澳 門 理 工 大 學
Universidade Politécnica de Macau
Macao Polytechnic University

Faculty of Applied Sciences
B.Sc. in Computing

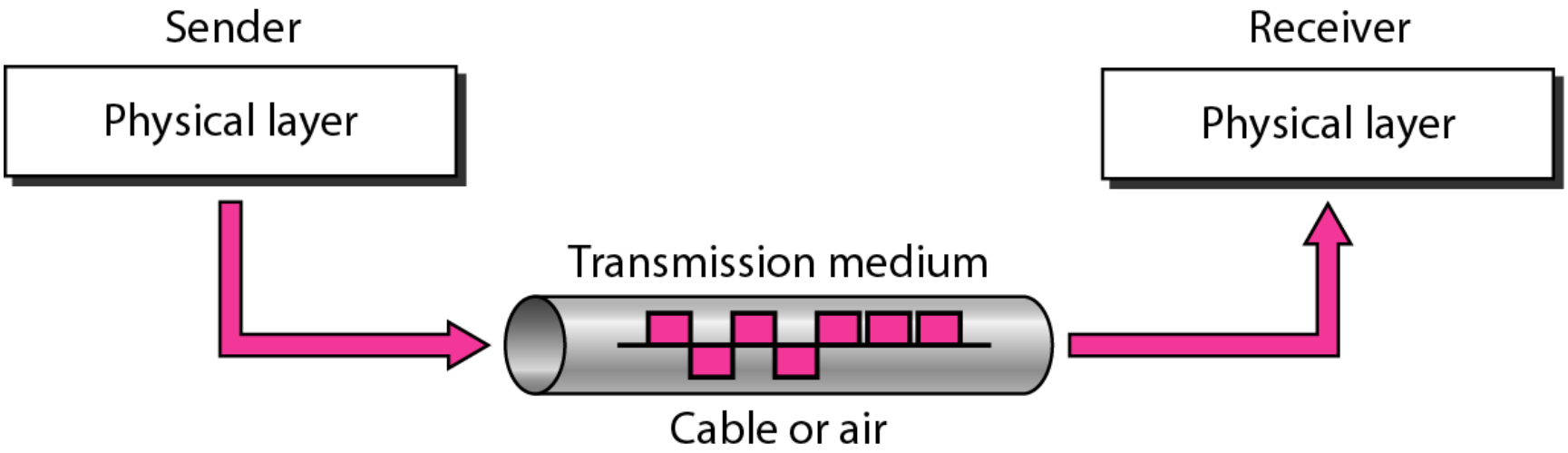
Academic Year 2022/2023 2nd Semester

COMP123 – 121/122

Data Communications

Transmission Media

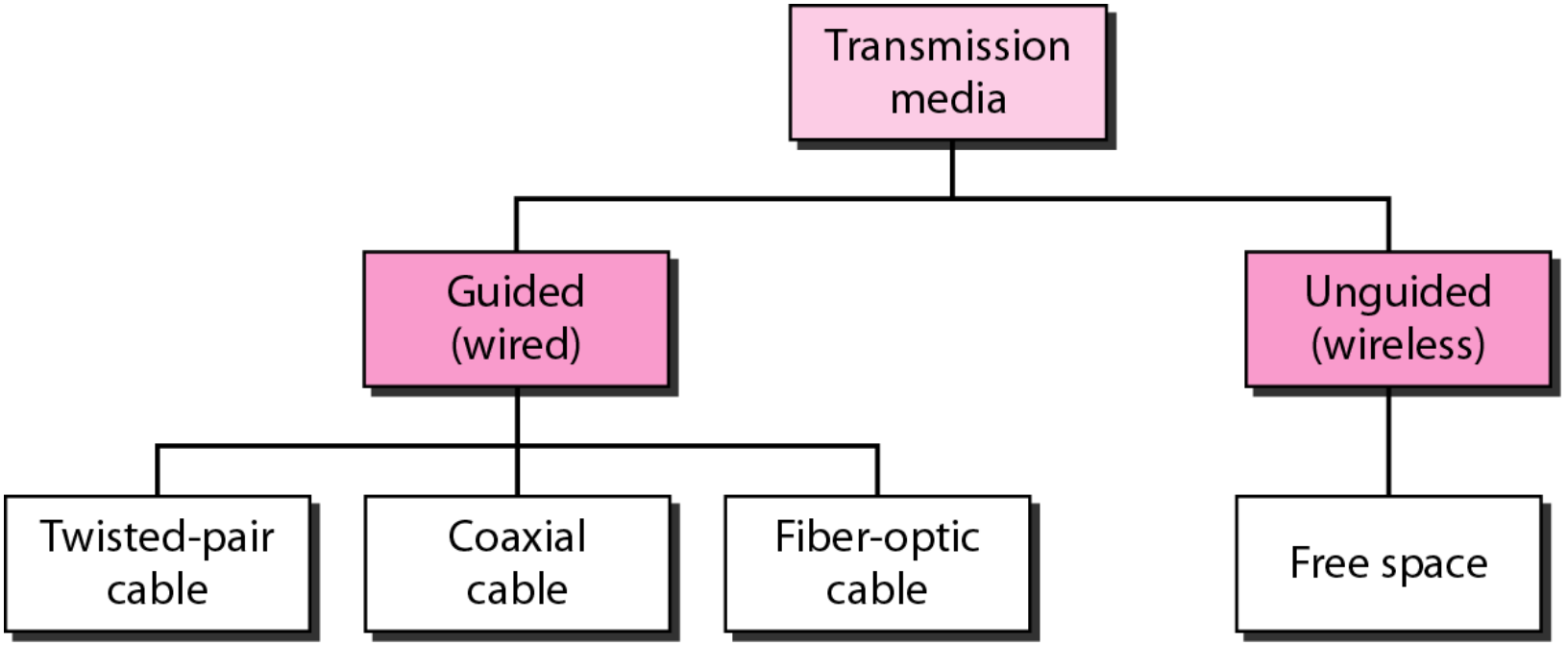
Transmission Medium and Physical Layer



Overview

- transmission medium is the physical path between transmitter and receiver
- guided media – guided along a solid medium
- unguided media – atmosphere, space, water
- characteristics and quality determined by medium and signal
  - guided media - medium is more important
  - unguided media - bandwidth produced by the antenna is more important
- key concerns are data rate and distance

Classes of Transmission Media



Design Factors Determining Data Rate and Distance

bandwidth

- **higher bandwidth gives higher data rate**

transmission impairments

- **impairments, such as attenuation, limit the distance**

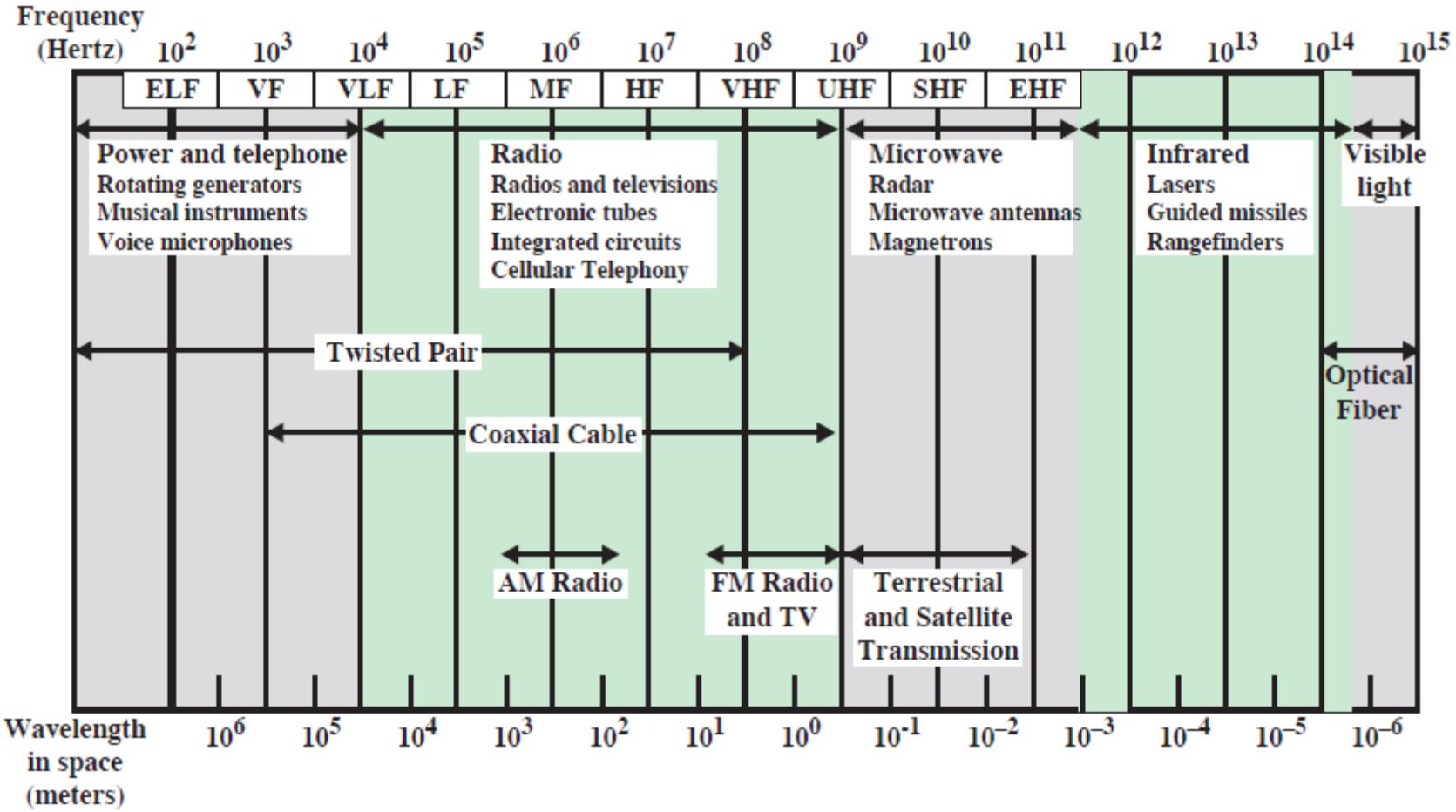
interference

- **overlapping frequency bands can distort or wipe out a signal**

number of receivers

- **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 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

Guided Transmission Media - Twisted Pair

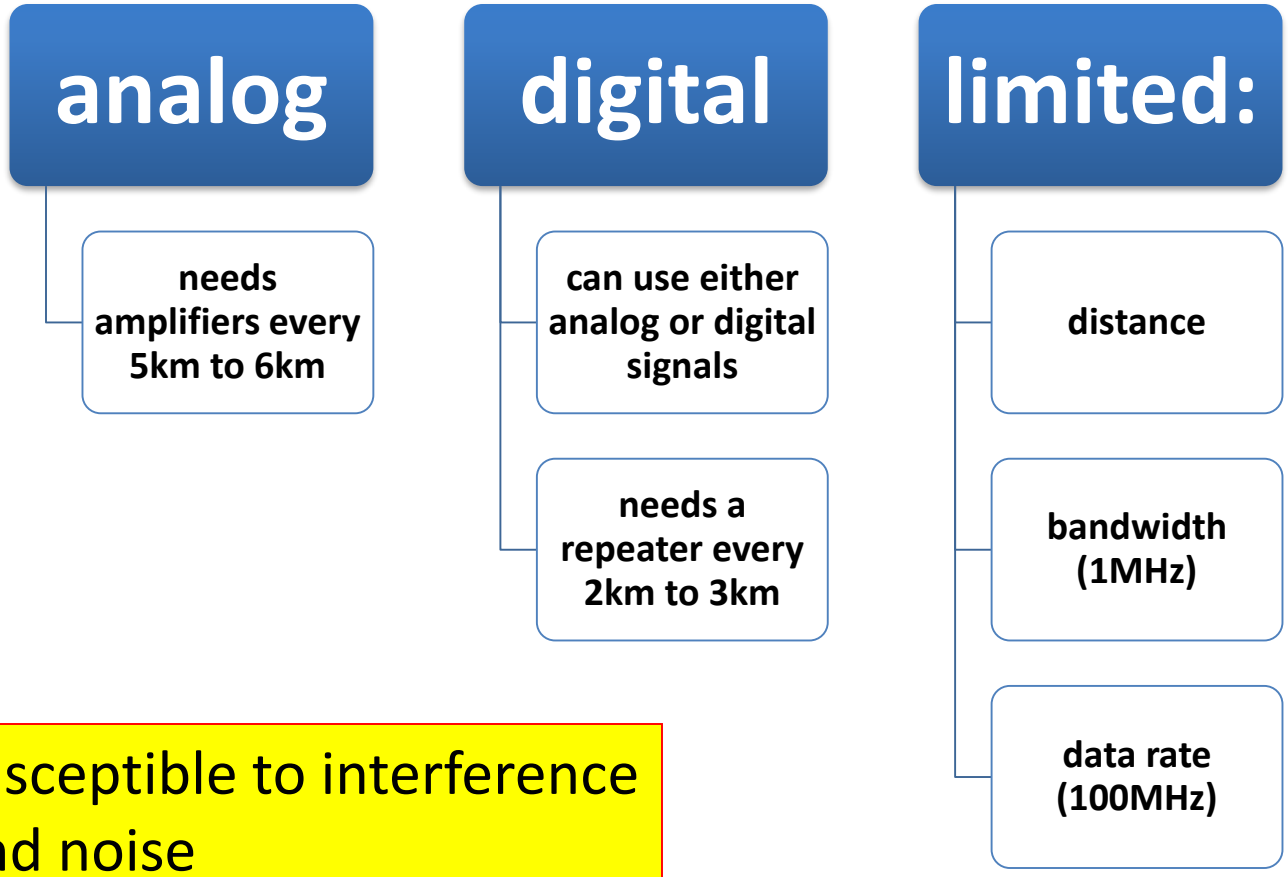
- Twisted pair is the least expensive and most widely used guided transmission medium
- Consists of two insulated copper wires arranged in a regular spiral pattern
- a wire pair acts as a single communication link
- pairs are bundled together into a cable
- most commonly used in the telephone network and for communications within buildings

Twisted Pair

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

(a) Twisted pair

Twisted Pair - Transmission Characteristics



susceptible to interference and noise

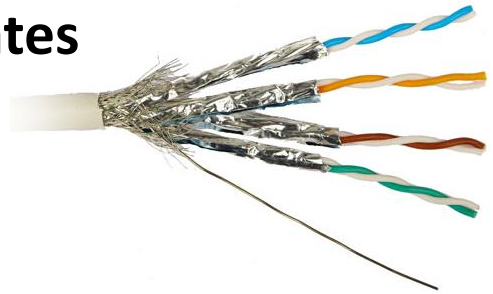
Unshielded vs. Shielded Twisted Pair

Unshielded Twisted Pair (UTP)

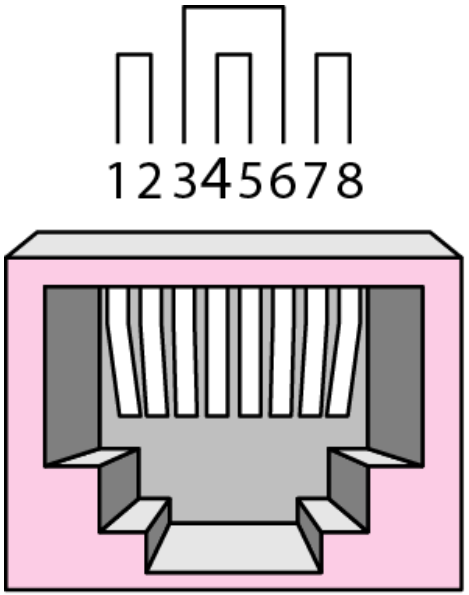
- ordinary telephone wire
- cheapest
- easiest to install
- suffers from external electromagnetic interference

Shielded Twisted Pair (STP)

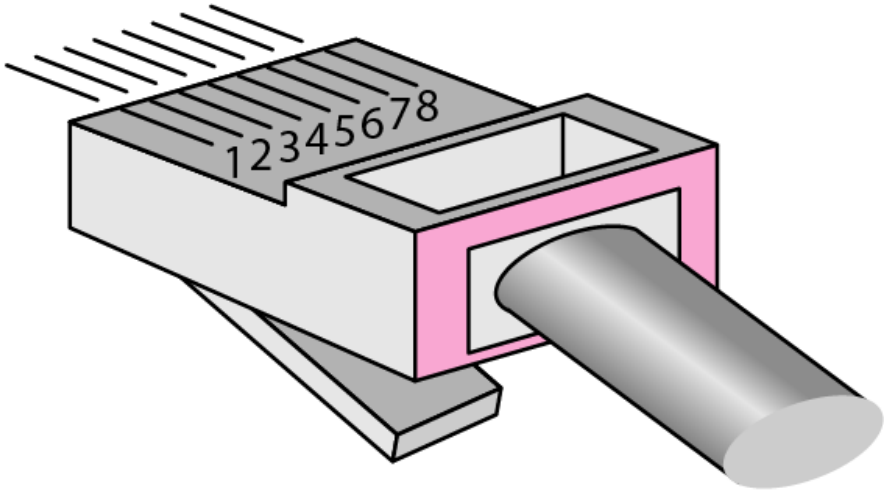
- has metal braid or sheathing that reduces interference
- provides better performance at higher data rates
- more expensive
- harder to handle (thick, heavy)



UTP Connector



RJ-45 Female



RJ-45 Male

Twisted Pair Categories and Classes

	Category 5e Class D	Category 6 Class E	Category 6A Class E_A	Category 7 Class F	Category 7_A Class F_A
Bandwidth	100 MHz	250 MHz	500 MHz	600 MHz	1,000 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	S/FTP	S/FTP
Insertion loss (dB)	24	21.3	20.9	20.8	20.3
NEXT loss (dB)	30.1	39.9	39.9	62.9	65
ACR (dB)	6.1	18.6	19	42.1	44.7

UTP = Unshielded twisted pair
FTP = Foil twisted pair
S/FTP = Shielded/foil twisted pair

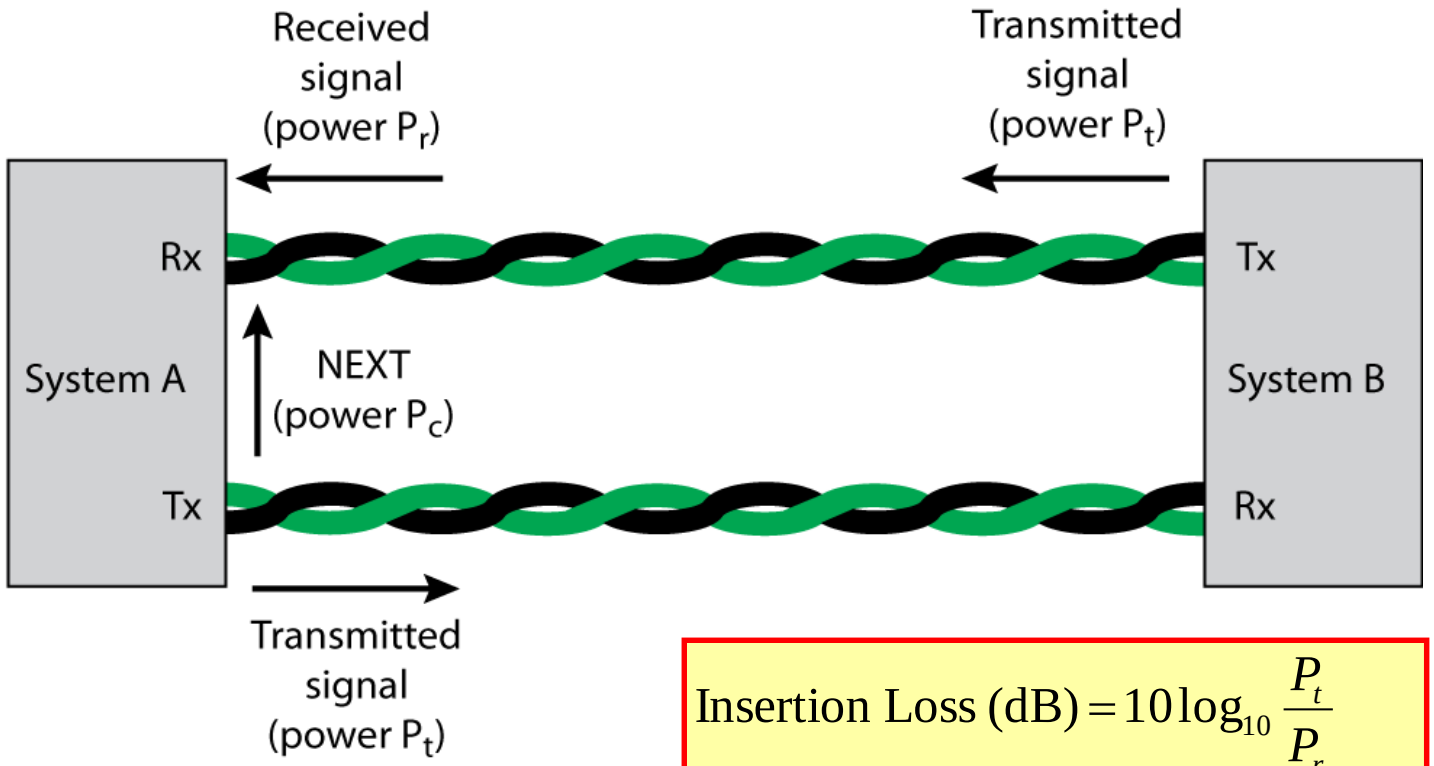
Insertion Loss (also referred to **attenuation**) is the loss of signal power resulting from the insertion of a device in a transmission line or optical fiber

NEXT = Near End Crosstalk
ACR = Attenuation-to-Crosstalk ratio

Near End Crosstalk (NEXT)

- Coupling of signal from one pair of conductors to another
- Occurs when transmit signal entering the link couples back to the receiving pair
- Near transmitted signal is picked up by near receiving pair
- Measured as the difference in amplitude (in dB) between a transmitted signal and the crosstalk received on other cable pairs at the same end of the cabling
- Higher NEXT values correspond to better cabling performance.

Signal Power Relationships



$$\text{Insertion Loss (dB)} = 10\log_{10}\frac{P_t}{P_r}$$

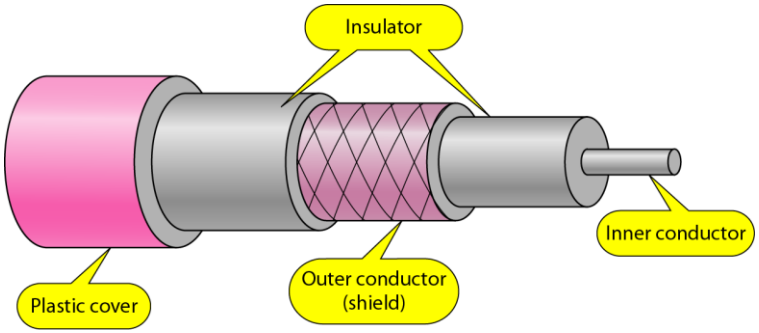
$$\text{NEXT (dB)} = 10\log_{10}\frac{P_r}{P_c}$$

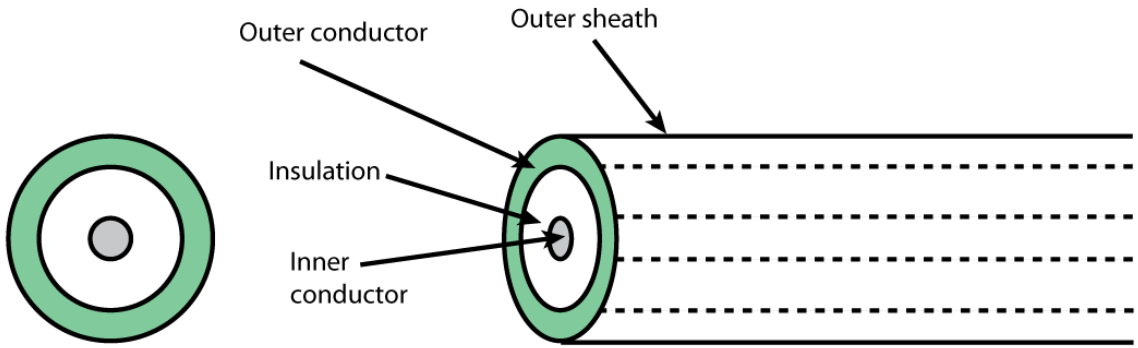
$$\text{ACR (dB)} = \text{NEXT} - \text{Insertion Loss}$$

Coaxial Cable

- can be used over longer distances and support more stations on a shared line than twisted pair
- a versatile transmission medium used in a wide variety of applications
- much less susceptible to interference and crosstalk
- widely used in long distance telecommunications
- performance, price and advantages have made it popular to use

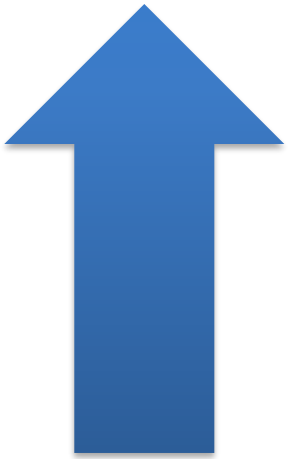
Coaxial Cable



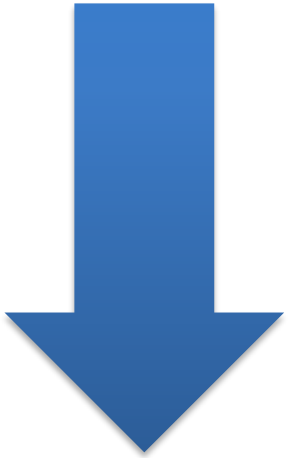


—Outer conductor is braided shield
—Inner conductor is solid metal
—Separated by insulating material
—Covered by padding

Coaxial Cable - Transmission Characteristics



frequency characteristics superior to twisted pair



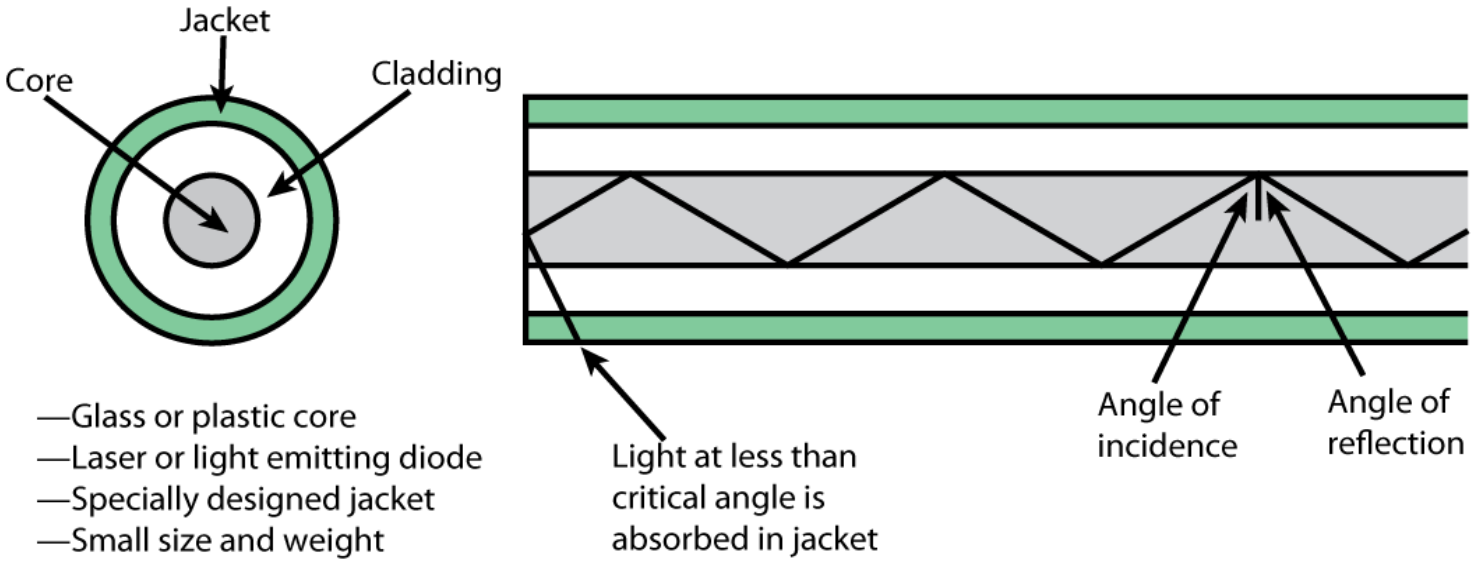
performance limited by attenuation & noise

analog signals	digital signals
• amplifiers needed every few kilometers - closer if higher frequency • usable spectrum extends up to 500MHz	• repeater every 1km - closer for higher data rates

Optical Fiber

- A thin flexible medium capable of guiding an optical ray
- Various glasses and plastics can be used to make optical fibers
- A cylindrical shape with three sections – core, cladding, jacket
- Widely used in long distance telecommunications
- Performance, price and advantages have made it popular to use

Optical Fiber



Optical Fiber - Benefits

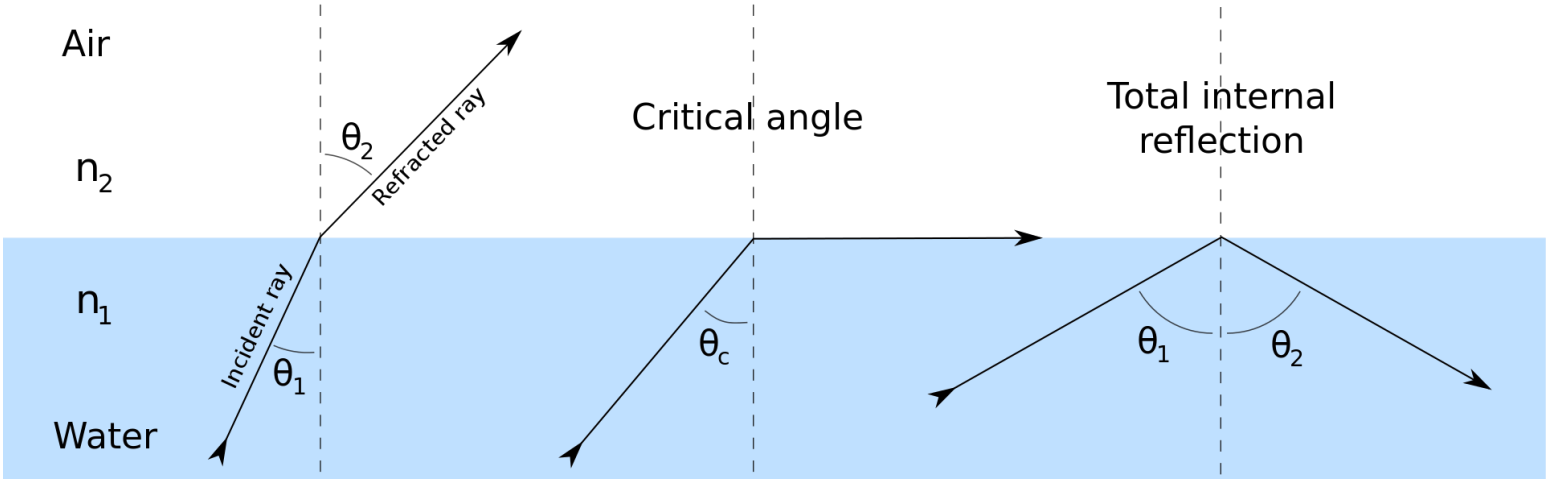
- greater capacity
  - data rates of hundreds of Gbps
- smaller size and lighter weight
  - considerably thinner than coaxial or twisted pair cable
  - reduces structural support requirements
- lower attenuation
- electromagnetic isolation
  - not vulnerable to interference, impulse noise, or crosstalk
  - high degree of security from eavesdropping
- greater repeater spacing
  - lower cost and fewer sources of error

Optical Fiber – Transmission Characteristics

- uses total internal reflection to transmit light
  - effectively acts as wave guide for 10^{14} to 10^{15} Hz
- light sources used:
  - ❑Light Emitting Diode (LED)
    - cheaper, operates over a greater temperature range, lasts longer
  - ❑Injection Laser Diode (ILD)
    - more efficient, has greater data rates

- has a relationship among wavelength, type of transmission and achievable data rate

Total Internal Reflection



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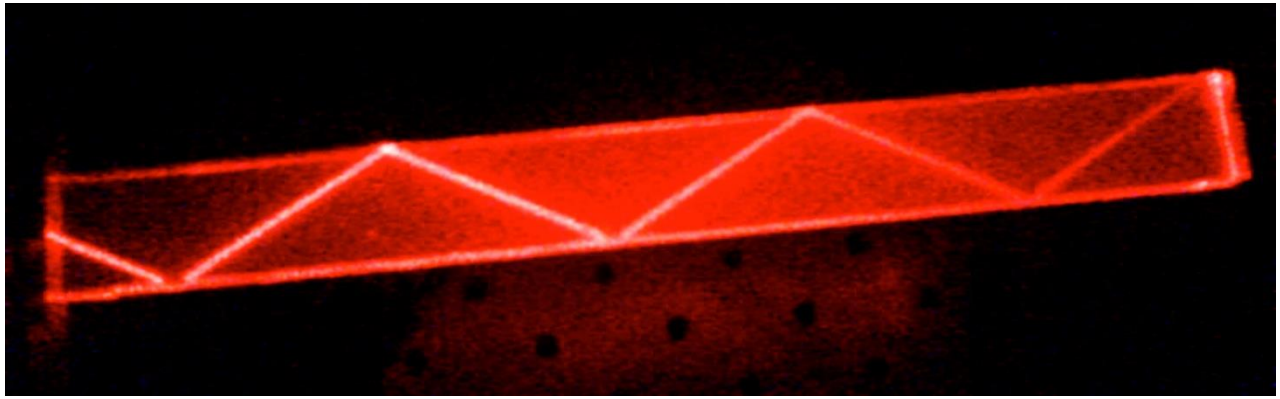

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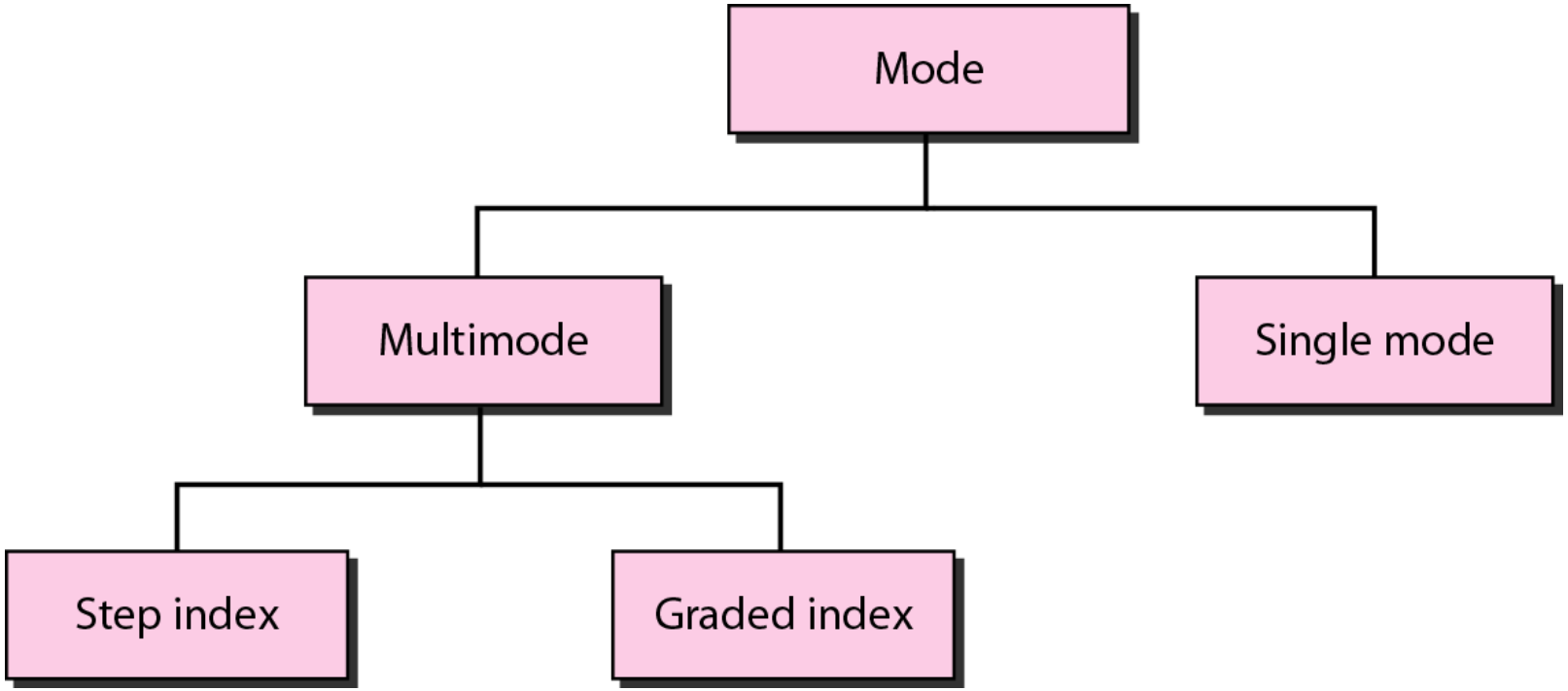
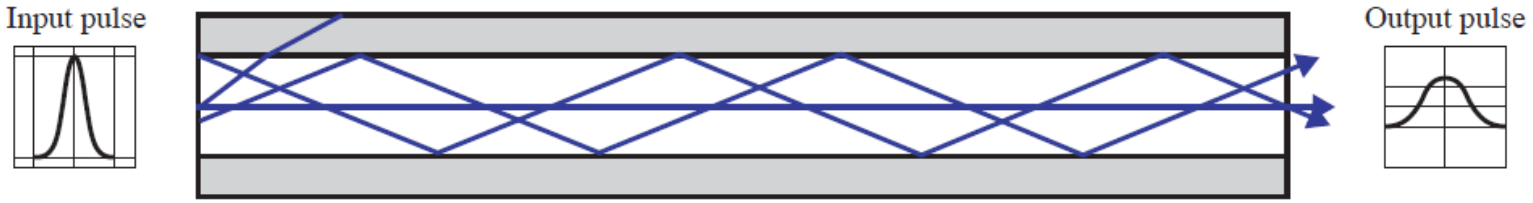
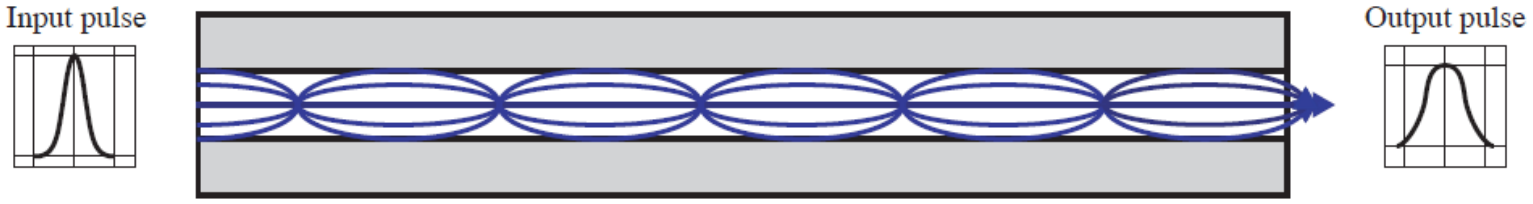
Optical Fiber Transmission Modes



Optical Fiber Transmission Modes



(a) Step-index multimode



(b) Graded-index multimode

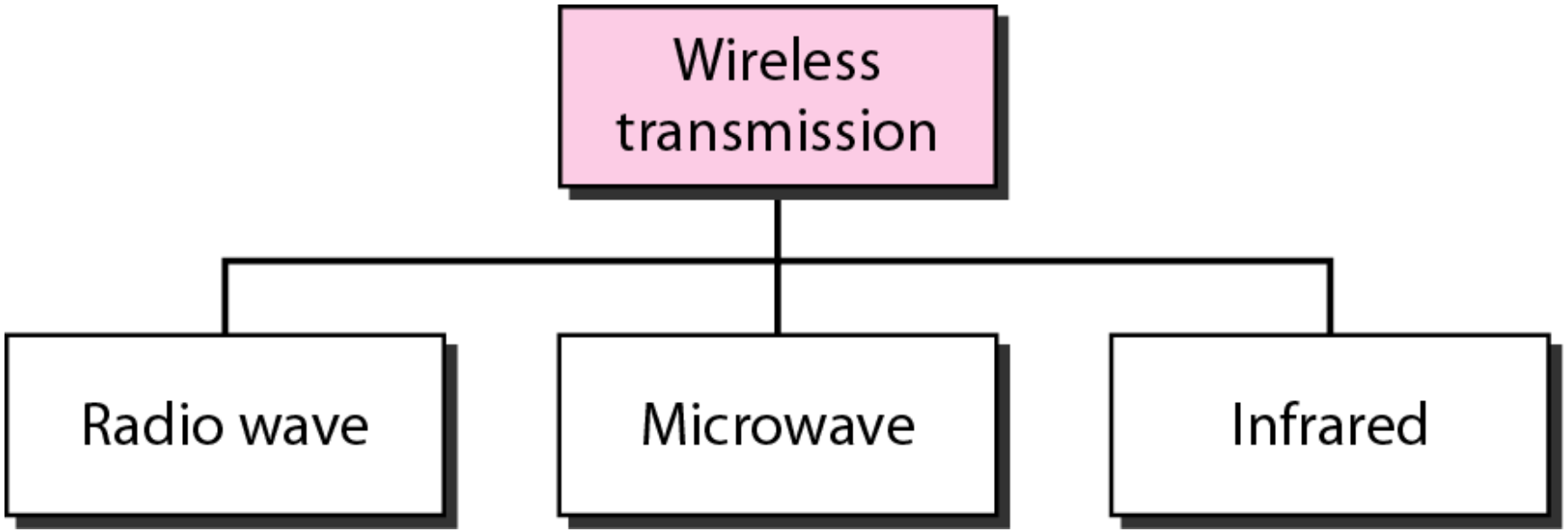
(c) Single mode

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	192 to 185	L	Single mode	WDM

WDM = wavelength division multiplexing
1THz = 1000 GHz
1nm = 1×10^{-9}m

Wireless Transmission Waves



Wireless Transmission Frequencies

1GHz to 40GHz

- referred to as **microwave frequencies**
- highly directional beams are possible
- suitable for point to point transmissions
- also used for satellite

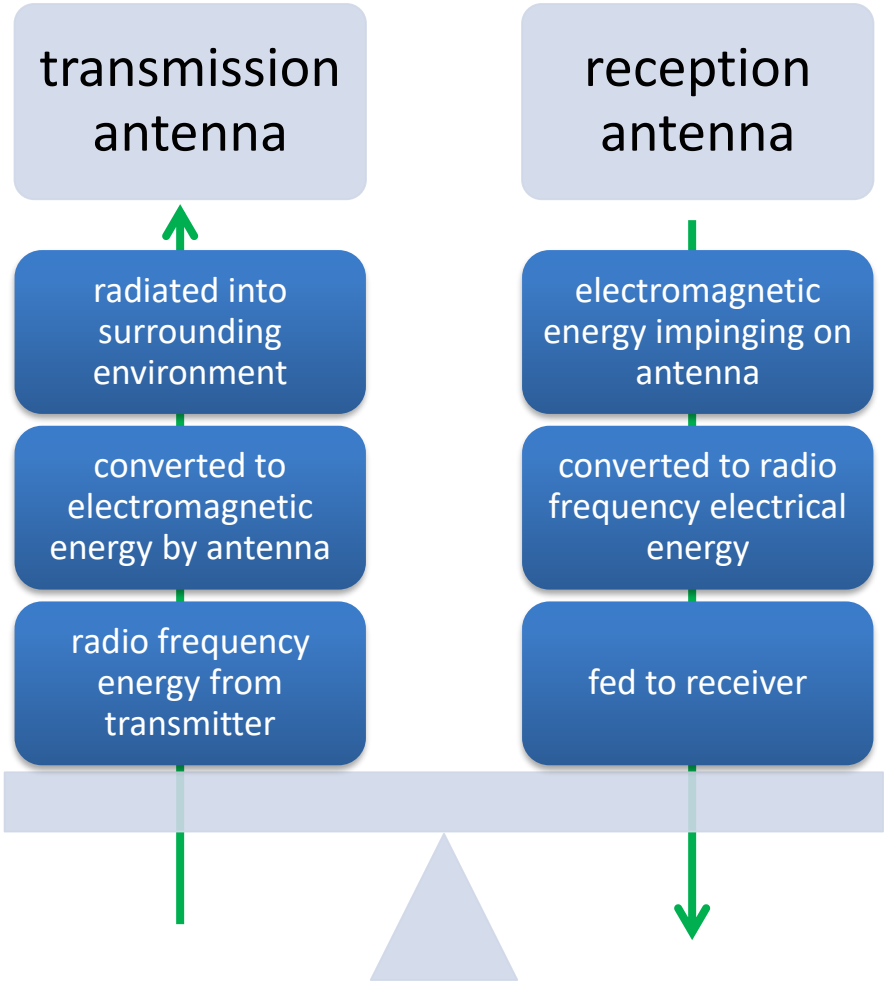
30MHz to 1GHz

- suitable for omnidirectional applications
- referred to as the **radio range**

3×10^{11} to 2×10^{14} Hz

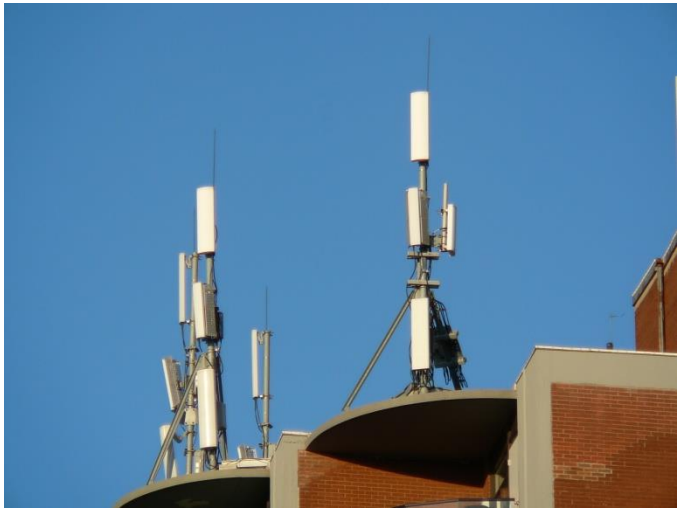
- **infrared** portion of the spectrum
- useful to local point-to-point and multipoint applications within confined areas

Antennas



- electrical conductors used to radiate or collect electromagnetic energy
- same antenna is often used for both purposes
  - characteristics are the same

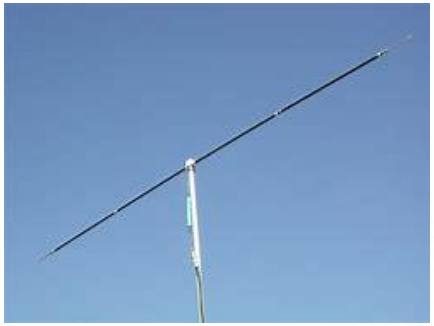
Examples of Antennas



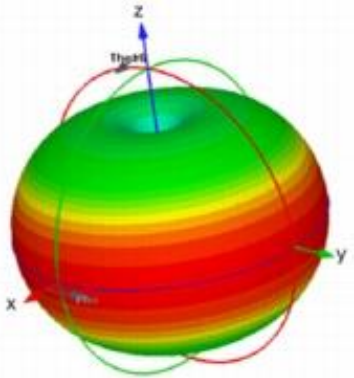
Radiation Pattern

- power radiated in all directions
- does not perform equally well in all directions
  - as seen in a radiation pattern diagram
- Radiation pattern - a graphical representation of the radiation properties of an antenna
- an isotropic antenna is a point in space that radiates power
  - in all directions equally
  - with a spherical radiation pattern

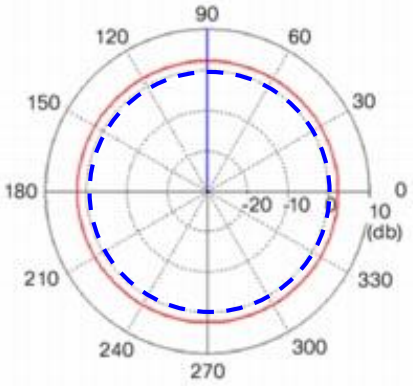
Radiation Pattern of Dipole Antenna



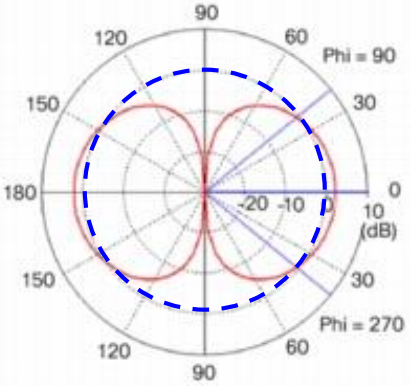
(a) Dipole Antenna Model



(b) Dipole 3D Radiation Pattern



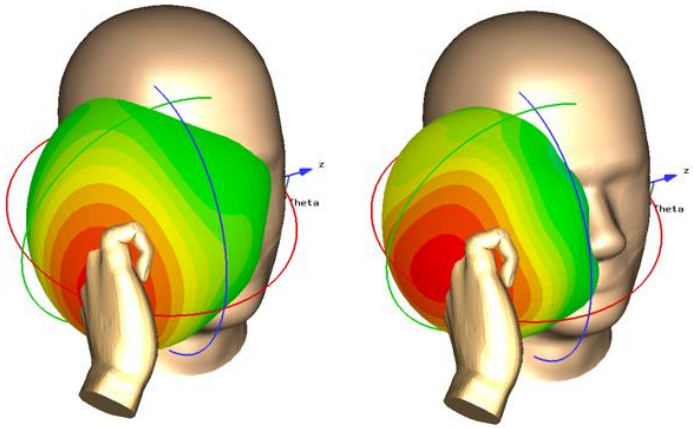
(c) Dipole Azimuth Plane Pattern

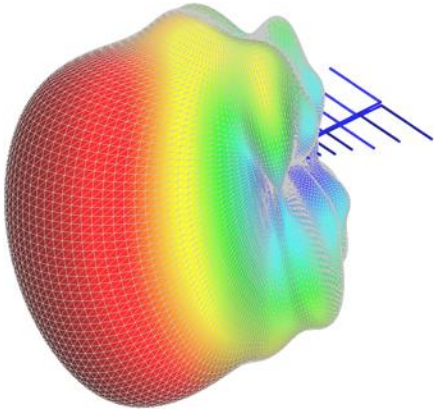


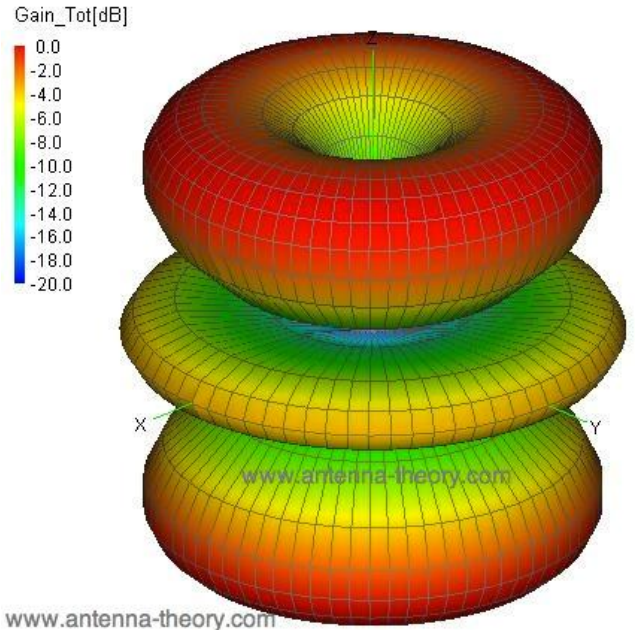
(d) Dipole Elevation Plane Pattern

Radiation pattern is a common way to characterize the performance of an antenna.

Other Example of Radiation Pattern







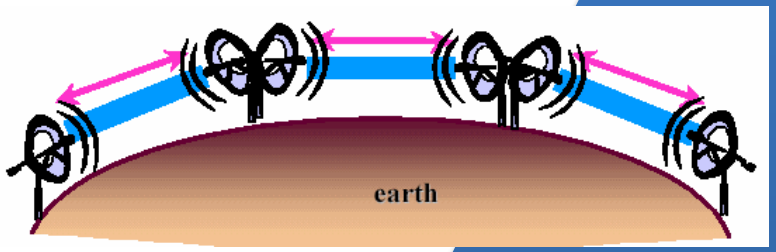
Antenna Gain

- measure of the directionality of an 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 physical size and shape

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

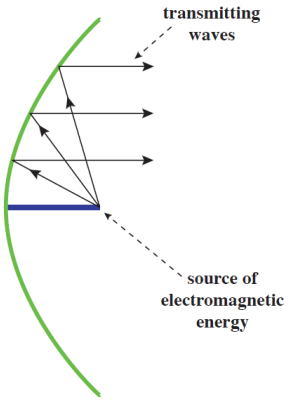
Terrestrial Microwave

most common type is a parabolic dish with an antenna focusing a narrow beam onto a receiving antenna



located at substantial heights above ground to extend range and transmit over obstacles

uses a series of microwave relay towers with point-to-point microwave links to achieve long distance transmission



Terrestrial Microwave Applications

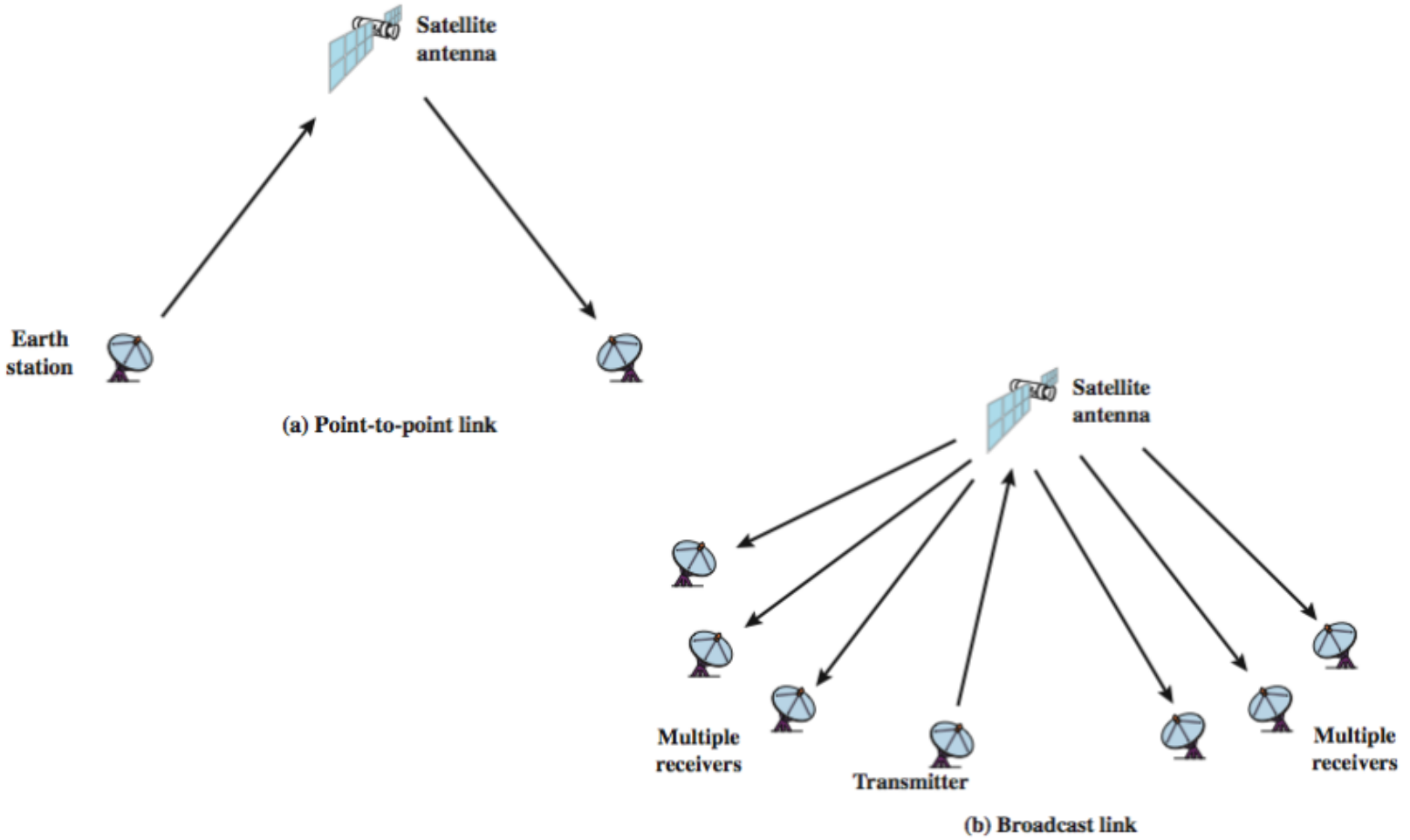
- used for long haul telecommunications, short point-to-point links between buildings and cellular systems
- used for both voice and TV transmission
- fewer repeaters but requires line of sight transmission
- 1-40GHz frequencies, with higher frequencies having higher data rates
- main source of loss is attenuation caused mostly by distance, rainfall and interference

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

Satellite Microwave

- a communication satellite is in effect a microwave relay station
- used to link two or more ground stations
- receives on one frequency, amplifies or repeats signal and transmits on another frequency
  - frequency bands are called transponder channels
- requires geo-stationary orbit
  - rotation match occurs at a height of 35,863km at the equator
  - need to be spaced at least 3° - 4° apart to avoid interfering with each other
  - spacing limits the number of possible satellites [www.satsig.net/sslist.htm]

Satellite Links



Satellite Microwave Applications

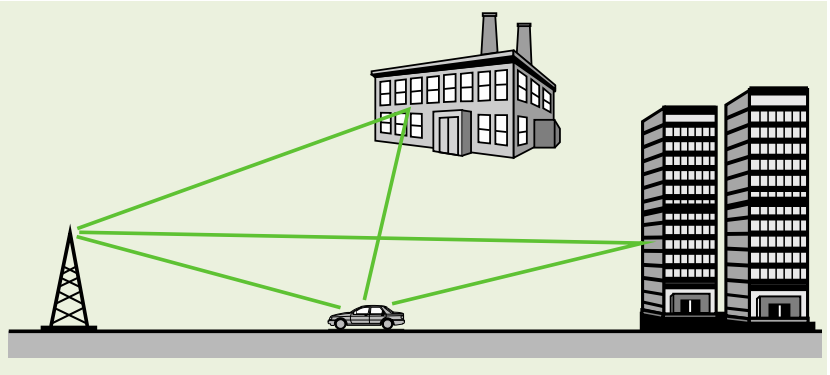
- private business networks
  - individual business users can lease private channel
- television distribution
  - can be used to distribute live TV programs
- global positioning
  - can be used for global position, e.g. Navstar GPS uses four or more satellites for positioning

Transmission Characteristics

- the optimum frequency range for satellite transmission is 1 to 10 GHz
  - lower has significant noise from natural sources
  - higher is attenuated by atmospheric absorption and precipitation
- satellites use a frequency bandwidth range of 5.925 to 6.425 GHz from earth to satellite (uplink) and a range of 3.7 to 4.2 GHz from satellite to earth (downlink)
  - referred to as the 4/6-GHz band
  - because of saturation the 12/14-GHz band has been developed (uplink: 14 - 14.5 GHz; downlink: 11.7 - 12.2 GH)

Broadcast Radio

- **radio** is the term used to encompass frequencies in the range of 3kHz to 300GHz
- **broadcast radio** (30MHz - 1GHz) covers
  - FM radio
  - UHF and VHF television
  - data networking applications
- **omnidirectional**
- limited to **line of sight**



- suffers from **multipath interference**
  - reflections from land, water, man-made objects

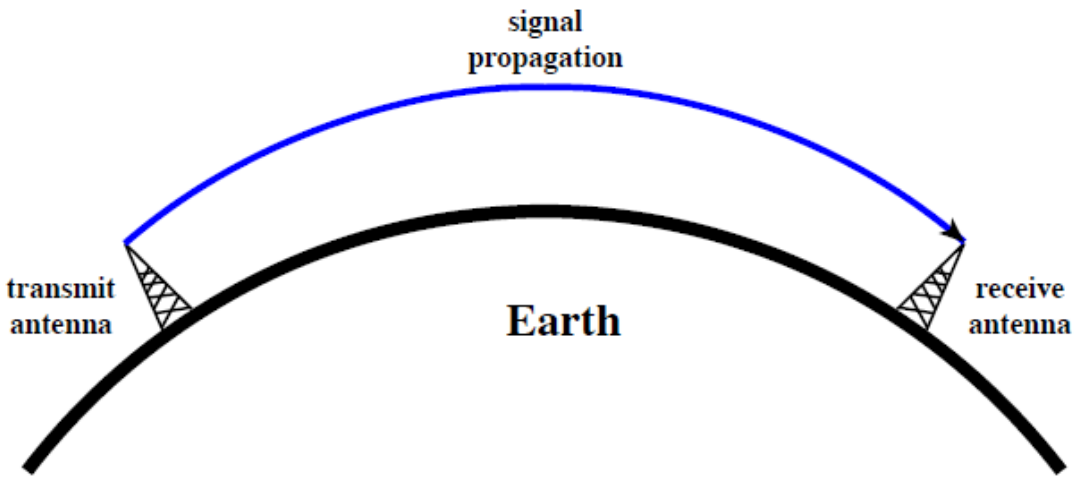
Infrared

- achieved using transceivers that modulate noncoherent infrared light
- transceivers must be within line of sight of each other directly or via reflection
- does not penetrate walls
- no licenses required
- no frequency allocation issues
- typical uses:
  - TV remote control

Frequency Bands

Band	Frequency Range	Free-Space Wavelength Range	Propagation Characteristics	Typical Use
ELF (extremely low frequency)	30 to 300 Hz	10,000 to 1000 km	GW	Power line frequencies; used by some home control systems.
VF (voice frequency)	300 to 3000 Hz	1000 to 100 km	GW	Used by the telephone system for analog subscriber lines.
VLF (very low frequency)	3 to 30 kHz	100 to 10 km	GW; low attenuation day and night; high atmospheric noise level	Long-range navigation; submarine communication
LF (low frequency)	30 to 300 kHz	10 to 1 km	GW; slightly less reliable than VLF; absorption in daytime	Long-range navigation; marine communication radio beacons
MF (medium frequency)	300 to 3000 kHz	1,000 to 100 m	GW and night SW; attenuation low at night, high in day; atmospheric noise	Maritime radio; direction finding; AM broadcasting.
HF (high frequency)	3 to 30 MHz	100 to 10 m	SW; quality varies with time of day, season, and frequency.	Amateur radio; military communication
VHF (very high frequency)	30 to 300 MHz	10 to 1 m	LOS; scattering because of temperature inversion; cosmic noise	VHF television; FM broadcast and two-way radio, AM aircraft communication; aircraft navigational aids
UHF (ultra high frequency)	300 to 3000 MHz	100 to 10 cm	LOS; cosmic noise	UHF television; cellular telephone; radar; microwave links; personal communications systems
SHF (super high frequency)	3 to 30 GHz	10 to 1 cm	LOS; rainfall attenuation above 10 GHz; atmospheric attenuation due to oxygen and water vapor	Satellite communication; radar; terrestrial microwave links; wireless local loop
EHF (extremely high frequency)	30 to 300 GHz	10 to 1 mm	LOS; atmospheric attenuation due to oxygen and water vapor	Experimental; wireless local loop; radio astronomy
Infrared	300 GHz to 400 THz	1 mm to 770 nm	LOS	Infrared LANs; consumer electronic applications
Visible light	400 THz to 900 THz	770 nm to 330 nm	LOS	Optical communication

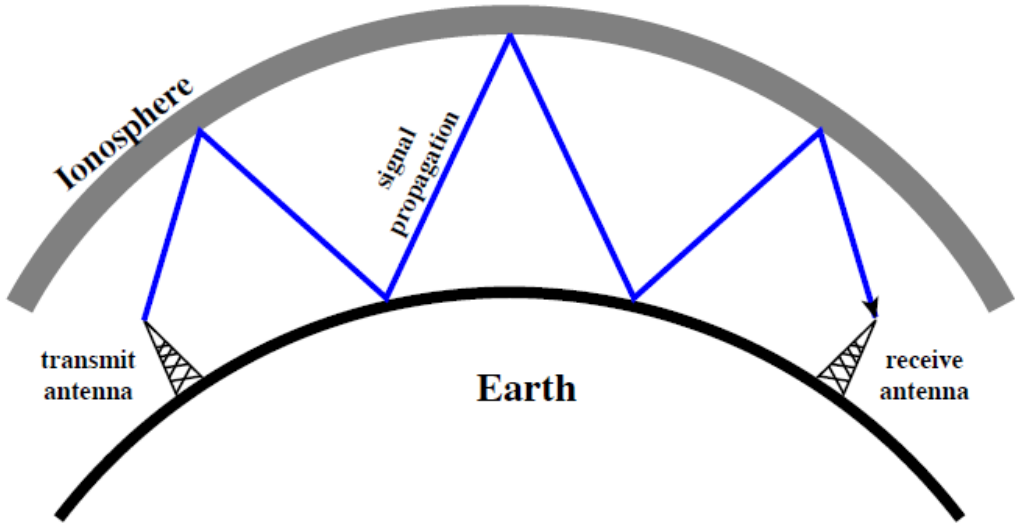
Wireless Propagation: Ground Wave



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

- ground wave propagation follows the contour of the earth and can propagate distances well over the visible horizon
- this effect is found in frequencies up to 2MHz
- the best known example of ground wave communication is AM radio

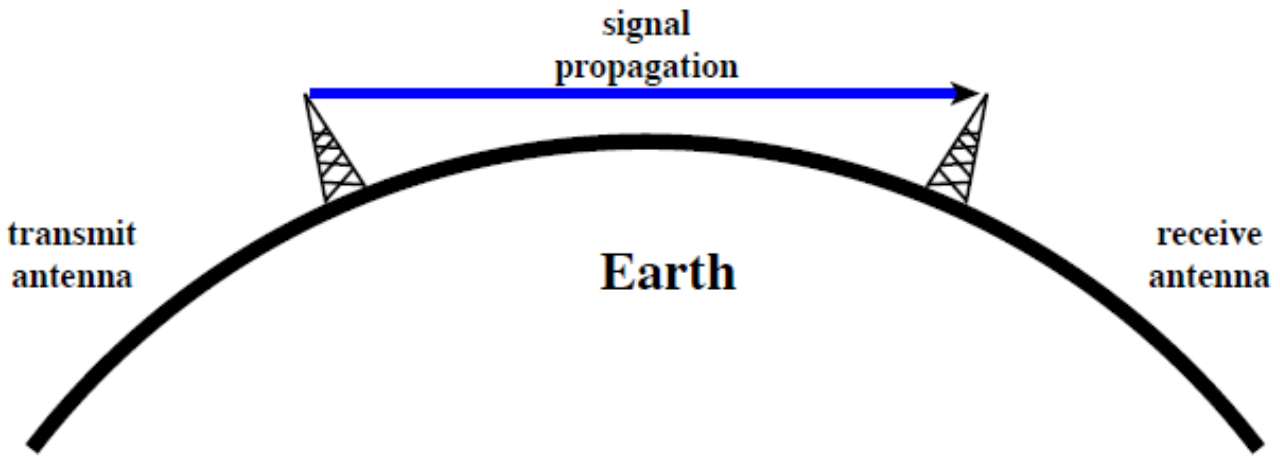
Wireless Propagation: Sky Wave



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

- sky wave propagation is used for amateur radio, CB radio, and international broadcasts such as BBC and Voice of America
- a signal from an earth based antenna is reflected from the ionized layer of the upper atmosphere back down to earth
- sky wave signals can travel through a number of hops, bouncing back and for the between the ionosphere and the earth's surface

Wireless Propagation: Line of Sight



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

- ground and sky wave propagation modes do not operate above 30 MHz – communication must be by line of sight

A Comparison of Transmission Media

Type	Advantages	Disadvantages
Twisted pair wire	Very inexpensive Easy to install Already installed in many locations	Doesn't pass high frequencies well Relatively low bandwidth
Coaxial cable	Shielded Fairly inexpensive Moderately high bandwidth	Bulky and somewhat inflexible
Fiber optic cable	Transmission unaffected by noise Very high bandwidth	Expensive to install Repeaters often required
Satellite	No line of sight needed No cabling needed between sites High bandwidth	Channels must be leased High initial equipment cost Long delays
Terrestrial microwave	No cabling needed between sites High bandwidth	Line of sight needed Towers and repeaters can be expensive High initial equipment cost

Summary

- transmission Media
  - physical path between transmitter and receiver
  - bandwidth, transmission impairments, interference, number of receivers
- guided Media
  - twisted pair, coaxial cable, optical fiber
- wireless Transmission
  - microwave frequencies
  - antennas, terrestrial microwave, satellite microwave, broadcast radio
- wireless Propagation
  - ground wave, sky wave, line of sight