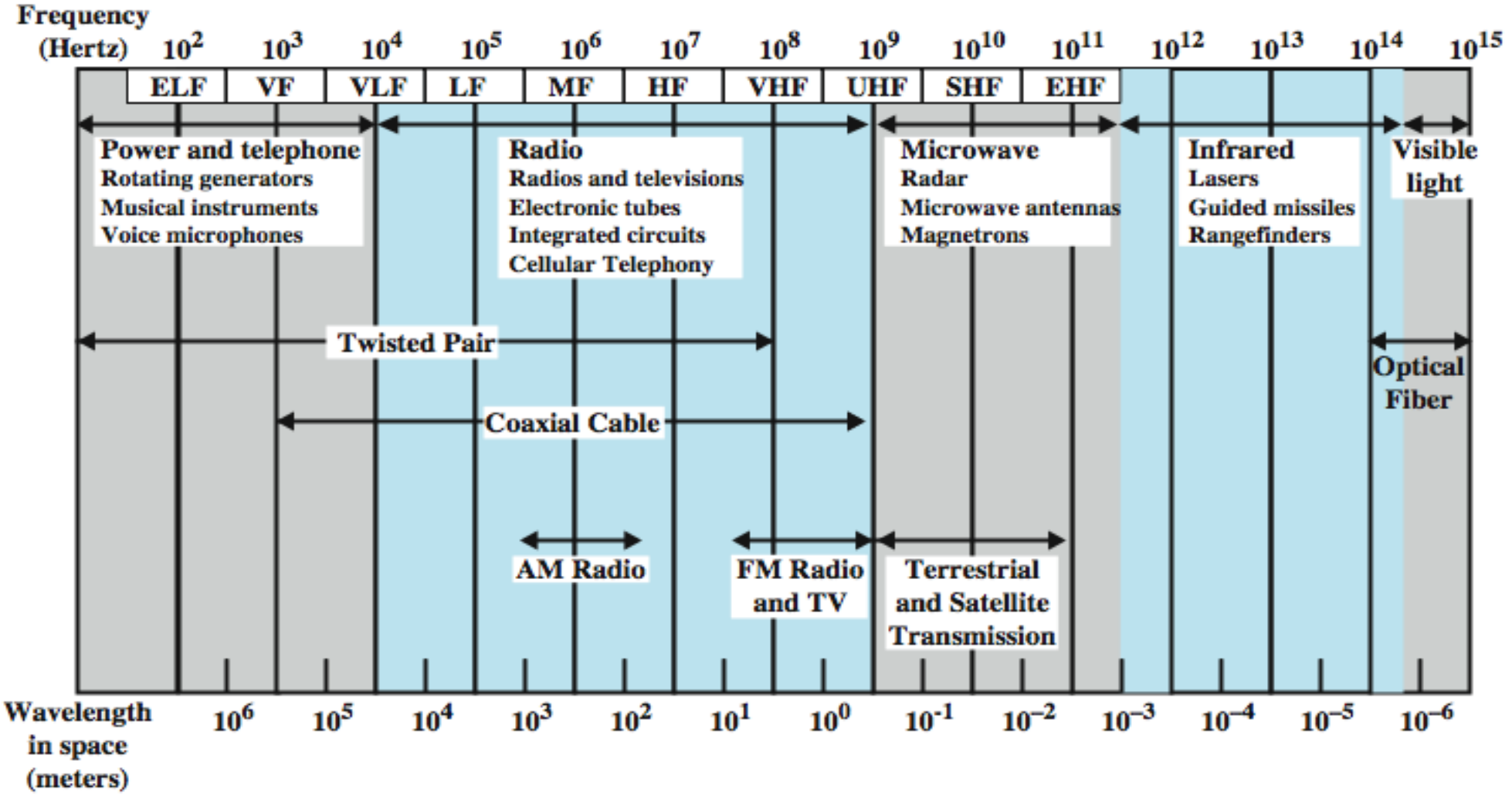
Transmission Media

Basic terminology

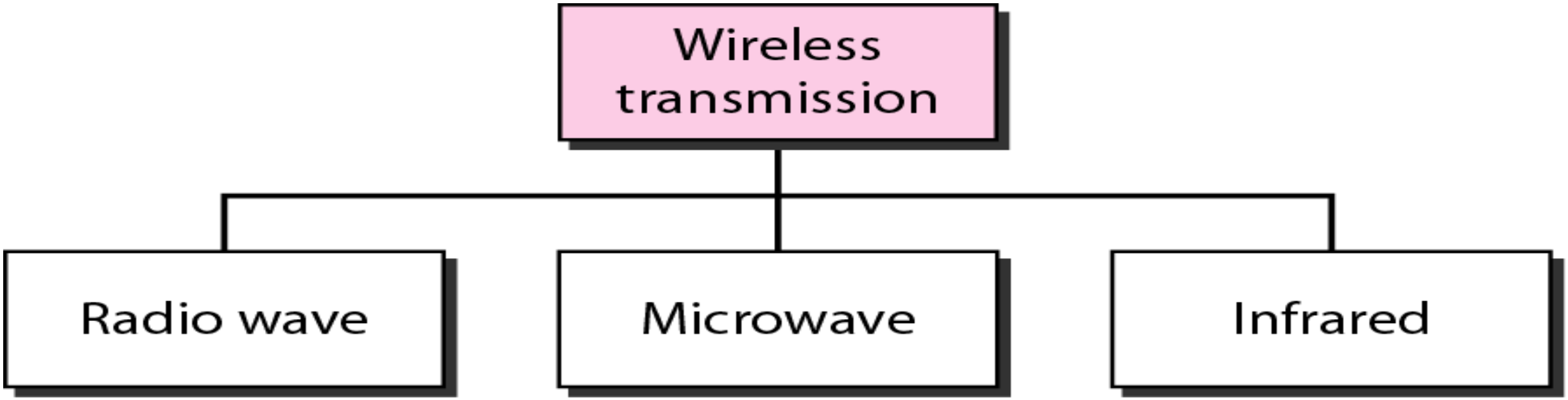
- EM energy propagation: velocity, wavelength
- Transmission medium: guided and unguided
  - Guided: point-to-point, energy confinement, capacity expansion,
  - Unguided: broadcast, frequency re-use, finite capacity
- Attenuation
  - Guided: exponential dependence with distance
  - Unguided: logarithmic dependence with distance
- Characteristics for wired links
  - Attenuation, interference, crosstalk, noise susceptibility
- Characteristics for wireless links
  - Antenna properties, attenuation, multipath fading, interference, noise
- Data rate and distance trade-off

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

Wireless Transmission Waves



used for multicast/broadcast communications, such as radio and television

used for unicast communication such as cellular telephones, satellite networks, and wireless LANs

used for short-range communication in a closed area using line-of-sight propagation

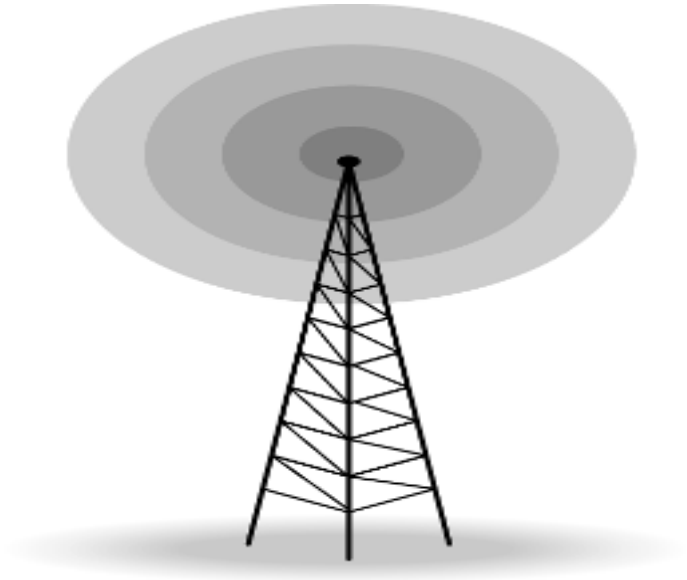
Wireless Transmission

- 2GHz to 40GHz: Microwave
  - highly directional, point to point, terrestrial or satellite
  - Unicast applications like cellular, WLANs, SatCom
- 30MHz to 1GHz: Radio
  - Omnidirectional
  - Multicast applications like radio, TV, paging
- 3×10^{11} to 2×10^{14}: Infrared
  - Local, line-of-sight indoor communication
  - Applications like PC-to-peripheral, PC-to-PC
- Antenna: conductor to radiate or collect electromagnetic energy
  - Isotropic (omnidirectional), parabolic

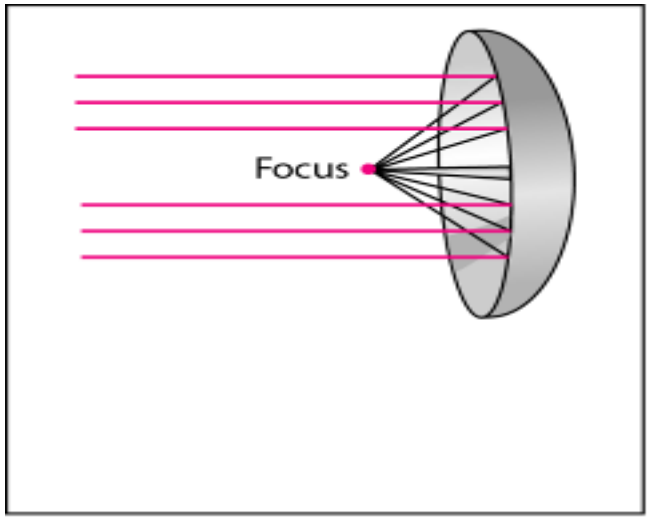
Antennas

- electrical conductor used to radiate or collect electromagnetic energy
- transmission antenna
  - radio frequency energy from transmitter
  - converted to electromagnetic energy byy antenna
  - radiated into surrounding environment
- reception antenna
  - electromagnetic energy impinging on antenna
  - converted to radio frequency electrical energy
  - fed to receiver
- same antenna is often used for both purposes

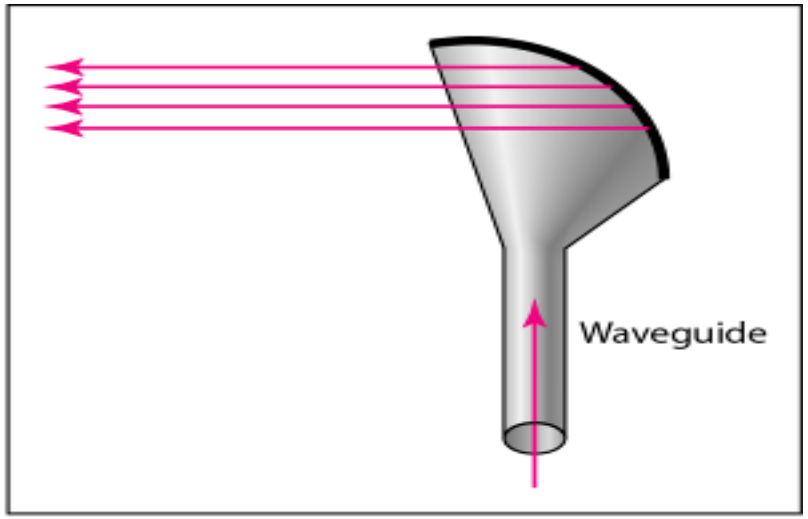
Antennas



Omni-directional Antenna



a. Dish antenna



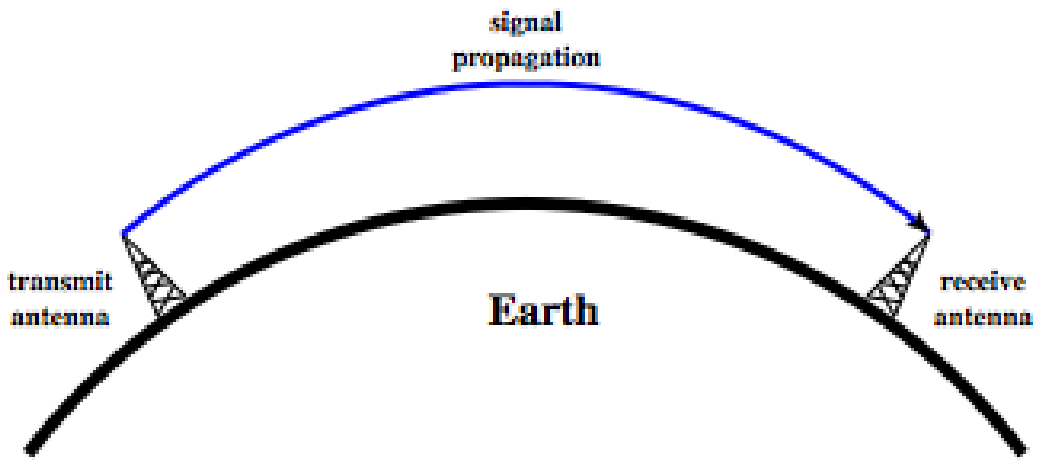
b. Horn antenna

Unidirectional Antennas

Radiation Pattern

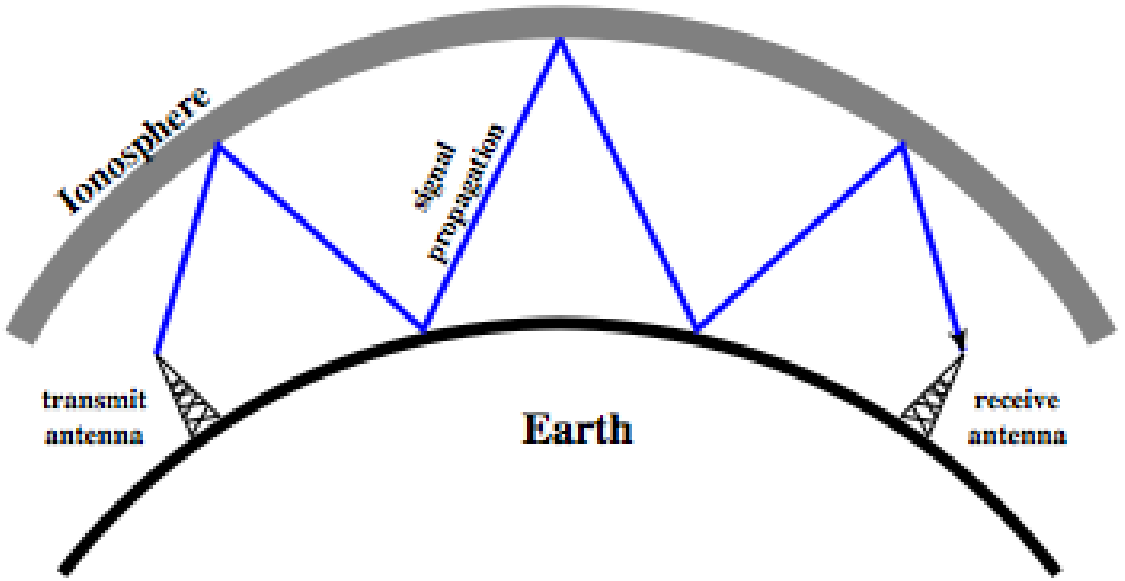
- power radiated in all directions
- not same performance in all directions
  - as seen in a radiation pattern diagram
- an isotropic antenna is a (theoretical) point in space
  - radiates in all directions equally
  - with a spherical radiation pattern
- Gain: power in a direction compared to isotropic
  - measured in decibels (dB)
  - results in loss in power in another direction
  - effective area relates to size and shape
  - $G = 4\pi A_e/\lambda^2$
  - Improves with frequency and area

Wireless Propagation
Ground Wave



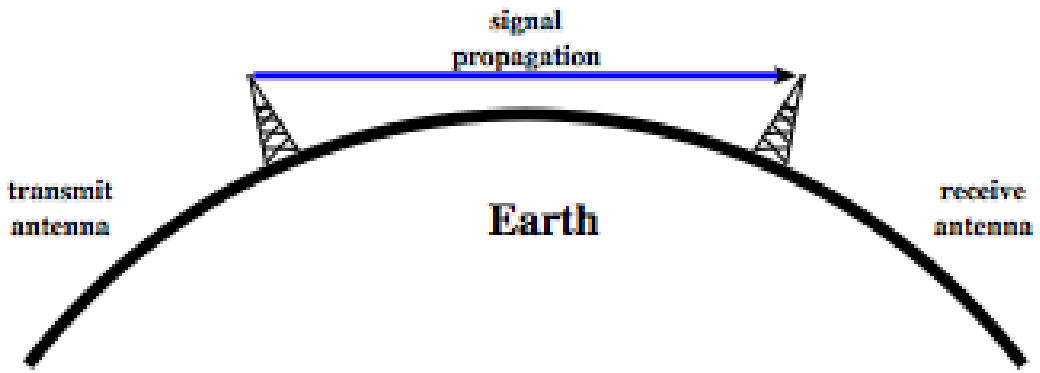
(a) Ground-wave propagation (below 2 MHz)

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)

Bands

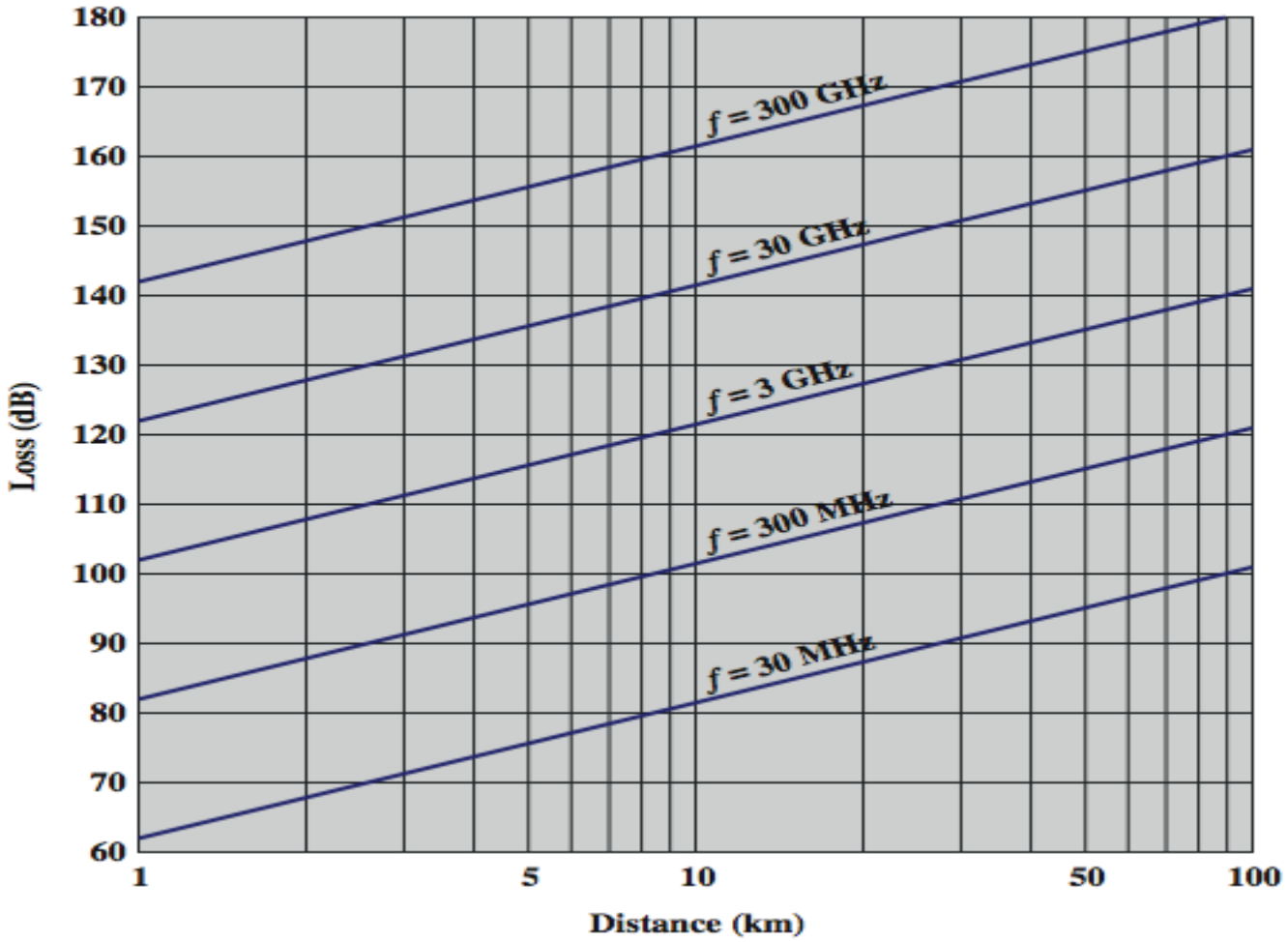
Band	*Range*	*Propagation*	*Application*
VLF (very low frequency)	3–30 kHz	Ground	Long-range radio navigation
LF (low frequency)	30–300 kHz	Ground	Radio beacons and navigational locators
MF (middle frequency)	300 kHz–3 MHz	Sky	AM radio
HF (high frequency)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft communication
VHF (very high frequency)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
UHF (ultrahigh frequency)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
SHF (superhigh frequency)	3–30 GHz	Line-of-sight	Satellite communication
EHF (extremely high frequency)	30–300 GHz	Line-of-sight	Radar, satellite

Line of Sight Transmission

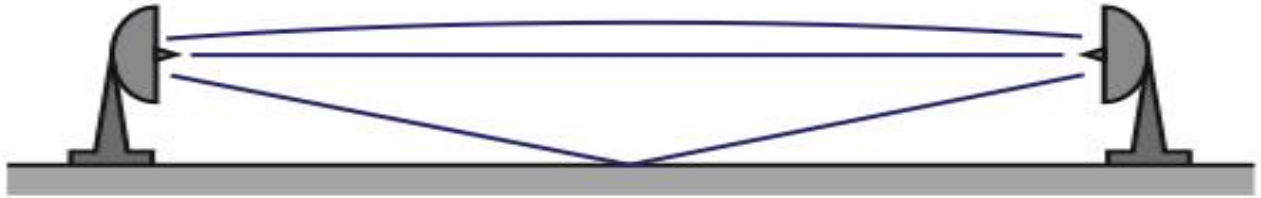
- Free space loss
  - loss of signal with distance
- Atmospheric Absorption
  - from water vapour and oxygen absorption
- Multipath
  - multiple interfering signals from reflections
- Refraction
  - bending signal away from receiver

Free Space Loss

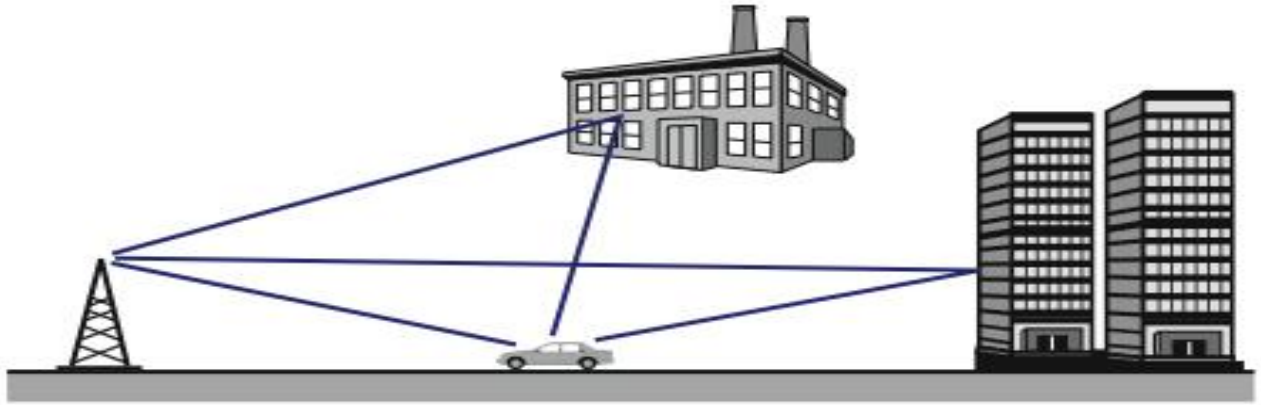
$$\frac{P_t}{P_r} = \frac{(4\pi fd)^2}{c^2}$$



Multipath Interference



(a) Microwave line of sight



(b) Mobile radio

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) is
  - `sin(incidence)/sin(refraction)`
  - varies with wavelength
- have gradual bending if medium density varies
  - density of atmosphere decreases with height
  - results in bending towards earth of radio waves
  - hence optical and radio horizons differ

$$d = 3.57\sqrt{\frac{4}{3}h}$$

Microwave Communication

- Terrestrial: long-haul telecom, 4-6 GHz/11-12GHz
  - LOS, repeaters between links
  - Attenuation due to distance, rainfall, external interference
  - Attenuation = $10\log (4\pi d/\lambda)^2$
- Satellite: TV, telecom, GPS
  - Uplink and downlink, eg. 5.925-6.425 GHz & 3.7-4.2 GHz
  - requires geo-stationary orbit (height of 35,863 km)
  - spaced at least 3-4° apart
- Impairments in LOS communication
  - Atmospheric absorption, multipath, refraction, attenuation

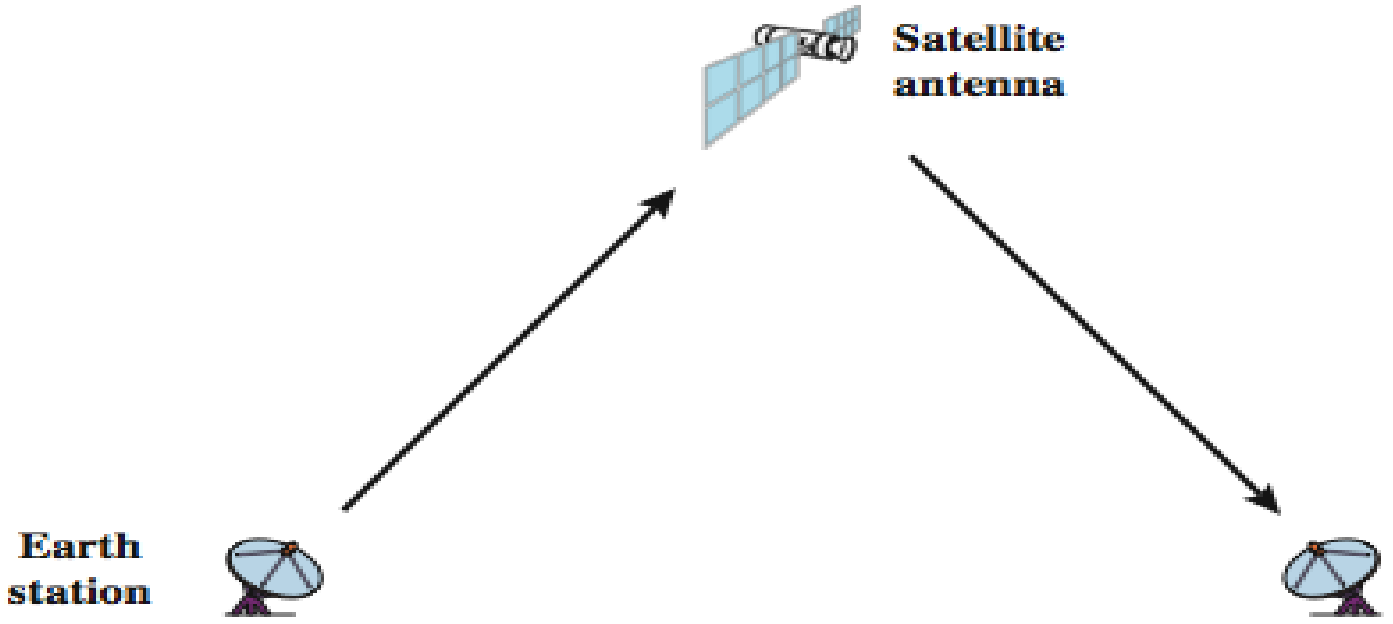
Terrestrial Microwave

- 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
  - distance, rainfall
- also prone to interference
- Attenuation = $10\log (4\pi d/\lambda)^2$

Satellite Microwave

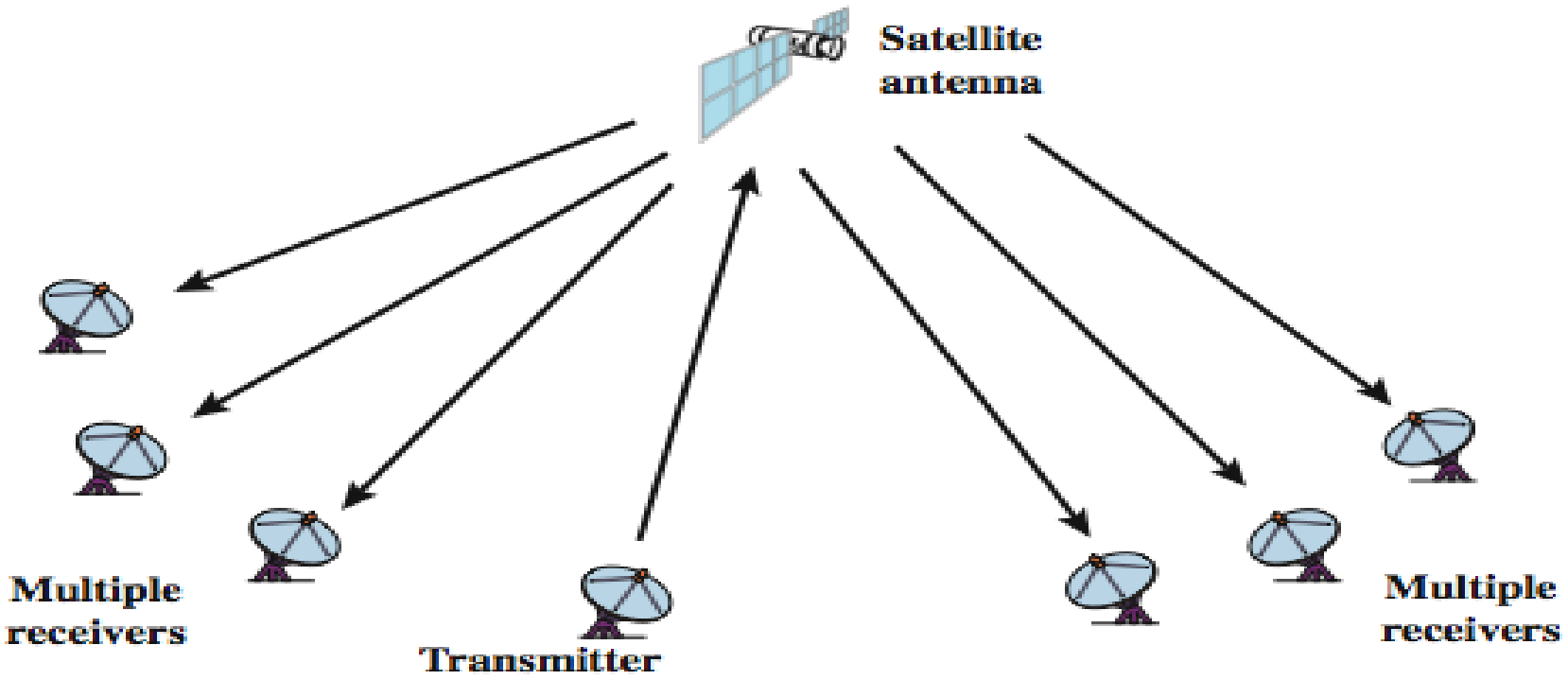
- satellite is relay station
- receives on one frequency, amplifies or repeats signal and transmits on another frequency
  - eg. uplink 5.925-6.425 GHz & downlink 3.7-4.2 GHz
- typically requires geo-stationary orbit
  - height of 35,784km
  - spaced at least 3-4° apart
- typical uses
  - television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

Satellite Point to Point Link



(a) Point-to-point link

Satellite Broadcast Link



(b) Broadcast link

Broadcast Radio

- radio is 3kHz to 300GHz
- use broadcast radio, 30MHz - 1GHz, for:
  - FM radio
  - UHF and VHF television
- is omnidirectional
- still need line of sight
- suffers from multipath interference
  - reflections from land, water, other objects

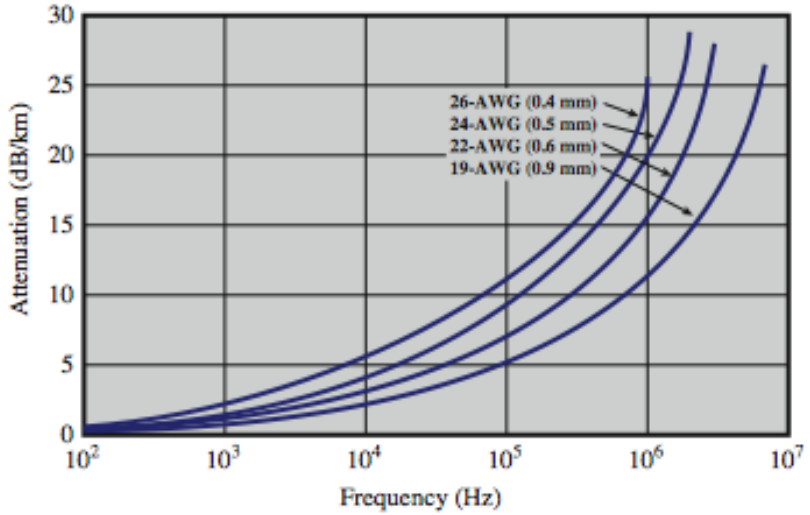
Infrared

- modulate noncoherent infrared light
- end line of sight (or reflection)
- are blocked by walls
- no licenses required
- typical uses
  - TV remote control
  - IRD port

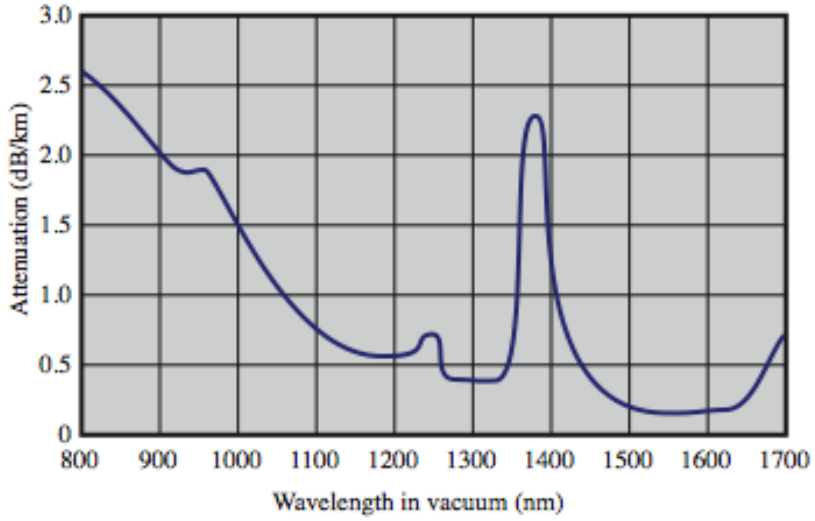
Transmission Characteristics of Guided Media

	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

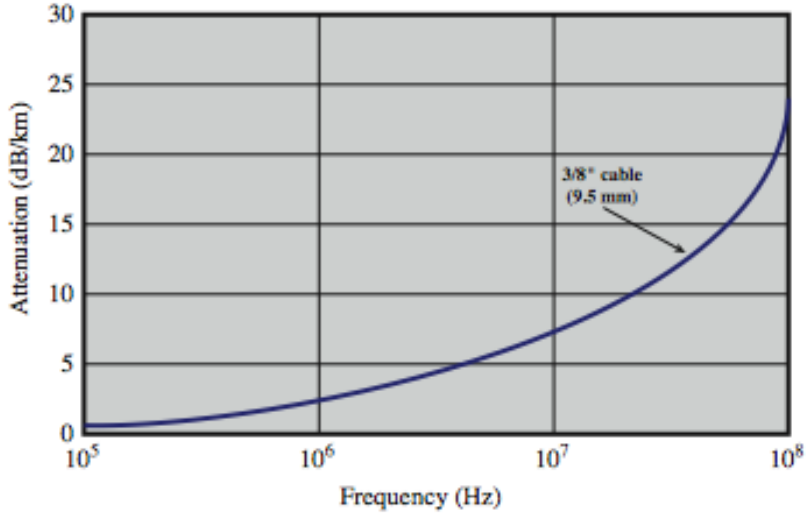
Attenuation in Guided Media



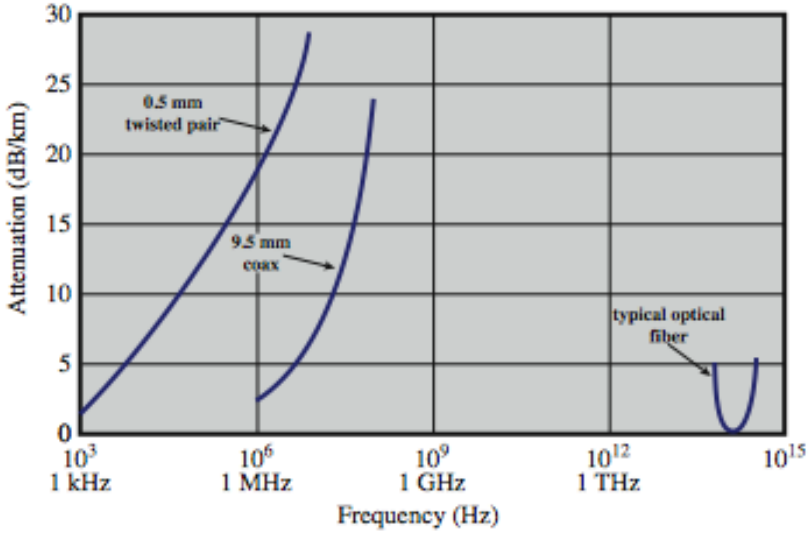
(a) Twisted pair (based on [REEV95])



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



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

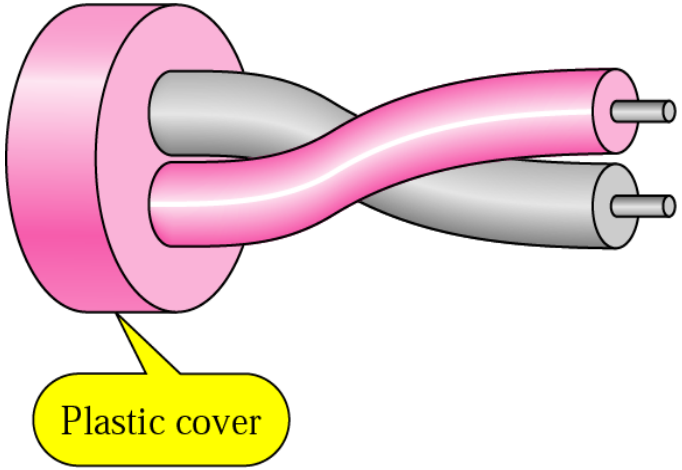


(d) Composite graph

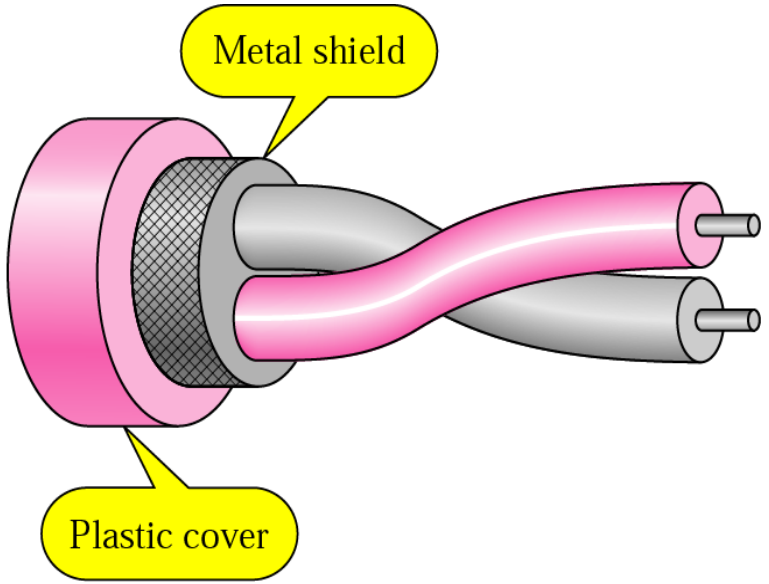
Twisted Pair

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

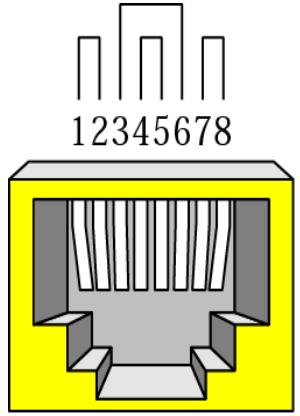
(a) Twisted pair



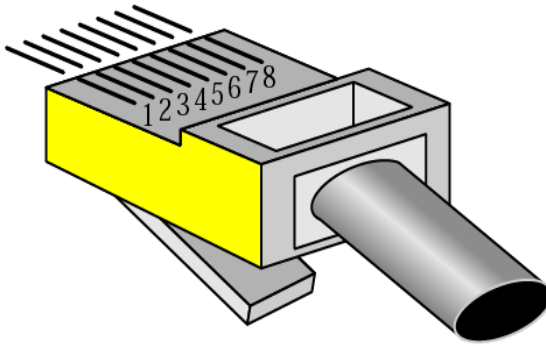
a. UTP



b. STP



RJ-45 Female



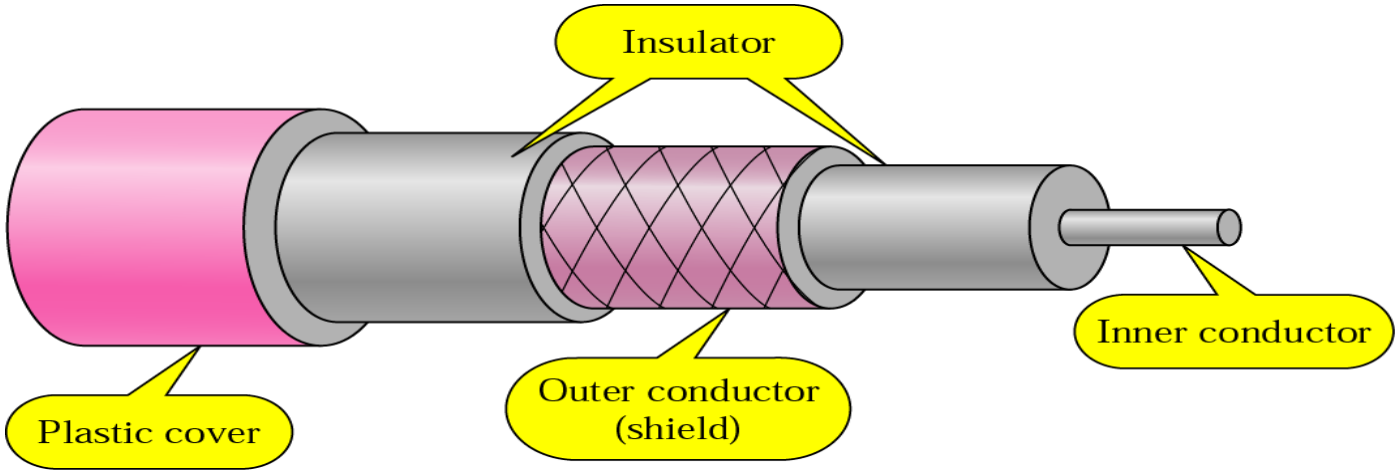
RJ-45 Male

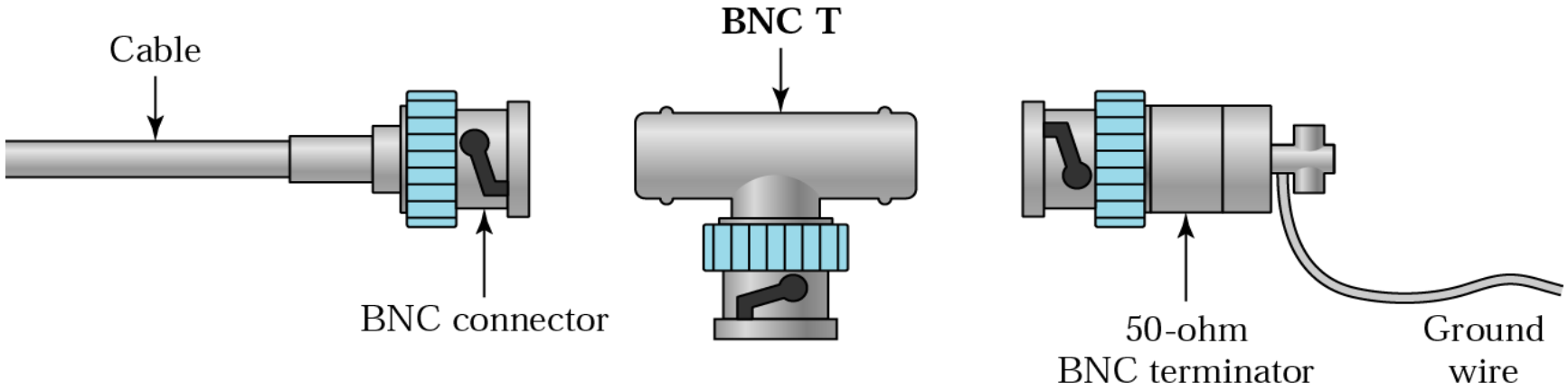
Categories of UTP

Category	Bandwidth	Data Rate	Digital/Analog	Use
1	very low	< 100 kbps	Analog	Telephone
2	< 2 MHz	2 Mbps	Analog/digital	T-1 lines
3	16 MHz	10 Mbps	Digital	LANs
4	20 MHz	20 Mbps	Digital	LANs
5	100 MHz	100 Mbps	Digital	LANs
6	200 MHz	200 Mbps	Digital	LANs
7	600 MHz	600 Mbps	Digital	LANs

Coaxial Cable

- Cable TV Transmission, LAN, Long-distance telephone
- Bandwidth upto 100 MHz, both analog and digital



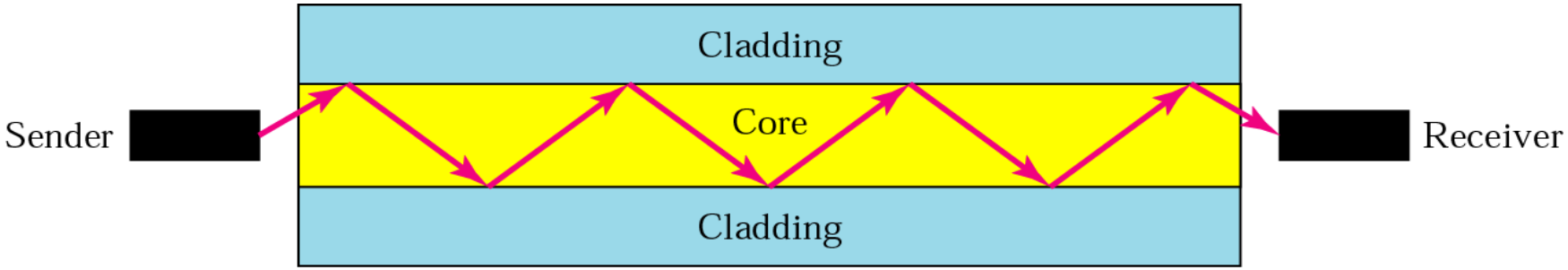


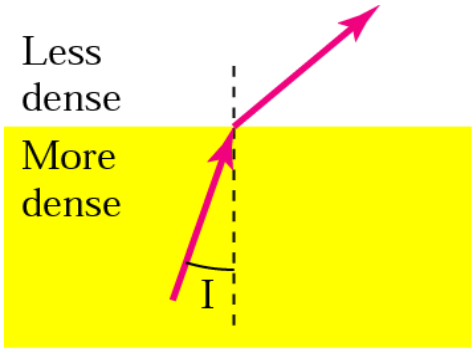
Categories of Coaxial Cables

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

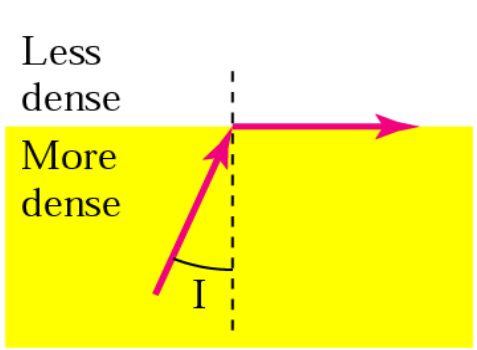
RG – Radio Government

Optical Fiber

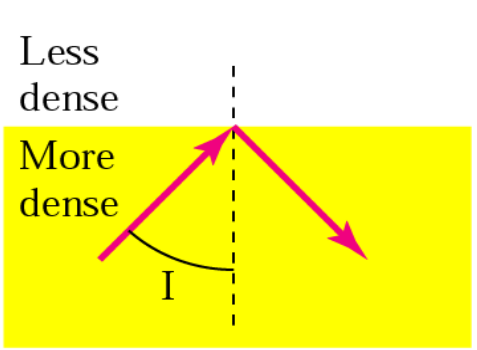




I < critical angle, refraction

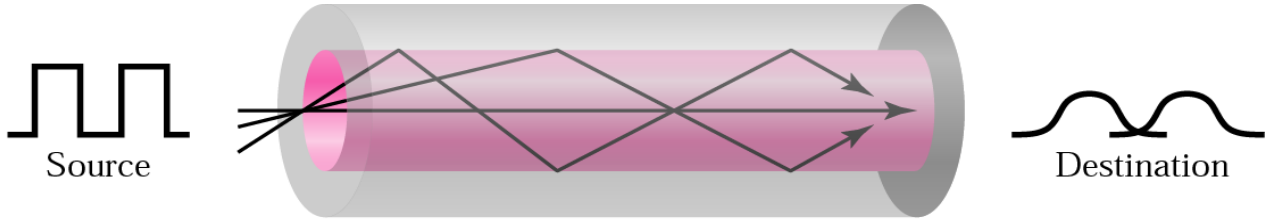


I = critical angle, refraction

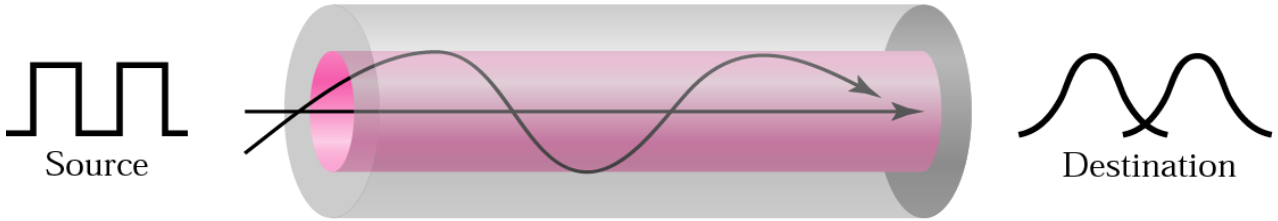


I > critical angle, reflection

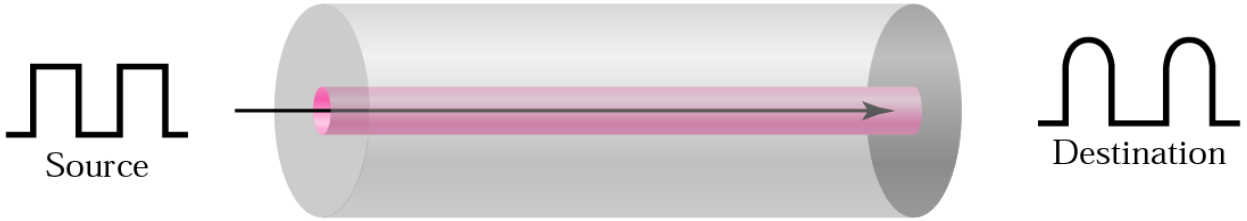
Types of Fiber



a. Multimode, step-index



b. Multimode, graded-index

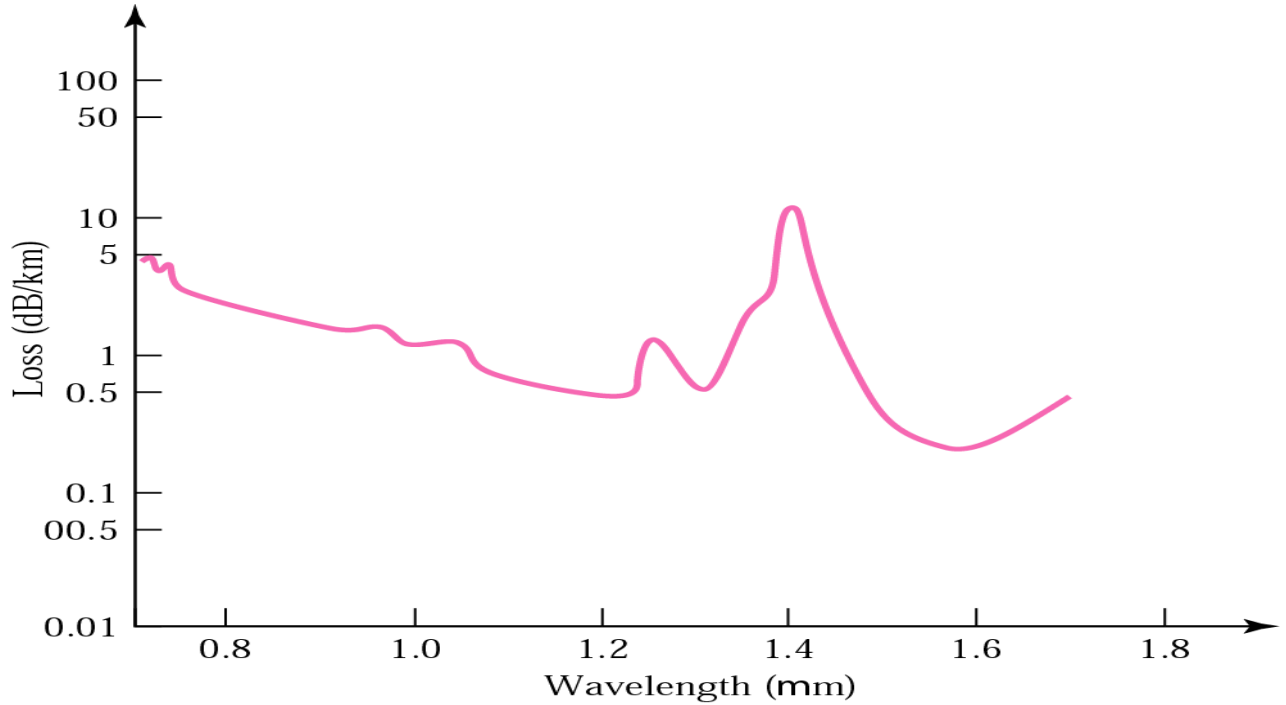


c. Single-mode

Type	Core	Cladding	Mode
50/125	50	125	Multimode, step-index
62.5/125	62.5	125	Multimode, graded-index
100/125	100	125	Multimode, graded-index
7/125	7	125	Single-mode

Optical Transmission Bands

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



Benefits of optical transmission

- Greater capacity
  - data rates of hundreds of Gbps
- Smaller size & weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing
  - 10s of km at least
- Wavelength division multiplexing