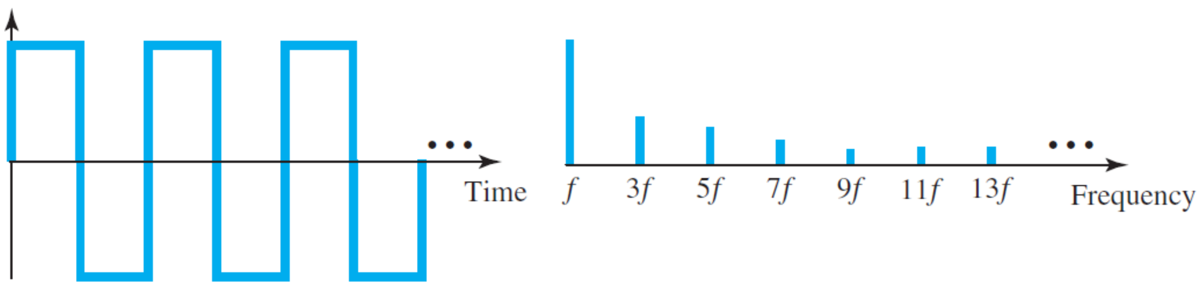
Chapter 5

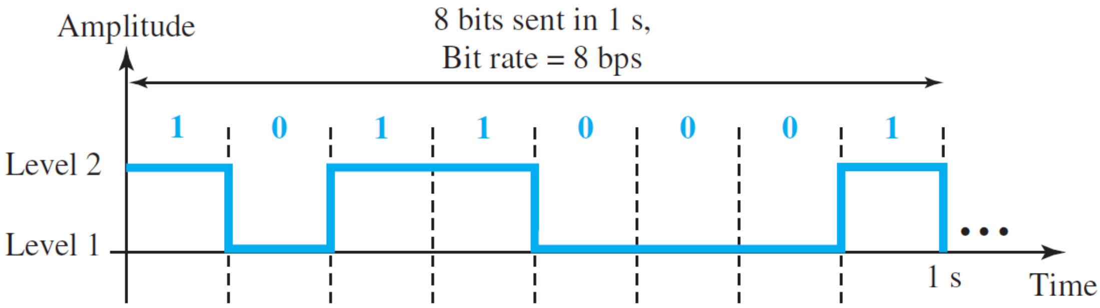
Data communication and Networks

Digital Signals & Transmission Impairment

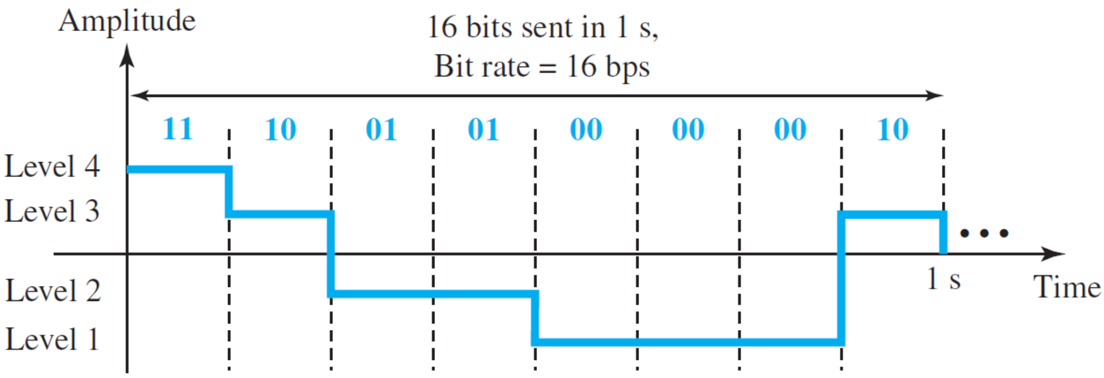


5. Digital Signals

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 5.1 shows two signals, one with two levels and the other with four. We send 1 bit per level in part a of the figure and 2 bits per level in part b of the figure.



a. A digital signal with two levels



b. A digital signal with four levels

Figure 5.1 Two digital signals: one with two signal levels and the other with four signal levels

5.1 Bit Rate

Most digital signals are nonperiodic, and thus period and frequency are not appropriate characteristics. Another term—*bit rate* (instead of *frequency*)—is used to describe digital signals. The bit rate is the number of bits sent in 1s, expressed in bits per second (bps). Figure 5.1 shows the bit rate for two signals.

Example 5.1

Assume we need to download text documents at the rate of 100 pages per second. What is the required bit rate of the channel?

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

/////// **100 x 24 x 80 x 8 = 1,536,000 bps = 1.536 Mbps** ///////

Example 5.2

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

The bit rate can be calculated as

/////// **2 x 4000 x 8 = 64,000 bps = 64 kbps** ///////

Example 5.3

What is the bit rate for high-definition TV (HDTV)?

Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16:9 (in contrast to 4:3 for regular TV), which means the screen is wider. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one colour pixel. We can calculate the bit rate as

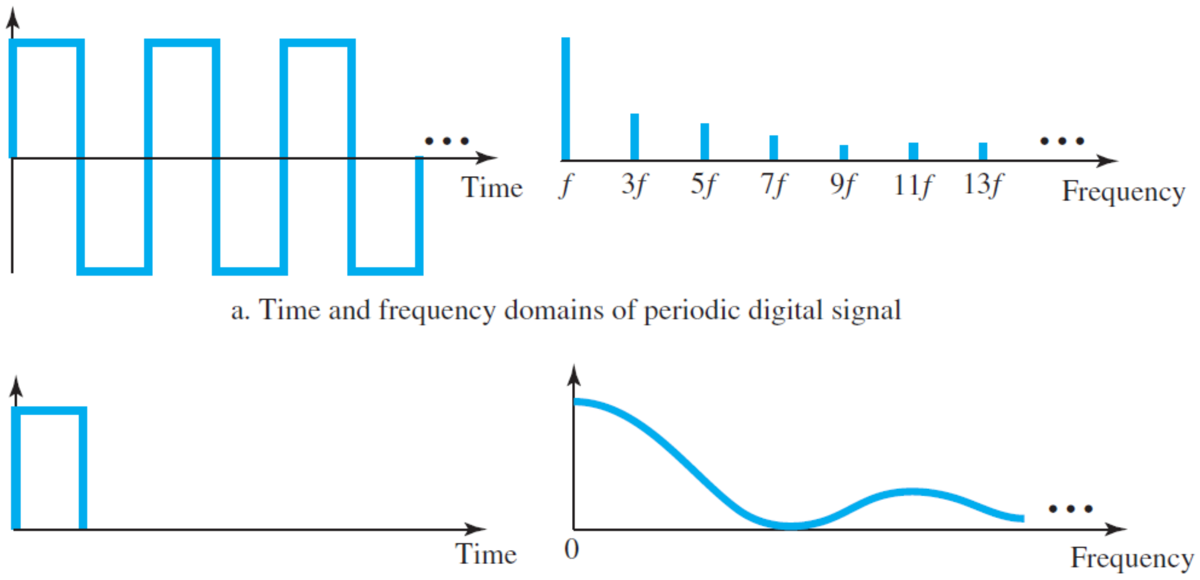
1920 x 1080 x 30 x 24 = 1,492,992,000 ≈ 1.5 Gbps

The TV stations reduce this rate to 20 to 40 Mbps through compression.

5.2 Digital Signal as a Composite Analog Signal

Based on Fourier analysis, a **digital signal** is a ***composite analog signal*** with an infinite bandwidth. A digital signal, in the time domain, comprises connected vertical and horizontal line segments as shown in Figure 5.2.

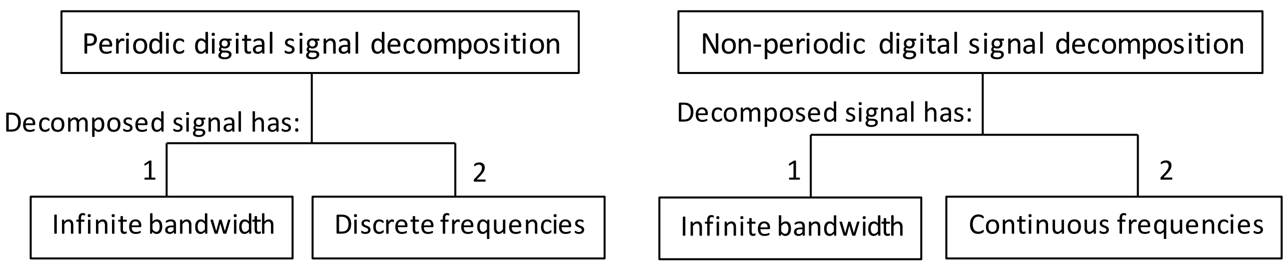
- A vertical line in the time domain means a frequency of infinity (sudden change in time);
- A horizontal line in the time domain means a frequency of zero (no change in time).



b. Time and frequency domains of nonperiodic digital signal

Figure 5.2 The time and frequency domains of periodic and nonperiodic digital signals

Fourier analysis can be used to decompose a digital signal as shown in the follwing char:



Note that both bandwidths are infinite, but the periodic signal has discrete frequencies while the nonperiodic signal has continuous frequencies.

5.3 Transmission of Digital Signals

We can transmit a digital signal from point *A* to point *B* by using one of two different approaches: ***baseband transmission*** or ***broadband transmission*** (using modulation).

For the remainder of this lecture, let us consider the case of a nonperiodic digital signal because it is used often in data communications.

5.3.1 Baseband Transmission

Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal. Figure 5.3 shows baseband transmission.

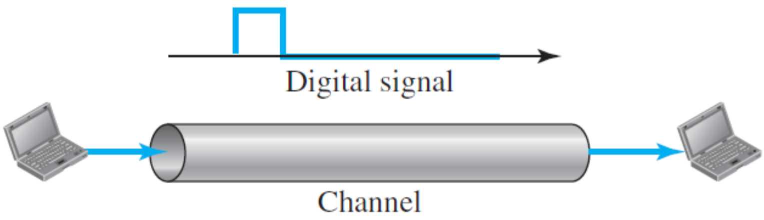


Figure 5.3 Baseband transmission

Baseband transmission requires a **low-pass channel**, a channel with a bandwidth that starts from zero. This is the case if we have a dedicated medium with a bandwidth constituting only one channel. 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.

5.3.2 Broadband Transmission (Using Modulation)

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. This type of channel is more available than a low-pass channel. Figure 5.4 shows a bandpass channel.

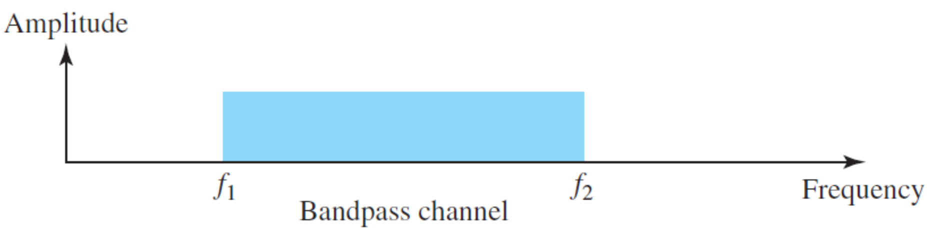


Figure 5.4 Bandwidth of a bandpass channel

Figure 5.5 shows the modulation of a digital signal. In the figure, a digital signal is converted to a composite analog signal. We have used a single-frequency analog signal (called a ***carrier***); the amplitude of the carrier has been changed to look like the digital signal. The result, however, is not a single-frequency signal; it is a composite signal. At the receiver, the received analog signal is converted to digital, and the result is a replica of what has been sent.

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.

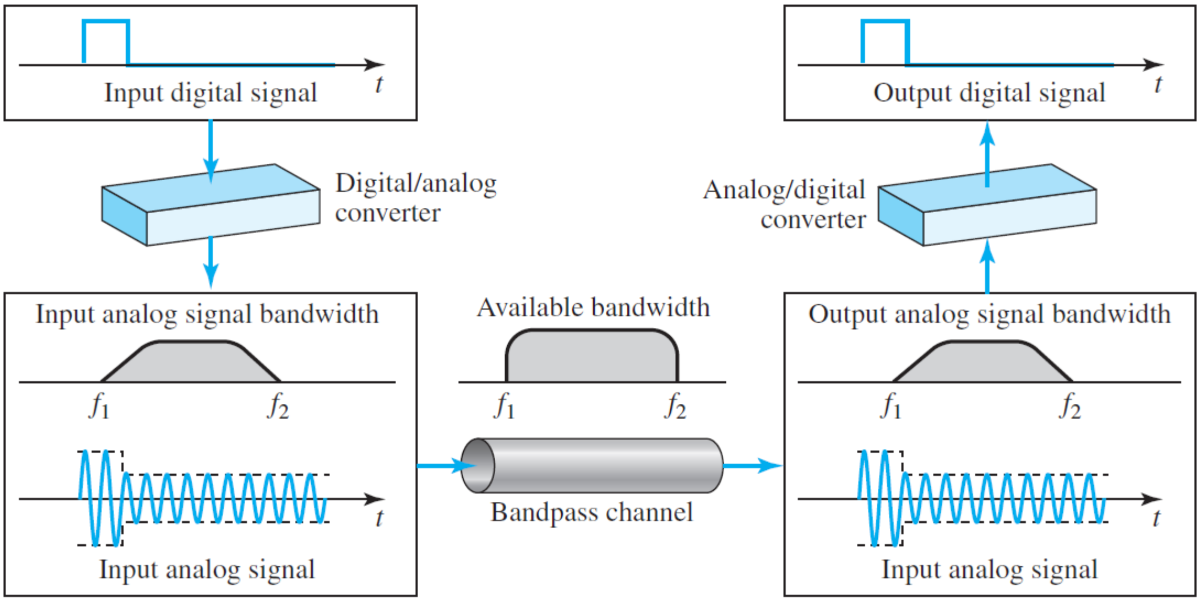


Figure 5.5 Modulation of a digital signal for transmission on a bandpass

Example 5.4

An example of broadband transmission using modulation is the sending of computer data through a telephone lines. The digital signal in the computer is converted to an analog signal, and then sending the analog signal. At the sending and receiving ends we can install two converters to change the digital signal to analog and vice versa. The converter, in this case, is called a ***modem*** (***mo***dulator/***dem***odulator).

Example 5.5

For better reception, the digital cellular phones convert the analog audio signal to digital and then convert it again to analog for transmission over a bandpass channel.

Analog audio signal → digital → analog --- Transmission ---→

5.4 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). The causes of impairment are ***attenuation, distortion,*** and ***noise*** (see Figure 5.6).

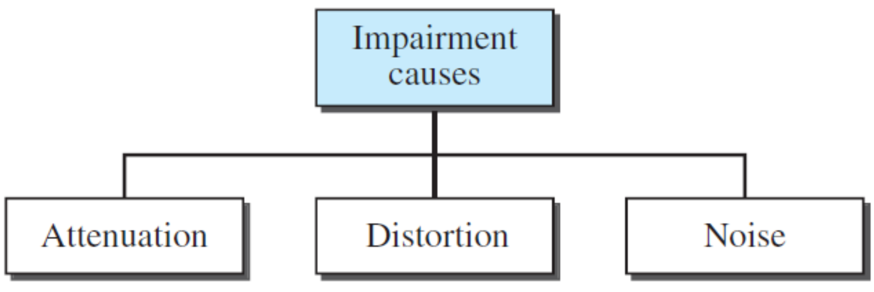


Figure 5.6 Causes of impairment

5.4.1 Attenuation

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 recover this loss, amplifiers are used to amplify the signal. Figure 5.7 shows the effect of attenuation and amplification.

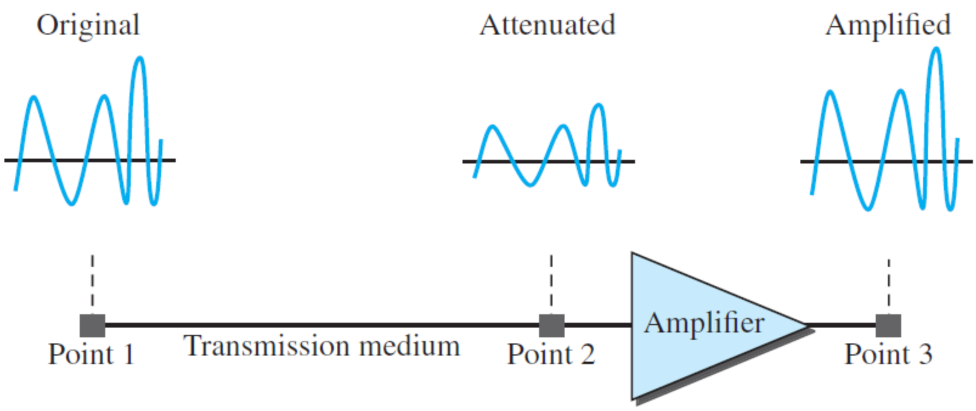


Figure 5.7 Attenuation and amplification

Decibel

To show that a signal has lost or gained strength, engineers use the unit of the decibel. The decibel (**dB**) measures the relative strengths of two signals or one signal at two different points. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

$$\mathbf{dB = 10\, log_{10} \frac{\mathit{P2}}{\mathit{P1}}}$$

Variables P1 and P2 are the powers of a signal at points 1 and 2.

The $\mathbf{log_{10}}$ means the logarithm to base 10, Which is called the *common logarithm* or the *decimal logarithm* (اللوغاريتم العام او العشري *).

في الرياضيات، اللوغاريتم هي العملية العكسية للدوال الأسية ويُعرَّف لوغاريتم عدد ما بالنسبة لأساس ما، بأنه الأس المرفوع على الأساس والذي سينتج ذلك العدد. فعلى سبيل المثال فلوغاريتم 1000 بالنسبة للأساس 10 هو 3 لأن:

$$10^3 = 10 \times 10 \times 10 = 1000 \quad (\log_{10} 1000 = 3)$$

* يُعرف اللوغاريتم العام او العشري بأنه لوغاريتم عدد ما بالنسبة للأساس 10 والذي يستخدم بشكل كبير في حساب التطبيقات العلمية والهندسية. **في هذه المحاضرة سيتم فقط استخدام اللوغارتم العشري**.

يوجد ايضا انواع اخرى (ليست مستخدمة في هذه المحاضرة) مثلا اللوغاريتم الطبيعي والذي له تطبيقات كثيرة في الحسابات الهندسية والعلمية و في الرياضيات البحتة وخاصة في التفاضل والتكامل. في حين يعرف اللوغاريتم الثنائي لعدد ما بأنه لوغاريتمه بالنسبة للأساس 2 ويستخدم بشكل كبير في علم الحاسوب والدوال المنطقية مثلا:

The binary logarithm of 4 is 2 ($\log_2 4 = 2$), and the binary logarithm of 32 is 5 ($\log_2 32 = 5$)

Example 5.6

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 = $\frac{1}{2}$ P1. In this case, the attenuation (loss of power) can be calculated as:

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

Example 5.7

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:

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

5.4.2 Distortion

Distortion means that the signal changes its form or shape. 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 (see Figure 5.8).

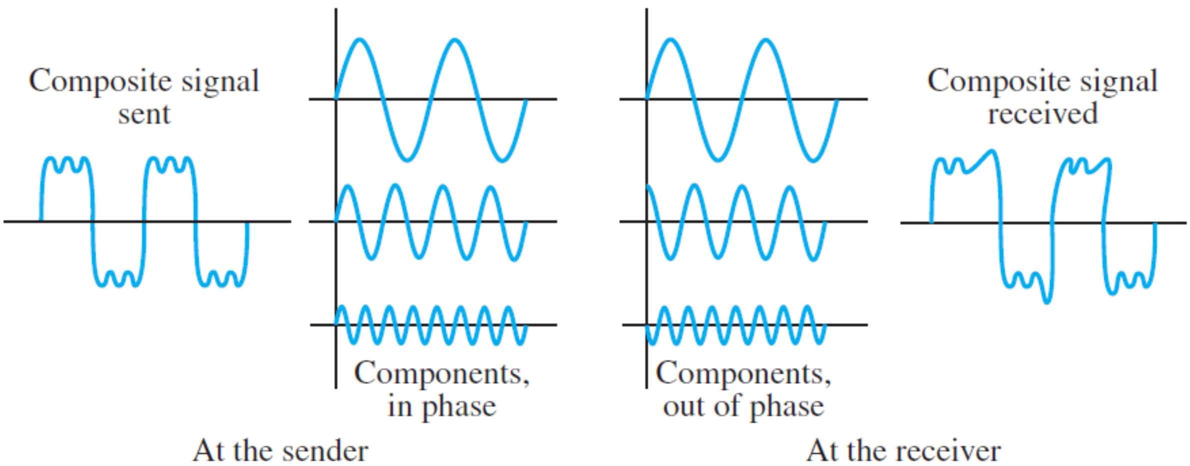


Figure 5.8 Distortion

5.4.3 Noise

Noise is another cause of impairment. Several types of noise, such as ***thermal noise, induced noise, crosstalk, and impulse 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 5.9 shows the effect of noise on a signal.

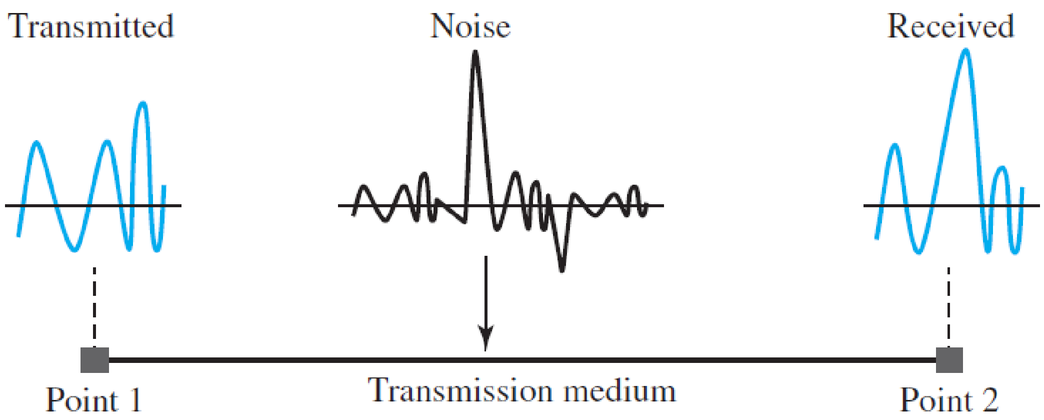


Figure 5.9 Noise

Signal-to-Noise Ratio (SNR)

The signal-to-noise ratio is defined as:

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

We need to consider the average signal power and the average noise power because these may change with time. Figure 5.10 shows the idea of SNR.

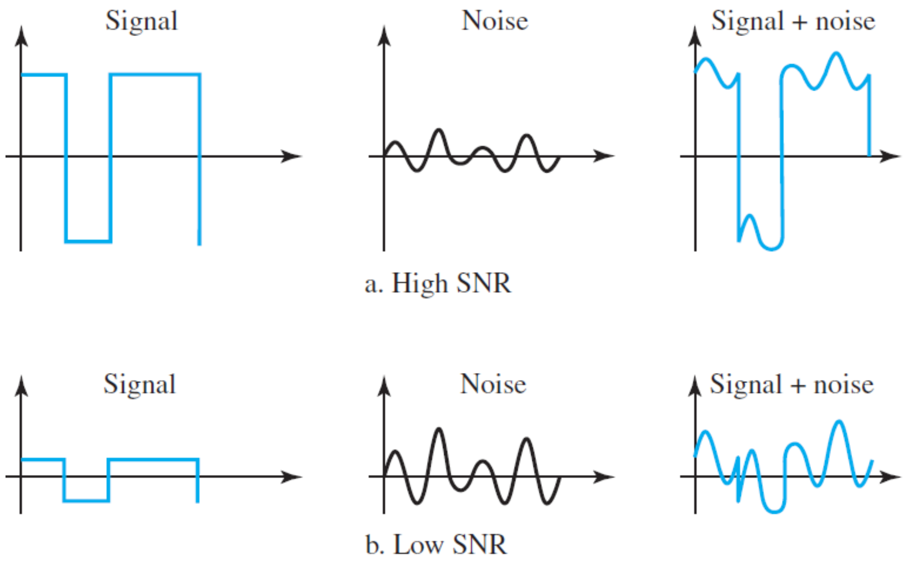


Figure 5.10 Two cases of SNR: a high SNR and a low SNR

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, SNR_{dB}, defined as

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

Example 5.8

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:

$$\mathbf{SNR = (10{,}000\ \mu w) / (1\ \mu w) = 10{,}000 \qquad SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40}$$

Example 5.9

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

$$\mathbf{SNR = (signal\ power) / 0 = \infty \quad \longrightarrow \quad SNR_{dB} = 10 \log_{10} \infty = \infty}$$

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