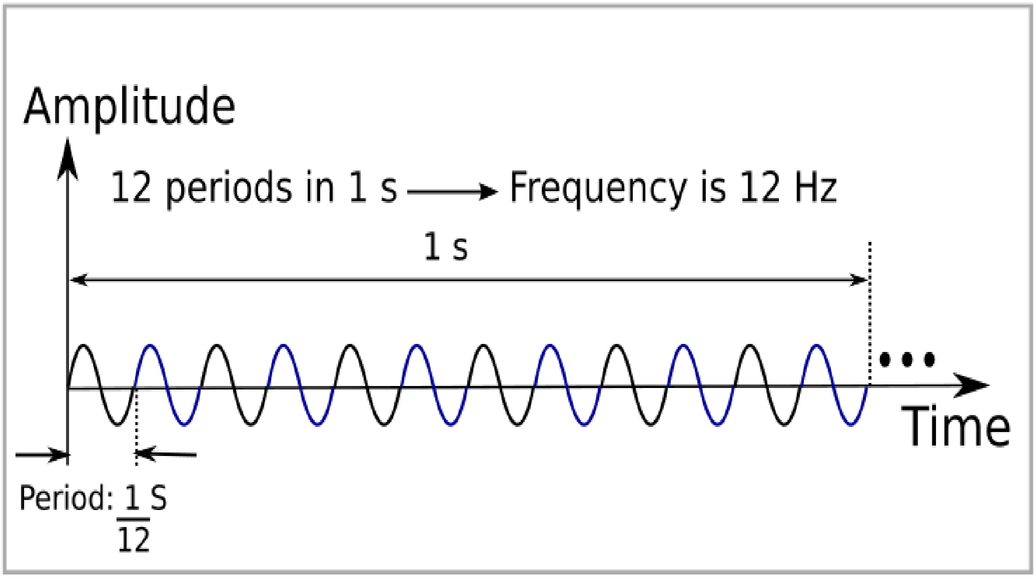
Data communication and Networks

Chapter 4: Data and Analog Signals



4. Data and Signals

One of the major functions of the *physical layer* is to move data in the form of electromagnetic signals across a transmission medium. Generally, the data usable to a person or application are not in a form that can be transmitted over a network. For example, a photograph must first be changed to a form that transmission media can accept. Transmission media work by conducting energy along a physical path.

4.1 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: the analog clock and the digital clock.

Digital data take on discrete values. For example, data are stored in computer memory in the form of 0s and 1s. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.

Therefore, data can be *analog* or *digital*. **Analog data** are continuous and take continuous values. **Digital data** have discrete states and take discrete values.

4.2 Analog and Digital Signals

Like the data they represent, signals can be either analog or digital. An analog signal has infinitely many levels of intensity over a period of time. 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.

Figure 3.1 illustrates an analog signal and a digital signal. The vertical axis represents the value or strength of a signal. The horizontal axis represents time.

Therefore, 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**.

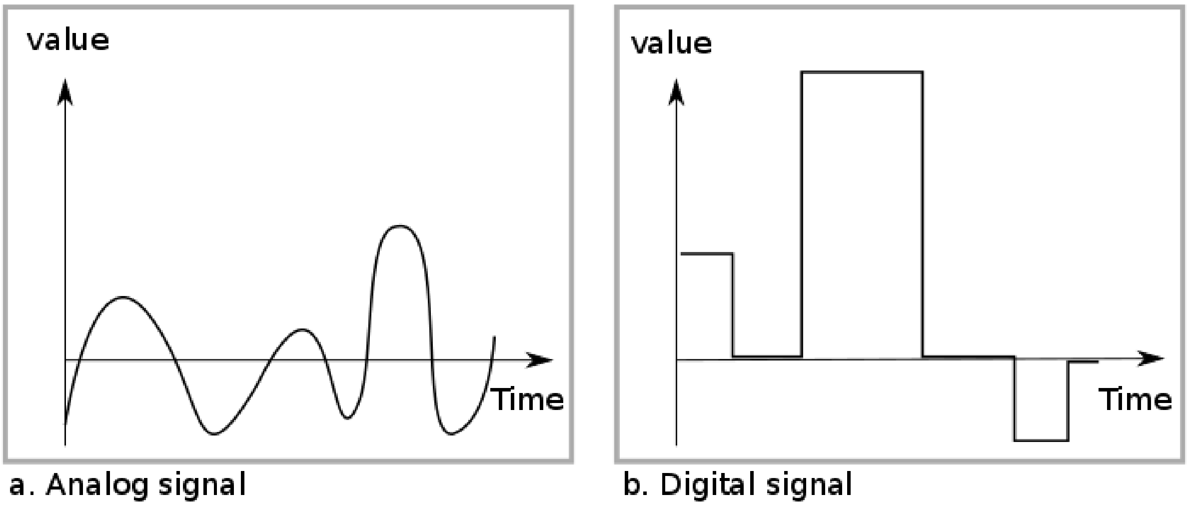


Figure 4.1 Comparison of analog and digital signals

Periodic and Non-periodic Signals

A periodic signal completes a pattern within a measurable time frame, called a **period**, and repeats that pattern over 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. Both analog and digital signals can be periodic or nonperiodic.

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).

4.3 Periodic analog signals

Periodic analog signals can be classified as simple or composite.

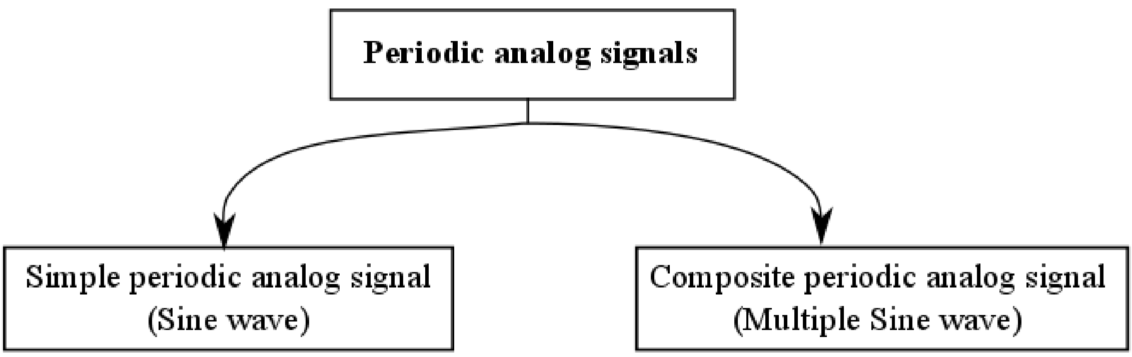


Figure 4.2 Classification of periodic analog signals

4.3.1 Sine Wave

Figure 4.3 shows a sine wave. Each cycle consists of a single arc above the time axis followed by a single arc below it. A sine wave can be represented by three parameters: the 1) *peak amplitude,* 2) the *frequency*, and 3) the *phase.*

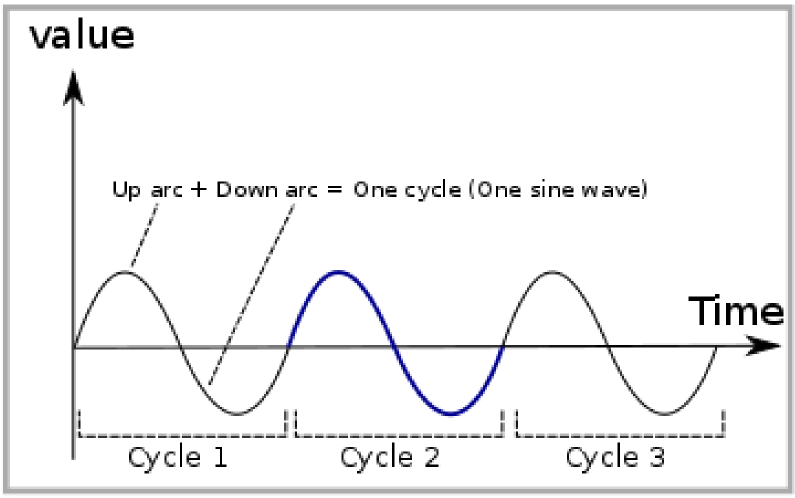


Figure 4.3 Sine wave

1) Peak amplitude

The peak amplitude of a signal is the absolute **value** of its highest intensity (the energy). Figure 4.4 shows two signals and their peak amplitudes. For electric signals, peak amplitude is normally measured in ***volts***. The power in your house can be represented by a sine wave with a peak amplitude of 220 to 240 V, whereas the peak value of an AA battery is normally 1.5 V.

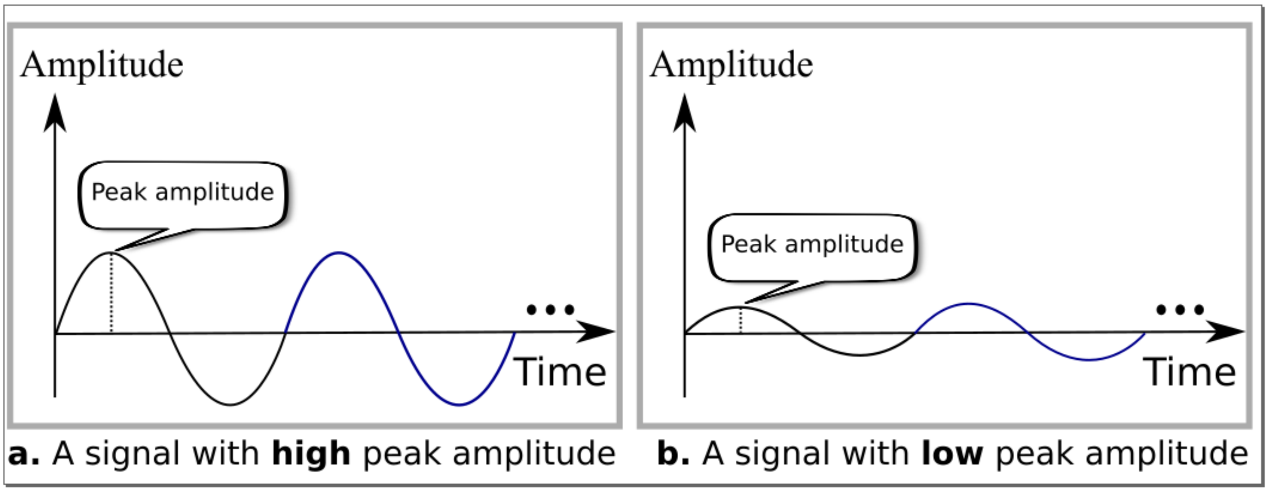


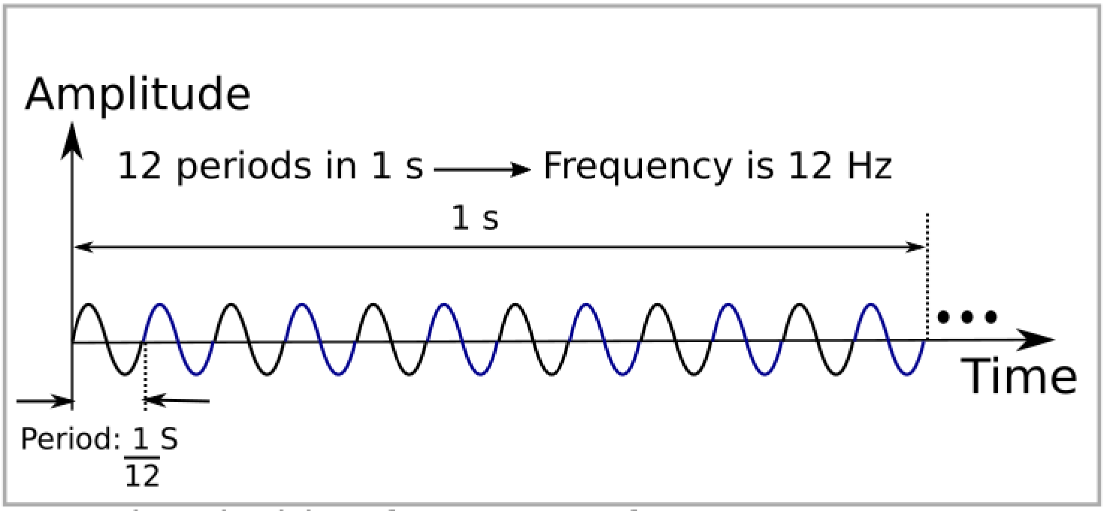
Figure 4.4 Two signals with the same phase and frequency, but different amplitudes

2) Period and Frequency

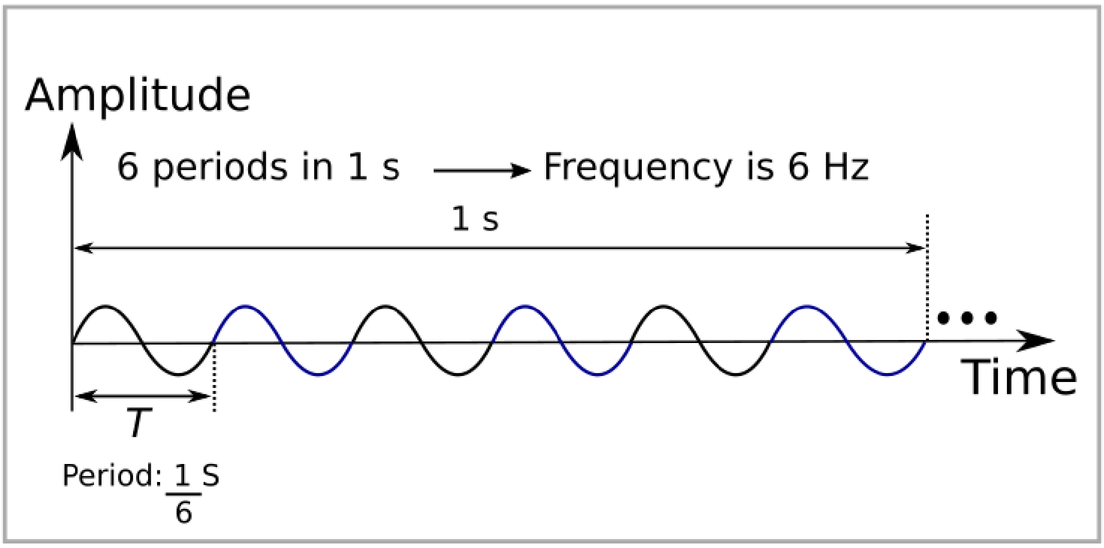
Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle. Frequency refers to the number of periods in 1 s. Note that period and frequency are just one characteristic defined in two ways. Period is the inverse of frequency, and frequency is the inverse of period, as the following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

$f = \frac{1}{T}$ and $T \frac{1}{f}$ (*f*: frequency T: time)

Figure 4.5 shows two signals and their frequencies.



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Figure 4.5 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 3.1.

Unit	***Equivalent***
Seconds (s)	1s
Milliseconds (ms)	10^{-3} s
Microseconds (μs)	10^{-6} s
Nanoseconds (ns)	10^{-9} s
Picoseconds (ps)	10^{-12} s

Units of period

Unit	***Equivalent***
Hertz (Hz)	1 Hz
Kilohertz (kHz)	10^{3} Hz
Megahertz (MHz)	10^{6} Hz
Gigahertz (GHz)	10^{9} Hz
Terahertz (THz)	10^{12} Hz

Units of frequency

Table 4.1 Units of period and frequency

Example 1

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

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

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.

<u>Solution</u>

From Table 4.1 we find the equivalents of 1 ms (l ms is 10^{-3} s) and 1 s (1 is 10^{6} μs). We make the following substitutions:

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

لتحويل الوقت من وحدة الملي ثانية (milliseconds) الى وحدة الثانية (second)

لتحويل الوقت من وحدة الثانية (second) الى وحدة المايكرو ثانية (Microseconds)

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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).

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

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

3) Phase

The term phase describes the position of the waveform relative to time 0. It indicates the status of the first cycle (how much the wave is shifted from 0 on the time axis).

Looking at Figure 4.6, we can say that

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.

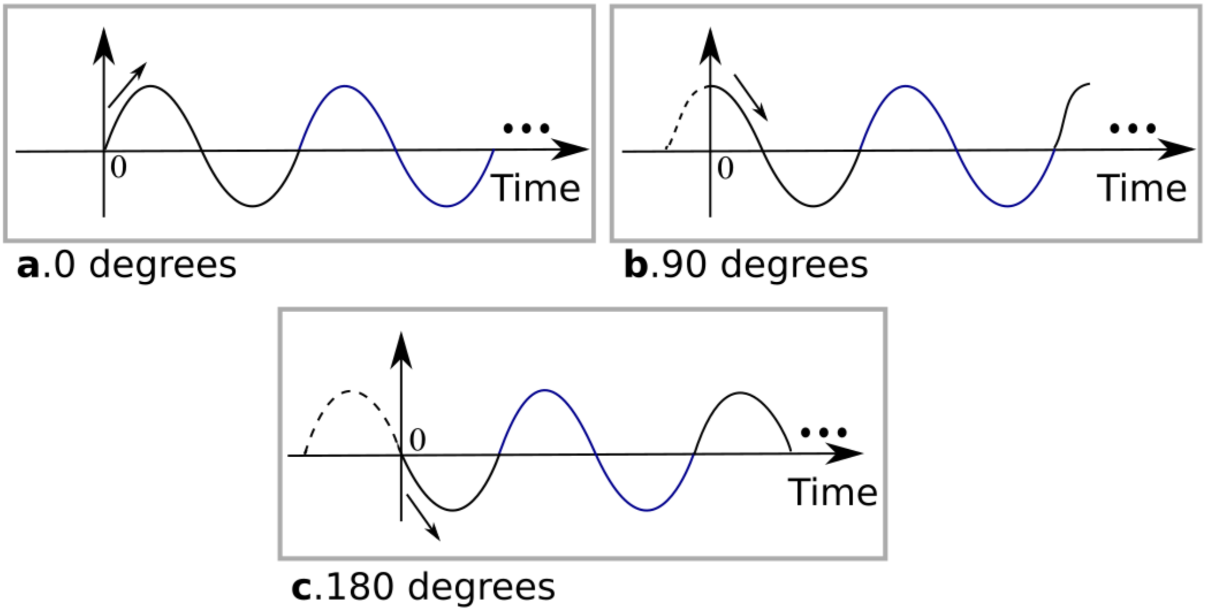

Figure 4.6 Three sine waves with the same amplitude and frequency, but different phases

4) 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 (see Figure 4.7).

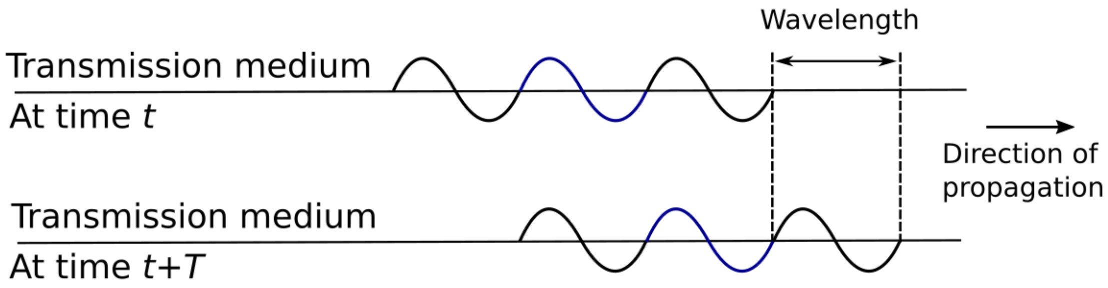

Figure 4.7 Wavelength and period

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

The wavelength is normally measured in micrometres (microns) instead of meters. For example, the wavelength of **red light in air** is 0.75 µs. In a **coaxial** or **fibre-optic** cable, however, the wavelength is shorter (0.5 µs) *because* the propagation speed in the cable is decreased.

4.3.2 Composite Signals

The previous section focused on simple sine waves which have many applications in daily life. We can send a single sine wave to carry electric energy from one place to another. For example, the power company sends a single sine wave with a frequency of 50 Hz to distribute electric energy to houses and businesses.

If we had only one single sine wave to convey a conversation over the phone, it would make no sense and carry no information. We would just hear a buzz. **Therefore,** we need to send a composite signal to communicate data; a single-frequency sine wave is not useful in data communications.

The **composite signal** is a combination of simple sine waves with different frequencies, amplitudes, and phases.

A composite signal can be periodic or nonperiodic as shown in the following:

- **A periodic composite signal** can be decomposed into a series of simple sine waves with *discrete frequencies* (the 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 (the frequencies that have real values: 0.1, 0.2, 0.3, and so on).

4.3.3 Bandwidth

Bandwidth is the range of frequencies contained in a composite signal. 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.

Figure 4.8 shows the concept of bandwidth. The bandwidth of the periodic signal contains all integer frequencies between 1000 and 5000 (1000, 1001, 1002, ...). The bandwidth of the nonperiodic signals has the same range, but the frequencies are **continuous**.

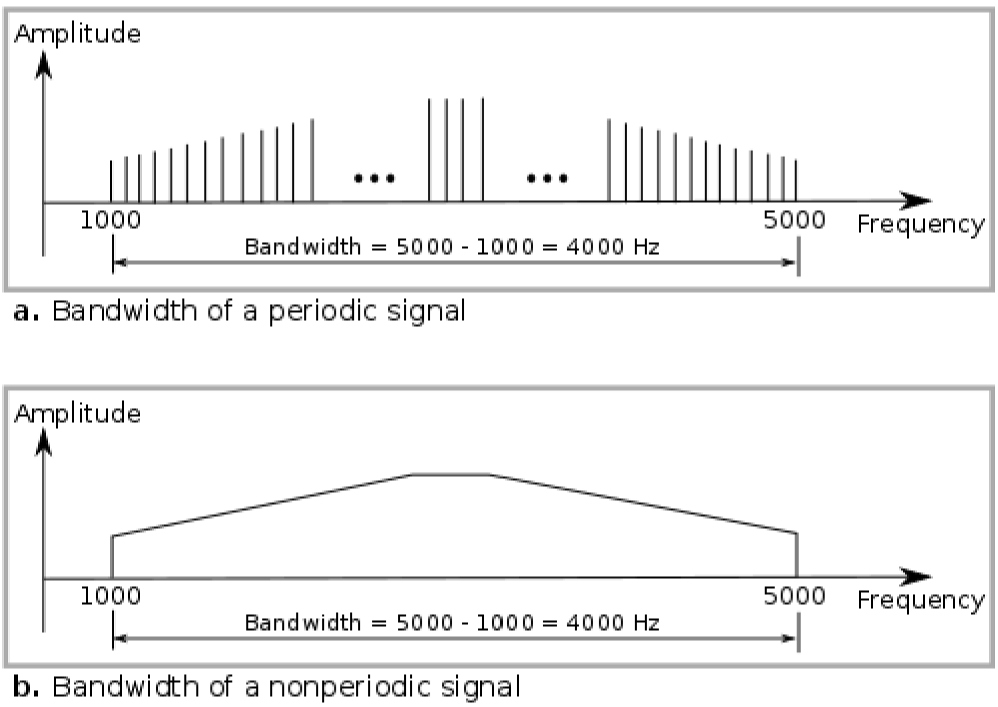

Figure 4.8 The bandwidth of periodic and nonperiodic composite signals

Example 4

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 *fh* be the highest frequency, *fl* the lowest frequency, and *B* the bandwidth.

Then: $B = fh - fl = 900 - 100 = 800$ Hz

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz (see Figure 4.9).

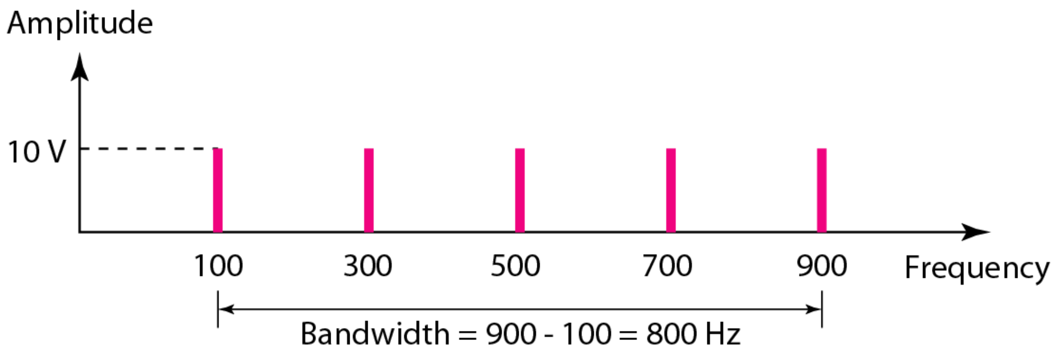

Figure 4.9 The bandwidth for Example 4

Example 5

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 *fh* be the highest frequency, *fl* the lowest frequency, and *B* the bandwidth.

Then: $B = fh - fl \rightarrow 20 = 60 - fl \rightarrow fl = 60 - 20 = 40$ Hz

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure 4.10).

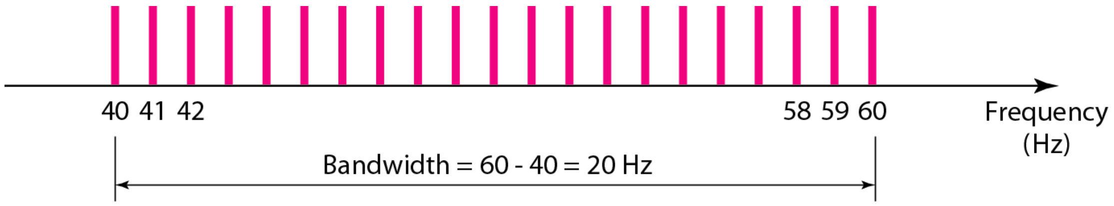

Figure 4.10 The bandwidth for Example 5