BLG 337E- Principles of Computer Communications

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-Physical Layer (PHY)-

References:

Data and Computer Communications, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

- PHY Transmission Terminology
- Wired Transmission Media
- PHY Transmission Impairments

Transmission Terminology

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

Communication Channel

- Pair of copper wires
- Coaxial cable
- Radio
- Light in optical fiber
- Light in air
- Infrared

Transmission Impairments

- Signal attenuation
- Signal distortion
- Spurious noise
- Interference from other signals

Transmission Terminology

Data transmission occurs between transmitter and receiver over some transmission medium.

Communication is in the form of electromagnetic waves.

Guided media

- twisted pair, coaxial cable, optical fiber

Unguided media (wireless)

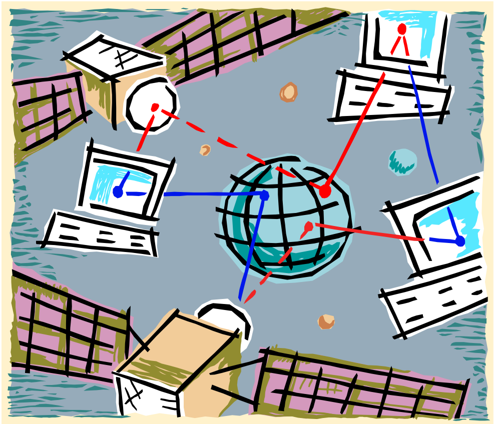
- air, vacuum, seawater

Transmission Terminology

Direct link
- no intermediate devices

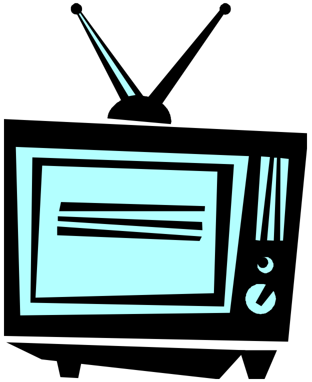
Point-to-point
- direct link
- only 2 devices share link

Multi-point
- more than two devices share the link

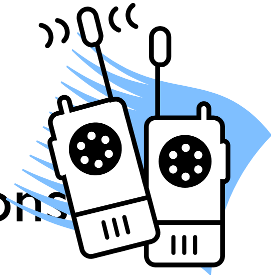


Transmission Terminology

- **Simplex**
  - signals transmitted in one direction
    - *eg. Television*



- **Half duplex**
  - both stations transmit, but only one at a time
    - *eg. police radio*



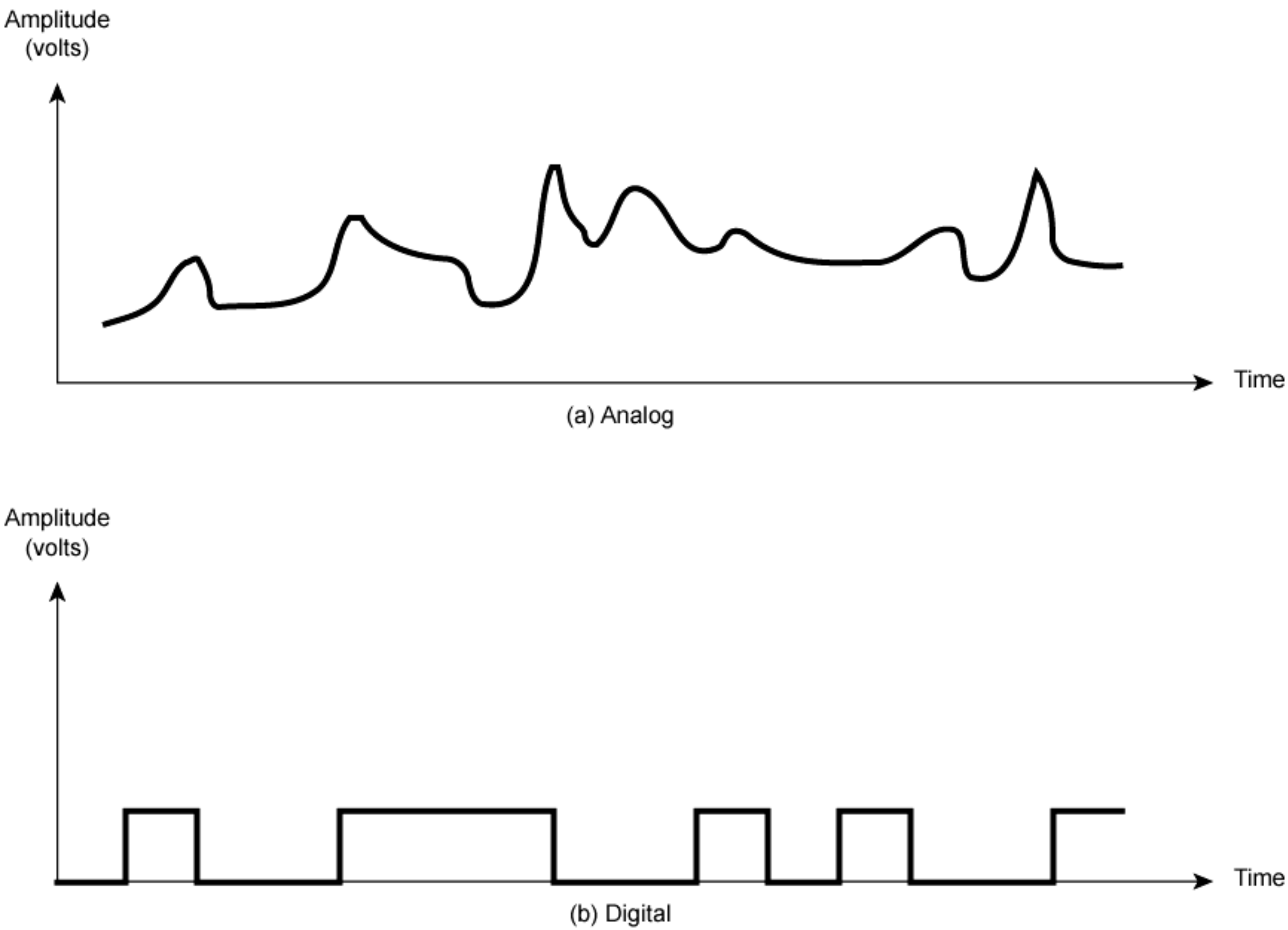
- **Full duplex**
  - simultaneous transmissions
    - *eg. telephone*

Frequency, Spectrum and Bandwidth

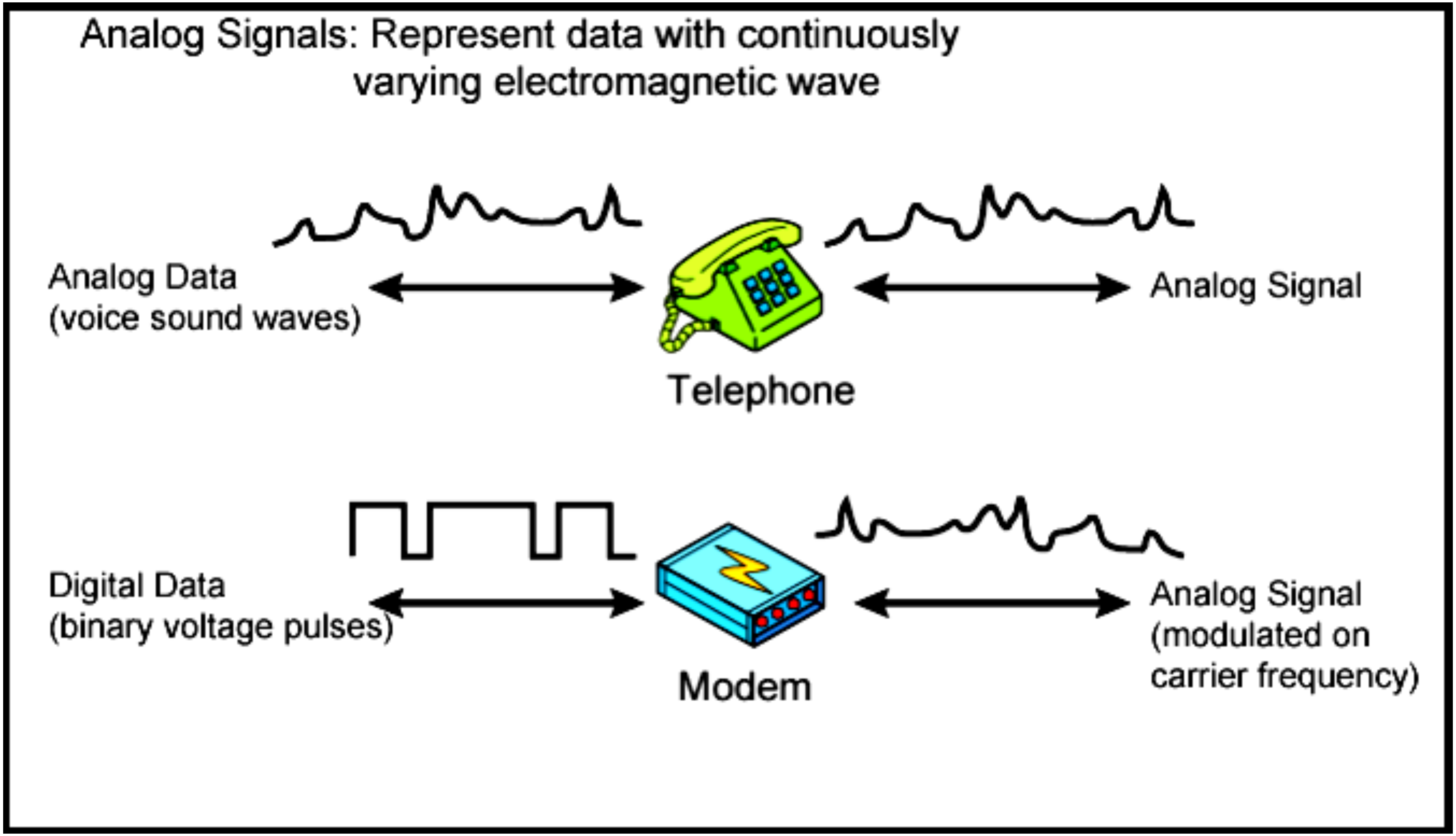
Time Domain Concepts

- **analog signal**
  - signal intensity varies smoothly with no breaks
- **digital signal**
  - signal intensity maintains a constant level and then abruptly changes to another level
- **periodic signal**
  - signal pattern repeats over time
- **aperiodic signal**
  - pattern not repeated over time

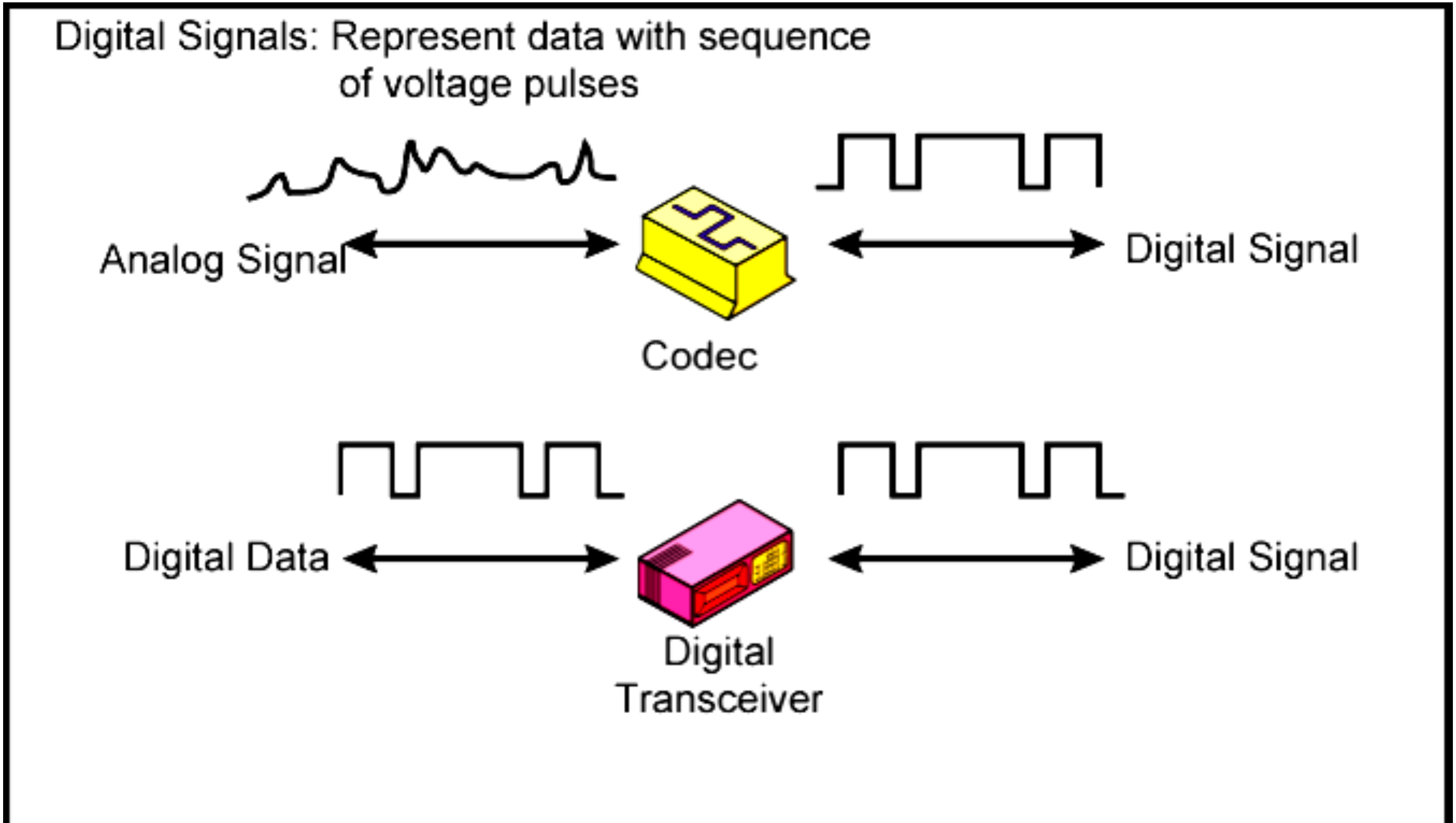
Analog and Digital Signals



Analog Signals



Digital Signals



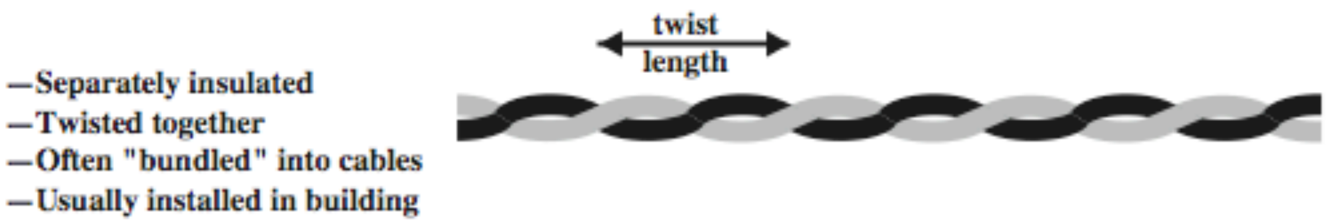
Overview of Transmission Media

- Guided - wire
- Unguided - wireless
- Characteristics and quality determined by medium and signal
  - For guided, the medium is more important
  - For unguided, the bandwidth produced by the antenna is more important
- Key concerns are data rate and distance

Design Factors

- Bandwidth
  - Higher bandwidth gives higher data rate
- Transmission impairments
  - Attenuation
- Interference
- Number of receivers
  - In guided media
  - More receivers (multi-point) introduce more attenuation

Twisted Pair



(a) Twisted pair

Twisted pair is the least expensive and most widely used guided transmission 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
- ➢ most commonly used in the telephone network and for communications within buildings

Unshielded vs. Shielded Twisted Pair

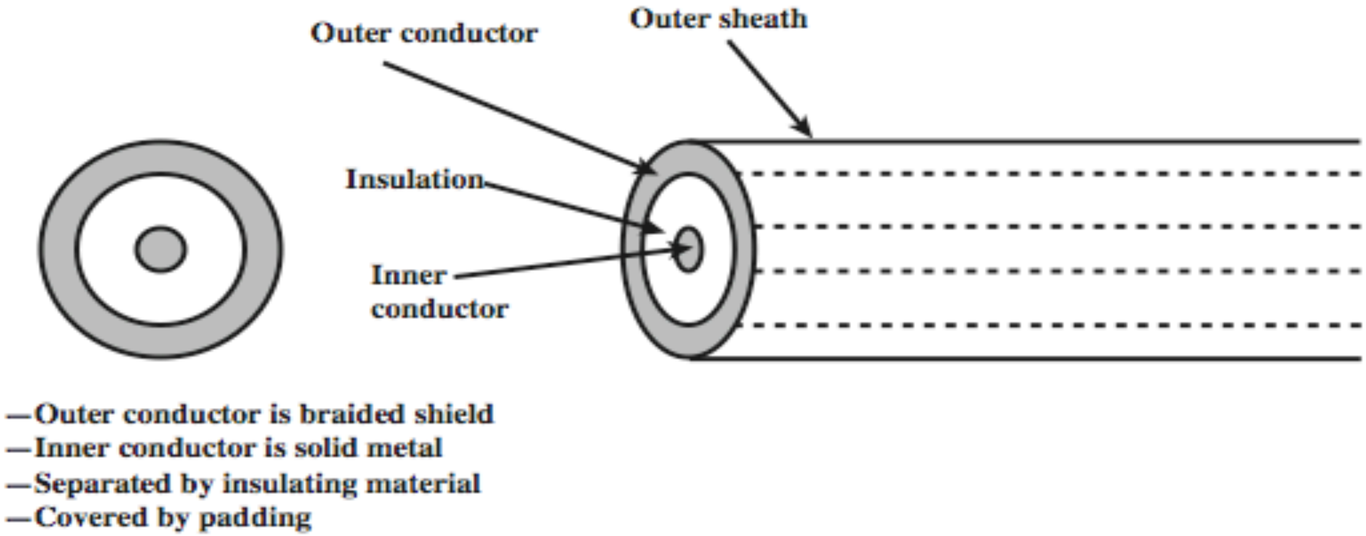
Unshielded Twisted Pair (UTP)

- **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

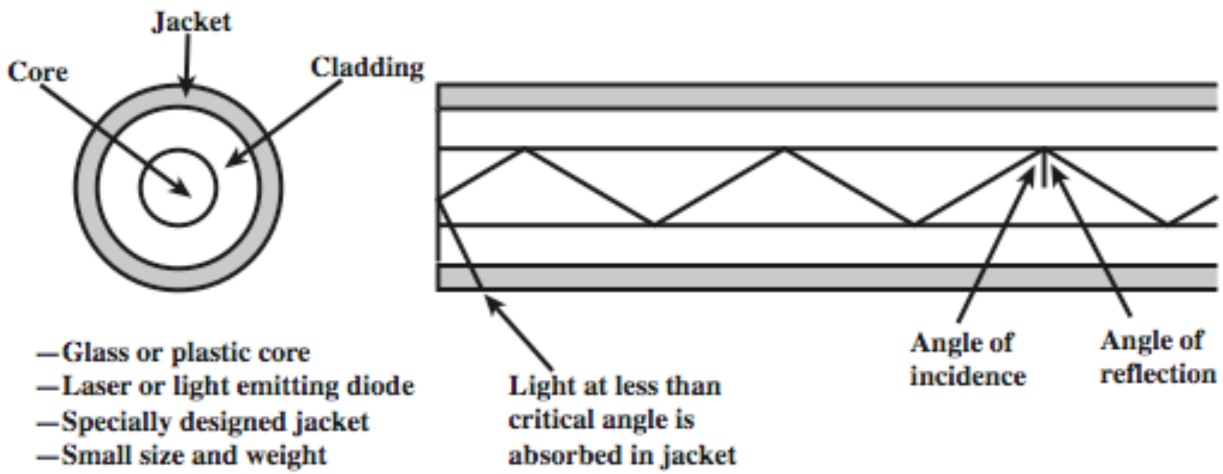


(b) Coaxial cable

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

- consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor
- is a versatile transmission medium used in a wide variety of applications
- used for TV distribution, long distance telephone transmission and LANs

Optical Fiber



(c) Optical fiber

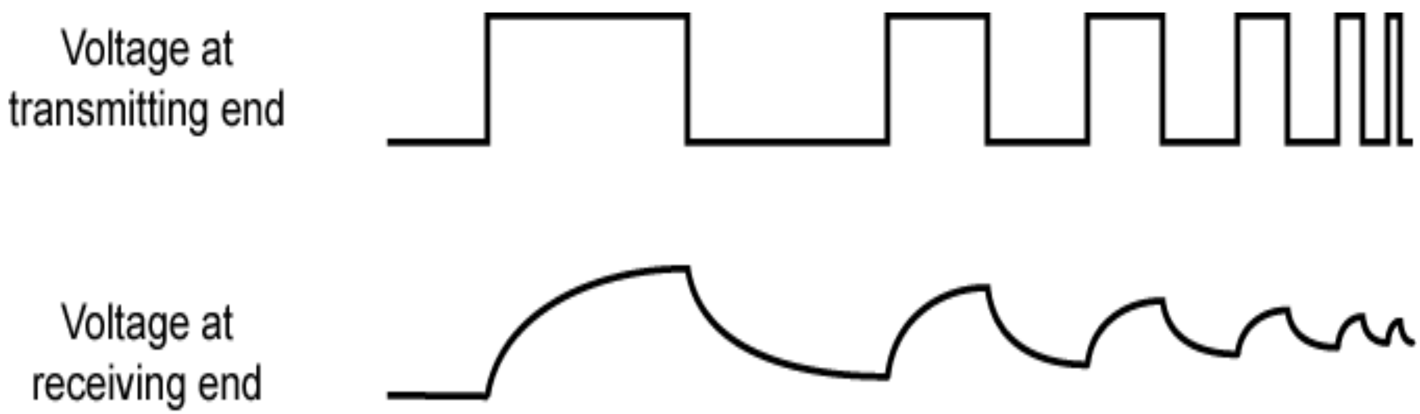
Optical fiber is a thin flexible medium capable of guiding an optical ray.

- ➢ 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

Transmission Impairments

- Signal received may differ from signal transmitted
- Analog - degradation of signal quality
- Digital - bit errors
- Mostly caused by
  - Attenuation and 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

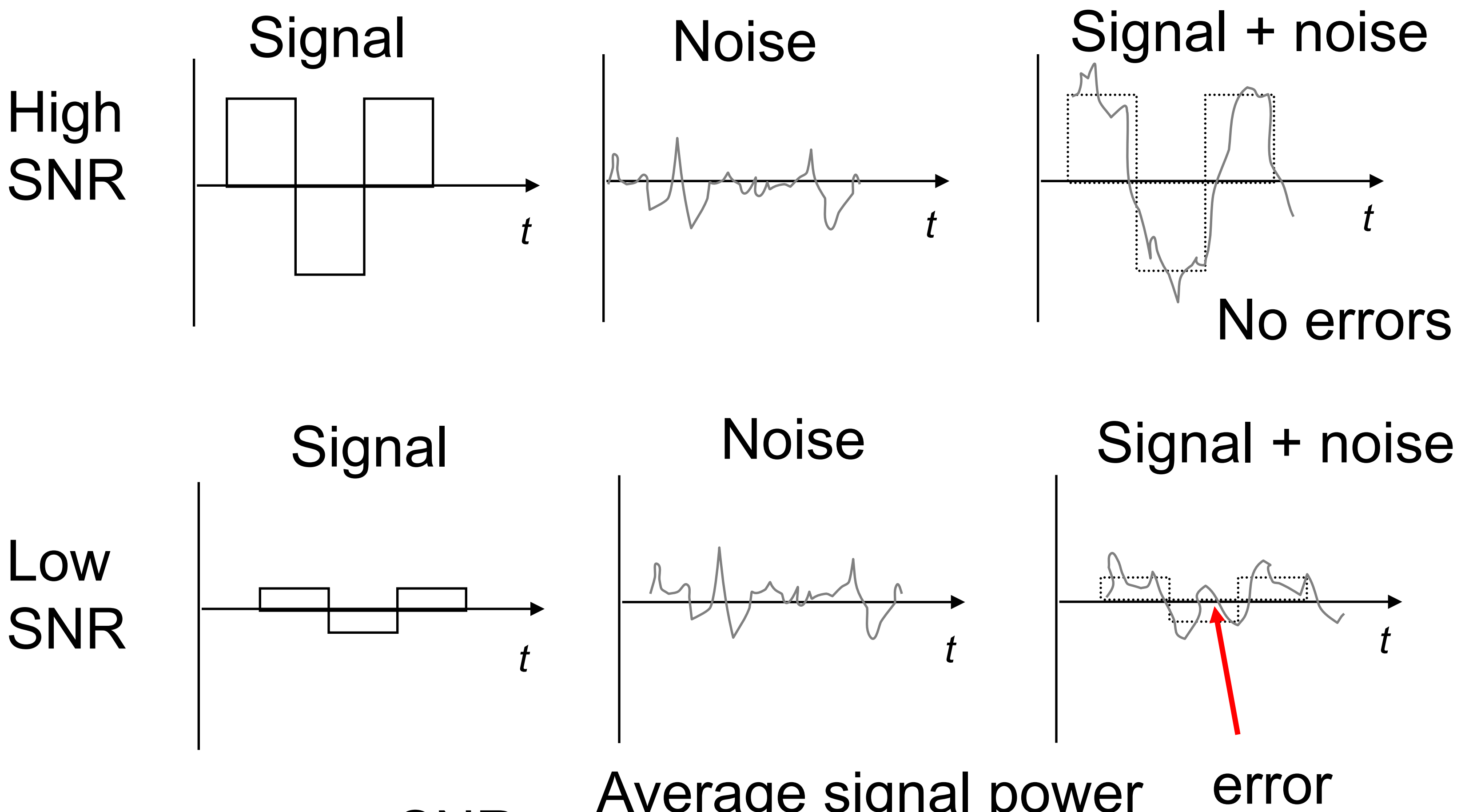
Noise

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.

unwanted signals inserted between transmitter and receiver

is the major limiting factor in communications system performance

Signal-to-Noise Ratio



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

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

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

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)

Increasing the levels of a signal increases the probability of an error occurring, in other words it reduces the reliability of the system..

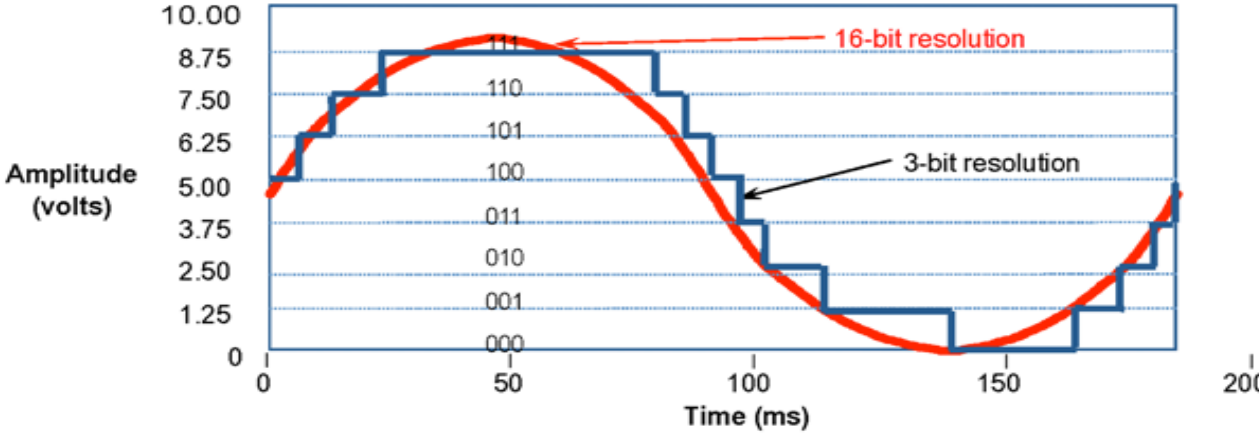


Figure 2. 16-Bit resolution versus 3-Bit resolution chart of a sine wave

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.

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

Example

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

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

Example

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

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.

Shannon's Theorem

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

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

Example

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

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

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

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.

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

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

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

Example

For practical purposes, when the SNR is very high, we can assume that SNR + 1 is almost the same as SNR. In these cases, the theoretical channel capacity can be simplified to

$$C = B \times \frac{\mathrm{SNR_{dB}}}{3}$$

For example, we can calculate the theoretical capacity of the previous example as

$$C = 2\ \mathrm{MHz} \times \frac{36}{3} = 24\ \mathrm{Mbps}$$

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.

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

Note

The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.