Data and Computer Communications

Tenth Edition

by William Stallings

CHAPTER 4

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

Design Factors Determining Data Rate and Distance

Bandwidth

- Higher bandwidth gives higher data rate

Transmission impairments

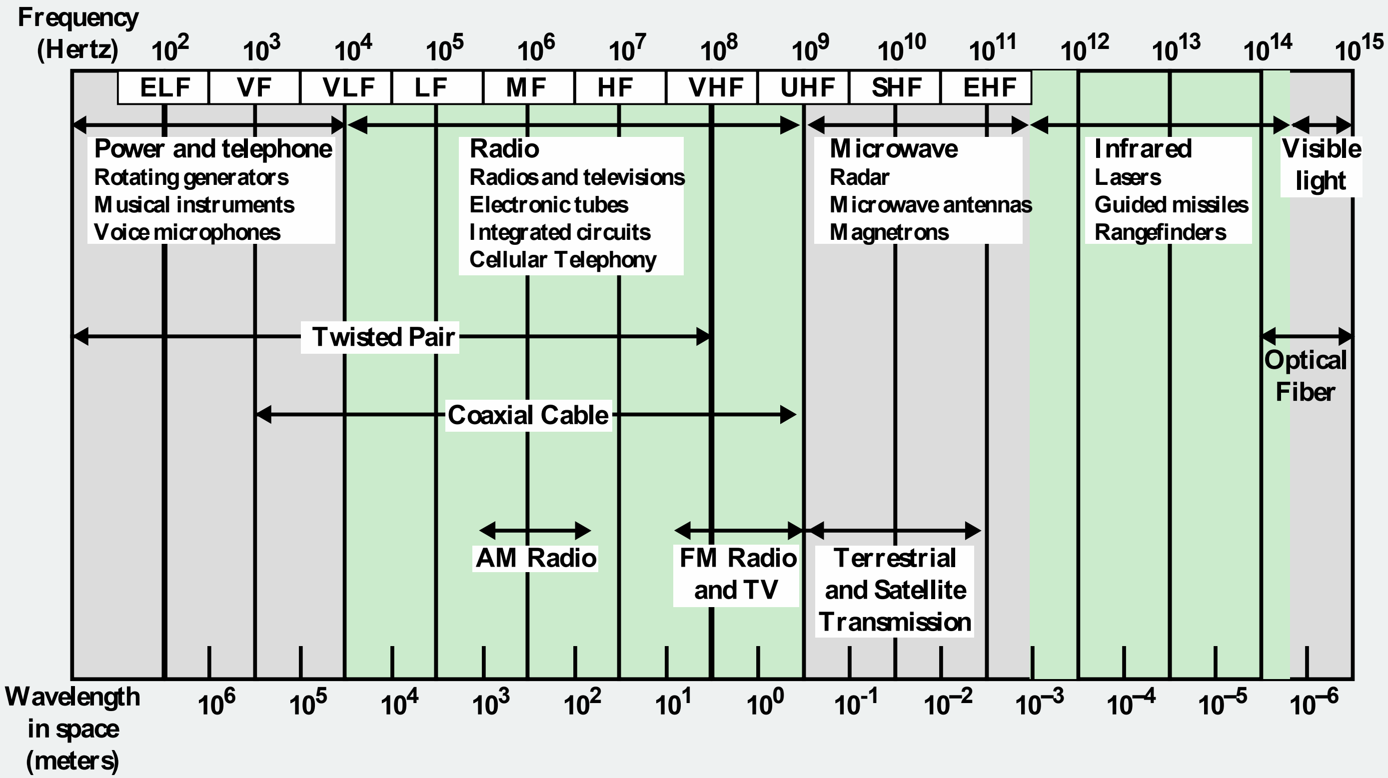
- Impairments, such as attenuation, limit the distance

Interference

- Overlapping frequency bands can distort or wipe out a signal

Number of receivers

- More receivers introduces more attenuation



ELF	=	Extremely low frequency	MF	=	Medium frequency	UHF	=	Ultrahigh frequency
VF	=	Voice frequency	HF	=	High frequency	SHF	=	Superhigh frequency
VLF	=	Very low frequency	VHF	=	Very high frequency	EHF	=	Extremely high frequency
LF	=	Low frequency						

Figure 4.1 Electromagnetic Spectrum for Telecommunications

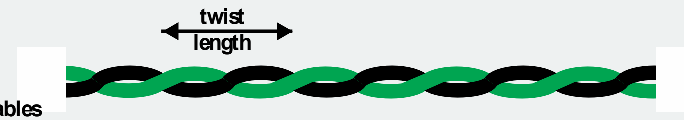
Table 4.1

Point-to-Point Transmission Characteristics of Guided Media

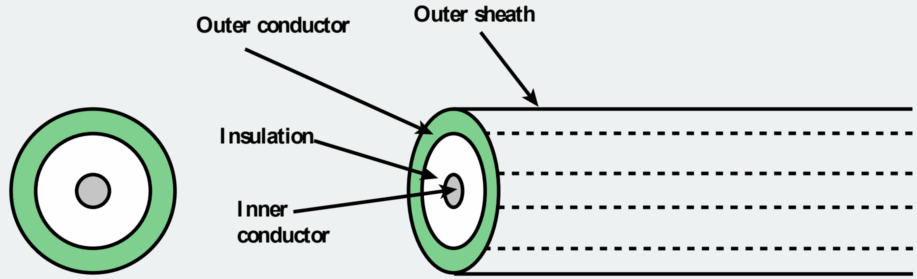
	Frequency Range	Typical Attenuation	Typical Delay	Repeater Spacing
Twisted pair (with loading)	0 to 3.5 kHz	0.2 dB/km @ 1 kHz	50 µs/km	2 km
Twisted pairs (multipair cables)	0 to 1 MHz	0.7 dB/km @ 1 kHz	5 µs/km	2 km
Coaxial cable	0 to 500 MHz	7 dB/km @ 10 MHz	4 µs/km	1 to 9 km
Optical fiber	186 to 370 THz	0.2 to 0.5 dB/km	5 µs/km	40 km

THz = terahertz = 10^{12} Hz

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

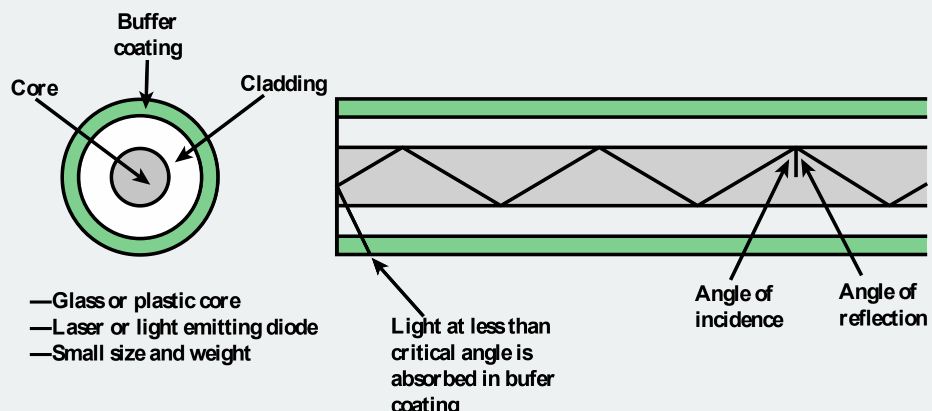


(a) Twisted pair



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

(b) Coaxial cable

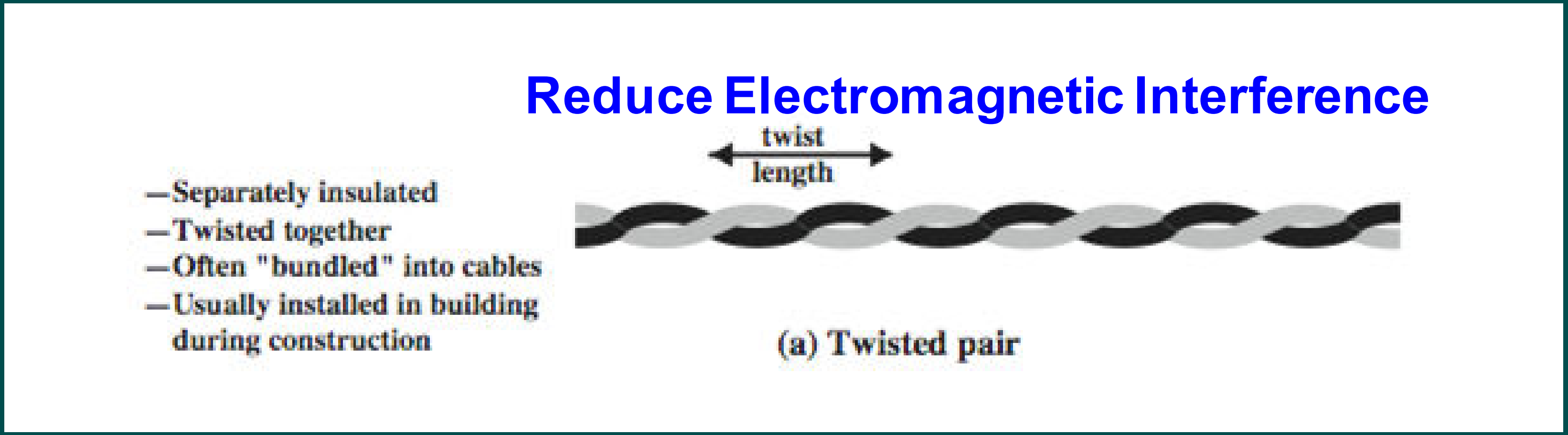


—Glass or plastic core
—Laser or light emitting diode
—Small size and weight

(c) Optical fiber

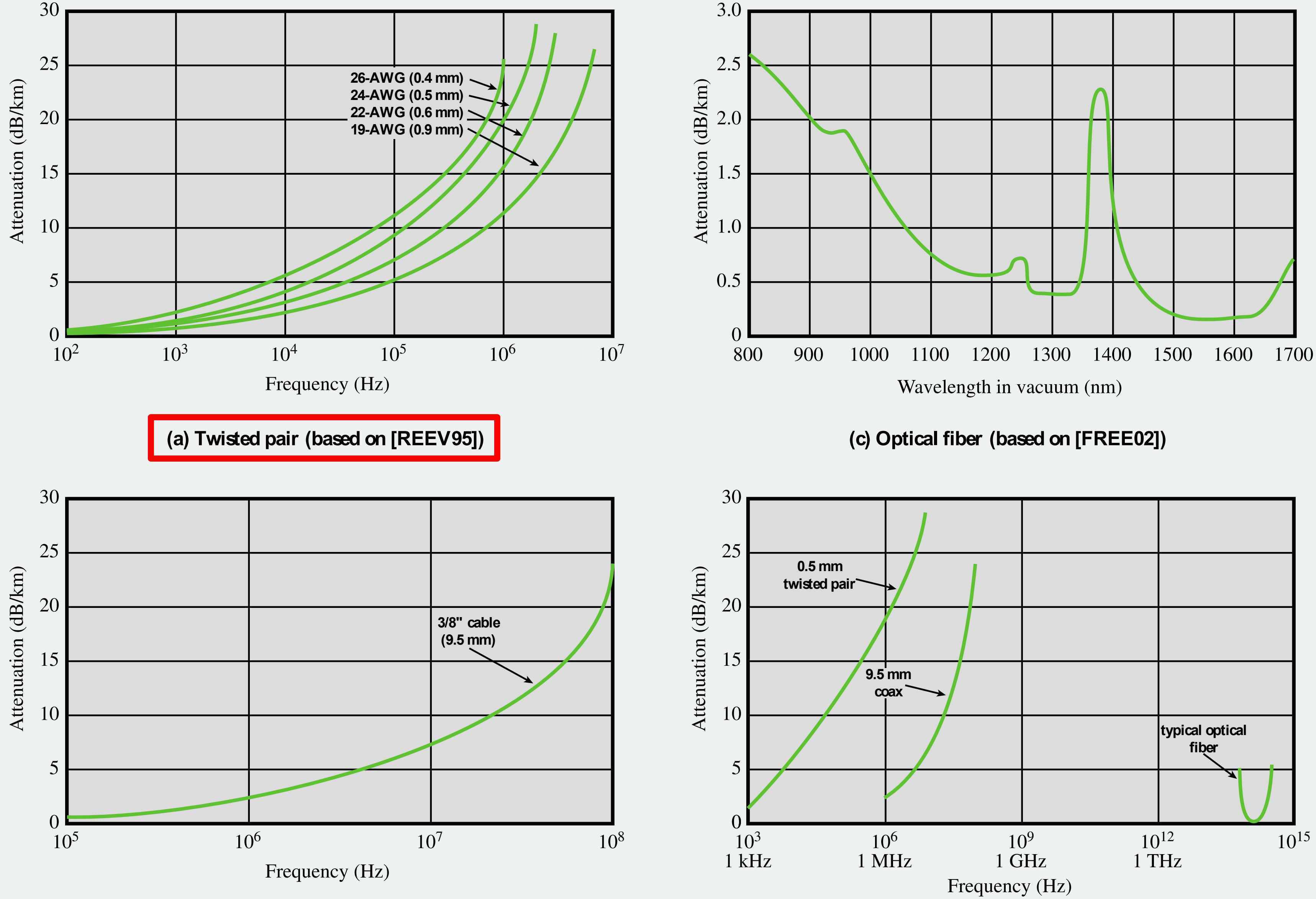
Figure 4.2 Guided Transmission Media

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



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

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

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

(d) Composite graph

Figure 4.3 Attenuation of Typical Guided Media

Unshielded and Shielded Twisted Pair

Unshielded Twisted Pair (UTP)

- Consists of one or more twisted-pair cables, typically enclosed within an overall thermoplastic jacket which provides no electromagnetic shielding
- Ordinary telephone wire
- Subject to external electromagnetic interference
- The tighter the twisting, the higher the supported transmission rate and the greater the cost per meter

Shielded Twisted Pair (STP)

- Has metal braid or sheathing that reduces interference
- Provides better performance at higher data rates
- More expensive

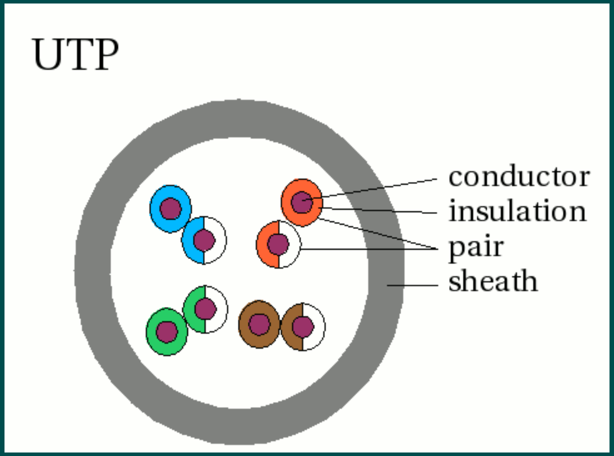
Table 4.2

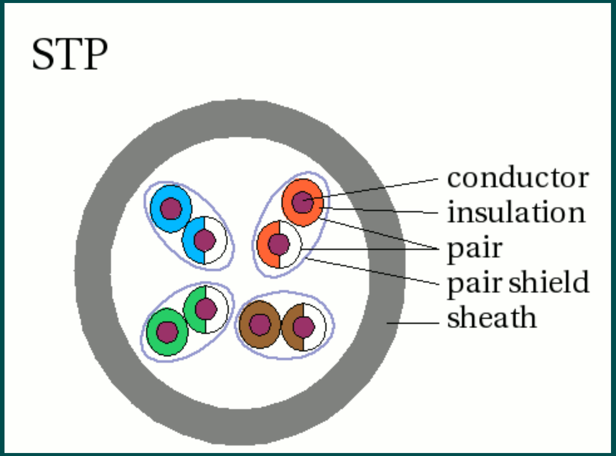
Twisted Pair Categories and Classes

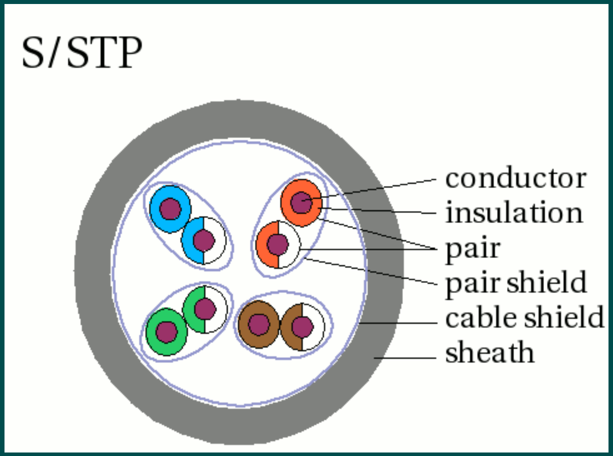
	Category 5e Class D	Category 6 Class E	Category 6A Class E_A	Category 7 Class F	Category 7_A Class F_A
Bandwidth	100 MHz	250 MHz	500 MHz	600 MHz	1,000 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	S/FTP	S/FTP
Insertion loss (dB)	24	21.3	20.9	20.8	20.3
NEXT loss (dB)	30.1	39.9	39.9	62.9	65
ACR (dB)	6.1	18.6	19	42.1	44.1

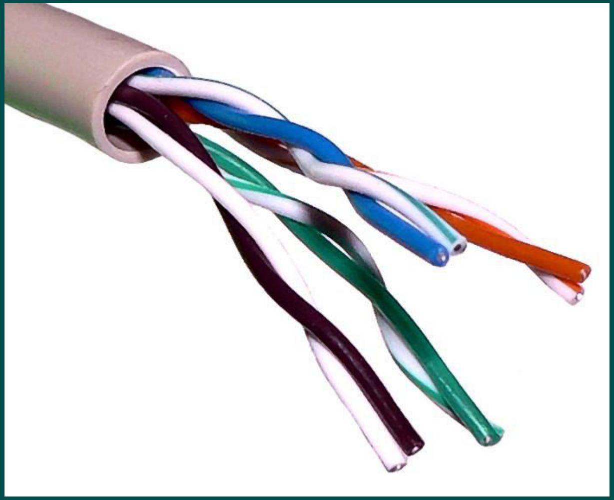
UTP = Unshielded twisted pair
FTP = Foil twisted pair
S/FTP = Shielded/foil twisted pair

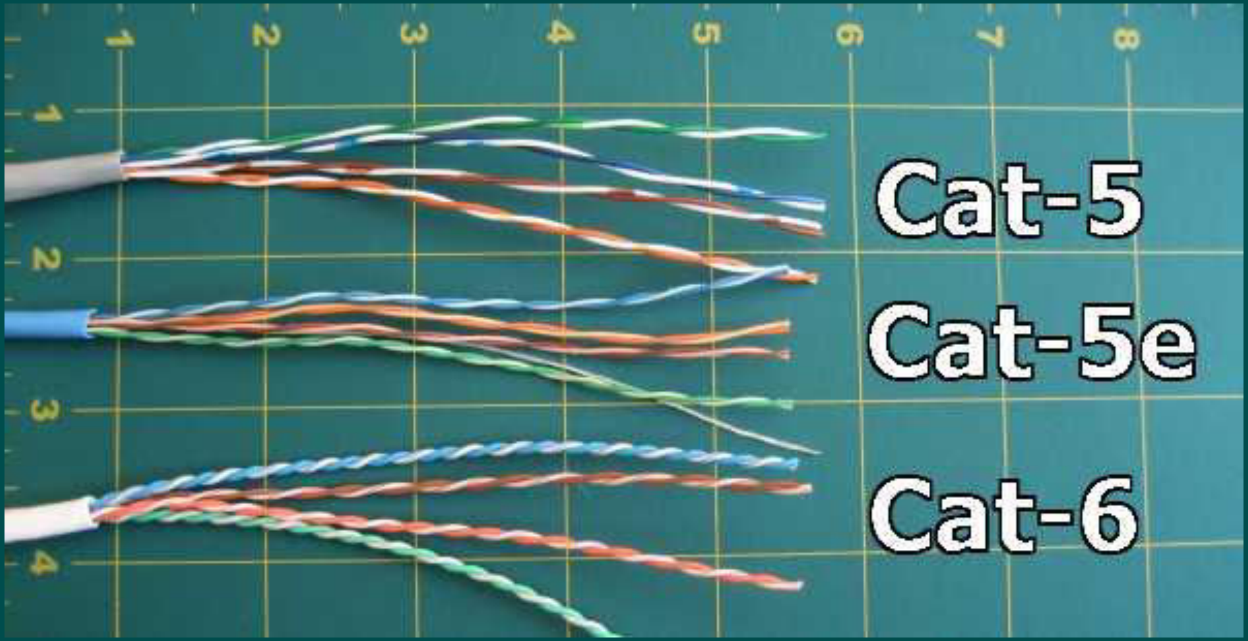
Twisted Pair





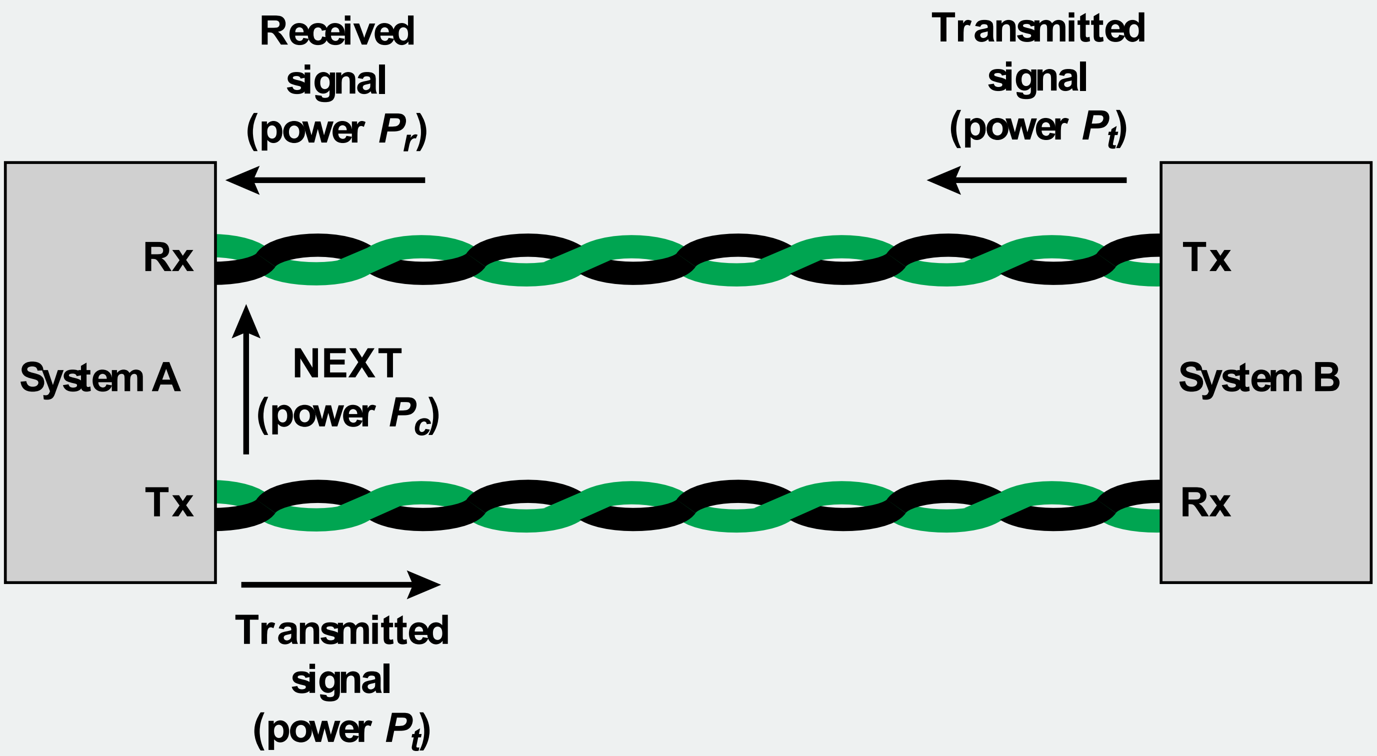


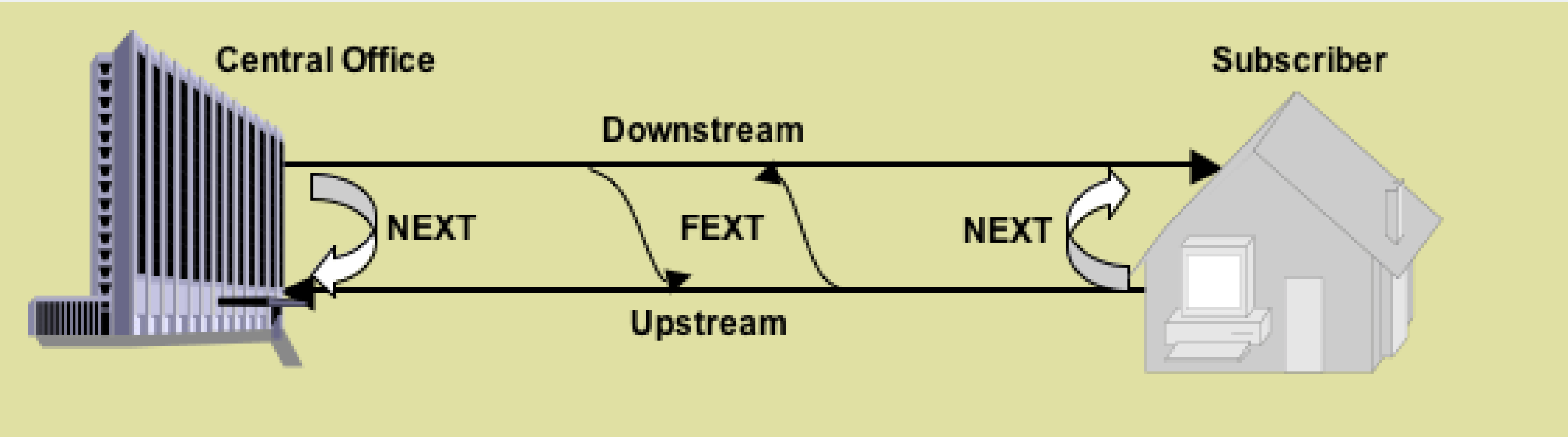


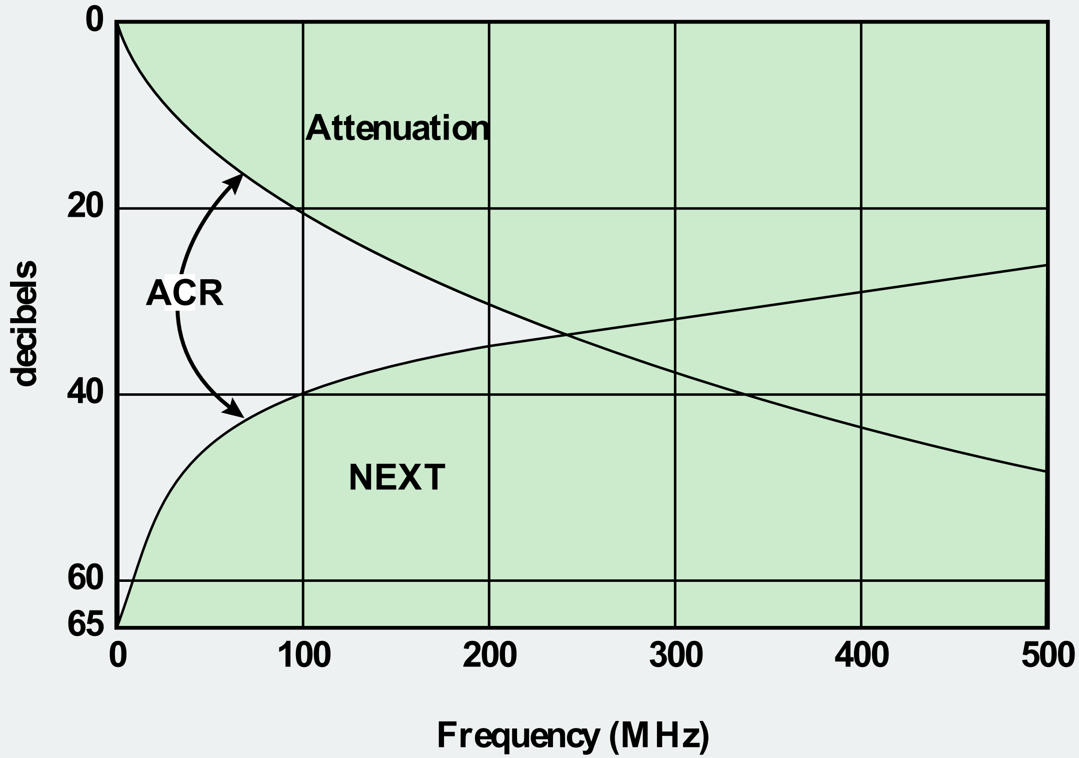


Near-End Crosstalk (NEXT)

- Coupling of signal from one pair of conductors to another
  - Conductors may be the metal pins in a connector or wire pairs in a cable
- Near end refers to coupling that takes place when the transmit signal entering the link couples back to the receive conductor pair at that same end of the link
- Greater NEXT loss magnitudes are associated with less crosstalk noise


Received
signal
(power P_r)
Transmitted
signal
(power P_t)
Rx
Tx
System A
System B
NEXT
(power P_c)
Tx
Rx
Transmitted
signal
(power P_t)

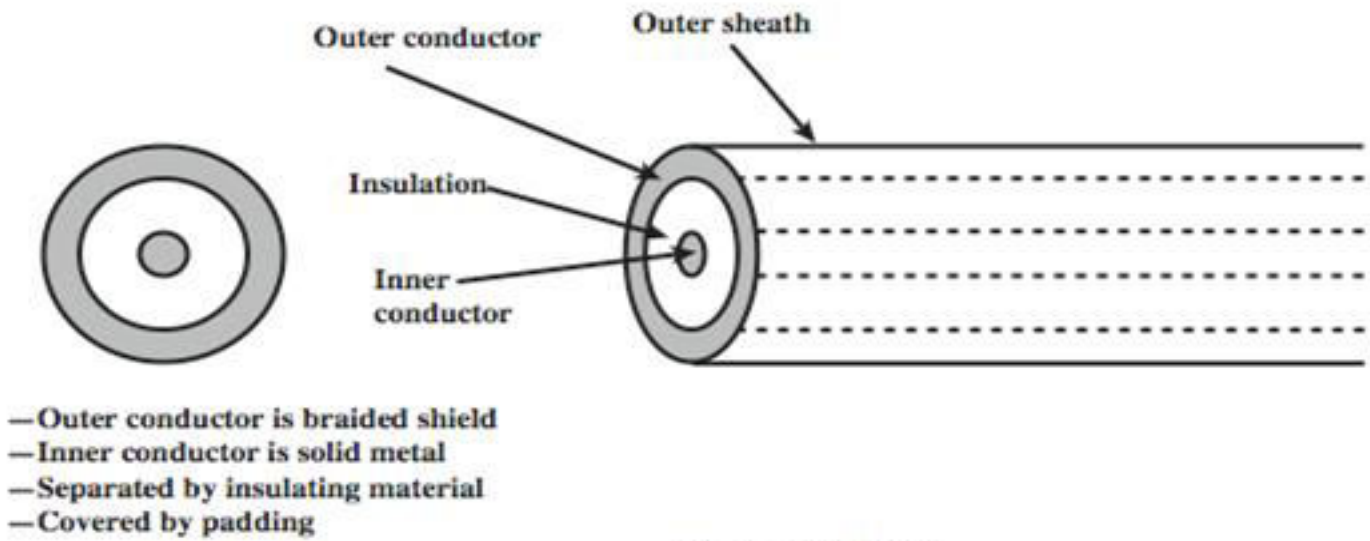

Central Office
Subscriber
Downstream
NEXT
FEXT
NEXT
Upstream



NEXT = near-end crosstalk
ACR = attenuation-to-crosstalk ratio

Figure 4.5 Category 6A Channel Requirements

Coaxial Cable



(b) Coaxial cable

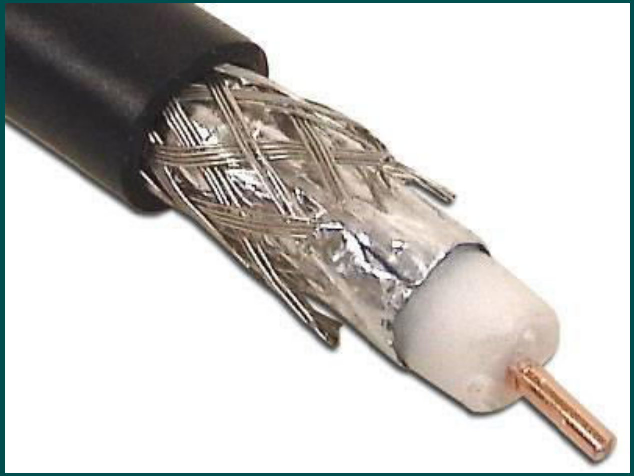
Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair

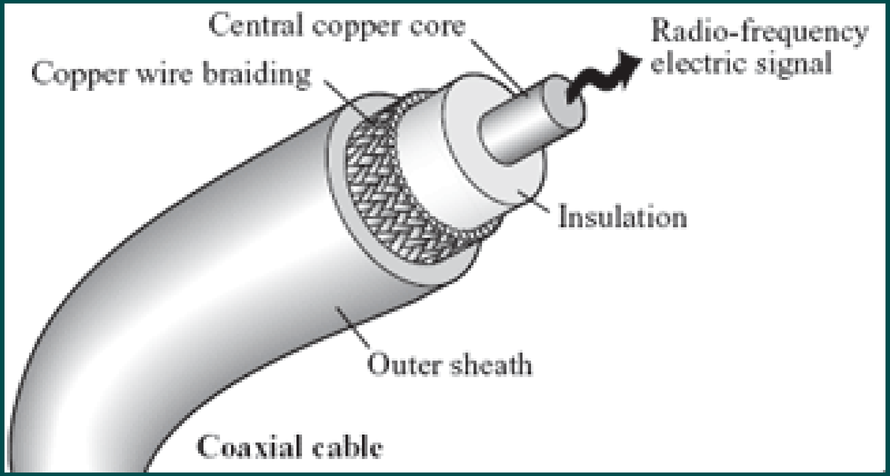
- Consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor
- Is a versatile transmission medium used in a wide variety of applications
- Used for TV distribution, long distance telephone transmission and LANs

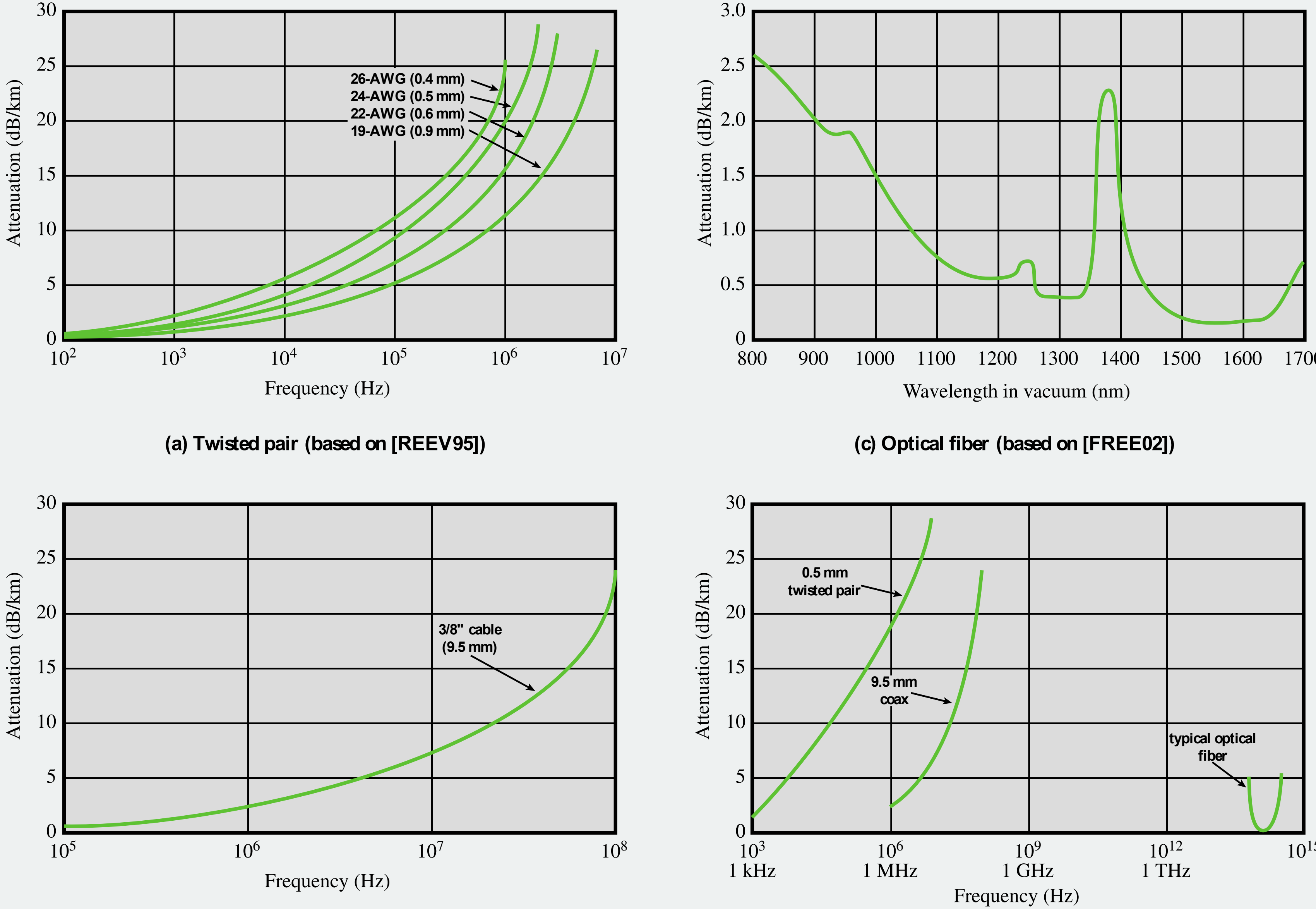
Coaxial Cable - Transmission Characteristics

- Frequency characteristics superior to twisted pair
- Performance limited by attenuation and noise

Analog signals	Digital signals
• Amplifiers are needed every few kilometers - closer if higher frequency • Usable spectrum extends up to 500MHz	• Repeater every 1km - closer for higher data rates







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

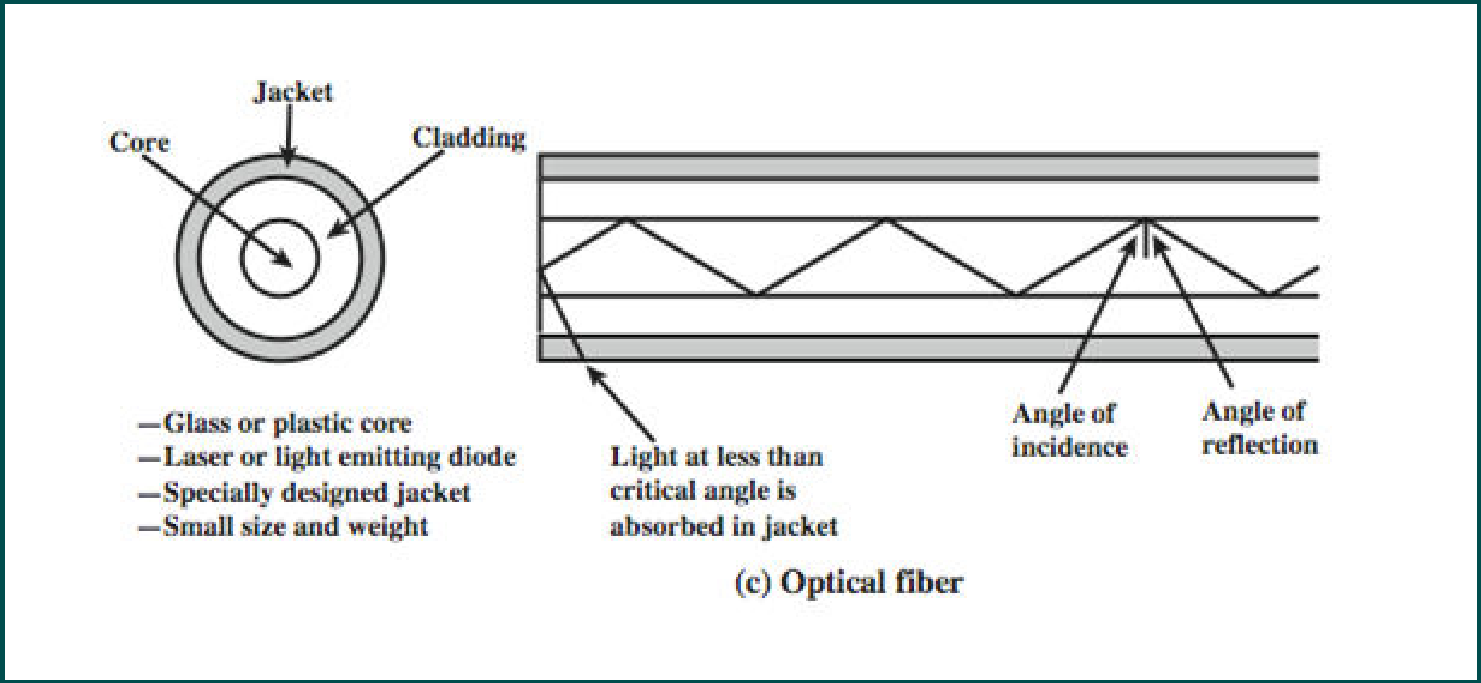
(c) Optical fiber (based on [FREE02])

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

(d) Composite graph

Figure 4.3 Attenuation of Typical Guided Media

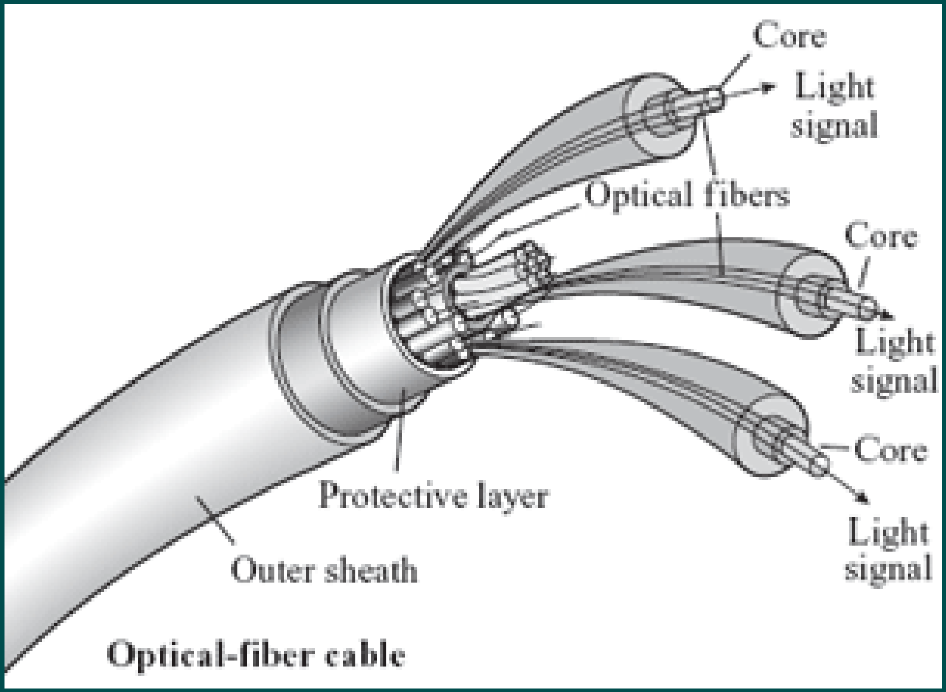
Optical Fiber

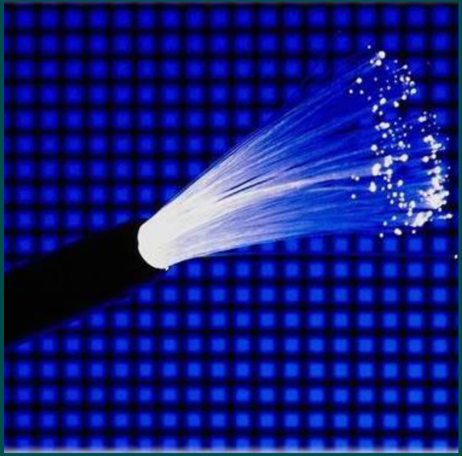


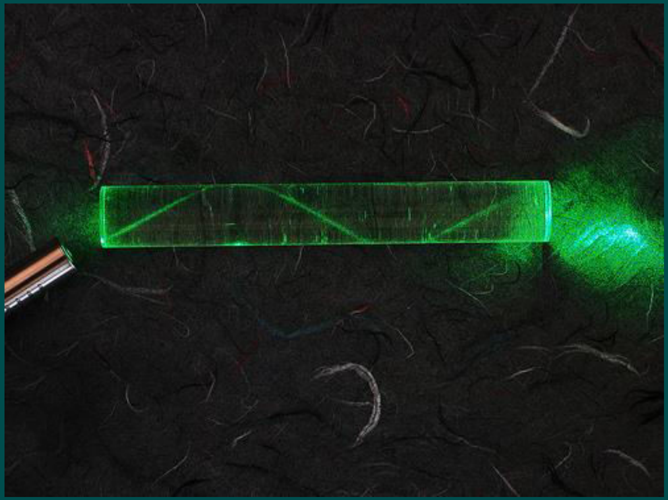
Optical fiber is a thin flexible medium capable of guiding an optical ray

- Various glasses and plastics can be used to make optical fibers
- Has 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





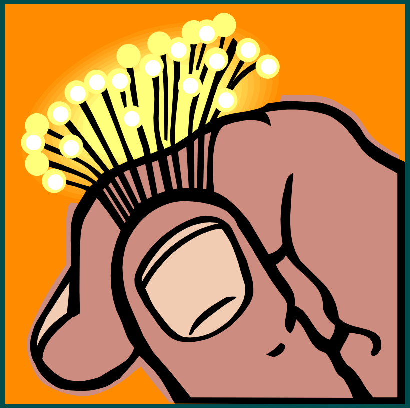


Optical Fiber - Benefits

- Greater capacity
  - Data rates of hundreds of Gbps over tens of kilometers have been demonstrated
- 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

Categories of Application

- Five basic categories of application have become important for optical fiber:
  - Long-haul trunks
  - Metropolitan trunks
  - Rural exchange trunks
  - Subscriber loops
  - Local area networks



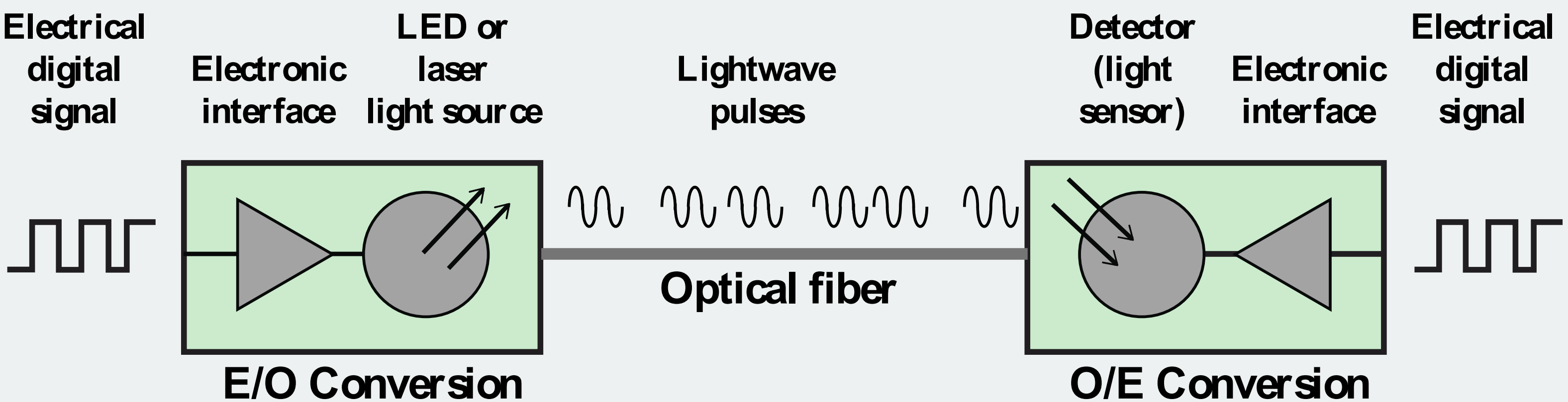


Figure 4.6 Optical Communication

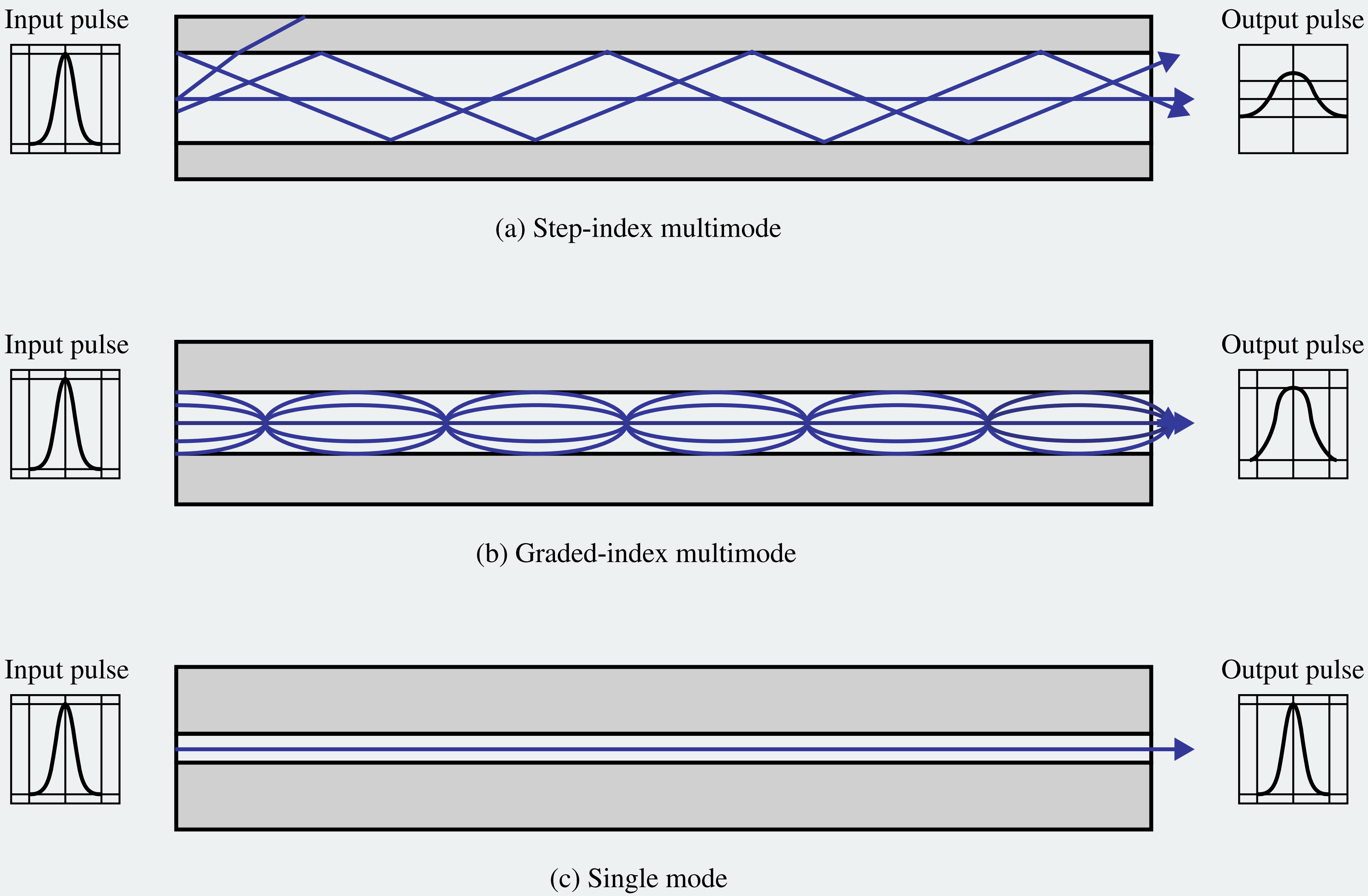


Figure 4.7 Optical Fiber Transmission Modes

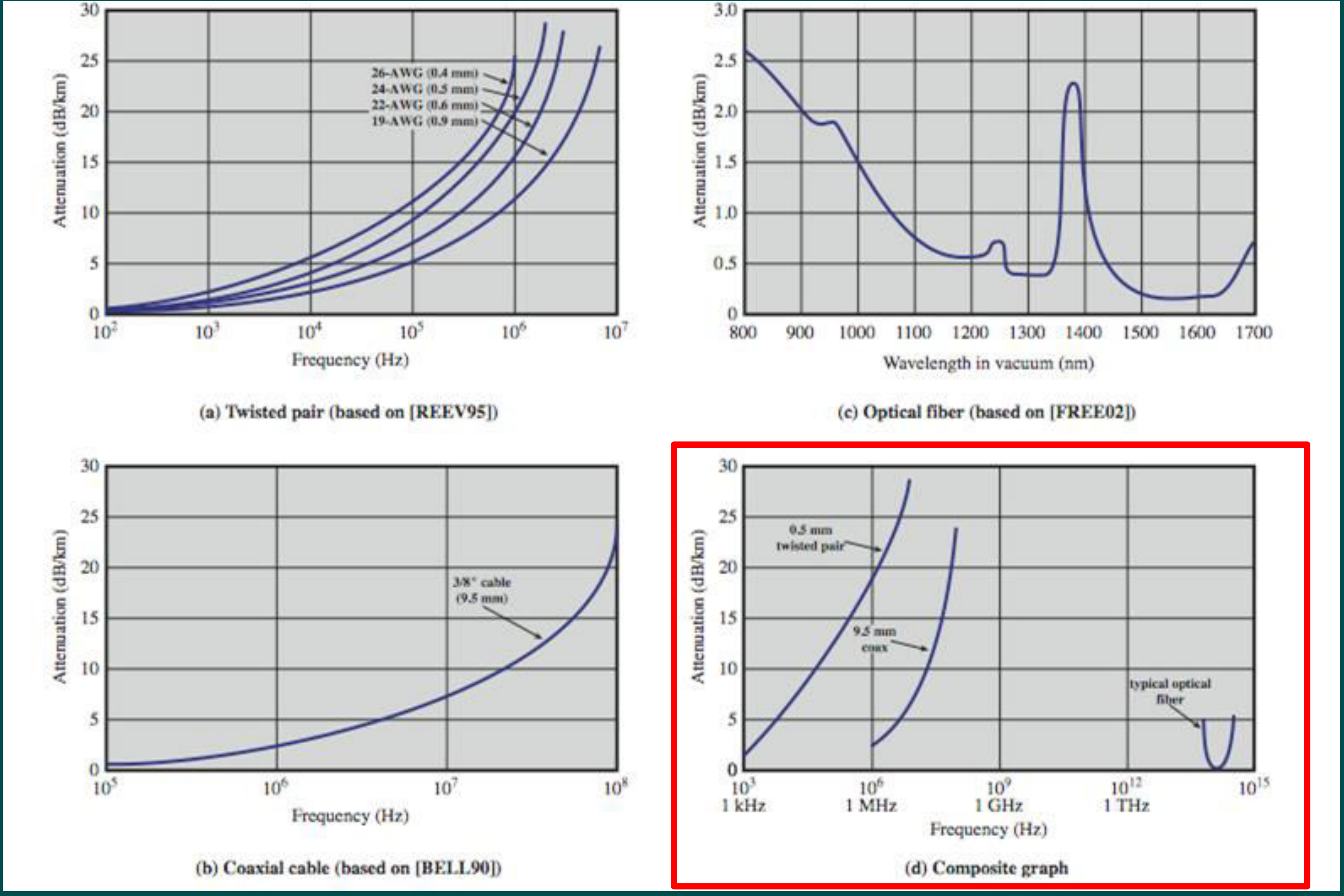
Table 4.3

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

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

1GHz to 40GHz

- Referred to as microwave frequencies
- Highly directional beams are possible
- Suitable for point to point transmissions
- Also used for satellite communications

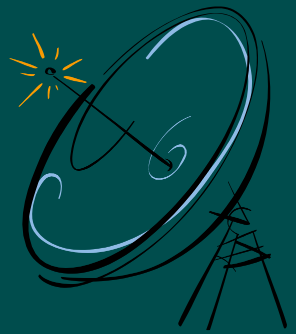
30MHz to 1GHz

- Suitable for omnidirectional applications
- Referred to as the radio range

3×10^{11} to 2×10^{14}

- Infrared portion of the spectrum
- Useful to local point-to-point and multipoint applications within confined areas

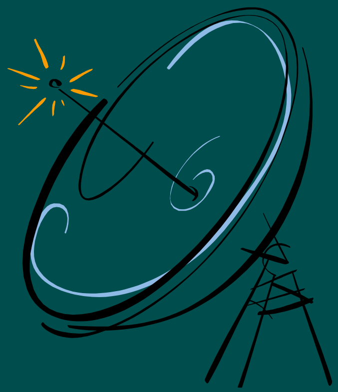
Antennas



- Electrical conductor or system of conductors used to radiate or collect electromagnetic energy
- Radio frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment
- Reception occurs when the electromagnetic signal intersects the antenna
- In two way communication, the same antenna can be used for both transmission and reception

Radiation Pattern

- Power radiated in all directions
  - Does not perform equally well in all directions
- Radiation pattern
  - A graphical representation of the radiation properties of an antenna as a function of space coordinates
- Isotropic antenna
  - A point in space that radiates power in all directions equally
  - Actual radiation pattern is a sphere with the antenna at the center



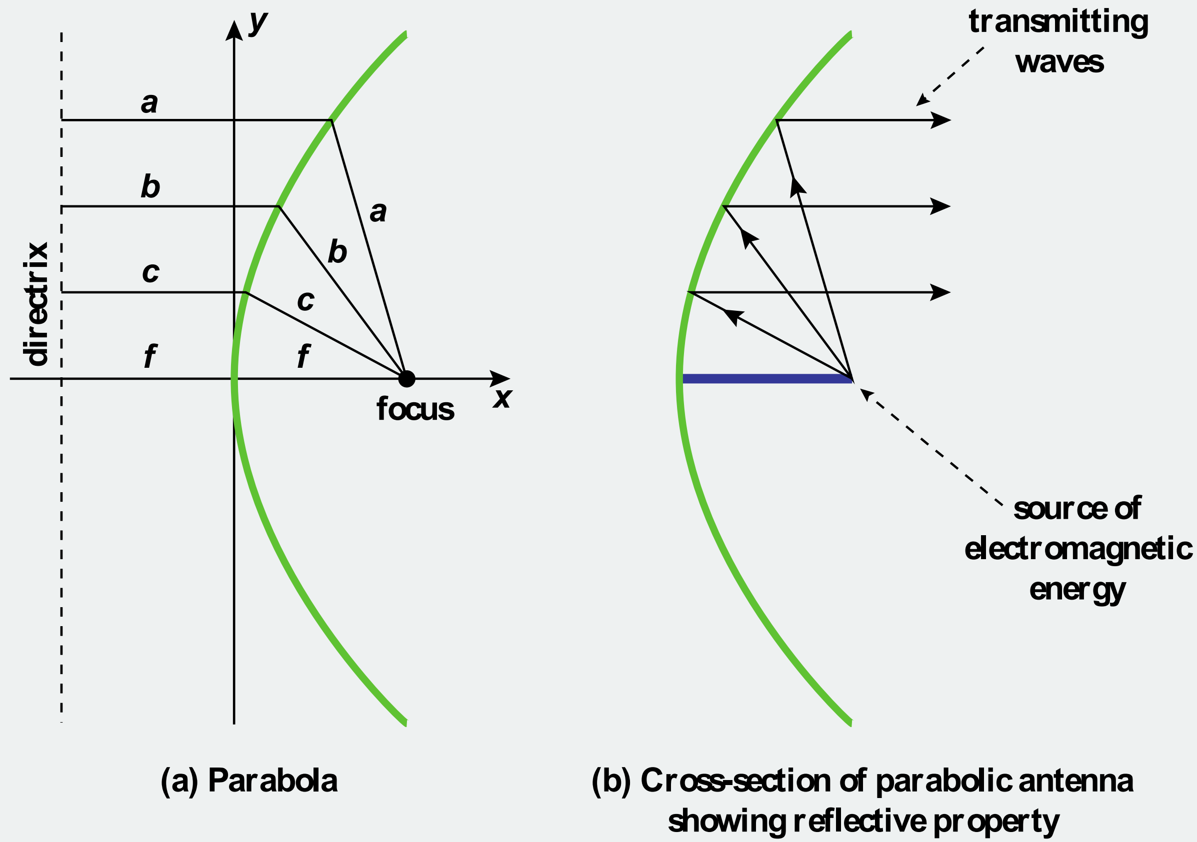


Figure 4.8 Parabolic Reflective Antenna

Antenna Gain

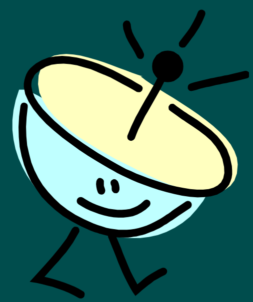
A measure of the directionality of an antenna

Defined as the power output in a particular direction versus that produced by an isotropic antenna

Measured in decibels (dB)

The increased power radiated in a given direction is at the expense of other directions

Effective area of an antenna is related to the physical size of the antenna and to its shape



Terrestrial Microwave

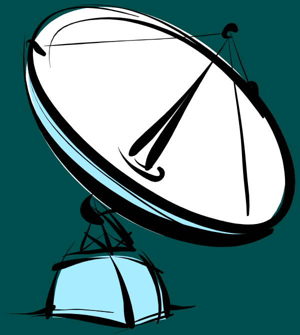
Most common type is the parabolic “dish”

Typical size is about 3 m in diameter

Antenna is fixed rigidly and focuses a narrow beam to achieve line-of-sight transmission to the receiving antenna

Usually located at substantial heights above ground level

A series of microwave relay towers is used to achieve long-distance transmission



Terrestrial Microwave Applications

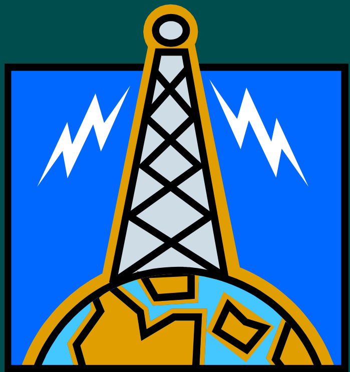
- Used for long haul telecommunications service as an alternative to coaxial cable or optical fiber
- Used for both voice and TV transmission
- Fewer repeaters but requires line-of-sight transmission
- 1-40GHz frequencies, with higher frequencies having higher data rates
- Main source of loss is attenuation caused mostly by distance, rainfall and interference

Table 4.4
Typical Digital Microwave Performance

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 transmissions on one frequency band, amplifies or repeats the signal, and transmits it on another frequency
  - Frequency bands are called transponder channels



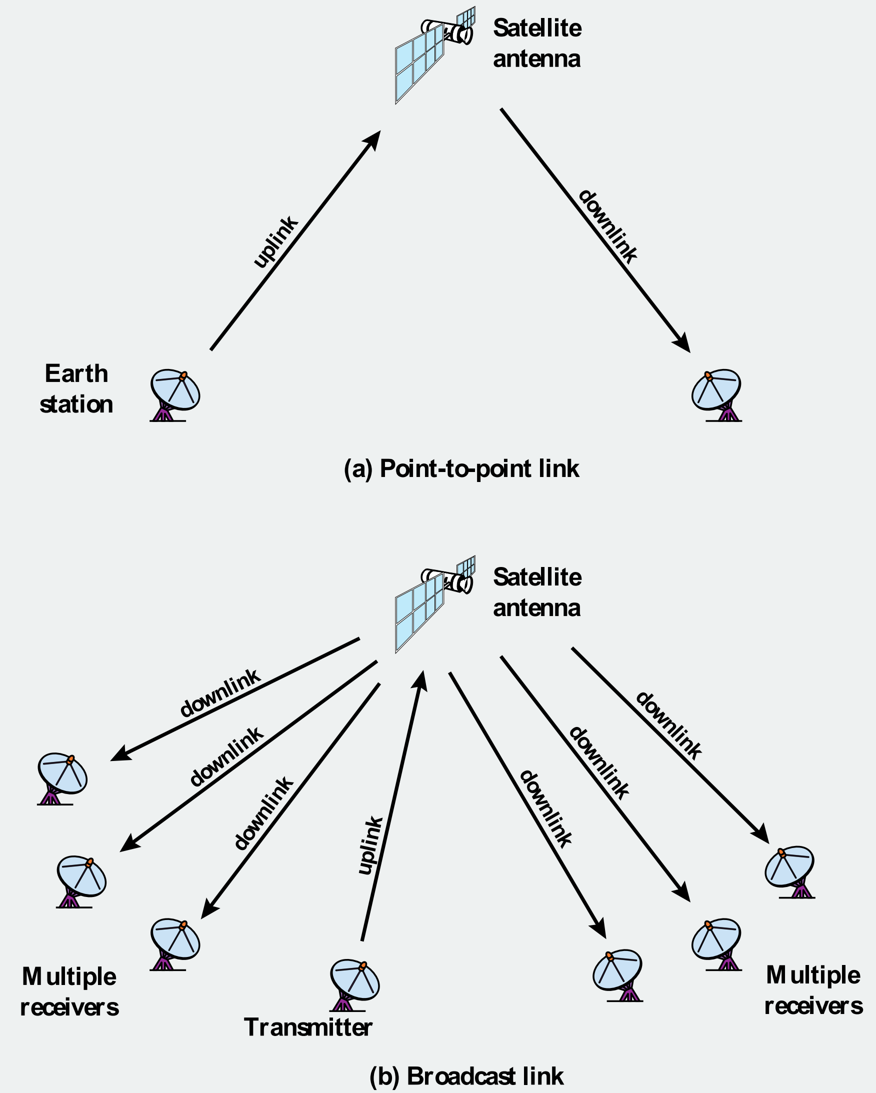


Figure 4.9 Satellite Communication Configurations

Satellite Microwave Applications

- Most important applications for satellites are:

Long-distance telephone transmission

- Is the optimum medium for high-usage international trunks

Private business networks

- Satellite providers can divide capacity into channels and lease these channels to individual business users

Global positioning

- Navstar Global Positioning System (GPS)

Television distribution

- Programs are transmitted to the satellite then broadcast down to a number of stations which then distribute the programs to individual viewers
- Direct Broadcast Satellite (DBS) transmits video signals directly to the home user

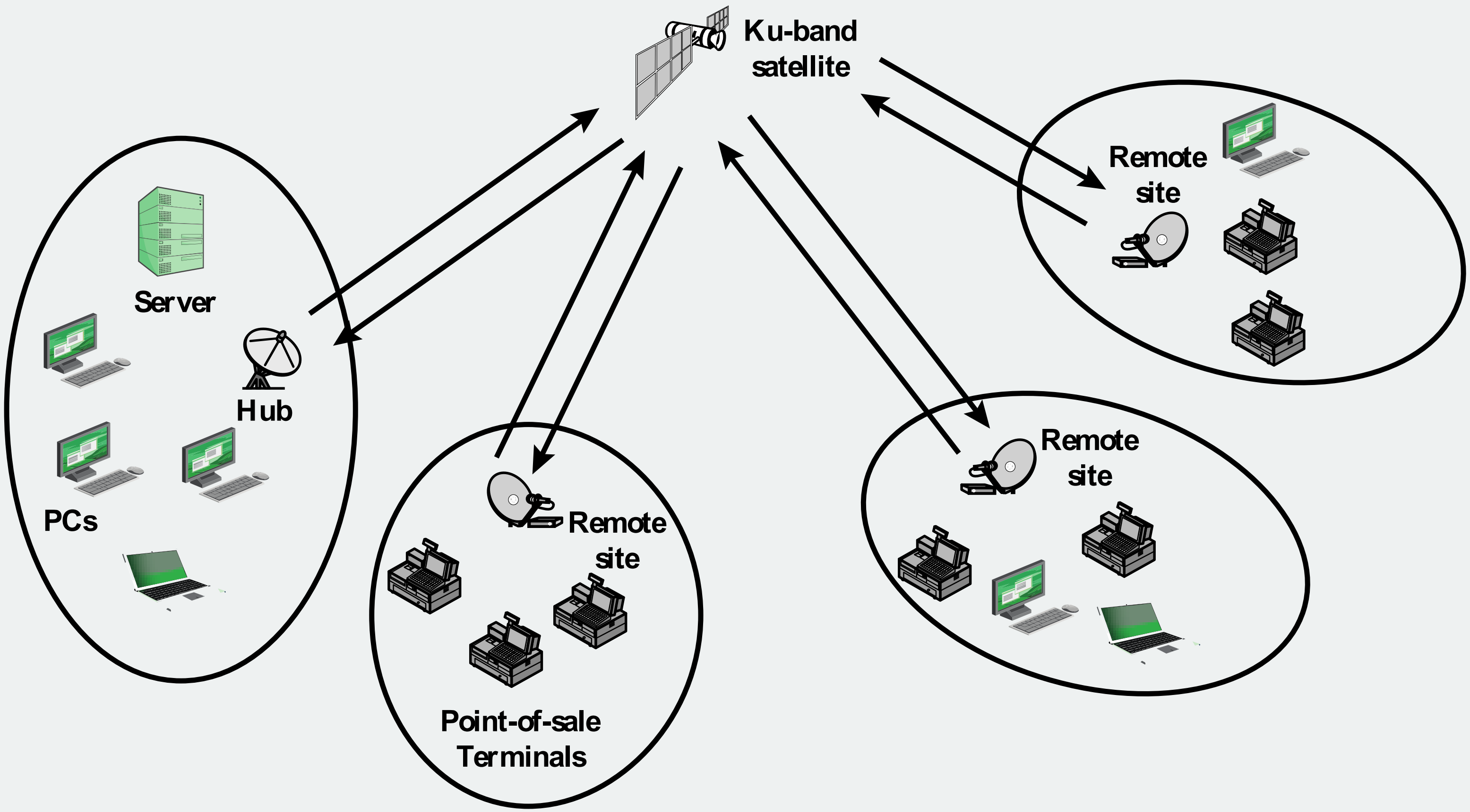


Figure 4.10 Typical VSAT Configuration

Transmission Characteristics

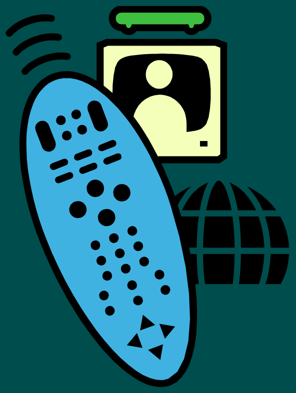
- The optimum frequency range for satellite transmission is 1 to 10 GHz
  - Below 1 GHz there is significant noise from natural sources
  - Above 10 GHz the signal is severely attenuated by atmospheric absorption and precipitation
- Satellites use a frequency bandwidth range of 5.925 to 6.425 GHz from earth to satellite (uplink) and a range of 3.7 to 4.2 GHz from satellite to earth (downlink)
  - This is referred to as the 4/6-GHz band
  - Because of saturation the 12/14-GHz band has been developed

Broadcast Radio

- Broadcast radio is omnidirectional and microwave is directional
- **Radio** is the term used to encompass frequencies in the range of 3kHz to 300GHz
- **Broadcast radio** (30MHz - 1GHz) covers:
  - FM radio and UHF and VHF television band
  - Data networking applications
- 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 licensing is required
- No frequency allocation issues



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

Table 4.5

Frequency Bands

(Table can be found on page 160 in textbook)

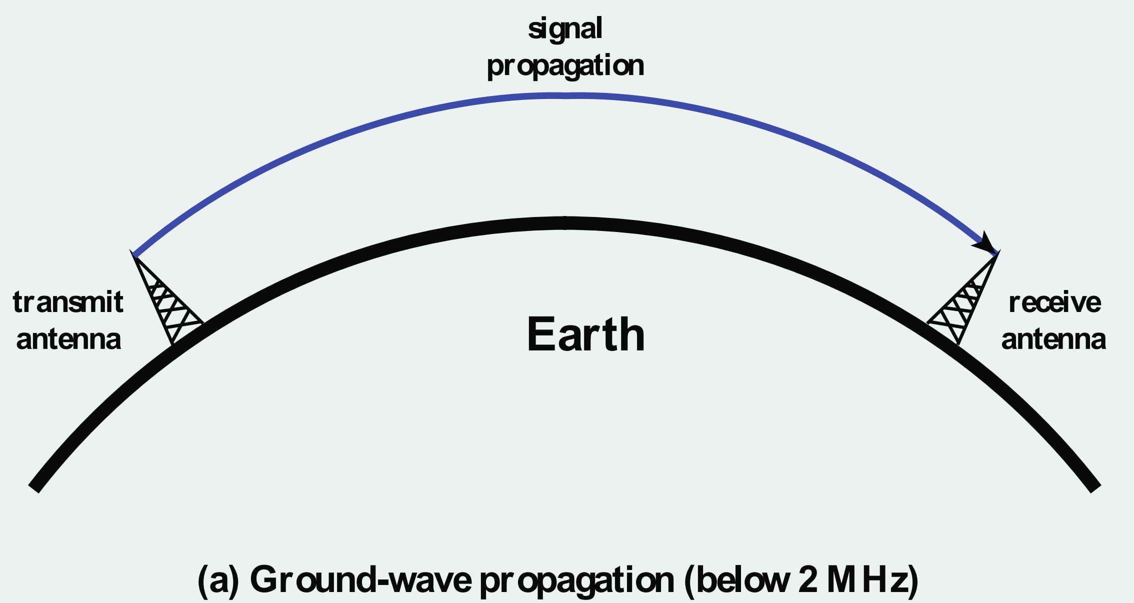
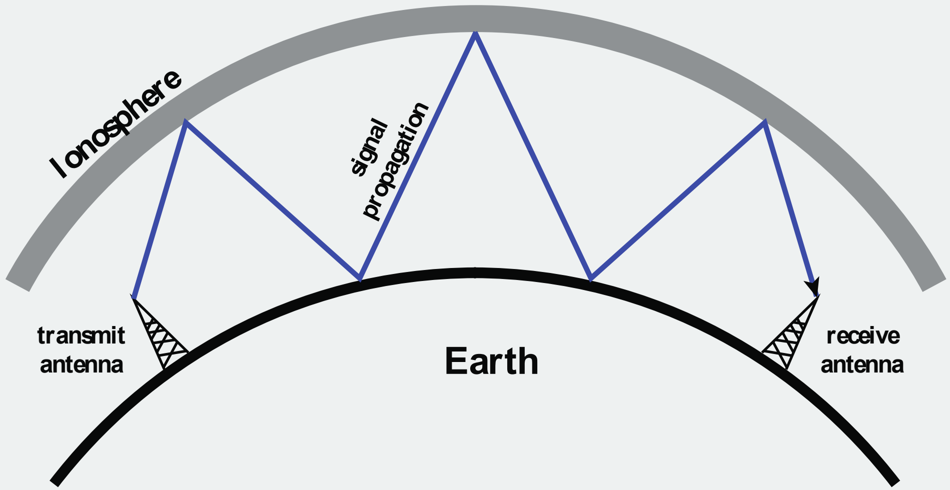


Figure 4.11 Wireless Propagation Modes

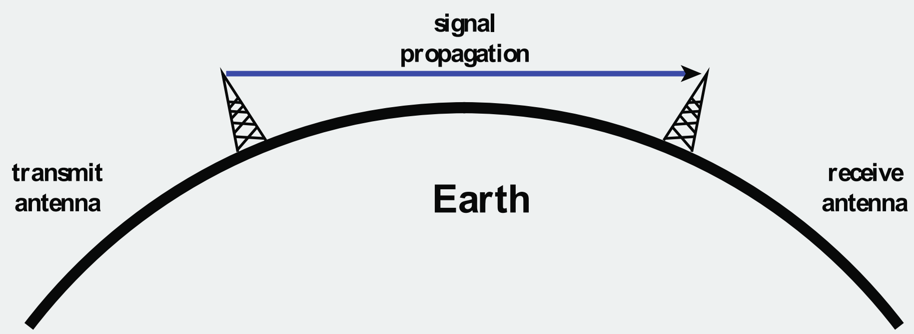
- Ground wave propagation follows the contour of the earth and can propagate distances well over the visual horizon
- This effect is found in frequencies up to about 2MHz
- The best known example of ground wave communication is AM radio



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

Figure 4.11 Wireless Propagation Modes

- Sky wave propagation is used for amateur 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 forth between the ionosphere and the earth's surface



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

Figure 4.11 Wireless Propagation Modes

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

Refraction

- Occurs because the velocity of an electromagnetic wave is a function of the density of the medium through which it travels
  - 3×10^8 m/s in a vacuum, less in anything else
- The speed changes with movement between a medium of one density to a medium of another density
- Index of refraction (refractive index)
  - The sine of the angle of incidence divided by the sine of the angle of refraction
  - Is also equal to the ratio of the respective velocities in the two media
  - Varies with wavelength
- Gradual bending
  - Density of atmosphere decreases with height, resulting in bending of radio waves toward the earth

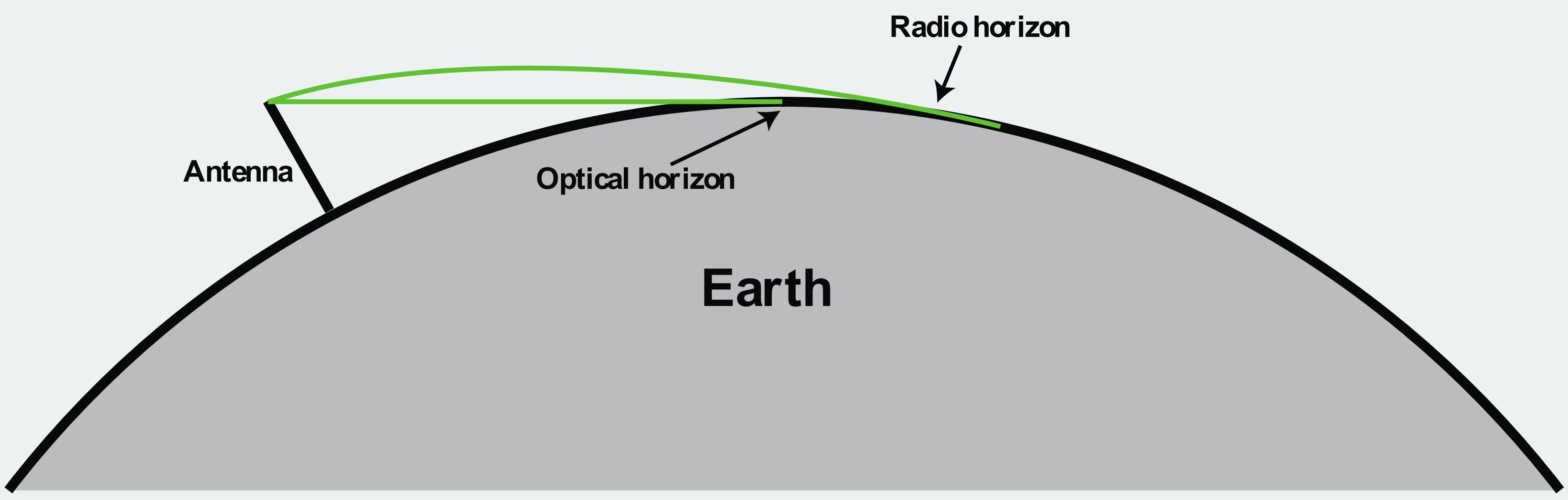


Figure 4.12 Optical and Radio Horizons

Line-of-Sight Transmission

Free space loss
- Loss of signal with distance

Atmospheric Absorption
- From water vapor and oxygen absorption

Multipath
- Multiple interfering signals from reflections

Refraction
- Bending signal away from receiver

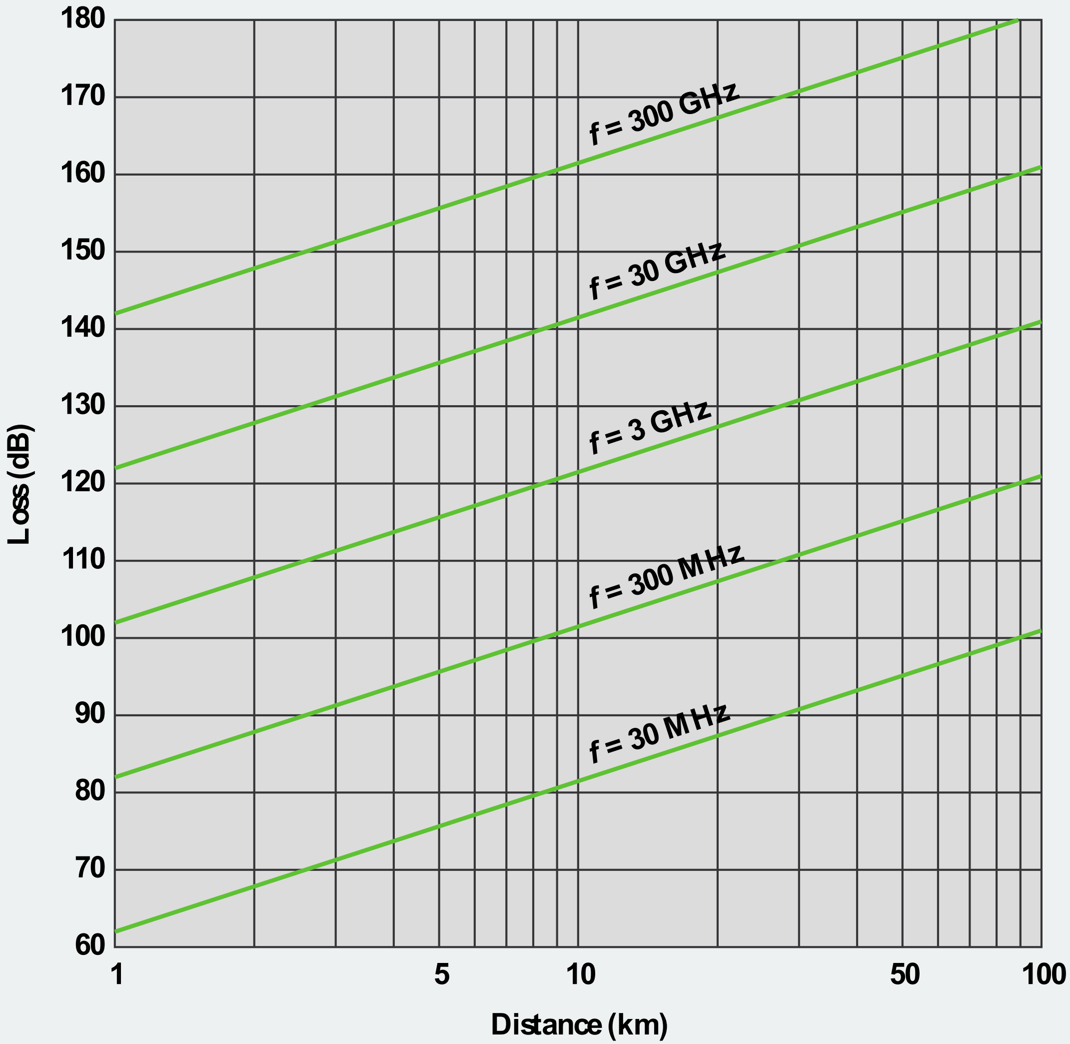
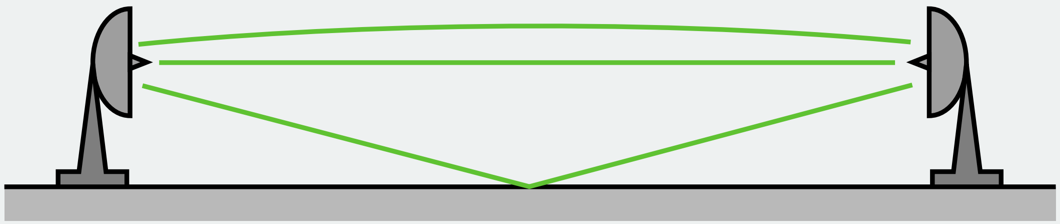
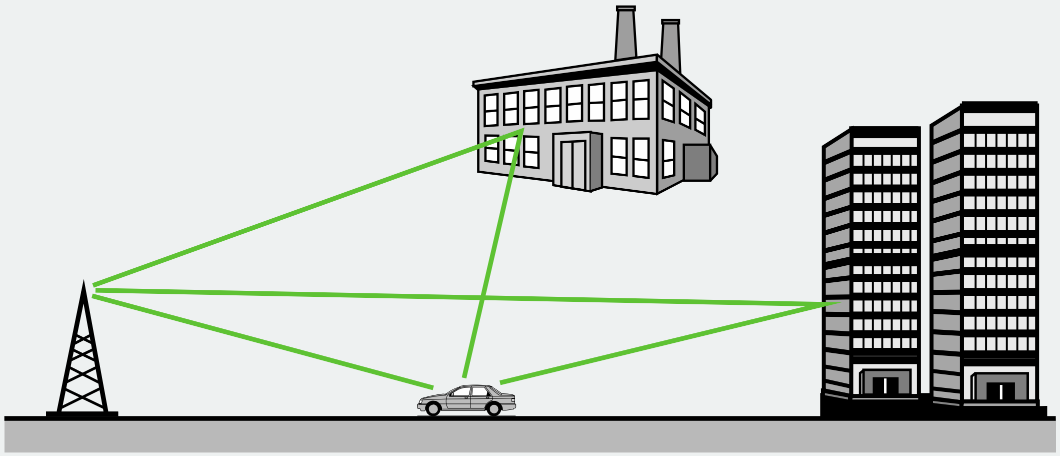


Figure 4.13 Free Space Loss



(a) Microwave line of sight



(b) Mobile radio

Figure 4.14 Examples of Multipath Interference

Summary

- Guided transmission media
  - Twisted pair
  - Coaxial cable
  - Optical fiber
- Wireless transmission
  - Antennas
  - Terrestrial microwave
  - Satellite microwave
  - Broadcast radio
  - Infrared
- Wireless propagation
  - Ground wave propagation
  - Sky wave propagation
  - Line-of-sight propagation
- Line-of-sight transmission
  - Free space loss
  - Atmospheric absorption
  - Multipath
  - Refraction