Lecture 2

Signals

Fall Term 2013-14

Sounds and Human Voice

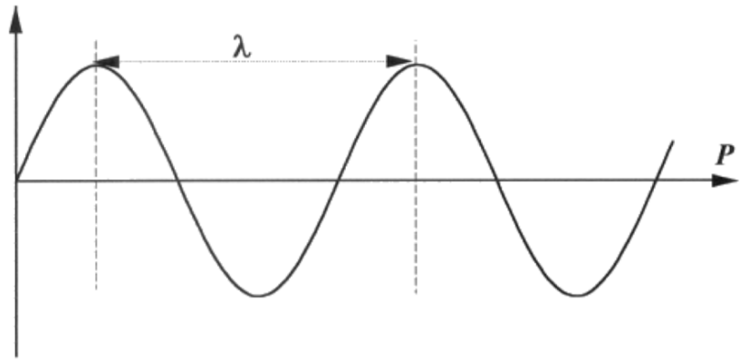
- The sound we hear consists of very small fluctuations above and below local barometric pressure levels that are traveling through an elastic medium, which is commonly air, in the form of sine waves, and at a speed such that:

$$\lambda = \frac{c}{f}$$

where: λ ..… wavelength (m)

c .….sound velocity (= 344 m/s)

f .…..frequency (Hz)



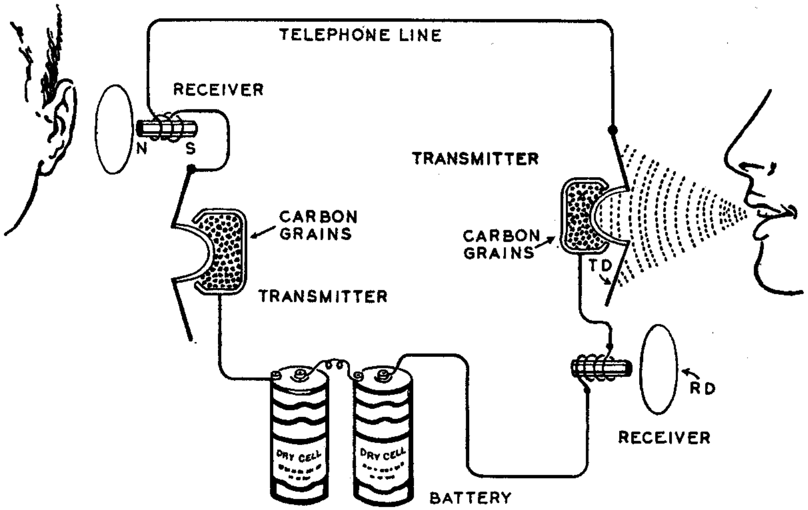
Sounds and Human Voice (cont.)

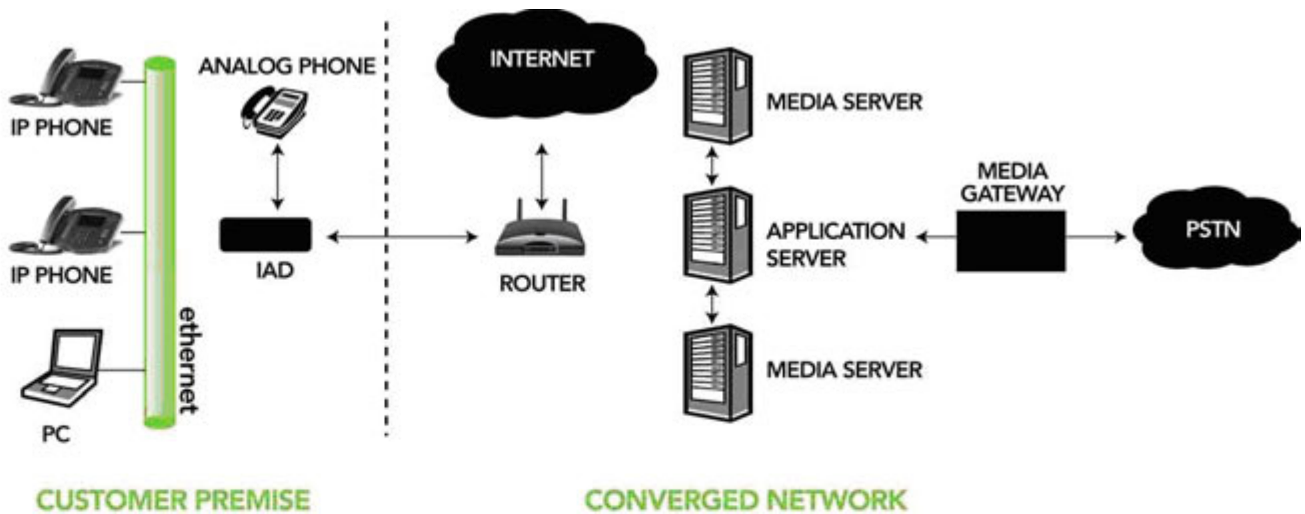
- When these sound fluctuations (waveforms) strike our ear drums they cause them to vibrate.
- This vibration is transmitted through the middle and inner parts of the ear to excite the nerve cells.
- That is, an ear is an energy converter of sound into electro-chemical energy transmitted to the brain that will understand these information.

Why Signals are Needed?

- If this is the case, why do we need signals???
- To send data for distances through which human voice can not reach!!!
- (You use a phone in AUB to call your parents because they can not hear you not matter how high you shout!!!!)

How does a phone system work





To be transmitted, data must be transformed to electromagnetic signals.

Topics discussed in this section:

- Analog and Digital Data
- Analog and Digital Signals
- Periodic and
- Non- periodic Signals

Analog and Digital Data

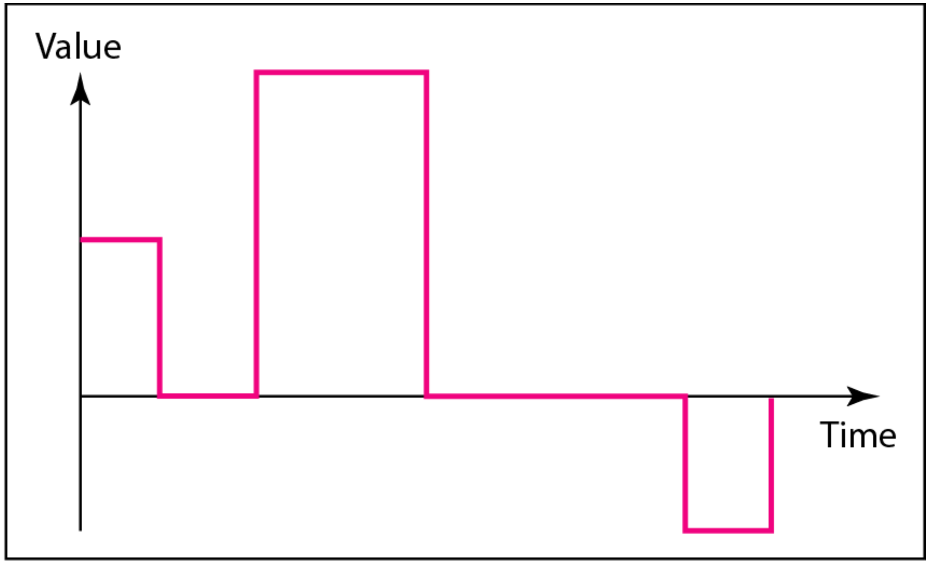
- Data can be analog or digital.
- Analog data refers to information that is continuous; Analog data take on continuous values.
- Digital data refers to information that has discrete states. Digital data take on discrete values.

Analog and Digital Signals

- Signals can be analog or digital.
- Analog signals can have an infinite number of values in a range.
- Digital signals can have only a limited number of values.

Figure 1: Comparison of analog and digital signals

a. Analog signal



b. Digital signal

PERIODIC ANALOG SIGNALS

- In data communications, we commonly use periodic analog signals and non- periodic digital signals.

- Periodic analog signals can be classified as simple or composite.
  - A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
  - A composite periodic analog signal is composed of multiple sine waves.

PERIODIC ANALOG SIGNALS (cont.)

- Topics discussed in this section:
  - Sine Wave
  - Wavelength
  - Time and Frequency Domain
  - Composite Signal

Figure 2: A sine wave

$$c(t) = A\sin(\omega t + \phi)$$

Amplitude

Frequency

Phase

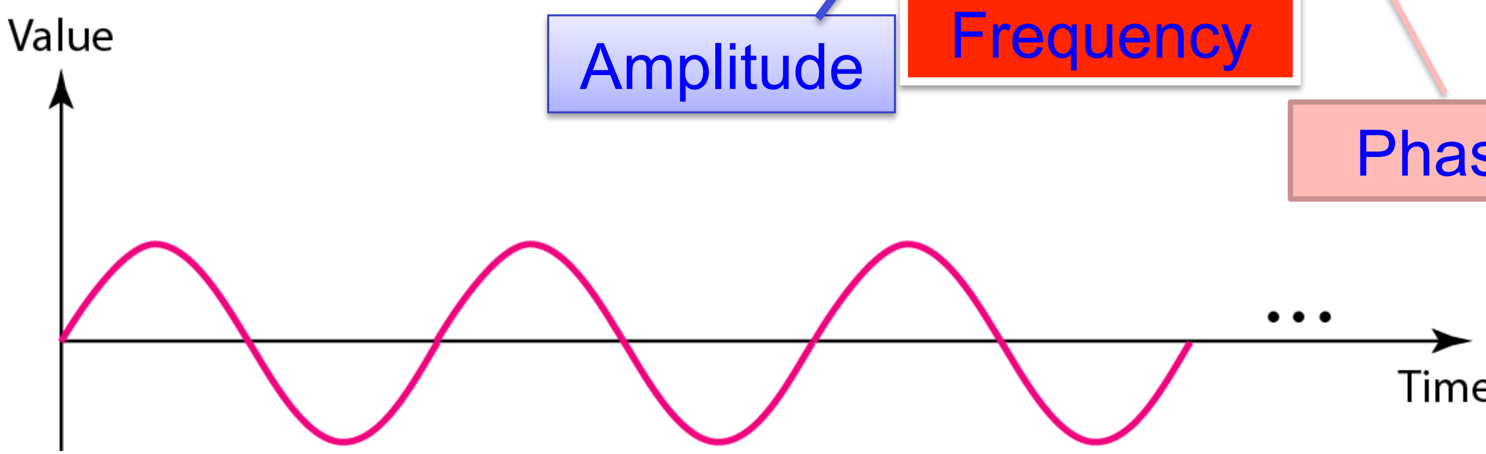
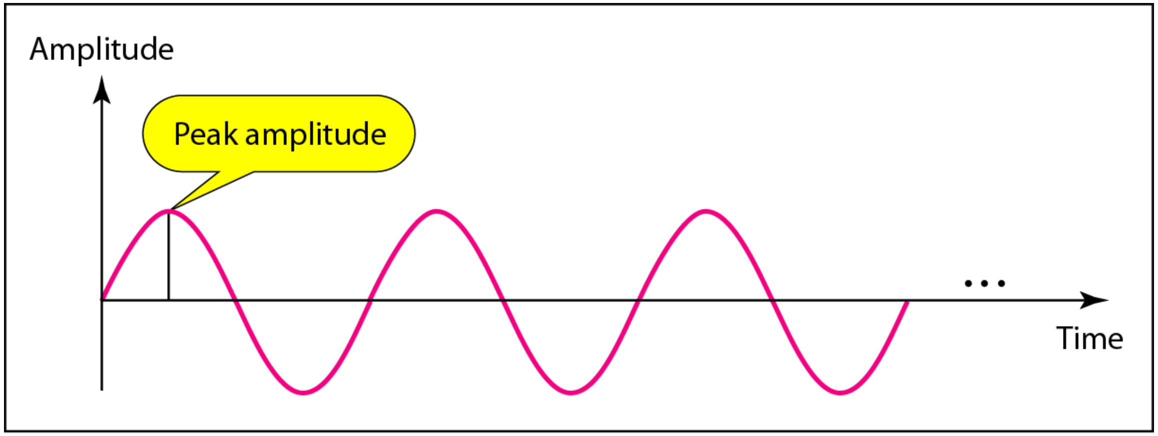
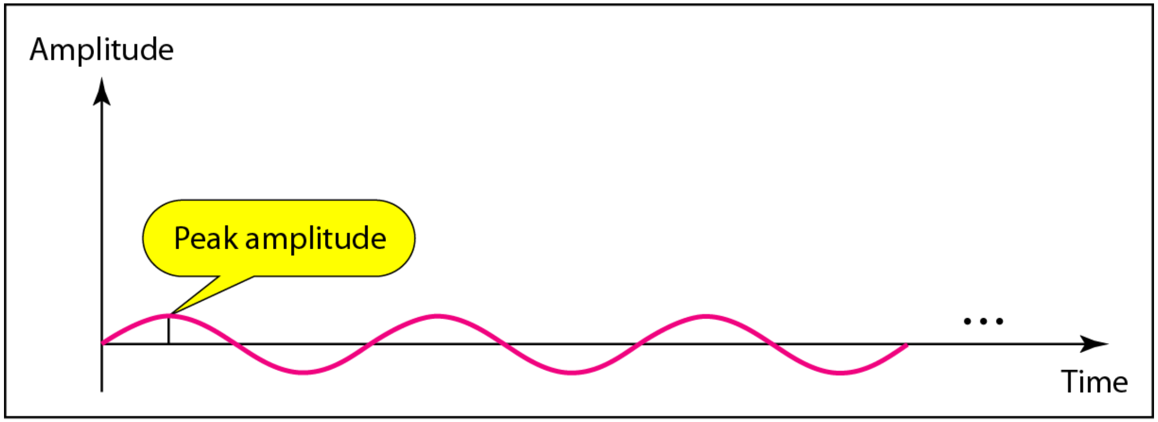


Figure 3: Two signals with the same phase and frequency, but different amplitudes



a. A signal with high peak amplitude

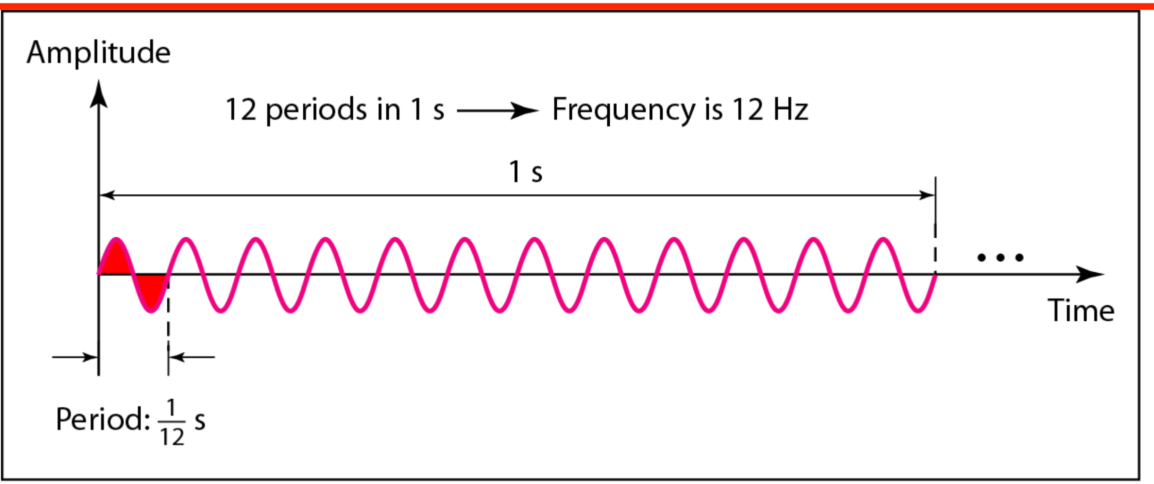


b. A signal with low peak amplitude

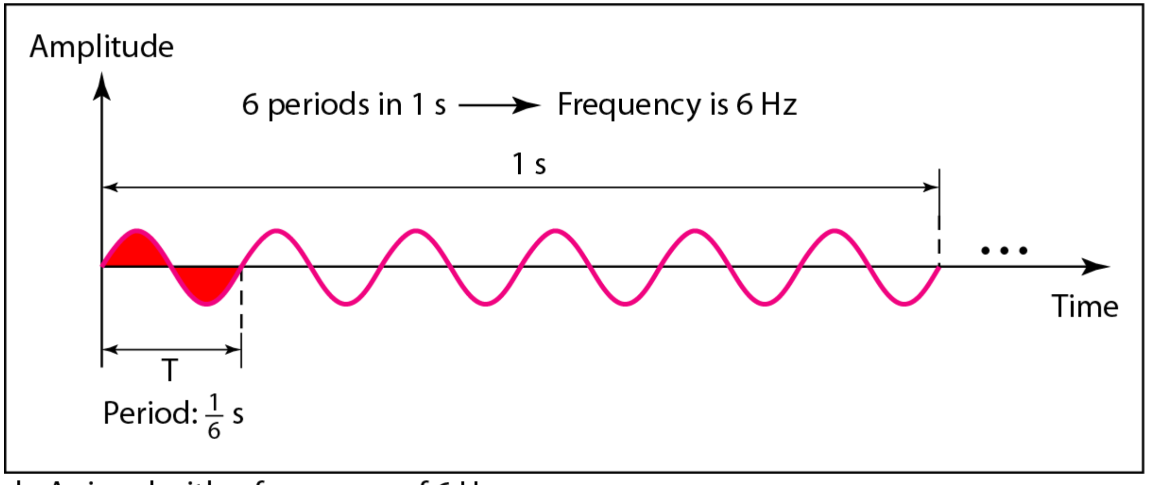
Frequency and period are the inverse of each other.

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

Figure 4: Two signals with the same amplitude and phase, but different frequencies



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Table 1: Units of period and frequency

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (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 50 Hz. The period of this sine wave can be determined as follows:

Solution:

$$T = \frac{1}{f} = \frac{1}{50} = 0.02s$$

Example 2:

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).

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

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

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.

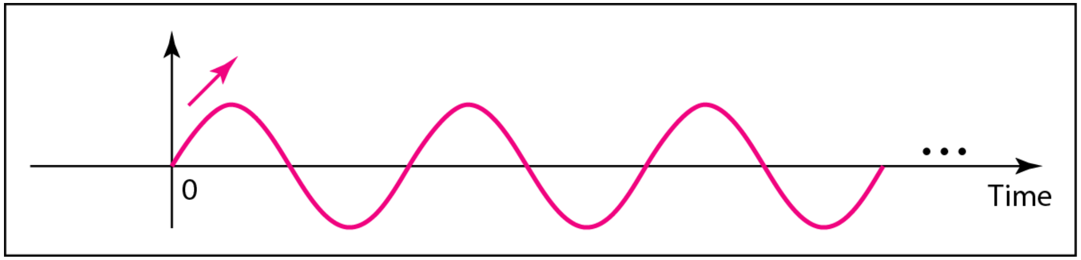
Phase describes the position of the waveform relative to time 0.

$$c(t) = A\sin(\omega t + \phi)$$

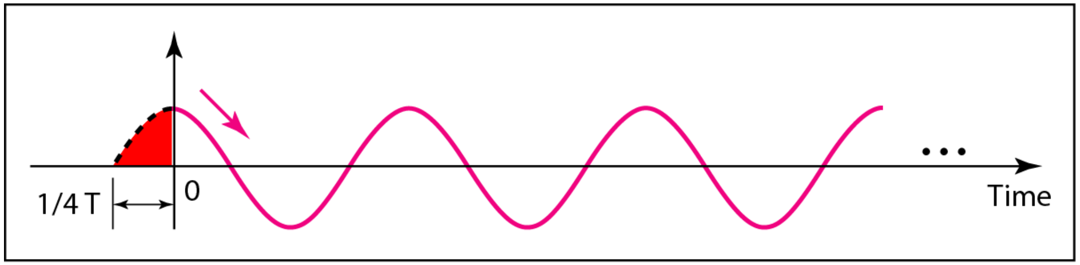
$$at \;\; t = 0s$$

$$c(t) = A\sin(\phi)$$

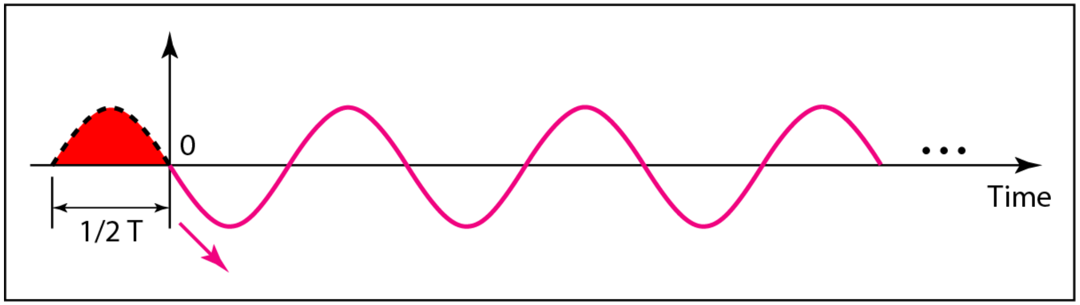
Figure 5: Three sine waves with the same amplitude and frequency, but different phases



a. 0 degrees



b. 90 degrees



c. 180 degrees

Example 3:

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

$$\boxed{\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}}$$

Figure 6: Wavelength and period

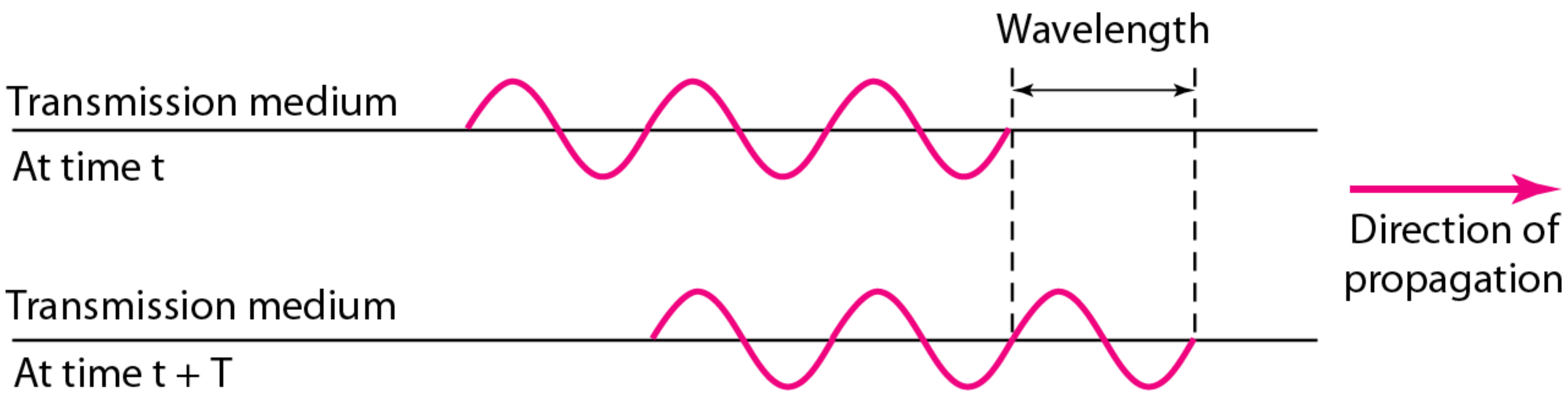
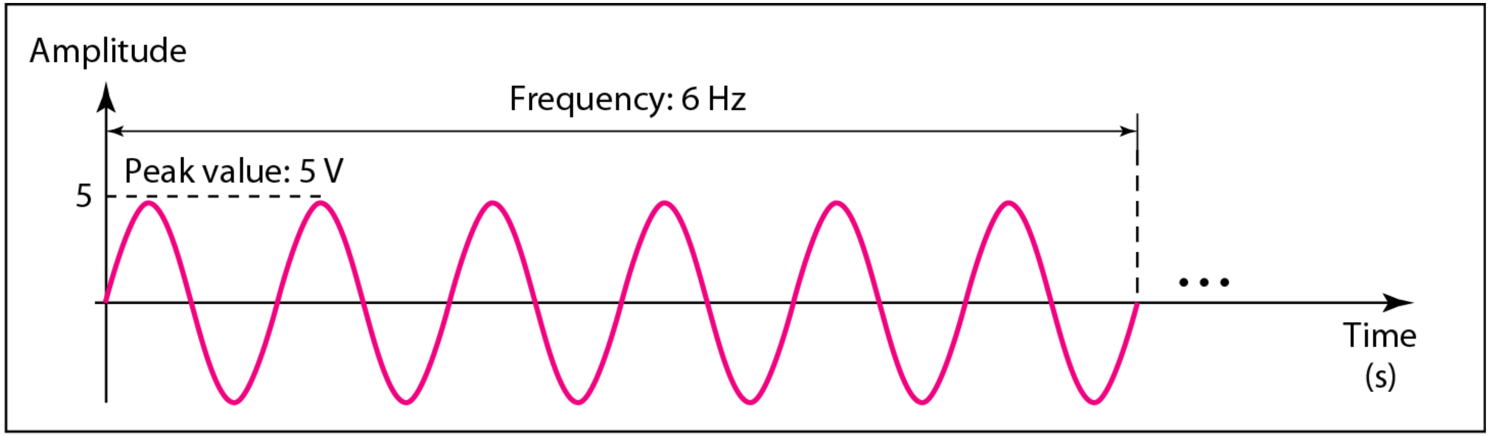
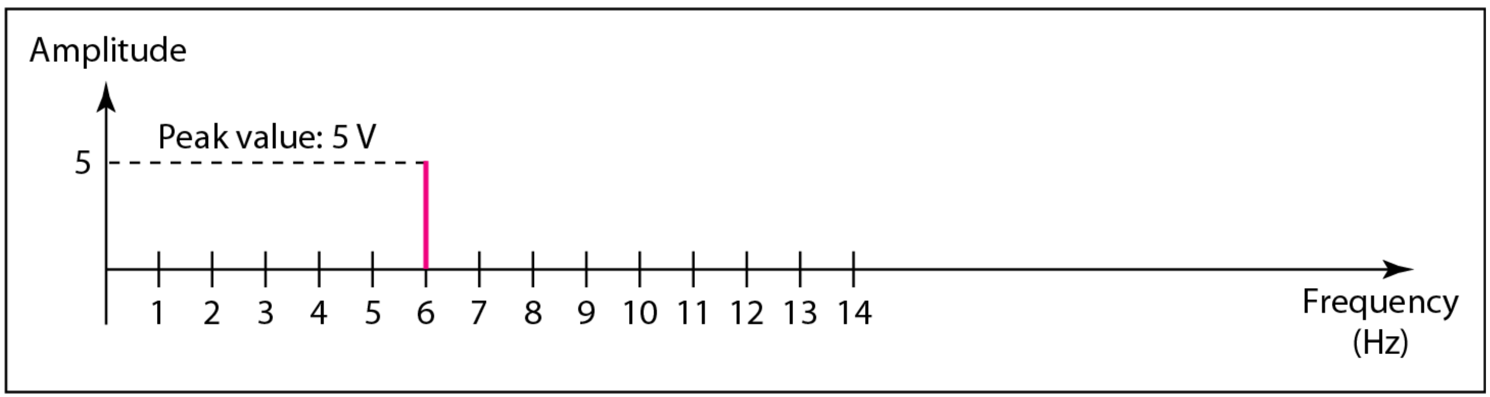


Figure 7 The time-domain and frequency-domain plots of a sine wave



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

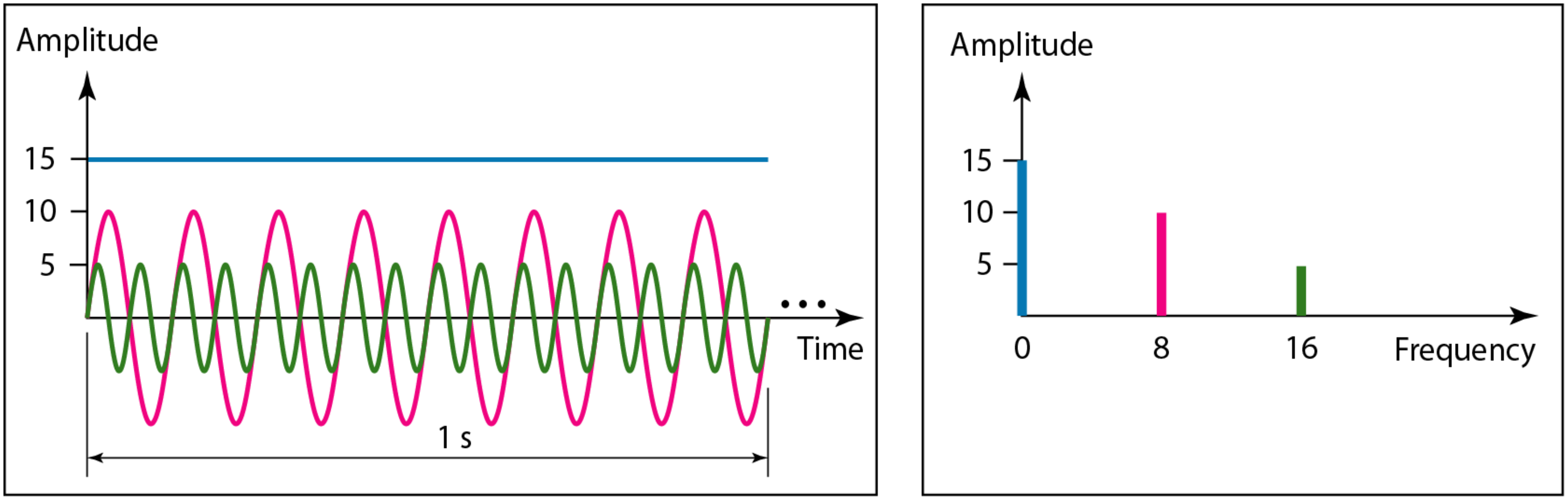


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Figure 8 The time domain and frequency domain of three sine waves

The frequency domain is more compact and useful when we are dealing with more than one sine wave.
For example, Figure 8 shows 3 sine waves, each with different amplitude and frequency. All can be represented by 3 spikes in the frequency domain.



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

b. Frequency-domain representation of the same three signals

Signals and Communication

- 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.

- According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Composite Signals and Periodicity

- If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies.
- If the composite signal is non-periodic, the decomposition gives a combination of sine waves with continuous frequencies.

Figure 9: A composite periodic signal

Example 4: Figure 9 shows a periodic composite signal with frequency f. This type of signal is not typical of those found in data communications.
We can consider it to be 3 alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.

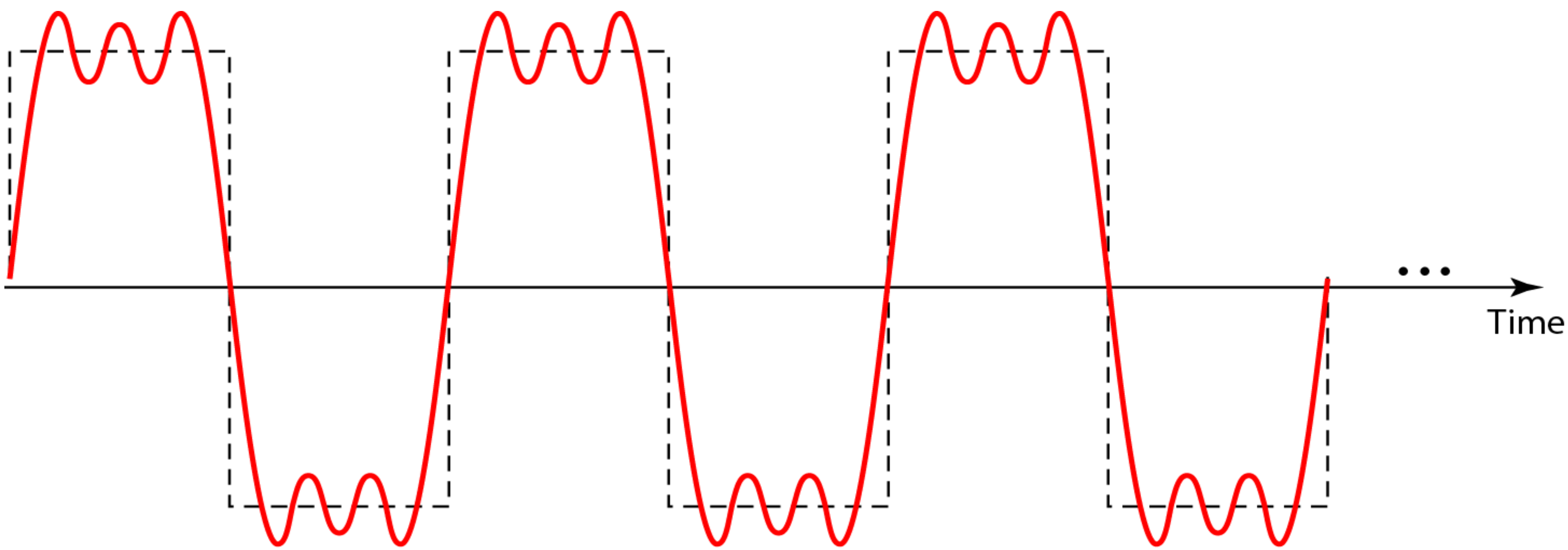
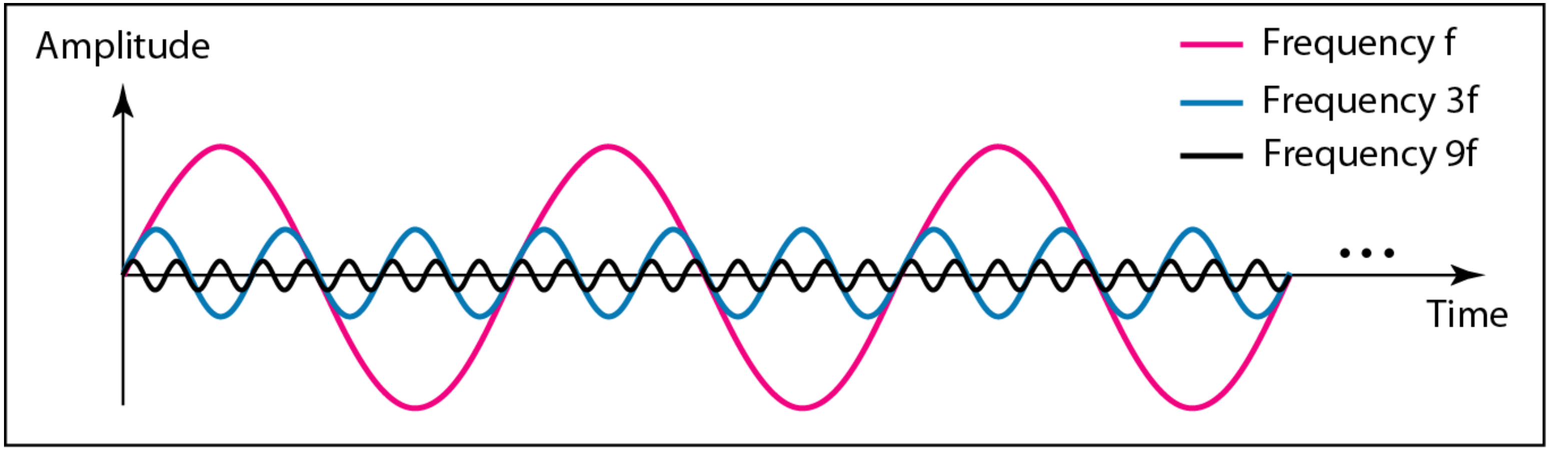
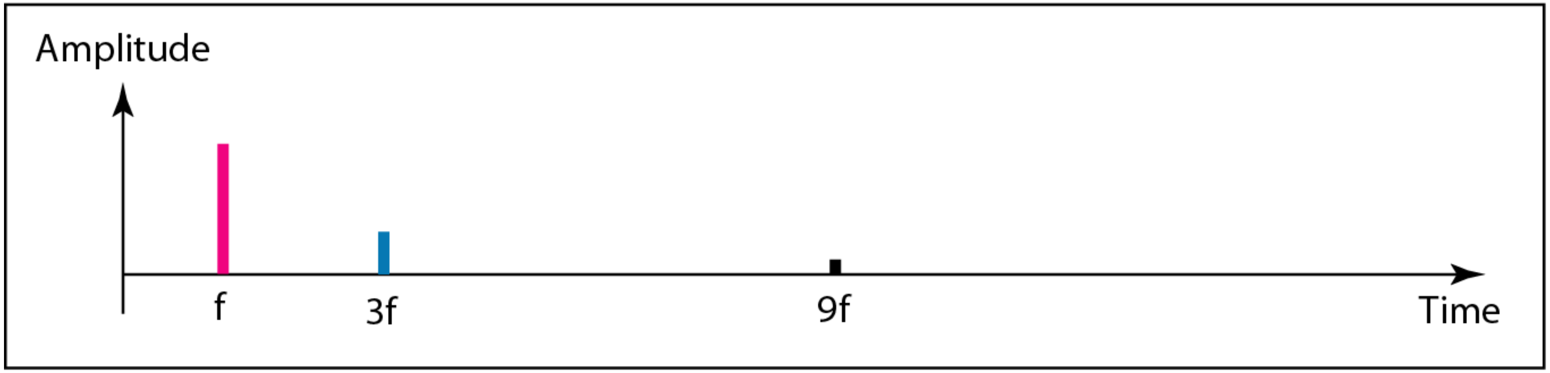


Figure 10: Decomposition of a composite periodic signal in the time and frequency domains



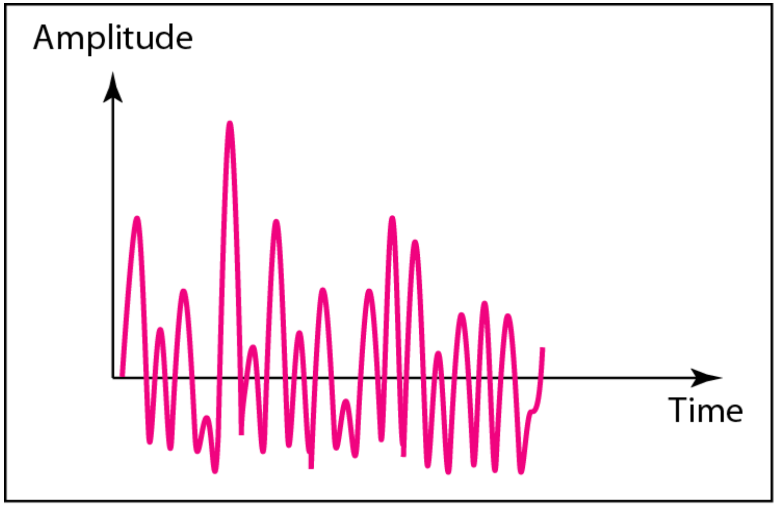
a. Time-domain decomposition of a composite signal



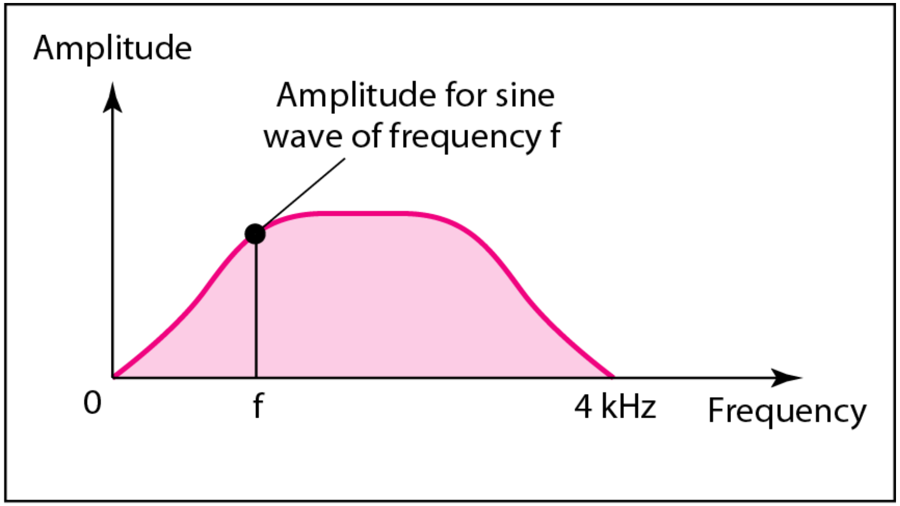
b. Frequency-domain decomposition of the composite signal

Figure 11: The time and frequency domains of a non-periodic signal

Example 5: Figure 11 shows a non-periodic composite signal.
It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.



a. Time domain



b. Frequency domain

Example 6:

An example of a non-periodic composite signal is the signal propagated by an AM radio station.

In Lebanon, each AM radio station is assigned a 10-kHz bandwidth. The total bandwidth dedicated to AM radio ranges from 530 to 1700 kHz.

Example 7:

Another example of a non-periodic composite signal is the signal propagated by an FM radio station.

In Lebanon, each FM radio station is assigned a 200-kHz bandwidth. The total bandwidth dedicated to FM radio ranges from 88 to 108 MHz.

Example 8:

Another example of a non-periodic composite signal is the signal received by an old- fashioned analog black-and-white TV:

A TV screen is made up of pixels. If we assume a resolution of 525 × 700, we have 367,500 pixels per screen.

If we scan the screen 30 times per second, this is 367,500 × 30 = 11,025,000 pixels per second.

The worst-case scenario is alternating black and white pixels. We can send 2 pixels per cycle. Therefore, we need 11,025,000/2 = 5,512,500 cycles per second, (or Hz).

Hence, The bandwidth needed is 5.5125 MHz.

Questions ??