Computer Networks (CS30006)

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Transmission Fundamentals

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Data

- Data is information that has been translated into a form that is efficient for movement or processing.
- Data can be analog or digital.

Analog Data

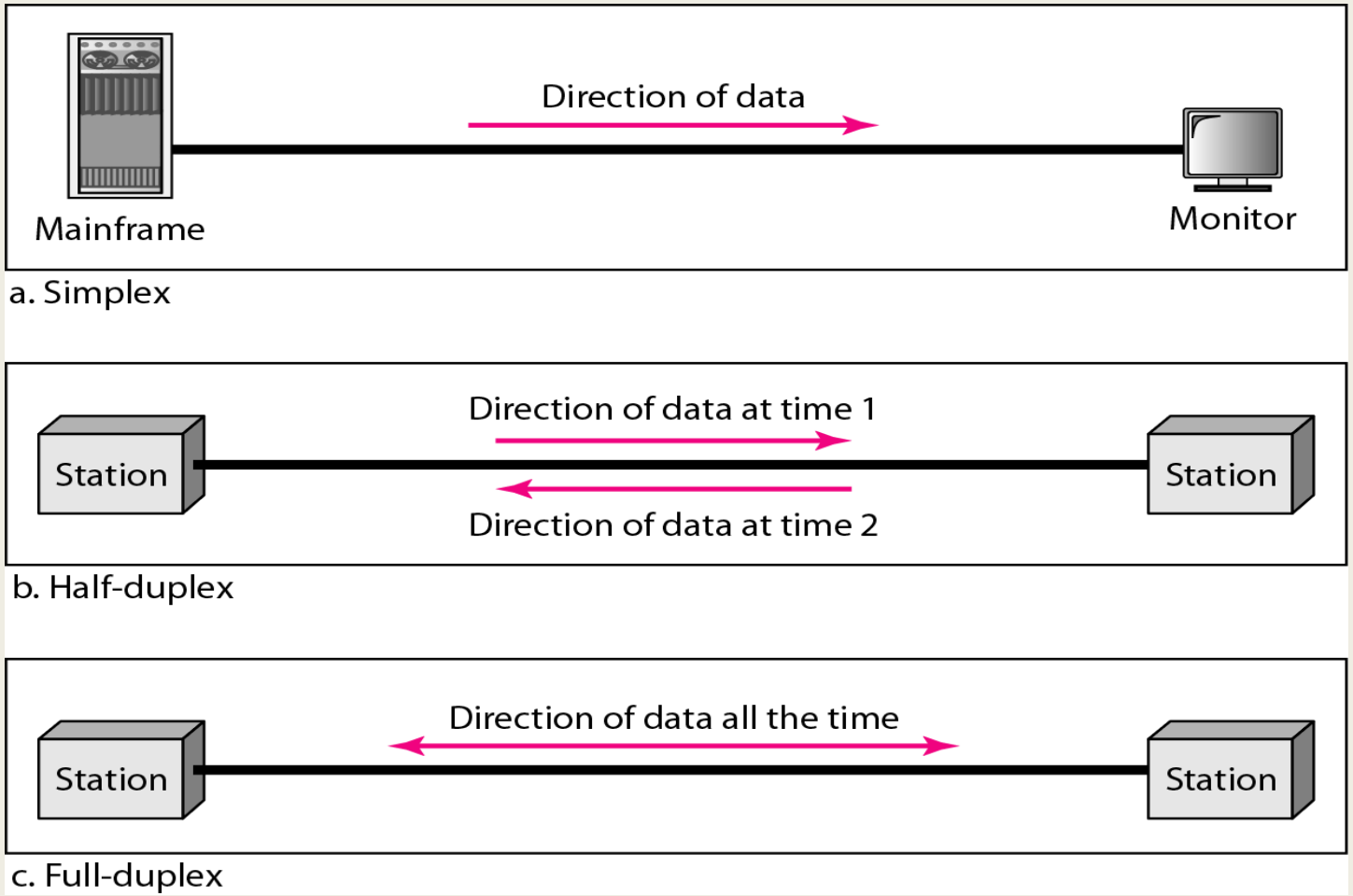
- The term analog data refers to information that is continuous.
- Analog data take on continuous values.

Digital Data

- Digital data refers to information that has discrete states.
- Digital data take on discrete values.

Data Flow

- Communication between two devices can be simplex, half-duplex, or full-duplex.



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Advantages of Digital Signal

- Digital signals can convey information with less noise, distortion, and interference.
- Digital circuits can be reproduced easily in mass quantities at comparatively low costs.
- Digital signal processing is more flexible because DSP operations can be altered using digitally programmable systems.
- Digital signal processing is more secure because digital information can be easily encrypted and compressed.
- Digital systems are more accurate, and the probability of error occurrence can be reduced by employing error detection and correction codes.
- Digital signals can be easily stored on any magnetic media or optical media using semiconductor chips.
- Digital signals can be transmitted over long distances.

Disadvantages of Digital Signal

- A higher bandwidth is required for digital communication when compared to analog transmission of the same information.
- DSP processes the signal at high speeds, and comprises more top internal hardware resources. This results in higher power dissipation compared to analog signal processing, which includes passive components that consume less energy.
- Digital systems and processing are typically more complex

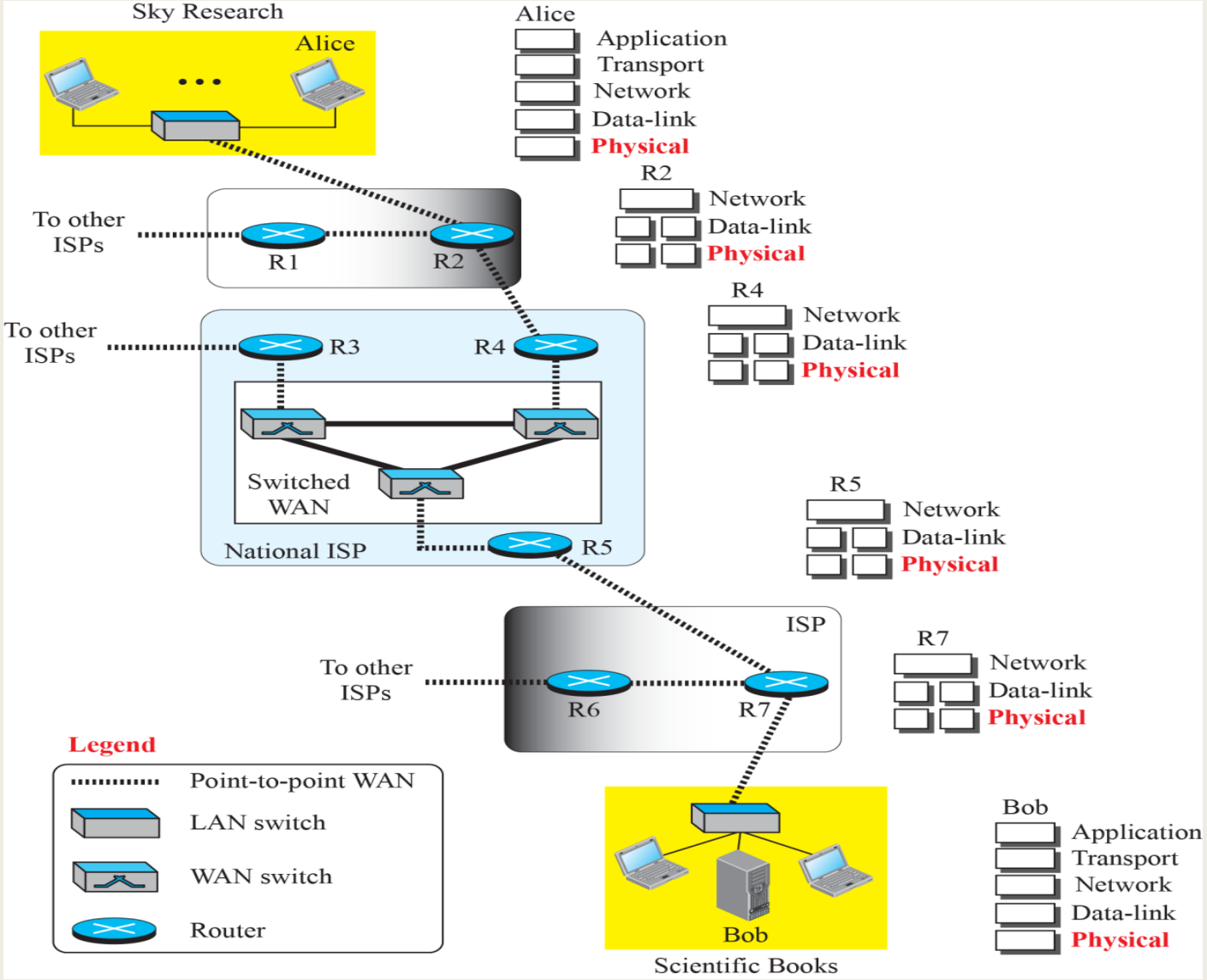
Advantages of Analog Signal

- Easier to process.
- Best suited for audio and video transmission.
- Have much higher density, and can present more refined information.
- Use less bandwidth than digital signals.
- Provide a more accurate representation of changes in physical phenomena, such as sound, light, temperature, position, or pressure.
- Less sensitive in terms of electrical tolerance.

Disadvantages of Analog Signal

- Data transmission at long distances may result in undesirable signal disturbances.
- Analog signals are prone to generation loss.
- Analog signals are subject to noise and distortion, as opposed to digital signals which have much higher immunity.
- Analog signals are generally lower quality signals than digital signals.

Communication at Physical Layer



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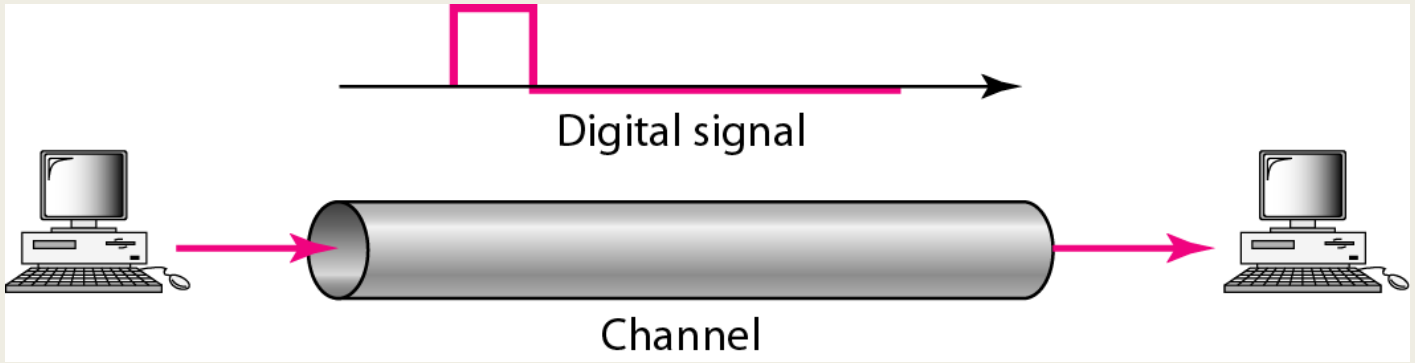
Baseband Transmission

- Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.



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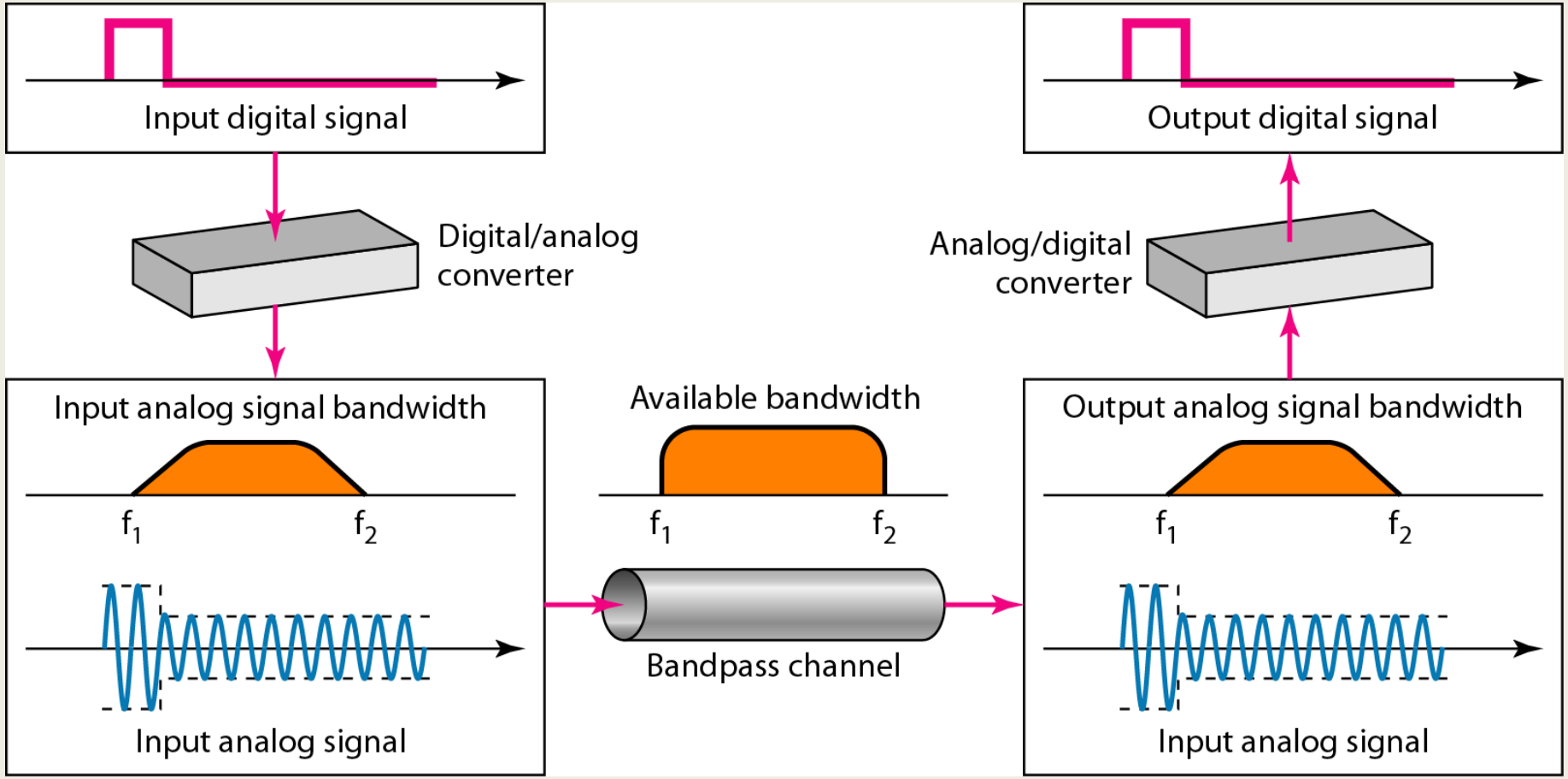
Modulation of a digital signal for transmission on a bandpass channel



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Example

- What is the required bandwidth of a low-pass channel if we need to send 1 Mbps by using baseband transmission?

Solution

The answer depends on the accuracy desired.

a. The minimum bandwidth, a rough approximation, is B = bit rate /2, or 500 kHz. We need a low-pass channel with frequencies between 0 and 500 kHz.

b. A better result can be achieved by using the first and the third harmonics with the required bandwidth B = 3 × 500 kHz = 1.5 MHz.

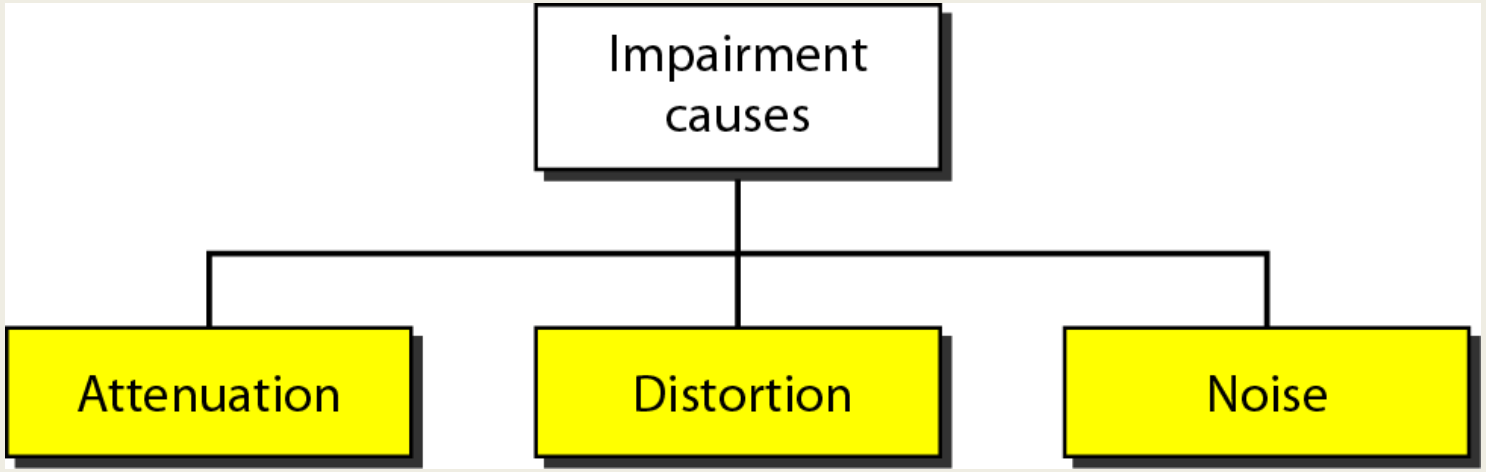
c. A still better result can be achieved by using the first, third, and fifth harmonics with B = 5 × 500 kHz = 2.5 MHz.

Broadband Transmission

- Broadband transmission or modulation means changing the digital signal to an analog signal for transmission.
- Modulation allows us to use a bandpass channel-a channel with a bandwidth that does not start from zero.

Transmission Impairment

- The signal at the beginning of the medium is not the same as the signal at the end of the medium.
- Three causes of impairment are attenuation, distortion, and noise.



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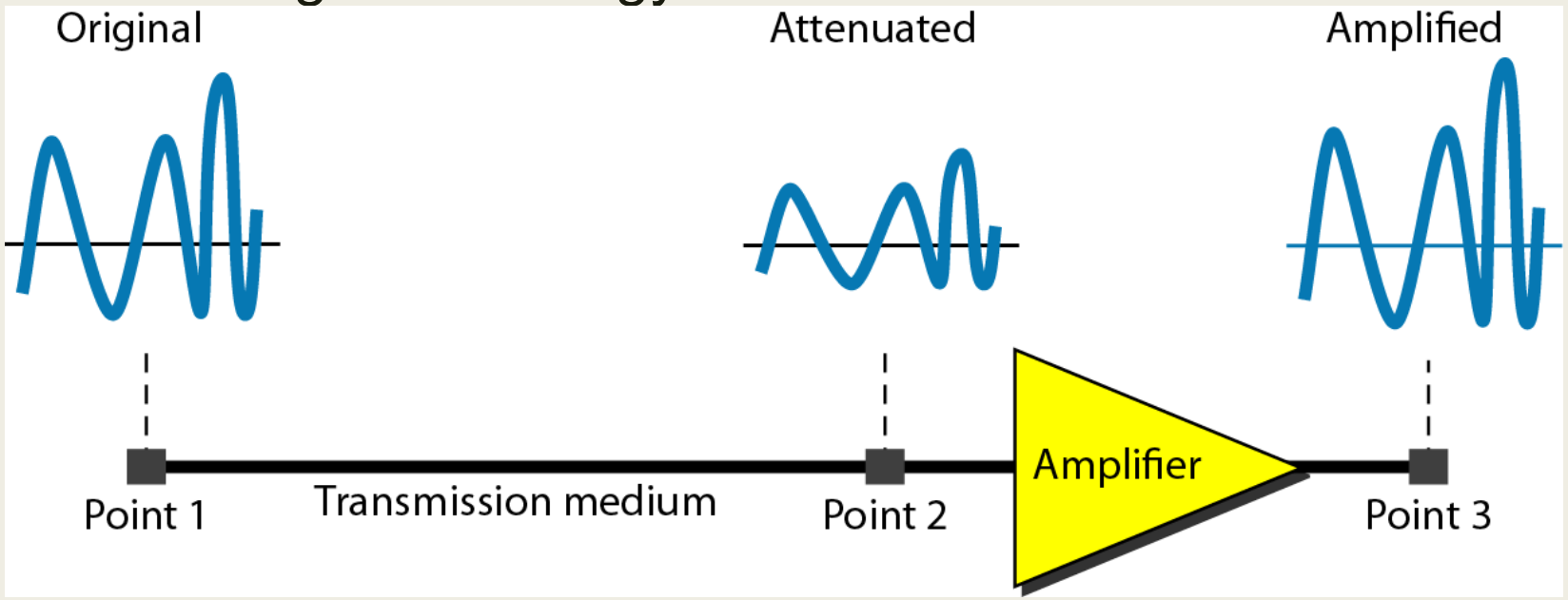
Attenuation

- Attenuation means a loss of energy.
- When a signal travels through a medium it loses energy overcoming the resistance of the medium.
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.
- To show the loss or gain of energy the unit “decibel” is used.



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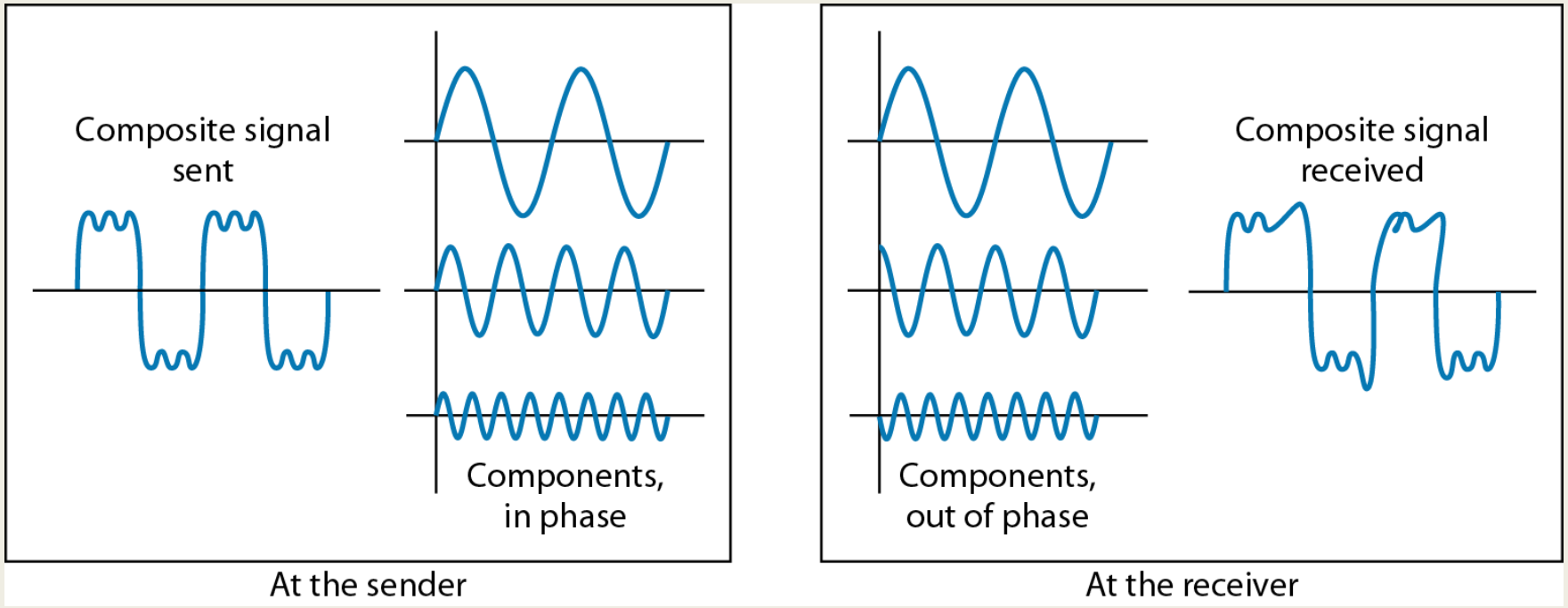
Distortion

- Means that the signal changes its form or shape.
- Distortion occurs in composite signals.



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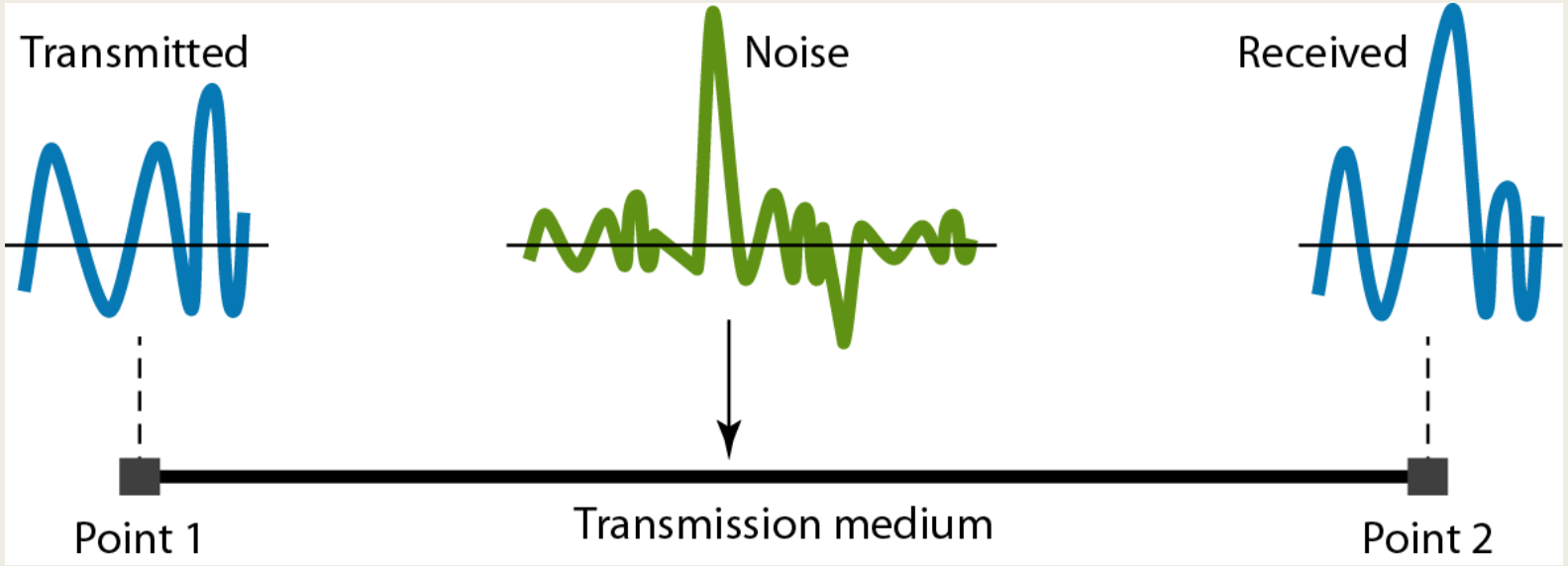
Noise

- Noise is unwanted electrical or electromagnetic energy that degrades the quality of signals and data.
- There are different types of noise: Thermal, Induced, Crosstalk, Impulse



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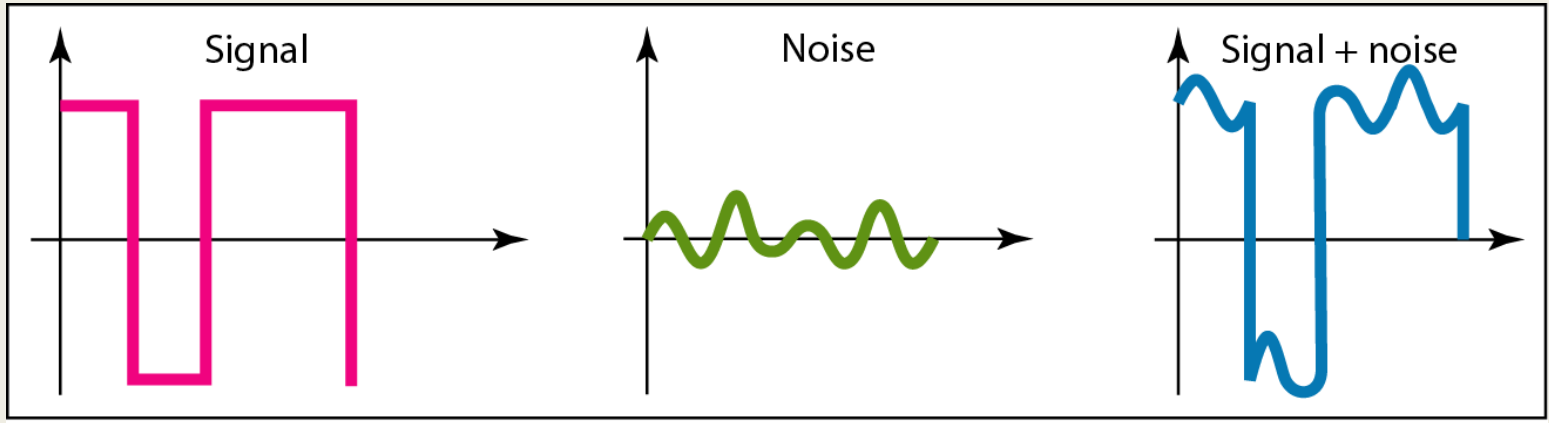
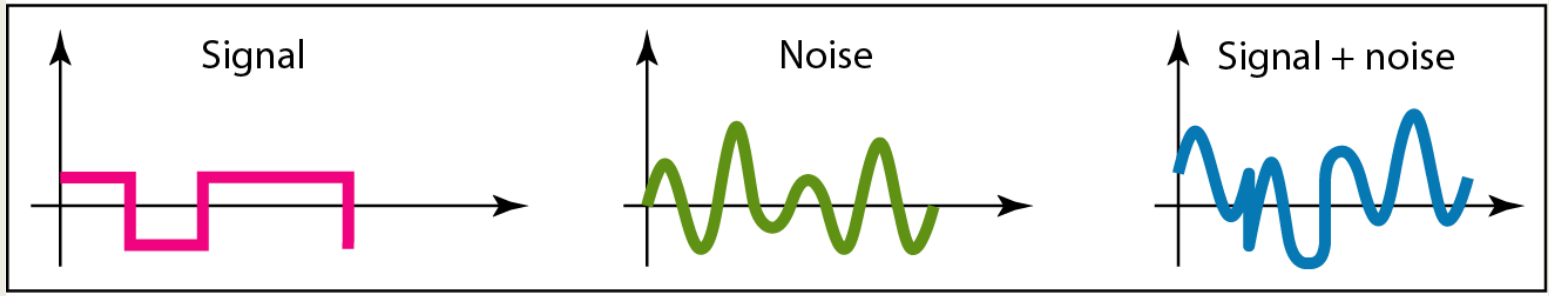
Signal to Noise Ratio

- It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.
- It is usually given in dB and referred to as SNR_{dB}.



a. Large SNR



b. Small SNR

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Data Rate Limit

- **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).

- **Noiseless Channel: Nyquist Bit Rate**
  For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate.

$$\text{Bit Rate} = 2 \times \text{bandwidth} \times \log_2 L$$

- **Noisy Channel: Shannon Capacity**
  The theoretical highest data rate for a noisy channel:

$$\text{Capacity} = \text{bandwidth} \times \log_2 (1 + \text{SNR})$$

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:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L \longrightarrow \log_2 L = 6.625 \longrightarrow L = 2^{6.625} = 98.7 \text{ levels}$$

L should always be a power of 2. Since 98.7 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

- 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.

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

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

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \longrightarrow L = 4$$

Propagation and Transmission Delay

- **Propagation speed** - speed at which a bit travels though the medium from source to destination.

  Propagation Delay = Distance/Propagation speed

- **Transmission speed** - the speed at which all the bits in a message arrive at the destination. (difference in arrival time of first and last bit)

  Transmission Delay = Message size/bandwidth bps

- **Latency = Propagation delay + Transmission delay + Queueing time + Processing time**

Example

1. A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

2. What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.

4.

Solution

We can calculate the throughput as

$$\text{Throughput} = (12{,}000 \times 10{,}000) / 60 = 2 \text{ Mbps}$$

We can calculate the propagation time as

$$\text{Propagation time} = \frac{12000 \text{ X } 1000 \text{ m}}{2.4 \text{ X } 10^8 \text{ secs}} = 50 \text{ milliseconds}$$

Thank You!!!

Appendix

Signal

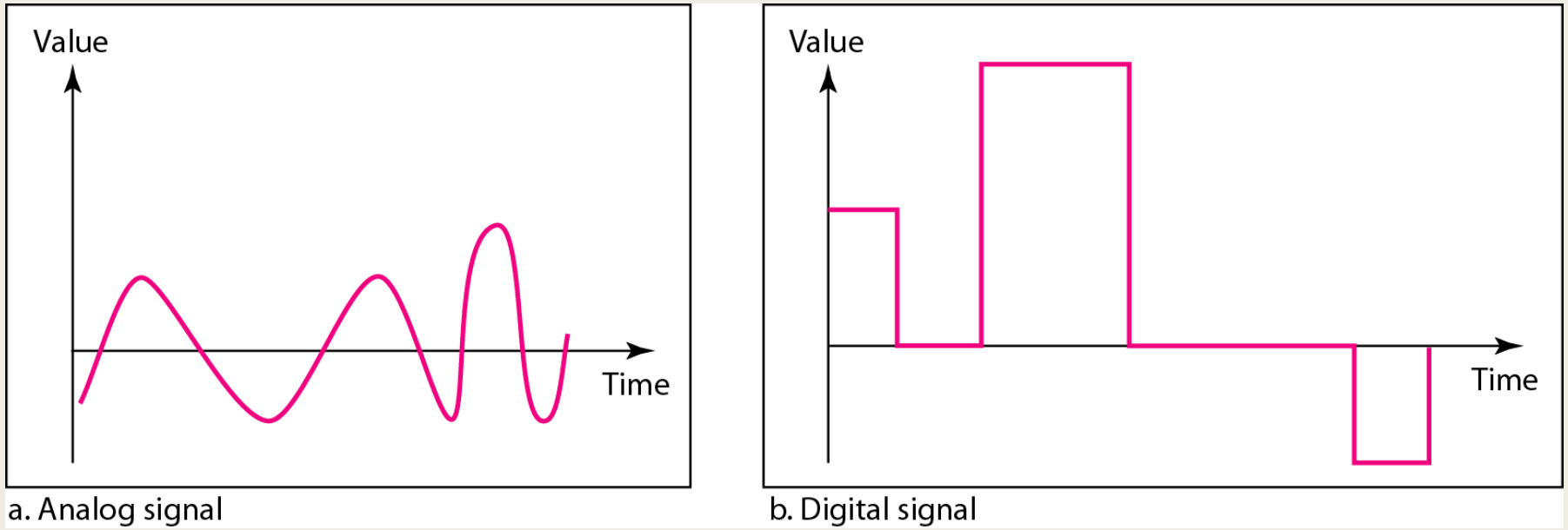
- Signals are the electric or electromagnetic impulses used to encode and transmit data.

Analog Data

- Analog signals can have an infinite number of values in a range.

Digital Data

- Digital signals can have only a limited number of values.



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Frequency and Phase

Frequency:

Frequency is the rate of change with respect to time.

If a signal does not change at all, its frequency is zero.

If a signal changes instantaneously, its frequency is infinite.

Phase:

Phase describes the position of the waveform relative to time 0.

Example

1. The period of a signal is 100 ms. What is its frequency in kilohertz?.

2. A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

Solution

1. First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

$$100\ \text{ms} = 100 \times 10^{-3}\ \text{s} = 10^{-1}\ \text{s}$$

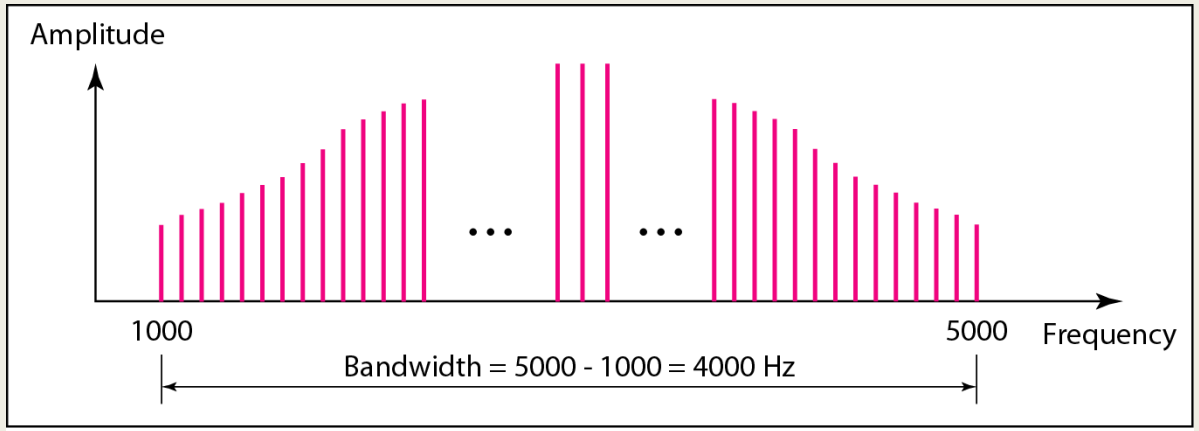
$$f = \frac{1}{T} = \frac{1}{10^{-1}}\text{Hz} = 10\ \text{Hz} = 10 \times 10^{-3}\ \text{kHz} = 10^{-2}\ \text{kHz}$$

2. We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

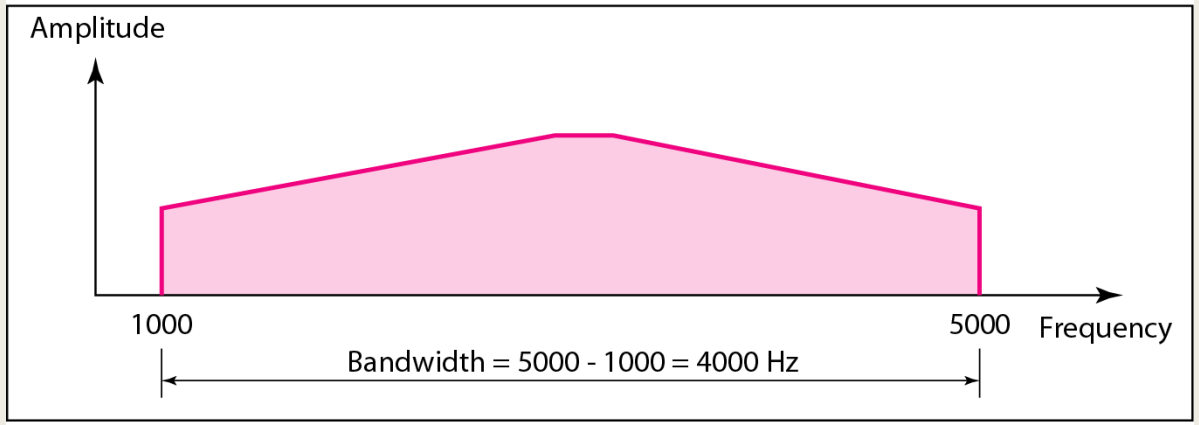
$$\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360}\ \text{rad} = \frac{\pi}{3}\ \text{rad} = 1.046\ \text{rad}$$

Bandwidth and Signal Frequency

- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

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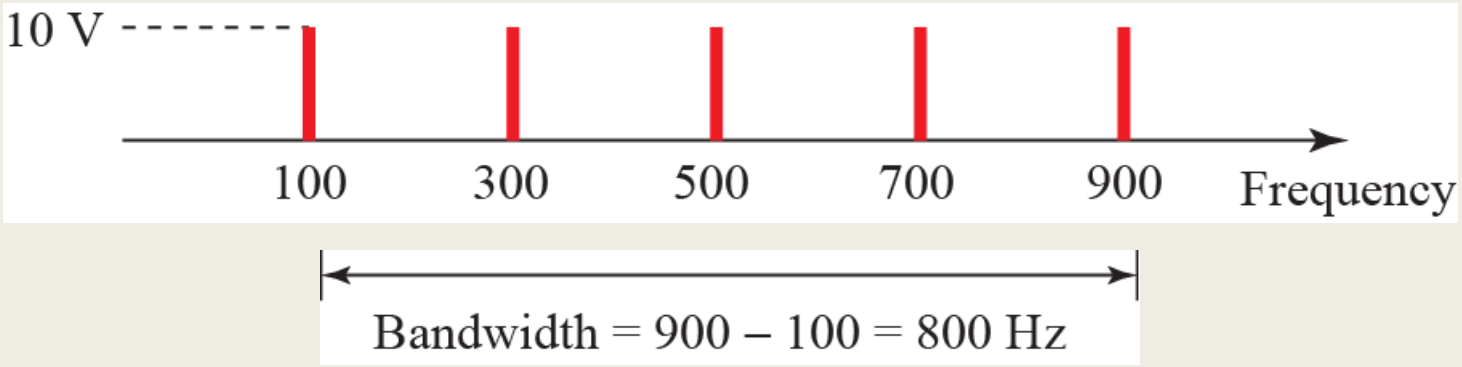
Example

- If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

- Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$



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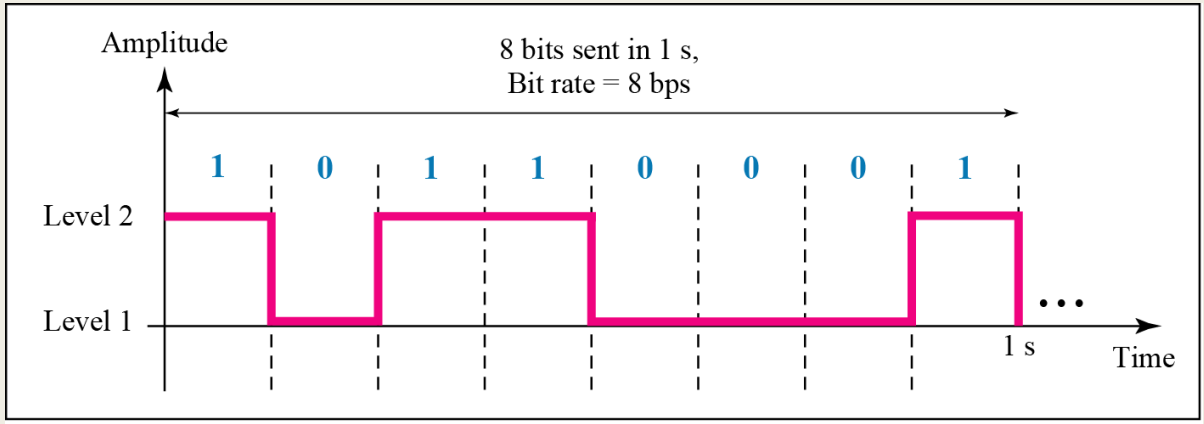
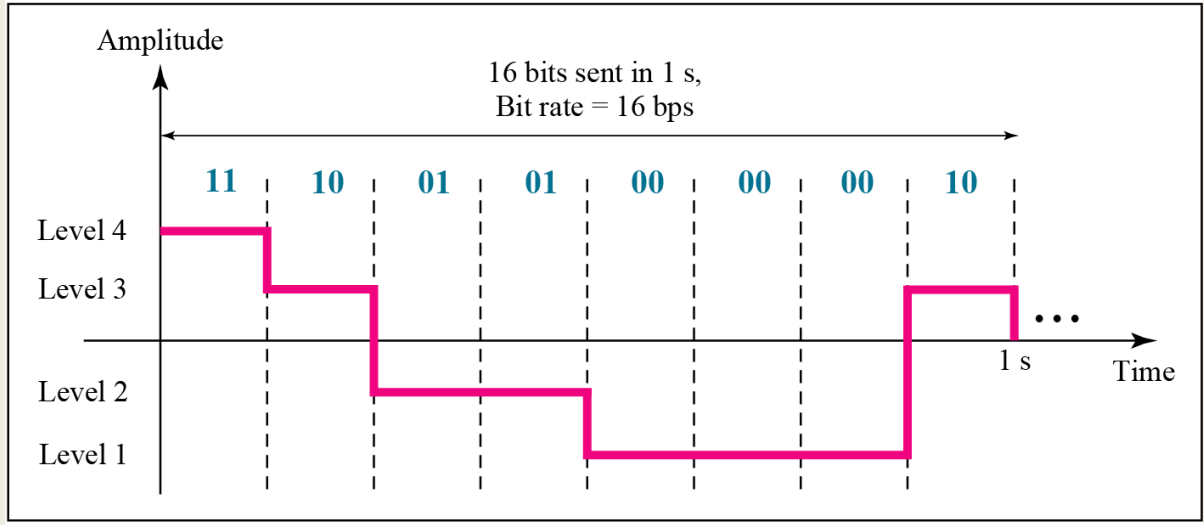
Digital Signal

- A digital signal is a signal that represents data as a sequence of discrete values.
- A digital signal can only take on one value from a finite set of possible values at a given time.
- With digital signals, the physical quantity representing the information can be many things: Variable electric current or voltage.



a. A digital signal with two levels



b. A digital signal with four levels

Source: B. A. Forouzan, " Data Communications and Networking ," *McGraw-Hill Forouzan Networking Series*,5E.

Bit Rate

- The bit rate is the number of bits sent in Is, expressed in bits per second (bps).

- Bit Length: The bit length is the distance one bit occupies on the transmission medium.

Bit length =propagation speed x bit duration

Example

- A digitized voice channel, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

- A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$