Lecture #3

Data Transmission & Media

Agenda

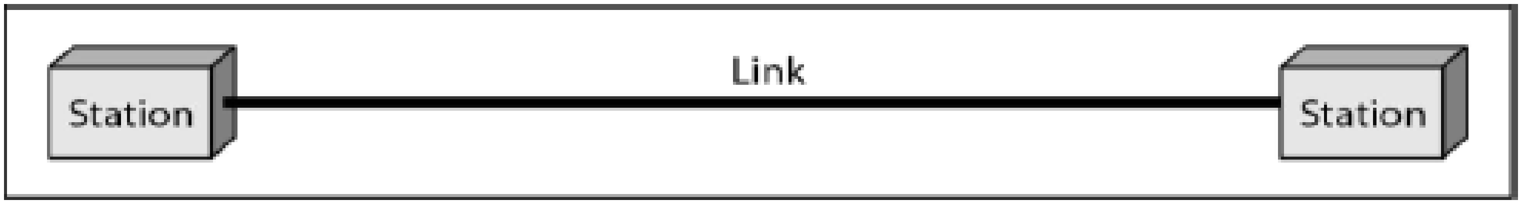
- Transmission Terminology
- Signals & Analog vs. Digital
- Frequency Domain Concepts
- Transmission Impairments
- Guided Transmission Media (Twisted pairs, coaxial,..)
- Wireless Transmission

Data Transmission

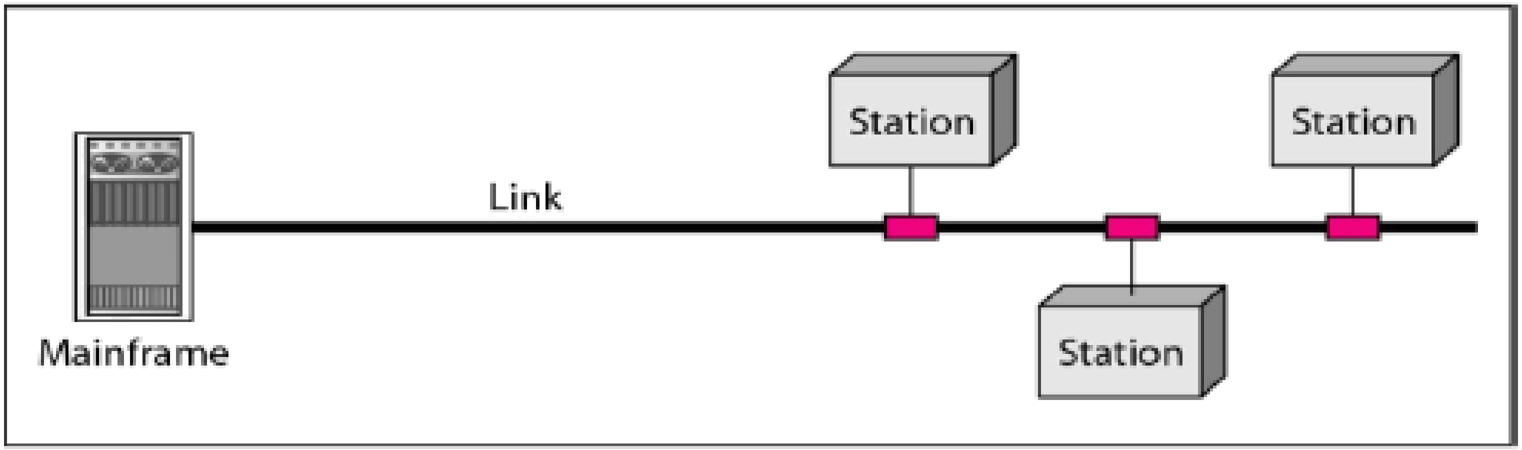
- The **successful** transmission of data depends on **two factors**:
  - The quality of the signal being transmitted
  - The characteristics of the transmission medium
- Data transmission occurs between a **transmitter** and a **receiver** over some transmission **medium**.
  - Guided media – physical path
    - twisted pair, coaxial cable, optical fiber
  - Unguided (wireless) media
    - Air, water , vacuum

Transmission Terminology

- Direct link
  - Transmission path from transmitter to receiver with **no intermediate devices**
    (other than amplifiers)
- Point to point
  - Direct link between the **only two devices** sharing the medium (Note: can apply to unguided media)
- Multipoint
  - **More than two devices** share the same medium



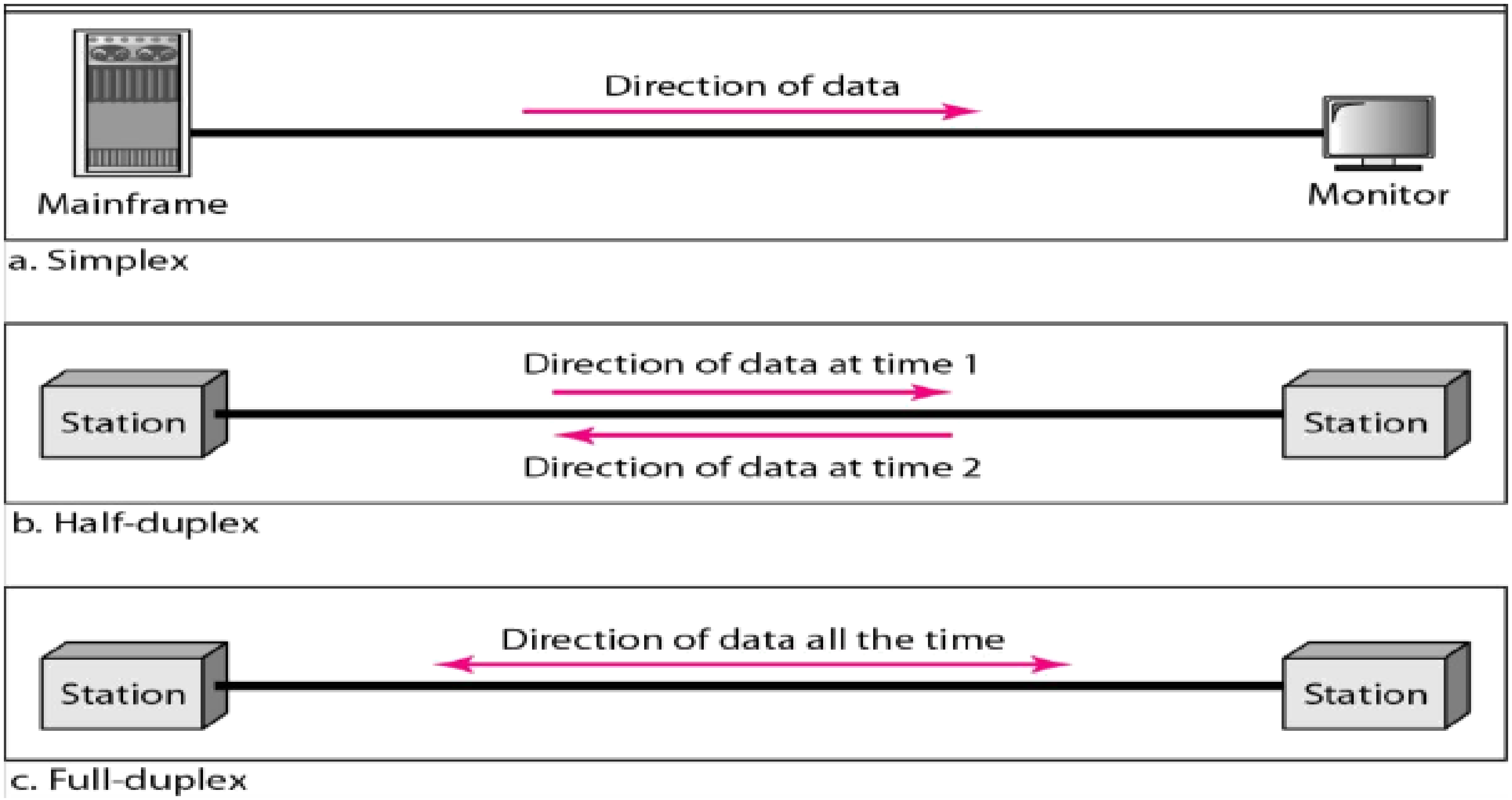
a. Point-to-point



b. Multipoint

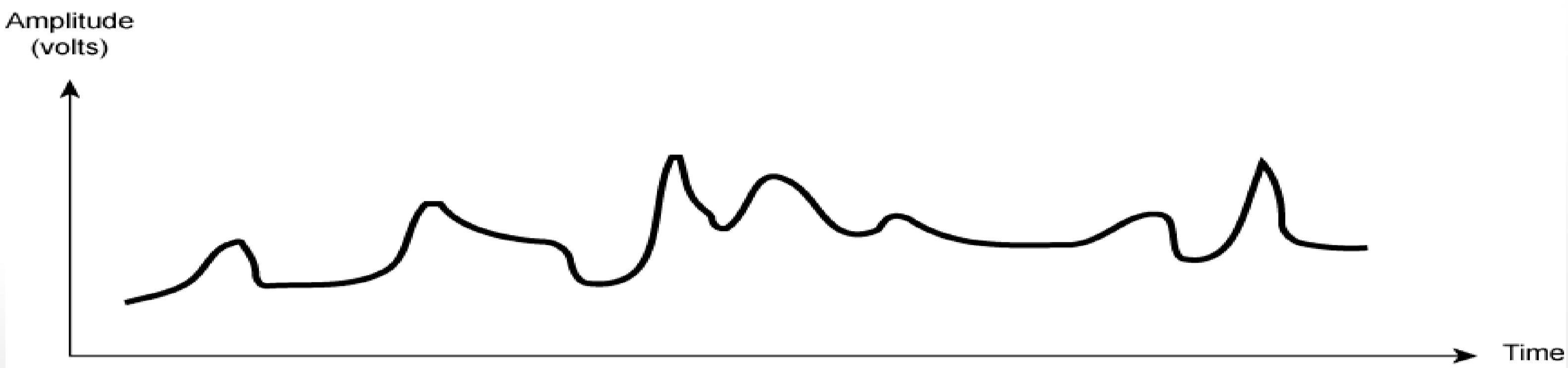
Transmission Terminology

- Simplex
  - Signal transmitted in **one direction**
    - e.g. cable television
- Half-duplex
  - Both stations may transmit, but **one at a time**
    - e.g. police radio
- Full-duplex
  - Both stations may transmit **simultaneously**
    - e.g. telephone

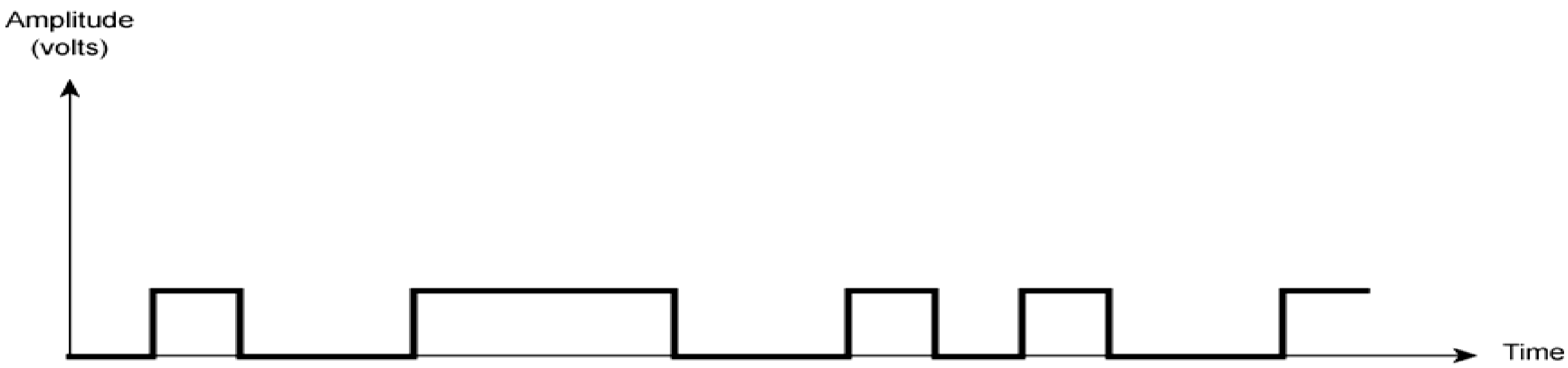


Analog vs. Digital

- Analog signal
  - Signal intensity varies in a smooth, **continuous**, fashion over time
    – no breaks
- Digital signal
  - Signal intensity maintains constant **level** for some period of time and then abruptly changes to another constant level – **discrete** signals



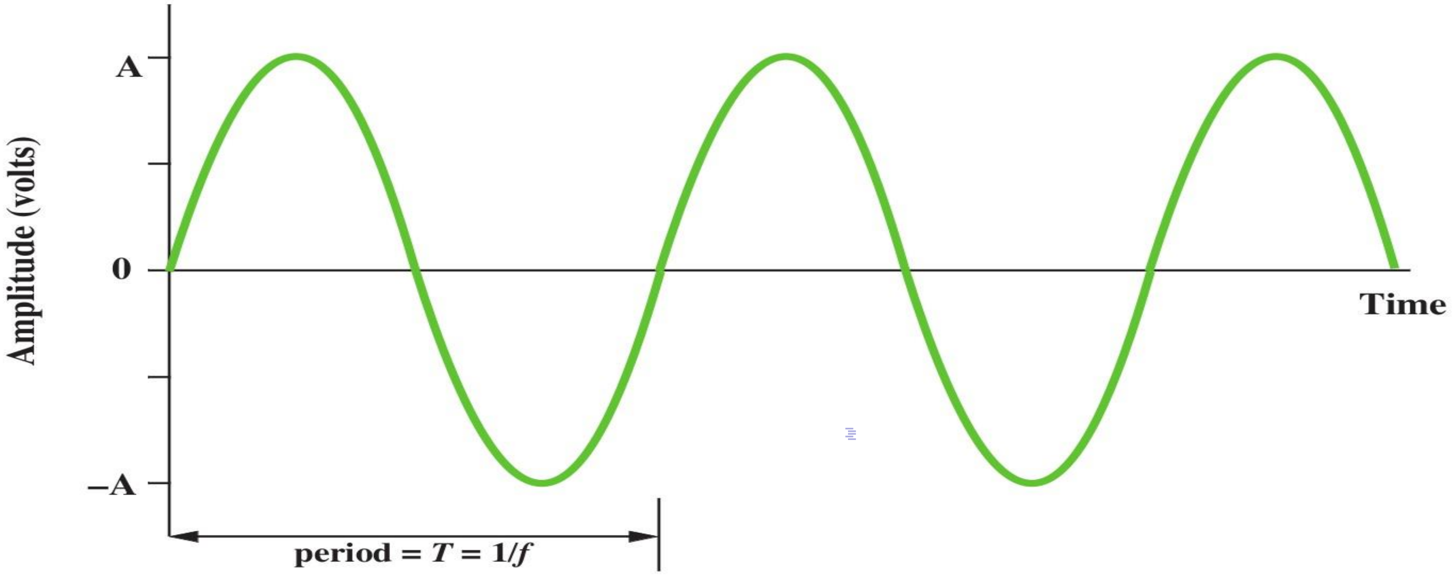
(a) Analog



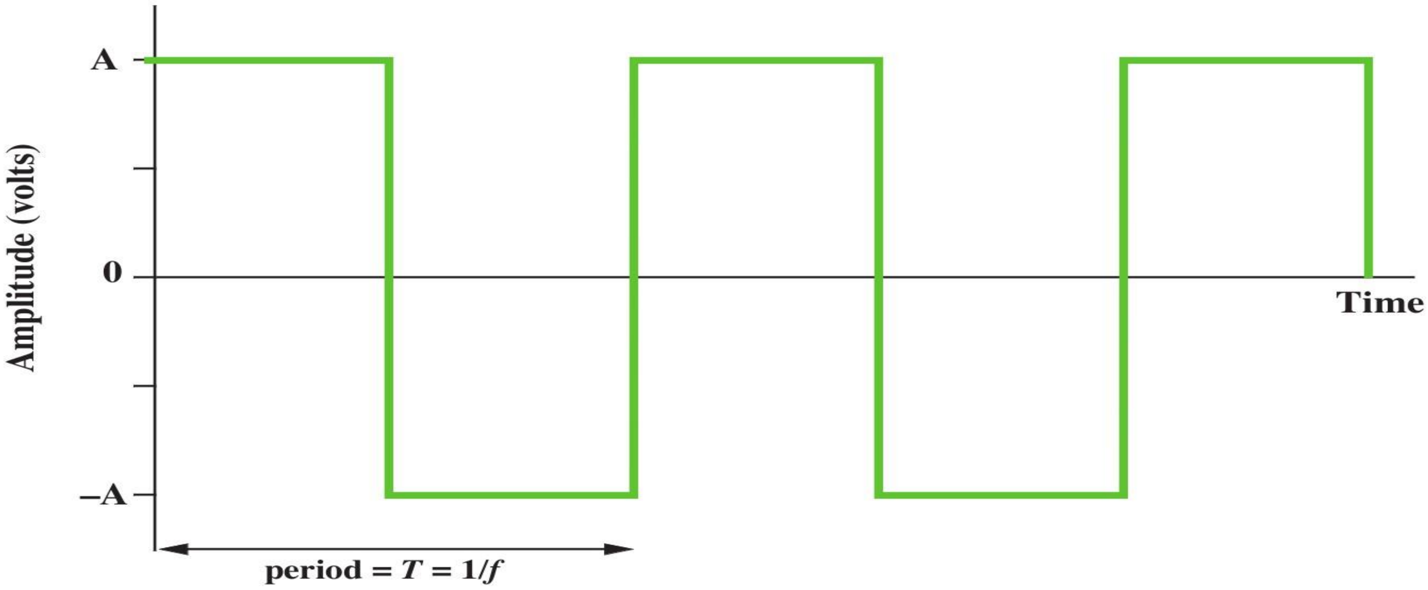
(b) Digital

Examples of Periodic Signals

Any signal is either periodic (the following two) or aperiodic



(a) Sine wave



(b) Square wave

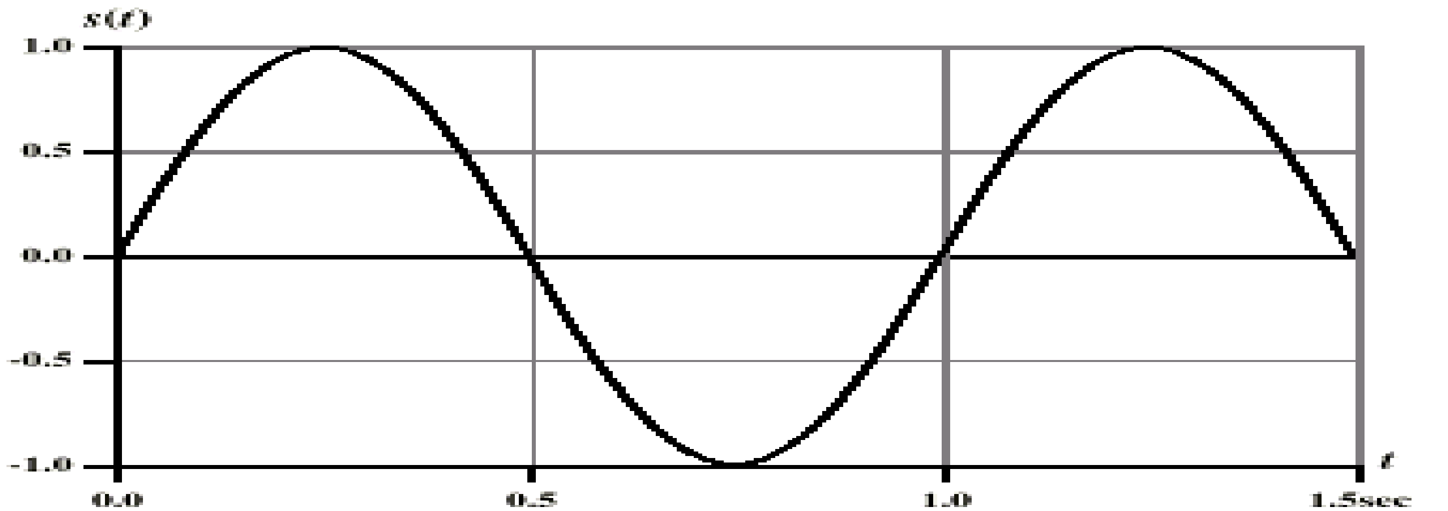
Sine Wave

(periodic continuous signal)

- Peak amplitude (A)
  - **Maximum strength** of signal
  - Typically measured in volts
- Frequency (f)
  - **Rate** at which signal **repeats**
  - Hertz (Hz) or cycles per second

$$T = 1 / f$$

  - Period (T) is time to repeat
- Phase (ϕ)
  - Relative **position in time** within a single period



(a) $A = 1, f = 1, \phi = 0$

Wavelength (λ)

- **Distance** occupied by a **single cycle**

  or

  Distance between **two points** of **corresponding phase** of two consecutive cycles
- Signal with velocity v, then wavelength is

  $\lambda = vT$ or $\lambda f = v$

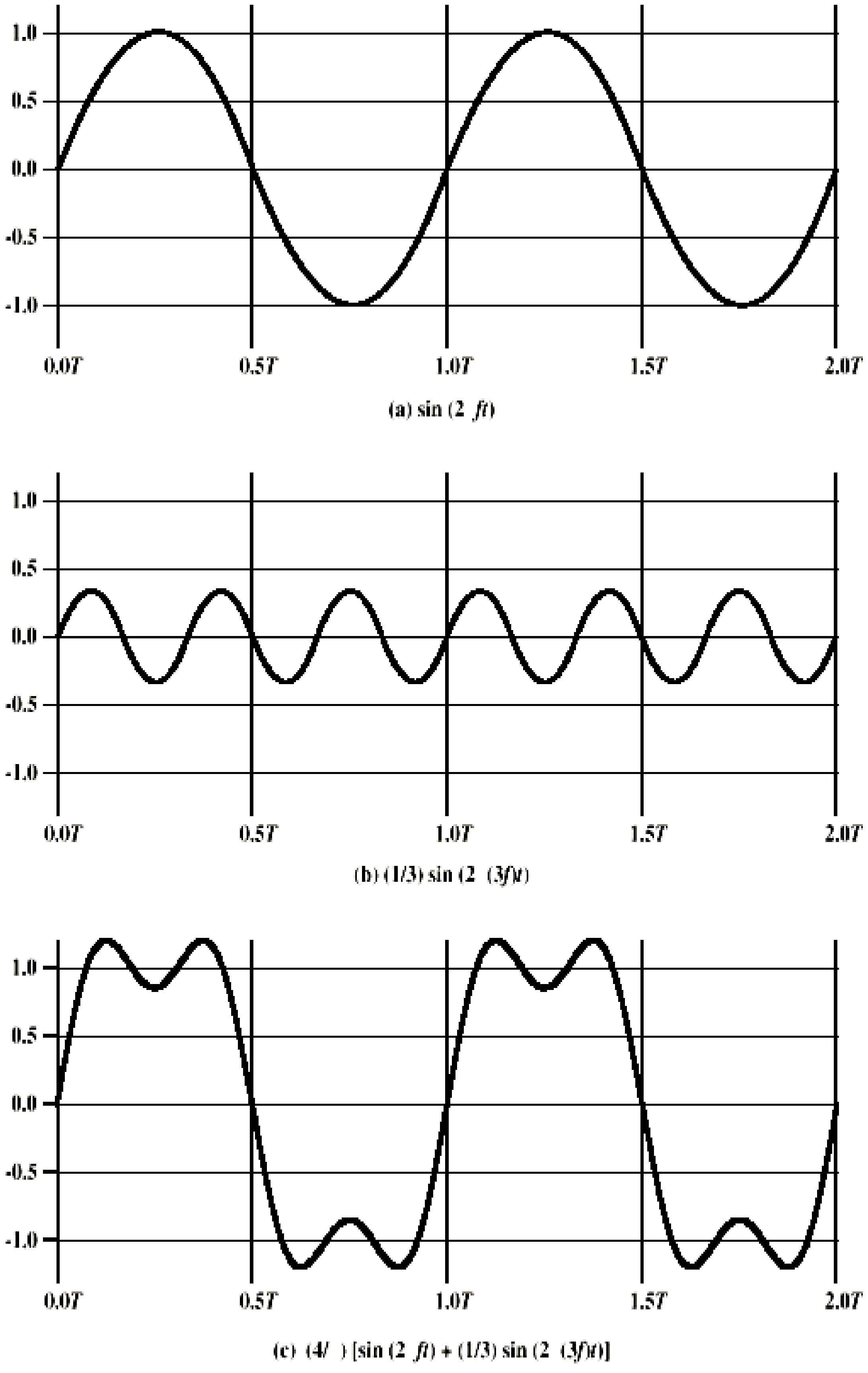
- Consider signal travelling at speed of light

  $v = c = 3 \times 10^8$ m/s

Frequency Domain Concepts

- Signals are made up of **many frequencies**
- Components are sine waves
- **Fourier analysis** can show any signal is made up of components at various frequencies
- Each component is a sinusoid
- Can plot frequency domain functions

Addition of Frequency Components (T = 1/f)



Spectrum & Bandwidth

- Spectrum
  - **Range of frequencies contained in a signal**
  - e.g. f and $3f$ on previous slide
- Absolute bandwidth
  - **Width of the spectrum**
  - e.g. $2f$
- Effective bandwidth (or just "bandwidth")
  - Narrow band of frequencies **containing most of the energy** in the signal

Data Rate and Bandwidth

- Any **transmission system** can carry only a **limited band of frequencies**
  - Limits the data rate that can be carried
- Square waves have infinite components
  - Infinite bandwidth
- Most energy in first few components
- Limiting bandwidth creates **distortions**

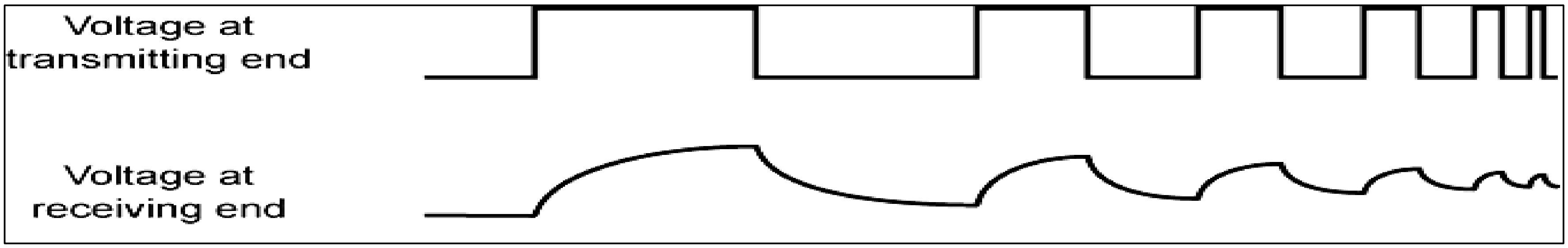
Data, Signals, and Transmission

- Data
  - Entities that convey **information**
- Signals
  - Electric or electromagnetic **representations of data**
- Signaling
  - Physical **propagation** of signal along medium
- Transmission
  - Communication of data by **propagation** and **processing** of signals

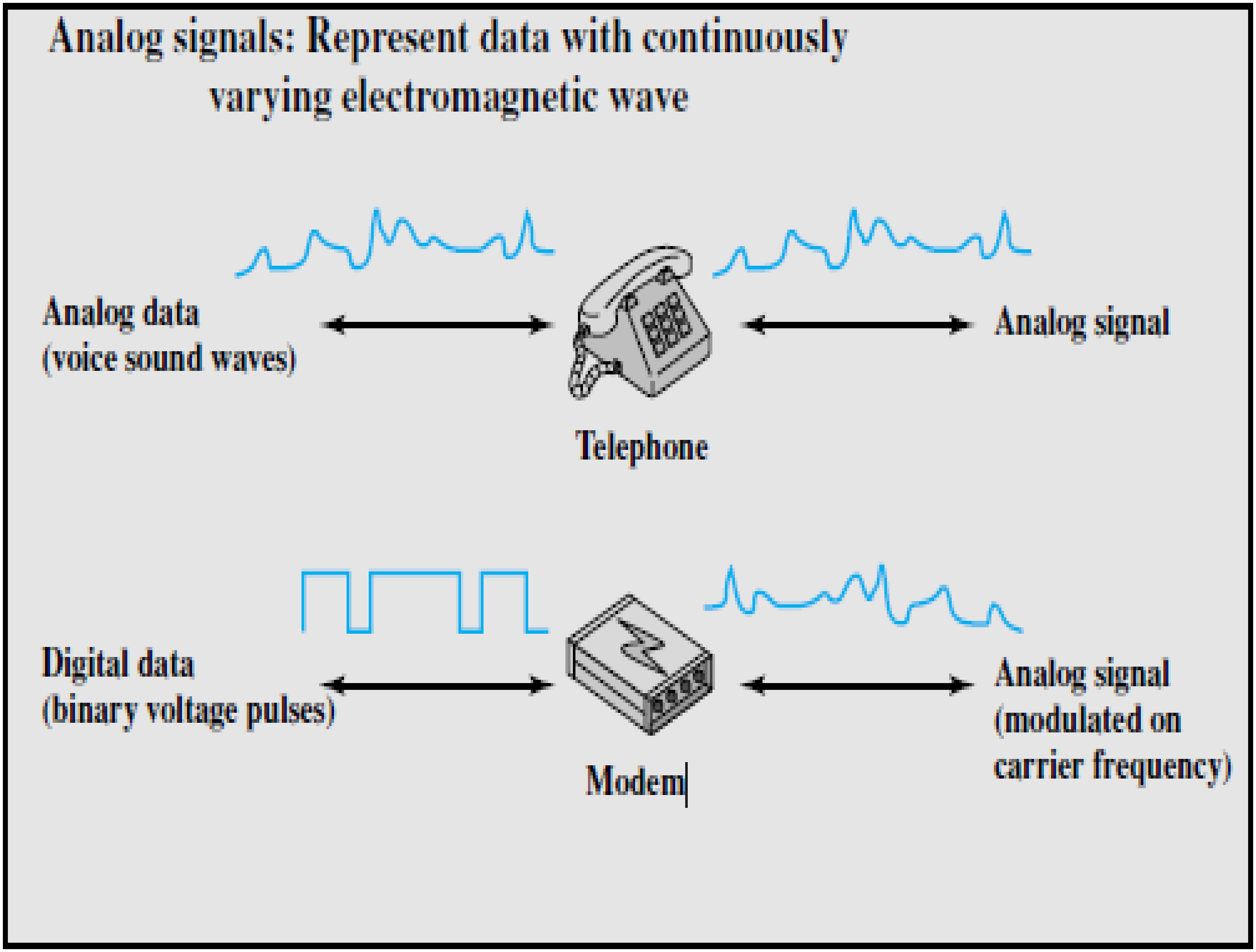
Digital Data & Signals

- Text (character strings)
  - Coded into sequence of bits
    - IRA – International Reference Alphabet (ASCII)
  - 7-bit code with parity bit
- Image
  - Coded into pixels with number of bits per pixel
  - May then be compressed

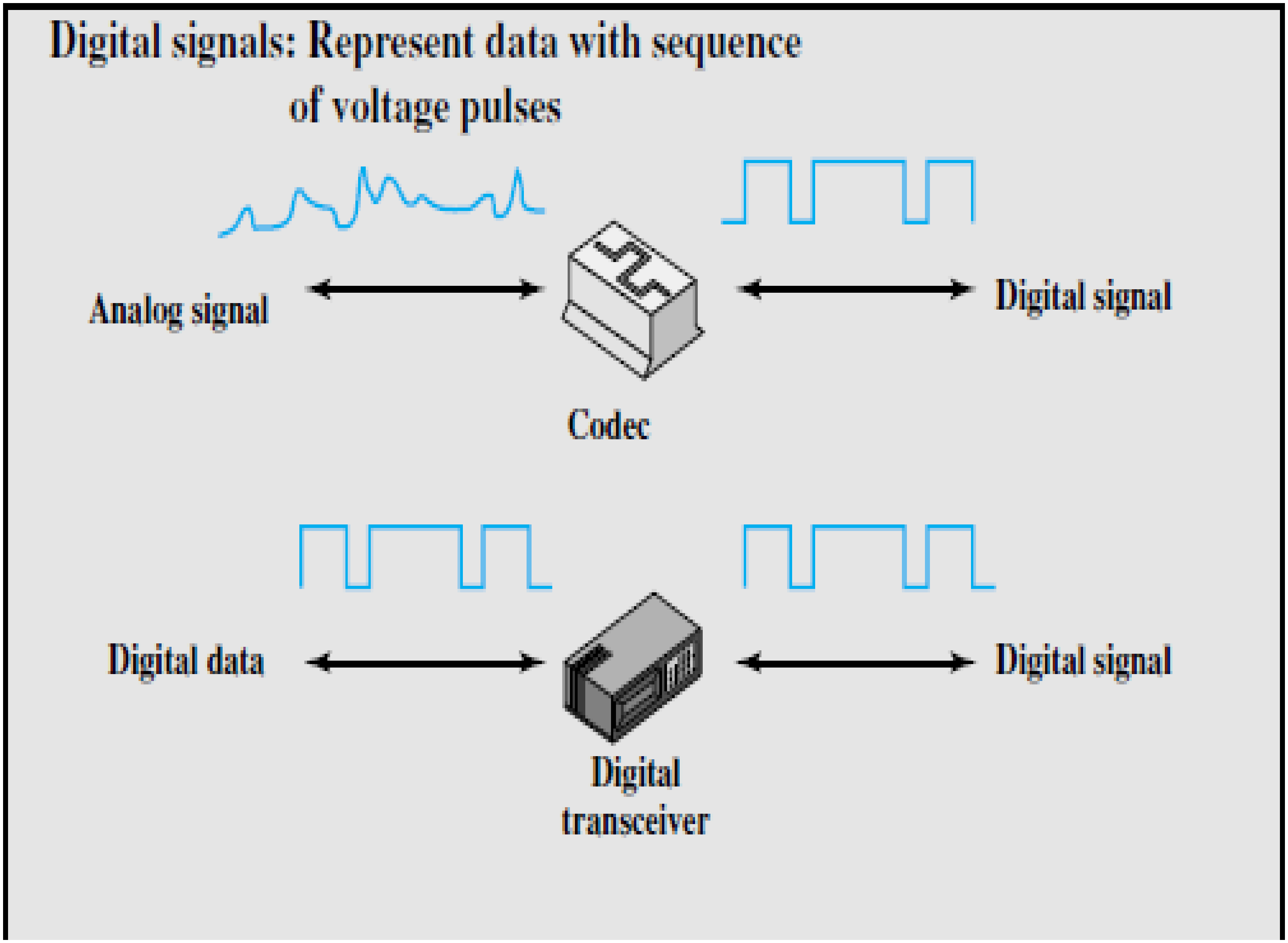
- Advantages
  - Cheaper
  - Less susceptible to noise interference
- Disadvantages
  - Suffer more from attenuation (strength loss)



Analog Signaling



Digital Signaling



Transmission Impairments

- signal received may differ from signal transmitted causing:
  - analog - **degradation of signal quality**
  - digital - **bit errors**
- most significant **impairments** are
  - attenuation
  - delay distortion
  - noise

Attenuation

- Signal **strength falls off** with distance over any communications medium
- Varies with frequency – higher has more
- Received signal strength must be:
  - **strong enough** to be detected
  - sufficiently **higher than noise** to be received without error
- Strength increased with **repeaters** or **amplifiers**
- Adjust for attenuation by amplifying more at higher frequencies

Delay Distortion

- occurs because **propagation velocity** of a signal through a guided medium varies with frequency
- various frequency **components arrive at different times** resulting in phase shifts between the frequencies
- particularly critical for digital data since parts of one bit spill over into others causing **intersymbol interference**

Noise

- **Unwanted signals** that are inserted somewhere between transmission and reception
- **Major limiting factor** in communications system performance

Categories of Noise

- Thermal Noise
  - **Thermal agitation of electrons**
  - Uniformly distributed across bandwidths
  - Referred to as "**white noise**"
- Intermodulation Noise
  - Produce **unwanted signals at a frequency that is the sum or difference of two original frequencies**
- e.g. signals at 4 KHz and 8 KHz may add noise at 12 KHz and interfere with a 12 KHz signal

Categories of Noise..

- Crosstalk
  - **a signal from one line is picked up by another**
  - can occur by electrical coupling between nearby twisted pairs or when microwave antennas pick up unwanted signals
- Impulse Noise
  - caused by **external electromagnetic interferences**
  - non-continuous, consisting of irregular pulses or spikes
  - short duration and high amplitude
  - **minor** annoyance for **analog** signals but a **major** source of error in
    digital data
    - For **example**, a sharp spike of energy of 0.01 s duration would not destroy any voice data but would wash out about 560 bits of digital data being transmitted at 56 kbps

Channel Capacity

- **Maximum rate** at which data can be transmitted over a given communications channel under given conditions
- Four concepts
  - Data rate - bits per second (bps))
  - Bandwidth - cycles per second – Hertz (Hz)
  - Noise – average noise level over path
  - Error rate – rate of corrupted bits
- **Limitations** are due to **physical properties**
- Main constraint on achieving efficiency is **noise**

Nyquist Bandwidth

In the case of a channel that **is noise free**:

- if rate of signal transmission is *2B* then can carry signal with frequencies no greater than *B*
  - **given bandwidth B, highest signal rate is 2B**
- for binary signals, *2B* bps needs bandwidth *B* Hz
- can increase rate by using *L* signal levels
- Nyquist Formula is: $\boldsymbol{C = 2B \log_2 L}$
- data rate can be increased by increasing signals
  - however this increases burden on receiver
  - noise & other impairments limit the value of *L*

1. A noiseless channel has a bandwidth of 4000 Hz and is transmitting a signal with two signal Levels. Calculate the maximum bit rate.

$$\text{Bit Rate} = 2 * \text{Bandwidth} * \log_2 L$$

$$\text{Bit Rate} = 2 * 4000 * \log_2 2$$

$$= 2 * 4000 * 1$$

$$= 8000 \text{ bps}$$

2. A noiseless channel has a bandwidth of 4000 Hz and is transmitting a signal with four signal Levels. Calculate the maximum bit rate.

$$\text{Bit Rate} = 2 * \text{Bandwidth} * \log_2 L$$

$$\text{Bit Rate} = 2 * 4000 * \log_2 4$$

$$= 2 * 4000 * 2$$

$$= 16{,}000 \text{ bps}$$

3. Consider a noiseless channel with a bandwidth of 20 KHz. We need to send 280 kbps over a channel. How many signal levels are required?

Bit Rate = 2 * Bandwidth * $\log_2 L$

$280 = 2 * 20 * \log_2 L$

$280/40 = \log_2 L$

$7 = \log_2 L$

$\log_2 L = 7$

$L = 2^7$

$L = 128$

Shannon Capacity Formula

- considering the **relation of data rate, <u>noise</u> and error rate**:
  - faster data rate shortens each bit so bursts of noise corrupts more bits
  - given noise level, higher rates mean higher errors
- Shannon developed formula relating these to signal to noise ratio (in decibels)
- $SNR_{db} = 10 \log_{10}(\text{signal/noise})$
- capacity $\boldsymbol{C = B \log_2(1+SNR)}$
  - **theoretical** maximum capacity
  - get much lower rates in practice

Shannon Capacity : Noisy Channel

$$\textbf{Capacity} = \textbf{Bandwidth} * \log_2(1+\textbf{SNR})$$

$$\text{SNR} = \frac{\text{Average Signal Power}}{\text{Average noise Power}}$$

$$\text{SNR}_{\text{dB}} = 10 \log_{10} \text{SNR}$$

1. Consider a extremely noisy channel in which signal to noise ratio is almost zero. Calculate the capacity of the channel.

$$\text{Capacity} = \text{Bandwidth} * \log_2(1+\text{SNR})$$

$$\text{SNR} = \frac{\text{Average Signal Power}}{\text{Average noise Power}}$$

$$\begin{aligned}\text{Capacity} &= B * \log_2(1+\text{SNR})\\ &= B * \log_2(1+0)\\ &= B * \log_2(1)\\ &= B*0\end{aligned}$$

2. Calculate the highest bit rate(capacity of a channel) if the bandwidth is 3000Hz and signal to noise ratio(SNR) is 3162.

Capacity =Bandwidth * $\log_2(1+SNR)$

$$
\begin{aligned}
\text{Capacity} &= B * \log_2(1+SNR) \\
&= 3000 * \log_2(1+3162) \\
&= 3000 * \log_2(3163) \\
&= 3000 * 11.627 \\
&= 34881 \text{ bps}
\end{aligned}
$$

3. Assume that $SNR_{dB} = 36$ and bandwidth of channel is 2MHz. Calculate channel capacity.

$$SNR_{dB} = 10 \log_{10} SNR$$

$$Capacity = Bandwidth * \log_2(1+SNR)$$

$SNR_{dB} = 10 \log_{10} SNR$

$SNR_{dB}/10 = \log_{10} SNR$

$\log_{10} SNR = SNR_{dB}/10$

$SNR = 10^{SNR_{dB}/10}$

$SNR = 10^{36/10}$

$SNR = 10^{3.6}$

$SNR = 3981$

$\log_a x = y$

$x = a^y$

$\log_{10} SNR = SNR_{dB}/10$

$SNR = 10^{SNR_{dB}/10}$

$$\begin{aligned} Capacity &= B * \log_2(1+SNR) \\ &= 2 * \log_2(1+3981) \\ &= 2 * \log_2(3982) \\ &= 2 * 11.959 \\ &= 23.91 \\ &= 24 \text{ Mbps approx.} \\ &= 24 * 10^6 \text{ bps} \end{aligned}$$

Transmission Media

- **Physical path** between transmitter and receiver
- conducted or **guided** media
  - use a conductor such as a wire or a fiber optic cable to move the signal from sender to receiver
- wireless or **unguided** media
  - use radio waves of different frequencies and do not need a wire or cable to transmit signals

Guided Transmission Media

- the transmission **capacity depends** on the **distance** and on whether the **medium** is point-to-point or multipoint
- e.g.
  - twisted pair wires
  - coaxial cables
  - optical fiber

Twisted Pair Wires

- consists **of two insulated copper wires** arranged in a regular spiral pattern to minimize the electromagnetic interference between adjacent pairs (**crosstalk**)
- often used at customer facilities and also over distances to carry voice as well as data communications
- **low frequency** transmission medium

Two varieties

- STP (shielded twisted pair)
  - the pair is wrapped with **metallic foil** or braid to insulate the pair from electromagnetic interference
- UTP (unshielded twisted pair)
  - each wire is insulated with **plastic wrap**, but the pair is encased in an outer covering

Twisted Pair Wires..

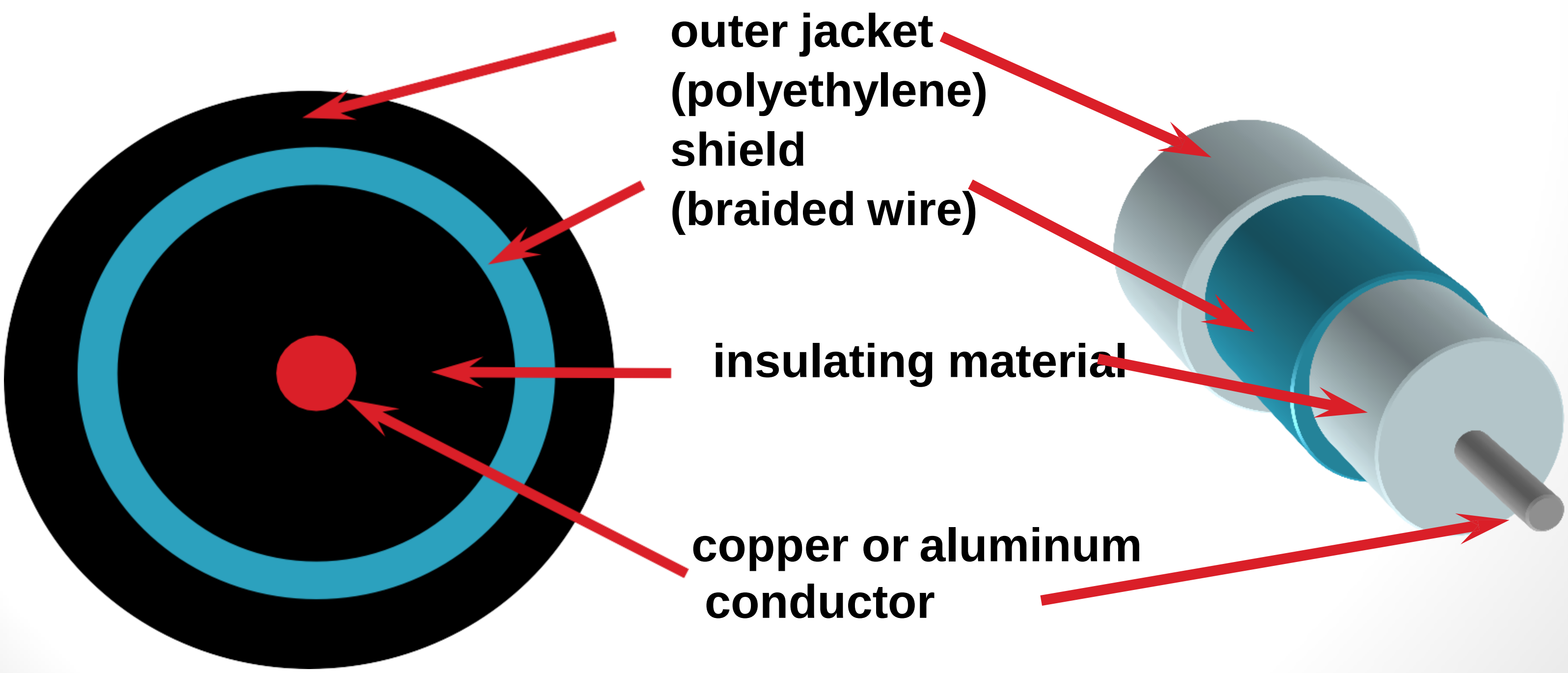
- Category 3 UTP
  - data rates of up to **16 Mbps** are achievable
- Category 5 UTP
  - data rates of up to **100 Mbps** are achievable
  - more tightly twisted than Category 3 cables
- Category 7 STP
  - Data rates in excess of **10 Gbps**
  - More expensive, harder to work with

Twisted Pair Adv & Disadv

- Advantages
  - **inexpensive** and readily available
  - flexible, light weight, **easy to install**
- Disadvantages
  - susceptibility to **interference** and noise
  - **attenuation** problem
    - For analog, repeaters needed every 5-6 km
    - For digital, repeaters needed every 2-3 km
  - relatively **low bandwidth** (100 MHz)

Coaxial Cable (or Coax)

- bandwidth of up to **500 MHz**
- has an **inner conductor** surrounded by a **braided mesh**
- both conductors **share a common center axial**, hence the term “**co-axia**l”



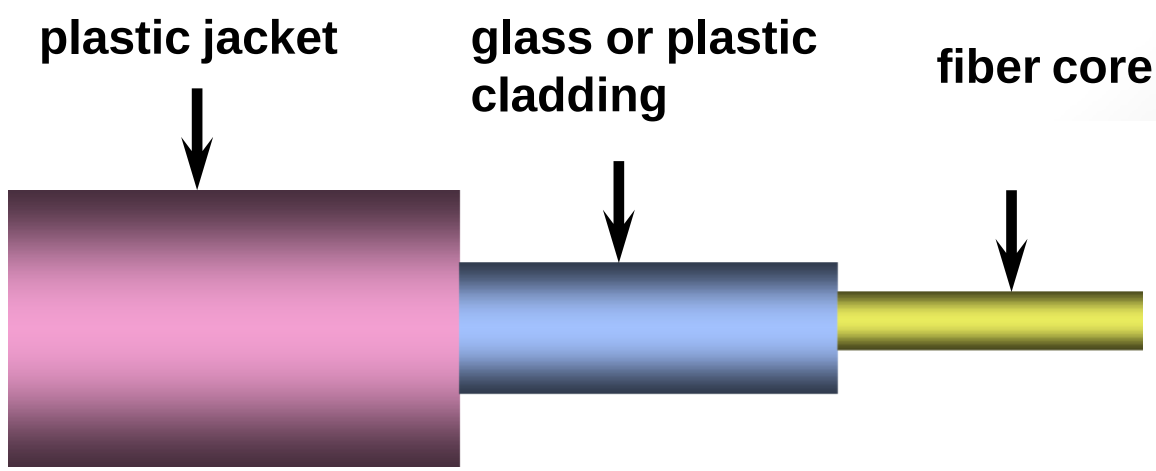
Coax Adv & Disadv

- ✓ higher **bandwidth**
  - ✓ 400 to 600 Mhz
  - ✓ Over 10,000 simultaneous voice conversations
- ✓ can be tapped easily (pros and cons)
- ✓ much **less** susceptible to **interference** than twisted pair
- ✓ Repeaters required every 2-3 km

- x high attenuation rate makes it **expensive over long distance** - more repeaters – especially for digital signaling at higher data rates
- x **bulky**

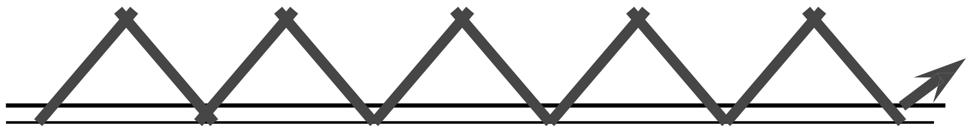
Fiber Optic Cable

- relatively new transmission medium used by **telephone companies** in place of **long-distance trunk lines**
- also used by **private companies** in implementing local data networks
- require a light source with injection **laser** diode (ILD) or light-emitting diodes (**LED**)
- consists of **three** concentric **sections**

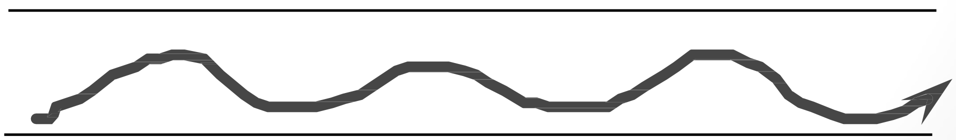


Fiber Optic Types

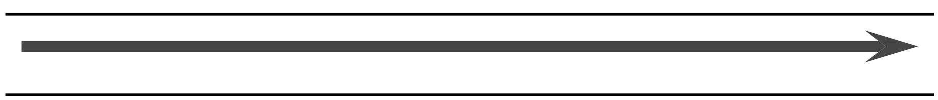
- multimode step-index fiber
  - the **reflective** walls of the fiber move the light pulses to the receiver



- multimode graded-index fiber
  - acts to **refract** the light toward the center of the fiber **by variations in the density**



- single mode fiber
  - the light is guided down the center of an extremely **narrow core**



Fiber Optic Adv & Disadv

- ✓ **greater capacity** (hundreds of Gbps)
- ✓ **smaller size** and lighter weight
- ✓ lower attenuation
- ✓ immunity to environmental interference
- ✓ Greater repeater spacing – 10s of km
- ✓ **highly secure** due to tap difficulty and lack of signal radiation

- x **expensive** over short distance
- x requires highly **skilled installers**
- x adding additional nodes is difficult

Guided Media Comparison

- Point-to-Point Characteristics

Transmission Medium	Rate Mbps	Bandwidth MHz	Repeaters km
Twisted Pair	100	3.5	2-6
Coaxial	500	500	1-10
Optical Fiber	200000	200000	10-50

Wireless Transmission

- Transmission and reception are achieved by means of an
  antenna
- **Directional** (higher frequencies)
  - transmitting antenna puts out **focused beam**
  - transmitter and receiver must be **aligned**
- **Omnidirectional** (lower frequencies)
  - signal spreads out in **all directions**
  - can be received by **many antennas**

Wireless Examples

- terrestrial microwave transmission
- satellite transmission
- broadcast radio
- infrared

Terrestrial Microwave

- uses the radio frequency spectrum, commonly from **2 to 40 Ghz**
- **parabolic dish transmitter**, mounted high as possible
- used by common carriers as well as private networks
- requires unobstructed **line of sight** between source and receiver
- curvature of the earth requires stations (called **repeaters**) to be ~50 km apart

Microwave Applications

- **long-haul telecommunications** service for both voice and television transmission
- **short point-to-point links** between buildings for closed-circuit TV or link between LANs
- **bypass application**
  - e.g. bypass local telephone company to reach long-distance
    carrier

Microwave Data Rates

Typical Digital Microwave Performance

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

Microwave

- <u>Advantages</u>
  - **no cabling** needed between sites
  - wide **bandwidth**
  - **multichannel** transmissions
- <u>Disadvantages</u>
  - **line of sight** requirement
  - **expensive** towers and repeaters
  - subject to **interference** - e.g. passing airplanes, rain

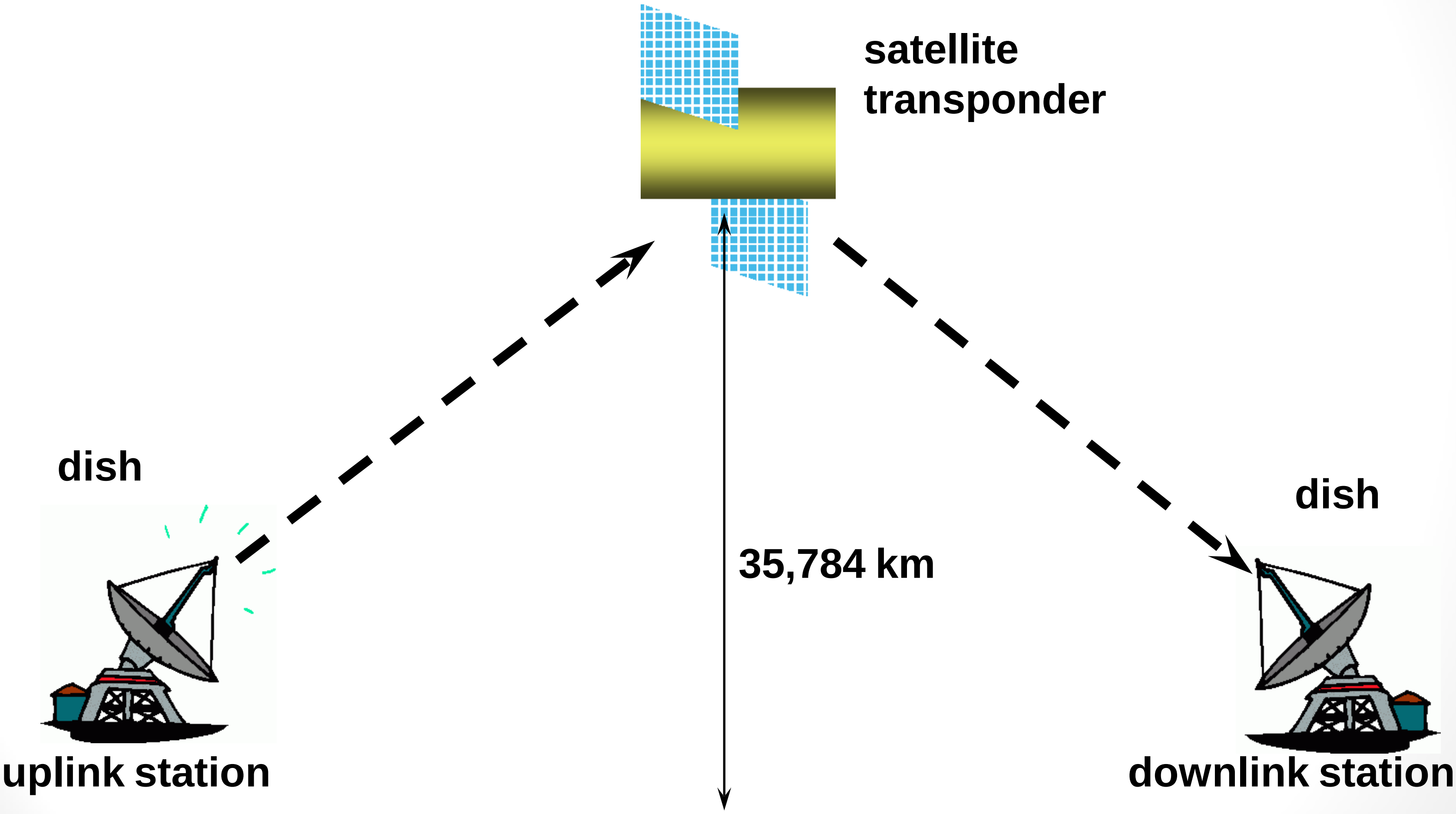
Satellite Transmission

- a microwave **relay station in space**
- can relay signals over **long distances**
- **geostationary** satellites
  - remain above the equator at **height of 35,863 km** (geosynchronous orbit)
  - **travel around the earth** in exactly the time the earth takes to rotate

Satellite Transmission Links

- earth stations communicate by sending signals to the satellite on an **uplink**
- the satellite then repeats those signals on a **downlink**
- the broadcast nature of the downlink makes it attractive for services such as the distribution of **television programming**

Satellite Transmission Process



Satellite Applications

- **television** distribution
  - a network provides programming from a central location
  - direct broadcast satellite (DBS)
- **long-distance telephone transmission**
  - high-usage international trunks
- private business networks
- **global positioning**
  - GPS services

Principal Satellite Bands

- **C band:** 4(downlink) - 6(uplink) GHz
  - the first to be designated
- **Ku band:** 12(downlink) -14(uplink) GHz
- smaller and cheaper earth stations used
  - rain interference is the major problem
- **Ka band:** 20(downlink) - 30(uplink) GHz
  - even smaller and cheaper receivers
  - Even greater attenuation

Satellite

- Advantages
  - can reach a **large** geographical **area**
  - **high bandwidth**
  - **cheaper** over long distances
- Disadvantages
  - **high initial cost**
  - susceptible to noise and interference
  - **propagation delay** (1/4 second)

Radio

- **Omnidirectional** and easily received
- Broadcast radio
  - 30 MHz to 1 GHz - FM, UHF, VHF television
- Mobile telephony
  - several bands below 1GHz
- Wireless LAN
  - 2.4 GHz range for 11 MB up to 525 ft.

Infrared

- Modulation of incoherent infrared light
- Wavelength 900 nm
- Up to 2 Mbps
- Does not penetrate walls
  - no licensing required