Introduction to Telecommunication Systems
Lecture 4

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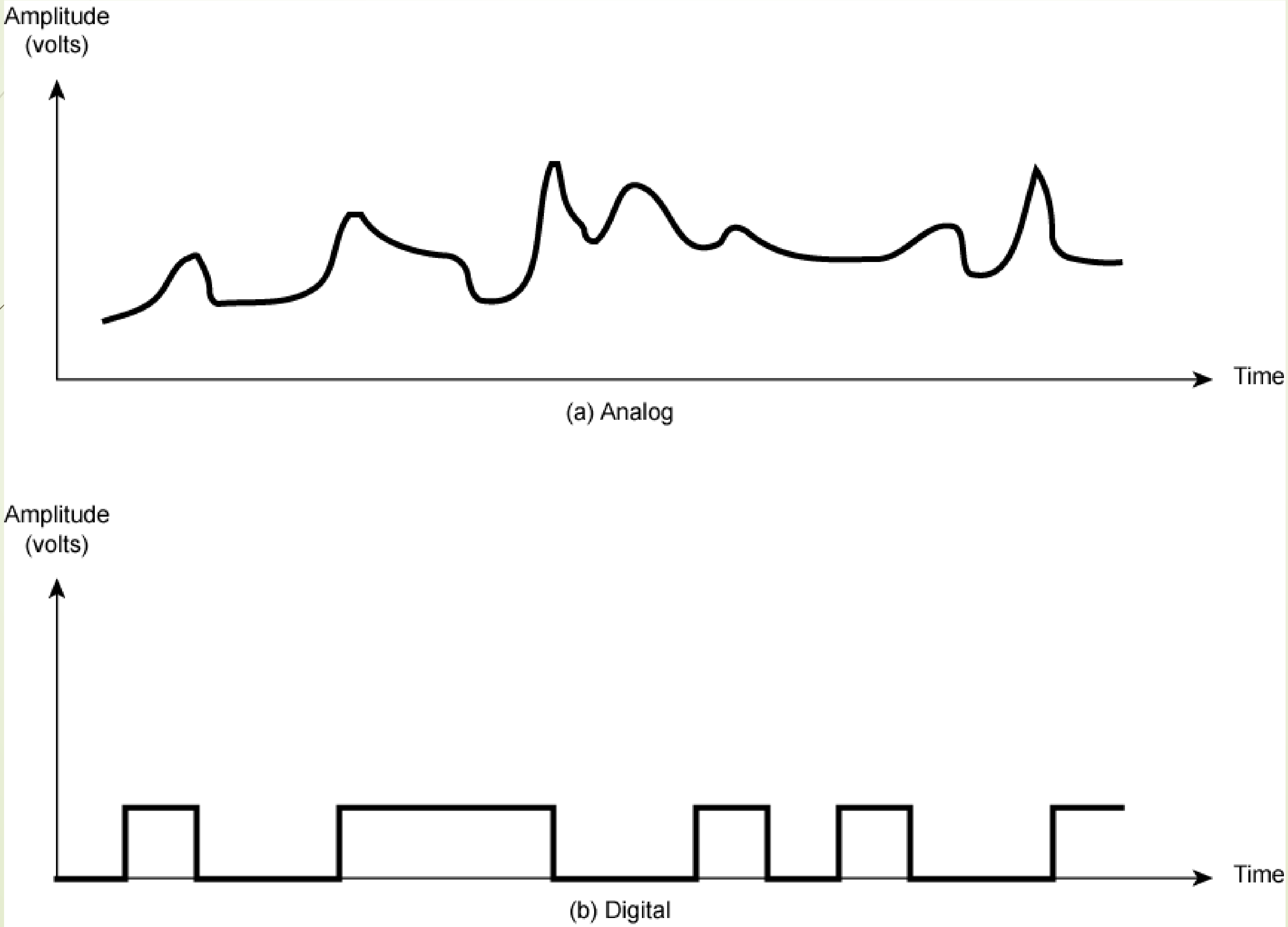
Analog & Digital Signals

- Data can be analog or digital.
- Analog data are continuous and take continuous values. Varies in a smooth way over time.
- Digital data have discrete states and take discrete values. Maintains a constant level then changes to another constant level.
- 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. This is called time domain.

Analog & Digital Signals



Periodic and Nonperiodic Signals

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

Sine Wave

- The sine wave is the most fundamental form of a periodic analog signal.
- A sine wave can be represented by three parameters:
  - Peak amplitude,
  - Frequency,
  - Phase.
- Peak amplitude:
  - is maximum strength of signal
  - For electric signals, peak amplitude is normally measured in volts.

Sine Wave

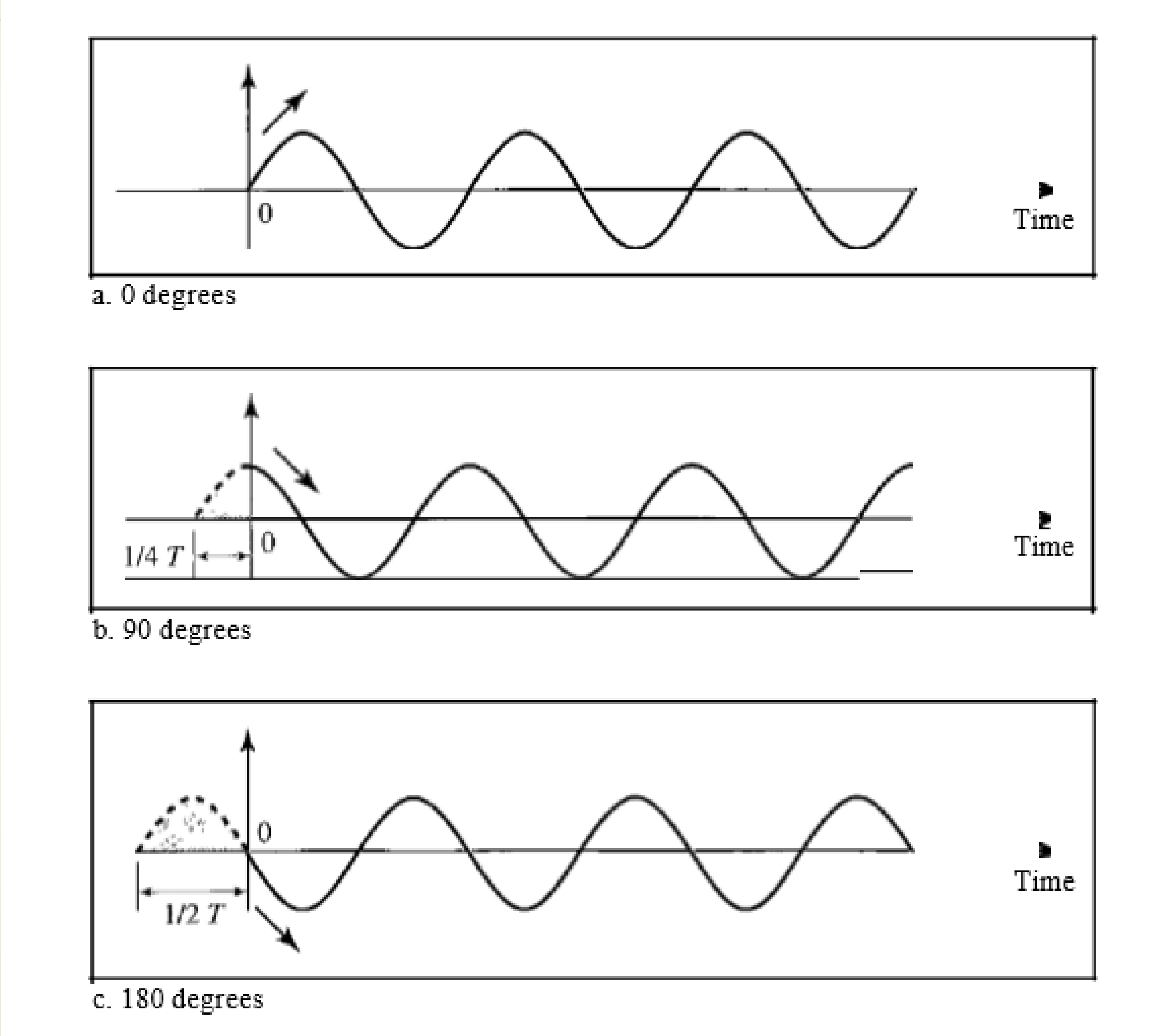
- Time Period and Frequency:
  - Time Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
  - Frequency refers to the number of time periods in I s. Note that period and frequency are just one characteristic defined in two ways.
  - Frequency and time period are the inverse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

$$F = 1/T \text{ and } T=1/f$$

Sine Wave

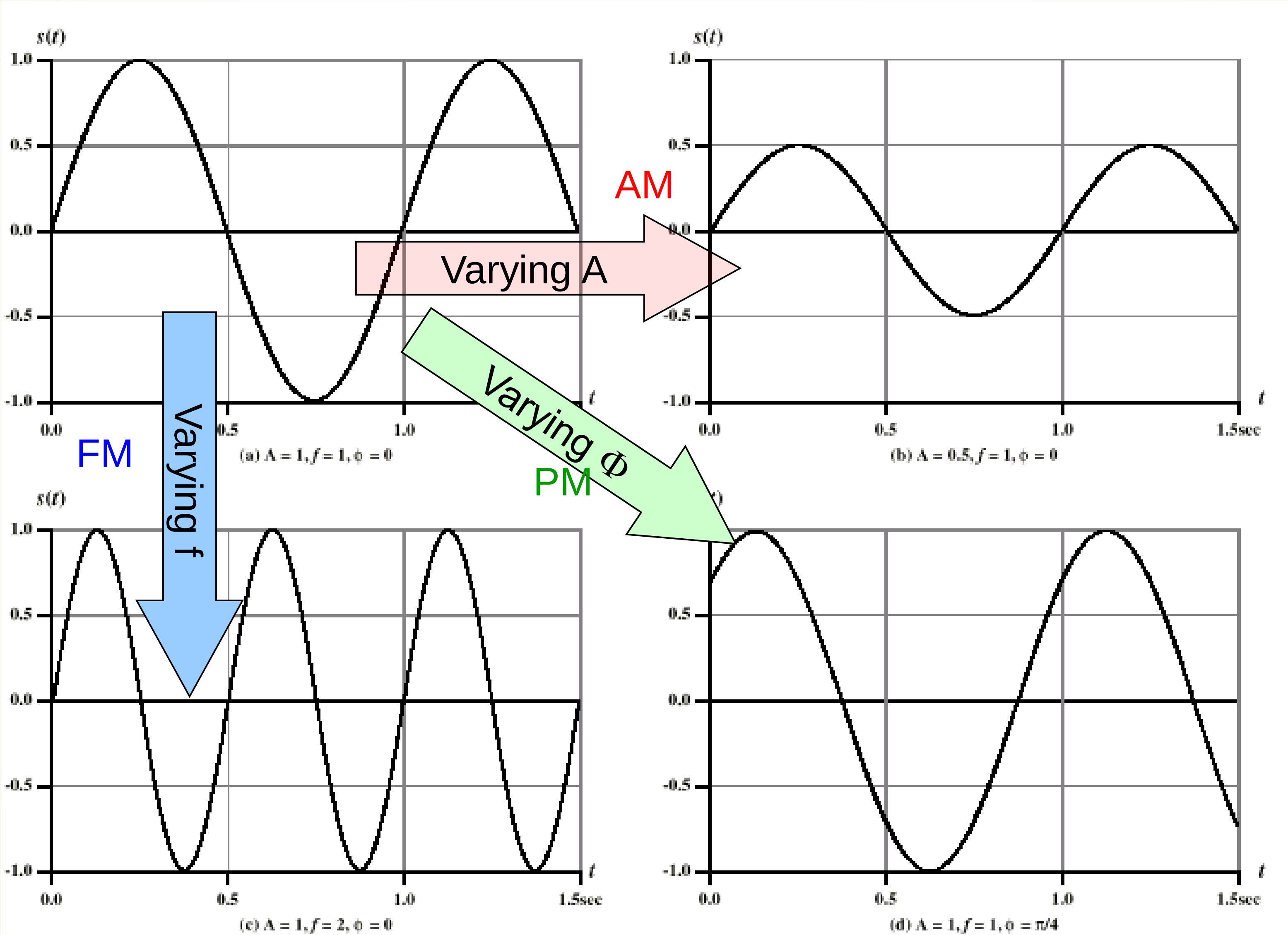
- Phase (ϕ)
  - Phase is a measure of the relative position in time within a single period of a signal.
  - The term phase describes the position of the waveform relative to time O. If we think of the wave as something that can be shifted backward or forward along the time axis, phase describes the amount of that shift. It indicates the status of the first cycle.

Sine Wave



Three sine waves with the same amplitude and frequency, but different phases.

Varying Sine Waves



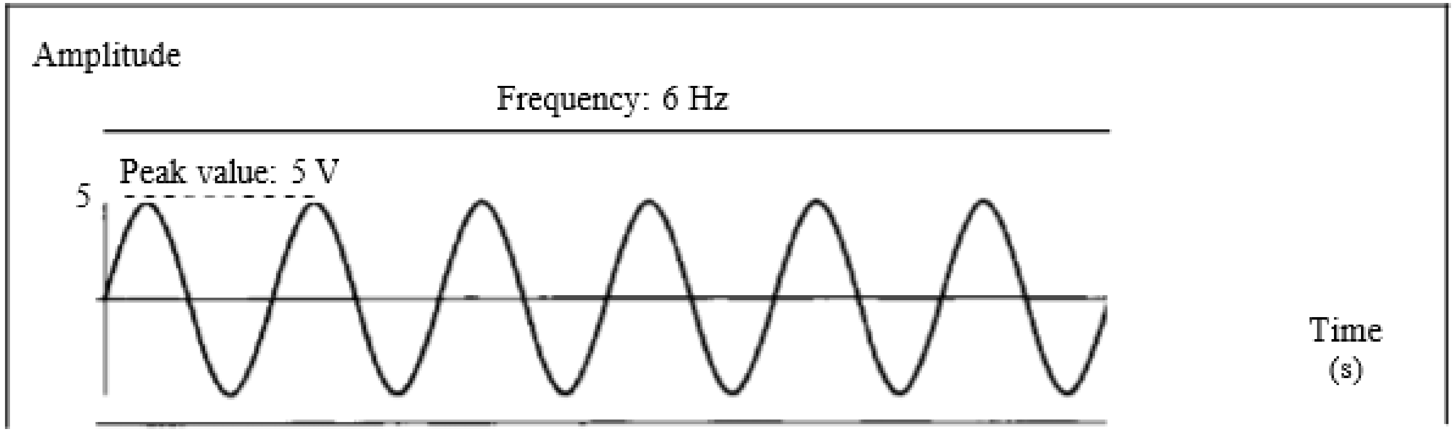
Wavelength

- Wavelength is the distance a simple signal can travel in one period.
- Distance between two points of corresponding phase in two consecutive cycles
- λ
- Assuming signal velocity *v*
  - $\lambda = vT$
  - $\lambda f = v$
  - $c = 3*10^8\ ms^{-1}$ (speed of light in free space)

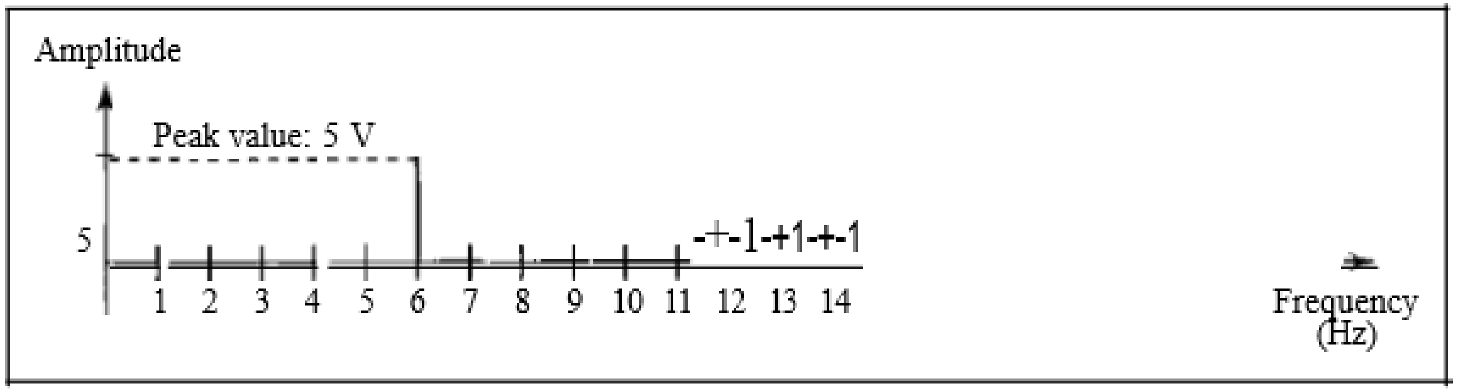
Time and Frequency Domains

- 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.

Time and Frequency Domains



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

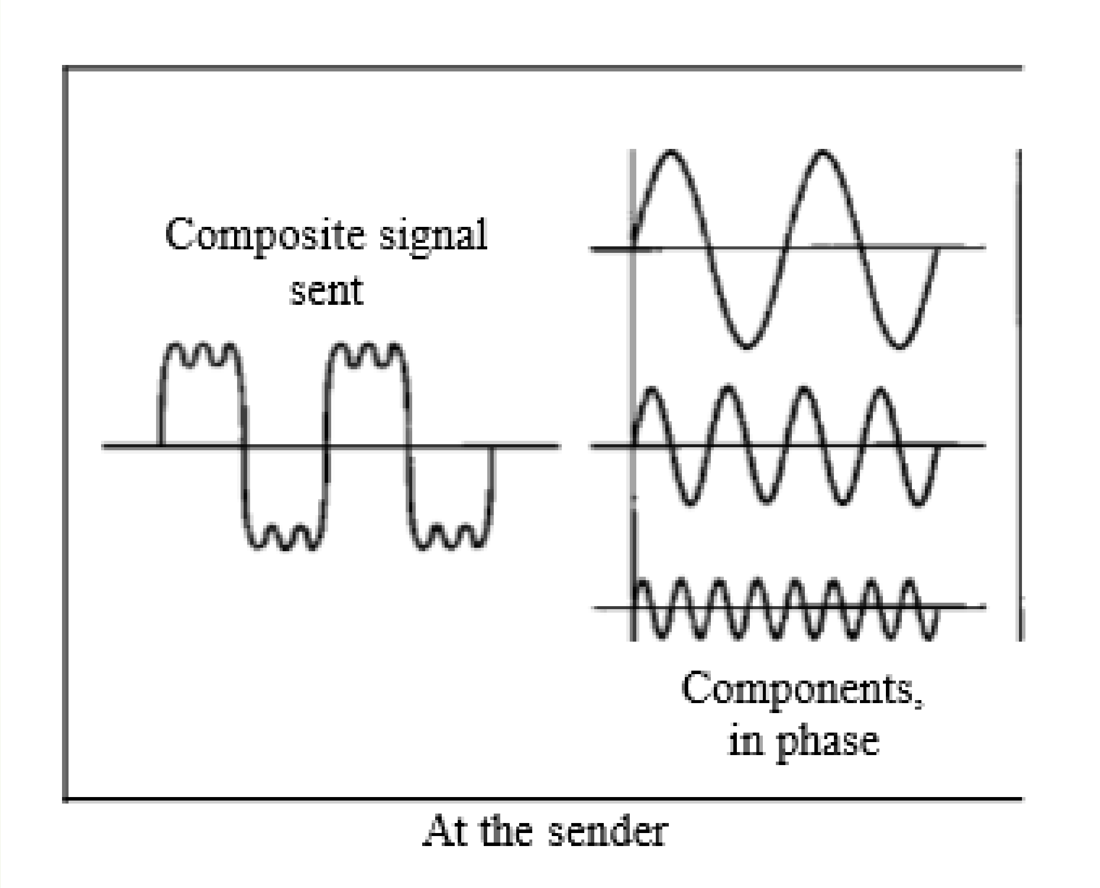


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

Frequency Domain Concepts

- A single frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.
- Can be shown (Fourier analysis) that any signal is made up of component sine waves.
- Can plot frequency domain functions.

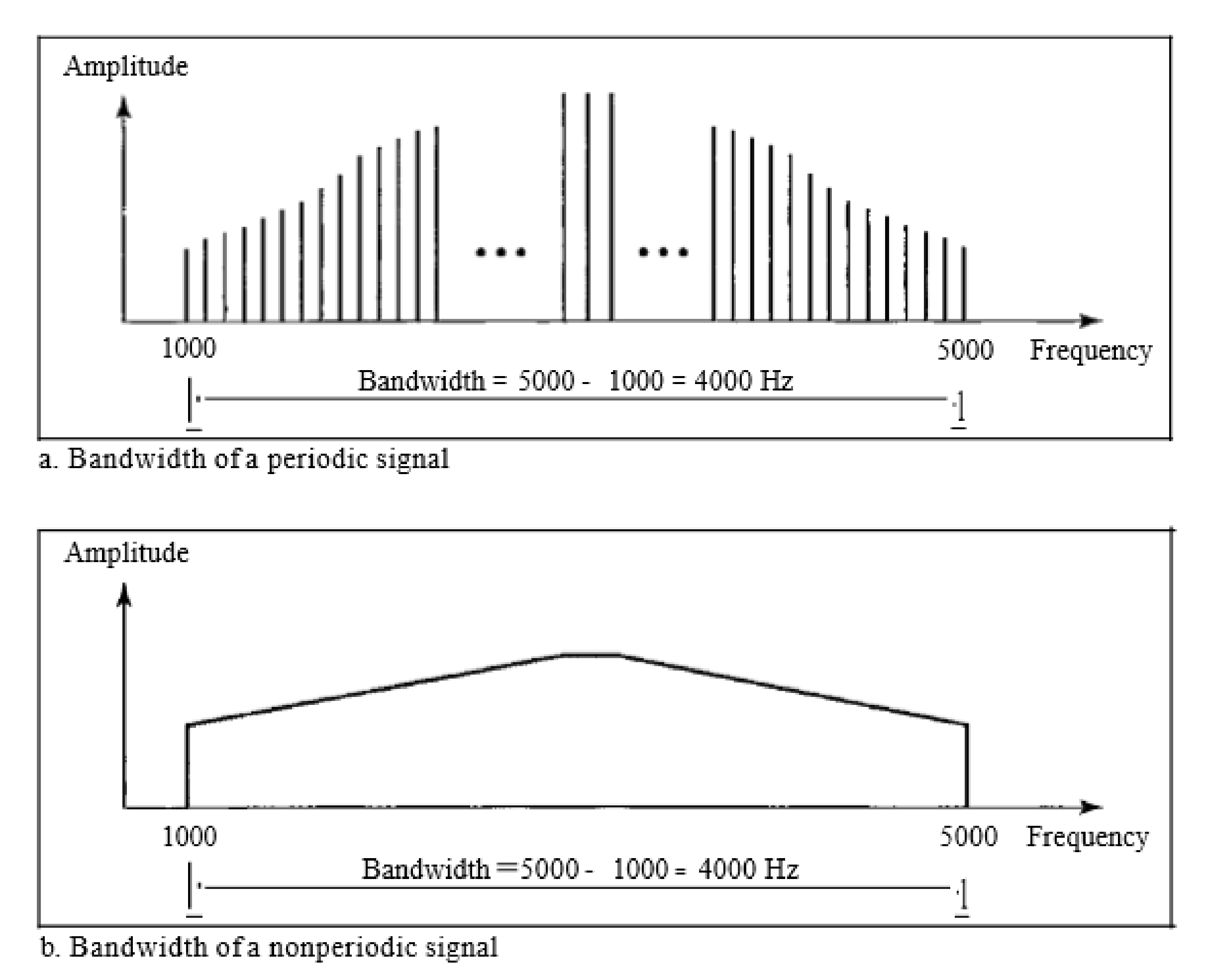
Composite Signal



Bandwidth

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

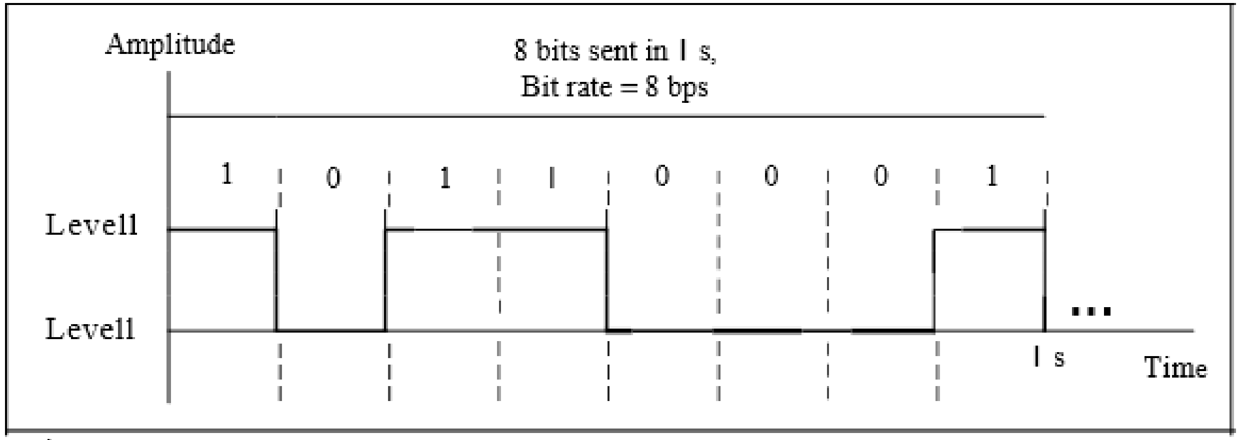
Bandwidth


Amplitude
1000
5000
Frequency
Bandwidth = 5000 - 1000 = 4000 Hz
a. Bandwidth of a periodic signal
Amplitude
1000
5000
Frequency
Bandwidth = 5000 - 1000 = 4000 Hz
b. Bandwidth of a nonperiodic signal

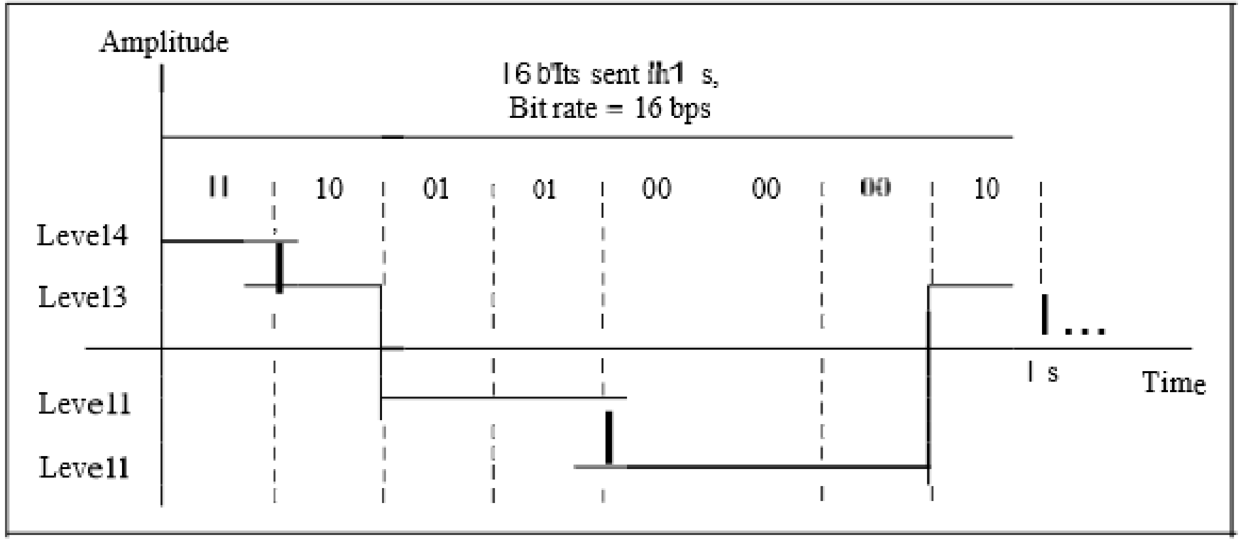
Digital Signals

- Information can also be represented by a digital signal.
- For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels.
- Figure shows two signals, one with two levels and the other with four.

Digital Signals



a. A digital signal with two levels



b. A digital signal with four levels

Two digital signals: one with two signal levels and the other with four signal levels

Digital Signals

Bit Rate

- Most digital signals are nonperiodic, and thus time period and frequency are not appropriate characteristics.
- Another term-bit rate (instead of frequency) is used to describe digital signals.
- The bit rate is the number of bits sent in 1s, expressed in bits per second (bps).

Digital Signals

Bit Length

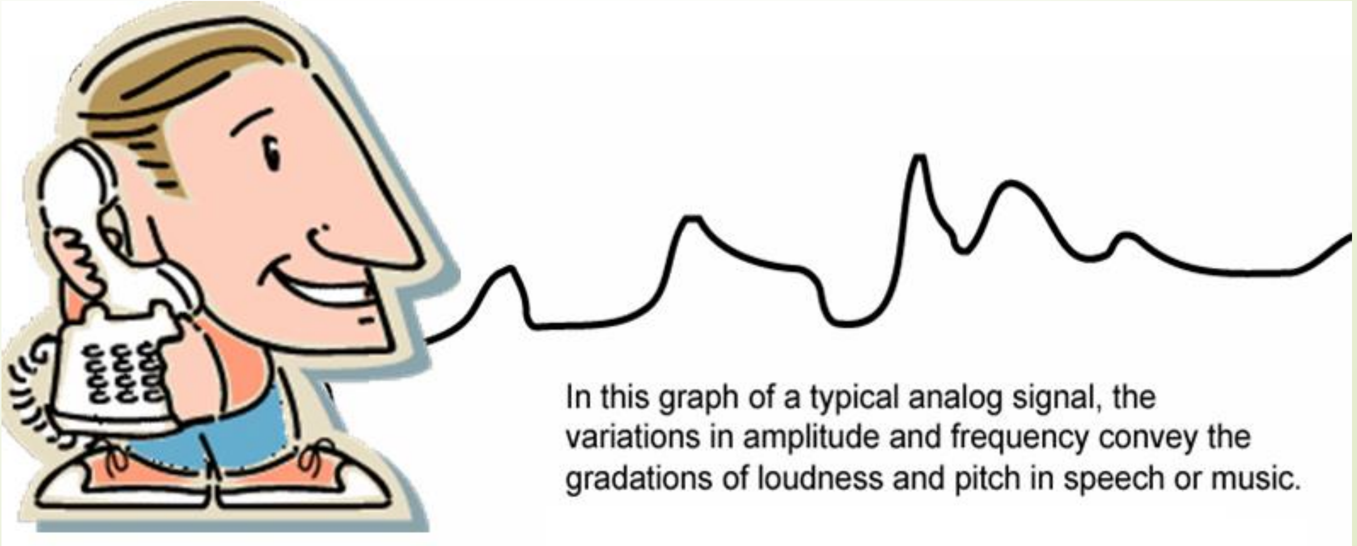
- We discussed the concept of the wavelength for an analog signal: the distance one cycle occupies on the transmission medium.
- We can define something similar for a digital signal: the bit length. The bit length is the distance one bit occupies on the transmission medium.
- Bit length = propagation speed x bit duration.

Transmission of Digital Signals

- We can transmit a digital signal by using one of two different approaches:
  - Baseband transmission: Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.
  - Broadband transmission (using modulation): Broadband transmission or modulation means changing the digital signal to an analog signal for transmission.

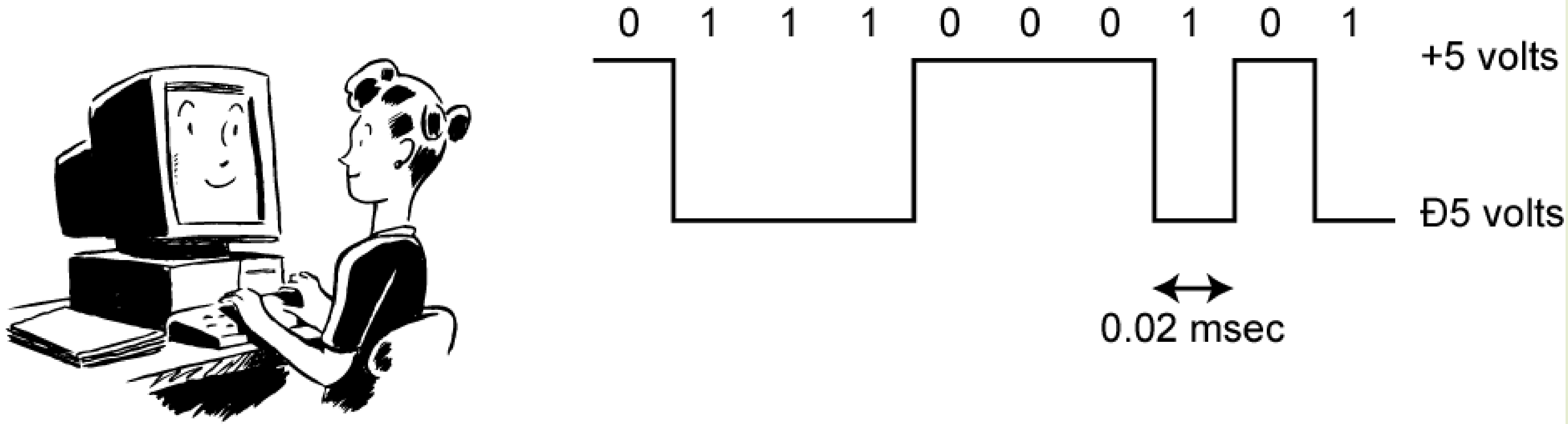
Conventional Telephony: Analog data – Analog Signal

- Telephone mouthpiece converts mechanical voice analog data into electromagnetic analog electrical signal
- Signal travels on telephone lines
- At receiver, speaker re-converts received electrical signal to voice



Binary Digital Data

- From computer terminals etc.
- Two dc components
- Bandwidth depends on data rate

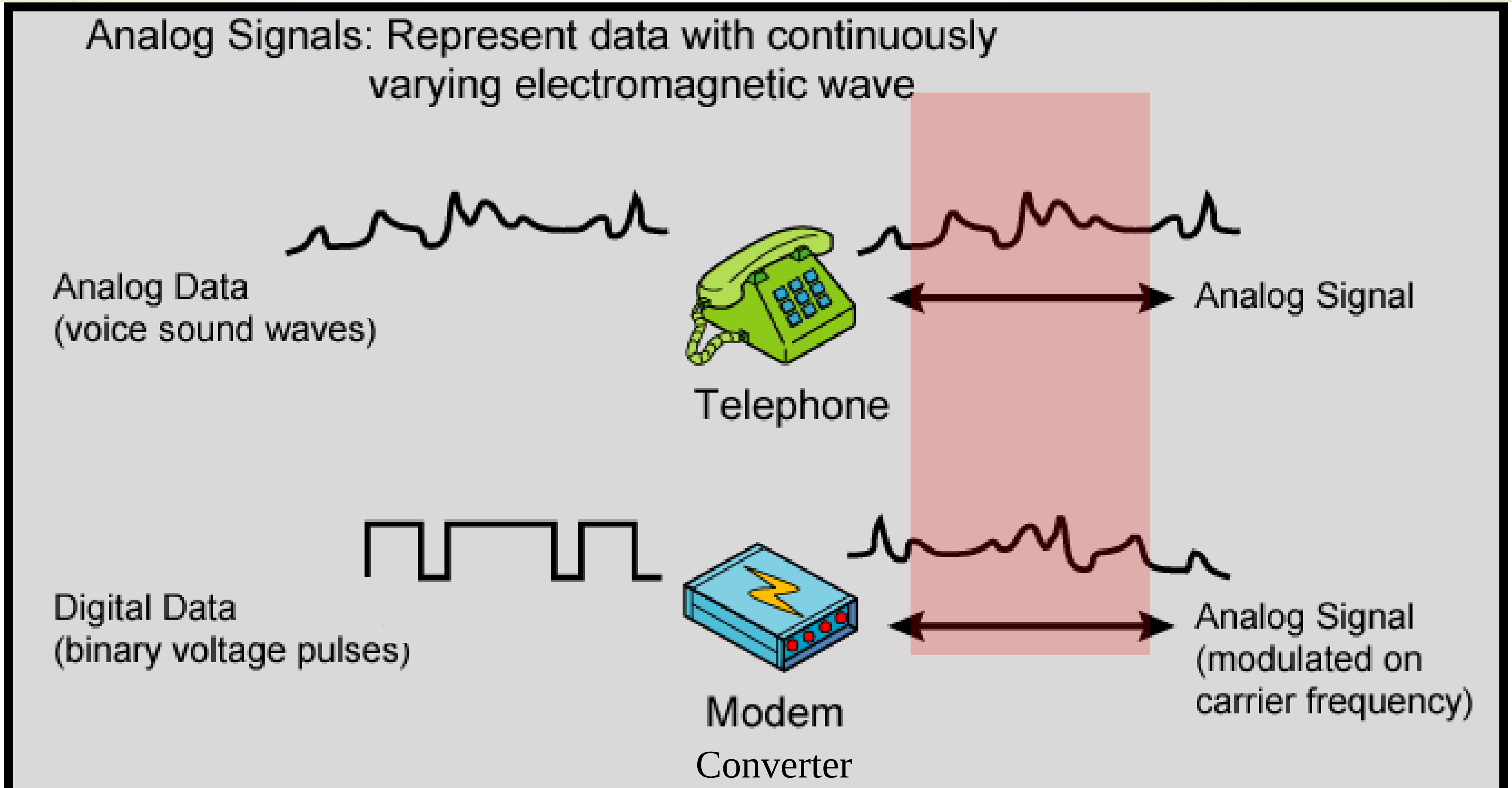


User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Ð5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).

Data and Signal combinations

- We have seen above: (data and signal of same type)
  - Analog signals carrying analog data: Telephony, Video
  - Digital signals carrying digital data: Keyboard to PC
    - Simple- one only needs a transducer/transceiver
- But we may also have: (data and signal of different types)
  - Analog signal representing digital data: Data over telephone wires (using a modem)
  - Digital signal representing analog data: CD Audio, PCM (pulse code modulation) (using a codec)
    - More complex- We Need a converter
- So, all the four data-signal combinations are possible!

Analog Signals can carry Analog Data or Digital Data

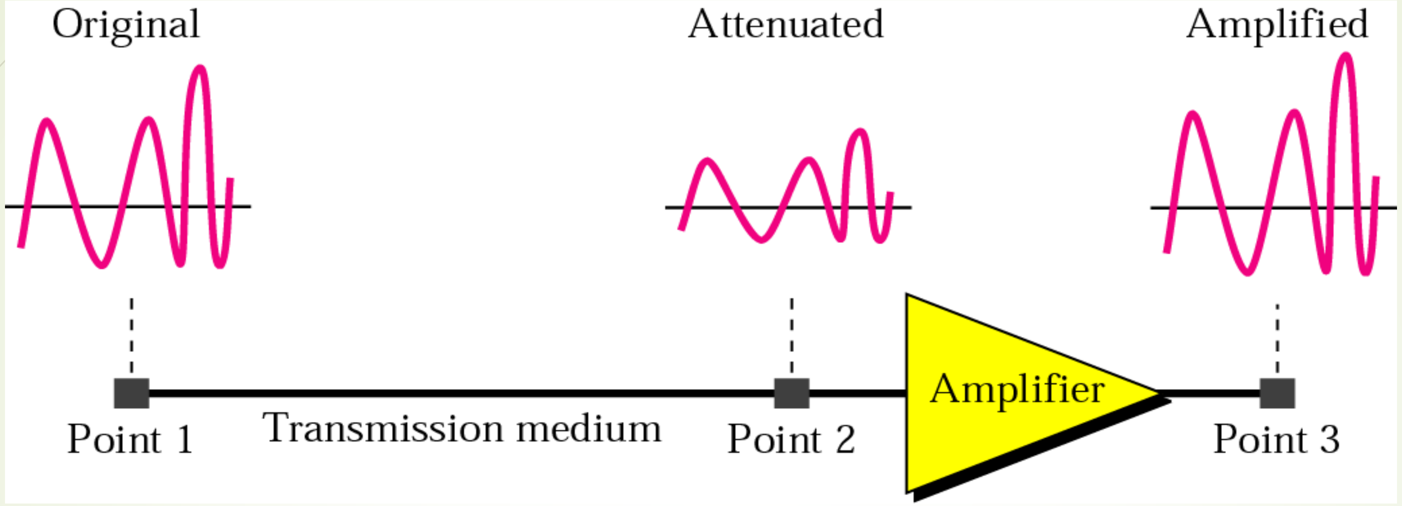


We need a converter when the signal type is different from the data type

Transmission Impairment

- Signals travel through transmission media, which are not perfect.
- The imperfection causes signal impairment. Signal received may differ from signal transmitted.
- There are three causes of transmission impairment:
  - Attenuation,
  - Distortion,
  - Noise

Attenuation

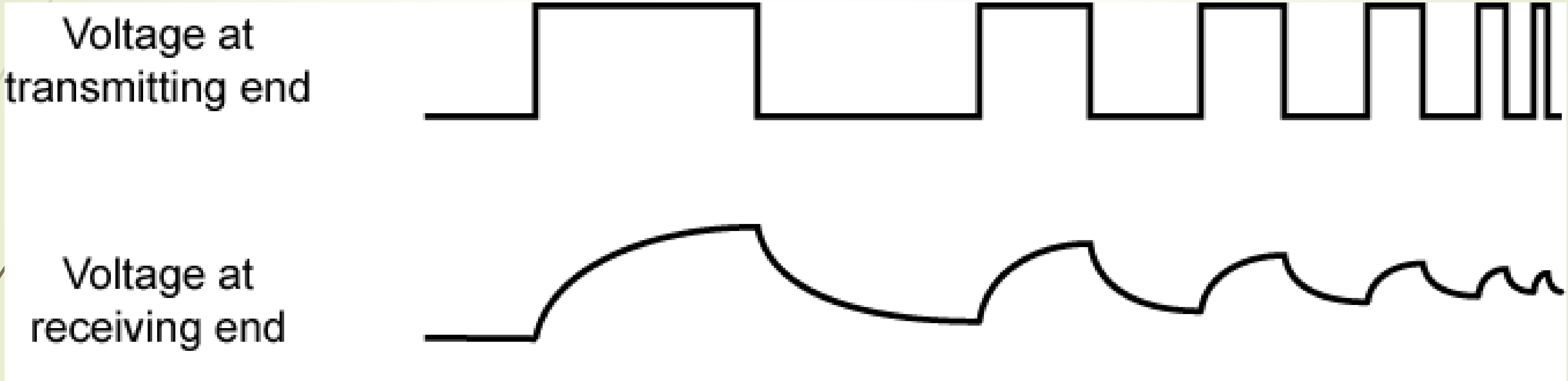


- Attenuation means loss of energy. Signal strength falls off with distance.
- Depends on medium.

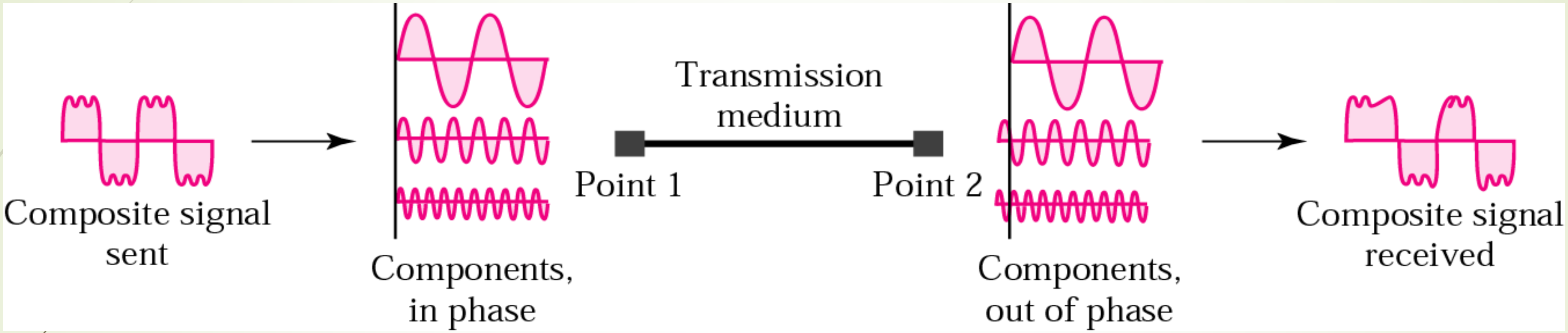
Attenuation

- 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.
- Received signal strength:
  - must be enough to be detected
  - must be sufficiently higher than noise to be received without error.

Attenuation of Digital Signals



Delay Distortion

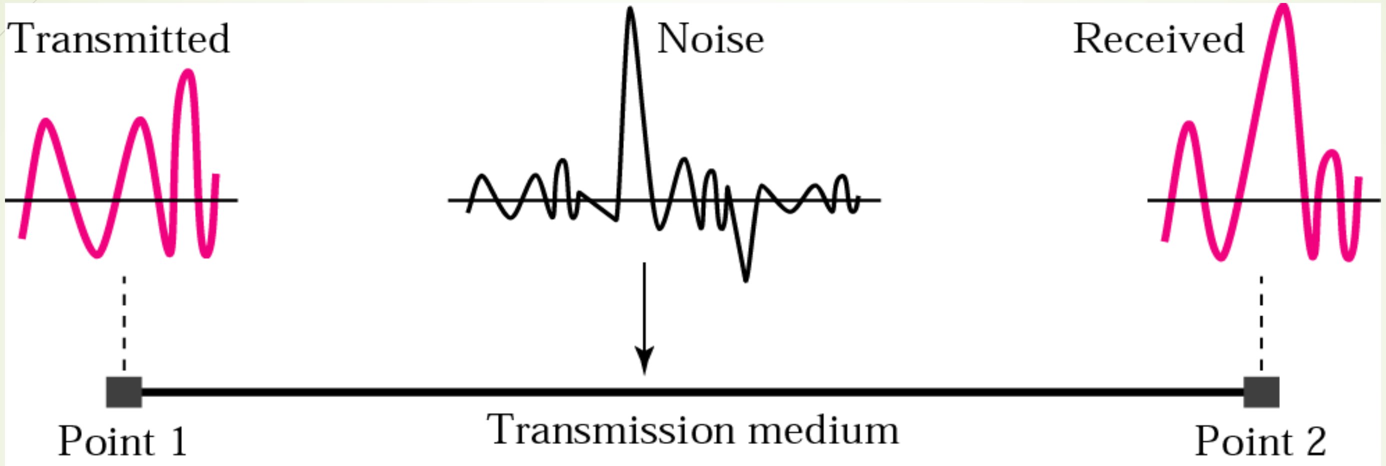


- Distortion means that the signal changes its form or shape.
- Distortion can occur in a composite signal made of different frequencies. Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination.

Delay Distortion

- 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.
- Affects digital data more: due to bit spill-over (timing is more critical here than for analog data).

Noise



- Additional signals inserted between transmitter and receiver
- Thermal
  - Due to thermal agitation of electrons
  - Uniformly distributed
  - White noise

Noise

- Induced Noise
  - Induced noise comes from sources such as motors and appliances.
- Crosstalk
  - A signal from one line is picked up by another.
- Impulse
  - Irregular pulses or spikes
  - e.g. External electromagnetic interference, from power lines, lightning, and so on.
  - Short duration
  - High amplitude

Noise

- Signal-to-Noise Ratio (SNR)
- To find the theoretical bit rate limit, we need to know the ratio of the signal power to the noise power. The signal-to-noise ratio is defined as
- SNR = average signal power/average noise power

Data Rate Limits

- A very important consideration in data communications is how fast we can send data, in bits per second. over a channel.
- Data rate depends on three factors:
  - The bandwidth available
  - The level of the signals we use
  - The quality of the channel (the level of noise)

Data Rate Limits

- Two theoretical formulas were developed to calculate the data rate:
  - Nyquist Bit Rate for a noiseless channel.
  - Shannon Bit Rate for a noisy channel.

Noiseless Channel: Nyquist Bit Rate

- For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate:
  - Bit Rate= 2 x bandwidth x 10g2 L
- In this formula, bandwidth is the bandwidth of the channel,
- L is the number of signal levels used to represent data, and
- Bit Rate is the bit rate in bits per second.

Noiseless Channel: Nyquist Bit Rate

- According to the formula, given a specific bandwidth, we can have any bit rate we want by increasing the number of signa1 1eve1s.
- But when we increase the number of signal1eve1s, we impose a burden on the receiver. If the number of levels in a signal is just 2, the receiver can easily distinguish between a 0 and a 1.
- If the level of a signal is 64, the receiver must be very sophisticated to distinguish between 64 different levels.
- Increasing the levels of a signal may reduce the reliability of the system.

Noisy Channel: Shannon Capacity

- In reality, we cannot have a noiseless channel; the channel is always noisy.
- In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel:
  - Capacity =bandwidth X log2 (1 +SNR)
- In this formula, bandwidth is the bandwidth of the channel,
- SNR is the signal-to noise ratio, and capacity is the capacity of the channel in bits per second.

Noisy Channel: Shannon Capacity

- Note that in the Shannon formula there is no indication of the signal level, which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel.
- In other words, the formula defines a characteristic of the channel, not the method of transmission.

End of Slides