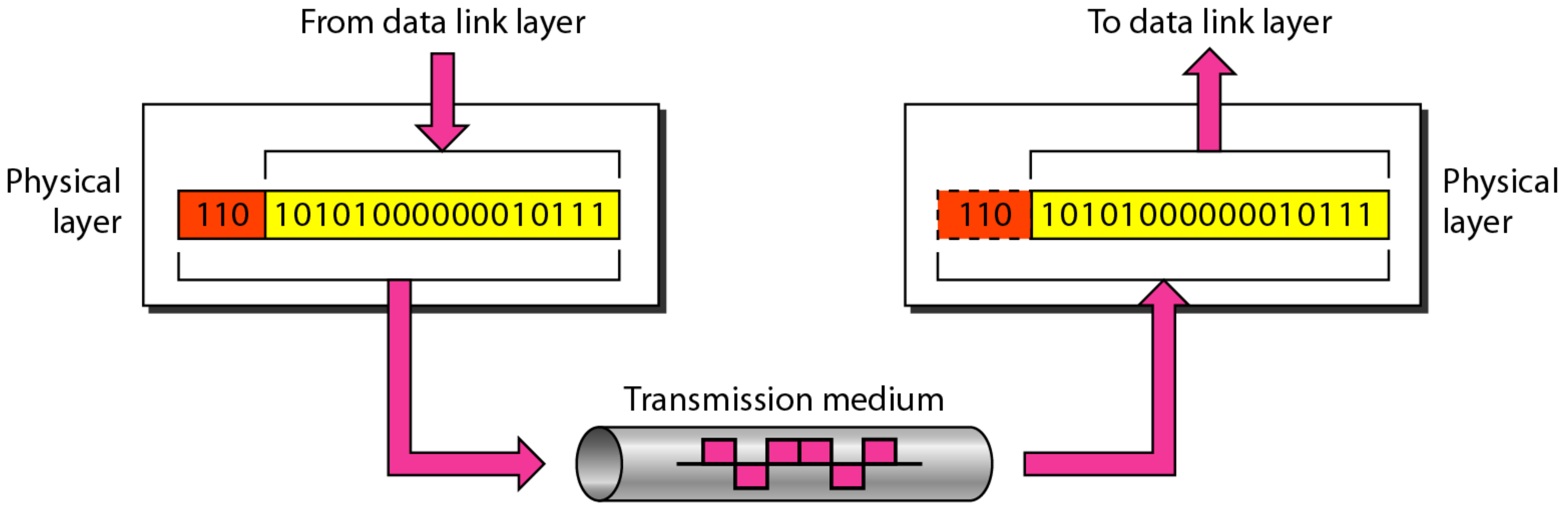
Physical Layer-Part-1

Signals and Its Properties

Physical layer



Data must be transformed to electromagnetic signals.

ANALOG AND DIGITAL

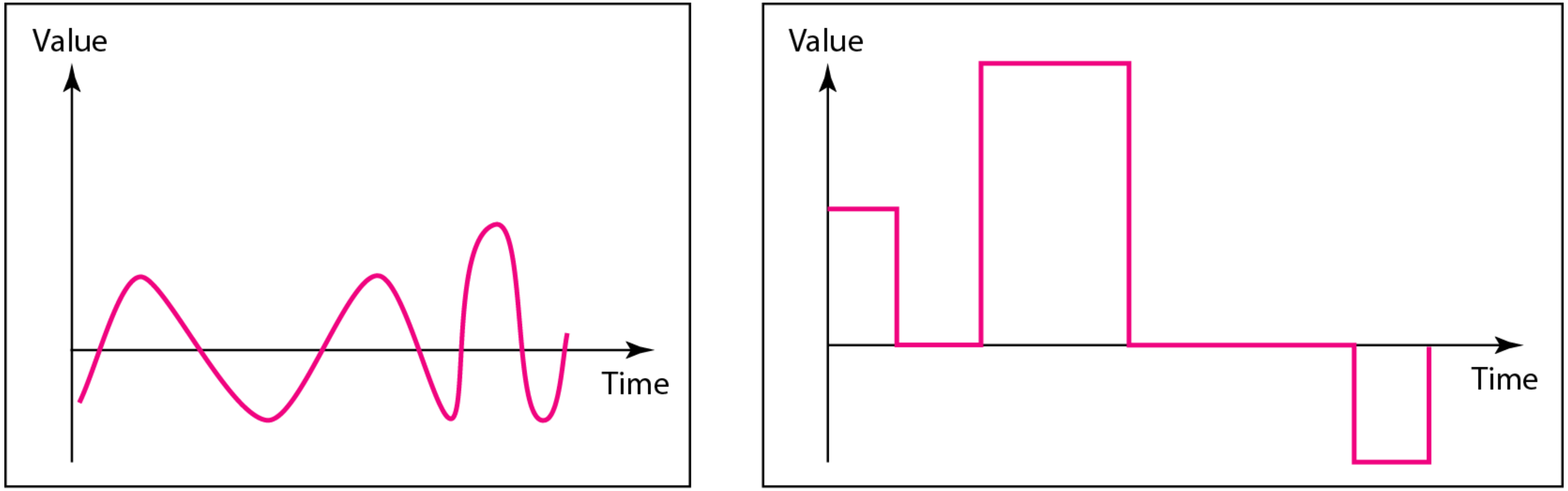
Data can be analog or digital

- Analog data refers to information that is continuous
- Analog data take on continuous values
- Analog signals can have an infinite number of values in a range

- Digital data refers to information that has discrete states
- Digital data take on discrete values
- Digital signals can have only a limited number of values

Commonly used signals in data communications are periodic analog signals and nonperiodic digital signals.

Comparison of analog and digital signals



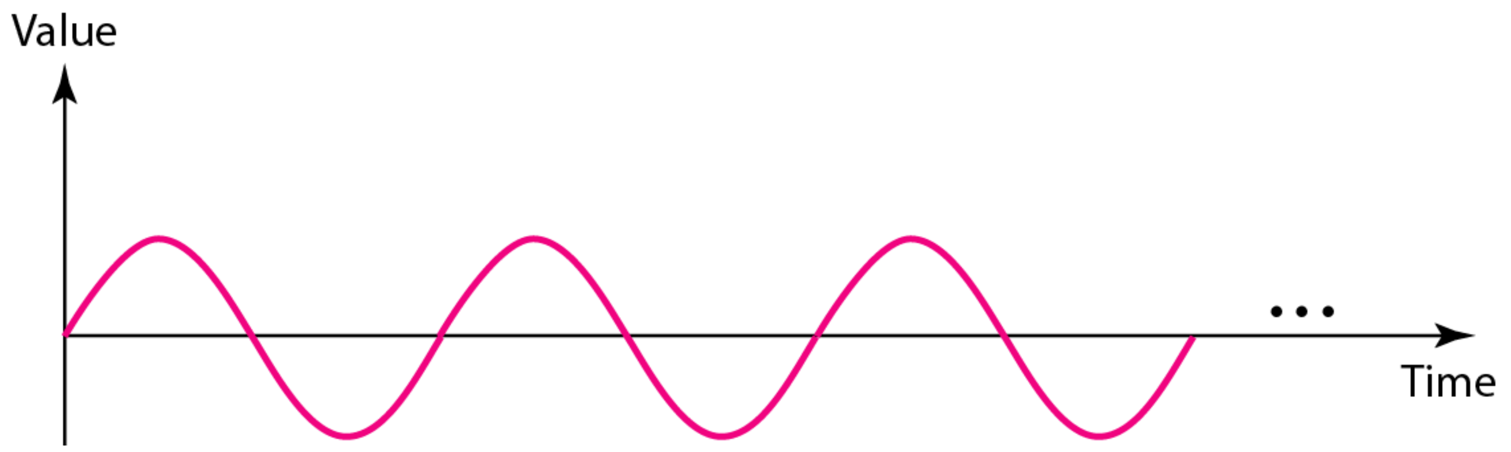
a. Analog signal

b. Digital signal

PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as simple or composite.

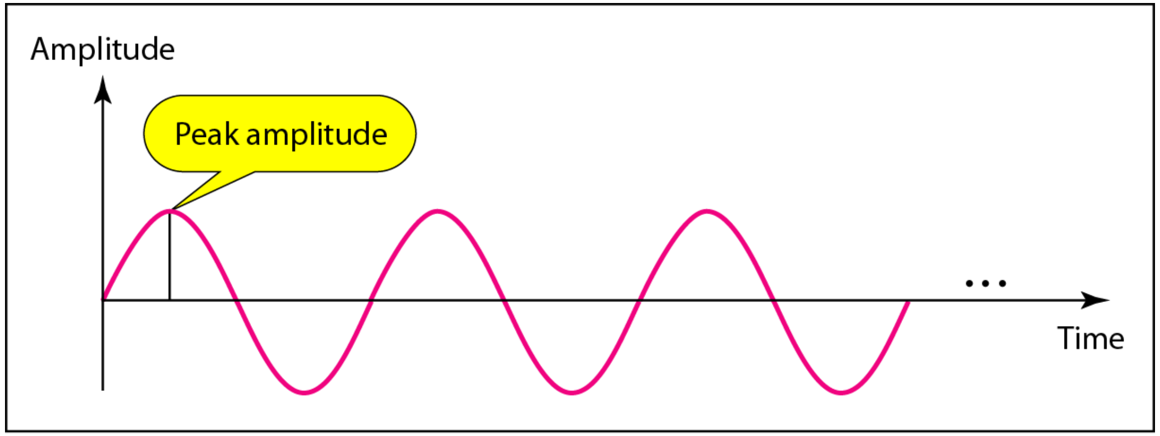
- A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves.



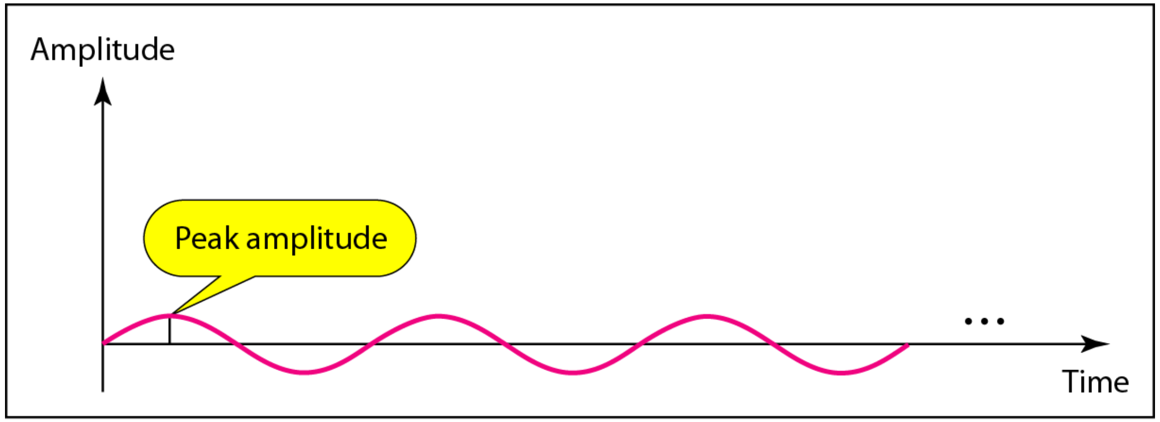
Parameters to describe a signal

- Peak Amplitude
- Frequency
- Phase

Signal amplitude



a. A signal with high peak amplitude



b. A signal with low peak amplitude

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

Frequency and Period

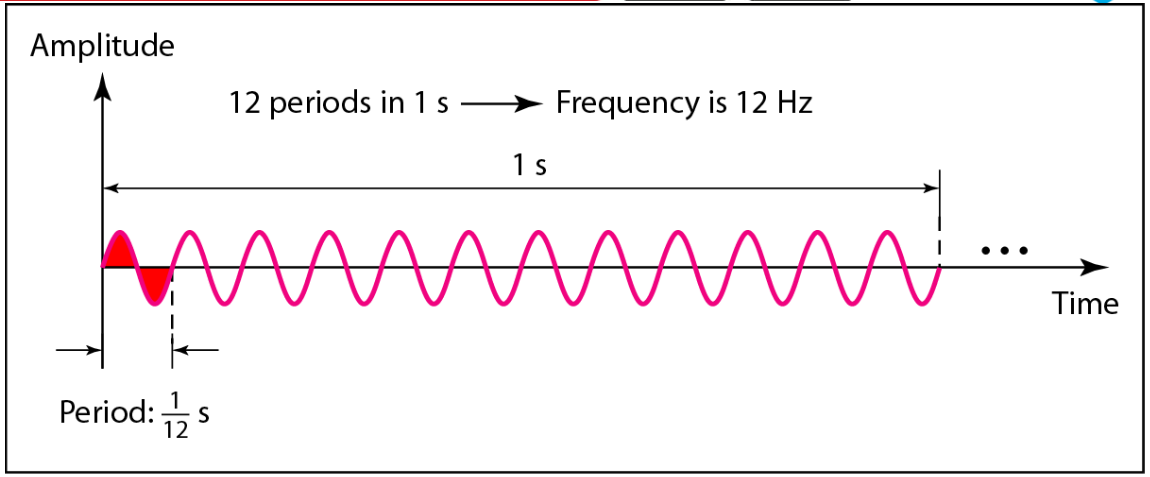
Frequency and period are the inverse of each other.

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

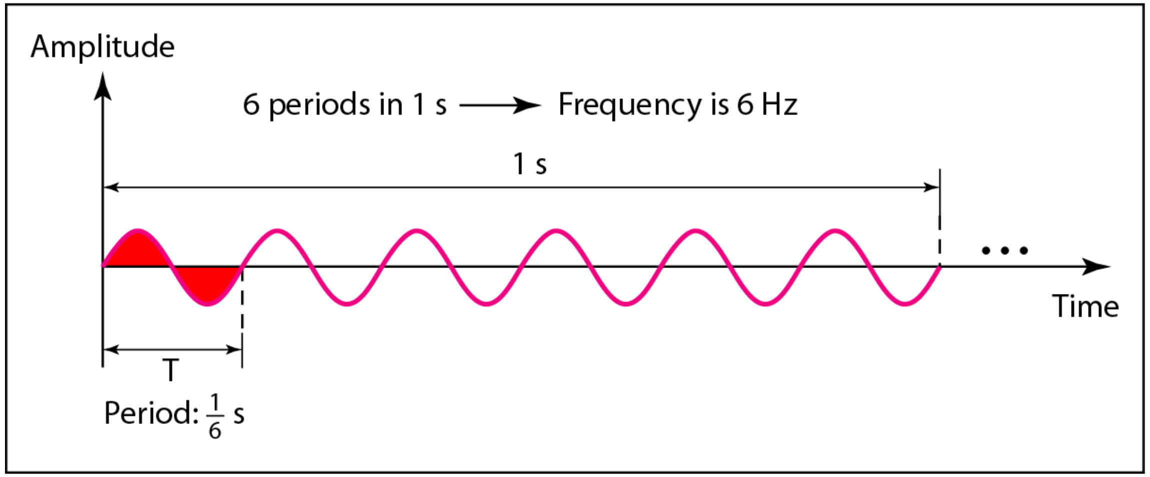
Units of period and frequency

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

Two signals with the same amplitude, but different frequencies



a. A signal with a frequency of 12 Hz

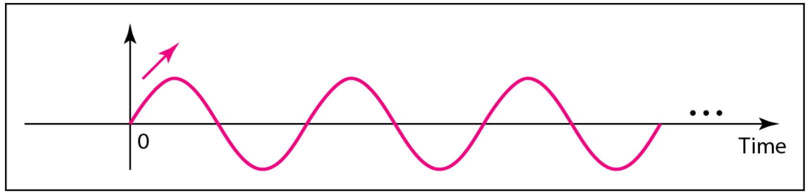


b. A signal with a frequency of 6 Hz

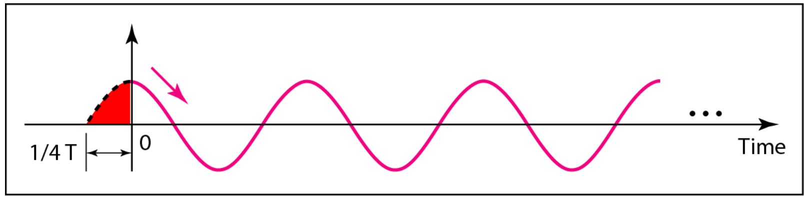
Phase

Phase describes the position of the waveform relative to time 0

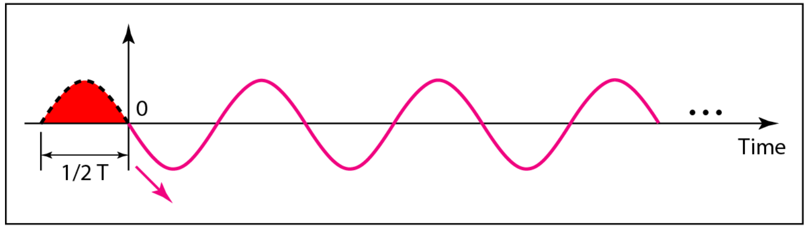
Three sine waves with the same amplitude and frequency,
but different phases



a. 0 degrees



b. 90 degrees



c. 180 degrees

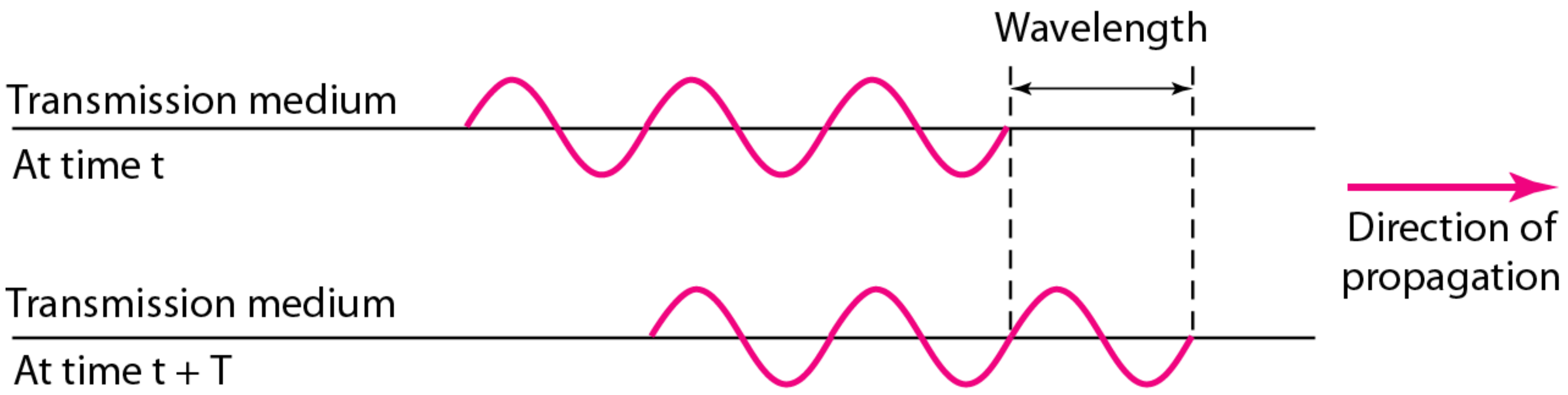
Example

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

1 cycle= $360°$
1/6 cycle= $360 \times (1/6)$
$= 60°$

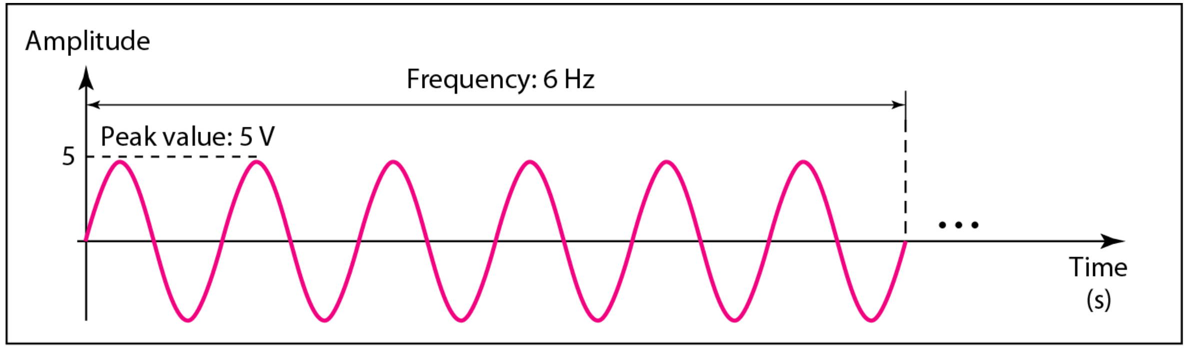
Wavelength and period

Wavelength = Propagation speed x Period
= Propagation speed / Frequency

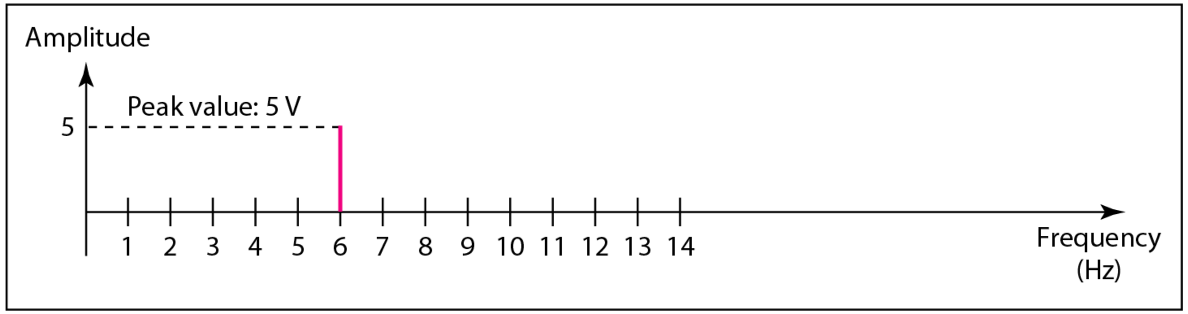


Time-domain and frequency-domain plots of a sine wave

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

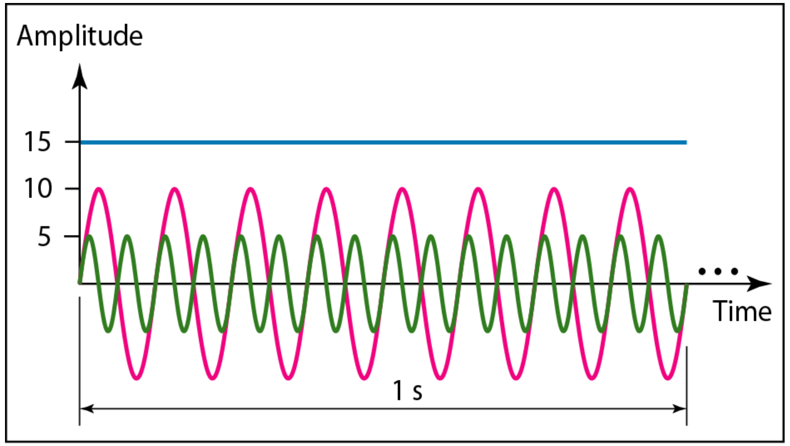


a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)

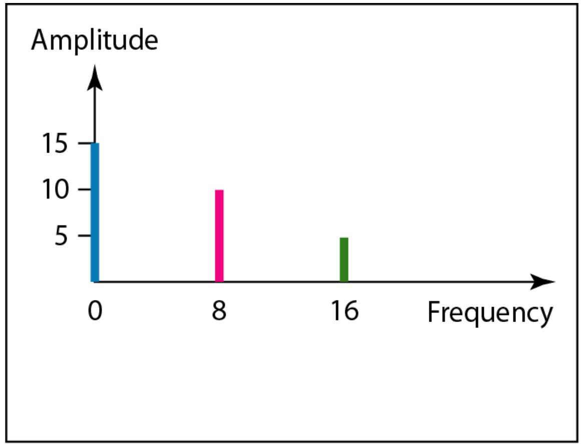


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

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

- The frequency domain is more compact and useful when we are dealing with more than one sine wave.

- A single-frequency sine wave is not useful in data communication
  - We need to send a composite signal, a signal made of many simple sine waves.

Fourier analysis

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.

Examples

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

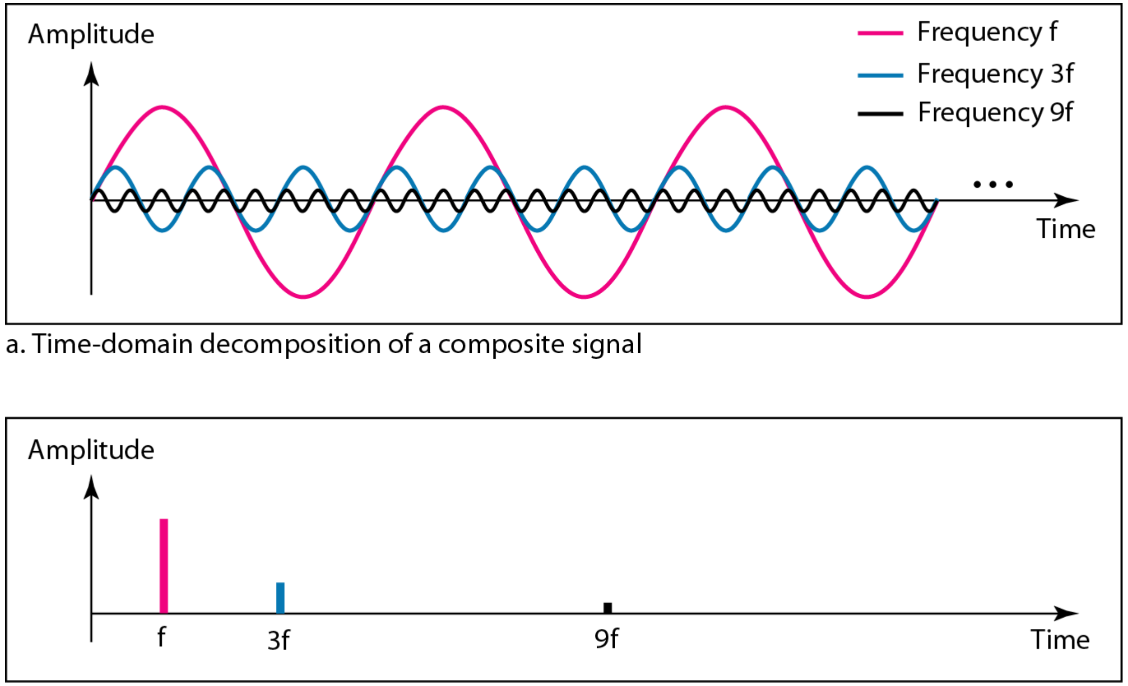
$$T = \frac{1}{f} = \frac{1}{60} = 0.0166 \text{ s} = 0.0166 \times 10^3 \text{ ms} = 16.6 \text{ ms}$$

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

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

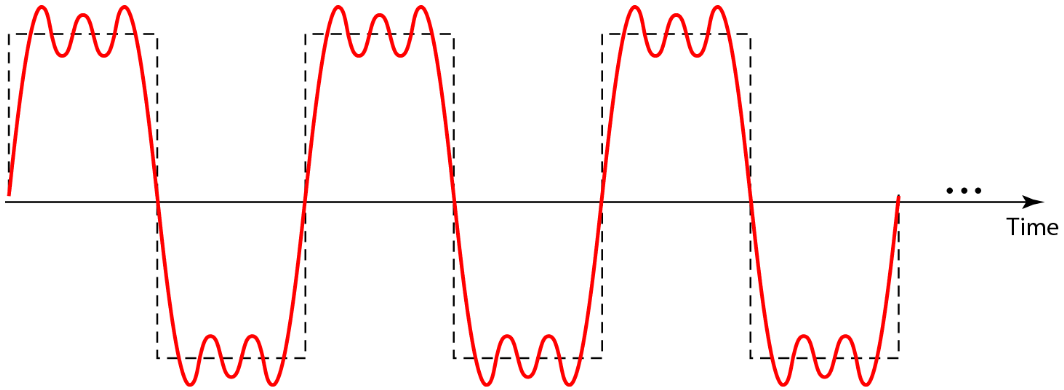
$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

A composite periodic signal



a. Time-domain decomposition of a composite signal

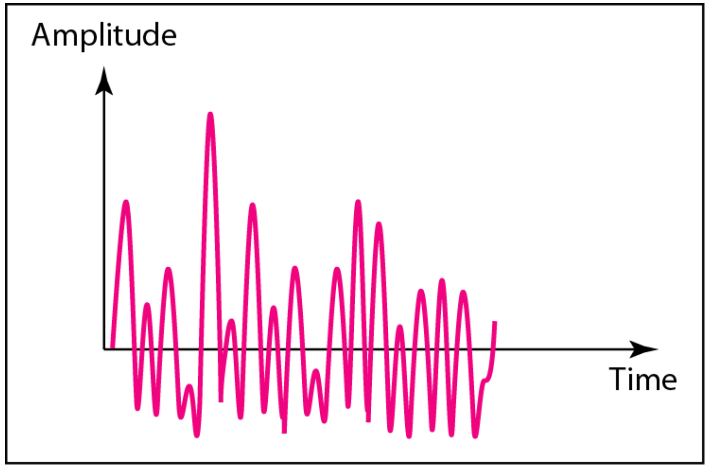
b. Frequency-domain decomposition of the composite signal



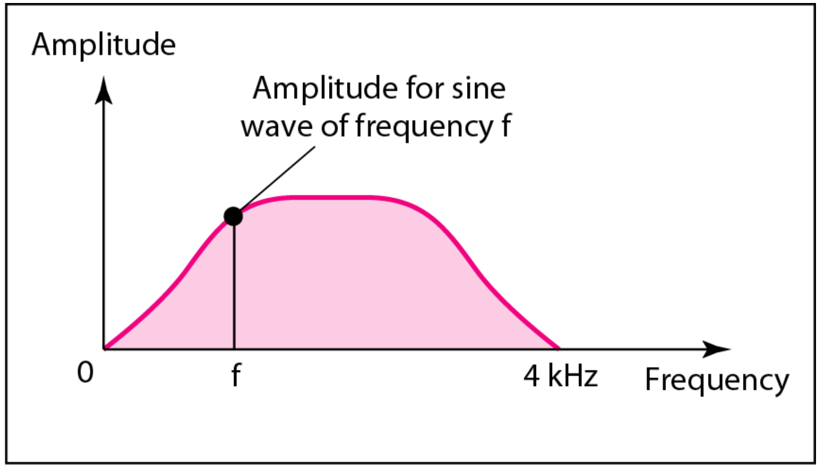
Decomposition of the composite periodic signal in the time and frequency domains

Time and frequency domains of a nonperiodic signal

- A nonperiodic composite signal
  - It can be a 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



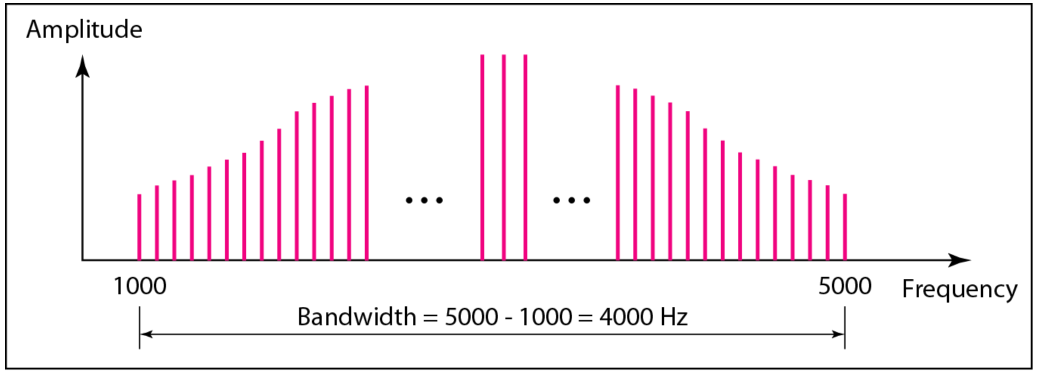
a. Time domain



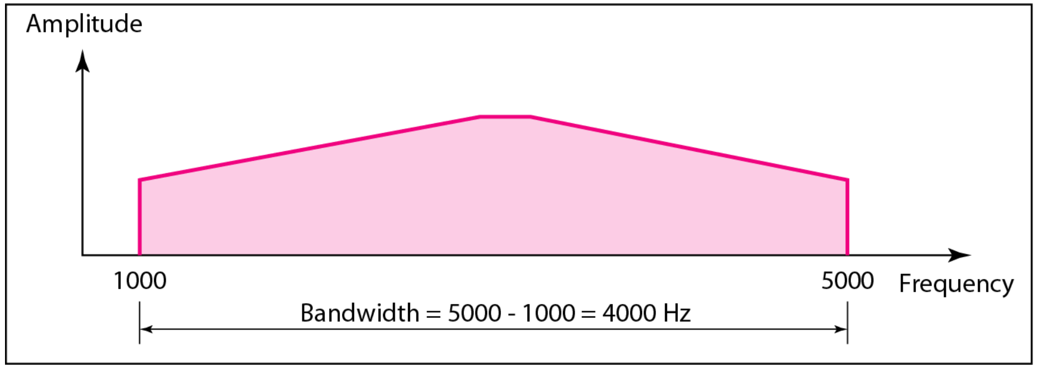
b. Frequency domain

Bandwidth

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



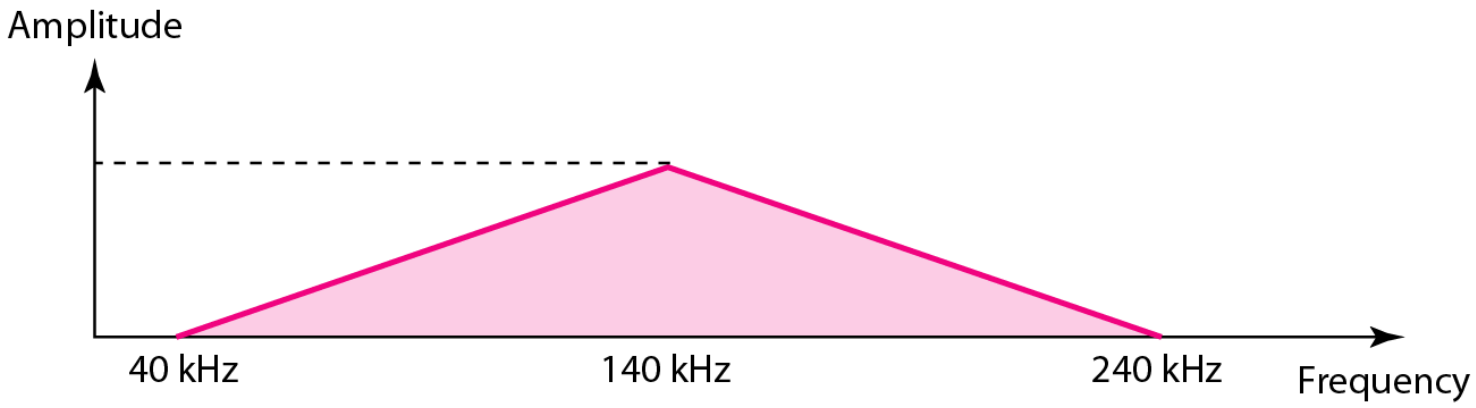
b. Bandwidth of a nonperiodic signal

Question

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

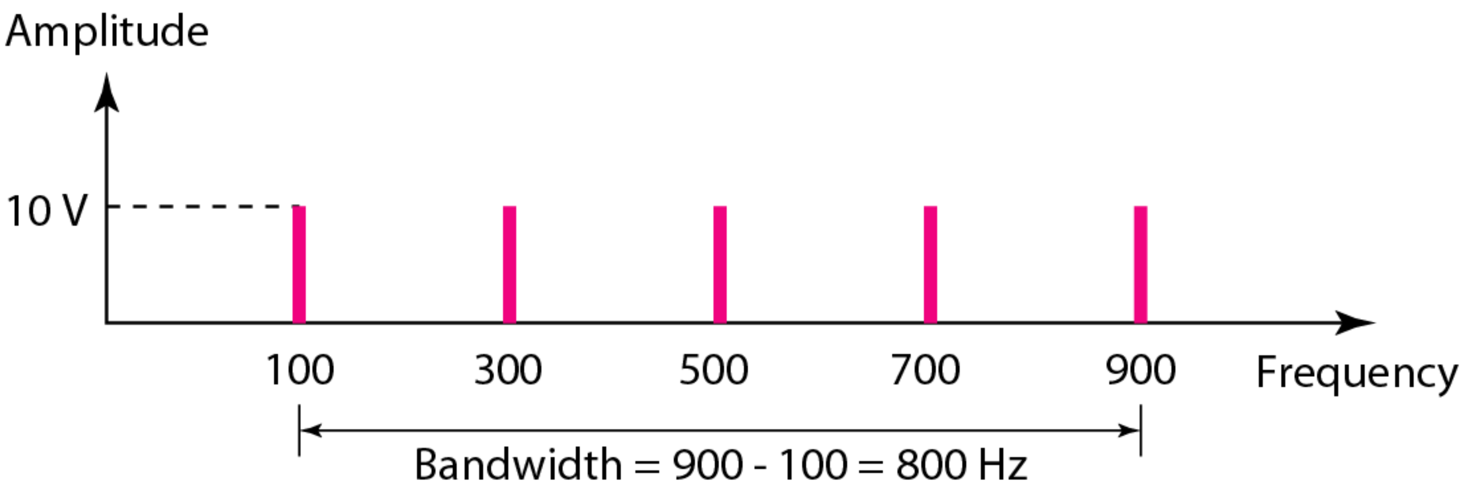
The lowest frequency must be at 40 kHz and the highest at 240 kHz.



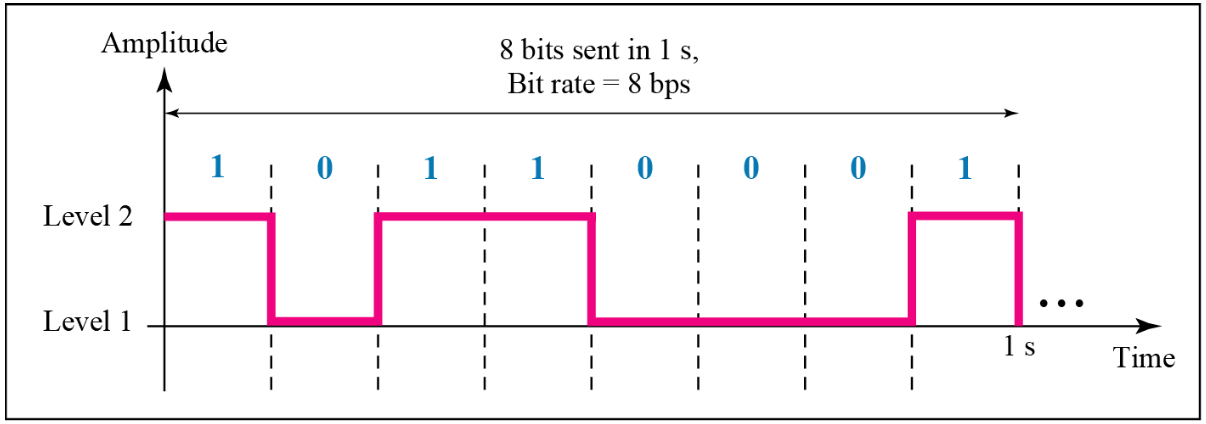
Question

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.

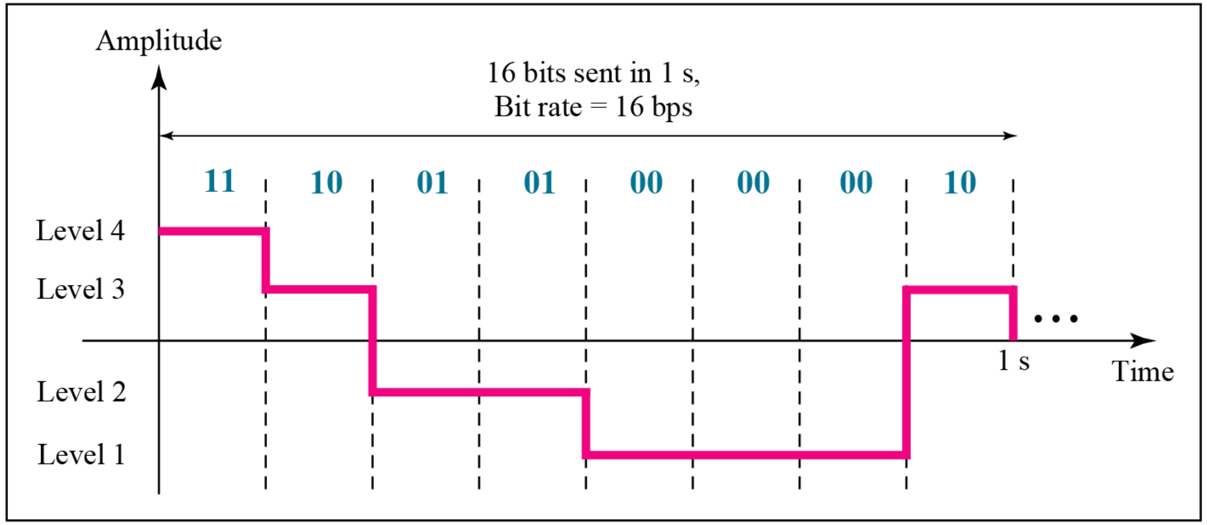
Solution



Digital signals with two different levels



a. A digital signal with two levels



b. A digital signal with four levels

Most digital signals used in data communication are non-periodic, another term '**Bit rate**' is used to describe the digital signals

Bit rate- It is referred as number of bits sent in 1 sec. It is expressed in **bits per second (bps).**

Question

A digital signal has eight levels. How many bits are needed per level?

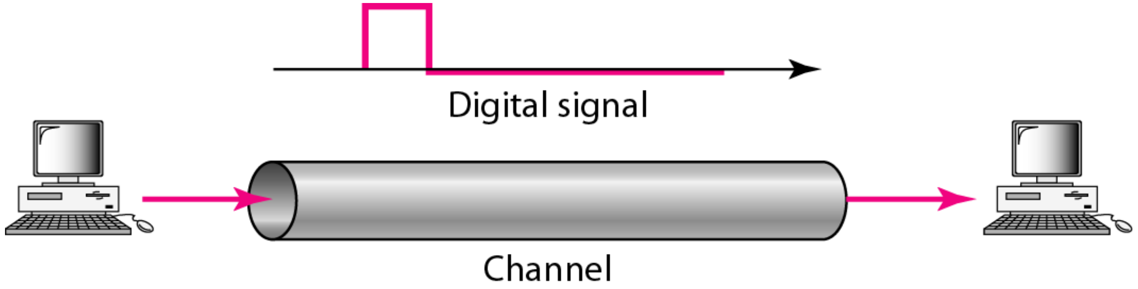
Solution

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

Each signal level is represented by 3 bits.

Digital Signal Transmission

1. **Baseband Transmission**
   - Communication technique in which digital signals are transmitted over a transmission medium without change in modulation.
   - Ethernet is an example of a baseband system found on many LANs

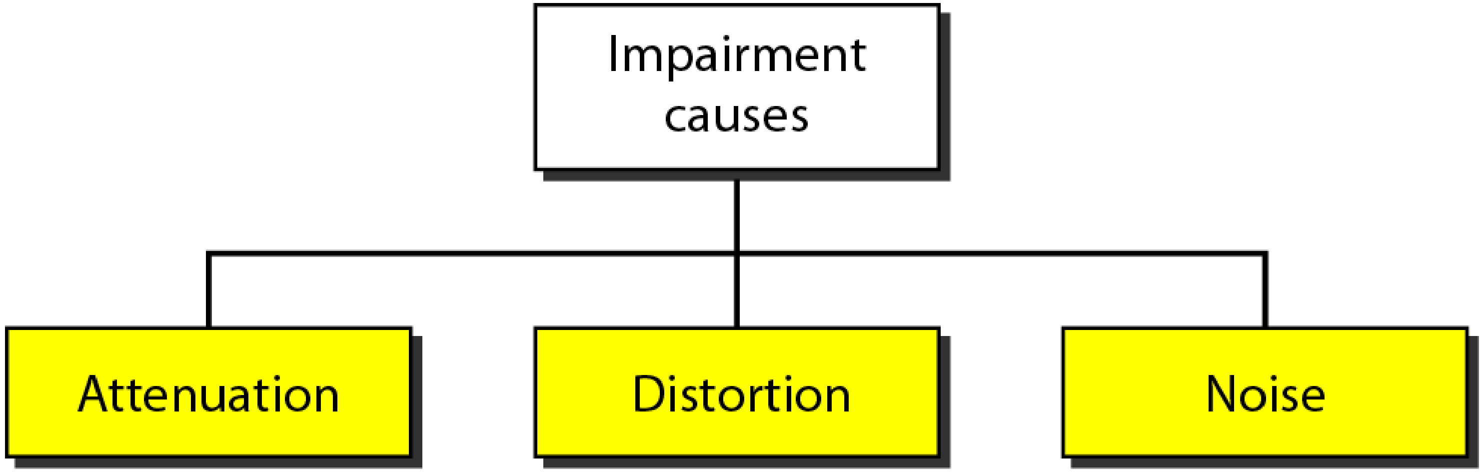


2. **Broadband Transmission**
   - Communication technique of transmitting large amount of data such as voice, videos over a long distance simultaneously by modulating each signal onto a different frequency.
   - Example - used in cable TV, and fiber optics media
   - More expensive than baseband

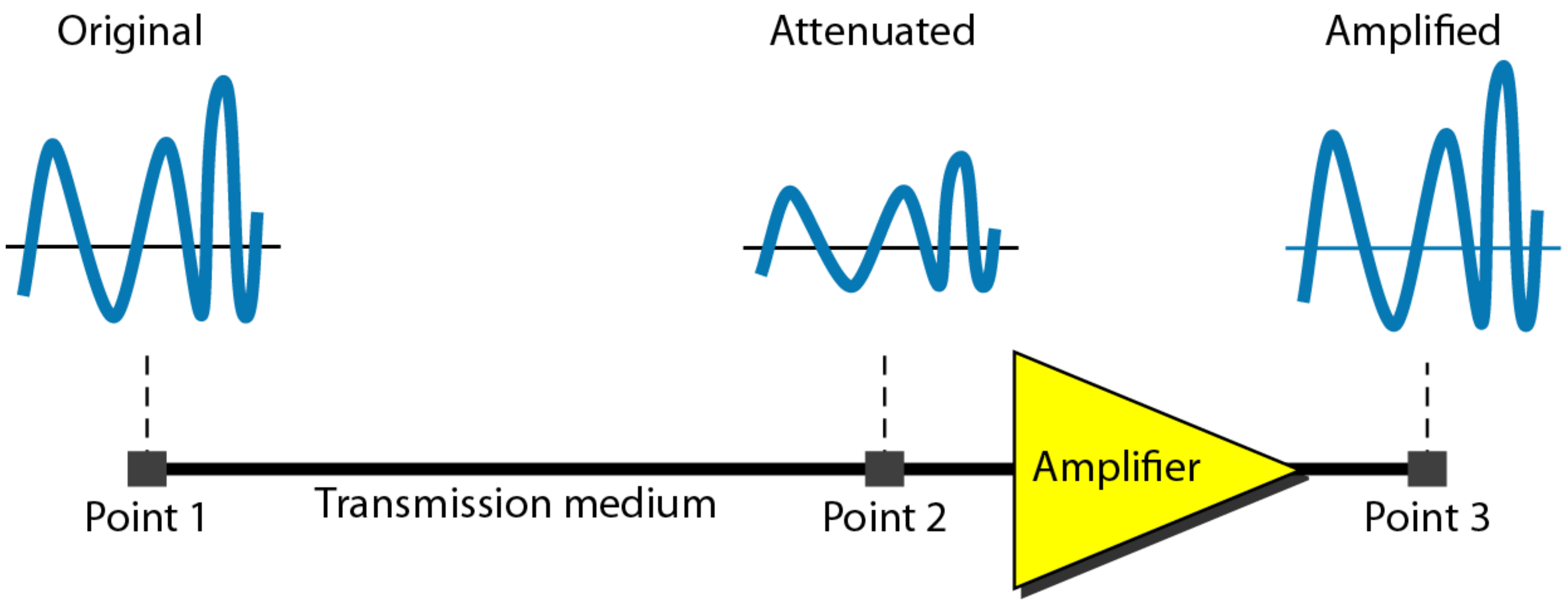
In baseband transmission, the required bandwidth is proportional to the bit rate;
if we need to send bits faster, we need more bandwidth.

Causes of Impairment

- Imperfection in the transmission media causes impairment



Attenuation



- Signal strength is expressed in decibel

$$dB = 10 \log_{10} \frac{P_2}{P_1}$$

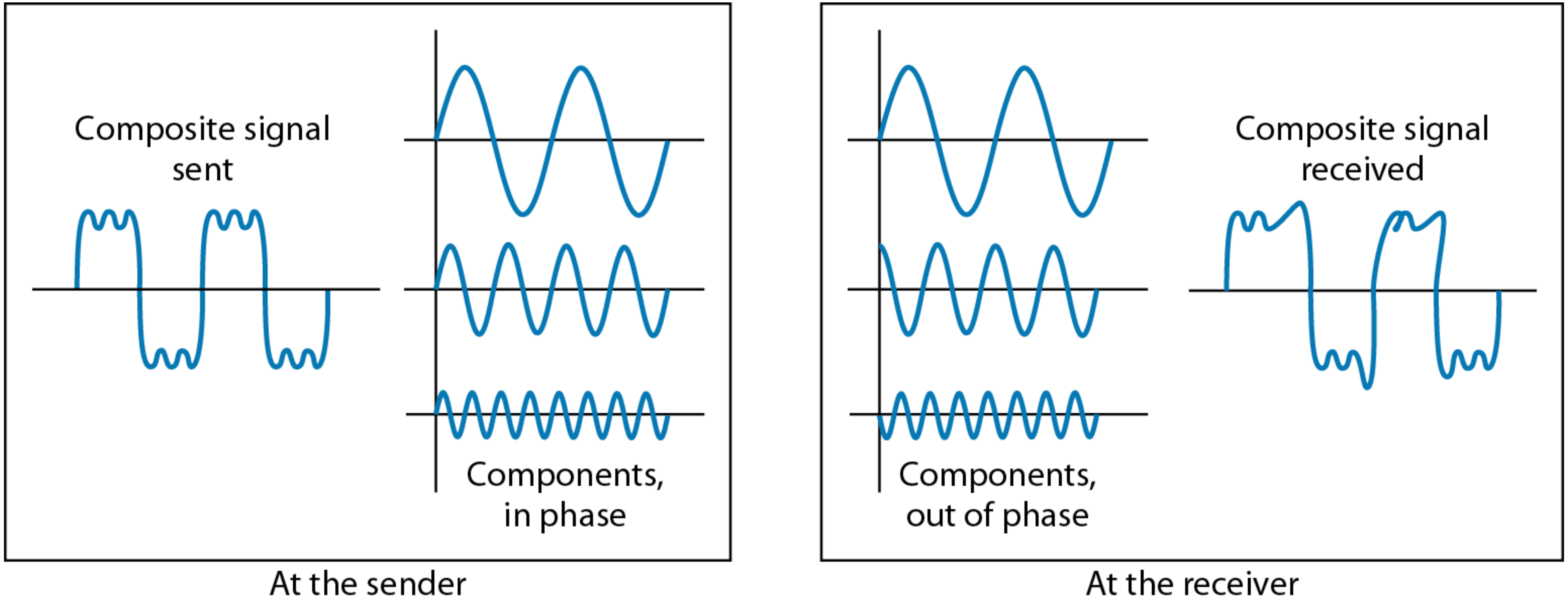
where P= Power of signal

Question

Suppose a signal travels through a transmission medium and its power is reduced to one-half. What is the attenuation?

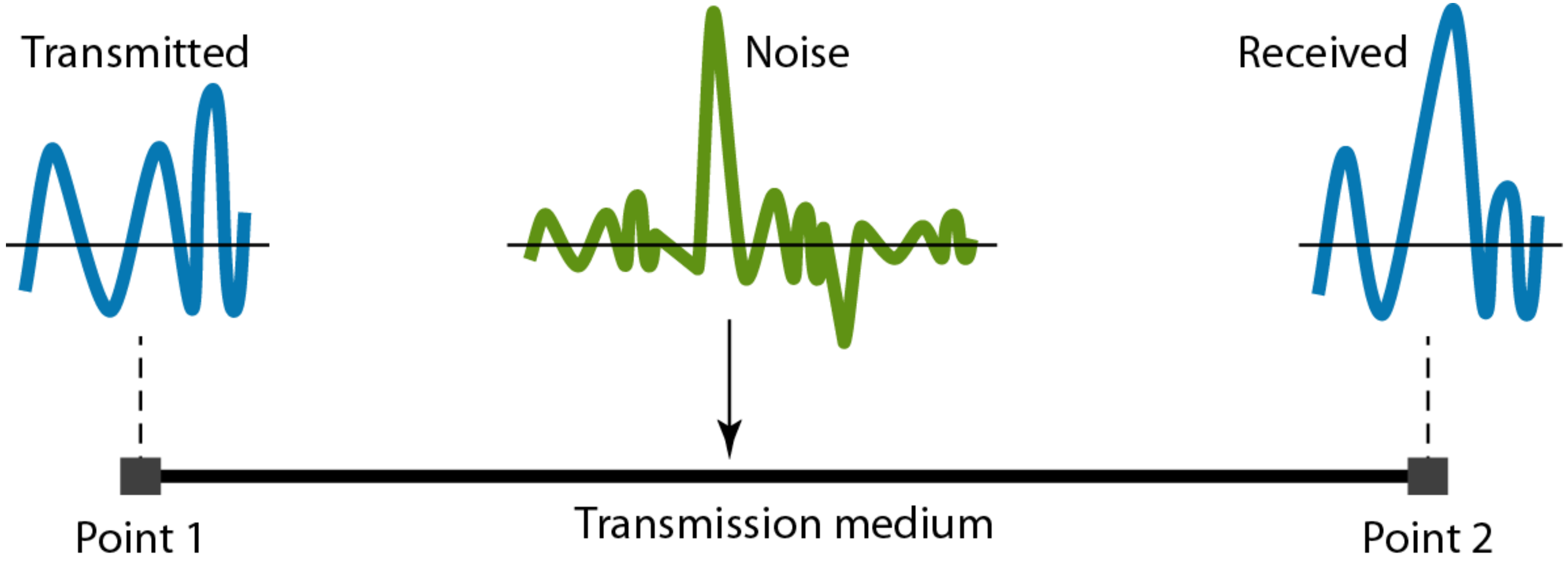
$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}}$$

Distortion



Composite signal
sent
Components,
in phase
At the sender
Components,
out of phase
Composite signal
received
At the receiver

Noise



Signal to Noise ratio (SNR) = (Average Signal Power/ Average Noise Power)

$SNR_{dB} = 10 \log_{10}(SNR)$

Question

The power of a signal is 10 mW and the power of the noise is 1μW; what are the values of SNR and SNR_{dB} ?

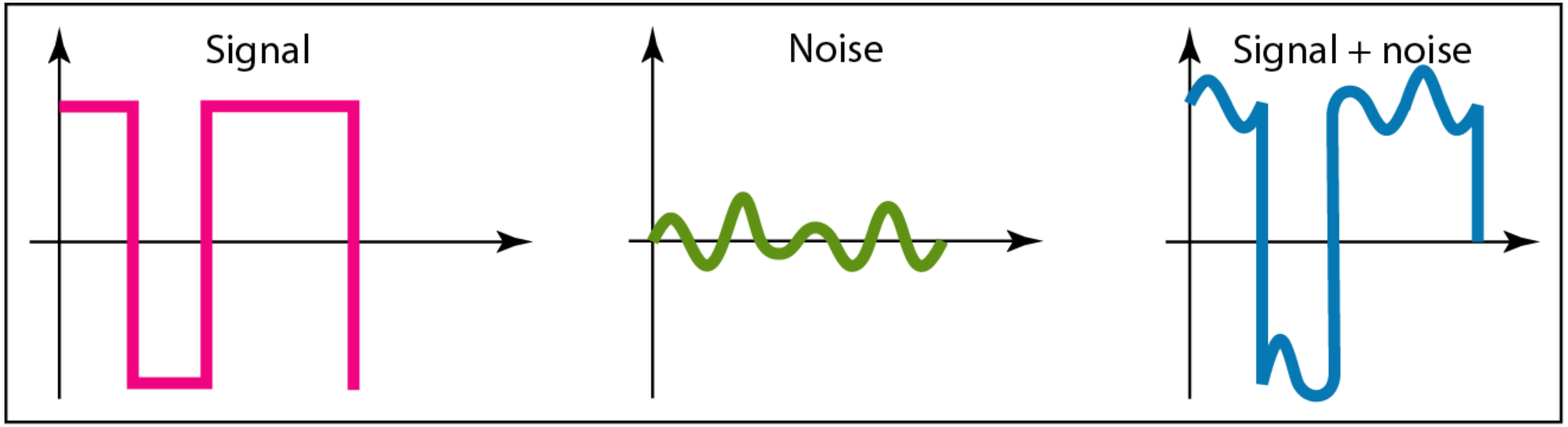
Solution

The values of SNR and SNR_{dB} can be calculated as follows:

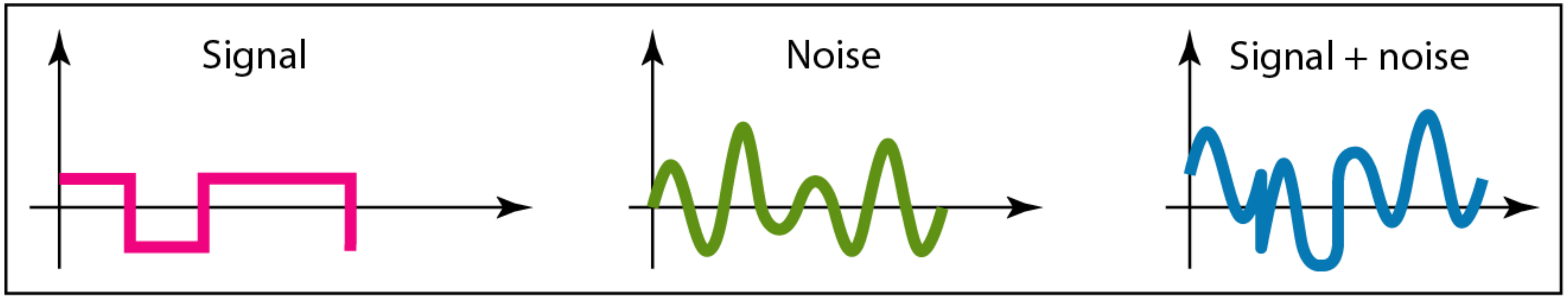
$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Two cases of SNR: a high SNR and a low SNR



a. Large SNR



b. Small SNR