(Network) Reference Models

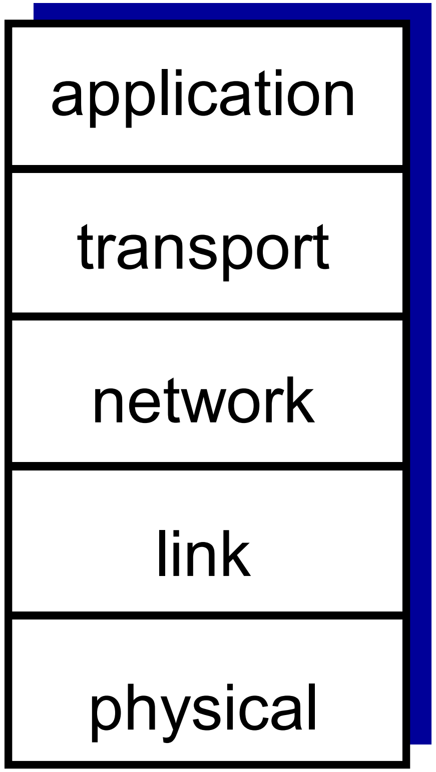
2 network models:

1. The OSI Reference Model (OSI)
2. The Internet Reference Model (TCP/IP)

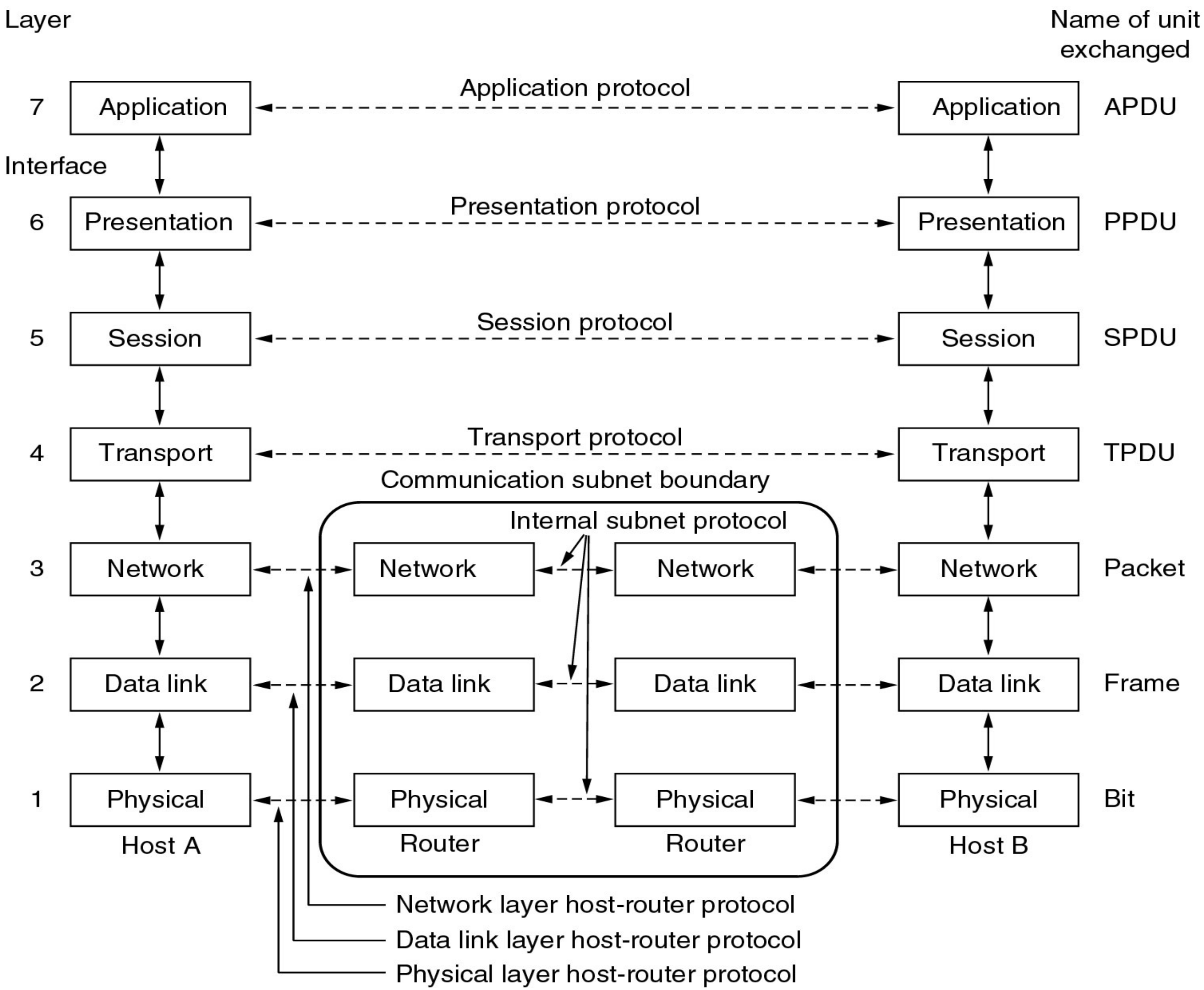
- A Comparison of OSI and TCP/IP
- A Critique of the OSI Model and Protocols
- A Critique of the TCP/IP Reference Model

Internet Model (aka Internet protocol stack)

- *application:* supporting network applications
  - FTP, SMTP, HTTP
- *transport:* process-process data transfer
  - TCP, UDP
- *network:* routing of datagrams from source to destination
  - IP, routing protocols
- *link:* data transfer between neighboring network elements
  - Ethernet, 802.111 (WiFi), PPP
- *physical:* bits "on the wire"



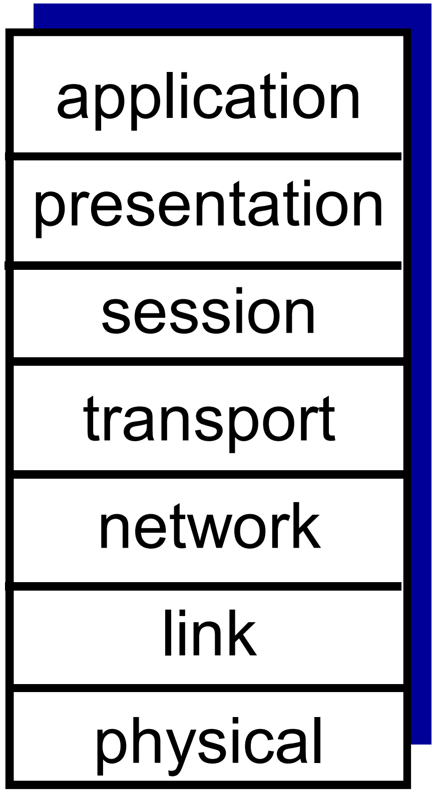
OSI Reference Model



The OSI reference model.

ISO/OSI reference model: 2 extra layers

- *presentation:* allow applications to interpret meaning of data, e.g., encryption, compression, machine-specific conventions
- *session:* synchronization, checkpointing, recovery of data exchange
- Internet stack "missing" these 2 layers!
  - these services, *if needed*, must be implemented in application
  - needed?



Internet protocol stack

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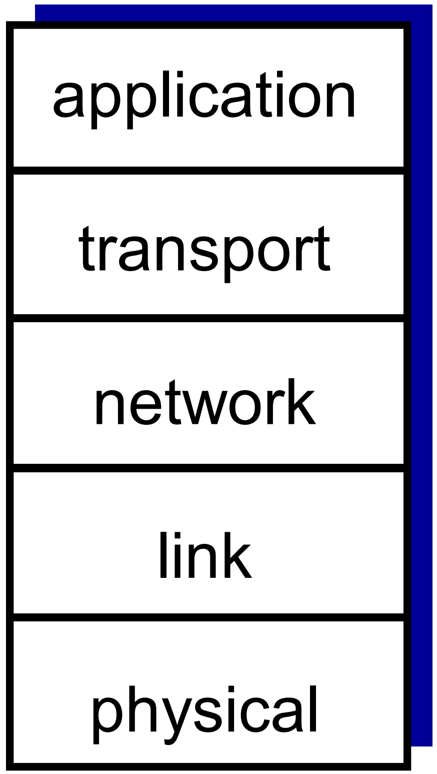
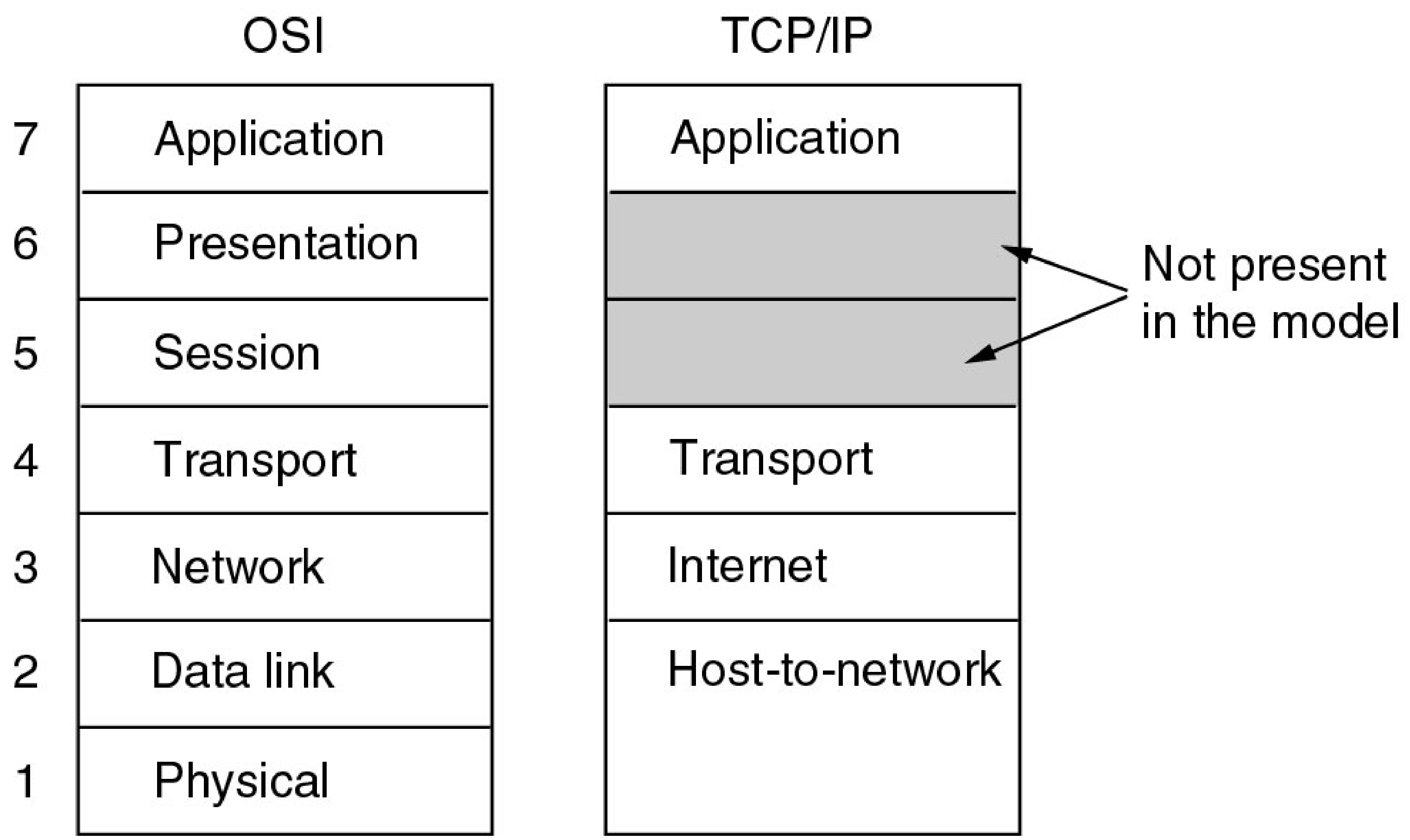
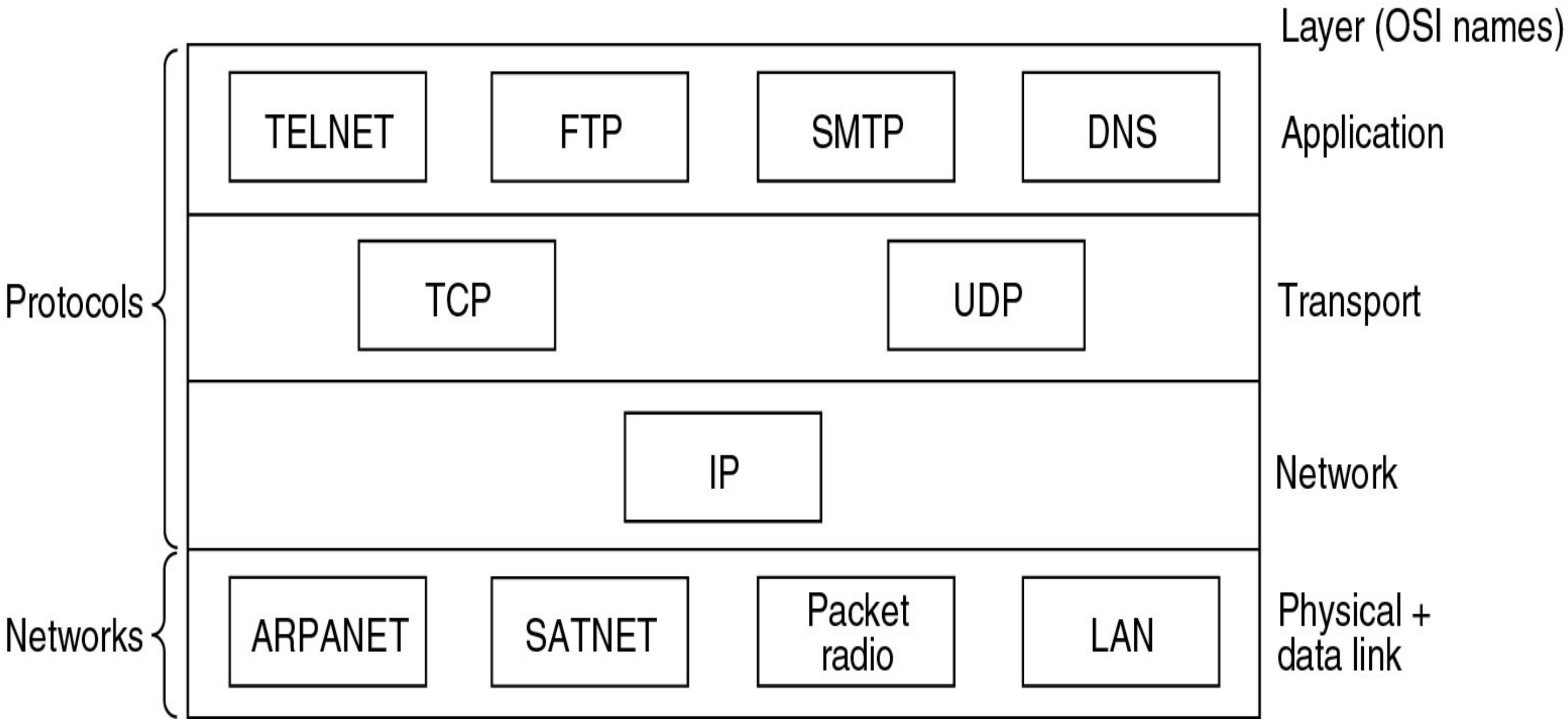


Reference Models Compared



The OSI and TCP/IP reference models.

TCP/IP Reference Model



Protocols and networks in the TCP/IP model initially.

Comparing OSI and TCP/IP Models

Concepts central to the OSI model

- Services
- Interfaces
- Protocols

- All are well-defined

A Critique of the OSI Model and Protocols

Why OSI did not take over the world

- Bad timing
- Bad technology
- Bad implementations
- Bad politics

A Critique of the TCP/IP Reference Model

Problems:

- Service, interface, and protocol not distinguished
- Not a general model
- Host-to-network "layer" not really a layer
- No mention of physical and data link layers
- Minor protocols deeply entrenched, hard to replace

Hybrid Model

5	Application layer
4	Transport layer
3	Network layer
2	Data link layer
1	Physical layer

The hybrid reference model.

Lec2: Background: Physical Layer (PHY)

PHY Transmission Terminology

Wired Transmission Media

PHY Transmission Impairments

Transmission of data

- Data must be transformed to electromagnetic signals to be transmitted. Why?

Transmitter

- Converts information into *signal* suitable for transmission
- Injects energy into communications medium or channel
  - Telephone converts voice into electric current
  - Modem converts bits into tones

Receiver

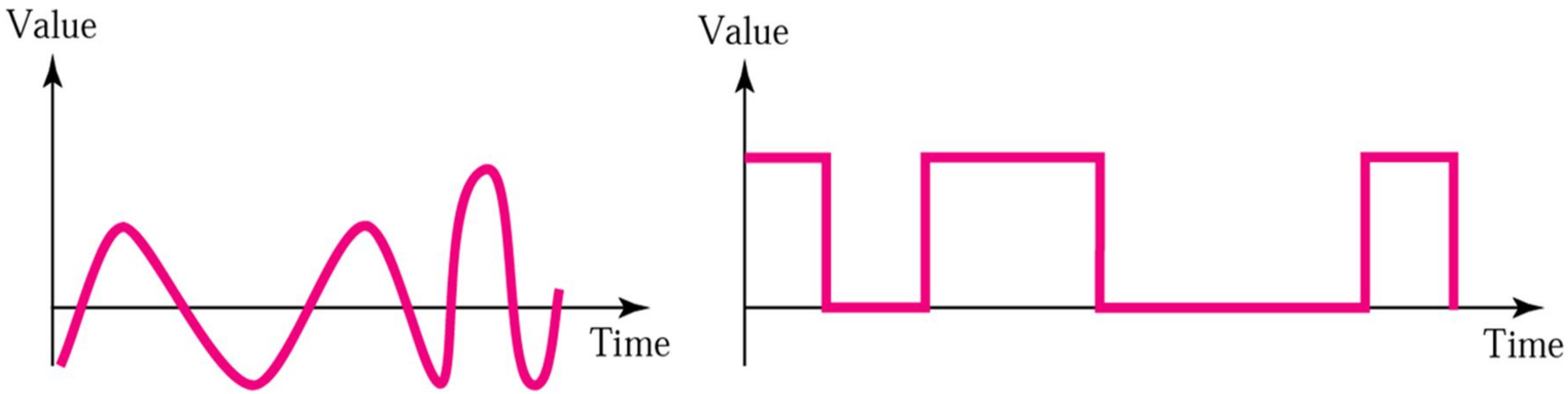
- Receives energy from medium
- Converts received signal into form suitable for delivery to user
  - Telephone converts current into voice
  - Modem converts tones into bits

Data : Analog or Digital Form

- Analog data : human voice, chirping of birds etc.
  - converted to Analog or digital signals
- Digital data: stored in computer memory,
  - converted to Analog or digital signals

Signals : Analog or digital

- 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) say, 0,1.

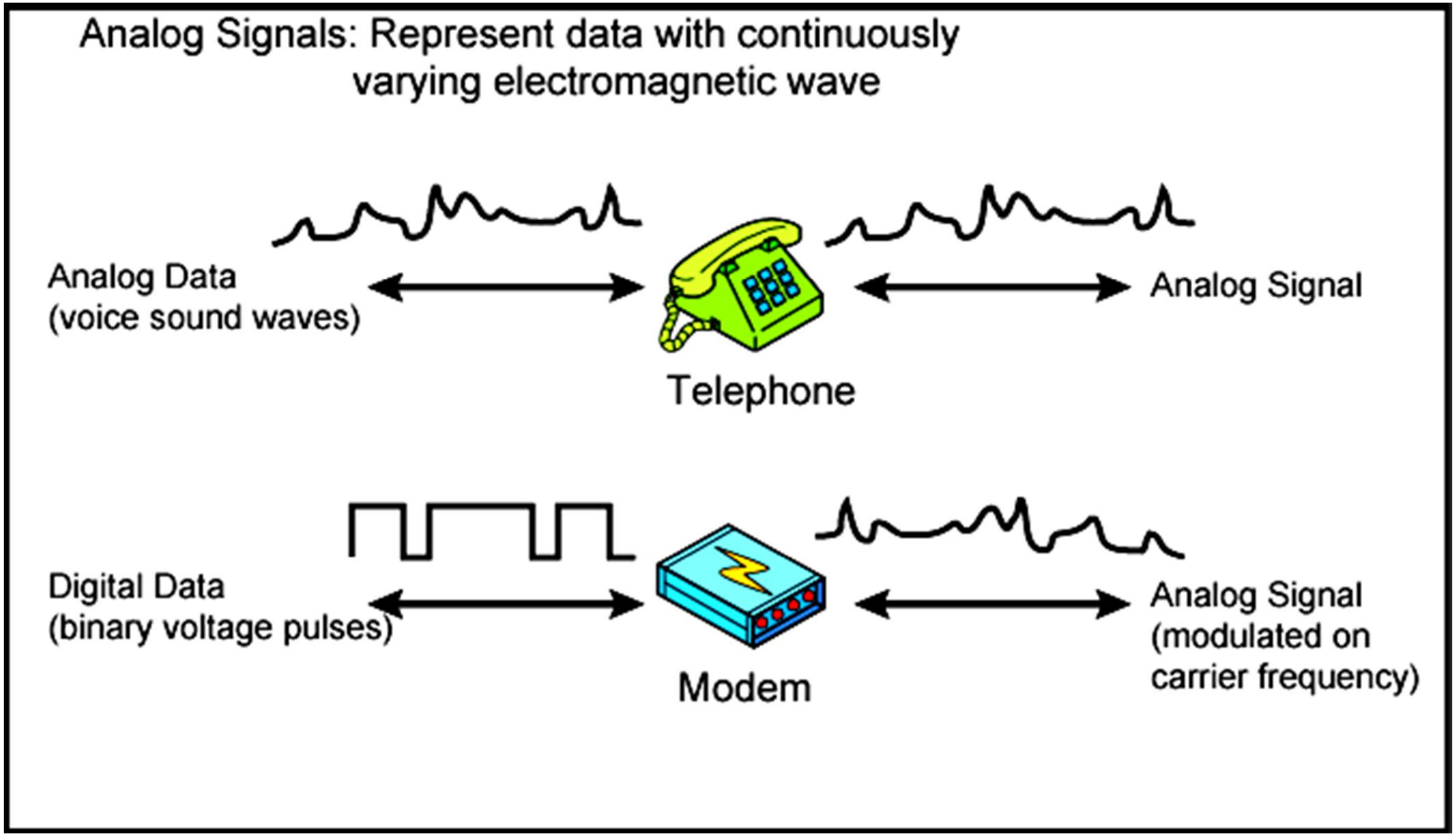


a. Analog signal b. Digital signal

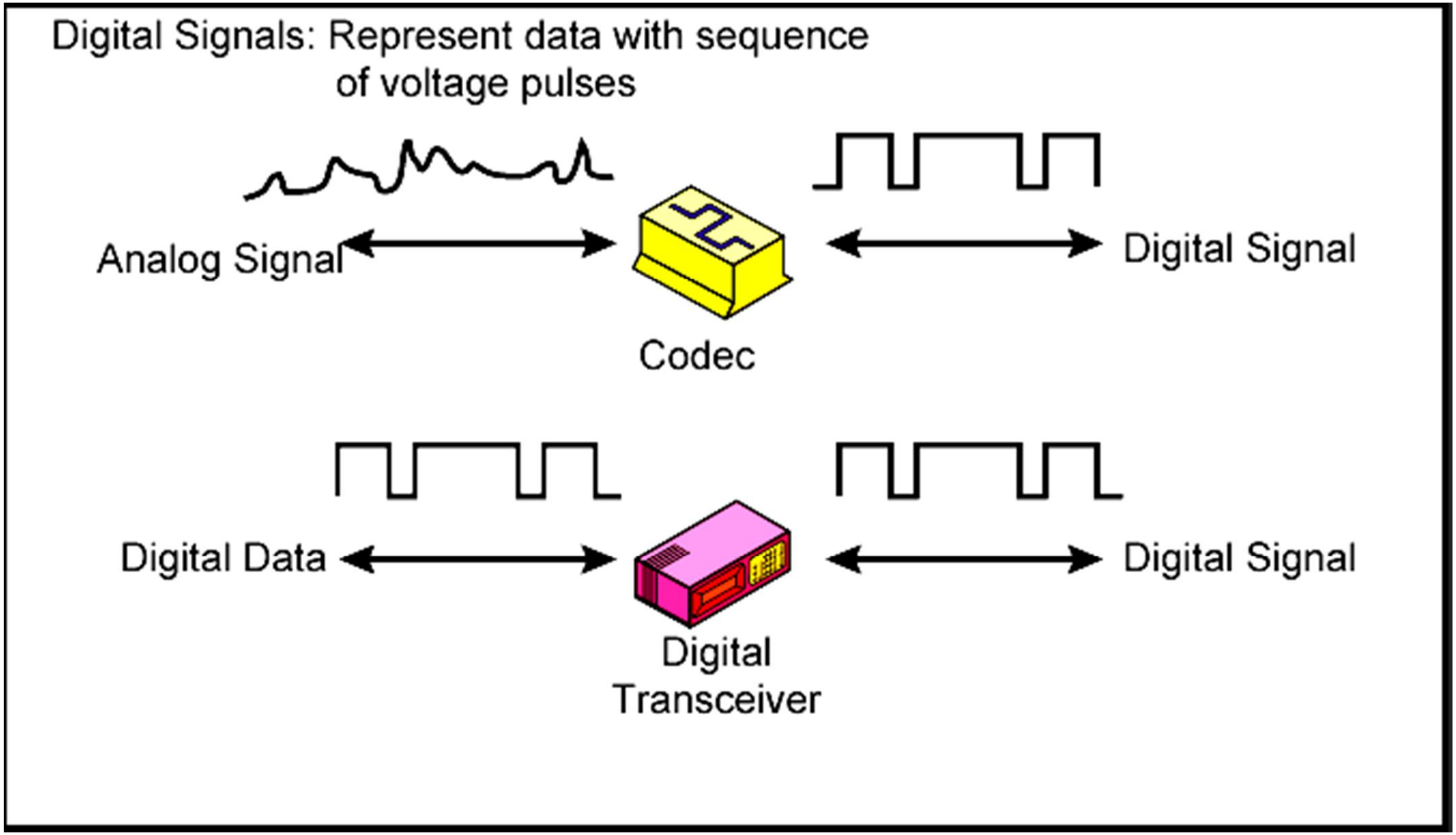
Examples of Transmision

- Analog data as analog signal : Human voice from our houses to the telephone exchange.
- Analog data as digital signal : most of the systems today : Say Human voice, images sent on digital lines .. New telephone system (digital exchanges)
- Digital data as analog signal : computer data sent over internet using analog line like telephone line. (say our house to the exchange)
- Digital data as digital signal: say from one digital exchange to another

Analog Signals

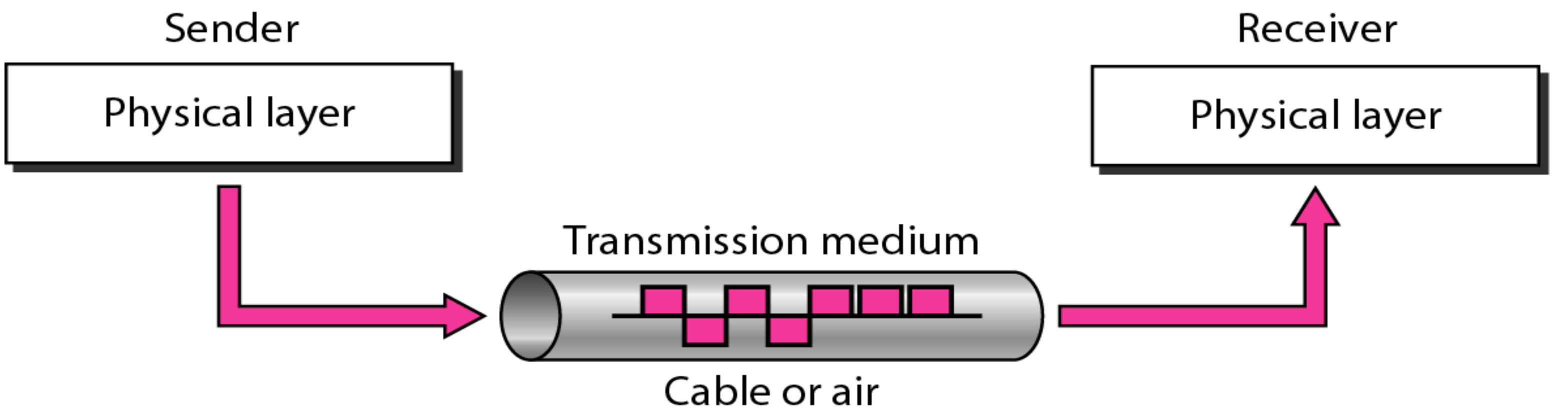


Digital Signals

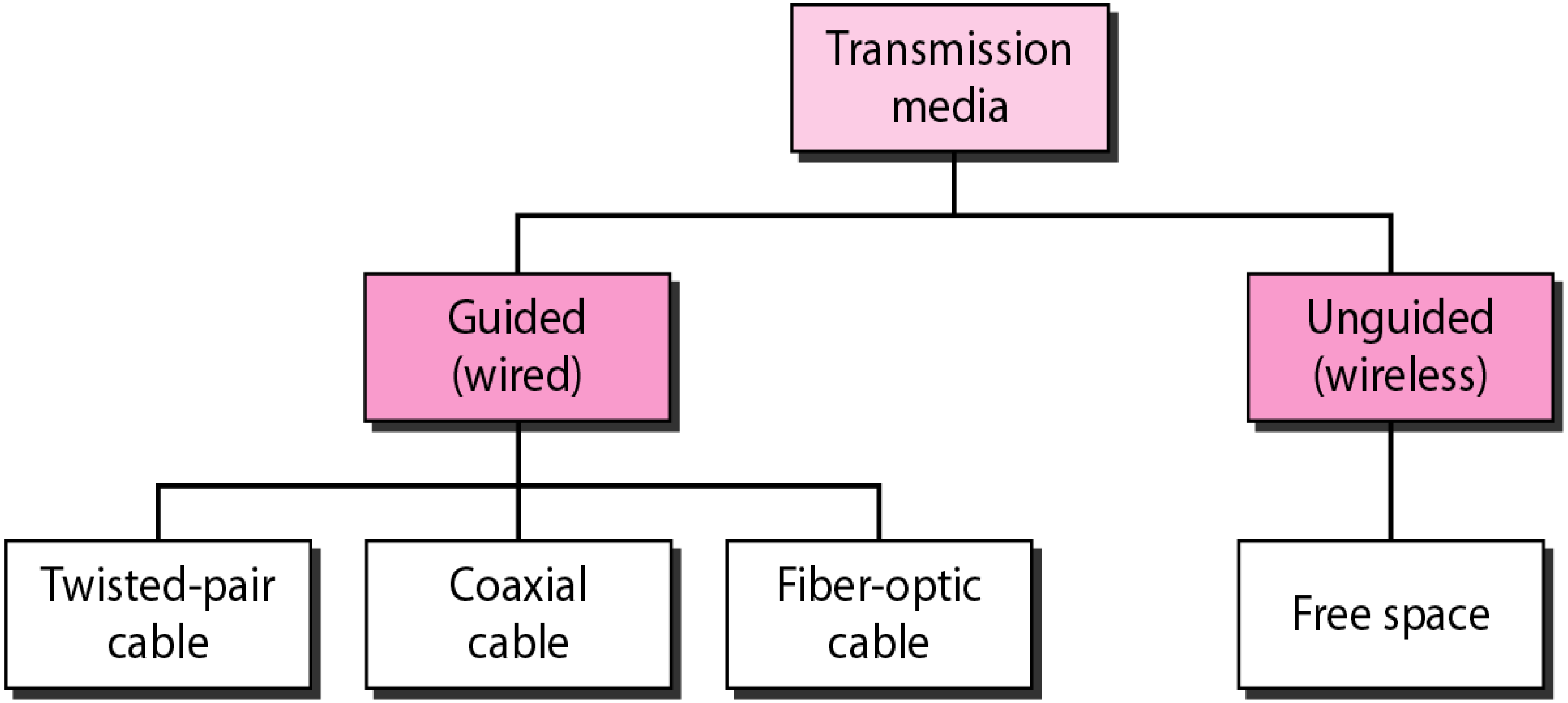


Transmission medium and physical layer

- Transmission media is not part of physical layer.
- It is below the physical layer (say layer 0?)
- But physical layer controls it
- **Communication:** in the form of electromagnetic waves

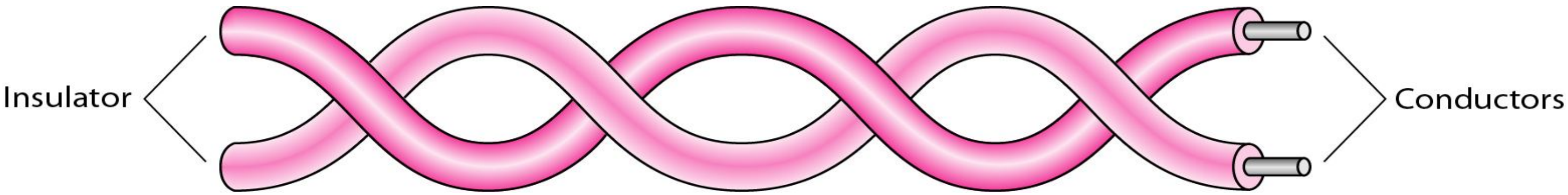


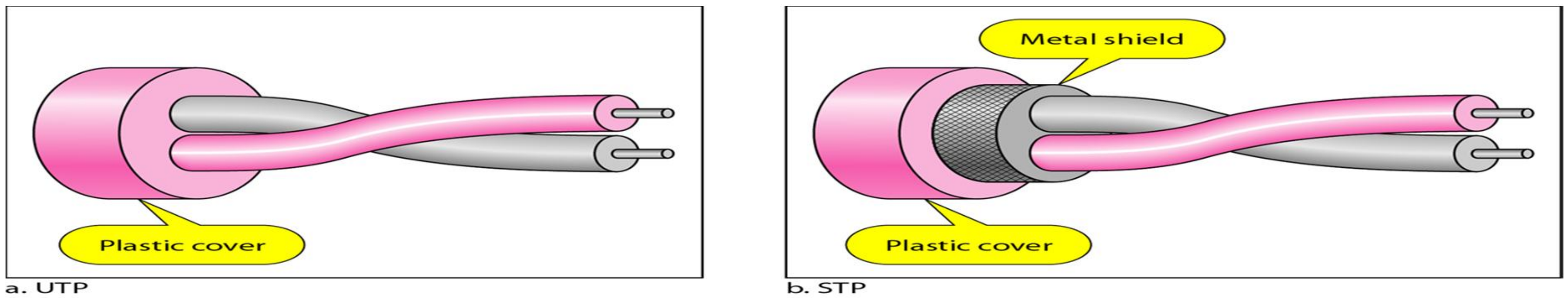
Classes of transmission media



Free space: air, vacuum, seawater

Twisted-pair cable





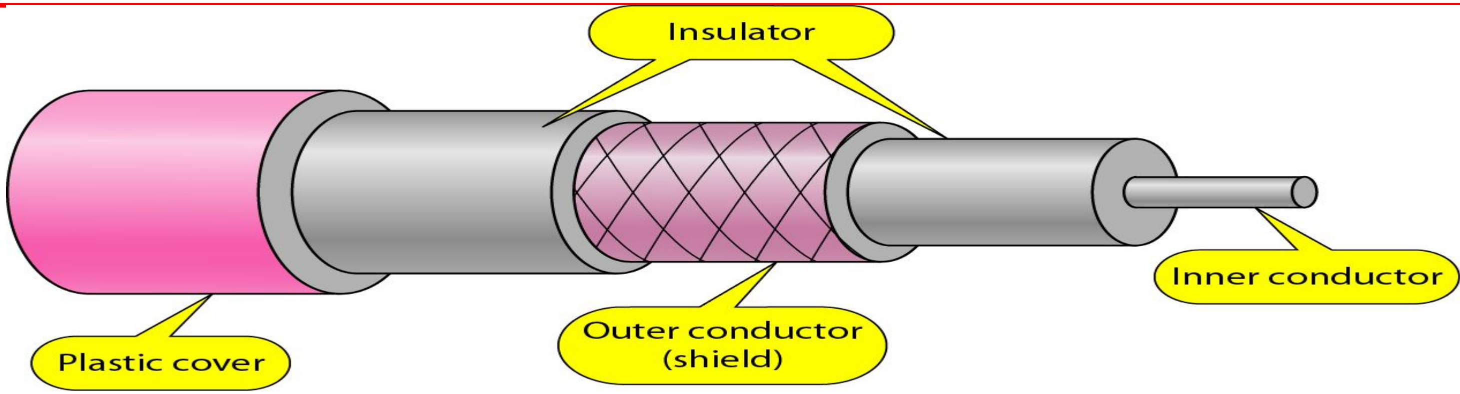
Twisted pair: least expensive, most widely used guided trans. medium.

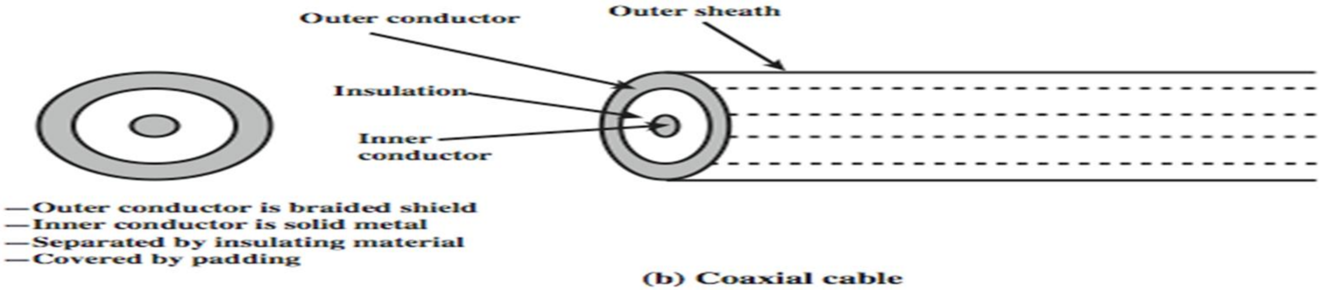
- **consists of two insulated copper wires arranged in a regular spiral pattern**
- **a wire pair acts as a single communication link**
- **pairs are bundled together into a cable**
- **commonly used in the telephone network and for communications w/n buildings**

Unshielded vs. Shielded Twisted Pair

- **Unshielded Twisted Pair (UTP)**
  - **ordinary telephone wire**
  - **cheapest**
  - **easiest to install**
  - **suffers from external electromagnetic interference**
- **Shielded Twisted Pair (STP)**
  - **has metal braid or sheathing that reduces interference**
  - **provides better performance at higher data rates**
  - **more expensive**
  - **harder to handle (thick, heavy)**

Coaxial cable

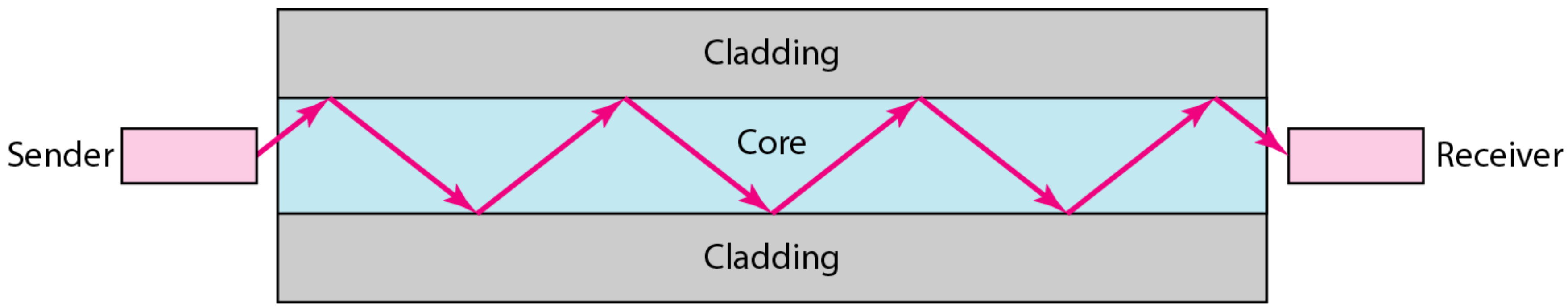




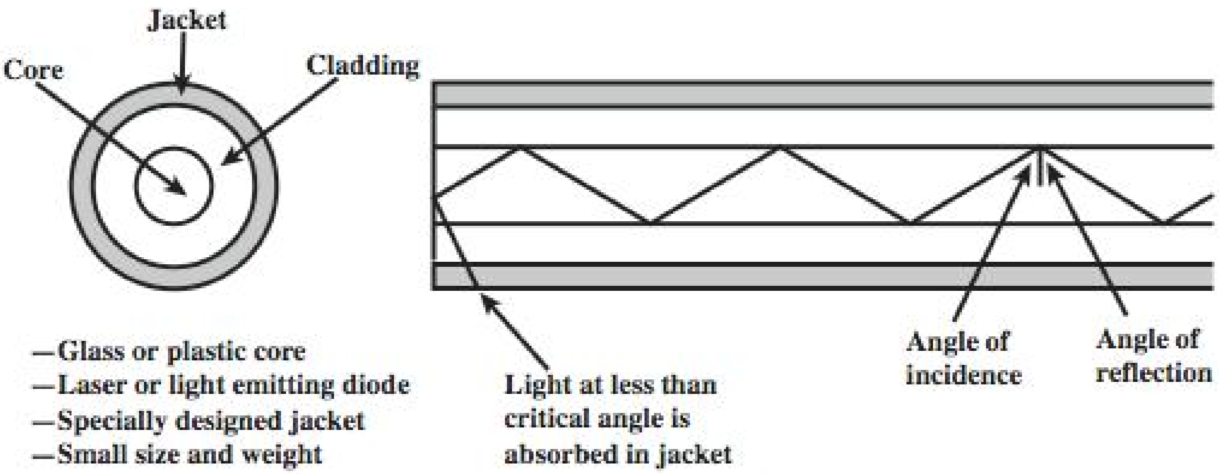
Coaxial cable: used over longer distances and support more stations on a shared line than twisted pair.

- consists of a hollow outer cylindric conductor that surrounds a single inner wire conductor
- widely used medium; in a wide variety of apps;TV dist, long distance tlf trans and LANs

Optical fiber



Optical Fiber



(c) Optical fiber

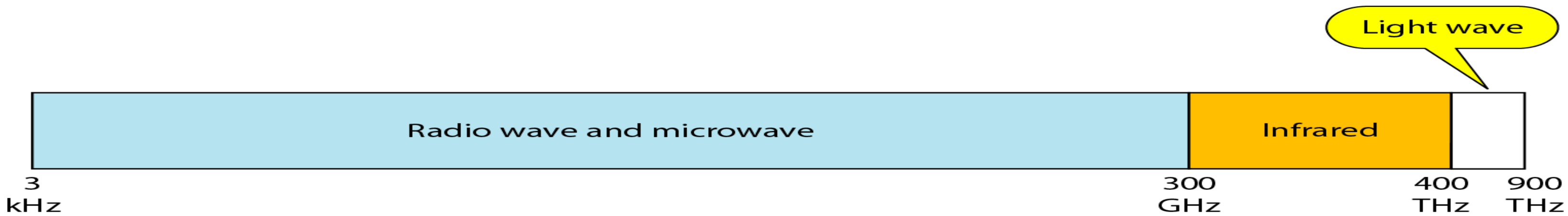
Optical fiber is a thin flexible medium capable of guiding an optical ray.

- **various glasses and plastics can be used to make optical fibers**
- **has a cylindrical shape with three sections – core, cladding, jacket**
- **widely used in long distance telecommunications**
- **performance, price and advantages have made it popular to use**

UNGUIDED MEDIA: WIRELESS

- *Unguided media transport electromagnetic waves without using a physical conductor.*
- *This type of communication is often referred to as* ***wireless communication****.*

- *Below is the* ***electromagnetic spectrum*** *for wireless communication*



Usages

- **Radio waves** are used for multicast communications, such as radio and television
- **Microwaves** are used for unicast communication such as cellular telephones, satellite networks, and wireless LANs.
- **Infrared signals** can be used for short-range communication in a closed area using line-of-sight propagation.

Transportation of Electronic Waves

- **direct link** :
  - transmission path between two devices in which signals propagate directly from transmitter to receiver
  - no intermediate device, other than amplifiers or repeaters used to increase signal strength. Note that this term can apply to both **guided and unguided media.**
- A **guided** transmission medium is **point-to-point** if it provides a direct link between two devices and those are the only two devices sharing the medium.
- In a **multipoint guided** configuration, more than two devices share the same medium.

Electromagnetic signals

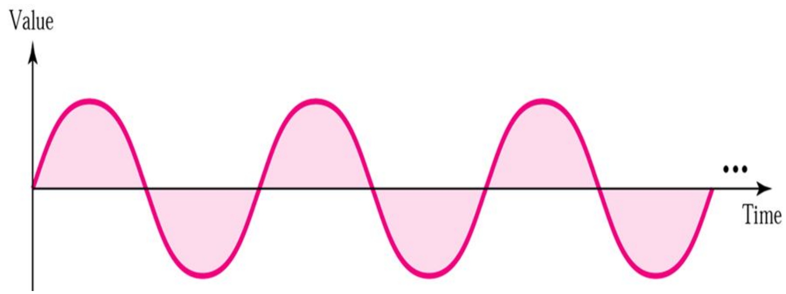
- used as a means to transmit data
- a signal is generated by the **transmitter** and transmitted over a medium.
- The signal is a function of time, but it can also be expressed as a function of frequency;
- that is, the signal consists of components of different frequencies. It turns out that the **frequency domain** view of a signal is more important to an understanding of data transmission than a **time domain** view.
- Both views are introduced here.

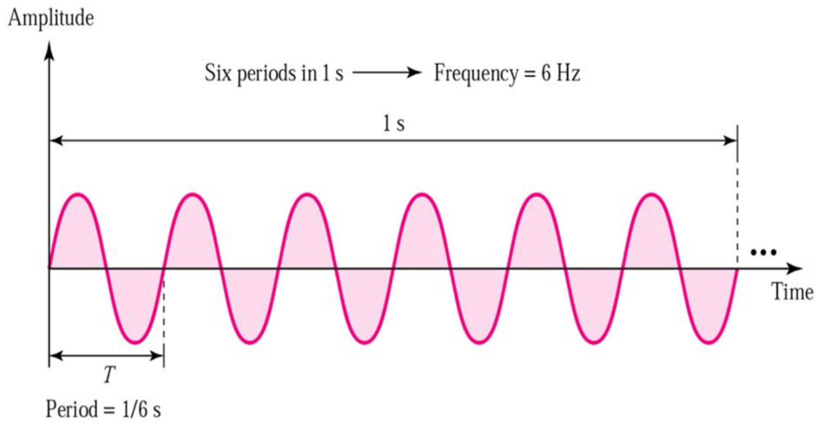
Time Domain Concepts

- Viewed as a function of time, an electromagnetic signal can be either analog or digital.
- An **analog signal** is one in which the signal intensity varies in a smooth, or **continuous**, fashion over time; no breaks or discontinuities in the signal.
- A **digital signal** is one in which the signal intensity maintains a constant level for some period of time and then abruptly changes to another constant level, in a **discrete** fashion.
- The analog signal might represent speech, and the digital signal might represent binary 1s and 0s.

Periodic vs aperiodic

- The simplest sort of signal
- **periodic signal** the same signal pattern repeats over time.
- shows an example of a periodic continuous signal (sine wave), period and frequency.

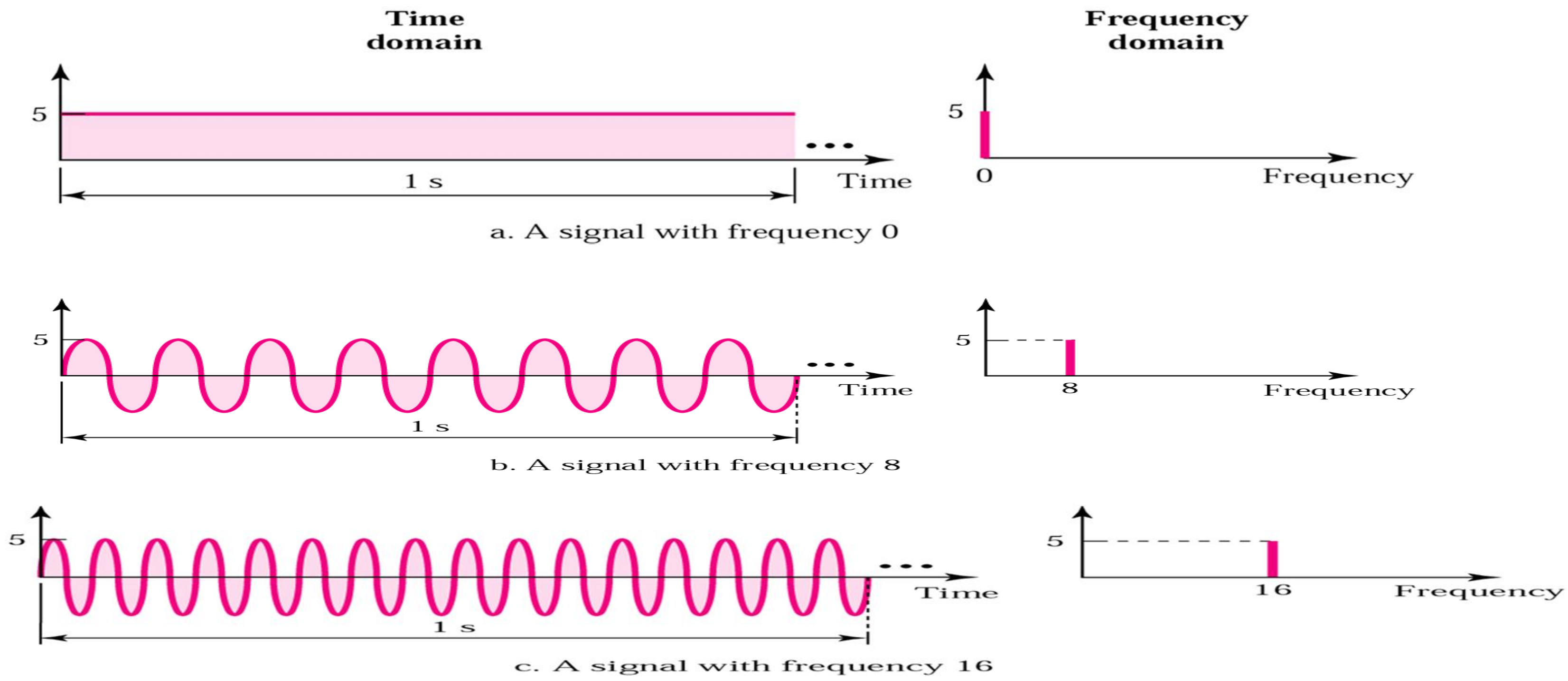




- Mathematically, a signal $s(t)$ is defined to be periodic if and only if
  - $s(t + T) = s(t) \qquad -\infty < t < +\infty$
- where the constant T is the period of the signal (T is the smallest value that satisfies the equation). Otherwise, a signal is **aperiodic**.

Frequency Domain

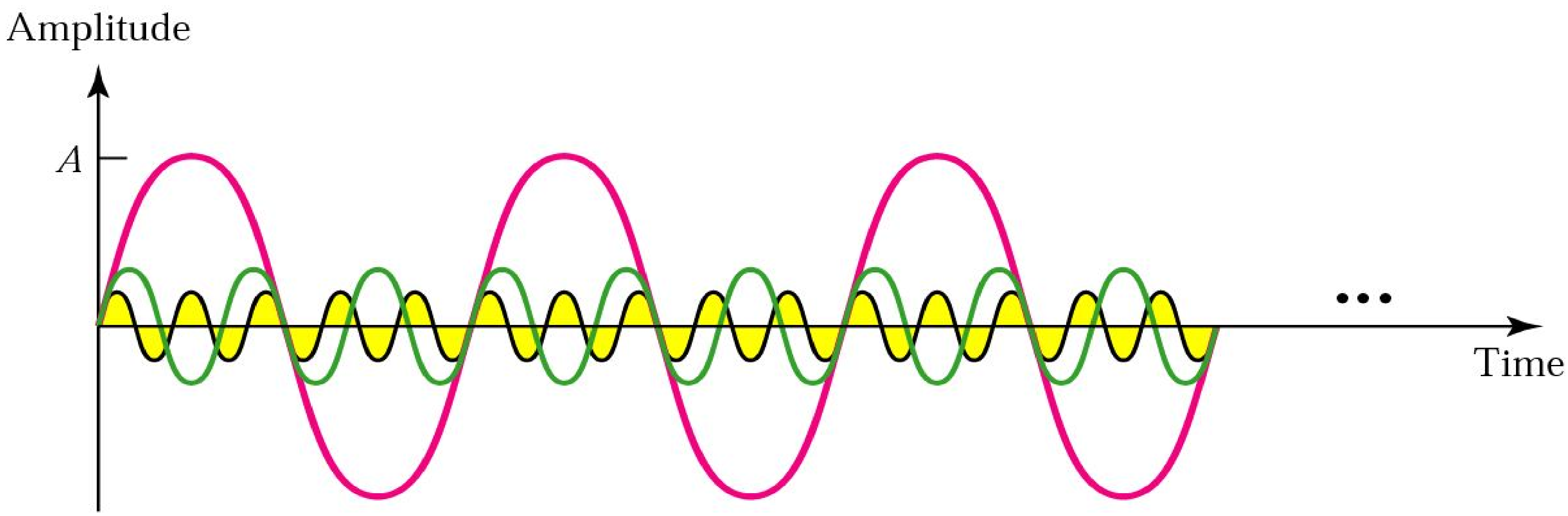
- If a signal does not change at all, its frequency is zero.
- If it changes instantaneously, its frequency is infinite.
- An analog signal is best represented in the frequency domain.



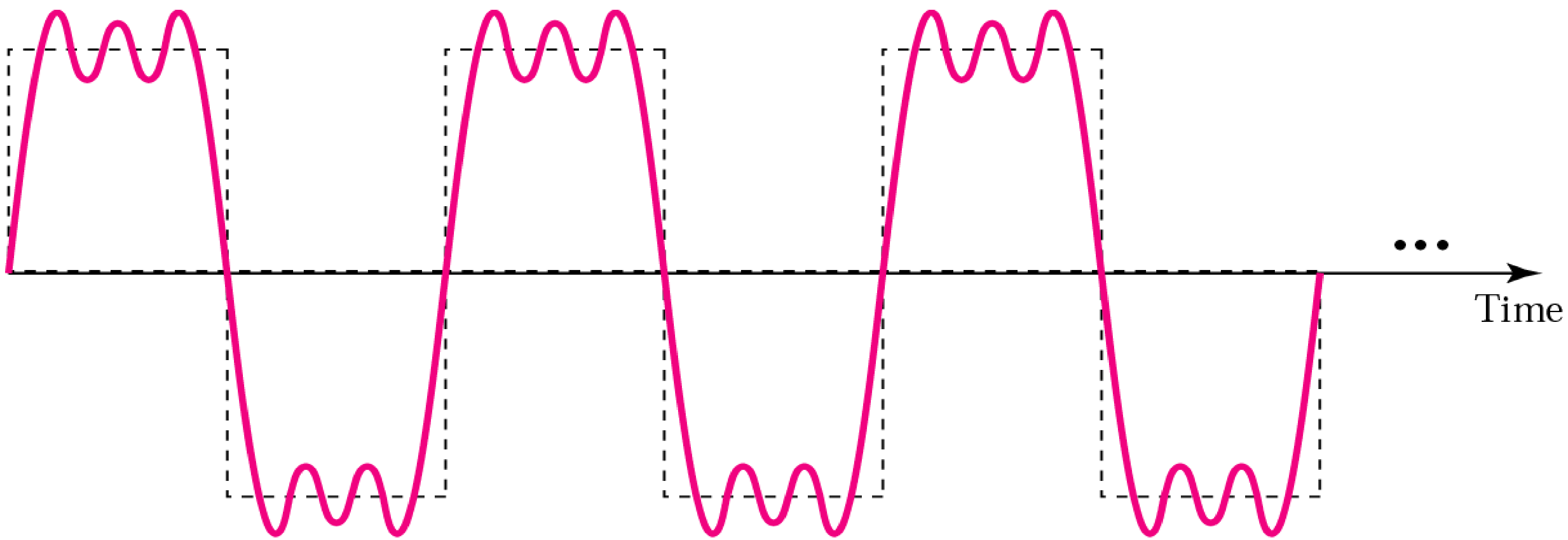
Composite Signals

- If we want to use sine wave for communication, we need to change one or more of its characteristics. For eg., to send 1 bit, we send a maximum amplitude, and to send 0, the minimum amplitude.
- When we change one or more characteristics of a single-frequency signal, it becomes a composite signal made up of many frequenies.

Three harmonics



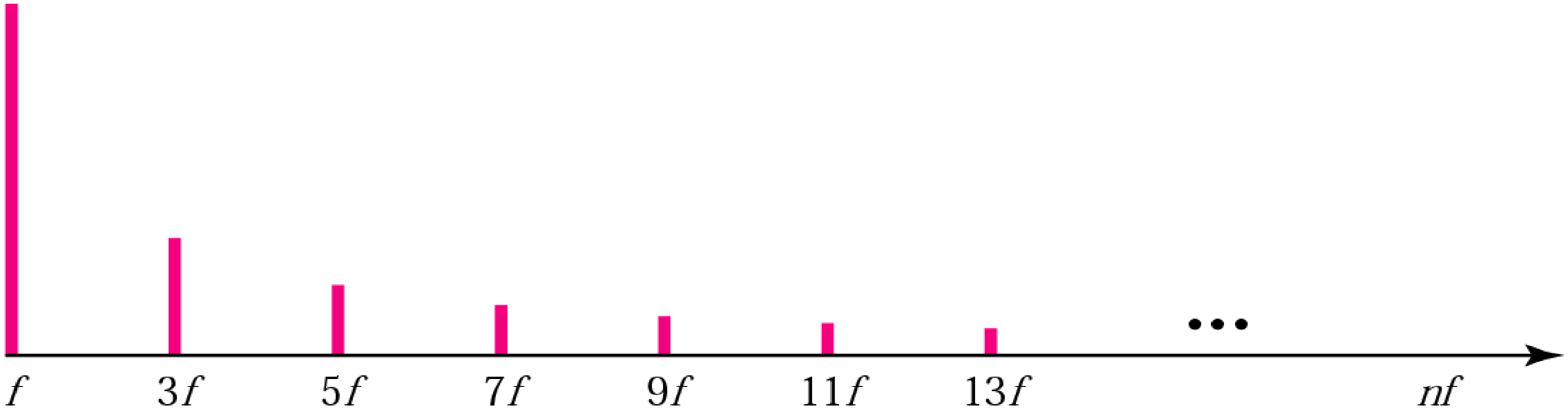
Adding first three harmonics



Frequency spectrum of a signal

- The description of a signal using the frequency domain and containing all its components is called the frequency spectrum of the signal.

Frequency spectrum comparison (shown by Fourier Analysis)

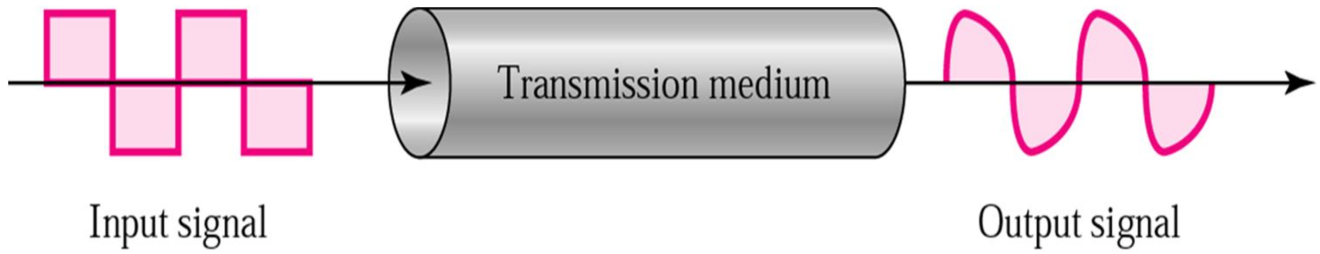


a. Frequency spectrum of a square wave

b. Frequency spectrum of an approximation with only three harmonics

Composite Signal and Transmission Medium

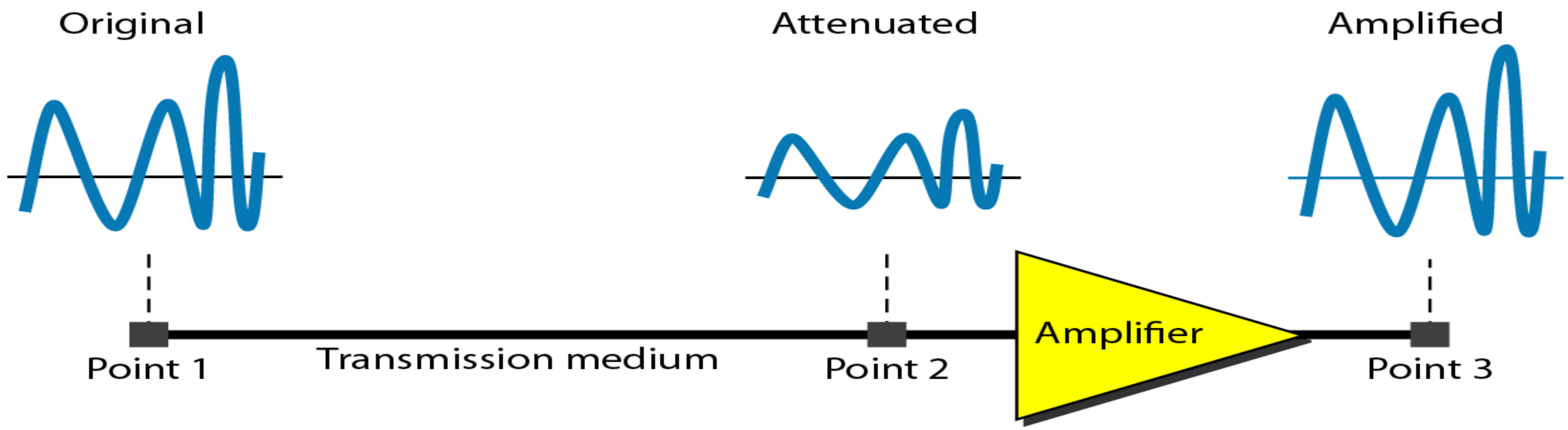
- A signal needs to pass thru a transmission medium. A transmission medium may pass some frequencies, may block few and weaken others.
- This means when a composite signal, containing many frequencies, is passed thru a transmission medium, we may not receive the same signal at the other end.



Transmission Impairments

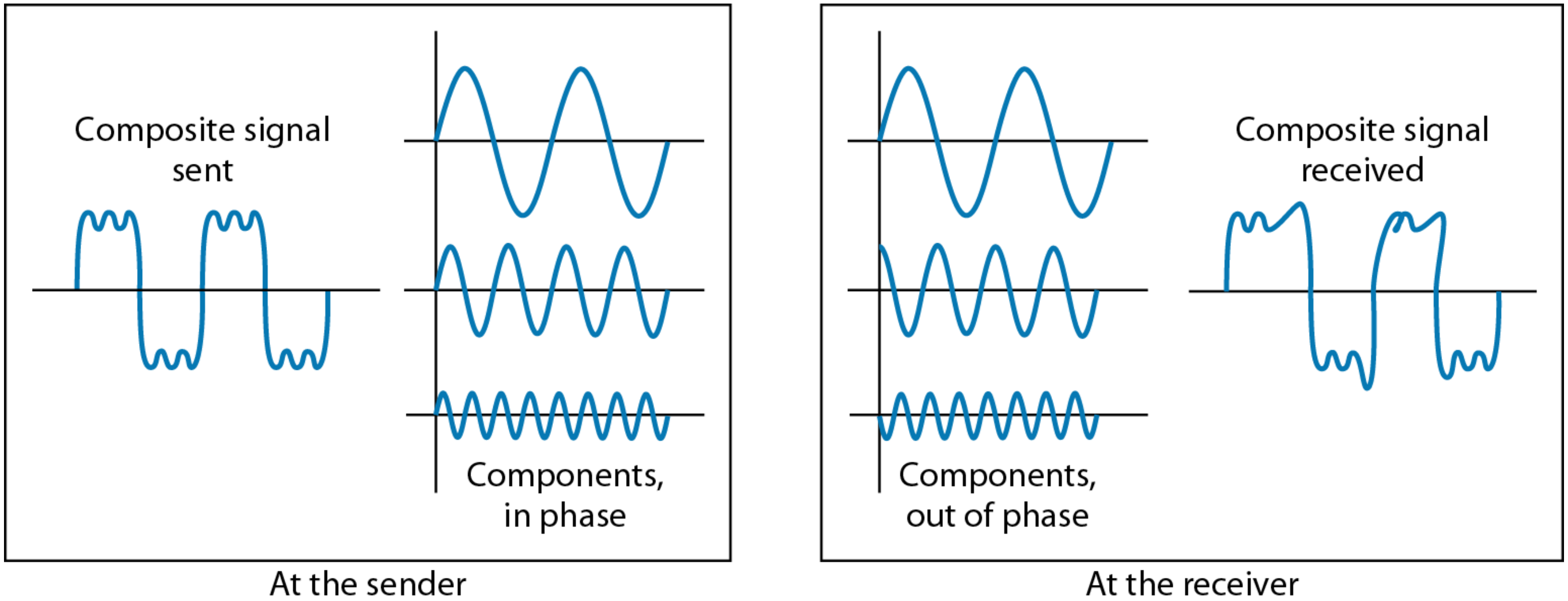
- Signal received may differ from signal transmitted
- Transmission media are not perfect. The imperfection causes signal impairment
- Analog - degradation of signal quality
- Digital - bit errors
- Mostly **caused** by
  - Attenuation
  - distortion
  - Noise
- Signal to Noise Ratio and Capacity calculation

Attenuation

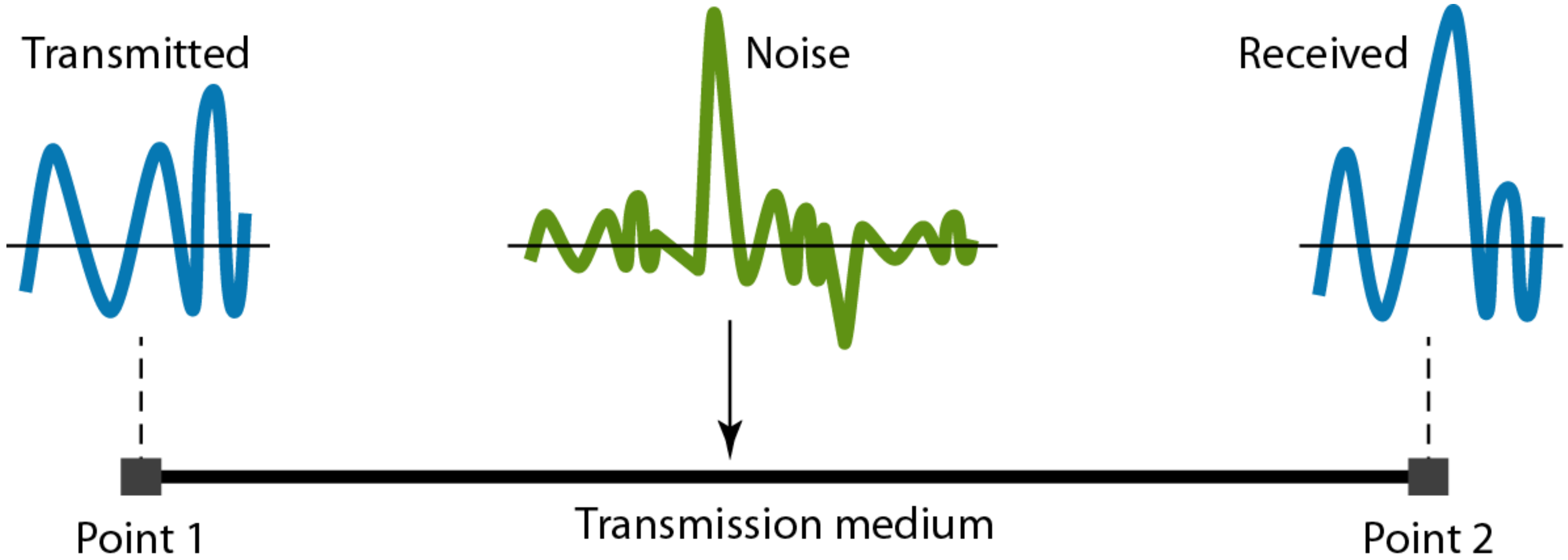


- Signal strength falls off with distance
- Depends on medium
- Received signal strength:
  - must be enough to be detected
  - must be sufficiently higher than noise to be received without error
- Attenuation is an increasing function of frequency

Distortion


Composite signal
sent
Components,
in phase
At the sender
Components,
out of phase
Composite signal
received
At the receiver

Noise

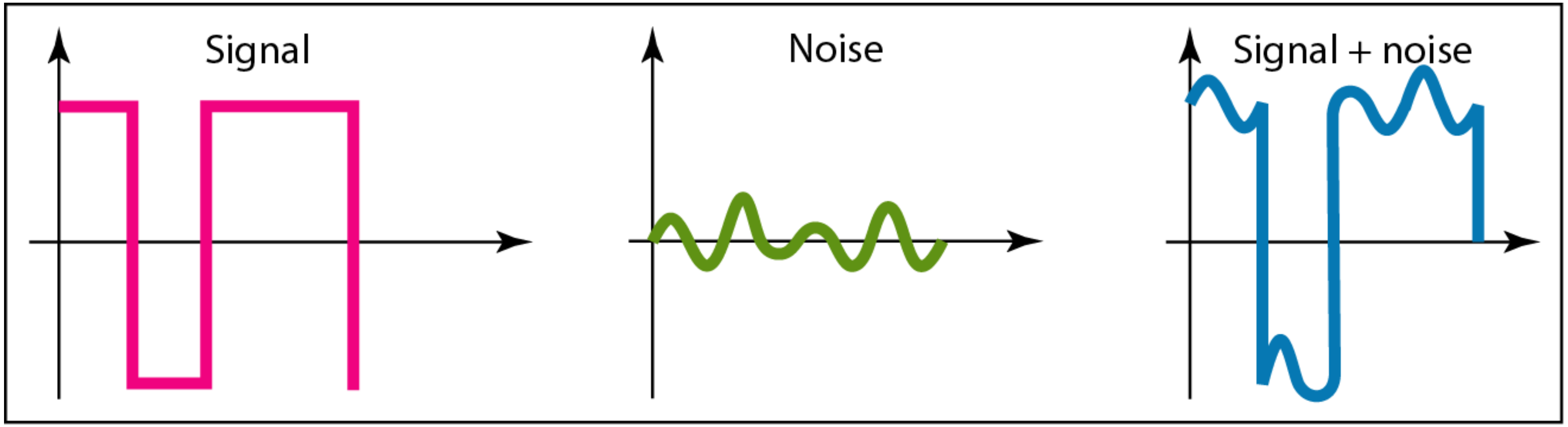

Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

Noise

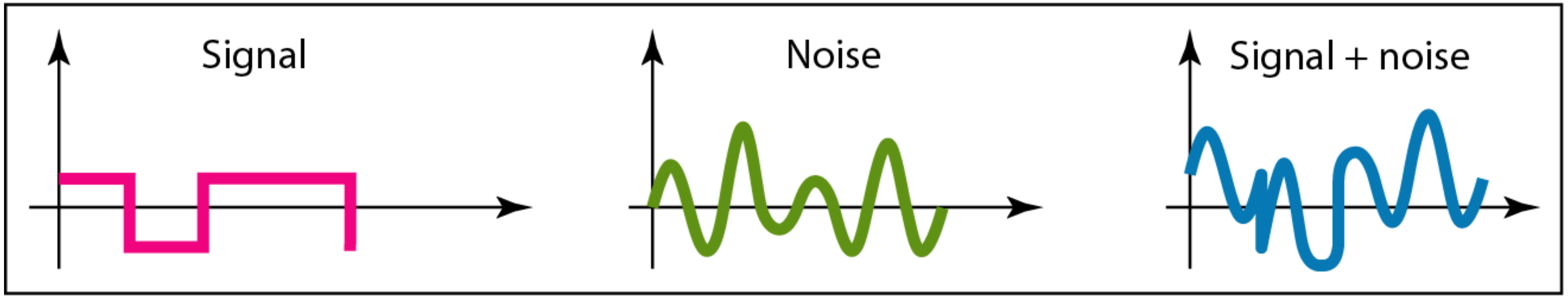
- **unwanted signals** inserted between transmitter and receiver
- **The received signal will consist of the transmitted signal, modified by the various distortions imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception. The latter, undesired signals are referred to as noise.**
- is the major limiting factor in communications system performance

- Noise may be divided into four categories:
  - Thermal noise
  - Intermodulation noise
  - Crosstalk
  - Impulse noise

Signal-to-Noise Ratio(***SNR): a high SNR and a low SNR***

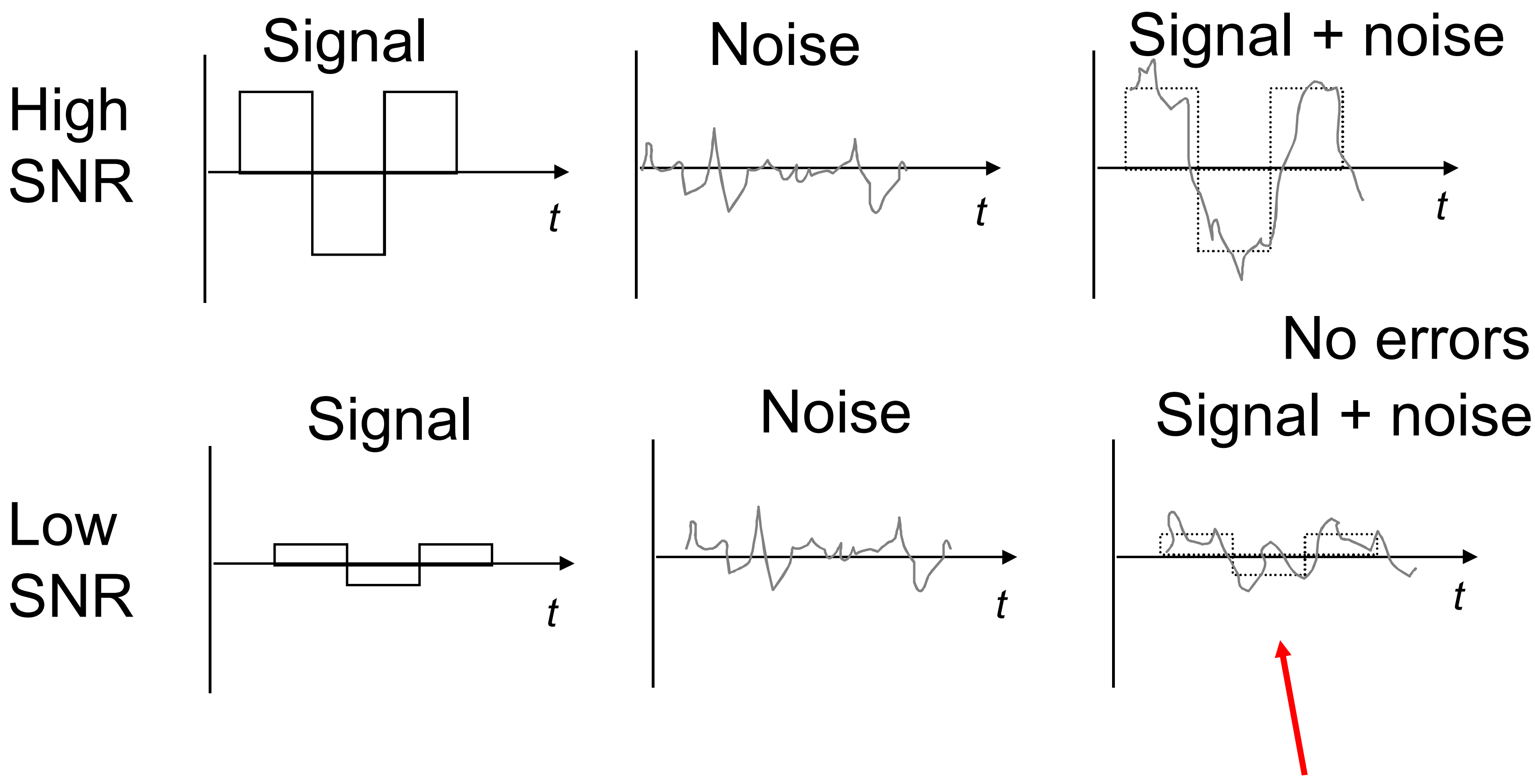


a. Large SNR



b. Small SNR

Formula for Signal-to-Noise Ratio



$$\text{SNR} = \frac{\text{Average signal power}}{\text{Average noise power}}$$

$$\text{SNR (dB)} = 10 \log_{10} \text{SNR}$$

Example1

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?

Solution

The values of SNR and SNR_{dB} can be calculated as follows:

$$\text{SNR} = \frac{10{,}000\ \mu\text{W}}{1\ \text{mW}} = 10{,}000$$

$$\text{SNR}_{\text{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Example2

The values of SNR and SNR$_{dB}$ for a noiseless channel are

$$SNR = \frac{\text{signal power}}{0} = \infty$$
$$SNR_{dB} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

Channel Capacity

- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium

Shannon Capacity

- Consider data rate, noise and error rate
- Faster data rate shortens each bit so burst of noise affects more bits
  - At a given noise level, high data rate means higher error rate
- Signal to noise ratio (in decibels)
- **SNR_{db}=10 $\log_{10}$ (signal/noise)**
- **Capacity C=B $\log_2$(1+SNR) (B: bandwidth)**
- This is error free capacity

3-5 DATA RATE LIMITS

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. ***The bandwidth available***
2. ***The level of the signals we use***
3. ***The quality of the channel (the level of noise)***

Topics discussed in this section:

Noiseless Channel: Nyquist Bit Rate
Noisy Channel: Shannon Capacity
Using Both Limits

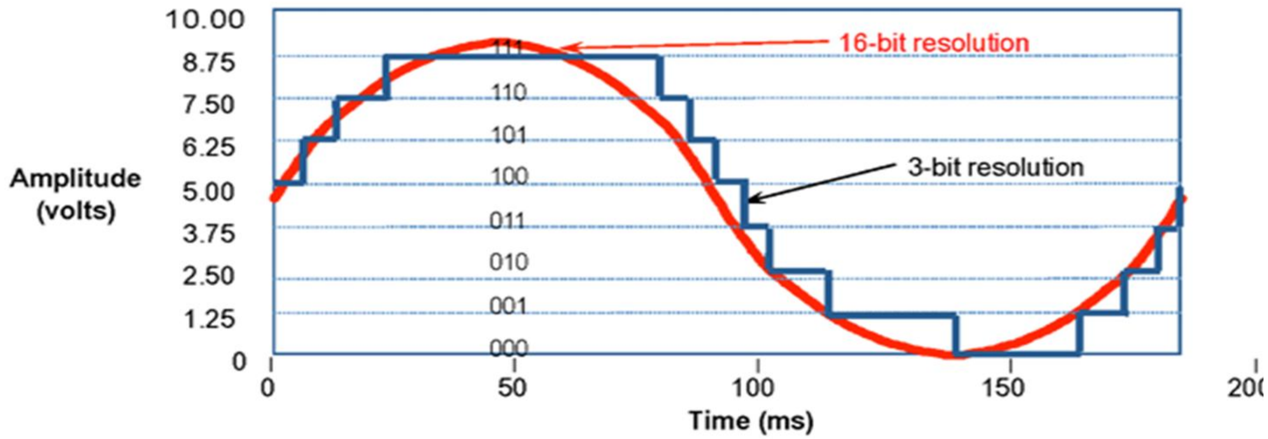


Figure 2. 16-Bit resolution versus 3-Bit resolution chart of a sine wave

Capacity of a System

- The bit rate of a system increases with an increase in the number of signal levels we use to denote a symbol.
- A symbol can consist of a single bit or "n" bits.
- The number of signal levels = 2^n.
- As the number of levels goes up, the spacing between level decreases -> increasing the probability of an error occurring in the presence of transmission impairments.

Noiseless Channel: Nyquist Bit rate

- $b = 2 B \log L$ (log is to base 2)

  b : bit rate

  B : Bandwidth

  L : number of levels

Nyquist Theorem

- Nyquist gives the upper bound for the bit rate of a transmission system by calculating the bit rate directly from the number of bits in a symbol (or signal levels) and the bandwidth of the system (assuming 2 symbols/per cycle and first harmonic).
- Nyquist theorem states that for a noiseless channel:

$$C = 2 B \log_2 2^n$$

C= capacity in bps

B = bandwidth in Hz

Example3

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}}$$

Example 4

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Example 5

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Example 6

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. For this channel the capacity C is calculated as

$$C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0$$

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

Example 7

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

$$C = B \log_2 (1 + \mathrm{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Shannon's Theorem

- Shannon's theorem gives the capacity of a system in the presence of noise.

$$C = B \log_2(1 + SNR)$$

Noisy channel : Shannon Capacity

- $C = B \log_2 (1 + SNR)$

  C = capacity of the channel in bps

  B = Bandwidth

  SNR = signal to noise ratio

Example

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Example

The signal-to-noise ratio is often given in decibels. Assume that SNR_{dB} = 36 and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Using both the limits

- In practice we use both the limits to determine, given the channel bandwidth, what should be the number of levels a signal should have.
- **The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.**

Example

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, we use the Shannon formula to find the upper limit.

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

Example

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$\boxed{4\ \text{Mbps} = 2 \times 1\ \text{MHz} \times \log_2 L \quad \Longrightarrow \quad L = 4}$$