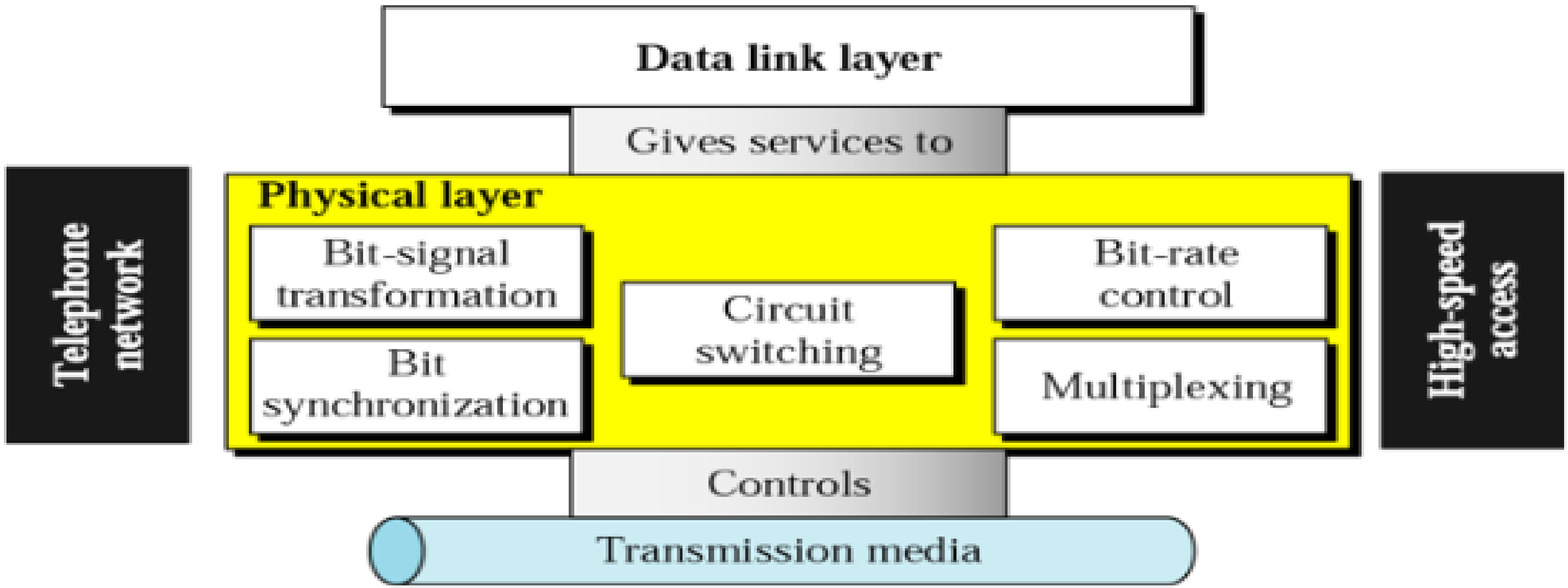
PHYSICAL LAYER

Data and Signals

Physical layer-functions

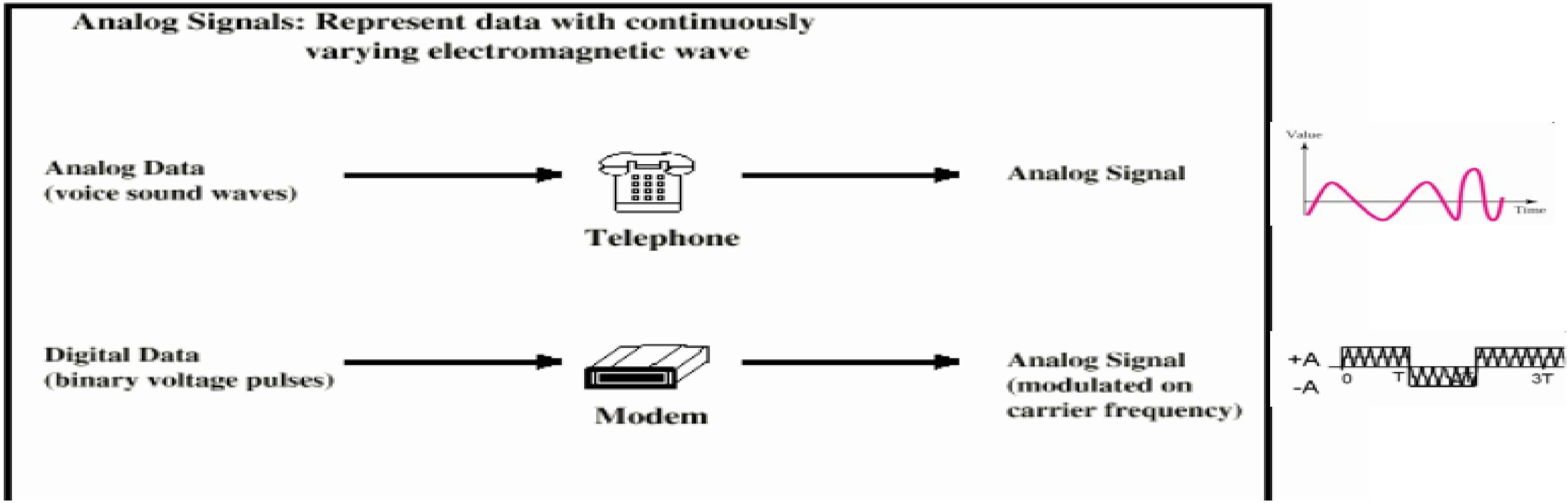


Data and Signal

- **Data:** information presented in whatever form is agreed upon by the parties creating and using the data.
- Data are entities that convey meaning (computer file, music on CD, results from a blood gas analysis machine)
- To be transmitted, data must be transformed to electromagnetic signals
- **Signal**: data on the link!
- Signals are the electric or electromagnetic encoding of data
- Computer networks and data/voice communication systems transmit signals

Analog and Digital

- Both data and the signals that represent them can be either **analog** or **digital** in form.



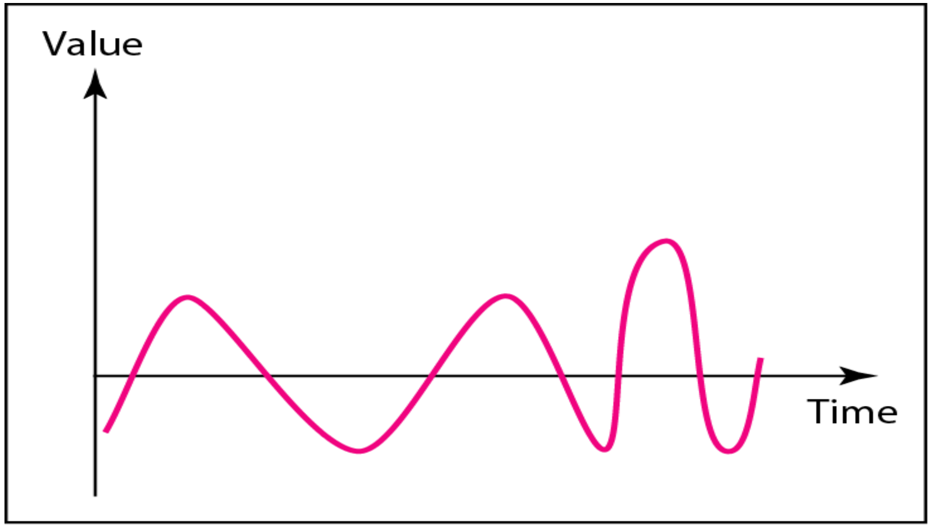
Analog vs Digital Data

- Analog data : information that is continuous
- Example: analog clock, human voice recording
- Analog data-analog signal-sampled- digital signal
- Digital data : information that has discrete states.
- Example: digital clock, data stored in a computer
- Digital data-digital signal-modulated-analog signal

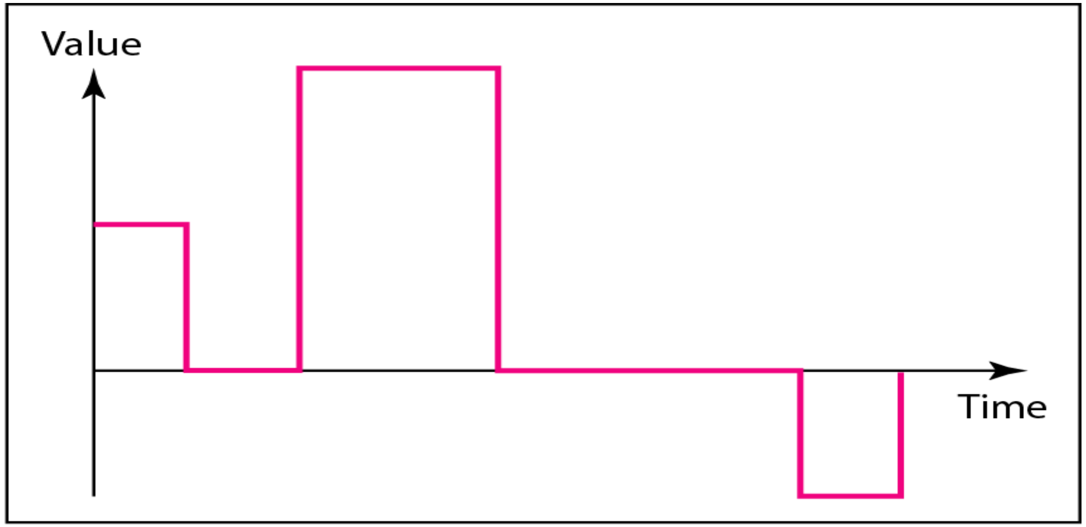
Analog vs. Digital Signals

- Signals can be interpreted as either analog or digital
- In reality, all signals are analog
- **Analog signals are continuous, non-discrete**
- **Digital signals are non-continuous, discrete**
- Digital signals lend themselves more nicely to **noise reduction** techniques

Comparison of analog and digital signals



a. Analog signal

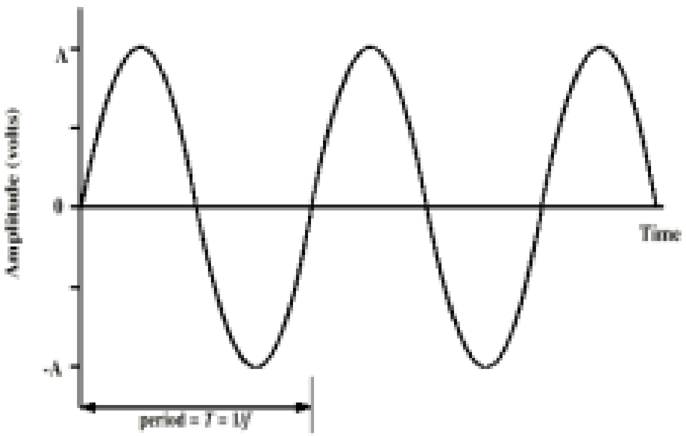


b. Digital signal

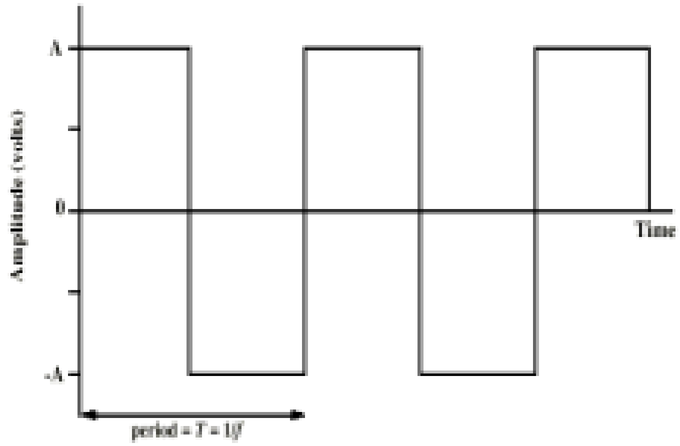
Periodic and Aperiodic Signal

- Both analog and digital signals can take one of two forms: periodic or nonperiodic
- Periodic signal
  - A periodic signal **completes a pattern within a measurable time frame, called a period**, and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a cycle. *.(*AM/FM radio)
- Aperiodic (non-periodic) signal
  - Pattern not repeated over time(human voice on microphone)
- In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

Periodic Signals

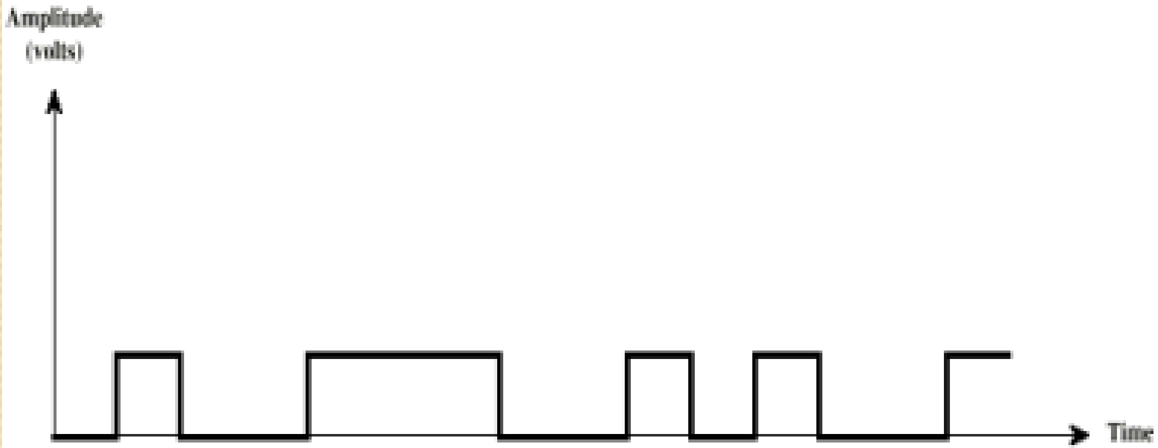


(a) Sine wave



Nonperiodic Signals

(a) Continuous



(b) Discrete

ANALOG SIGNAL

PERIODIC ANALOG SIGNALS

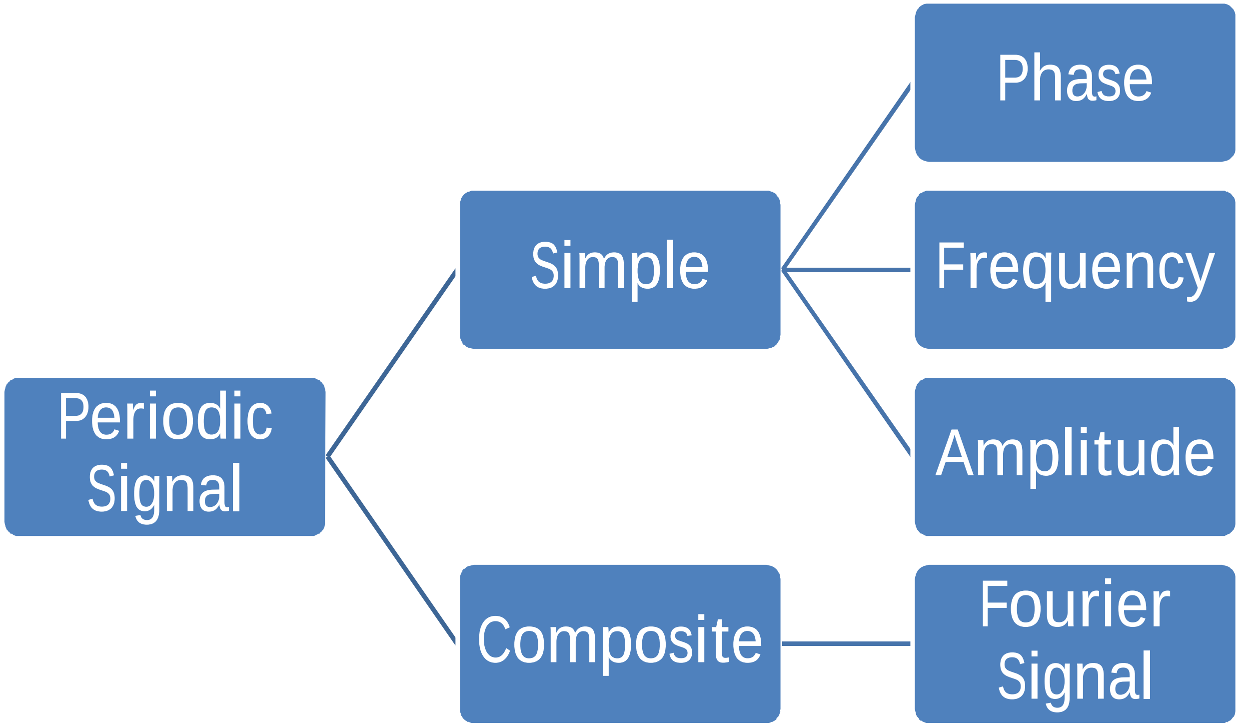
- *Periodic analog signals can be classified as simple or composite.*

- *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.*

Signal Properties

- All signals are composed of three properties/ A sine wave can be represented by three parameters:



1.Peak Amplitude

- The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries.
- For electric signals, peak amplitude is normally measured in volts
- For example, the peak value of an AA battery is normally 1.5 V.
- The voltage of a battery is a constant. Has 0 frequency –does not have any duration that repeat itself-no frequency –no change

Example

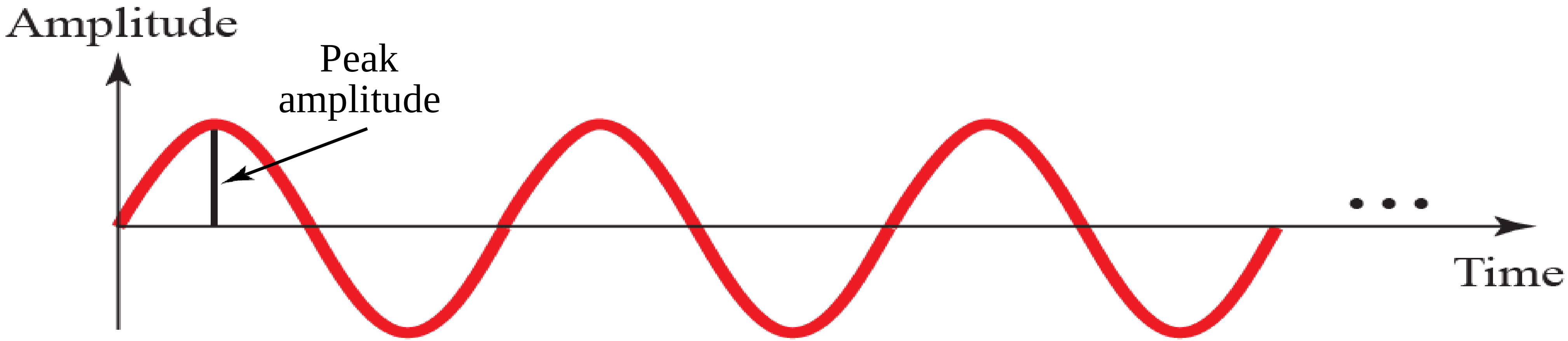
The power in your house can be represented by a sine wave with a peak amplitude of 155 to 170 V. However, it is common knowledge that the voltage of the power in U.S. homes is 110 to 120 V. This discrepancy is due to the fact that these are root mean square (rms) values. The signal is squared and then the average amplitude is calculated. The peak value is equal to $2^{1/2} \times$ rms value.

Peak Amplitude = $2^{1/2} \times$ rms

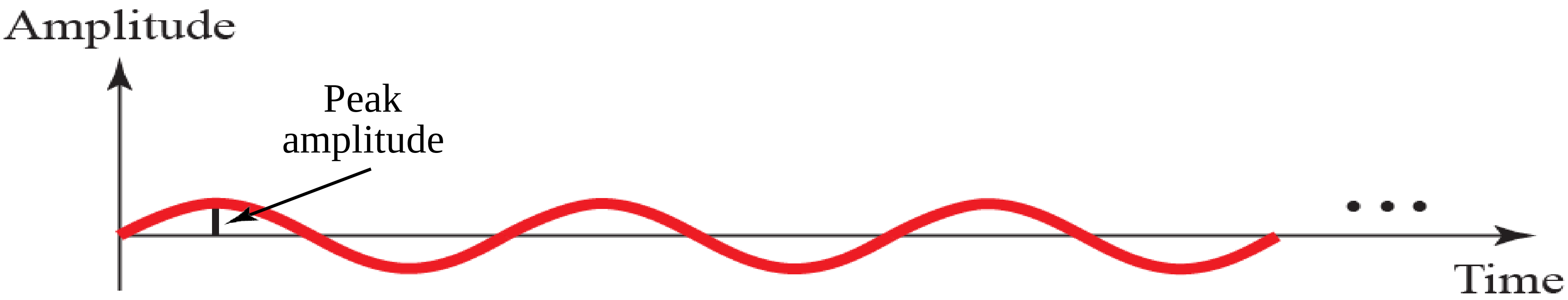
So, what voltage is coming to Indian Home? 250v

What will be the peak amplitude? 350v

Two signals with two different amplitudes



a. A signal with high peak amplitude

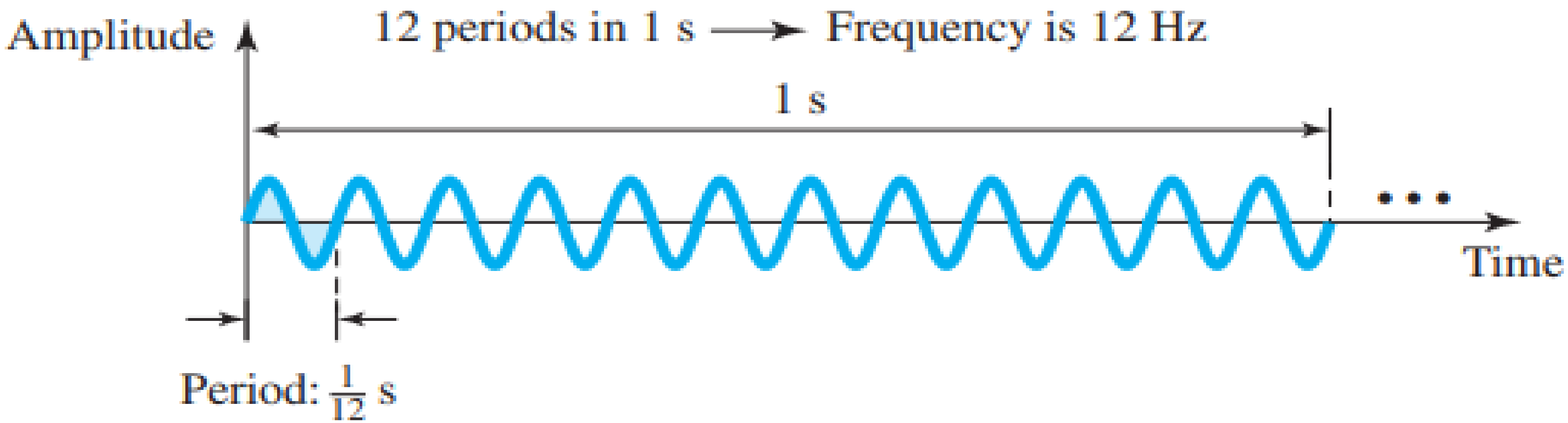


b. A signal with low peak amplitude

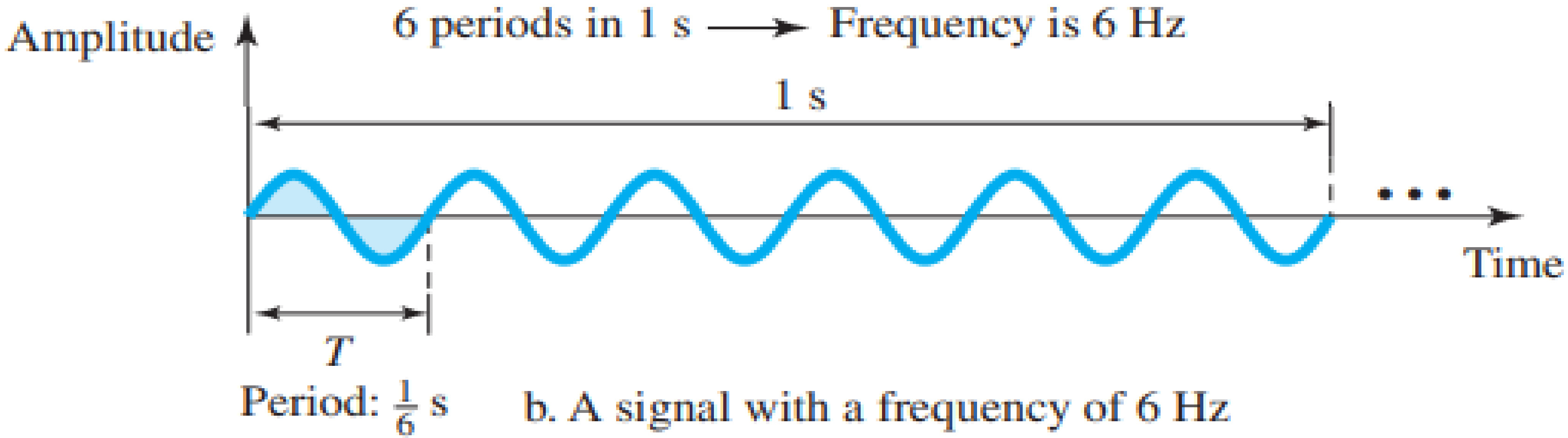
2.Period and Frequency

- Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.
- Frequency refers to the number of cycle/periods in 1 s.
- Note that period and frequency are just one characteristic defined in two ways
- Period is formally expressed in seconds. Frequency is formally expressed in Hertz (Hz), which is cycle per second.

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



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Units of Period and Frequency

Period		*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 60 Hz. What is the period of this sine wave?

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The power we use at home has a frequency of 60 Hz. What is the period of this sine wave?

$f = 60\ Hz$

$= \frac{1}{f} = \frac{1}{60}\ sec$

$\simeq 0.0166\ s$

$= 16.6\ ms$

Example-2

- Express a period of 100 ms in microseconds.

Example-2

- Express a period of 100 ms in microseconds.

Solution

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

$$100\,ms = 100 \times 10^{3}\,\mu s$$
$$= 10^{5}\,\mu s$$

Example-3

The period of a signal is 100 ms. What is its frequency in kilohertz?

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).

$T = 100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 0.1 \text{ s}$

$f = \frac{1}{T} \text{ Hz} = \frac{1}{0.1} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz}$

$= 10^{-2} \text{ KHz}$

Principle: when we use formulas, we always need to use the standard units.

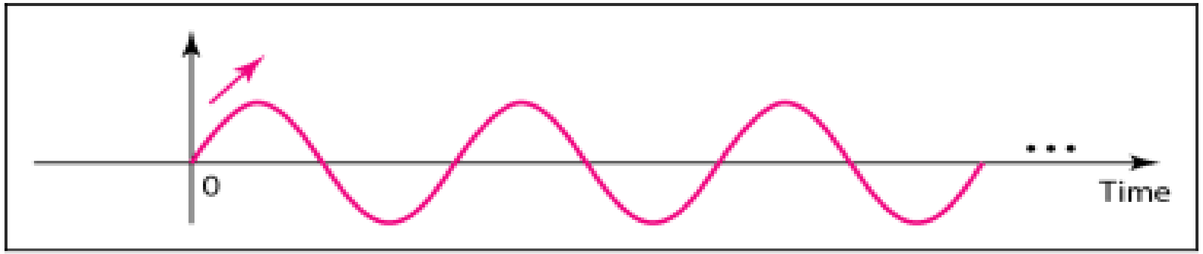
General Concepts

- 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 (in zero time) instantaneously, its frequency is infinite Ex **digital signal –has infinite frequency**

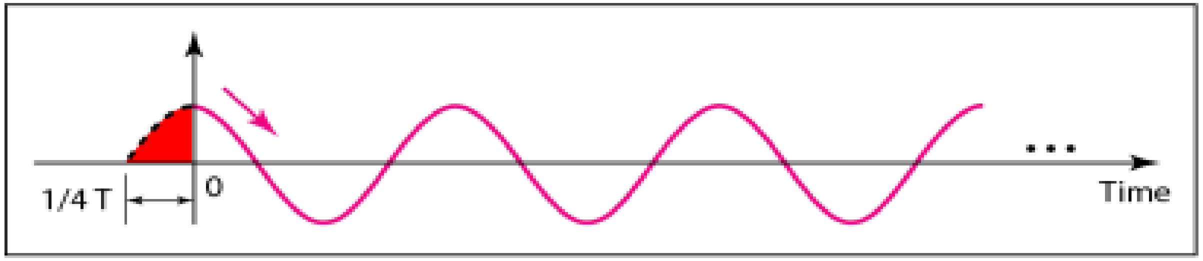
3.Phase

- The term phase describes the position of the waveform relative to time 0.
- 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.
- Phase is measured in degrees or radians [**360° is 2∏ rad**; **1° is 2∏/360 rad**, and 1 rad is 360/(2∏)].
- A phase shift of 360° corresponds to a shift of a complete period; a phase shift of 180° corresponds to a shift of one-half of a period; and a phase shift of 90° corresponds to a shift of one-quarter of a period

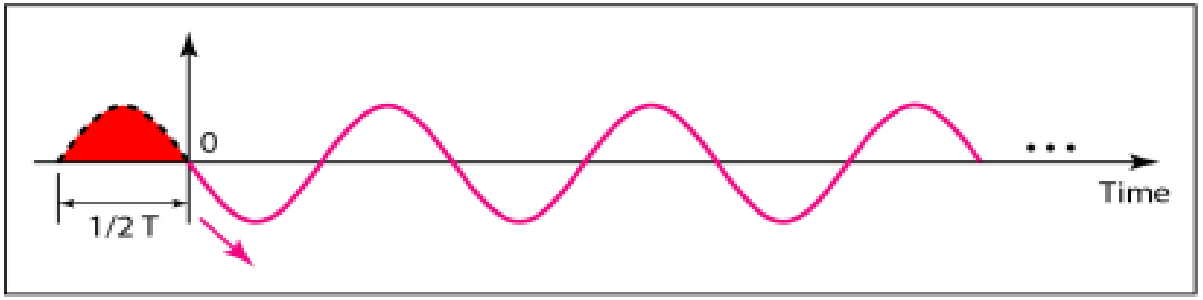
Three sine waves with the same amplitude and frequency but different phases



a. 0 degrees



b. 90 degrees



c. 180 degrees

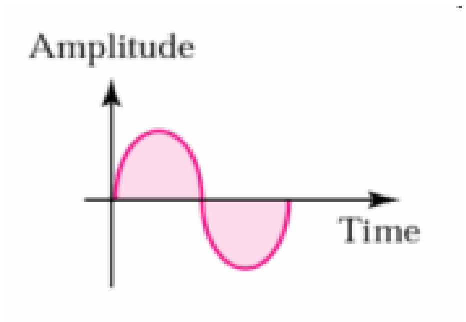
1. A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitude is increasing.
2. A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing.
3. A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.

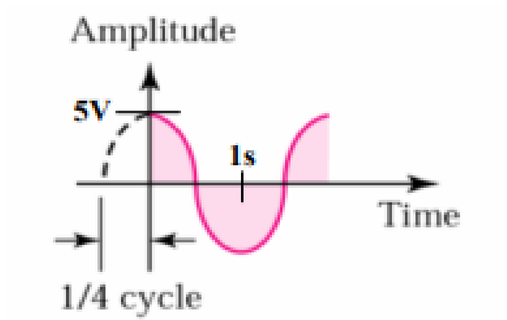
Another way to look at the phase is in terms of shift or offset. We can say that

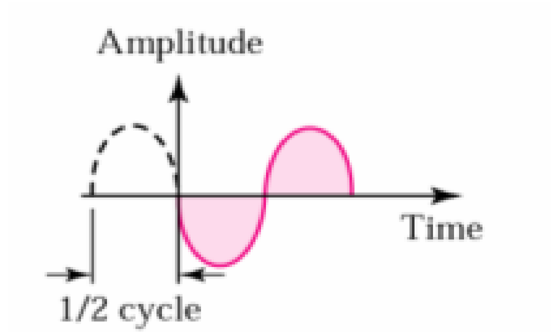
1. A sine wave with a phase of 0° is not shifted.
2. A sine wave with a phase of 90° is shifted to the left by 1/4 cycle. However, note that the signal does not really exist before time 0.
3. A sine wave with a phase of 180° is shifted to the left by 1/2 cycle. However, note that the signal does not really exist before time 0.

Phase in Simple Analog Signals – measured in degrees or radians

- $360^o = 2\pi$ rad
- $1^o = 2\pi/360$ rad
- 1 rad = $(360/2\pi)^o$ = 57.29578°
- phase shift of 360° = shift of 1 complete period
- phase shift of 180° = shift of 1/2 period
- phase shift of 90° = shift of 1/4 period



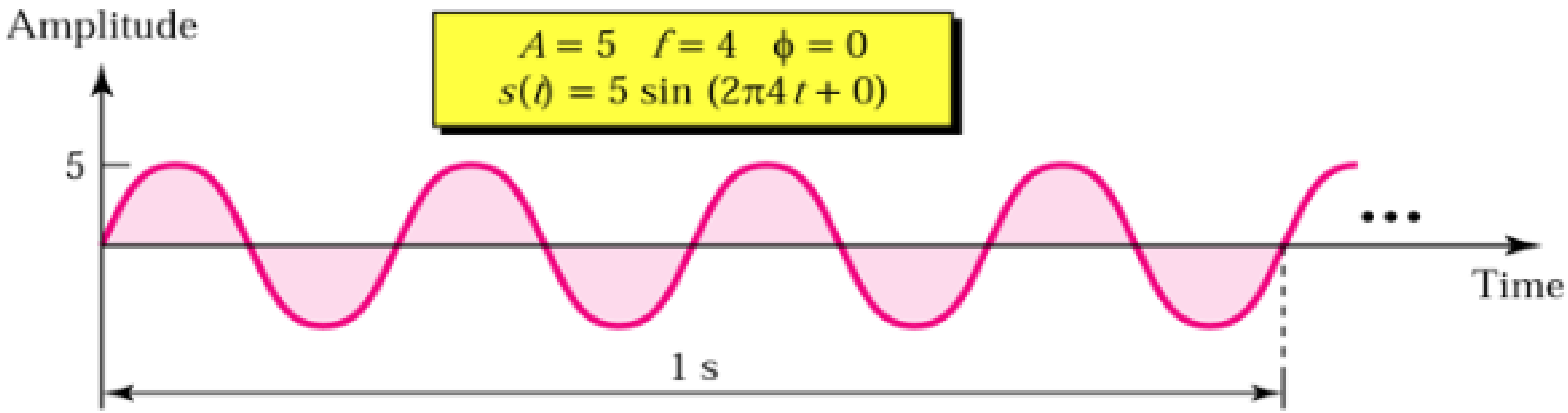




$\varphi = 0^o$ or 360^o

Sine wave and its properties

$$y(t) = A\sin(2\pi ft + \varphi)$$



Example-4

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

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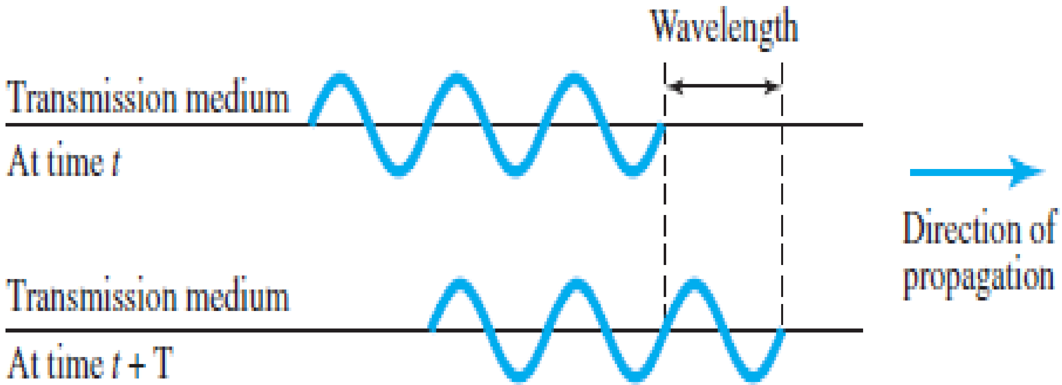
- A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

$$360^\circ \Leftrightarrow 2\pi \text{ rad}$$

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

4.Wavelength

- Wavelength is distance signal travels over one cycle in a transmission media with specific speed
- Another word, distance is a simple signal travels in one period between two points of corresponding phase in two consecutive cycles.
- *Wavelength (meter) binds the period or the frequency of a simple sine wave to the propagation* ***speed*** *of the* ***medium***.



4.Wavelength

- the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium.

$$\text{Wavelength} = (\text{propagation speed}) \times \text{period} = \frac{\text{propagation speed}}{\text{frequency}}$$

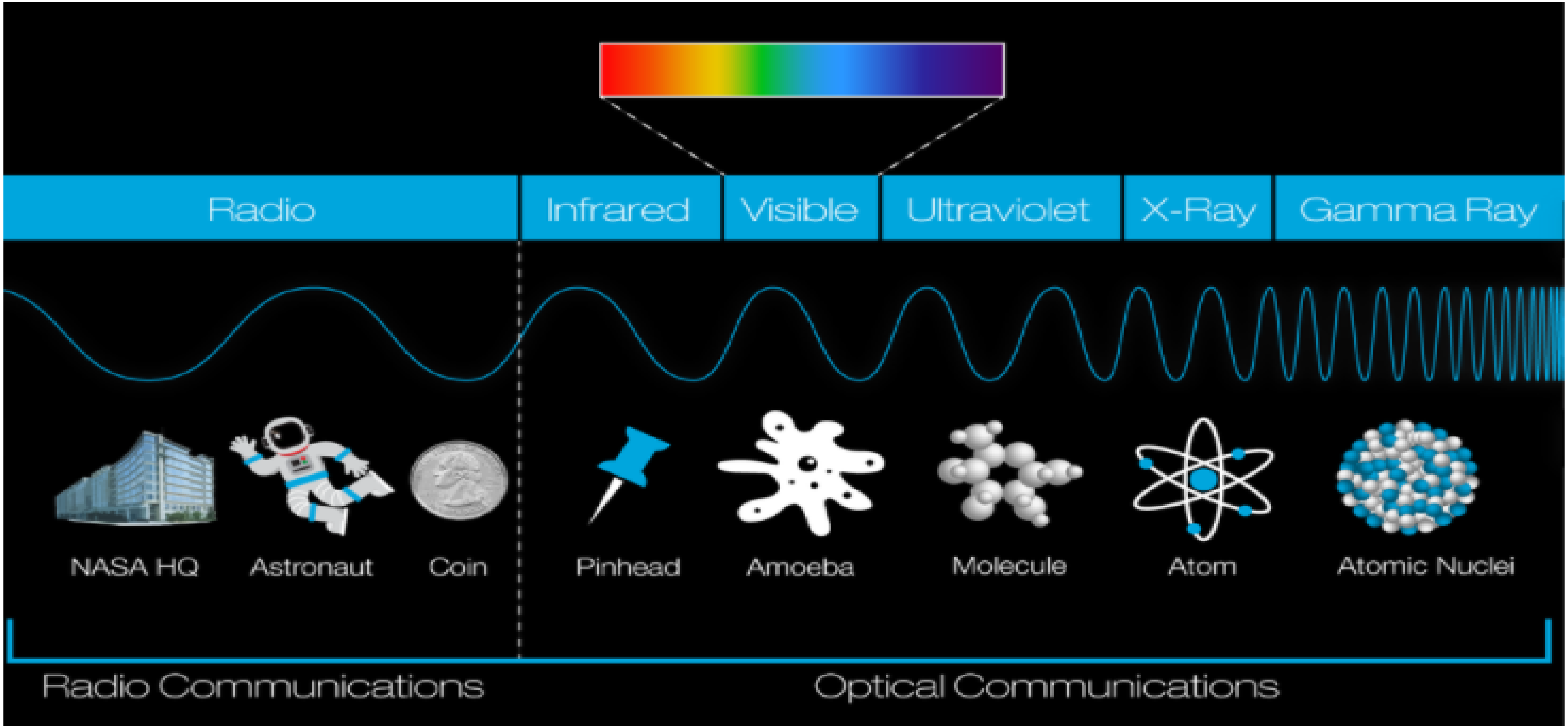
$$\lambda = \frac{c}{f}$$

- For example, in a vacuum, light is propagated with a speed of 3 × 108 m/s.less in air and still less in medium

wavelength of red light (frequency = 4×10^{14}) in air is

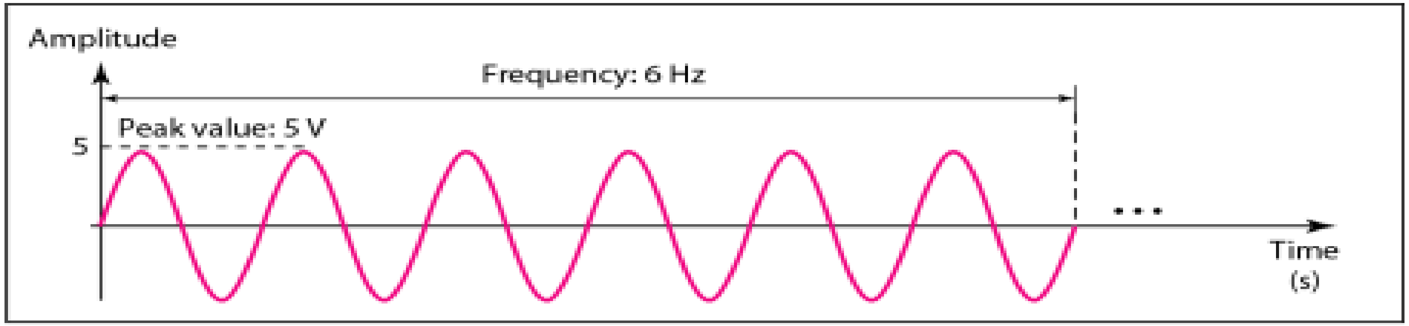
$$\lambda = \frac{c}{f} = \frac{3\times10^{8}}{4\times10^{14}} = 0.75 \times 10^{-6}\ \text{m} = 0.75\ \mu\text{m}$$

EM Radiation

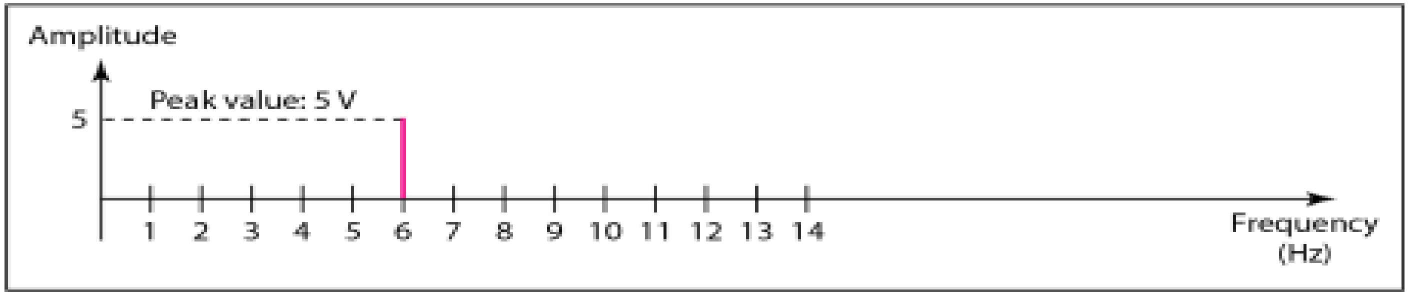


The time-domain and frequency-domain plots of a sine wave

- To show the relationship between amplitude and frequency, we can use what is called a frequency-domain plot. A frequency-domain plot is concerned with only the peak value and the frequency. Changes of amplitude during one period are not shown. Figure 3.7 shows a signal in both the time and frequency domains.



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

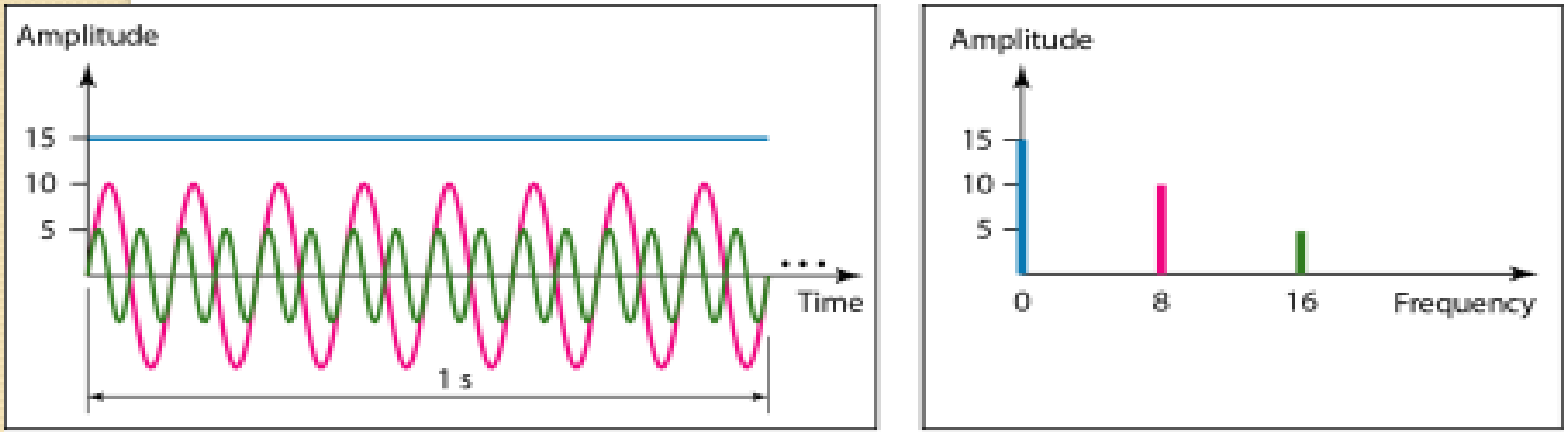


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

The description of a signal using the frequency domain and containing all its components is called the frequency spectrum of that signal.

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. Figure shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.



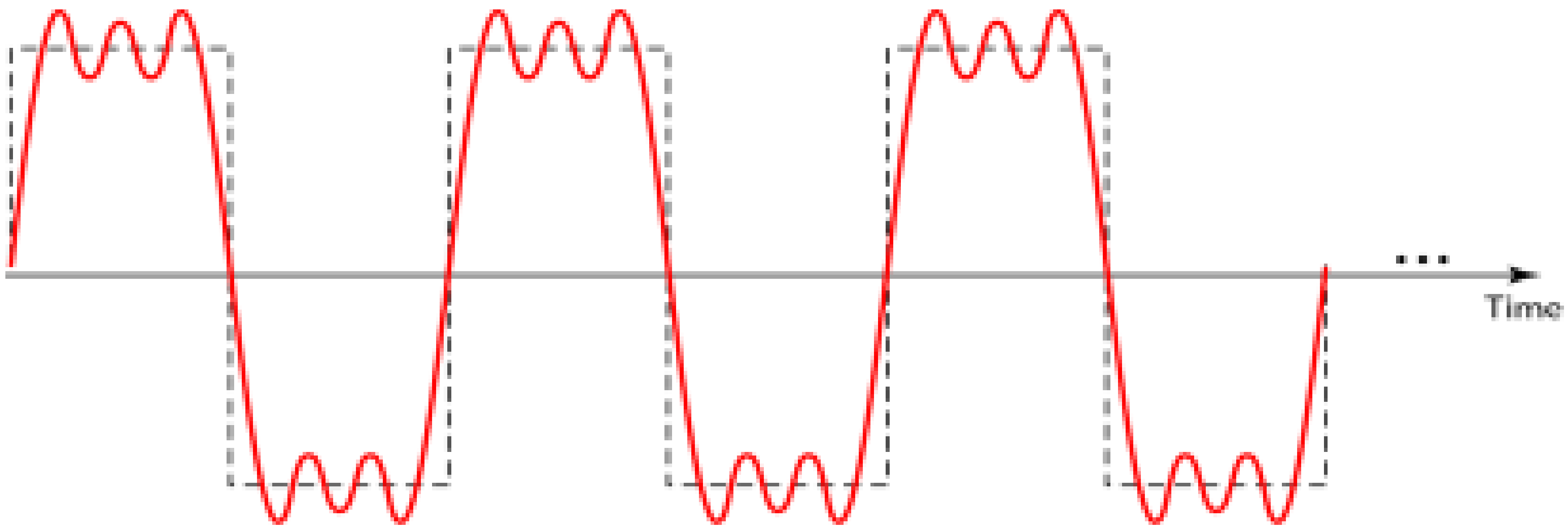
a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

b. Frequency-domain representation of the same three signals

Composite Signals

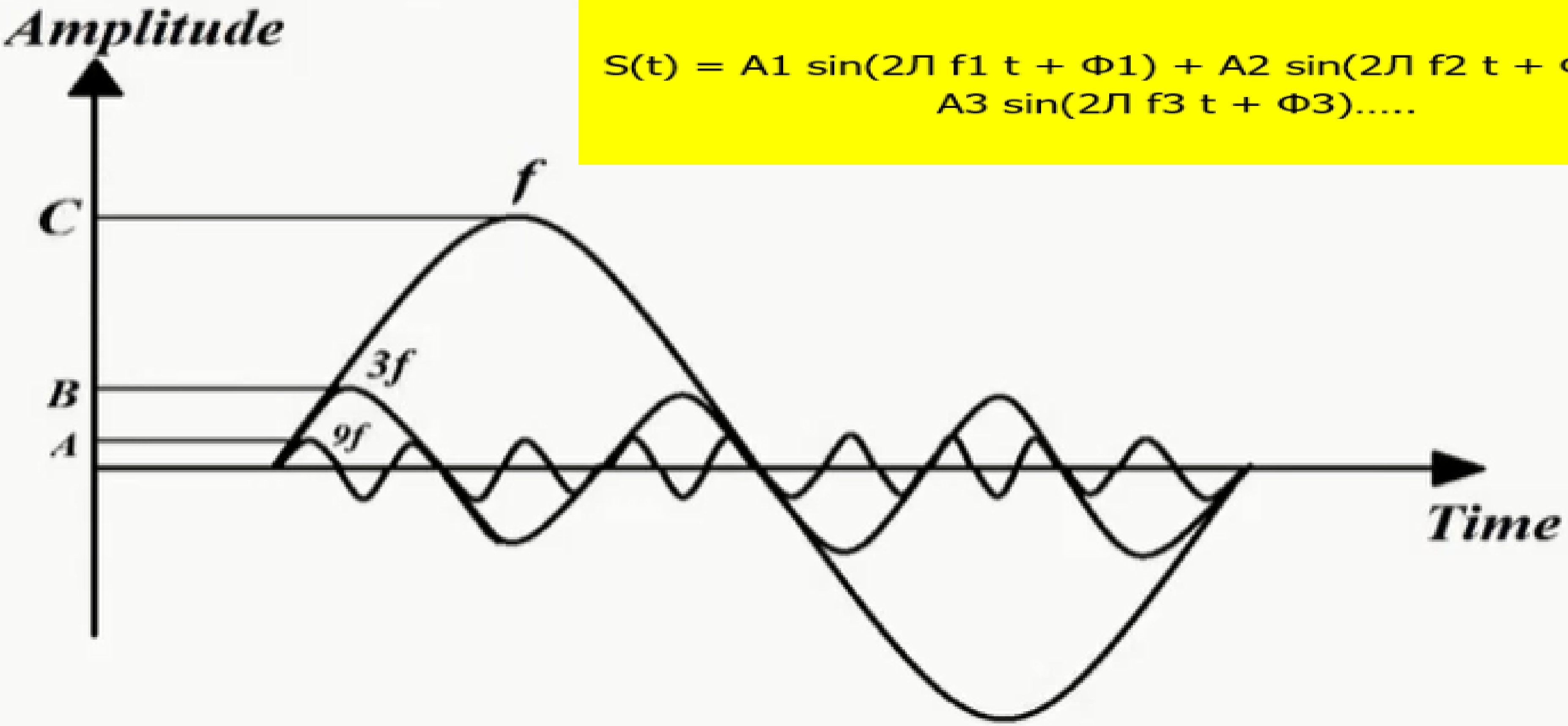
Composite Periodic Signal

Figure 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.

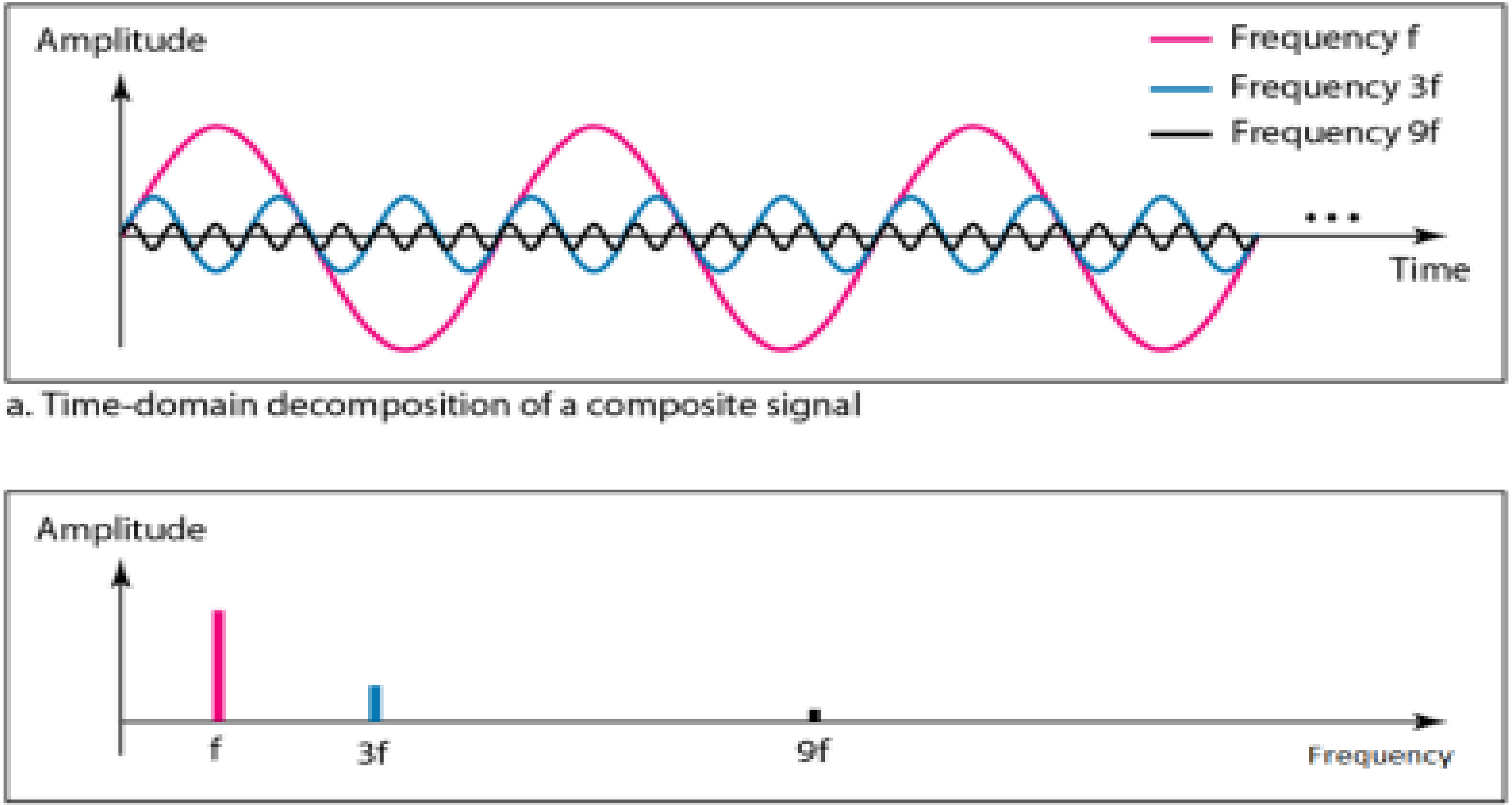


Decomposition of a Composite Periodic Signal

$$S(t) = A1 \sin(2\pi f1\ t + \Phi1) + A2 \sin(2\pi f2\ t + \Phi2) + A3 \sin(2\pi f3\ t + \Phi3).....$$



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

Composite Signals

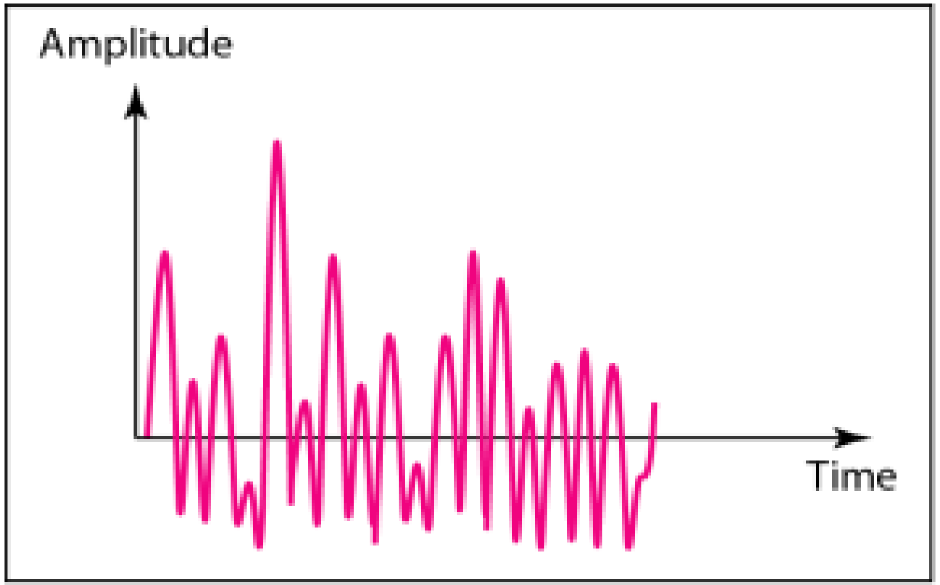
- Simple sine waves have many applications in daily life.
- We can send a single sine wave to carry **electric energy** from one place to another. For example, the power company sends a single sine wave with a frequency of 60 Hz to distribute electric energy to houses and businesses
- If we had only 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.
- we need to send a **composite signal to communicate data**. A composite signal is made of many simple sine waves.

Composite Periodic Signal

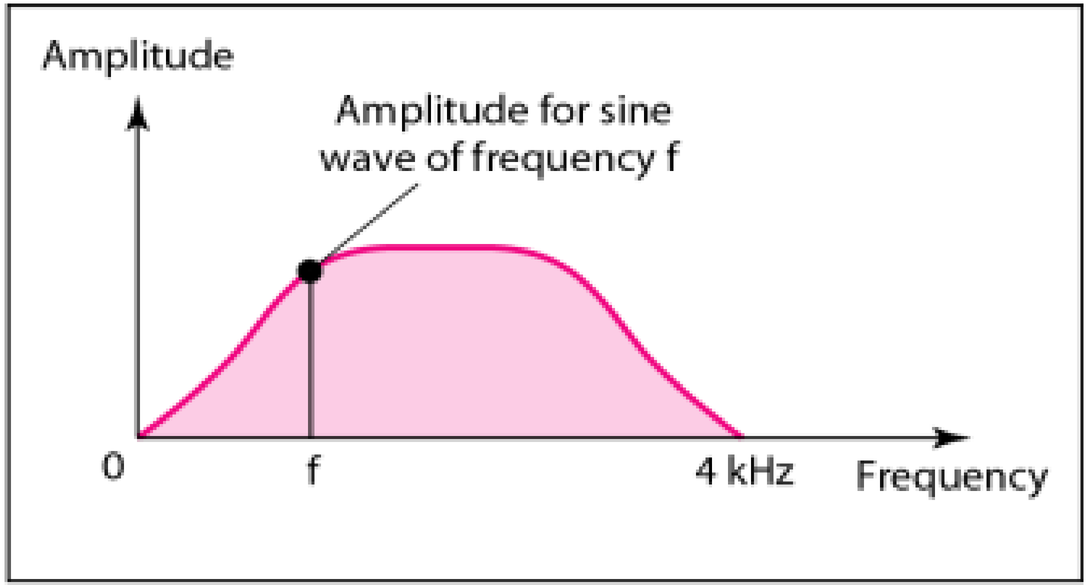
- A single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.
- According to **Fourier analysis**, **any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases**
- If 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**.

The time and frequency domains of a non periodic signal

- In a time-domain representation of this composite signal, there are an infinite number of simple sine frequencies. Although the number of frequencies in a human voice is infinite, the range is limited. A normal human being can create a continuous range of frequencies between 0 and 4 kHz.



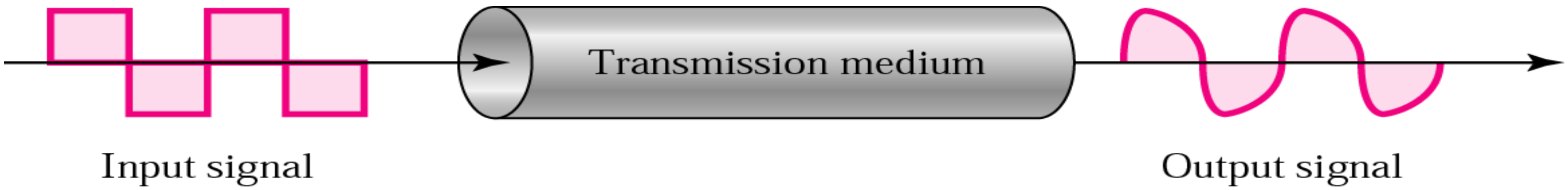
a. Time domain



b. Frequency domain

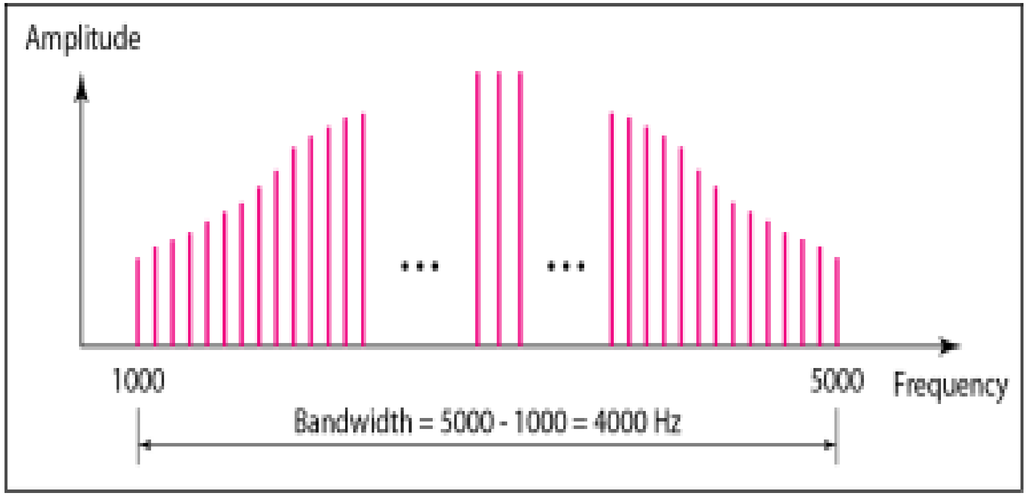
Bandwidth

- A medium (cable or air) is required for signal to transmit.
- Each medium has its own characteristics it may pass some frequencies and may block or weaken others.
- No medium is perfect, each medium **passes some frequencies, weakens others and blocks still others**.
- The range of frequencies that a medium can pass is called its bandwidth.
- As mediums are not perfect bandwidth refers to the range of frequencies that a medium can pass without losing one half of the power contained in the signal.

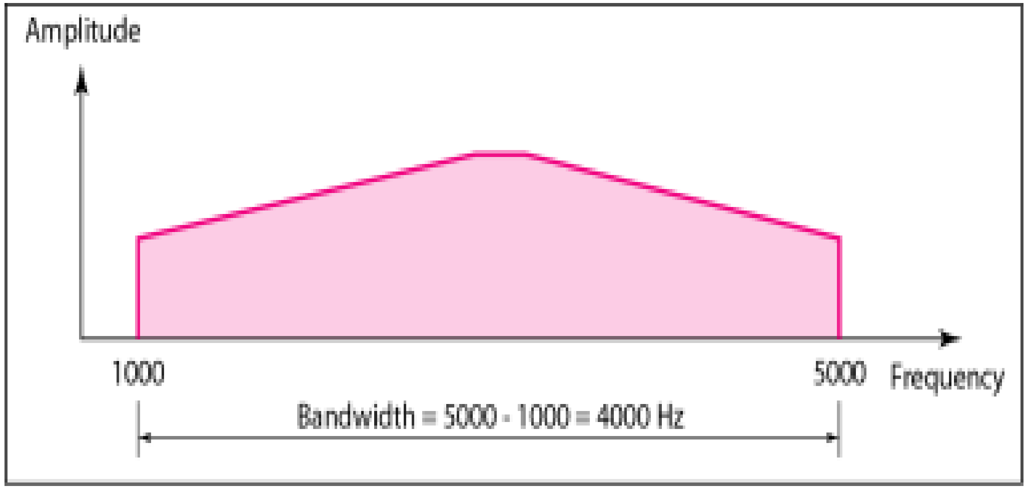


Bandwidth

- The **range of frequencies** contained in a composite signal is its bandwidth.
- *It is the* ***difference between the highest and the lowest frequencies*** *that the medium can satisfactorily pass.*
- 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
- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.



a. Bandwidth of a periodic signal



Example

- 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.

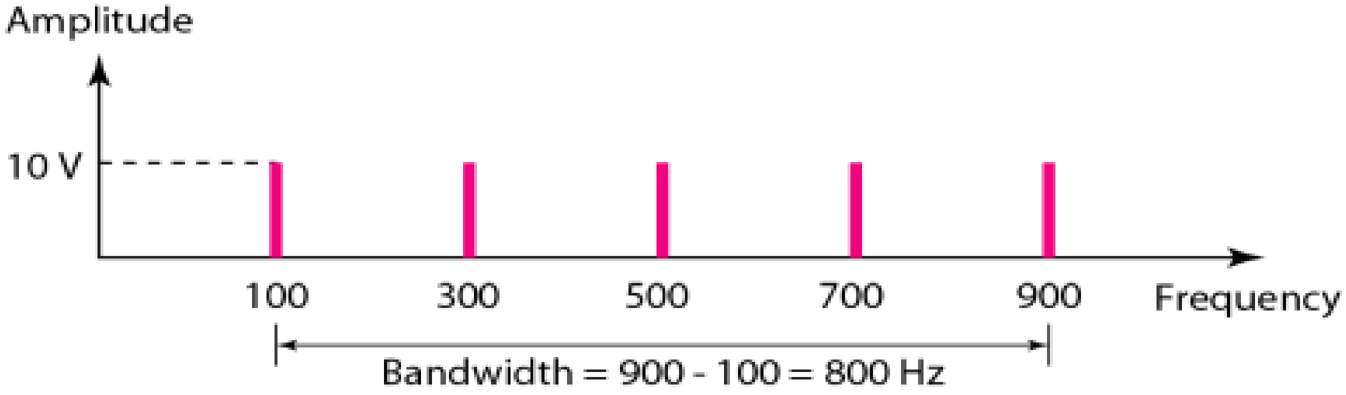
Example

- 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

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

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



Example

- 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.

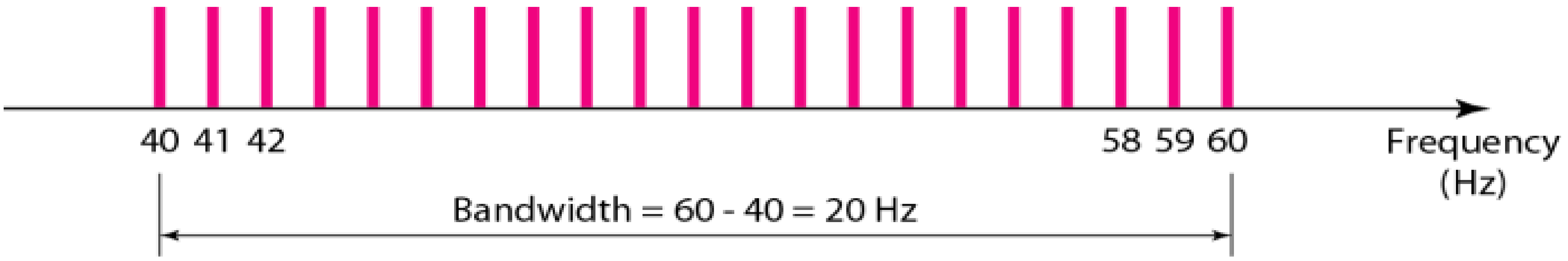
Example

- 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

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

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure 3.14).



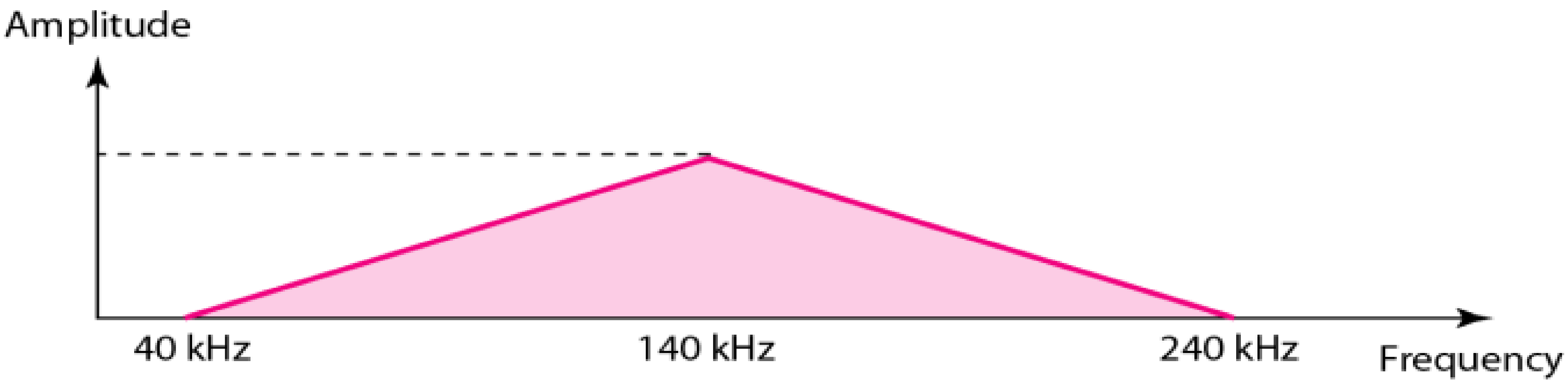
Example

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.

Example

- A non periodic 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.



Example

A signal has a spectrum with frequencies between 1000 and 2000 Hz (bandwidth of 1000 Hz). A medium can pass frequencies from 3000 to 4000 Hz (a bandwidth of 1000 Hz). Can this signal faithfully pass through this medium?

Solution

The answer is definitely no. Although the signal can have the same bandwidth (1000 Hz), the range does not overlap. The medium can only pass the frequencies between 3000 and 4000 Hz; the signal is totally lost.

Example

- An example of a non periodic 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. We will show the rationale behind this 10-kHz bandwidth in Chapter 5.
- Another example of a non periodic 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. We will show the rationale behind this 200-kHz bandwidth in Chapter 5.
- 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. The bandwidth needed is 5.5125 MHz.

Digital Signal

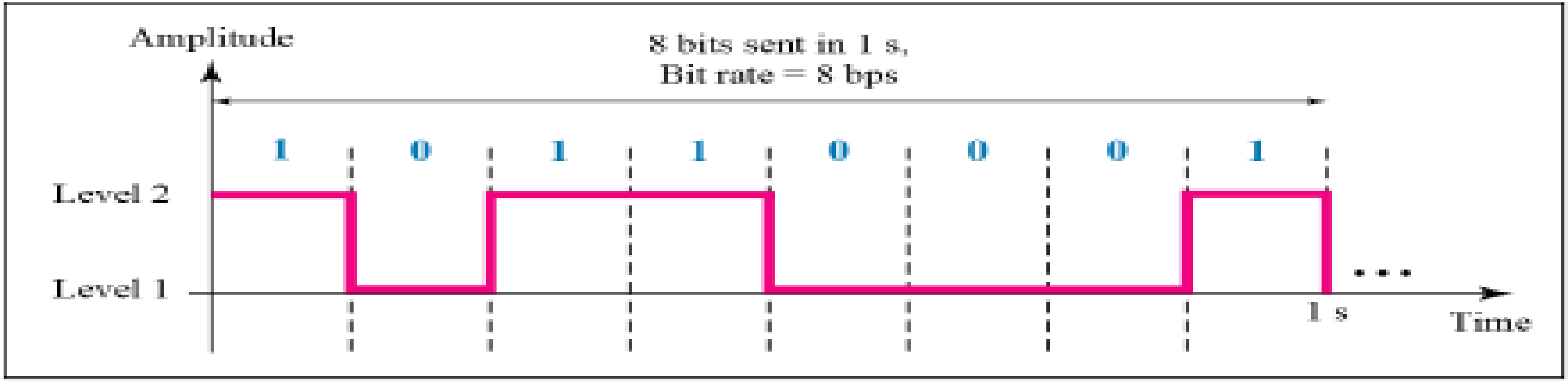
Digital Signal

- Have finite levels-representation 0 & 1
- 1 can be encoded as positive voltage and a 0 as zero voltage.
- A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level
- Most digital signals are non periodic, and thus period and frequency are not appropriate characteristics. Another term **bit rate** (instead of frequency) is used to describe digital signals.
- The **bit rate i s the number of bits sent in 1s**,expressed in bits per second (bps).
- Number of level increases –bit rate increases
- Bit length= length of 1 bit(bit duration)* propogation speed

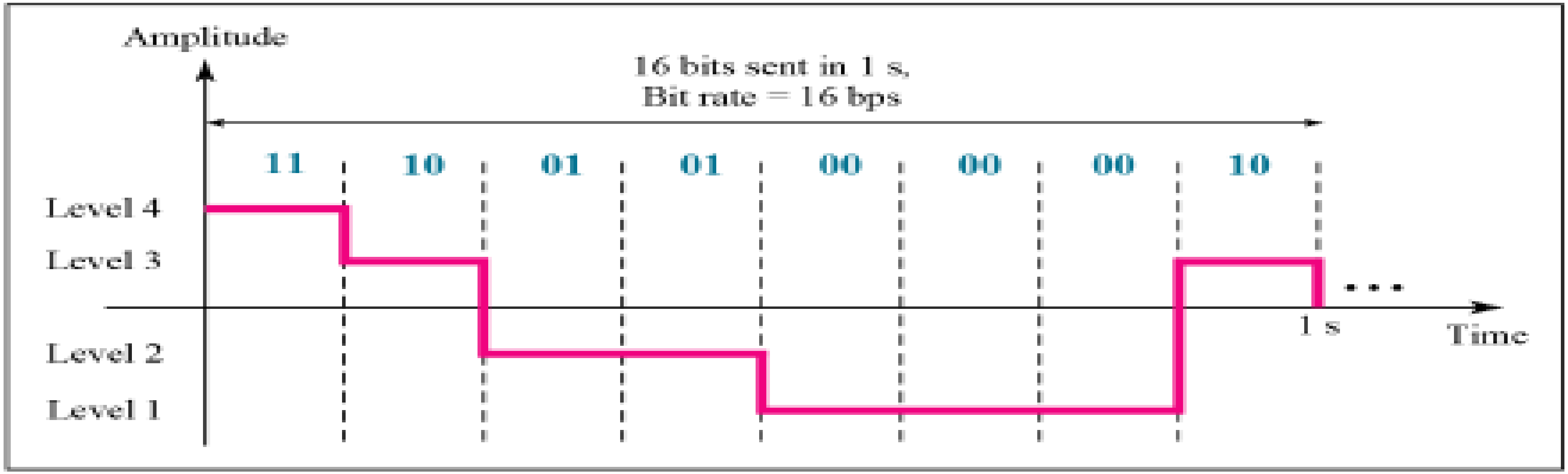
Bit Length

- The concept of the wavelength for an analog signal: the distance on 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

$$\boxed{\text{Bit length} = \text{propagation speed} \times \text{bit duration}}$$



a. A digital signal with two levels



b. A digital signal with four levels

Example (1)

- A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

- Each signal level is represented by 3 bits.

Example (2)

- Assume we need to download text documents at the rate of 100 pages per $\boxed{\text{secs}}$ What is the required bit rate of the channel?
- **Solution**
  - A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$\boxed{100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}}$$

Example (4)

- What is the bit rate for high-definition TV (HDTV)?

- **Solution**
  - HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16 : 9. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel.

$$\boxed{1920 \times 1080 \times 30 \times 24 = 1{,}492{,}992{,}000 \text{ or } 1.5 \text{ Gbps}}$$

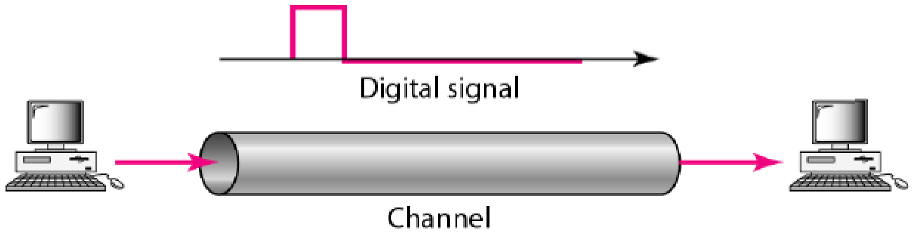
  - The TV stations reduce this rate to 20 to 40 Mbps through compression.

Transmission of Digital Signal

- We can transmit a digital signal by using one of two different approaches:
- **baseband transmission or broadband transmission (using modulation)**

Baseband Transmission

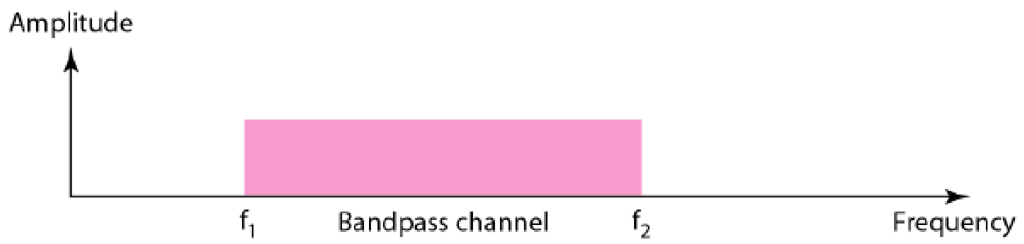
- Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.



- Baseband transmission requires that we have a low pass channel, a channel with a bandwidth that starts from zero.
- dedicated medium with a bandwidth constituting only one channel.

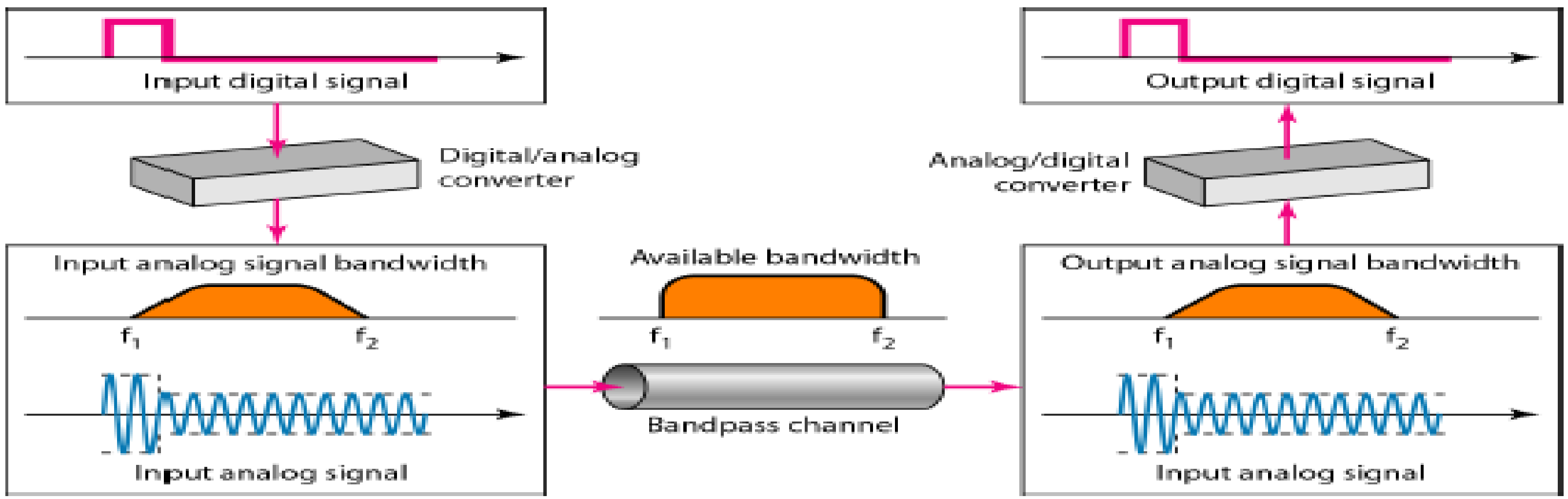
Broadband Transmission (Using Modulation)

- Broadband transmission or modulation means changing the digital signal to an analog signal for transmission.
- use a bandpass channel-a channel with a bandwidth that does not start from zero.



Modulation of a digital signal for transmission on a bandpass channel

- Digital signal is converted to a composite analog signal. We have used a single-frequency analog signal (called a carrier); the amplitude of the carrier has been changed to look like the digital signal. The result, however, is not a single frequency signal; it is a composite signal.At the receiver,the received analog signal is converted to digital, and the result is a replica of what has been sent.



Example

- An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office. These lines are designed to carry voice with a limited bandwidth. The channel is considered a bandpass channel. We convert the digital signal from the computer to an analog signal, and send the analog signal. We can install two converters to change the digital signal to analog and vice versa at the receiving end. The converter, in this case, is called a modem.
- A second example is the digital cellular telephone. For better reception, digital cellular phones convert the analog voice signal to a digital signal. Although the bandwidth allocated to a company providing digital cellular phone service is very wide, we still cannot send the digital signal without conversion. The reason is that we only have a bandpass channel available between caller and callee. We need to convert the digitized voice to a composite analog signal before sending.