# MODULE 2
PHYSICAL LAYER
ANALOG AND DIGITAL

Both data and the signals that represent them can be either **analog or digital** in form.

Analog and Digital Data and Signals

Data can be analog or digital. The term **analog data** refers to information that is continuous; **digital data** refers to information that has discrete states. Analog data, such as the sounds made by a human voice, take on continuous values. When someone speaks, an analog wave is created in the air. This can be captured by a microphone and converted to an analog signal or sampled and converted to a digital signal. Digital data take on discrete values. For example, data are stored in computer memory in the form of Os and 1s. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.

Signals can 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.

Figure 3.2 *Comparison of analog and digital signals*
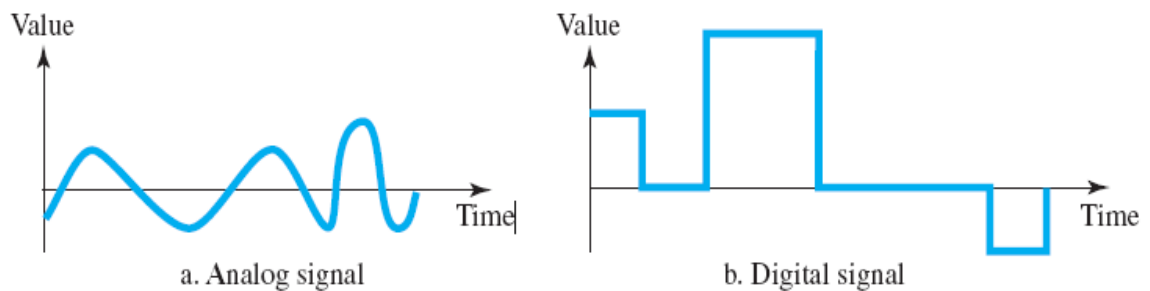
Periodic and Nonperiodic Signals

Both analog and digital signals can take one of two forms: *periodic* or *nonperiodic* .A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a cycle. A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.

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.

Sine Wave

The sine wave is the most fundamental form of a periodic analog signal. When we visualize it as a simple oscillating curve, its change over the course of a cycle is smooth and consistent, a continuous, rolling flow. Figure below shows a sine wave. Each cycle consists of a single arc above the time axis followed by a single arc below it.
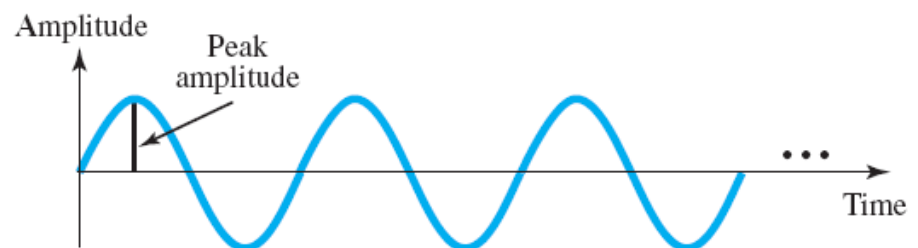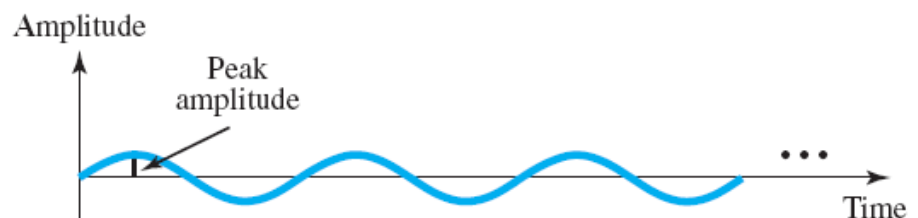
Figure 3.3 *A sine wave*
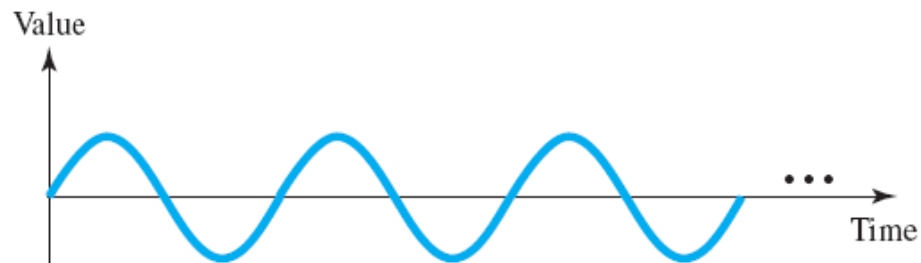
Peak Amplitude

The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries. For electric signals, peak amplitude is normally measured in *volts.*

Figure 3.4 *Two signals with the same phase and frequency, but different amplitudes*

a. A signal with high peak amplitude

b. A signal with low peak amplitude

Period and Frequency

Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
Frequency refers to the number of periods in I s. Note that period and frequency are just one characteristic defined in two ways. Period is the inverse of frequency, and frequency is the inverse of period, as the following formulas show.
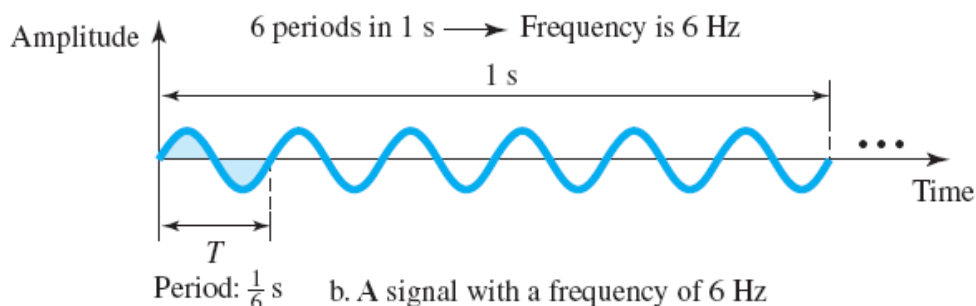
$T=1/f$

and $f=1/T$

Period is formally expressed in seconds. Frequency is formally expressed in Hertz (Hz), which is cycle per second.

Figure 3.5 *Two signals with the same amplitude and phase, but different frequencies*
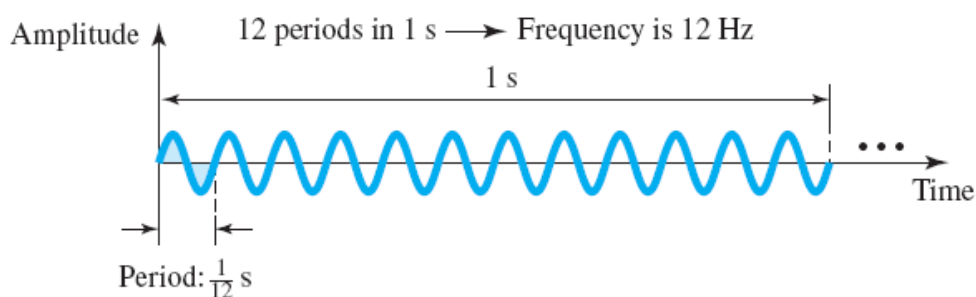
a. A signal with a frequency of 12 Hz

b. A signal with a frequency of 6 Hz

Units of period and frequency

Unit	Equivalent	Unit	Equivalent
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^3 Hz
Microseconds (Ils)	10^{-6} s	Megahertz (MHz)	10^6 Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^9 Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Example 3.4
Express a period of 100 ms in microseconds.
Solution
From Table 3.1 we find the equivalents of 1 ms (I ms is 10-3 s) and 1 s (1 sis 106118). We make the following substitutions:
100 ms= 100 x 10⁻³ = 100 x 10⁻³ x 10⁶ µs=10² x 10⁻³ x 10⁶ µs =10⁵ µs
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.

Phase

The term phase describes the position of the waveform relative to time O. If we think of the wave as something that can be shifted backward or forward along the time axis, phase describes the amount of that shift. It indicates the status of the first cycle. Phase is measured in degrees or radians [360° is *2n* rad; 1° is *2n/360* rad, and 1 rad is *360/(2n)*]. A phase shift of 360° corresponds to a shift of a complete period; a phase shift of 180° corresponds to a shift of one-half of a period; and a phase shift of 90° corresponds to a shift of one-quarter of a period.

Figure 3.6   *Three sine waves with the same amplitude and frequency, but different phases*

a. 0 degrees

b. 90 degrees

c. 180 degrees
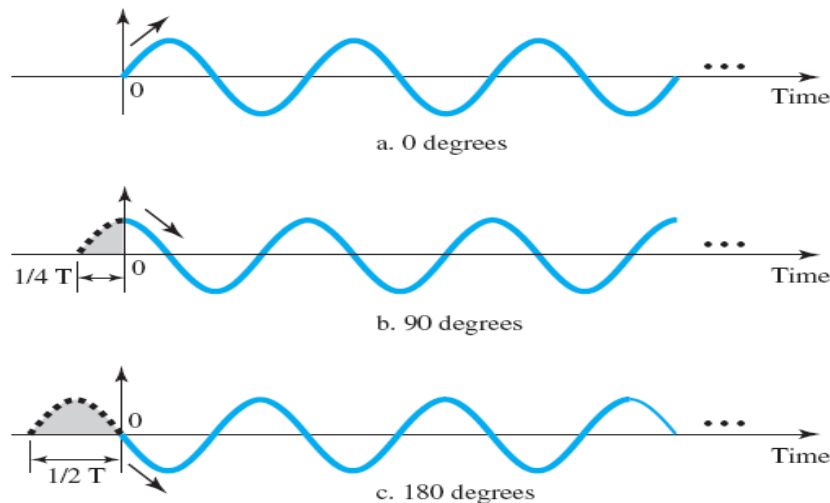
1. A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitude is increasing.
2. A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing.
3. A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.
Another way to look at the phase is in terms of shift or offset. We can say that

1. A sine wave with a phase of 0° is not shifted.
2. A sine wave with a phase of 90° is shifted to the left by 1/4 cycle.
3. A sine wave with a phase of 180° is shifted to the left by 1/2cycle.

Wavelength

Wavelength is another characteristic of a signal traveling through a transmission medium. Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium. While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium. Wavelength is a property of any type of signal. In data communications, we often use wavelength to describe the transmission of light in an optical fiber. The wavelength is the distance a simple signal can travel in one period.

Wavelength can be calculated if one is given the propagation speed (the speed of light) and the period of the signal. However, since period and frequency are related to each other, if we represent wavelength by A, propagation speed by c (speed of light), and frequency by *1,* we get

Wavelength =propagation speed x period = propagation speed/frequency
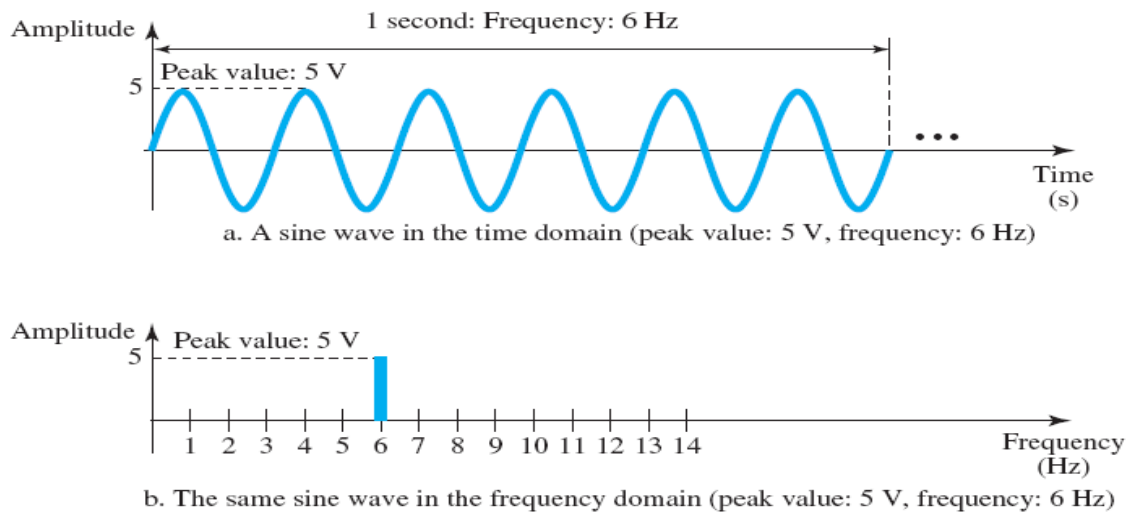
$$\lambda = c/f$$

Figure 3.7   *Wavelength and period*
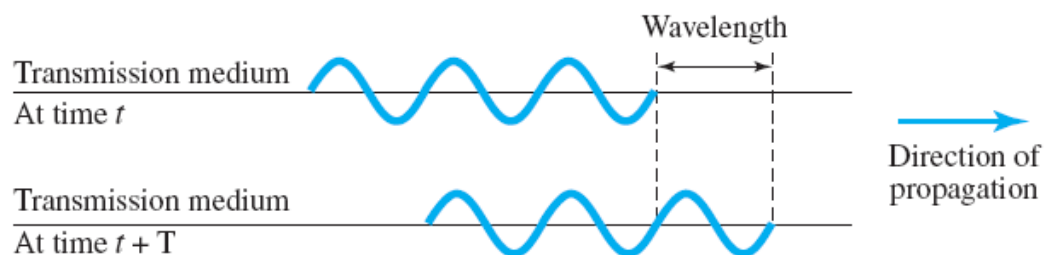
Time and Frequency Domains

A sine wave is comprehensively defined by its amplitude, frequency, and phase. We have been showing a sine wave by using what is called a time-domain plot. The time-domain plot shows changes in signal amplitude with respect to time (it is an amplitude-versus-time plot). Phase is not explicitly shown on a time-domain plot. To show the relationship between amplitude and frequency, we can use what is called a frequency-domain plot. A frequency-domain plot is concerned with only the peak value and the frequency. Changes of amplitude during one period are not shown.

Figure 3.8 *The time-domain and frequency-domain plots of a sine wave*

Amplitude

1 second: Frequency: 6 Hz

Peak value: 5 V

5

Time (s)

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

Amplitude

Peak value: 5 V

5

1 2 3 4 5 6 7 8 9 10 11 12 13 14

Frequency (Hz)

b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

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 ontinuous frequencies.
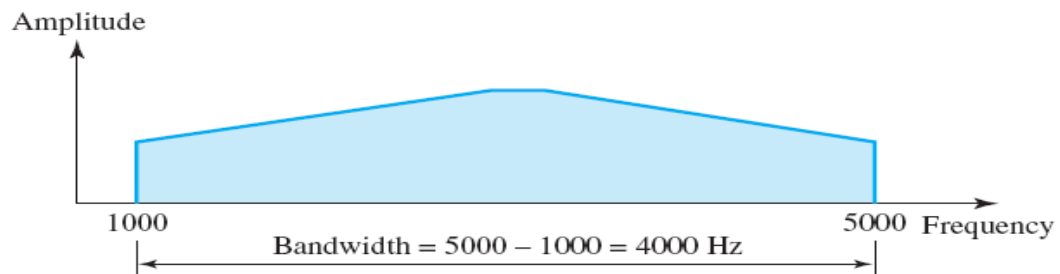
Bandwidth

The range of frequencies contained in a composite signal is its bandwidth. The bandwidth is normally a difference between two numbers. For example, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 - 1000, or 4000. The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

Figure 3.13 *The bandwidth of periodic and nonperiodic composite signals*

Bandwidth = 5000 − 1000 = 4000 Hz
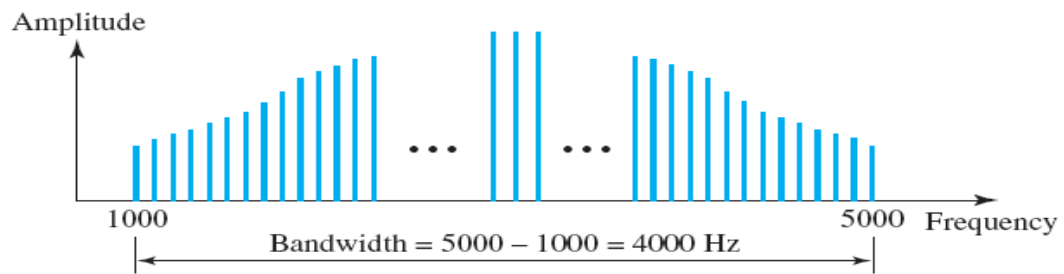
a. Bandwidth of a periodic signal

Bandwidth = 5000 − 1000 = 4000 Hz

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 I 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.

Bit rate is the number of bits sent in Is, expressed in bits per second (bps).

Bit length is the distance one bit occupies on the transmission medium.

Bit length =propagation speed x bit duration

Figure 3.17 *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
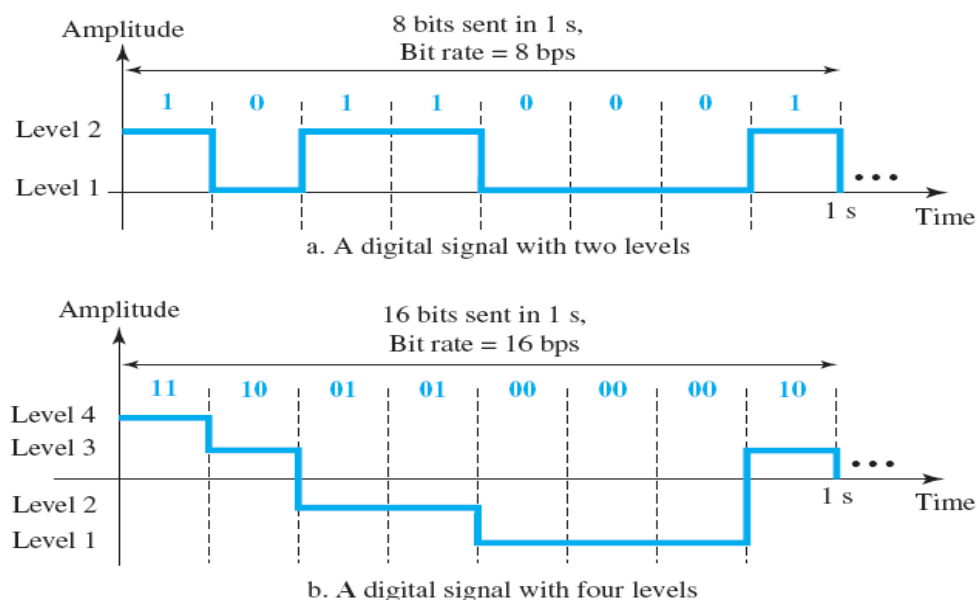
Transmission of Digital Signals

The previous discussion asserts that a digital signal, periodic or nonperiodic, is a composite analog signal with frequencies between zero and infinity. We can transmit a digital signal by using one of two different approaches:

1. baseband transmission
2. broadband transmission (using modulation).

1. Baseband Transmission

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

Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth. In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more bandwidth.
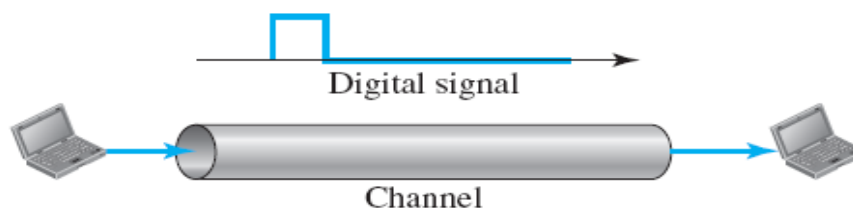
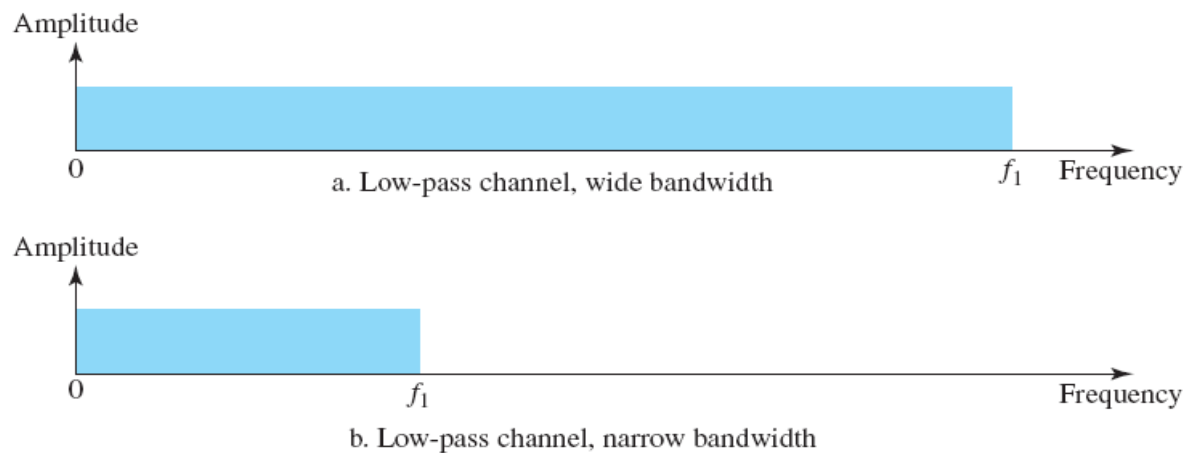**Figure 3.19** *Baseband transmission*

Digital signal

Channel

Figure 3.20 *Bandwidths of two low-pass channels*

Amplitude

0   a. Low-pass channel, wide bandwidth f_1 Frequency

Amplitude

0   f_1 Frequency

b. Low-pass channel, narrow bandwidth

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

Figure 3.24 *Bandwidth of a bandpass channel*

Amplitude

f_1 f_2 Frequency

Bandpass channel
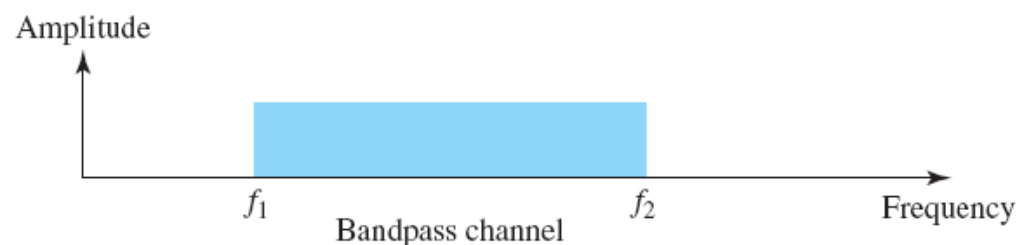
TRANSMISSION IMPAIRMENT

Signals travel through transmission media, which are not petfect. The impetfection 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.
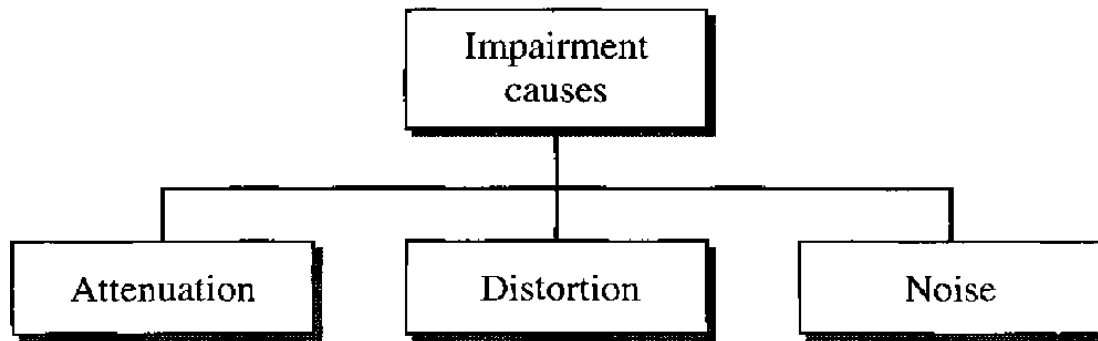
Figure : Causes of Impairements

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 3.27 *Attenuation*
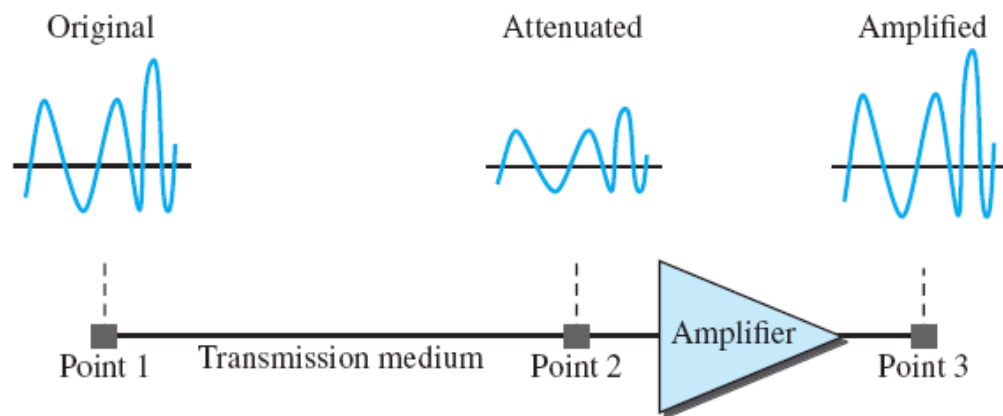
Distortion

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 (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.

Figure 3.29 *Distortion*

Composite signal sent

Components, in phase

At the sender

Composite signal received

Components, out of phase

At the receiver
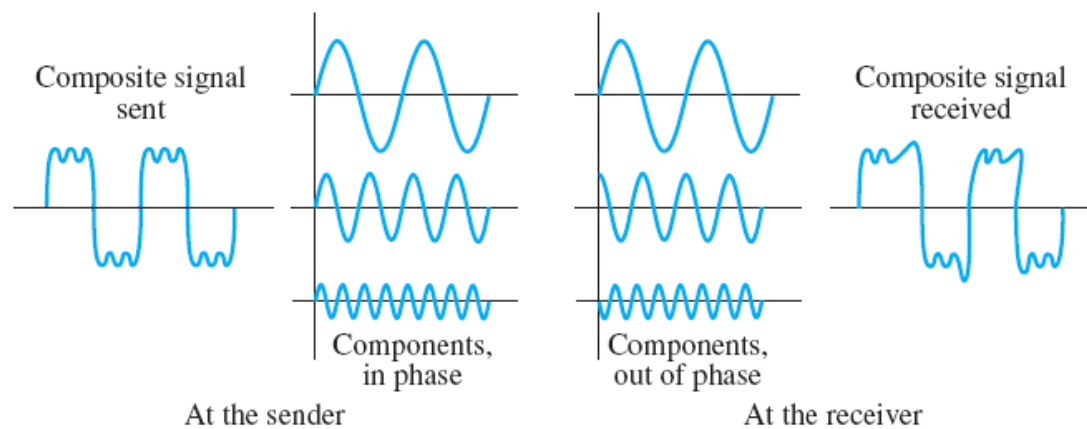
Noise

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.

Figure 3.30 *Noise*

Transmitted

Noise

Received

Point 1

Transmission medium

Point 2
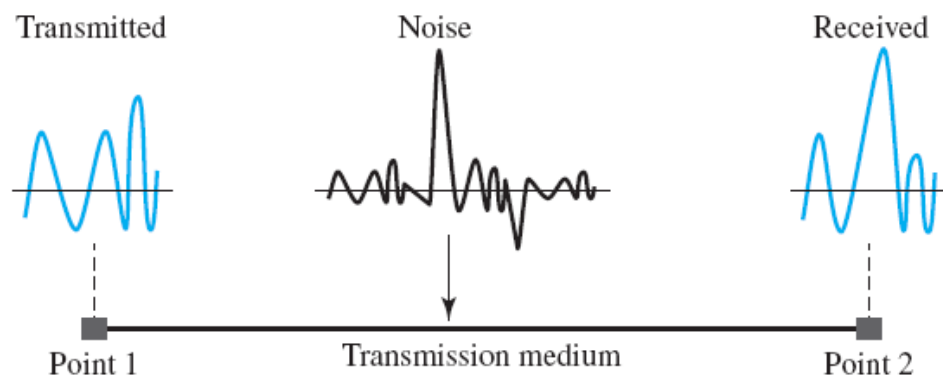
Signal-to-Noise Ratio (SNR)

The signal-to-noise ratio is defined as

SNR $=$ average signal power/average noise power

Characteristics of Network Performances
- Bandwidth

Bandwidth *in hertz,* refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass. Bandwidth *in bits per second,* refers to the speed of bit transmission in a channel or link.

- Throughput

The throughput is a measure of how fast we can actually send data through a network.

- Latency (Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

Latency =propagation time +transmission time +queuing time + processing delay

- Jitter

Another performance issue that is related to delay is **jitter.** We can roughly say that jitter is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive
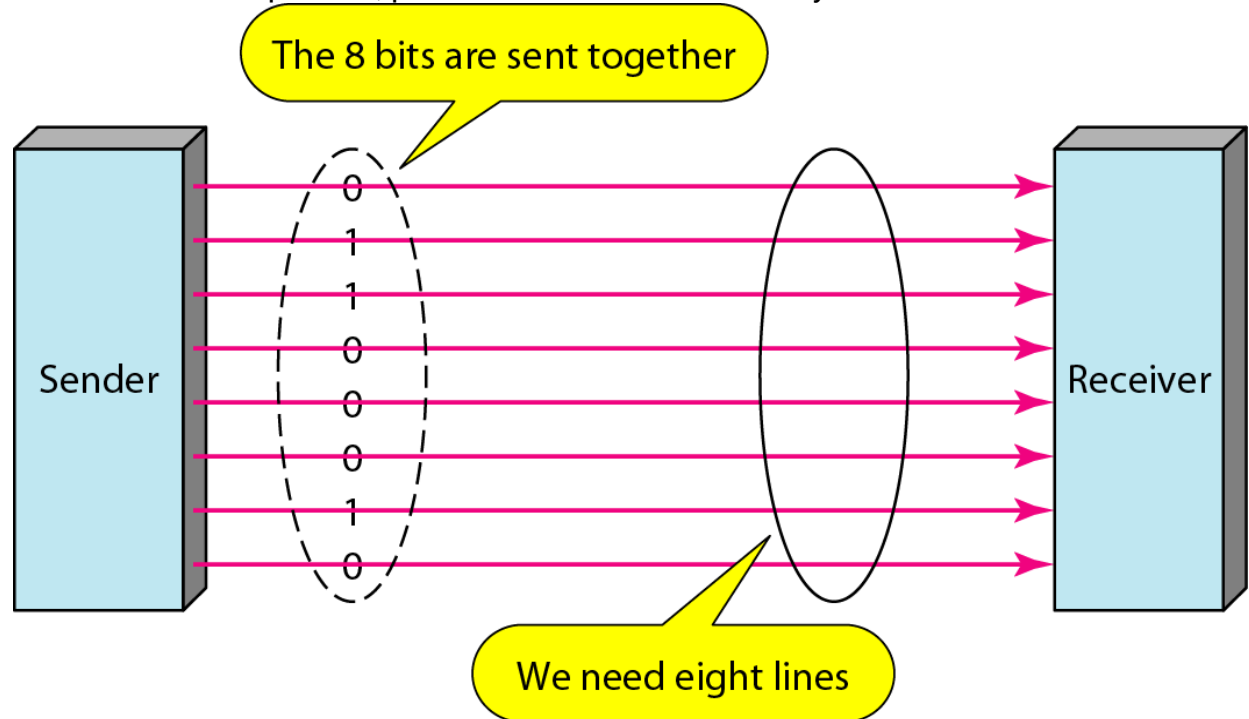
TRANSMISSION MODES

The transmission of binary data across a link can be accomplished in either parallel or serial mode. In parallel mode, multiple bits are sent with each clock tick. In serial mode, 1 bit is sent with each clock tick. While there is only one way to send parallel data, there are three subclasses of serial transmission: asynchronous, synchronous, and isochronous
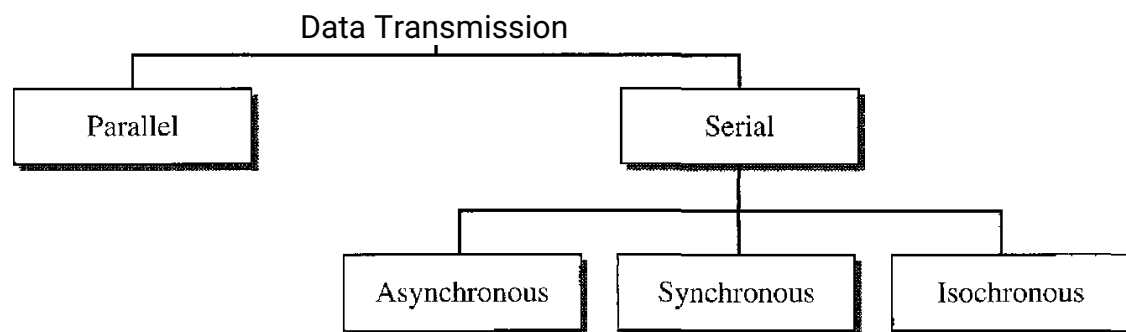

Parallel Transmission

Binary data, consisting of Is and Os, may be organized into groups of *n* bits each. Computers produce and consume data in groups of bits much as we conceive of and use spoken language in the form of words rather than letters. By grouping, we can send data *n* bits at a time instead of 1. This is called parallel transmission. The mechanism for parallel transmission is a conceptually simple one: Use *n* wires to send *n* bits at one time. That way each bit has its own wire, and all *n* bits of one group can be transmitted with each clock tick from one device to another. The advantage of parallel transmission is speed. All else being equal, parallel transmission can increase the transfer speed by a factor of *n* over serial transmission. But there is a significant disadvantage: cost.

Parallel transmission requires *n* communication lines just to transmit the data stream. Because this is expensive, parallel transmission is usually limited to short distances.

The 8 bits are sent together

We need eight lines

Serial Transmission

In serial transmission one bit follows another, so we need only one communication channel rather than *n* to transmit data between two communicating devices. The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission over parallel by roughly a factor of *n.* Since communication within devices is parallel, conversion devices are required at the interface between the sender and the line (parallel-to-serial) and between the line and the receiver (serial-to-parallel). Serial transmission occurs in one of three ways: asynchronous, synchronous, and isochronous.
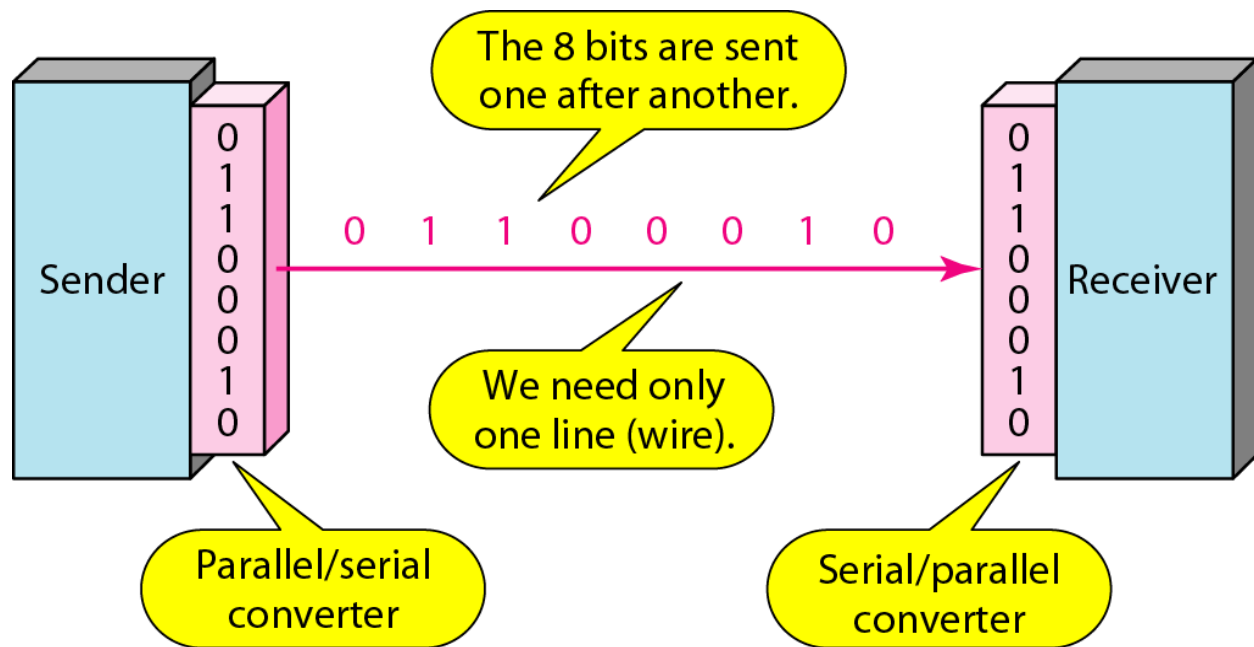
Asynchronous Transmission

Asynchronous transmission is so named because the timing of a signal is unimportant. Instead, information is received and translated by agreed upon patterns. As long as those patterns are followed, the receiving device can retrieve the information without regard to the rhythm in which it is sent. Patterns are based on grouping the bit stream into bytes. Each group, usually 8 bits, is sent along the link as a unit. The sending system handles each group independently, relaying it to the link whenever ready, without regard to a timer. In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (Is) at the end of each byte. There may be a gap between each byte.
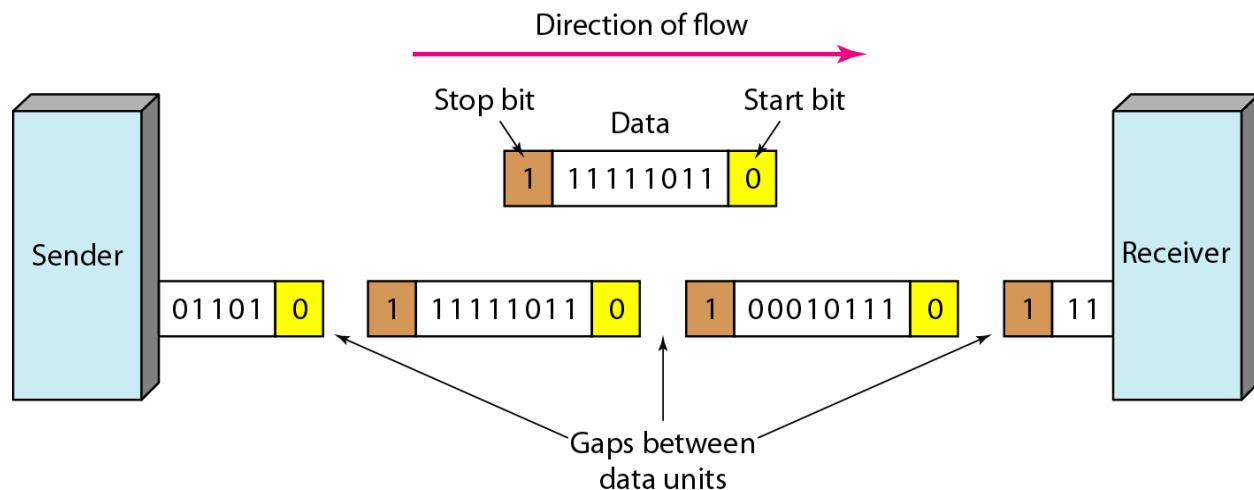
Synchronous Transmission

In synchronous transmission, the bit stream is combined into longer "frames," which may contain multiple bytes. Each byte, however, is introduced onto the transmission link without a gap between it and the next one. It is left to the receiver to

separate the bit stream into bytes for decoding purposes. In other words, data are transmitted as an unbroken string of 1s and Os, and the receiver separates that string into the bytes, or characters, it needs to reconstruct the information. **In** synchronous transmission, we send bits one after another without start or stop bits or gaps. It is the responsibility of the receiver to group the bits.

Direction of flow

Sender

110111

Frame

| 11111011 | 11110110 | ••• | 11110111 |

Frame

Receiver

1111