MODULE 1

DATA TRANSMISSION

Data:

Data refers to information presented in whatever form is agreed upon by the parties creating and using the data.

Data communication:

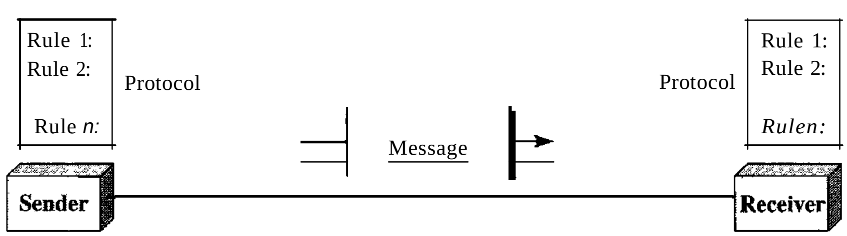
Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable. For data communications to occur, the communicating devices must be part of a communication system made up of a combination of hardware (physical equipment) and software (programs).

Fundamental characteristics:

1. **Delivery**. The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.
2. **Accuracy**. The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.
3. **Timeliness**. The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called **real-time transmission.**
4. **Jitter**. Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets. For example, let us assume that video packets are sent every 3D ms. If some of the packets arrive with 3D-ms delay and others with4D-ms delay, an uneven quality in the video is the result.

Components:

A data communications system has five components



Transmission Medium

1. **Message**. The message is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video.
2. **Sender**. The sender is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.
3. **Receiver**. The receiver is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on
4. **Transmission medium**. The transmission medium is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted-pair wire, coaxial cable, fiber-optic cable, and radio waves.
5. **Protocol**. A protocol is a set of rules that govern data communications. It represents an agreement between the communicating devices. Without a protocol, two devices may be connected but not communicating, just as a person speaking French cannot be understood by a person who speaks only Japanese.

Data Representation:

Information comes in different forms such as text, numbers, images, audio, and video.

1. **Text -** Text is represented as a bit pattern, a sequence of bits (0s or 1s). Different sets of bit patterns have been designed to represent text symbols. Each set is called a **code**, and the process of representing symbols is called **coding**. Coding system called **Unicode**, which uses 32 bits to represent a symbol or character used in any language in the world. The **American Standard Code for Information Interchange (ASCII)** constitutes the first 127 characters in Unicode and is also referred to as Basic Latin.
2. **Numbers -** Numbers are also represented by bit patterns. However, a code such as ASCII is not used to represent numbers; the number is directly converted to a binary number to simplify mathematical operations.
3. **Images -** Images are also represented by bit patterns. An image is composed of a matrix of pixels (picture elements), where each **pixel** is a **small dot**. The size of the pixel depends on the resolution. After an image is divided into pixels, each pixel is assigned a bit pattern. The size and the value of the pattern depend on the image.

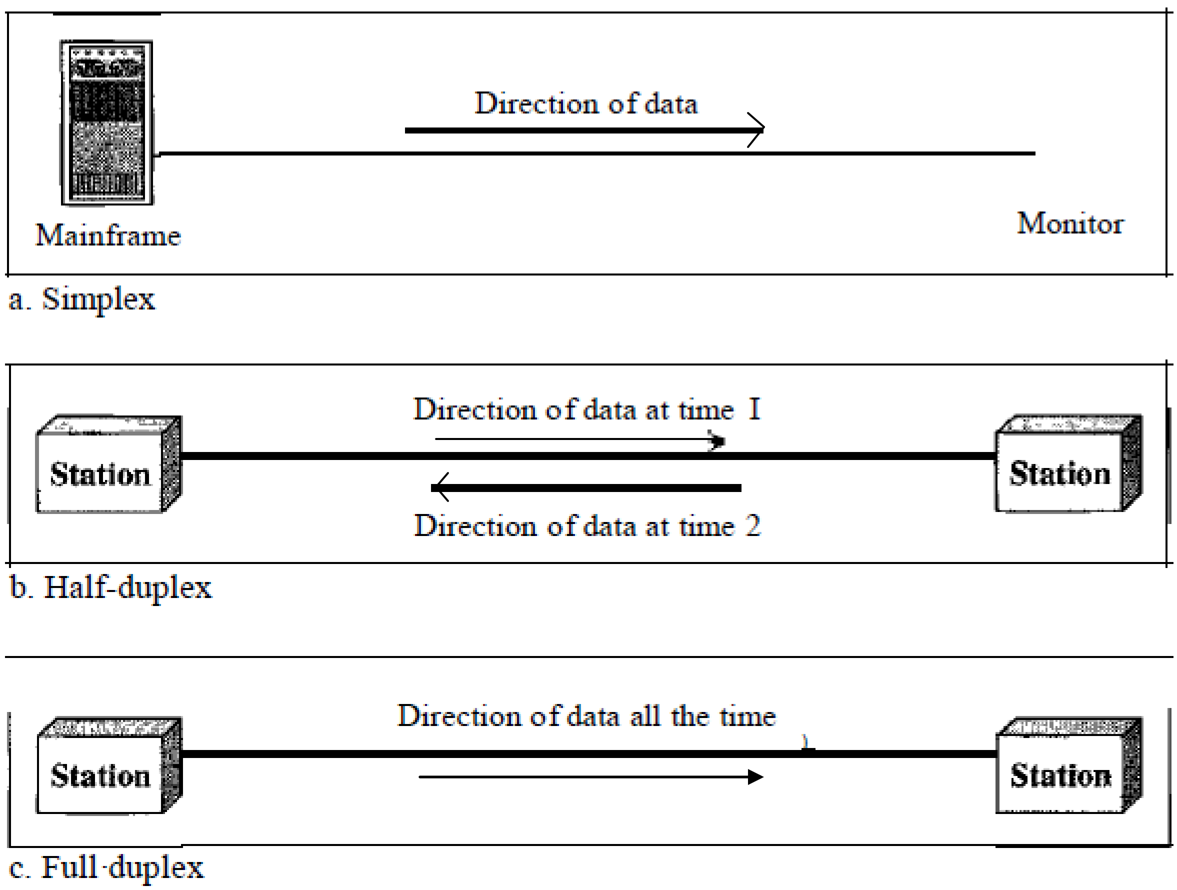
   For an image made of only black and-white dots (e.g., a chessboard), a 1-bit pattern is enough to represent a pixel. If an image is not made of pure white and pure black pixels, you can increase the size of the bit pattern to include **gray scale**. For example, to show four levels of gray scale, you can use 2-bit patterns. A black pixel can be represented by 00, a dark gray pixel by 01, a light gray pixel by 10, and a white pixel by 11.

   There are several methods to represent color images. One method is called **RGB**, so called because each color is made of a combination of three primary colors: red, green, and blue. Another method is called **YCM**, in which a color is made of a combination of three other primary colors: yellow, cyan, and magenta.

4. **Audio -** Audio refers to the recording or broadcasting of sound or music. It is continuous, not discrete. Even when we use a microphone to change voice or music to an electric signal, we create a continuous signal.
5. **Video -** Video refers to the recording or broadcasting of a picture or movie. Video can either be produced as a continuous entity (e.g., by a TV camera), or it can be a combination of images, each a discrete entity, arranged to convey the idea of motion.

Communication Models / Data flow / Transmission Modes:

Communication between two devices can be (1)Simplex (2) Half-duplex (3) Full-duplex



1. **Simplex -** In simplex mode, the communication is unidirectional, as on a one-way street. Only one of the two devices on a link can transmit; the other can only receive. The simplex mode can use the entire capacity of the channel to send data in one direction.

   Examples: Keyboards and traditional monitors. The keyboard can only introduce input; the monitor can only accept output.

2. **Half-Duplex -** In half-duplex mode, each station can both transmit and receive, but not at the same time. When one device is sending, the other can only receive, and vice versa. The entire capacity of a channel is taken over by whichever of the two devices is transmitting at the time.

   Examples: Walkie-talkies and CB (citizens band) radios

3. **Full-Duplex/ Duplex -** In full-duplex, both stations can transmit and receive simultaneously. In full-duplex mode, signals going in one direction share the capacity of the link with signals going in the other direction. The full-duplex mode is used when communication in both directions is required all the time. The capacity of the channel must be divided between the two directions.

   The **sharing** of capacity can occur in two ways:

   (1) Either the link must contain two physically separate paths, one for sending and the other for receiving

   (2) The capacity of the channel is divided between signals traveling in both directions.

   Example: Telephone network. When two people are communicating by a telephone line, both can talk and listen at the same time.

DATA AND SIGNALS

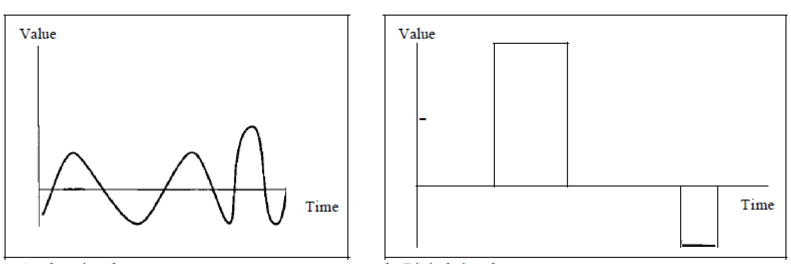
Analog and Digital Data:

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. For **example**, an analog clock that has hour, minute, and second hands gives information in a continuous form; the movements of the hands are continuous. A digital clock that reports the hours and the minutes will change suddenly from 8:05 to 8:06.

Analog and Digital Signals:

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 0.

The simplest way to show signals is by plotting them on a pair of perpendicular axes. The vertical axis represents the value or strength of a signal. The horizontal axis represents time. Figure illustrates an analog signal and a digital signal. The curve representing the analog signal passes through an infinite number of points. The vertical lines of the digital signal, however, demonstrate the sudden jump that the signal makes from value to value.



a. Analog signal b. Digital signal

Periodic and Nonperiodic Signals:

Both analog and digital signals can take one of two forms: periodic or nonperiodic (sometimes refer to as aperiodic). 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. In data communications, we commonly use periodic analog signals (because they need less bandwidth) and nonperiodic digital signals (because they can represent variation in data).

PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as **simple or composite**.

(1) A **simple** periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
(2) A **composite** periodic analog signal is composed of multiple sine waves.

(a) 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.
- Each cycle consists of a single arc above the time axis followed by a single arc below it.

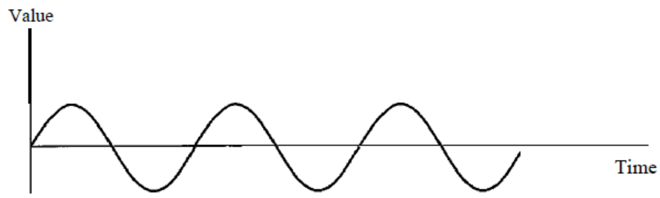
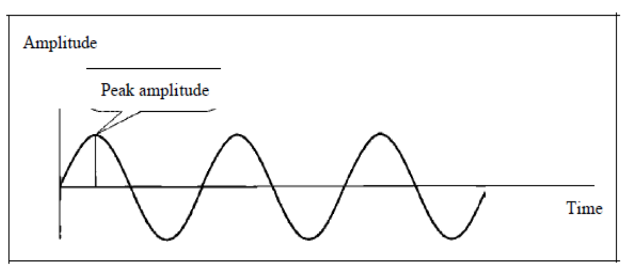


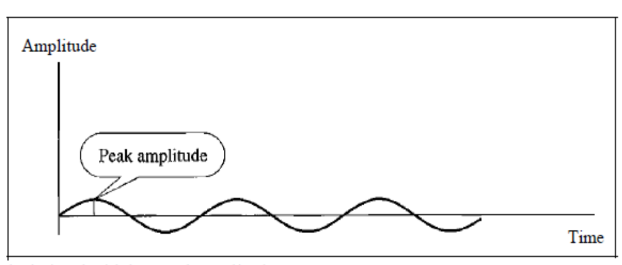
Fig: A Sine Wave

A sine wave can be represented by three **parameters**: (1) the peak amplitude (2) the frequency (3) the phase.

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** shows two signals with same phase and frequency but different amplitudes.



a. A signal with high peak amplitude



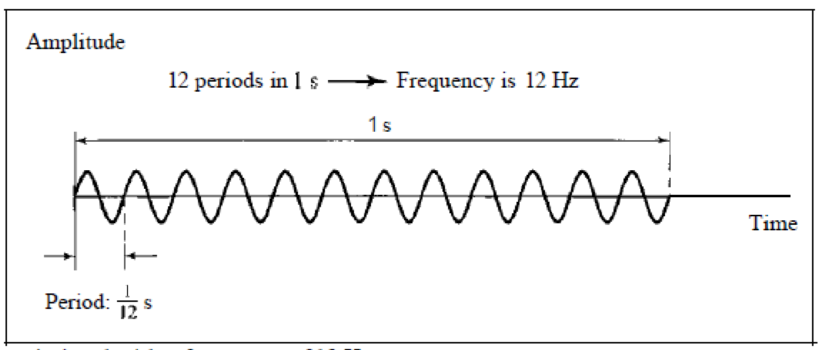
b. A signal with low peak amplitude

Example: The power in your house can be represented by a sine wave with peak amplitude of 155 to 170 V. However, it is common knowledge that the voltage of the power in U.S. homes is 110 to 120 V. This discrepancy is due to the fact that these are root mean square (rms) values. The signal is squared and then the average amplitude is calculated. The peak value is equal to $2^{1/2}$ x rms value

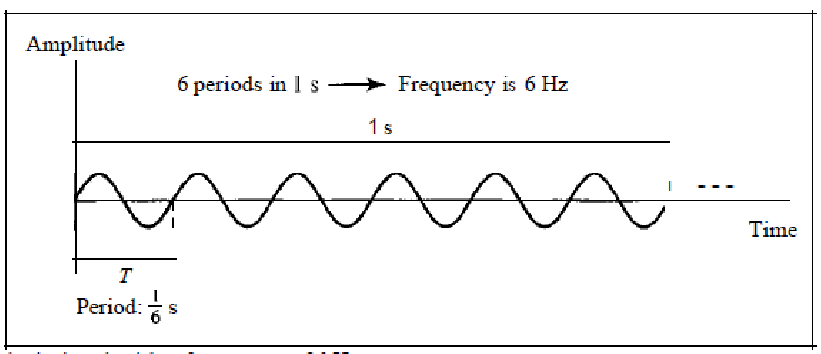
Period and Frequency - Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle. **Frequency** refers to the number of periods in 1s. Period is the inverse of frequency, and frequency is the inverse of period.

f = 1/T and T=1/f

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. If the value of a signal changes over a very short span of time, its frequency is **high**. If it changes over a long span of time, its frequency is **low**.



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Fig: Two signals with the same amplitude and phase, but different frequencies

Period is formally expressed in seconds. Frequency is formally expressed in Hertz (Hz), which is cycle per second. Units of period and frequency are shown in Table.

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

Example 1:

The power we use at home has a frequency of 60 Hz (50 Hz in Europe). The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166 \text{ s} = 0.0166 \times 10^3 \text{ ms} = 16.6 \text{ ms}$$

This means that the period of the power for our lights at home is 0.0116 s, or 16.6 ms. Our eyes are not sensitive enough to distinguish these rapid changes in amplitude.

Example 2:

Express a period of 100 ms in microseconds.

Solution

From Table 3.1 we find the equivalents of 1 ms (1 ms is 10^{-3} s) and 1 s (1 s is 10^6 µs). We make the following substitutions:

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 100 \times 10^{-3} \times 10^{6} \text{ µs} = 10^2 \times 10^{-3} \times 10^6 \text{ µs} = 10^5 \text{ µs}$$

Example 3:

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

Solution

First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

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

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

(b) Phase:

- Phase describes the **position of the waveform relative to time 0.**
- 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.

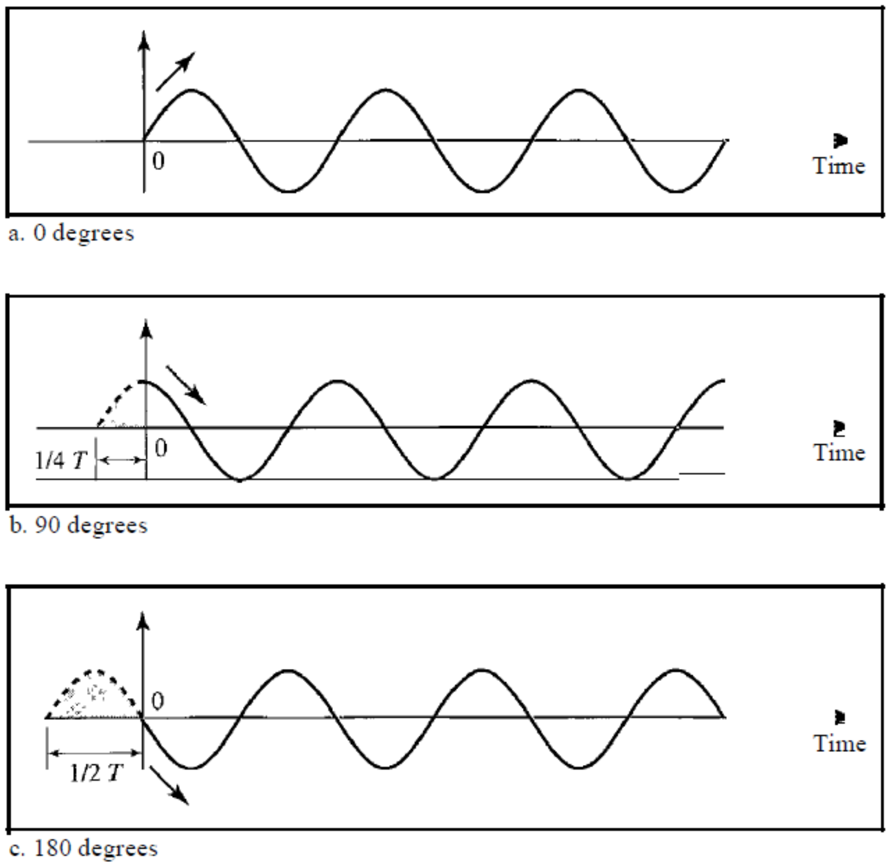


Fig: Three sine waves with the same amplitude and frequency but different phases

From Figure,

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.

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 ¼ cycle. However, note that the signal does not really exist before time 0.
3. A sine wave with a phase of 180° is shifted to the left by ½ cycle. However, note that the signal does not really exist before time 0.

Example: A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

Solution: We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

1/6 x 360 = 600 = 60 x (2π/360)rad =π/3 rad =1.046 rad

(c) 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.

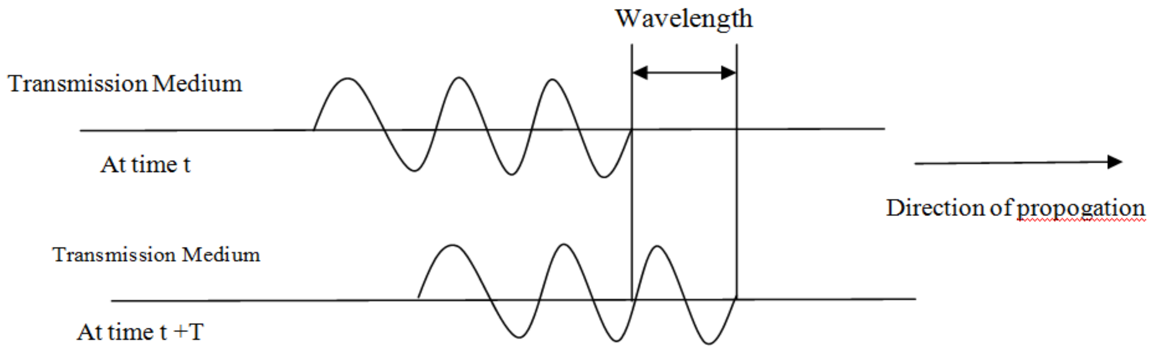


Fig: Wavelength and period

Difference between frequency & wavelength:

While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium.

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

$$\text{wavelength} = (\text{propogation speed}) \times \text{period} = \frac{\text{propogation speed}}{\text{frequency}}$$

$$\lambda = c/f$$

The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal. For example, in a vacuum, light is propagated with a speed of 3×10^8 mls. That speed is lower in air and even lower in cable.

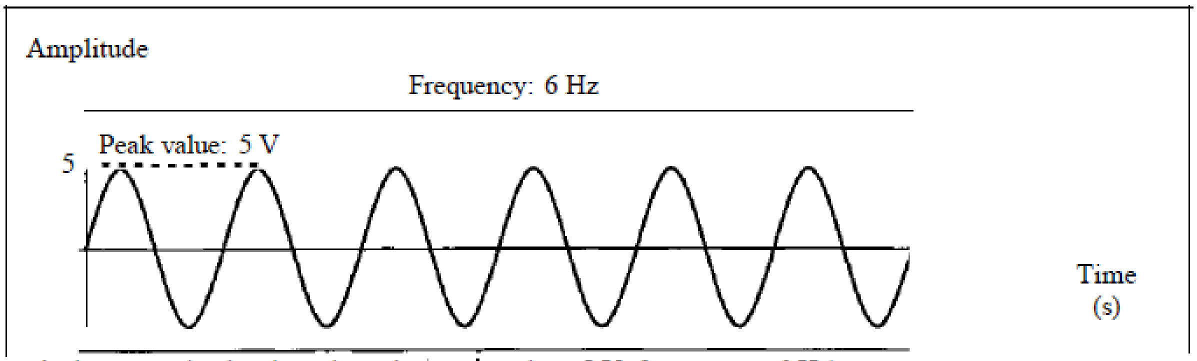
The wavelength is normally measured in micrometers (microns) instead of meters. For example, the wavelength of red light (frequency $= 4 \times 10^{14}$) in air is

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{4 \times 10^{14}} = 0.75 \times 10^{-6}\ \text{m} = 0.75\ \mu\text{m}$$

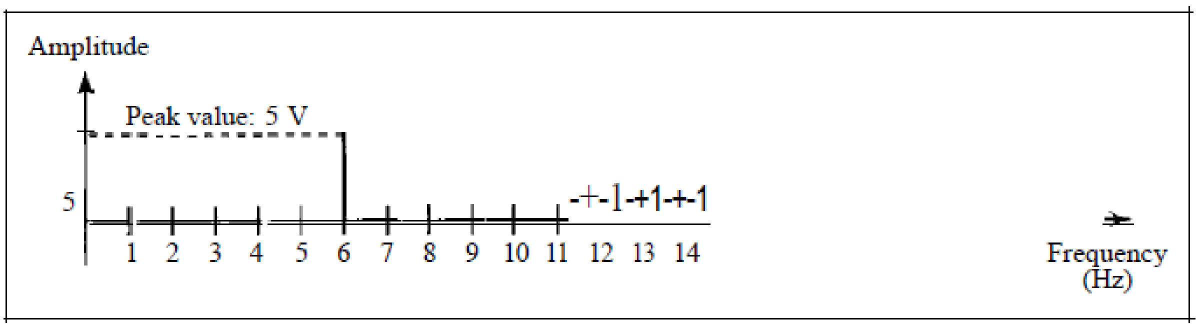
In a coaxial or fiber-optic cable, however, the wavelength is shorter (0.5 µm) because the propagation speed in the cable is decreased.

(d) Time and Frequency Domains:

- 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.
- A **frequency-domain** plot is concerned with only the peak value and the frequency.
- Changes of amplitude during one period are not shown.



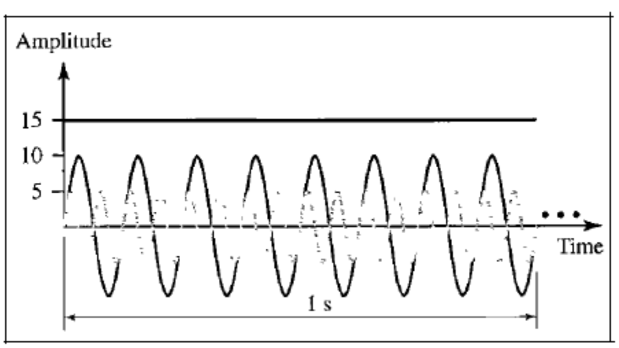
a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



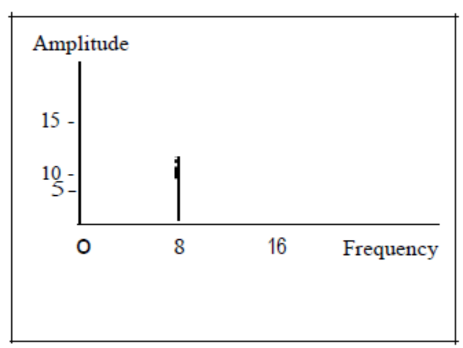
b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

Fig: The time domain and frequency domain plots of a sine wave

- The advantage of the frequency domain is that we can immediately see the values of the frequency and peak amplitude.
- A complete sine wave is represented by one spike.
- The position of the spike shows the frequency; its height shows the peak amplitude.



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



b. Frequency-domain representation of the same three signals

Fig: The time domain and frequency domain of three sine waves

(e) Composite Signals:

- A single frequency sine wave is not useful in data communication. We need to send composite signal that is made of many simple sine waves.
- According to Fourier analysis, any composite signal is actually a combination of simple sine waves with different frequencies, amplitudes, and phases.
- A composite signal can be periodic or nonperiodic.
- A **periodic** composite signal can be decomposed into a series of simple sine waves with discrete frequencies frequencies that have integer values (1, 2, 3, and so on).
- A **nonperiodic** composite signal can be decomposed into a combination of an infinite number of simple sine waves with continuous frequencies, frequencies that have real values.

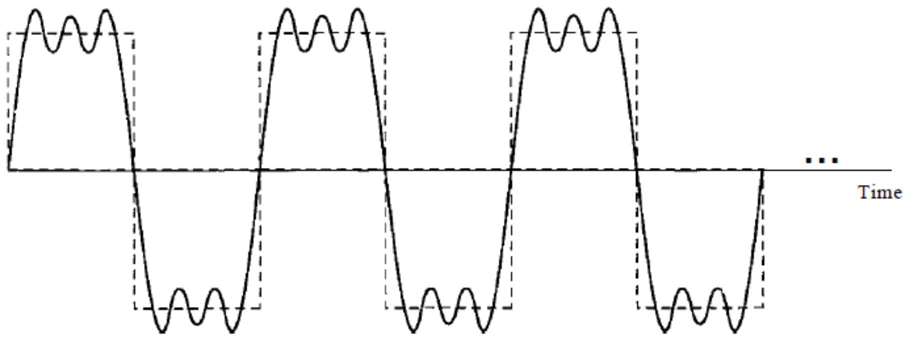
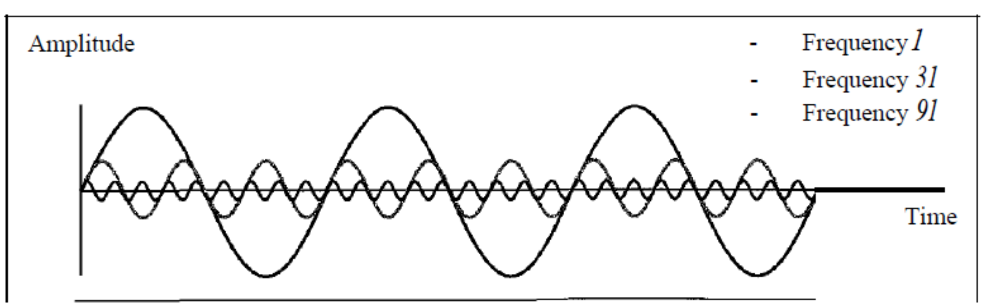
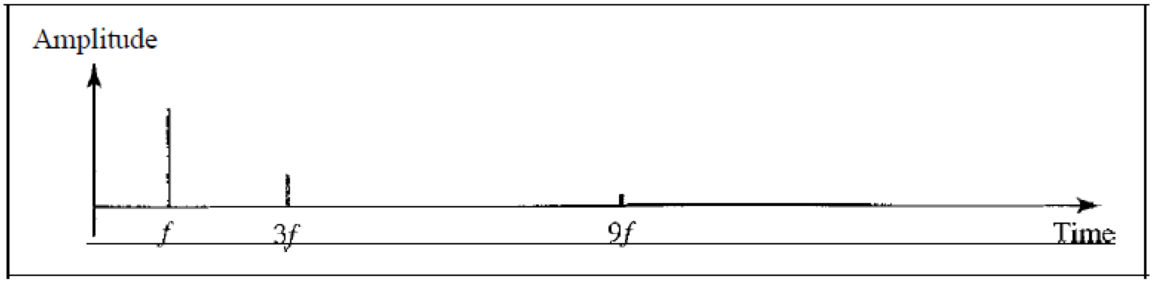


Fig: A composite periodic signal

- 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 9fhas a frequency of 9 times the fundamental frequency; it is called the **ninth harmonic**.
- 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

Fig: Decomposition of a composite periodic signal in the time and frequency domains

- A **nonperiodic** composite signal can be created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic.

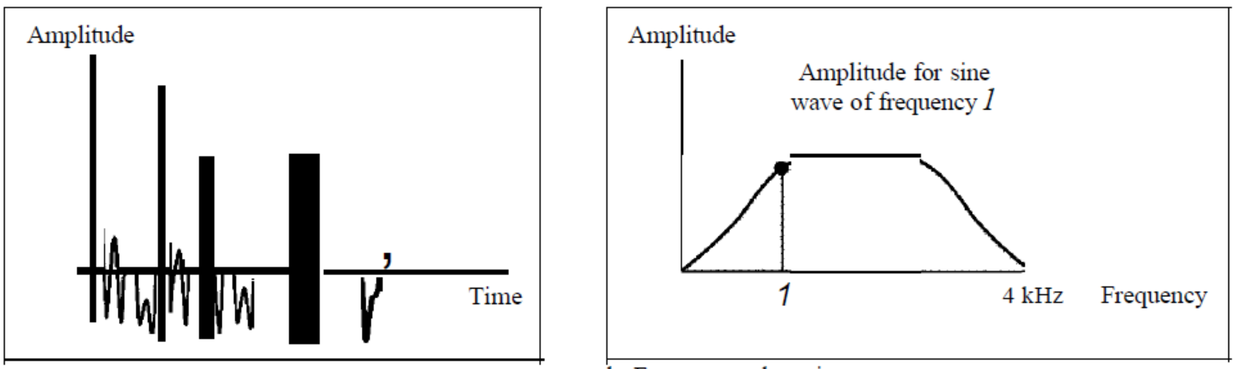
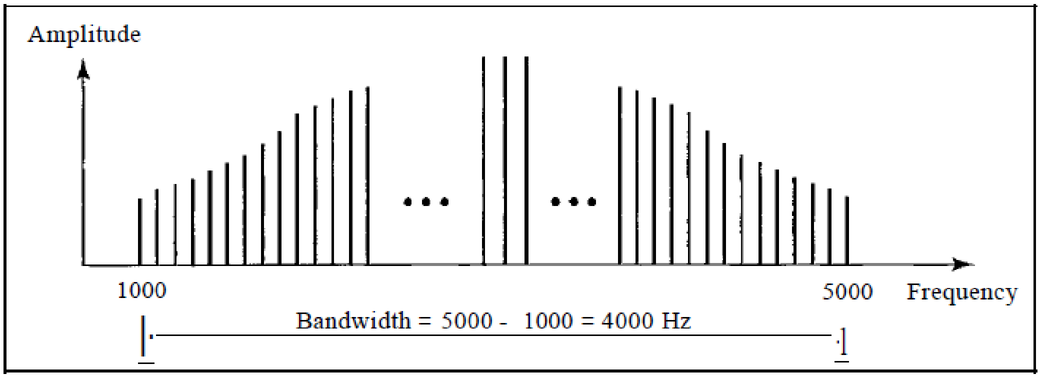


Fig: The time and frequency domains of a non-periodic signal

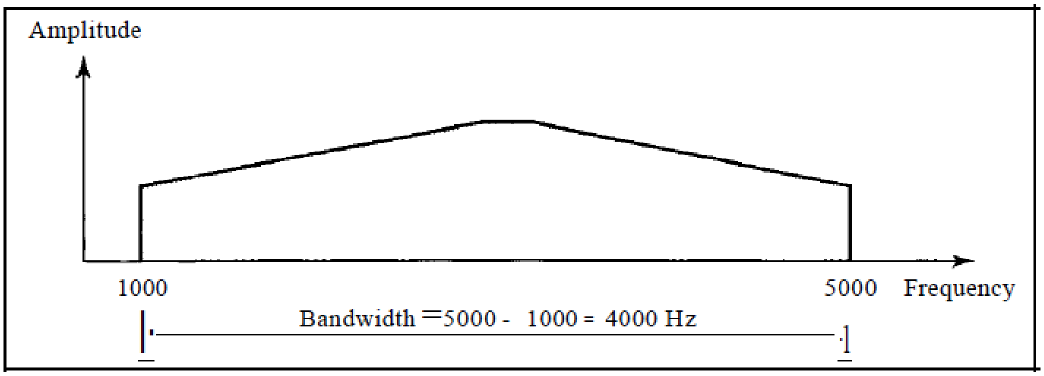
- In a time-domain representation of this composite signal, there are an infinite number of simple sine frequencies.
- A normal human being can create a continuous range of frequencies between 0 and 4 kHz.
- The frequency decomposition of the signal yields a continuous curve.
- There are an infinite number of frequencies between 0.0 and 4000.0 (real values).

(f) Bandwidth:

- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.
- For example, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 – 1000 = 4000.
- The bandwidth of the periodic signal contains all integer frequencies between 1000 and 5000



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Fig: Bandwidth of periodic and non periodic composite signals

Example 3.10

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.

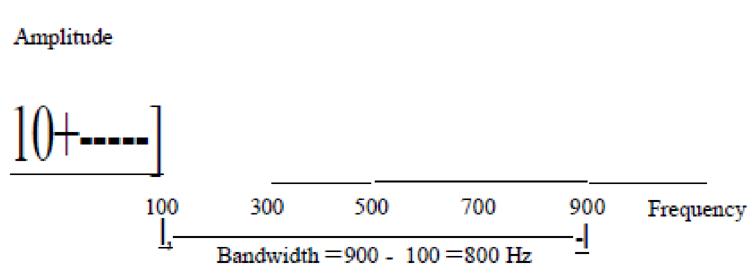
Solution

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

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

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz (see Figure 3.13).

Figure 3.13 *The bandwidth for Example 3.10*



Example 3.11

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.

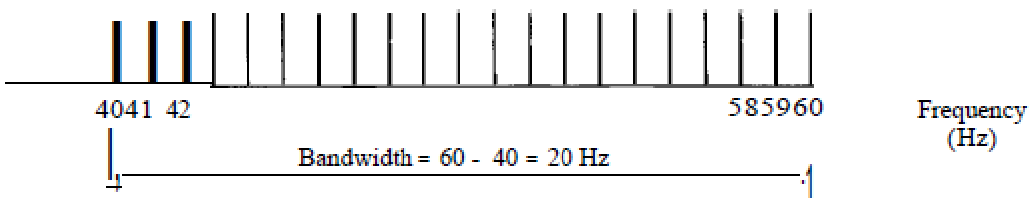
Solution

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

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

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure 3.14).

Figure 3.14 *The bandwidth for Example 3.11*



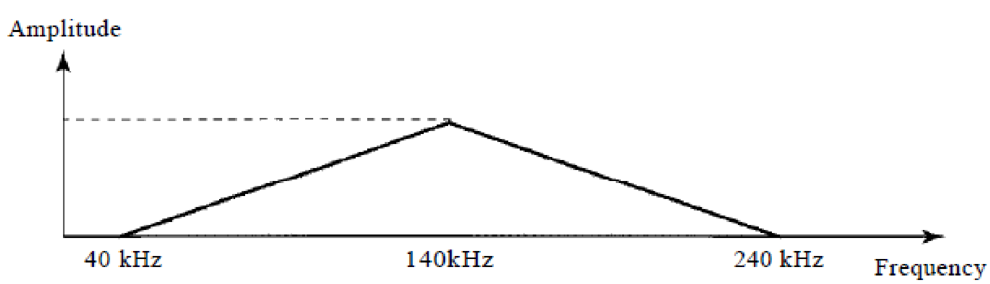
Example 3.12

A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

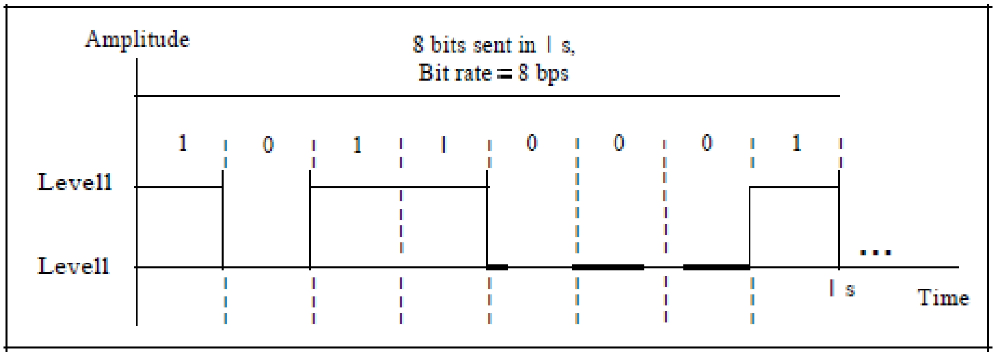
The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.

Figure 3.15 *The bandwidth for Example 3.12*

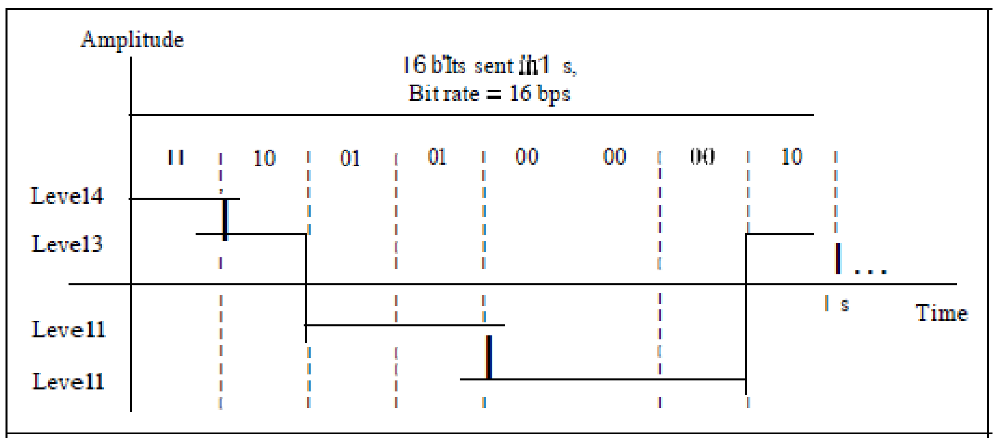


DIGITAL SIGNALS

- Data can 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.



a. A digital signal with two levels



b. A digital signal with four levels

Fig: Two digital signals

Example - A digital signal has eight levels. How many bits are needed per level?

We calculate the number of bits from the formula

$$\textbf{Number of bits per level} = \log_2 8 = 3$$

Each signal level is represented by 3 bits.

Example - A digital signal has nine levels. How many bits are needed per level?

We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

- **Bit Interval** (instead of period) – The time required to send one single bit.
- **Bit Rate** (Instead of frequency) – The number of bit intervals per second.
- **Bit Length** (Instead of wavelength in DS) - The distance one bit occupies on the transmission medium.

(a) Bit Rate:

Bit Rate (Instead of frequency) – The number of bit sent in 1s, expressed in **bits per seconds (bps)**

Example - 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 x 24 x 80 x 8 =1,636,000 bps =1.636 Mbps

Example - 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 - 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 color pixel. We can calculate the bit rate as

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

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

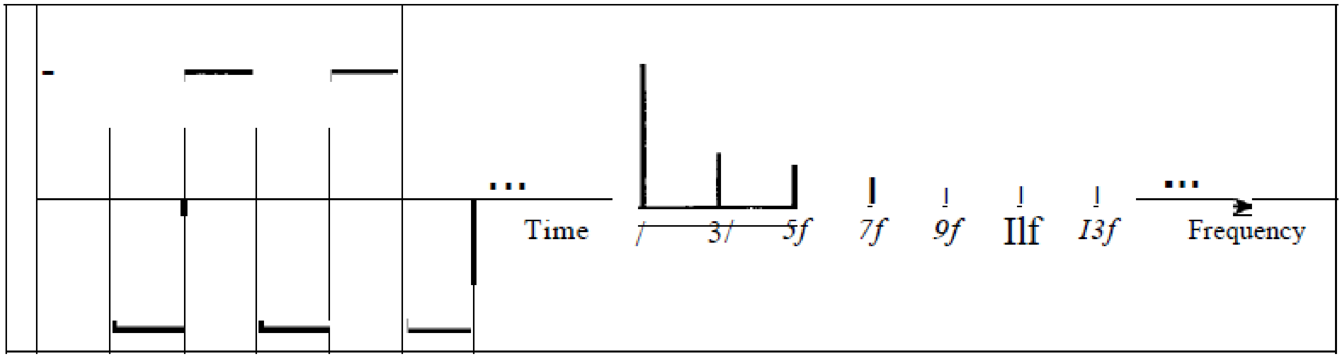
(b)Bit Length:

Bit Length (instead of wavelength in DS) - The distance one bit occupies on the transmission medium.

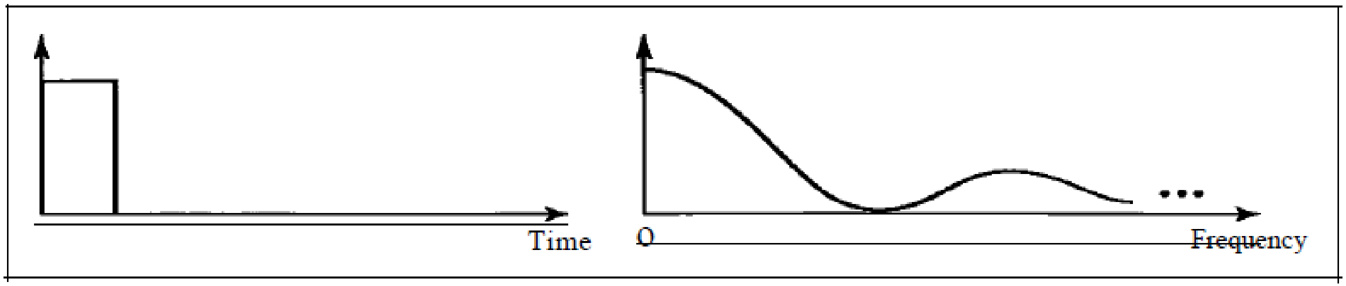
Bit length = propogation speed x bit duration

(c)Digital signal as a composite 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).
- 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.



a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

(d)Transmission of digital signals:

Two approaches can be used to transmit a digital signal

1. Baseband transmission
2. Broadband Transmission

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
- A digital signal is a composite analog signal with an infinite bandwidth.
- 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.

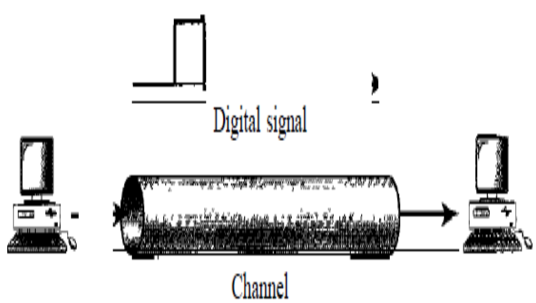


Fig: Baseband Transmission

- A low-pass channel, use two low-pass channels: one with a narrow bandwidth and the other with a wide bandwidth.

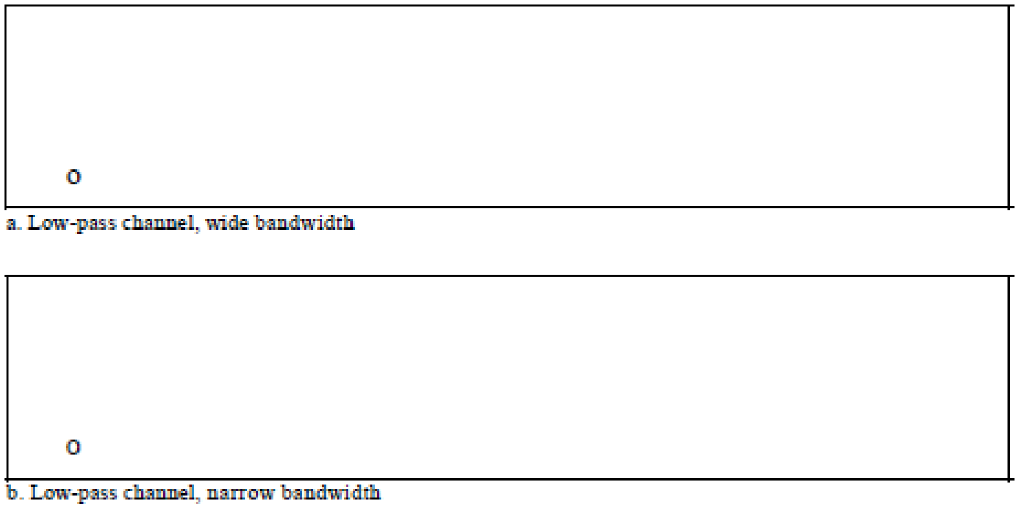


Fig: Bandwidth of two low – pass channels

Case 1: Low-Pass channel with wide bandwidth

- If we want to preserve the exact form of a nonperiodic digital signal with vertical segments vertical and horizontal segments horizontal, we need to send the entire spectrum, the continuous range of frequencies between zero and infinity.
- This is possible if we have a dedicated medium with an infinite bandwidth between the sender and receiver that preserves the exact amplitude of each component of the composite signal.
- This means that if we have a medium, such as a coaxial cable or fiber optic, with a very wide bandwidth, two stations can communicate by using digital signals with very good accuracy, as shown in Figure. Note that f1 is close to zero, and f2 is very high.
- Although the output signal is not an exact replica of the original signal, the data can still be deduced from the received signal. Since some of the frequencies are blocked by the medium, they are not critical.

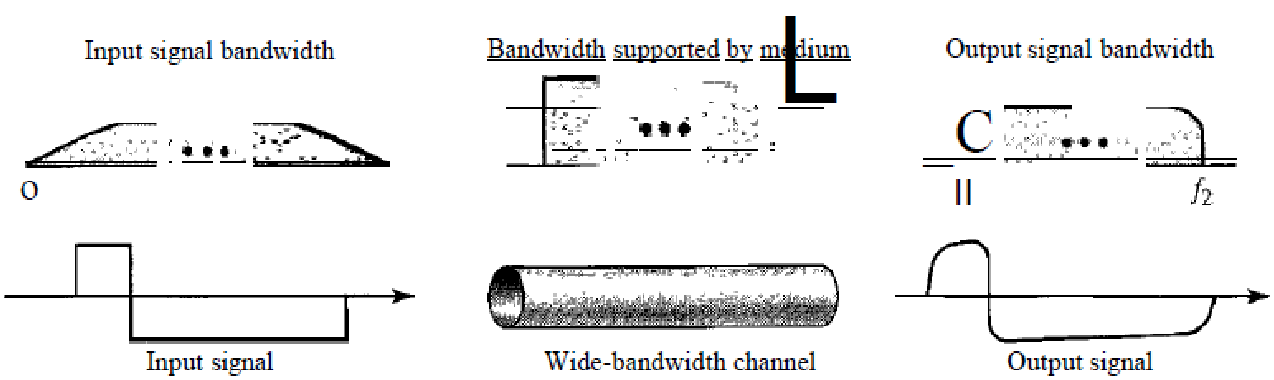


Fig: Baseband Transmission using a dedicated medium

Case 2: Low-Pass channel with limited bandwidth

- In a low-pass channel with limited bandwidth, we approximate the digital signal with an analog signal.
- The level of approximation depends on the bandwidth available.

Rough Approximation

Let us assume that we have a digital signal of bit rate N. If we want to send analog signals to roughly simulate this signal, we need to consider the worst case, a maximum number of changes in the digital signal. This happens when the signal carries the sequence 01010101 ... or the sequence 10101010 ...

To simulate these two cases, we need an analog signal of frequency f = N/2. Let 1 be the positive peak value and 0 be the negative peak value. We send 2 bits in each cycle; the frequency of the analog signal is one-half of the bit rate, or N/2. The maximum frequency is N/2.

Let us see how a digital signal with a 3-bit pattern can be simulated by using analog signals. The two similar cases (000 and 111) are simulated with a signal with frequency f = 0 and a phase of 180° for 000 and a phase of 0° for 111. The two worst cases (010 and 101) are simulated with an analog signal with frequency f =N/2 and phases of 180° and 0°. The other four cases can only be simulated with an analog signal with f = N/4 and phases of 180°, 270°, 90°, and 0°.We need a channel that can handle frequencies 0, N/4, and N/2. This rough approximation is referred to as using the first harmonic (N/2) frequency. The required bandwidth is

Bandwidth = N/2 – 0 = N/2

Fig book 2 page 73

Better Approximation

To make the shape of the analog signal look more like that of a digital signal, we need to add more harmonics of the frequencies. We need to increase the bandwidth. We can increase the bandwidth to 3N/2, 5N/2, 7N/2, and so on.

Fig 74

In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more 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.
- At the receiver, the received analog signal is converted to digital, and the result is a replica of what has been sent.

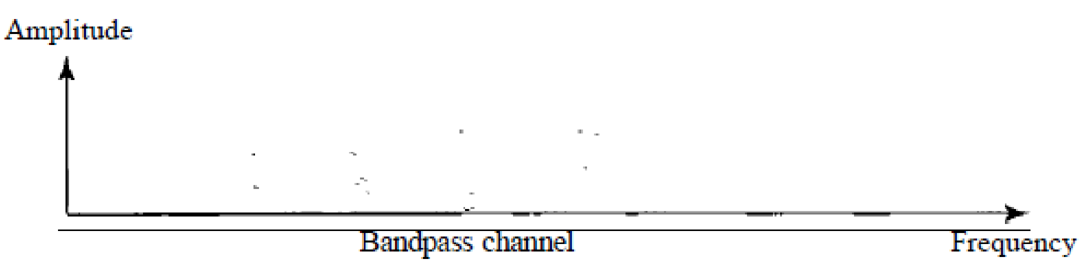


Fig: Bandwidth of a bandpass channel

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.

Fig 76

ANALOG AND DIGITAL DATA TRANSMISSION

In transmitting data from a source to a destination, one must be concerned with the nature of the data. The actual physical means used to propogate the data and the type of processing or adjustments may be required along the way to assure that the received data are intelligible.

The terms analog and digital correspond roughly to **continuous and discrete** respectively. These two terms are used in data communication in atleast three contexts

(1) Data (2) Signaling (3) Transmission

- **Data** is deined as entities that convey meaning, or information.
- **Signals** are electric or electromagnetic representations of data.
- **Signaling** is the physical propagation of the signal along a suitable medium.
- **Transmission** is the communication of data by the propagation and processing of signals.

1.Analog and Digital Data:

- **Analog data** take on continuous values in some interval.
- For example, voice and video are continuously varying patterns of intensity.
- **Digital data** take on discrete values; examples are text and integers.

The most familiar **example** of analog data is **audio**, which, in the form of acoustic sound waves, can be perceived directly by human beings. Frequency components of typical speech may be found between approximately 100 Hz and 7 kHz.

Another common **example** of analog data is **video**. To produce a picture on the screen, an electron beam scans across the surface of the screen from left to right and top to bottom. For black-and-white television, the amount of illumination produced at any point is proportional to the intensity of the beam as it passes that point. Thus at any instant in time the beam takes on an analog value of intensity to produce the desired brightness at that point on the screen. Further as, the beam scans, the analog value changes. Thus the video image can be thought of as a time-varying analog signal. Figure 3.10 depicts the scanning process. At the end of each scan line, the beam is swept rapidly back to the left (horizontal retrace).When the beam reaches the bottom, it is swept rapidly back to the top (vertical retrace).The beam is turned off (blanked out) during the retrace intervals. To achieve adequate resolution, the beam produces a total of 483 horizontal lines at a rate of 30 complete scans of the screen per second. Tests have shown that this rate will produce a sensation of flicker rather than smooth motion. To provide a flicker-free image without increasing the bandwidth requirement, a technique known as **interlacing** is used. As Figure shows, the odd numbered scan lines and the even numbered scan lines are scanned separately, with odd and even fields alternating on successive scans.

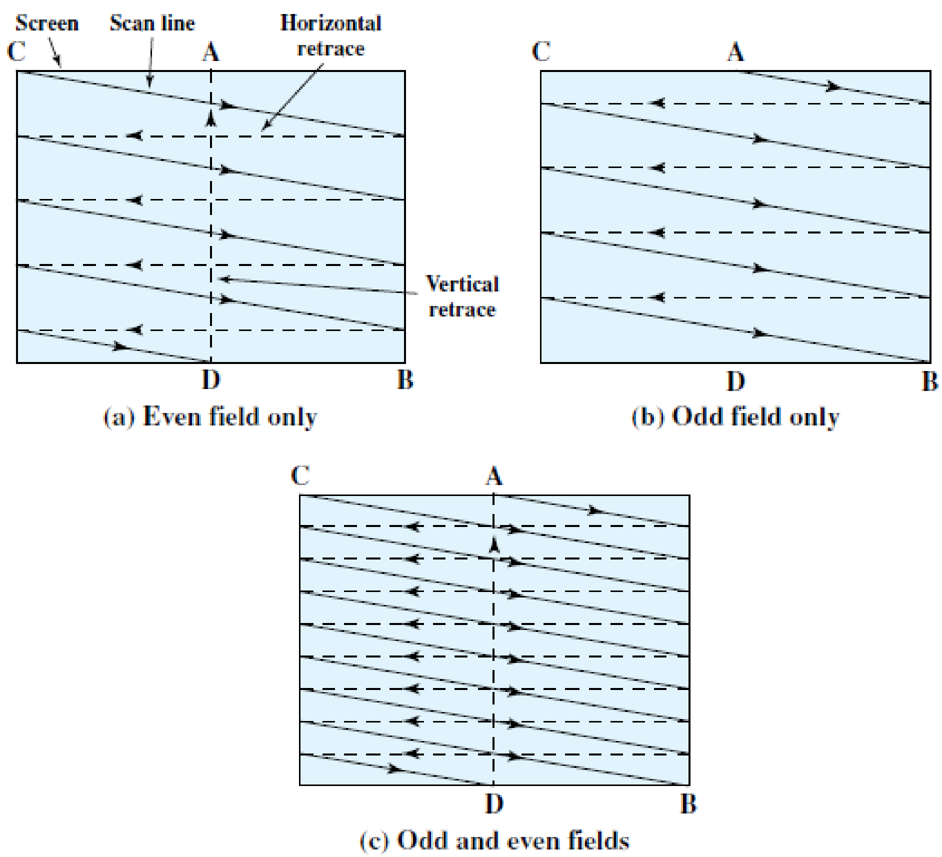


Fig: Video Interlaced Scanning

A familiar **example** of digital data is **text or character strings**. While textual data are most convenient for human beings, character form cannot be easily stored or transmitted by data processing and communications systems. Such systems are designed for binary data. Thus a number of codes are represented by a sequence of bits. The most commonly used text code is the **International Reference Alphabet (IRA).** Each character in this code is represented by a unique 7-bit pattern; thus 128 different characters can be represented.

2.Analog and Digital Signals:

- In a communications system, data are propagated from one point to another by means of **electromagnetic signals**.
- An **analog signal** is a continuously varying electromagnetic wave that may be propagated over a variety of media, depending on spectrum; examples are wire media, such as twisted pair and coaxial cable; fiber optic cable; and unguided media, such as atmosphere or space propagation
- A **digital signal** is a sequence of voltage pulses that may be transmitted over a wire medium; for example, a constant positive voltage level may represent binary 0 and a constant negative voltage level may represent binary 1.
- The **advantages** of digital signaling are that it is generally **cheaper** than analog signaling and is **less susceptible to noise interference.**
- The **disadvantage** is that digital signals suffer more from **attenuation** than do analog signals.

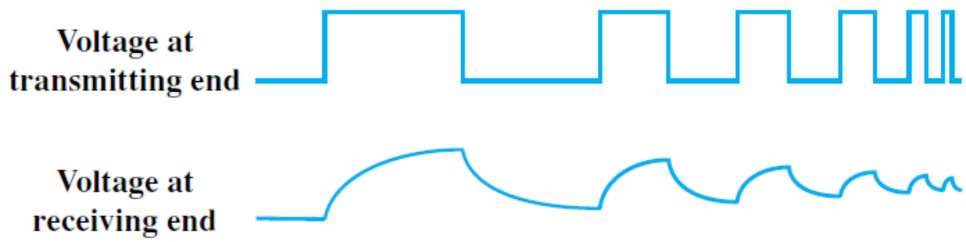


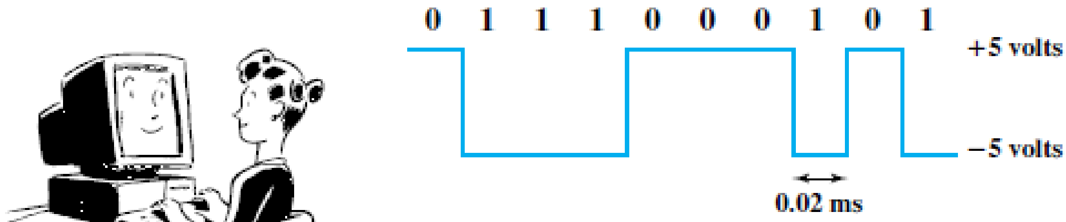
Fig: Attenuation of digital signals

Figure shows a sequence of voltage pulses, generated by a source using two voltage levels, and the received voltage some distance down a conducting medium. Because of the attenuation, or reduction, of signal strength at higher frequencies, the pulses become rounded and smaller. It should be clear that this attenuation can lead rather quickly to the loss of the information contained in the propagated signal.

The most familiar **example** of analog information is **audio**, or acoustic, information, which, in the form of sound waves, can be perceived directly by human beings. One form of acoustic information, of course, is human speech. This form of information is easily converted to an **electromagnetic signal** for transmission. In essence, all of the sound frequencies, whose amplitude is measured in terms of loudness, are converted into electromagnetic frequencies, whose amplitude is measured in volts. The telephone handset contains a simple mechanism for making such a conversion.

Now let us look at the **video signal**. To produce a video signal, a TV camera, which performs similar functions to the TV receiver, is used. One component of the camera is a photosensitive plate, upon which a scene is optically focused. An electron beam sweeps across the plate from left to right and top to bottom. As the beam sweeps, an analog electric signal is developed proportional to the brightness of the scene at a particular spot.

The third example is the case of **binary data**. Binary data is generated by terminals, computers, and other data processing equipment and then converted into **digital voltage pulses** for transmission, A commonly used signal for such data uses two constant (dc) voltage levels, one level for binary 1 and one level for binary 0.

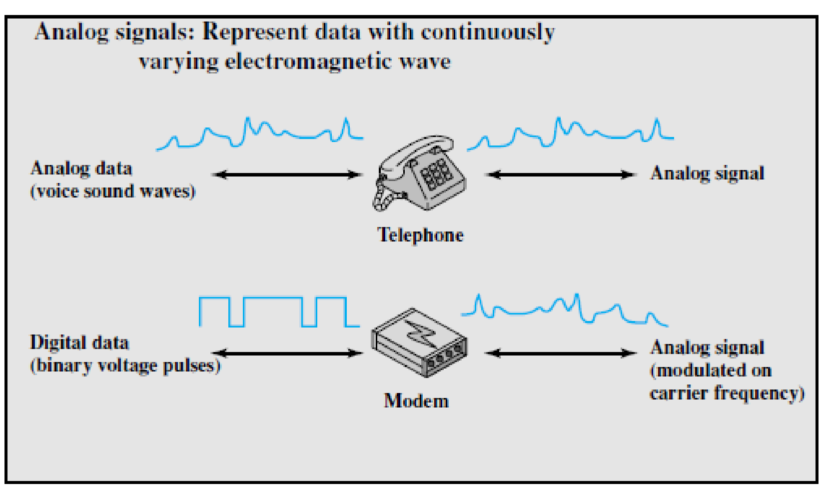


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by −5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 ms, giving a data rate of 50,000 bits per second (50 kbps).

Fig: Conversion of PC Input to digital signal

Data and Signals - Analog data are a function of time and occupy a limited frequency spectrum; such data can be represented by an electromagnetic signal occupying the same spectrum. **Digital data** can be represented by digital signals, with a different voltage level for each of the two binary digits. Digital data can also be represented by analog signals by use of a modem (modulator/demodulator). The modem converts a series of binary (two-valued) voltage pulses into an analog signal by encoding the digital data onto a carrier frequency. The resulting signal occupies a certain spectrum of frequency centered about the carrier and may be propagated across a medium suitable for that carrier.

The most common modems represent digital data in the voice spectrum and hence allow those data to be propagated over ordinary voice-grade telephone lines. At the other end of the line, another modem demodulates the signal to recover the original data. The device that performs this function for voice data is a codec (coder-decoder). In essence, the codec takes an analog signal that directly represents the voice data and approximates that signal by a bit stream. At the receiving end, the bit stream is used to reconstruct the analog data.



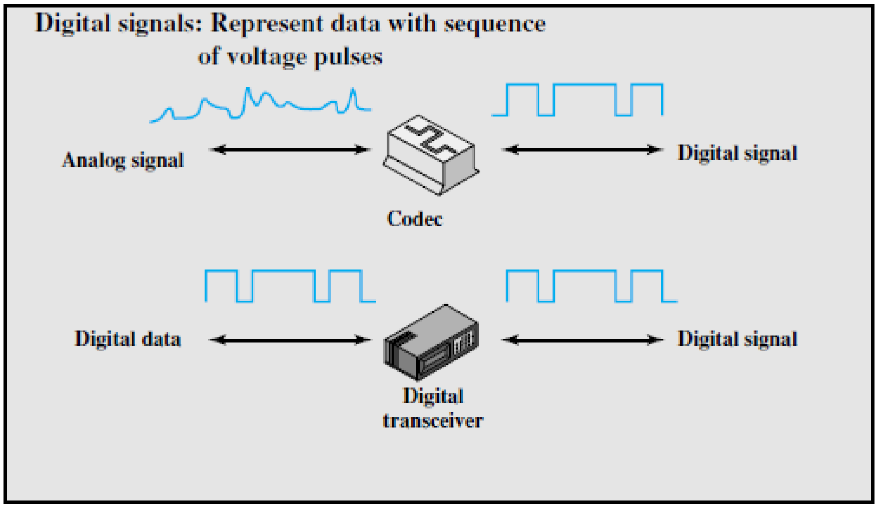


Fig: Analog and digital signaling of analog and digital data

3.Analog and Digital Transmission:

Analog transmission is a means of transmitting analog signals without regard to their content; the signals may represent analog data (e.g., voice) or digital data (e.g., binary data that pass through a modem). In either case, the analog signal will become weaker (attenuate) after a certain distance. To achieve longer distances, the analog transmission system includes amplifiers that boost the energy in the signal. Unfortunately, the amplifier also boosts the noise components. With amplifiers cascaded to achieve long distances, the signal becomes more and more distorted.

Digital transmission, in contrast, assumes a binary content to the signal. A digital signal can be transmitted only a limited distance before attenuation, noise, and other impairments endanger the integrity of the data. To achieve greater distances, repeaters are used. A repeater receives the digital signal, recovers the pattern of 1s and 0s, and retransmits a new signal. Thus the attenuation is overcome.

(a) Data and Signals

	Analog Signal	Digital Signal
Analog Data	Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum.	Analog data are encoded using a codec to produce a digital bit stream.
Digital Data	Digital data are encoded using a modem to produce analog signal.	Two alternatives: (1) signal consists of two voltage levels to represent the two binary values; (2) digital data are encoded to produce a digital signal with desir ed properties.

(b) Treatment of Signals

	Analog Transmission	Digital Transmission
Analog Signal	Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.	Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal.
Digital Signal	Not used	Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal.

Table -Analog and Digital Transmission

Reasons for preferring digital transmission method:

1. **Digital technology**: The advent of large-scale integration (LSI) and very-largescale integration (VLSI) technology has caused a continuing drop in the cost and size of digital circuitry. Analog equipment has not shown a similar drop.
2. **Data integrity**: With the use of repeaters rather than amplifiers, the effects of noise and other signal impairments are not cumulative. Thus it is possible to transmit data longer distances and over lower quality lines by digital means while maintaining the integrity of the data.
3. **Capacity utilization**: It has become economical to build transmission links of very high bandwidth, including satellite channels and optical fiber. A high degree of multiplexing is needed to utilize such capacity effectively, and this is more easily and cheaply achieved with digital (time division) rather than analog (frequency division) techniques.
4. **Security and privacy**: Encryption techniques can be readily applied to digital data and to analog data that have been digitized.
5. **Integration**: By treating both analog and digital data digitally, all signals have the same form and can be treated similarly. Thus economies of scale and convenience can be achieved by integrating voice, video, and digital data.

TRANSMISSION IMPAIRMENTS

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

1. Attenuation
2. Delay Distortion
3. Noise

1.Attenuation:

- The strength of a signal falls off with distance over any transmission medium.
- For **guided media**, this reduction in strength, or attenuation, is generally exponential and thus is typically expressed as a constant number of decibels per unit distance.
- For **unguided media**, attenuation is a more complex function of distance and the makeup of the atmosphere.

Attenuation introduces three considerations for the transmission engineer.

1. First, a received signal must have sufficient strength so that the electronic circuitry in the receiver can detect the signal.
2. Second, the signal must maintain a level sufficiently higher than noise to be received without error.
3. Third, attenuation varies with frequency.

- The first and second problems are dealt with by attention to signal strength and the use of amplifiers or repeaters.
- For a point-to-point link, the signal strength of the transmitter must be strong enough to be received intelligibly, but not so strong as to overload the circuitry of the transmitter or receiver, which would cause distortion.
- Beyond a certain distance, the attenuation becomes unacceptably great, and repeaters or amplifiers are used to boost the signal at regular intervals.
- The third problem is particularly noticeable for analog signals.
- Because the attenuation varies as a function of frequency, the received signal is distorted, reducing intelligibility.
- To overcome this problem, techniques are available for equalizing attenuation across a band of frequencies.

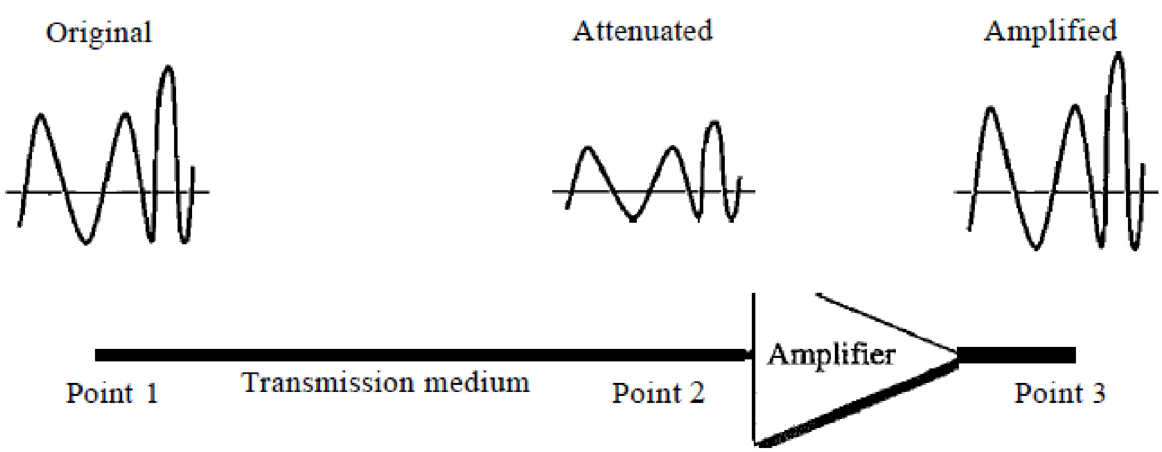


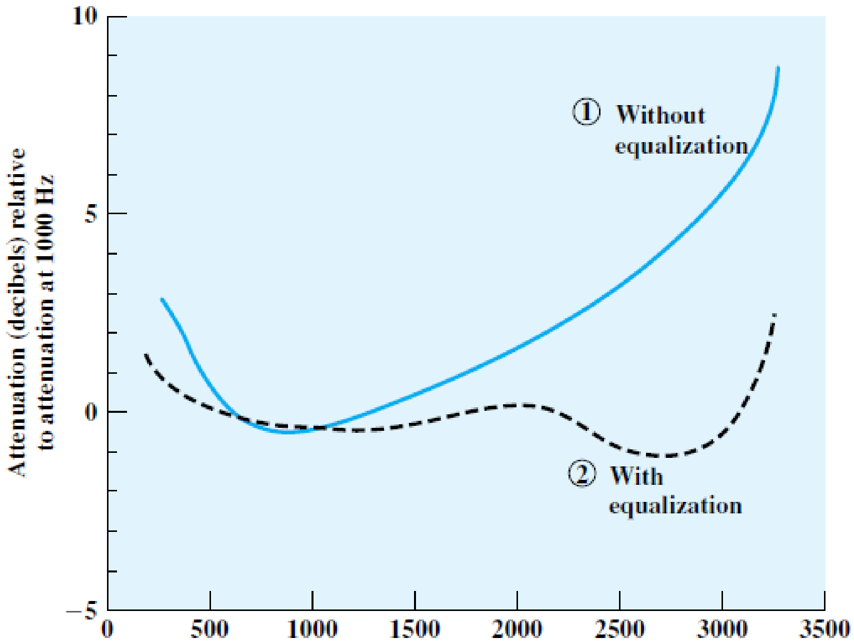
Fig: Attenuation

Decibel (dB) – It measures the relative strengths of two signals or one signal at two different points. The decibel is negative if a signal is attenuated and positive if a signal is amplified.

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

Variables *PI* and *P2* are the powers of a signal at points 1 and 2, respectively.

In the figure, frequency components at the upper end of the voice band are attenuated much more than those at lower frequencies.



(a) Attenuation

Example: Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that $P_2 = ½\, P_1$. In this case, the attenuation (loss of power) can be calculated as

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

Example: A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

Example: 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 3.27 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.

In this case, the decibel value can be calculated as

dB=-3+7-3=+1

The signal has gained in power.

Example: Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as dB_m = 10 loglO Pm' where Pm is the power in milliwatts. Calculate the power of a signal if its dB_m =-30.

Solution

We can calculate the power in the signal as

Example: 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

2.Delay Distortion:

- Delay distortion occurs because the velocity of propagation of a signal through a guided medium varies with frequency.
- For a band limited signal, the velocity tends to be highest near the center frequency and fall off toward the two edges of the band.
- Thus various frequency components of a signal will arrive at the receiver at different times, resulting in phase shifts between the different frequencies.
- This effect is referred to as delay distortion because the received signal is distorted due to varying delays experienced at its constituent frequencies.
- Delay distortion is particularly critical for digital data.
- Consider that a sequence of bits is being transmitted, using either analog or digital signals.
- Because of delay distortion, some of the signal components of one bit position will spill over into other bit positions, causing intersymbol interference, which is a major limitation to maximum bit rate over a transmission channel.
- Equalizing can also be used for delay distortion.

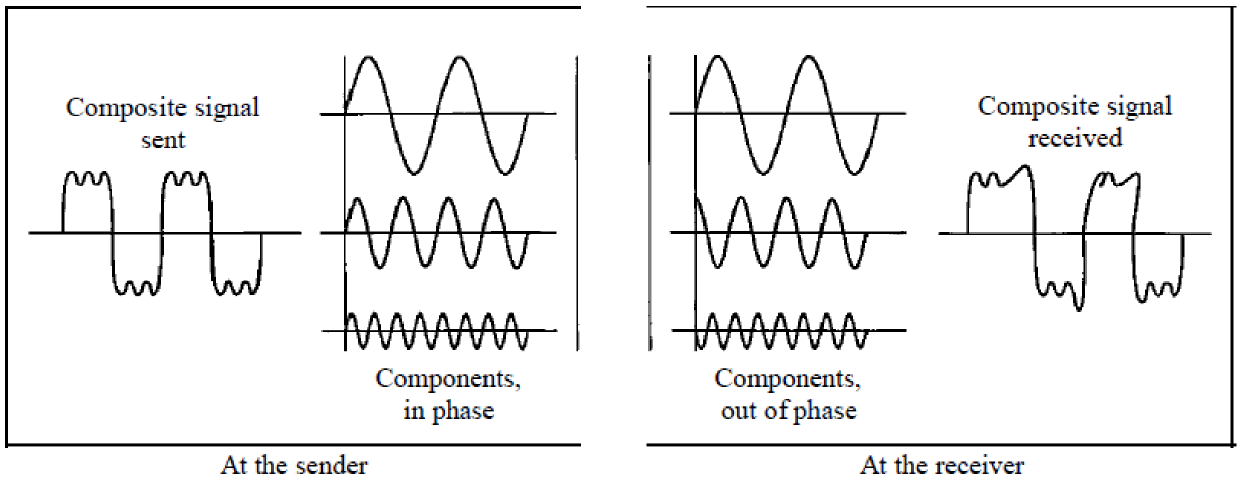
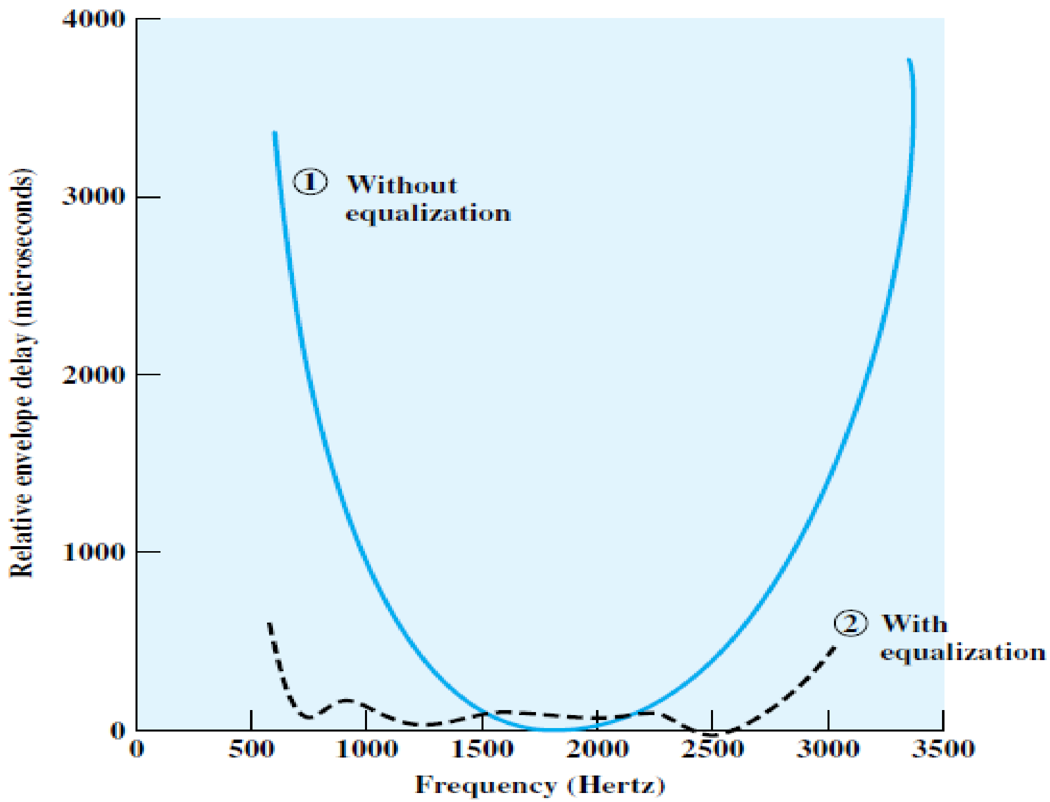


Fig: Distortion



(b) Delay distortion

3.Noise:

- For any data transmission event, the received signal will consist of the transmitted signal, modified by the various distortions imposed by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception.
- The latter, undesired signals are referred to as noise.
- Noise is the major limiting factor in communications system performance.

Noise may be divided into four categories:

1. Thermal noise
2. Intermodulation noise / Induced noise
3. Crosstalk
4. Impulse noise

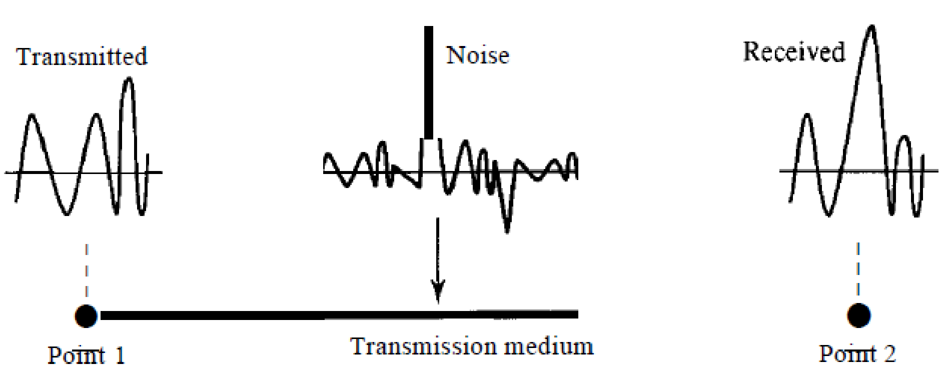


Fig: Noise

1.Thermal noise - It is due to thermal agitation of electrons. It is present in all electronic devices and transmission media and is a function of temperature. Thermal noise is uniformly distributed across the bandwidths typically used in communications systems and hence is often referred to as white noise. Thermal noise cannot be eliminated.

The amount of thermal noise to be found in a bandwidth of 1 Hz in any device or conductor is

$$N0 = kT(W/Hz)$$

where,

N0 = noise power density in watts per 1 Hz of bandwidth

k = Boltzmann's constant = 1.38 x $^{10-23}$ J/K

T = temperature, in kelvins (absolute temperature) where the symbol K is used to represent 1 kelvin

book 1 page 91 ex 3,4

2.Intermodulation Noise - When signals at different frequencies share the same transmission medium, the result may be intermodulation noise. The effect of intermodulation noise is to produce signals at a frequency that is the sum or difference of the two original frequencies or multiples of those frequencies. For example, the mixing of signals at frequencies f1 and f2 might produce energy at the frequency f1+f2. This derived signal could interfere with an intended signal at the frequency f1+f2.

3.Crosstalk - Crosstalk has been experienced by anyone who, while using the telephone, has been able to hear another conversation; it is an unwanted coupling between signal paths. It can occur by electrical coupling between nearby twisted pairs or, rarely, coax cable lines carrying multiple signals. Crosstalk can also occur when microwave antennas pick up unwanted signals; although highly directional antennas are used, microwave energy does spread during propagation.

4.Impulse Noise - Impulse noise, however, is noncontinuous, consisting of irregular pulses or noise spikes of short duration and of relatively high amplitude. It is generated from a variety of causes, including external electromagnetic disturbances, such as lightning, and faults and flaws in the communications system.

Signal–to-noise ratio (SNR):

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

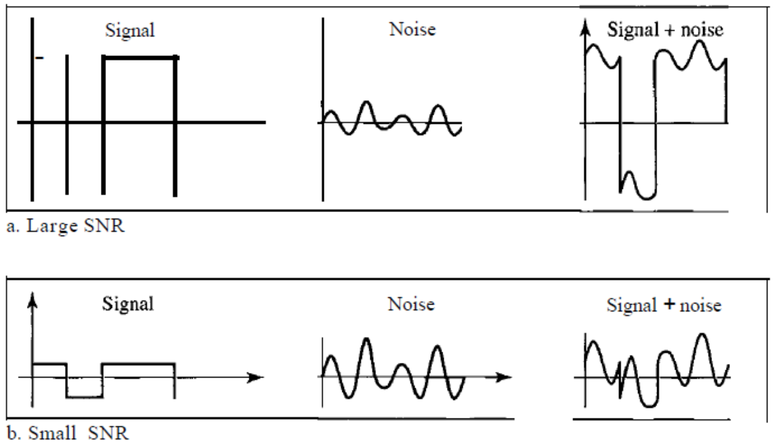


Fig: Two cases of SNR –high SNR and low SNR

- 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

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

CHANNEL CAPACITY

The maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions, is referred to as the **channel capacity.**

There are four concepts :

- **Data rate**: The rate, in bits per second (bps), at which data can be communicated.
- **Bandwidth**: The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or Hertz.
- **Noise**: The average level of noise over the communications path.
- **Error rate**: The rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted.

Two theoretical formulas were developed to calculate data rate.

1. Nyquist bandwidth for noiseless channel
2. Shannon's Capacity Formula for noisy channel

1.Noiseless Channel: Nyquist Bit rate

For a noiseless channel, the **Nyquist bit rate** formula defines the theoretical maximum bit rate

$$\textbf{BitRate} = 2 \times \textbf{bandwidth} \times \log_2 L$$

In this formula,
bandwidth is the bandwidth of the channel,
L is the number of signal levels used to represent data
BitRate is the bit rate in bits per second.

Increasing the levels of a signal may reduce the reliability of the system.

page 82 foruzon

2.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:

$$\textbf{Capacity} = \textbf{bandwidth} \times \log_2 (1 + \textbf{SNR})$$

In this formula,
bandwidth is the bandwidth of the channel
SNR is the signal-to-noise ratio
capacity is the capacity of the channel in bits per second.

The SNR is the statistical ratio of the power of the signal to the power of the noise.

$$SNR_{dB} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

page 83 foruzon