EECS 369: Introduction to Sensor Networks

Peter Scheuermann and Goce Trajcevski

Week2: Overview of Communication and Networking – PartI

Electromagnetic Signals – time domain

- Strength of the signal (at space) = Function of time
- Can also be expressed as a function of frequency
  - Signal consists of components of different frequencies
- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
- Digital signal - signal intensity maintains a constant level for some period of time and then changes to another constant level
- Periodic signal - analog or digital signal pattern that repeats over time
  - $s(t+T) = s(t)$
    - where T is the period of the signal

Electromagnetic Signals – time domain

- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time
- Peak amplitude (*A*) - maximum value or strength of the signal over time (e.g., measured in volts)
- Frequency (*f*)
  - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats

- Period (*T*) - amount of time it takes for one repetition of the signal
  - $T = 1/f$
- Phase (ϕ) - measure of the relative position in time within a single period of a signal
- Wavelength (λ) - distance occupied by a single cycle of the signal
  - Or, the distance between two points of corresponding phase of two consecutive cycles

Electromagnetic Signals – time domain (sine-waves)

- General sine wave
  - $s(t) = A \sin(2\pi f t + \phi)$
- One can vary each of the three parameters in the definition
  - (a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$s
  - (b) Reduced peak amplitude; A=0.5
  - (c) Increased frequency; $f = 2$, thus $T = ½$
  - (d) Phase shift; $\phi = \pi/4$ radians (45 degrees)
- note: 2π radians = 360° = 1 period

- When the horizontal axis is *time*, graphs show value of a signal at a given point in *space* as a function of *time*
- With the horizontal axis in *space*, graphs show value of a signal at a given point in *time* as a function of *distance*
  - At a particular instant of time, the intensity of the signal varies as a function of distance from the source

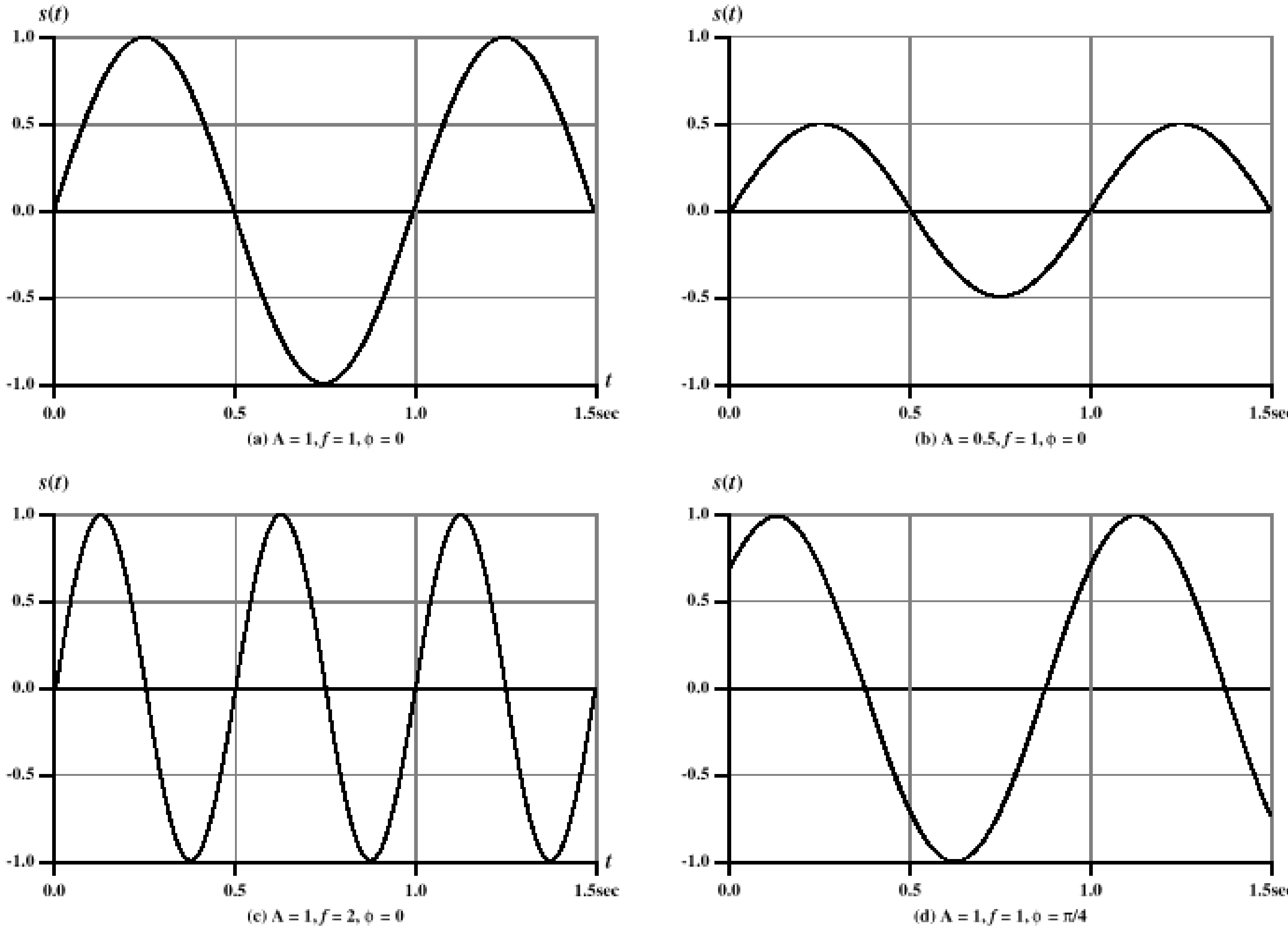


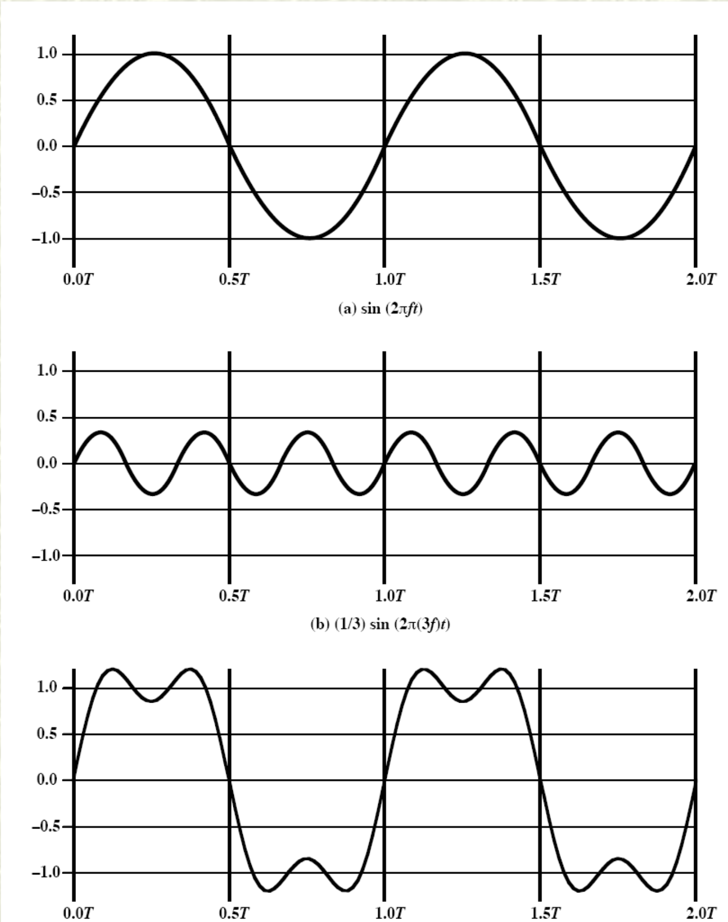
Figure 2.3 $s(t) = A \sin (2 \ ft + \phi)$

Electromagnetic signals: frequency-domain

- **Fundamental frequency** – the one of which all other frequency components of a signal are integer multiples of
- Spectrum - range of frequencies that a signal contains
- Absolute bandwidth - width of the spectrum of a signal
- Effective bandwidth (or just bandwidth) - narrow band of frequencies that most of the signal's energy is contained in

- Any (including electromagnetic) signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases (Note: aperiodic signals have a ***continuum*** of frequencies in their spectrum…)
- Key mathematical tool: ***Fourier Transform***

Electromagnetic signals – time vs. frequency

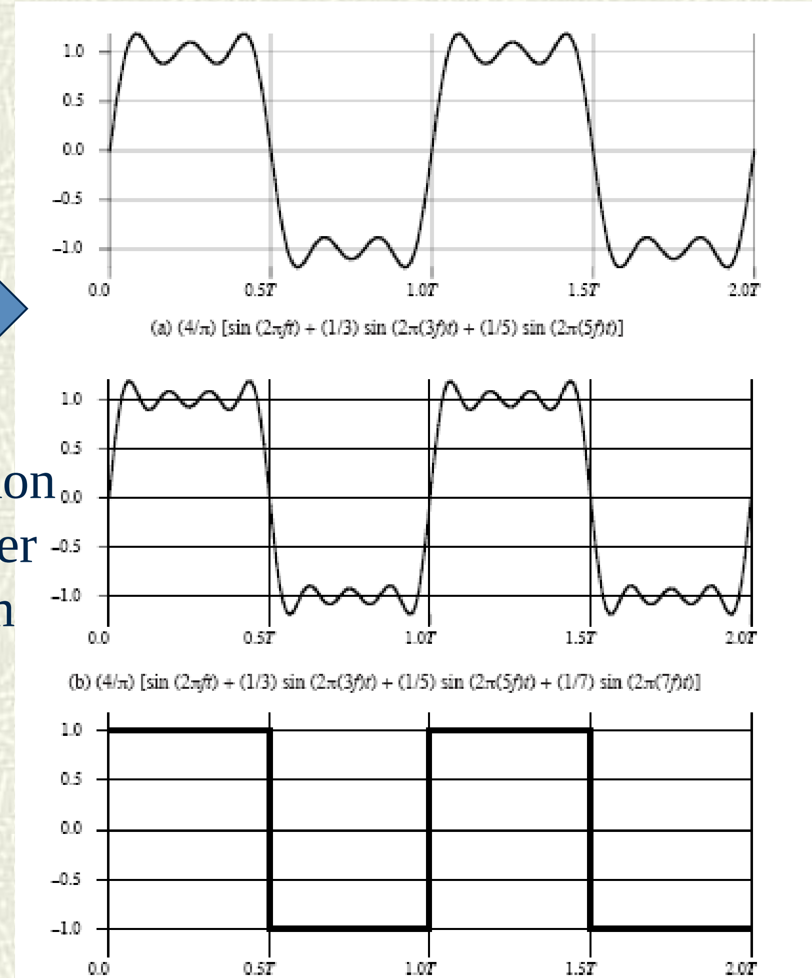


(a) $\sin(2\pi f t)$

(b) $(1/3)\sin(2\pi(3f)t)$

(c) $(4/\pi)\,[\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t)]$

Illustration of Fourier Theorem



(a) $(4/\pi)\,[\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$

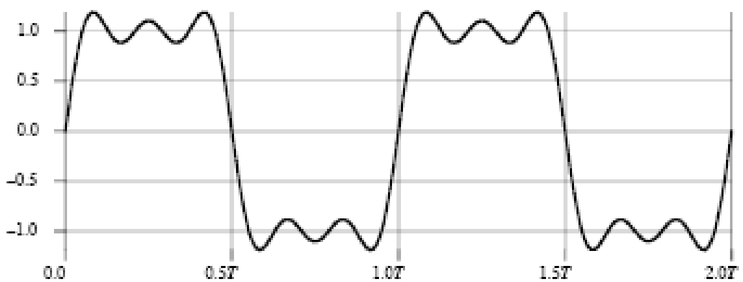
(b) $(4/\pi)\,[\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$

(c) $(4/\pi)\sum (1/k)\sin(2\pi(kf)t)$, for k odd

Adding different frequencies

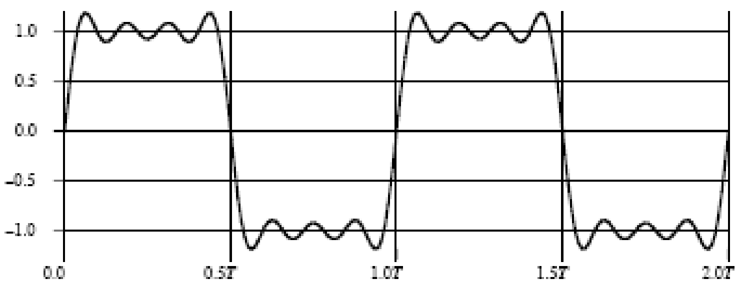
Approximating periodic signal
With sine waves…

Electromagnetic signals – Fourier, spectra, bandwidth



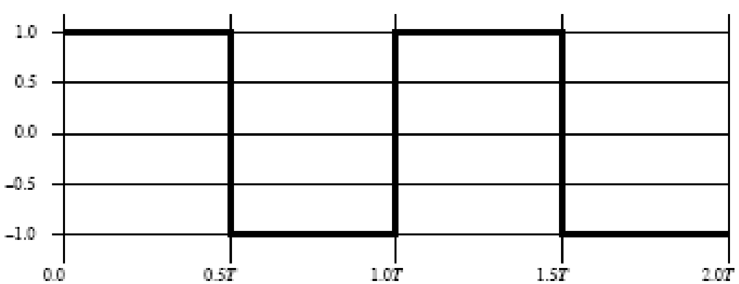
(a) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$

Fundamental: *f*
Spectrum: {*f*,*3f*,*5f*}
Bandwidth: [*5f* – *f*] = *4f*



(b) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$

Fundamental: *f*
Spectrum: {*f*,*3f*,*5f*,*7f*}
Bandwidth: [*7f* – *f*] = *6f*



(c) $(4/\pi)\sum (1/k)\sin(2\pi(kf)t)$, for k odd

Fundamental: *f*
Spectrum: {*f*,*3f*,*5f*,*7f*,*9f*,*11f*,… }
Bandwidth: infinite…

NOTE: power = *F*(amplitude) => most of the useful "information" contained in a "narrow" bandwidth

Electromagnetic signals – Fourier, spectra, bandwidth…

(Example:) Approximate the square wave of "0" and "1" with 3 sin-waves;
Assume that the main frequency is ***f = 1MHz***;
Then:

- the bandwidth of the signal is ***5f – f = 4f = 4MHz.***

Now, for ***f = 1MHz,*** the period is ***t = 1/f =*** 10^{-6}***sec.*** To get a "feeling" about the ***capacity*** of a channel transmitting such signal, assume that this represents an alternating-bit-sequence: e.g., "1" or "0" occurs every half-period, which is, a new bit every ***T/2 = 0.5μs***. Then:

- the speed of transmission (data rate) is ***2***x10^6***bps = 2Mbps,*** for a channel with bandwidth of ***4MHz*** with a fundamental frequency of ***1MHz***

Conclusions:

-Greater bandwidth => greater information-carrying capacity;
-A digital signal (even periodic!) will have infinite bandwidth;
-The system will limit the "useful" bandwidth (cost!)
-Any limit of the bandwidth will distort the signal…

Data, Signals, Communication…

- Data - entities that convey meaning, or information
  - **Analog**
    - Video
    - Audio
  - **Digital**
    - Text
    - Integers
- Signals - electric or electromagnetic representations of data
- Transmission - communication of the data via the propagation and processing of the corresponding signals

Analog vs. Digital Signals

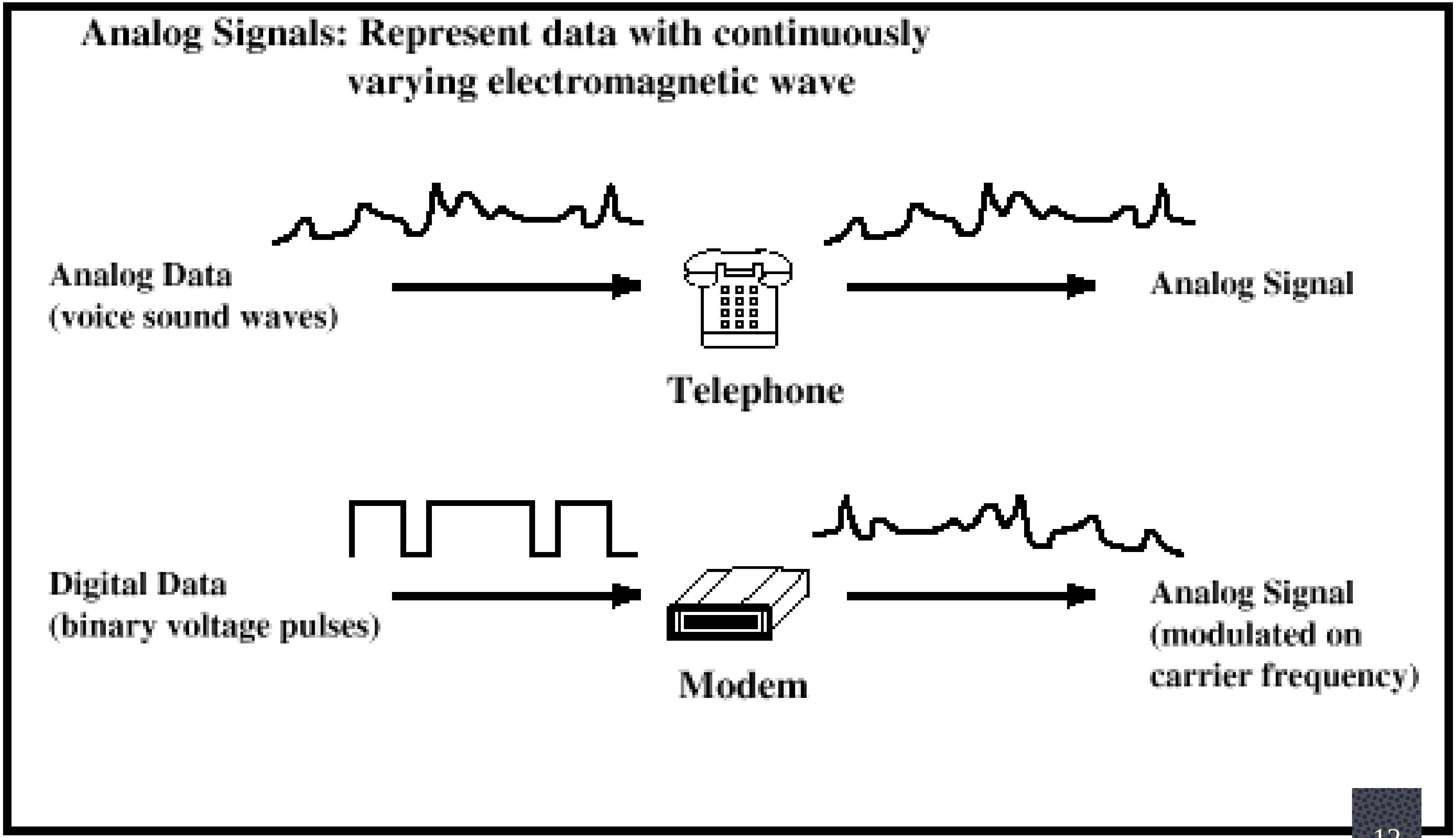
D G T L
I I A

- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- Suffer more from attenuation
- Digital signals can propagate analog and digital data

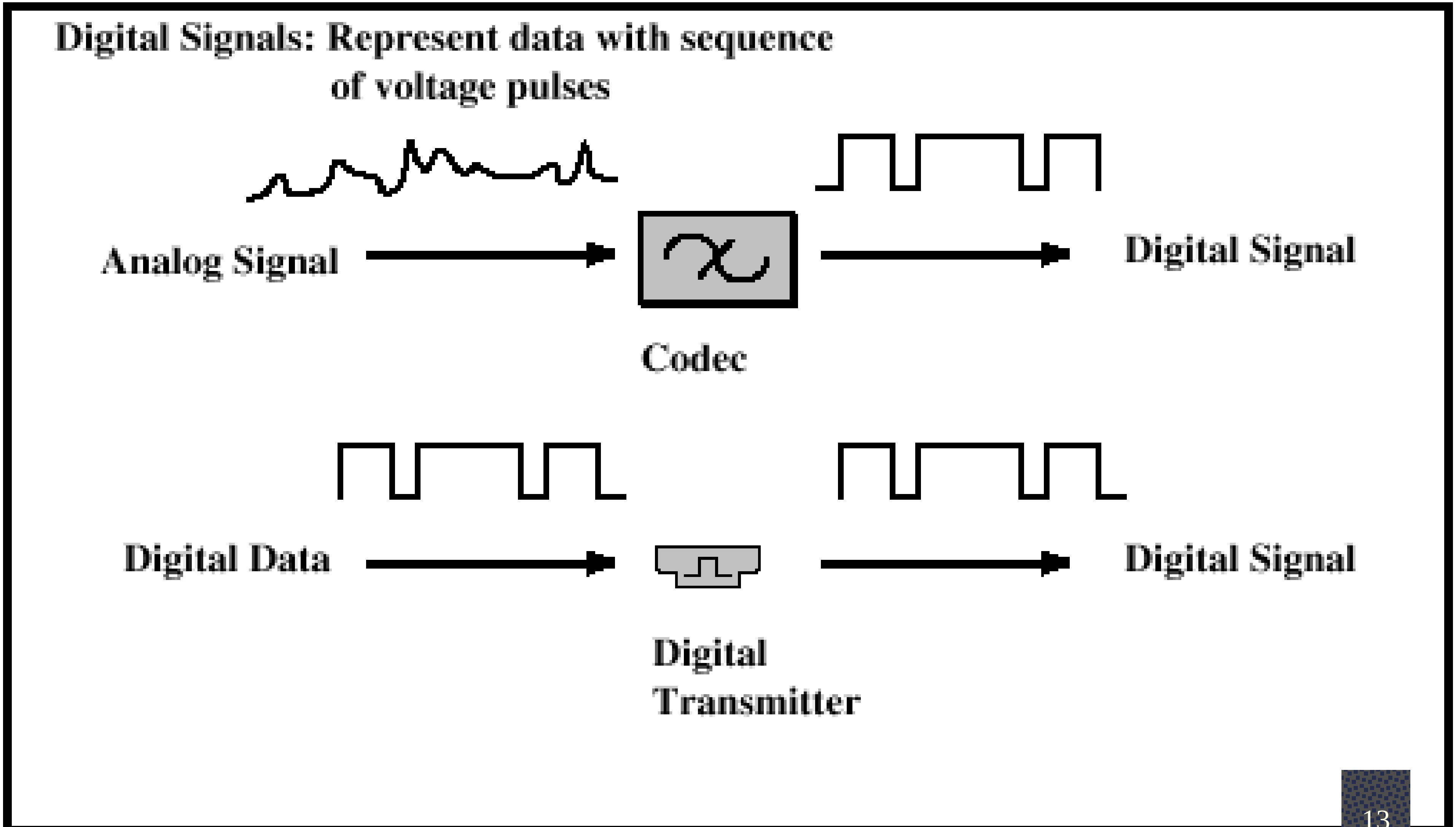
Analog

- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency
- Examples of media:
  - Copper wire media (twisted pair and coaxial cable)
  - Fiber optic cable
  - Atmosphere or space propagation
- Analog signals can propagate analog and digital data

Analog Signaling



Digital Signaling



Choosing (Data, Signal) Combinations

- Digital data, digital signal
  - Equipment for encoding is less expensive than digital-to-analog equipment
- Analog data, digital signal
  - Conversion permits use of modern digital transmission and switching equipment
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - Examples include optical fiber and satellite
- Analog data, analog signal
  - Analog data easily converted to analog signal

NORTHWESTERN UNIVERSITY

Analog Transmission

- Transmit analog signals without regard to content
- Attenuation limits length of transmission link
- Cascaded amplifiers boost signal's energy for longer distances but cause distortion
  - Analog data can tolerate distortion
  - Introduces errors in digital data

NORTHWESTERN UNIVERSITY

Digital Transmission

- Concerned with the **<u>content</u>** of the signal
- Attenuation endangers integrity of data
- Digital Signal
  - Repeaters achieve greater distance
  - Repeaters recover the signal and retransmit
- Analog signal carrying digital data
  - Retransmission device recovers the digital data from analog signal
  - Generates new, clean analog signal

Digital Channel Capacity

- Impairments, such as noise, limit data rate that can be achieved
- For digital data, to what extent do impairments limit data rate?
- Channel Capacity – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions
- Data rate - rate at which data can be communicated (bps)
- Bandwidth - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)

Multi-level improvements: Nyquist Bandwidth

- Noise - average level of noise over the communications path
- Error rate - rate at which errors occur
  - Error = transmit 1 and receive 0; transmit 0 and receive 1

- Recall the Example: for binary signals (two voltage levels)
  - $C = 2B$
- Can be improved with multilevel signaling:
  - $C = 2B \log_2 M$
    - M = number of discrete signal or voltage levels

In the context of the previous example, all other things being equal, if we have 8 different voltage levels, than the capacity of the channel would increase to 6 Mbps…

Noise Impact: Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\mathrm{dB}} = 10\log_{10}\frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal, low number of required intermediate repeaters
- SNR sets upper bound on achievable data rate, theoretically (Shannon):

$$C = B\log_2\left(1+\mathrm{SNR}\right)$$

In practice, only much lower rates achieved:

- Formula assumes white noise (thermal noise), e.g., impulse noise is not accounted for
- Attenuation distortion or delay distortion not accounted for

Realistic Channel (Nyquist + Shannon) Example:

- Assume: spectrum of a channel between 3 MHz and 4 MHz ; SNR_{dB} = 24 dB. Then:

$$B = 4\,\text{MHz} - 3\,\text{MHz} = 1\,\text{MHz}$$
$$\text{SNR}_{\text{dB}} = 24\,\text{dB} = 10\log_{10}(\text{SNR})$$
$$\text{SNR} = 251$$

- Using Shannon's formula

$$C = 10^6 \times \log_2(1 + 251) \approx 10^6 \times 8 = 8\text{Mbps}$$

- This can be achieved with: different signaling levels

$$C = 2B\log_2 M$$
$$8 \times 10^6 = 2 \times (10^6) \times \log_2 M$$
$$4 = \log_2 M$$
$$M = 16$$

Types of Transmission Media

- **Transmission Medium** = Physical path between transmitter and receiver
- **Guided Media** = Waves are guided along a solid medium
  - E.g., copper twisted pair, copper coaxial cable, optical fiber
- **Unguided Media** = Provides means of transmission but does not guide electromagnetic signals
  - Usually referred to as wireless transmission
  - E.g., atmosphere, outer space
  - Transmission AND Reception done by an antenna (directional/omnidirectional)

General Frequency Ranges

802.11b;Bluetooth -> 2.4GHz
802.11a -> 5GHz

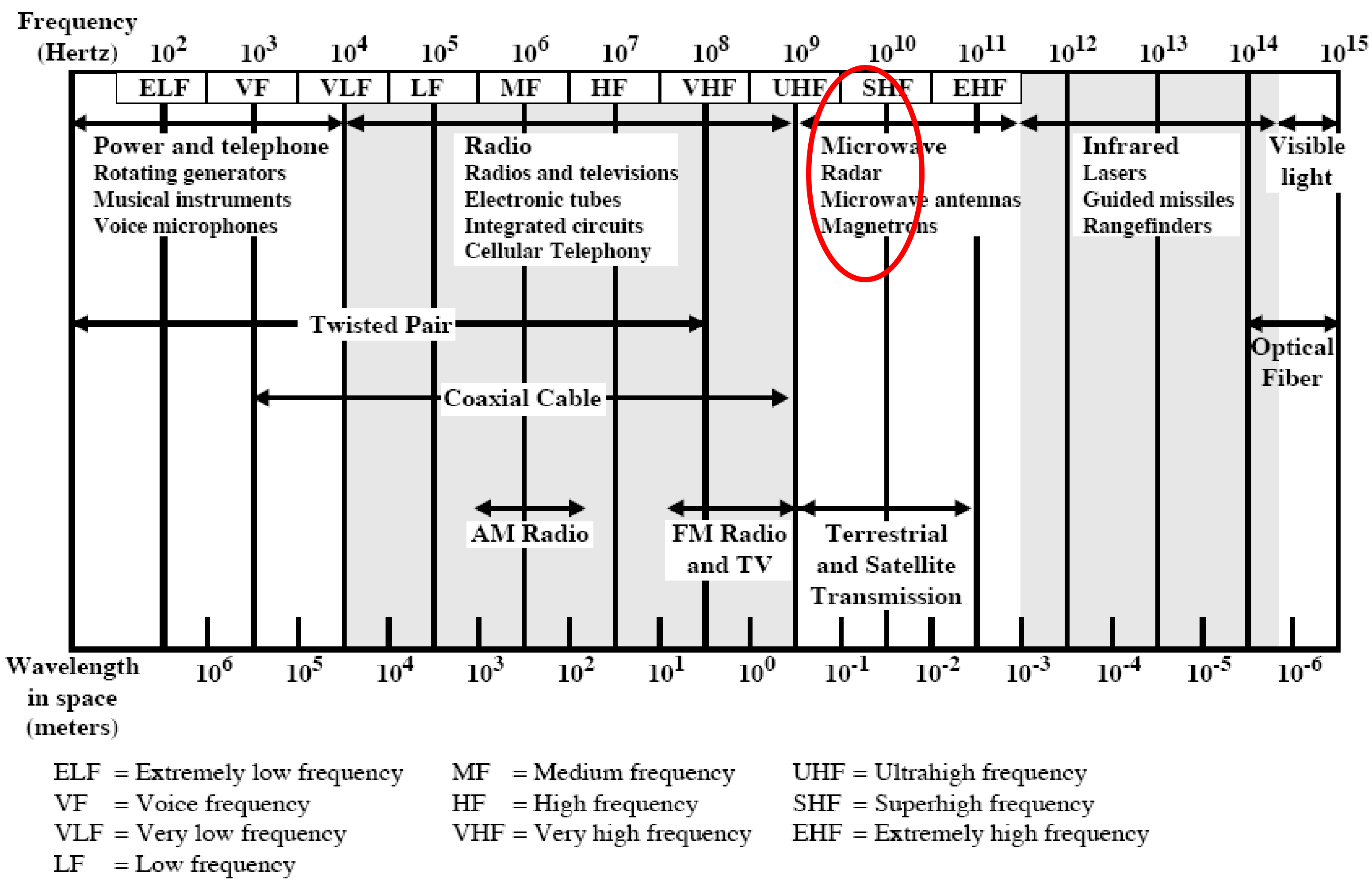
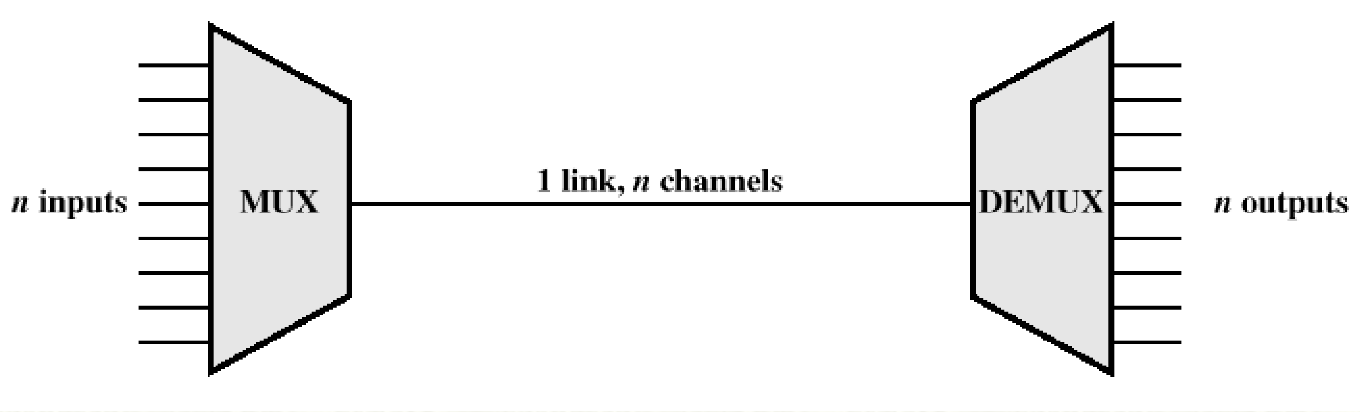


Figure 2.10 Electromagnetic Spectrum for Telecommunications

Multiplexing in Communication

- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal
- Multiplexing - carrying multiple signals on a single medium
  - More efficient use of transmission medium

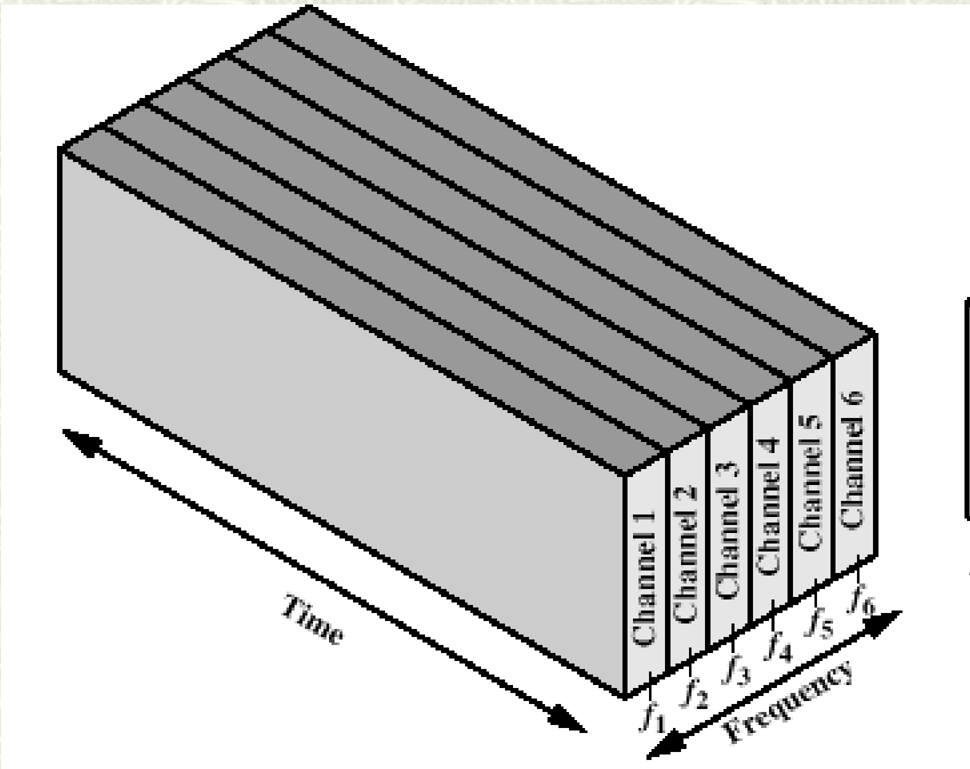


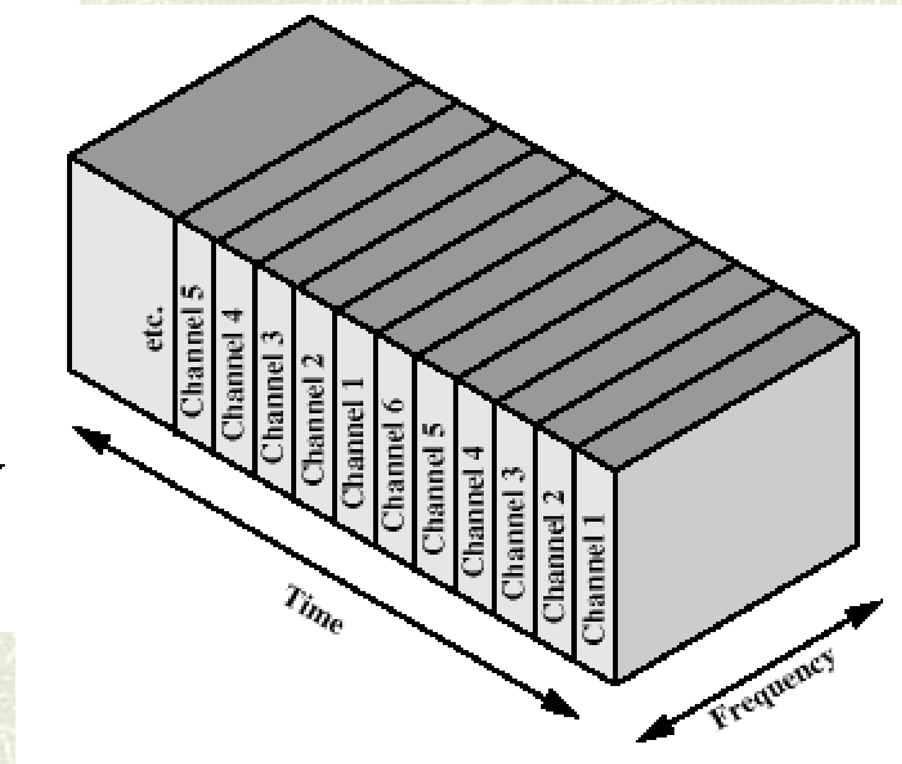
Why Multiplexing…(FDM vs. TDM)

- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Most individual data communicating devices require relatively modest data rate support

- Frequency-division multiplexing (FDM)
  - Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal
- Time-division multiplexing (TDM)
  - Takes advantage of the fact that the achievable bit rate of the medium exceeds the required data rate of a digital signal

FDM vs. TDM


Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 6
f_1
f_2
f_3
f_4
f_5
f_6
Time
Frequency


etc.
Channel 5
Channel 4
Channel 3
Channel 2
Channel 1
Channel 6
Channel 5
Channel 4
Channel 3
Channel 2
Channel 1
Time
Frequency

Transmission – Signal Encoding Criteria

- What determines how successful a receiver will be in interpreting an incoming signal?
  - Signal-to-noise ratio
  - Data rate
  - Bandwidth
- An increase in data rate increases bit error rate
- An increase in SNR decreases bit error rate
- An increase in bandwidth allows an increase in data rate
- Signal spectrum
  - With lack of high-frequency components, less bandwidth required
  - With no dc component, ac coupling via transformer possible
  - Transfer function of a channel is worse near band edges
- Clocking
  - Ease of determining beginning and end of each bit position
- Signal interference and noise immunity
  - Performance in the presence of noise
- Cost and complexity
  - The higher the signal rate to achieve a given data rate, the greater the cost

Transmission – Digital-to-Analog Encoding

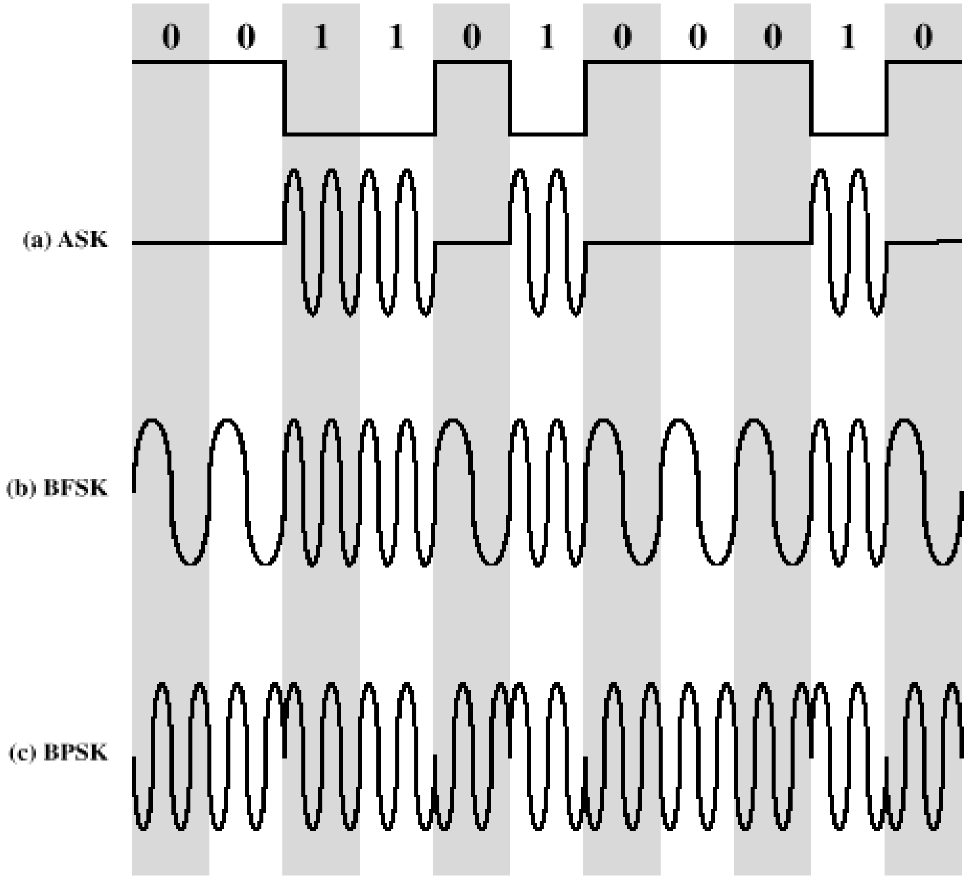
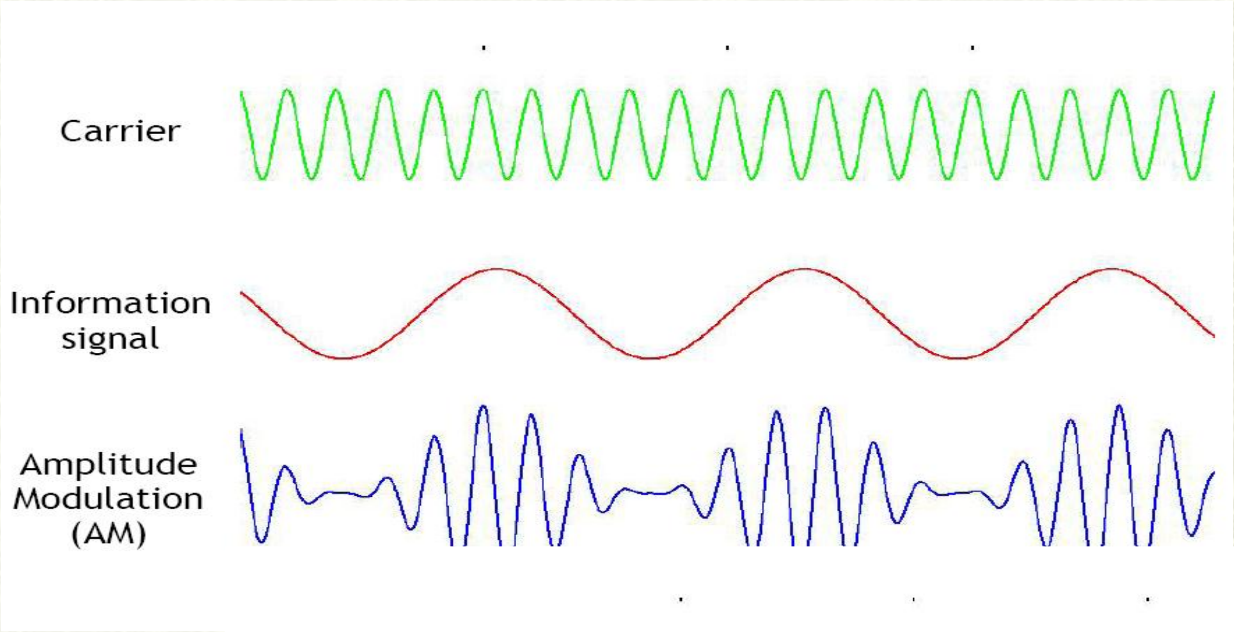


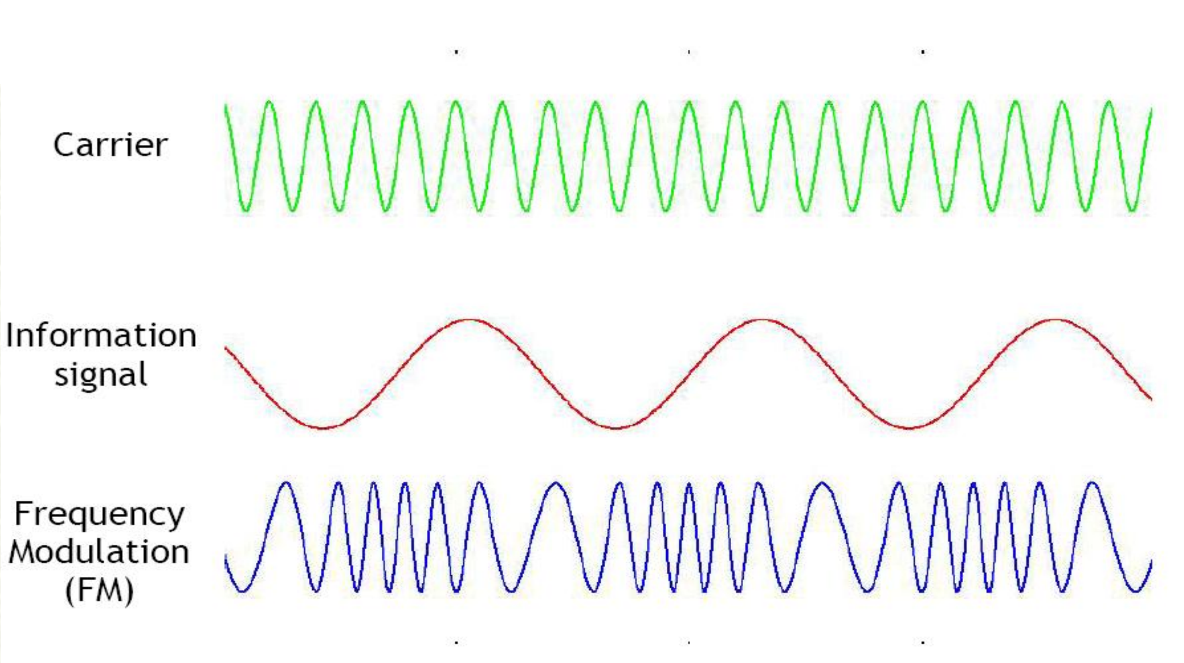
Figure 6.2 Modulation of Analog Signals for Digital Data

-Can have ***multiple*** frequency shift key (MFSK)

-Can combine ASK and PSK to obtain QAM (Quadrature Amplitude modulation), enabling two different signals to be sent on one carrier frequency

Transmission – Analog-to-Analog Encoding





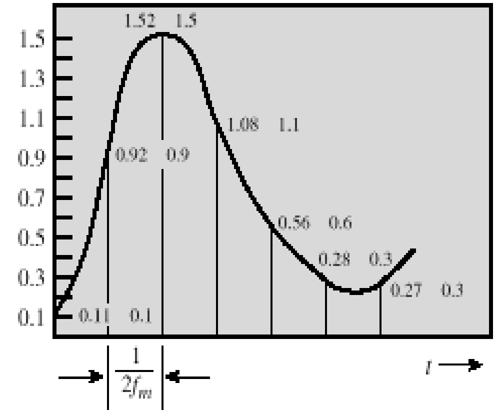
Carrier frequency needs
To be much higher, to
“minimize” the propagation
losses

NOTE: modulation
enables FDM…

NORTHWESTERN
UNIVERSITY

Transmission – Analog-to-Digital Encoding

1. PCM (Pulse-Code Modulation)



(a)

- Based on the sampling theorem
- Each analog sample is assigned a binary code
  - Analog samples are referred to as pulse amplitude modulation (PAM) samples
- The digital signal consists of block of *n* bits, where each *n*-bit number is the amplitude of a PCM pulse

Digit	Binary Equivalent	PCM waveform
0	0000	
1	0001	
2	0010	
3	0011	
4	0100	
5	0101	
6	0110	
7	0111	

Digit	Binary Equivalent	PCM waveform
8	1000	
9	1001	
10	1010	
11	1011	
12	1100	
13	1101	
14	1110	
15	1111	

(b)

Transmission – Analog-to-Digital Encoding

2. DM (Delta Modulation)

- Analog input is approximated by staircase function
  - Moves up or down by one quantization level (δ) at each sampling interval
- The bit stream approximates derivative of analog signal (rather than amplitude)
  - 1 is generated if function goes up
  - 0 otherwise

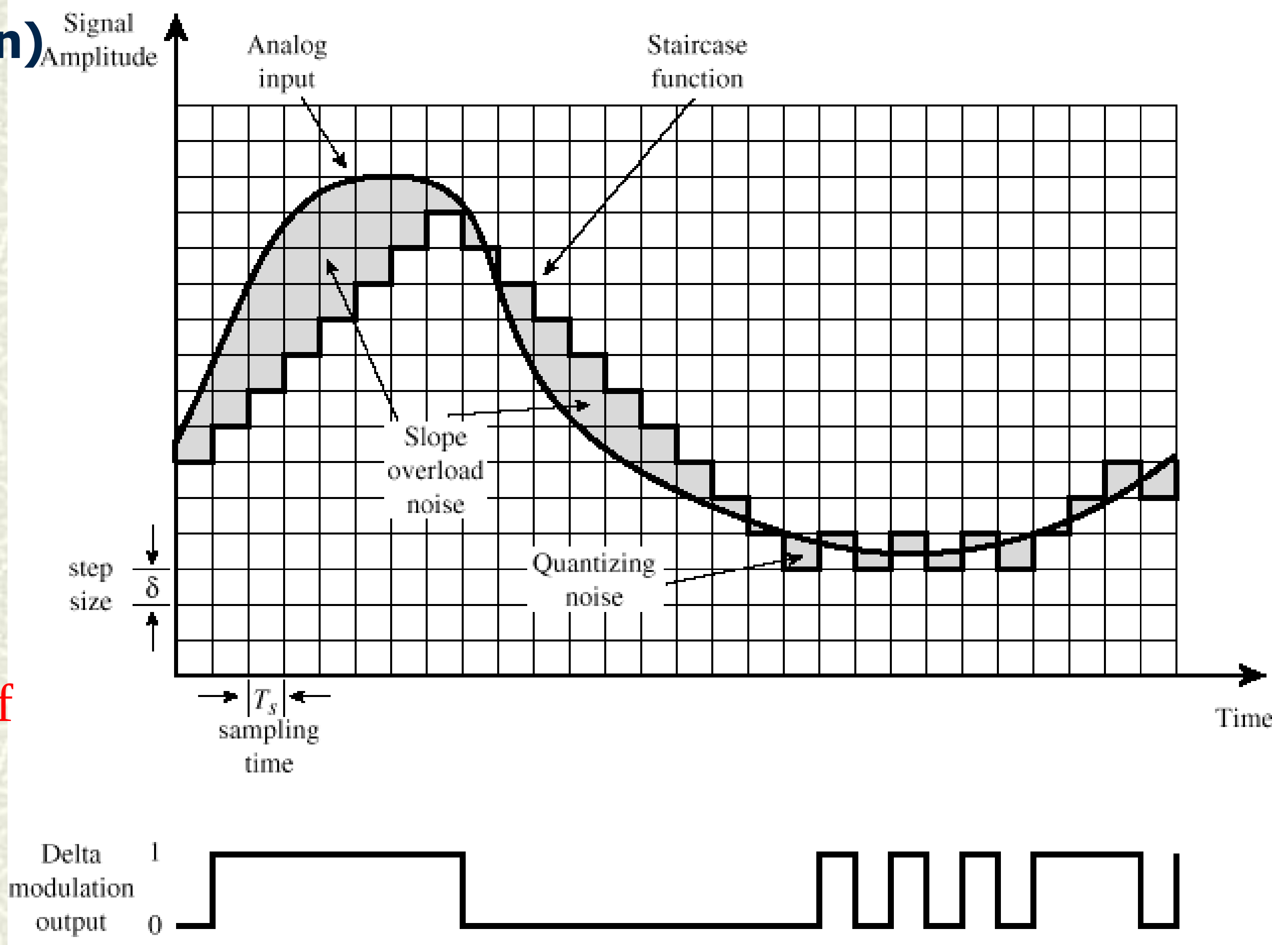


Figure 6.18 Example of Delta Modulation

Transmission – Analog-to-Digital Encoding

NOTE:

- Accuracy improved by increasing sampling rate
  - However, this increases the data rate
- Advantage of DM over PCM is the simplicity of its implementation
- Two important parameters
  - Size of step assigned to each binary digit (δ)
  - Sampling rate

- Growth in popularity of digital techniques for sending analog data
  - Repeaters are used instead of amplifiers
    - No additive noise
  - TDM is used instead of FDM
    - No intermodulation noise
  - Conversion to digital signaling allows use of more efficient digital switching techniques

Transmission – Spread-Spectrum Encoding

- Input is fed into a channel encoder
  - Produces analog signal with narrow bandwidth
- Signal is further modulated using sequence of digits
  - Spreading code or spreading sequence
  - Generated by pseudonoise, or pseudo-random number generator
- Effect of modulation is to increase bandwidth of signal to be transmitted

- On receiving end, digit sequence is used to demodulate the spread spectrum signal
- Signal is fed into a channel decoder to recover data

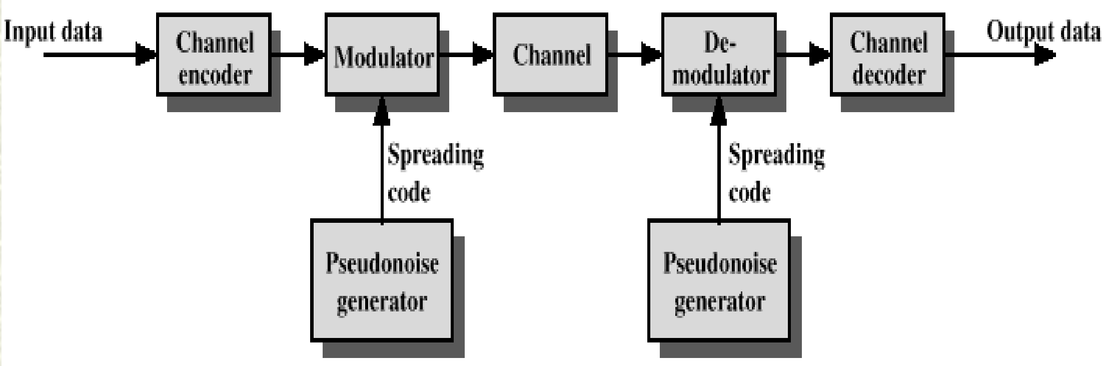


Figure 7.1 General Model of Spread Spectrum Digital Communication System

Transmission – Spread-Spectrum Encoding

- What can be gained from apparent waste of spectrum?
  - Immunity from various kinds of noise and multipath distortion
  - Can be used for hiding and encrypting signals
  - Several users can independently use the same higher bandwidth with very little interference

- Signal is broadcast over seemingly random series of radio frequencies
  - A number of channels allocated for the FH signal
  - Width of each channel corresponds to bandwidth of input signal
- Signal hops from frequency to frequency at fixed intervals
  - Transmitter operates in one channel at a time
  - Bits are transmitted using some encoding scheme
  - At each successive interval, a new carrier frequency is selected

Channel sequence dictated by spreading code; Receiver, hopping between frequencies in synchronization with transmitter, picks up message…
- Advantages: Eavesdroppers hear only unintelligible blips

Attempts to jam signal on one frequency succeed only at knocking out a few bits

NORTHWESTERN UNIVERSITY

Transmission – Spread-Spectrum Encoding

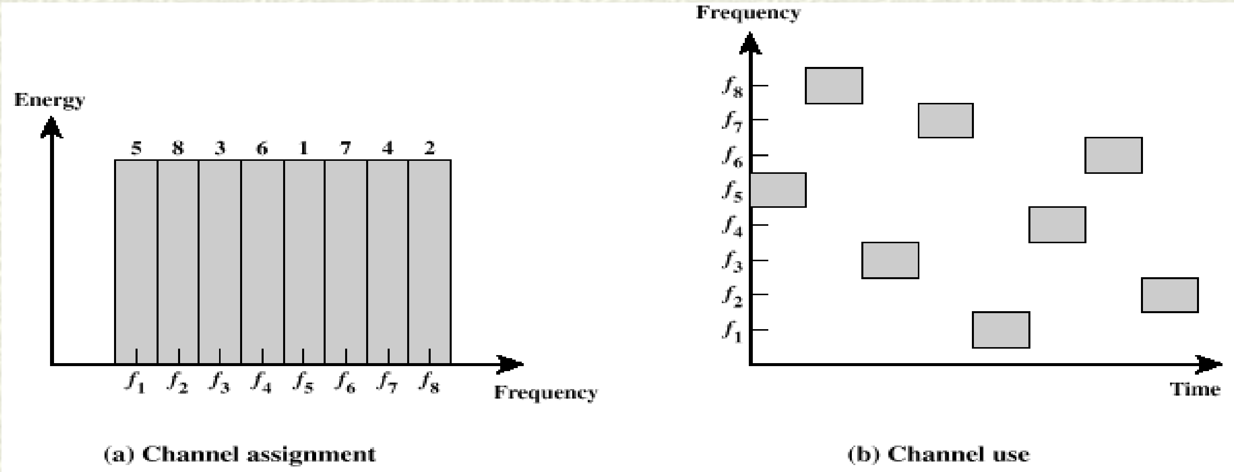


Figure 7.2 Frequency Hopping Example

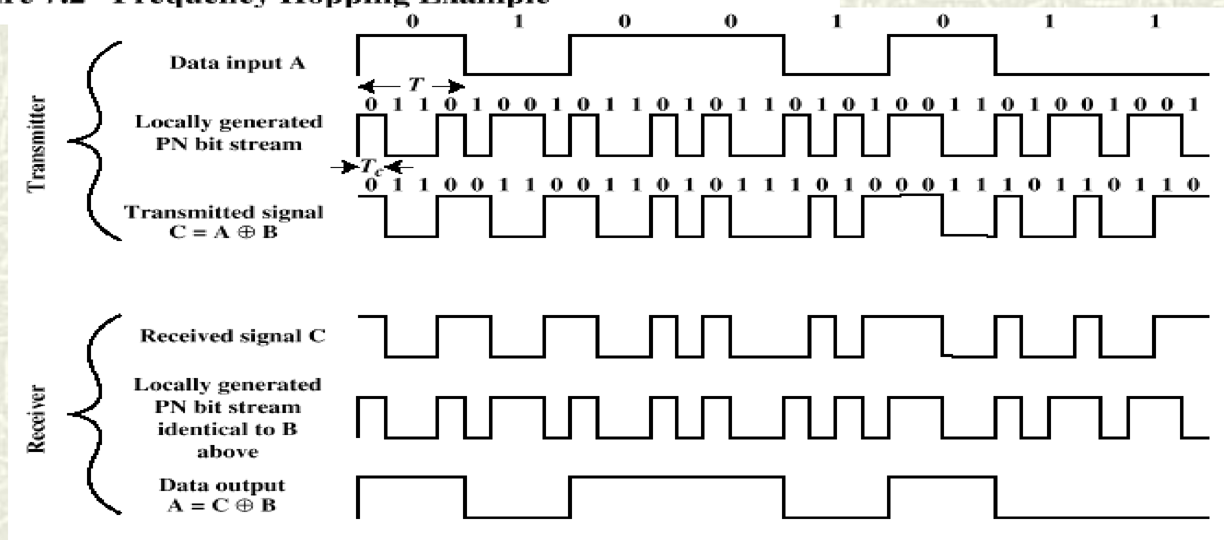


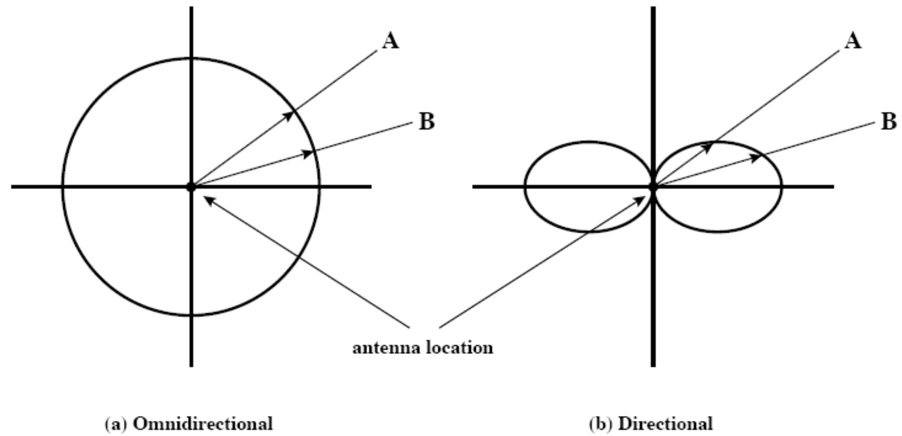
Figure 7.6 Example of Direct Sequence Spread Spectrum

Antennas and Signal Propagation

- An antenna is an electrical conductor or system of conductors
  - Transmission - radiates electromagnetic energy into space
  - Reception - collects electromagnetic energy from space
- In two-way communication, the same antenna can be used for transmission and reception

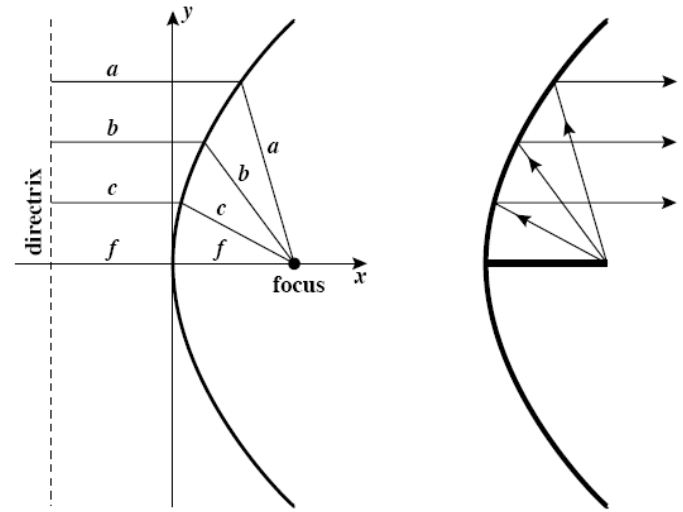
- Radiation pattern
  - Graphical representation of radiation properties of an antenna
  - Depicted as two-dimensional cross section
- Beam width (or half-power beam width)
  - Measure of directivity of antenna
- Reception pattern
  - Receiving antenna's equivalent to radiation pattern

Antennas and Signal Propagation



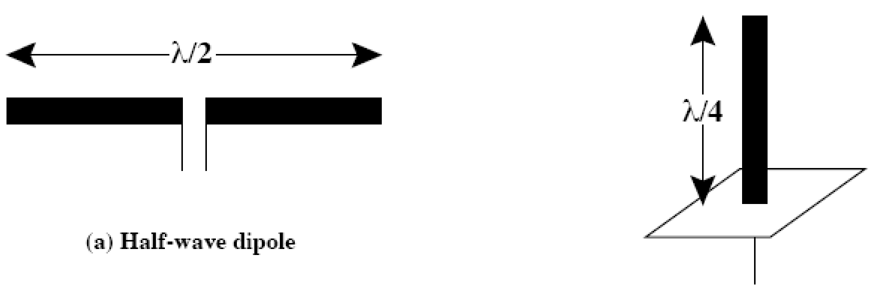
(a) Omnidirectional (b) Directional

Figure 5.1 Idealized Radiation Patterns



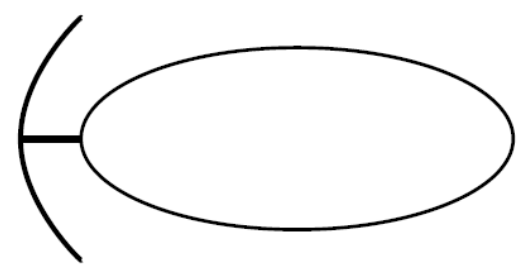
(a) Parabola

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

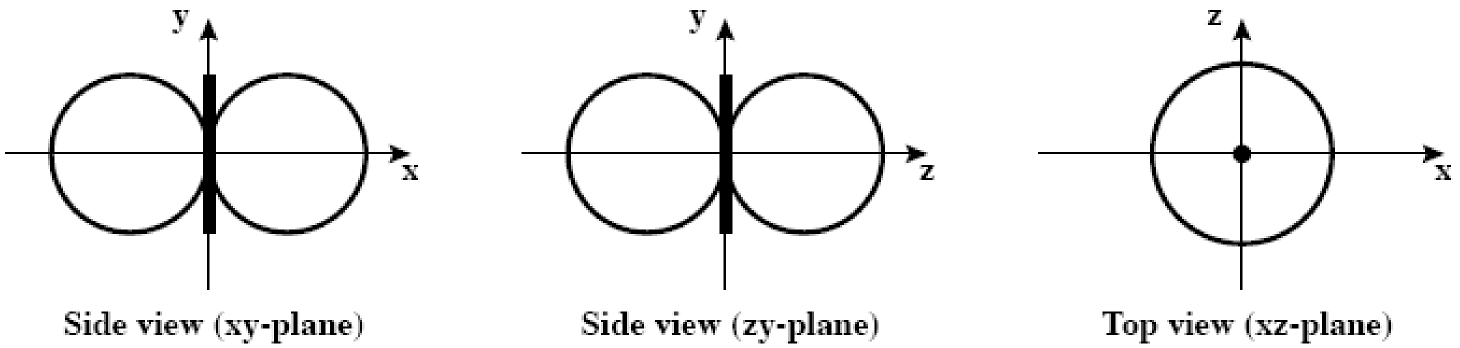


(a) Half-wave dipole

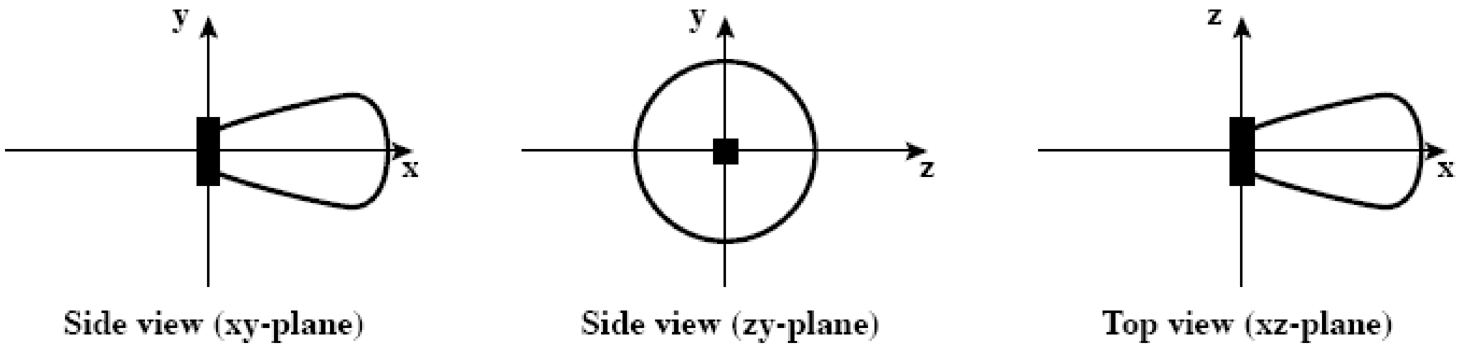
(b) Quarter-wave antenna



Antennas: Radiation Patterns

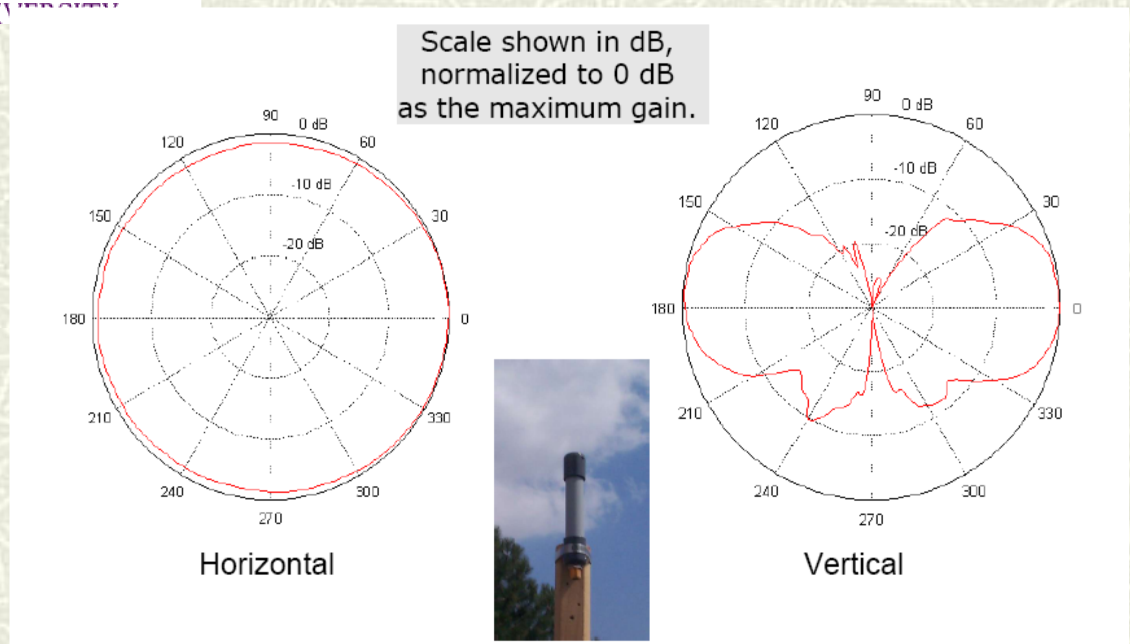


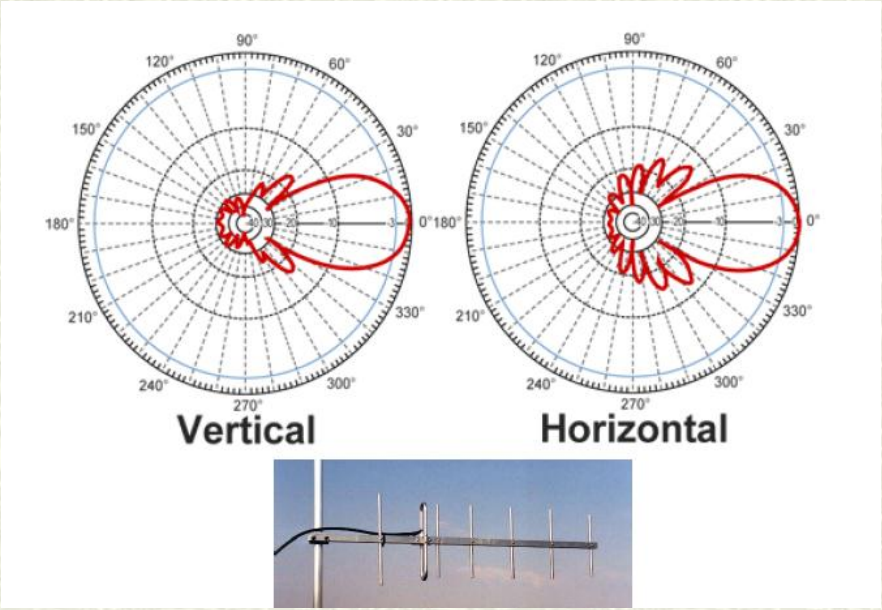
(a) Simple dipole



(b) Directed antenna

Antennas: Radiation Patterns





Most of the antennas do NOT operate equally-well in all directions…

Antennas and Propagation

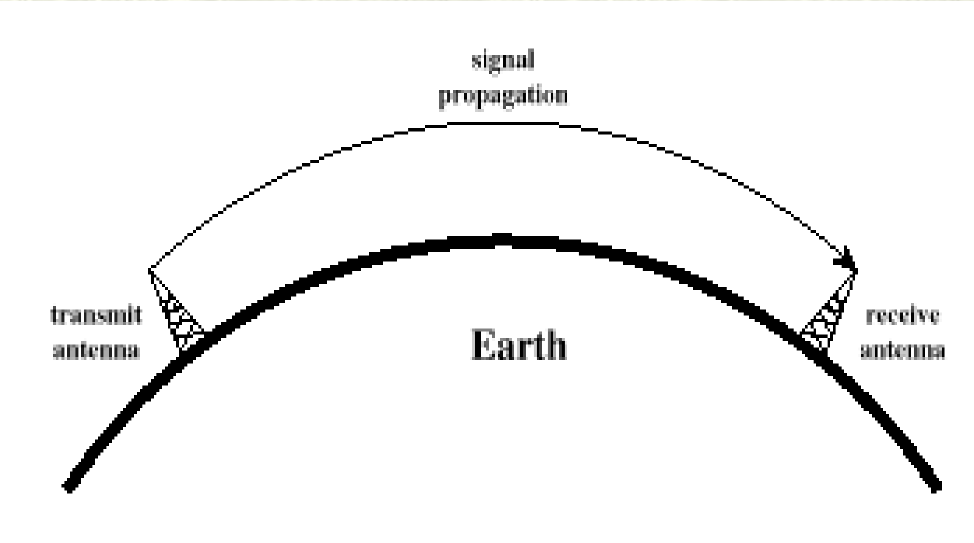
- Antenna gain
  - Power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna)
- Effective area
  - Related to physical size and shape of antenna

- Relationship between antenna gain and effective area

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

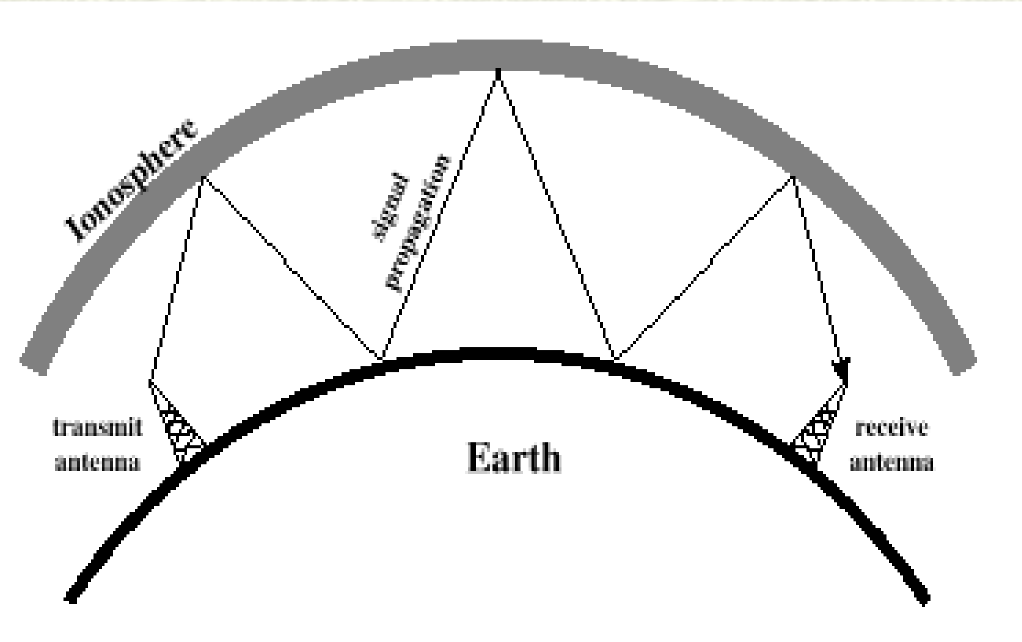
  - *G* = antenna gain
  - *Ae* = effective area
  - *f* = carrier frequency
  - c = speed of light (≈ 3 ´ 10^8 m/s)
  - λ = carrier wavelength

Antennas and Propagation



Ground-wave propagation:

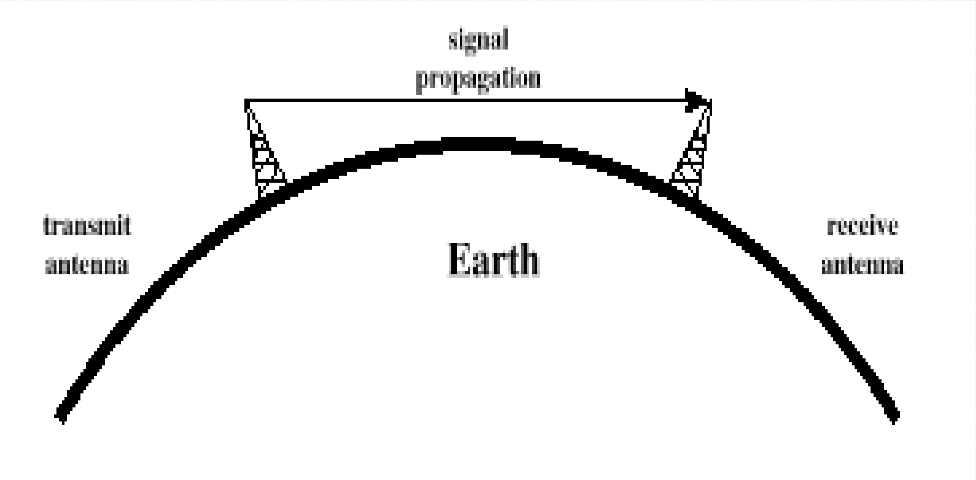
- Follows contour of the earth
- Can Propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio

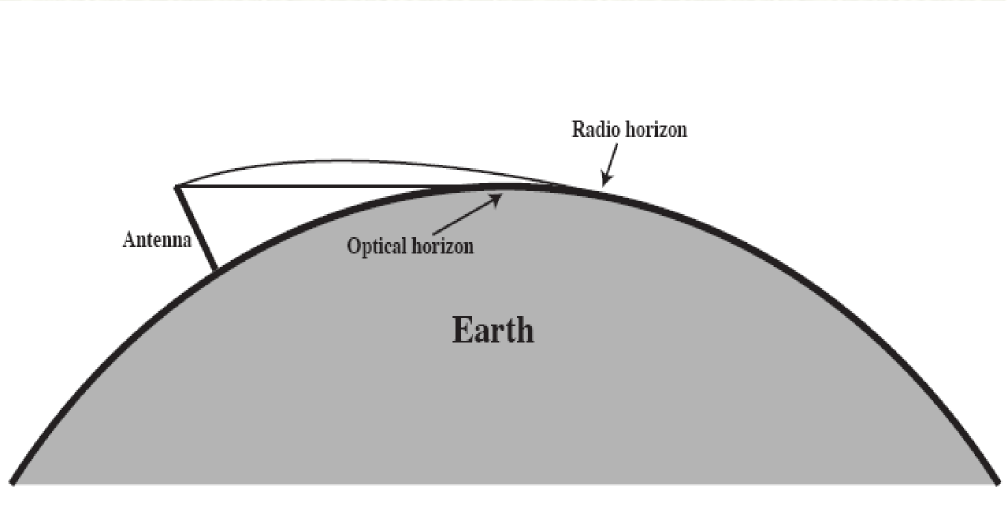


Sky-Wave Propagation

- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth's surface (1000's of Km)
- Reflection effect caused by refraction
- Examples
  - Amateur radio
  - CB radio

Antennas and Propagation: Line-Of-Sight (LOS)





- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of site due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums

$$3.57\left(\sqrt{Kh_1}+\sqrt{Kh_2}\right)$$

K = 4/3

Antennas: Reality-Check…

- Attenuation and attenuation distortion
- Free space loss
- Noise
- Atmospheric absorption
- Multipath
- Refraction
- Thermal noise

- Strength of signal falls off with distance over transmission medium
- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

NORTHWESTERN UNIVERSITY

Antennas: Reality-Check...

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media
- Cannot be eliminated
- Function of temperature
- Particularly significant for satellite communication

NOTE: independent of frequency
⇒For a bandwidth “B”, just multiply the RHS of the equation

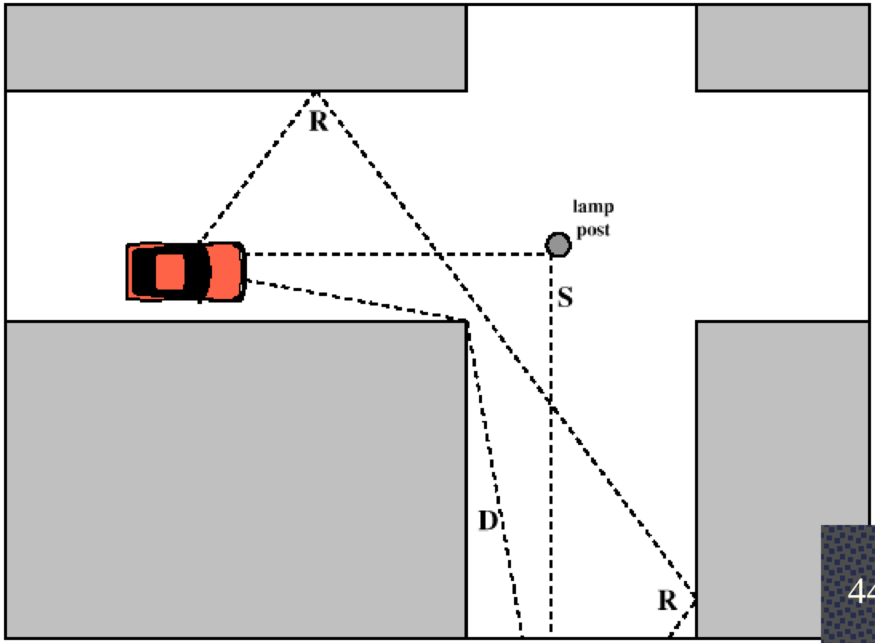
- Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

$$N_0 = \mathrm{k}T\ (\mathrm{W/Hz})$$

  - *N*0 = noise power density in watts per 1 Hz of bandwidth
  - k = Boltzmann's constant = 1.3803 ´ 10-23 J/K
  - *T* = temperature, in kelvins (absolute temperature)

Antennas: Reality-Check…

- Intermodulation noise – occurs if signals with different frequencies share the same medium
  - Interference caused by a signal produced at a frequency that is the sum or difference of original frequencies
- Crosstalk – unwanted coupling between signal paths
- Impulse noise – irregular pulses or noise spikes
  - Short duration and of relatively high amplitude
  - Caused by external electromagnetic disturbances, or faults and flaws in the communications system
- Atmospheric absorption – water vapor and oxygen contribute to attenuation
- Multipath – obstacles reflect signals so that multiple copies with varying delays are received
- Refraction – bending of radio waves as they propagate through the atmosphere



NORTHWESTERN UNIVERSITY

Antennas: Reality-Check…

- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

Dealing with "Reality":

- Transmitter adds error-correcting code to data block
  - Code is a function of the data bits
- Receiver calculates error-correcting code from incoming data bits
  - If calculated code matches incoming code, no error occurred
  - If error-correcting codes don't match, receiver attempts to determine bits in error and correct

…plus, some sophisticated signal-processing algorithms to deal with intersymbol interference

Satellite Communication

- Earth Stations – antenna systems on or near earth
- Uplink – transmission from an earth station to a satellite
- Downlink – transmission from a satellite to an earth station
- Transponder – electronics in the satellite that convert uplink signals to downlink signals

- Coverage area
  - Global, regional, national
- Service type
  - Fixed service satellite (FSS)
  - Broadcast service satellite (BSS)
  - Mobile service satellite (MSS)
- General usage
  - Commercial, military, amateur, experimental

- Circular or elliptical orbit
  - Circular with center at earth's center
  - Elliptical with one foci at earth's center
- Orbit around earth in different planes
  - Equatorial orbit above earth's equator
  - Polar orbit passes over both poles
  - Other orbits referred to as inclined orbits
- Altitude of satellites
  - Geostationary orbit (GEO)
  - Medium earth orbit (MEO)
  - Low earth orbit (LEO)

Satellites…

GEO:

- Advantages of the the GEO orbit
  - No problem with frequency changes
  - Tracking of the satellite is simplified
  - High coverage area
- Disadvantages of the GEO orbit
  - Weak signal after traveling over 35,000 km
  - Polar regions are poorly served
  - Signal sending delay is substantial

LEO:

- Circular/slightly elliptical orbit under 2000 km
- Orbit period ranges from 1.5 to 2 hours
- Diameter of coverage is about 8000 km
- Round-trip signal propagation delay less than 20 ms
- Maximum satellite visible time up to 20 min
- System must cope with large Doppler shifts
- Atmospheric drag results in orbital deterioration

- Little LEOs: Frequencies below 1 GHz ; 5MHz of Bandwidth; Data rates up to 10 kbps…

Aimed at paging, tracking, and low-rate messaging

-Big LEOs: Frequencies above 1 GHz; Support data rates up to a few megabits per sec; Offer same services as little LEOs in addition to voice and positioning services

Satellites…

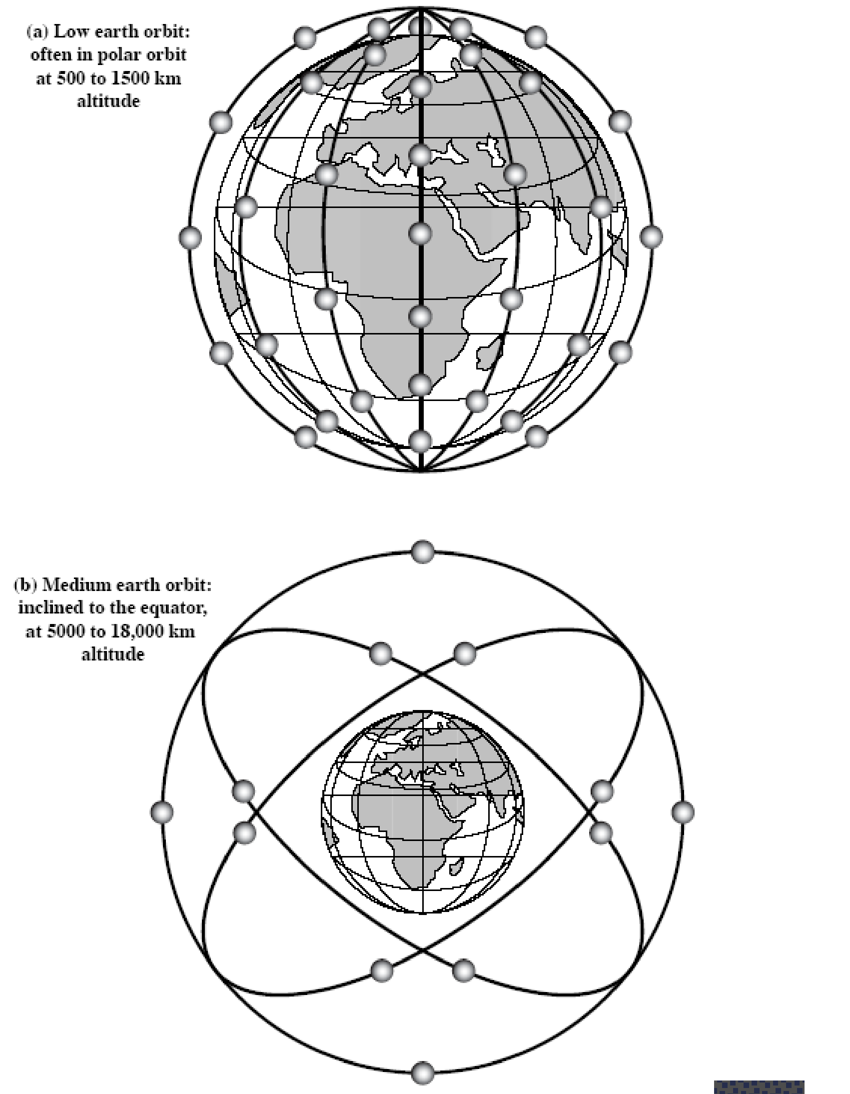
MEO:

- Circular orbit at an altitude in the range of 5000 to 12,000 km
- Orbit period of 6 hours
- Diameter of coverage is 10,000 to 15,000 km
- Round trip signal propagation delay less than 50 ms
- Maximum satellite visible time is a few hours

Band	Frequency Range	Total Bandwidth	General Application
L	1 to 2 GHz	1 GHz	Mobile satellite service (MSS)
S	2 to 4 GHz	2 GHz	MSS, NASA, deep space research
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	FSS military, terrestrial earth exploration, and meteorological satellites
Ku	12.5 to 18 GHz	5.5 GHz	FSS, broadcast satellite service (BSS)
K	18 to 26.5 GHz	8.5 GHz	BSS, FSS
Ka	26.5 to 40 GHz	13.5 GHz	FSS

Satellites…


Orbit: 35,863 km
at the equator
= satellite


(a) Low earth orbit:
often in polar orbit
at 500 to 1500 km
altitude
(b) Medium earth orbit:
inclined to the equator,
at 5000 to 18,000 km
altitude

Satellites and Networking

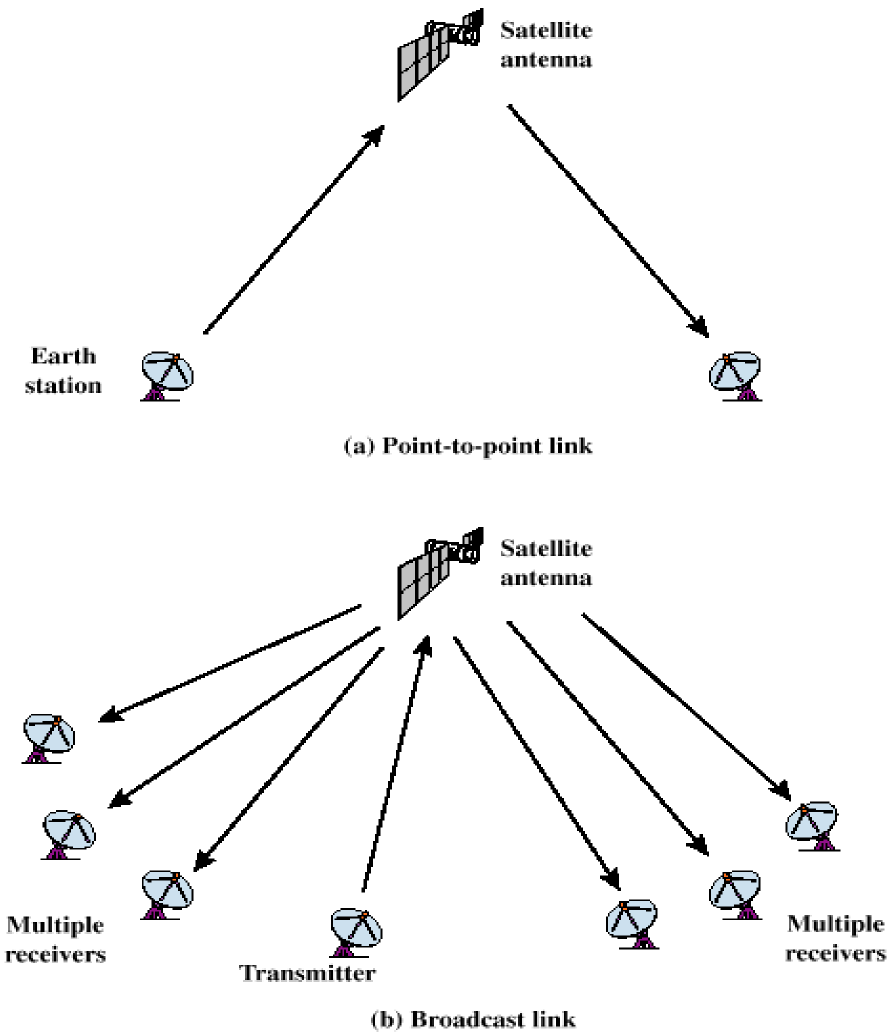


Figure 9.8 Satellite Communication Configurations

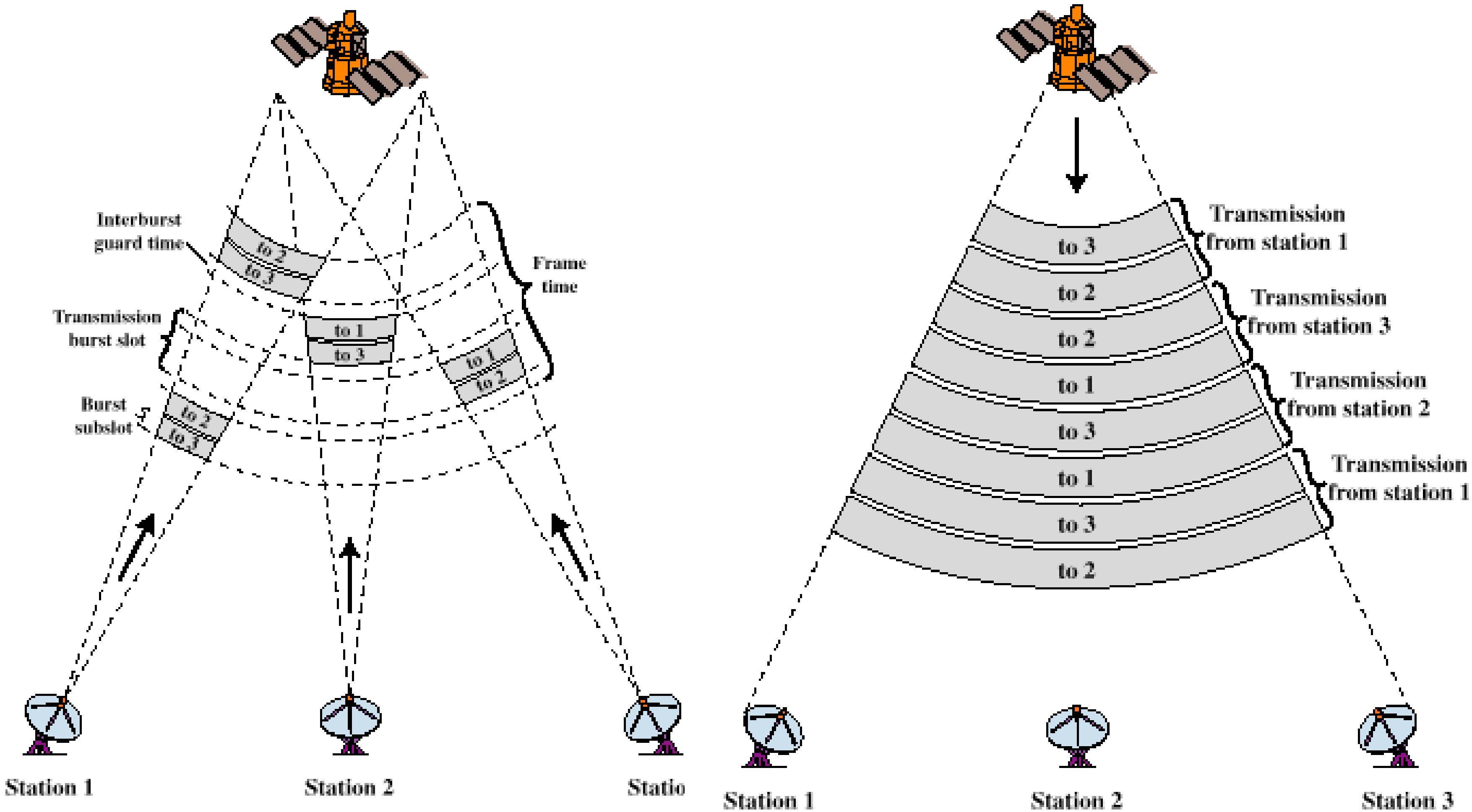
Capacity Management Schemes:

- Frequency division multiple access (FDMA)
- Time division multiple access (TDMA)
- Code division multiple access (CDMA)

Example (FDMA):

-1200 voice-frequency (VF) voice channels
-One 50-Mbps data stream
-16 channels of 1.544 Mbps each
-400 channels of 64 kbps each
-600 channels of 40 kbps each
-One analog video signal
-Six to nine digital video signals

Satellites and Networking…



(a) Uplink

(b) Downlink