

Data and Computer Communications

Transmission Media



Transmission Media

Communication channels in the animal world include touch, sound, sight, and scent. Electric eels even use electric pulses. Ravens also are very expressive. By a combination voice, patterns of feather erection and body posture ravens communicate so clearly that an experienced observer can identify anger, affection, hunger, curiosity, playfulness, fright, boldness, and depression. —Mind of the Raven, Bernd Heinrich

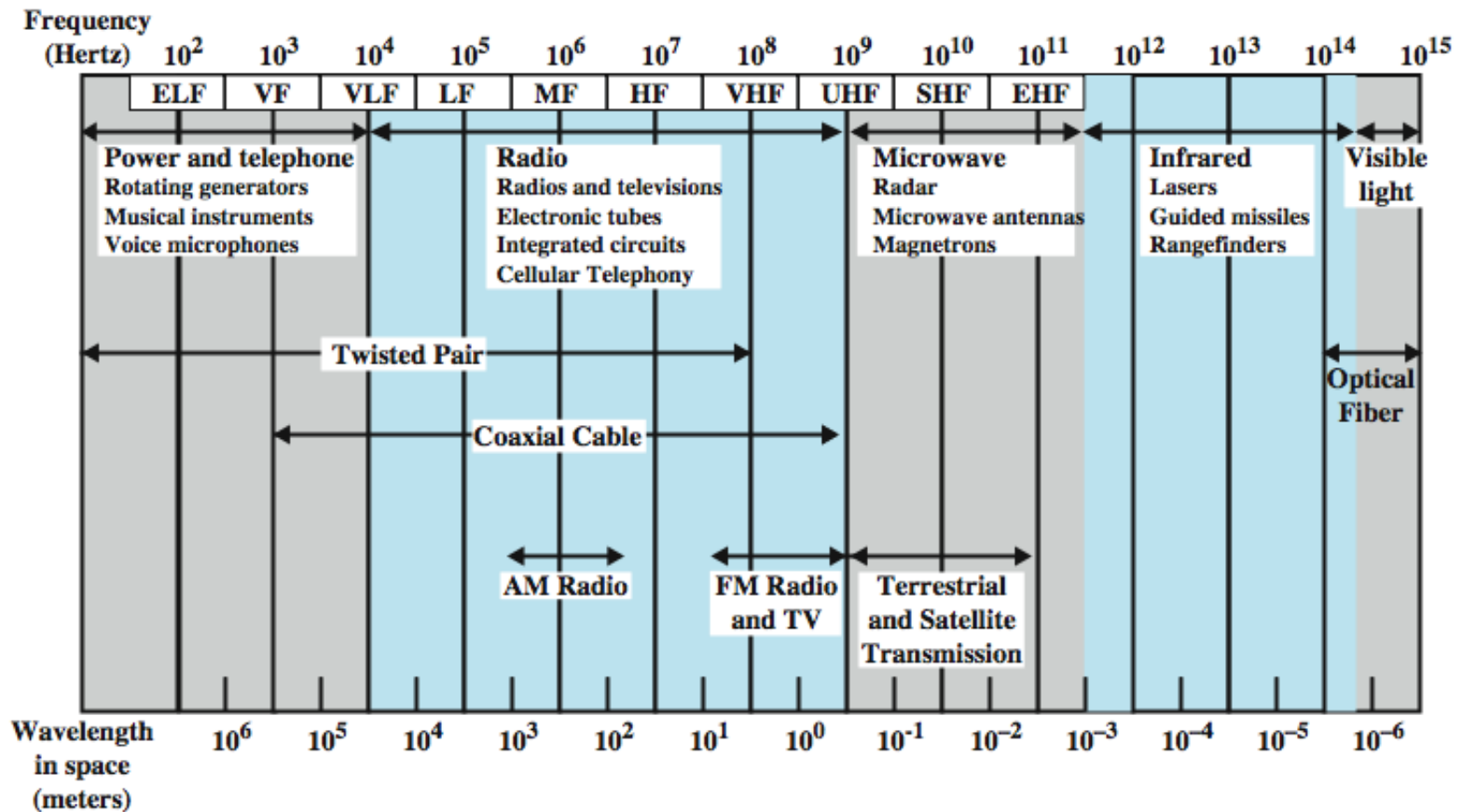
Overview

- 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

- bandwidth
 - higher bandwidth gives higher data rate
- transmission impairments
 - eg. attenuation
- interference
- number of receivers in guided media
 - more receivers introduces more attenuation

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 (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 μ s/km	2 km
Twisted pairs (multi-pair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 μ s/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 μ s/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 μ s/km	40 km

Twisted Pair

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



(a) Twisted pair

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 (100MHz)
- 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)
- in a variety of categories - see EIA-568

UTP Categories

	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

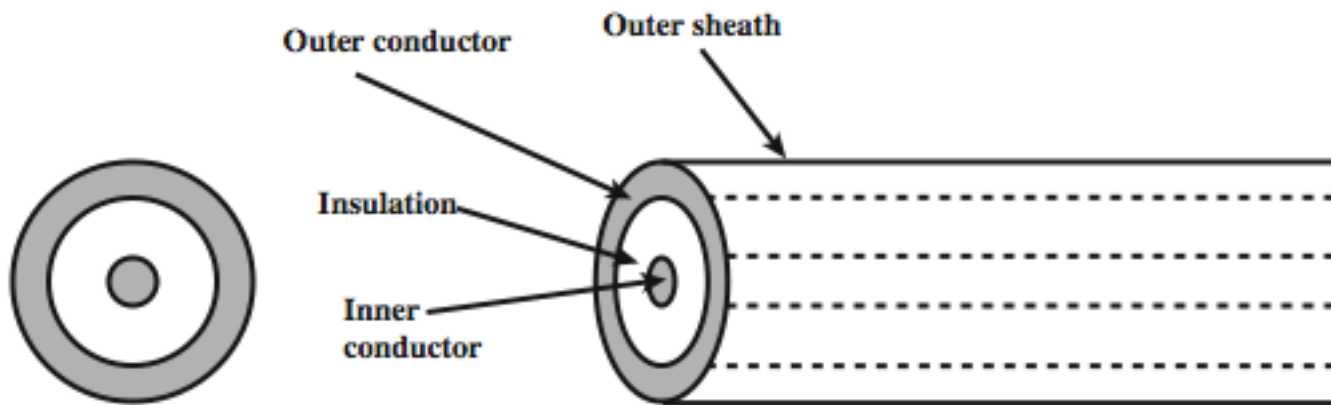
Comparison of Shielded and Unshielded Twisted Pair

Frequency (MHz)	Attenuation (dB per 100 m)			Near-end Crosstalk (dB)		
	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

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



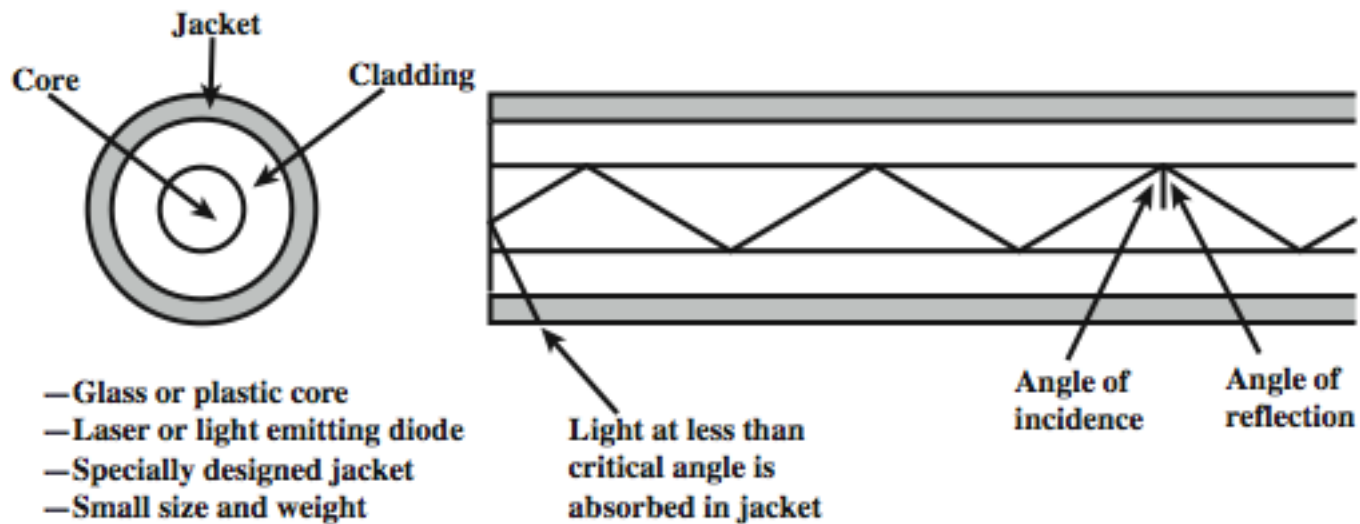
- Outer conductor is braided shield
- Inner conductor is solid metal
- Separated by insulating material
- Covered by padding

(b) Coaxial cable

Coaxial Cable - 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

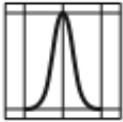
- greater capacity
 - data rates of hundreds of Gbps
- smaller size & weight
- lower attenuation
- electromagnetic isolation
- greater repeater spacing
 - 10s of km at least

Optical Fiber - Transmission Characteristics

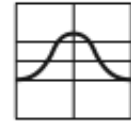
- uses total internal reflection to transmit light
 - effectively acts as wave guide for 10^{14} to 10^{15} Hz
- can use several different light sources
 - Light Emitting Diode (LED)
 - cheaper, wider operating temp range, lasts longer
 - Injection Laser Diode (ILD)
 - more efficient, has greater data rate
- relation of wavelength, type & data rate

Optical Fiber Transmission Modes

Input pulse

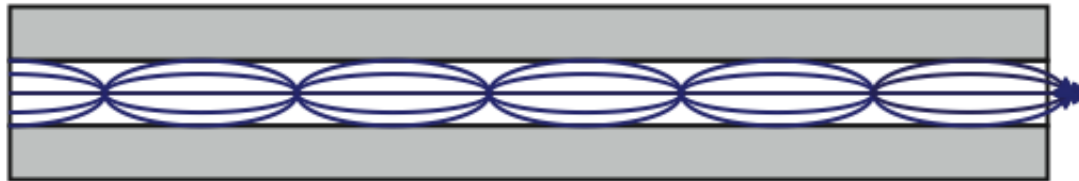


Output pulse

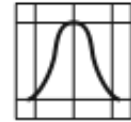


(a) Step-index multimode

Input pulse

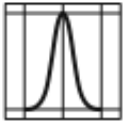


Output pulse

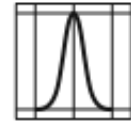


(b) Graded-index multimode

Input pulse



Output pulse

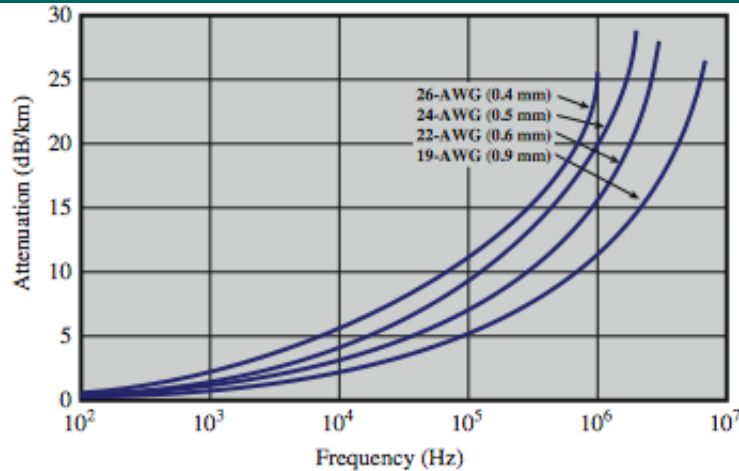


(c) Single mode

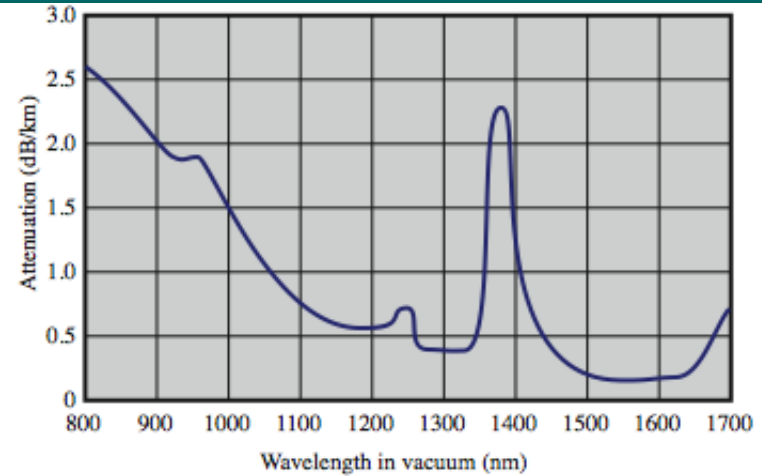
Frequency Utilization for Fiber Applications

Wave length (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

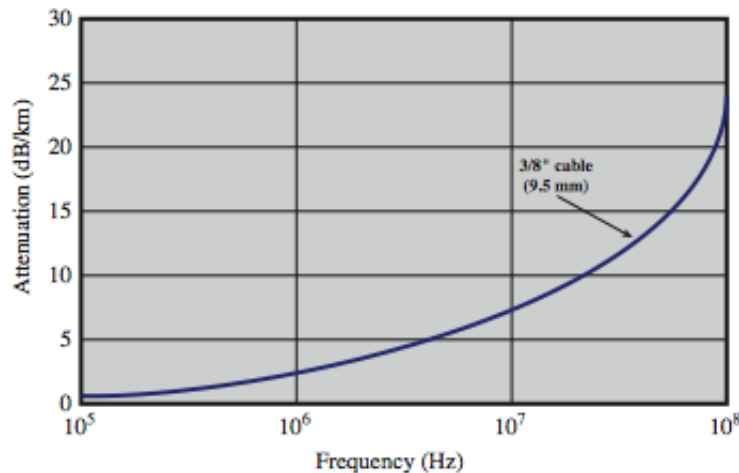
Attenuation in Guided Media



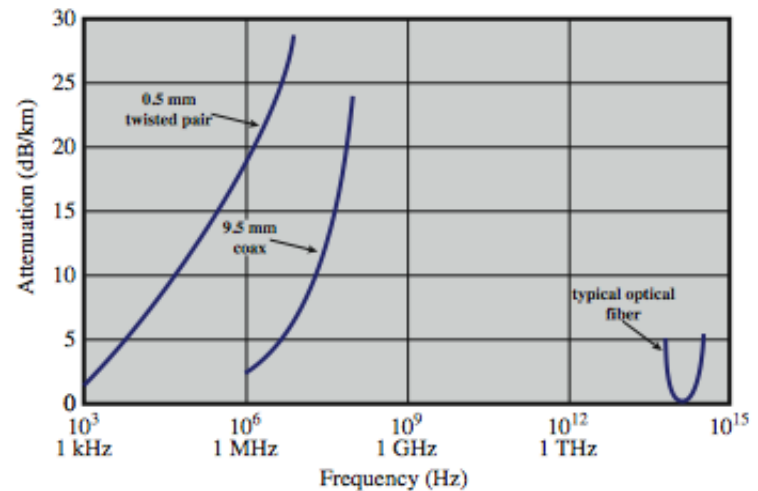
(a) Twisted pair (based on [REEV95])



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



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



(d) Composite graph

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

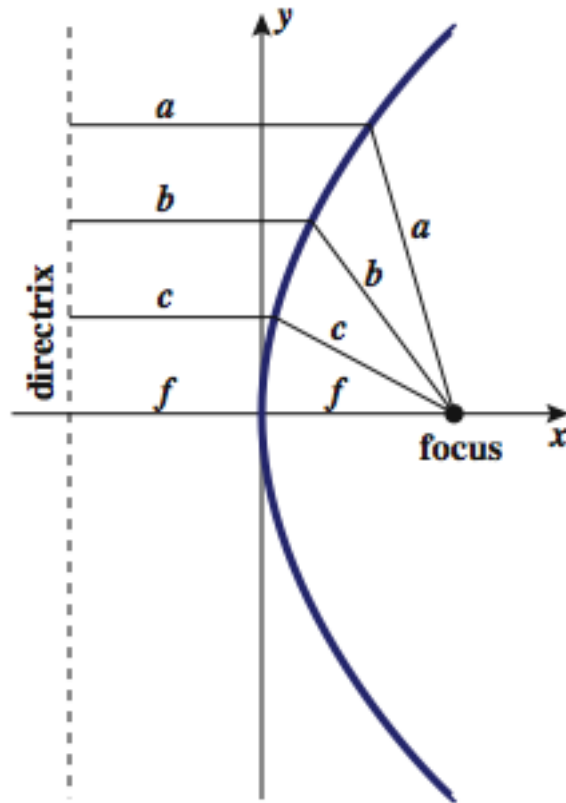
Antennas

- 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
 - electromagnetic energy impinging on antenna
 - converted to radio frequency electrical energy
 - fed to receiver
- same antenna is often used for both purposes

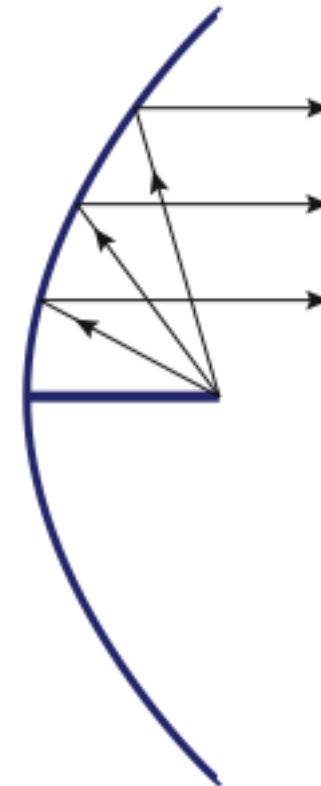
Radiation Pattern

- power radiated in all directions
- 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

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 verses that produced by an isotropic antenna
- measured in decibels (dB)
- results in loss in power in another direction
- effective area relates to size and shape
 - related to gain

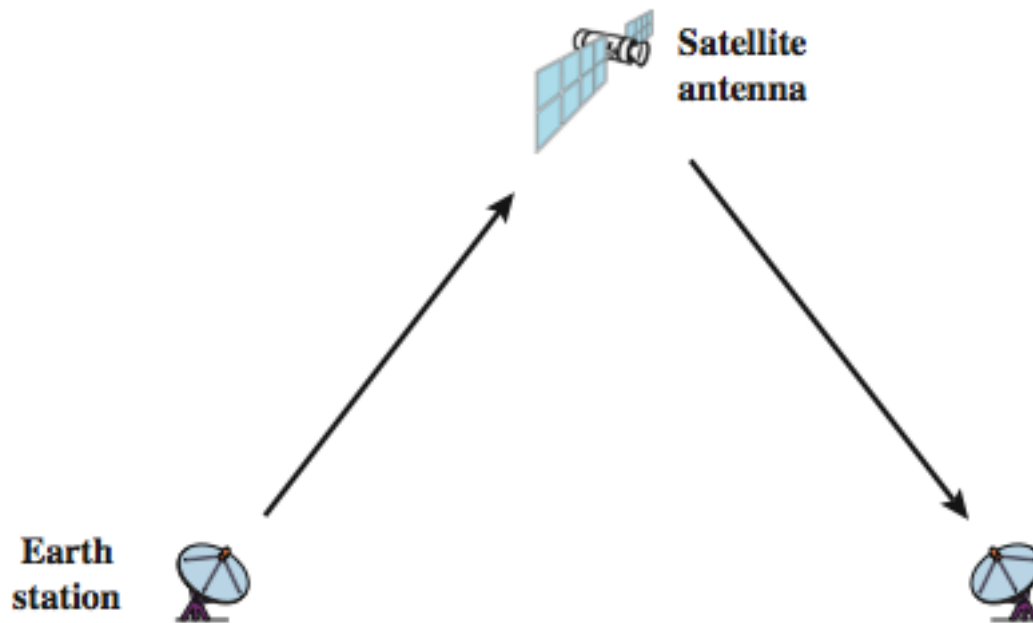
Terrestrial Microwave

- 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 interference

Satellite Microwave

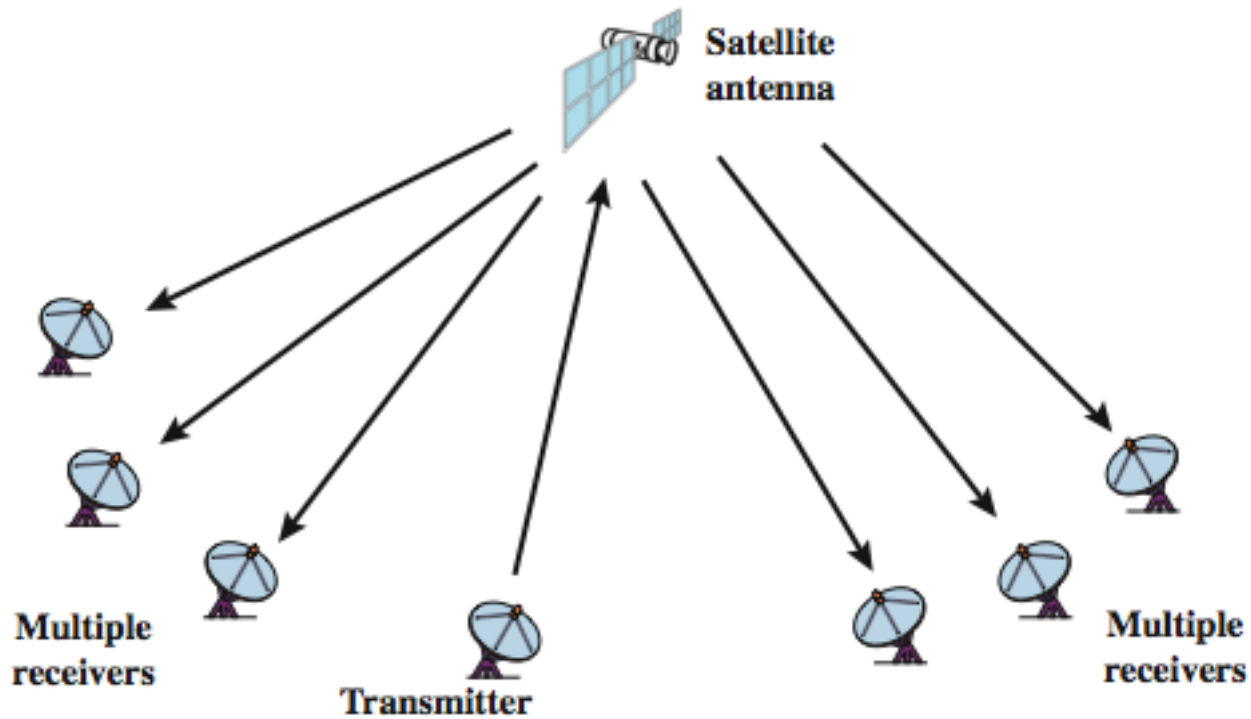
- satellite is relay station
- receives on one frequency, amplifies or repeats signal and transmits on another frequency
 - eg. uplink 5.925-6.425 GHz & downlink 3.7-4.2 GHz
- typically requires geo-stationary orbit
 - height of 35,784km
 - spaced at least 3-4° apart
- typical uses
 - television
 - long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

Satellite Point to Point Link



(a) Point-to-point link

Satellite Broadcast Link



(b) Broadcast link

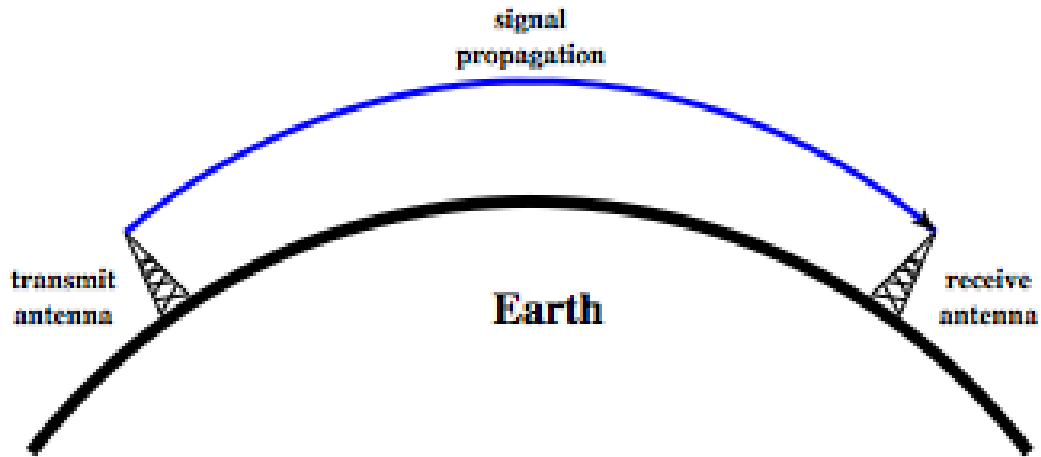
Broadcast Radio

- 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

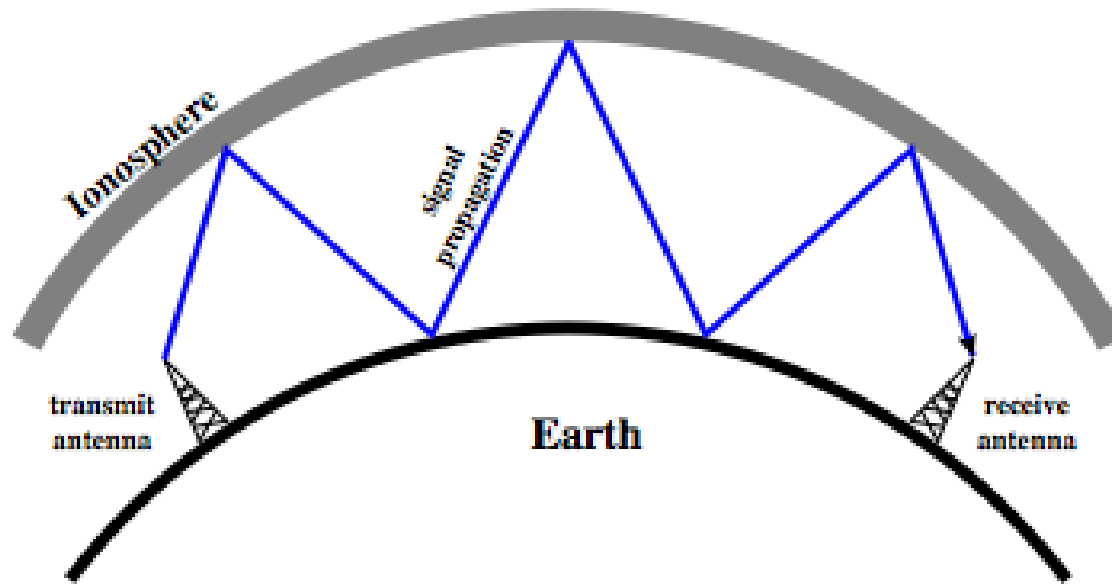
- modulate noncoherent infrared light
- end line of sight (or reflection)
- are blocked by walls
- no licenses required
- typical uses
 - TV remote control
 - IRD port

Wireless Propagation Ground Wave



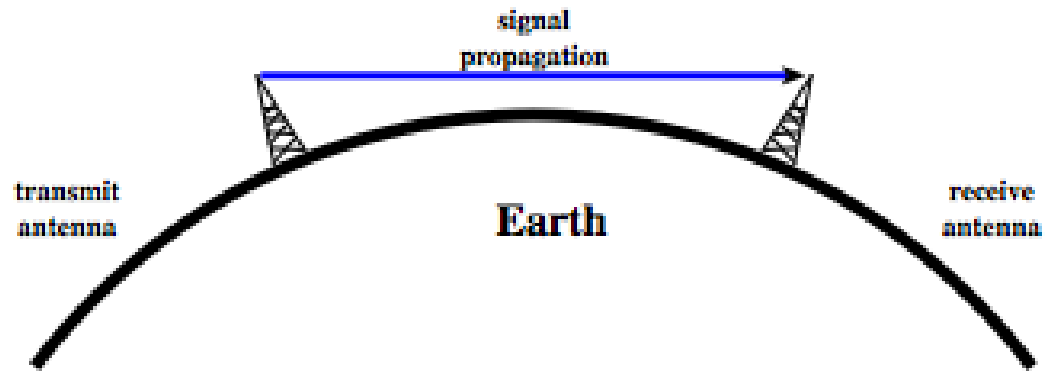
(a) Ground-wave propagation (below 2 MHz)

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)

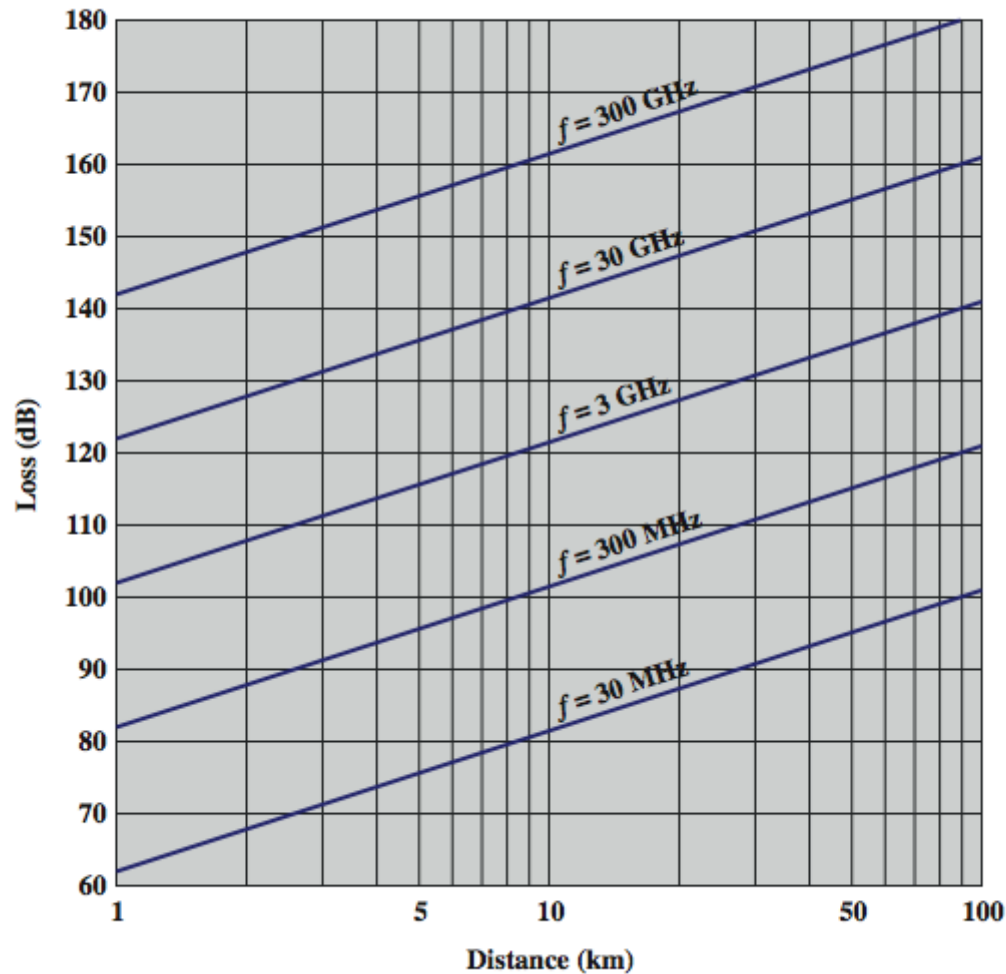
Refraction

- velocity of electromagnetic wave is a function of density of material
 - ~ 3×10^8 m/s in vacuum, less in anything else
- speed changes as move between media
- Index of refraction (refractive index) is
 - $\sin(\text{incidence})/\sin(\text{refraction})$
 - 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

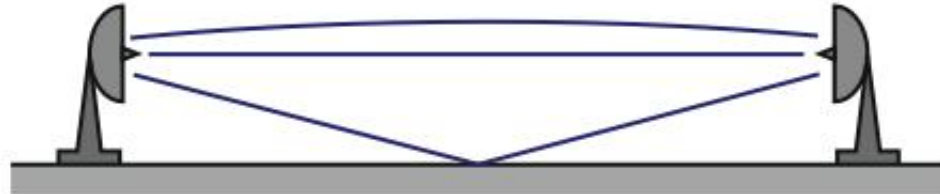
Line of Sight Transmission

- 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

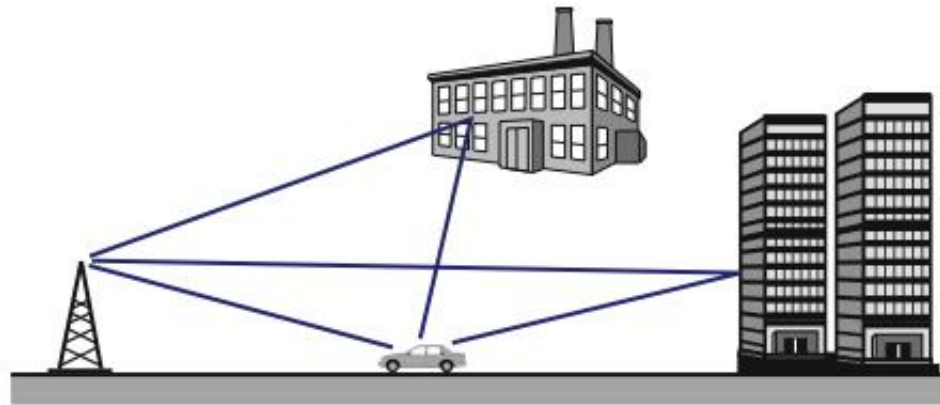
Free Space Loss



Multipath Interference



(a) Microwave line of sight



(b) Mobile radio

Summary

- looked at data transmission issues
- frequency, spectrum & bandwidth
- analog vs digital signals
- transmission impairments