4

Data Communication

Week 4 Data and Signals

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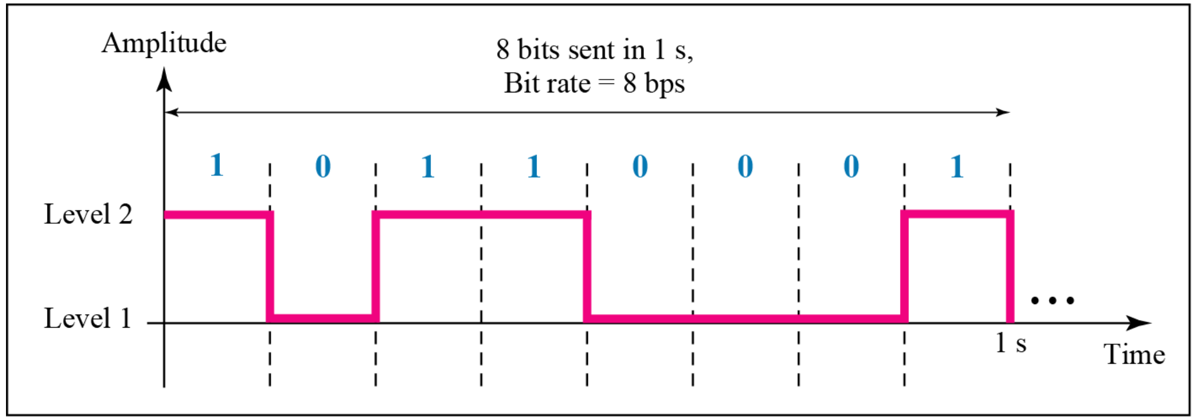
Digital Signal

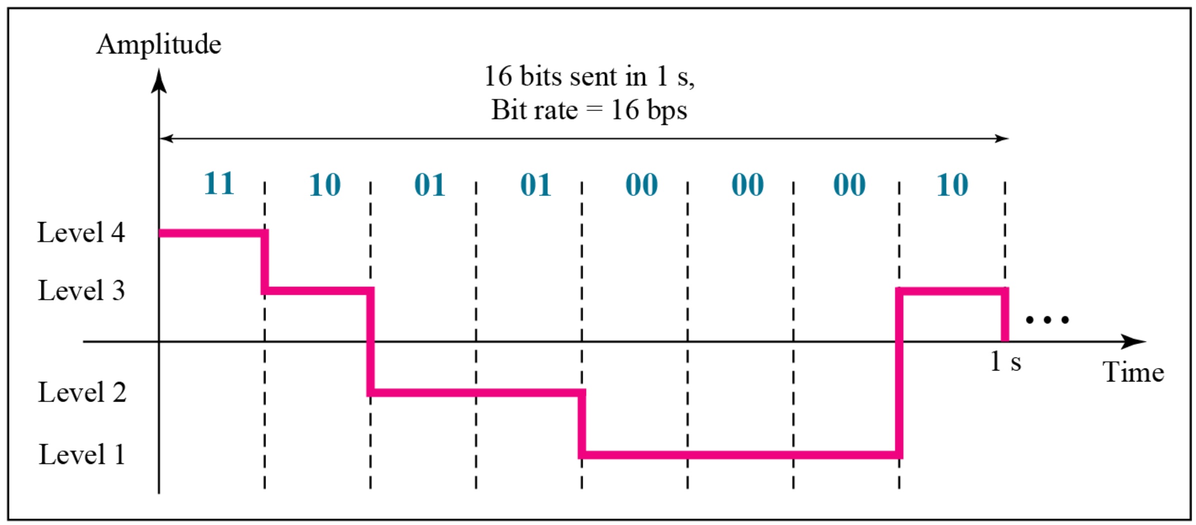
- In addition to being represented by an analog signal, information can also be represented by a digital signal
- For example, a 1 can be encoded as positive voltage and a 0 as zero voltage.
- A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level

Bit Rate

- Most digital signals are non periodic, 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).



a. A digital signal with two levels



b. A digital signal with four levels

Example (1)

- 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.

Example (2)

- Assume we need to download text documents at the rate of 100 pages per minute. 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

$$100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}$$

Example (3)

- 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

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

Example (4)

- 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. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel.

$$1920 \times 1080 \times 30 \times 24 = 1,492,992,000 \text{ or } 1.5 \text{ Gbps}$$

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

Bit Length

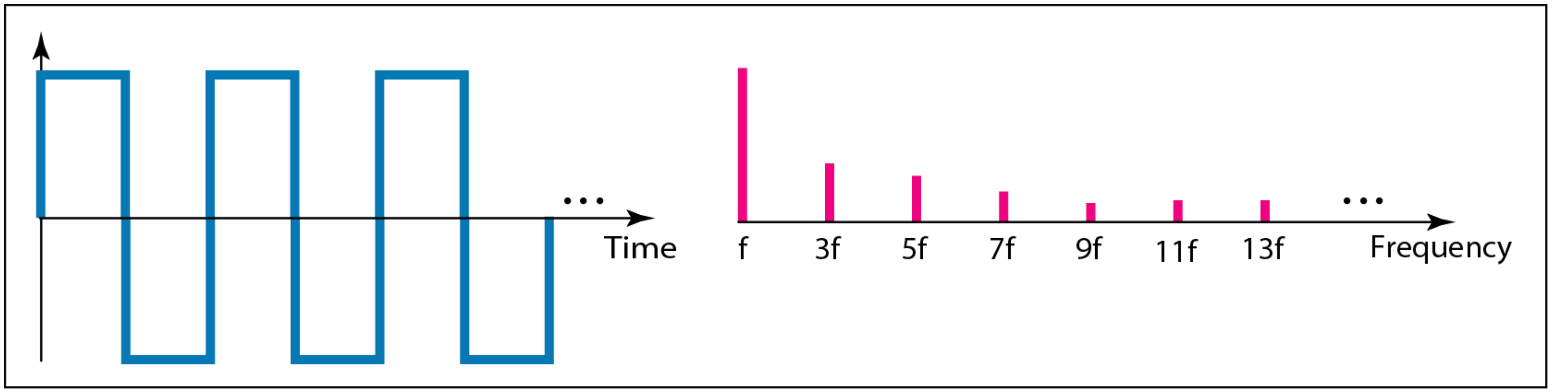
- The concept of the wavelength for an analog signal: the distance on cycle occupies on the transmission medium
- We can define something similar for a digital signal: the bit length.
- The bit length is the distance one bit occupies on the transmission medium

$$\text{Bit length} = \text{propagation speed x bit duration}$$

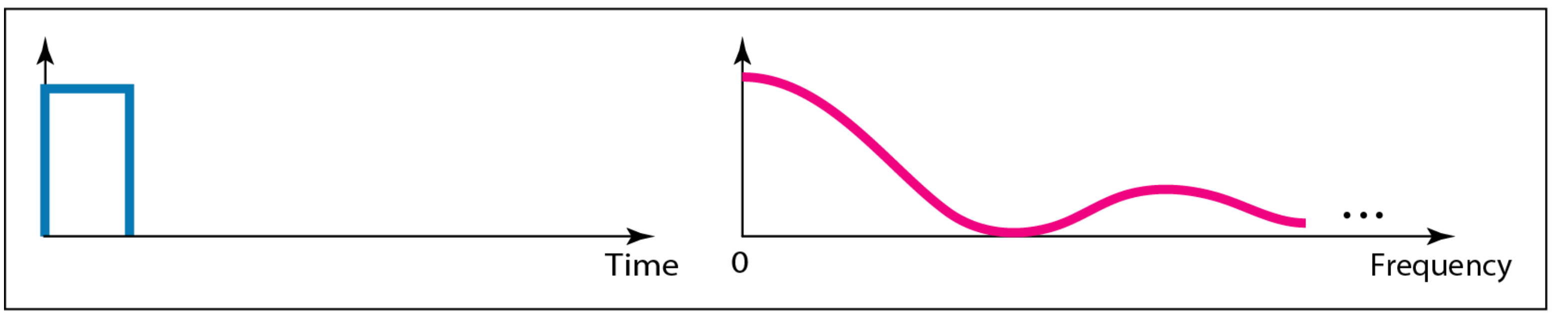
Digital Signal as a Composite Signal

- Based on Fourier analysisi, a digital signal is a composite analog signal. The bandwidth is infinite, as you may have guessed. We can intuitively come up with this concept when we consider a digital signal. A digital signal, in the time domain, comprises connected vertical and horizontal line segments. 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). Going from a frequency of zero to a frequency of infinity (and vice versa) implies all frequencies in between are part of the domain.
- Fourier analysis can be used to decompose a digital signal. If the digital signal is periodic, which is rare in data communications, the decomposed signal has a frequency-domain representation with an infinite bandwidth and discrete frequencies. If the digital signal is nonperiodic, the decomposed signal still has an infinite bandwidth, but the frequencies are continuous. Figure 3.17 shows a periodic and a nonperiodic digital signal and their bandwidths.

The time and frequency domains of periodic and nonperiodic digital signals



a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

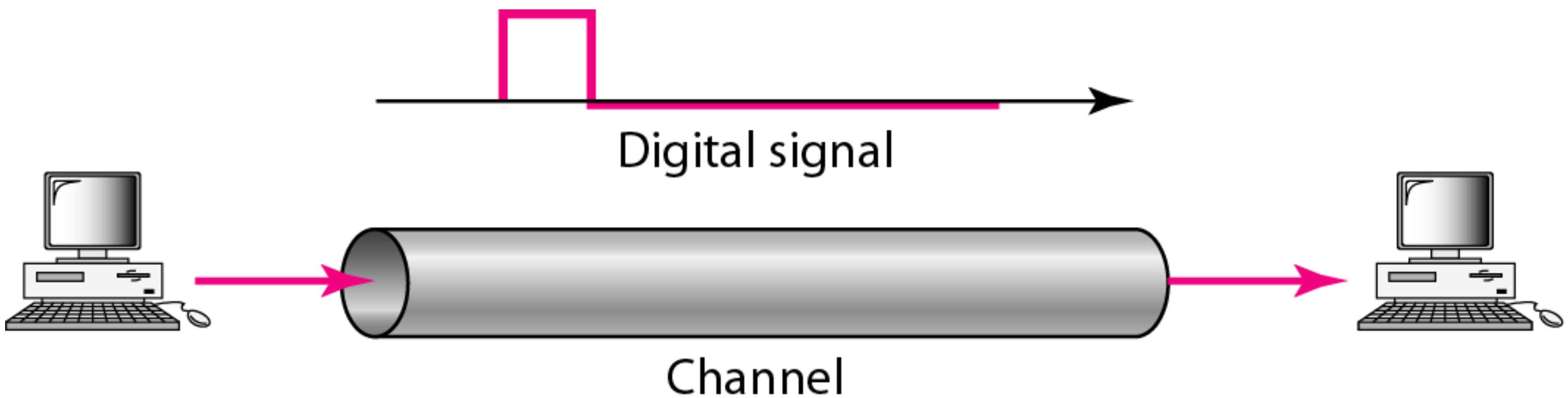
- Note that both bandwidth are infinite, but the period signal has discrete frequencies while the nonperiodic signal has continuous frequencies.

Transmission of Digital Signal

- The previous discussion asserts that a digital signal, periodic or nonperiodic, is a composite analog signal with frequencies between zero and infinity. For the remainder of the discussion, let us consider the case of a nonperiodic digital signal, similar to the ones we encounter in data communications.
- The fundamental question is, How can we send a digital signal from point A to point B?
    - We can transmit a digital signal by using one of two different approaches: **baseband transmission** or **broadband transmission (using modulation)**

Baseband Transmission (1)

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

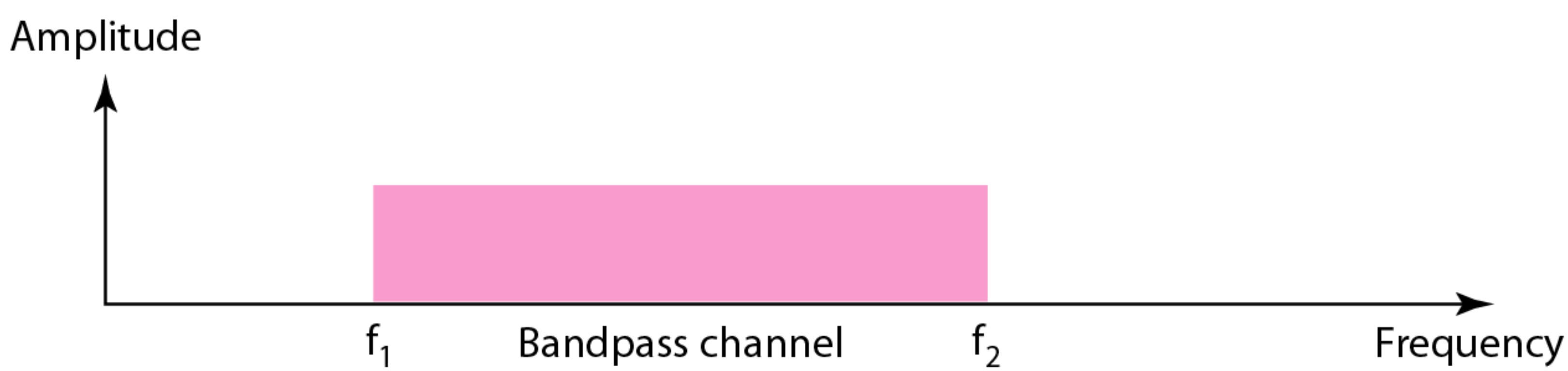


Baseband Transmission (2)

- Baseband transmission requires that we have 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. Again we have a low-pass channel, and we can use it for baseband communication. Figure 3.19 shows two low-pass channels: one with a narrow bandwidth and the other with a wide bandwidth. We need to remember that 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.

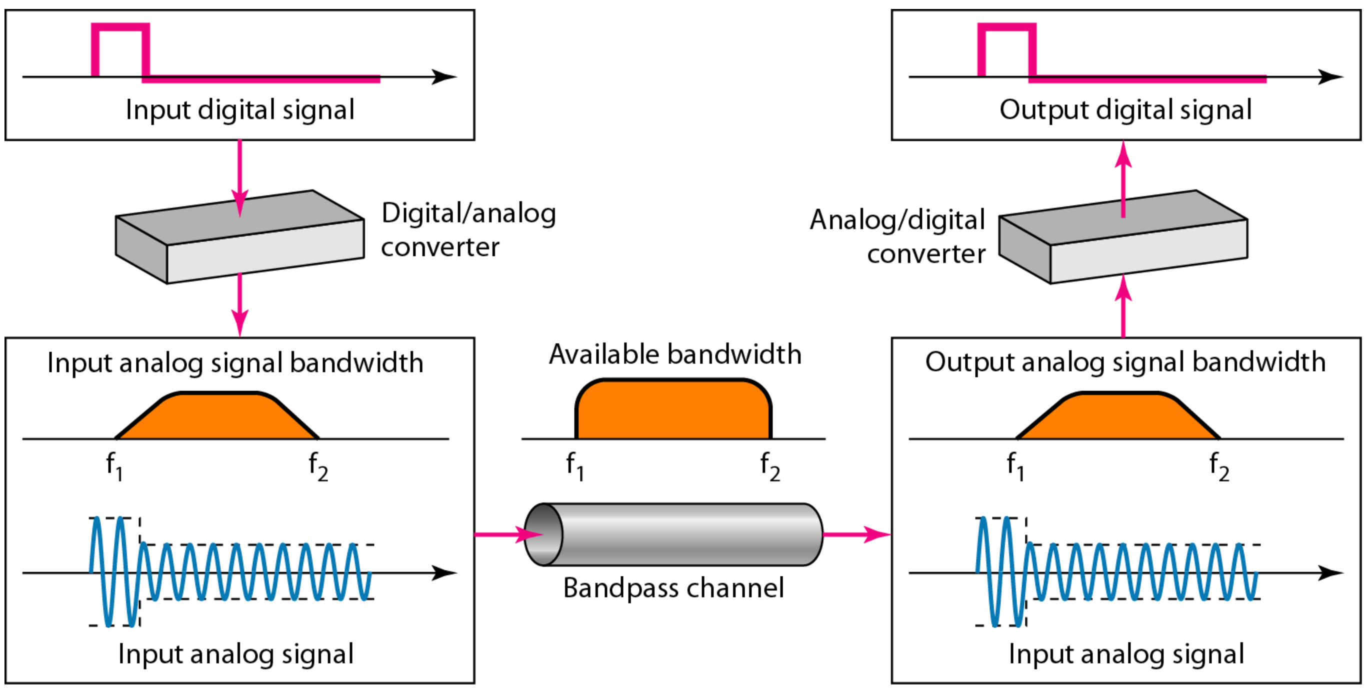
Broadband Transmission (using Modulation)

- 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.
- Note that a low-pass channel can be considered a bandpass channel with the lower frequency starting at zero.



Modulation of a digital signal for transmission on a bandpass channel

- 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, as we will see in Chapter 5. At the receiver, the received analog signal is converted to digital, and the result is a replica of what has been sent.



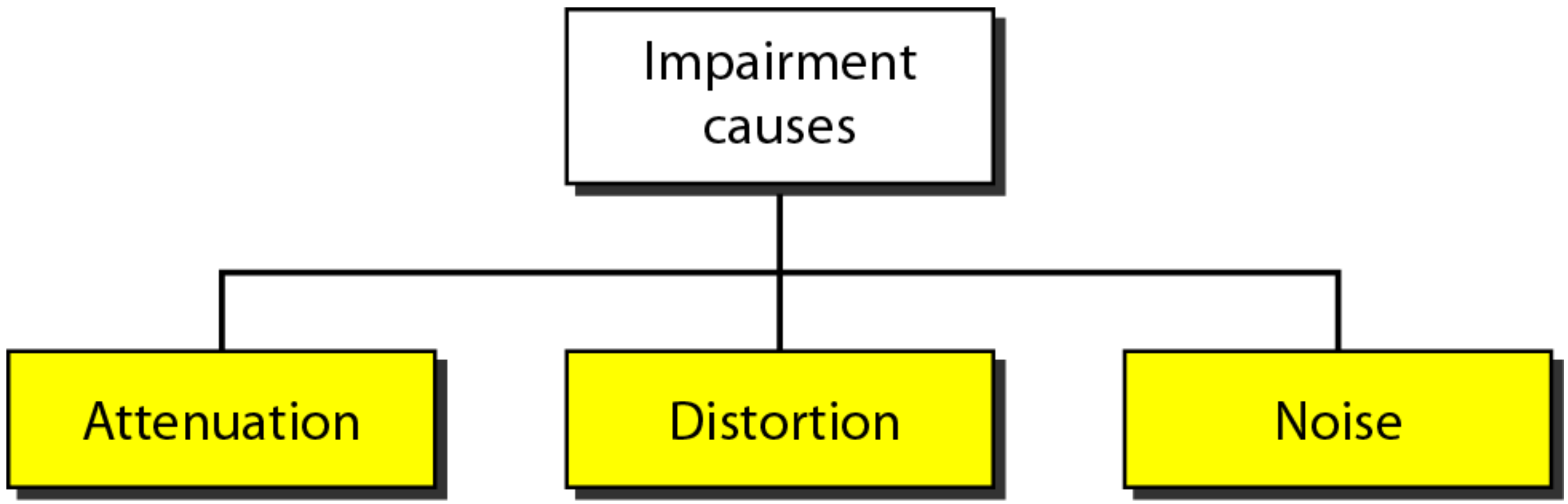
Example

- An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office. These lines are designed to carry voice with a limited bandwidth. The channel is considered a bandpass channel. We convert the digital signal from the computer to an analog signal, and send the analog signal. We can install two converters to change the digital signal to analog and vice versa at the receiving end. The converter, in this case, is called a modem.
- A second example is the digital cellular telephone. For better reception, digital cellular phones convert the analog voice signal to a digital signal. Although the bandwidth allocated to a company providing digital cellular phone service is very wide, we still cannot send the digital signal without conversion. The reason is that we only have a bandpass channel available between caller and callee. We need to convert the digitized voice to a composite analog signal before sending.

Transmission Impairment

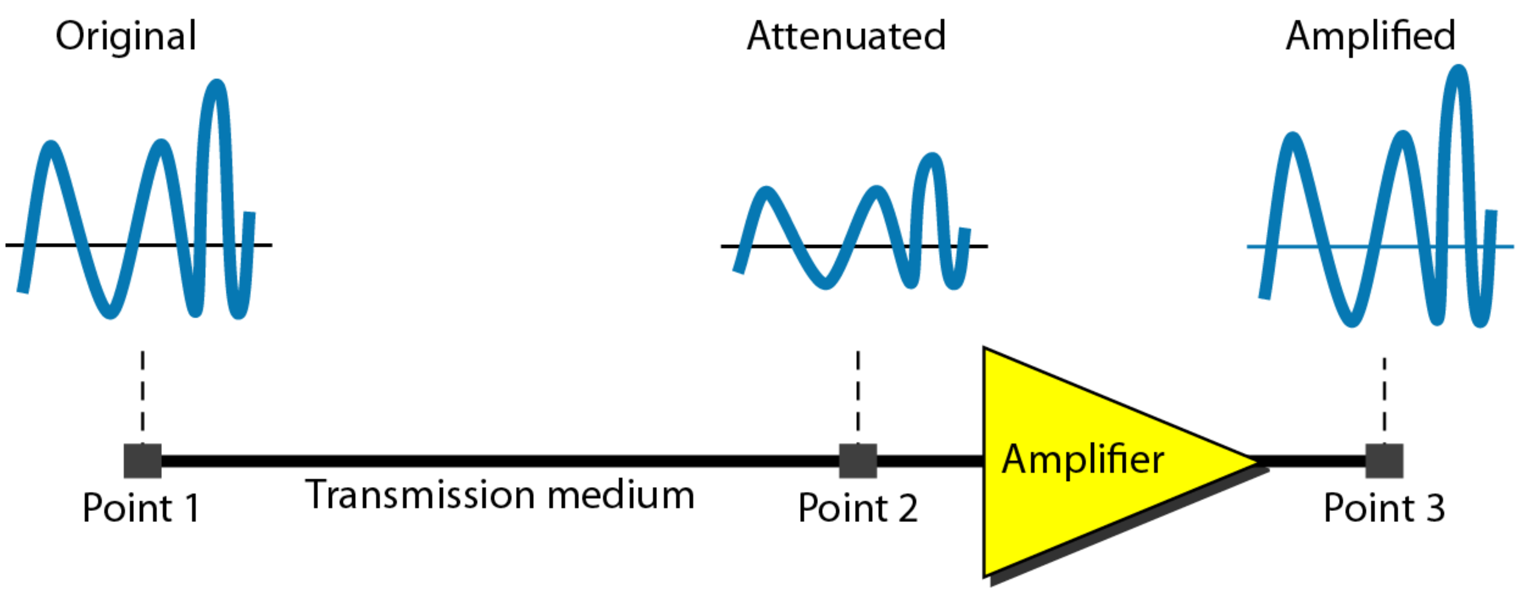
Transmission Impairment

- 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.



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 compensate for this loss, amplifiers are used to amplify the signal. Figure 3.26 shows the effect of 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.

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

- Variables P1 and P2 are the powers of a signal at points 1 and 2, respectively. Note that some engineering books define the decibel in terms of voltage instead of power. In this case, because power is proportional to the square of the voltage, the formula is dB = 20 log 10 (V2/V1). In this text, we express dB in terms of power.

Example (1)

- 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

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

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

Example (2)

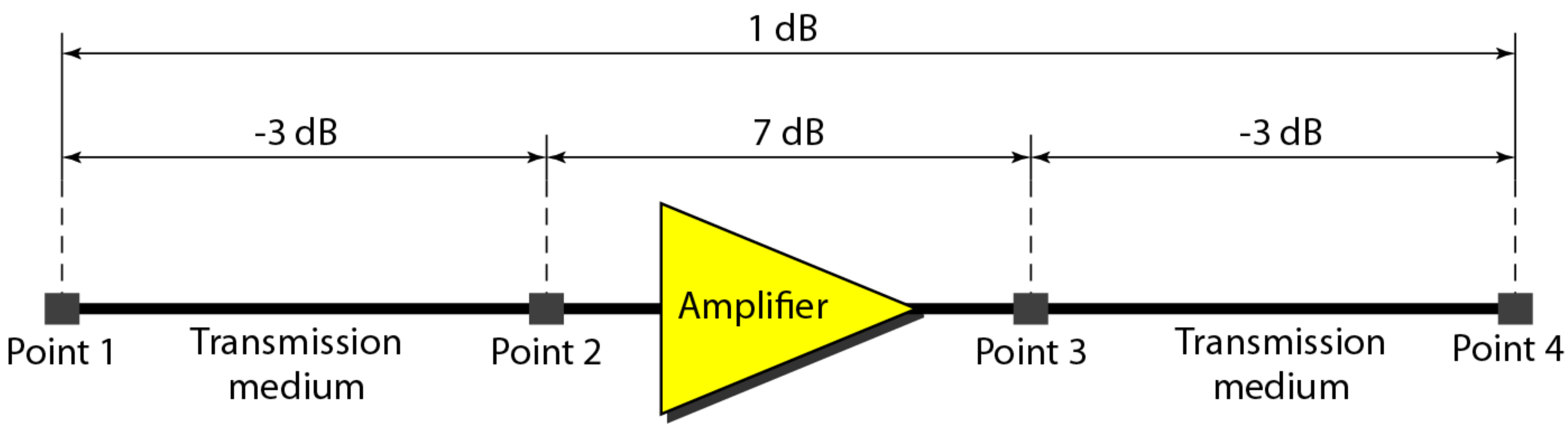
- A signal travels through an amplifier, and its power is increased 10 times. This means that P2 = 10P1 . In this case, the amplification (gain of power) can be calculated as

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

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

Example (3)

- 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 of a signal travels from point 1 to point 4.



- In this case, the decibel value can be calculated as

$$dB = -3 + 7 - 3 = +1$$

Example (4)

- 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

$$\text{dB}_\text{m} = 10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \text{mW}$$

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

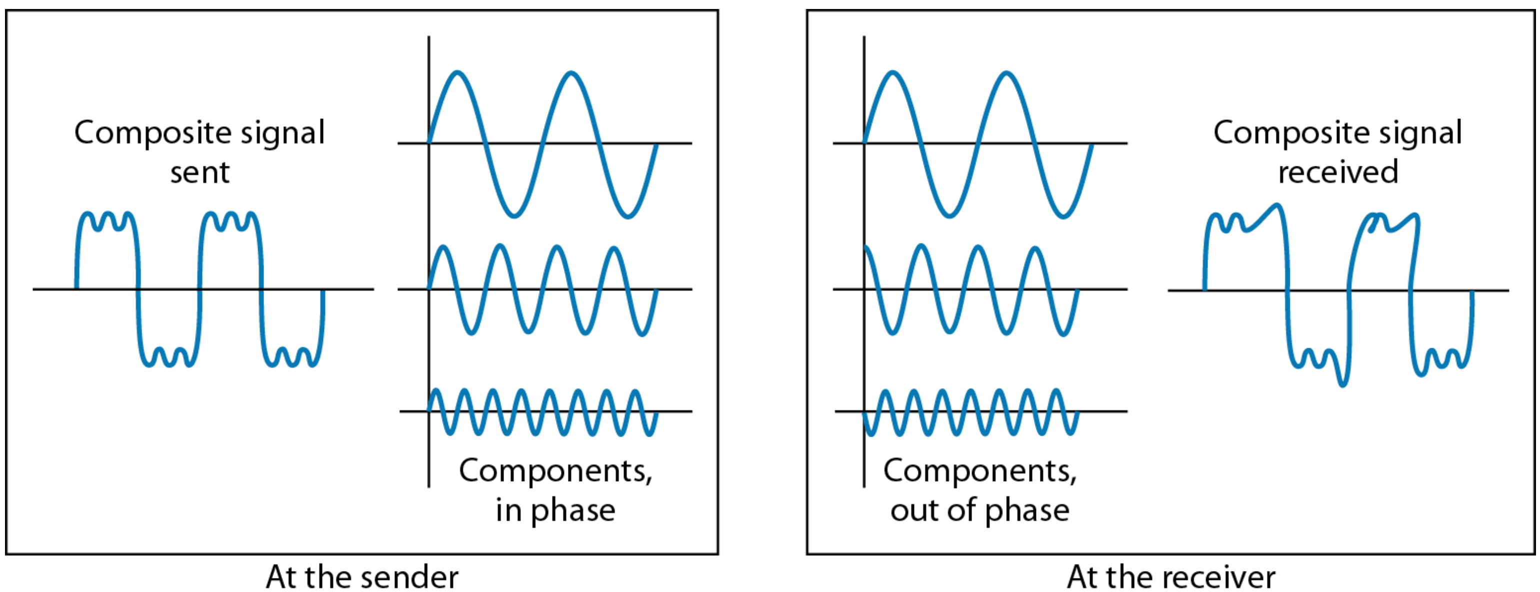
$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

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

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

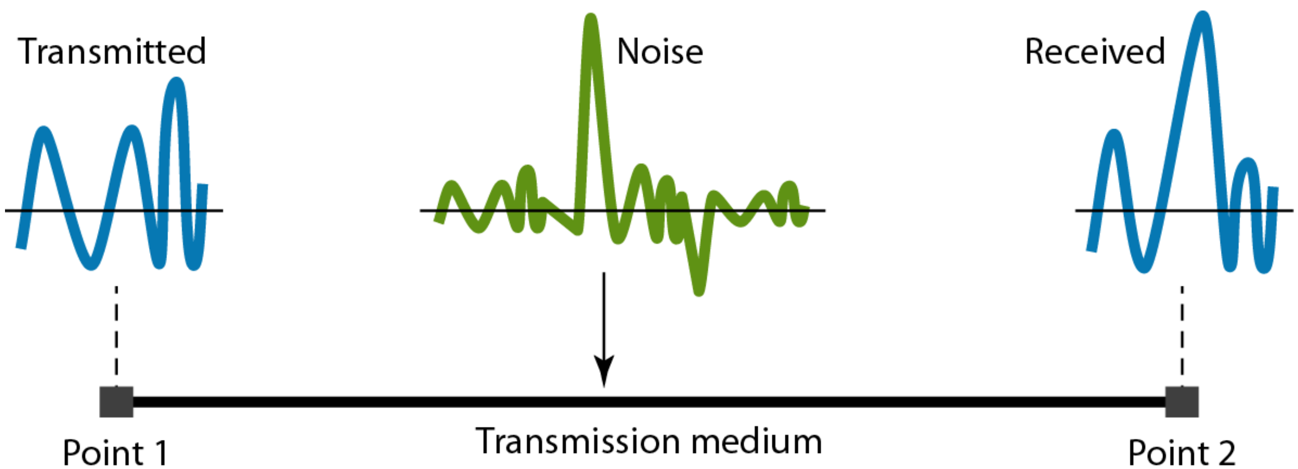
Distortion

- Distortion means that the signal changes its form or shape. Distortion can occure in a composite signal made of different frequencies. Each signal component has its own propagation speed (see the next section) 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.



Noise

- Several type of noice, such as termal 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.



SNR in Decibel

- The values of SNR and SNRdB 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.

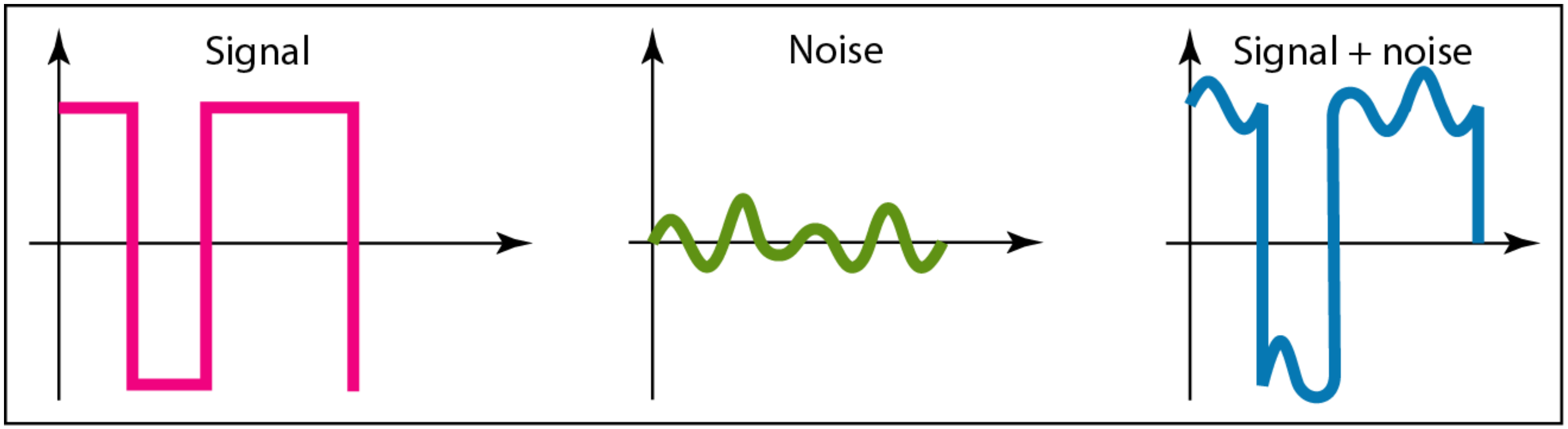
- The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNRdB ?

- Solution
  - The values of SNR and SNRdB can be calculated as follows:

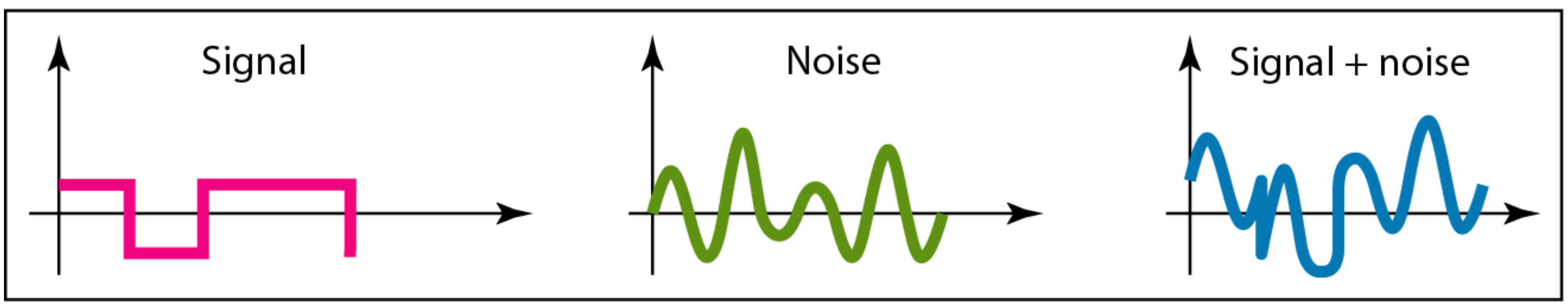
$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

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

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



a. Large SNR



b. Small SNR

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)

Exercise

1. What is the bit rate for a signal in which 1 bit last 0.001s?
2. A signal travels from point A to point B. At point A, the signal power is 100W. At point B, the power is 90 W. What is the attenuation in decibels?
3. Two transmitters are each operating with a transmit power level of 100mW. When you compare the two absolute power levels, what is the result in dB?
4. A transmitter is configured to use a power level of 17mW. One day it is reconfigured to transmit at a new power level of 34 mW. How much has the power level increased in dB?
5. A signal has passed through three cascade amplifiers, each with a 4dB gain. What is the total gain? How much is the signal amplified?
6. A signal with 200 milliwatts power passes through 10 devices, each with an average noise of 2microwatts. What is the SNR? What is the SNRdB?
7. What is the theoretical capacity of a channel in each of Bandwidth 20KHz, SNRdB = 40?
8. What is the length of a bit in a channel with propagation speed of 2 x 108 m/s. If the channel bandwidth is 1 Mbps?