



# **Chapter 3**Data and Signals



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

#### 3-1 ANALOG AND DIGITAL

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

#### Topics discussed in this section:

- Analog and Digital Data
- Analog and Digital Signals
- Periodic and Nonperiodic Signals

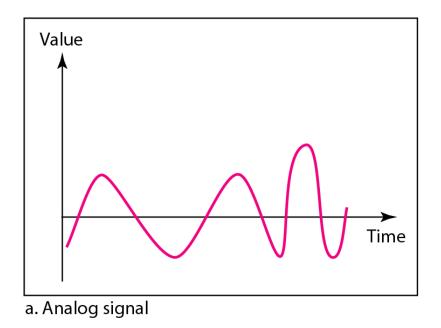
### **Analog and Digital Data**

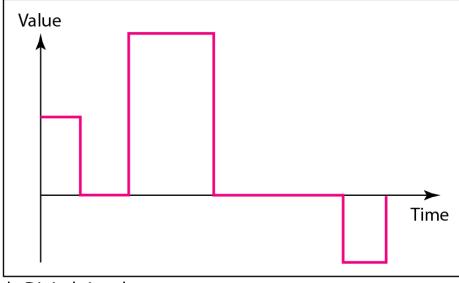
- Data can be analog or digital.
- Analog data are continuous and take continuous values.
- Digital data have discrete states and take discrete values.

### 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 3.1 Comparison of analog and digital signals





#### 3-2 PERIODIC ANALOG SIGNALS

In data communications, we commonly use periodic analog signals and nonperiodic 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.

#### Topics discussed in this section:

- Sine Wave
- Wavelength
- **Time and Frequency Domain**
- Composite Signals
- Bandwidth

#### Figure 3.2 A sine wave

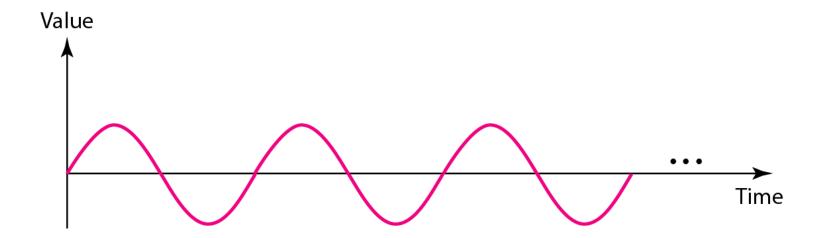
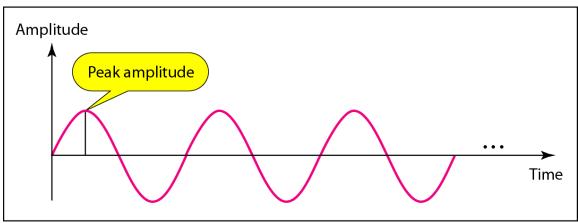
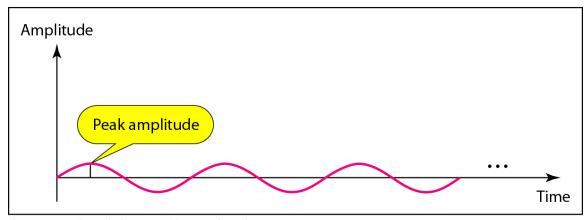


Figure 3.3 Two signals with the same phase and frequency, but different amplitudes



a. A signal with high peak amplitude



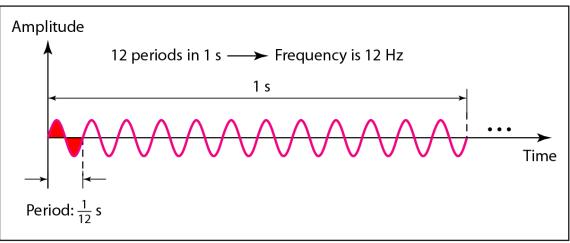
b. A signal with low peak amplitude

Note

# Frequency and period are the inverse of each other.

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

## Figure 3.4 Two signals with the same amplitude and phase, but different frequencies



a. A signal with a frequency of 12 Hz

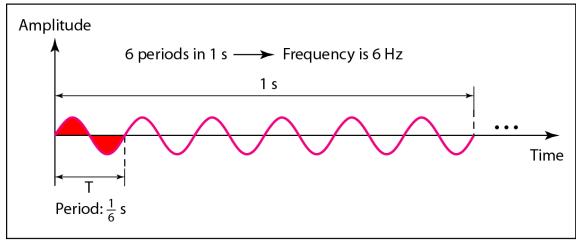


 Table 3.1
 Units of period and frequency

Unit	Equivalent	Unit	Equivalent
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	$10^{-3} \text{ s}$	Kilohertz (kHz)	10 <sup>3</sup> Hz
Microseconds (μs)	$10^{-6} \text{ s}$	Megahertz (MHz)	10 <sup>6</sup> Hz
Nanoseconds (ns)	$10^{-9}  \mathrm{s}$	Gigahertz (GHz)	10 <sup>9</sup> Hz
Picoseconds (ps)	$10^{-12} \text{ s}$	Terahertz (THz)	10 <sup>12</sup> Hz



#### Example 3.1

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

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



#### Example 3.2

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.

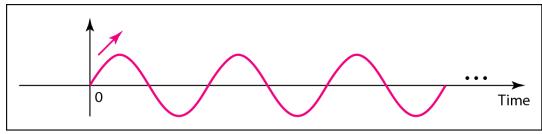
If a signal changes instantaneously, its frequency is infinite.

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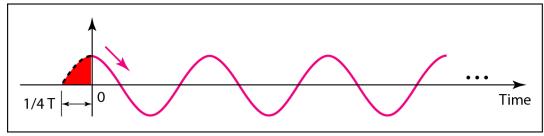
#### Note

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

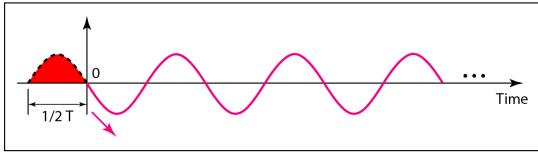
Figure 3.5 Three sine waves with the same amplitude and frequency, but different phases



a. 0 degrees



b. 90 degrees



c. 180 degrees



#### Example 3.3

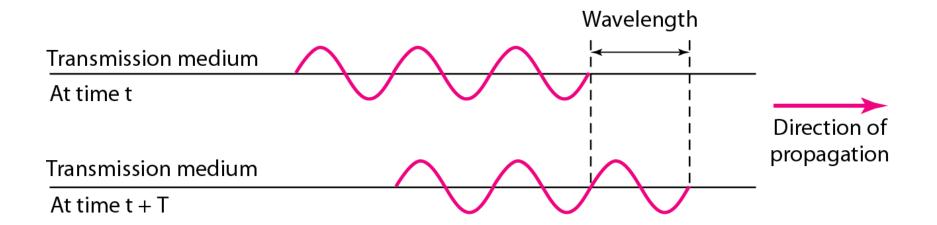
A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

#### Solution

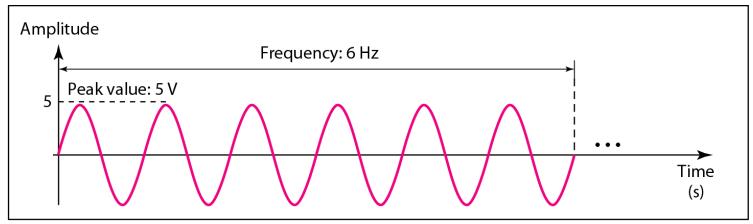
We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

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

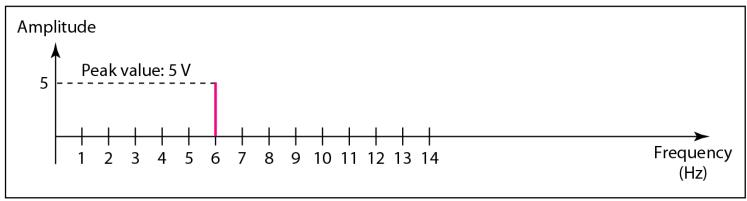
#### Figure 3.6 Wavelength and period



#### Figure 3.7 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)

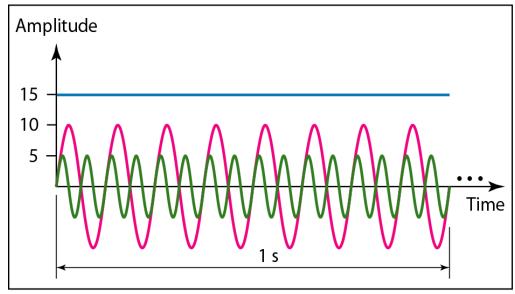
Note

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

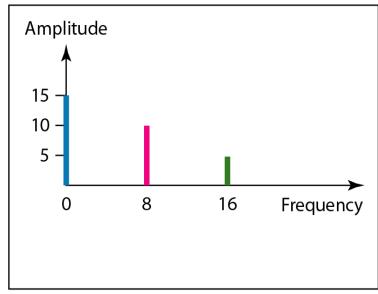


The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, Figure 3.8 shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.

#### Figure 3.8 The time domain and frequency domain of three sine waves



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.

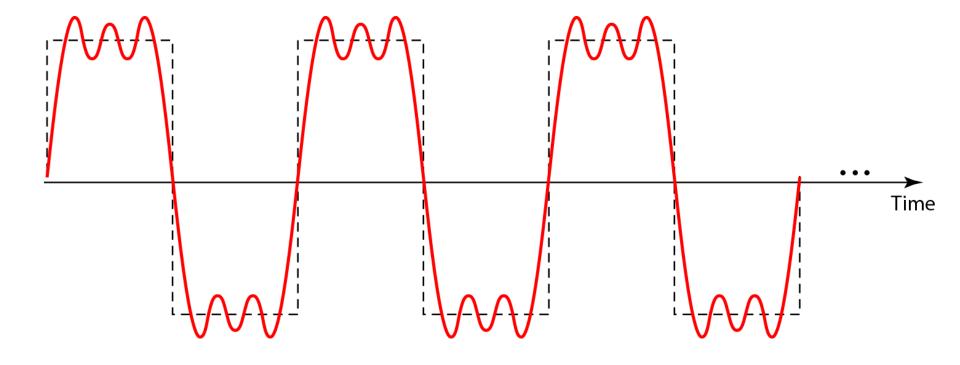
# Composite Signals and Periodicity

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

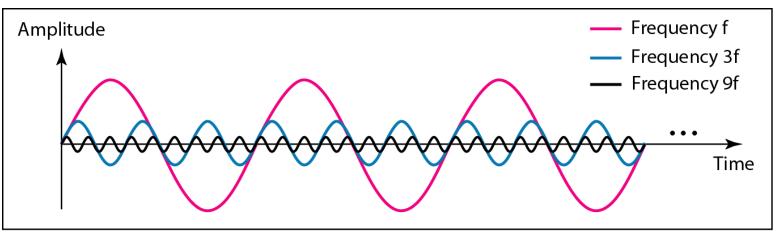


Figure 3.9 shows a periodic composite signal with frequency f. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.

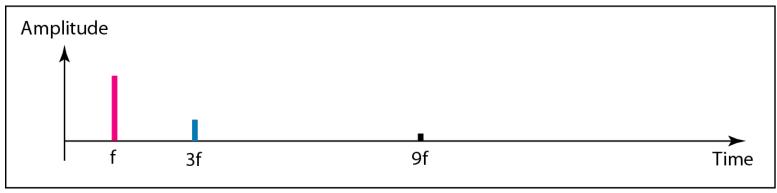
Figure 3.9 A composite periodic signal



## Figure 3.10 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

# Bandwidth and Signal Frequency

The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.



#### Example 3.6

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.

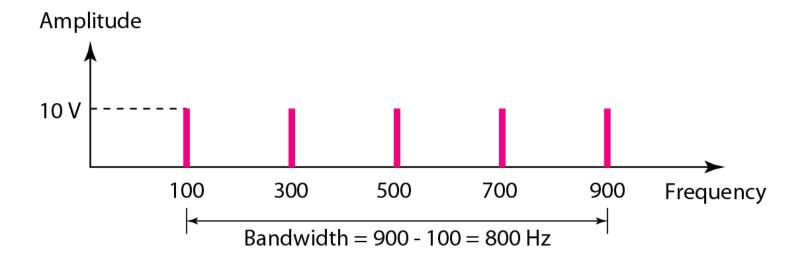
Solution

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 3.6





#### Example 3.7

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.

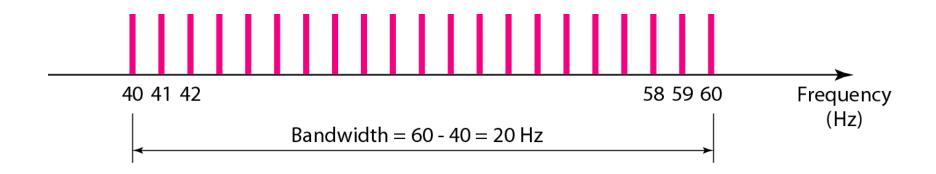
#### Solution

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

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

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 3.7



# Example 3.8

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 3.8

