Data Communication

Data and Signals

Math = 10
Bandwidth - 3
bit - 1
Power dB - 5
SNR(dB) - 1

Signals and Communication

- 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.
- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Composite Signals and Periodicity

- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies.
- If the composite signal is non-periodic, the decomposition gives a combination of sine waves with continuous frequencies.

Example

Following Figure shows a periodic composite signal with frequency *f*. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.

Example

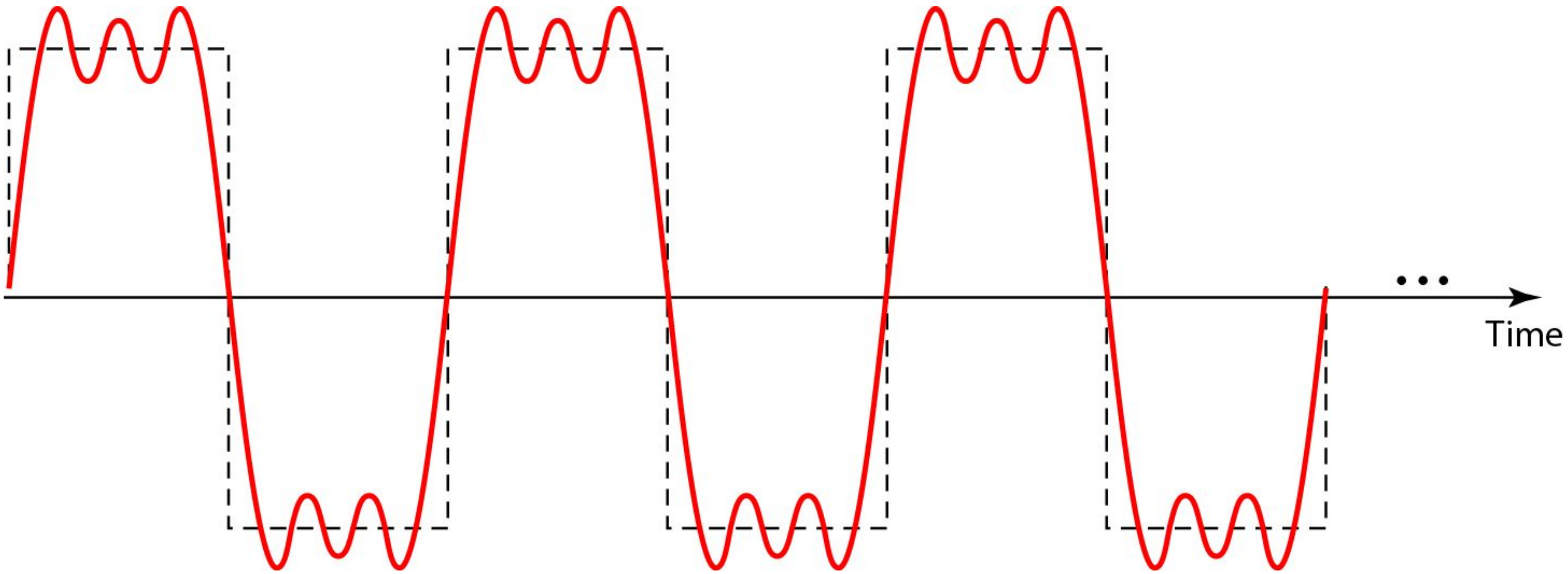
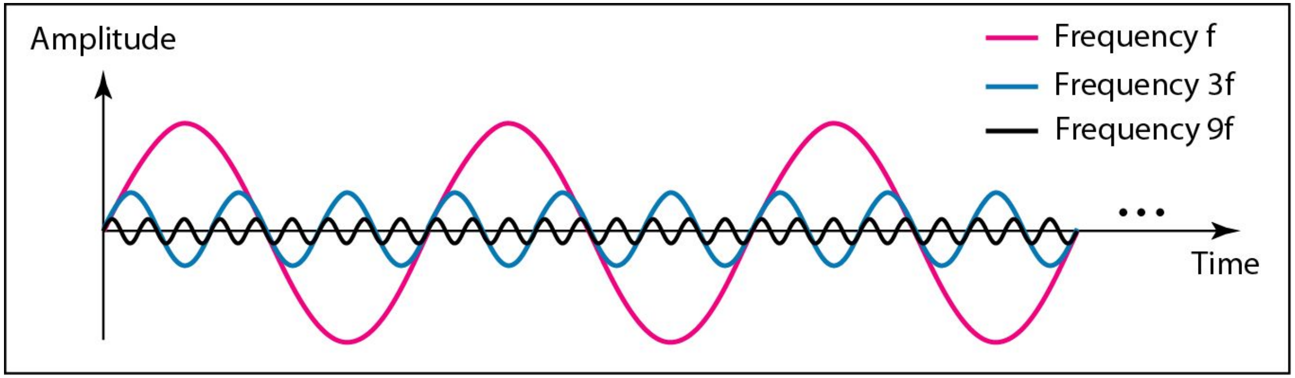
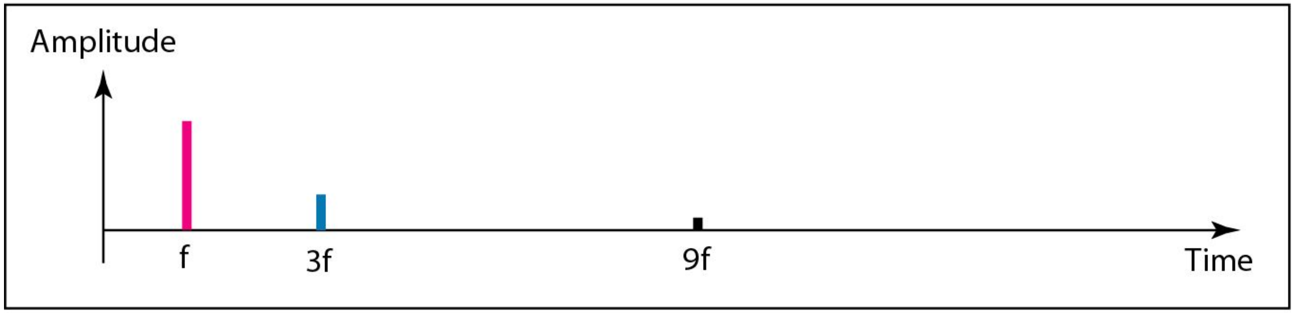


Figure 3.9 A composite periodic signal

Example



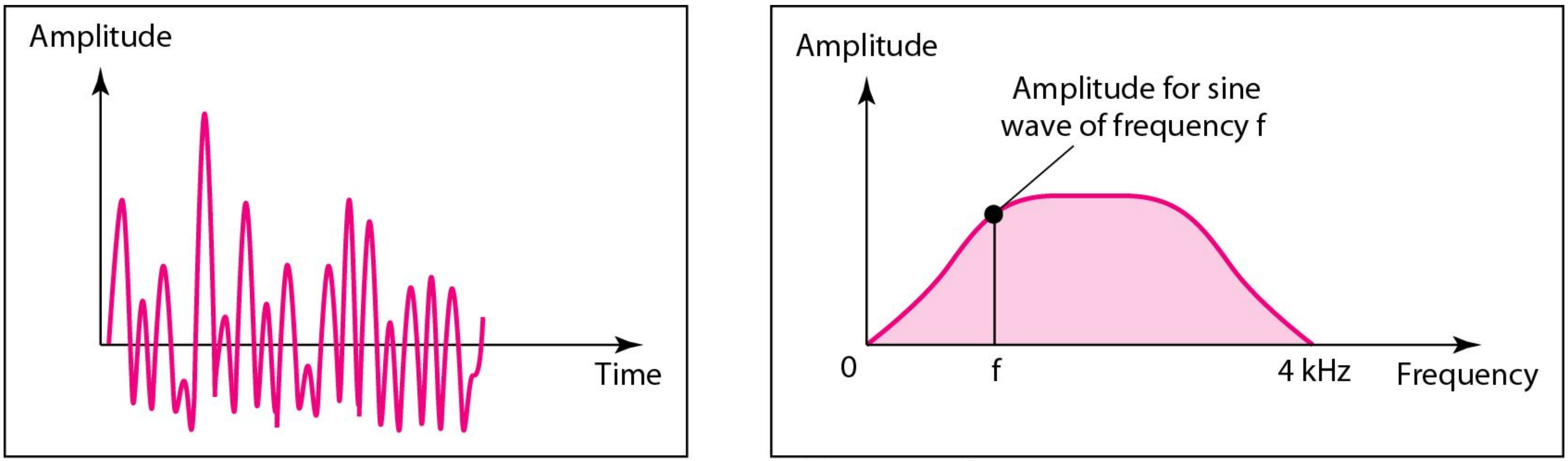
a. Time-domain decomposition of a composite signal



b. Frequency-domain decomposition of the composite signal

Figure 3.10 **Decomposition of a composite periodic signal in the time and frequency domains**

Example



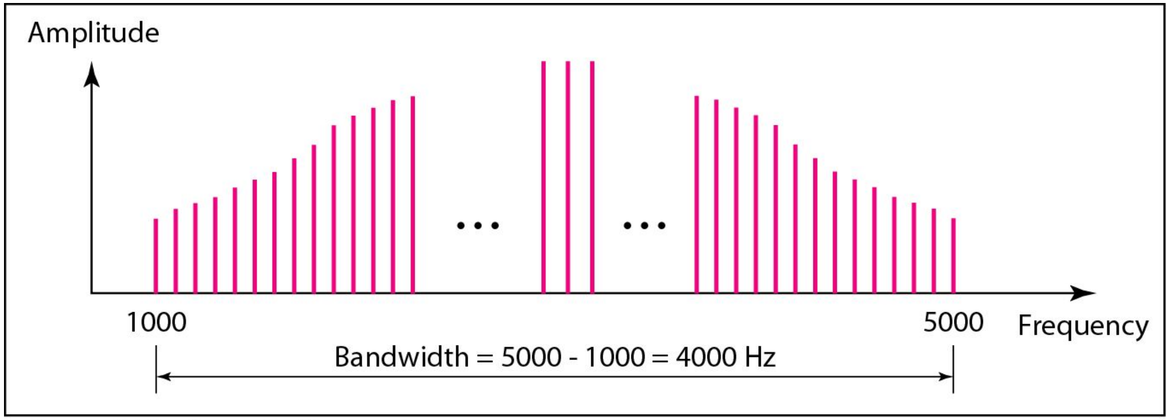
a. Time domain

b. Frequency domain

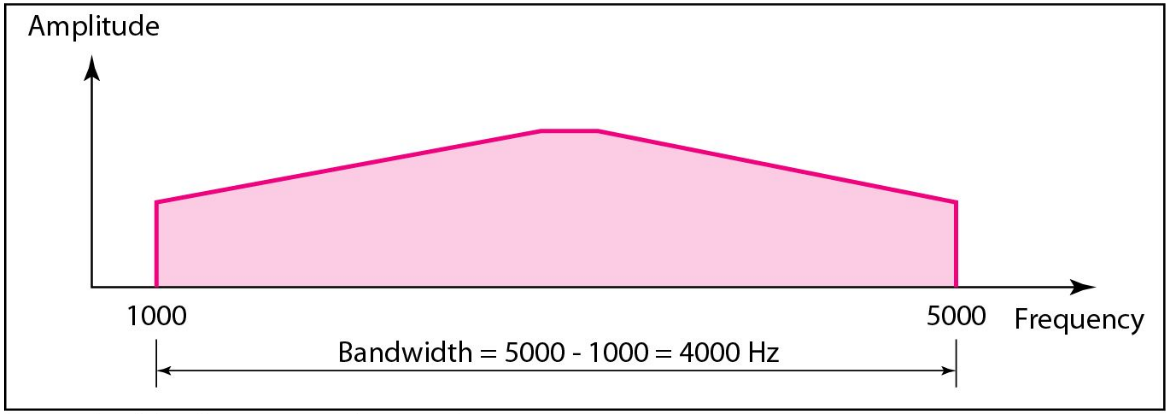
Figure 3.11 **The time and frequency domains of a non-periodic signal**

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

Figure 3.12 The bandwidth of periodic and non-periodic composite signals

Mathematical problems

P1: 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. The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz.

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

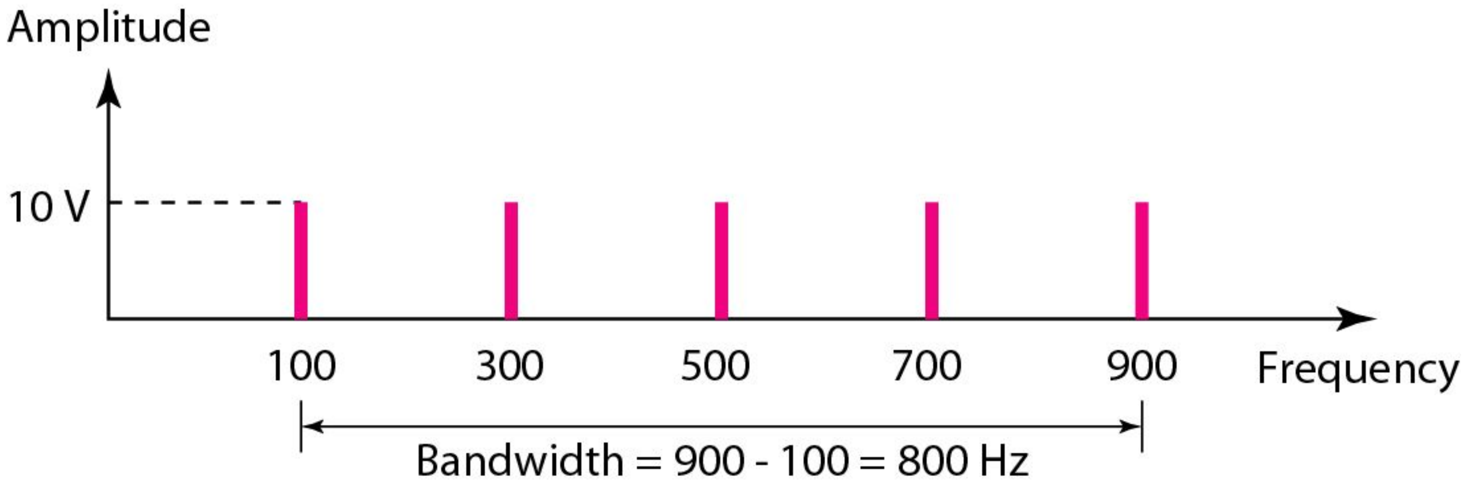


Figure 3.13 **The bandwidth for Example P1**

Mathematical problems

P2: A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

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

$$\boxed{B = f_h - f_l \quad \Rightarrow \quad 20 = 60 - f_l \quad \Rightarrow \quad f_l = 60 - 20 = 40 \text{ Hz}}$$

The spectrum contains all integer frequencies. We show this by a series of spikes

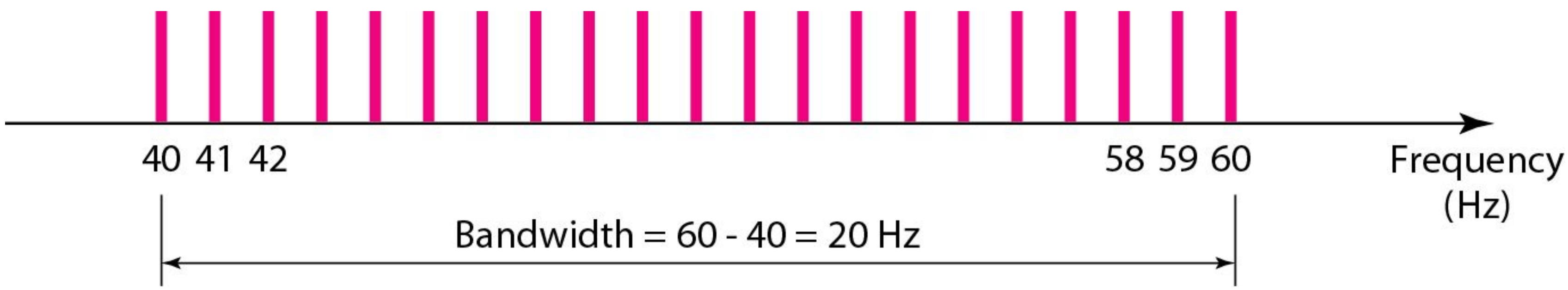


Figure 3.13 **The bandwidth for Example P2**

Mathematical problems

P3: A non-periodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

- Solution
- The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.

B = fh - fl

* middle of freq = 140
* B = 200
>B = 200/2 (middle freq)

fh = 140 + 100
fl = 140 - 100

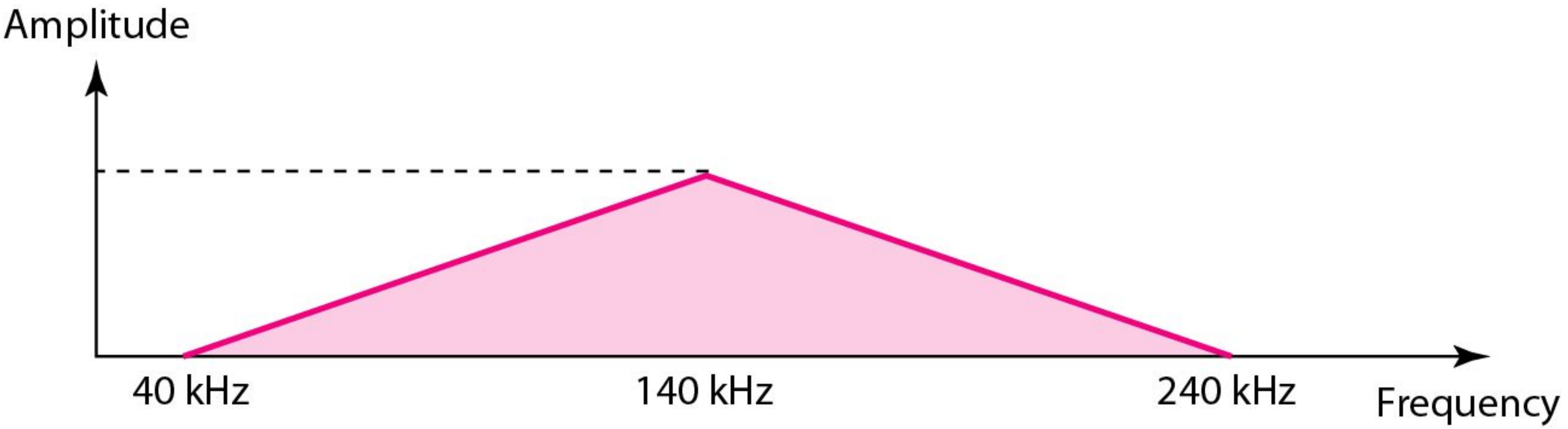


Figure 3.13 **The bandwidth for Example P3**

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.

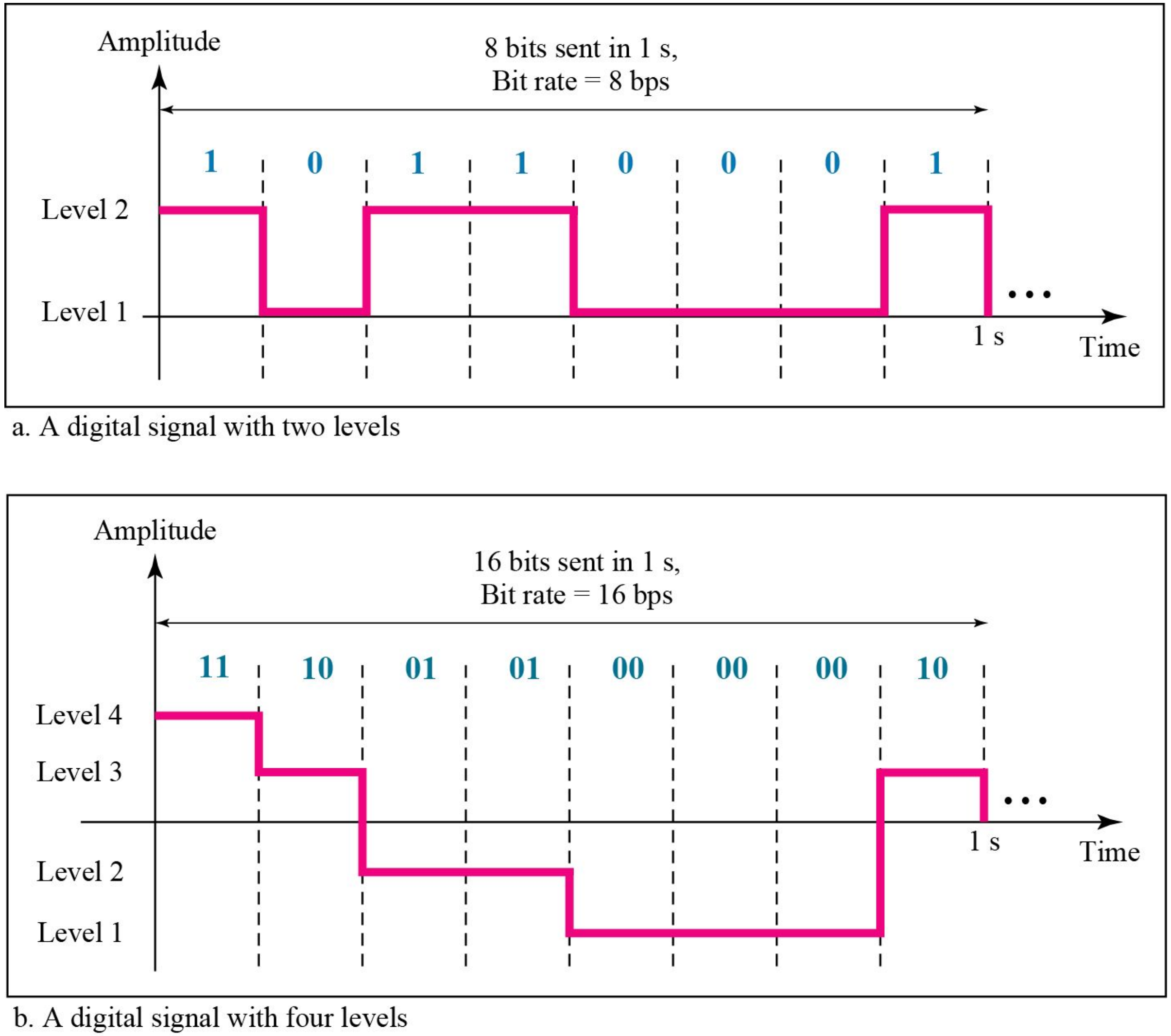


Figure 3.16 **Two digital signals: one with two signal levels and the other with four signal levels**

Mathematical Problems

P4: A digital signal has eight levels. How many bits are needed per level?

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

- Each signal level is represented by 3 bits.

Mathematical Problems

P4: A digital signal has nine levels. How many bits are needed per level?

We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits.

However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

TRANSMISSION IMPAIRMENT

- 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.

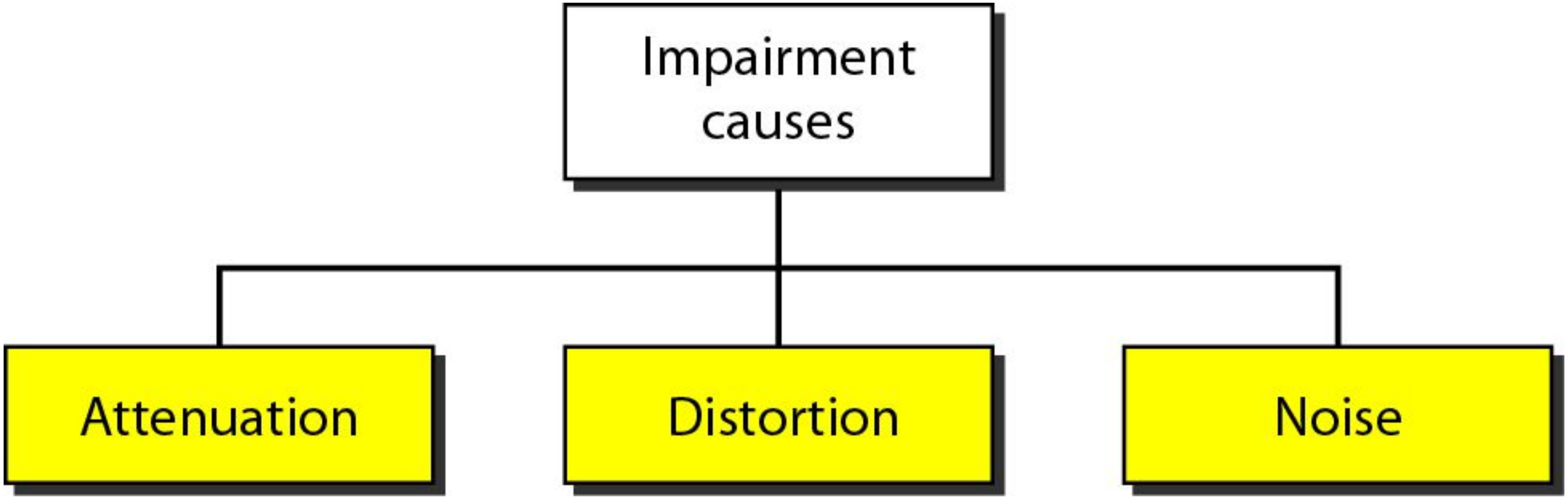


Figure 3.25 Causes of impairment

Attenuation

- Means 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.

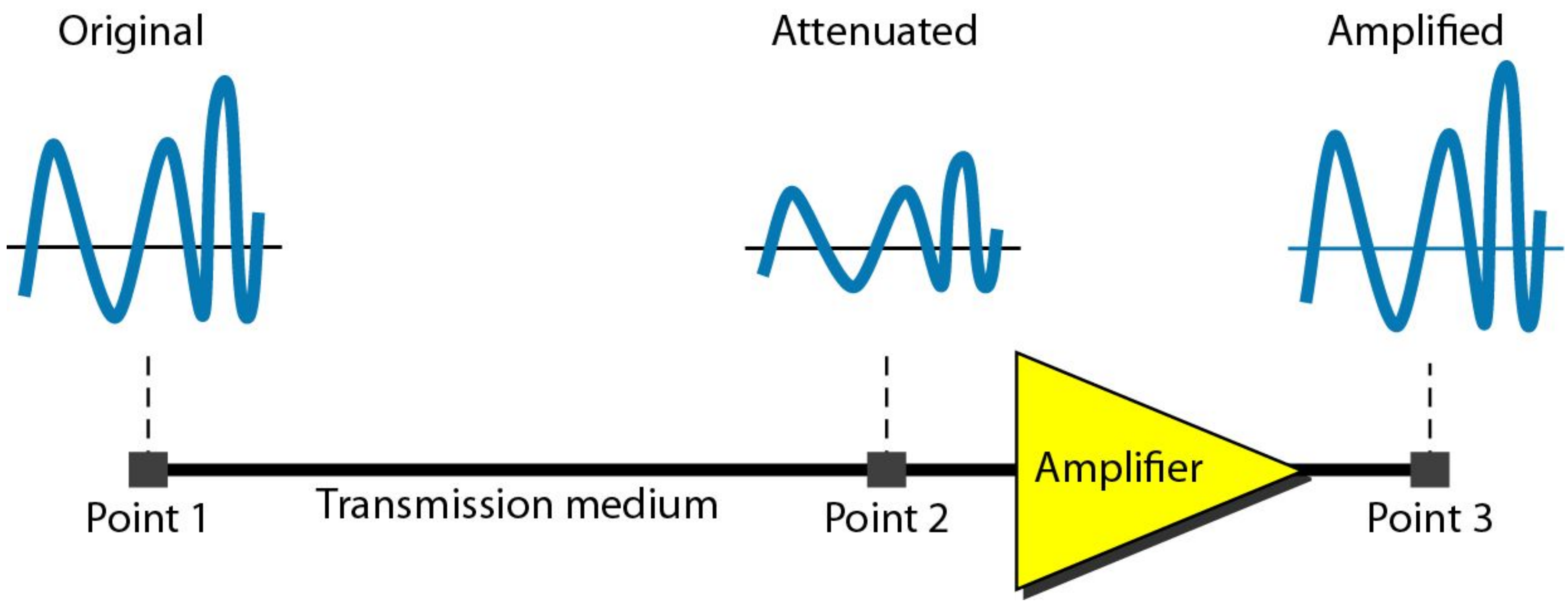


Figure 3.26 Attenuation

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 power

P_2 - output signal power

Example

- 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

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

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

Example

- A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}$$

$$= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

Example

- 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

$$\boxed{\mathrm{dB} = -3 + 7 - 3 = +1}$$

Example

- 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

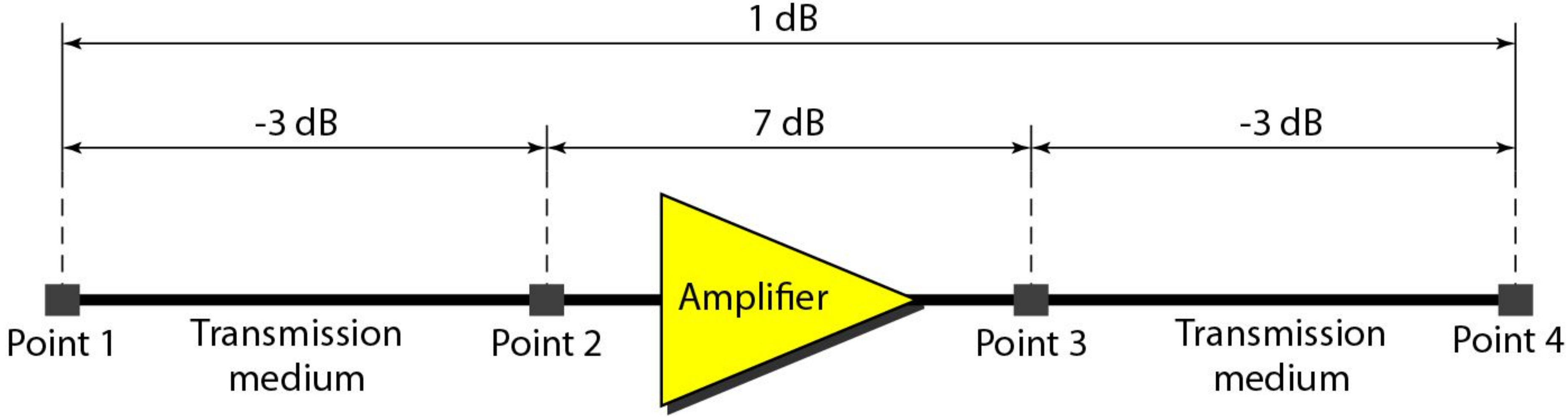


Figure 3.27 Decibels for Example 3.28

Example

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

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

Example

- The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

* Power of signal in 5km is the last moment (P2).
* Power of the signal is 2 mW (P1).

- Solution
- The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as

$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

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.

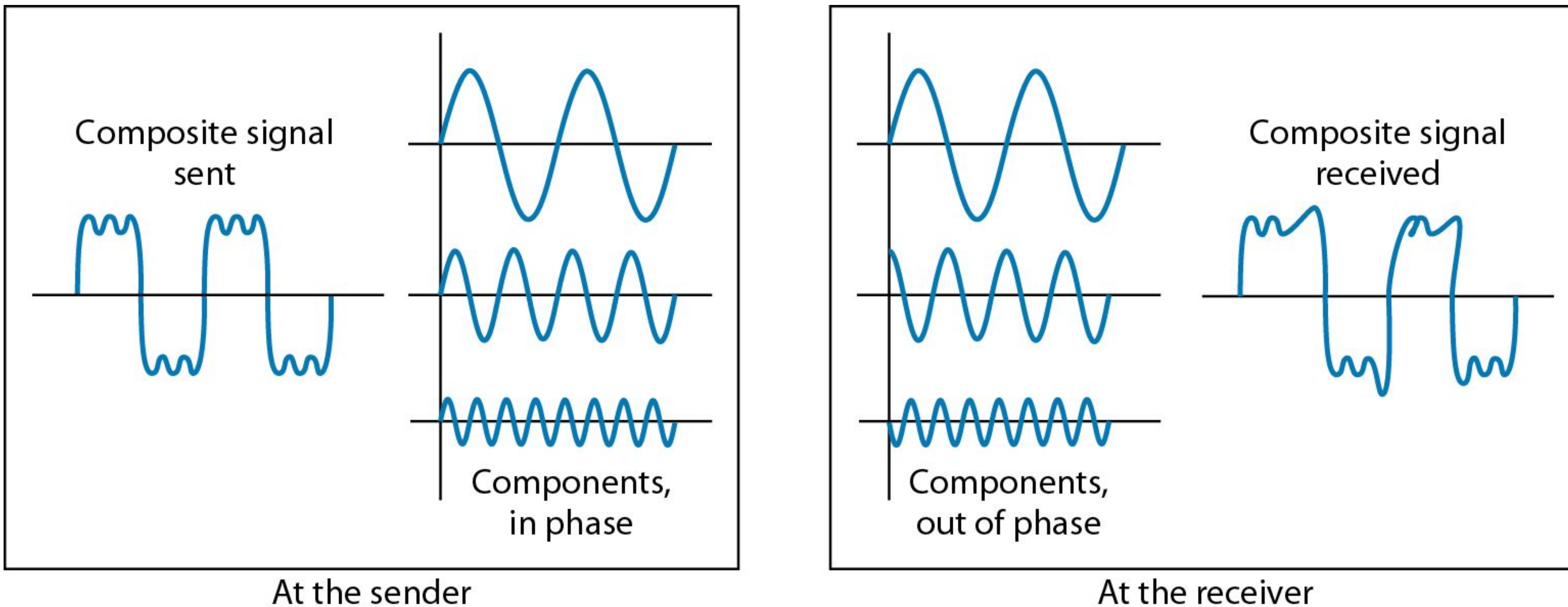


Figure 3.28 Distortion

Noise

- There are different types of noise
  - Thermal - random noise of electrons in the wire creates an extra signal
  - Induced - from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
  - Crosstalk - same as above but between two wires.
  - Impulse - Spikes that result from power lines, lightning, etc.

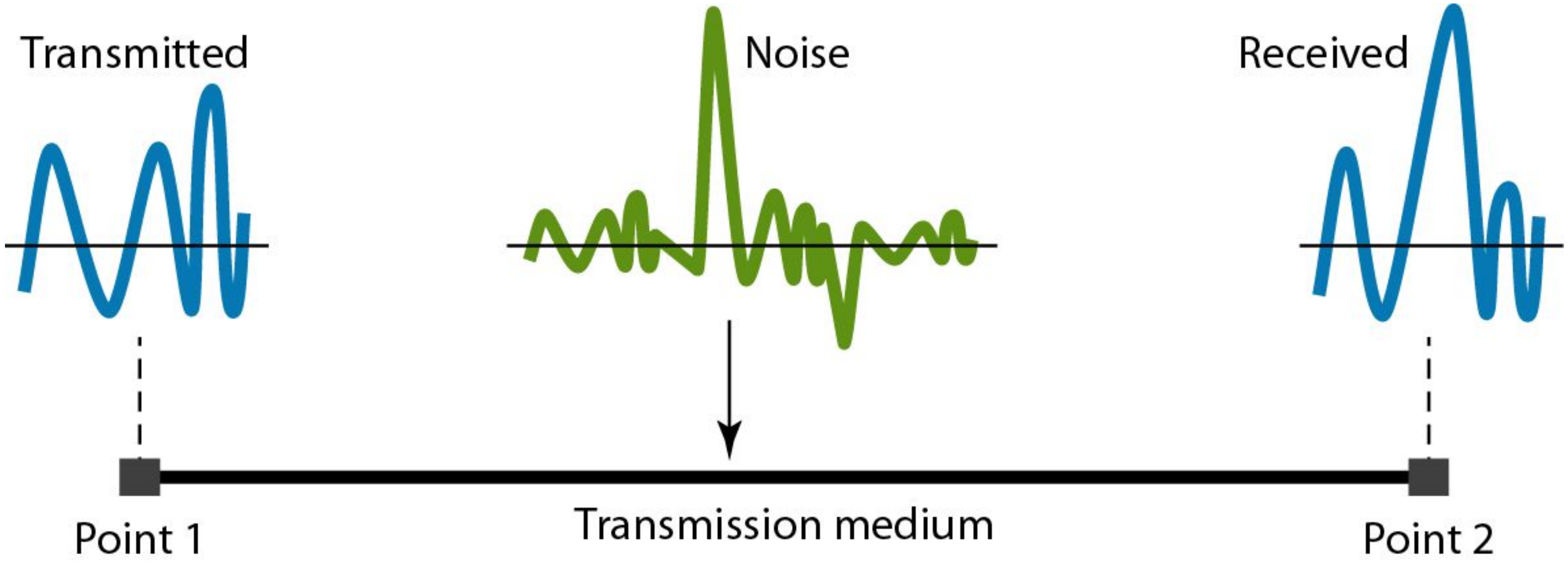


Figure 3.29 Noise

Signal to Noise Ratio (SNR)

- To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.

SNR = S / N

- It is the ratio between two powers.
- It is usually given in dB and referred to as SNR_{dB}.

Mathematical problem

- 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 SNRdB can be calculated as follows:

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

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

Ideal Condition

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

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

SNR

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

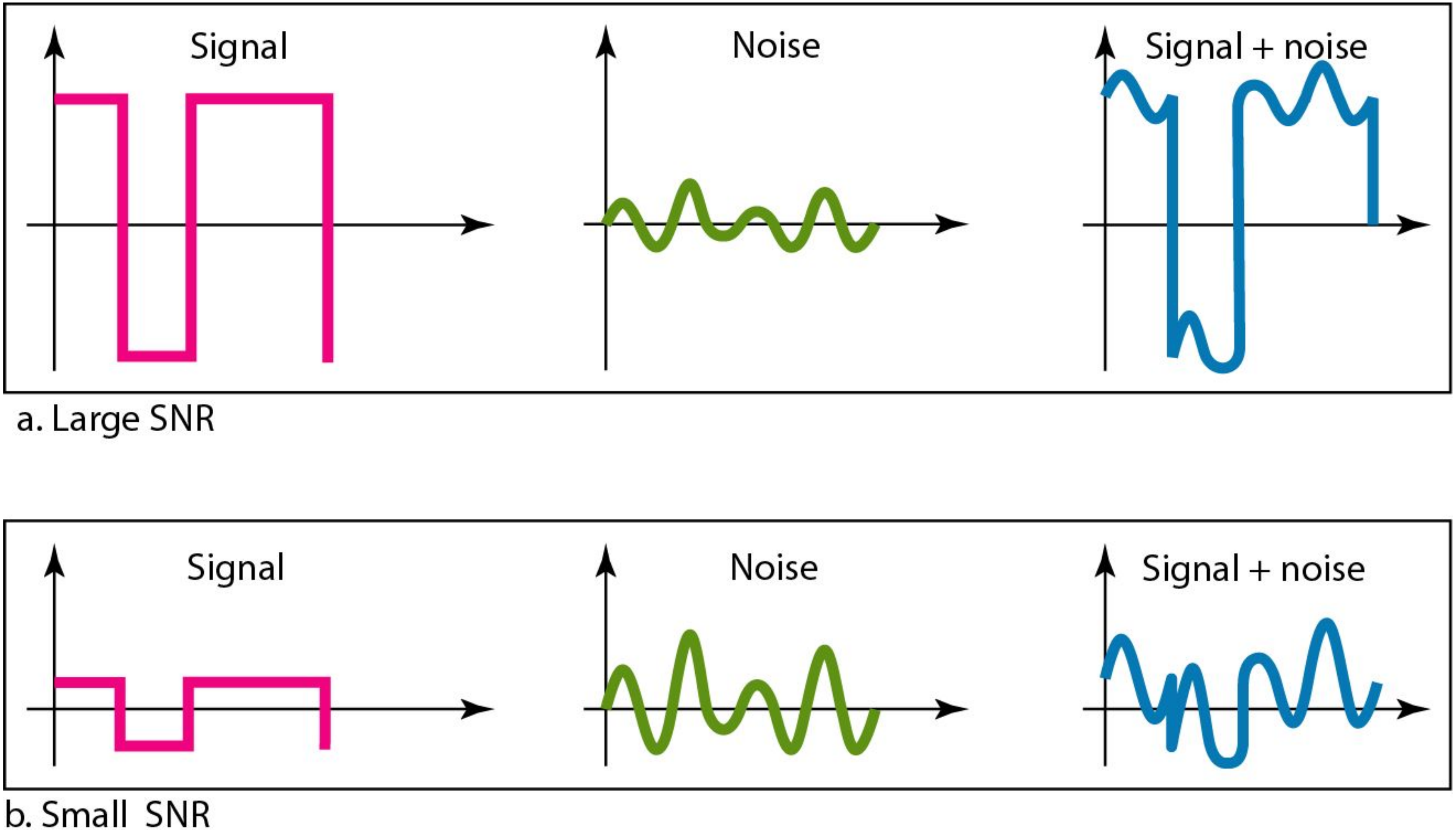


Figure 3.30 Two cases of SNR: a high SNR and a low SNR