IT-5301-3

Data Communications and Computer Networks

University of Education

Lecture 05-07 Fundamentals of Data and signals

Lecture 05 - Roadmap

- Analog and Digital Data
  - Analog Signals, Digital Signals
  - Periodic and Aperiodic Signals
  - Peak Amplitude
  - Time Period and Frequency,
  - Phase, Time
- Time Domain Concepts
- Frequency Domains
  - Fundamental Frequency
  - Spectrum
  - Bandwidth
- Composite Signals, Bit Interval and Bit Rate

Data and Signals

- Data are entities that convey meaning
- Signals are the electric or electromagnetic encoding of data
- Computer networks and data / voice communication systems transmit signals

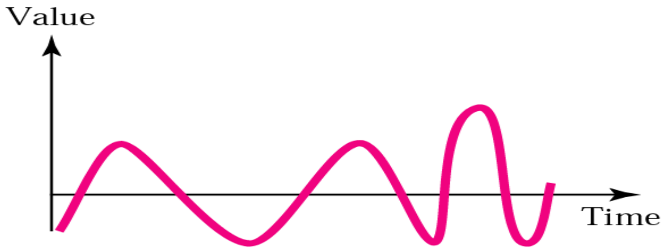
- Data and signals can be analog or digital
  – Human voice is an example of analog data.
  – Data stored in the memory of a computer in the form of 0s and 1s is an example of digital data.

Terminology

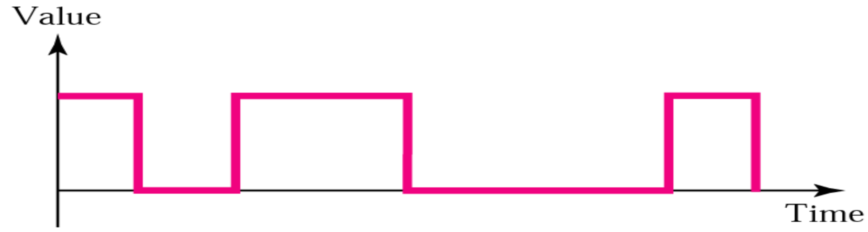
- Transmitter
- Receiver
- Medium
  - Guided medium : Media in which signal is guided along a physical path.
    - e.g. twisted pair, coaxial cable, optical fiber
  - Unguided medium : Media in which signal is not guided.
    - e.g. air, water, vacuum

Analog and Digital Signals

- Continuous or Analog signal
  - Various in a smooth way over time. e.g., speech
  - Analog signals can have an infinite number of values in a range
- Discrete or Digital signal
  - Maintains a constant level then changes to another constant level. e.g., binary 1's and 0's.
  - Digital signals can have only a limited number of values.

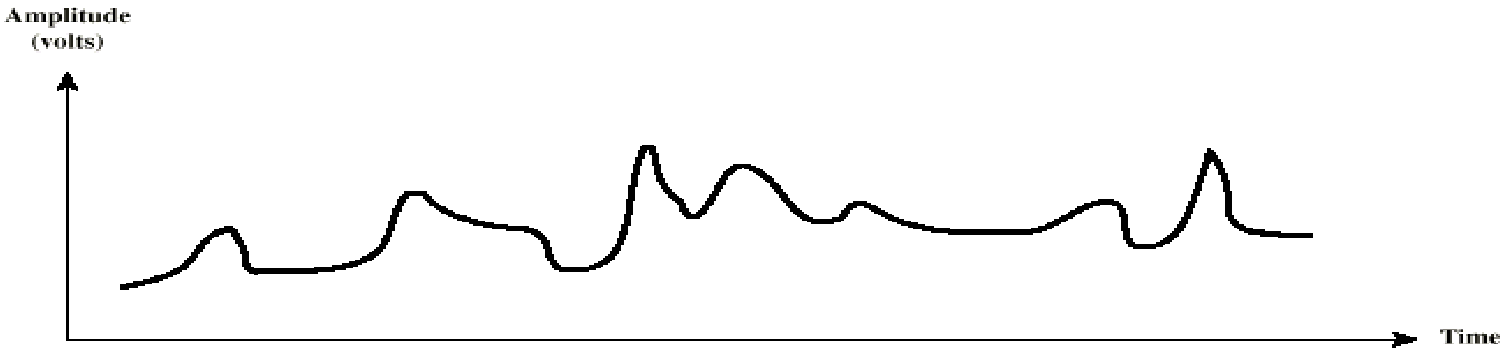


a. Analog signal

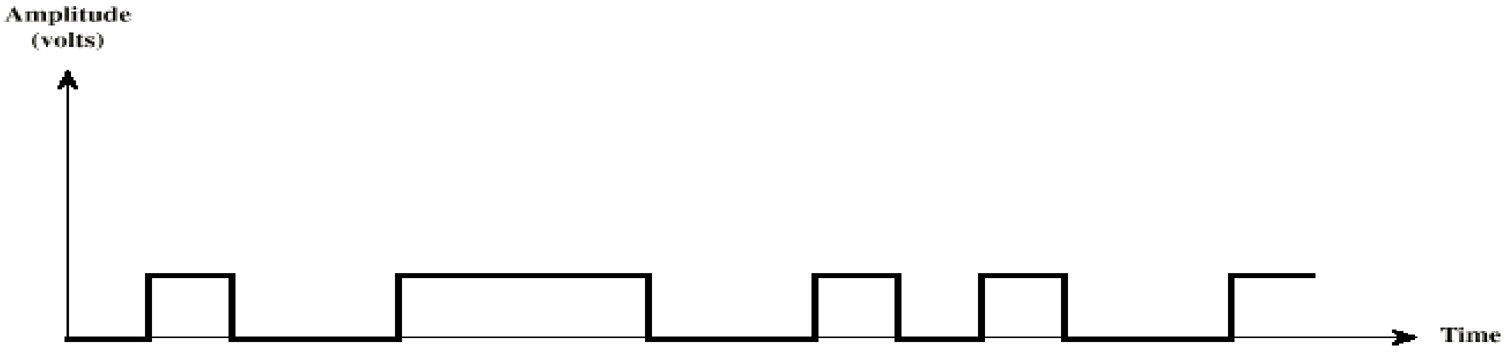


b. Digital signal

Continuous & Discrete Signals



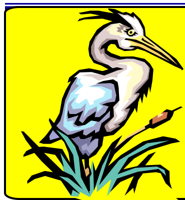
(a) Continuous



(b) Discrete

Periodic and Aperiodic Signals

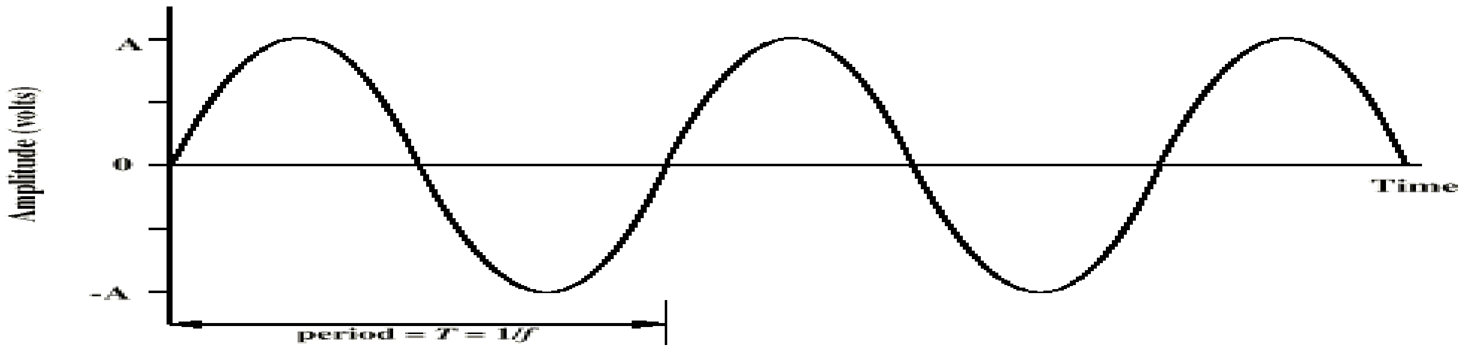
- Periodic signal
  - Pattern repeated over time
  - A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a cycle.
- Aperiodic signal
  - Pattern not repeated over time
  - An aperiodic signal changes without exhibiting a pattern or cycle that repeats over time.



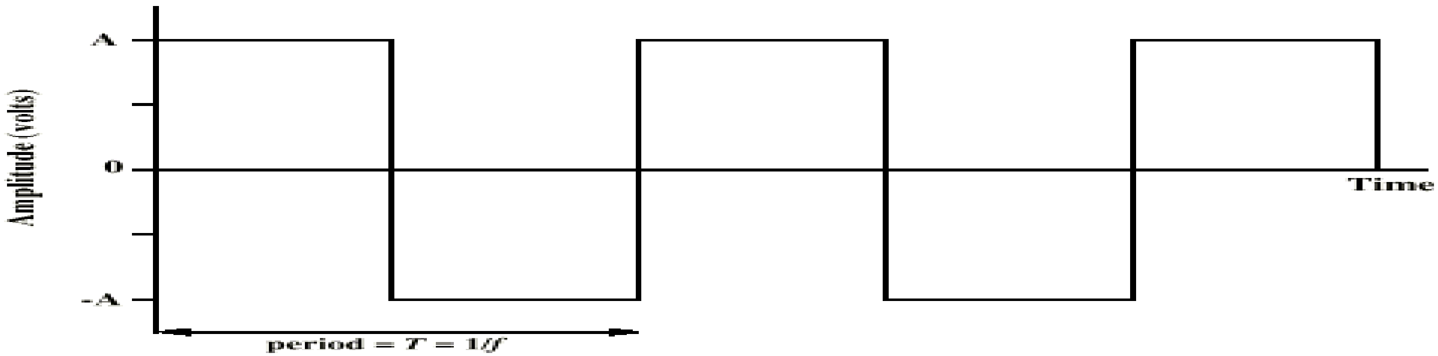
Note:

- In data communication, we commonly use periodic analog signals and aperiodic digital signals.

Periodic Signals



(a) Sine wave



(b) Square wave

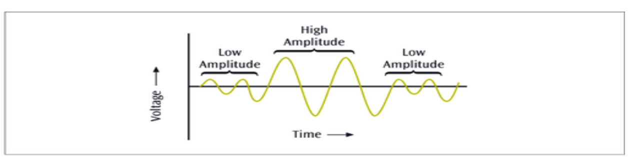
Components of Analog Signals

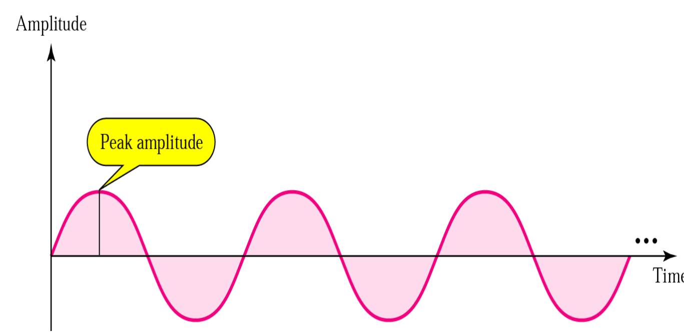
- Analog Signals: Have Three Components:-
  - Amplitude
  - Frequency
  - Phase

Amplitude

- The amplitude of a signal is the height of the wave above or below a given reference point.
- The Peak amplitude of a signal represents the absolute value of its highest intensity, proportional to the energy it carries. For electric signals it measured in volts.

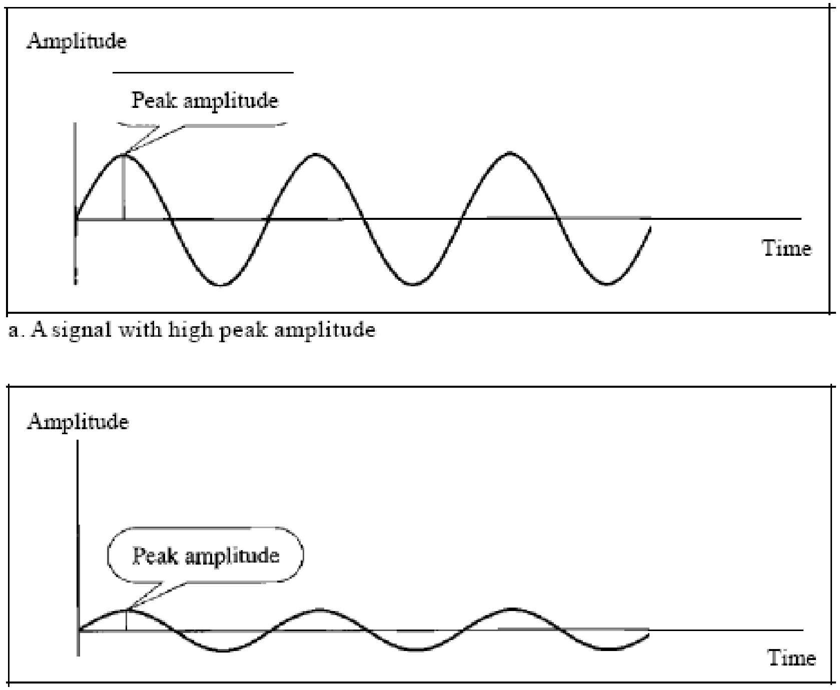
Figure 2-6
A signal with two different amplitudes





Amplitude

Figure 3.3 *Two signals with the same phase and frequency, but different amplitudes*

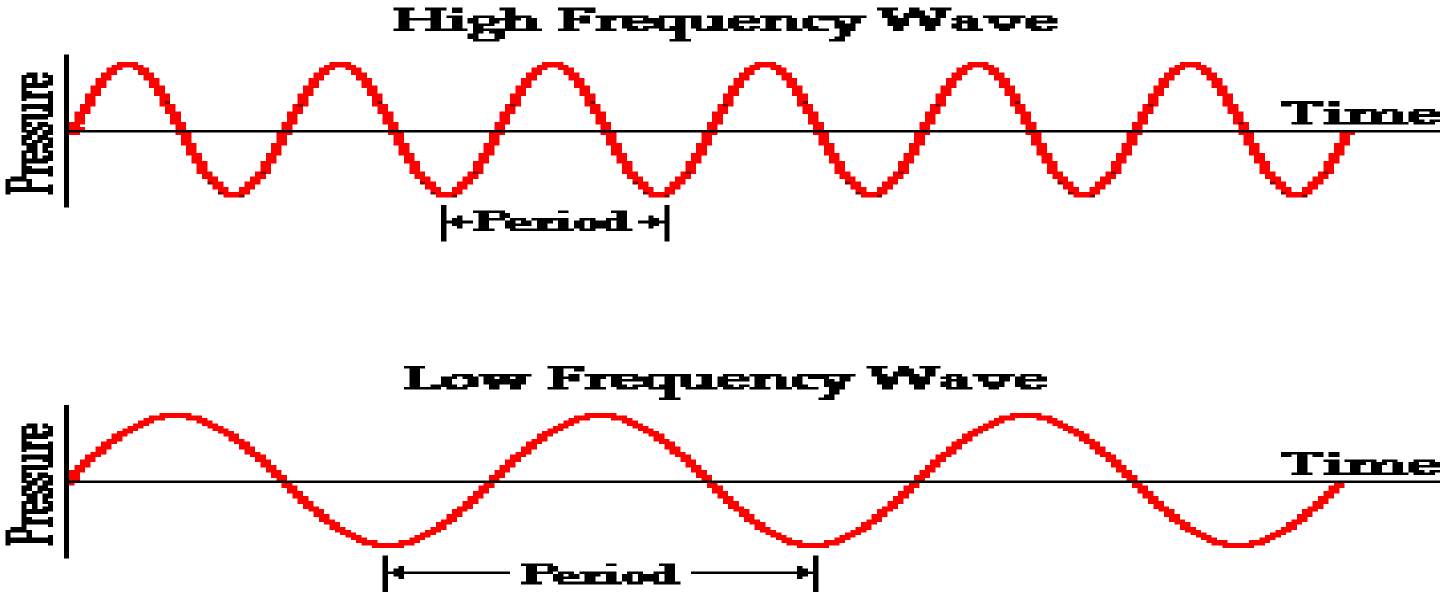


a. A signal with high peak amplitude

b. A signal with low peak amplitude

Frequency

- Rate at which signal repeats
- Measured in Hertz



Frequency and Time Period

- Frequency refers to the number of periods in one second.
- Period refers to the amount of time, in seconds , a signal to complete one cycle.
- Relation between Frequency and Time Period

$$f=1/T$$

Frequency

- 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 a signal does not change at all, its frequency is zero. If a signal changes instantaneously, its frequency is infinite.

Signals with different frequencies

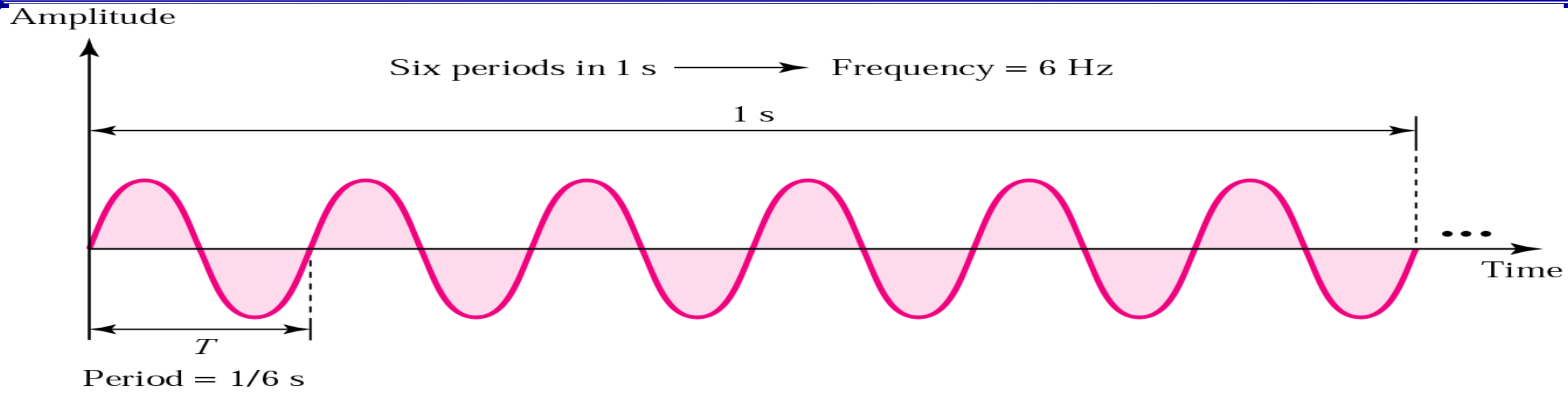
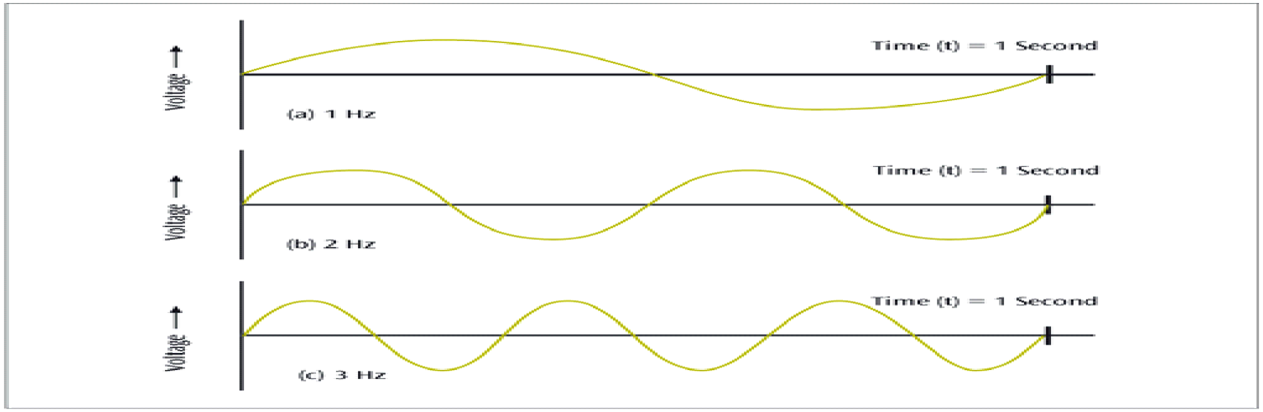


Figure 2-7
Three signals of 1 Hz, 2 Hz, and 3 Hz



Units of periods and frequencies

Unit	Equivalent	Unit	Equivalent
Seconds (s)	1 s	**hertz (Hz)**	1 Hz
Milliseconds (ms)	10^{-3} s	**kilohertz (KHz)**	10^{3} Hz
Microseconds (ms)	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

Express a period of 100 ms in microseconds, and express the corresponding frequency in kilohertz.

Solution

From Table we find the equivalent of 1 ms.We make the following substitutions:

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

Now we use the inverse relationship to find the frequency, changing hertz to kilohertz

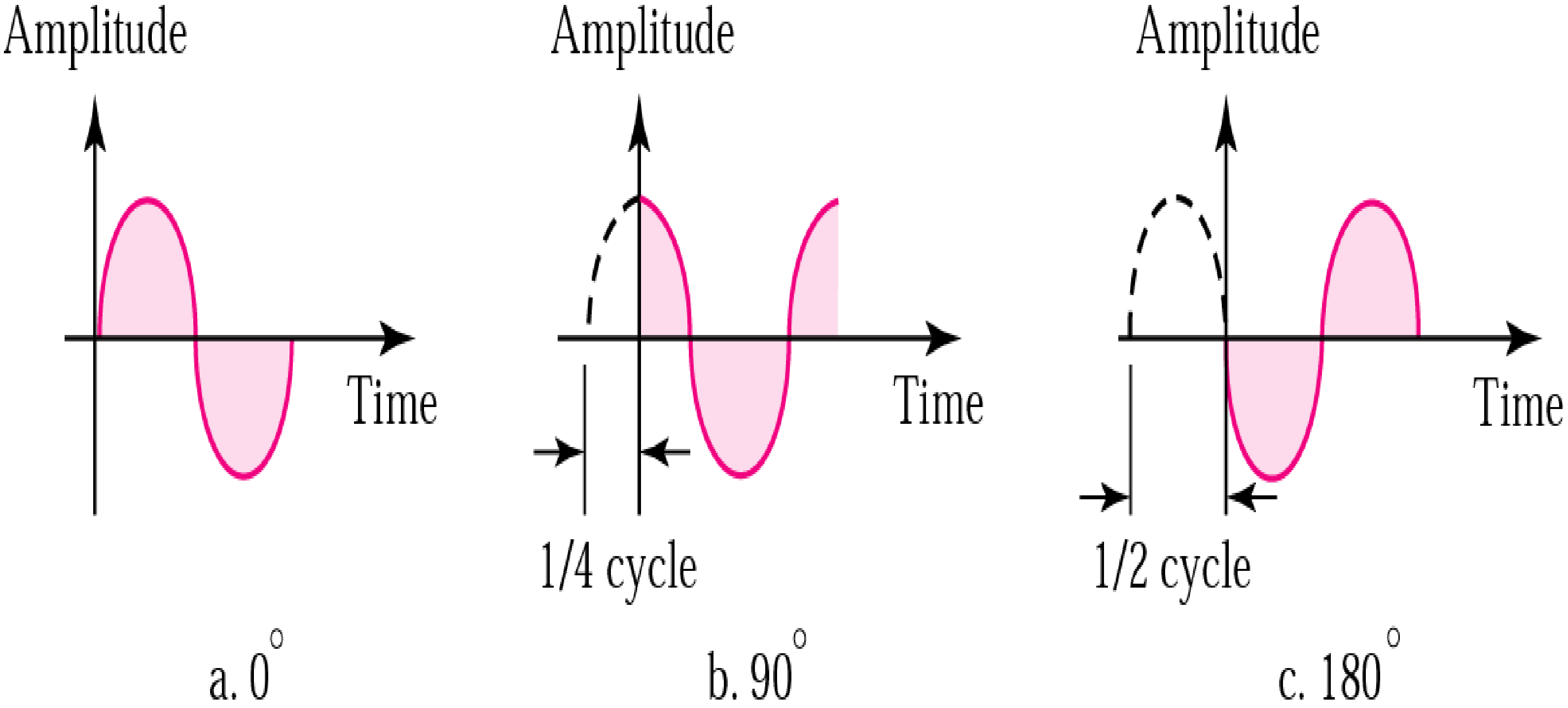
$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$

$f = 1/10^{-1} \text{ Hz} = 10 \times 10^{-3} \text{ KHz} = 10^{-2} \text{ KHz}$

Phase

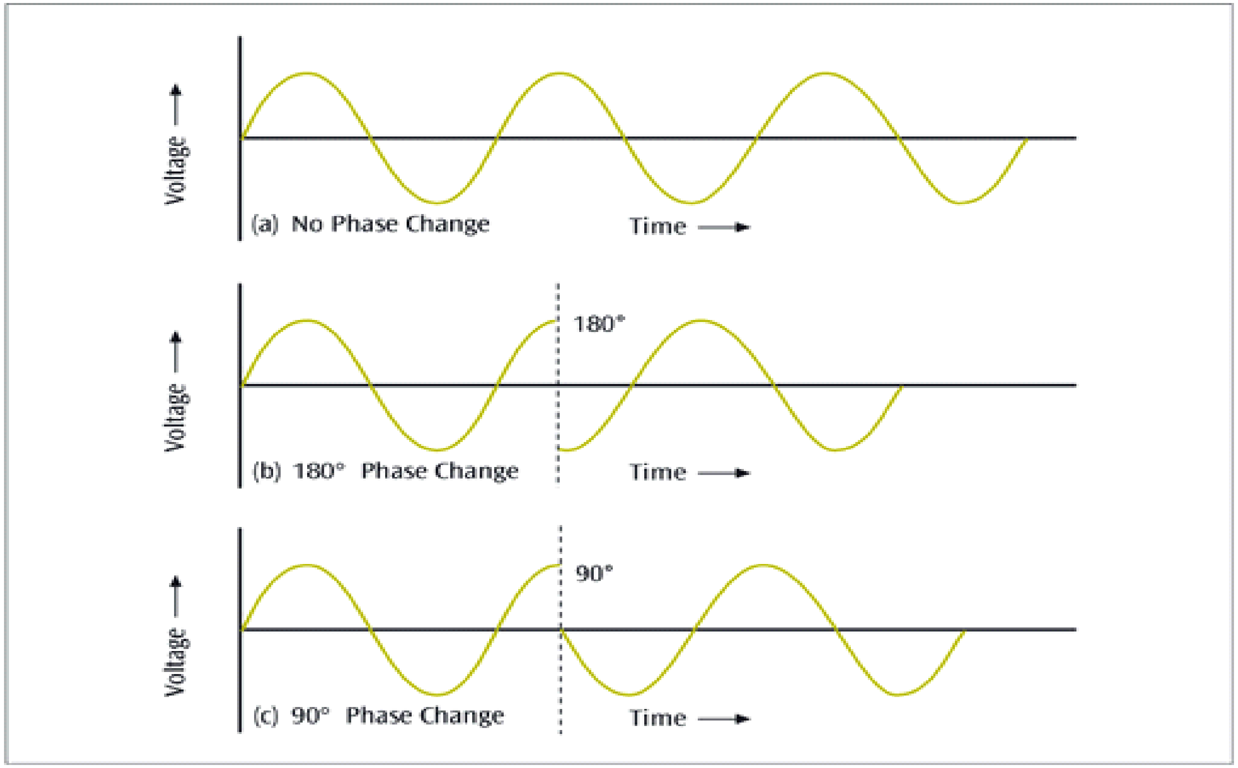
- The phase of a signal is the position of the waveform relative to a given moment of time or relative to time zero.
- A change in phase can be any number of angles between 0 and 360 degrees.
- Phase changes often occur on common angles, such as 45, 90, 135, etc.

Phase Changes



Phase Changes

Figure 2-8
A sine wave showing no phase change (a), a 180-degree phase change (b), and a 90-degree phase change (c)



Example

Example 2

A sine wave is offset one-sixth of a cycle with respect to time zero. What is its phase in degrees and radians?

Solution

We know that one complete cycle is 360 degrees.

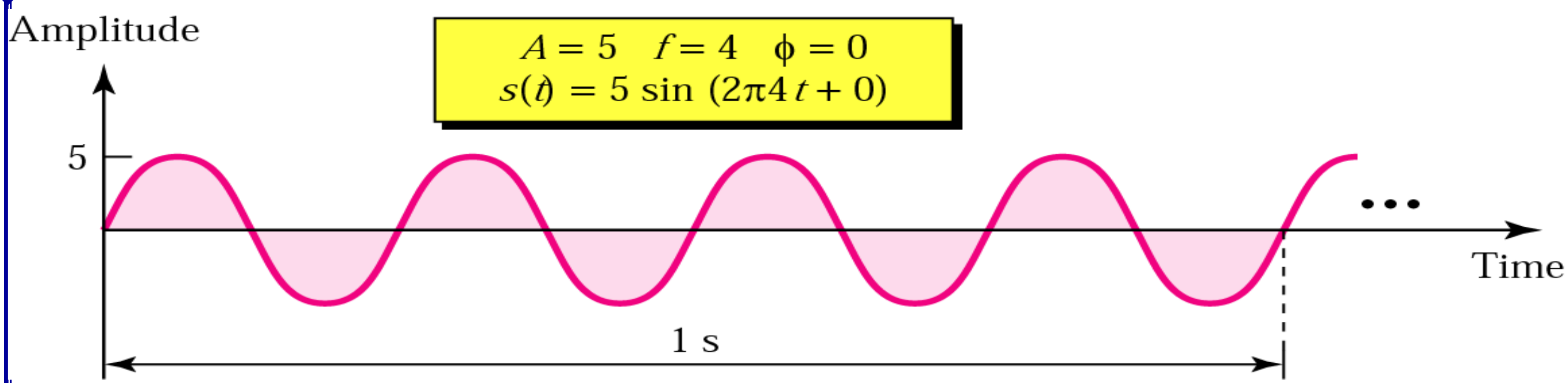
Therefore, 1/6 cycle is

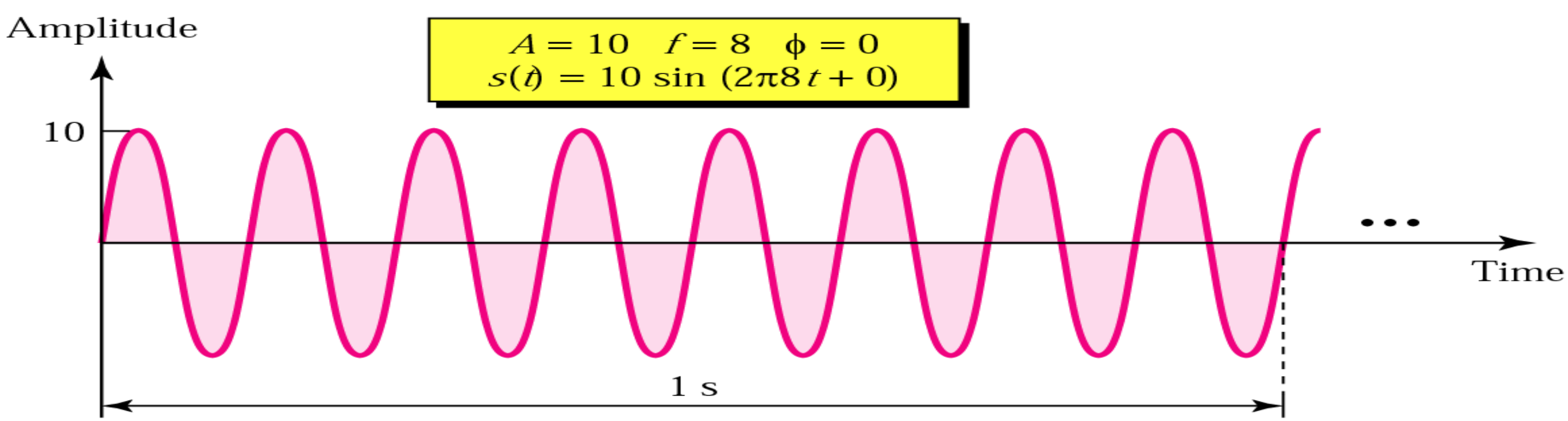
(1/6) 360 = 60 degrees = 60 x 2π /360 rad = 1.046 rad

Sine Wave

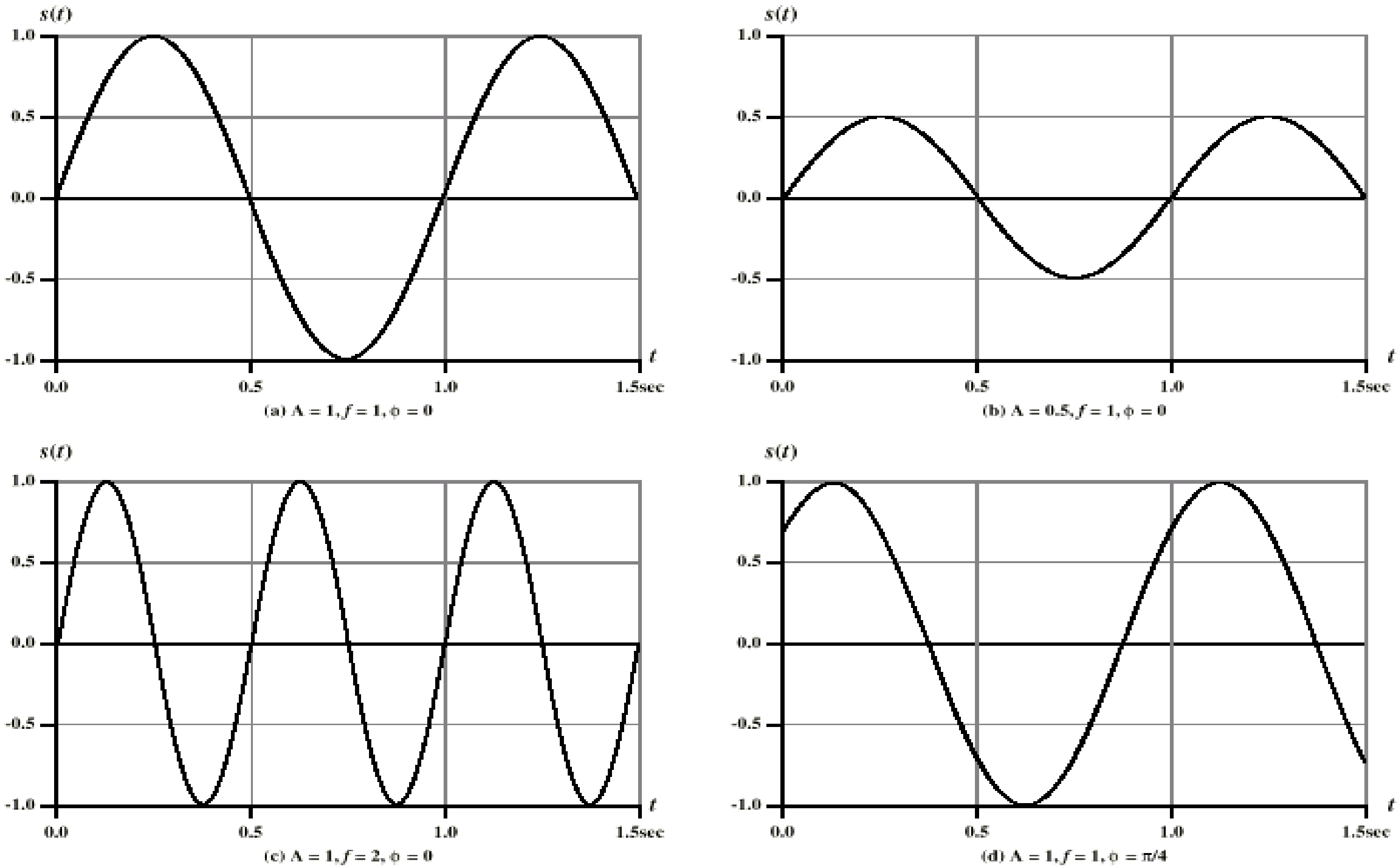
- Peak Amplitude (A)
  - maximum strength of signal
  - volts
- Frequency (f)
  - Rate of change of signal
  - Hertz (Hz) or cycles per second
  - Period = time for one repetition (T)
  - $T = 1/f$
- Phase (ϕ)
  - Relative position in time

Sine wave examples





Varying Sine Waves

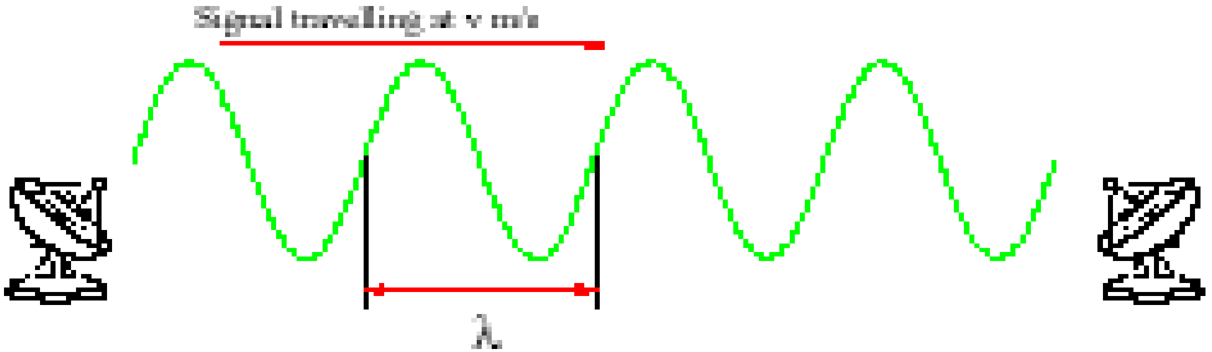


Wavelength

– Distance occupied by one cycle
– Distance between two points of corresponding phase in two consecutive cycles

Assuming signal velocity v

$\lambda = vT \Rightarrow \lambda f = v$



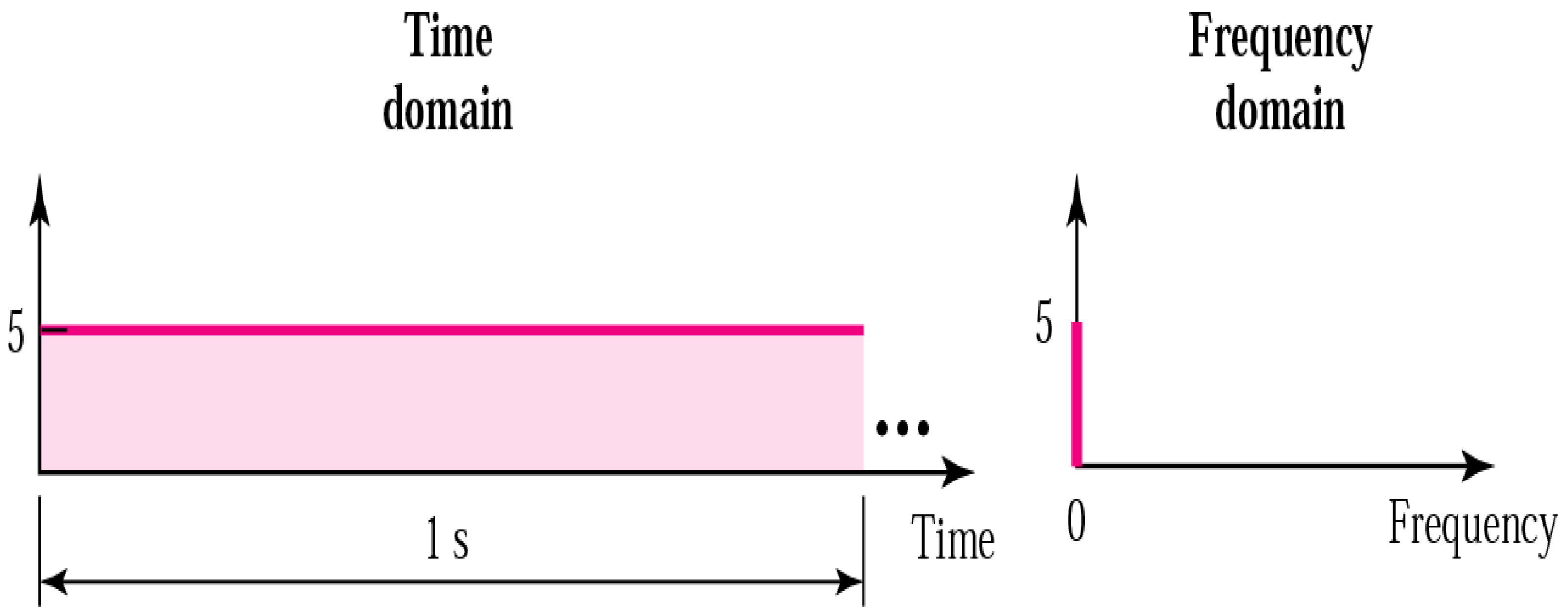
Frequency Domain Concepts

- A frequency-domain plot is concerned with only the peak value and the frequency
- Changes of amplitude during one period are not shown
- easy to plot and conveys the information
- we can immediately see the values of the frequency and peak amplitude
- An analog signal is best represented in the frequency domain.
- The advantage of the frequency domain is that we can immediately see the values of the frequency and peak amplitude

Time Domain Concepts

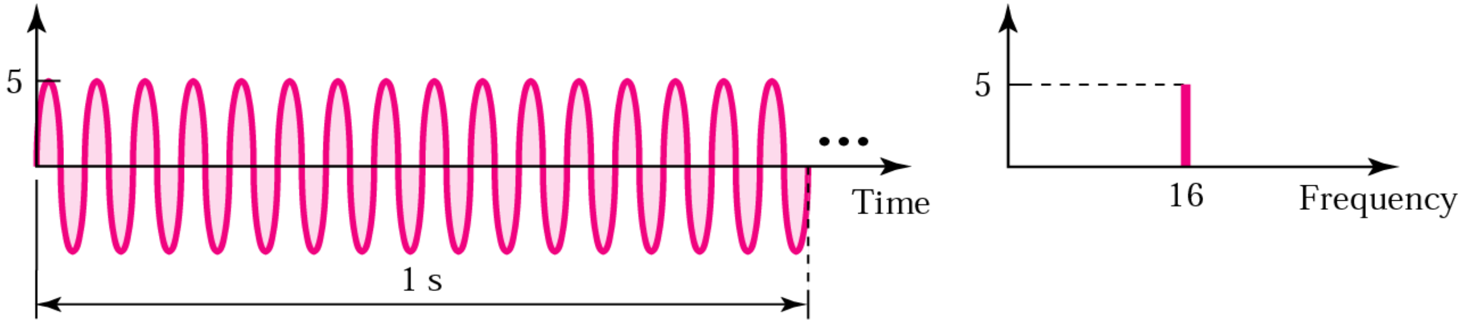
- Time-domain plot shows changes in signal amplitude with respect to time
- It is an amplitude-versus-time plot

Time and Frequency Domain

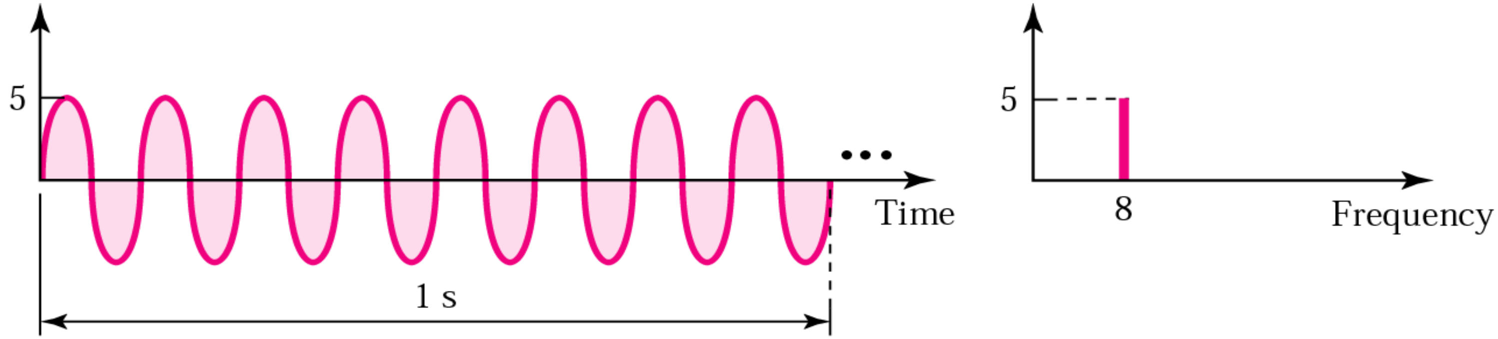


a. A signal with frequency 0

Time and Frequency Domain



c. A signal with frequency 16



b. A signal with frequency 8

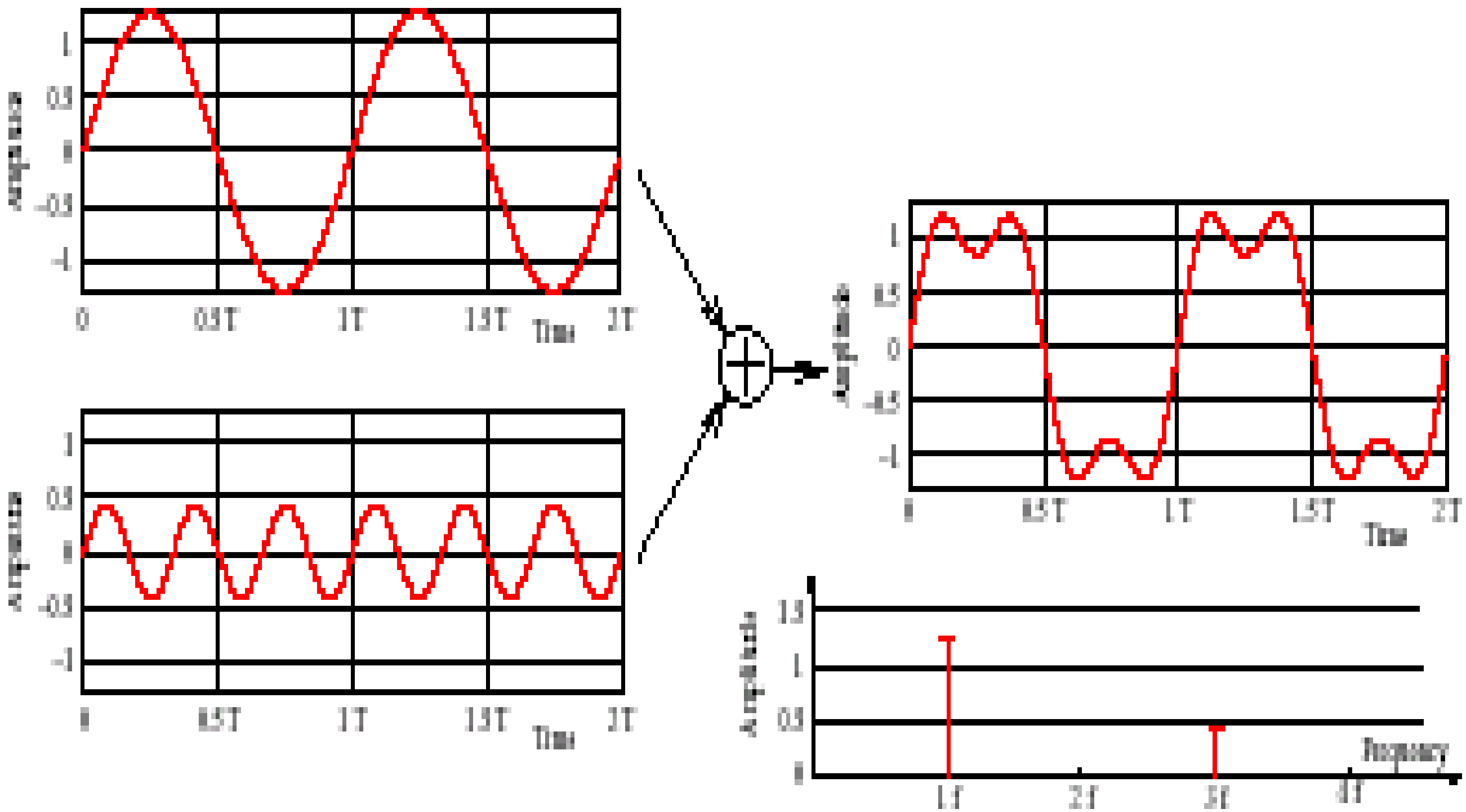
Composite Signal

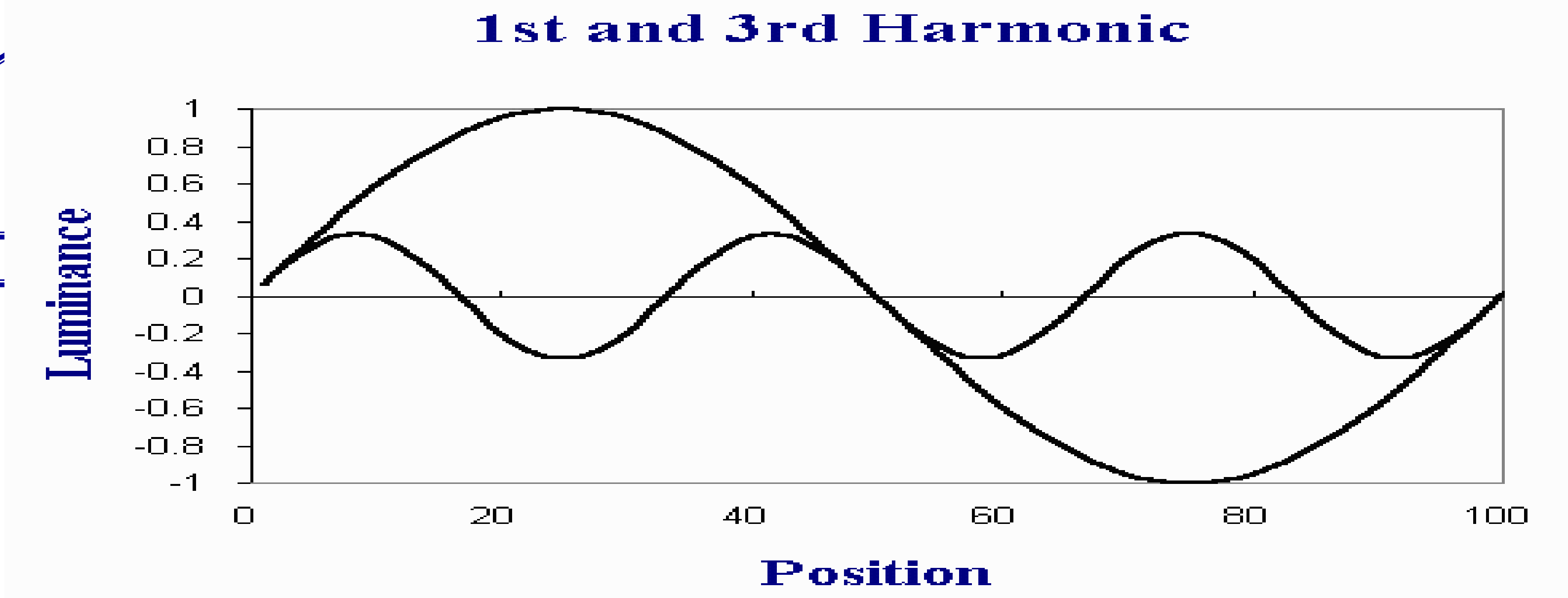
- A single-frequency sine wave is not useful in data communications; we need to change one or more of its characteristics to make it useful.
- When we change one or more characteristics of a single-frequency signal, it becomes a composite signal made of many frequencies
- According to Fourier analysis, any composite signal can be represented as a combination of simple sine waves with different frequencies, phases, and amplitudes.

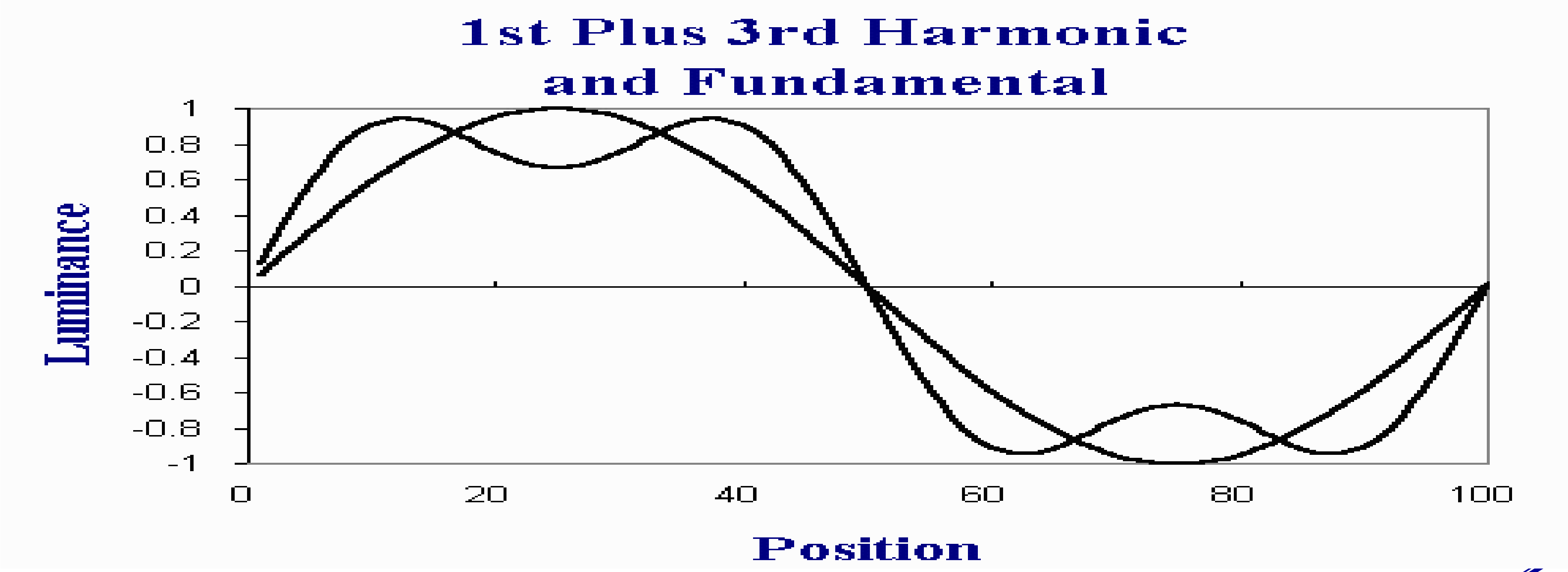
Fundamental and Harmonics

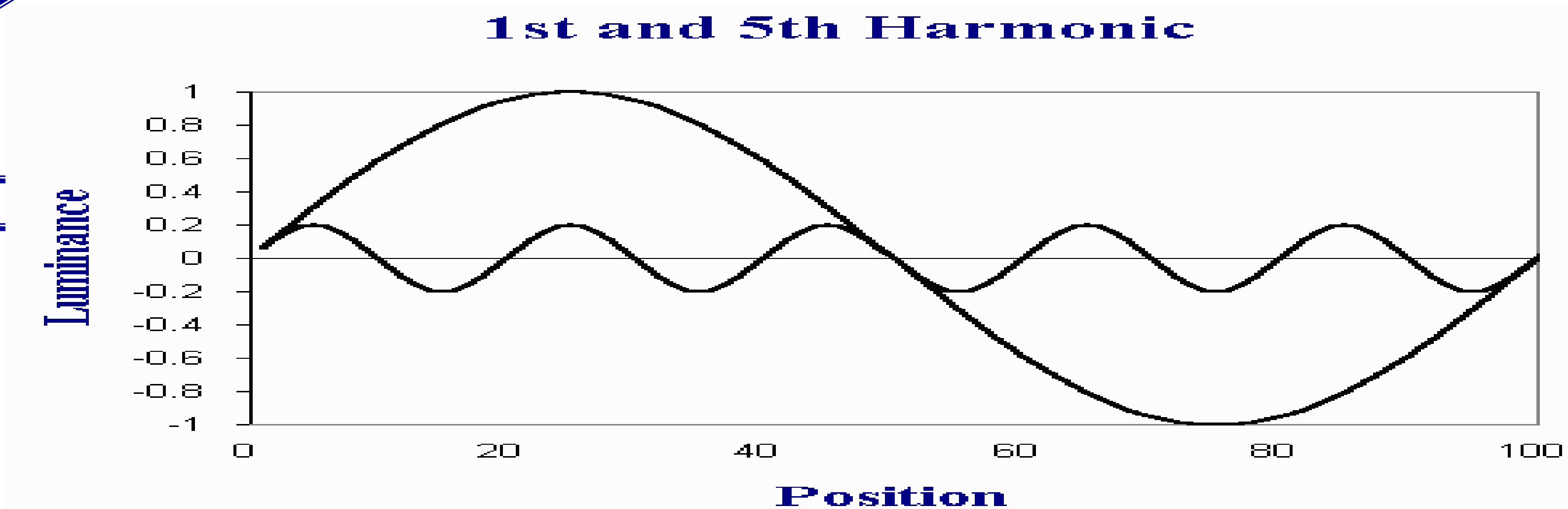
- Fundamental Sine wave is the one that has the lowest frequency and biggest amplitude
- The harmonics are multiples of the fundamental frequency
- Time period of total signal is equal to the time period of fundamental frequency
- All frequencies higher than the fundamental are referred to as harmonics.

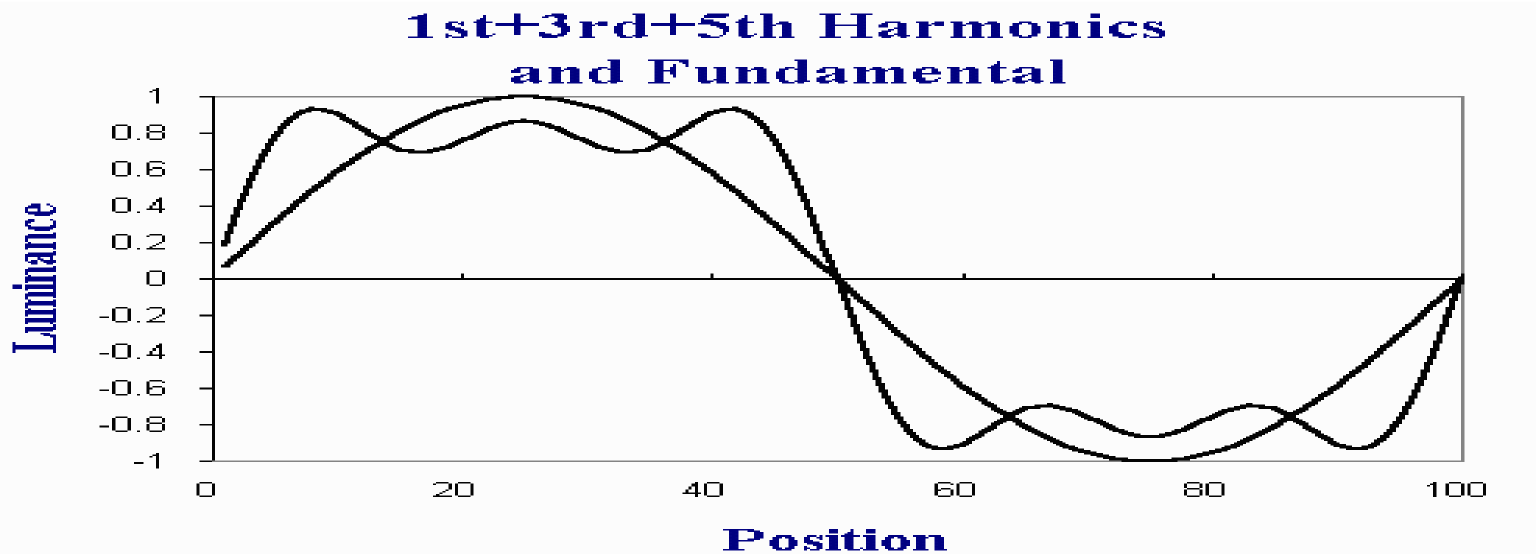
Addition of Frequency Components

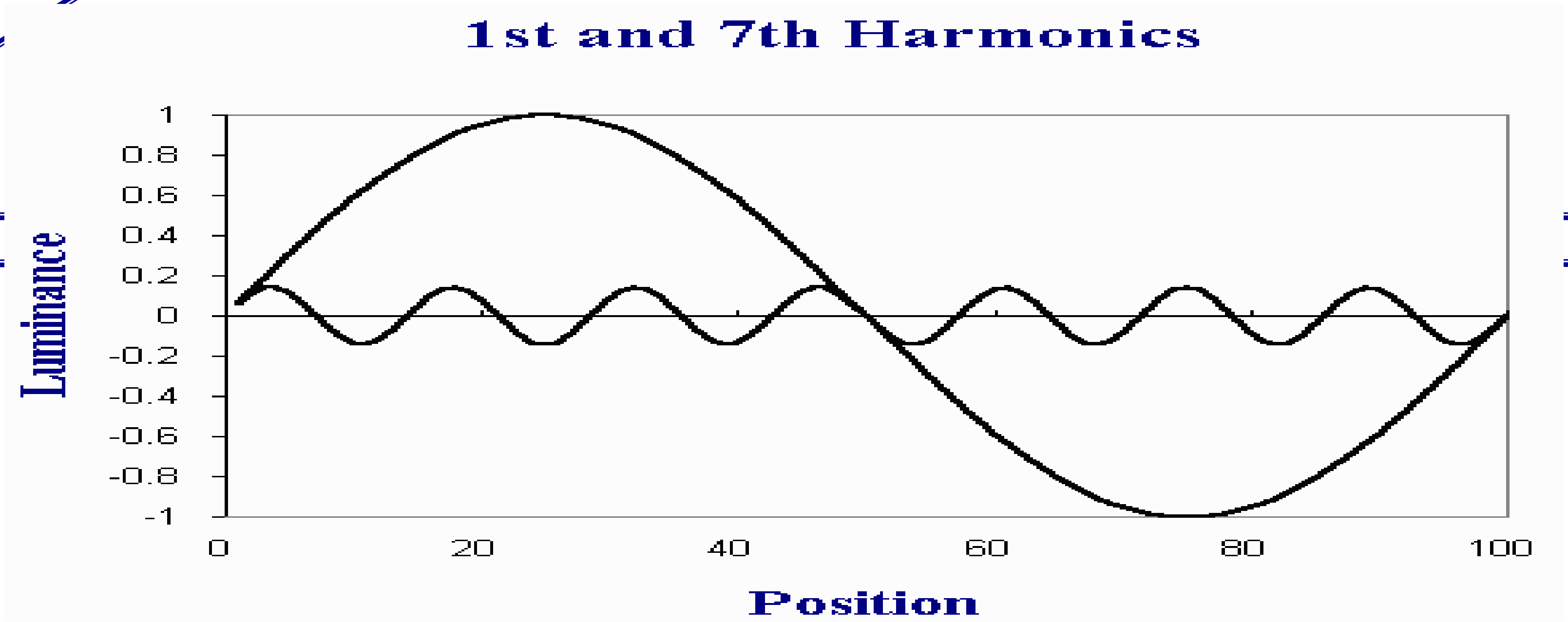


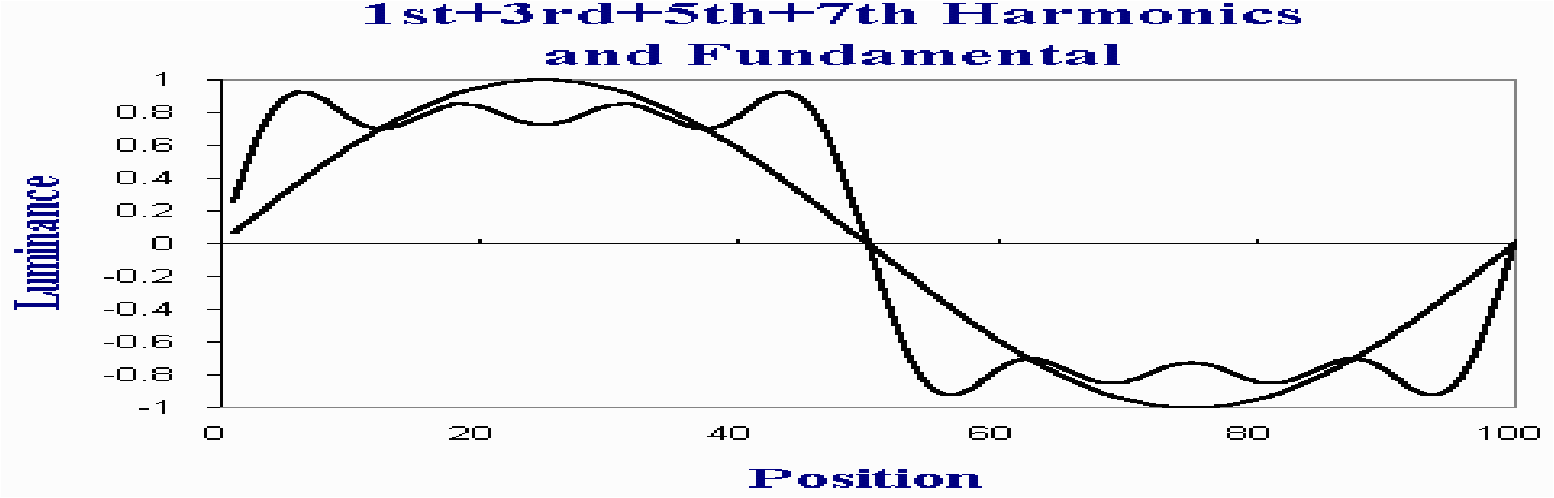

1st and 3rd Harmonic
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position

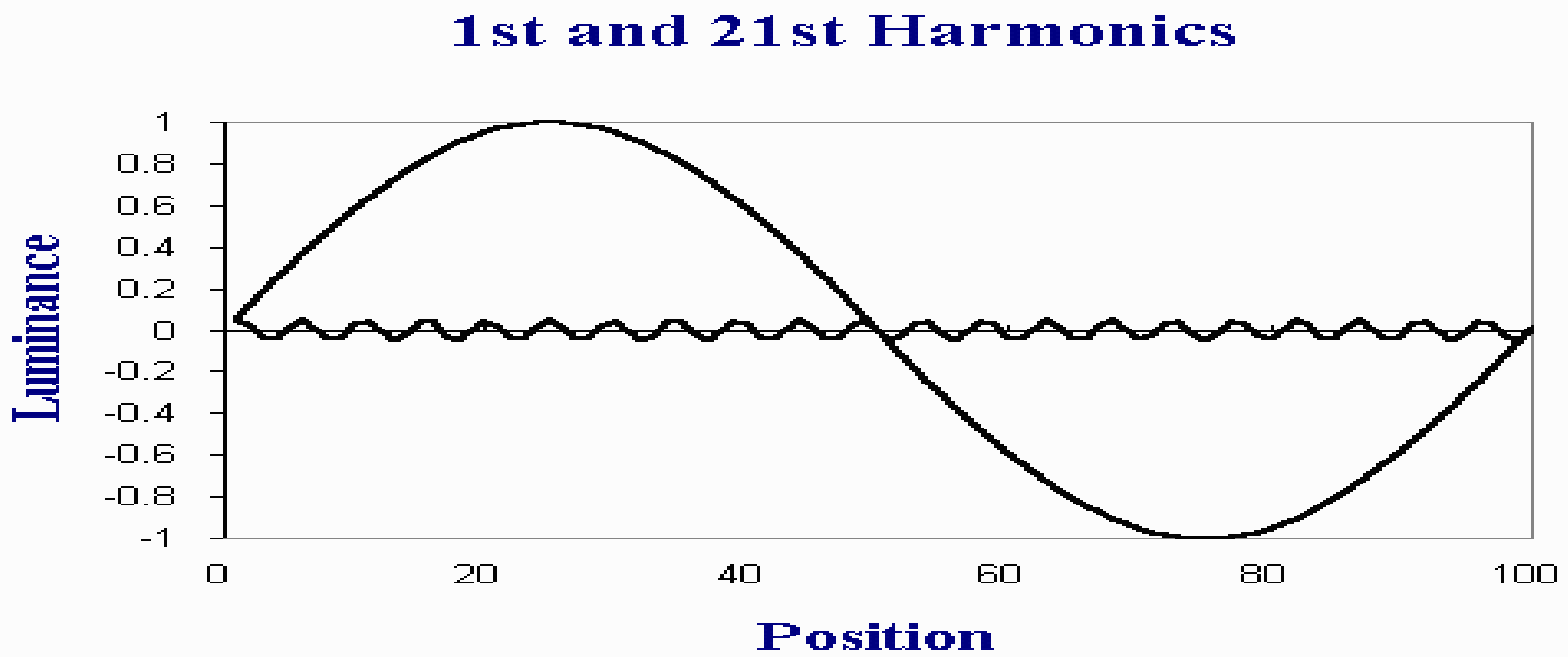

1st Plus 3rd Harmonic
and Fundamental
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position

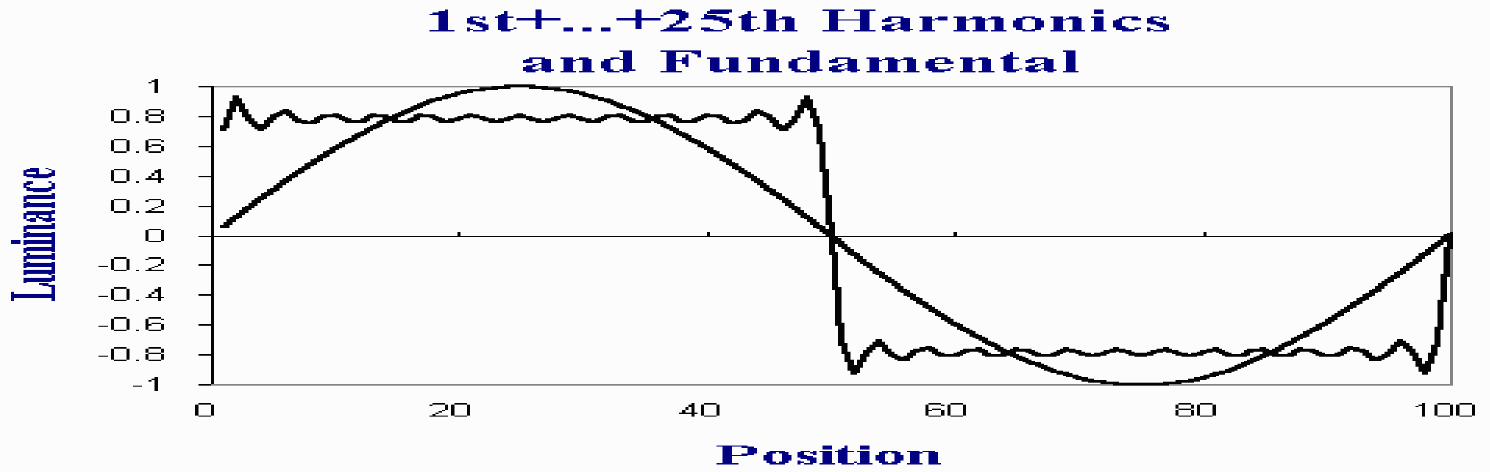

1st and 5th Harmonic
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position


1st+3rd+5th Harmonics
and Fundamental
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position


1st and 7th Harmonics
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position


1st+3rd+5th+7th Harmonics
and Fundamental
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position


1st and 21st Harmonics
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position


1st+...+25th Harmonics
and Fundamental
Luminance
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
20
40
60
80
100
Position

Spectrum & Bandwidth

- Spectrum
  - The range of frequencies that a signal spans from minimum to maximum.
- Absolute bandwidth
  - width of spectrum
- Effective bandwidth
  - Often just bandwidth
- DC Component
  - Component of zero frequency
  - With a dc component, average amplitude of signal becomes nonzero.

Example of Spectrum and Bandwidth

Consider an average voice:

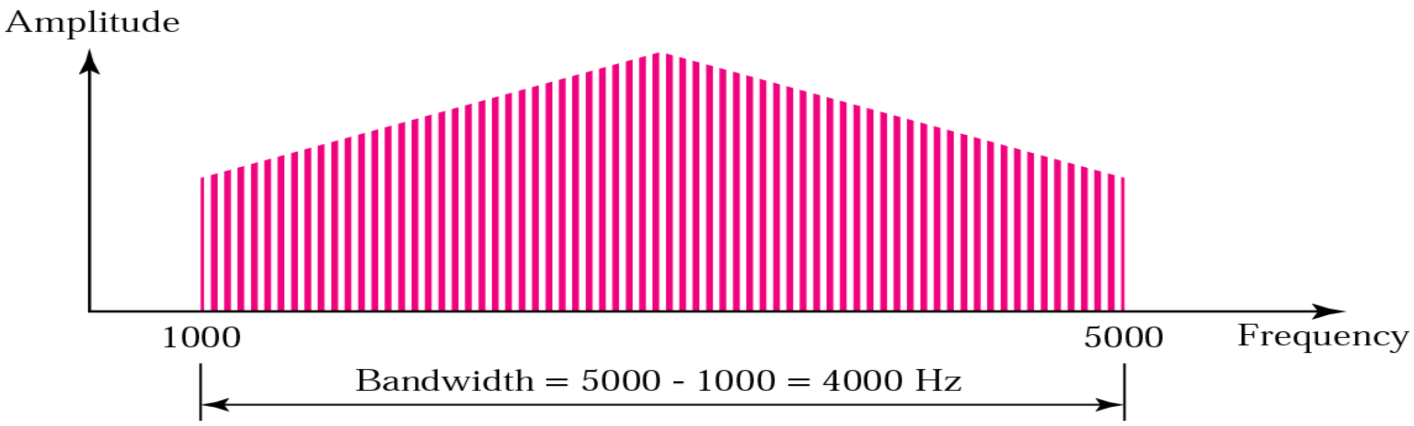
The average voice has a frequency range of roughly 300 Hz to 3100 Hz.

The spectrum would thus be 300 - 3100 Hz

The bandwidth would be 2800 Hz

Data Rate and Bandwidth

- The bandwidth is a property of a medium: It is the difference between the highest and the lowest frequencies that the medium can satisfactorily pass.
- In this course, we use the term bandwidth to refer to the property of a medium or the width of a single spectrum.



Example

Example 3

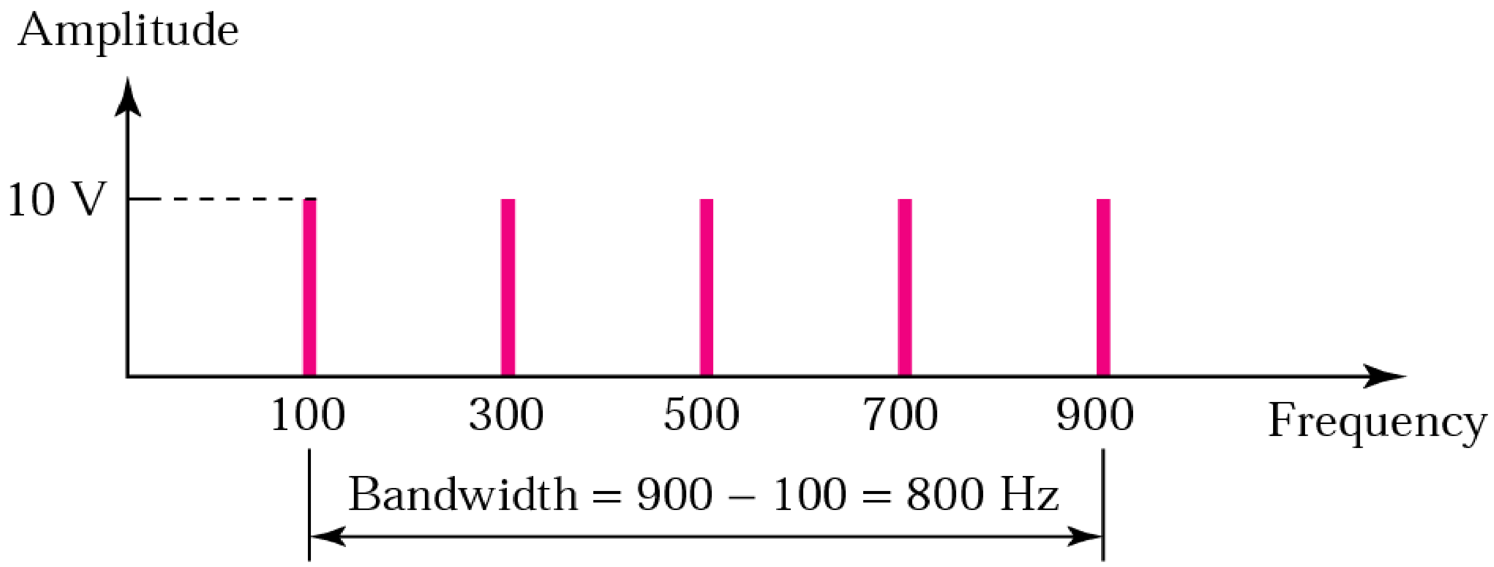
If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is the bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

Solution

$B = f_h - f_l = 900 - 100 = 800$ Hz

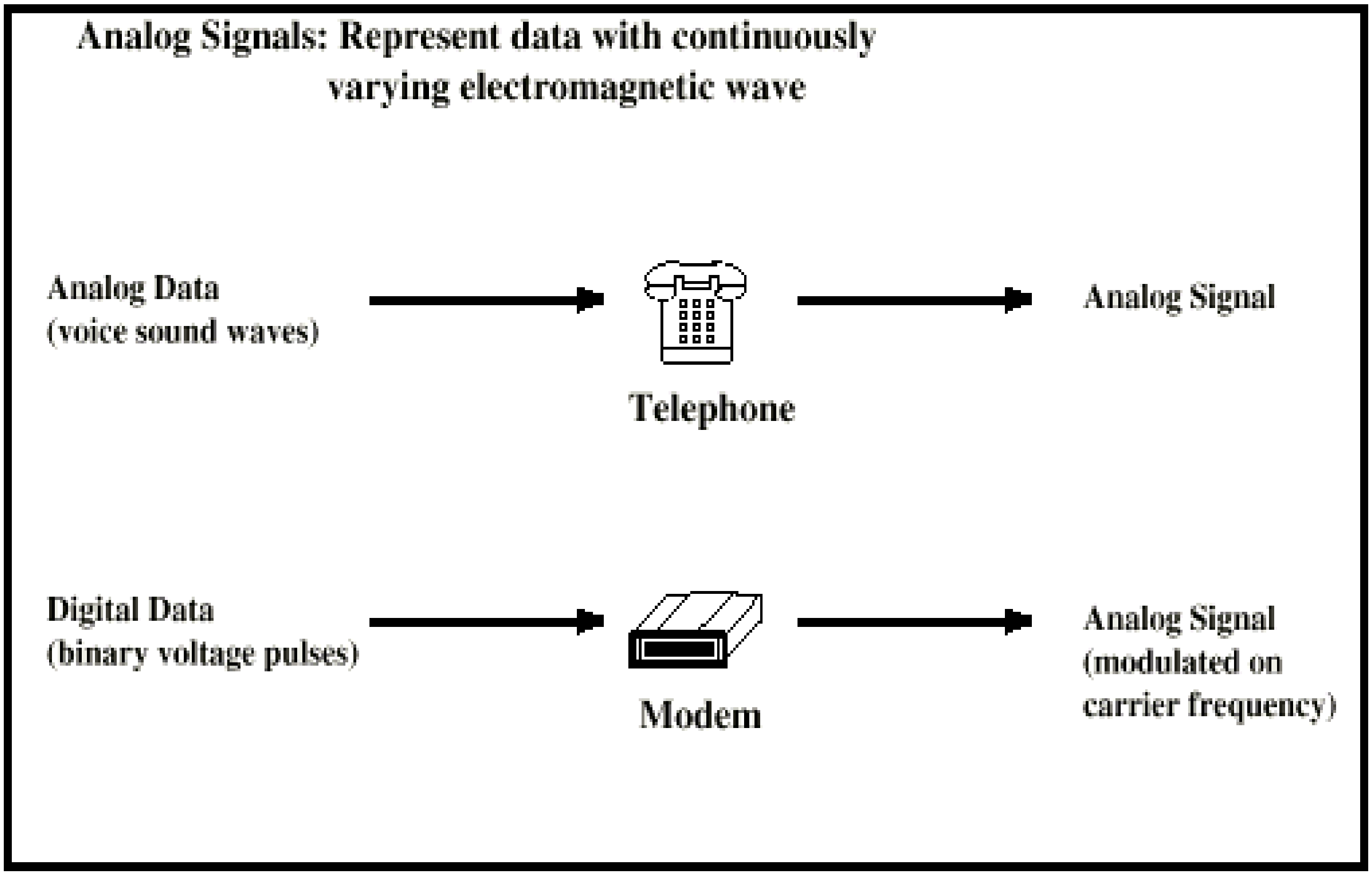
The spectrum has only five spikes, at 100, 300, 500, 700, and 900

Example

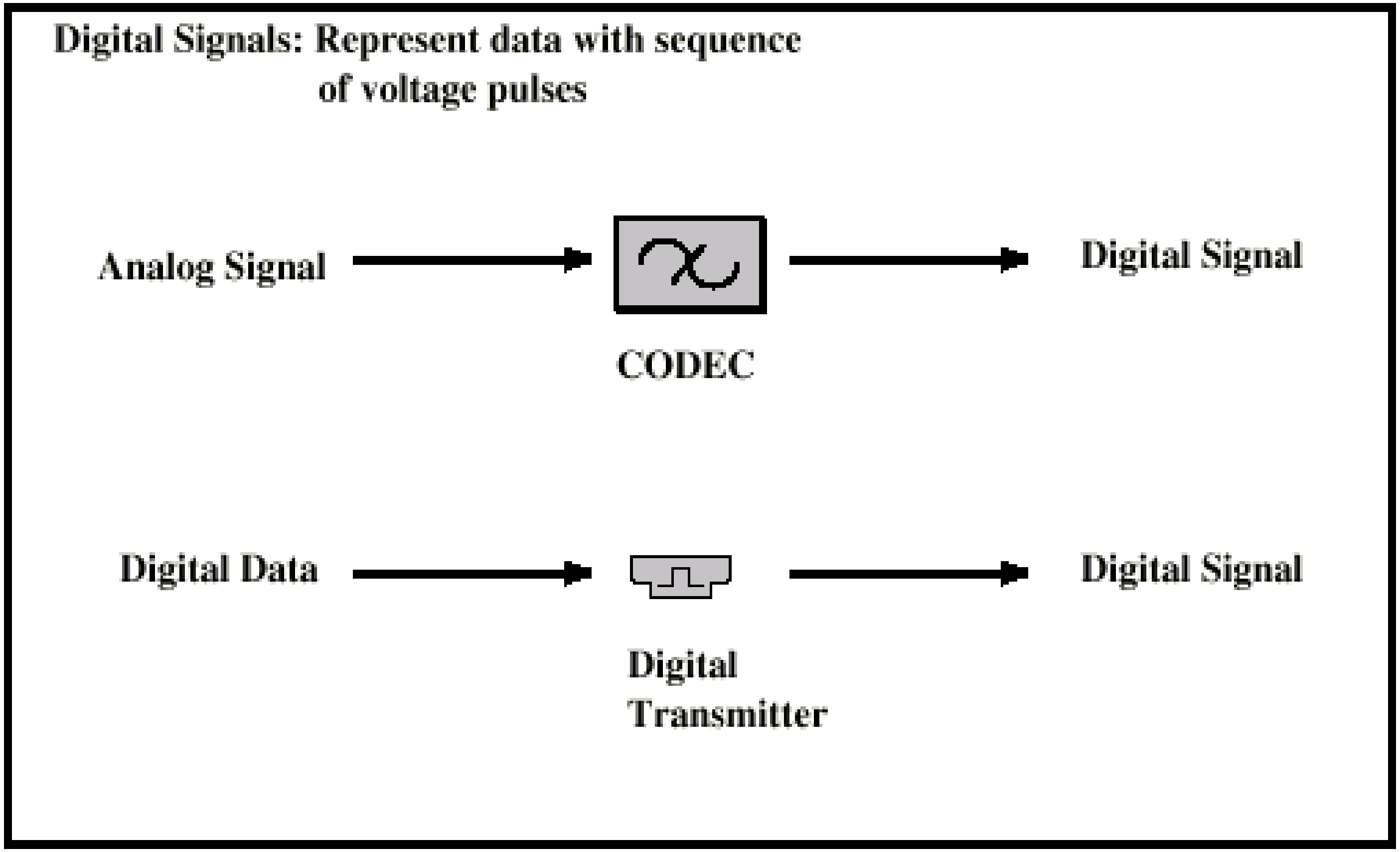


Amplitude
10 V
100
300
500
700
900
Frequency
Bandwidth = 900 − 100 = 800 Hz

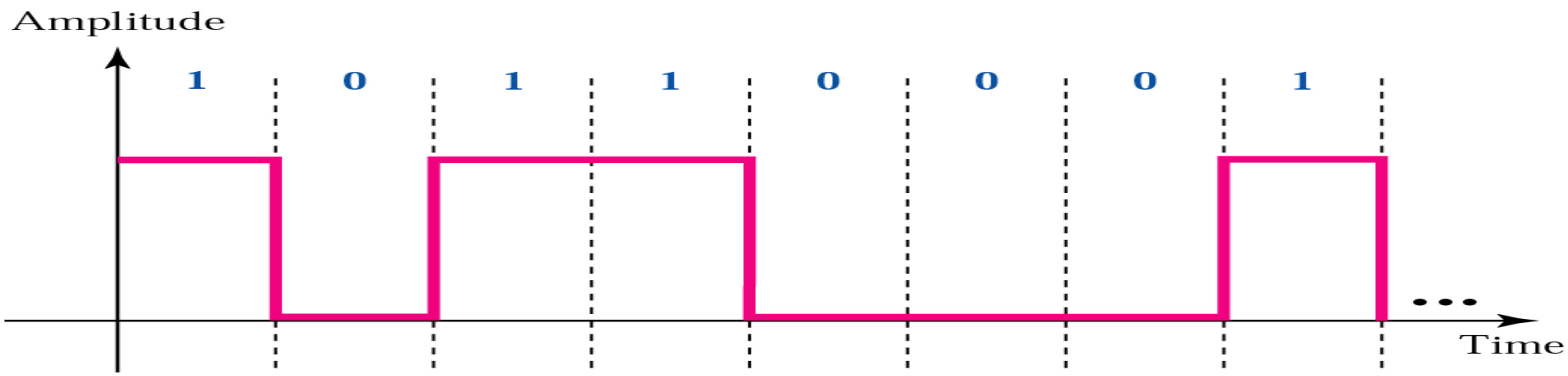
Analog Signals Carrying Analog and Digital Data



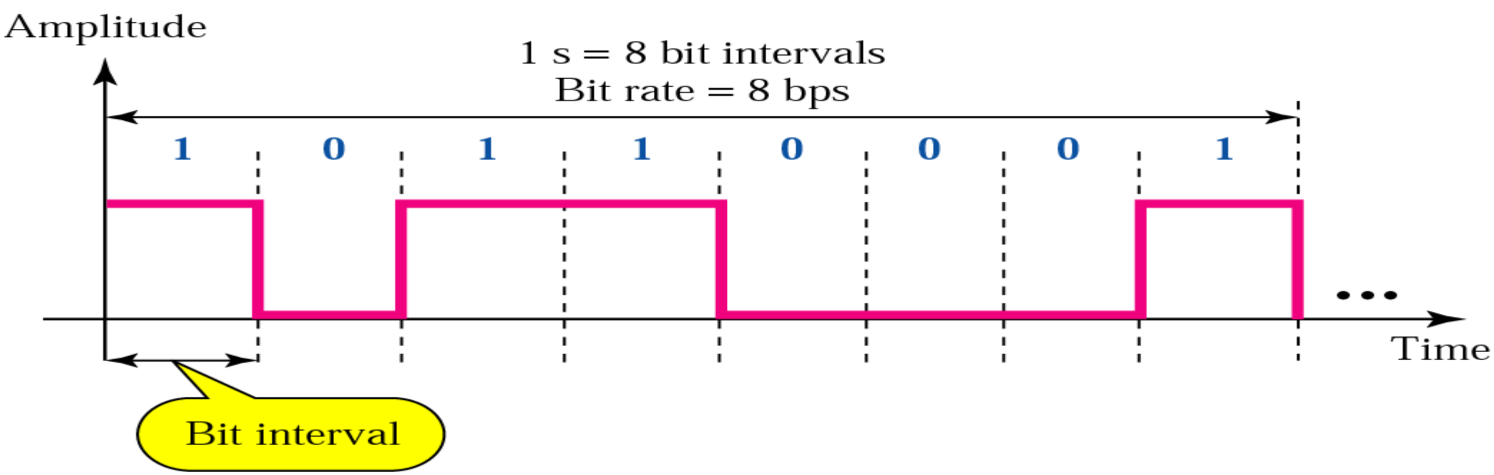
Digital Signals Carrying Analog and Digital Data



A digital signal



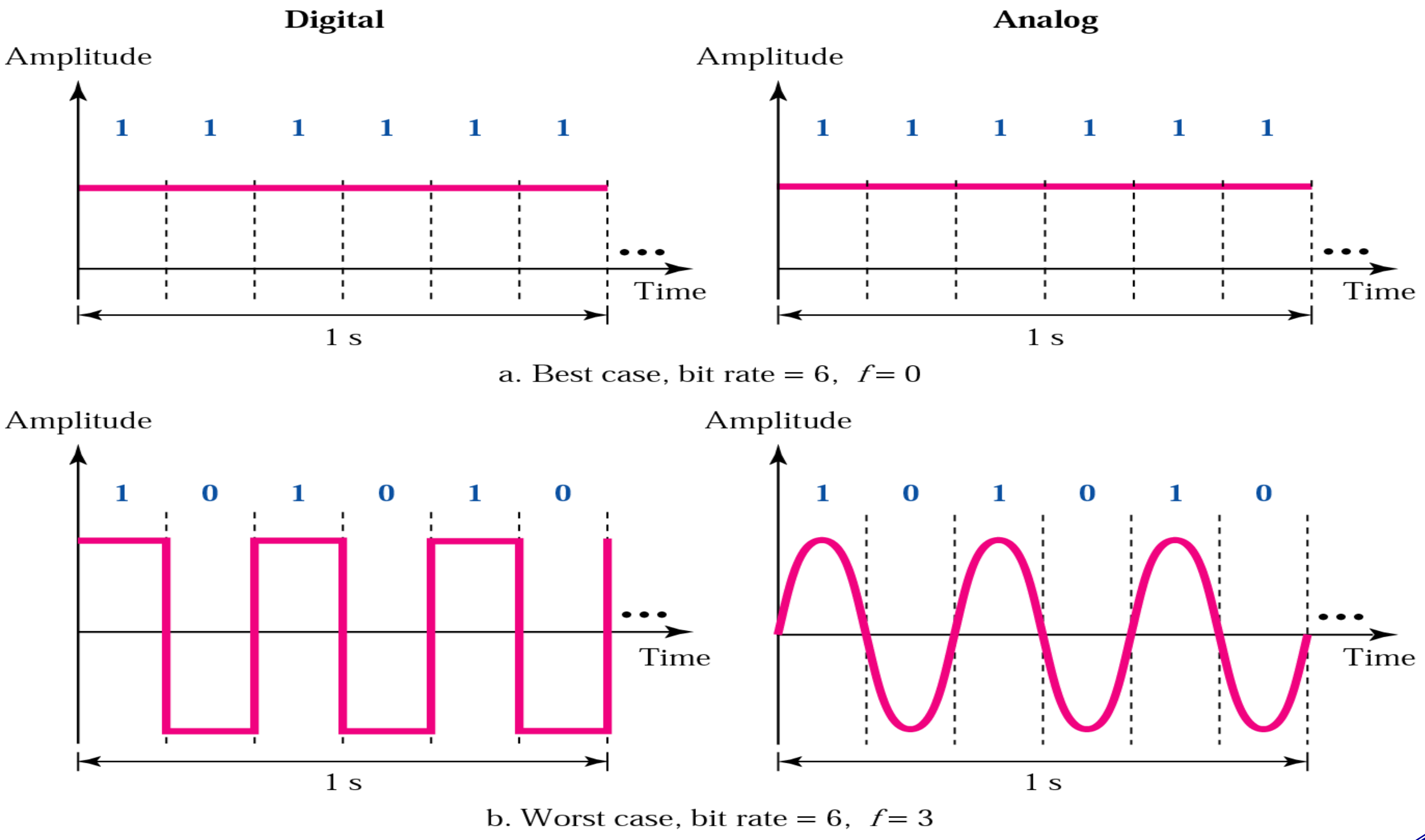
Bit rate and bit interval



Digital Signals

- Digital Signal as Composite Analog Signal
- Digital Signal Through a Wide-Bandwidth Medium
- Digital Signal Through a Band-Limited Medium

Digital vs Analog



More about Bandwidth

- A digital signal is a composite signal with an infinite bandwidth.
- The bit rate and the bandwidth are proportional to each other.
- The analog bandwidth of a medium is expressed in hertz; the digital bandwidth, in bits per second

Analog and Digital Data Transmission

- Data
  - Entities that convey meaning
- Signals
  - Electric or electromagnetic representations of data
- Signaling
  - The physical propagation of signals along a suitable medium
- Transmission
  - Communication of data by propagation and processing of signals

Analog Transmission

- May be analog or digital data
- Attenuated over distance
- Use amplifiers to boost signal
- Also amplifies noise
- Use Band-Pass Channel
  - A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that rang

Digital Transmission

- Integrity endangered by noise, attenuation etc.
- Repeaters used
- Repeater receives signal
- Extracts bit pattern
- Retransmits
- Attenuation is overcome
- Noise is not amplified
- Use Low-Pass Channel
  - **low-pass filter** is a filter that passes low-frequency signals but attenuates (reduces the amplitude of) signals with frequencies higher than the cutoff frequency

Advantages of Digital Transmission

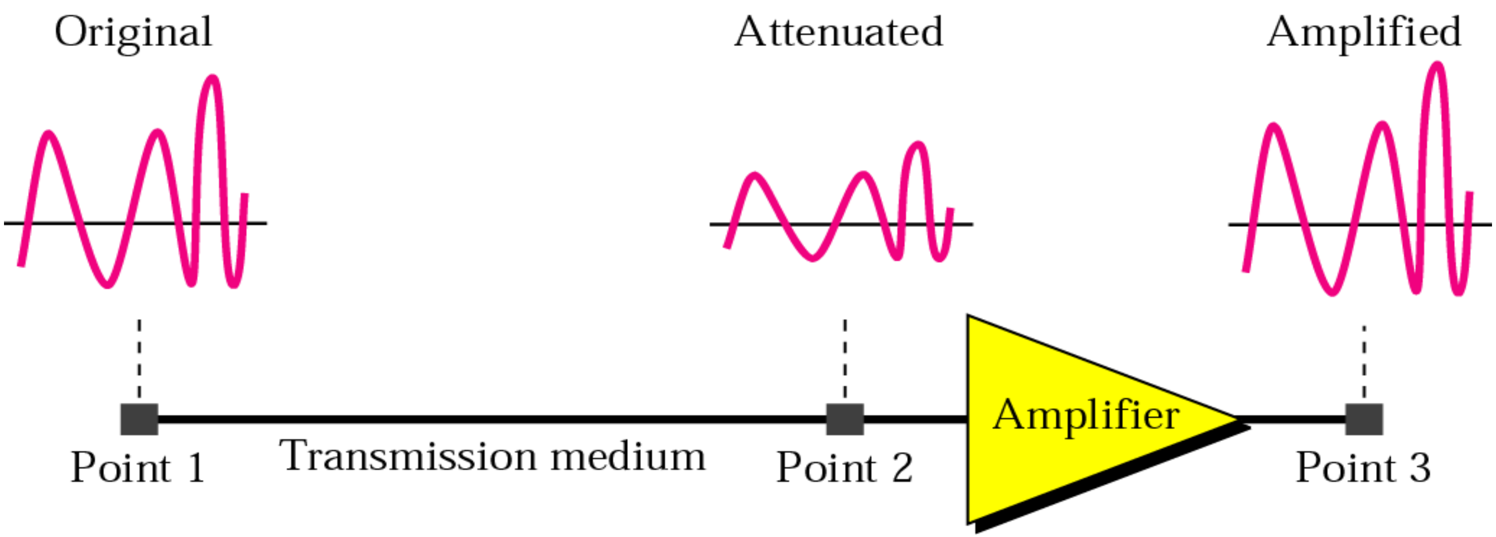
- Digital technology
- Data integrity
  - Longer distances over lower quality lines
- Capacity utilization
  - High bandwidth links economical
  - High degree of multiplexing easier with digital techniques
- Security & Privacy
  - Encryption
- Integration
  - Can treat analog and digital data similarly

Transmission Impairments

- Signal received may differ from signal transmitted
- Signals travel through transmission media, which are not perfect. The imperfection cause impairment in the signal.
- Analog Signals- degradation of signal quality
- Digital Signals - bit errors
- Most significant Impairments are:
  - Attenuation
  - Delay distortion
  - Noise

Attenuation

- Attenuation means loss of energy. When a signal , simple or composite , travels through a medium, it loses some of its energy so that it can overcome the resistance of the medium.



Decibel

- The decibel is a measure of relative strength of two signal levels:

  NdB = 10 log P2/P1

  Where,

  NdB = number of decibels

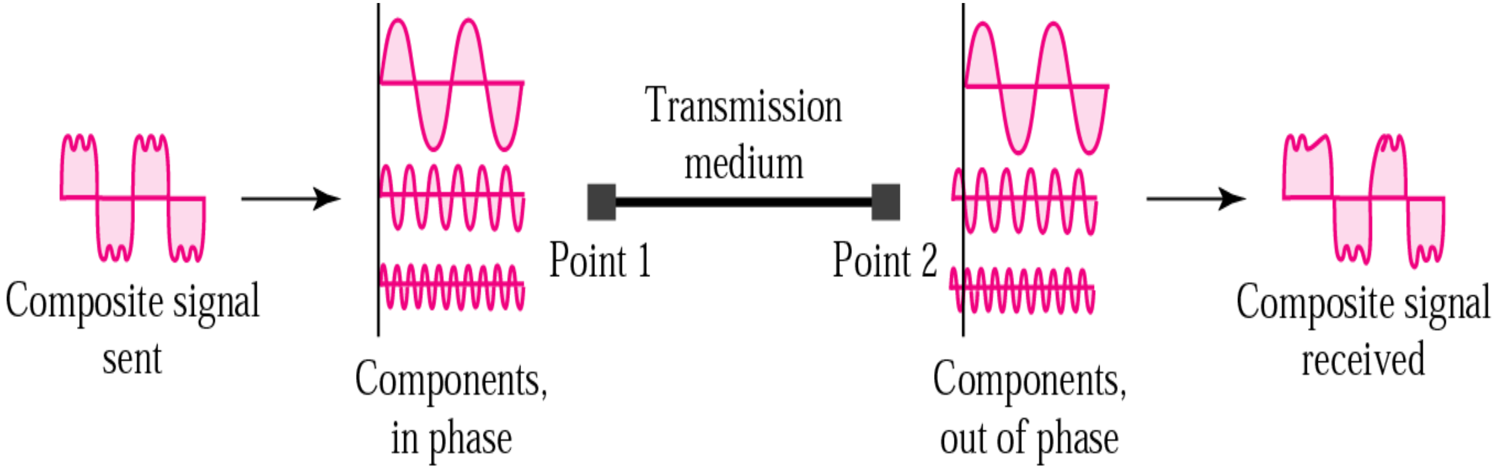
  P1 = input power level

  P2 = output power level

  Log 10 = logarithm to base 10

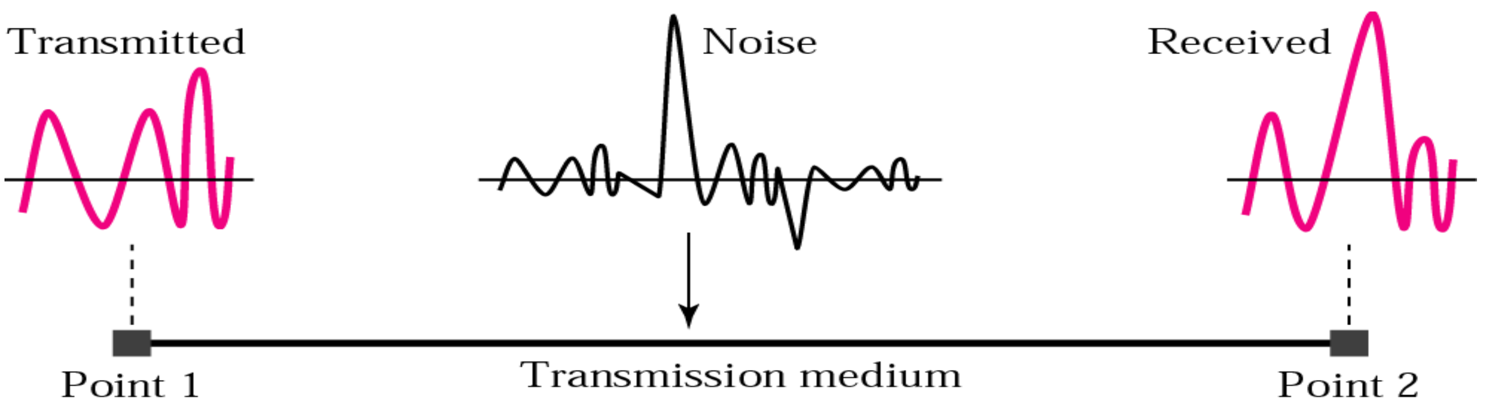
Delay Distortion

- Distortion means that the signal changes its form or shape. Distortion occurs in a composite signal, made of different frequencies some of those frequency components arrive at destination sooner than others.
- Only in guided media
- Equalizing techniques can be used to overcome it.



Noise

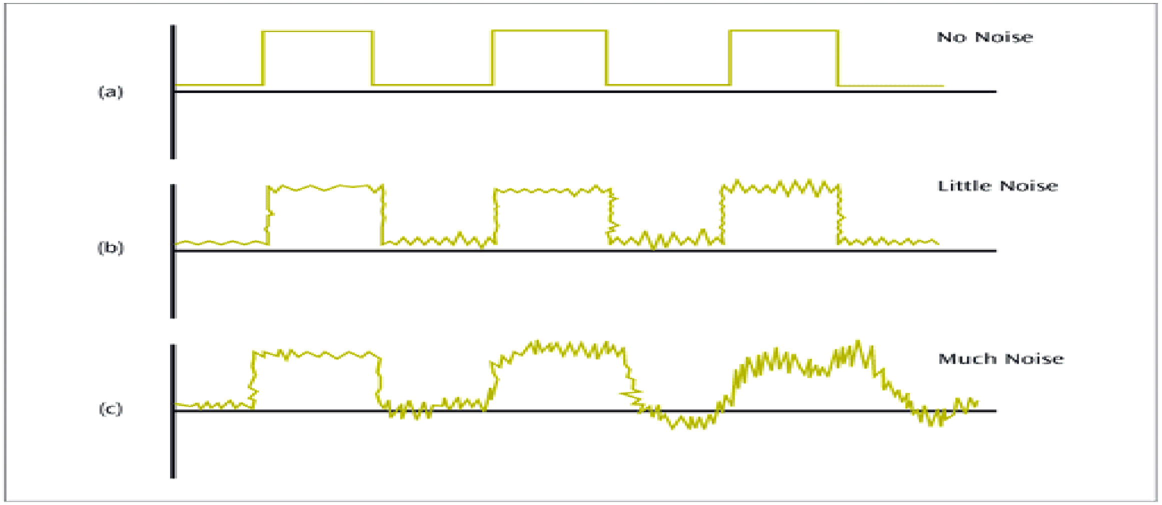
- Additional signals inserted between transmitter and receiver
- Several types of noise are exists such as
- thermal noise, Induced noise, Crosstalk, and Impulse noise



Thermal Noise

- Due to thermal agitation of electrons
- Uniformly distributed

Figure 6-1
White noise as it interferes with a digital signal



Induced Noise

- Induced noise comes from sources such as motors and appliance.
- These devices act as sending antenna and the transmission medium act as the receiving antenna.

Cross Talk

- Crosstalk
  - A signal from one line is picked up by another
  - Occur due to the electrical coupling between near by twisted pair cable or unwanted signals picked by microwave antennas

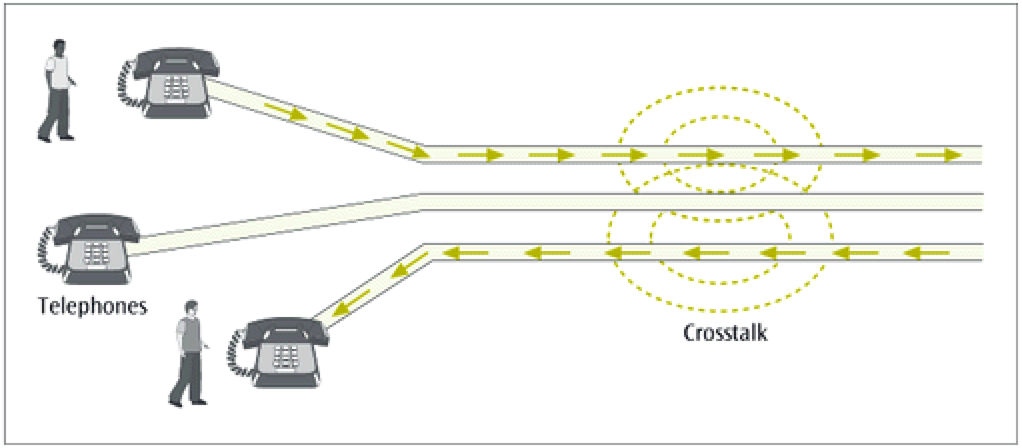
Unwanted coupling between two different signal paths.

For example, hearing another conversation while talking on the telephone.

Relatively constant and can be reduced with proper measures.

Cross Talk

Figure 6-4
Two telephone circuits experiencing crosstalk



Impulse Noise

- Impulse
  - Irregular pulses or spikes
  - e.g. External electromagnetic interference
  - Short duration, High amplitude

Difficult to remove from an analog signal because it may be hard to distinguish from the original signal.

Impulse noise can damage more bits if the bits are closer together (transmitted at a faster rate).

Figure 6-2
The effect of impulse noise on a digital signal

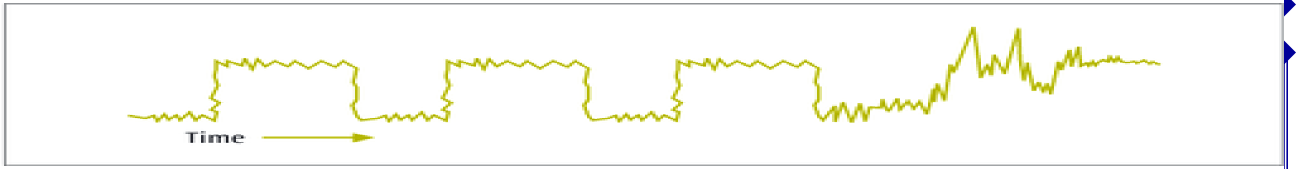
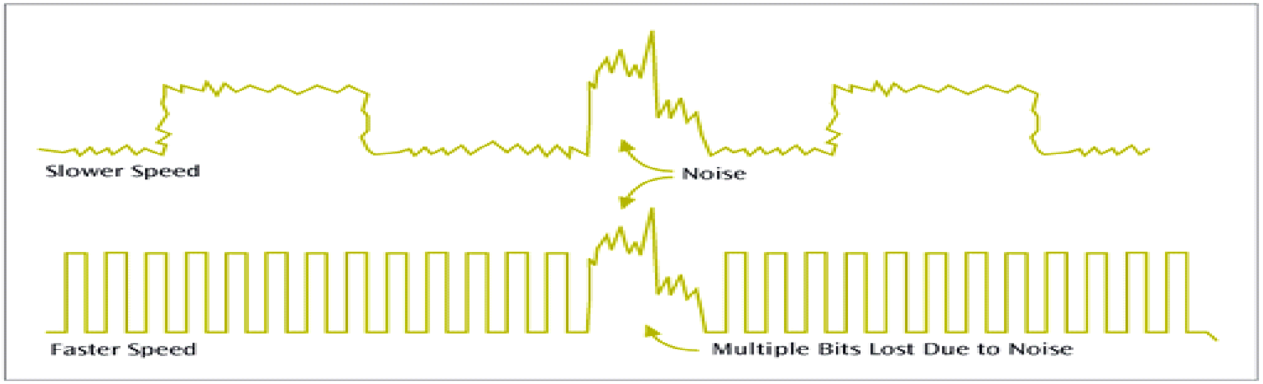


Figure 6-3
Transmission speed and its relationship to noise



Channel Capacity

- Channel capacity is the maximum rate at which the data can be transmitted over a given communication path, or channel, under given conditions.
- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium

Nyquist Bandwidth

- Nyquist states that if the rate of signal transmission is 2B, then a signal with frequencies no greater than B is sufficient to carry the signal rate.
- Nyquist's formula indicates that all the other things being equal, doubling the bandwidth, doubles the data rate

$$C = 2B \log_2 M$$

Where, M = number of discrete voltage levels

C = capacity of channel

B = Bandwidth of the signal

Shannon Capacity Formula

- At a given noise level, the higher the data rate, the higher the error rate.
- The Shannon's result is that the maximum error free channel capacity is:

$$C = B \log_2 (1+SNR)$$

Where, C = capacity of channel in bits per second

B = Bandwidth of the signal in Hertz

SNR = Signal to Noise Ratio

(SNR)dB = 10 log10 (signal power/noise)

High SNR means a high quality signal and low number of required intermediate repeaters

As bandwidth increases, SNR decreases because more noise will be admitted to the system.

Example

Example 1

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

Solution

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Example

Example 2

Consider the same noiseless channel, transmitting a signal with four signal levels (for each level, we send two bits). The maximum bit rate can be calculated as:

Solution

$$\text{Bit Rate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

Example

Example 3

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity is calculated as

Solution

$$C = B \log_2 (1 + SNR) = B \log_2 (1 + 0)$$

$$= B \log_2 (1) = B \times 0 = 0$$

Example

Example 4

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 Hz to 3300 Hz). The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

Solution

$$C = B \log_2 (1 + SNR) = 3000 \log_2 (1 + 3162)$$
$$= 3000 \log_2 (3163)$$
$$C = 3000 \times 11.62 = 34{,}860 \text{ bps}$$

Example

Example 5

We have a channel with a 1 MHz bandwidth. The SNR for this channel is 63; what is the appropriate bit rate and signal level?

Solution

First, we use the Shannon formula to find our upper limit.

$$C = B \log_2 (1 + SNR) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 (64) = 6 \text{ Mbps}$$

Then we use the Nyquist formula to find the number of signal levels.

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \rightarrow L = 4$$