Data Communication & Networks

Chapter 2: Introduction to Physical Layer

Physical Layer

- **Physical layer:**
  - ➢ Data transmission from sender to receiver
  - ➢ Transform Data into Digital signals (Bits representation)
  - ➢ We will study Transmission impairments and Network parameters.

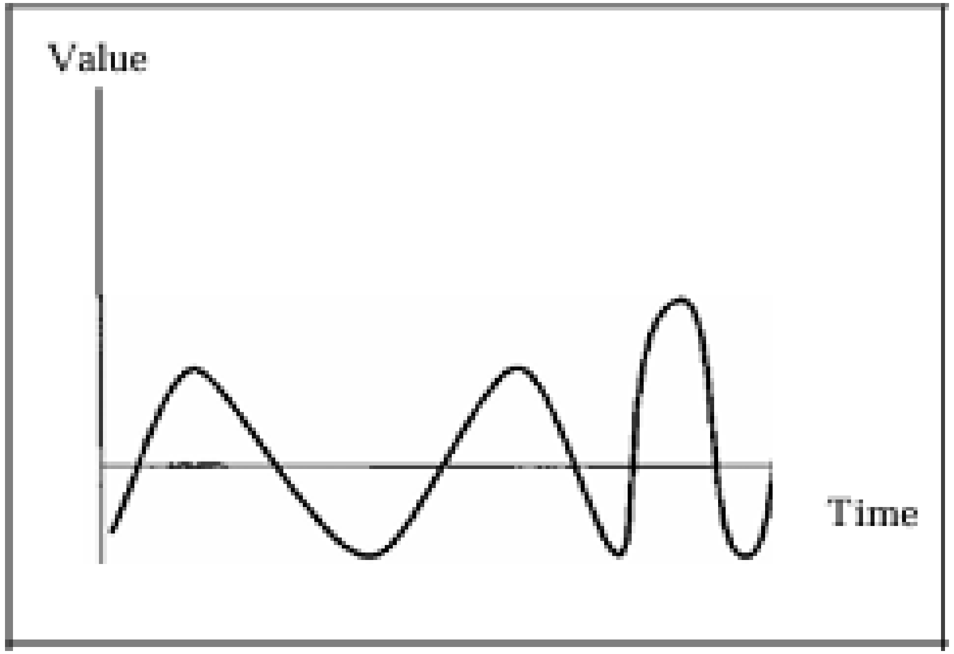
Physical Layer: Prerequisites

- **Analog Signal/Digital Signal:**

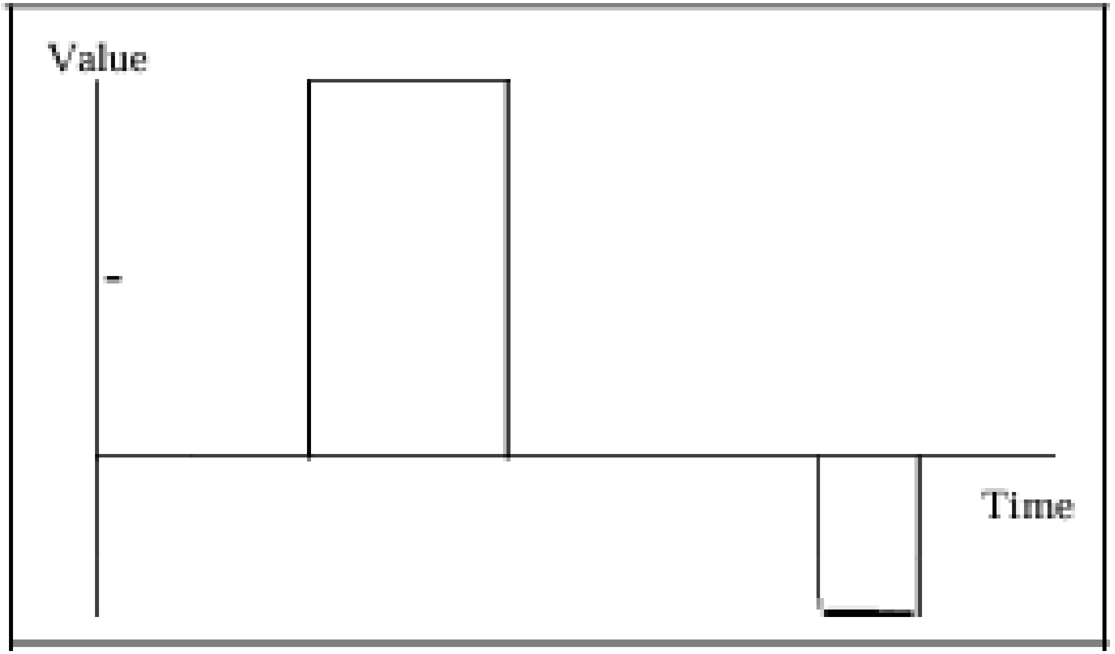
➢ Analog Signal: Infinite number of values in a range

➢ Digital Signal: Limited number of values (Levels)

Figure 3.1 *Comparison of analog and digital signals*



a. Analog signal

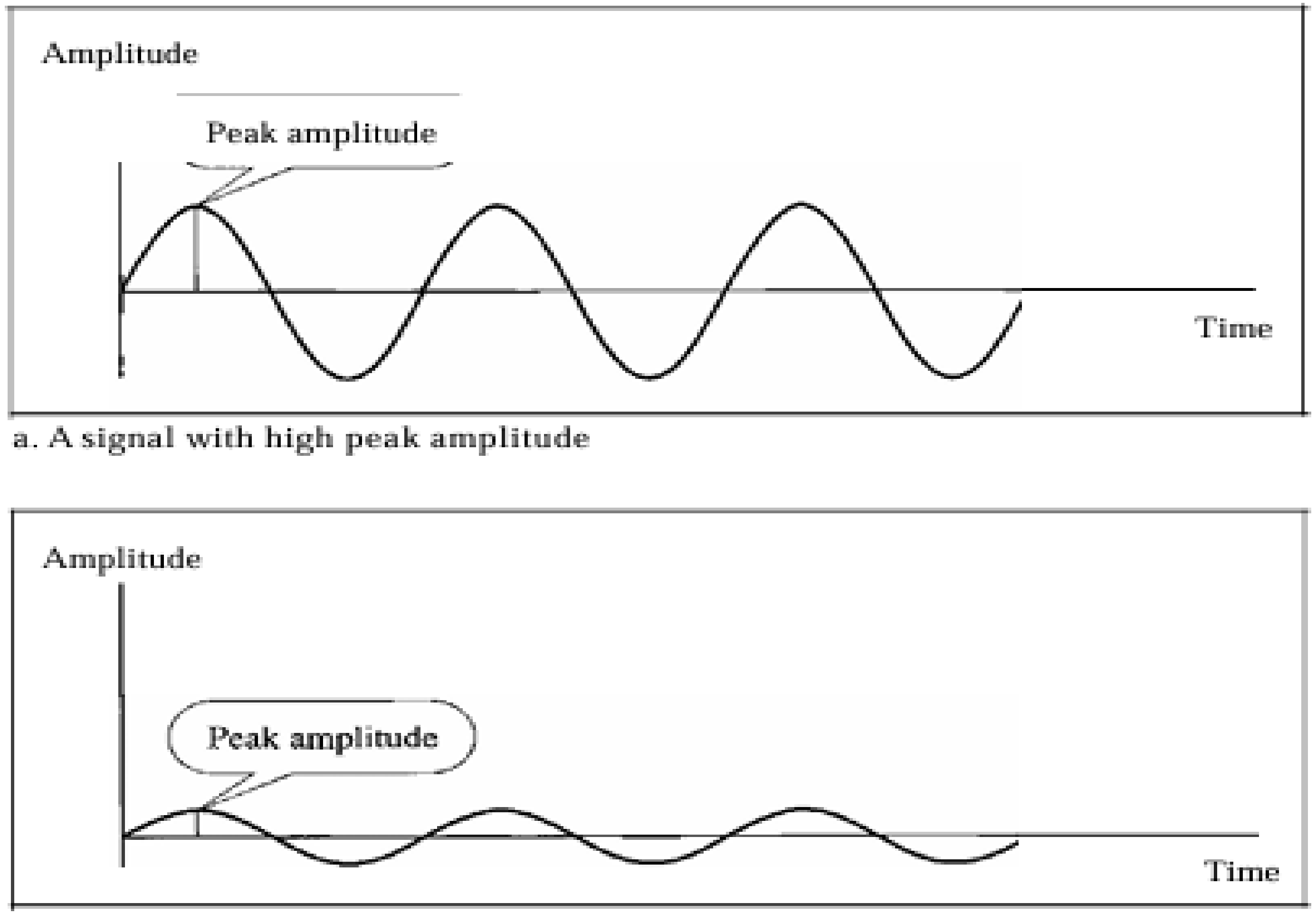


b. Digital signal

Physical Layer: Prerequisites

- **Periodic Signal:**

Figure 3.3 *Two signals with the same phase and frequency, but different amplitudes*

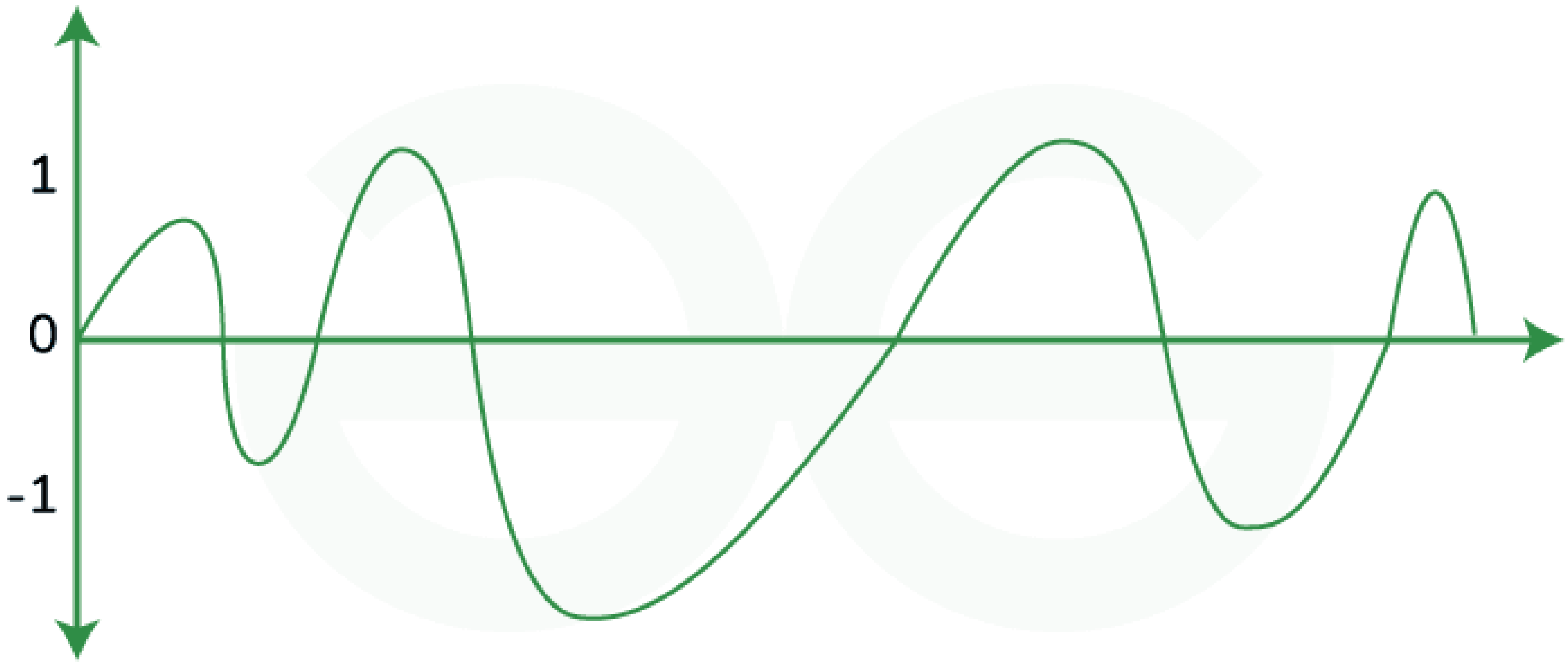


a. A signal with high peak amplitude

b. A signal with low peak amplitude

Physical Layer: Prerequisites

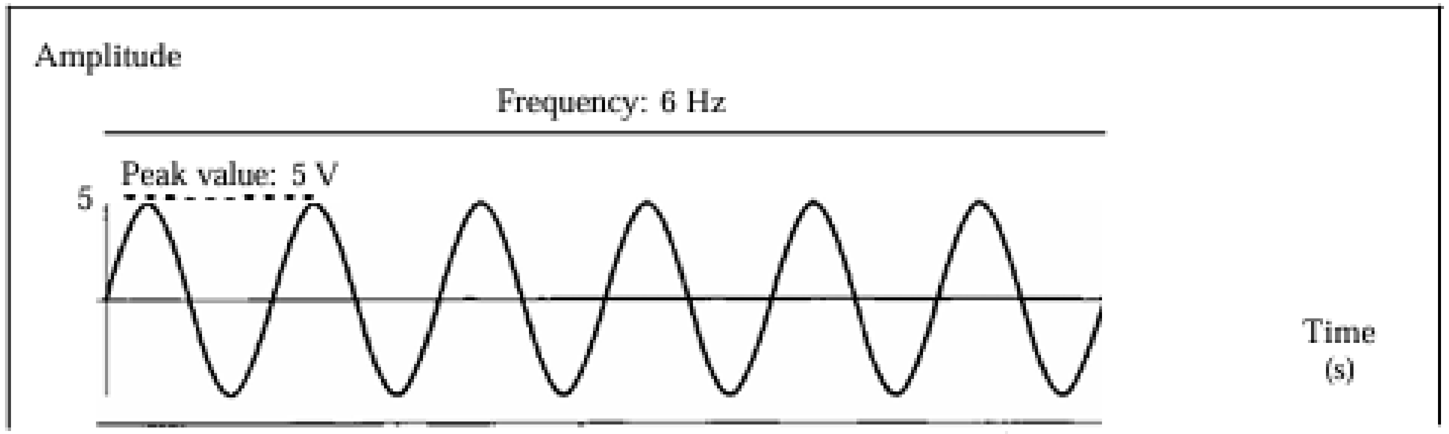
- **Aperiodic (Non-periodic) Signal:**



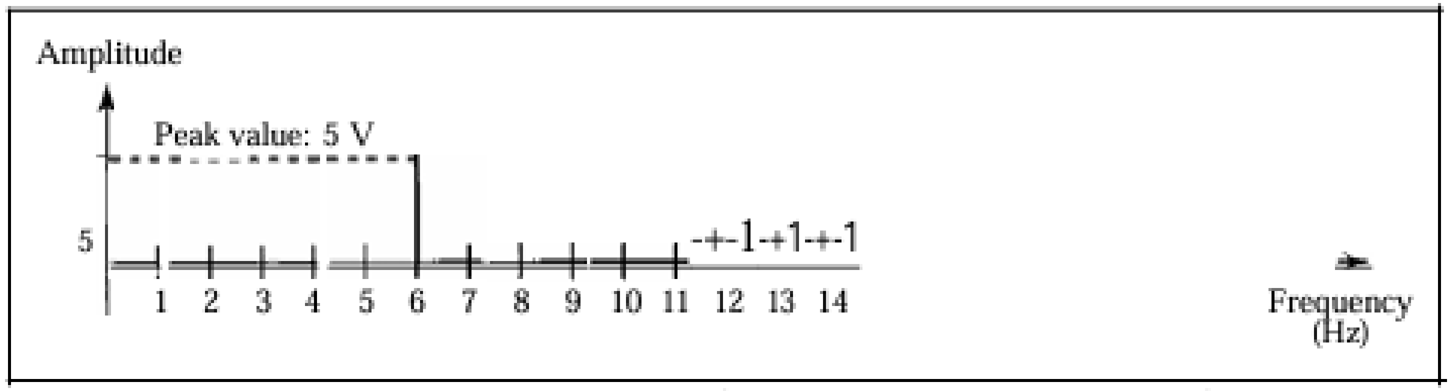
Physical Layer: Prerequisites

- **Time Domain/Frequency Domain**

Figure 3.7 *The time-domain andfrequency-domain plots ofa sine wave*



a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)

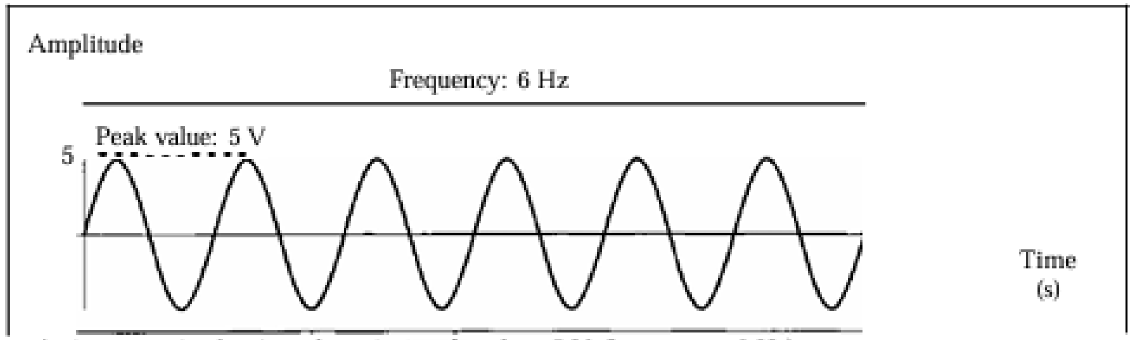


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

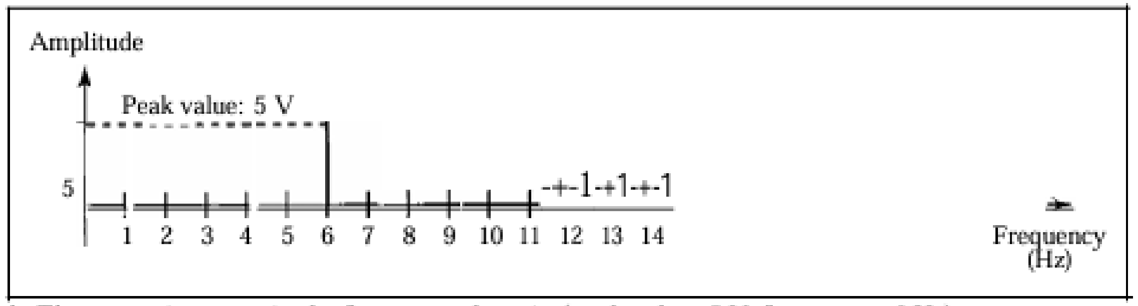
Physical Layer: Prerequisites

- **Time Domain/Frequency Domain**

Figure 3.7 *The time-domain andfrequency-domain plots ofa sine wave*



a. A sine wave in the time domain (**peak** value: 5 V, frequency: 6 Hz)



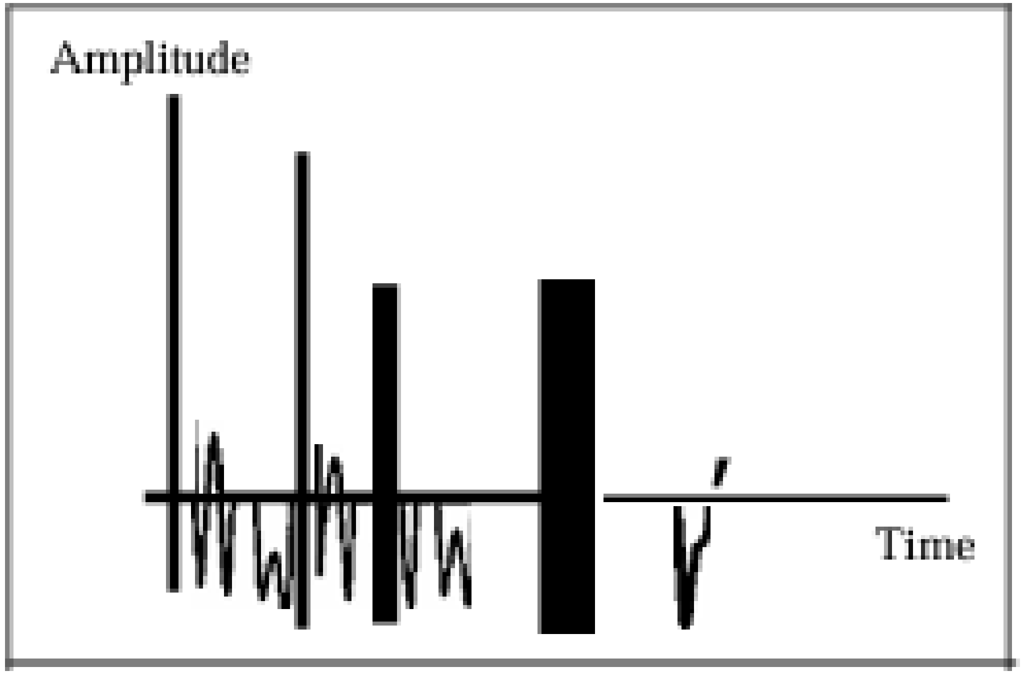
b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

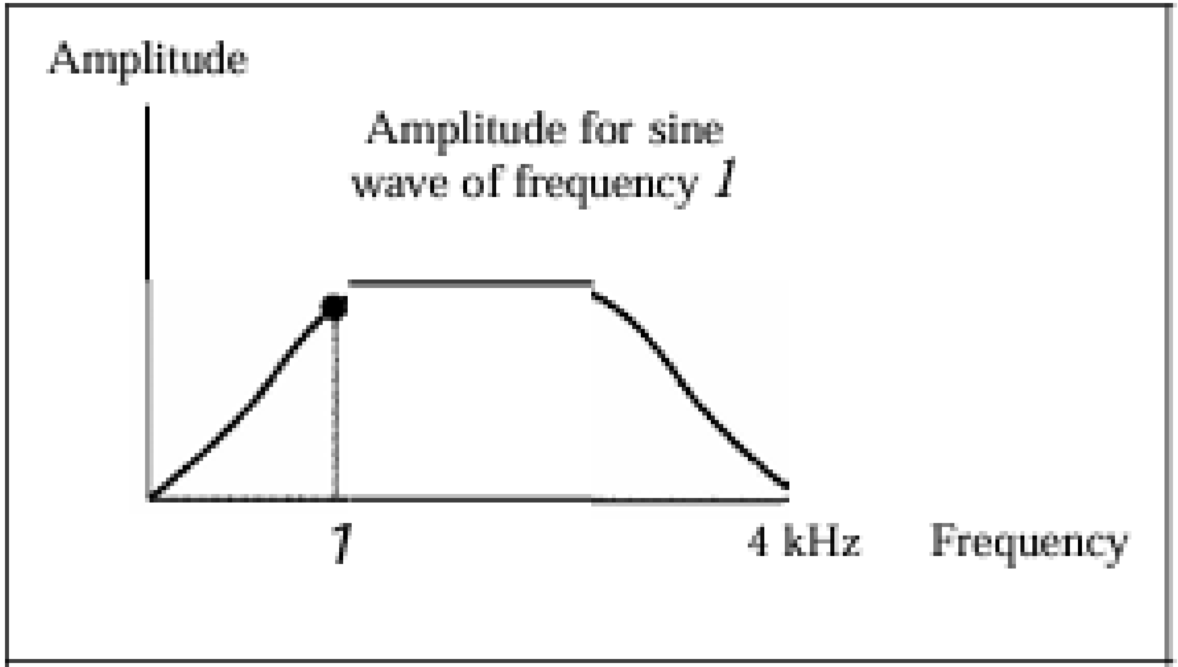
Physical Layer: Prerequisites

- **Composite Signal (Aperiodic signal): A signal consisting of many sine waves of different frequencies.**

Figure 3.11 *The time andfrequency domains ofa nonperiodic signal*



a. Time domain

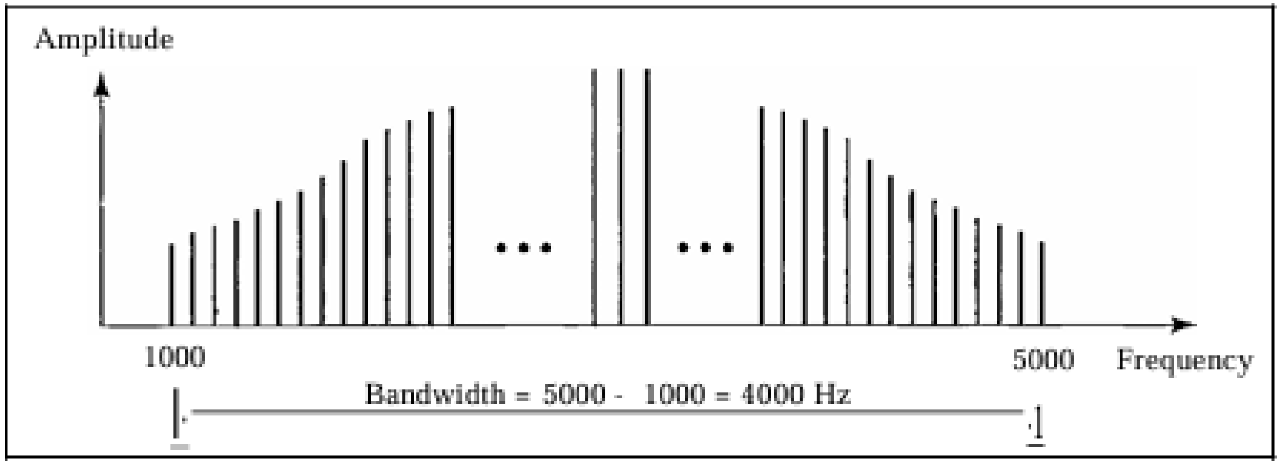


b. Frequency domain

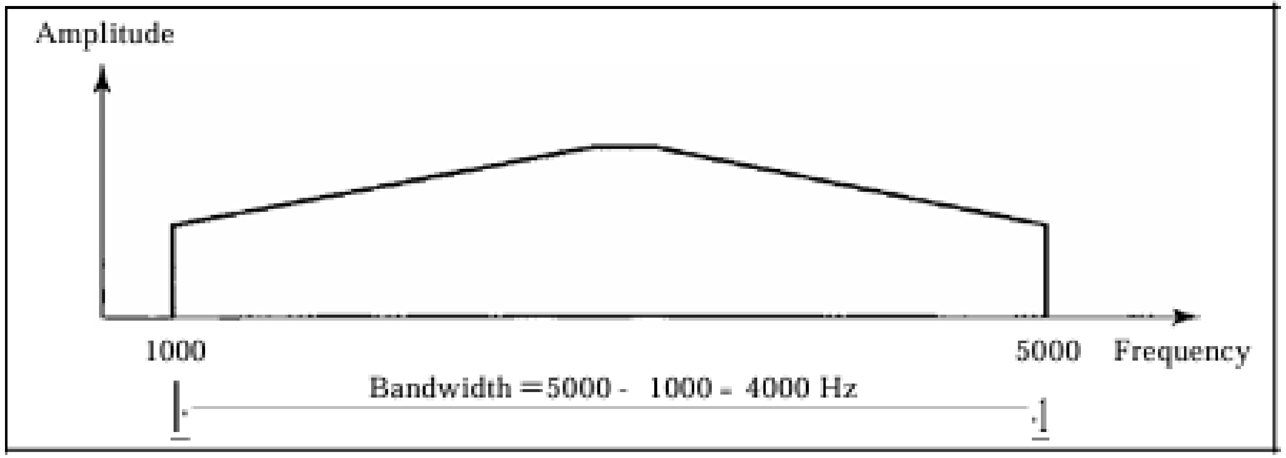
Physical Layer: Prerequisites

- **Bandwidth**

Figure 3.12 *The bandwidth ofperiodic and nonperiodic composite signals*



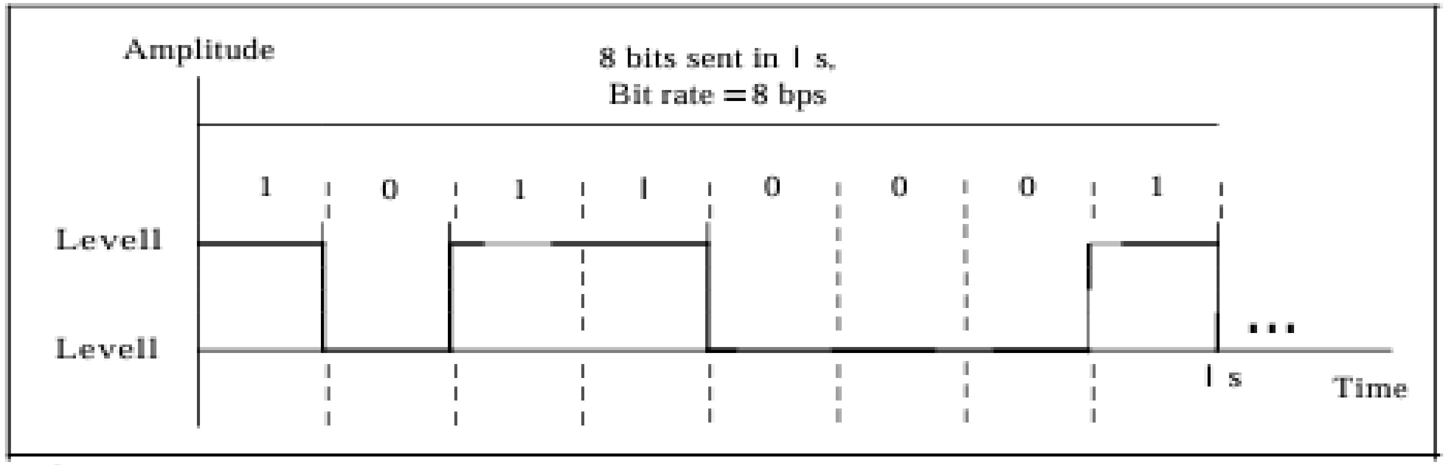
a. Bandwidth of a periodic signal



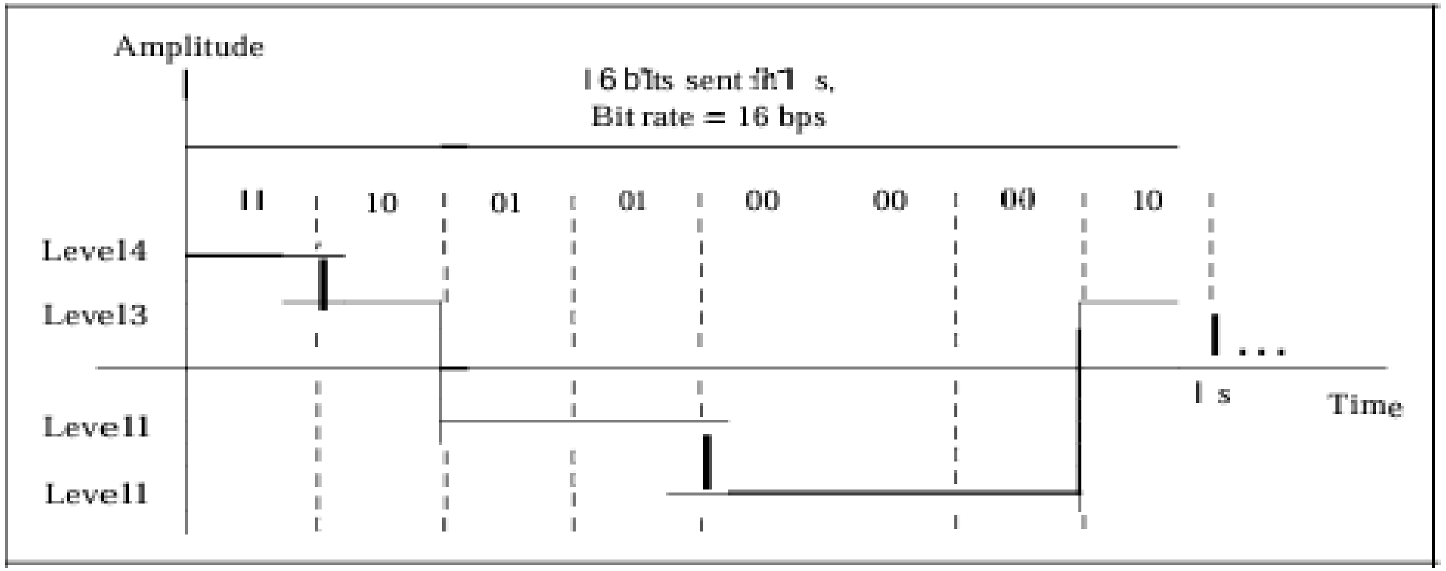
b. Bandwidth of a nonperiodic signal

Physical Layer: Prerequisites

➢ Digital Signals



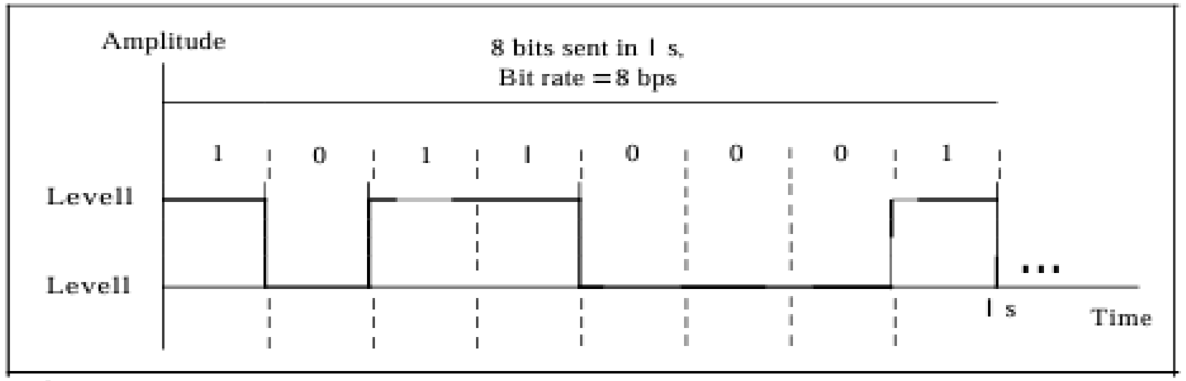
a. A digital signal with two levels



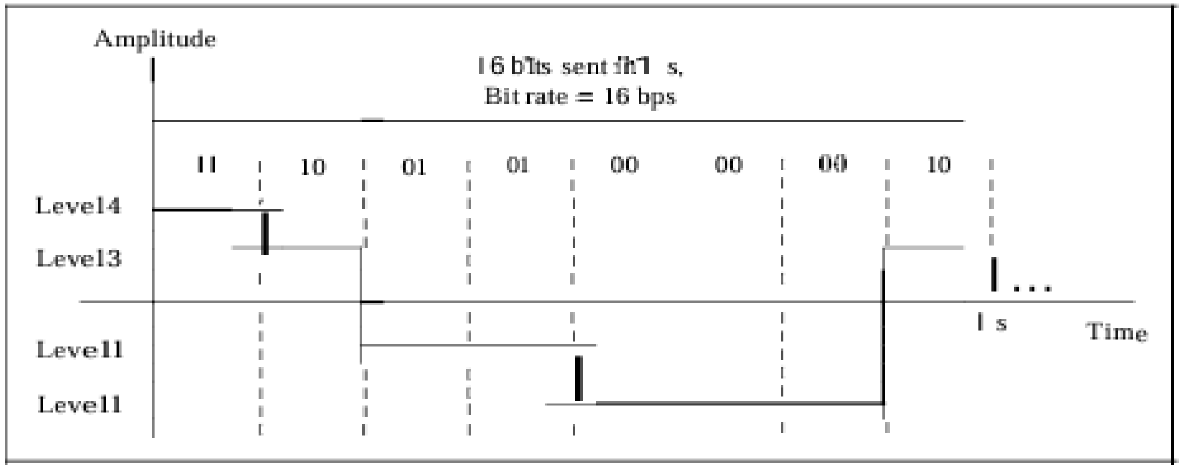
b. A digital signal with four levels

Physical Layer: Prerequisites

➢ Digital Signals



a. A digital signal with two levels



b. A digital signal with four levels

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

Physical Layer: Prerequisites

- Digital Signals

Example 3.16

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\text{Number of bits per level} = \log_2 8 = 3$$

Each signal level is represented by 3 bits.

Physical Layer: Prerequisites

- Digital Signals

Bit Rate

Most digital signals are nonperiodic, and thus period and frequency are not appropriate characteristics. Another *term-bit rate* (instead *ofjrequency)-is* used to describe digital signals. The bit rate is the number of bits sent in Is, expressed in bits per second (bps). Figure 3.16 shows the bit rate for two signals.

Physical Layer: Prerequisites

- Digital Signals

Example 3.19

A digitized voice channel, as we will see in Chapter 4, 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

The bit rate can be calculated as

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

- **Solve Example 3.18 & 3.20**

Physical Layer: Prerequisites

- Digital Signals
- **Bit Length:**

The bit length is the distance one bit occupies on the transmission medium.

Bit length = propagation speed x bit duration

Physical Layer: Prerequisites

➢ Transmission of Digital Signals

Baseband Transmission

Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal. Figure 3.18 shows baseband transmission.

Acts as Low Pass Filter

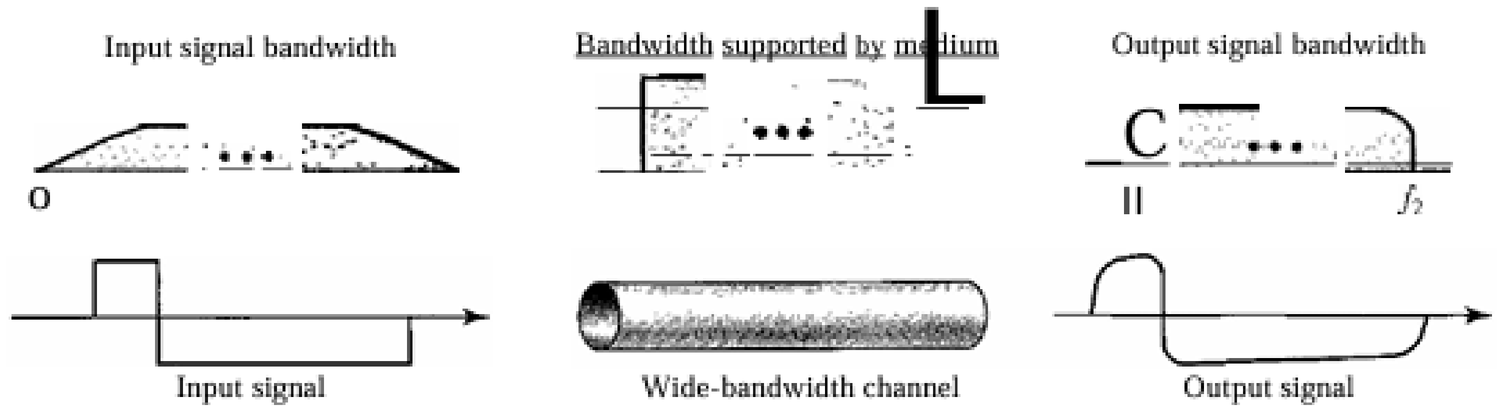
Figure 3.18 *Baseband transmission*

A digital signal is a composite analog signal with an infinite bandwidth.

Physical Layer: Prerequisites

- Baseband Transmission with Limited Bandwidth and Wider Bandwidth

Figure 3.20 *Baseband transmission using a dedicated medium*



Although the output signal is not an exact replica of the original signal, the data can still be deduced from the received signal. Note that although some of the frequencies are blocked by the medium, they are not critical.

Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.

Example of Wider bandwidth

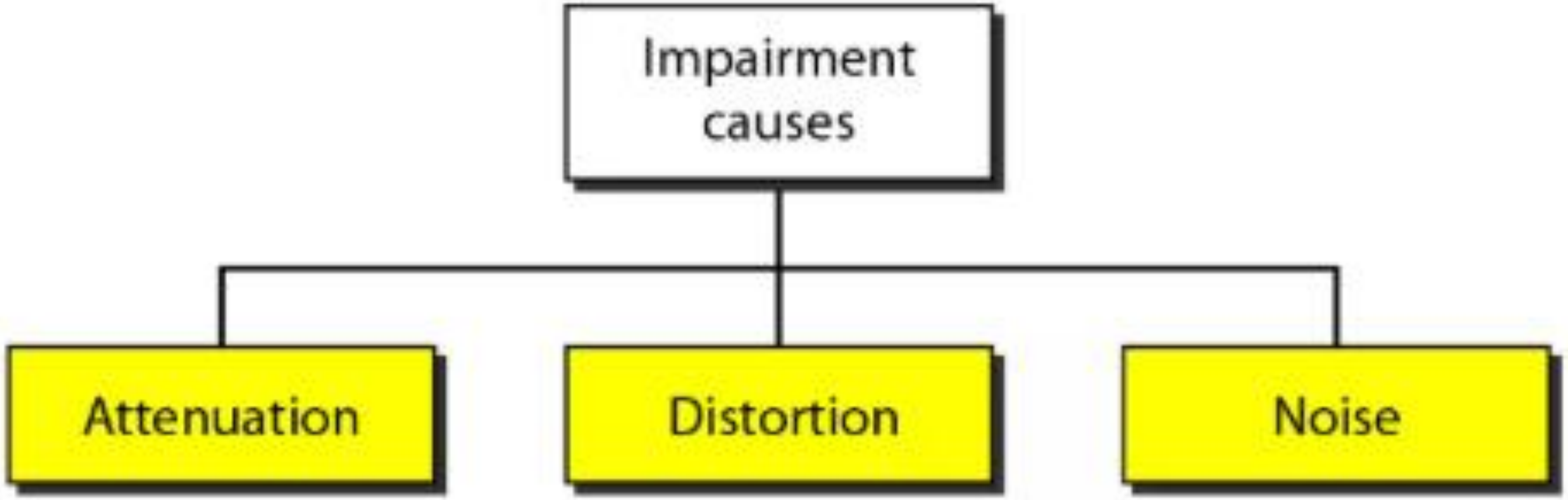
Transmission Impairments

3.4 TRANSMISSION IMPAIRMENT

Signals travel through transmission media, which are not petfect. The impetfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise (see Figure 3.25).

Transmission Impairments

Figure 3.25 ***Causes of impairment***



Transmission Impairments: Attenuation

Attenuation

- Means loss of energy -> weaker signal
- 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.

Transmission Impairments

Measurement of Attenuation

- To show the loss or gain of energy the unit “decibel” is used.

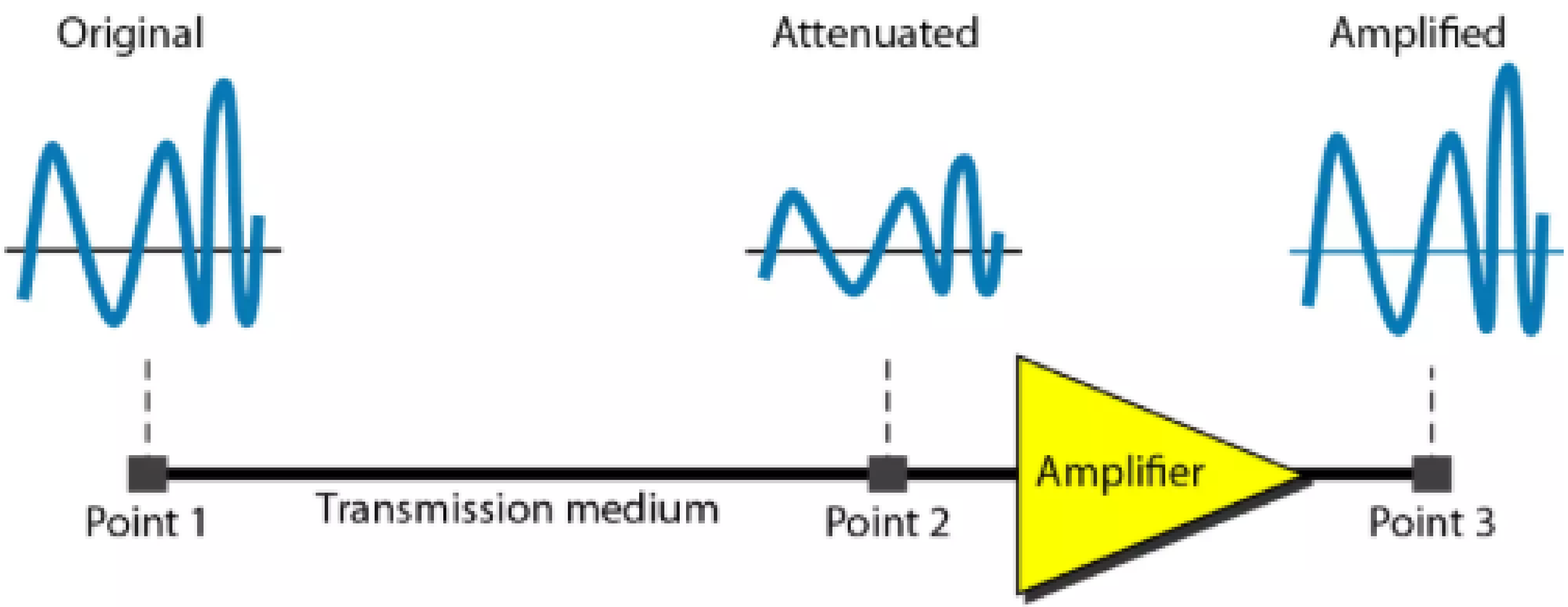
$$dB = 10\log_{10} P_2/P_1$$

P_1 - input signal

P_2 - output signal

Transmission Impairments

Figure 3.26 ***Attenuation***



Transmission Impairments

Example 3.26

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P_2 is $(1/2)P_1$. In this case, the attenuation (loss of power) can be calculated as

$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}}$$

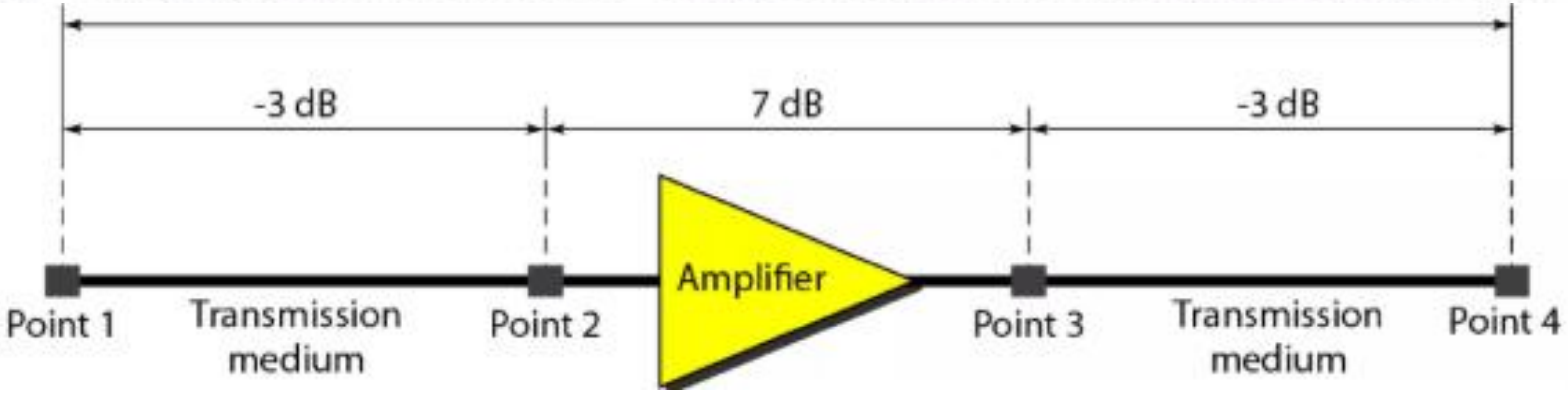
A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

- **Solve Example 3.27**

Transmission Impairments

Example 3.28

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure 3.27 a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as



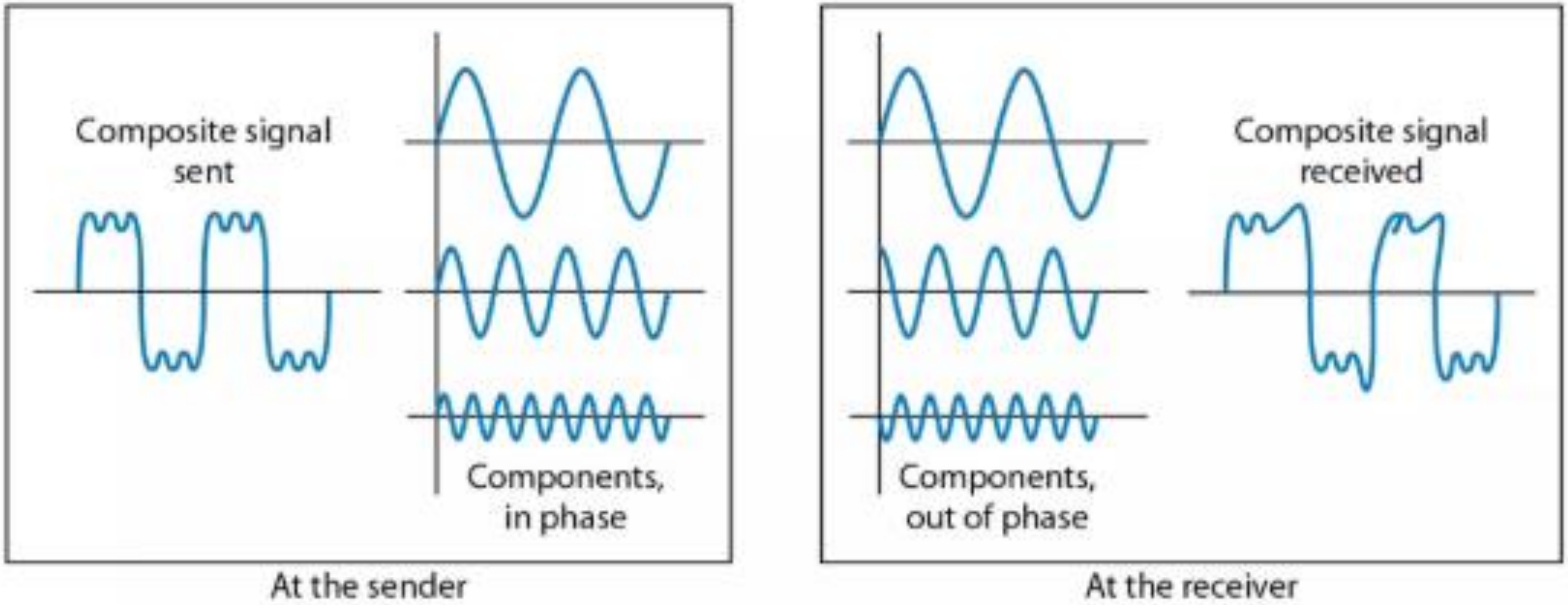
Transmission Impairments: Distortion

Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.

Transmission Impairments: Distortion

Figure 3.28 ***Distortion***

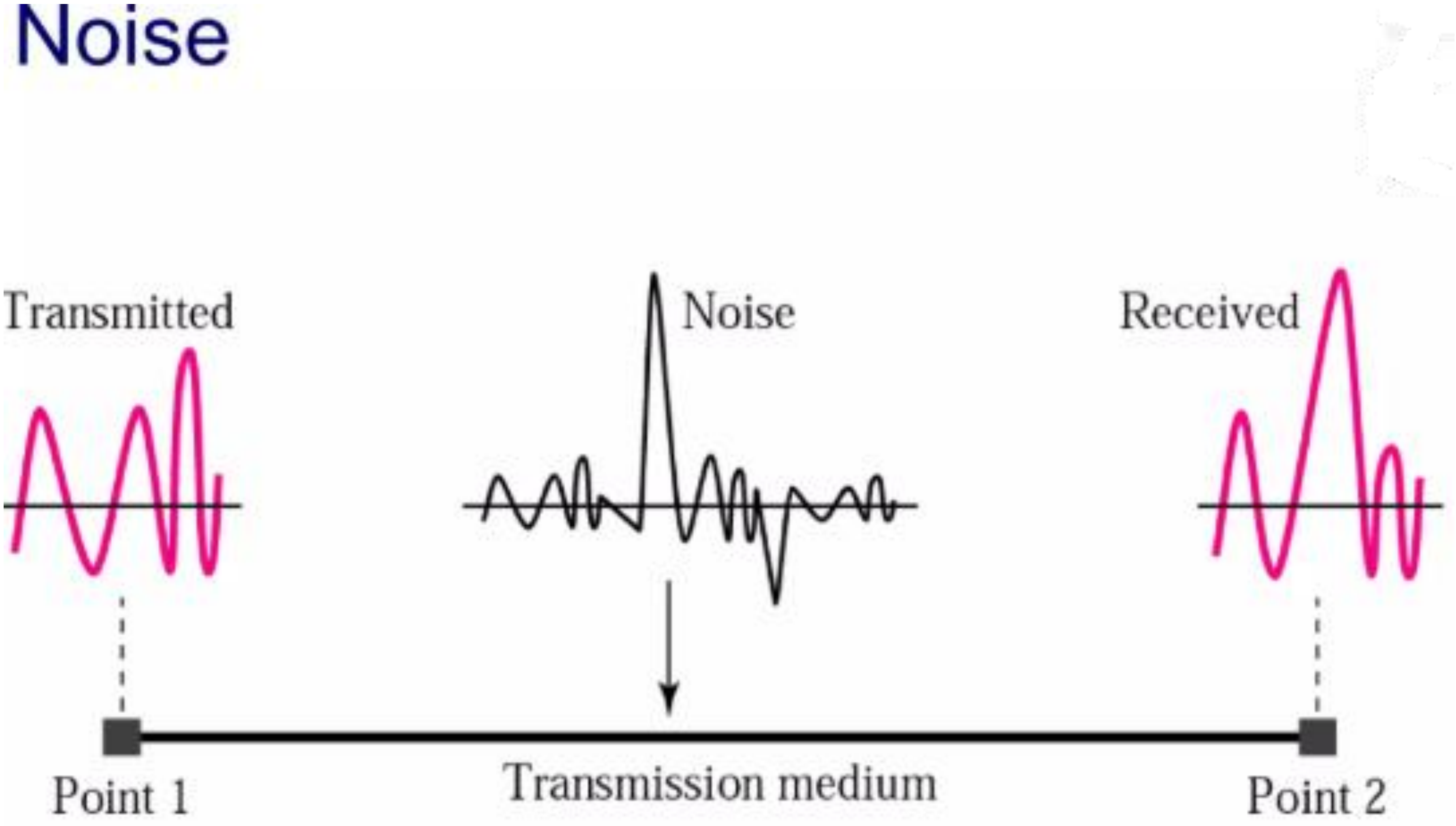


Transmission Impairments: Noise

Noise

- Corruption caused by
  - Thermal noise – random motion of electrons, creating an extra signal
  - Induced noise – outside sources such as motors and appliances
  - Crosstalk – effect of one wire on another
  - Impulse noise – a spike for a short period from power lines, lightning, etc.

Transmission Impairments: Noise



Transmission Impairments: Noise

Signal-to-Noise Ratio (SNR)

As we will see later, to find the theoretical bit rate limit, we need to know the ratio of the signal power to the noise power. The signal-to-noise ratio is defined as

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

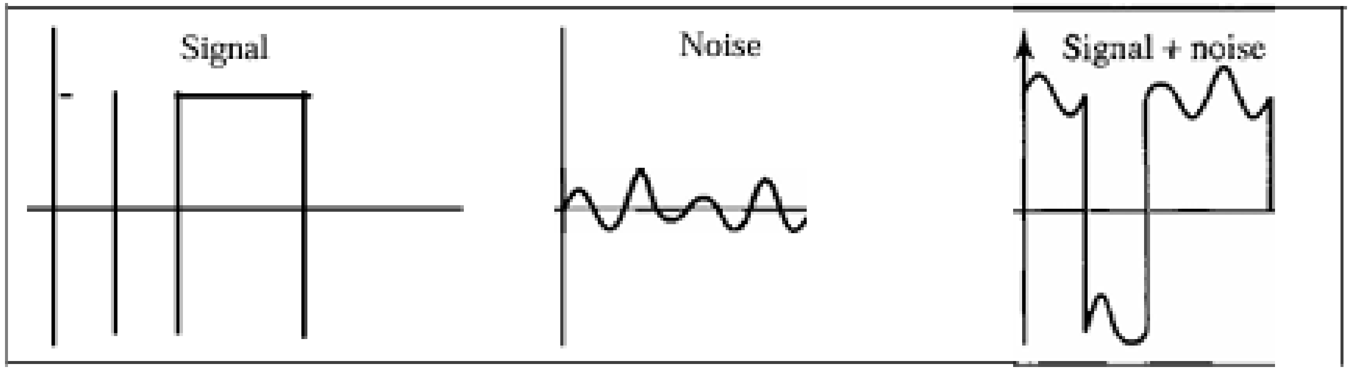
$$\mathbf{SNR_{dB}} = 10 \log_{10} \text{SNR}$$

Transmission Impairments: Noise

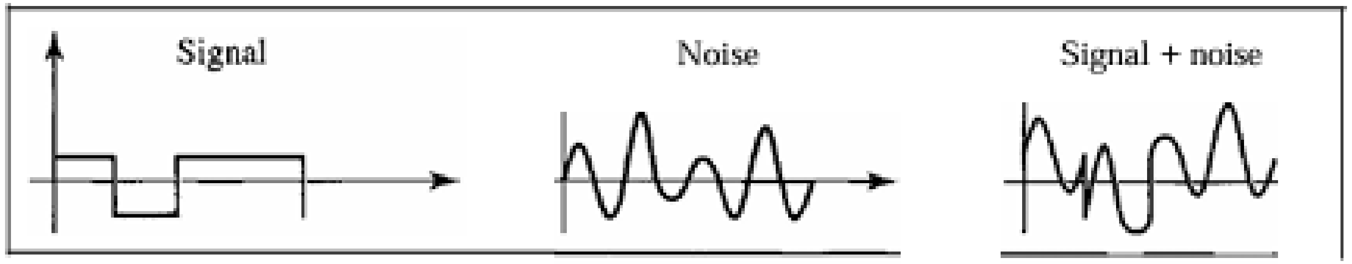
Example 3.31

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}?

Figure 3.30 *Two cases of SNR: a high SNR and a low SNR*



a. Large SNR



b. Small SNR

Transmission Impairments: Noise

Example 3.31

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:

$$SNR = \frac{10.000\ \mu W}{1 mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Example 3.32

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.

Data Rate Limit

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)

Data Rate Limit

Noiseless Channel: Nyquist Bit Rate

For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

Increasing the levels of a signal may reduce the reliability of the system.

Data Rate Limit

Example 3.34

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

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

- **Solve Example 3.35 & 3.36**

Data Rate Limit of a Noisy Channel: Shannon Capacity

Noisy Channel: Shannon Capacity

- Determine the theoretical highest data rate for a noisy channel

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

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. For this channel the capacity is calculated as

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 (3163)$$

$$C = 3000 \times 11.62 = 34{,}860 \text{ bps}$$

Data Rate Limit of a Noisy Channel: Shannon Capacity

Example 3.37

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

$$C = B \log 2\ (1 + \mathrm{SNR}) = B\ 10\mathrm{g}_Z\ (\mathrm{l} + 0) = B \log 2\ 1 = B \times 0 = 0$$

Example 3.38

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

$$C = B \log 2\ (1 + \mathrm{SNR}) = 3000 \log 2\ (\mathrm{l} + 3162) = 3000 \log 2\ 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

Data Rate Limit of a Noisy Channel: Shannon Capacity

Example 3.39

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

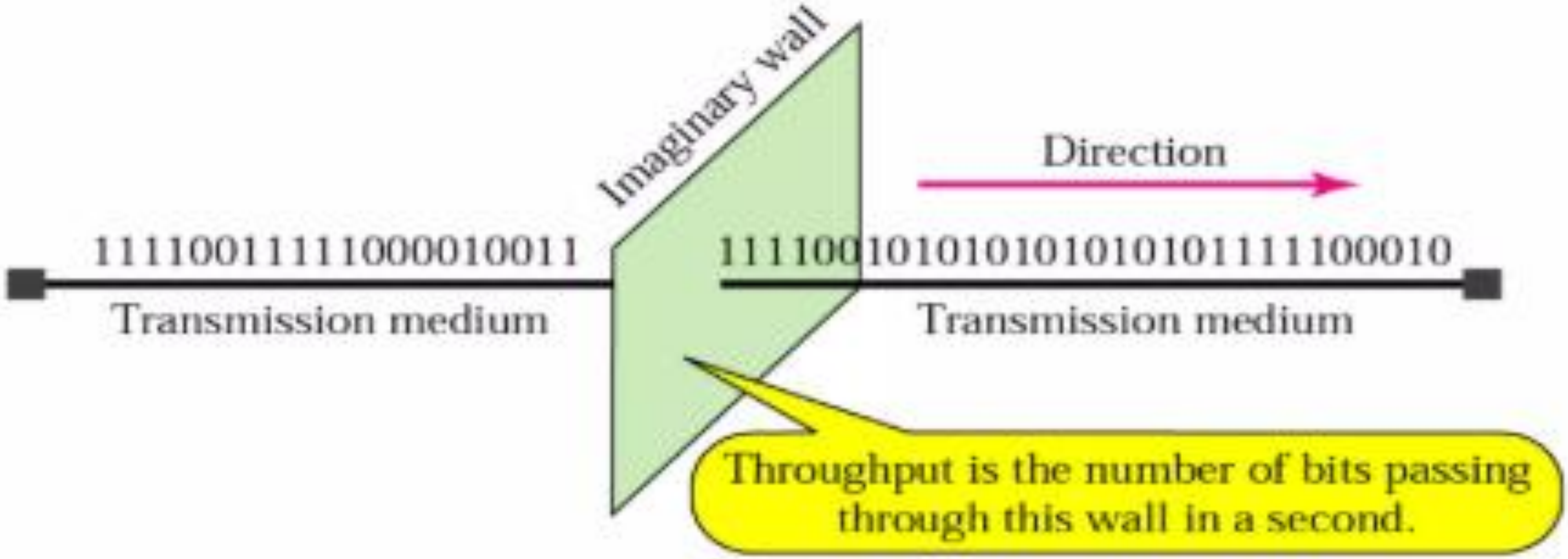
$$SNR_{dB} = 10 \log_{10} SNR \quad \Rightarrow \quad SNR = 10^{SNR_{dB}/10} \quad \Rightarrow \quad SNR = 10^{3.6} = 3981$$

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

- **Solve Example 3.41: Important**

Transmission Performance

Throughput - how fast data can pass through an entity (such as a point or network)



Transmission Performance

Example 3.44

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?

Solution

We can calculate the throughput as

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}$$

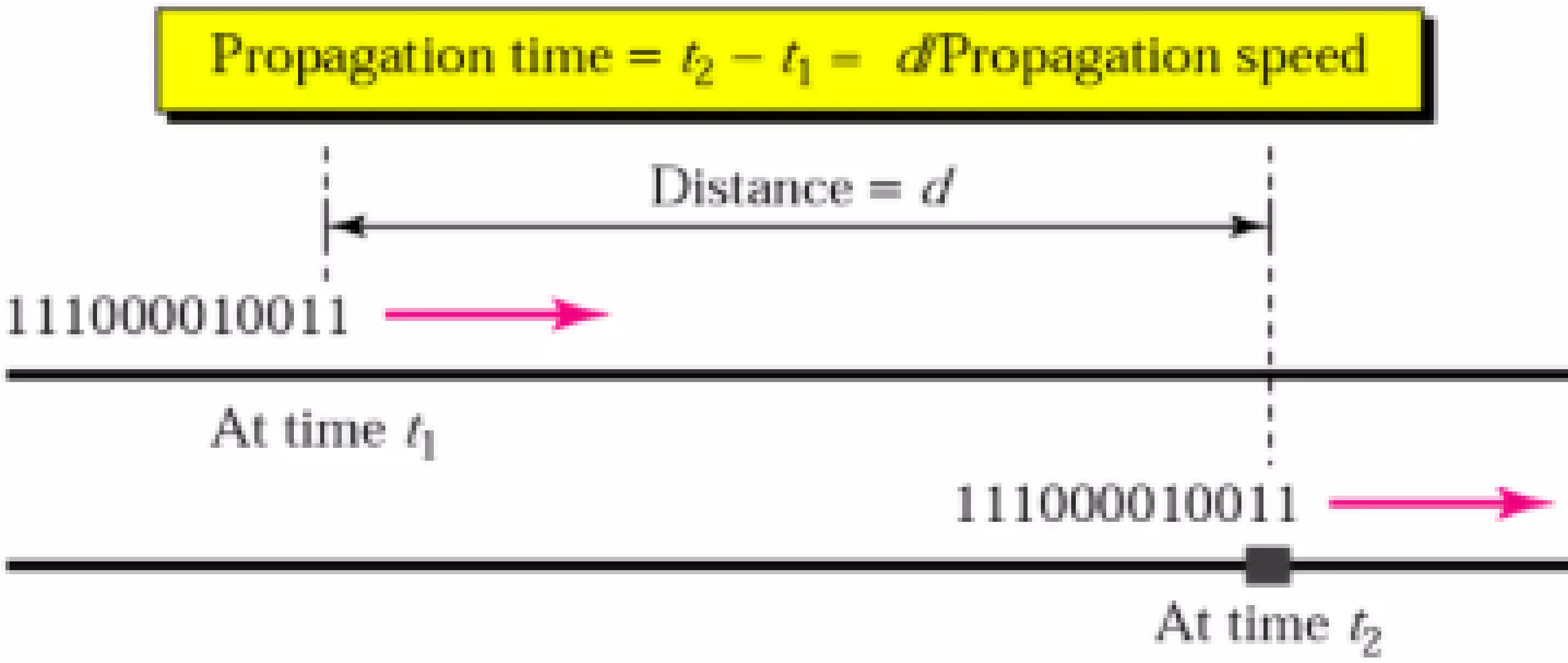
The throughput is almost one-fifth of the bandwidth in this case.

Transmission Performance

- Propagation speed – distance a signal or bit can travel through a medium in one second depend on
  - Medium
  - Frequency

Transmission Performance

Propagation time = Distance/Propagation speed



Transmission Performance

Latency (Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source. We can say that latency is made of four components: propagation time, transmission time, queuing time and processing delay.

$$\text{Latency} = \text{propagation time} + \text{transmission time} + \text{queuing time} + \text{processing delay}$$