Data and Signals

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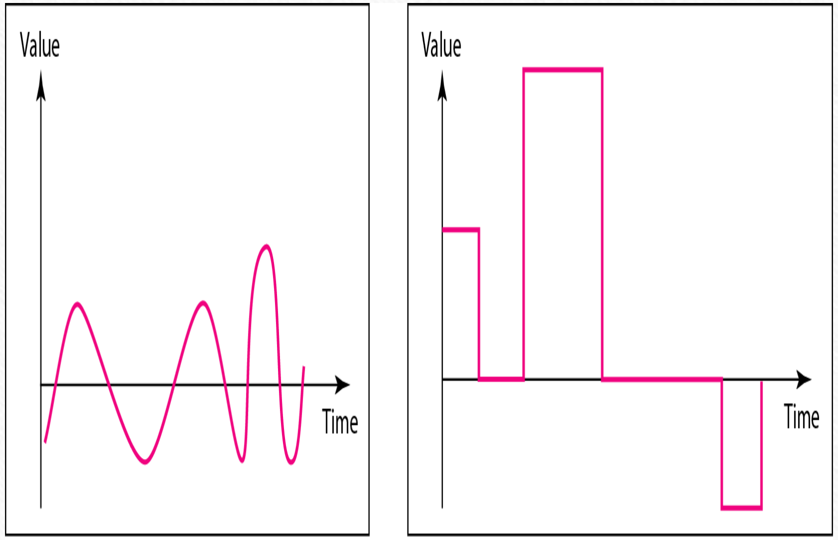
- One of the major functions of the physical layer is to move data in the form of electromagnetic signals across a transmission medium. Whether you are collecting numerical statistics, sending animated pictures , or causing a bell to ring at a distant control center, you are working with the transmission of **data** across network connections.

Analog and Digital Data

- 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 O's and 1's. 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.
- Instead of sending the actual photograph, you can use an encoder to create a stream of 1's and 0's that tells the receiving device how to reconstruct the photograph, But even 1's and 0's cannot be sent as such across network links. They must be further converted into a form that transmission media can accept
- To be transmitted, data must be transformed to electromagnetic signals.

Analog or Digital Data

- Analog data are continuous and take continuous values
- Digital data have discrete states and take discrete values.
- **Analog and Digital Signals**
- Like ~~the data they represent, signals can be either analog or digital. An analog signal has infinitely many~~ levels of intensity over a period of time. As the wave moves from value *A* to value *B,* it passes through and includes an infinite number of values along its path. A digital signal, on the other hand, can have only a limited number of defined values. Although each value can be any number, it is often as simple as 1 and O.

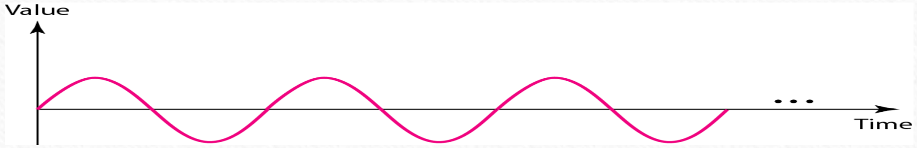


a. Analog signal b. Digital signal

ANALOG DATA	DIGITAL DATA
Analog is Continuous	Digital is Discrete
Changes continuously w.r.to time	Sudden jump
Includes an infinte number of values along its value	It can have only limited no of values,0&1
Eg : Human voice, Analog clock	Eg : Data stored in memory, Digital clock

Periodic and Nonperiodic Signals

- Both analog and digital signals can take one of two forms: ***periodic* or *nonperiodic*** (sometimes refer to as *aperiodic,* because the prefix *a* in Greek means "non").
- 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 **Period** is defined as the amount of time (in seconds) required to complete one full cycle.
- A **periodic signal** consists of a continuously repeated pattern.
- A **non periodic signal** changes without exhibiting a pattern or cycle that repeats over time.
- Both analog and digital signals can be periodic or nonperiodic. In data communications, we commonly use periodic analog signals (because they need less bandwidth, In data communications, we commonly use periodic analog signals and nonperiodic digital signals.)
- **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 (simplest)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.
- According to fourier transform, any aperiodic signal can be decomposed into an infinite no of periodic signals.

A sine wave can be represented by three parameters**: the *peak amplitude,* the period or *frequency,* and the *phase.*** These three parameters fully describe a sine wave.

1. **Amplitude**-

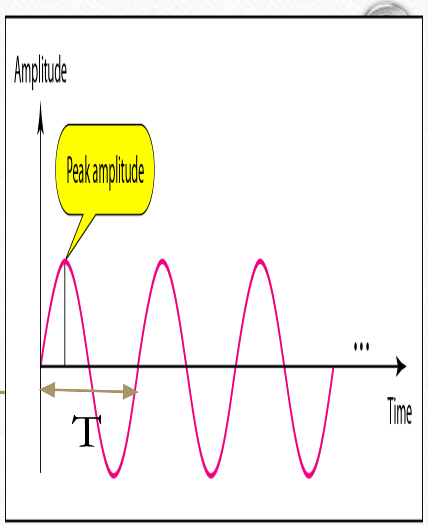
- **The value of a signal at any point on the wave**. It is equal to the vertical distance from a given point on the wave form to the horizontal axis.
- **Peak Amplitude-**The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries. For electric signals, peak amplitude is normally measured in ***volts.***

2. **Period and Frequency**

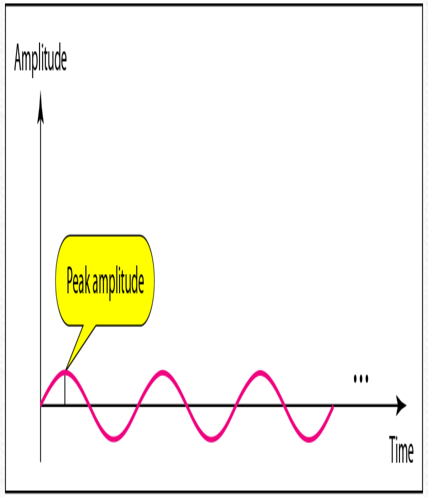
- **Period** refers to the **amount of time, in seconds, a signal needs to complete 1 cycle.**
- **Frequency** refers to **the number of periods in 1 s**. Note that period and frequency are just one characteristic defined in two ways.
- Period is the inverse of frequency, and frequency is the inverse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

$$\boxed{f = \frac{1}{T} \qquad \text{and} \qquad T = \frac{1}{f}}$$

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



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	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

Unit & Description
Kilobyte (KB), 1 KB = 1024 Bytes
Megabyte (MB),1 MB = 1024 KB
GigaByte (GB),1 GB = 1024 MB
TeraByte (TB),1 TB = 1024 GB
PetaByte (PB),1 PB = 1024 TB

Eg; The period of a signal is 100 ms. What is its frequency in kilohertz?

- Solution- First we change lOO ms to seconds, and then we calculate the frequency from the period

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

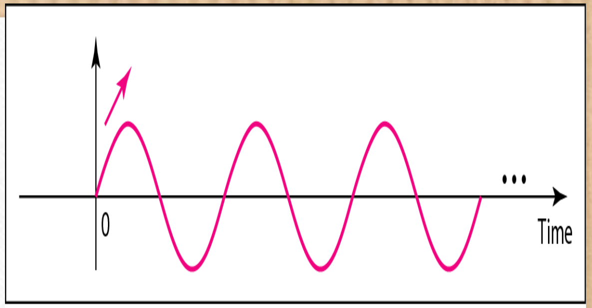
$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

3. Phase

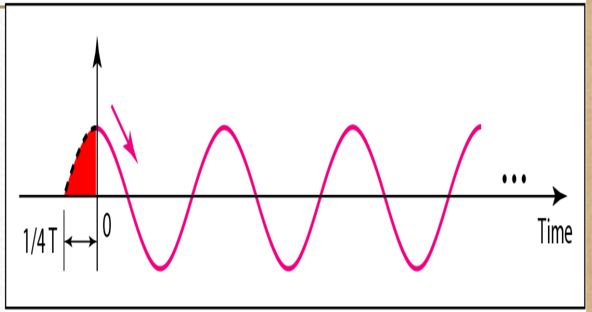
- The term phase describes the **position of the waveform relative to time O**. If we think of the wave as something that can be shifted backward or forward along the time axis, phase describes the amount of that shift. It indicates the status of the first cycle.
- Phase is measured in degrees or radians [360° is 2π rad; A phase shift of **360°** corresponds to a **shift of a complete period**;
- A sine wave with a phase of **0°** is **not shifted.**
- and a phase shift of **90°** corresponds to a **shift of one-quarter** of a period
- a phase shift of **180°** corresponds to a shift of **one-half of a period**;

4. Wavelength

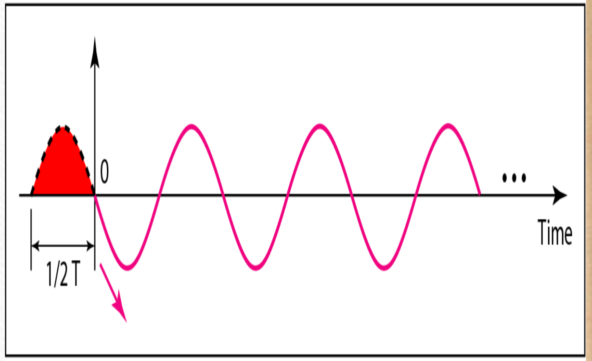
- While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium. Wavelength is a property of any type of signal. In data communications, we often use wavelength to describe the transmission of light in an optical fiber.
- **The wavelength is the distance a simple signal can travel in one period.**
- Wavelength is another characteristic of a signal traveling through a transmission medium
- Wave Length= Propagation speed* period= Propagation speed/frequency



a. 0 degrees



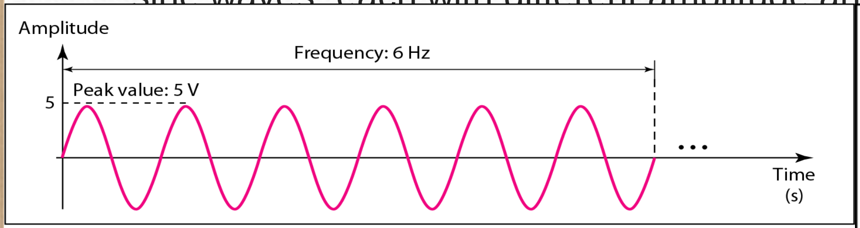
b. 90 degrees



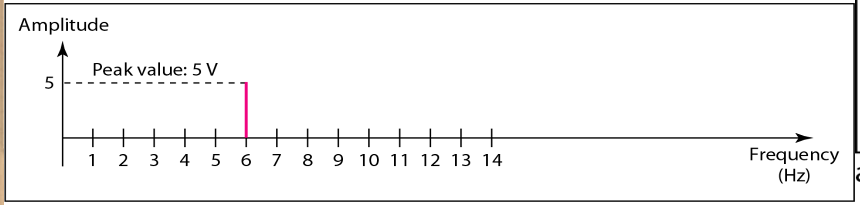
c. 180 degrees

Time and Frequency Domains

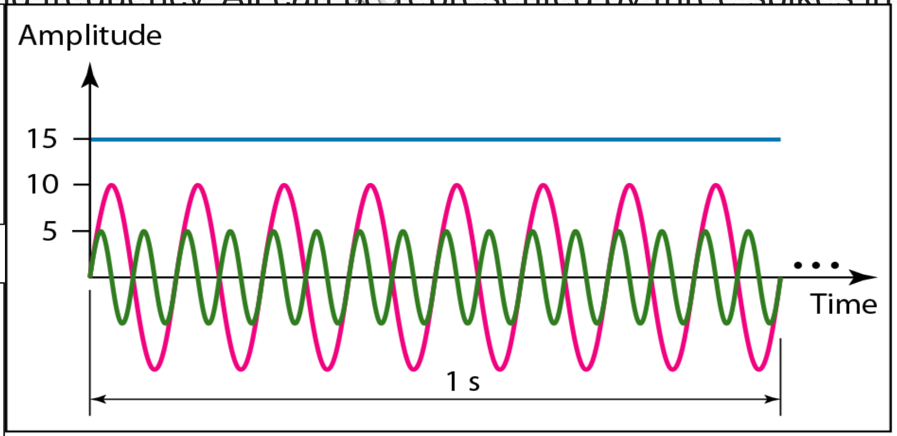
- A sine wave is comprehensively defined by its amplitude, frequency, and phase.
- **The time-domain plot** shows changes in signal **amplitude with respect to time** (it is an amplitude-versus-time plot). Phase is not explicitly shown on a time-domain plot. To show the relationship between amplitude and frequency, we can use what is called a frequency-domain plot.
- **A frequency-domain plot** is concerned with only the peak **amplitude value and the frequency**. Changes of amplitude during one period are not shown. Figure shows a signal in both the time and frequency domains. A complete sine wave in the time domain can be represented by one single spike in the frequency domain.
- **Composite Signals**
- Simple sine waves have many applications in daily life. We can send a single sine wave to carry electric energy from one place to another. As example, we can use a single sine wave to send an alarm to a security center when a burglar opens a door or window in the house. If we had only one single sine wave to convey a conversation over the phone, it would make no sense and carry no information. We would just hear a buzz.
- We need to send a composite signal to communicate data. A **composite signal** is 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.
- 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 continuous frequencies.
- The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.



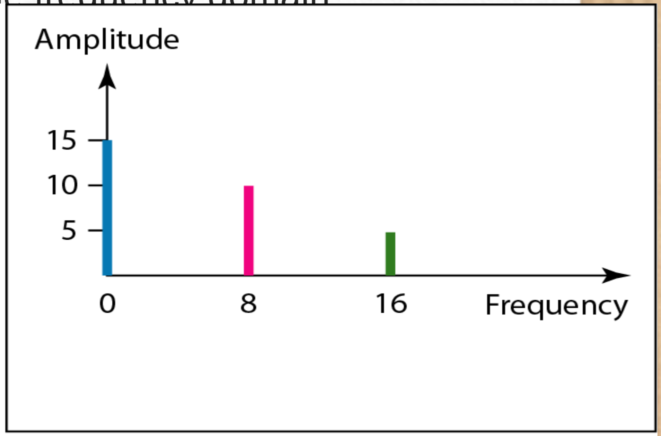
a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



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

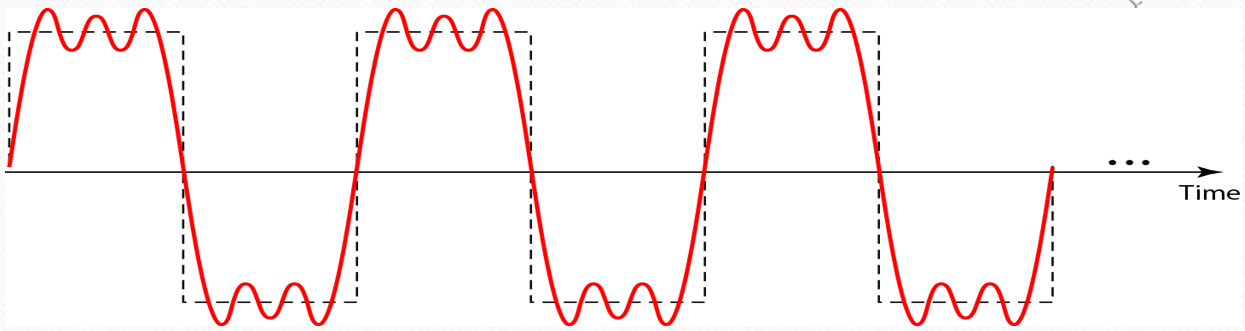


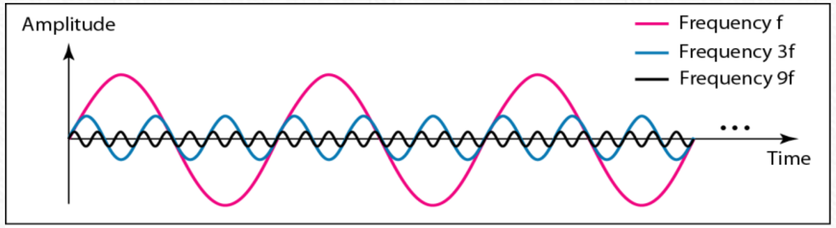
a. Time-domain representation of three sine waves with frequencies 0, 8, and 16



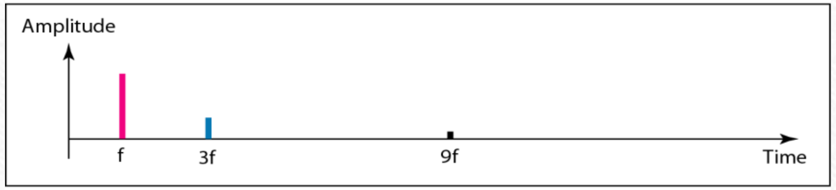
b. Frequency-domain representation of the same three signals

- It is very difficult to manually decompose this signal into a series of simple sine waves. However, there are tools, both hardware and software, that can help us do the job. Figure shows the result of decomposing the above signal in both the time and frequency domains.
- The amplitude of the sine wave with frequency *f* is almost the same as the peak amplitude of the composite signal. The amplitude of the sine wave with frequency *3f* is one-third of that of the first, and the amplitude of the sine wave with frequency *9f* is one-ninth of the first.
- ~~The frequency of the sine wave with frequency *f* is the same as the frequency of the composite signal; it is~~ called the fundamental frequency, or first harmonic. The sine wave with frequency 3f has a frequency of 3 times the fundamental frequency; it is called the third harmonic. The third sine wave with frequency *9f has* a frequency of 9 times the fundamental frequency; it is called the ninth harmonic.
- Note that the frequency decomposition of the signal is discrete; it has frequencies f, *3f,* and *9f* Because *f* is an integral number, *3f* and *9f* are also integral numbers. There are no frequencies such as *1.2f* or *2.6f* The frequency domain of a periodic composite signal is always made of discrete spikes.





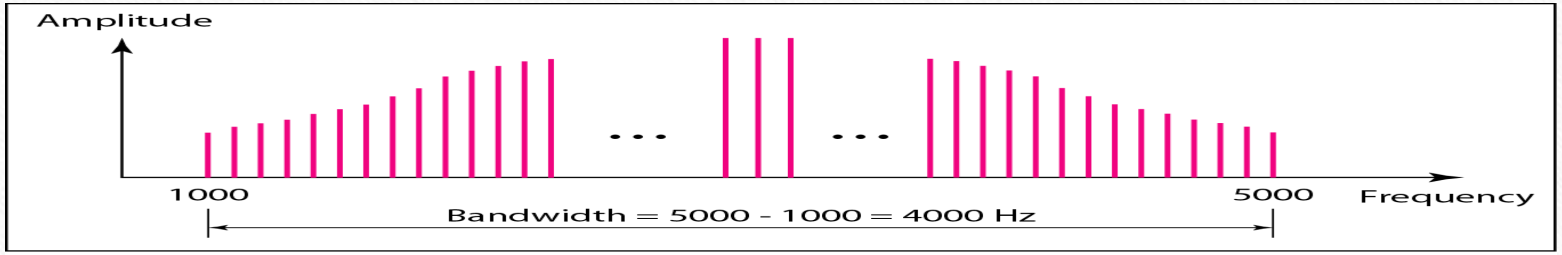
a. Time-domain decomposition of a composite signal



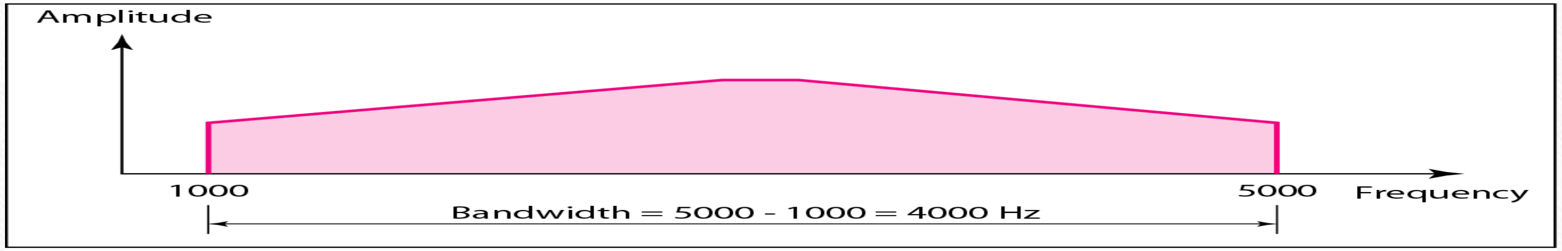
b. Frequency-domain decomposition of the composite signal

Bandwidth

- The width range of frequencies contained in a composite signal is its bandwidth.
- The band width 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 shows the concept of bandwidth. The figure depicts two composite signals, one periodic and the other nonperiodic. The bandwidth of the periodic signal contains all integer frequencies between 1000 and 5000 (1000, 100 I, 1002, ...).



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

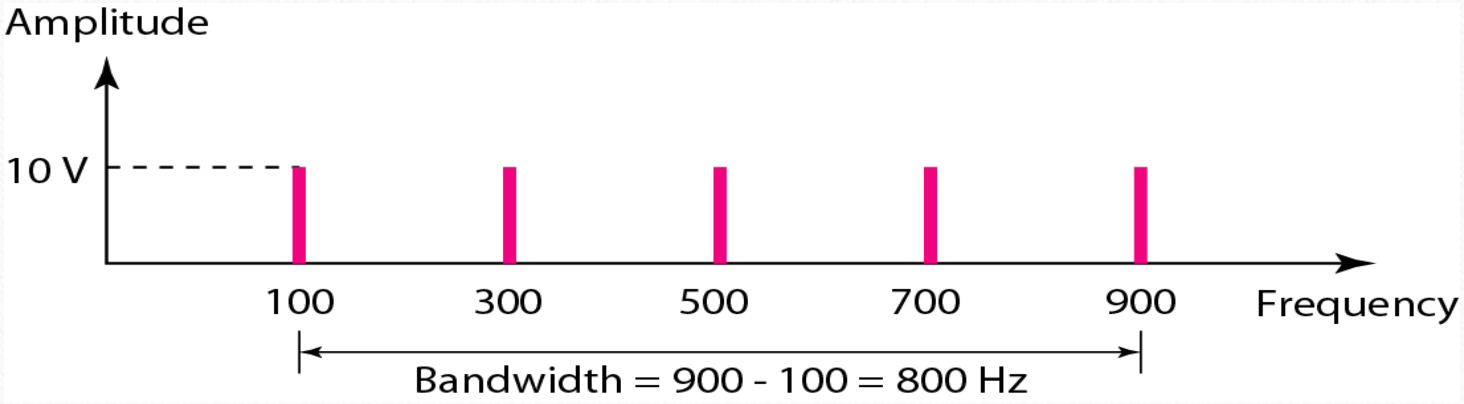
- If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

- Solution

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

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

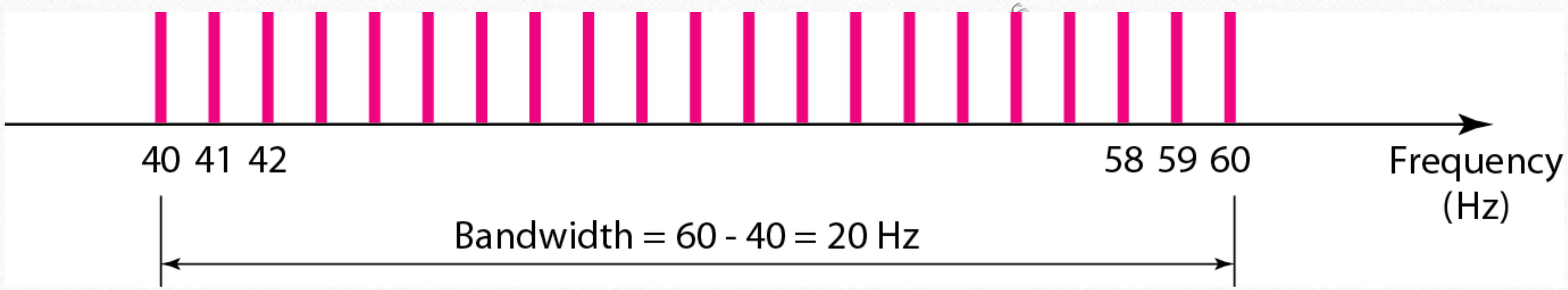
- The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz



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

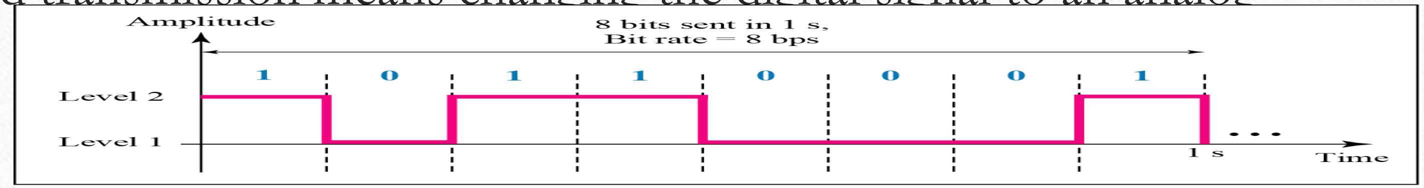
$$\boxed{B = f_h - f_l \quad \Rightarrow \quad 20 = 60 - f_l \quad \Rightarrow \quad f_l = 60 - 20 = 40 \text{ Hz}}$$



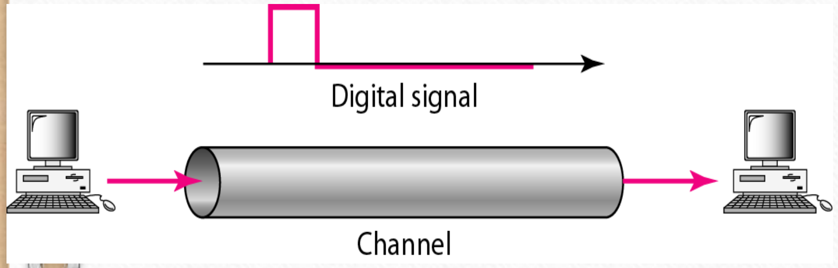
DIGITAL SIGNALS

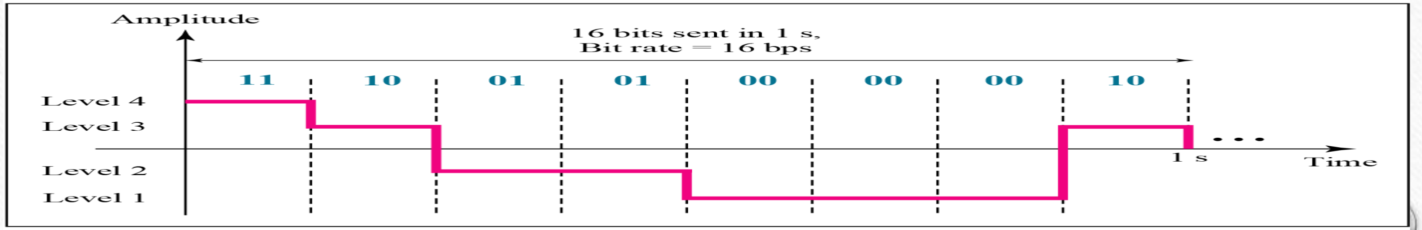
In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

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



a. A digital signal with two levels





b. A digital signal with four levels

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 I s**, expressed in bits per second (bps). It is also known as datarate

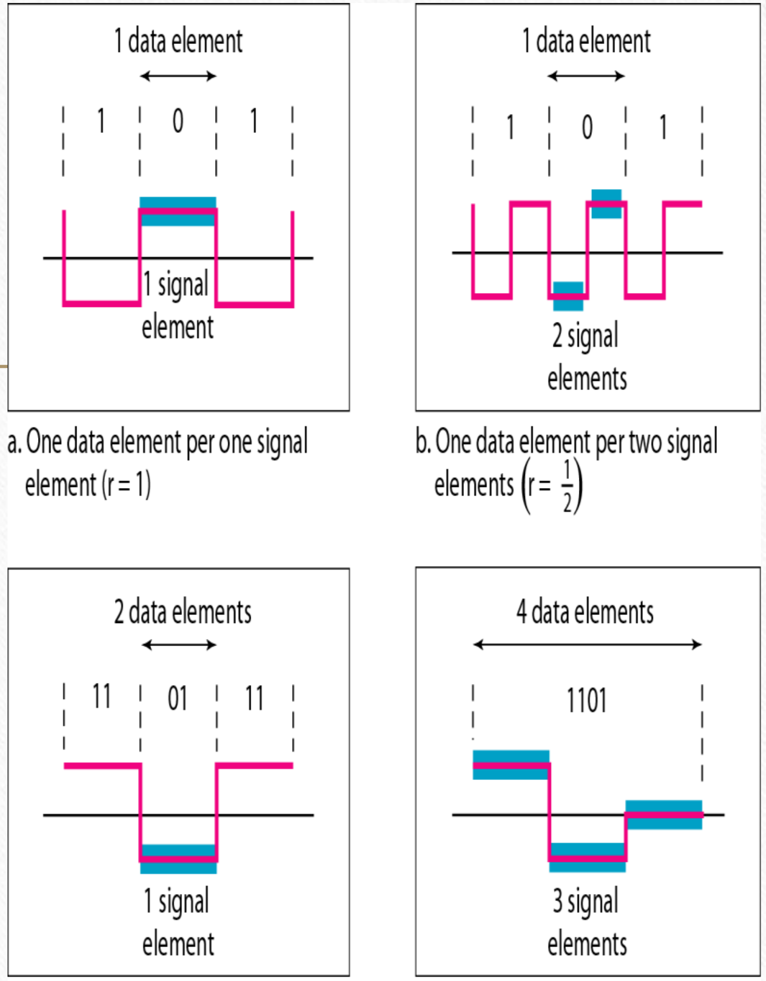
- # Baud Rate

- Data Rate Versus Signal Rate **The data rate** defines the number of data elements (bits) sent in Is. The unit is bits per second (bps). The **signal rate(baud rate)** is the number of signal elements sent in Is. The unit is the baud. There are several common terminologies used in the literature. The data rate is sometimes called the bit rate; the signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.

- One goal in data communications is to increase the data rate while decreasing the signal rate. Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement. In our vehicle-people analogy, we need to carry more people in fewer vehicles to prevent traffic jams. We have a limited *bandwidth* in our transportation system.

- # Bit Length

- We discussed the concept of the 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.**



a. One data element per one signal element ($r = 1$)

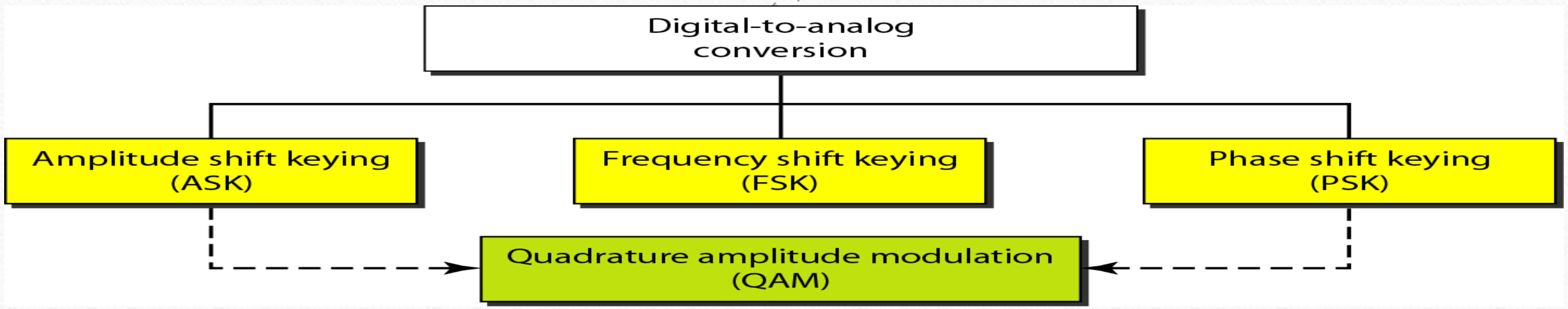
b. One data element per two signal elements ($r = \frac{1}{2}$)

c. Two data elements per one signal element ($r = 2$)

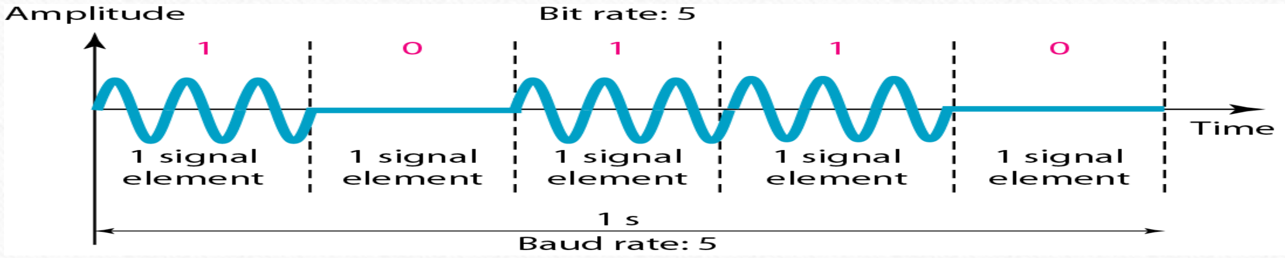
d. Four data elements per three signal elements ($r = \frac{4}{3}$)

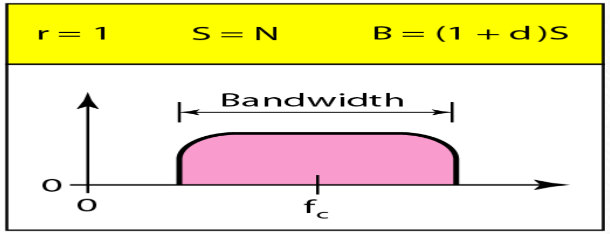
Types of digital-to-analog conversion

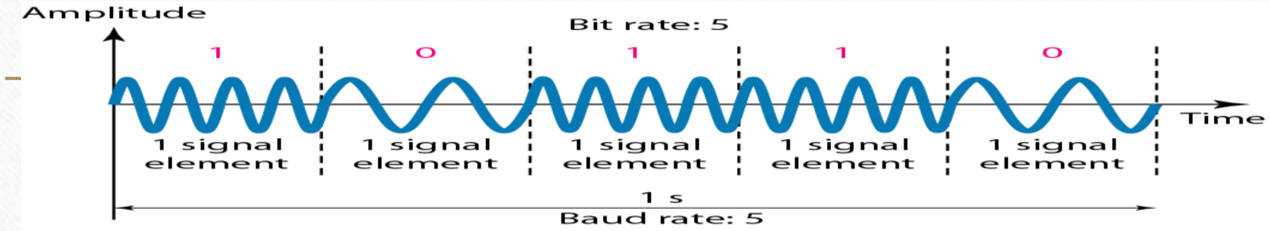
- A sine wave is defined by three characteristics: amplitude, frequency, and phase. When we **vary anyone of these characteristics, we create a different version of that wave**. So, by changing one characteristic of a simple electric signal, we can use it to represent digital data. Any of the three characteristics can be altered in this way, giving us at least three mechanisms for modulating digital data into an analog signal: amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). In addition, there is a fourth (and better) mechanism that combines changing both the amplitude and phase, called quadrature amplitude modulation (QAM).
- ***Carrier Signal***- In analog transmission, the **sending device produces a high-frequency signal that acts as a base for the information signal.** This base signal is called the carrier signal or carrier frequency. The receiving device is tuned to the frequency of the carrier signal that it expects from the sender. Digital information then changes the carrier signal by modifying one or more of its characteristics (amplitude, frequency, or phase). This kind of modification is called modulation (shift keying).

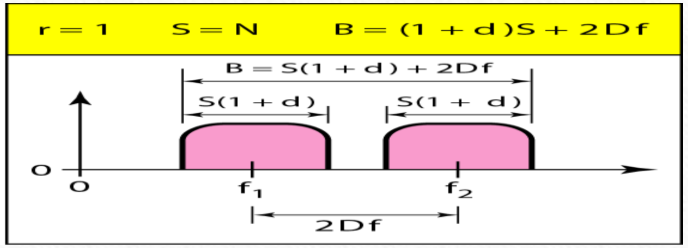


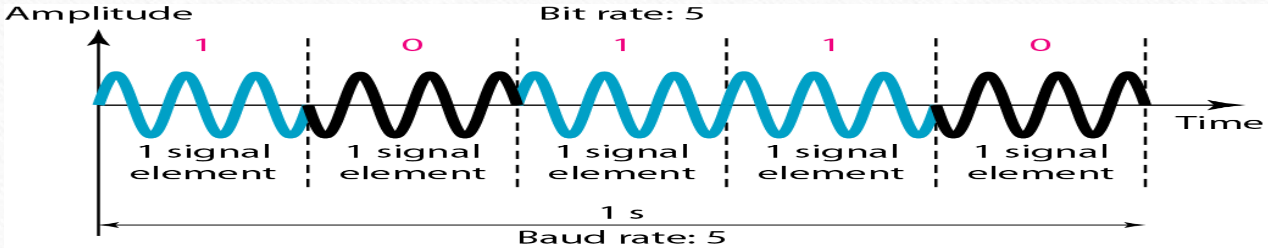
- **Amplitude Shift Keying-** In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes.
- **Frequency Shift Keying-** In frequency shift keying, the frequency of the carrier signal is varied to represent data. The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes. Both peak amplitude and phase remain constant for all signal elements.
- **Phase Shift Keying**- In phase shift keying, the phase of the carrier is varied to represent two or more differrent signal elements. Both peak amplitude and frequency remain constant as the phase changes. Today, PSK is more common than ASK or FSK. However, we will see Sh0l1ly that QAM, which combines ASK and PSK, is the dominant method of digital• to-analog modulation.
- **Quadrature amplitude modulation** is a combination of ASK and PSK.

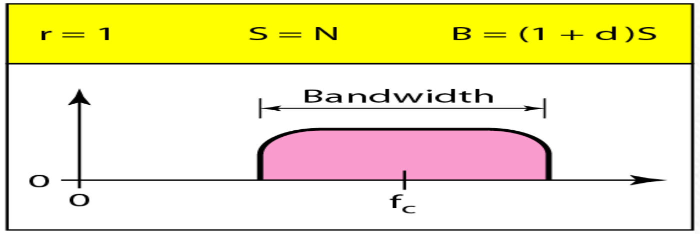










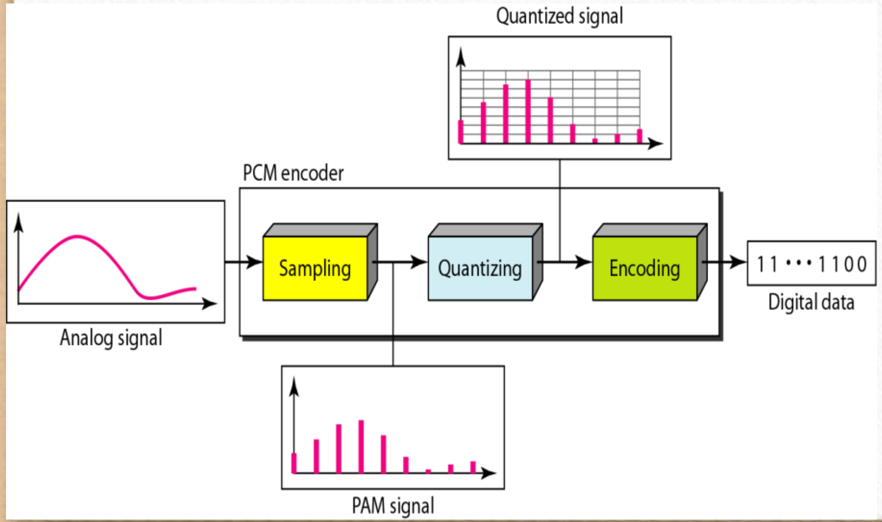


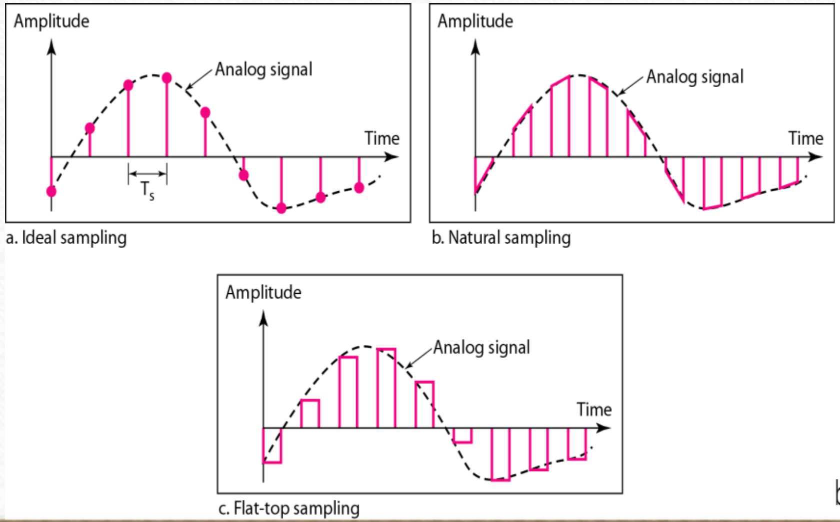
Analog-to-analog conversion

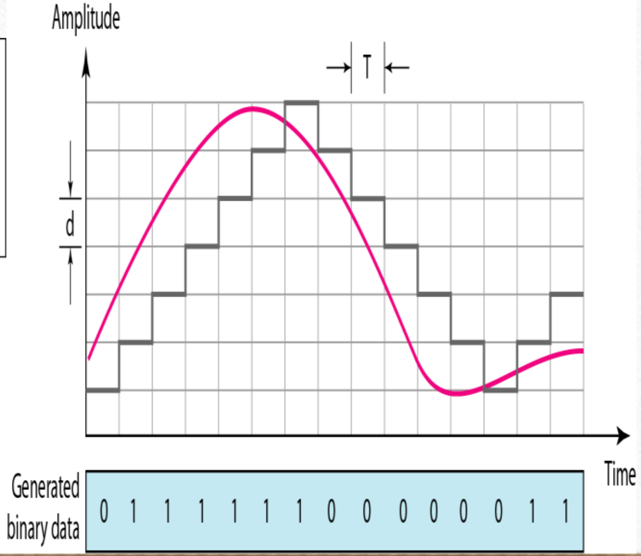
- Amplitude modulation
- Frequency modulation
- Phase modulation

Types of Analog-to-Digital conversion

- **The process of converting analog data into digital data is called digitization and the device is codec coder - decoder**
- **Pulse Code Modulation (PCM)-**The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM).If a signal is sampled at regular intervals at a rate higher than twice the highest frequency, then samples contain all the information of the orginal signal. A PCM encoder has three processes, as shown in Figure .
- **Delta Modulation** (DM)-PCM is a very complex technique. Other techniques have been developed to reduce the complexity of PCM. The simplest is *delta modulation.An analog input is approximated by a stair case function that moves up and down by one quantization level at each samling interval.* PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample. Figure shows the process. Note that there are no code words here; bits are sent one after another.

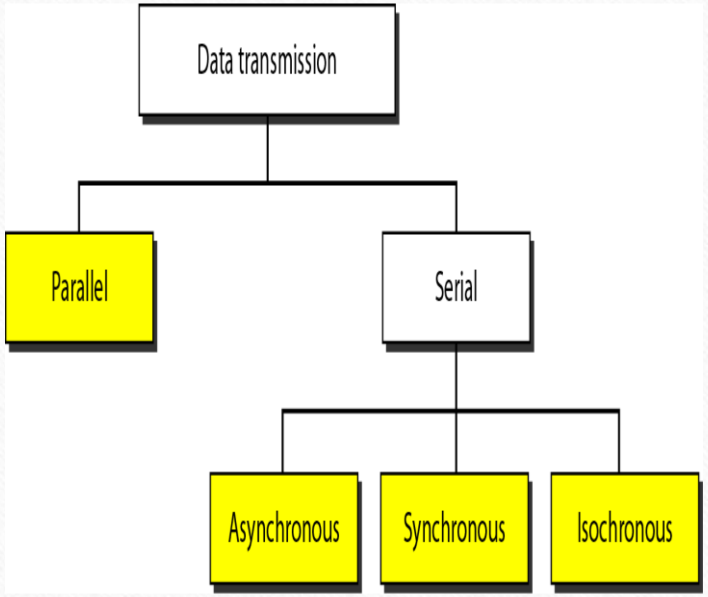


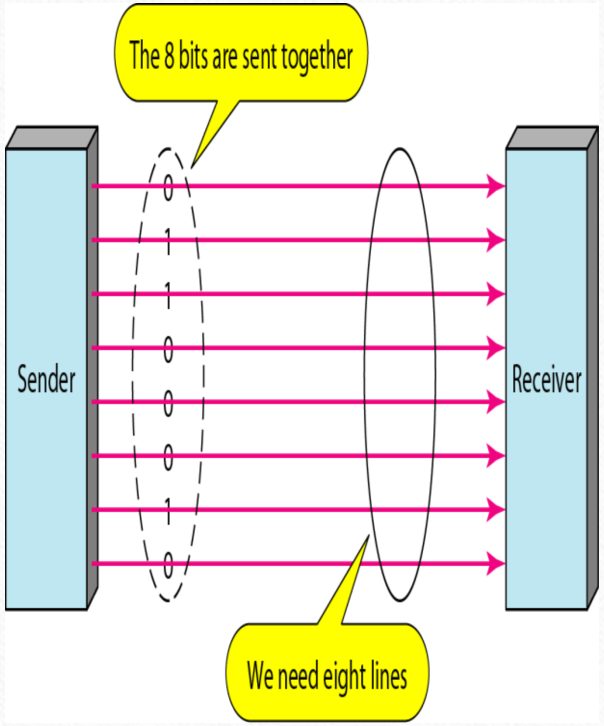


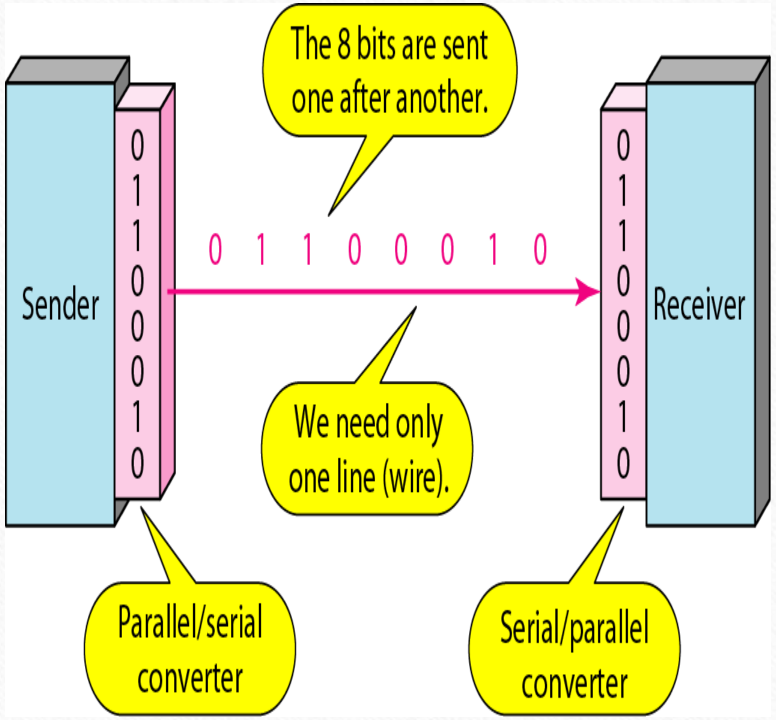


Data transmission and modes

- ***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***



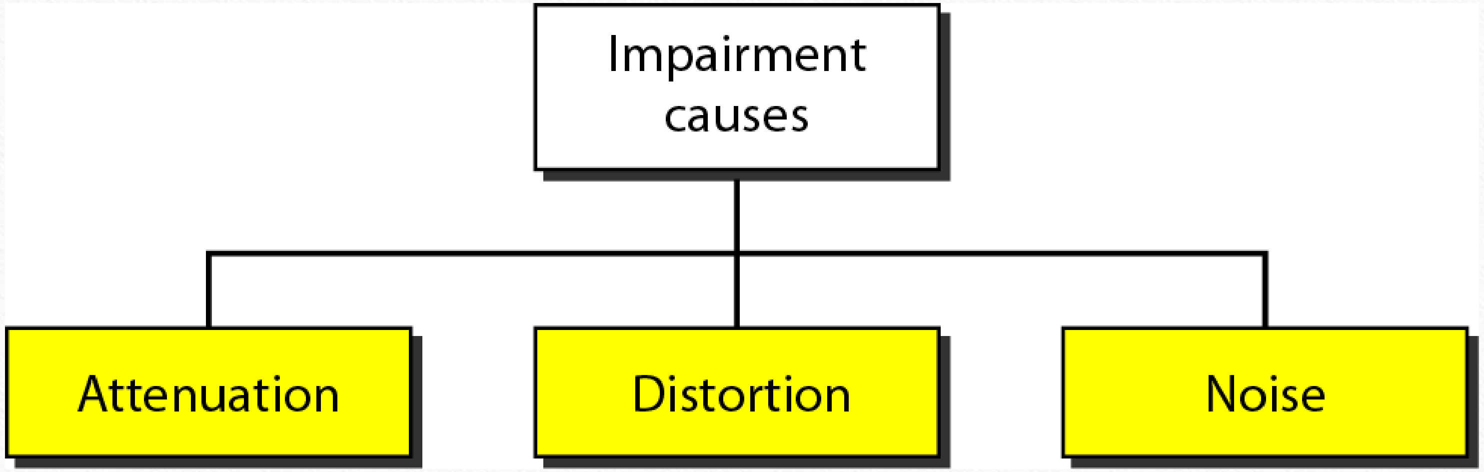




- **Parallel Transmission**
- Binary data, consisting of Is and Os, may be organized into groups of *n* bits each. Computers produce and consume data in groups of bits much as we conceive of and use spoken language in the form of words rather than letters. By grouping, we can send data *n* bits at a 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 Serial Transmission
- **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 with each clock tick from one device to another.
- ***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.

TRANSMISSION IMPAIRMENT

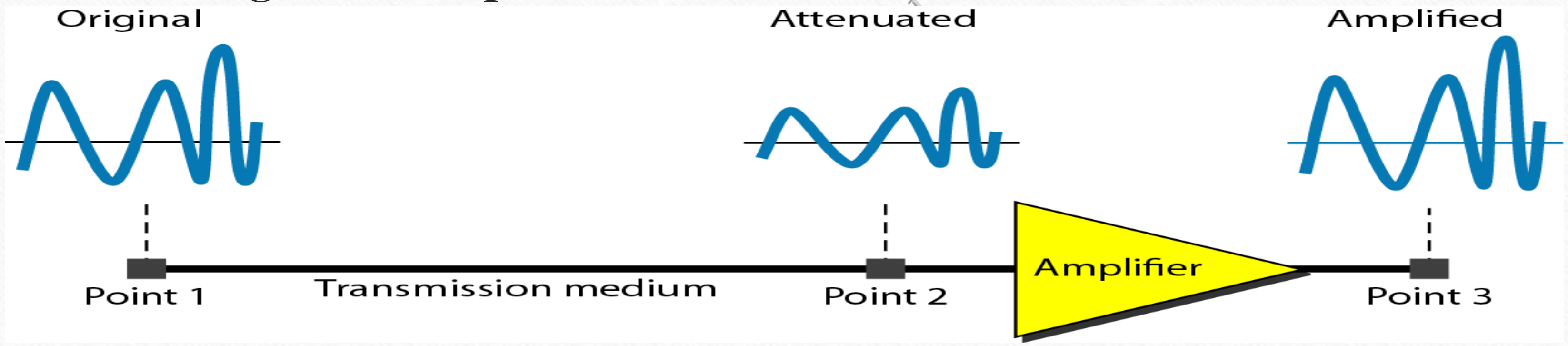
- Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise.
- For analog signals these impairments can degrade the signal quality. For digital signals, bit errors may be introduced.



Attenuation

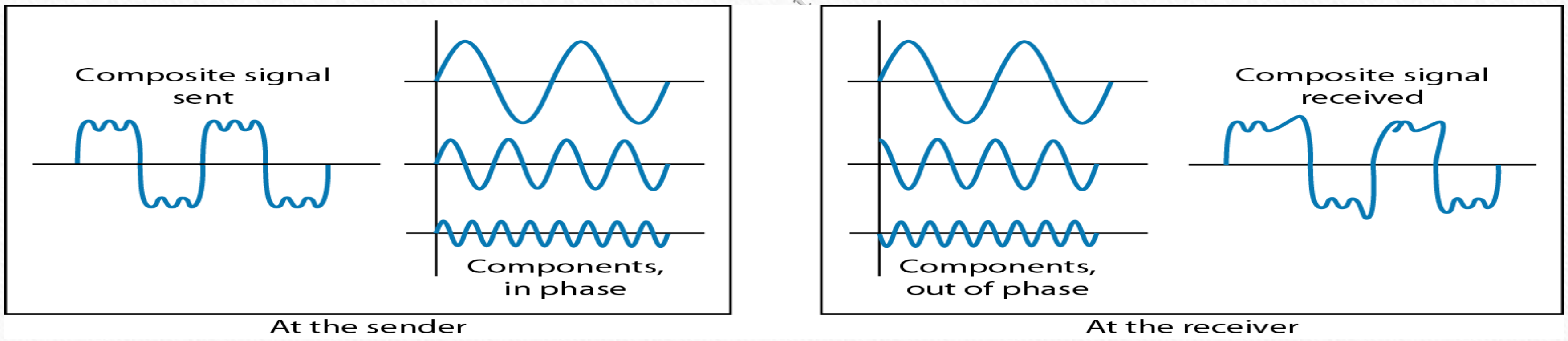
- Attenuation means a loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium. That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifiers are used to amplify the signal. Figure 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.



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. The velocity tends to be highest near the center frequency and fall off towards the two edges of the band.This effect is known as delay distortion. 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 shows the effect of distortion on a composite signal.



Noise

- The unwanted energy from sources other than transmitter.
- Several types of noise are thermal noise, induced noise, cross talk and impulse noise
- **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- electrical coupling between near by antennas. 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. Impulse noise, is non continuous, consisting of irregular pulses or noise spikes of short duration of time, and of relatively high amplitude. Figure 3.29 shows the effect of noise on a signal.crosstalk, and impulse noise, may corrupt the signal.