Data and Signals

1 ANALOG AND DIGITAL

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

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.

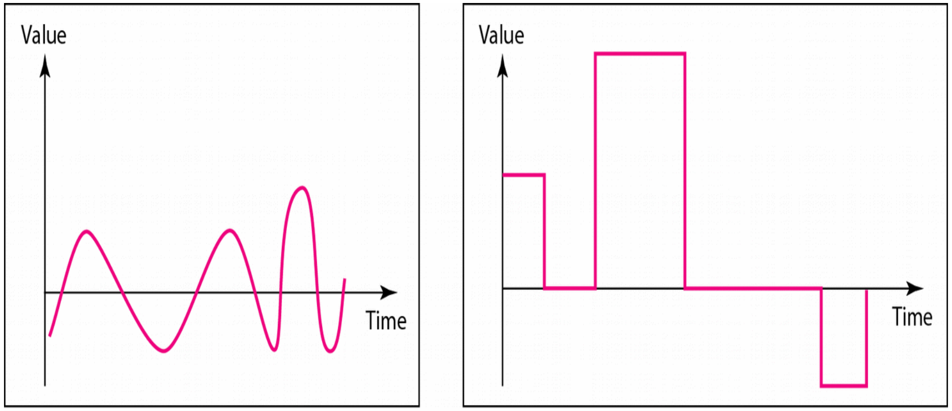
Data can be analog or digital.
Analog data are continuous and take continuous values.
Digital data have discrete states and take discrete values.

1 ANALOG AND DIGITAL

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.



a. Analog signal b. Digital signal

1 ANALOG AND DIGITAL

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

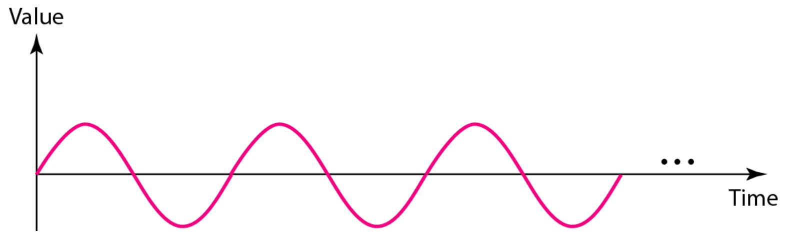
Periodic analog signals *can be classified as simple or composite.*

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.

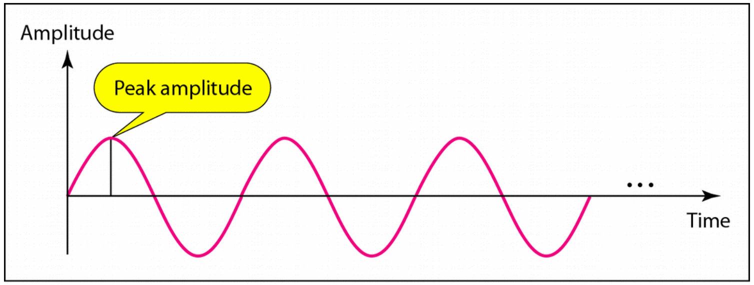
1 ANALOG AND DIGITAL

Periodic Signals

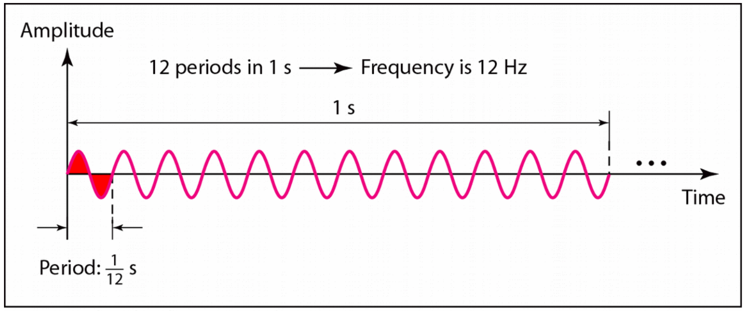


Frequency and period are the inverse of each other.

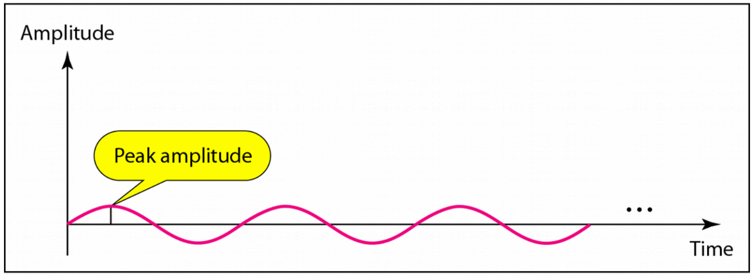
$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$



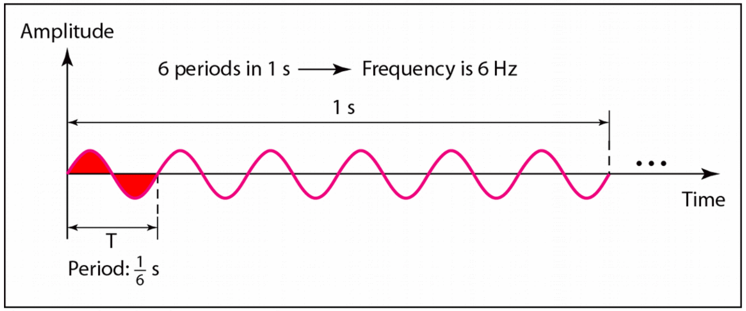
a. A signal with high peak amplitude



a. A signal with a frequency of 12 Hz



b. A signal with low peak amplitude



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 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).

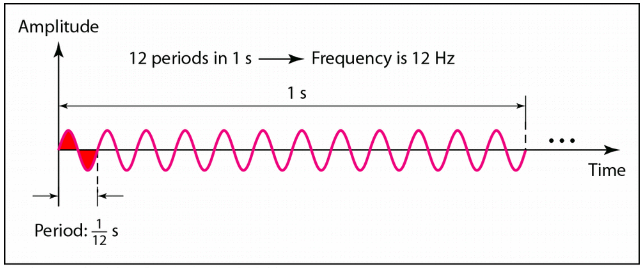
$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

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

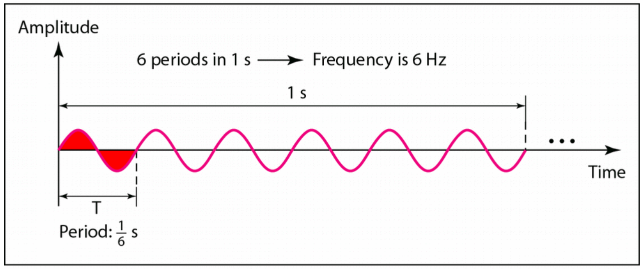
1 ANALOG AND DIGITAL

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.



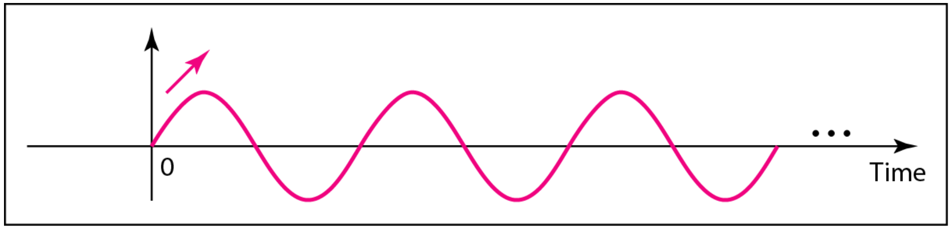
a. A signal with a frequency of 12 Hz



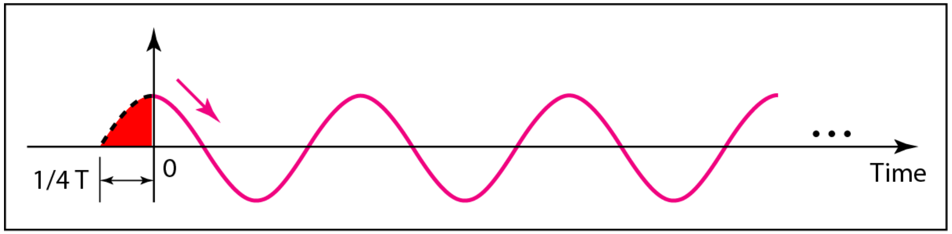
b. A signal with a frequency of 6 Hz

1 ANALOG AND DIGITAL

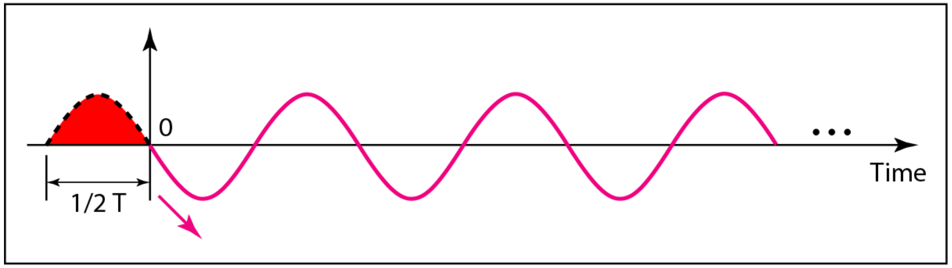
Phase describes the position of the waveform relative to time 0.



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?

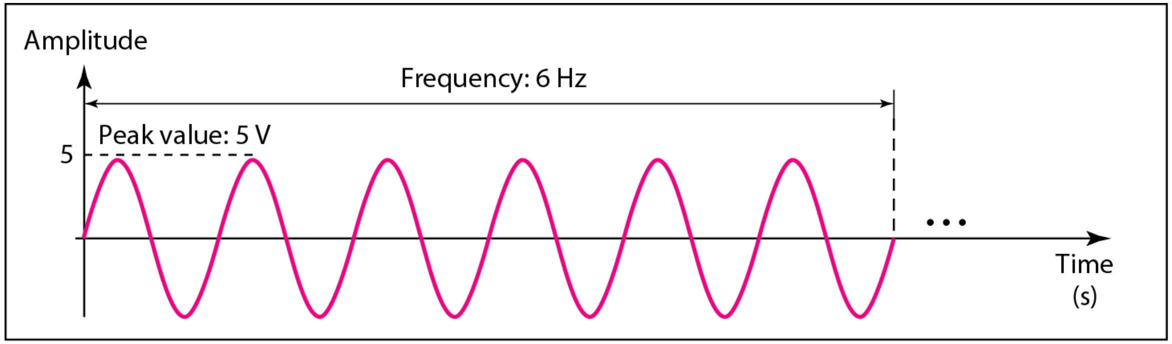
Solution

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

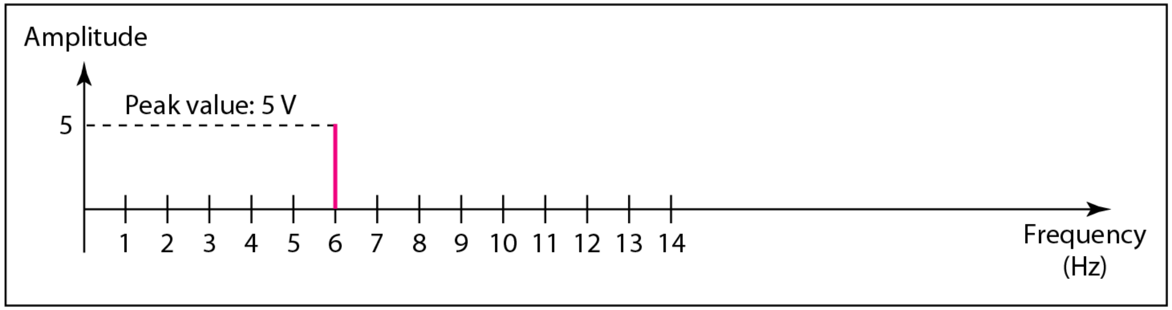
$$\boxed{\frac{1}{6} \times 360 = 60° = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}}$$

1 ANALOG AND DIGITAL

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

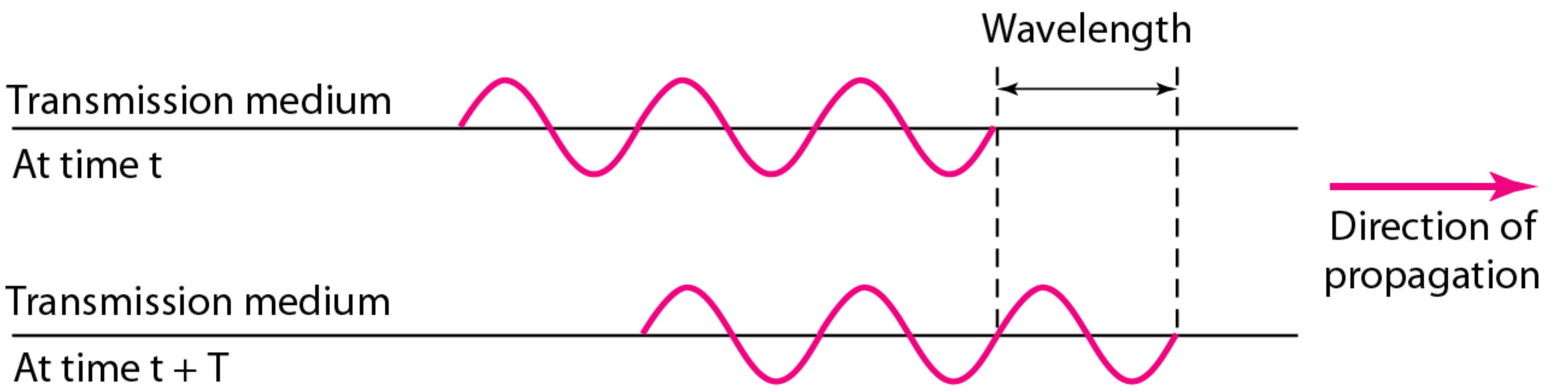


a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



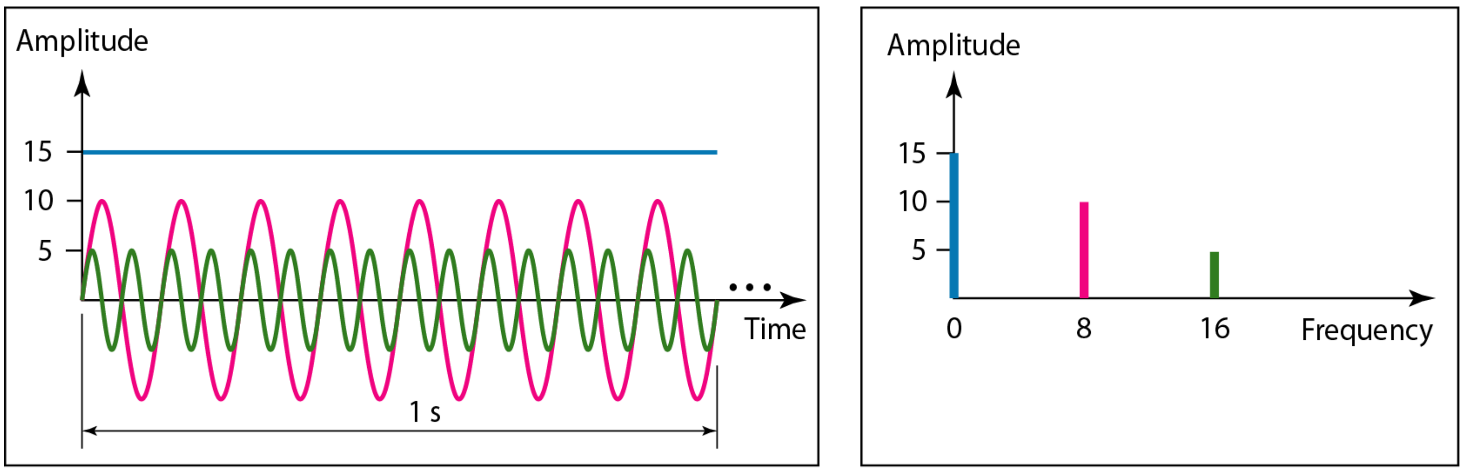
b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

Figure 3.6 *Wavelength and period*



1 ANALOG AND DIGITAL

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



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

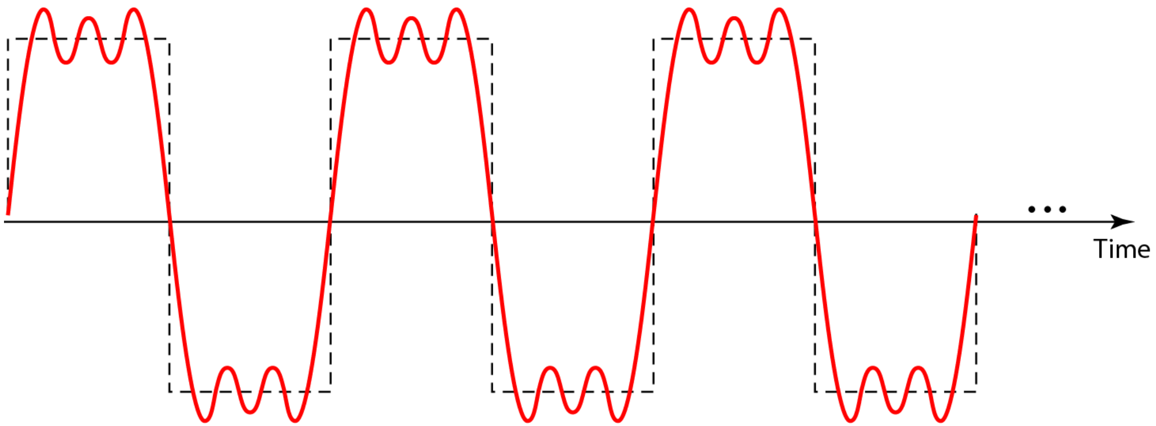
b. Frequency-domain representation of the same three signals

1 ANALOG AND DIGITAL

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.

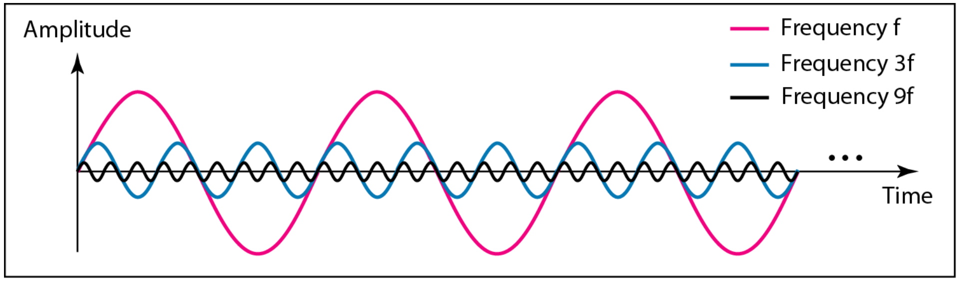
According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.



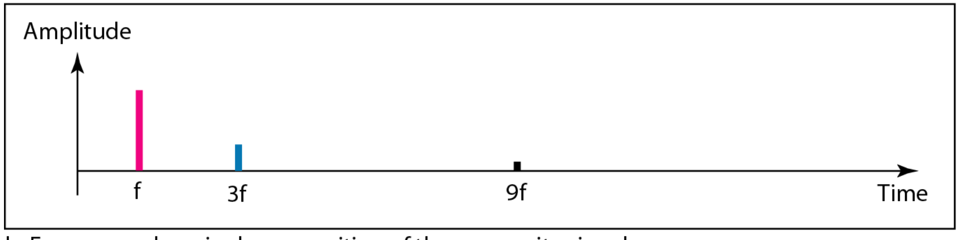
1 ANALOG AND DIGITAL

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.



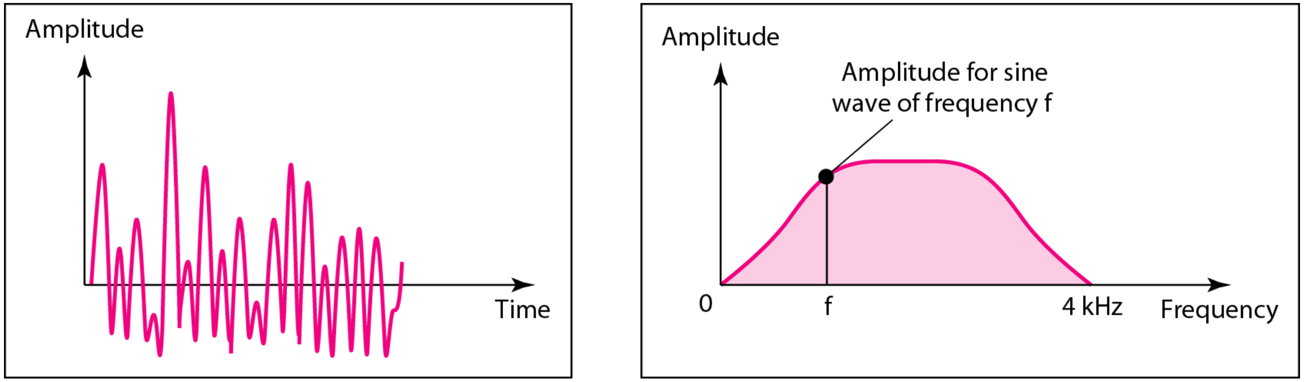
a. Time-domain decomposition of a composite signal



b. Frequency-domain decomposition of the composite signal

1 ANALOG AND DIGITAL

Figure shows a nonperiodic 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.

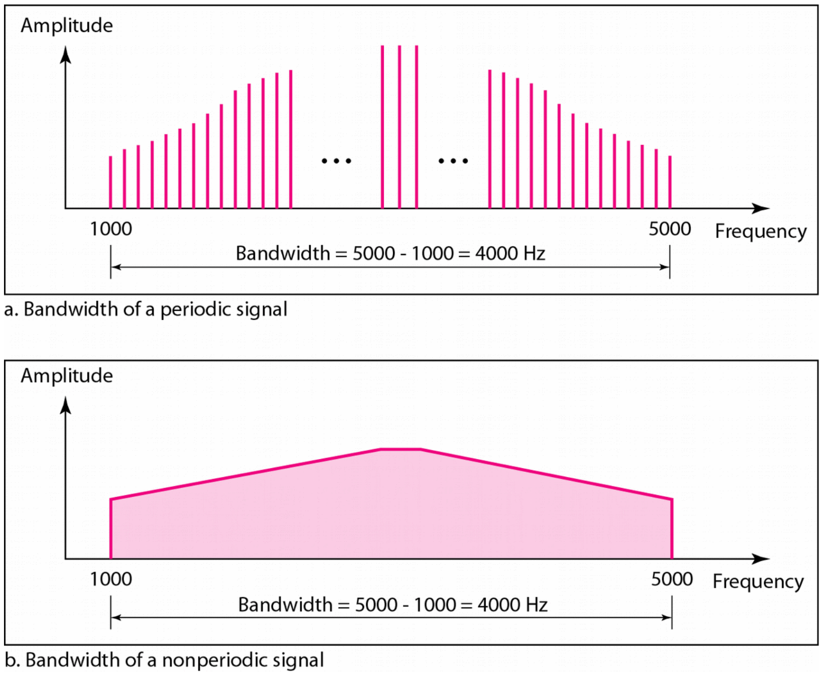


a. Time domain

b. Frequency domain

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.

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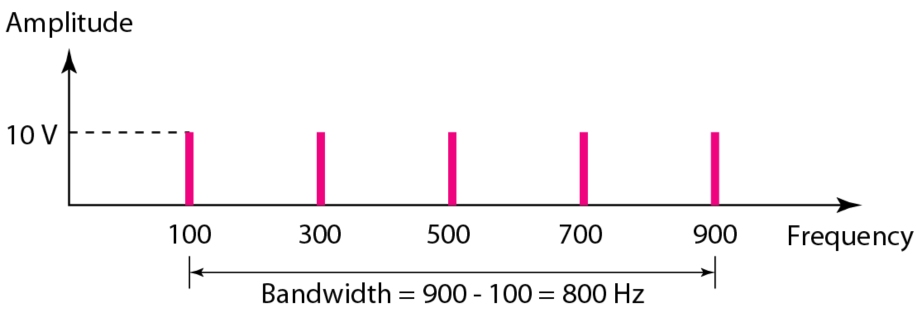
Solution

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

$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$

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



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.

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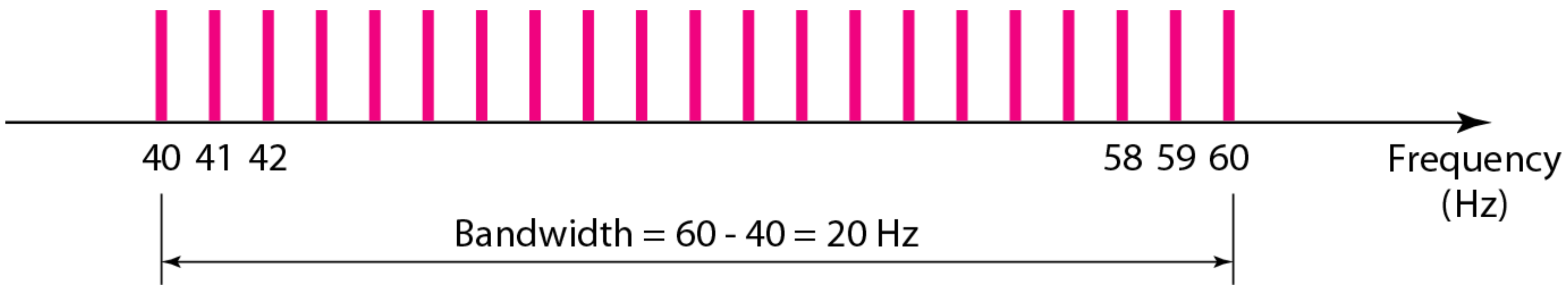
Solution

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

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

The spectrum contains all integer frequencies. We show this by a series of spikes

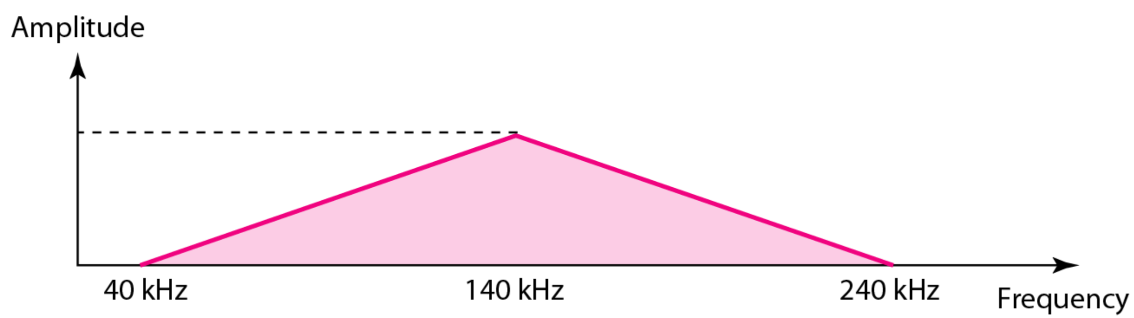


Example 3.8

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 shows the frequency domain and the bandwidth.



Example 3.9

An example of a nonperiodic composite signal is the signal propagated by an AM radio station. In the United States, each AM radio station is assigned a 10-kHz bandwidth. The total bandwidth dedicated to AM radio ranges from 530 to 1700 kHz.

Another example of a nonperiodic composite signal is the signal propagated by an FM radio station. In the United States, each FM radio station is assigned a 200-kHz bandwidth. The total bandwidth dedicated to FM radio ranges from 88 to 108 MHz.

Reference

Data Communication and Networking , Behrouz A Forouzan , 4th Edition, 2017.