

CSE 350

DATA COMMUNICATIONS

Lecture 4: Transmission Media



Overview

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- 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**



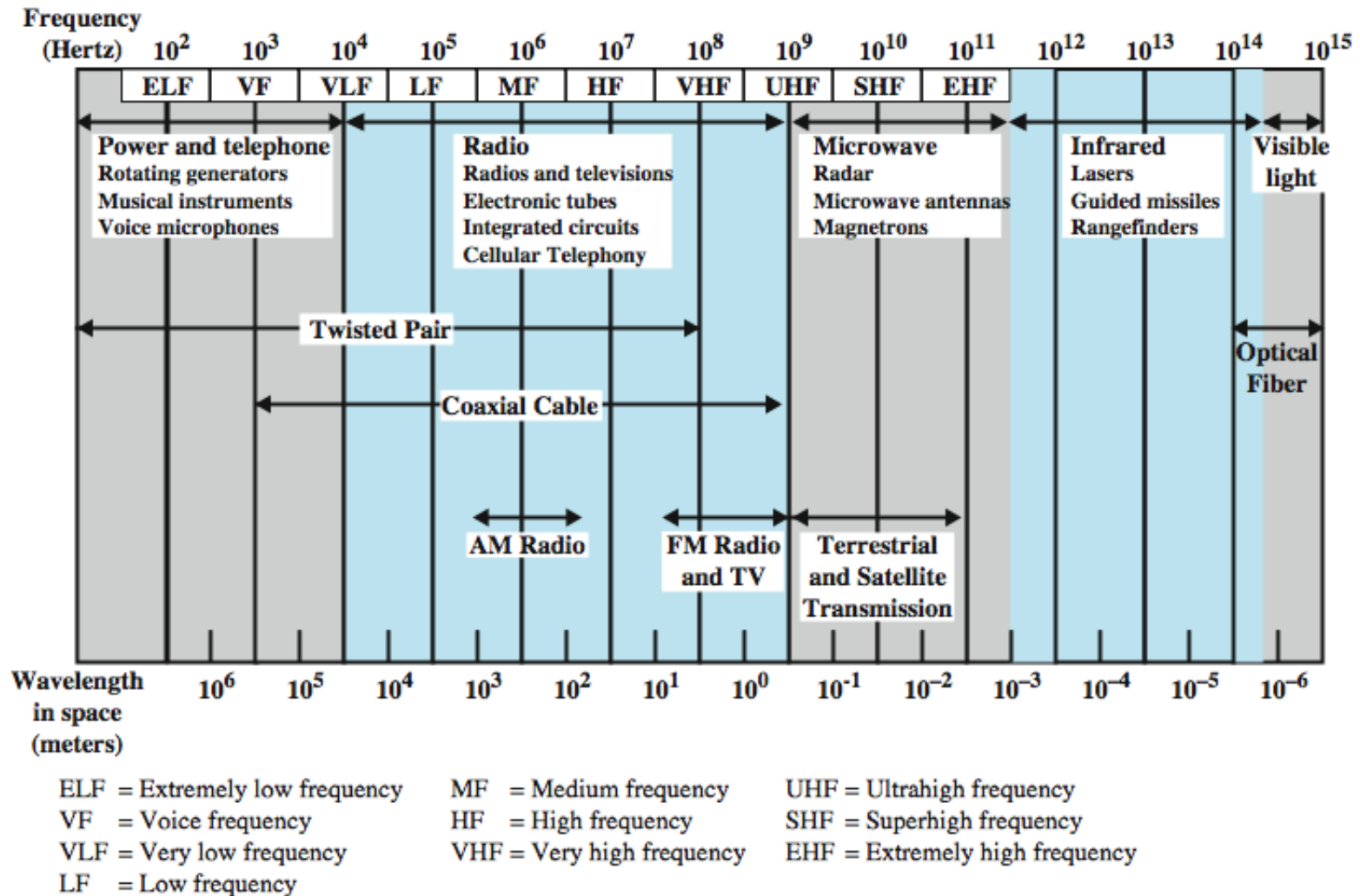
Design Factors

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- 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

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Transmission Characteristics of Guided Media

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	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

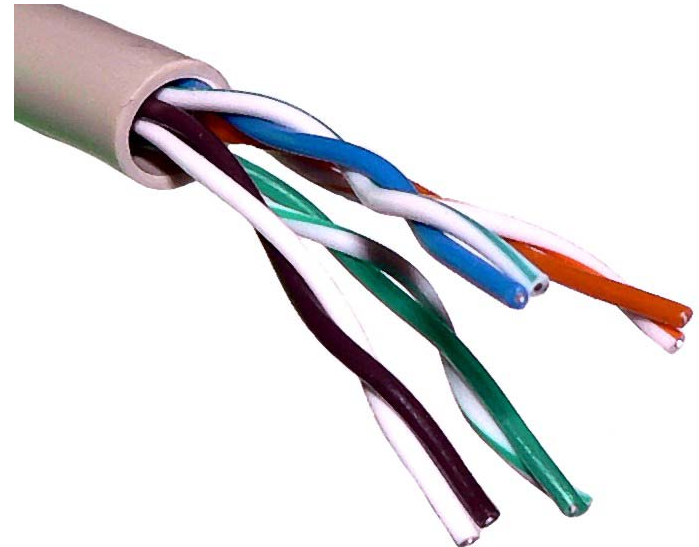
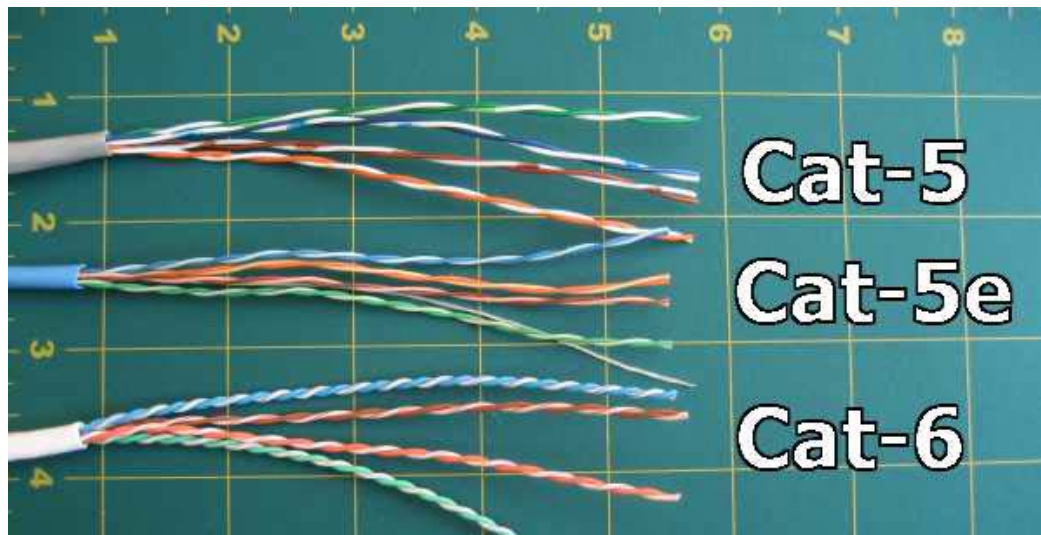
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Reduce Electromagnetic Interference

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



(a) Twisted pair





Twisted Pair - Transmission Characteristics

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- 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

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- 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

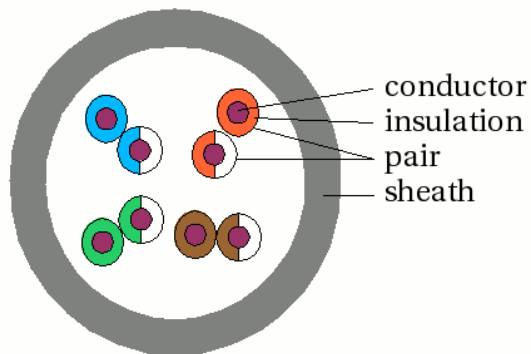
UTP Categories

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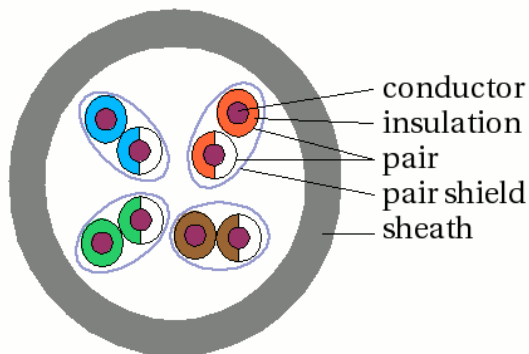
7.5~10 cm 0.6~0.85cm

	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

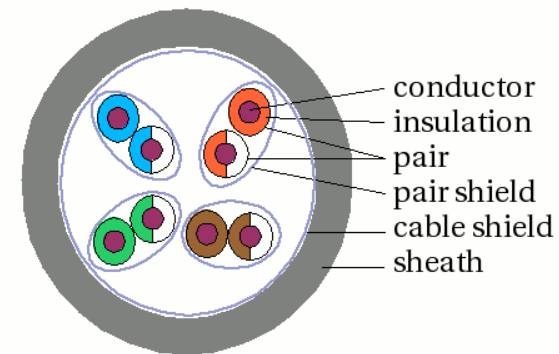
UTP



STP



S/STP

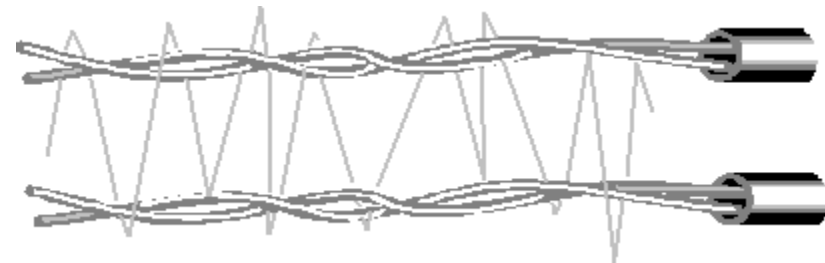




Comparison of Shielded and Unshielded Twisted Pair

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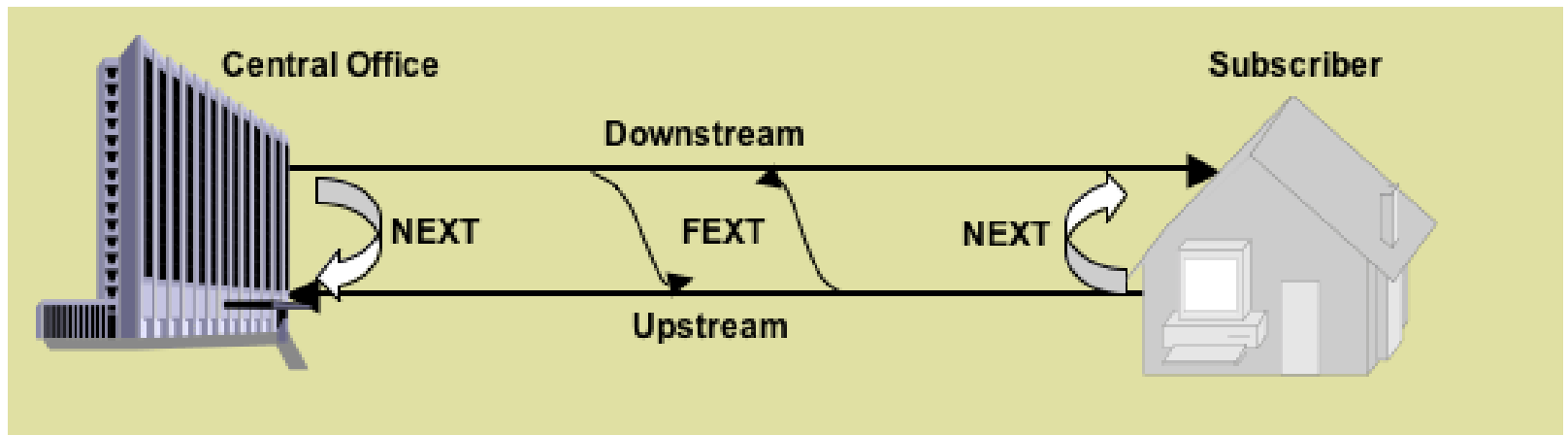
Frequency (MHz)	Attenuation (dB per 100 m)			Near-end Crosstalk (dB)		
	Category 3 UTP	Category 5 UTP	150-ohm STP	Category 3 UTP	Category 5 UTP	150-ohm STP
1	2.6	2.0	1.1	41	62	58
4	5.6	4.1	2.2	32	53	58
16	13.1	8.2	4.4	23	44	50.4
25	—	10.4	6.2	—	41	47.5
100	—	22.0	12.3	—	32	38.5
300	—	—	21.4	—	—	31.3



Near End Crosstalk

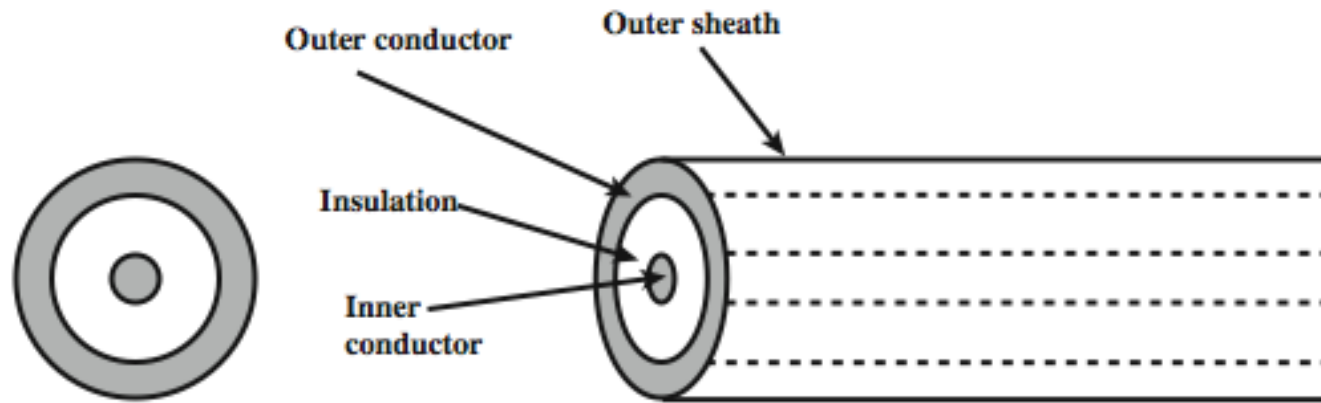
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- coupling of signal from one pair to another
- occurs when transmit signal entering the link couples back to receiving pair
- ie. near transmitted signal is picked up by near receiving pair

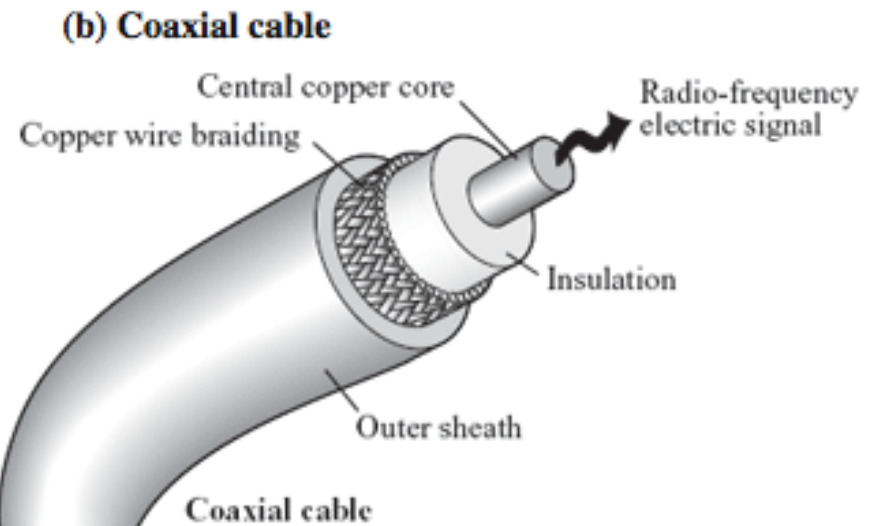
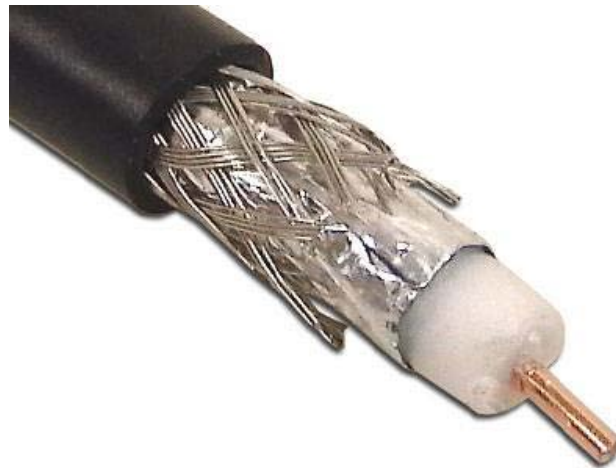


Coaxial Cable

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



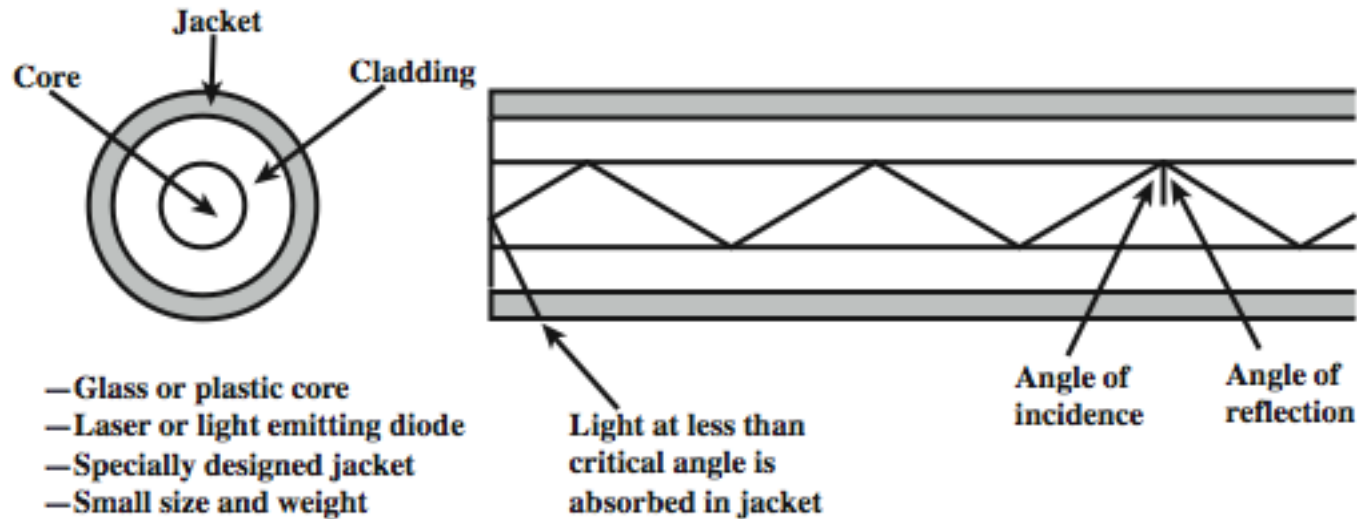


Coaxial Cable - Transmission Characteristics

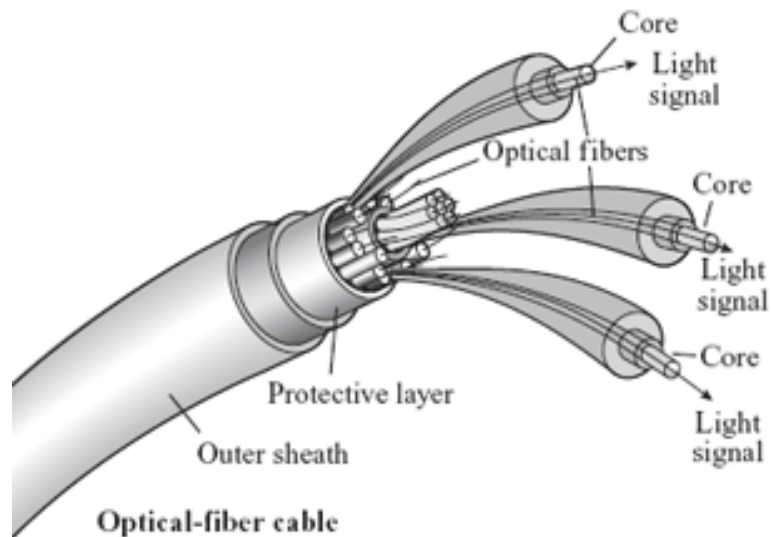
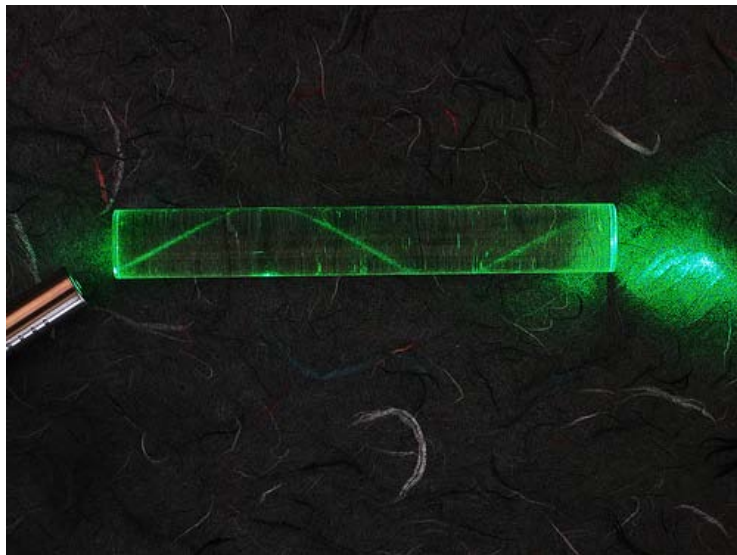
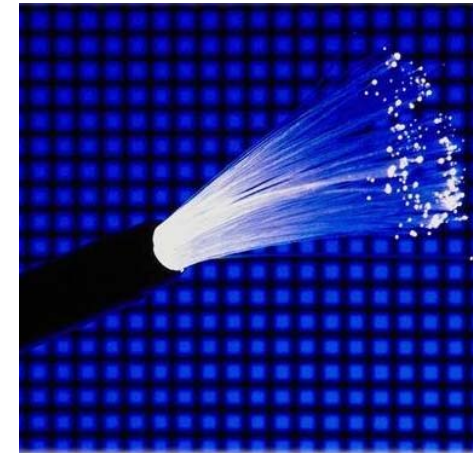
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- superior frequency characteristics to TP
- performance limited by attenuation & noise
- analog signals
 - ▣ amplifiers every few km
 - ▣ closer if higher frequency
 - ▣ up to 500MHz
- digital signals
 - ▣ repeater every 1km
 - ▣ closer for higher data rates

Optical Fiber



(c) Optical fiber





Optical Fiber - Benefits

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- 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

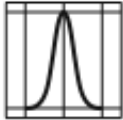
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- uses total internal reflection to transmit light
 - ▣ effectively acts as wave guide for 10^{14} to 10^{15} Hz
- can use several different light sources
 - ▣ Light Emitting Diode (LED)
 - cheaper, wider operating temp range, lasts longer
 - ▣ Injection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

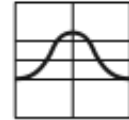
Optical Fiber Transmission Modes

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Input pulse

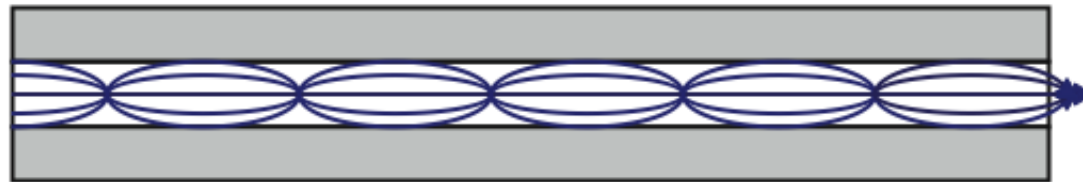


Output pulse

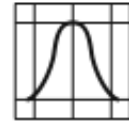


(a) Step-index multimode

Input pulse

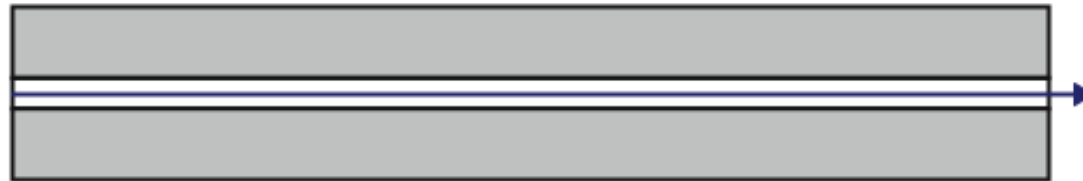


Output pulse

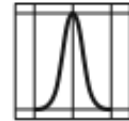


(b) Graded-index multimode

Input pulse



Output pulse



(c) Single mode



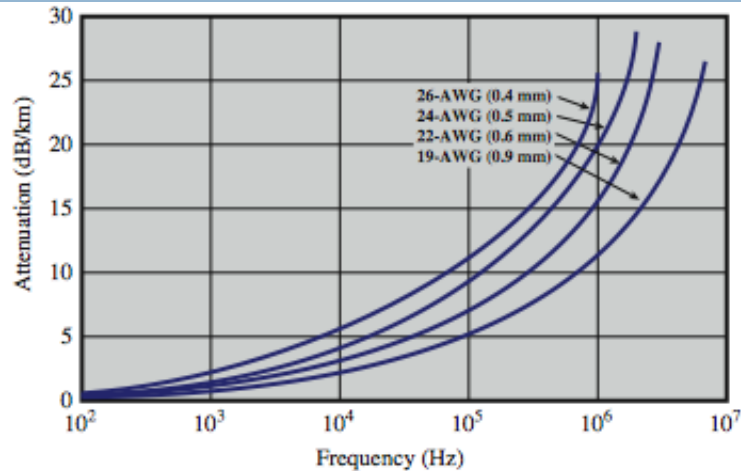
Frequency Utilization for Fiber Applications

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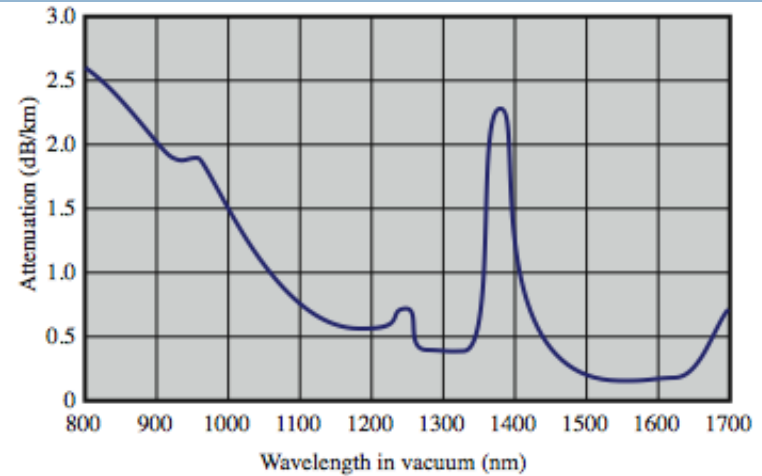
Wavelength (in vacuum) range (nm)	Frequency Range (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	192 to 185	L	Single mode	WDM

Attenuation in Guided Media

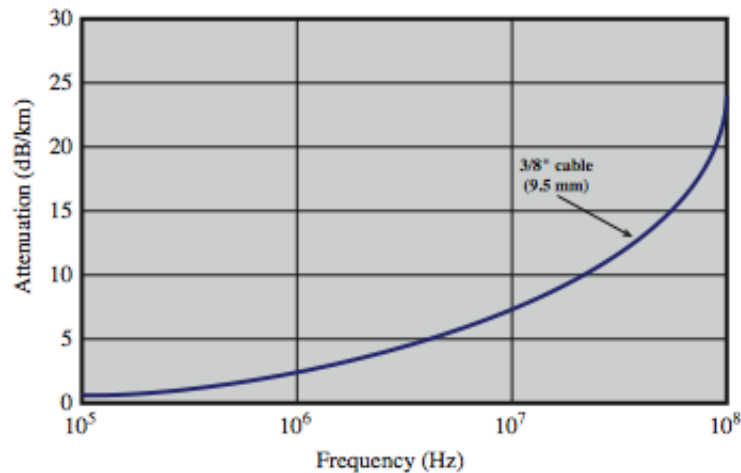
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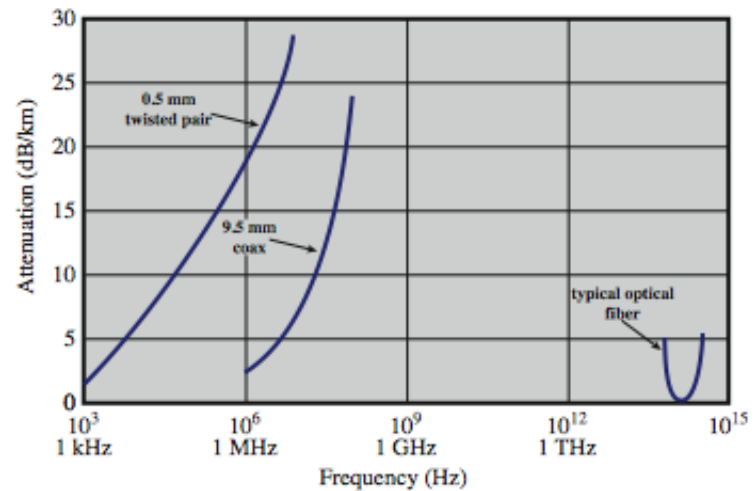
(a) Twisted pair (based on [REEV95])



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



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



(d) Composite graph



Wireless Transmission Frequencies

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- 30MHz to 1 GHz
 - ▣ Broadcast radio, omni-directional
- 2GHz to 40GHz
 - ▣ Microwave, highly directional
 - ▣ point to point
 - ▣ satellite
- 3×10^{11} to 2×10^{14}
 - ▣ infrared
 - ▣ local



Antennas

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- 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



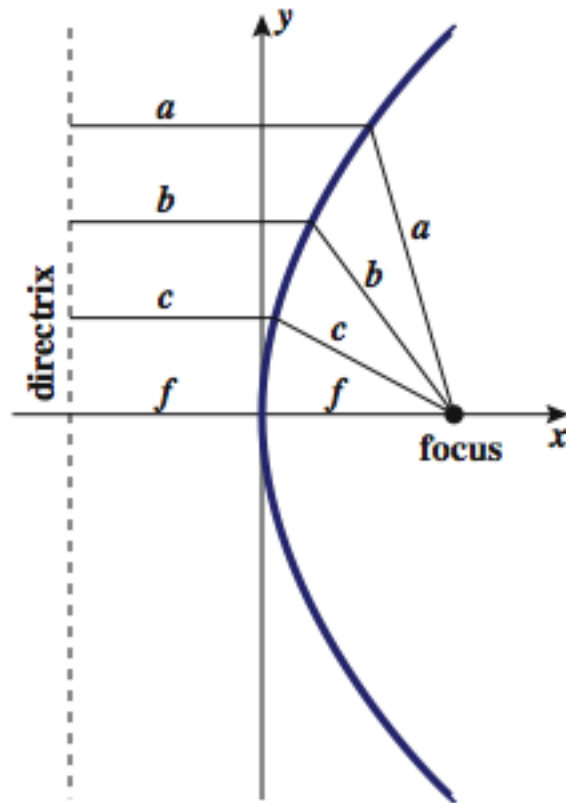
Radiation Pattern

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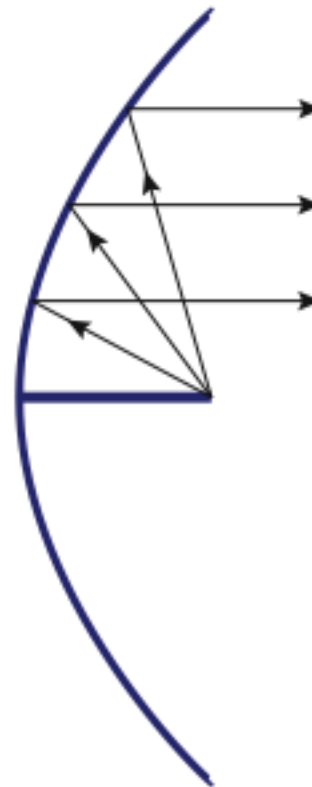
- power radiated in all directions
- not same performance in all directions
 - ▣ as seen in a radiation pattern diagram
- an isotropic antenna is a (theoretical) point in space
 - ▣ radiates in all directions equally
 - ▣ with a spherical radiation pattern

Parabolic Reflective Antenna

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(a) Parabola



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



Antenna Gain

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- 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



Broadcast Radio

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



Terrestrial Microwave

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- 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



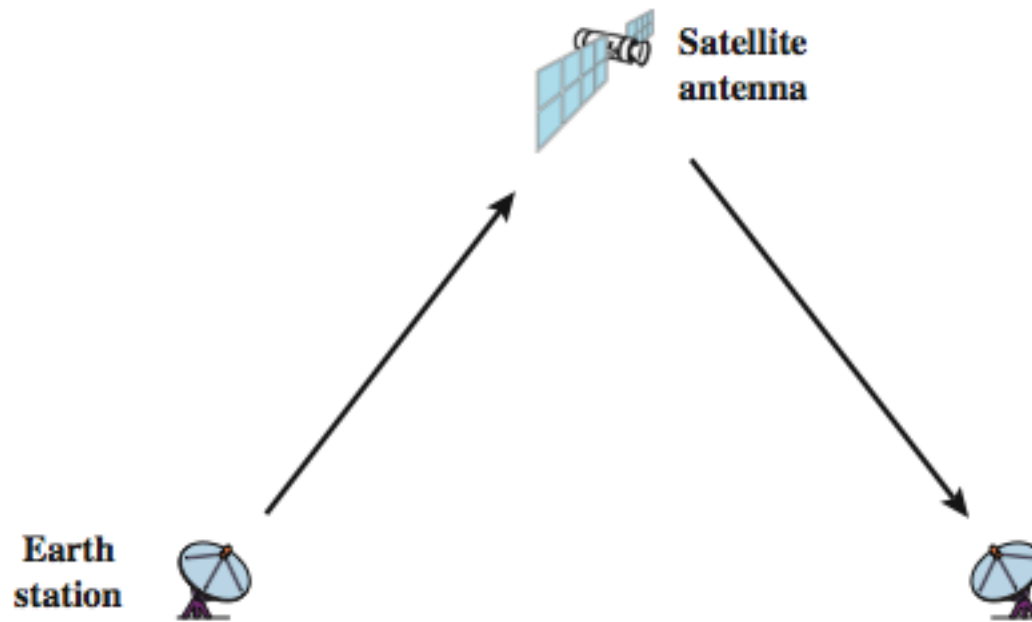
Satellite Microwave

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- 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

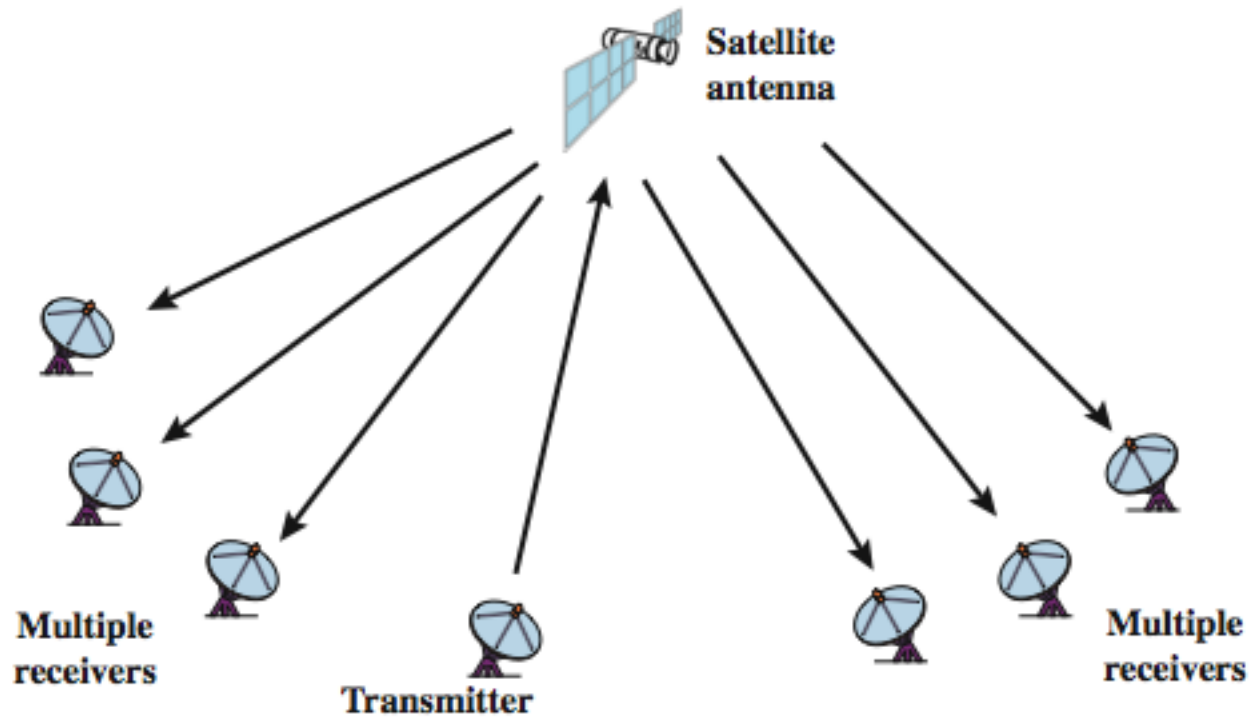
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(a) Point-to-point link

Satellite Broadcast Link

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(b) Broadcast link



Infrared

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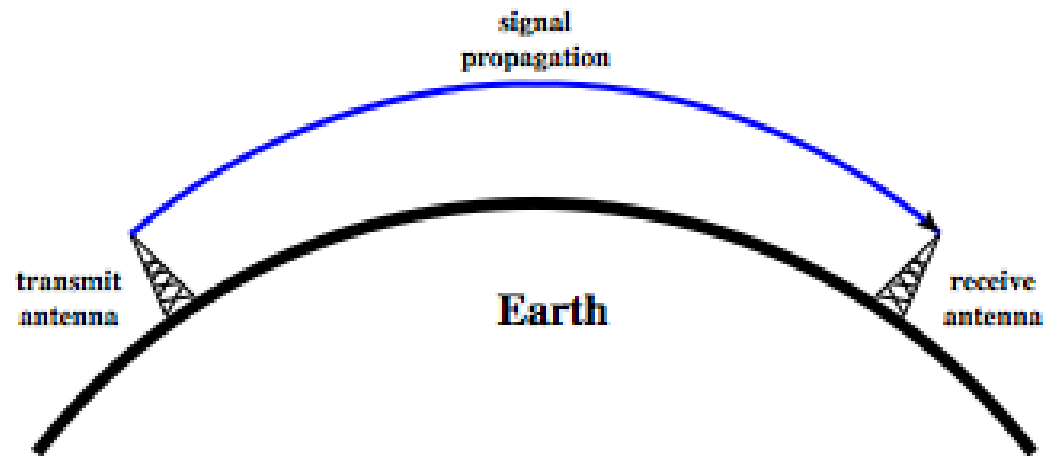
- modulate non-coherent infrared light
- end line of sight (or reflection)
- are blocked by walls
- no licenses required
- typical uses
 - ▣ TV remote control
 - ▣ IRD port



Wireless Propagation

Ground Wave

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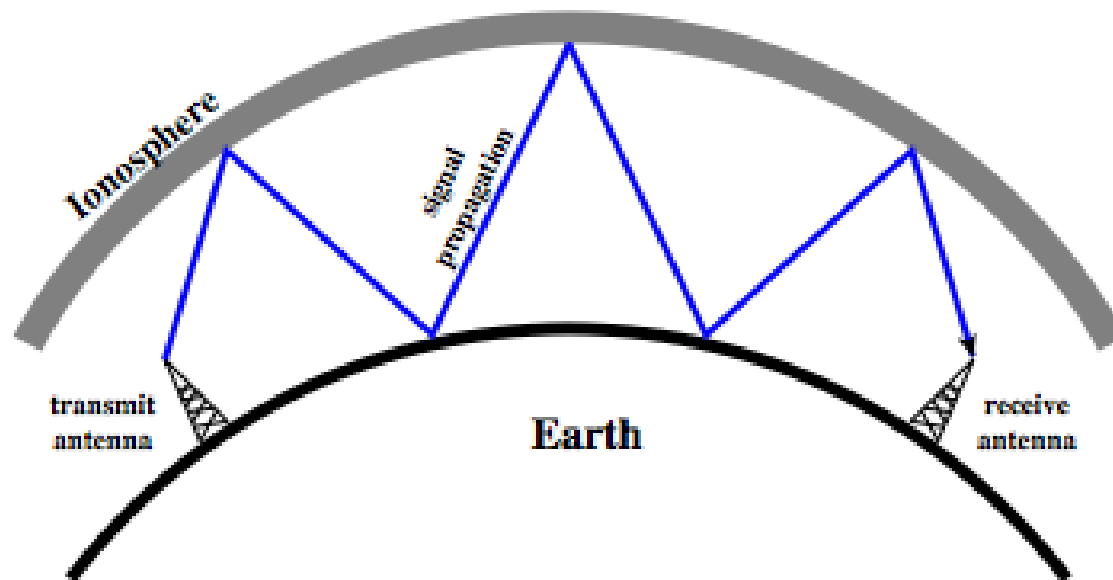
(a) Ground-wave propagation (below 2 MHz)



Wireless Propagation

Sky Wave

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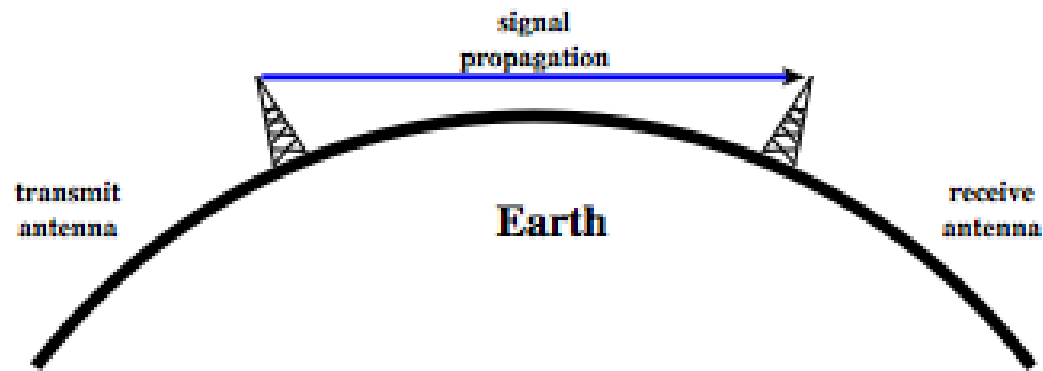
(b) Sky-wave propagation (2 to 30 MHz)



Wireless Propagation

Line of Sight

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



Refraction

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- velocity of electromagnetic wave is a function of density of material
 - $\sim 3 \times 10^8$ 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

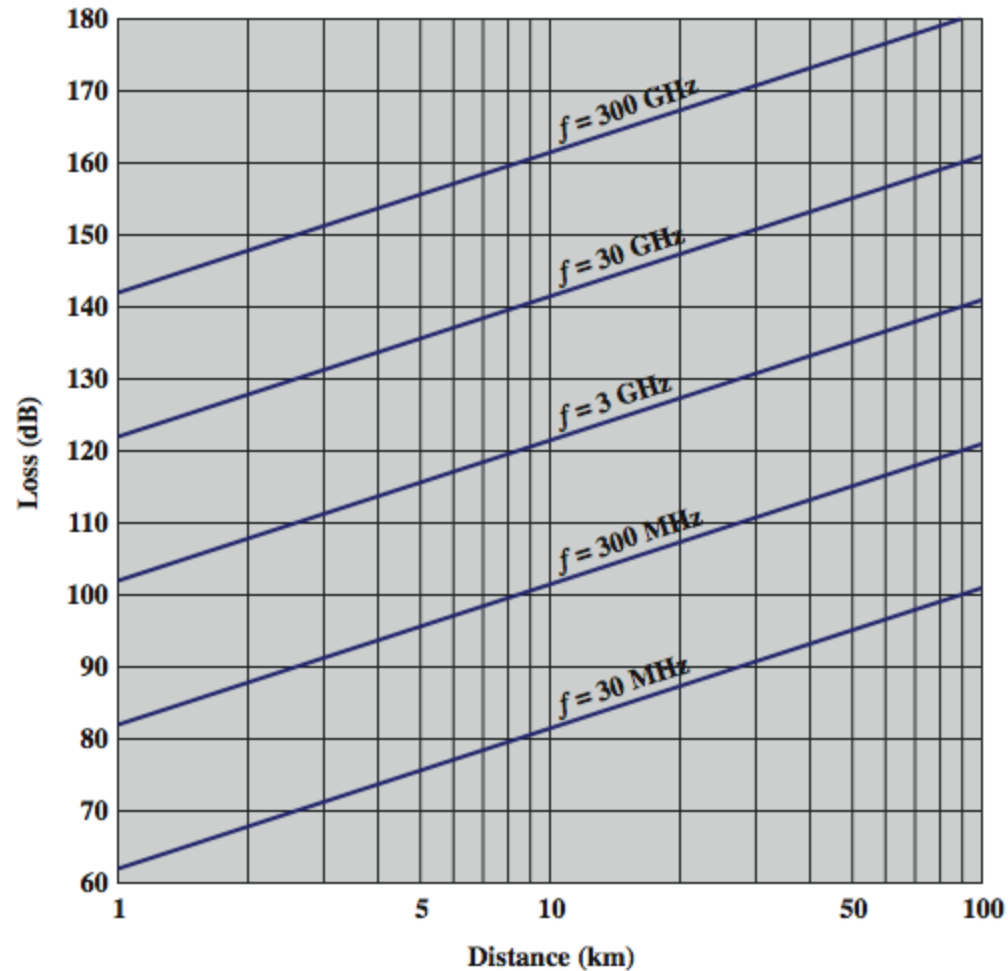
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- Free space loss
 - ▣ loss of signal with distance
- Atmospheric Absorption
 - ▣ from water vapour and oxygen absorption
- Multipath
 - ▣ multiple interfering signals from reflections
- Refraction
 - ▣ bending signal away from receiver



Free Space Loss

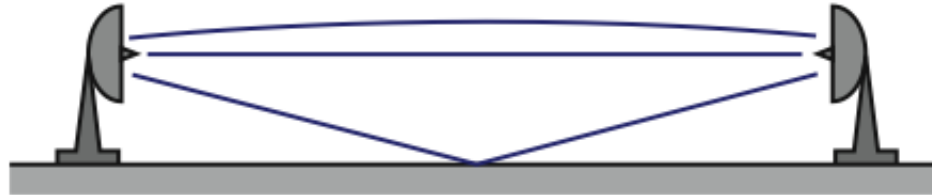
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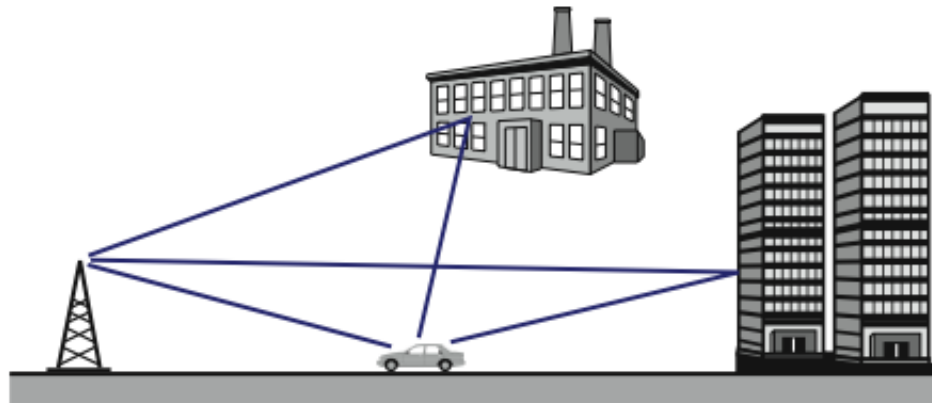


Multipath Interference

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(a) Microwave line of sight



(b) Mobile radio



Summary

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