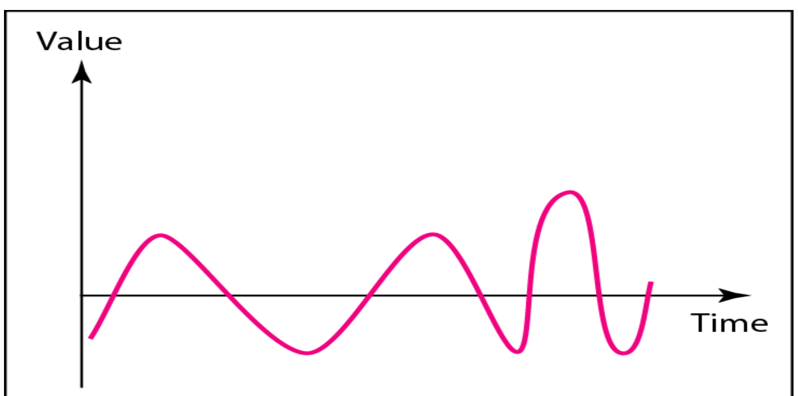
Chapter 3: Data and Signals

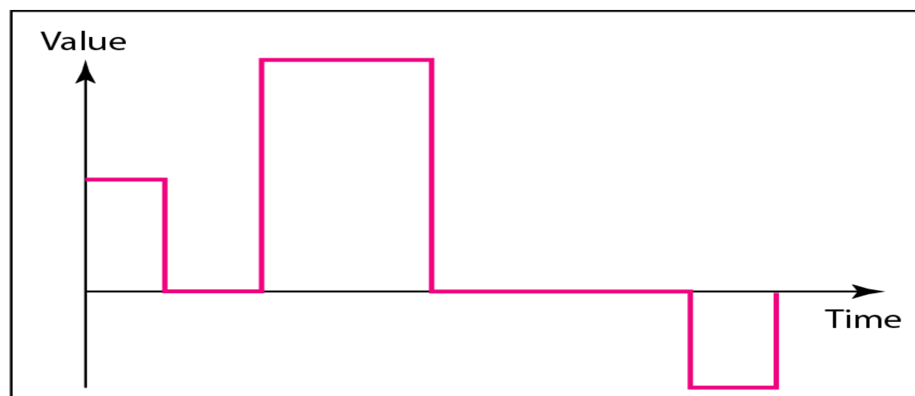
- One of the major functions of the physical layer is to move data in the form of elctro magnetic signal across a transmission medium.

ANALOG AND DIGITAL

- To be transmitted, data must be transformed to electromagnetic signals.
- Data can be analog or digital. Analog data are continuous and take continuous values. Digital data have discrete states and take discrete values.
- Signals can also be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.



a. Analog signal



b. Digital signal

ANALOG AND DIGITAL

- Both analog and digital signal can be periodic or non periodic.
- A periodic signal completes a pattern within a measurable time frame called period and repeats the pattern over subsequent identical period.
- Completion a full pattern is called a cycle.
- In data communications, we commonly use periodic analog signals and non-periodic digital signals.

PERIODIC ANALOG SIGNALS

- Periodic analog signals can be classified as simple or composite.
- A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves.
- The sine wave is the most fundamental form of a periodic analog signal.
- A sine wave can be represented by three parameters: the peak amplitude, the frequency and the phase

PERIODIC ANALOG SIGNALS

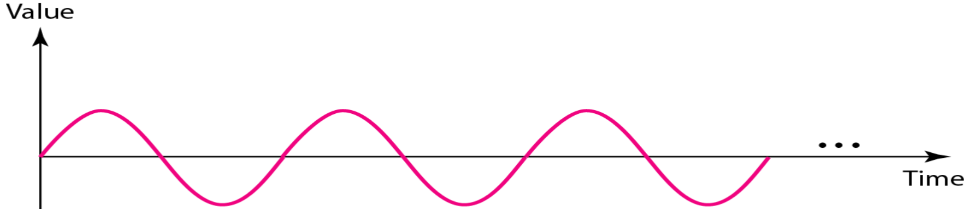
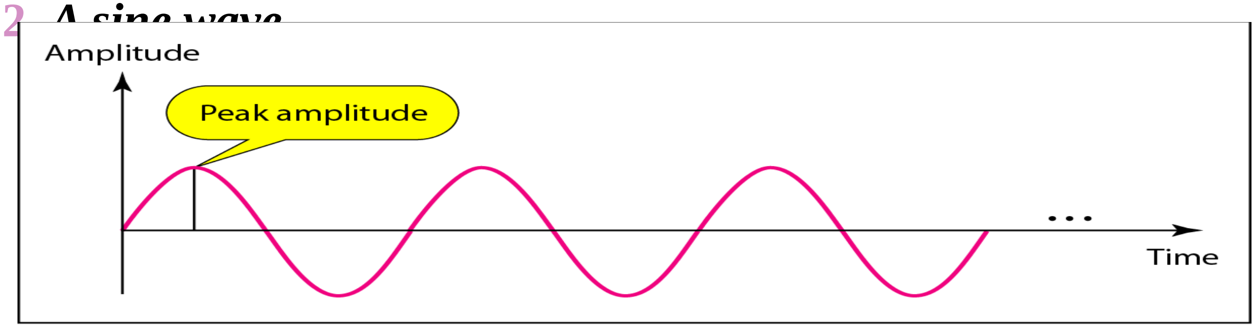
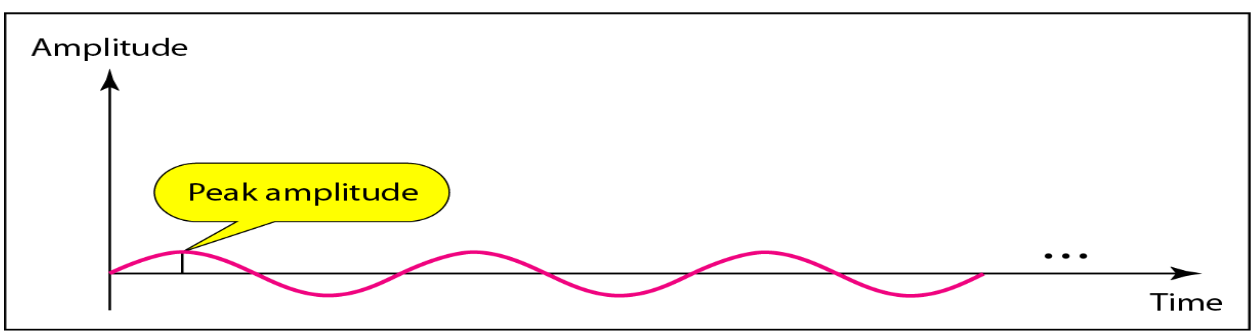


Figure 3.2 *A sine wave*



a. A signal with high peak amplitude

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



b. A signal with low peak amplitude

- Frequency and period are the inverse of each other.
- Frequency is the rate of change with respect to time. Change in a short span of time means high frequency.
- Change over a long span of time means low frequency.

PERIODIC ANALOG SIGNALS

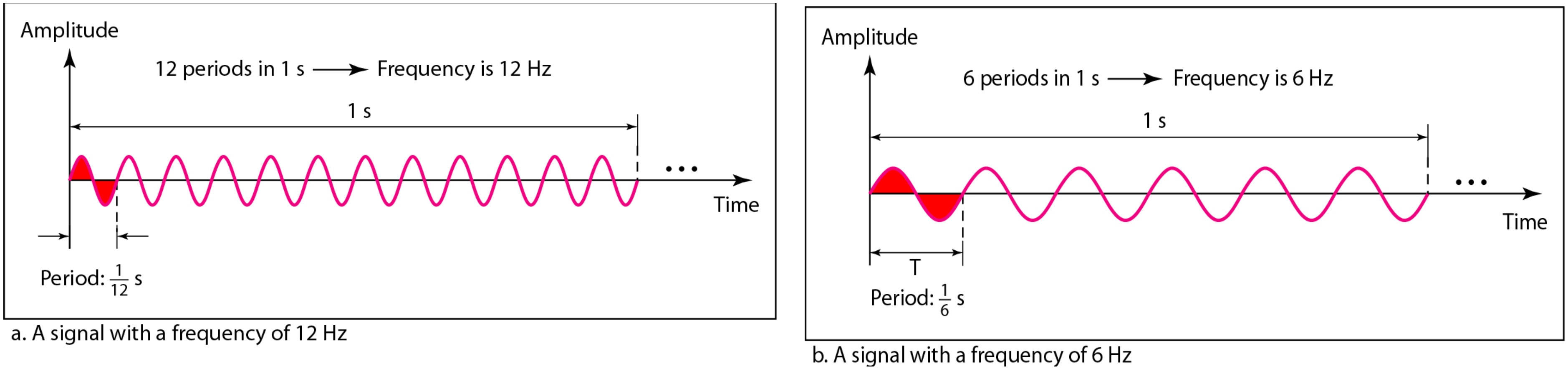


Figure 3.4 ***Two signals with the same amplitude and phase, but different frequencies***

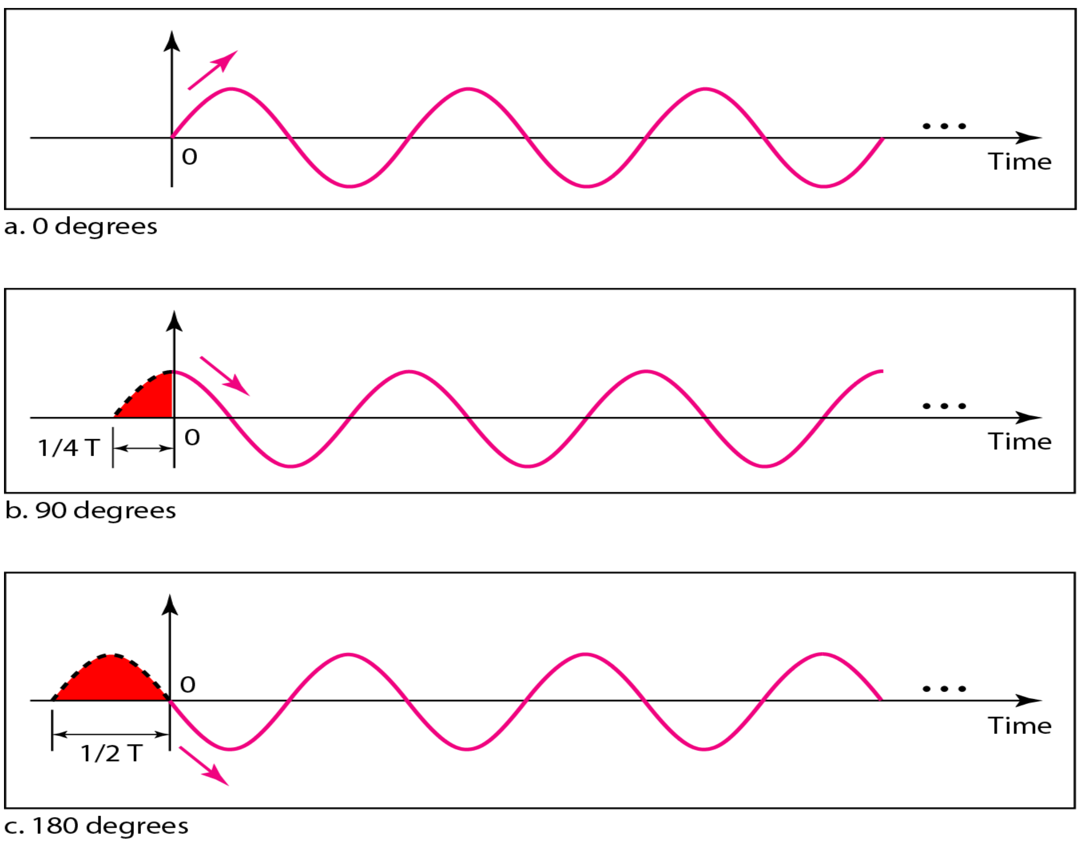
frequency= $\boxed{f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}}$ T = Time

The voltage of a battery is a constant; this constant value can be considered a sine wave, For example, the peak value of an AA battery is normally 1.5 V.

Frequency and phase

- If a signal does not change at all, its frequency is zero.
- If a signal changes instantaneously, its frequency is infinite.
- Phase describes the position of waveform relative to time 0.

Figure 3.5 ***Three sine waves with the same amplitude and frequency, but different phases***



Phase 0 : at time 0 start with 0 amplitude and then increase amplitude

Phase 90 : at time 0 start with peak amplitude and then decrease amplitude

Phase 180 : at time 0 start with 0 amplitude and then decrease amplitude

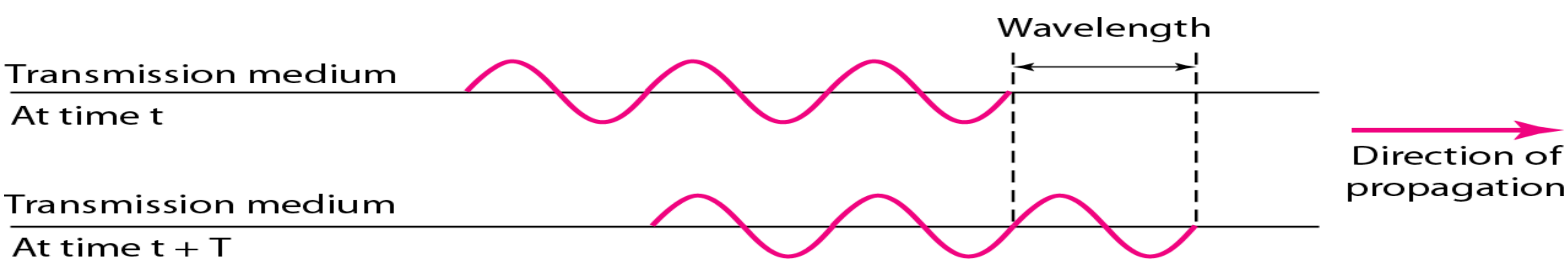
Wavelength and propagation speed

- Wavelength: the distance a simple signal can travel in one period.
- Propagation speed: the rate at which a signal or bit travels; measured by distance/second.
- Propagation time: the time required for a signal to travel from one point to another.
- Wavelength = propagation speed x period =

  = propagation speed /frequency

$$\lambda = \frac{c}{f}$$

- λ : wavelength c: speed of light f : frequency

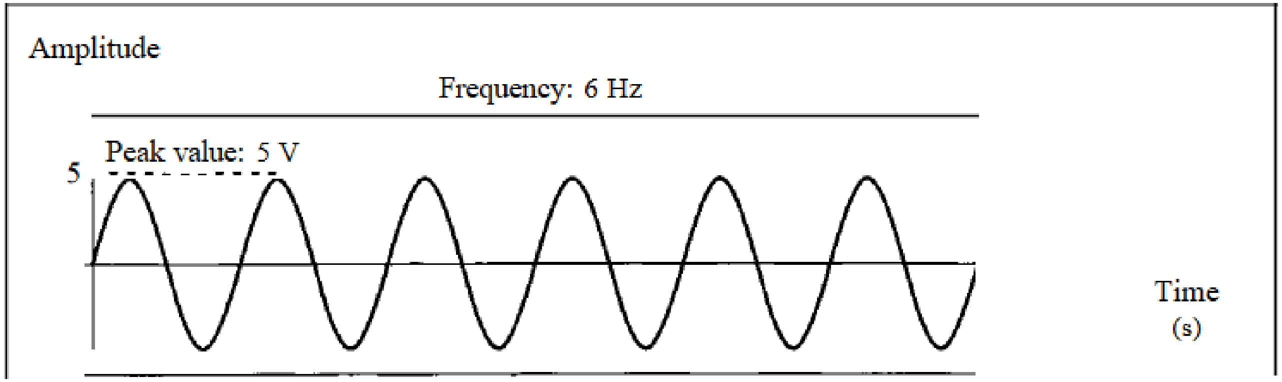


- The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal.
- For example, in a vacuum, light is propagated with a speed of 3 x 108 m/s. That speed is lower in air and even lower in cable.

- The wavelength is normally measured in micrometers (microns) instead of meters. In a coaxial or fiber-optic cable, however, the wavelength is shorter (0.5 μm) because the propagation speed in the cable is decreased.

Time frequency domain

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

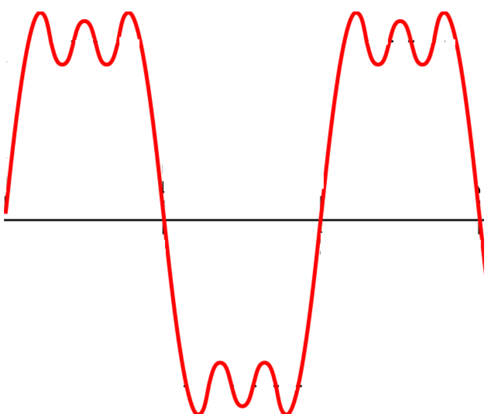


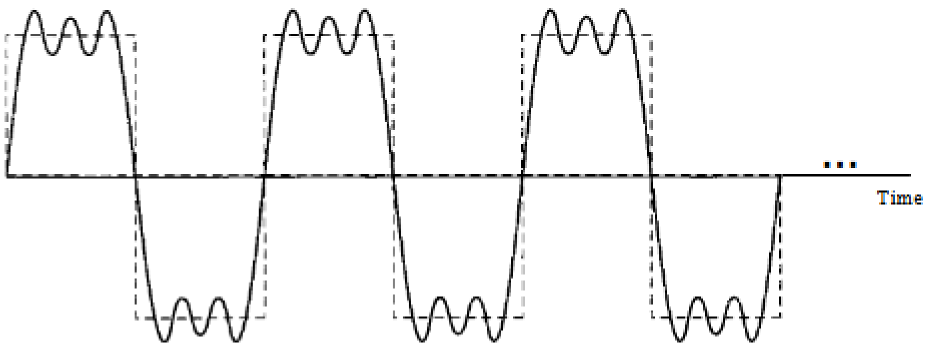
a. A sine wave in the time domain (**peak** value: 5 V, frequency: 6 Hz)

Composite signal

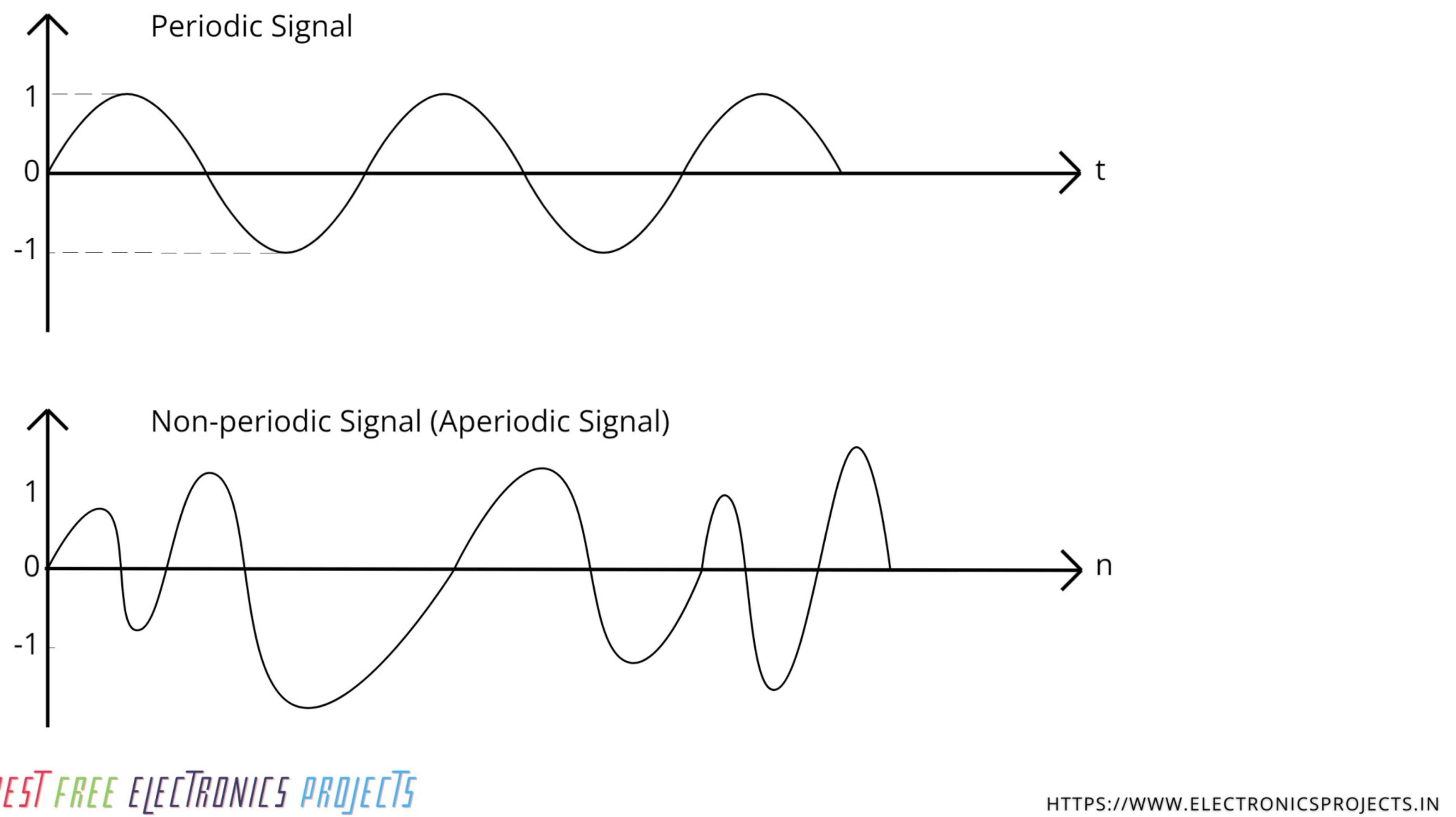
- A single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.
- Composite signal A signal composed of more than one sine wave.
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.
- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies;
- if the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

A **periodic signal** is one that repeats the sequence of values exactly after a fixed length of time,





PERIODIC SIGNAL AND APERIODIC SIGNAL



Bandwidth

- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.
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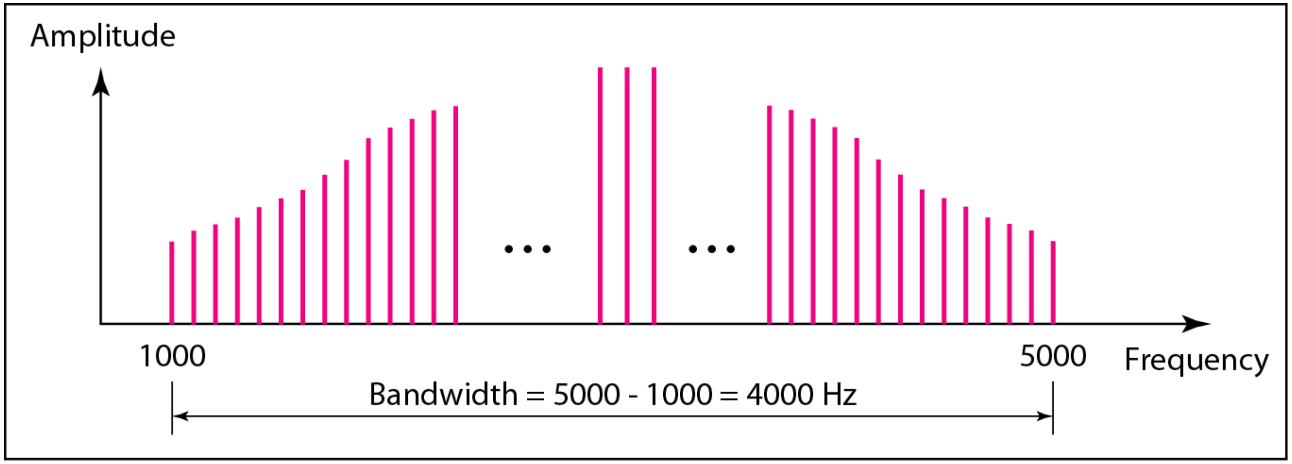
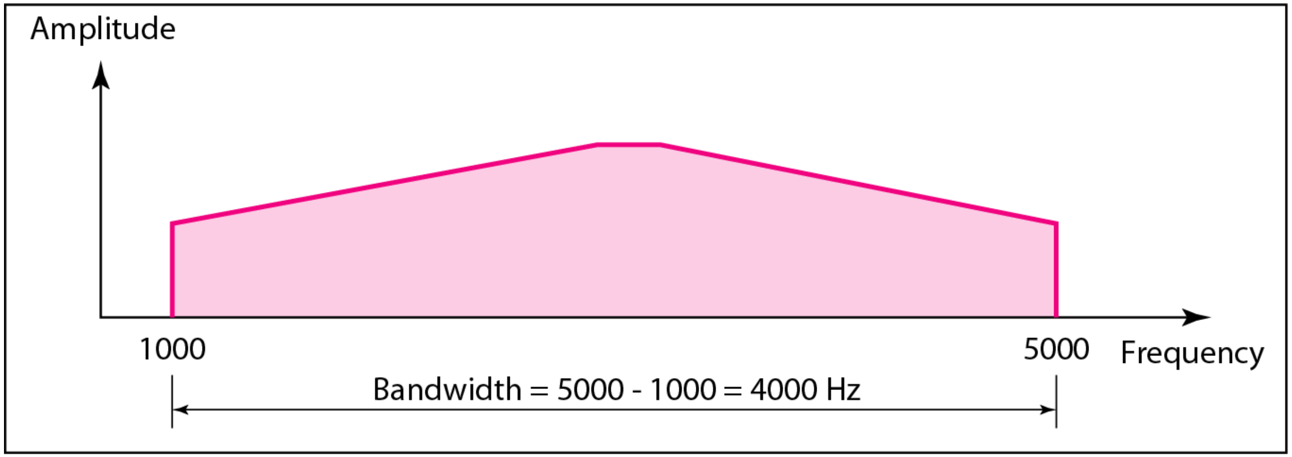
- The bandwidth of the periodic signal contains all integer frequencies between 1000 and 5000 (1000, 100 I, 1002, ...).
- The band-width of the non-periodic signals has the same range, but the frequencies are continuous



a. Bandwidth of a periodic signal

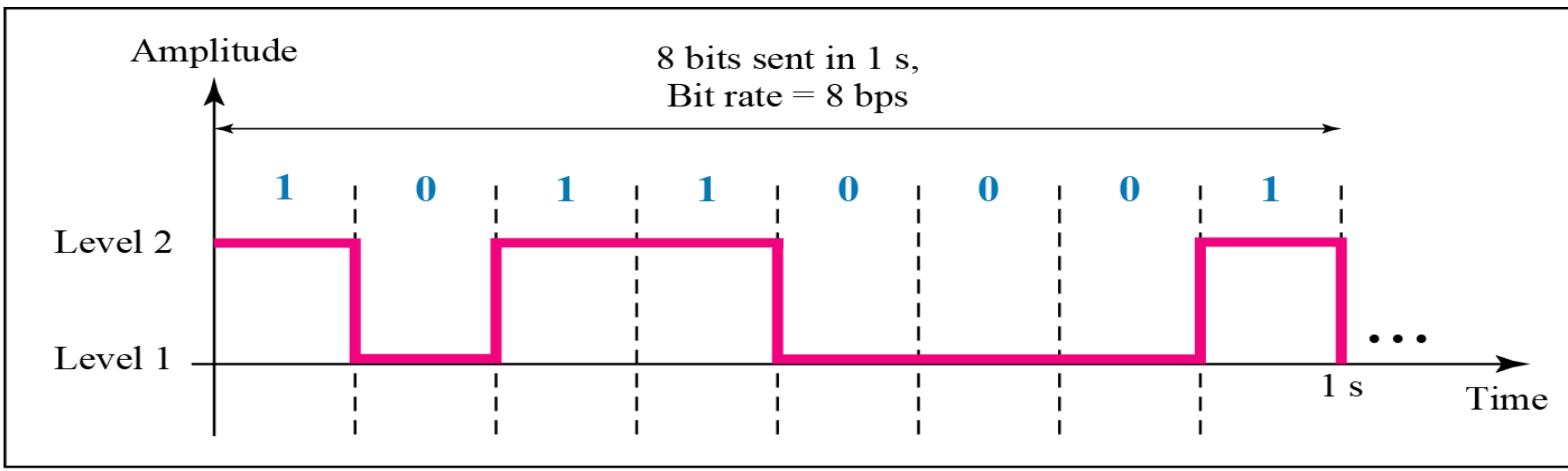


b. Bandwidth of a nonperiodic signal

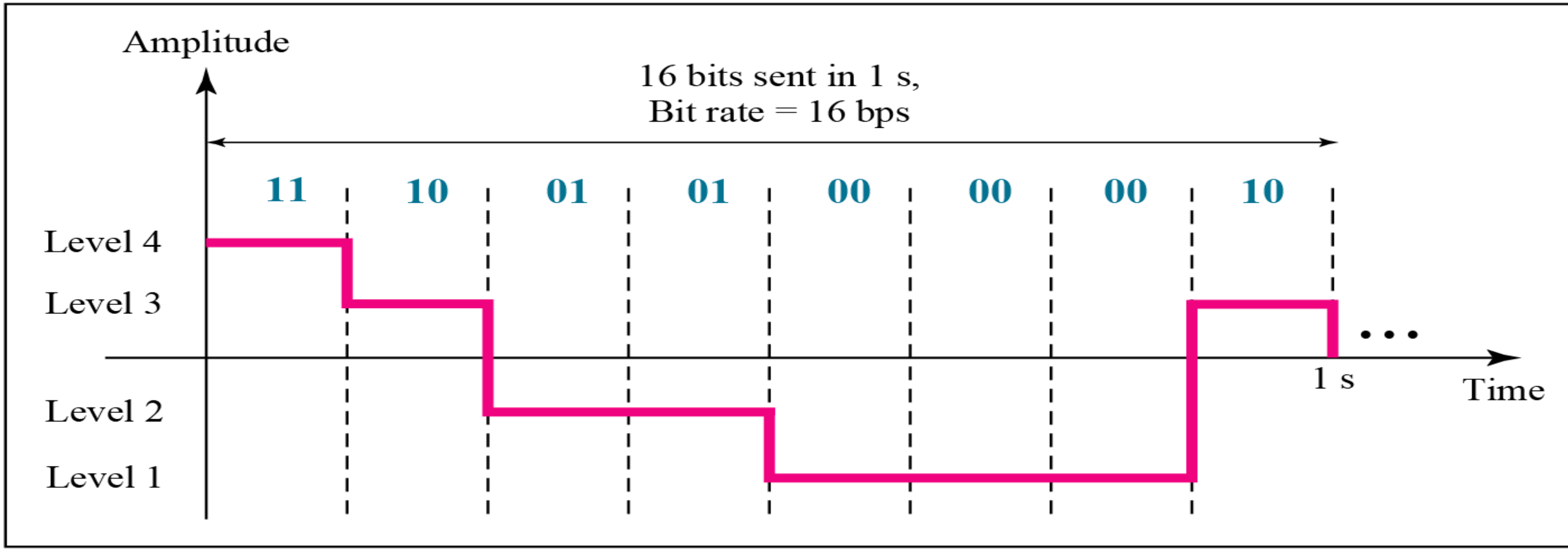
DIGITAL SIGNALS

- In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage.
- A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

Figure 3.16 ***Two digital signals: one with two signal levels and the other with four signal levels***



a. A digital signal with two levels



b. A digital signal with four levels

Bit length

- the concept of the wavelength for an analog signal: the distance one cycle occupies on the transmission medium.
- We can define something similar for a digital signal: the bit length.
- The bit length is the distance one bit occupies on the transmission medium.

Bit length = propagation speed * bit duration

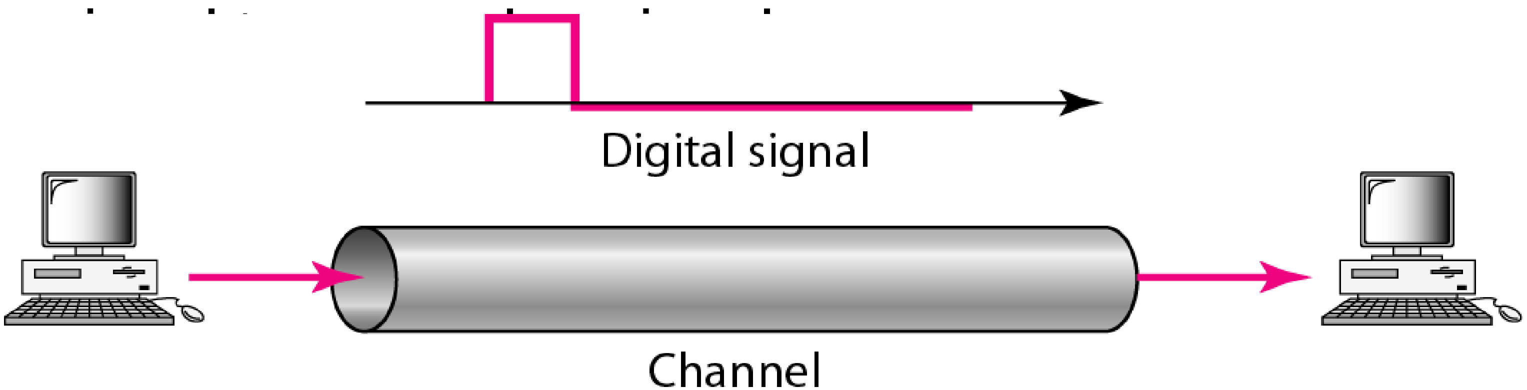
Digital Signal as a Composite Analog Signal

- Based on Fourier analysis, a digital signal is a composite analog signal.
- The bandwidth is infinite, but the periodic signal has discrete frequencies while the nonperiodic signal has continuous frequencies.

Transmission of Digital Signals

- We can transmit a digital signal by using one of two different approaches:
- ***baseband transmission.***
- ***broadband transmission (using modulation).***

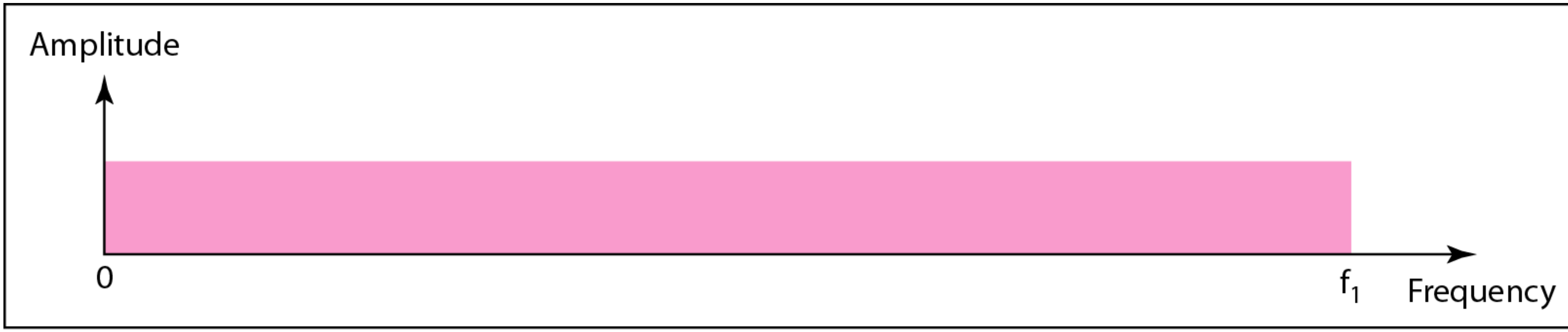
- Baseband transmission means sending a digital signal over a channel without changing the digital



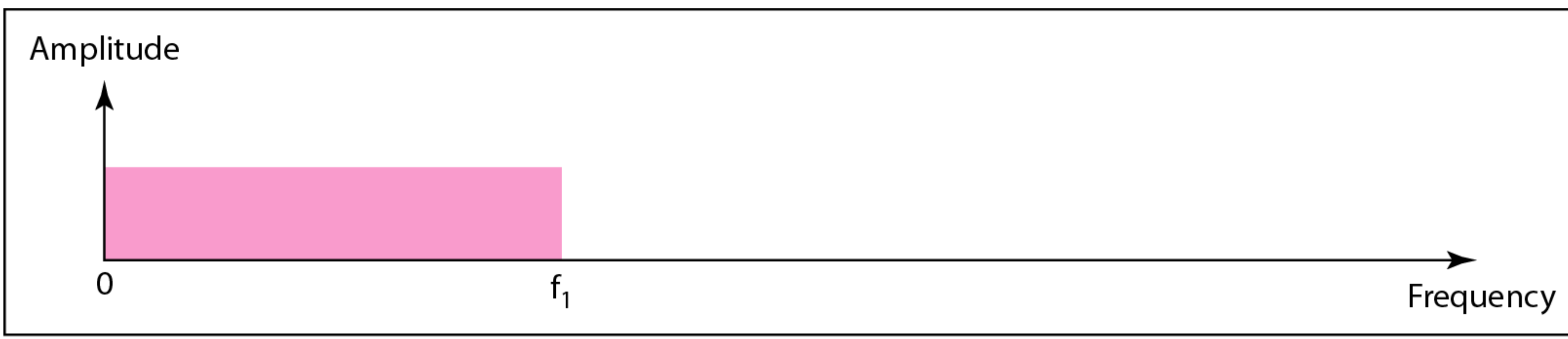
- Baseband transmission requires that we have a low-pass channel, a channel with a bandwidth that starts from zero.
- For example, the entire bandwidth of a cable connecting two computers is one single channel.
- As another example, we may connect several computers to a bus, but not allow more than two stations to communicate at a time.

Figure 3.19 *Bandwidths of two low-pass channels*

- A low-pass channel with infinite band-width is ideal, but we cannot have such a channel in real life. However, we can get close.



a. Low-pass channel, wide bandwidth



b. Low-pass channel, narrow bandwidth

●Broadband transmission (using modulation): If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.

Figure 3.23 ***Bandwidth of a bandpass channel***

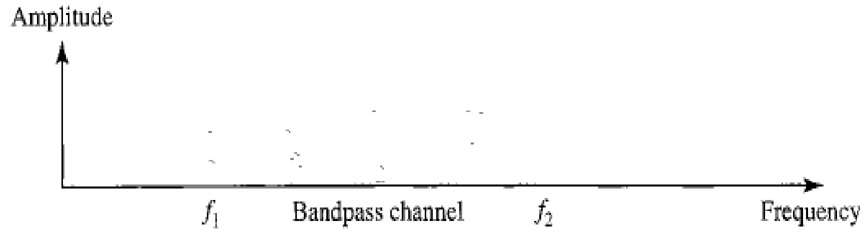
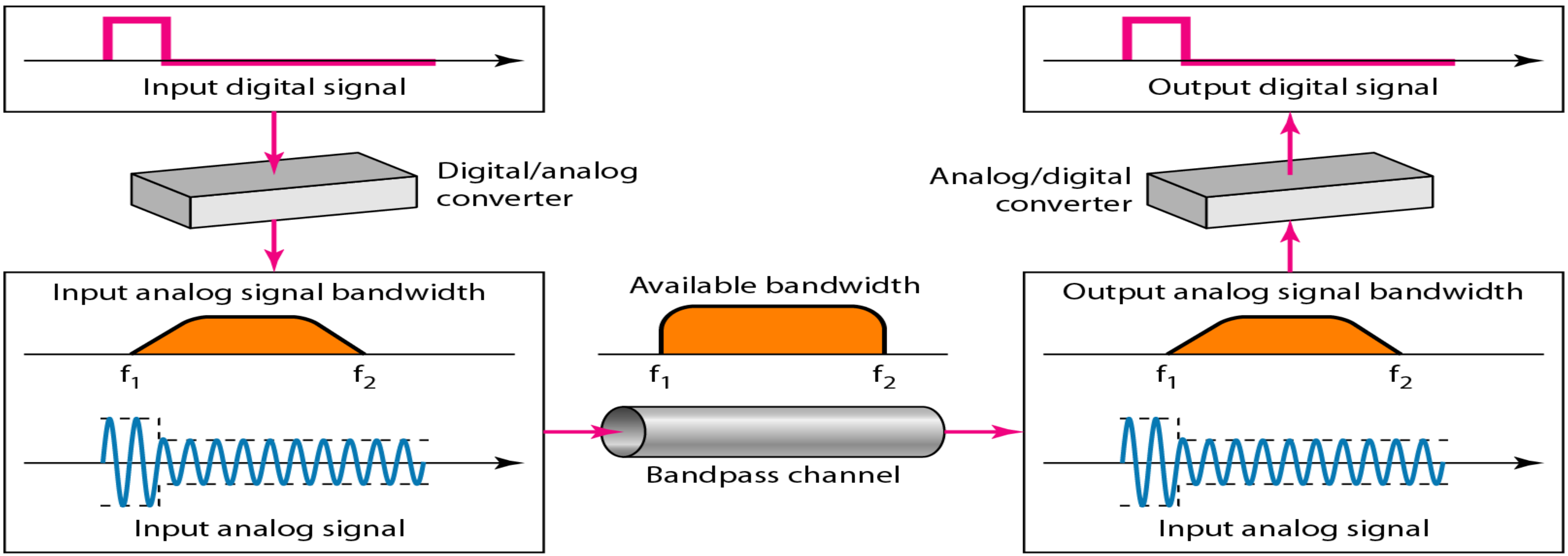


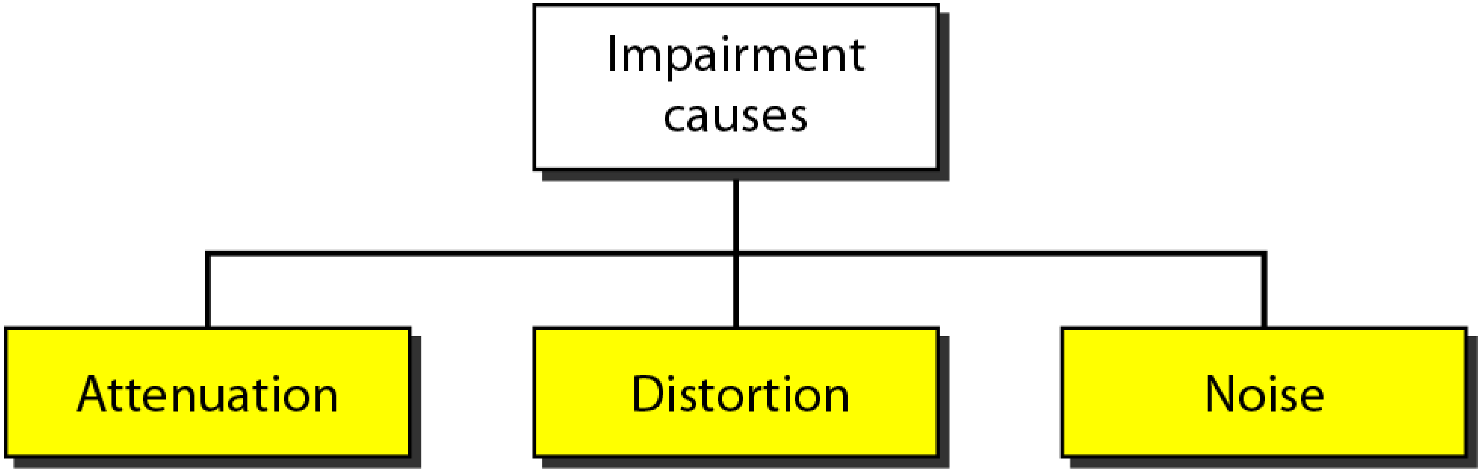
Figure 3.24 ***Modulation of a digital signal for transmission on a bandpass channel***



TRANSMISSION IMPAIRMENT(damage/weaken)

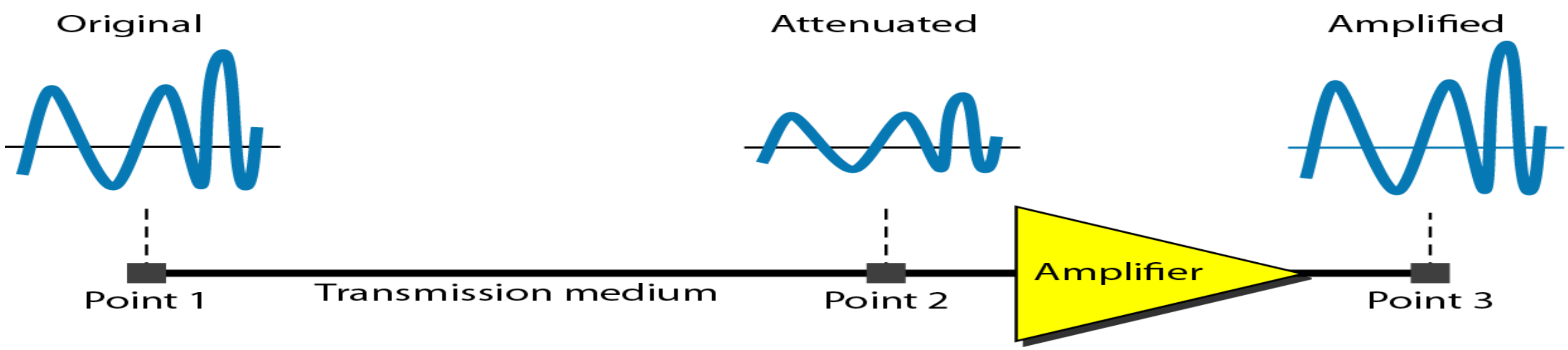
- Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.
- What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise.

Figure 3.25 ***Causes of impairment***



- ***Attenuation*** means a loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium.
- That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat.
- To compensate for this loss, amplifiers are used to amplify the signal. Figure 3.26 shows the effect of attenuation and amplification.

Figure 3.26 ***Attenuation***



Example 3.26

- Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. 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.

Example 3.27

- A signal travels through an amplifier, and its power is increased 10 times. This means that P2 = 10P1 . In this case, the amplification (gain of power) can be calculated as:

$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}} \quad \boxed{= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}}$$

Example 3.29

- Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dBm and is calculated as dBm = 10 log10 Pm , where Pm is the power in milliwatts. Calculate the power of a signal with dBm = −30.
- Solution
- We can calculate the power in the signal as

$$\boxed{\begin{array}{c} \mathrm{dB_m} = 10 \log_{10} P_m = -30 \\ \log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW} \end{array}}$$

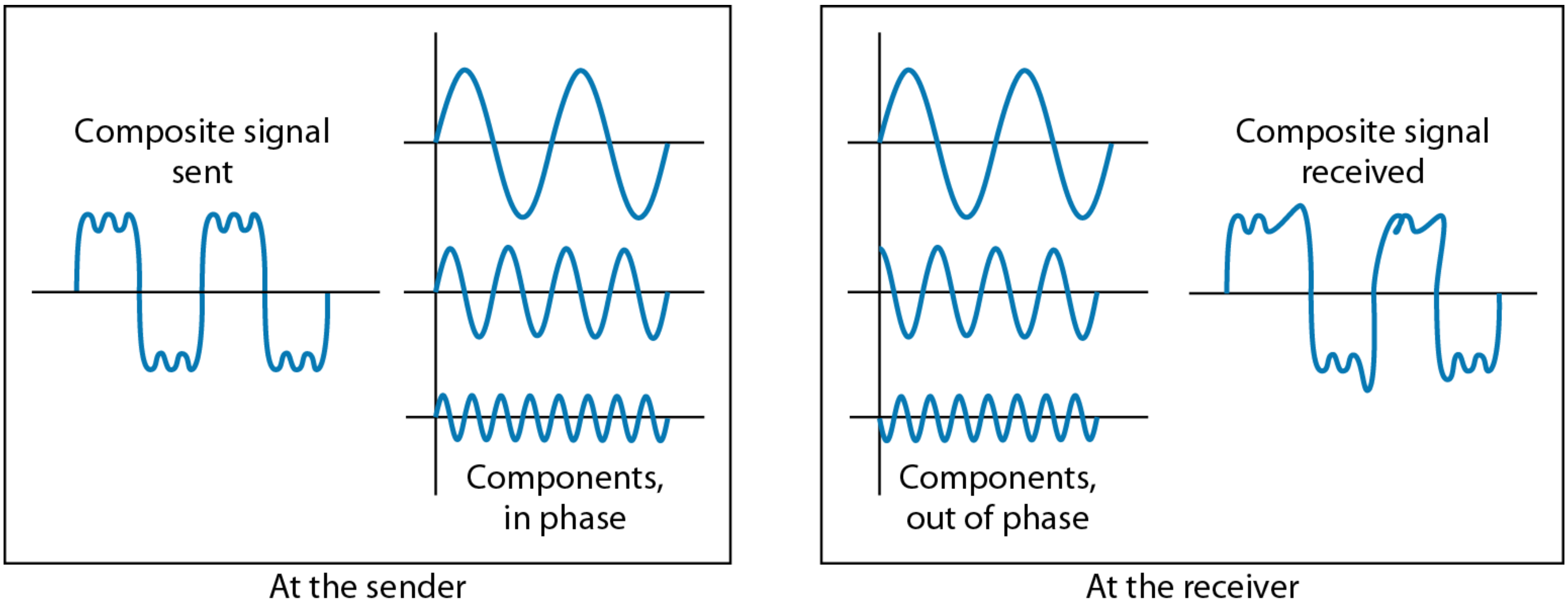
- ***Distortion*** means that the signal changes its form or shape. A digital signal is a composite analog signal with an infinite bandwidth.

- Distortion can occur in a composite signal made of different frequencies.
- Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination.

- Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration. In other words, signal components at the receiver have phases different from what they had at the sender.

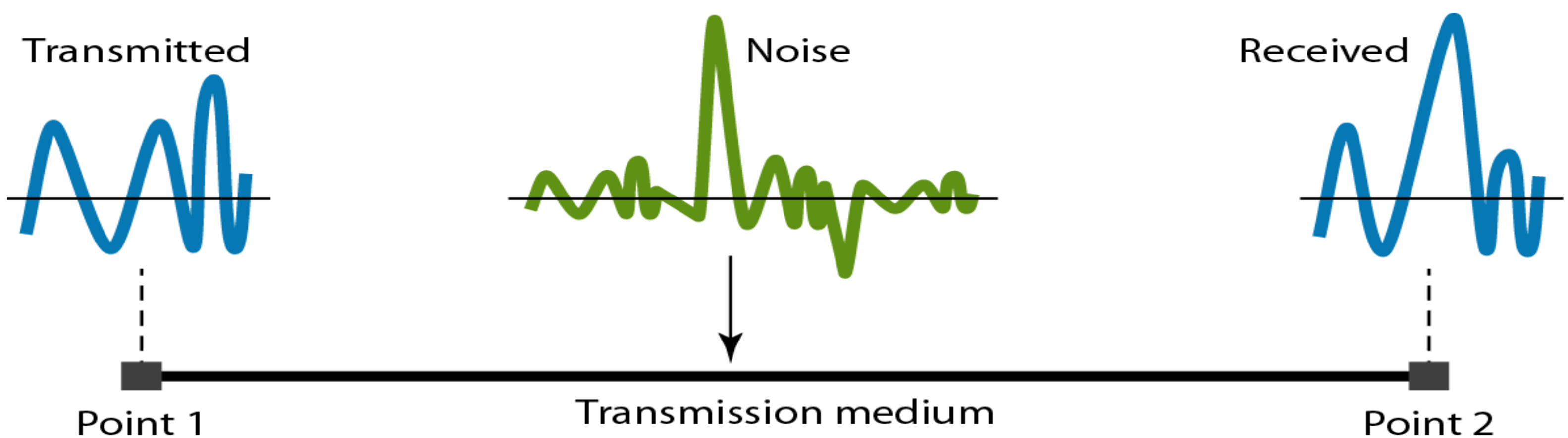
- The shape of the composite signal is therefore not the same..

Figure 3.28 *Distortion*



- ***Noise*** is another cause of impairment. Several types of noise may corrupt the signal.
- ***Thermal noise*** is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter.
- ***Induced noise*** comes from sources such as motors and appliances. These devices act as a sending antenna, and the transmission medium acts as the receiving antenna.
- ***Crosstalk*** is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.
- ***Impulse noise*** is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.

Figure 3.29 *Noise*



- Signal-to-Noise Ratio (SNR)
- 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
- **SNR = average signal power \average noise power**
- We need to consider the average signal power and the average noise power because these may change with time.
- SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise).
- A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise. Because SNR is the ratio of two powers, it is often described in decibel units, SNRdB, defined as $\mathbf{SNR = 10 \log_{10} SNR}$

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:

Example 3.31

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

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

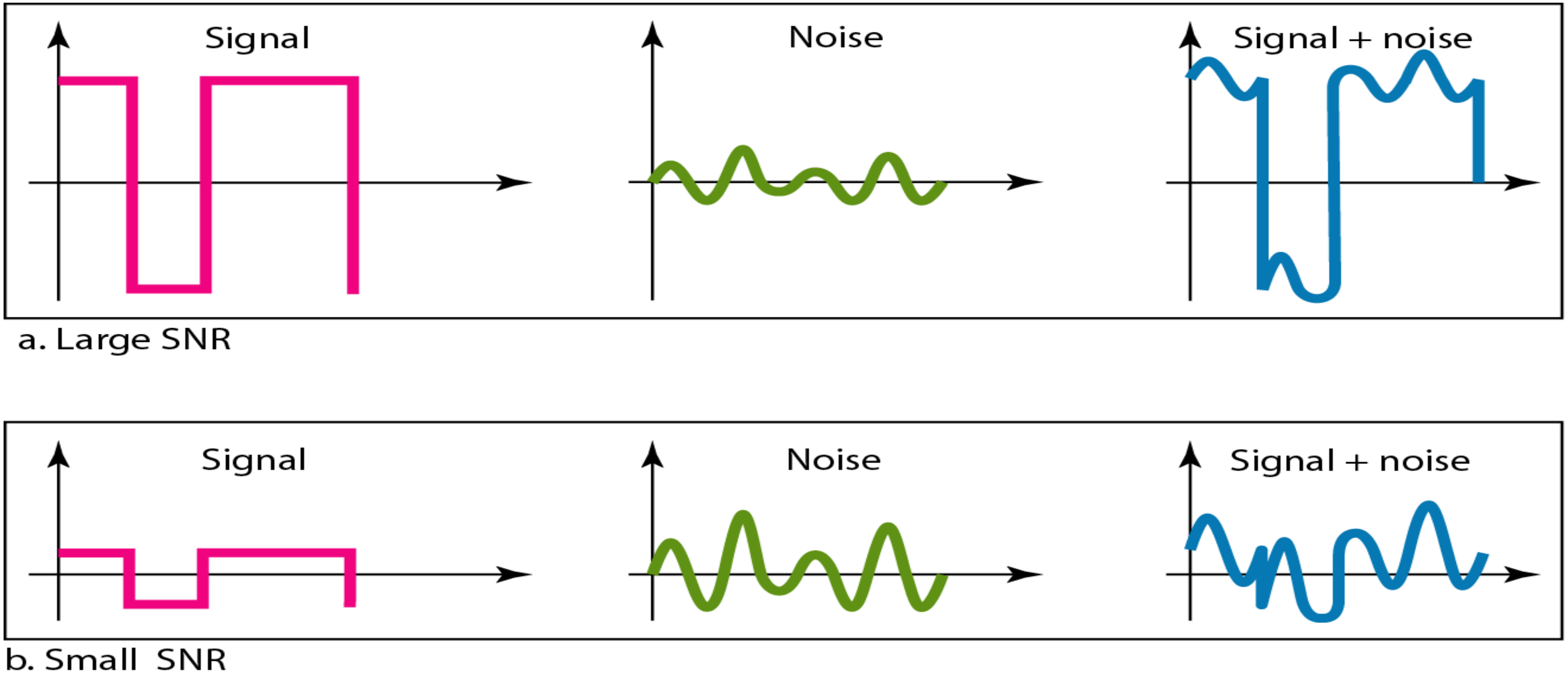
Example 3.32

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

$$\boxed{\begin{aligned} \mathrm{SNR} &= \frac{\text{signal power}}{0} = \infty \\ \mathrm{SNR_{dB}} &= 10 \log_{10} \infty = \infty \end{aligned}}$$

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

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



Throughput and latency

- The throughput is a measure of how fast we can actually send data through a network. Bandwidth and throughput is not same. For example a link with bandwidth 1 Mbps but can handle only 200 kbps so throughput will be 200 kbps.
- The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the first bit is sent out from the source.
- **Latency= propagation time+ transmission time + queuing time + processing time**
- Propagation time : measures the time required for a bit to travel from the source to the destination.
- Transmission time : is the time between the first bit leaving the sender and the last bit arriving at the receiver.
- Queuing time : is the required time for each intermediate or end device to hold the message before it can be processed.