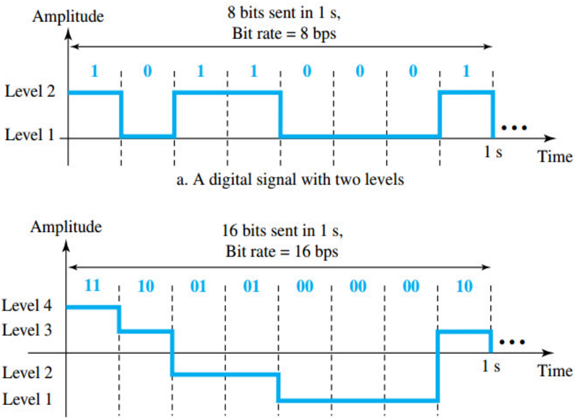
Principles of Data Communications

Reference Book: Data Communications and Networking by Behrouz A. Forouzan

DIGITAL SIGNALS

- 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 (binary digital).
- A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

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

- Figure 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.

- In general, if a signal has L levels, each level needs $log_2 L$ bits. For this reason, we can send $log_2 4 = 2$ bits in part b.
- A digital signal has eight levels. How many bits are needed per level?

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

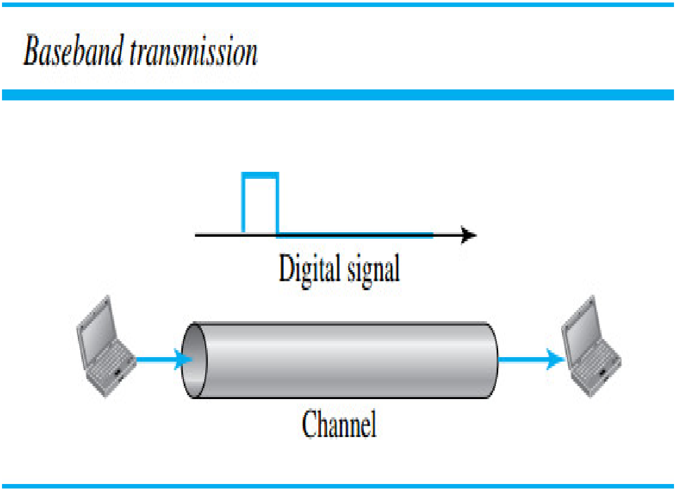
Bit Length

- 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 x bit duration.

Transmission of Digital Signals

- 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



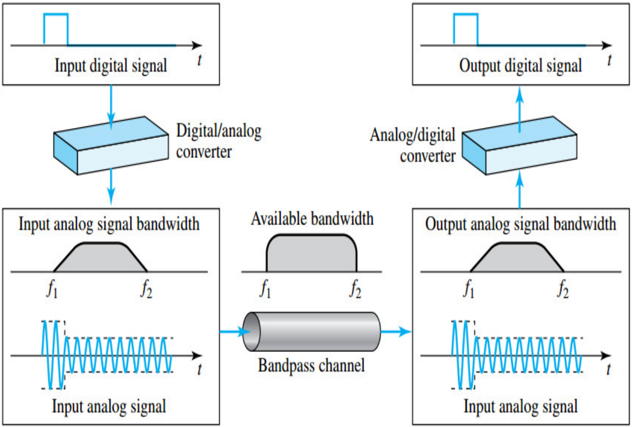
- Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.

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.

- 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.

Modulation of a digital signal for transmission on a bandpass channel

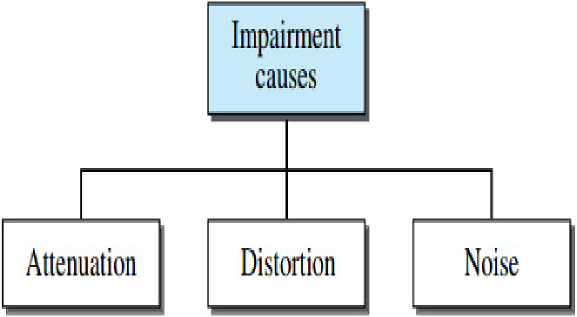


- An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office.
- Convert the digital signal from the computer to an analog signal, and send the analog signal.
- We can install 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 (modulator/demodulator).

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
    - Noise

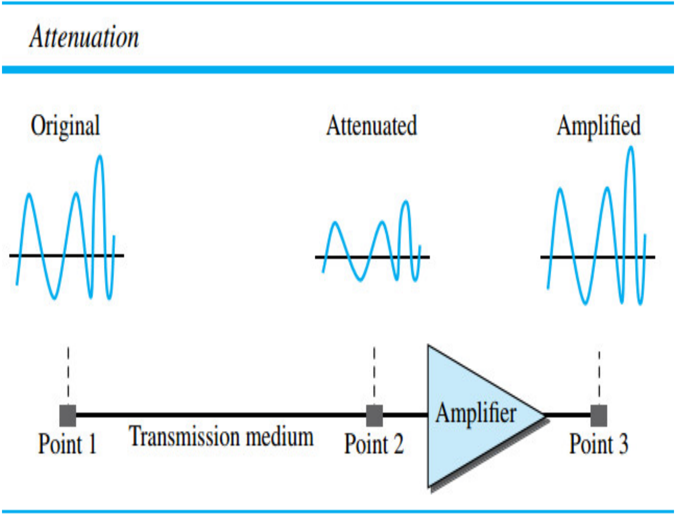
Causes of impairment



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.

Attenuation



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.
- $dB = 10log_{10}(P_2/P_1)$
- Variables P_1 and P_2 are the powers of a signal at points 1 and 2, respectively.

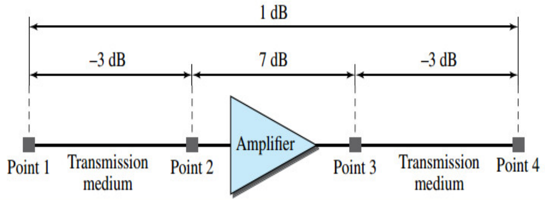
- Suppose a signal travels through a transmission medium and its power is reduced to one-half. Calculate the attenuation (loss of power).

- A signal travels through an amplifier, and its power is increased 10 times. Calculate the amplification (gain of power).

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 3.28 a signal travels from point 1 to point 4. The signal is attenuated by the time it reaches point 2. Between points 2 and 3, the signal is amplified. Again, between points 3 and 4, the signal is attenuated. We can find the resultant decibel value for the signal just by adding the decibel measurements between each set of points.

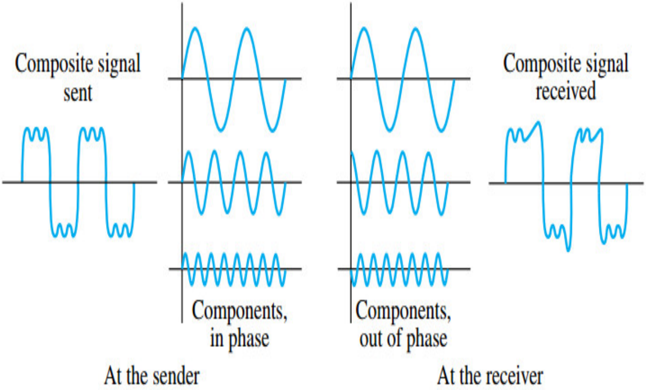
Figure 3.28 *Decibels for Example 3.28*



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. 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.

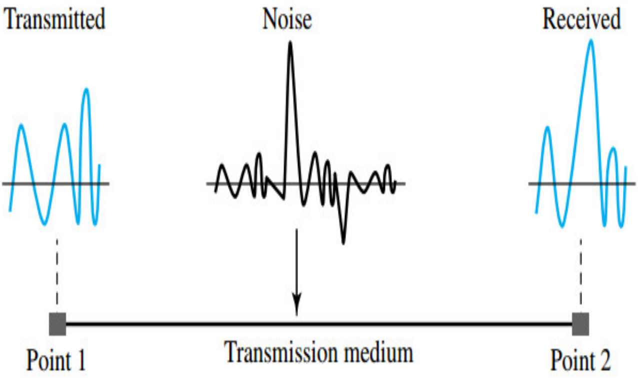
Distortion


Composite signal sent
Components, in phase
At the sender
Components, out of phase
Composite signal received
At the receiver

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.

Noise


Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

Signal-to-Noise Ratio (SNR)

- The signal-to-noise ratio is defined as
  SNR = Average Signal Power/ Average Noise Power

- 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
    - $SNR_{dB} = 10 log_{10} SNR$

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:
    - The bandwidth available
    - The level of the signals we use
    - The quality of the channel (the level of noise)
- Two theoretical formulas were developed to calculate the data rate: one by Nyquist for a noiseless channel, another by Shannon for a noisy channel.

Noiseless Channel: Nyquist Bit Rate

- For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate
- $BitRate = 2 \times bandwidth \times log_2 L$
- Bandwidth is the bandwidth of the channel, L is the number of signal levels used to represent data, and BitRate is the bit rate in bits per second.

- According to the formula, we might think that, given a specific bandwidth, we can have any bit rate we want by increasing the number of signal levels.
- Although the idea is theoretically correct, practically there is a limit. When we increase the number of signal levels, we impose a burden on the receiver.
- If the number of levels in a signal is just 2, the receiver can easily distinguish between a 0 and a 1.
- If the level of a signal is 64, the receiver must be very sophisticated to distinguish between 64 different levels. In other words, **increasing the levels of a signal reduces the reliability of the system**.

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy.
- In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel:
- $Capacity = bandwidth \times log_2(1 + SNR)$
- In this formula, bandwidth is the bandwidth of the channel, SNR is the signal-to-noise ratio, and capacity is the capacity of the channel in bits per second.
- Note that in the Shannon formula there is no indication of the signal level, which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel. In other words, the formula defines a characteristic of the channel, not the method of transmission.

Summary

- Digital Signals
- Transmission of Digital Signals- baseband, broadband
- Transmission Impairment- Attenuation, Distortion, Noise
- Nyquist Bit Rate- Noiseless Channel
- Shannon Capacity- Noisy Channel

THANK YOU