# I226
# Computer Networks

## Chapter 2

## Physical Layer

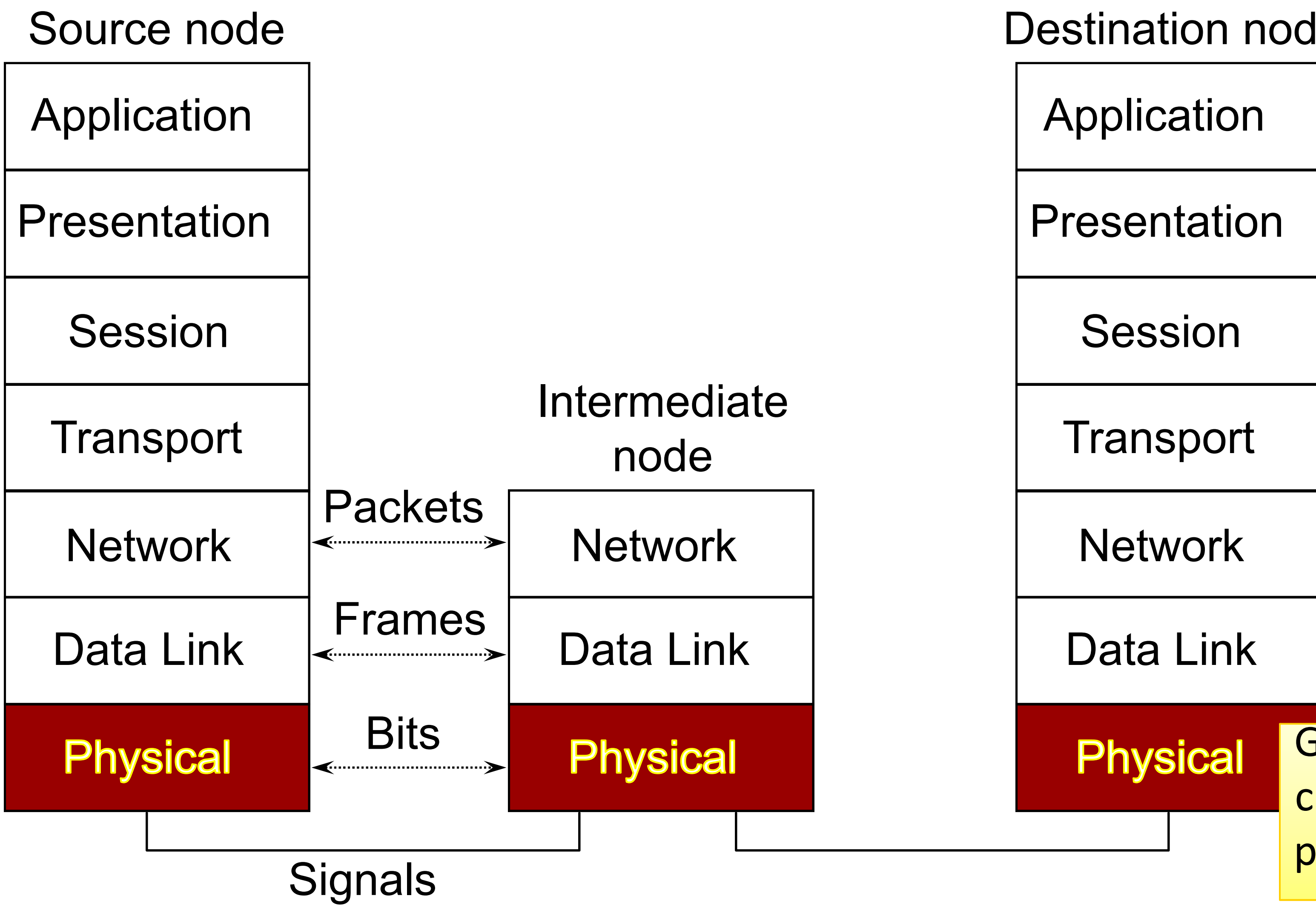
**Assoc. Prof. Yuto Lim**

School of Information Science
Japan Advanced Institute of Science and Technology
Nomi, Ishikawa, Japan

# Objectives of this Chapter

- Furnish a fundamental knowledge of data communications in terms of signal, encoding, modulation, and multiplexing
- Give an insight of Nyquist bandwidth and Shannon capacity
- Explain the guided and unguided transmission media

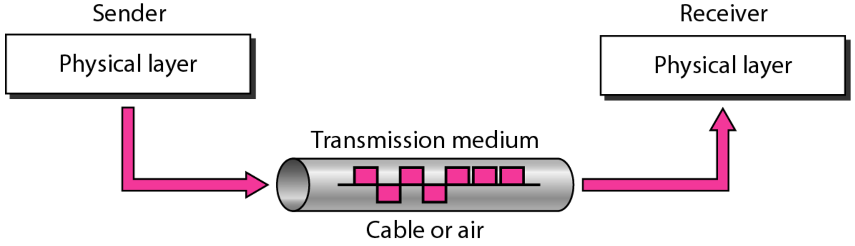
# Physical Layer




Go to ch.01 pg.36

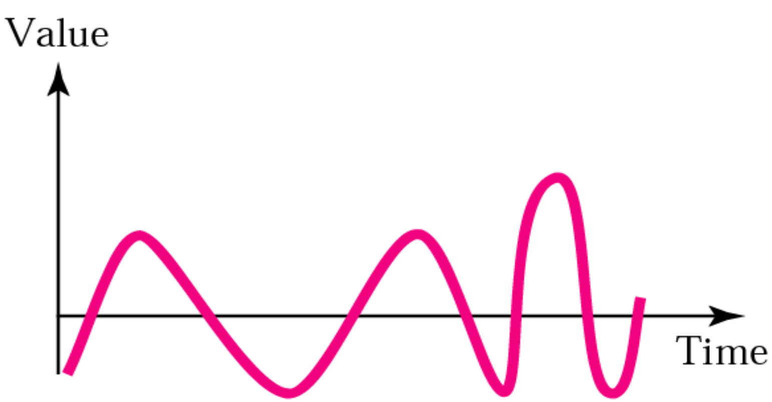
# Outline

- Theoretical Basis for Data Communication
  - Signal: Analog or Digital
  - Fourier Analysis, Nyquist, Shannon Capacity
  - Encoding, Modulation, Multiplexing
- Guided Transmission Media
  - Twisted Pair
  - Coaxial Cable
  - Fiber Optics
- Unguided Transmission Media
  - Infrared
  - Radio
  - Microwave

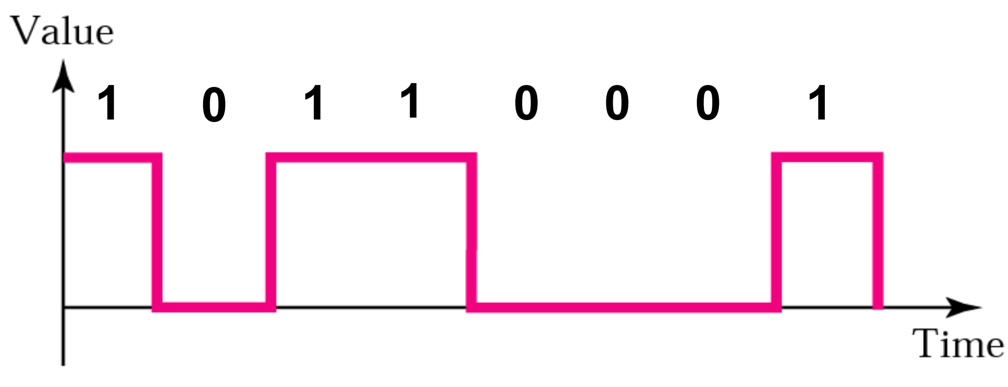


# Transmission of Data

- Data must be transformed to electromagnetic signals to be transmitted
- Analog signal has infinitely many levels of intensity (infinitely many values, continuous values) over a period of time
- Digital signal has only a limited number of defined values (discrete values), e.g., 0 or 1



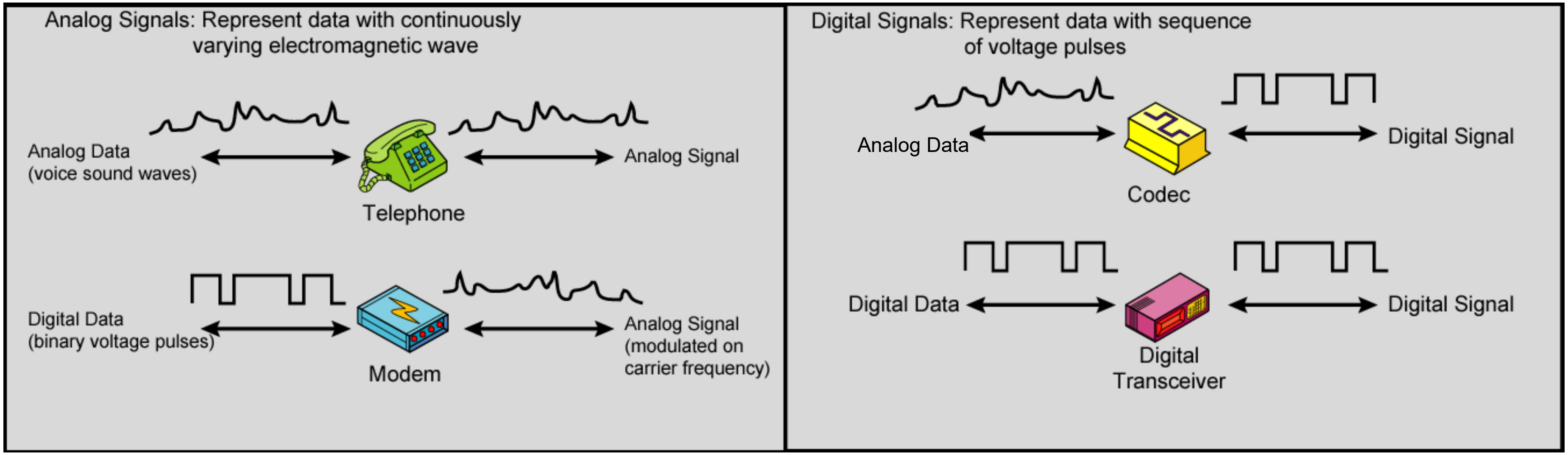

a. Analog signal




b. Digital signal

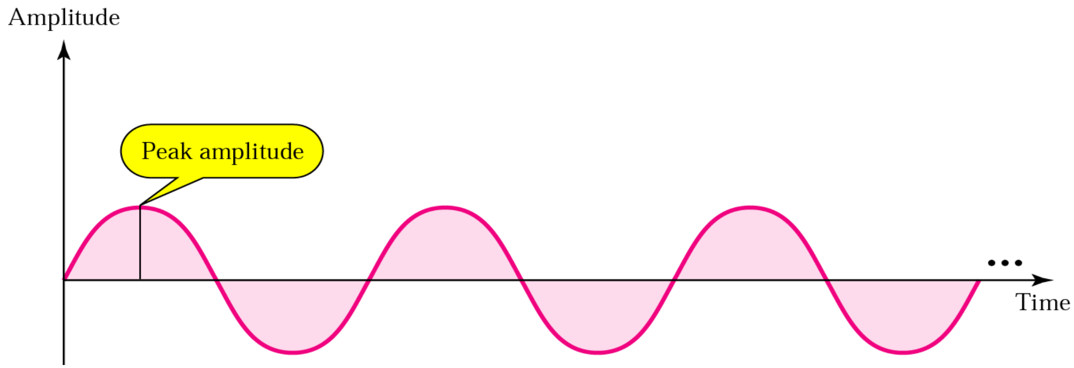
# Signals: Analog or Digital

- Analog data (human voice, chirping of birds, etc) is converted to
  - Analog signal, e.g., human voice to the telephone exchange
  - Digital signal, e.g., human voice and images sent on digital lines using digital telephone system
- Digital data (data stored in computer memory, etc) is converted to
  - Analog signal, e.g., computer data sent over internet using analog telephone line
  - Digital signal, e.g., from one digital exchange to another digital exchange

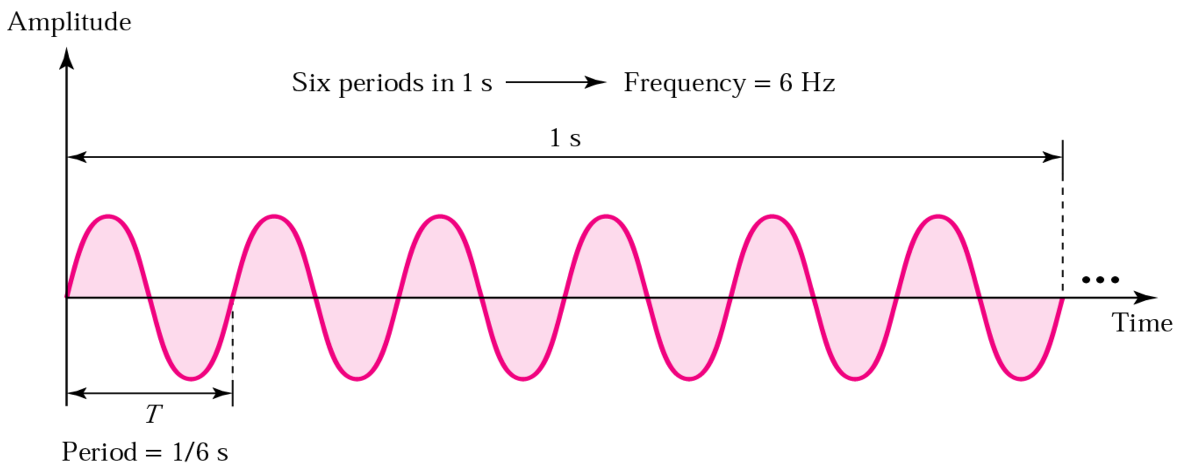


# Sine Wave

- Amplitude




- Period and Frequency

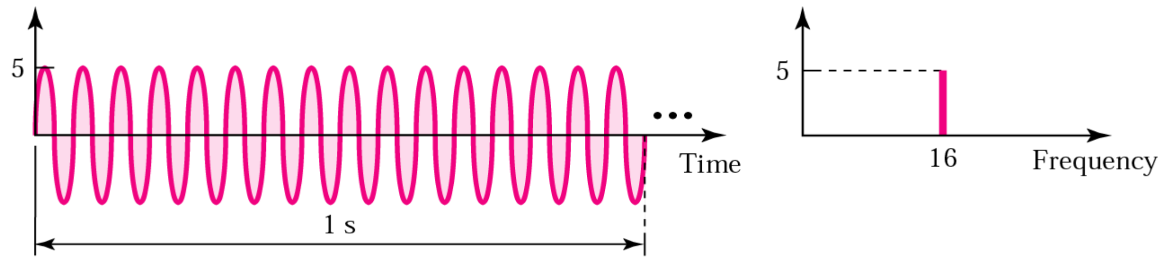


# Sine Wave for Data Communication

- Single-frequency sine wave is not useful for data communication
  - Single sine wave can carry electric energy, e.g., the power company sends a sine wave with 50Hz/60Hz to distribute electric energy to our houses
  - If single sine wave was used to convey conversation over the telephone, we heard just a buzz
  - If we send one sine wave to transfer data, we actually send an alternating 0's and 1's, which does not have any communication value
  - If we want to use sine wave for communication, we need to change one or more of its characteristics, e.g., to send 1 bit, we use maximum amplitude, and to send 0 bit, we use minimum amplitude
  - When we change one or more characteristics of single-frequency signal, it becomes a composite signal made up of many frequencies

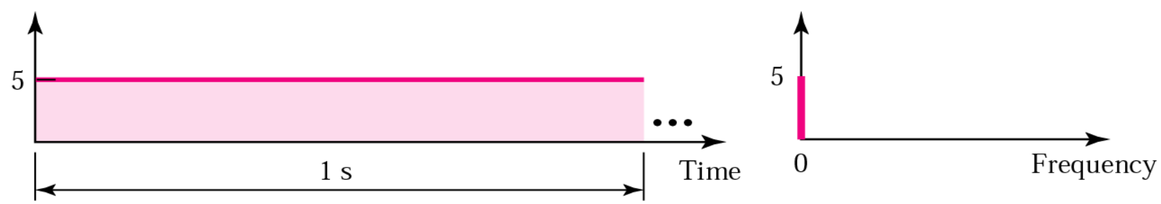
# Analog Signal in Frequency Domain

- An analog signal is best represented in the frequency domain




A signal with frequency 16

- If an analog signal does not change at all, its frequency is zero

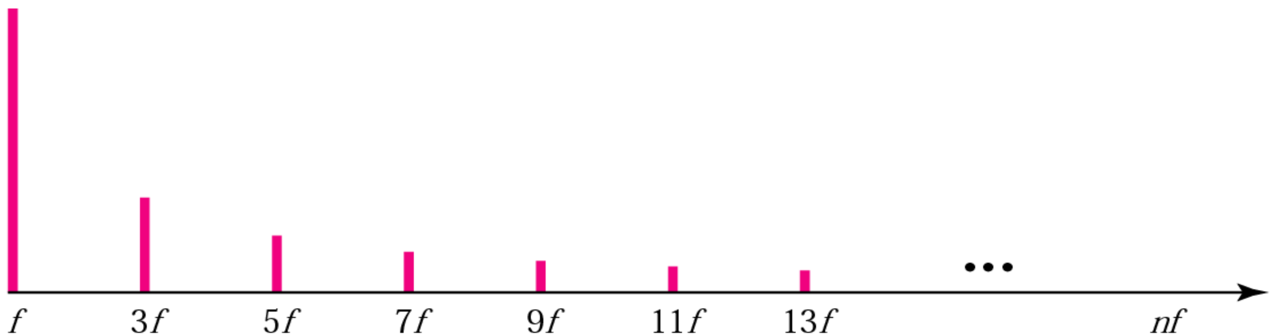



A signal with frequency 0

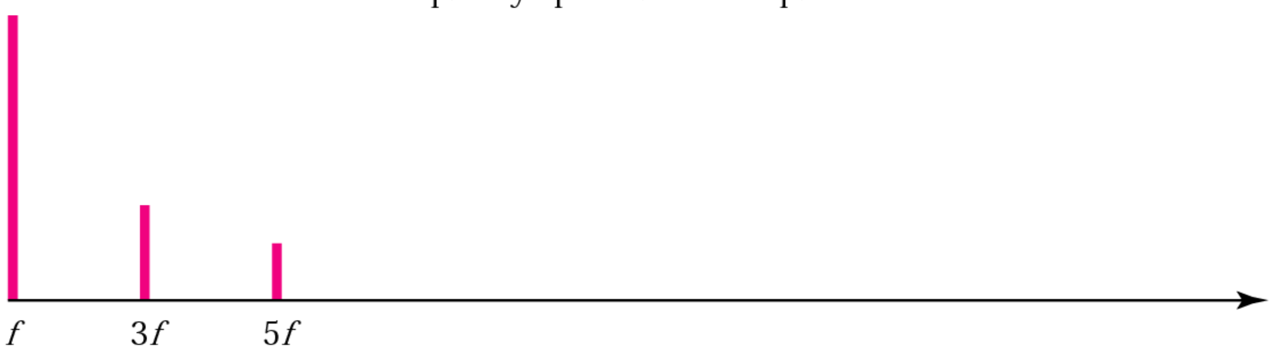
- If an analog signal changes instantaneously, its frequency is infinite

# Frequency Spectrum of a Signal

- The description of a signal using the frequency domain and containing all its components is called the <u>frequency spectrum of the signal</u>

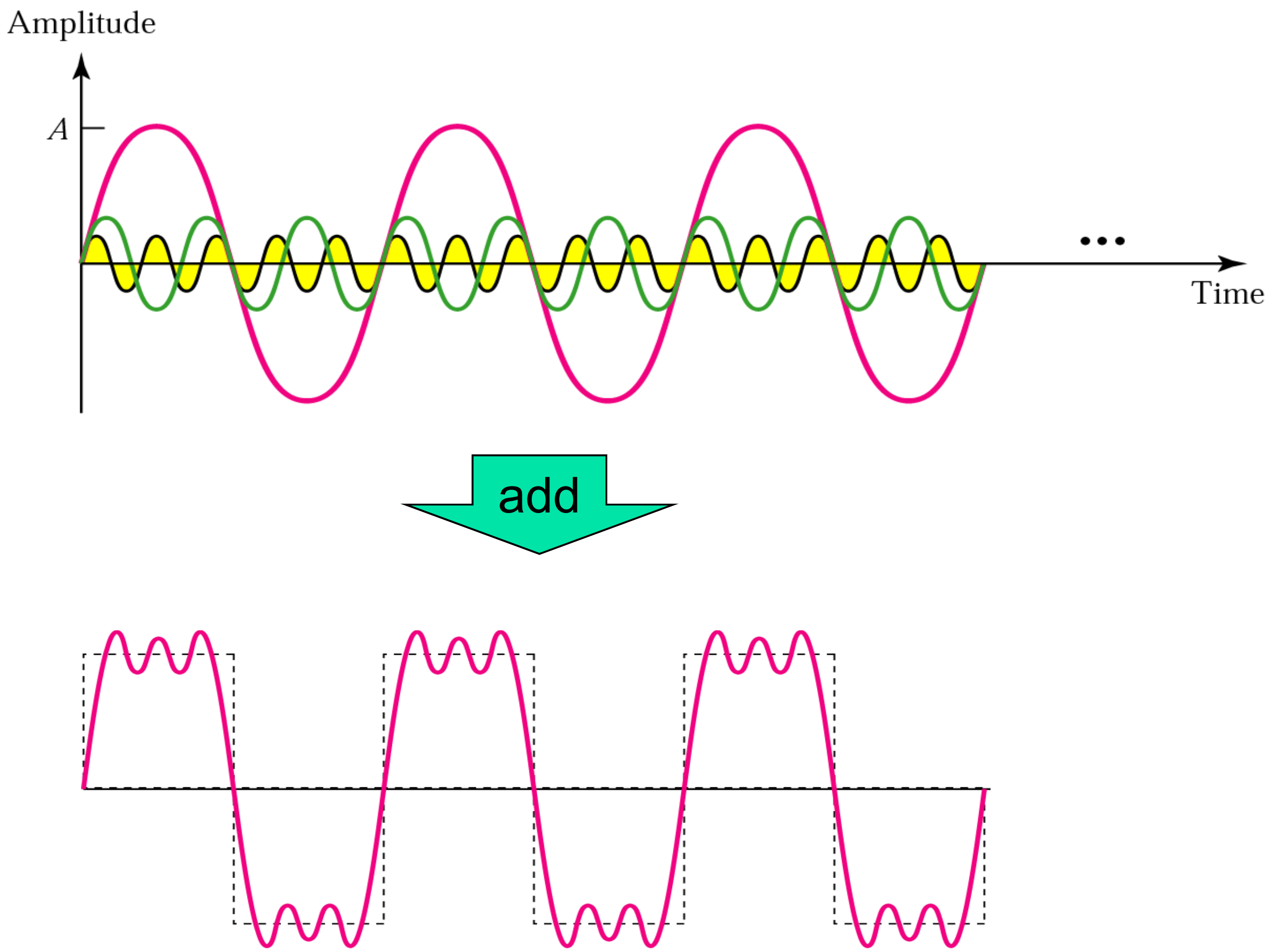



a. Frequency spectrum of a square wave



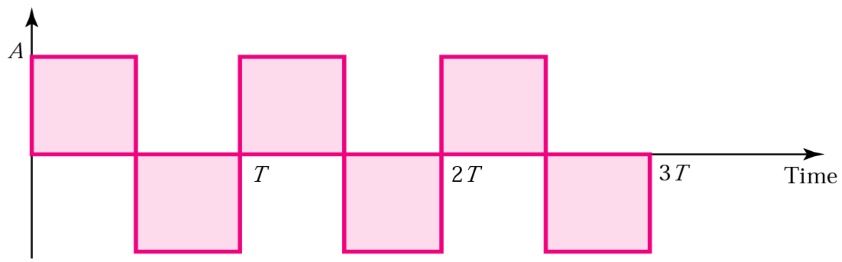

b. Frequency spectrum of an approximation with only three harmonics

# Composite Signal



# Fourier Analysis

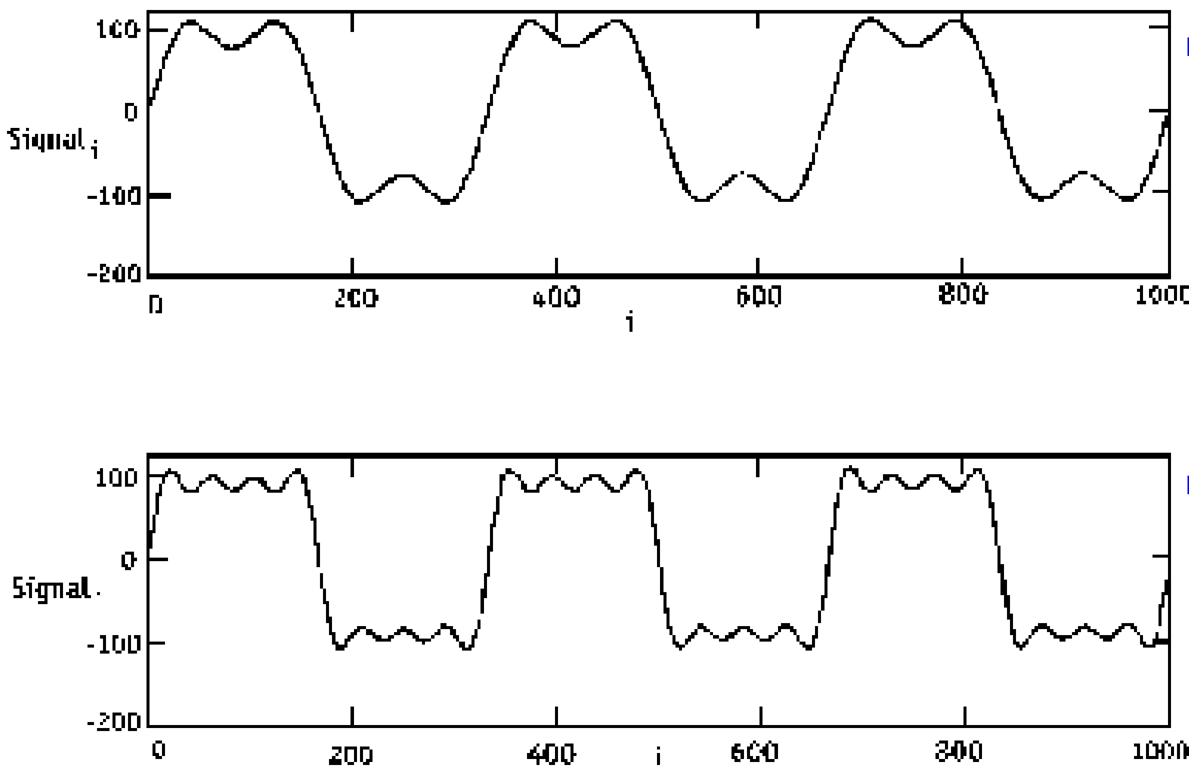
- In early 1900s, French Mathematician Jean Baptiste Fourier showed that any composite signal can be represented as a combination of simple sine waves with different frequencies, phases, and amplitudes
  - Square wave signal consists of a series of sine waves with frequencies 1f, 3f, 5f, 7f,… and amplitudes 4A/π, 4A/3π, 4A/5π, 4A/7π,…




  - where f is the fundamental frequency. A is the maximum amplitude. T is the time period. The terms with frequency 1f, 3f,… are called 1st harmonic, 3rd harmonic,… respectively
- Better approximation can be achieved by increasing more harmonics

# Better Approximation

Voltage [V]

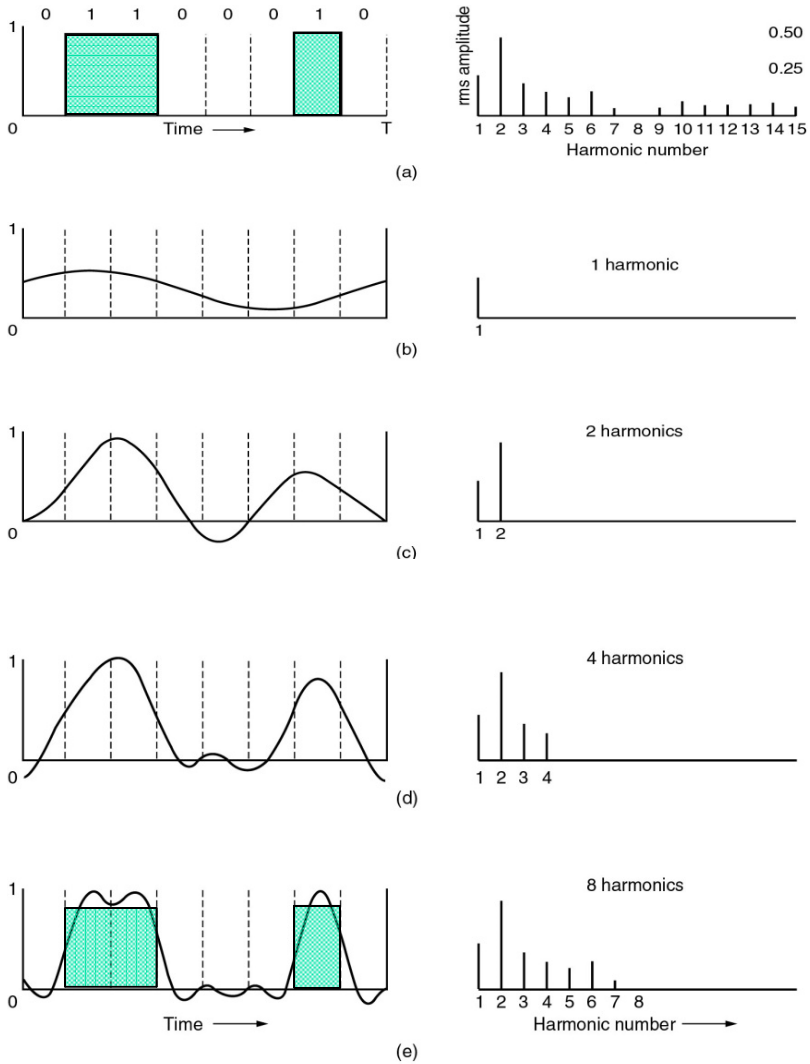



Time [milliseconds]

Figure: Time-voltage graph

- This trace is sum of 2 sine waves with
  - f1 = 3 Hz
  - f3 = 9 Hz
- This trace is sum of 4 sine waves with
  - f1 = 3 Hz
  - f3 = 9 Hz
  - f5 = 15 Hz
  - f7 = 21 Hz
- It is clearly a better approximation for the second trace

# Better Approximation (cont.)




Original

As we add more harmonics the signal reproduces the original more closely

Figure: Successive approximations to the original signal.

# Mathematic Representation: Fourier

- A periodic function, g(t) is a sum of a number of sines and cosines

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

$T$ : period

$f = 1/T$ : fundamental frequency

$a_n, b_n$ : sine and cosine amplitude of the $n$th harmonics

$c$ : constant

- By multiplying both sides of above equation by $sin(2\pi kft)$ and then integrating from 0 to $T$. We can find the coefficients

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)dt$$

$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)dt$$

$$c = \frac{2}{T}\int_0^T g(t)dt$$

# Example 1

- Consider a transmission of the ASCII character ‘b’ encoded in an 8-bit byte with bit pattern of ‘01100010’

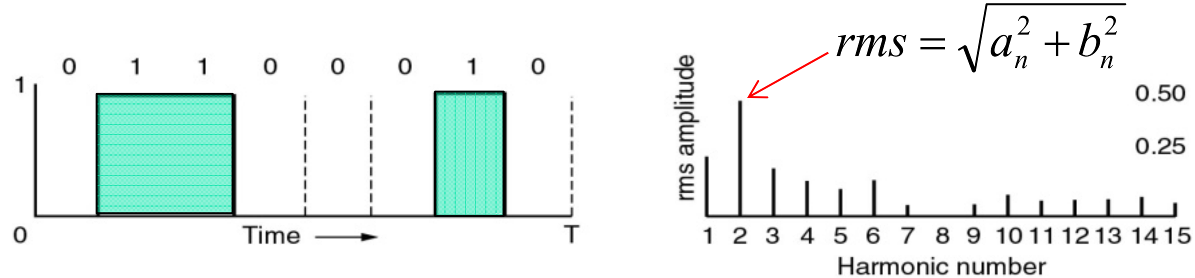



Figure: A binary signal and its root-mean-square Fourier amplitudes.

- Answer: The Fourier analysis of this signal yields the coefficients:

$$a_n = \frac{1}{\pi n}\left[\cos(\pi n/4) - \cos(3\pi n/4) + \cos(6\pi n/4) - \cos(7\pi n/4)\right]$$

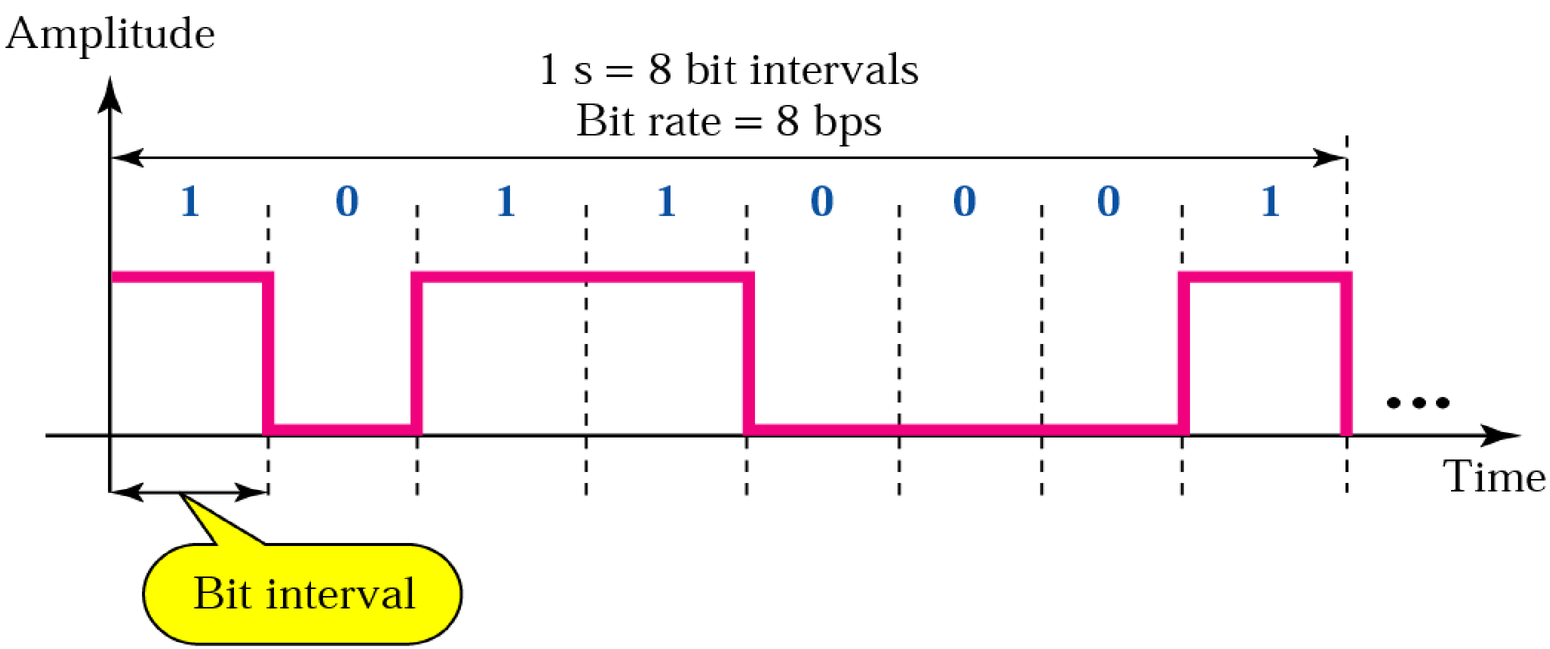
$$b_n = \frac{1}{\pi n}\left[-\sin(\pi n/4) + \sin(3\pi n/4) - \sin(6\pi n/4) + \sin(7\pi n/4)\right]$$

$$c = 3/4$$

# Data as Digital Signals

- '1' can be encoded as a positive voltage of 5 volts, '0' as zero volts (or a negative voltage of –5 volts)

- Most digital signals are aperiodic. Thus we use
  - Bit interval (instead of period) : time required to send one bit
  - Bit rate (instead of frequency) : number of bits per second



# Digital Signal as Composite Signal

- Digital signal is a composite analog signal with an infinite bandwidth
- Digital signal theoretically needs a bandwidth between 0 and infinity. The lower limit 0 is fixed. The upper limit may be compromised

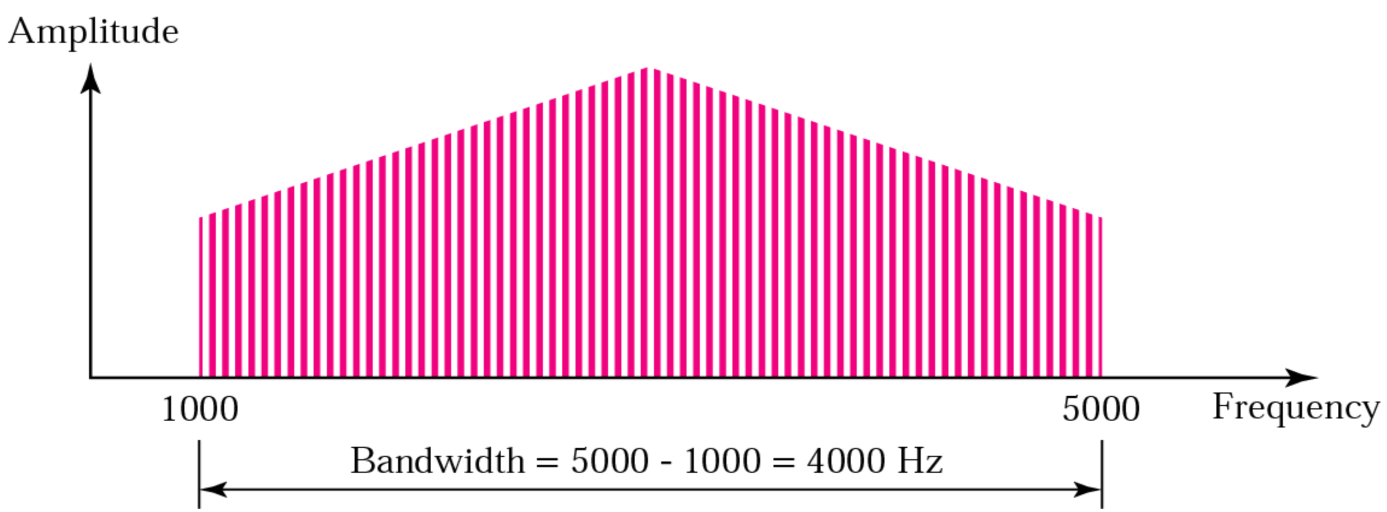
# Composite Signal & Transmission Medium

- A signal needs to pass through a transmission medium, which may pass some frequencies, may block few and weaken others
- This means when a composite signal, containing many frequencies, is passed through a transmission medium, we may not receive the same signal at the other end

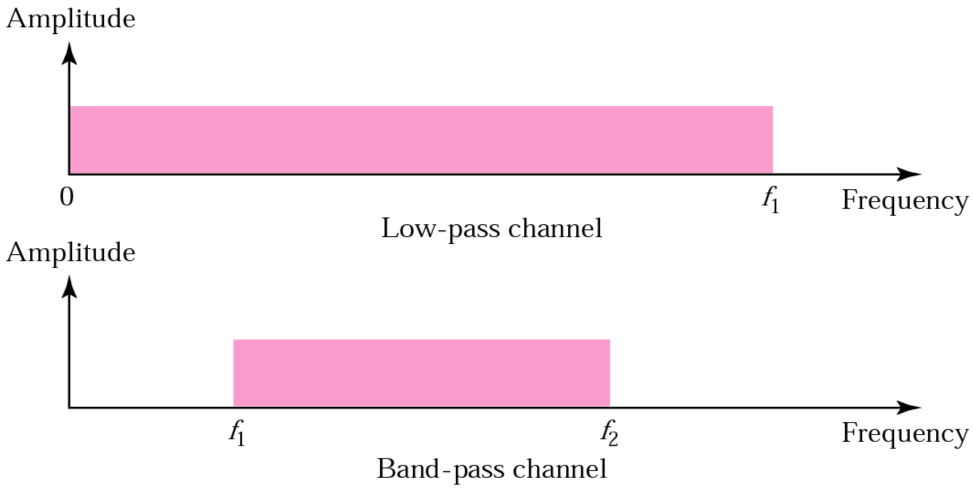

Go to OneNote

# Bandwidth of a Channel

- The range of frequencies that a medium can pass without loosing one-half of the power contained in that signal is called its <u>bandwidth</u>
- Bandwidth is a physical property of the transmission medium and depends on the construction, thickness, and length of the medium



# Low Pass vs. Band Pass




- Low-pass channel has a bandwidth with frequencies between 0 and f
  - Raw digital signal transmission
  - Mainly for short-distance transmission, e.g., LAN
  - Make a simple circuit

- Band-pass channel has a bandwidth with frequencies between f1 (≥0) and f2
  - Convert to analog signal transmission
  - Require a conversion equipment (modem)
  - Mainly for long-haul transmission, e.g., WAN, Cable TV, ADSL
  - It can transmit multi-channel

- A band-pass channel is more easily available than a low-pass channel

# Bit Rate vs. Required Bandwidth

- Imagine that our computer creates 6 bps. In 1 second, the data created
  - 111111 : no change in the values, best case
  - 101010 : maximum change in the values, worst case
  - 001010 : change in between the above two cases

- Using single harmonic (just to get the intuition)
  - 111111 (or 000000) can be simulated by sending a single-frequency signal with frequency 0 Hz
  - 101010 (or 010101) can be simulated by sending a single-frequency signal with frequency 3 Hz. (3 signals or sine waves per second)
  - All other cases are between the best and the worst cases. We can simulate other cases with a single frequency of 1 Hz or 2 Hz (using appropriate phase)

- We have already shown that more the changes higher are the frequency components (i.e., max change here is **3 Hz**)

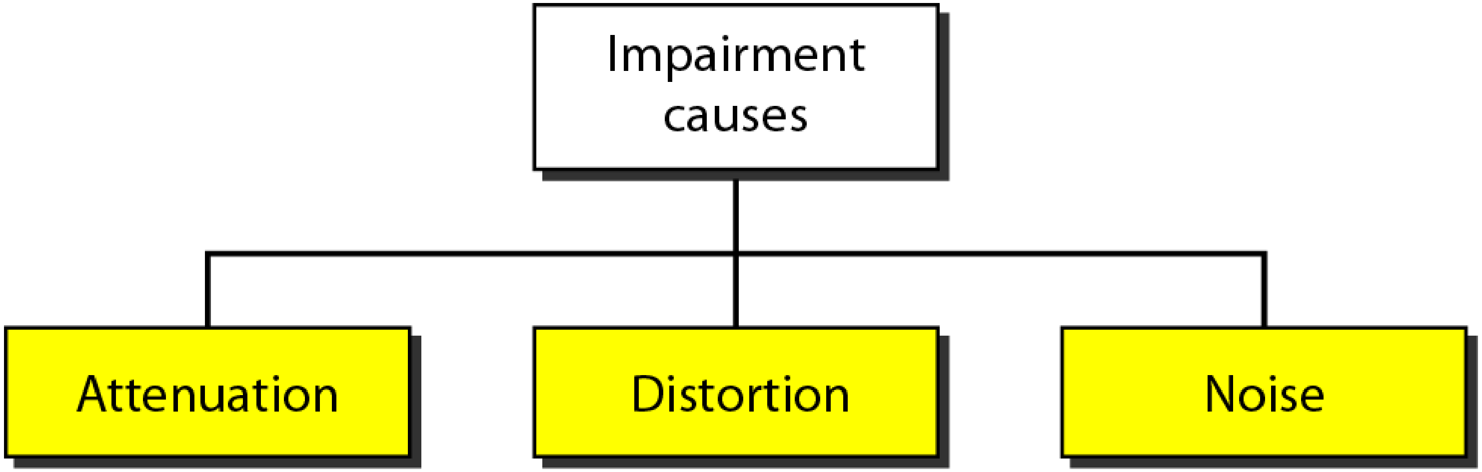
 

# One Harmonic vs. More Harmonics

- Thus, using one harmonic to send $n$ bps:
  - For best case, the frequency is 0 Hz
  - For worst case, the frequency is $n/2$ Hz
    - Hence, the required bandwidth (B) = $n/2$ Hz
- However, one harmonic does not approximate the digital signal nicely and more harmonics are required to approximate the digital signal
- For a digital signal that consists of odd harmonics
  - When we add 3rd harmonic to the worst case, we need $B = n/2 + 3n/2 = 4n/2$
  - When we add 5th harmonic to the worst case, we need $B = n/2 + 3n/2 + 5n/2 = 9n/2$
  - And so on. In other words, $B \geq n/2$ (or $n \leq 2B$) $\Rightarrow$ $n\uparrow$ results $B\uparrow$
- Hence we conclude that bit rate and the required bandwidth of a channel are proportional to each other

# Transmission Impairments

- Signal received may differ from signal transmitted causing
  - analog – degradation of signal quality
  - digital – bit errors (‘1’ as ‘0’ or vice-versa)
- Most significant impairments are
  - attenuation
  - delay distortion
  - noise



# Attenuation

- Received signal strength falls off with distance
- It depends on medium
- It introduces three considerations for engineer
  1. Received signal must have strong enough to be detected
  2. Received signal must sufficiently higher than noise to receive without error
  3. Attenuation varies with frequency
- For 1 & 2, the signal strength can be increased using amplifiers/repeaters
- For 3, techniques that are equalizing attenuation across band of frequencies can be used
  - e.g., voice-grade telephone lines by using loading coils that change the electrical properties of the line. This result is to smooth out attenuation effects

# Delay Distortion

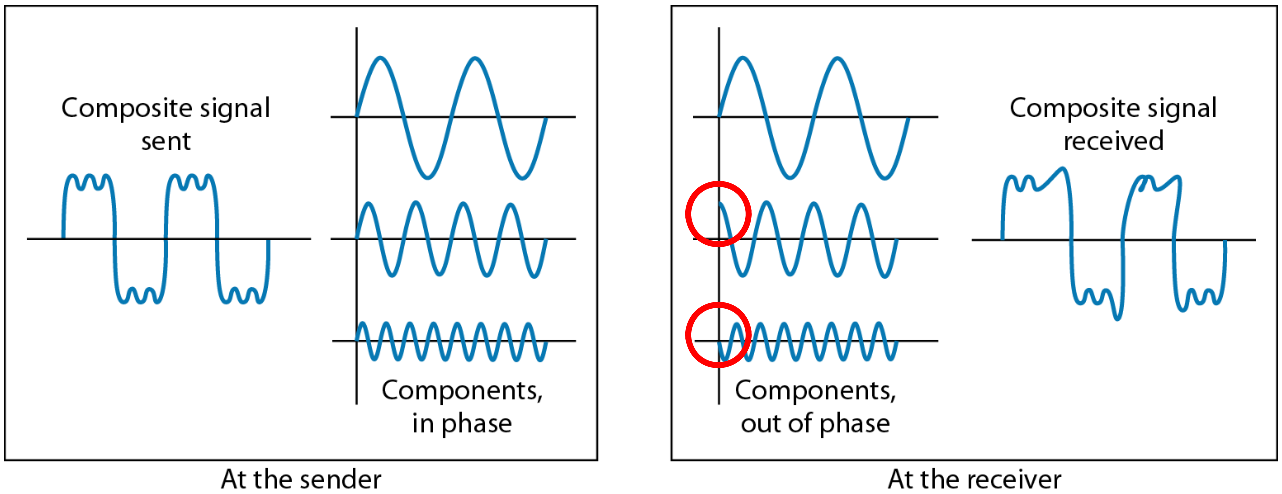



Figure: Distortion – change of signal form resulting from different propagation speeds.

- It occurs because the velocity of a signal through a guided medium varies with frequency
  - For a band-limited signal, the velocity tends to be highest near center frequency and fall off toward the two edges of the band. Various frequency components of signal arrive at different times
- Particularly critical for digital data
- Since parts of one bit spill over into other bit positions, causing inter-symbol interference

# Noise

- Additional signals inserted b/w transmitter & receiver
- Thermal
  - Due to thermal agitation of electrons
  - Uniformly distributed across typical bandwidth
  - White noise
- Inter-modulation
  - Signals that are the sum and difference (or multiples) of original frequencies sharing a medium
- Crosstalk
  - A signal from one path/line is picked up by another
- Impulse
  - Irregular pulses, e.g., external electromagnetic interference
  - Short duration and high amplitude
  - A minor annoyance for analog signals, but a major source of error in digital data – a noise spike could corrupt many bits

# Channel Capacity

- Maximum possible data rate on a communication channel
  - data rate - in bits per second
  - bandwidth - in cycles per second or Hertz
  - noise - on communication link
  - error rate - of corrupted bits
- Limitations due to physical properties
- Want most efficient use of capacity

# Nyquist Bandwidth

- Consider noise free channels
- If the rate of signal transmission is 2B, then it can carry signal with frequencies no greater than B
  - i.e., given bandwidth B, highest signal rate is 2B
- For binary signals, 2B bps needs bandwidth B Hz

Recall pg. 23

- Can increase rate by using M signal levels
- Nyquist Formula for a capacity of the noise free channel,

$$C = 2B \log_2 (M)$$

| C | M |
|---|---|
| 2B | 2 |
| 4B | 4 |
| 6B | 8 |
| … | |

- So increase rate by increasing signal levels
  - at the cost of receiver complexity
  - limited by noise & other impairments

# Shannon Capacity Formula

- Consider relation of data rate, noise, and error rate
  - Faster data rate shortens each bit, so bursts of noise affects more bits
  - Given noise level, higher rates means higher errors

- Shannon developed formula relating these to signal to noise ratio in dB (decibels)

- $SNR = 10 \log_{10}(\frac{S}{N})$

$$SNR[\mathrm{dB}] = 10 \log_{10} \frac{S[\mathrm{W}]}{N[\mathrm{W}]}$$

$$\frac{SNR[\mathrm{dB}]}{10} = \log_{10} \frac{S[\mathrm{W}]}{N[\mathrm{W}]}$$

$$\therefore \quad \frac{S[\mathrm{W}]}{N[\mathrm{W}]} = 10^{\frac{SNR[\mathrm{dB}]}{10}}$$

- Shannon Capacity
  - $C = B \log_2 (1 + \frac{S}{N})$
  - C is measured in bps, B is in Hz
  - Logarithm is taken in base 2
  - Signal and noise powers $S$ and $N$ are measured in watts, so the signal-to-noise ratio here is expressed as a power ratio, not in decibels (dB) e.g., 30 dB is a power ratio of 1000
  - theoretical maximum capacity and get lower in practice

# Limits of Digital Rate

- Data rate depends on 3 factors:
  - Bandwidth available, B
  - Number of levels of signals, M
  - Quality of the channel (noise level), S/N

**Note:**

$\frac{S}{N}$ = S/N

- Noiseless Channel: Nyquist Bandwidth
  - $C = 2B \log_2 (M)$
  - where B is bandwidth and M is number of signal levels

- Noisy channel: Shannon Capacity Formula
  - $C = B \log_2 (1 + S/N)$
  - where C is capacity of the channel in bps and S/N is signal-to-noise ratio

# Example 2

- Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint.
  - Answer: For this channel the capacity is calculated as

    $C = B \log_2 (1 + S/N) = B \log_2 (1 + 0) = 0$ bps

- We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 Hz to 3300 Hz). The signal-to-noise ratio is usually 3162.
  - Answer: For this channel the capacity is calculated as

    $C = B \log_2 (1 + S/N) = 3000 \log_2 (1 + 3162) = 34{,}860$ bps

# Example 3

- We have a channel with a 1 MHz bandwidth. The S/N for this channel is 63; what is the appropriate bit rate and signal level?
  - Answer: First, we use the Shannon formula to find the upper limit

    $C = B \log_2 (1 + S/N) = 1{,}000{,}000 \log_2 (1 + 63) = 6$ Mbps

    Then, we use the Nyquist bandwidth formula to find the number of signal levels

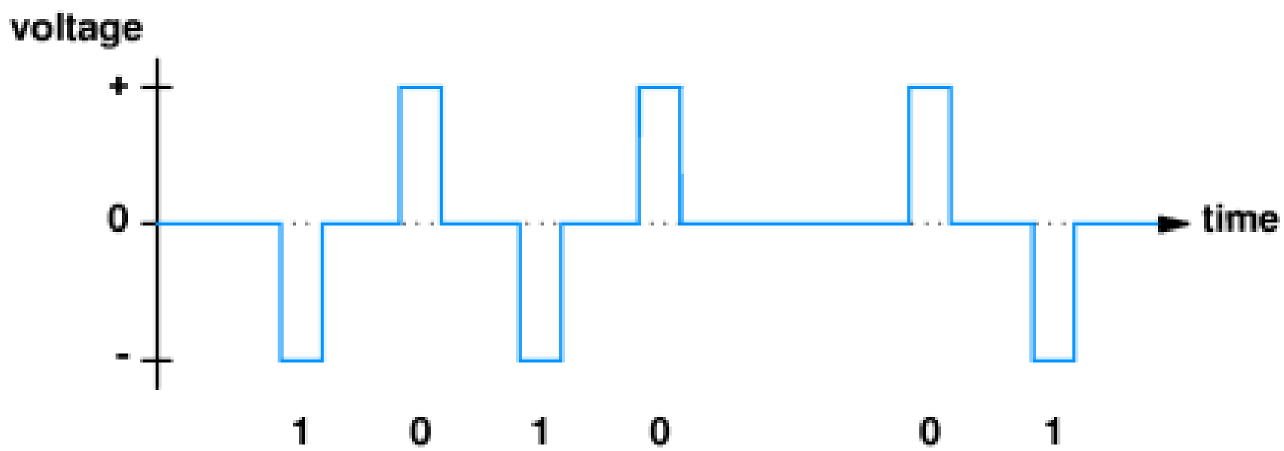
    $\Rightarrow \quad C = 2B \log_2 (M)$
    $\Rightarrow \quad 6 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 (M)$
    $\Rightarrow \quad 2^3 = M$

    $\therefore \underline{M = 8}$

# Bit Rate vs. Baud Rate

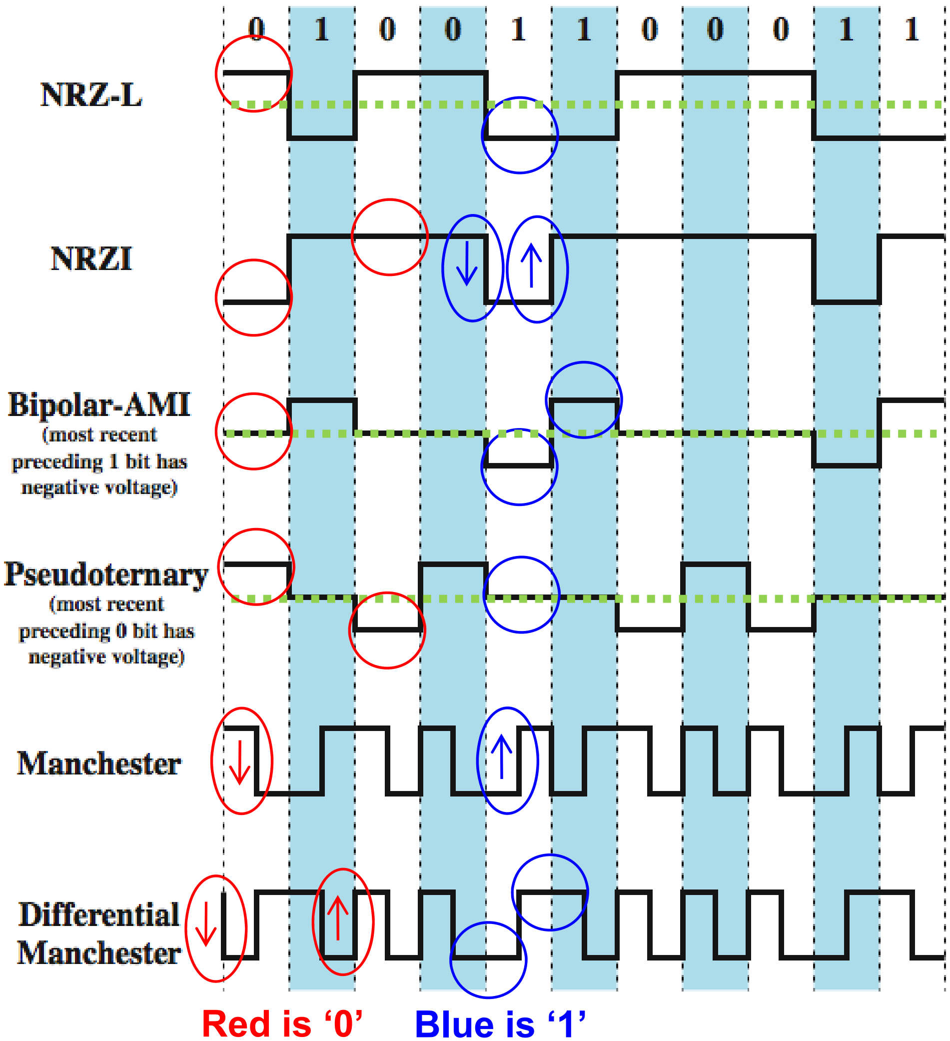
- Transmission speed is measured in bits per second (bps)
- Technically, transmission is rated in baud (symbol), the number of symbol changes in the signal per second that the hardware generates
- Baud rate, $f_s$ [Baud] = $1/T_s$, $T_s$ is the symbol duration time
  - 1 kBaud is synonymous to a symbol rate of 1000 symbols per second
- If k-bit conveys to one symbol, then a bit rate [bps] = $f_s$ * k
  - consider M = $2^k$ different symbols are used, the bit rate = $f_s$ * $\log_2$(M)
  - e.g., consider modem can generate M = 4 = $2^2$ different symbols and transmits using 1200 Baud. Thus, bit rate = 1200 * 2 = 2.4 kbps
- Consequently, the bit rate depends on two parameters
  - $f_s$, the frequency with which a component can change (baud rate)
  - k, the number of bits in the string. That is why the formula: (signal may have up to $2^k$ different amplitudes)

# Electric Current and Data Bits




- The simplest electronic communication systems use a small electric current to encode data
- Positive voltage – represents 0 (or 1)
- Negative voltage – represents 1 (or 0)
- A waveform diagram can be used to illustrate how data bits are represented and transmitted

# Encoding Schemes using Digital Signals



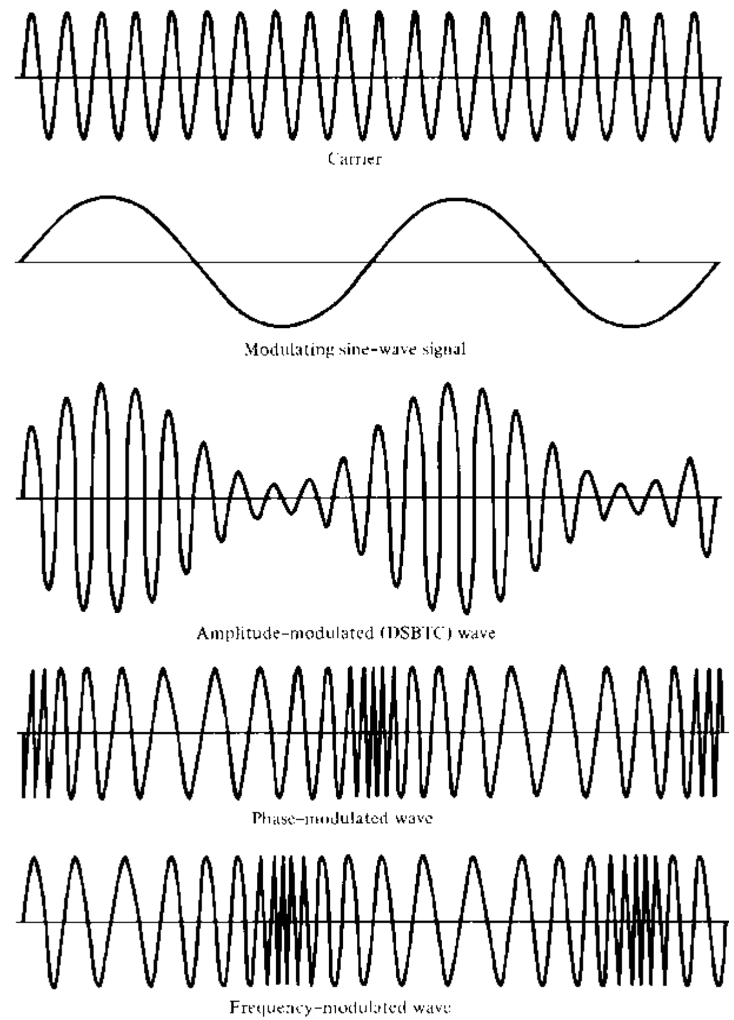

- Nonreturn to Zero-Level
  - High (positive) voltage = 0 bit, low (negative) voltage = 1 bit
  - Voltage constant during bit interval - no transition i.e., no return to zero voltage
- Nonreturn to Zero Inverted
  - No transition as 0 bit, transition (low-to-high or high-to-low) as 1 bit
  - Data represented by changes rather than levels, therefore more reliable detection of transition rather than level
- Multilevel Binary Bipolar- Alternate Mark Inversion
  - No line signal = 0 bit, positive or negative pulse = 1 bit
  - Bit 1 pulses must alternate in polarity
- Multilevel Binary Pseudoternary
  - Alternating positive and negative = 0 bit, absence of line signal = 1 bit
- Manchester
  - It has transition in the middle of each bit period
  - High-to-low = 0 bit, low-to-high = 1 bit
  - Transition serves as clock and data
- Differential Manchester
  - Mid-bit transition is clocking only
  - Transition at start of bit period = 0 bit, no transition at start of bit period = 1 bit

# Limitations of Using Digital Signals

- Digital signals cannot be used to transmit across a long distance
- During transmitting digital signals, it is susceptible to interference easily
- Digital encoding schemes are widely used in recording
- Instead, analog signals are used to transmit even digital data bits
- How can one use analog signals to represent digital data bits?
  - convert digital data to analog signal at the sender side
  - convert analog data back to digital data at the receiver side

# Analog Signals

- Modulate carrier frequency with analog data
- Why modulate analog signals?
  - higher frequency can give more efficient transmission
  - permits frequency division multiplexing
- Types of modulation
  - Amplitude modulation (AM)
  - Phase modulation (PM)
  - Frequency modulation (FM)



# Modulation Techniques

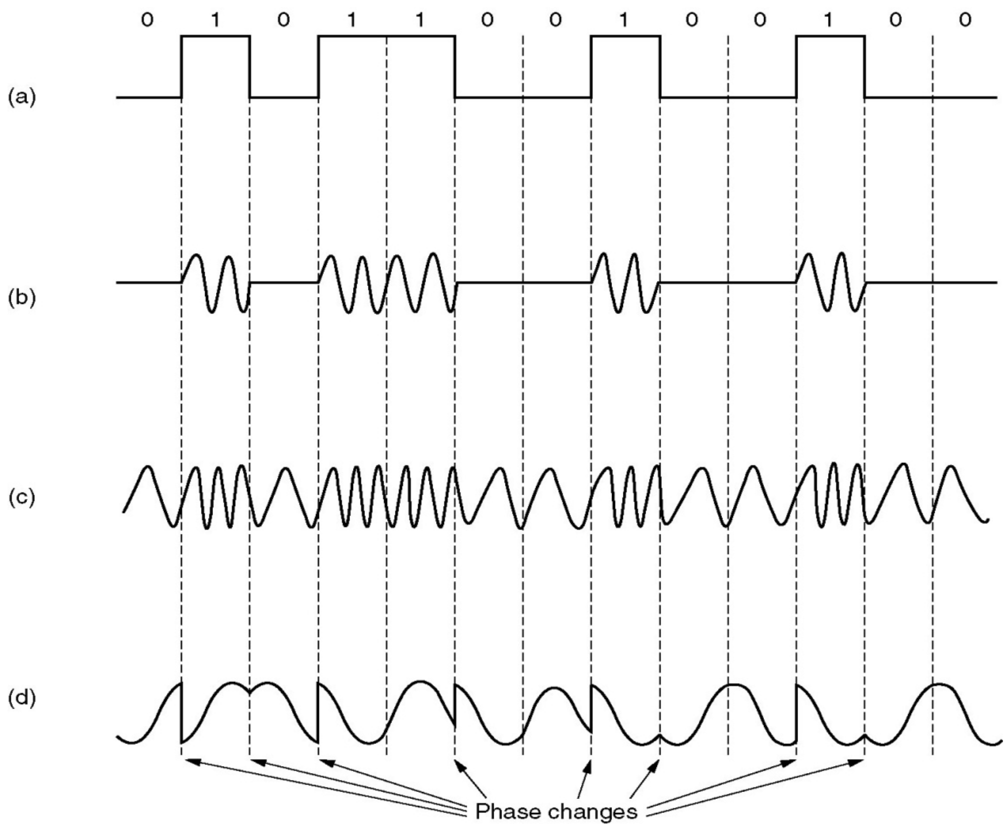



Figure: (a) A binary signal, (b) Amplitude modulation, (c) Frequency modulation, (d) Phase modulation

- Amplitude Shift Keying (ASK)
  - encode 0/1 by different carrier amplitudes
  - susceptible to sudden gain changes and inefficient
  - used for up to 1200 bps on voice grade lines or very high speeds over optical fiber
- Frequency Shift Keying (FSK)
  - binary FSK – two binary values represented by two different frequencies (near carrier)
  - less susceptible to error than ASK
  - used for up to 1200 bps on voice grade lines or high frequency radio or higher frequency on LANs using coaxial cable
- Phase Shift Keying (PSK)
  - phase of carrier signal is shifted to represent data
  - binary PSK – two phases represent two binary digits

# Quadrature Amplitude Modulation

- More signals means a greater bit rate with a given baud rate
- The problem is that a higher bit rate requires more signals and reduces the differences among them and makes the receiver’s job more difficult
- Another approach is to use a combination of frequencies, amplitudes, or phase shifts, which allows us to use a larger group of legitimate signals while maintaining larger differences among them
- This technique is Quadrature Amplitude Modulation (QAM), in which a group of bits is assigned a signal defined by its amplitude and phase shift

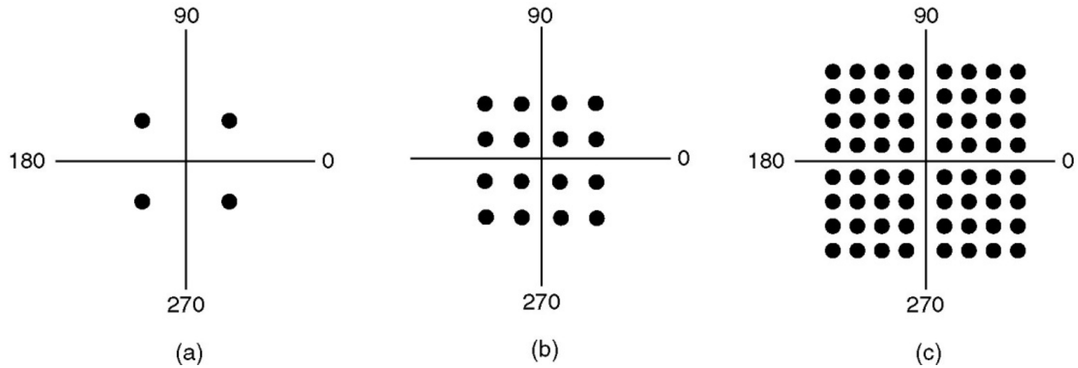



Figure: (a) QPSK, (b) QAM-16, (c) QAM-64

# Multiplexing Techniques

- Technique that allows the simultaneous transmission of multiple signal across a single data link

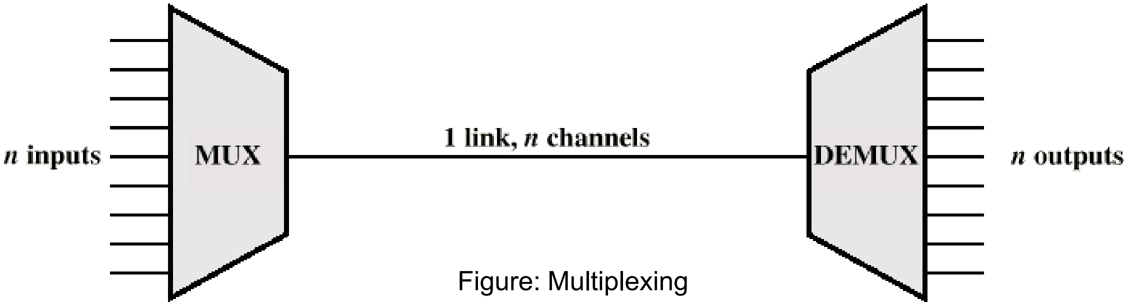
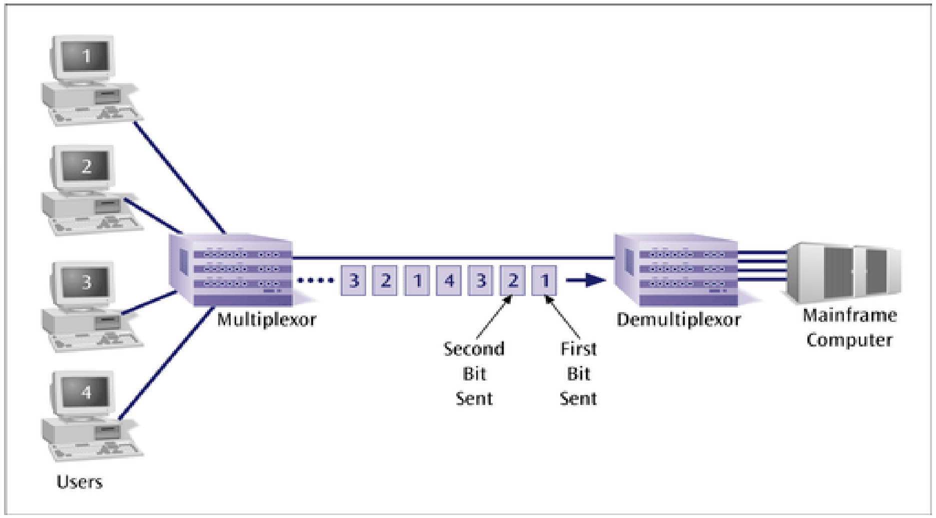



Figure: Multiplexing

- Time division multiplexing (TDM)
  - Sharing of the signal by dividing available transmission time on a medium
  - Digital signaling is used exclusively
  - Two forms: Synchronous TDM and Asynchronous (Statistical) TDM
- Code division multiplexing (CDM)
  - Advanced technique that allows multiple devices to transmit on the same frequencies at the same time using different codes
  - Used for mobile communications
- Frequency division multiplexing (FDM)
  - Useful bandwidth of medium exceeds required bandwidth of channel
  - Each signal is modulated to a different carrier frequency, so signals do not overlap (guard bands)
- Wavelength division multiplexing (WDM)
  - Give each message a different wavelength (frequency)
  - Easy to do with optical fiber

# Time Division Multiplexing



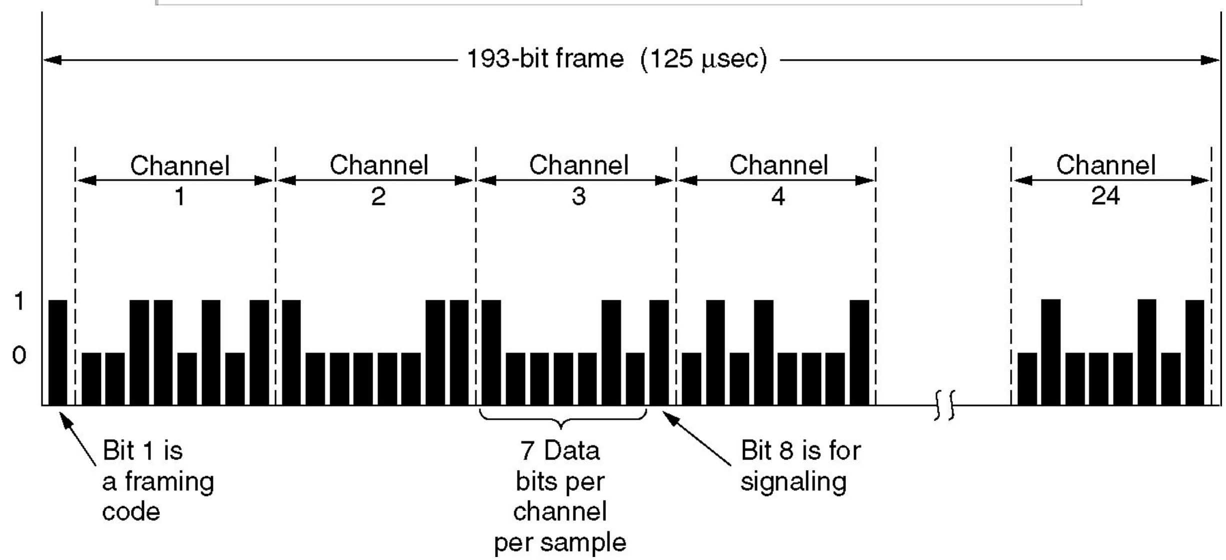




Figure: The T1 carrier (1.544 Mbps)

# Frequency Division Multiplexing

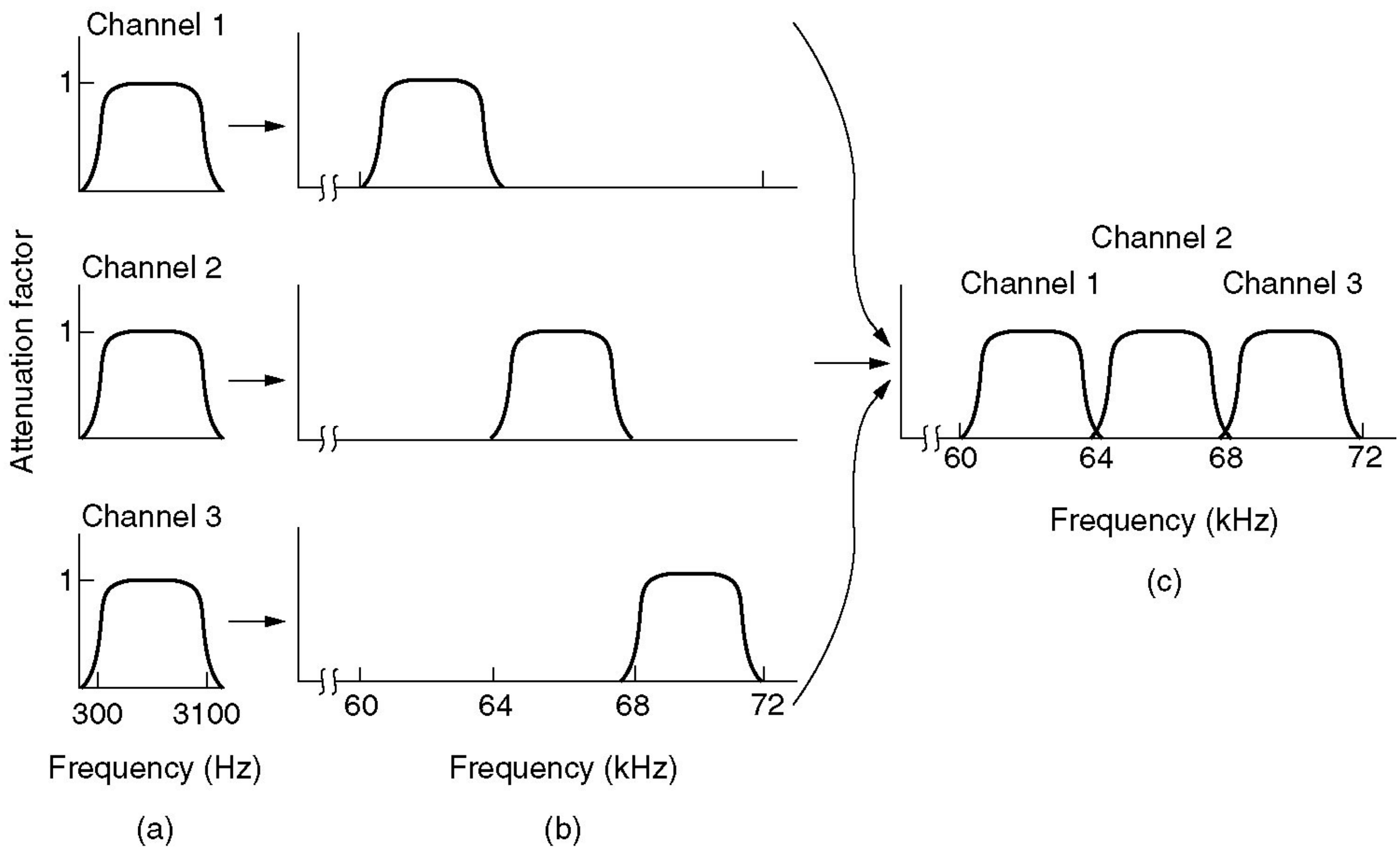



Figure: (a) The original bandwidths, (b) The bandwidths raised in frequency, (b) The multiplexed channel

# Wavelength Division Multiplexing

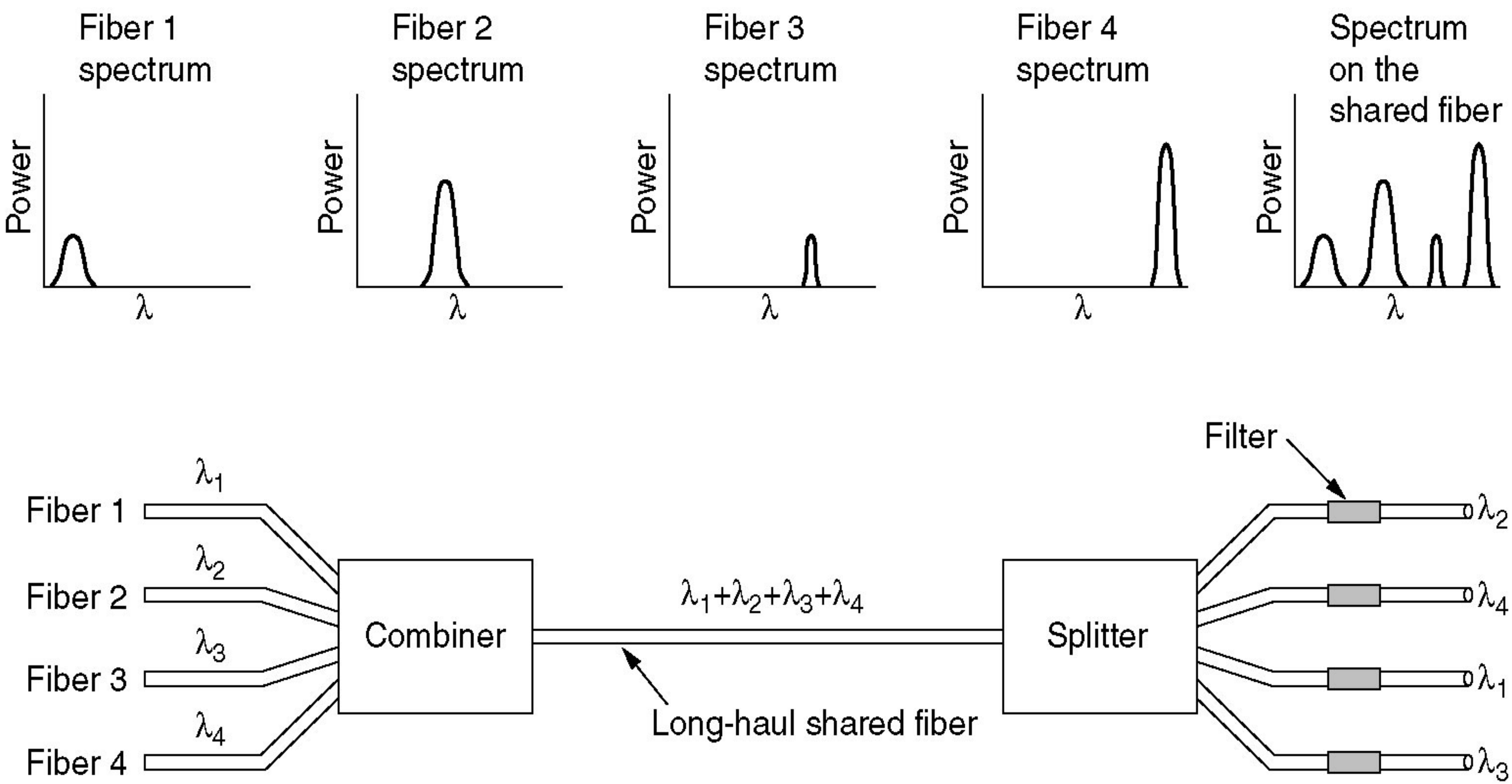



Figure: Different wavelength used in fiber optics transmission

# Code Division Multiple Access

A: 0 0 0 1 1 0 1 1
B: 0 0 1 0 1 1 1 0
C: 0 1 0 1 1 1 0 0
D: 0 1 0 0 0 0 1 0

(a)

A: (−1 −1 −1 +1 +1 −1 +1 +1)
B: (−1 −1 +1 −1 +1 +1 +1 −1)
C: (−1 +1 −1 +1 +1 +1 −1 −1)
D: (−1 +1 −1 −1 −1 −1 +1 −1)

(b)

Six examples:

| | | |
|---|---|---|
| – – 1 – | **C** | $S_1 = (-1\ {+1}\ {-1}\ {+1}\ {+1}\ {+1}\ {-1}\ {-1})$ |
| – 1 1 – | **B + C** | $S_2 = (-2\ \ 0\ \ 0\ \ 0\ {+2}\ {+2}\ \ 0\ {-2})$ |
| 1 0 – – | **A +** $\bar{\mathbf{B}}$ | $S_3 = (\ 0\ \ 0\ {-2}\ {+2}\ \ 0\ {-2}\ \ 0\ {+2})$ |
| 1 0 1 – | **A +** $\bar{\mathbf{B}}$ **+ C** | $S_4 = (-1\ {+1}\ {-3}\ {+3}\ {+1}\ {-1}\ {-1}\ {+1})$ |
| 1 1 1 1 | **A + B + C + D** | $S_5 = (-4\ \ 0\ {-2}\ \ 0\ {+2}\ \ 0\ {+2}\ {-2})$ |
| 1 1 0 1 | **A + B +** $\bar{\mathbf{C}}$ **+ D** | $S_6 = (-2\ {-2}\ \ 0\ {-2}\ \ 0\ {-2}\ {+4}\ \ 0)$ |

(c)

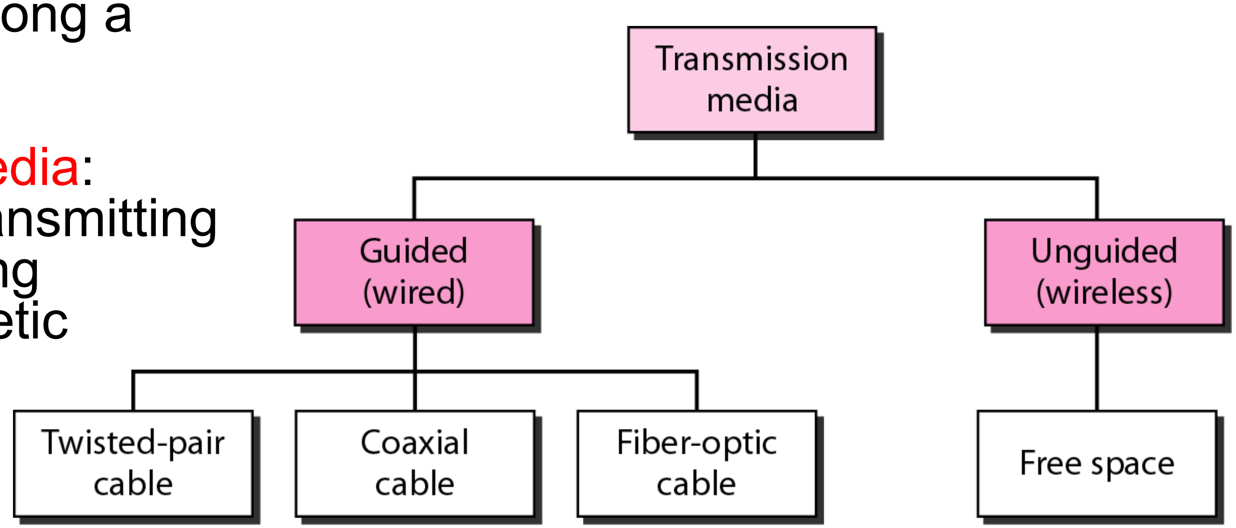
$S_1 \bullet C = (1 +1 +1 +1 +1 +1 +1 +1)/8 = 1$
$S_2 \bullet C = (2 +0 +0 +0 +2 +2 +0 +2)/8 = 1$
$S_3 \bullet C = (0 +0 +2 +2 +0 -2 +0 -2)/8 = 0$
$S_4 \bullet C = (1 +1 +3 +3 +1 -1 +1 -1)/8 = 1$
$S_5 \bullet C = (4 +0 +2 +0 +2 +0 -2 +2)/8 = 1$
$S_6 \bullet C = (2 -2 +0 -2 +0 -2 -4 +0)/8 = -1$

(d)

Figure: (a) Binary chip sequences for four stations, (b) Bipolar chip sequences, (c) Six examples of transmissions, (d) Recovery of station C's signal

# Transmission Media

- Transmission medium – the physical path between transmitter and receiver
- Repeaters or amplifiers may be used to extend the length of the medium
- Transmission media
  - Guided media: waves are guided along a physical path
  - Unguided media: means for transmitting but not guiding electromagnetic waves



# Twisted Pair

- Two insulated wires arranged in a spiral pattern
- Copper/steel coated with copper
- The signal is transmitted through one wire and a ground reference is transmitted in the other wire
- Typically twisted pair is installed in building telephone wiring
- Local loop connection to central telephone exchange is twisted pair
- Limited in distance, bandwidth and data rate due to problems with attenuation, interference and noise
  - "twisting" reduces low-frequency interference and crosstalk
  - "shielding" wire (e.g., STP) with metallic braid or sheathing reduces interference

# Shielded & Unshielded Twisted Pair

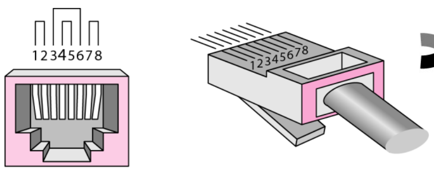
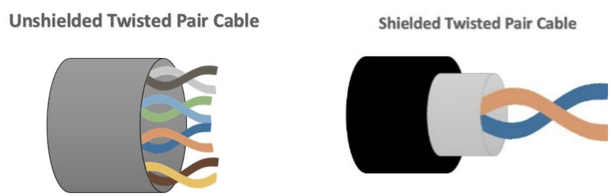



Figure: UTP connector


Figure: (a) Category 3 UTP, (b) Category 5 UTP



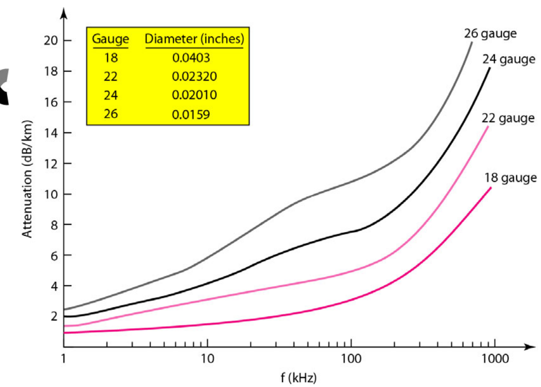



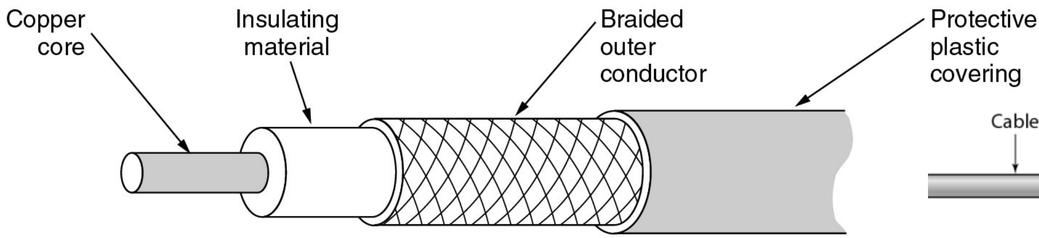

Figure: UTP performance

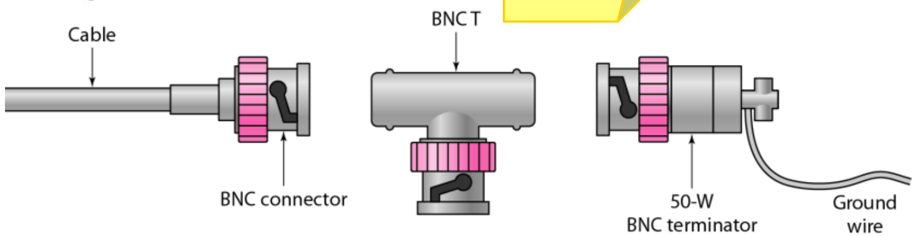
| Comparison | UTP | STP |
|---|---|---|
| Basic | a cable with wires that are twisted together | a twisted pair cable enclosed in foil or mesh shield. |
| Noise and crosstalk generation | High comparatively | Less susceptible to noise and crosstalk |
| Grounding cable | Not required | Necessarily required |
| Ease of handling | Easily installed as cables are smaller, lighter, and flexible | Installation of cables is difficult comparatively |
| Cost | Cheaper and does not require much maintenance | Moderately expensive |
| Data Rates | Slow comparatively | Provides high data rates |

| *Category* | *Specification* | *Data Rate (Mbps)* | *Use* |
|---|---|---|---|
| 1 | Unshielded twisted-pair used in telephone | < 0.1 | Telephone |
| 2 | Unshielded twisted-pair originally used in T-lines | 2 | T-1 lines |
| 3 | Improved CAT 2 used in LANs | 10 | LANs |
| 4 | Improved CAT 3 used in Token Ring networks | 20 | LANs |
| 5 | Cable wire is normally 24 AWG with a jacket and outside sheath | 100 | LANs |
| 5E | An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference | 125 | LANs |
| 6 | A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate. | 200 | LANs |
| 7 | Sometimes called SSTP (shielded screen twisted-pair). Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate. | 600 | LANs |

# Coaxial Cable

Go to ch.01 pg.19




- Two basic categories for coaxial cable used in LANs
  - Impedance of 50-ohm cable [baseband]
  - Impedance of 75-ohm cable [broadband or single channel baseband]
- Coaxial cable has better noise immunity for higher frequencies than twisted pair
- Coaxial cable provides much higher bandwidth than twisted pair
- However, coaxial cable is 'bulky'

# Baseband Coax vs. Broadband Coax

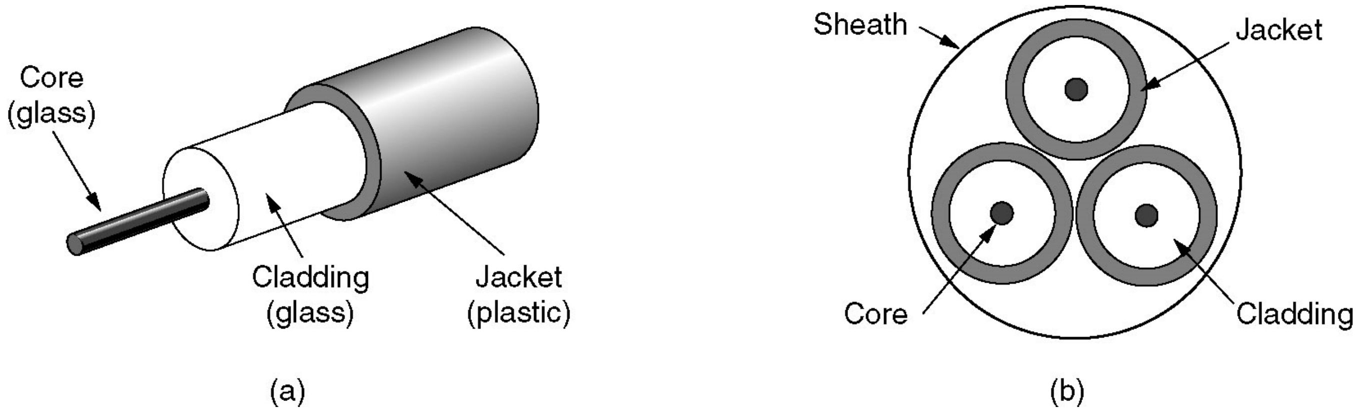
- Baseband Coax
  - 50-ohm cable (digital transmissions)
  - Uses Manchester encoding, geographical limit is a few kilometers
  - 10Base5 Thick Ethernet: thick (10 mm) coax, 10 Mbps, 500 m maximum segment length, 100 devices/segment, awkward to handle and install
  - 10Base2 Thin Ethernet: thin (5 mm) coax, 10 Mbps, 185 m maximum segment length, 30 devices/segment, easier to handle, uses T-shaped connectors

- Broadband Coax
  - 75-ohm cable (CATV system standard)
  - Used for both analog and digital signaling
  - Analog signaling – frequencies up to 500 MHz are possible
  - When FDM used, referred to as broadband
  - For long-distance transmission of analog signals, amplifiers are needed every few kilometers

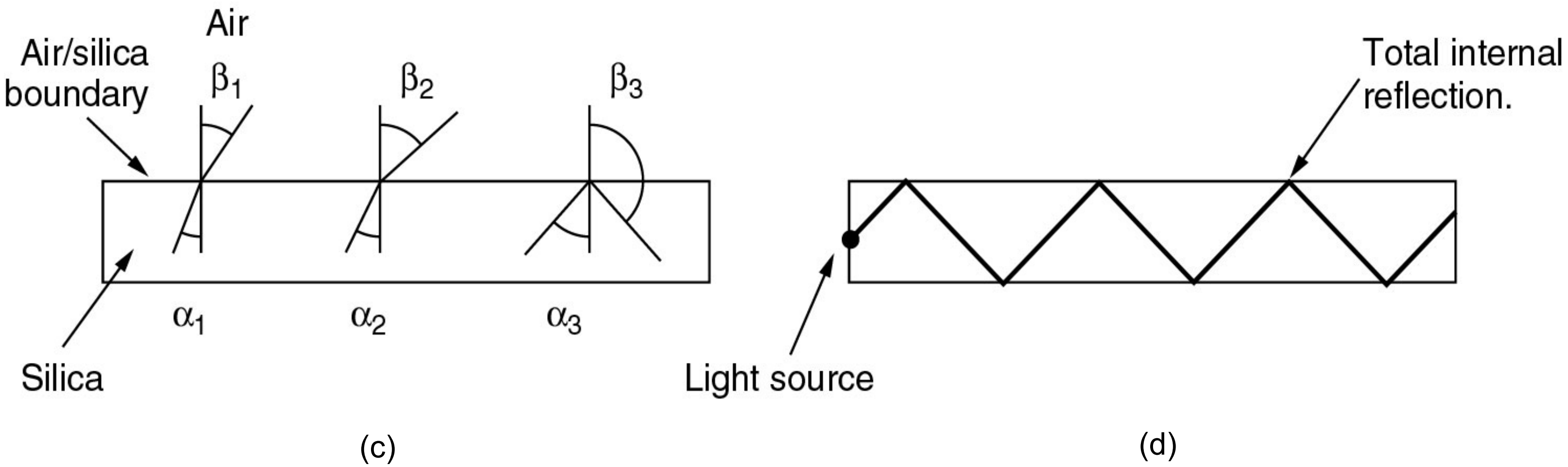
# Optical Fiber

- A thin flexible medium capable of conducting optical rays. Optical fiber consists of a very fine cylinder of glass (core) surrounded by concentric layers of glass (cladding)
- A signal-encoded beam of light (a fluctuating beam) is transmitted by total internal reflection, which occurs in the core because it has a higher optical density (index of refraction) than the cladding
- Attenuation in the fiber can be kept low by controlling the impurities in the glass
- Lowest signal losses are for ultrapure fused silica – but difficult to manufacture
- Optical fiber acts as a wavelength guide for frequencies in the range $10^{14}$ to $10^{15}$ Hz which covers the visible and part of the infrared spectrum
- 3 standard wavelengths: 850 nm (nanometers), 1300 nm, 1500 nm
- 1st generation: 850 nm, using LED (light-emitting diode) sources, 10 Mbps
- 2nd and 3rd generation: 1300 and 1500 nm using ILD (injection laser diode) sources, a few Gbps

# Optical Fiber (cont.)



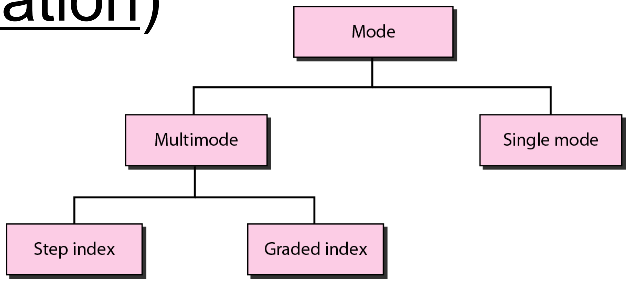

(a) Side view of a single fiber
(b) End view of a sheath with three fibers




(c) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles
(d) Light trapped by total internal reflection

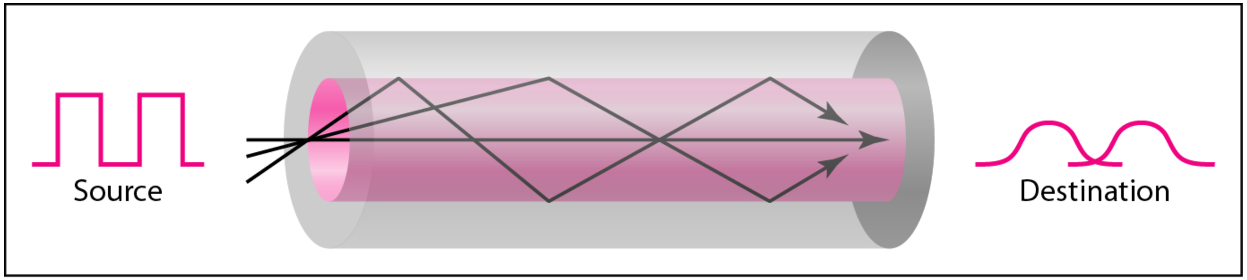
# Optical Fiber (cont.)

- Attenuation loss is lower at higher wavelengths
- 2 types of detectors used at the receiving end to convert light into electrical energy (photo diodes)
  - PIN detectors – less expensive, less sensitive
  - APD detectors
- ASK is commonly used to transmit digital data over optical fiber (referred to as intensity modulation)
- Three techniques:
  - Multimode step-index
  - Multimode graded-index
  - Single-mode step-index

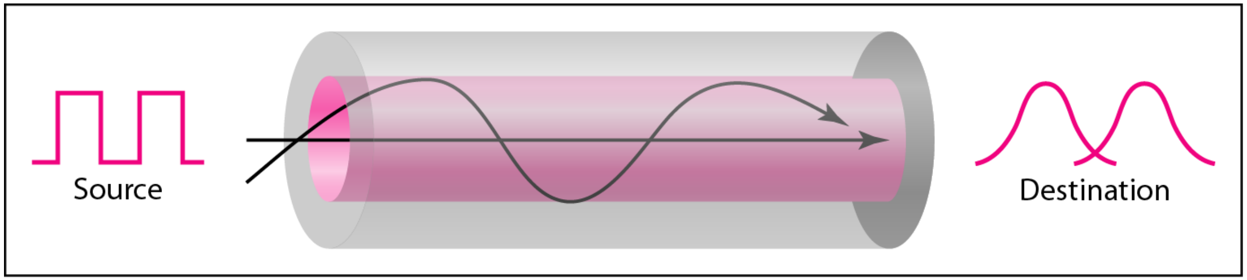



- Presence of multiple paths → differences in delay → optical rays interfere with each other
- A narrow core can create a single direct path which yields higher speeds. WDM yields more available capacity

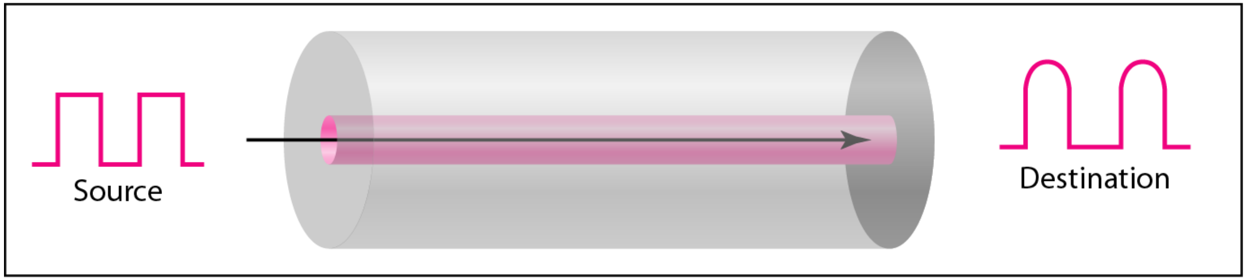
# Modes




a. Multimode, step index

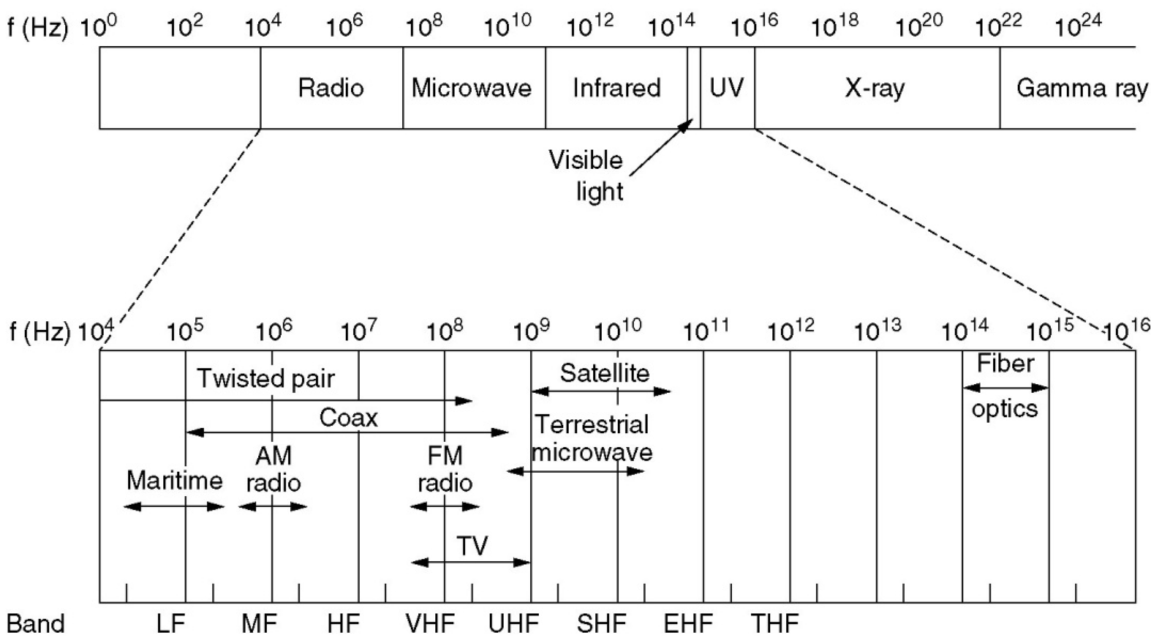



b. Multimode, graded index




c. Single mode

# Wireless Transmission




- Electromagnetic spectrum and its uses for communication
- Method of wireless transmission is classified into
  - Lightwave: Laser
  - Infrared
  - Radio wave: Narrow-band and Spread-spectrum
  - Microwave: Terrestrial and Satellite

# Lightwave Transmission

- Laser
  - High-powered laser transmitters can transmit data for several kilometers when line-of-sight communication is possible
  - Lasers can be used in many of the same situations as microwave links, without requiring an FCC license
  - Laser light technology is similar to infrared technology

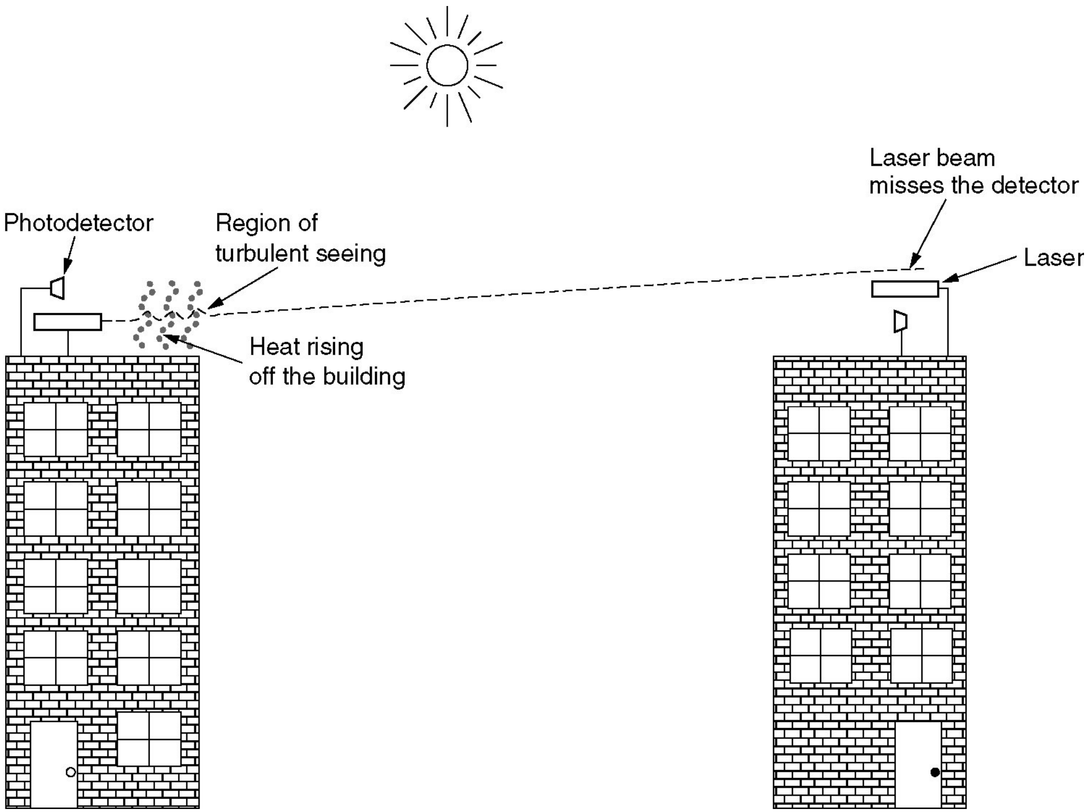



Figure: Convection currents can interfere with laser communication systems.
A bidirectional system with two lasers is pictured here

# Infrared

- Infrared technology allows computing devices to communicate via short-range wireless signals using infrared lights
- Typically limited to within 30 meters
- Infrared devices are insensitive to radio-frequency interference, but reception can be degraded by bright light
- For varieties of infrared communications
  - broadband optical telepoint
  - line-of-sight infrared
  - reflective infrared
  - scatter infrared

# Radio Wave

- Narrow-Band (NB) Radio Transmission
  - In NB (also called single-frequency radio), transmissions occur at a single radio frequency
  - The range of NB radio is higher than infrared, effectively enabling mobile computing over a limited area
  - Neither the receiver nor the transmitter must be placed along a direct line of sight; the signal can bounce off walls, buildings, and even the atmosphere, but heavy walls, such as steel or concrete enclosures, can block the signal
- Spread-Spectrum (SS) Radio Transmission
  - SS transmission uses multiple frequencies to transmit messages
  - It is a technique originally developed by the military to solve several communication problems
  - SS improves reliability, reduces sensitivity to interference and jamming
  - Two techniques employed are frequency hopping and direct sequence modulation

# Microwave

- Microwave
  - Microwave has applications in all three of the wireless networking scenarios: LAN, extended LAN, and mobile networking
  - Microwave communication can take two forms: terrestrial (ground) links and satellite links
  - The frequencies and technologies employed by these two forms are <u>same</u>
- Terrestrial microwave (TM)
  - TM communication employs <u>earth-based</u> transmitters and receivers
  - The frequencies used are in the low-GHz range, which limits all communications to line-of-sight
- Satellite microwave (SM)
  - SM systems relay transmissions through <u>communication satellites</u> that operate in geosynchronous orbits 22,300 miles above the earth
  - Satellites orbiting at this distance remain located above a fixed point
  - Earth stations use <u>parabolic antennas</u> to communicate with satellites
  - These satellites then can retransmit signals in broad or narrow beams, depending on the locations set to receive the signals

# Communication Satellites

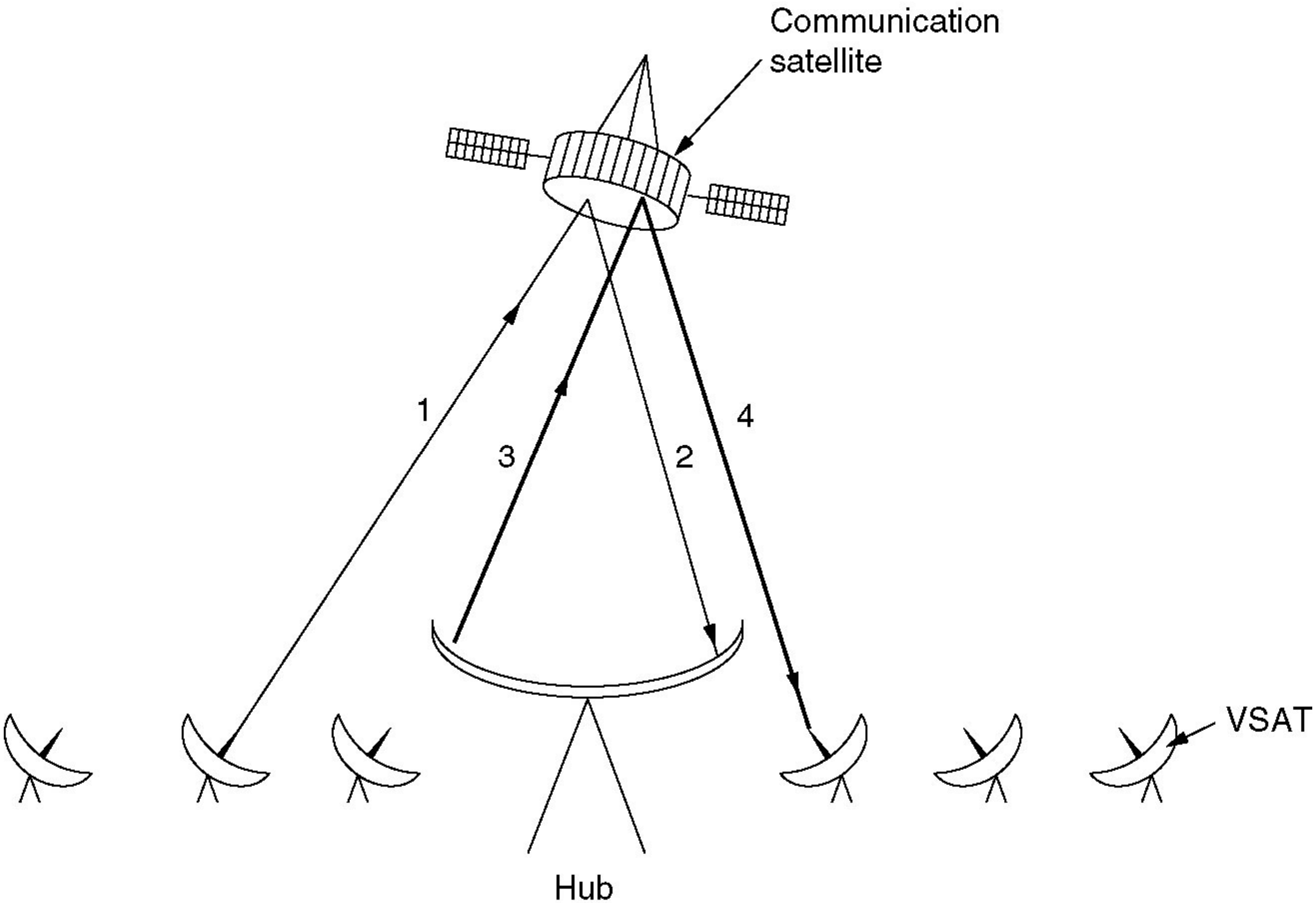



Figure: VSATs using a hub

# Announcement

- Next is Chapter 3 Data Link Layer
- 10:50 ~ 12:30 on 19 October (Wednesday)