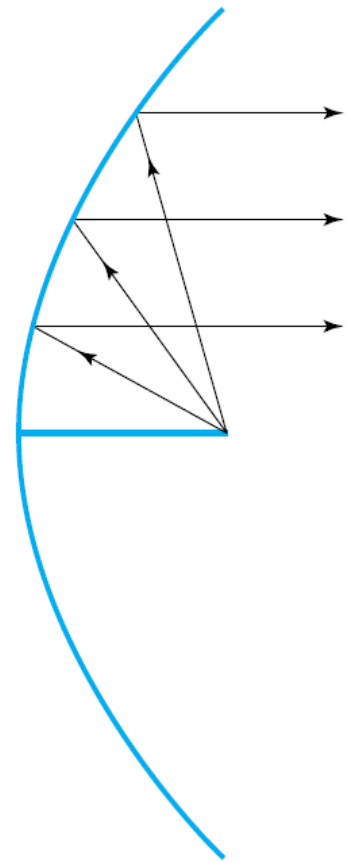
PARABOLIC REFLECTIVE ANTENNA

- An important type of antenna
- Terrestrial microwave and satellite applications
- If a source of electromagnetic energy is placed at the focus of the paraboloid reflecting surface
- The wave bounce back in lines parallel to the axis of the paraboloid

PARABOLIC REFLECTIVE ANTENNA



(a) Parabola



(b) Cross section of parabolic antenna showing reflective property

PARABOLIC REFLECTIVE ANTENNA

- On Transmission
  - In theory, creating a parallel beam without dispersion
  - Source of energy must occupy more than one point
  - In practice, there will be some dispersion
- On reception
  - If incoming waves are parallel to the axis of the reflecting paraboloid
  - The resulting signal will be concentrated at the focus

ANTENNA GAIN, G

- A measure of antenna directionality
- Power output of the antenna in a particular direction compared to that produced by a perfect omnidirectional (isotropic) antenna
- Can be expressed in decibels (dB, dBi)
- Antenna gain does not refer to obtaining more output power than input power, but rather to directionality
- Increased power radiated in one direction causes less power radiated in another direction (Total power is fixed)

ANTENNA GAIN, G

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

- A_e: Effective area
  - Related to size and shape of antenna
  - Determines the antenna gain
- Gain in dB = 10 log G

ANTENNA GAIN, EFFECTIVE AREAS

- Isotropic antenna

$$A_e = \frac{\lambda^2}{4\pi} \qquad G = \frac{4\pi A_e}{\lambda^2} = 1 \quad (0 \ \ dB)$$

- Parabolic antenna

$$A = Actual\ Area = \pi\, r^2 \qquad A_e = 0.56A$$

$$G = \frac{4\pi(0.56A)}{\lambda^2} \approx \frac{7A}{\lambda^2}$$

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TERRESTRIAL MICROWAVE

- Parabolic dish
- A typical size: 3 m in diameter
- Focused beam
- Line of sight requirement
  - Beam should not be obstructed
  - Curvature of earth limits maximum range
    - Use relays to increase range (multi-hop link)

TERRESTRIAL MICROWAVE APPLICATIONS

- Long haul telecommunications
  - Channels over long distances between large cities
  - An alternative to coaxial cable or optical fiber
  - Intermediate relays
- Short wireless links between buildings
- Cellular Telephony

TERRESTRIAL MICROWAVE TRANSMISSION PROPERTIES

- 1 - 40 GHz
- Higher f Advantages
  - Larger bandwidth
    - Higher data rate
  - Smaller λ
    - Smaller (lighter, cheaper) antenna for an antenna gain

Band (GHz)	Bandwidth (MHz)	Data Rate (Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

- Higher f Disadvantages
  - Larger attenuation due propagation and absorption by rain

TERRESTRIAL MICROWAVE TRANSMISSION TRADEOFF

- Long-haul links
  - Long distances
  - To avoid large attenuation
  - Operating at lower frequencies (4-6 GHz,11 GHz)
- Short links between close-by buildings
  - Attenuation is not a big problem for the short distances
  - Operating at higher frequencies (e.g. 22 GHz)
  - Smaller antenna size

WIRELESS TRANSMISSION

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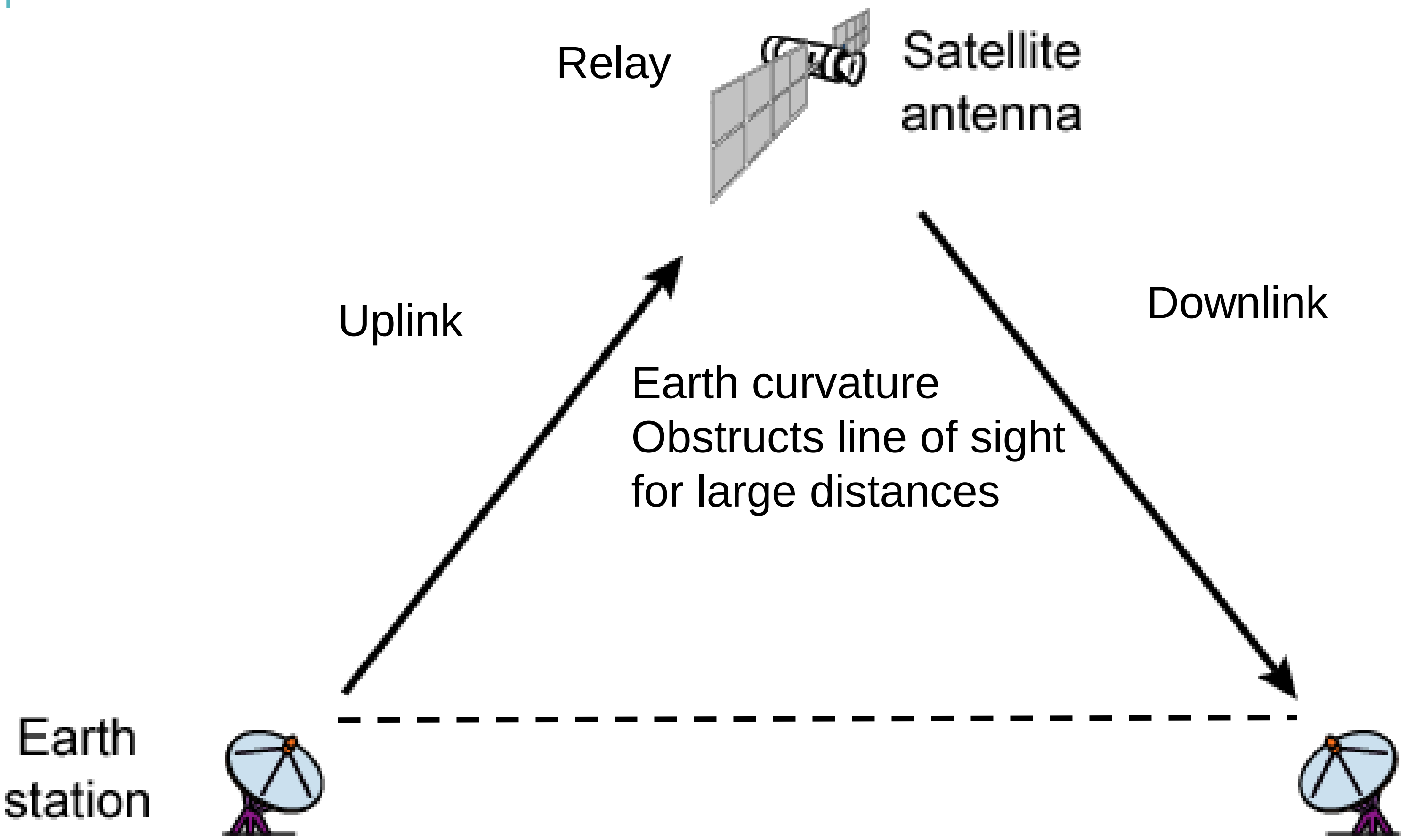
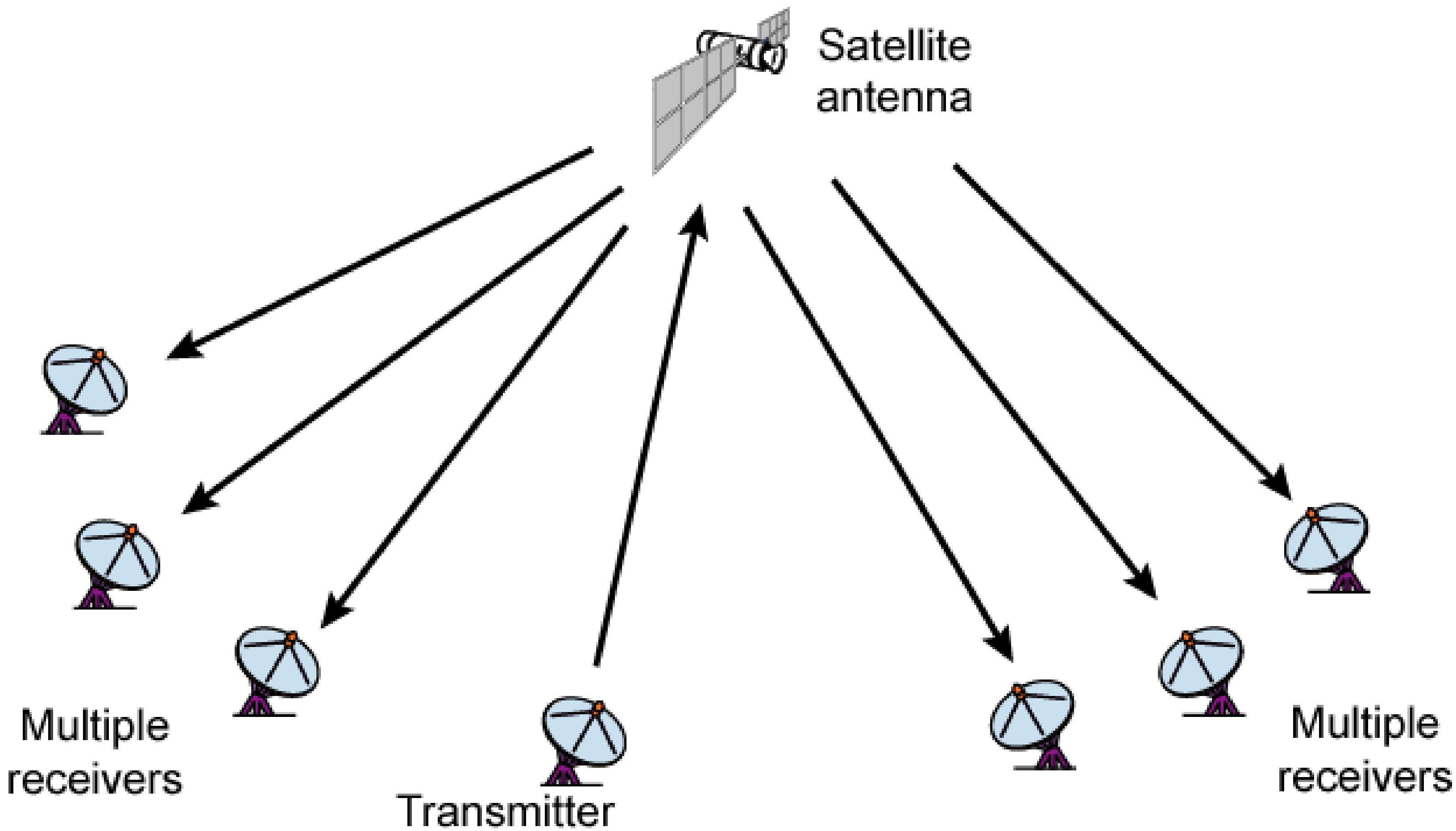
SATELLITE MICROWAVE

- Satellite acts as a relay station
- Receives on one frequency (uplink)
- Amplifies or repeats signal
- Retransmits it on another frequency (downlink)
- To avoid interference from neighboring TXs
  - Spatial angular separation (e.g. 3^{o})

SATELLITE POINT TO POINT LINK



SATELLITE BROADCAST LINK



SATELLITE MICROWAVE

- Require a geo-stationary orbit
  - Satellite rotates at the same speed of earth rotation
  - Appearing stationary
  - Being in the line of site of Earth stations
  - Height: 35,784 km
  - Long link, large transmission delays
- Applications
  - Television distribution
  - Long-distance telephone transmission
  - Private business networks
  - Global positioning

SATELLITE MICROWAVE TRANSMISSION CHARACTERISTICS

- 1 - 10 GHz
- Lower frequencies
  - More noise and interference
- Higher frequencies
  - Larger rain attenuation
  - Smaller antennas
- Delay = 0.25 s
  - Noticeable for telephony
- Inherently a broadcasting facility

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BROADCAST RADIO

- 30 MHz – 1 GHz
- Omni directional
  - No need for antenna directionality
  - No dishes
  - No line of sight requirement
  - No antenna alignment requirement/problems
- Applications
  - FM radio
  - UHF and VHF television

BROADCAST RADIO CHARACTERISTICS

- Choice of frequency range
- Reflections from ionosphere < 30 MHz -1 GHz < Rain
- Propagation attenuation Lower than Microwaves (λ larger)

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

- Problems
  - Multi-path Interference
    - TV reception displays multiple images as an airplane passes

WIRELESS TRANSMISSION

- Introduction
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- Broadcast Radio
- **Infrared**
- Wireless Propagation

INFRARED

- Data Modulates an infrared light
- Relies on line of sight (or reflections through walls or ceiling)
- Blocked by walls (unlike microwaves)
- No licensing required for frequency allocation
- Applications
  - TV remote control
  - Wireless LAN within a room

WIRELESS TRANSMISSION

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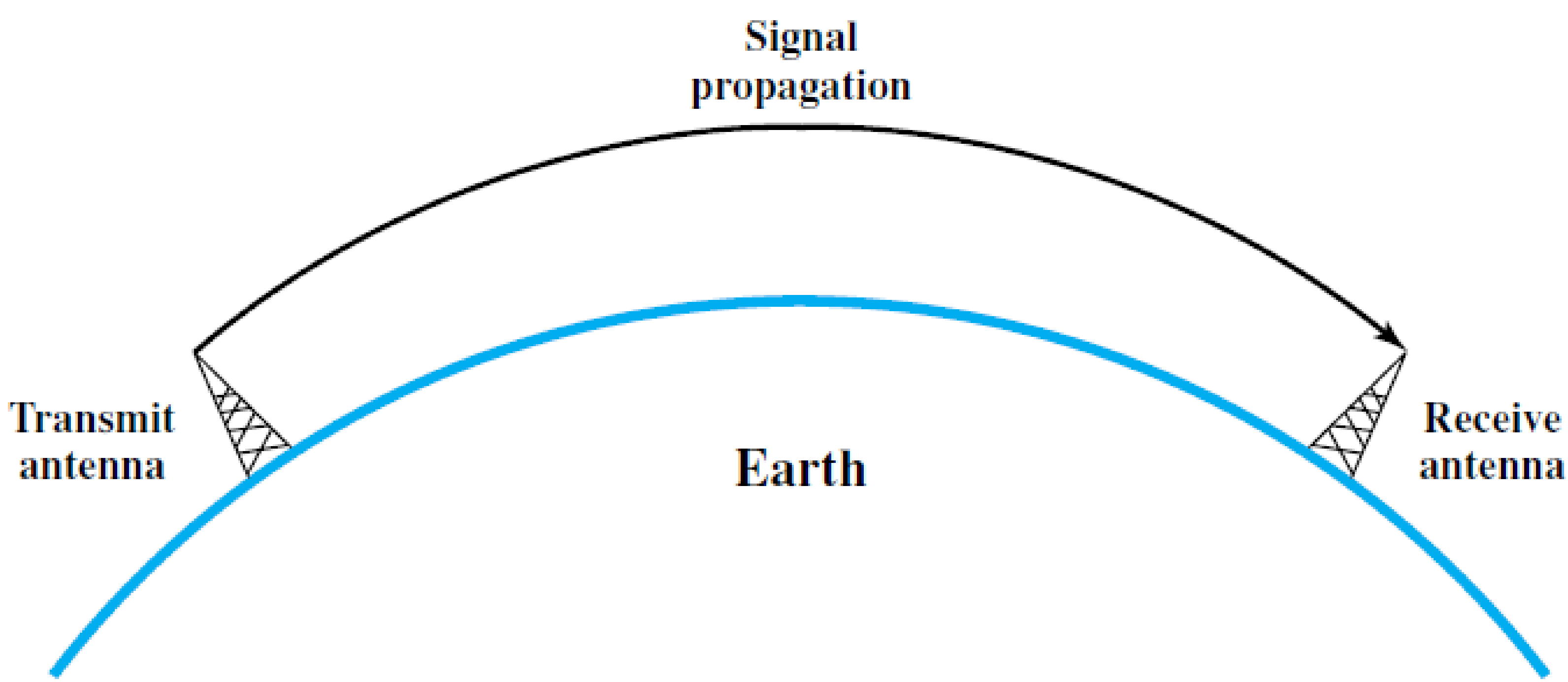
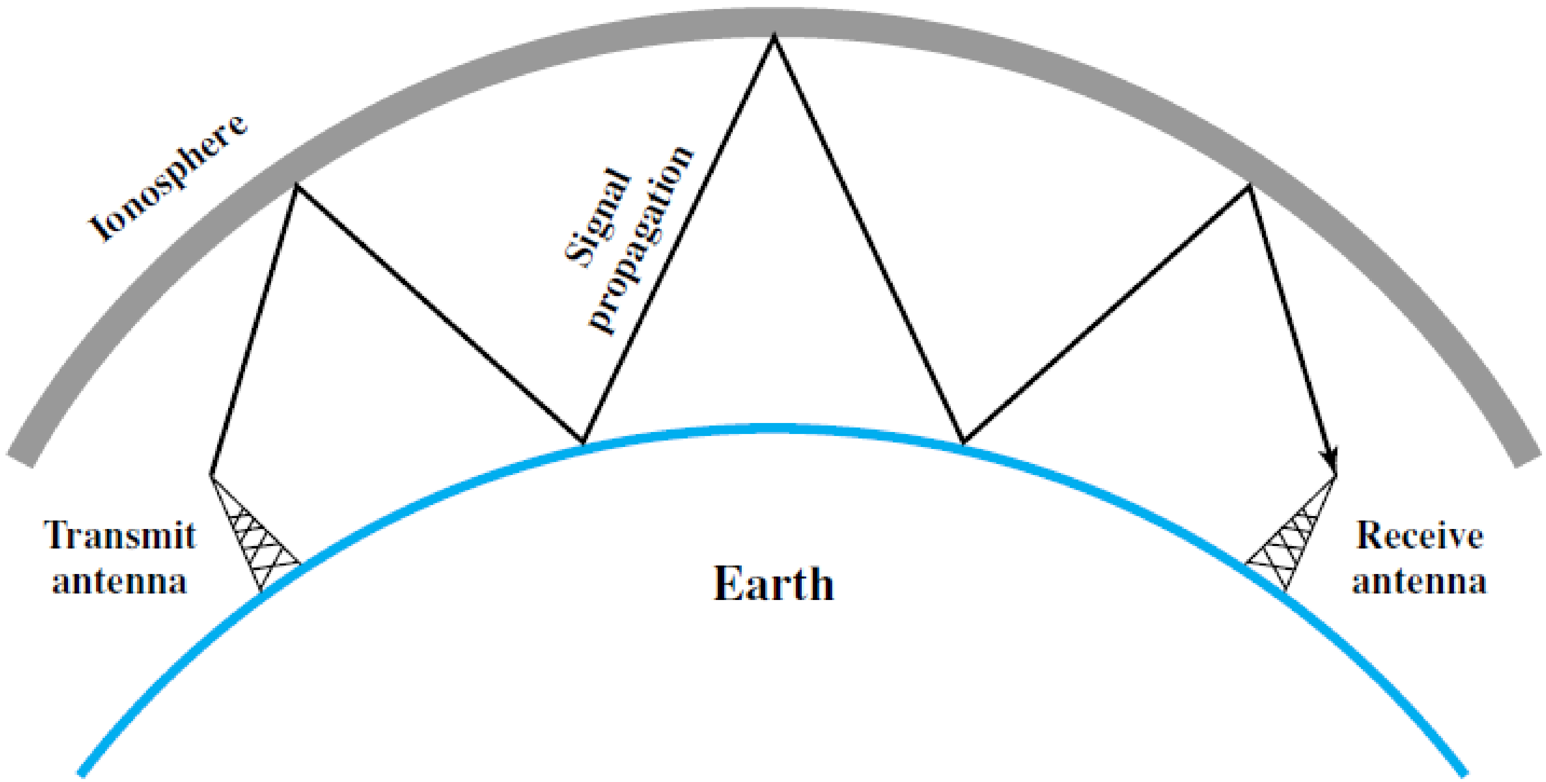
WIRELESS PROPAGATION
GROUND WAVE



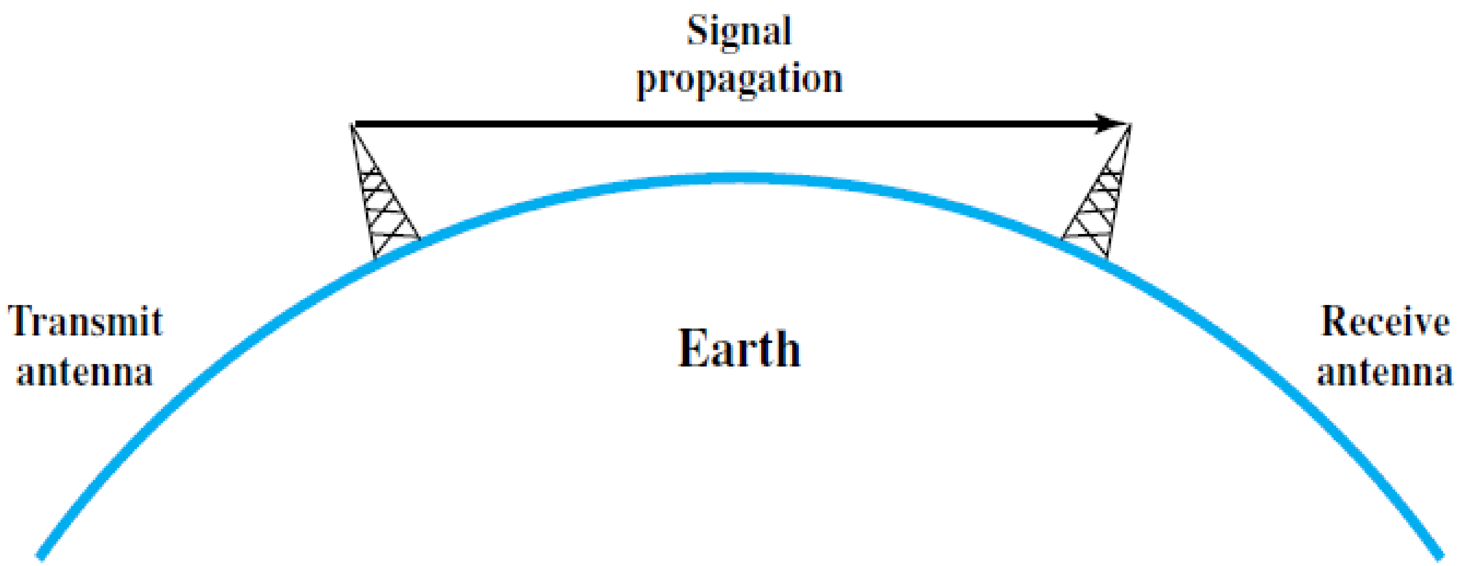
(a) Ground wave propagation (below 2 MHz)

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)

LINE OF SIGHT TRANSMISSION IMPAIRMENTS

- 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

- For ideal isotropic antenna

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

- P_t = signal power at transmitting antenna
- P_r = signal power at 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)

FREE SPACE LOSS

- Free space loss equation can be recast:

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

$$= -20\log(\lambda) + 20\log(d) + 21.98\,\text{dB}$$

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

FREE SPACE LOSS

- Free space loss for other antennas

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

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

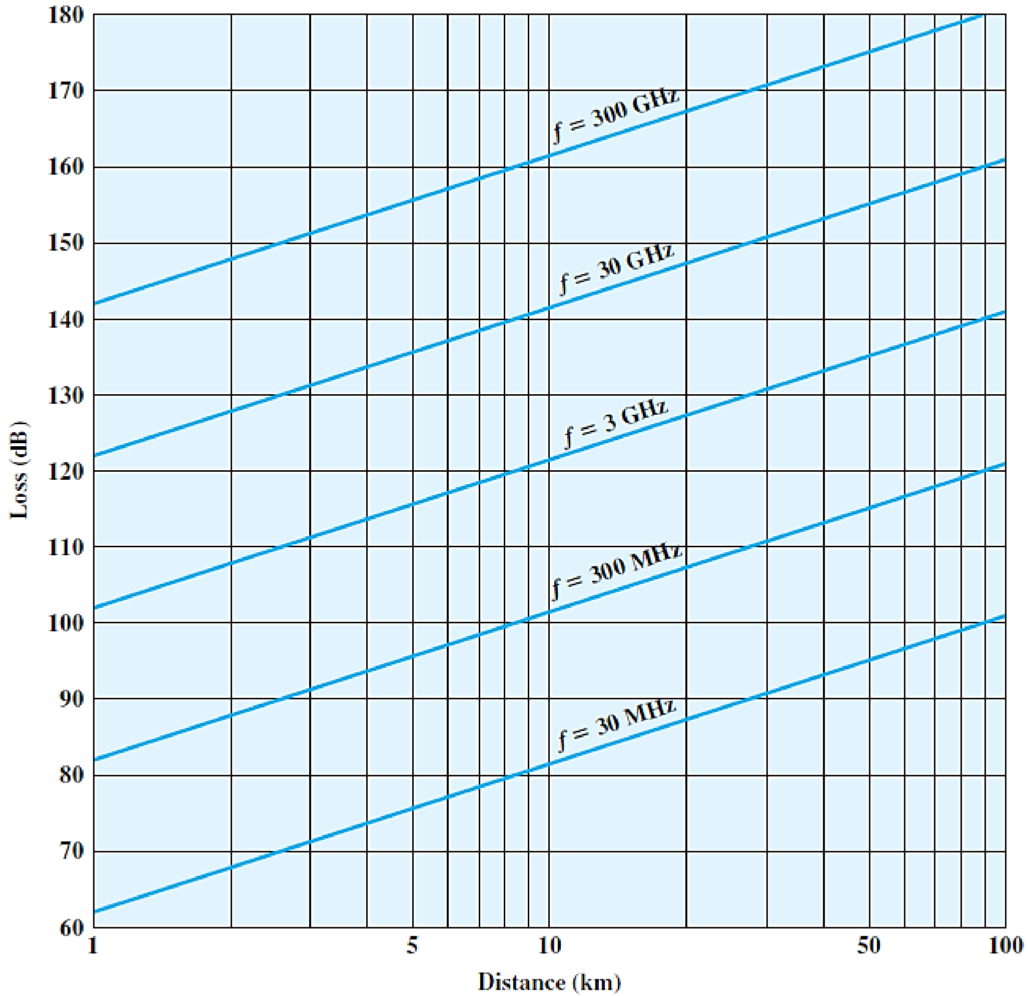
FREE SPACE LOSS

- Free space loss for other antennas can be recast as

$$L_{dB} = 20\log(\lambda) + 20\log(d) - 10\log(A_t A_r)$$

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

FREE SPACE LOSS

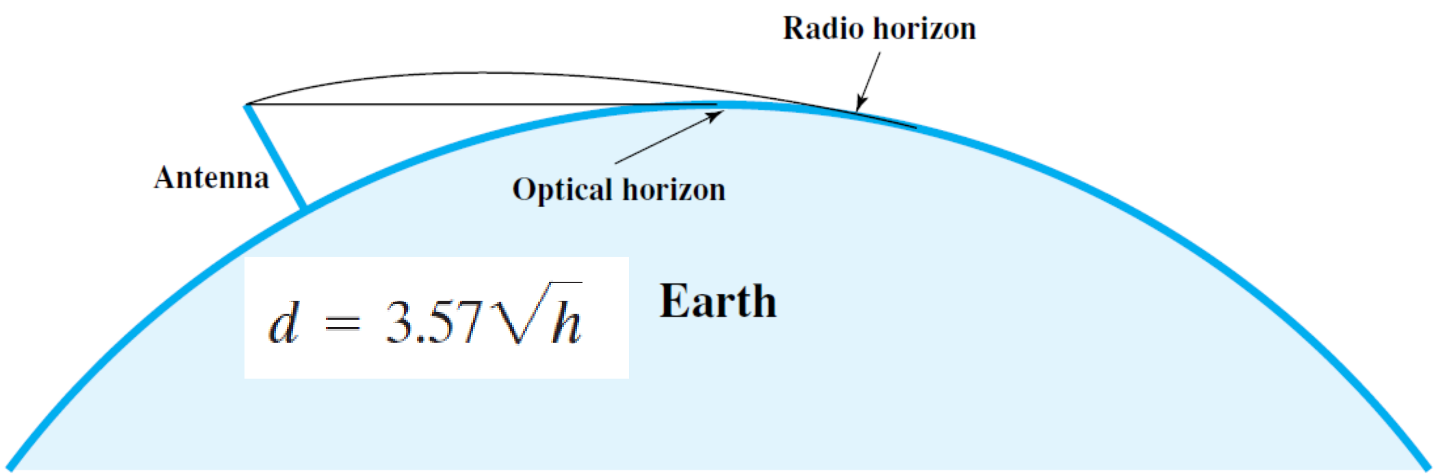


REFRACTION

- 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
- Density of atmosphere decreases with height
- Results in bending towards earth of radio waves
- Optical and radio horizons differ

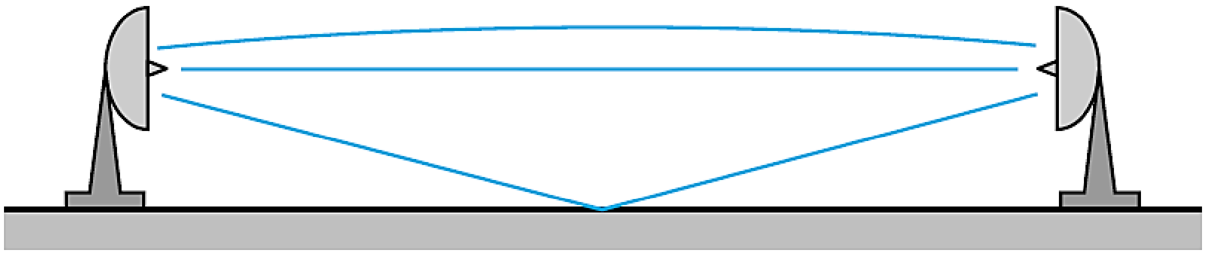
OPTICAL AND RADIO HORIZONS

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

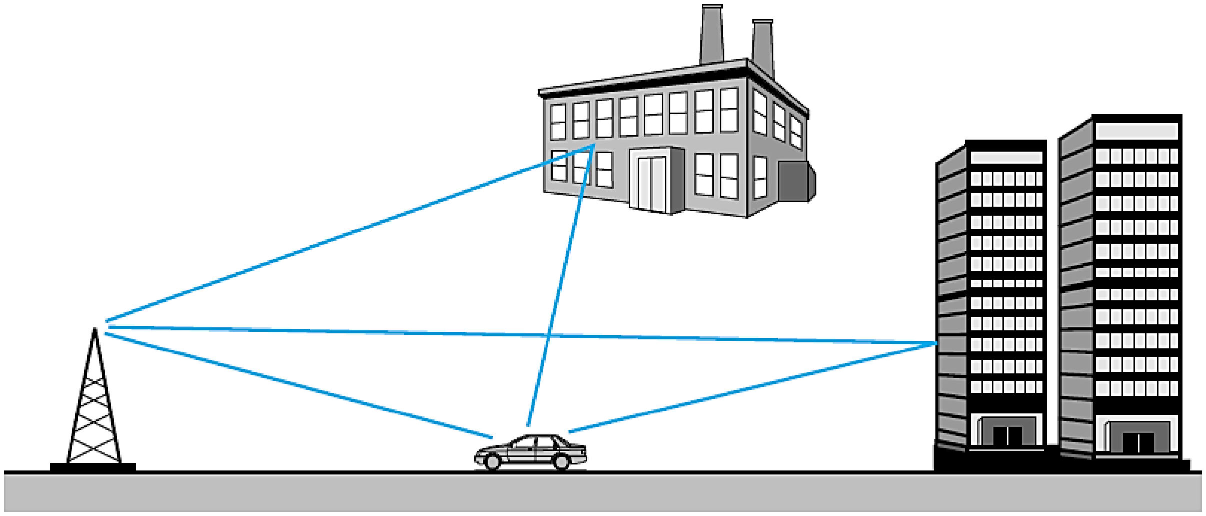


d : Distance between an antenna and the horizon in kilometers
h : Antenna height in meters

MULTIPATH INTERFERENCE



(a) Microwave line of sight



(b) Mobile radio

THE EFFECTS OF MULTIPATH PROPAGATION

- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

WIRELESS & WIRED MEDIA

Wired Media

- Signal energy guided within medium
- Spectrum can be reused in separate media (wires or cables)
- More scalable
- Extremely high bandwidth
- Complex infrastructure

Wireless Media

- Signal energy propagates in space
- Interference possible, so spectrum regulated
- Limited bandwidth
- Simple infrastructure: antennas & transmitters
- No physical connection between network & user
- Mobility