CNL
Communications & Networking
Laboratory

ECE 462 – Data and Computer Communications

Lecture 5-6: Transmission Media

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Outline

- Guided and Unguided
- Wireless transmission
- Wireless Propagation
- Line of Sight

Note: Some material adapted from various textbook. In particular, the sequences of slides have been sorted to match closely that of the textbook Data and Computer Communications by W. Stallings, 7th Edition, Prentice Hall, 2007

Physical Media

- Bit: propagates between transmitter/rcvr pairs
- physical link: what lies between transmitter & receiver
- guided media:
  - signals propagate in solid media: copper, fiber, coax
- unguided media:
  - signals propagate freely, e.g., radio

Guided Transmission Media

- Twisted Pair
- Coaxial cable
- Optical fiber

Physical media: radio

- signal carried in electromagnetic spectrum
- no physical “wire”
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

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 (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

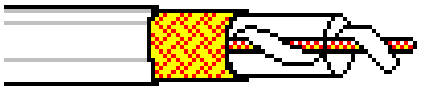
Physical Media Twisted Pair (TP)

- Two insulated copper wires
- Two separately insulated wires
- Often budled into cabels
- Types
  - Category 3: traditional phone wires, 10 Mbps Ethernet
  - Category 5 TP: 100Mbps Ethernet

Twist length

Physical Media: coax cable

- Two concentric copper conductors
- bidirectional
- baseband:
  - single channel on cable
  - legacy Ethernet
- broadband:
  - multiple channel on cable
  - HFC



Physical Media: Fiber Optic Cable

- Glass fiber carrying light pulses, each pulse a bit
- high-speed operation:
  - high-speed point-to-point transmission (e.g., 5 Gbps)
- low error rate: repeaters spaced far apart; immune to electromagnetic noise

Design Factors

- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - Attenuation
- Interference
- Number of receivers
  - In guided media
  - More receivers (multi-point) introduce more attenuation

Twisted Pair - Applications

- Most common medium
- Telephone network
  - Between house and local exchange (subscriber loop)
- Within buildings
  - To private branch exchange (PBX)
- For local area networks (LAN)
  - 10Mbps or 100Mbps

Twisted Pair –advantages and disadvantages

- Easy to work with
- Inexpensive
- Short range
- Low data rate

Near End Crosstalk

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

Unshielded and 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)

UTP Categories

- Cat 3
  - up to 16MHz
  - Voice grade found in most offices
  - Twist length of 7.5 cm to 10 cm
- Cat 4
  - up to 20 MHz
- Cat 5
  - up to 100MHz
  - Commonly pre-installed in new office buildings
  - Twist length 0.6 cm to 0.85 cm
- Cat 5E (Enhanced) –see tables
- Cat 6
- Cat 7

Comparison of Shielded and Unshielded Twisted Pair

	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

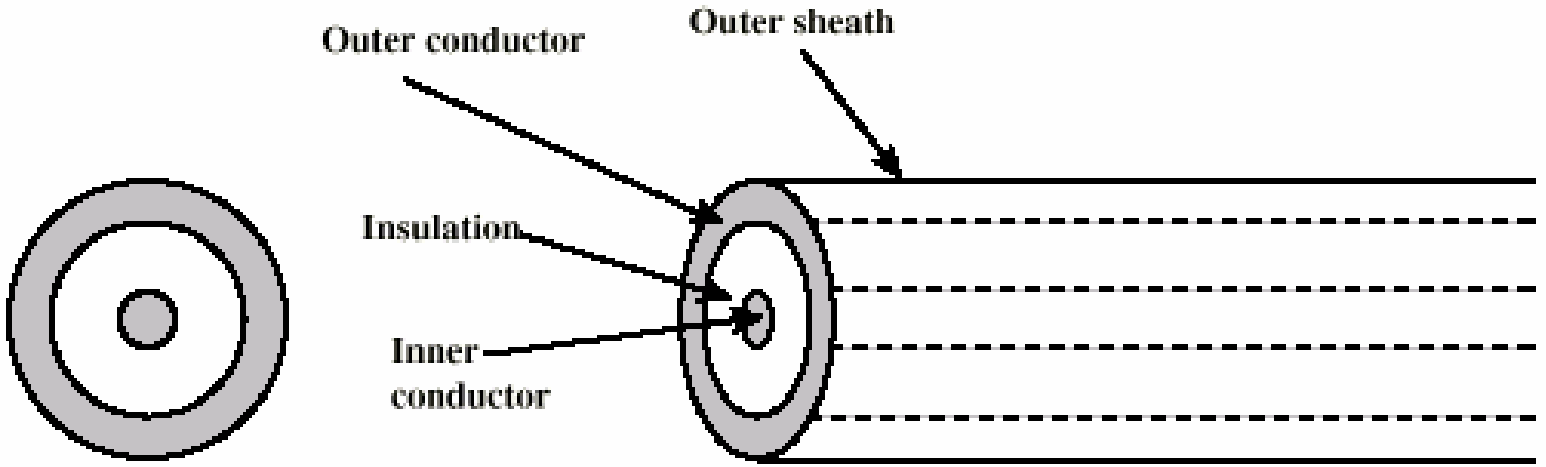
Twisted Pair - Transmission Characteristics

- Analog
  - Amplifiers every 5km to 6km
- Digital
  - Use either analog or digital signals
  - repeater every 2km or 3km
- Limited distance
- Limited bandwidth (1MHz)
- Limited data rate (100MHz)
- Susceptible to interference and noise

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

Coaxial Cable



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

Coaxial Cable Applications

- Most versatile medium
- Television distribution
  - Ariel to TV
  - Cable TV
- Long distance telephone transmission
  - Can carry 10,000 voice calls simultaneously
  - Being replaced by fiber optic
- Short distance computer systems links
- Local area networks

Coaxial Cable - Transmission Characteristics

- Analog
  - Amplifiers every few km
  - Closer if higher frequency
  - Up to 500MHz
- Digital
  - Repeater every 1km
  - Closer for higher data rates

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

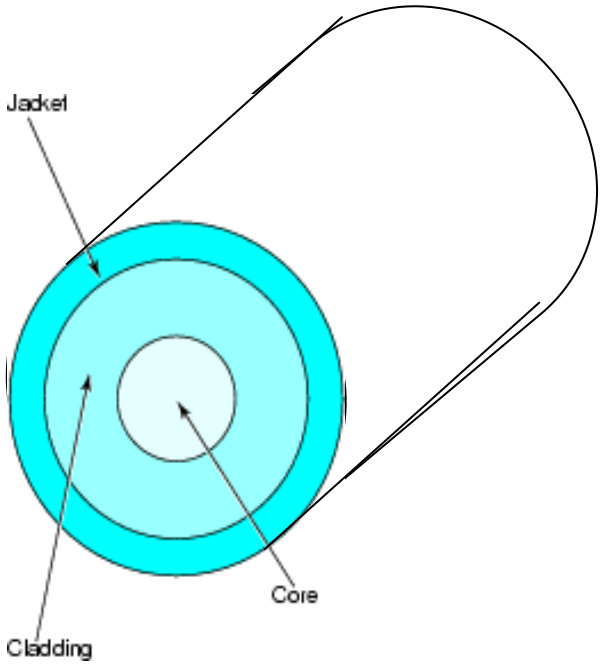
Optical Fiber - Applications

- Long-haul trunks
- Metropolitan trunks
- Rural exchange trunks
- Subscriber loops
- LANs

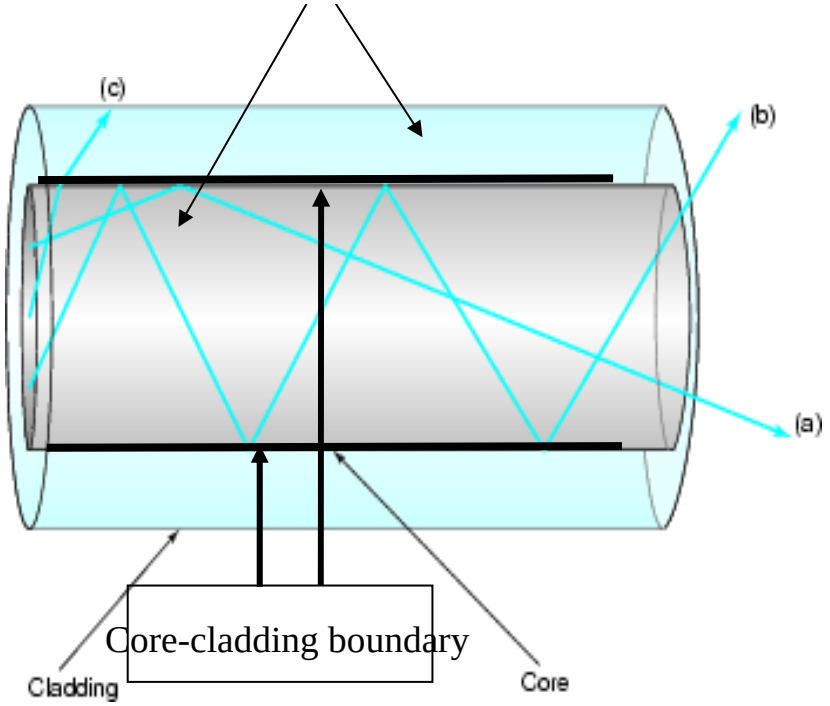
Optical Fiber Transmission Medium

- A fiber optic cable is a coaxial arrangement of glass or plastic material of immense clarity (i.e., highly transparent)
- Information is carried through a fiber optic cable by transmitting pulses of light
- A clear cylinder of optical material called the ***core*** is surrounded by another clear wrapper of optical material called the ***cladding***
- These two materials are selected to have different ***indices of refraction***
- The fiber is surrounded by a plastic or teflon ***jacket*** to protect and stiffen the fiber
- Light is guided through the optical fiber by continual reflection from the core-cladding boundary
- This is made possible due to the different refractive indices of the core and cladding materials
- The ***index of refraction (n)*** of a material affects the angle by which a light ray is bent while passing through the material
- If the light incident on the core-cladding boundary is at a suitable angle, then the light will be totally reflected from the boundary. This is called ***total internal reflection***

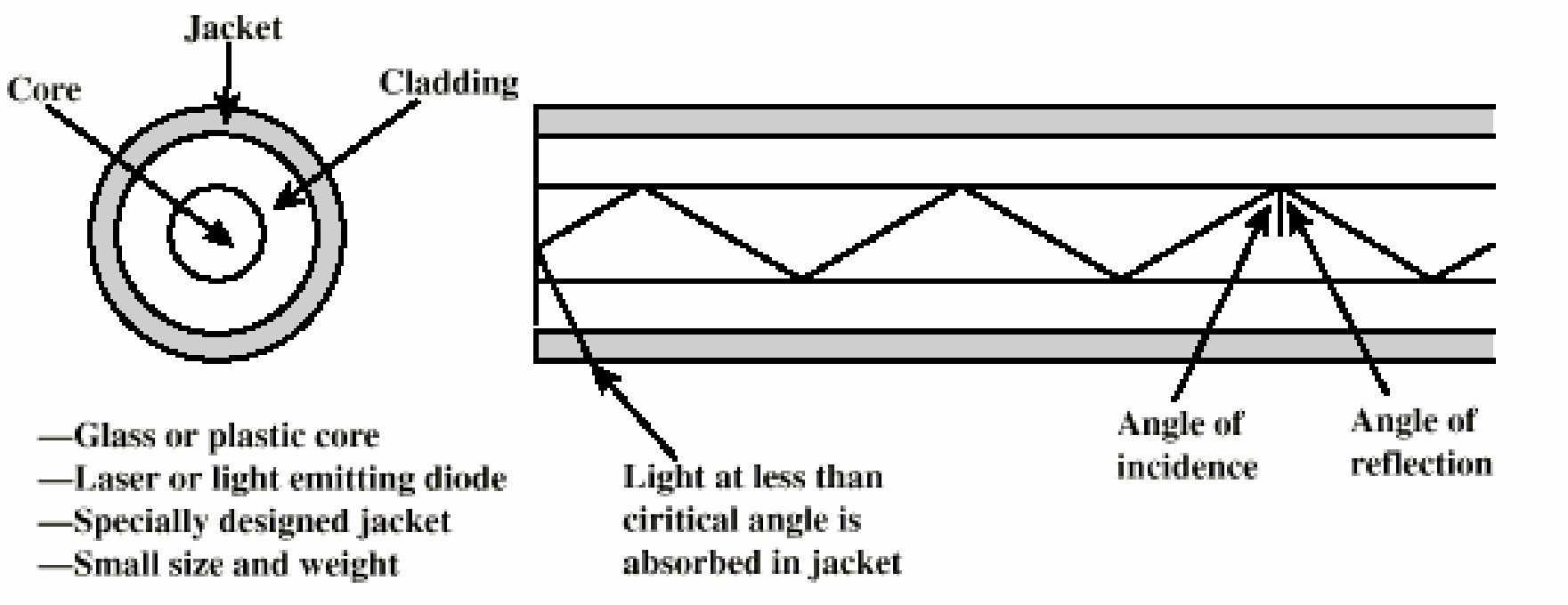
Fiber Optic Cable



Core and cladding with different indices of refraction



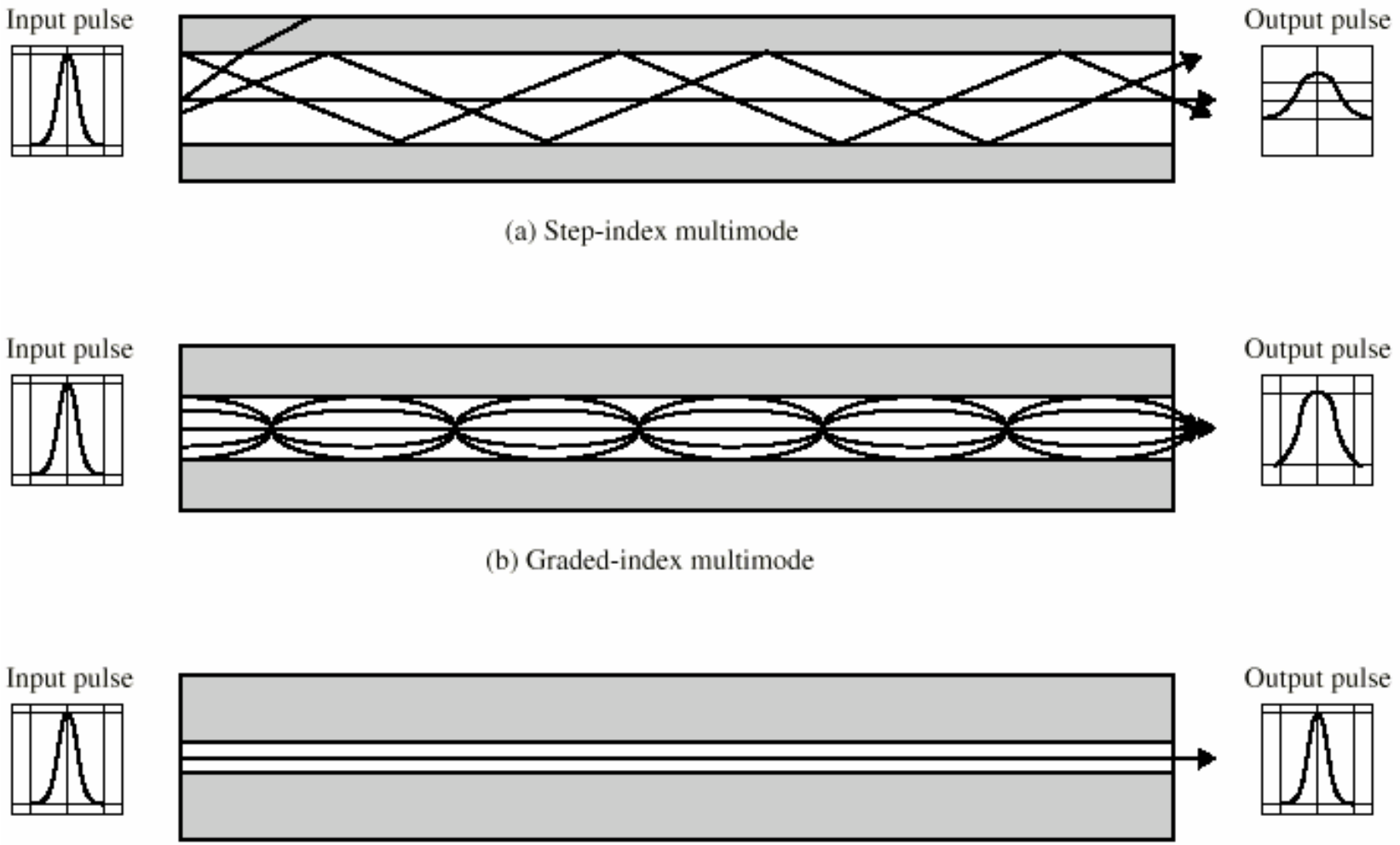
Optical Fiber



Optical Fiber - Transmission Characteristics

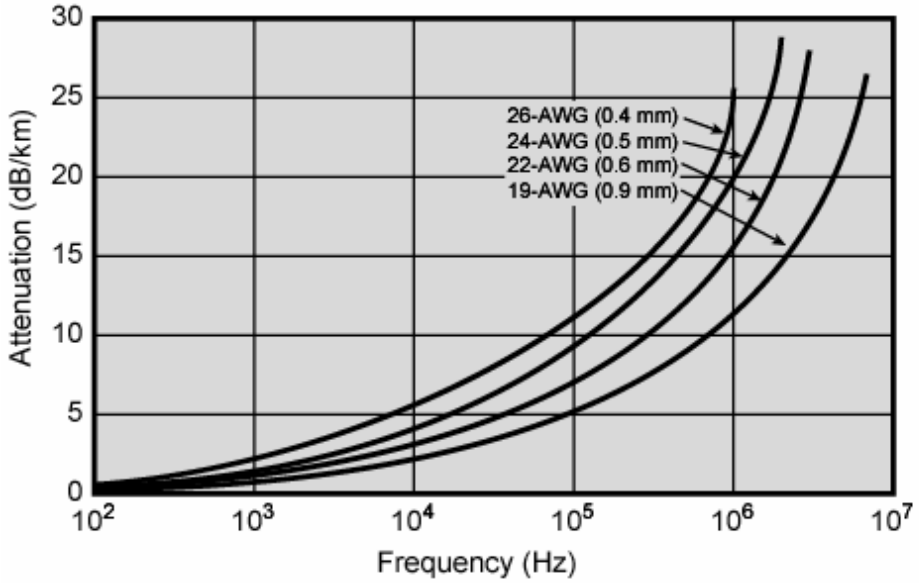
- Act as wave guide for 10^{14} to 10^{15} Hz
  - Portions of infrared and visible spectrum
- Light Emitting Diode (LED)
  - Cheaper
  - Wider operating temp range
  - Last longer
- Injection Laser Diode (ILD)
  - More efficient
  - Greater data rate
- Wavelength Division Multiplexing

Optical Fiber Transmission Modes

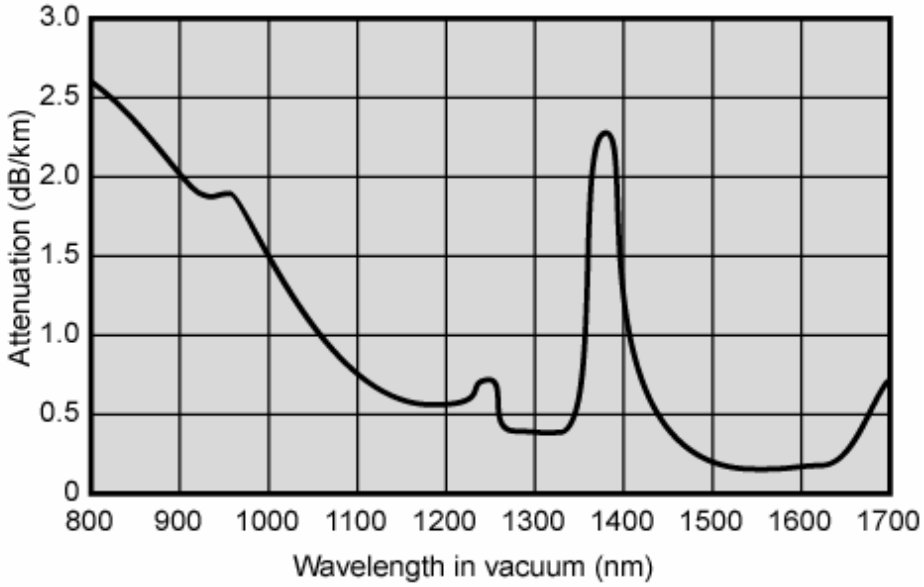


Frequency Utilization for Fiber Applications

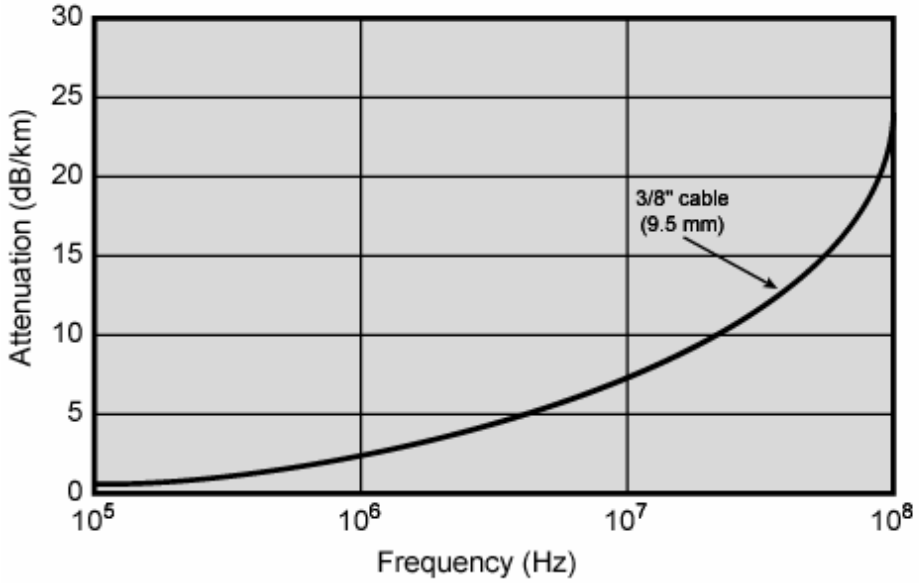
Wavelength (in vacuum) range (nm)	Frequency range (THz)	Band label	Fiber type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	185 to 192	L	Single mode	WDM



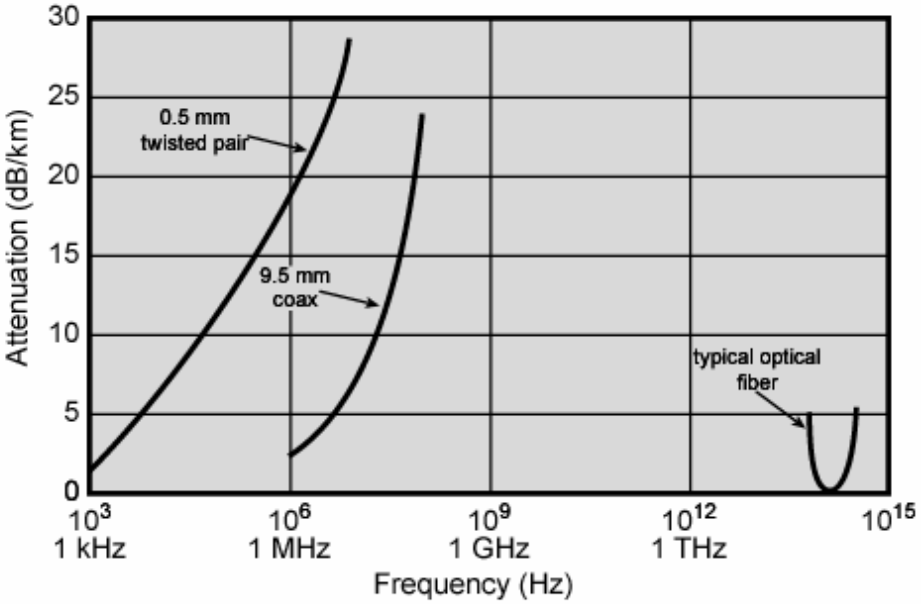
(a) Twisted pair (based on [REEV95])



(c) Optical fiber (based on [FREE02])

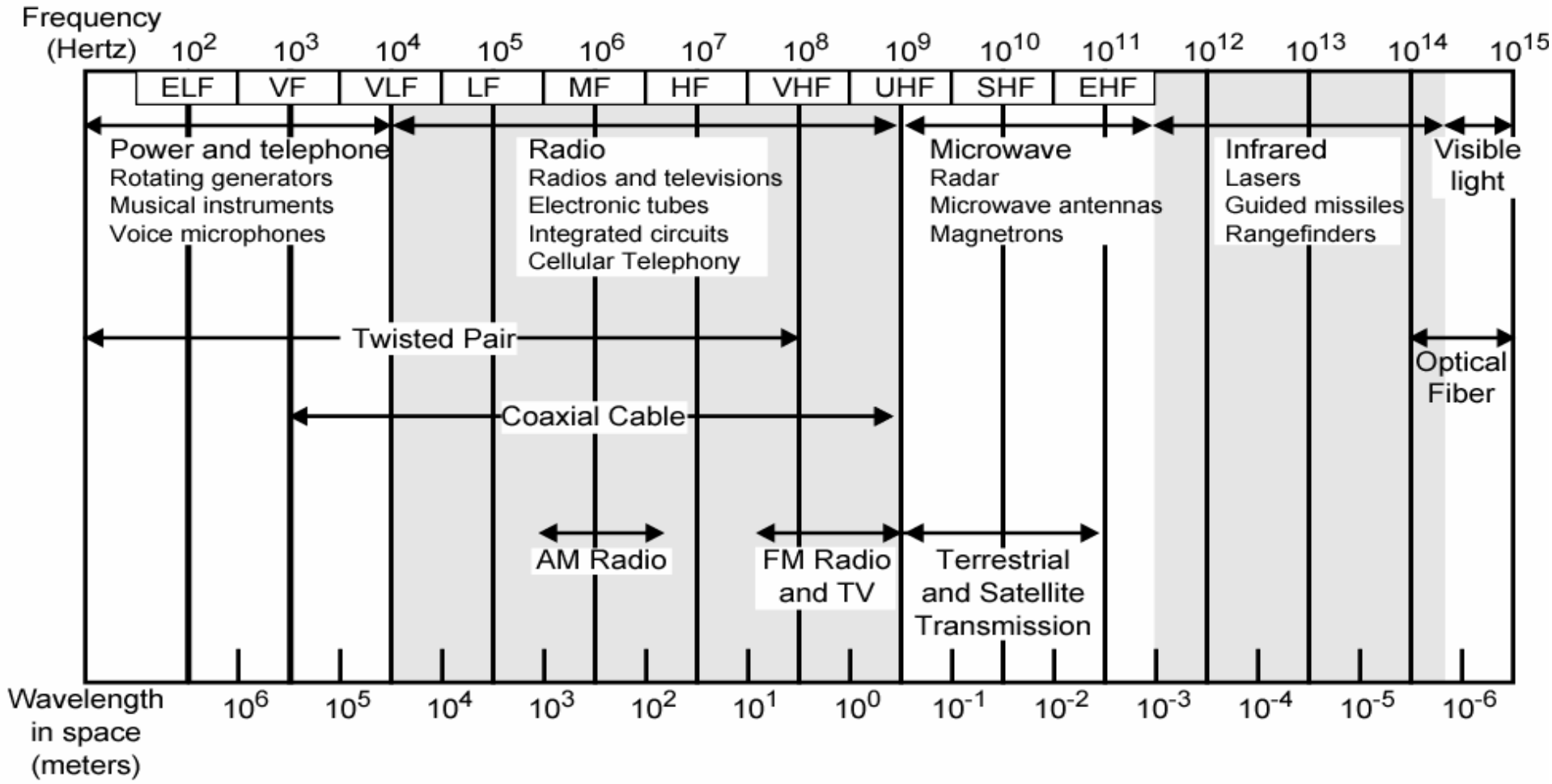


(b) Coaxial cable (based on [BELL90])



(d) Composite graph

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

Physical media: radio link types

- Terrestrial microwave
  - e.g. up to 45 Mbps channels
- LAN (e.g., WaveLAN)
  - 2Mbps, 11Mbps
- wide-area (e.g., cellular)
  - e.g. 3G: hundreds of kbps
- satellite
  - up to 50Mbps channel (or multiple smaller channels)
  - 270 msec end-end delay
  - geosynchronous versus LEOS

Wireless Transmission Frequencies

- 2GHz to 40GHz
  - Microwave
  - Highly directional
  - Point to point
  - Satellite
- 30MHz to 1GHz
  - Omnidirectional
  - Broadcast radio
- 3×10^{11} to 2×10^{14}
  - Infrared
  - Local

Radiation Pattern

- Power radiated in all directions
- Not same performance in all directions
- Isotropic antenna is (theoretical) point in space
  - Radiates in all directions equally
  - Gives spherical radiation pattern

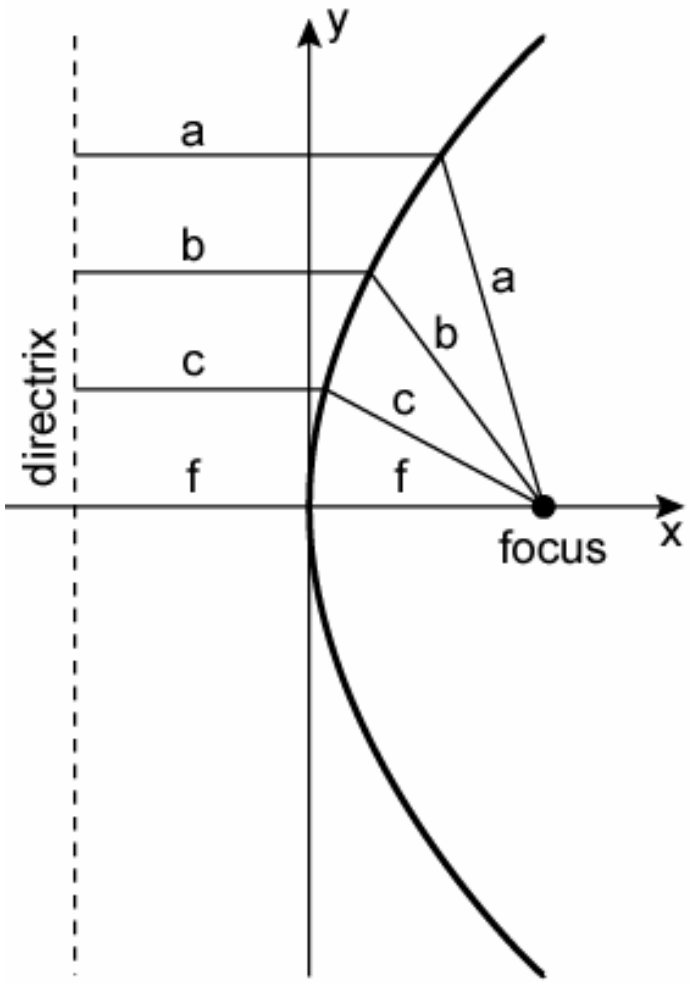
Antennas

- Electrical conductor used to radiate electromagnetic energy or collect electromagnetic energy
- Transmission
  - Radio frequency energy from transmitter
  - Converted to electromagnetic energy by antenna
  - Radiated into surrounding environment
- Reception
  - Electromagnetic energy impinging on antenna
  - Converted to radio frequency electrical energy
  - Fed to receiver
- Same antenna often used for both

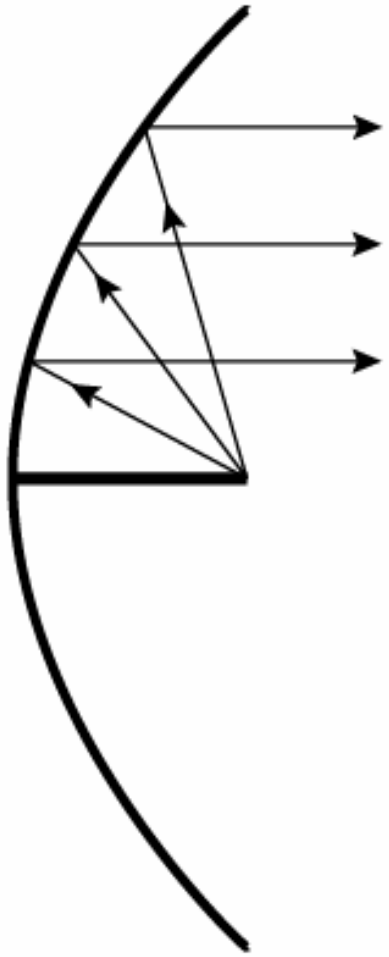
Parabolic Reflective Antenna

- Used for terrestrial and satellite microwave
- Parabola is locus of point equidistant from a line and a point not on that line
- Revolve parabola about axis to get paraboloid
  - Cross section parallel to axis gives parabola
  - Cross section perpendicular to axis gives circle
- Source placed at focus will produce waves reflected from parabola in parallel to axis
  - Creates (theoretical) parallel beam of light/sound/radio
- On reception, signal is concentrated at focus, where detector is placed

Parabolic Reflective Antenna



(a) Parabola



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

Antenna Gain

- Measure of directionality of antenna
- Power output in particular direction compared with that produced by isotropic antenna
- Measured in decibels (dB)
- Results in loss in power in another direction
- Effective area relates to size and shape
  - Related to gain

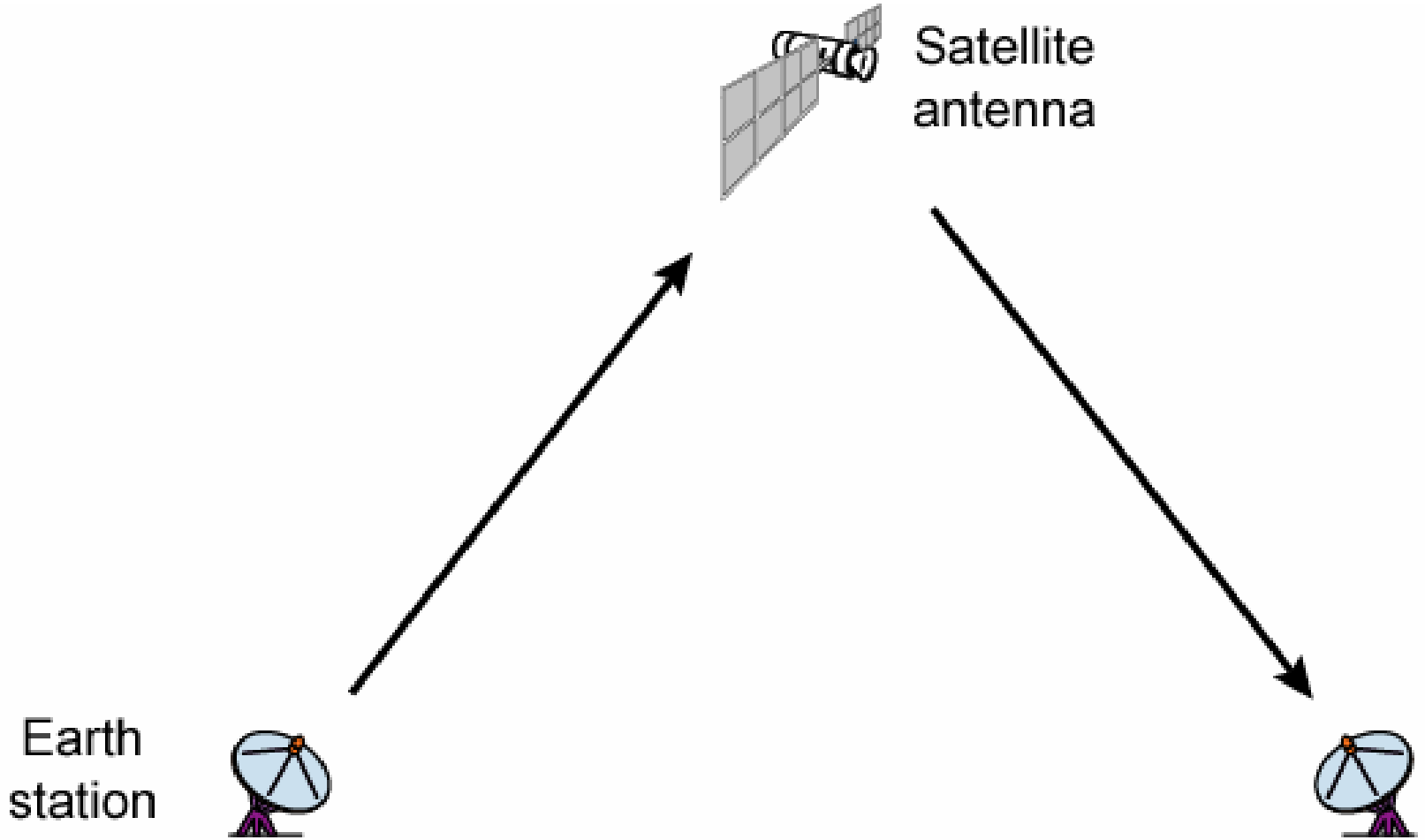
Terrestrial Microwave

- Parabolic dish
- Focused beam
- Line of sight
- Long haul telecommunications
- Higher frequencies give higher data rates

Satellite Microwave

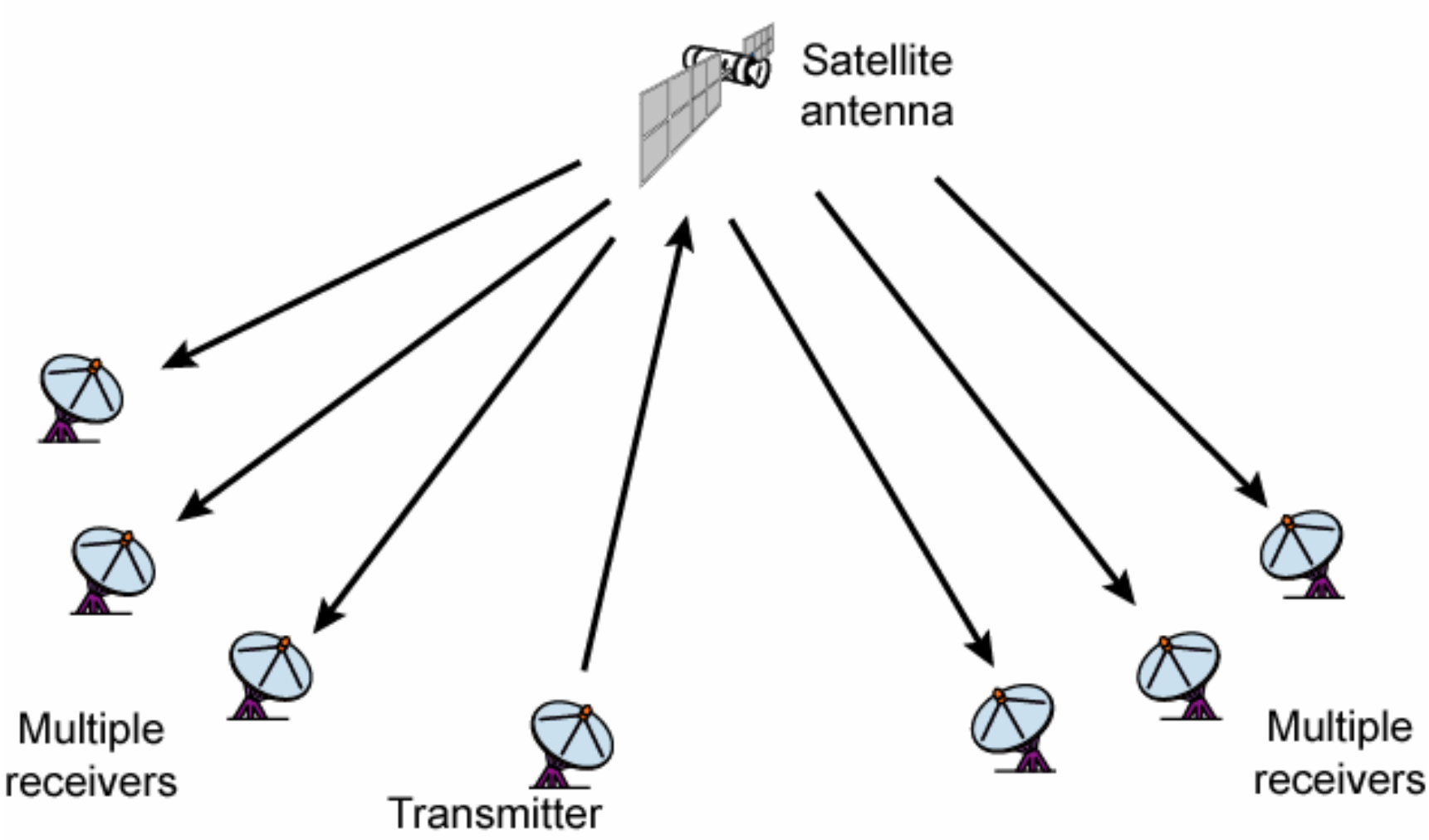
- Satellite is relay station
- Satellite receives on one frequency, amplifies or repeats signal and transmits on another frequency
- Requires geo-stationary orbit
  - Distance height of 35,784km
- Television
- Long distance telephone
- Private business networks

Satellite Point to Point Link



(a) Point-to-point link

Satellite Broadcast Link



(b) Broadcast link

Broadcast Radio

- Omnidirectional
- FM radio
- UHF and VHF television
- Line of sight
- Suffers from multipath interference
  - Reflections

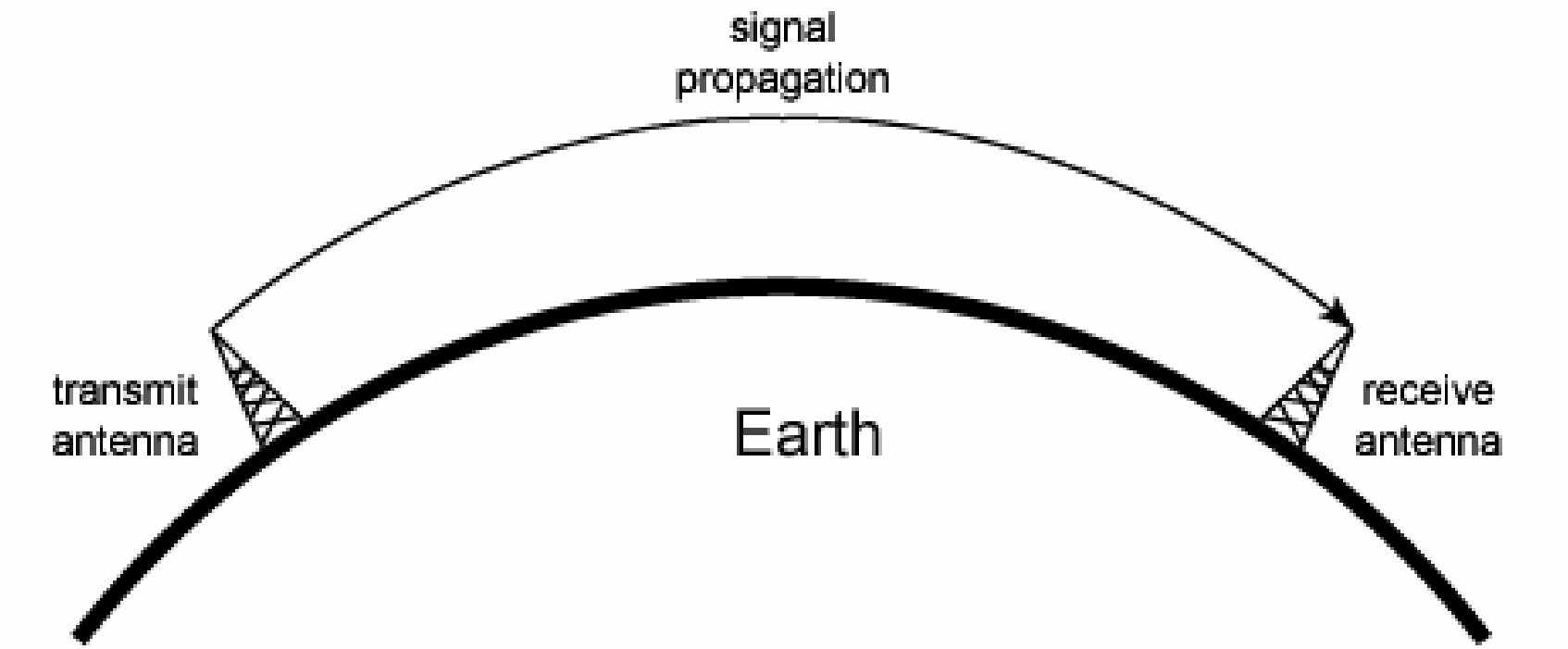
Infrared

- Modulate noncoherent infrared light
- Line of sight (or reflection)
- Blocked by walls
- e.g. TV remote control, IRD port

Wireless Propagation

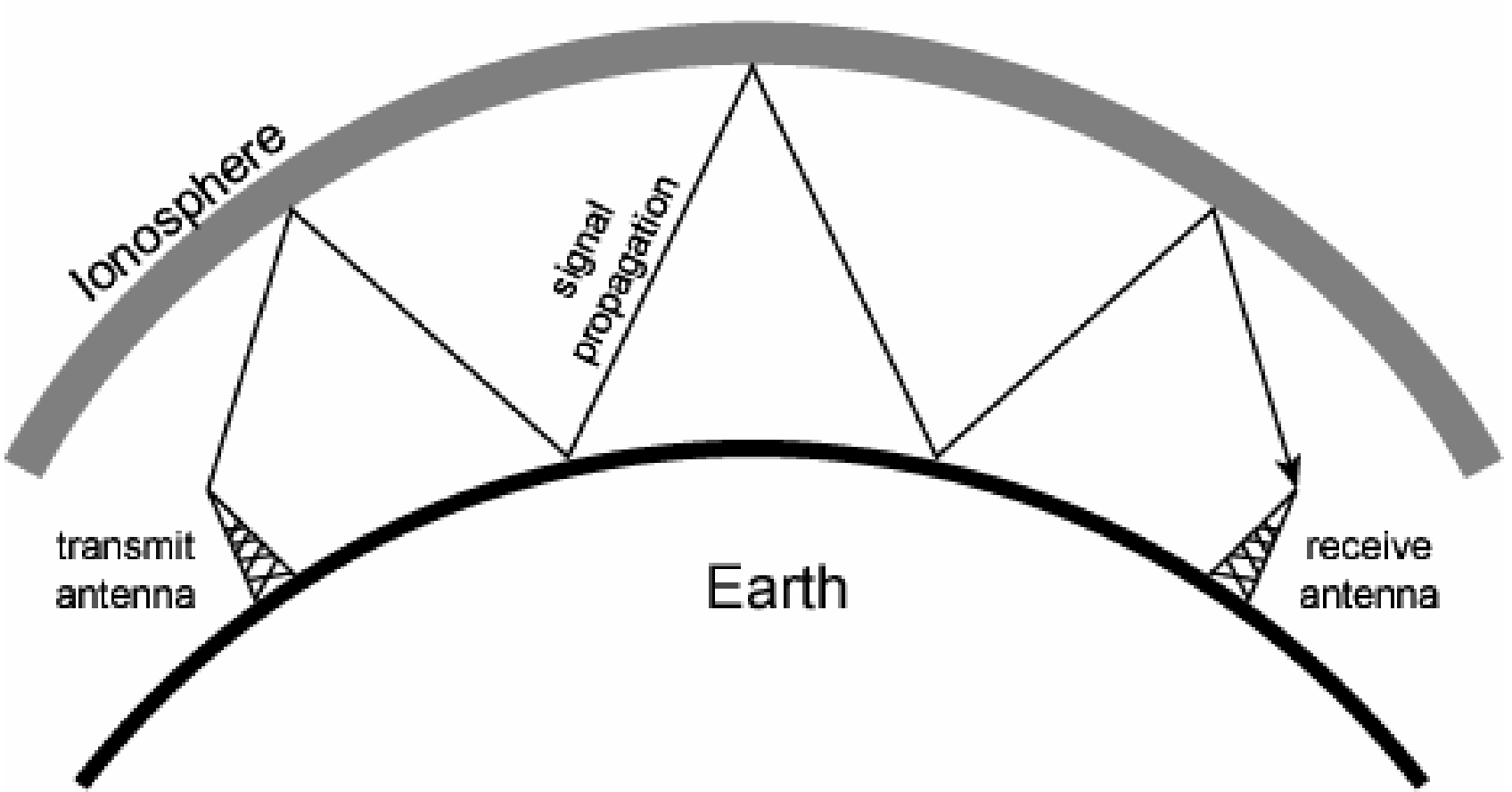
- Signal travels along three routes
  - Ground wave
    - Follows contour of earth
    - Up to 2MHz
    - AM radio
  - Sky wave
    - Refracted
    - Amateur radio, Voice of America
    - Signal reflected from ionosphere layer of upper atmosphere
  - Line of sight
    - Above 30Mhz
    - May be further than optical line of sight due to refraction
    - More later...

Ground Wave Propagation



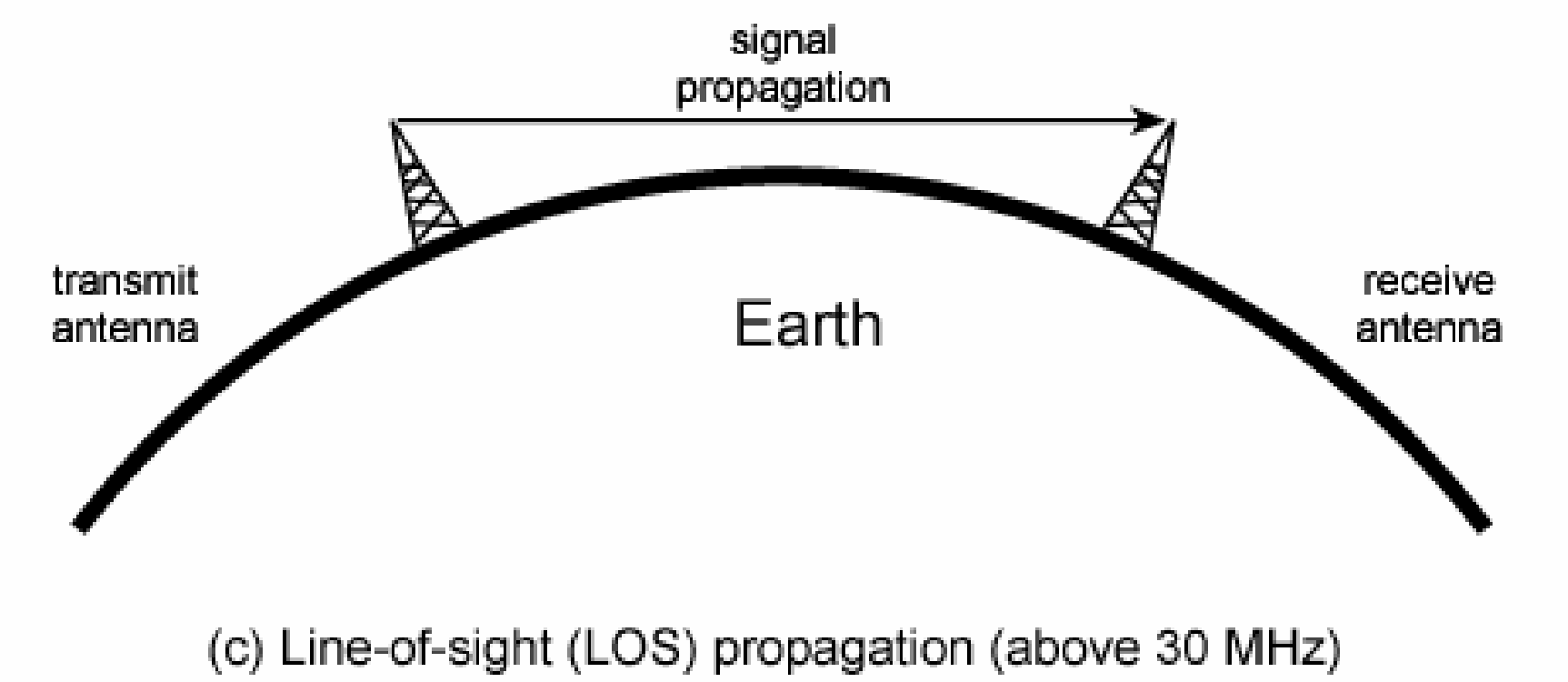
(a) Ground-wave propagation (below 2 MHz)

Sky Wave Propagation



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

Line of Sight Propagation

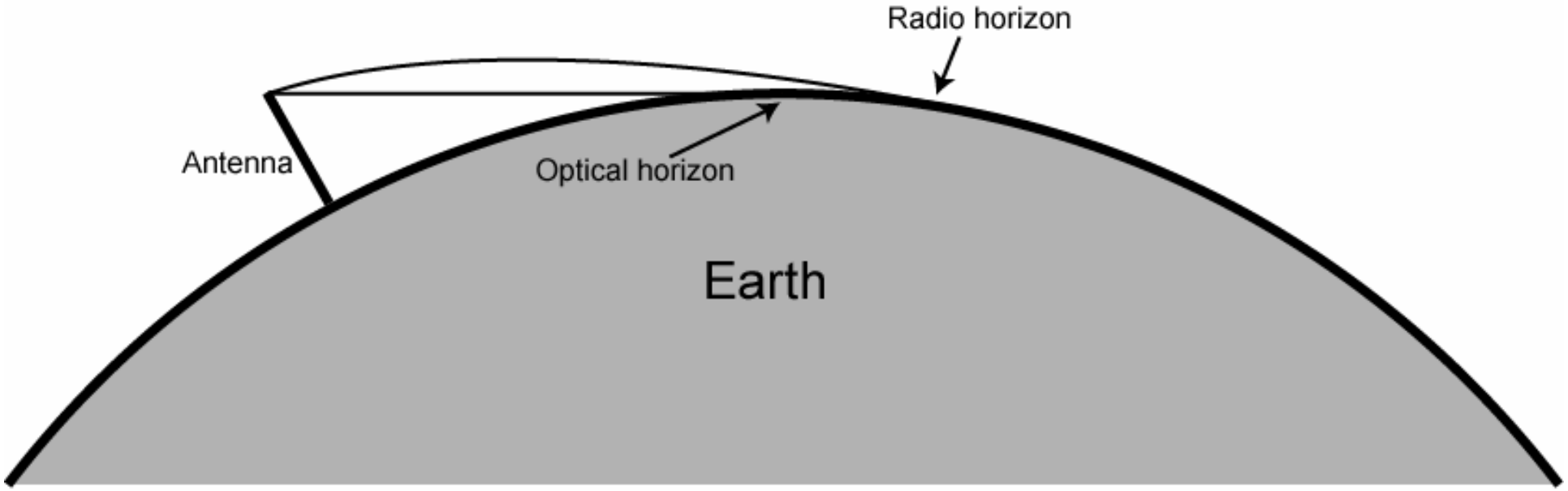


(c) Line-of-sight (LOS) propagation (above 30 MHz)

Refraction

- Velocity of electromagnetic wave is a function of density of material
  - ~3 x 10^8 m/s in vacuum, less in anything else
- As wave moves from one medium to another, its speed changes
  - Causes bending of direction of wave at boundary
  - Towards more dense medium
- Index of refraction (refractive index) is
  - Sin(angle of incidence)/sin(angle of refraction)
  - Varies with wavelength
- May cause sudden change of direction at transition between media
- May cause gradual bending if medium density is varying
  - Density of atmosphere decreases with height
  - Results in bending towards earth of radio waves

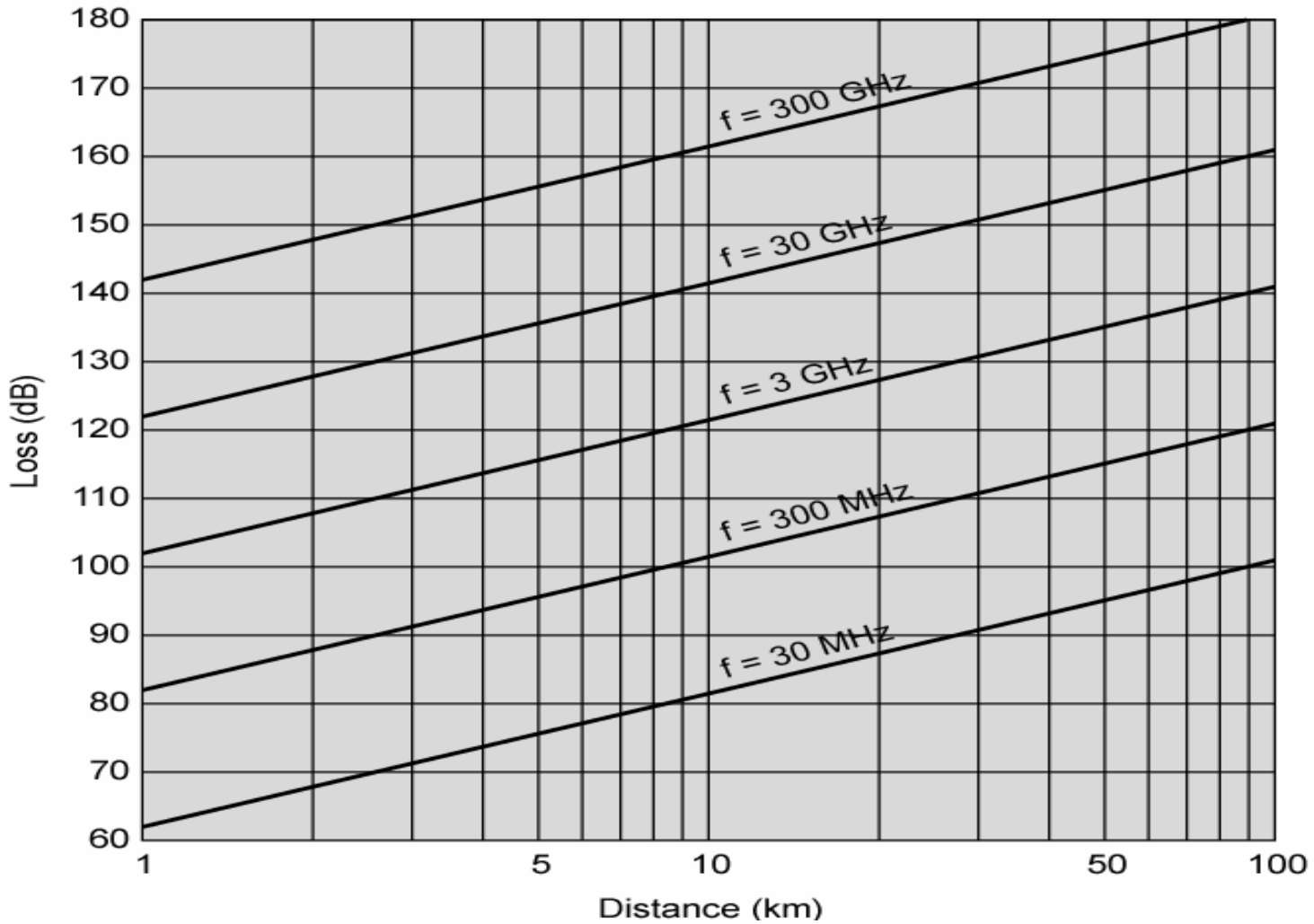
Optical and Radio Horizons



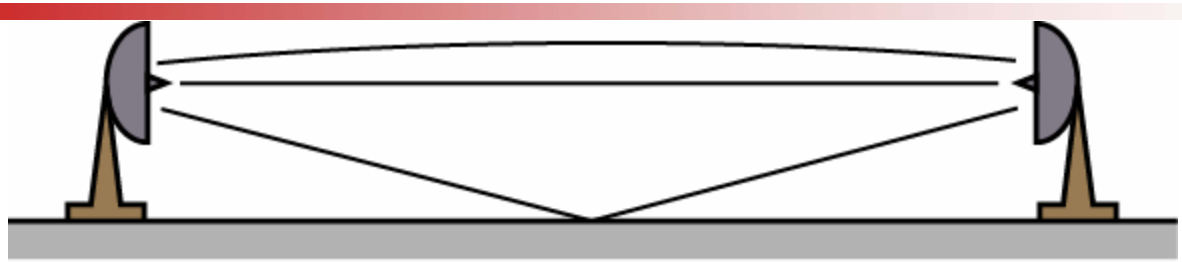
Line of Sight Transmission

- Free space loss
  - Signal disperses with distance
  - Greater for lower frequencies (longer wavelengths)
- Atmospheric Absorption
  - Water vapour and oxygen absorb radio signals
  - Water greatest at 22GHz, less below 15GHz
  - Oxygen greater at 60GHz, less below 30GHz
  - Rain and fog scatter radio waves
- Multipath
  - Better to get line of sight if possible
  - Signal can be reflected causing multiple copies to be received
  - May be no direct signal at all
  - May reinforce or cancel direct signal
- Refraction
  - May result in partial or total loss of signal at receiver

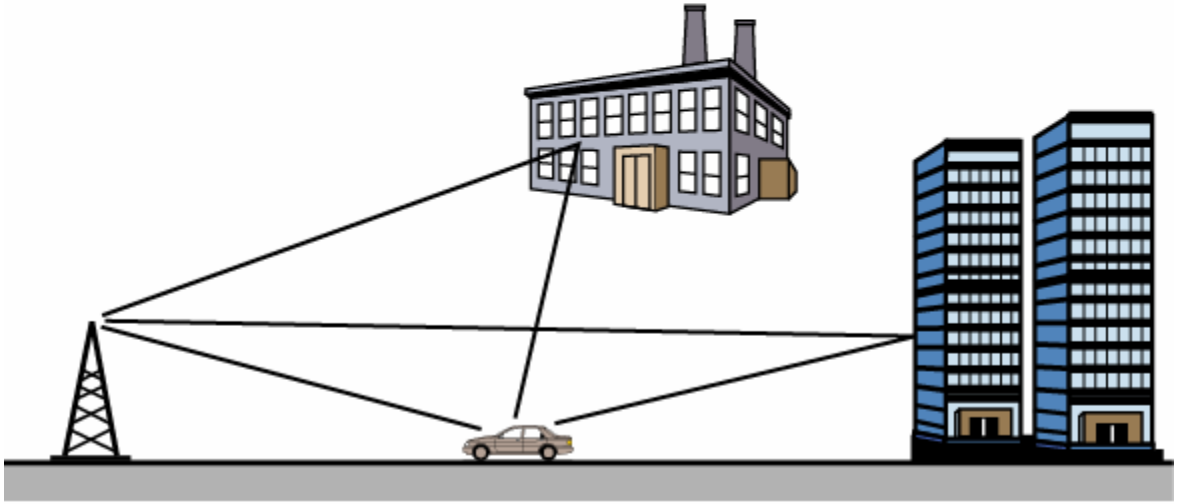
Free Space Loss



Multipath Interference



(a) Microwave line of sight



(b) Mobile radio