CSCD 433/533
Network Programming
Winter 2017

Lecture 3
Physical Layer Line Coding

Physical Layer Topics

- Motivation for studying this topic
- Definitions of terms
- Analog vs Digital
- Characteristics of physical media
- Wireless

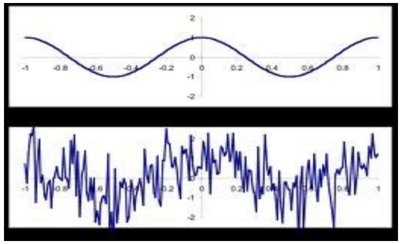
- Reading: Tanenbaum, Chapter 2

Motivation

- Why study the physical layer?
- Need to know basic data transmission concepts
- Understand physical layer to understand media influence on network performance

  - Answer Questions such as:
    - What transmission speed is possible with various media?
    - Where and how are errors introduced?

Physical Layer - Purpose



- Transmit information across a distance
- Source
  - Transmit bits from one point to another
  - Encode bits onto a signal
- Destination
  - Receive signals, interpret or extract bits

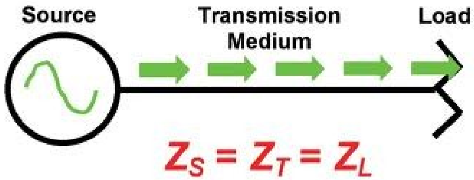
What is a Signal?

1. Mechanism used to carry information over time or distance
2. Sign or gesture giving information
3. Sequence of electrical or optical impulses or waves

Signals

- **Examples**
  - Physical gesture, wave, hand signal
  - Morse code
  - Sound: vary tone, loudness or duration
  - Flags
  - Smoke
  - Electical voltages

Transmission



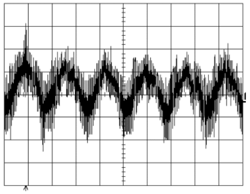
1. Action of conveying electrical or optical signals from 1 point to 1 or more other points in space
2. Process of sending information from 1 point to another

What do you need for a Transmission System ?

- Medium for signal transfer
- Method to transform signal to appropriate form
- Way to transmit the signal
- Way to remove, receive or detect the signal

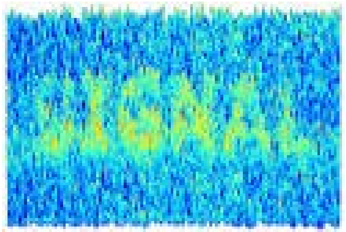
Transmission Not Perfect

- Along the way, signals are subject to less than favorable conditions
- Distance affects the signal
  - Loss of signal strength with distance
  - Recall what that is called?
    - Attenuation



- Noise affects the signal
  - Line noise obscures the signal
  - Can make it impossible to send information

Line Noise



- Defined
- Unwanted electrical or electromagnetic energy that degrades quality of signals and data
  - External noise from appliances in area, from electrical transformers, from atmosphere (wired connections)
- Communications engineers are constantly striving to develop better ways to deal with noise

Bandwidth

- What is bandwidth? More than one definition?

  Network bandwidth defined

  - Bandwidth is same as data transfer rate, amount of data that can be carried from one point to another in a given time period
  - Network bandwidth is usually expressed in bits per second (bps)

  Signal Processing bandwidth defined

  - Bandwidth is range of frequencies carried by a channel.
  - Difference between highest-frequency signal component and the lowest-frequency signal component
  - Bandwidth is measured in hertz (cycles per second)

What is Attenuation?

Attenuation is …

- Reduction of signal strength during transmission
- Attenuation is gradual loss in intensity of **any** kind of flux through a medium

Ex. Reduction in signal strength from length of phone line

Sunlight is attenuated by dark glasses, and

X-rays are attenuated by lea

Attenuation Continued

- Attenuation is measured in **decibels**
  - **Decibel (dB)** is used to measure sound, but also widely used in electronics, signals and communication
  - **Decibel (dB)** measures relative strengths of two signals or a signal at two different points
- The lower the Attenuation the stronger the received signal

Note that decibel is negative if a signal is attenuated and positive if a signal is amplified.

Attenuation can be measured by:

$$dB = 10 \log_{10} (P2 / P1)$$

where P1 and P2 are the powers of a signal at points 1 and 2, respectively.

Examples

What happens if we lose power? $p1 < p2$

$dB = 10 \log (p1/p2)$ $p1=1$ and $p2=10$

$dB = 10 \log (0.10)$

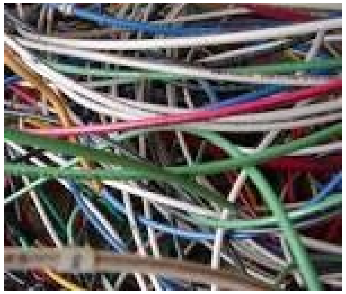
$dB = 10 \times (-1) = -10$ decibels

Negative sign tells us there is a loss of power,
known as attenuation

What if there is a gain of power? $p1 > p2$

$dB = 10 \log (20/10) = 10 \log (2) = 10 \text{ x } .3 = 3.0$ dB

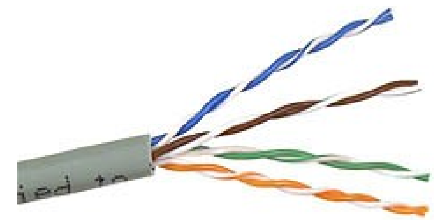
Positive sign means a gain of power,
known as amplification



Transmission Media

Twisted Pair

- Oldest transmission medium
  - Historical use, Phone systems
- Two insulated Copper wires
  - Wires twisted together
  - Straight they would interfere
    - To reduce electromagnetic induction between pairs of wires, two insulated copper wires are twisted around each other
  - Twisted pair cabling – Several varieties
    - Category 5 – Two insulated wires – 4 pairs
    - Encased in a protective plastic sheath
    - Category 7 – Higher quality yet
    - Has added shielding on individual twisted pairs
    - Helps reduce external interference and crosstalk



Twisted Pair Bit Rates

Data rates of 24-gauge twisted pair

Standard	**Data Rate**	**Distance**
T-1	1.544 Mbps	18,000 feet, 5.5 km
DS2	6.312 Mbps	12,000 feet, 3.7 km
1/4 STS-1	12.960 Mbps	4500 feet, 1.4 km
1/2 STS-1	25.920 Mbps	3000 feet, 0.9 km
STS-1	51.840 Mbps	1000 feet, 300 m

STS - Synchronous Transport Signal

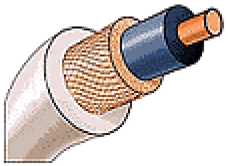
- Twisted pairs can provide high bit rates at short distances
- Asymmetric Digital Subscriber Loop (ADSL)
  - High-speed Internet Access
  - Lower 3 kHz for voice
  - Upper band for data
- Much higher rates possible at shorter distances
  - Strategy for telephone companies is to bring fiber close to home & then twisted pair
  - Higher-speed access + video
- Still widely used in buildings and telephone applications

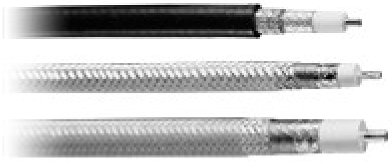
Coaxial Cable

- Better shielding and greater bandwidth than unshielded twisted pairs
- Can handle longer distance at higher speeds
- Coaxial cable is stiff copper wire surrounded by insulation
  - Encased in conductor – woven mesh and finally a plastic sheath
  - Cable has bandwidth up to a few GHz
  - Has been replaced by fiber optics in Telco systems

Coaxial Cable

- Construction of cable allows
- High interference immunity
- Higher bandwidth than twisted pair
- Hundreds of MHz





Who uses this?

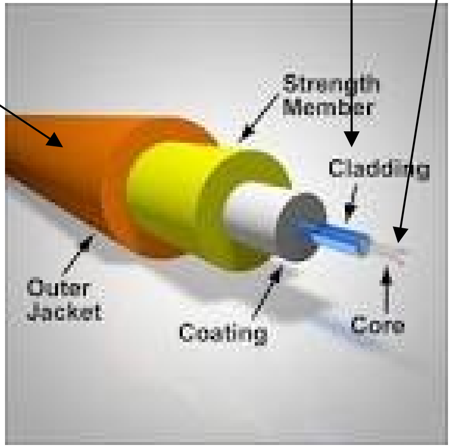
- Cable TV distribution
- Long distance telephone transmission
- Original Ethernet LAN mediumis

Fiber Optics

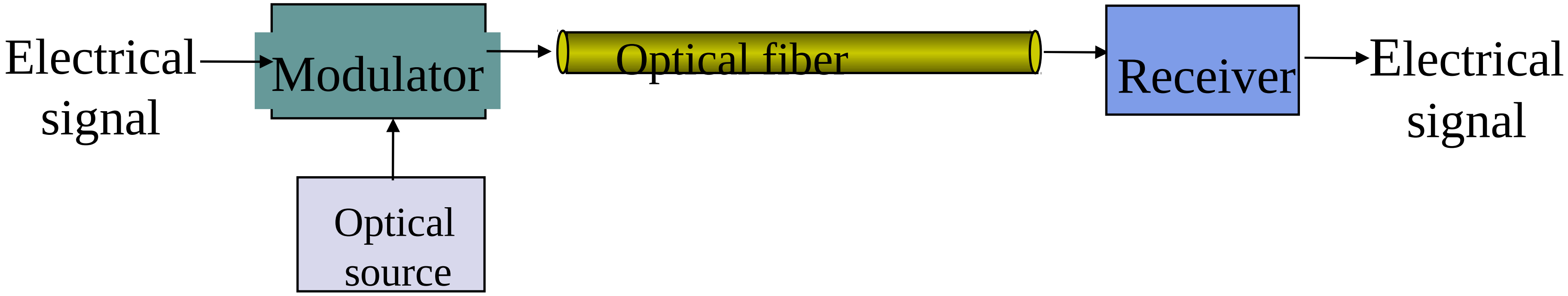
- Fiber consists of a light, transmission medium and detector
- Transmission medium is thin fiber of glass
  - Detector generates a pulse when it detects a light
  - So, attach a light at one end, detector at other end
  - Accepts electrical signals, converts and transmits light pulses and converts back to signals at receiving end

Fiber Optics

- Consists of core of glass, very thin
- Surrounded by glass cladding to keep all light in the core
- Surrounded by plastic jacket



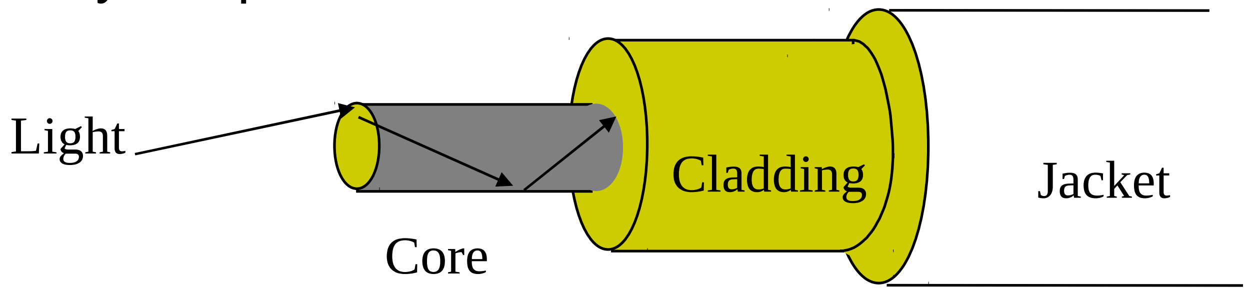
Optical Fiber



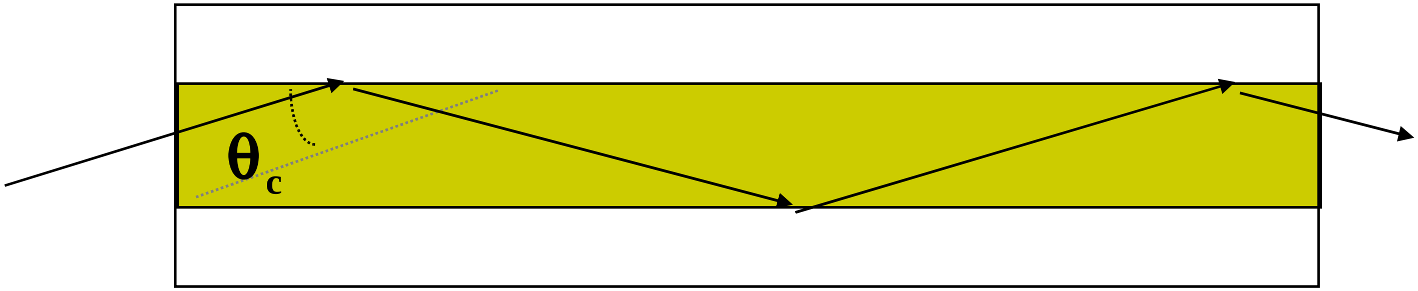
- Light sources (lasers, LEDs) generate pulses of light that are transmitted on optical fiber
  - Very long distances (>1000 km)
  - Very high speeds   (> 40 Gbps/wavelength)
  - Nearly error-free
- Huge influence on network architecture
  - Dominates long distance transmission
  - Distance less of a cost factor in communications
  - Plentiful bandwidth for new services

Transmission in Optical Fiber

Geometry of optical fiber



Total Internal Reflection in optical fiber



- Very fine glass cylindrical core surrounded by concentric layer of glass (cladding)
- Core has higher index of refraction than cladding
- Light rays incident at less than critical angle θ_c is completely reflected back into the core

Optical Fiber Properties

Advantages

- Very low attenuation
- Noise immunity
- Extremely high bandwidth
- Security: Very difficult to tap without breaking
- No corrosion
- More compact & lighter than copper wire

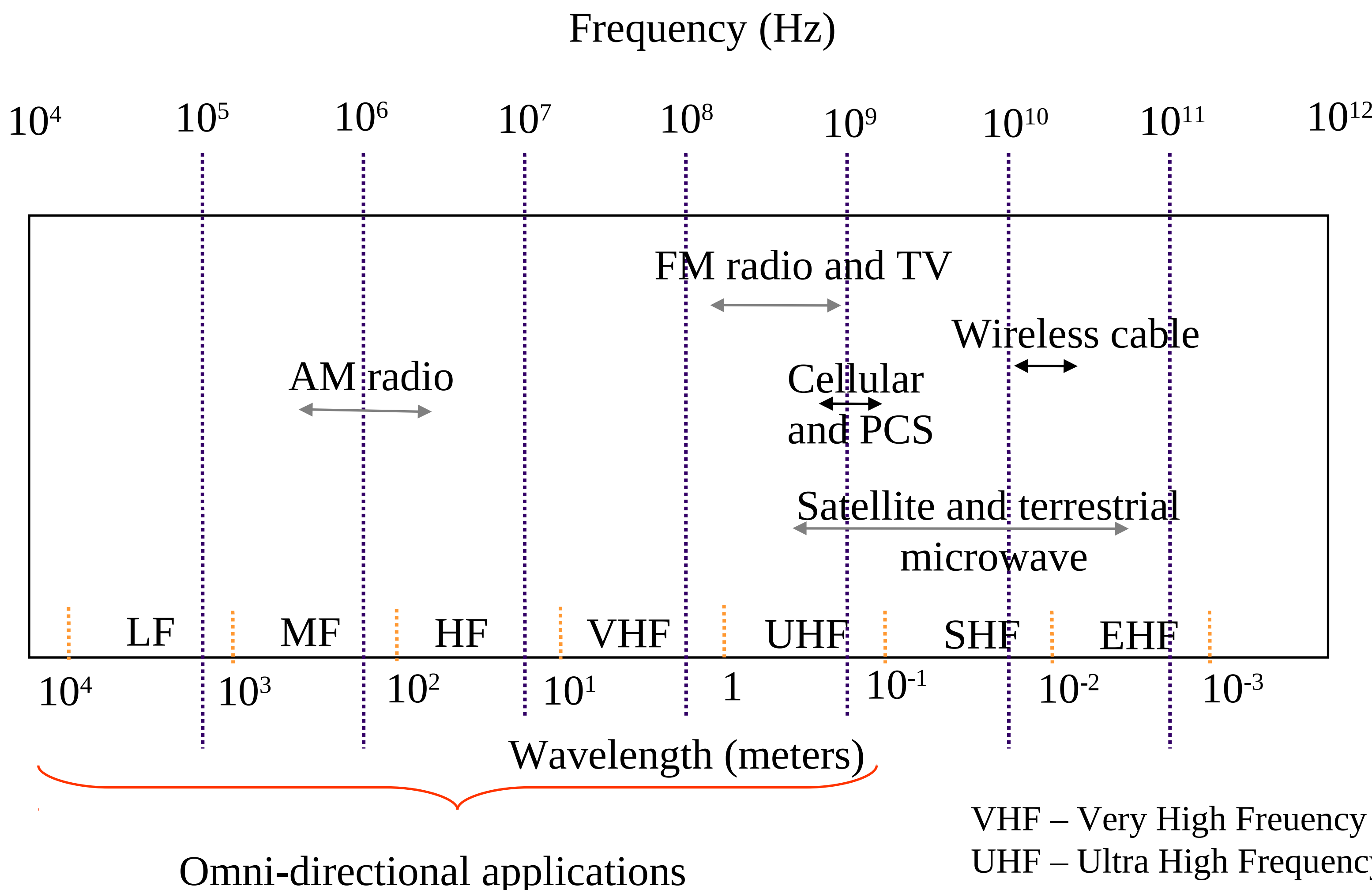
Disadvantages

- New types of optical signal impairments & dispersion
- Difficult to splice
- Mechanical vibration becomes signal noise

Radios

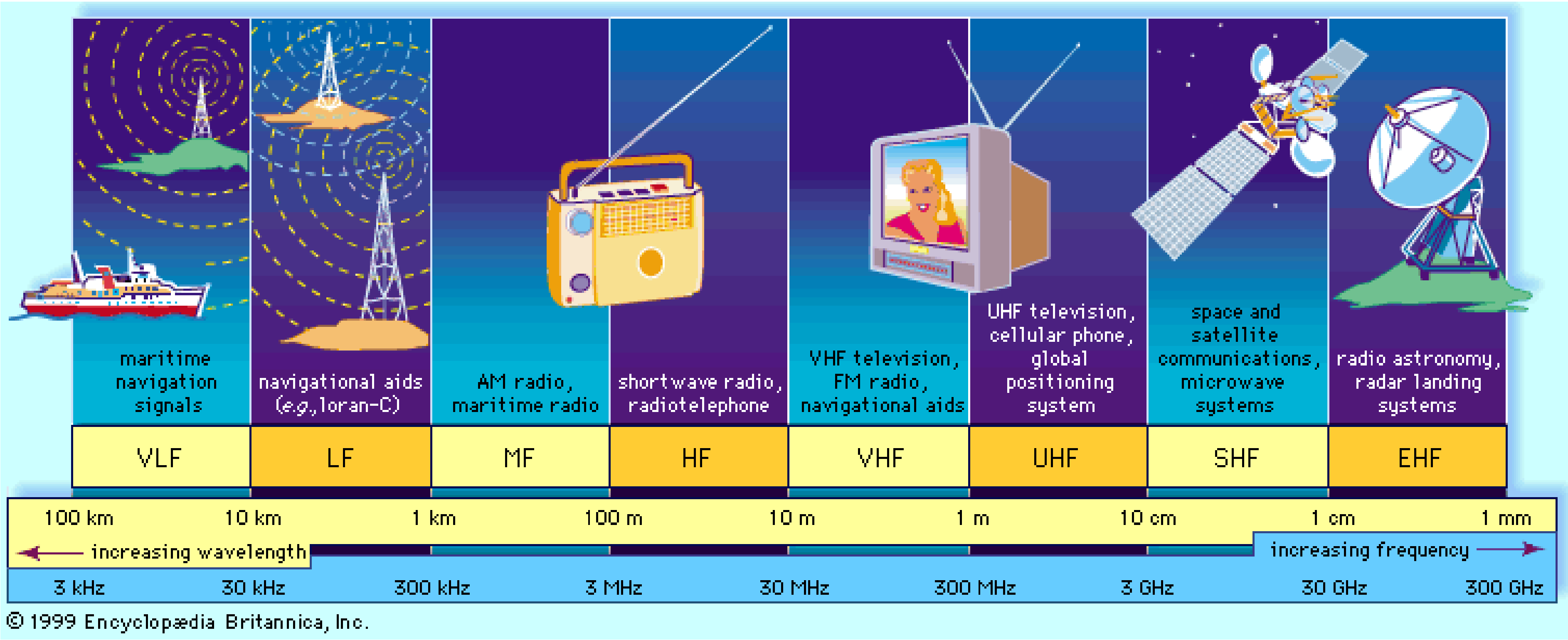
- Radios work by Frequency
  - Frequencies are easy to generate
  - Can travel long distances
  - Penetrate buildings
  - Widely used for communications, waves are omnidirectional
  - Low frequencies pass through obstacles well, but power falls off sharply with distance from source

Radio Spectrum

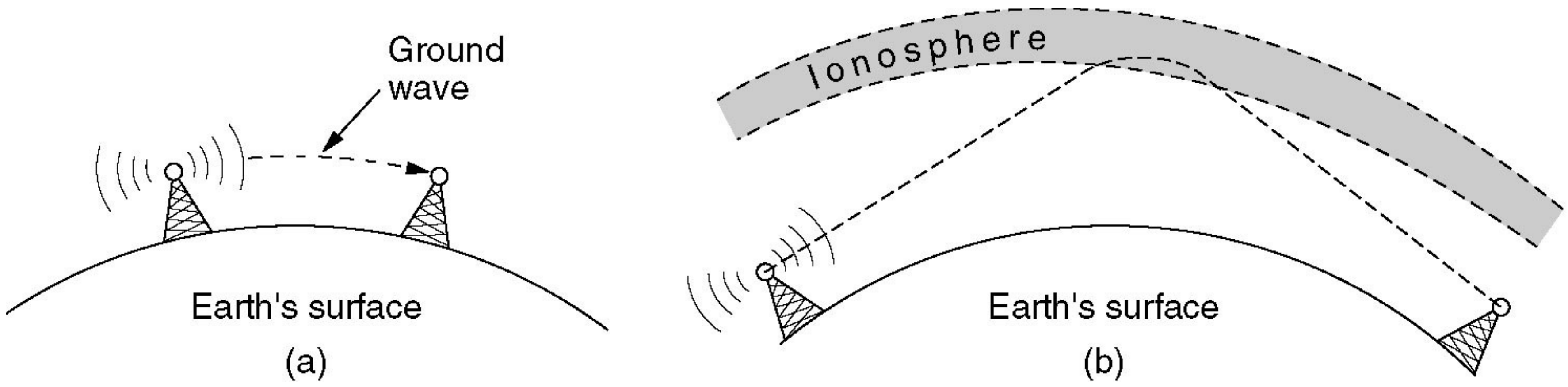


VHF – Very High Freuency
UHF – Ultra High Frequency
SHF – Super High Frequency
EHF – Extremely High Frequency

More Complete Spectrum



Radio Transmission



(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.

(b) In the HF band, they bounce off the ionosphere.

Radio Spectrum Examples

Cellular Phone

- Allocated spectrum
- **1st generation:**
  - 800, 900 MHz
  - Initially analog voice
- **2nd generation:**
  - 1800-1900 MHz
  - Digital voice, messaging

Wireless LAN

- Unlicenced ISM spectrum
  - Industrial, Scientific, Medical
  - 902-928 MHz, 2.400-2.4835 GHz, 5.725-5.850 GHz
- IEEE 802.11 LAN standard
  - 11-54 Mbps

Point-to-Multipoint Systems

- Directional antennas at microwave frequencies
- High-speed digital communications between sites
- High-speed Internet Access Radio backbone links for rural areas

Satellite Communications

- Geostationary satellite @ 36000 km above equator
- Relays microwave signals from uplink frequency to downlink frequency
- Long distance telephone
- Satellite TV broadcast

Compare Wireless to Wired Media

Wireless Media

- Signal energy propagates in space
- Interference possible, so spectrum regulated
- Limited bandwidth
- Simple infrastructure: antennas & transmitters
- No physical connection between network & user
- Users can move

Wired Media

- Signal energy contained & guided within medium
- Spectrum can be directed separate media (wires or cables), more scalable
- Extremely high bandwidth
- Complex infrastructure:
  Physical ducts, conduits, poles, right-of-way
- Users at not mobile

Microwave Transmission

- Above 100 MHz, waves travel in nearly straight lines
  - Uses transmitting and receiving antennas
  - Before fiber optics, for decades microwaves formed heart of long-distance telephone transmission system
  - MCI – Built system with microwave communications – stands for Microwave Communication Incorporated

Infrared Transmission

- Unguided infrared waves
  - Used for short range communication
  - Remote controls for TV, VCR and Stereos
  - Cheap, easy to build but has a major drawback
  - What is it?
    - Can't pass through solid walls
    - Advantage – No interference in other rooms
      - Don't need a government license

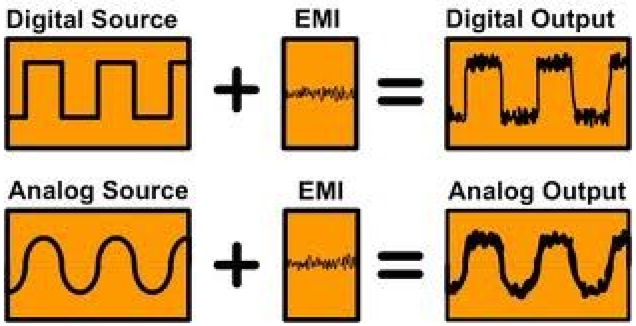
Politics

- National and International agreements
  - FCC regulates spectrum for United States
  - AM/FM radio, TV and mobile phones
  - They regulate some frequencies of the spectrum
  - Unregulated frequencies
    - ISM – Industrial, Scientific and Medical unlicensed bands
    - Garage door openers, cordless phones, radio controlled toys and wireless mice
    - FCC mandates all devices limit power in this unlicensed band

Politics

- In the US,
  - 900 Hz was used for early versions of 802.11
    - It was crowded
    - Baby monitors, garage door openers, cordless phones

  - So, **802.11** moved to different frequency bands
  - 2.4 GHz band is available in most countries for 802.11 b/g/n and Bluetooth
  - 5 GHz is partly used for 802.11a/n



Digital vs Analog

Analog and Digital

Both data and signals that represent them can take either analog or digital form.

Digital signal has discrete values, not continuous

Example of Digital data or signal

Example of Digital data or signal?

0's and 1's stored in computer as a number

Analog and Digital

Both data and signals that represent them can take either analog or digital form.

Analog has continuous values, not discrete

Example of Analog Signal

What might be an example of an Analog signal?

Human voice.

Analog wave is created in the air

Analog vs. Digital Signals

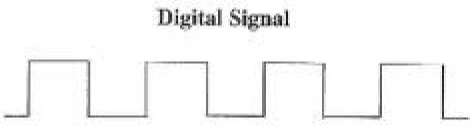
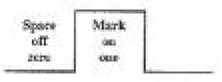


Figure 3.8

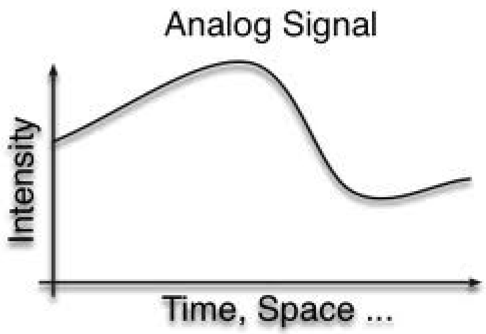
Digital Signal

1. Limited to finite number of values
2. Has meaning only at discrete points in time



Examples: Text, bits, integers

Analog vs. Digital Signals

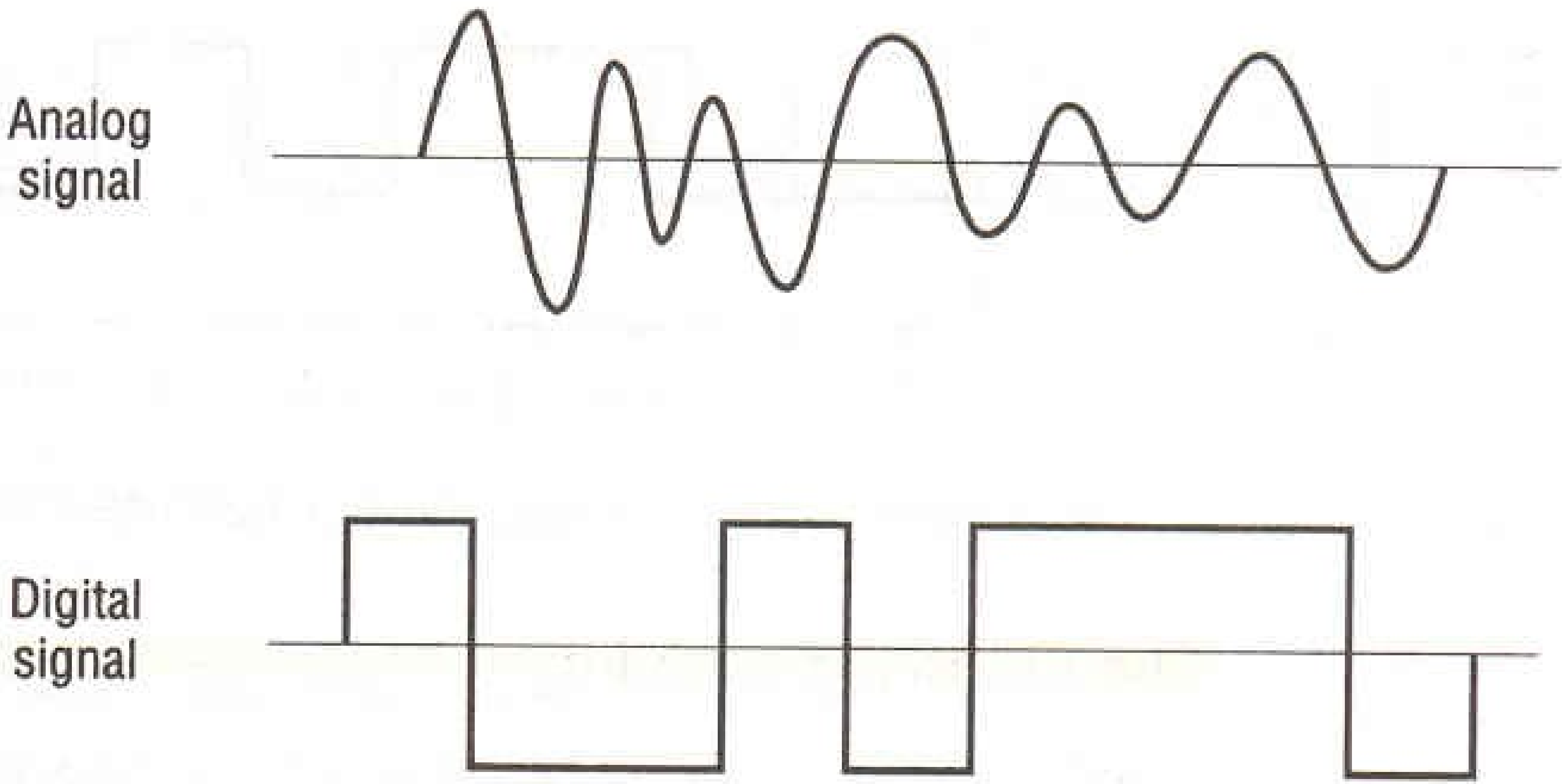


Analog Signal

1. Signal that is an analog of the quantity being represented
2. Continuous range of values
3. Also continuous in time, always valued

Examples: Sound, vision, music, original TV signal

Analog vs. Digital



Analog Signals

- An analog signal is continuous has infinite number of values in a range
- Primary shortcoming of analog signals is difficulty to separate noise from original waveform
- An example is a sine wave which can be specified by three characteristics:

$$\omega(t) = A \sin(2 \pi f t + p)$$

A: amplitude or height

f : frequency

p : phase

Sine Waves Characteristics

Amplitude, height (intensity) of wave

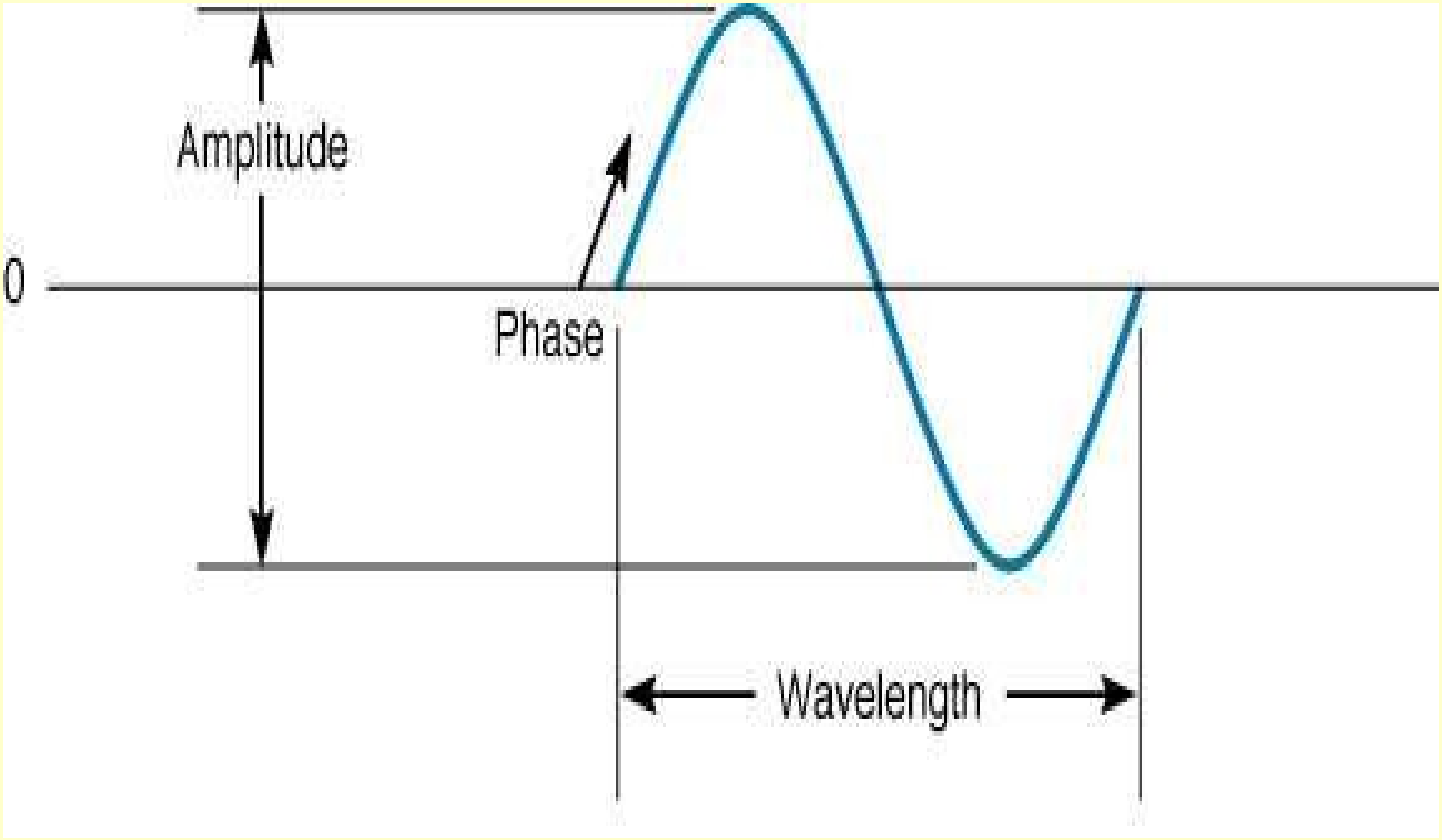
Frequency, number of waves that pass in a single second and is measured in Hertz (cycles/second) (**wavelength**, the length of the wave from crest to crest, is related to frequency)

Phase is a third characteristic

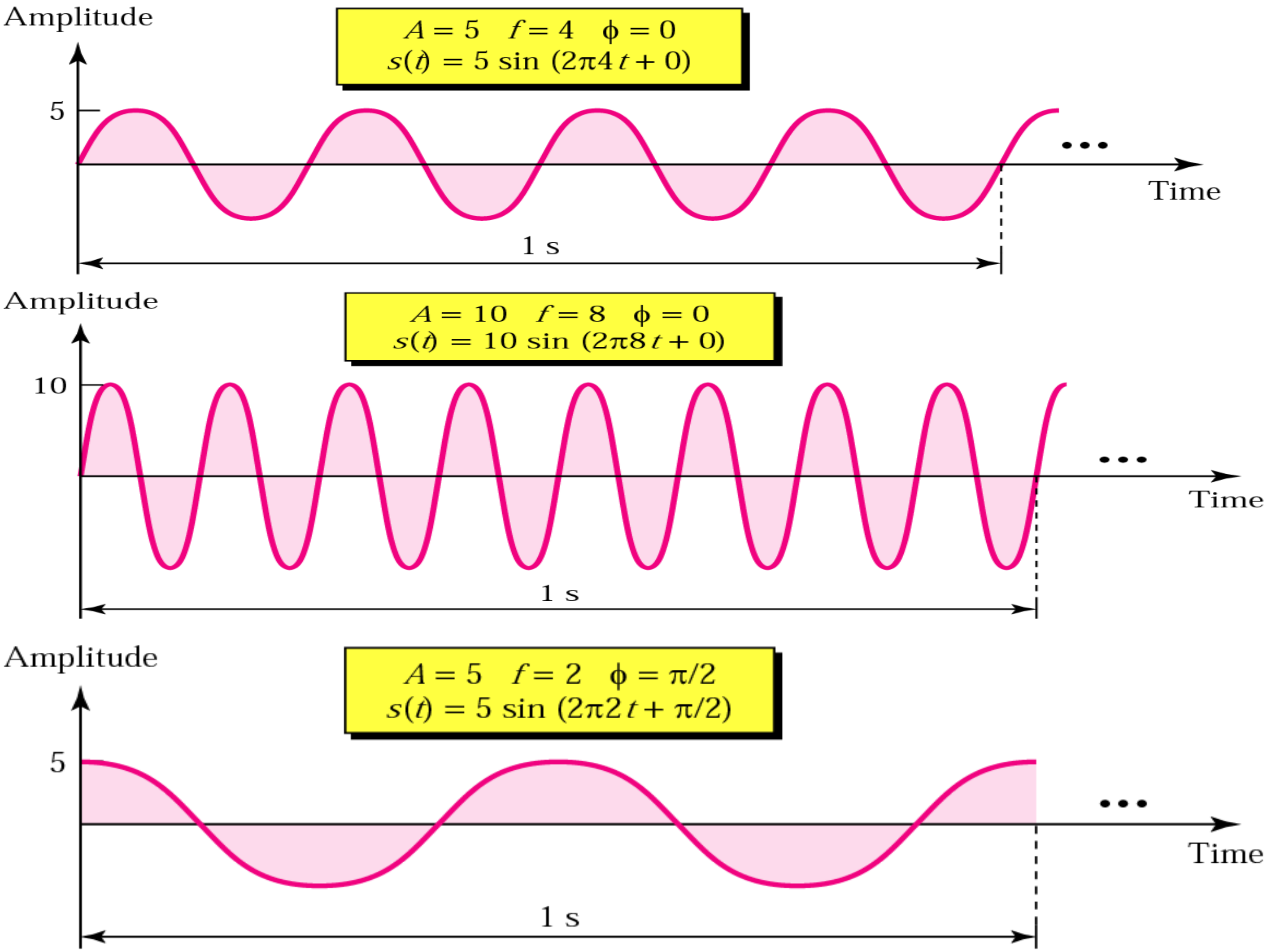
Describes point in wave's cycle at which a wave begins and is measured in degrees

How is the wavelength related to frequency?

A Carrier Wave

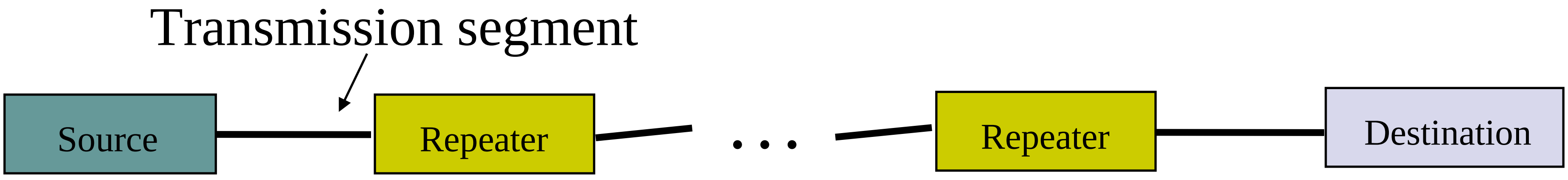


Sine Wave



Amplitude
$A = 5 \quad f = 4 \quad \phi = 0$
$s(t) = 5 \sin (2\pi 4 t + 0)$
5
Time
1 s
Amplitude
$A = 10 \quad f = 8 \quad \phi = 0$
$s(t) = 10 \sin (2\pi 8 t + 0)$
10
Time
1 s
Amplitude
$A = 5 \quad f = 2 \quad \phi = \pi/2$
$s(t) = 5 \sin (2\pi 2 t + \pi/2)$
5
Time
1 s

Analog Long-Distance Communications



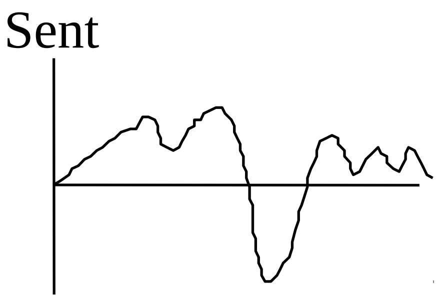
- Used repeaters to boost signal - attempts to restore analog signal to its original form
- Restoration is imperfect
  - Distortion not completely eliminated
  - Noise & interference only partially removed
- Signal quality decreases with increased repeaters
- Communications is distance-limited
- Still used in analog cable TV systems
- Analogy: Copy a song using a cassette recorder

Digital Long-Distance Communications

- Regenerator recovers original data sequence and retransmits on next segment
- Can design so error probability is very small
- Each regeneration is like the first time!
- Analogy: Copy an MP3 file
- Communications possible over very long distances
- Other Advantages of Digital systems vs. analog systems
  - Less power, longer distances, lower system cost

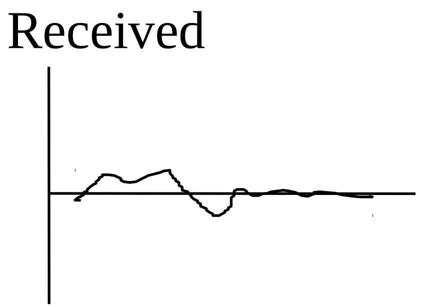
Analog vs. Digital Transmission

Analog transmission: all details must be reproduced accurately

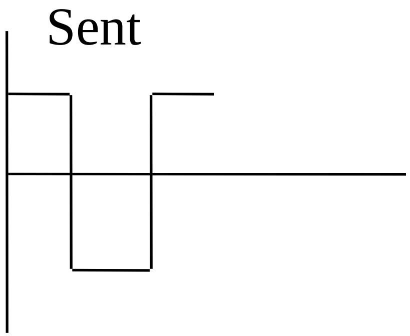


Distortion

Attenuation

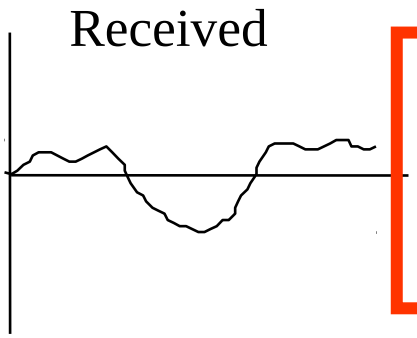


Digital transmission: only discrete levels need to be reproduced



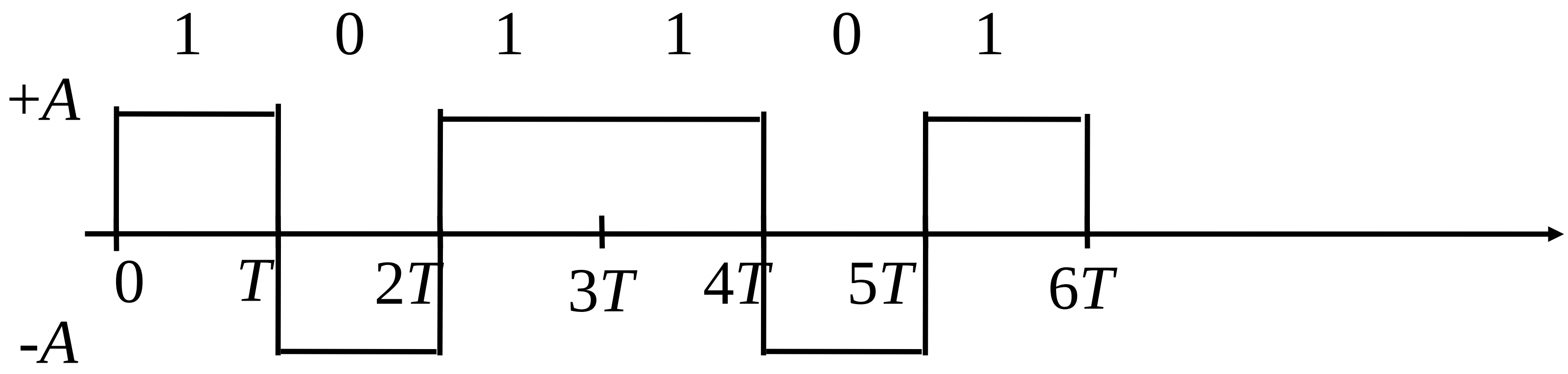
Distortion

Attenuation



Receiver: Was original pulse positive or negative?

Digital Binary Signal

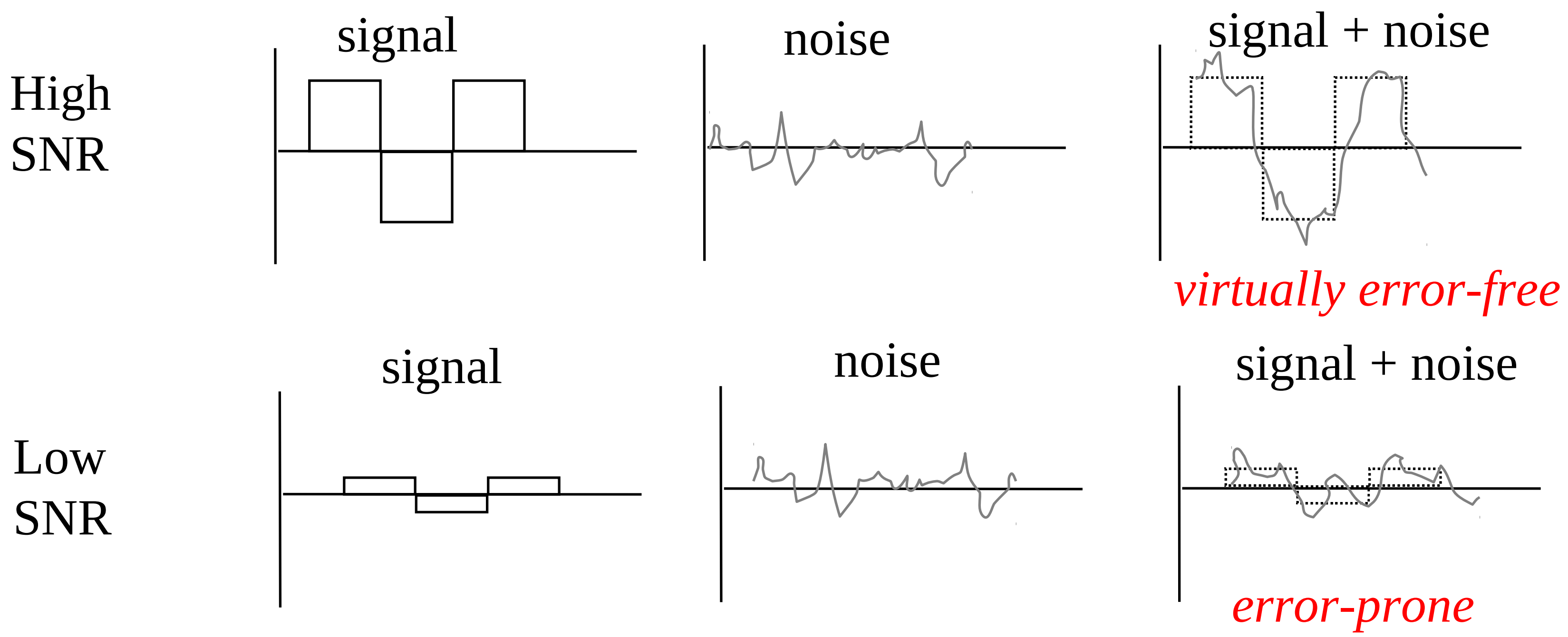


$$Bit\ rate = 1\ \ bit\ /\ second$$

For a given communications medium

- How do we increase transmission speed?
- How do we achieve reliable communications?
- Are there limits to speed and reliability?

Channel Noise affects Reliability

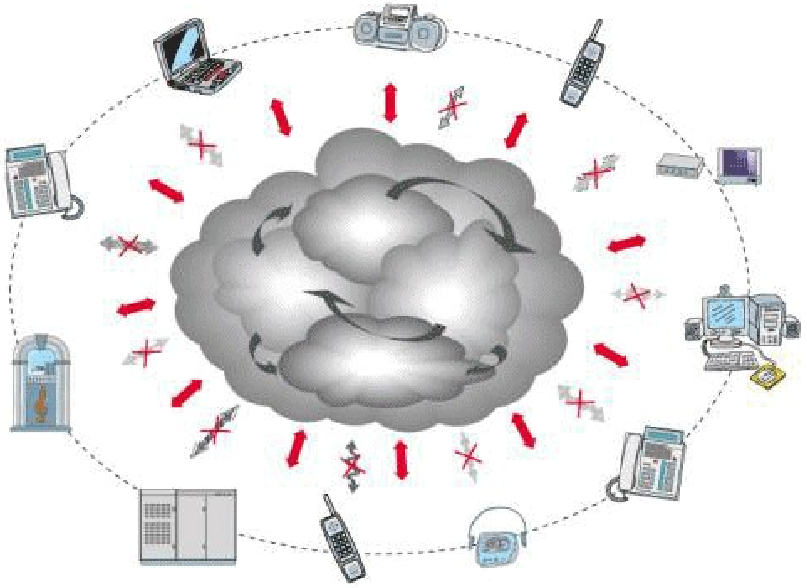


SNR (dB) = 10 $\log_{10}$ (Ave Signal Power/ Ave Noise Power)

SNR – Signal to Noise Ratio, measures signal strength with addition of noise

Summary

- Looked physical medium and began to look at analog vs digital
- Continue this ….



Read Chapter 2 - Textbook

- Also, review basic Wireshark Lab
  - I will put it on the Lab page

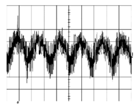
No Class Monday – Holiday.

There will be a lab on Tuesday related to Wireshark.

Transmission Not Perfect

- Along the way, signals are subject to less than favorable conditions
- Distance affects the signal
    - Loss of signal strength with distance
    - Recall what that is called?
        - Attenuation

- Noise affects the signal
    - Line noise obscures the signal
    - Can make it impossible to send information



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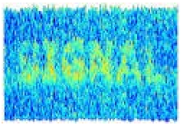

- Defined
- Unwanted electrical or electromagnetic energy that degrades quality of signals and data
  - External noise from appliances in area, from electrical transformers, from atmosphere (wired connections)
- Communications engineers are constantly striving to develop better ways to deal with noise

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- What is bandwidth? More than one definition?

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Ex. Reduction in signal strength from length of phone line

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X-rays are attenuated by lea 

Attenuation Continued

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  - **Decibel (dB)** is used to measure sound, but
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Note that decibel is negative if a signal is attenuated and positive if a signal is amplified.

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Examples

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dB = 10 log (0.10)
dB = 10 × (–1) = –10 decibels
Negative sign tells us there is a loss of power,
known as attenuation

What if there is a gain of power? $p1 > p2$
dB = 10 log (20/10) = 10 log (2) = 10 x .3 = 3.0 dB
Positive sign means a gain of power,
known as amplification

Transmission Media

Twisted Pair

- Oldest transmission medium
  - Historical use, Phone systems
- Two insulated Copper wires
  - Wires twisted together
  - Straight they would interfere
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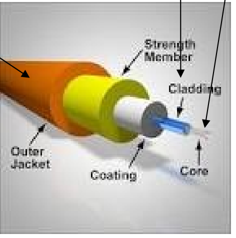
- Transmission medium is thin fiber of glass
  - Detector generates a pulse when it detects a light
  - So, attach a light at one end, detector at other end
  - Accepts electrical signals, converts and transmits light pulses and converts back to signals at receiving end

Fiber Optics

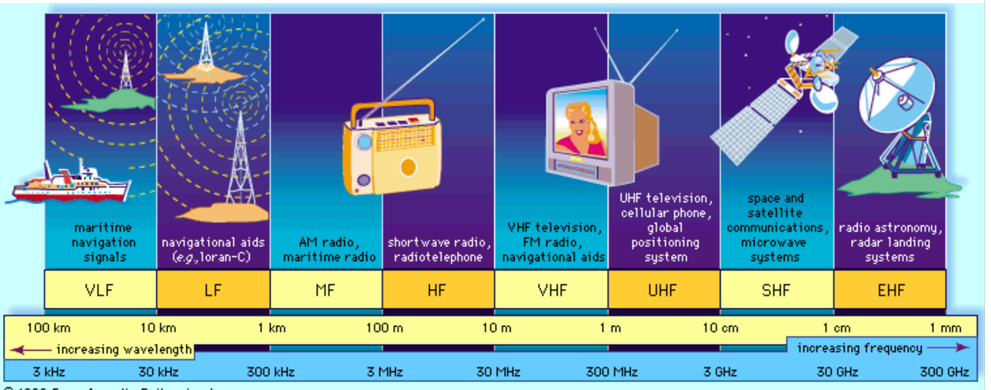
- Consists of core of glass, very thin
- Surrounded by glass cladding to keep all light in the core
- Surrounded by plastic jacket



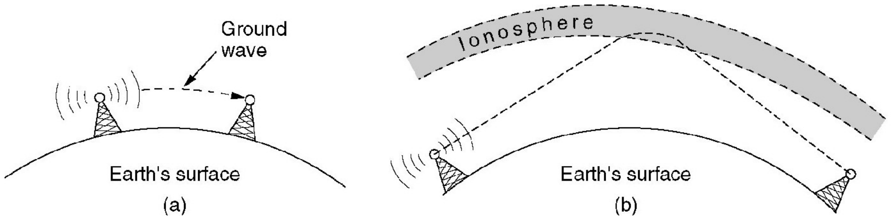
Radios

- Radios work by Frequency
  - Frequencies are easy to generate
  - Can travel long distances
  - Penetrate buildings
  - Widely used for communications, waves are omnidirectional
  - Low frequencies pass through obstacles well, but power falls off sharply with distance from source

More Complete Spectrum



Radio Transmission



(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.

(b) In the HF band, they bounce off the ionosphere.

Microwave Transmission

- Above 100 MHz, waves travel in nearly straight lines
  - Uses transmitting and receiving antennas
  - Before fiber optics, for decades microwaves formed heart of long-distance telephone transmission system
  - MCI – Built system with microwave communications – stands for Microwave Communication Incorporated

Infrared Transmission

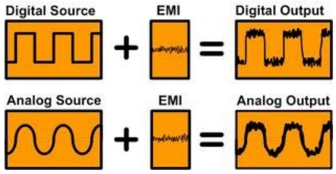
- Unguided infrared waves
  - Used for short range communication
  - Remote controls for TV, VCR and Stereos
  - Cheap, easy to build but has a major drawback
  - What is it?
    - Can't pass through solid walls
    - Advantage – No interference in other rooms
      - Don't need a government license

Politics

- National and International agreements
  - FCC regulates spectrum for United States
  - AM/FM radio, TV and mobile phones
  - They regulate some frequencies of the spectrum
  - Unregulated frequencies
    - ISM – Industrial, Scientific and Medical unlicensed bands
    - Garage door openers, cordless phones, radio controlled toys and wireless mice
    - FCC mandates all devices limit power in this unlicensed band

Politics

- In the US,
  - 900 Hz was used for early versions of 802.11
    - It was crowded
    - Baby monitors, garage door openers, cordless phones
  - So, **802.11** moved to different frequency bands
  - 2.4 GHz band is available in most countries for 802.11 b/g/n and Bluetooth
  - 5 GHz is partly used for 802.11a/n



Digital vs Analog

Analog and Digital

Both data and signals that represent them can take either analog or digital form.

Digital signal has discrete values, not continuous

Example of Digital data or signal

Example of Digital data or signal?

0's and 1's stored in computer as a number

Analog and Digital

Both data and signals that represent them can take either analog or digital form.

Analog has continuous values, not discrete

Example of Analog Signal

What might be an example of an Analog signal?

Human voice.

Analog wave is created in the air

Sine Waves Characteristics

Amplitude, height (intensity) of wave

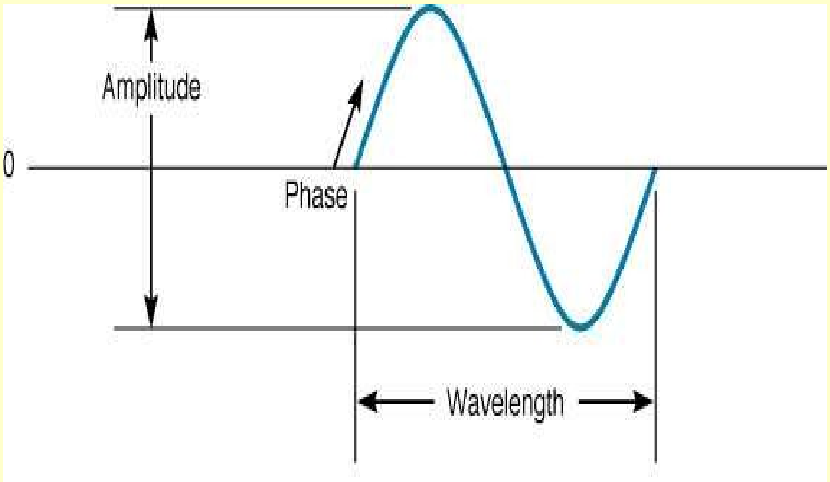
Frequency, number of waves that pass in a single second and is measured in Hertz (cycles/second) (**wavelength**, the length of the wave from crest to crest, is related to frequency)

Phase is a third characteristic

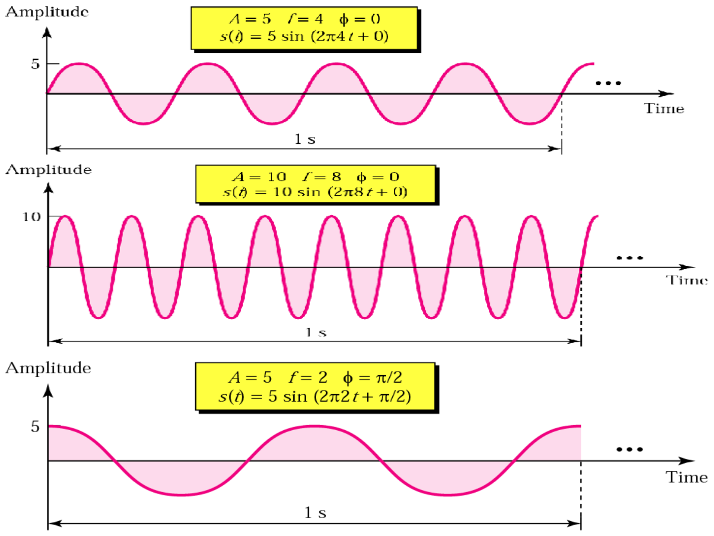
Describes point in wave's cycle at which a wave begins and is measured in degrees

How is the wavelength related to frequency?

A Carrier Wave



Sine Wave



Amplitude
A = 5 f = 4 ϕ = 0
s(t) = 5 sin (2π4t + 0)
5
Time
1 s
Amplitude
A = 10 f = 8 ϕ = 0
s(t) = 10 sin (2π8t + 0)
10
Time
1 s
Amplitude
A = 5 f = 2 ϕ = π/2
s(t) = 5 sin (2π2t + π/2)
5
Time
1 s

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