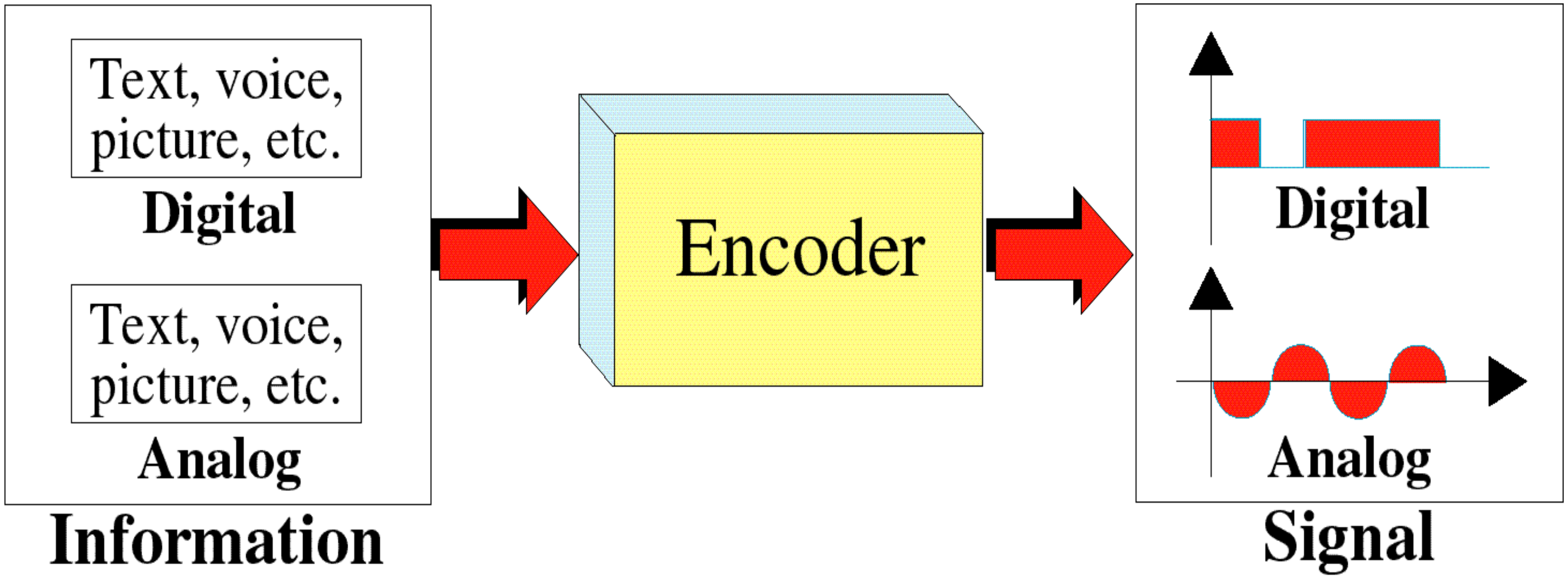
Data and Signals

Signals

- **Analog and digital**
- **Aperiodic and periodic signals**
- **Analog signals**

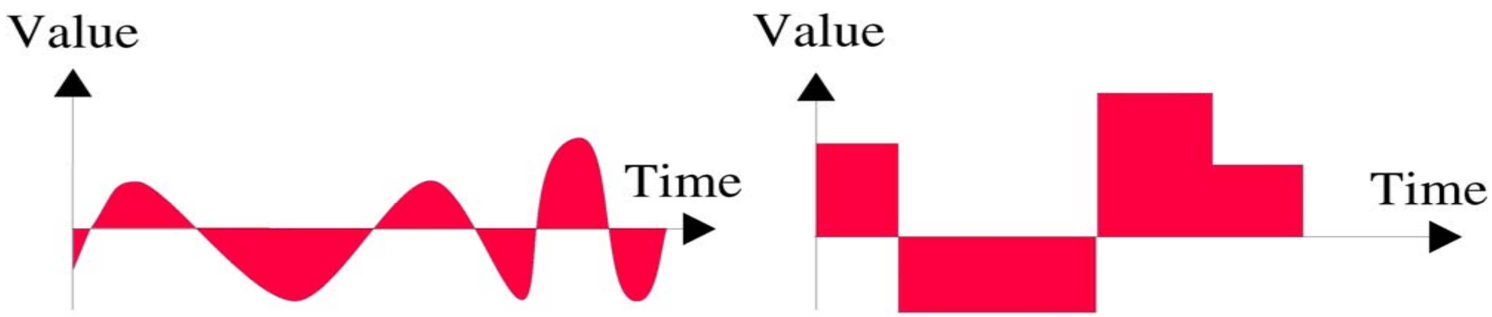
Transformation of Information to Signals



Analog and Digital Signals

- An **Analog signal** is a continuous wave form that changes smoothly over time
  - It includes infinite number of values along the path.

- A **Digital signal** is discrete – can have limited number of values, usually 0 and 1.
  - The vertical lines of the digital signal shows the sudden jump, and
  - The flat lines shows that those values are fixed.



a. Analog signal

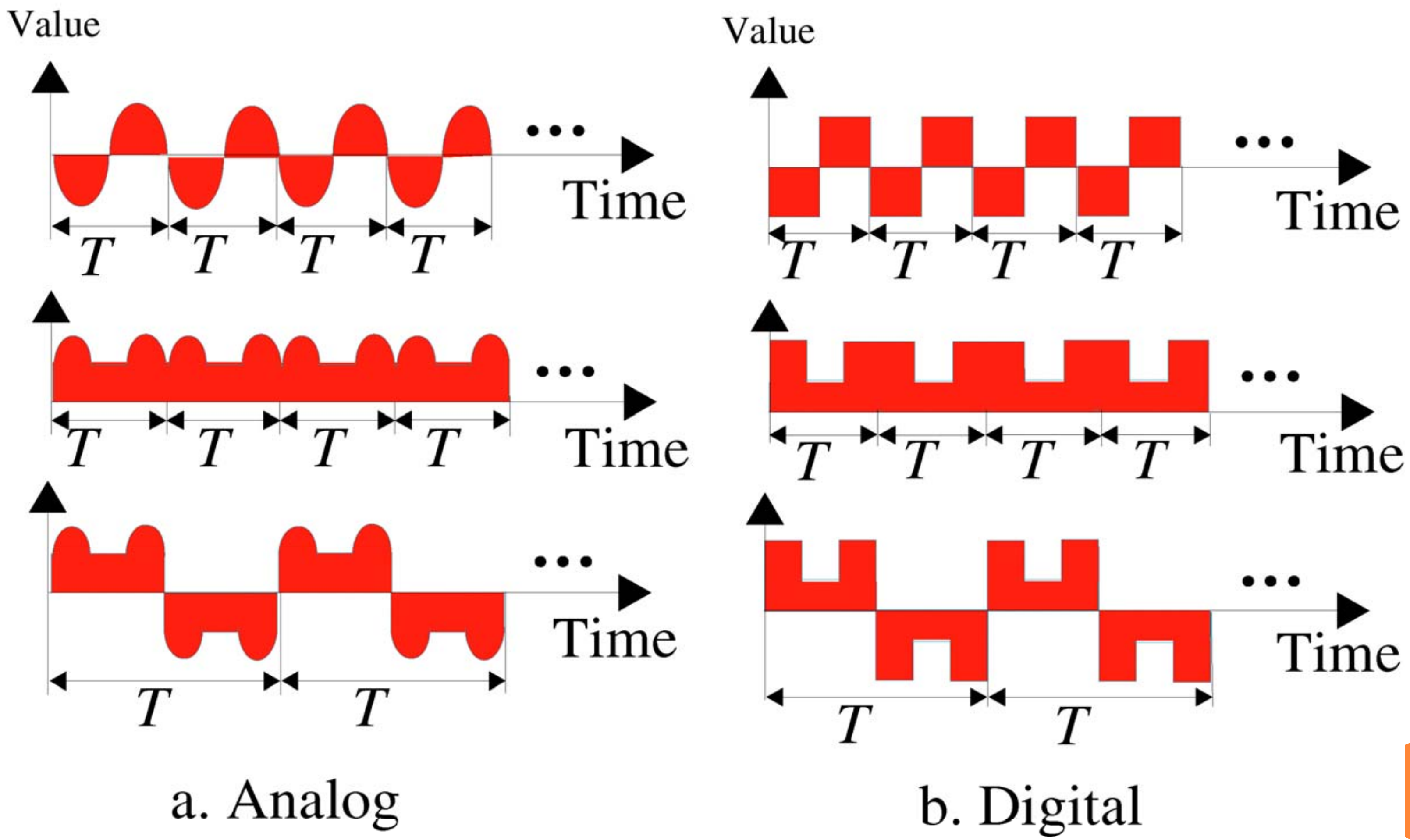
b. Digital signal

Periodic and Aperiodic Signals

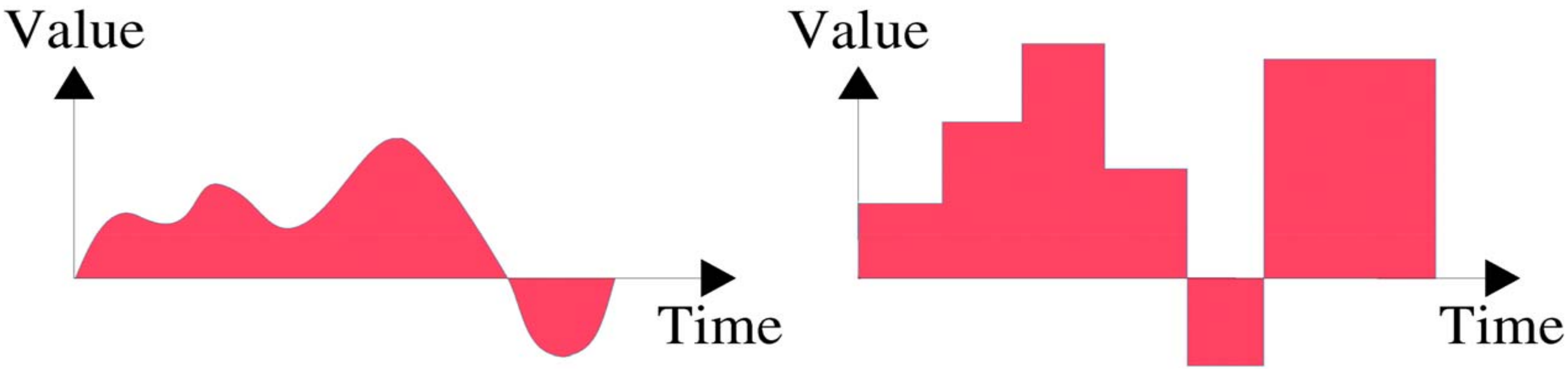
- Periodic Signals:
  - A periodic signal completes a pattern within a measurable time frame called a **period**, and repeats that pattern over identical subsequent periods.
  - The period is expressed in seconds.

- Aperiodic Signals:
  - An aperiodic signal changes constant without exhibiting a pattern or cycle that repeats over time.

Periodic Signals



Aperiodic Signals



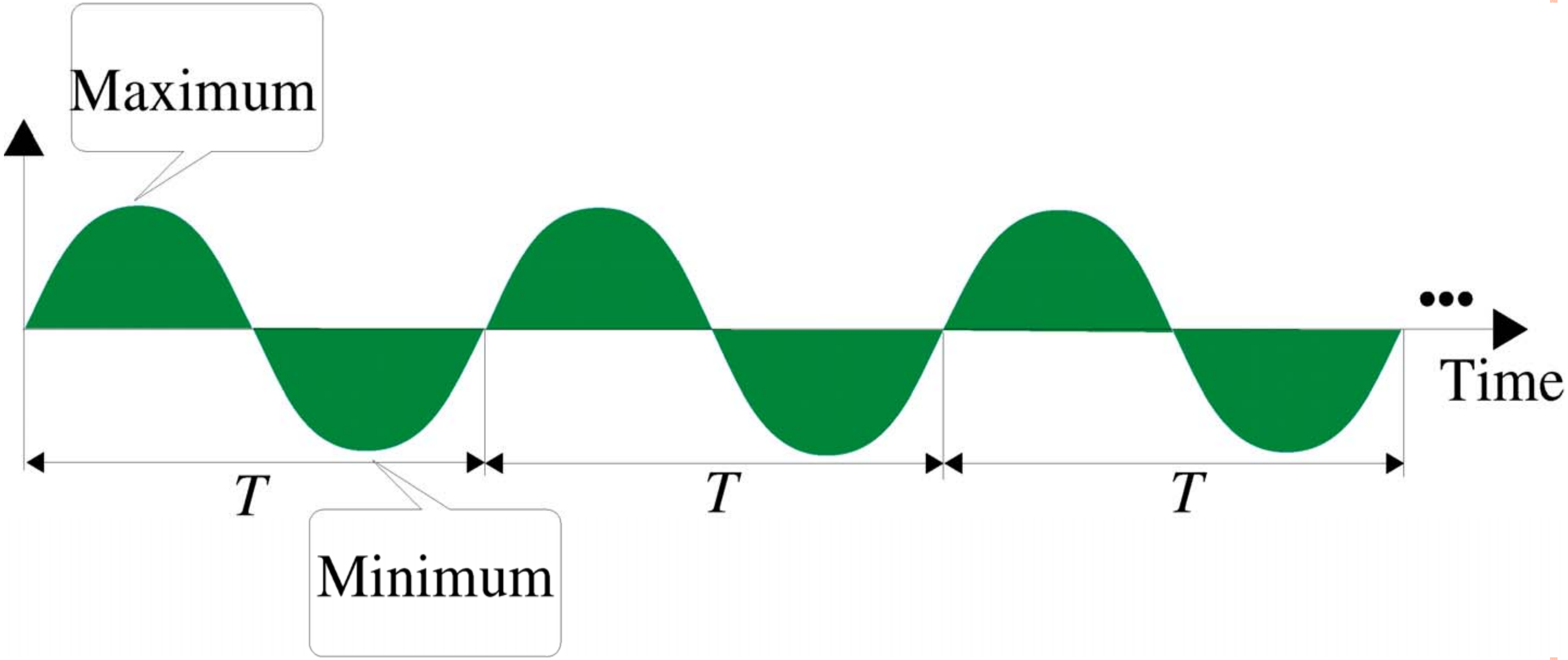
a. Analog

b. Digital

Periodic & Aperiodic signals

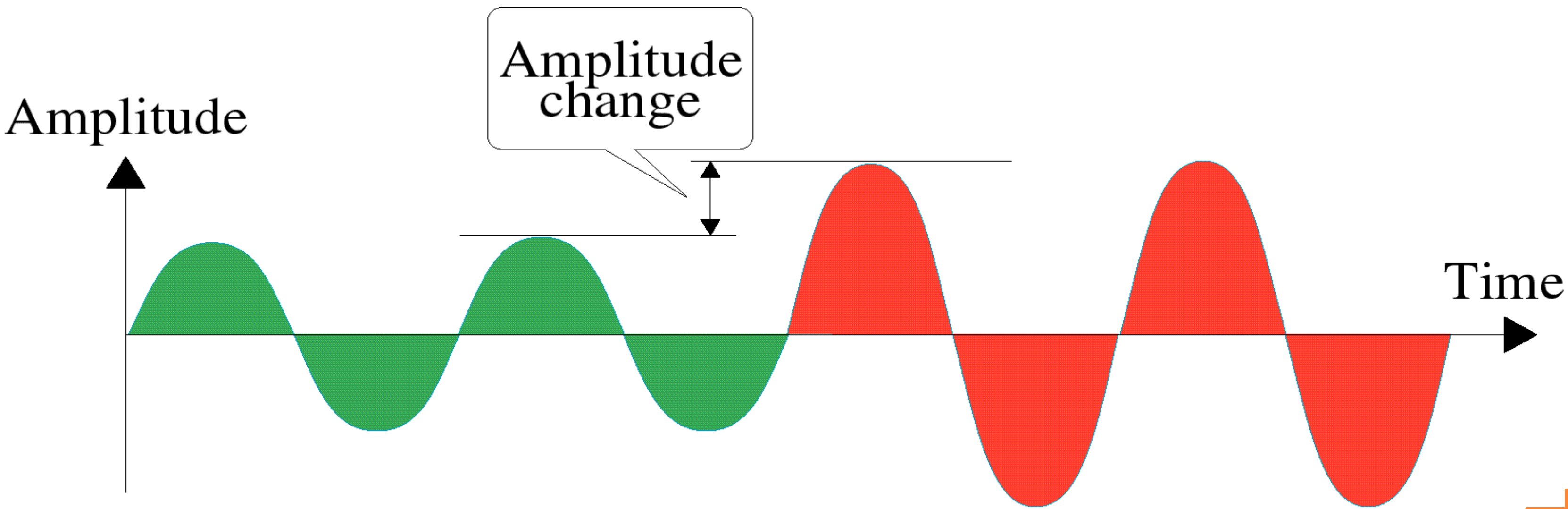
- By **Fourier transformation**, any aperiodic signal can be decomposed into an infinite number of periodic signals.
- A **Sine** wave is the simplest periodic signal – i.e., it can not be decomposed into simpler signals.
- A sine wave can be fully described by three characteristics: Amplitude, Period or Frequency and Phase.

Sine Wave



Amplitude

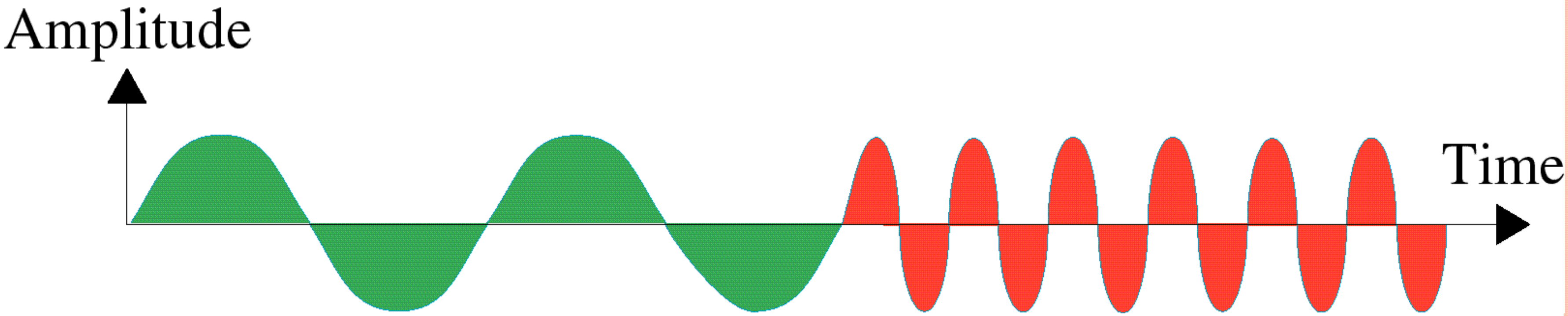
- Amplitude is the value of the signal at any point on the wave.
- Maximum amplitude is the highest value



Period and Frequency

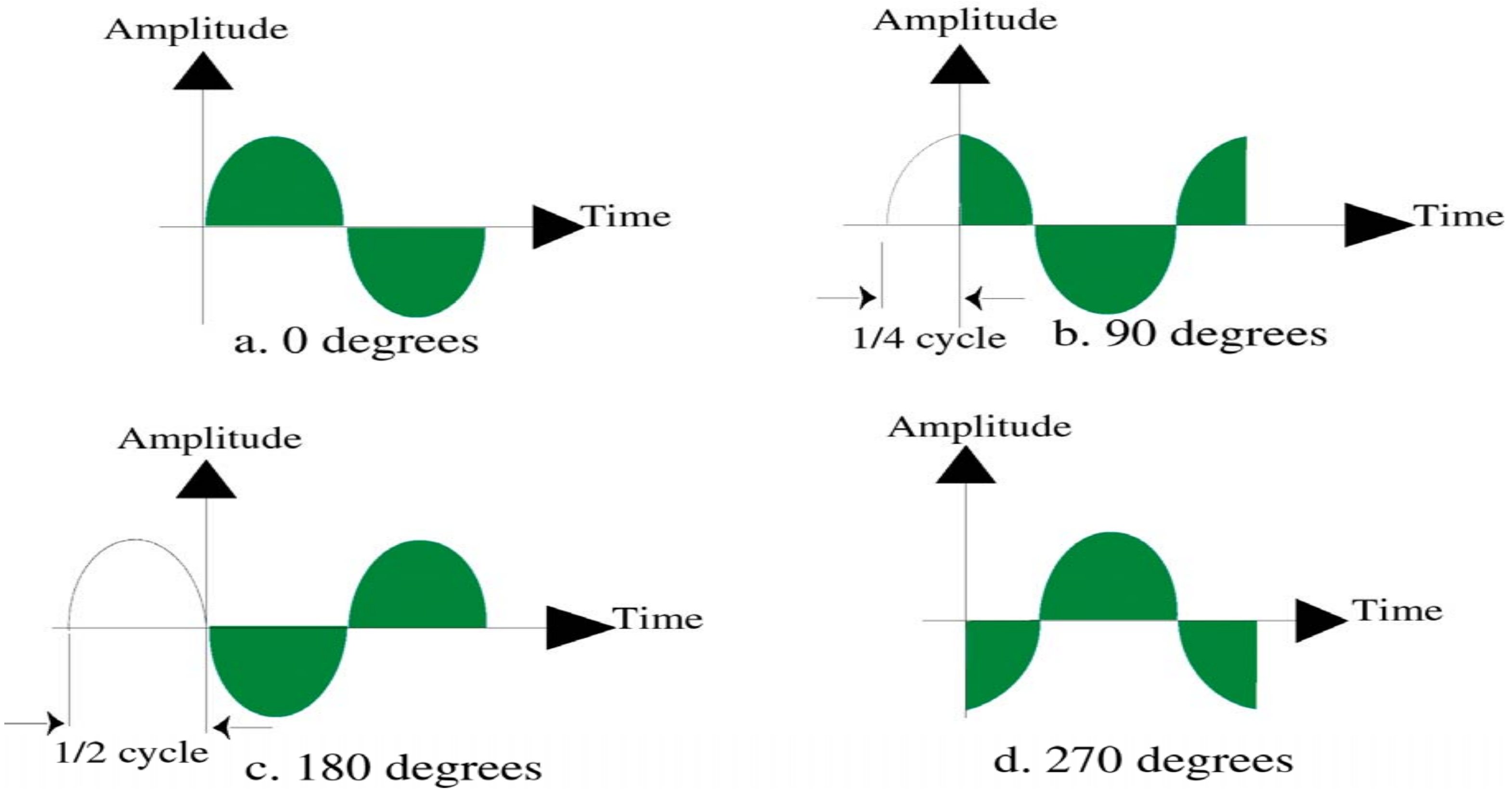
- Period is the time a signal needs to complete one cycle.
- Frequency the number of cycles per second.
- Frequency is expressed in hertz (Hz).

$$Frequency = \frac{1}{Period}$$

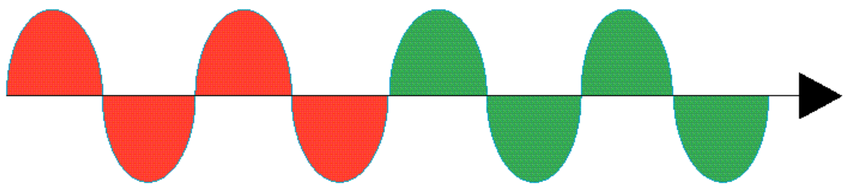


Phases

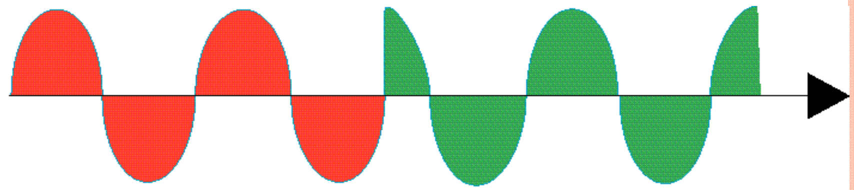
- Phase describes the position of the waveform relative to the time zero.
- Phase describes the amount of shift along the time axis.
- Phase is measured in degree or radian.



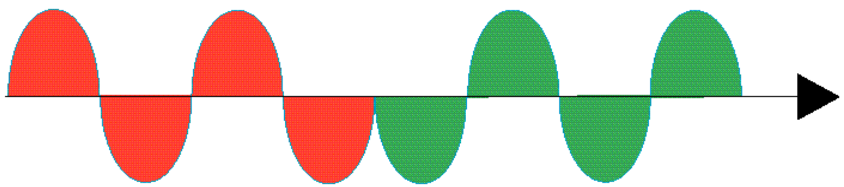
Phase Change



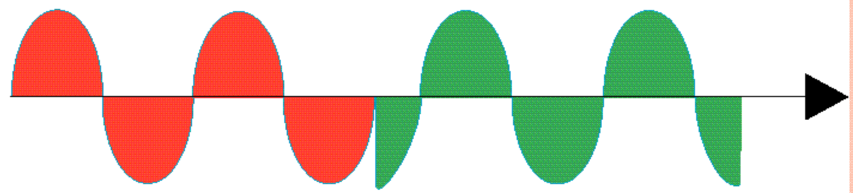
a. No phase change



b. 90 degree phase change



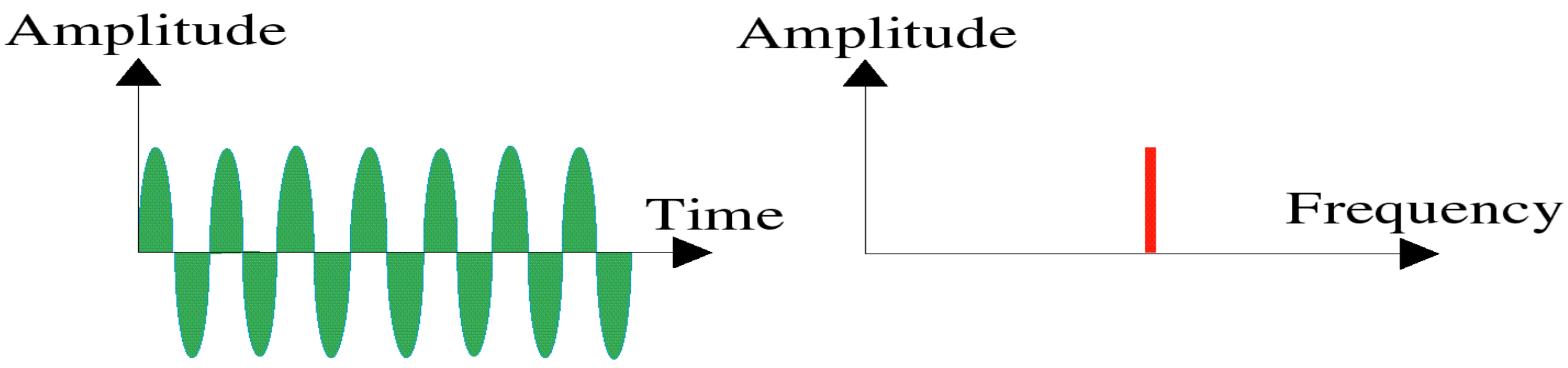
c. 180 degree phase change



d. 270 degree phase change

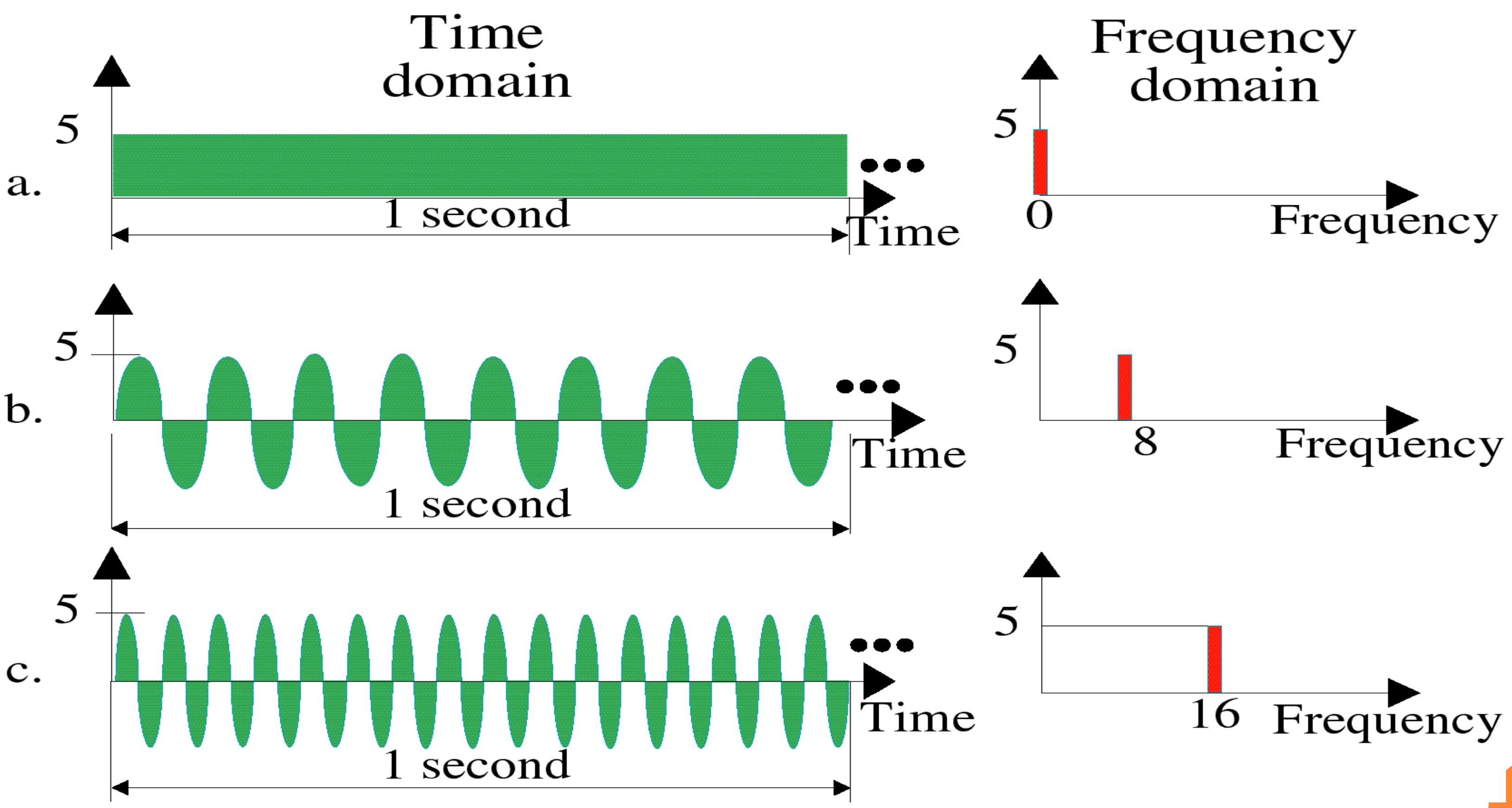
Time and Frequency Domains

- Time-domain plot shows the change in amplitude w.r.t. time.
- A frequency domain plot shows the relationship between amplitude and frequency.



a. Time domain   b. Frequency domain

Examples



Time domain
Frequency domain
a.
5
1 second
Time
5
0
Frequency
b.
5
1 second
Time
5
8
Frequency
c.
5
1 second
Time
5
16
Frequency

Composite Signals

- What about wave forms that are not simple or periodic (sine waves).
- For composite signals, we use Fourier transformation to decompose it into its components.

- French Mathematician, Jean-Baptiste Fourier proved that any reasonably behaved periodic function, g(t) with period T can be constructed as the sum of a number of sines and cosines

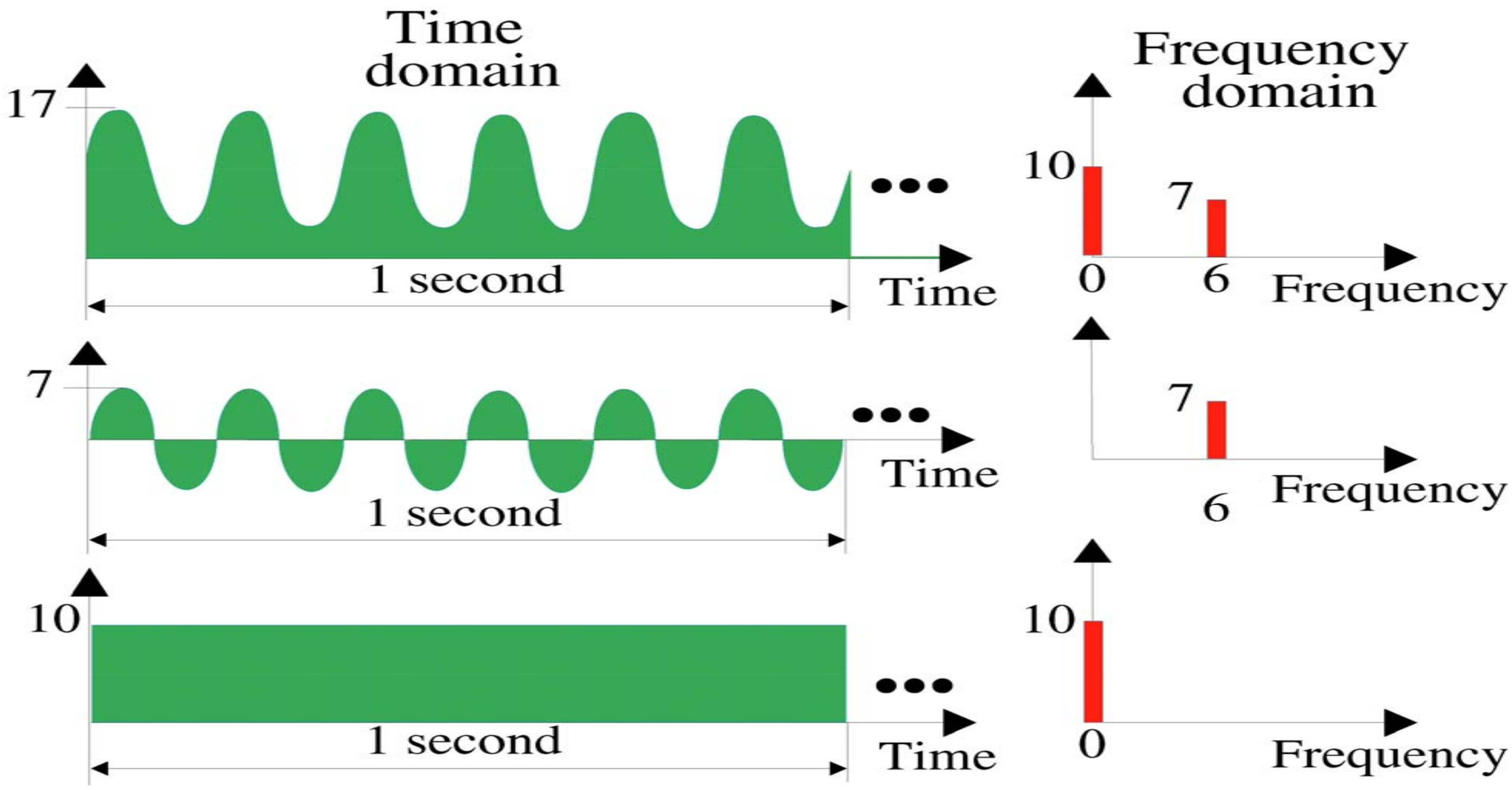
$$g(t) = ½c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

c is a constant

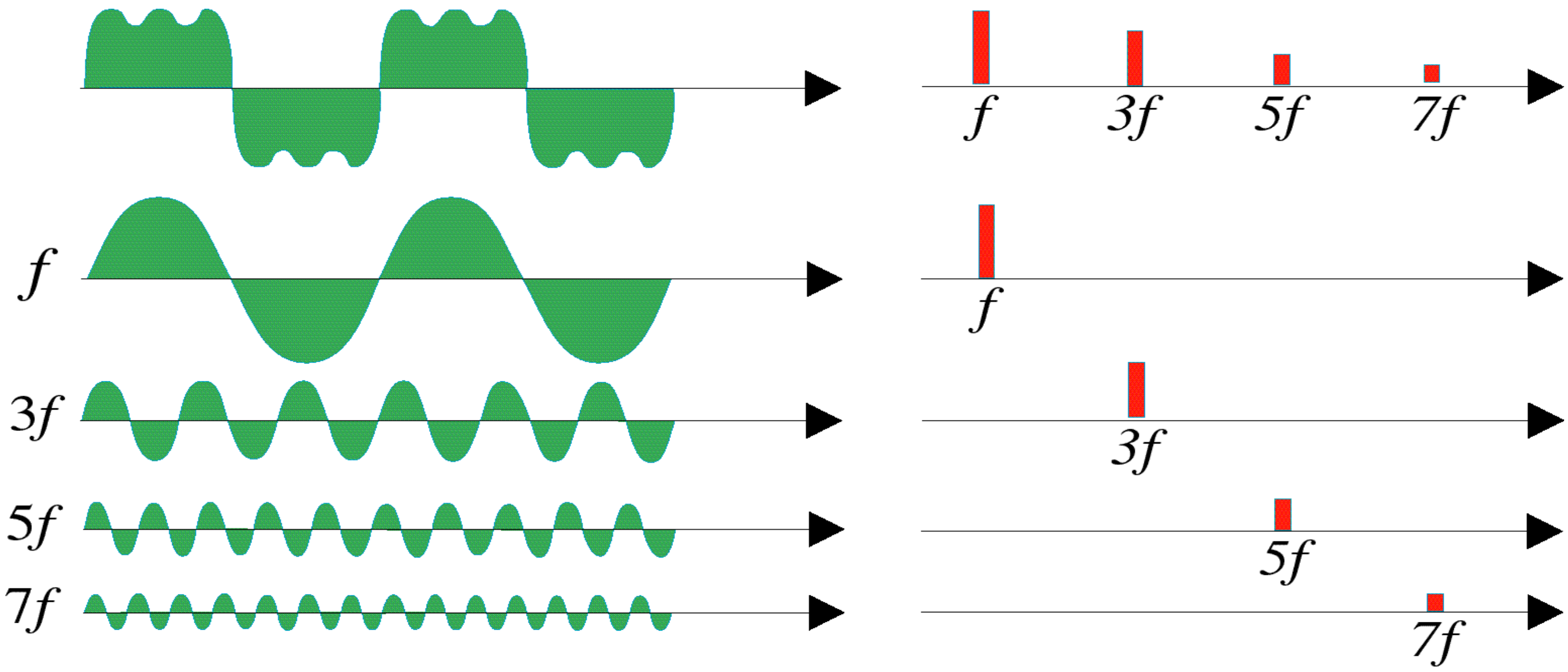
a_n and b_n are the sine and cosine amplitudes of the nth harmonics

$f = \frac{1}{T}$ is the fundamental frequency.

Composite Signals



Complex Waveform



a. Time domain

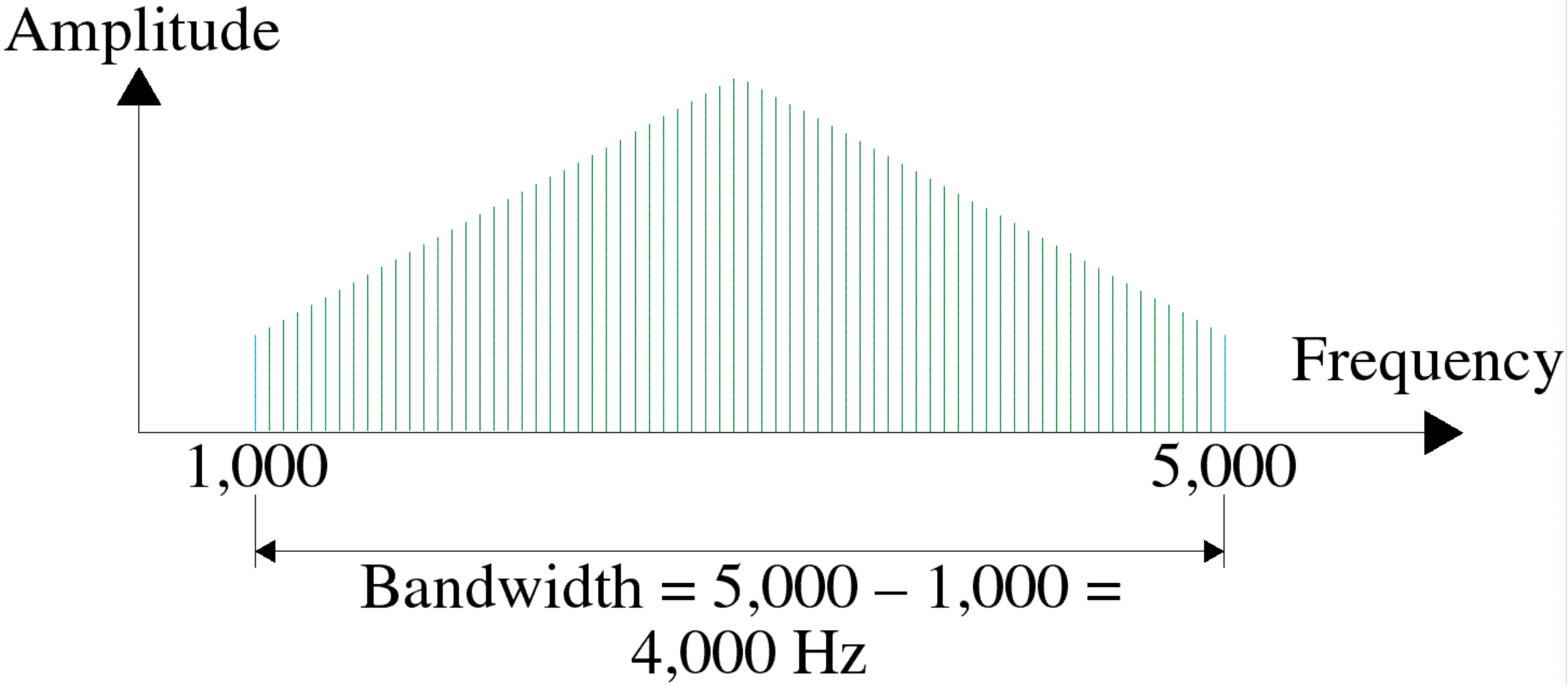
b. Frequency domain

FREQUENCY SPECTRUM AND BANDWIDTH

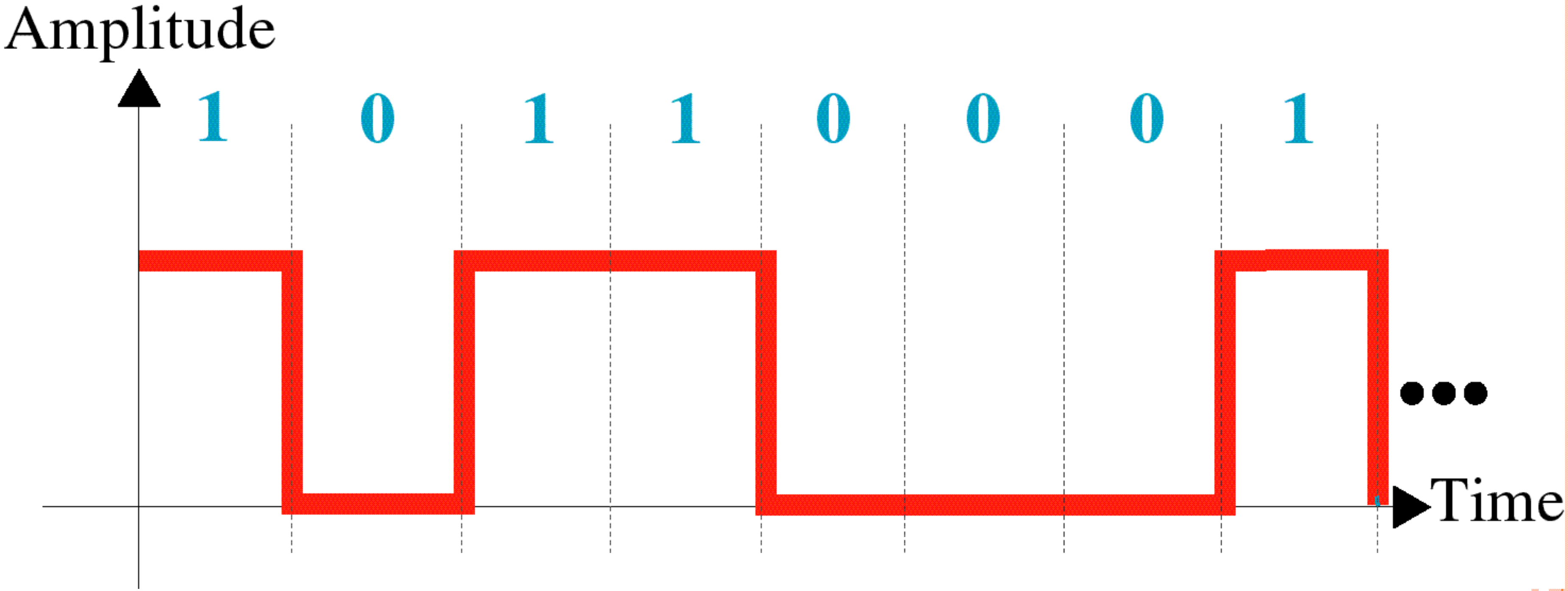
- The **frequency spectrum** of a signal is the collection of all the component frequencies it contains.
- That is, the combination of all sine waves that forms the signals

- The **bandwidth** of a signal is the width of the frequency spectrum.
- To calculate bandwidth – subtract the lowest and highest frequency of a signal.

Bandwidth



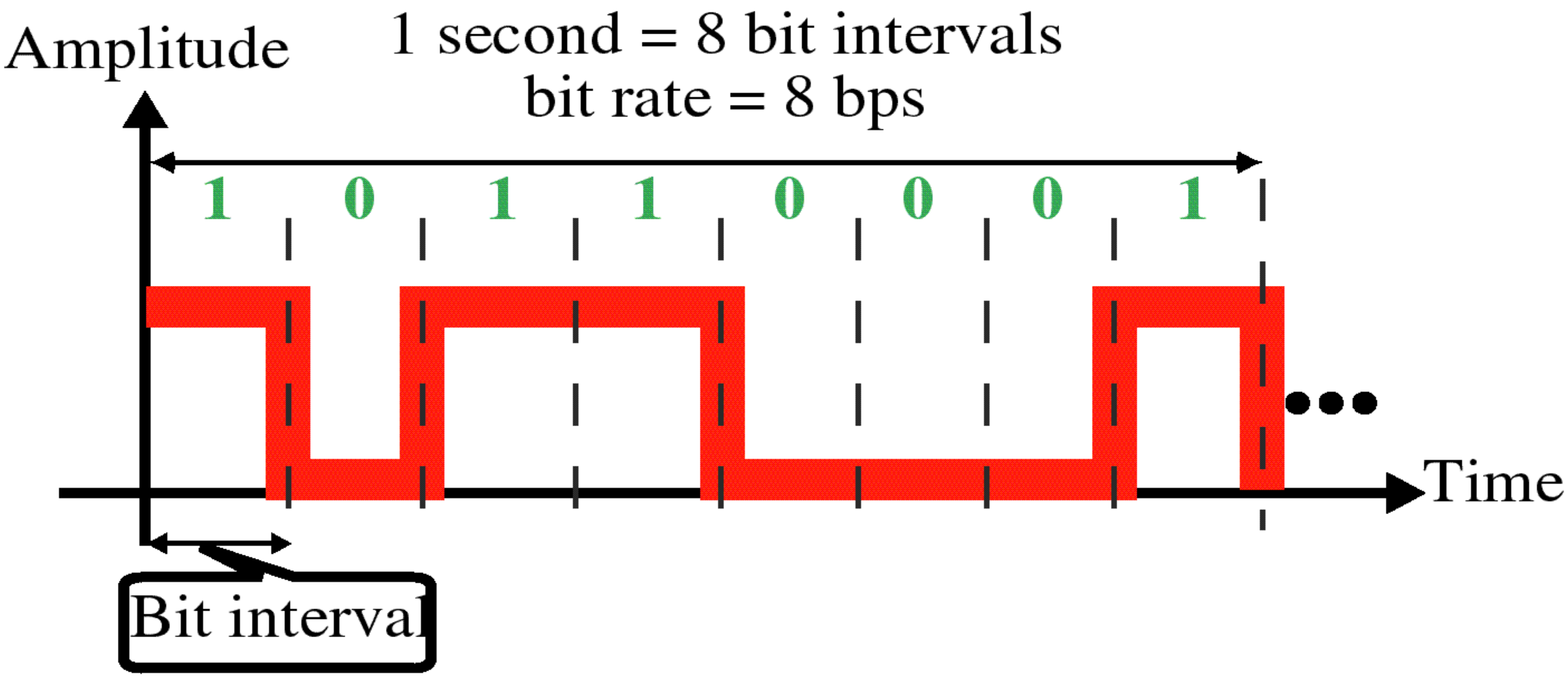
Digital Signals



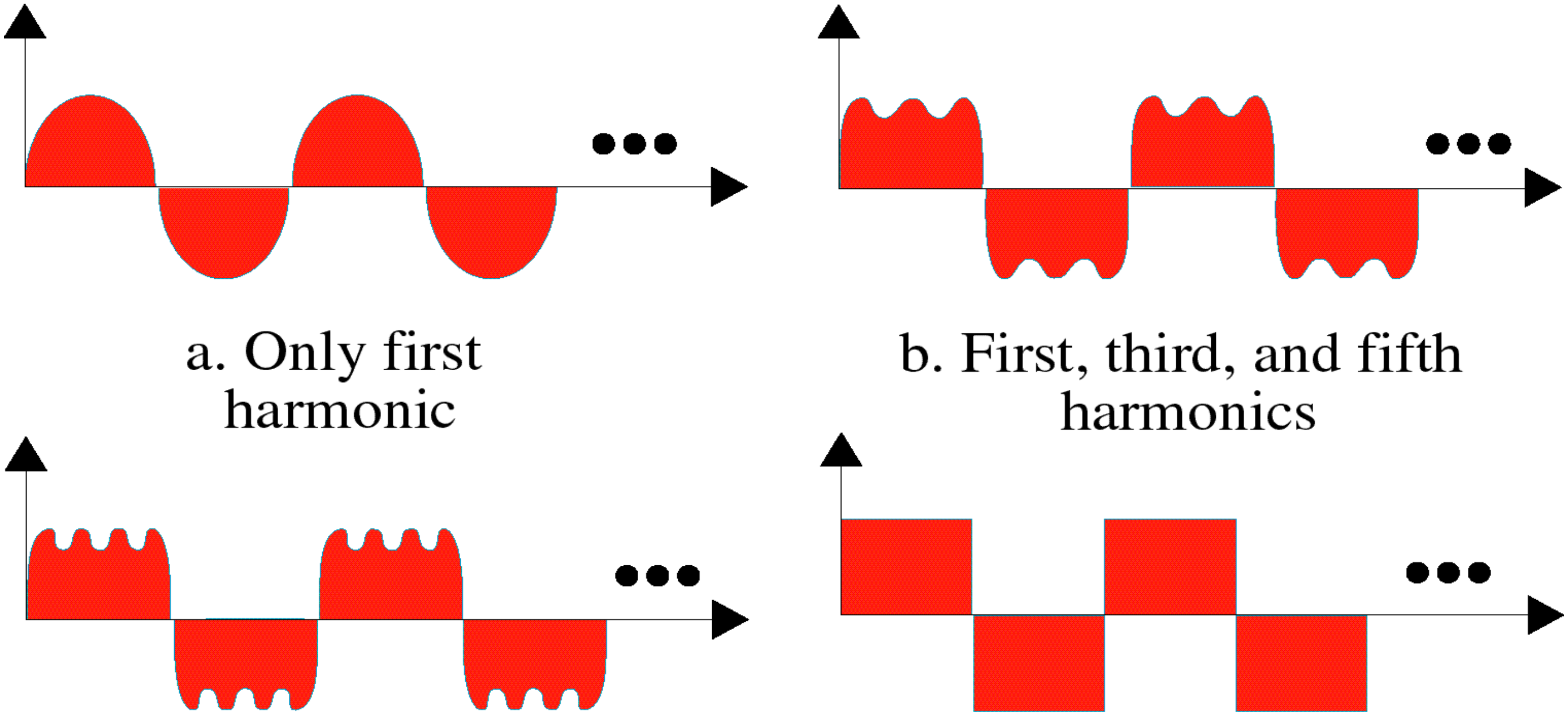
Bit Interval and Bit Rate

- Bit Interval (like period) is the time required to send one single bit.
- Bit Rate (like frequency) is the number of bit intervals per seconds or bits per second (bps).

Bit Rate and Bit Interval



Harmonics of a Digital Signal



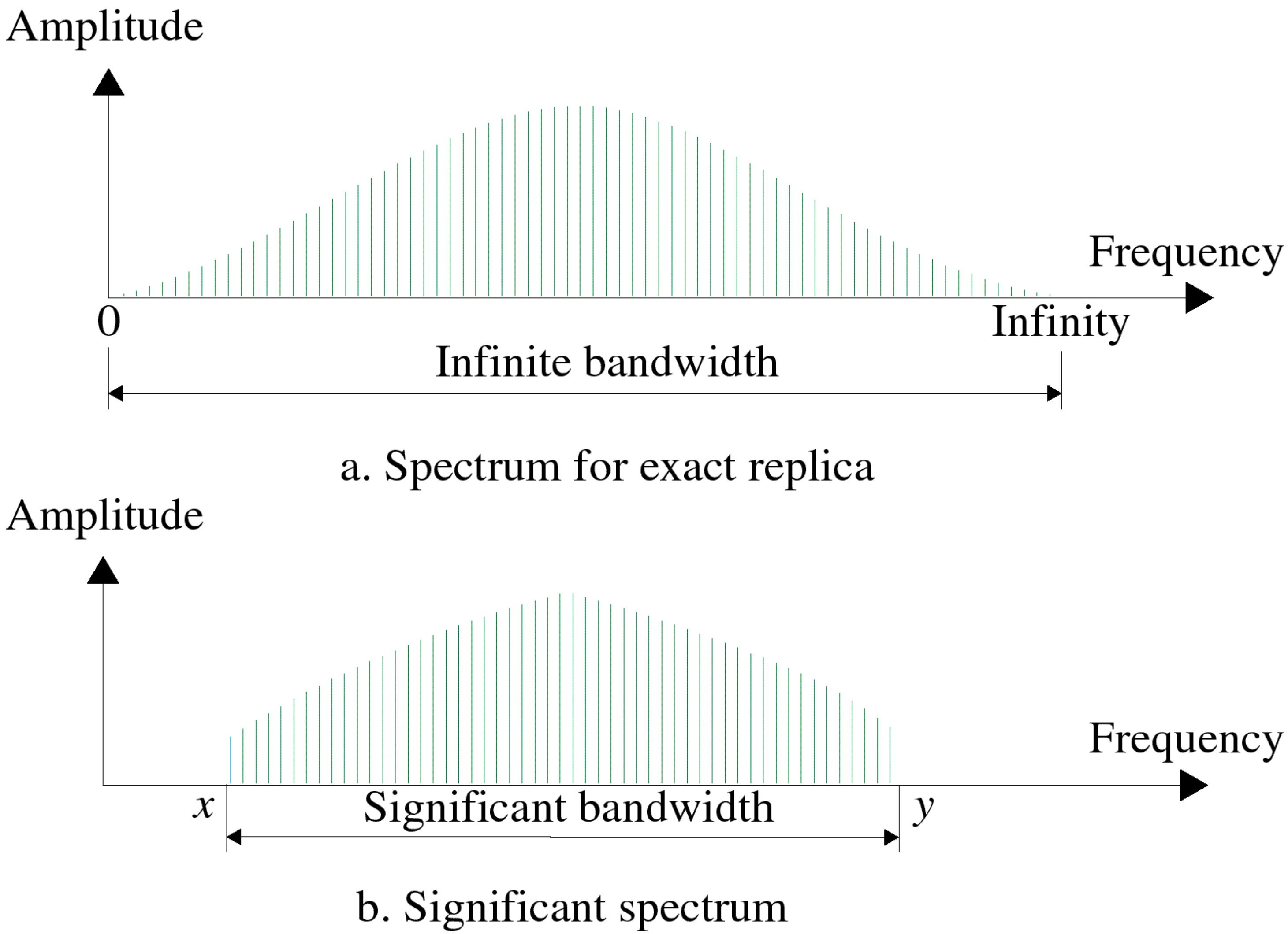
a. Only first harmonic

b. First, third, and fifth harmonics

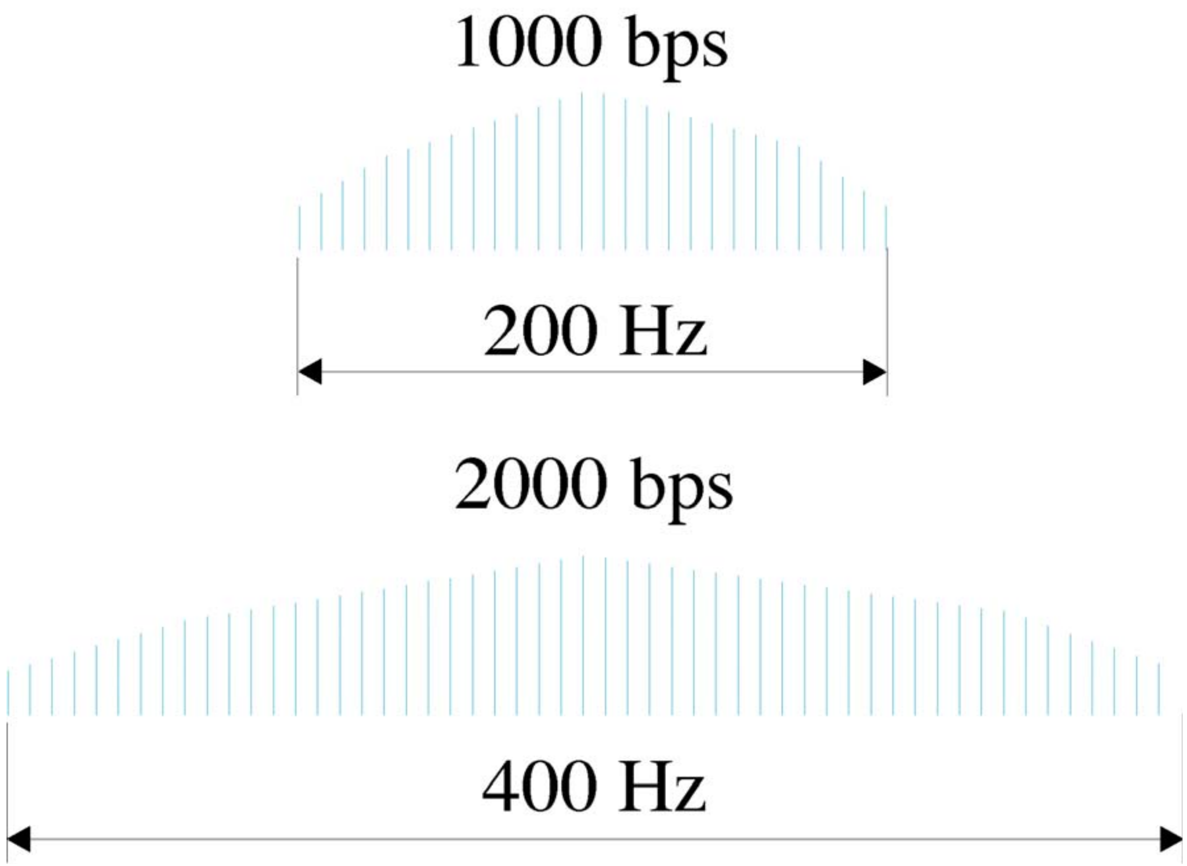
c. First, third, fifth, and seventh harmonics

d. Infinite number of harmonics

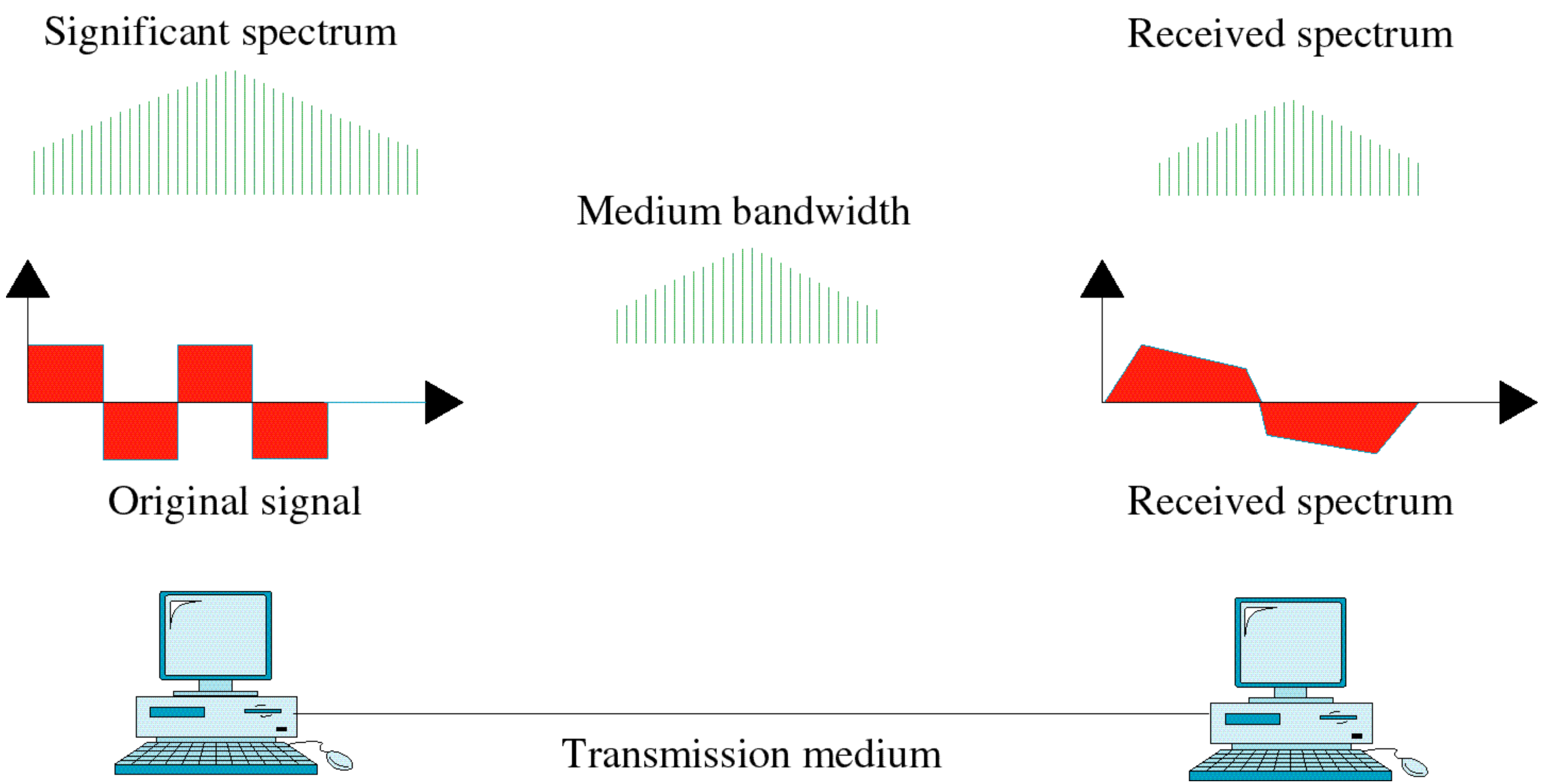
Exact and Significant Spectrums



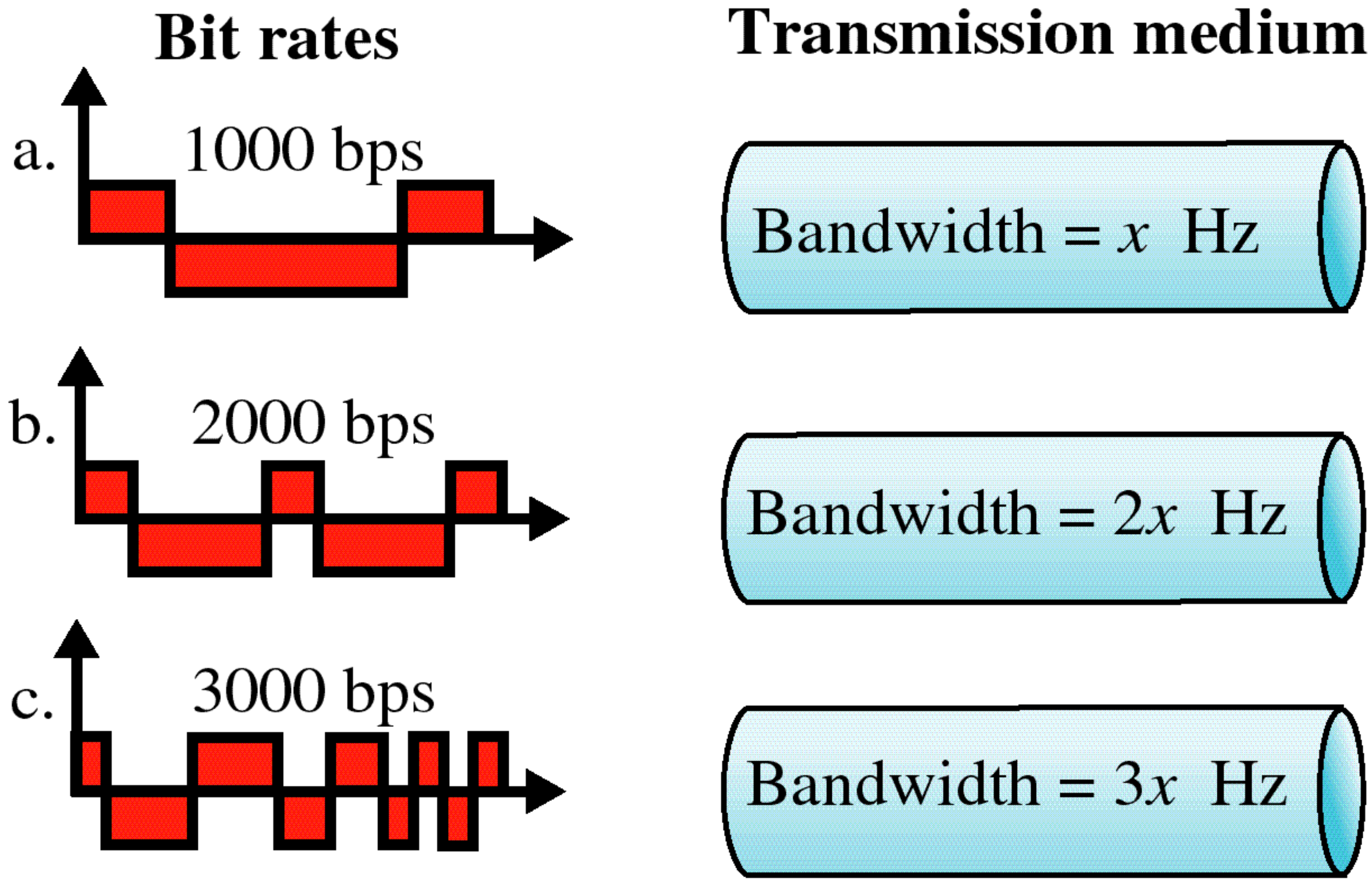
Bit Rates and Significant Spectrums



Corruption Due to Insufficient Bandwidth



Bandwidth and Data Rate



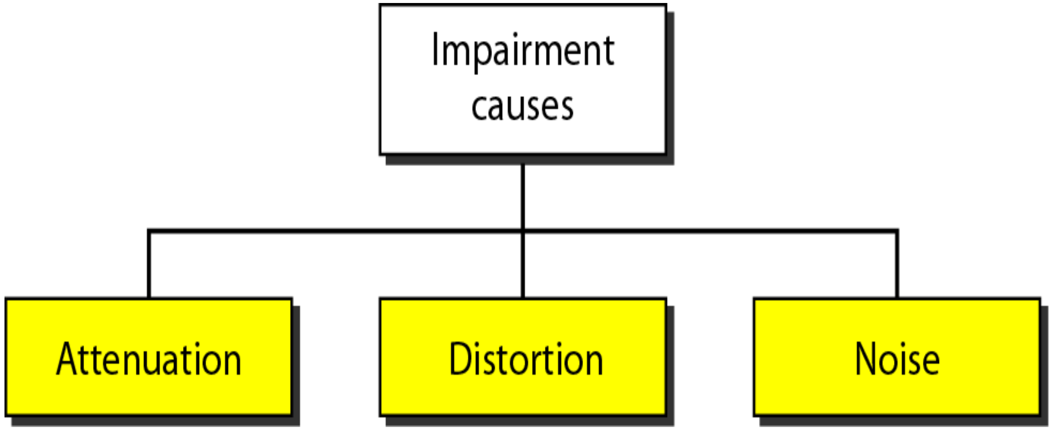
Bandwidth

- In networking, we use the term bandwidth in two contexts.
  - The first, **bandwidth in hertz**, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.
  - The second, **bandwidth in bits per second**, refers to the speed of bit transmission in a channel or link. Often referred to as Capacity.
- An increase in bandwidth in Hz means an increase in bandwidth in bps.

Transmission Impairment

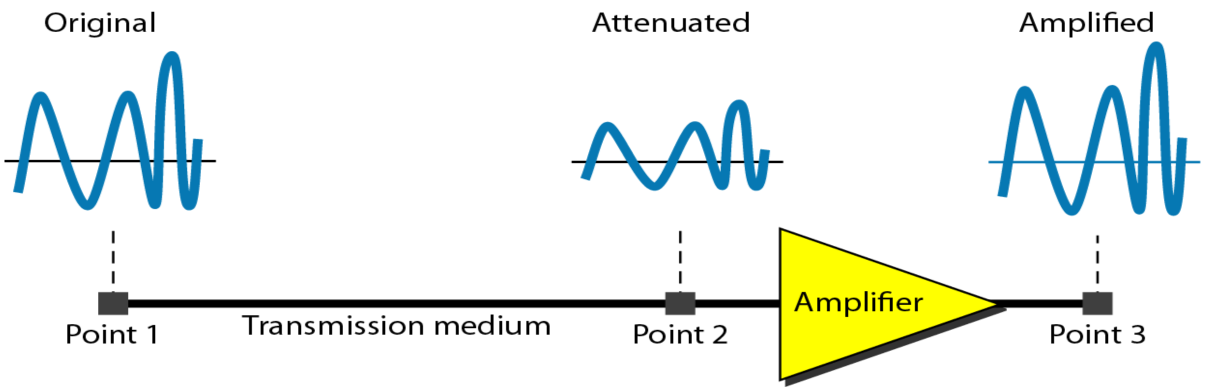
- Signals travelling through a medium may get corrupted. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.

- Three causes of impairment are:
  - Attenuation
  - Distortion
  - Noise



Attenuation

- Means loss of energy -- weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.



Measurement of Attenuation

- To show the loss or gain of energy the unit "decibel" is used.
- The decibel is –ve if the signal is attenuated and +ve if a signal is amplified

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

P_1 – power of input signal

P_2 – power of output signal

$$dB = 20\log_{10}V_2/V_1$$

P_1 – voltage of input signal

P_2 – voltage of output signal

Measurement of Attenuation (Examples)

- Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is (1/2)P1. In this case, the attenuation (loss of power) can be calculated as

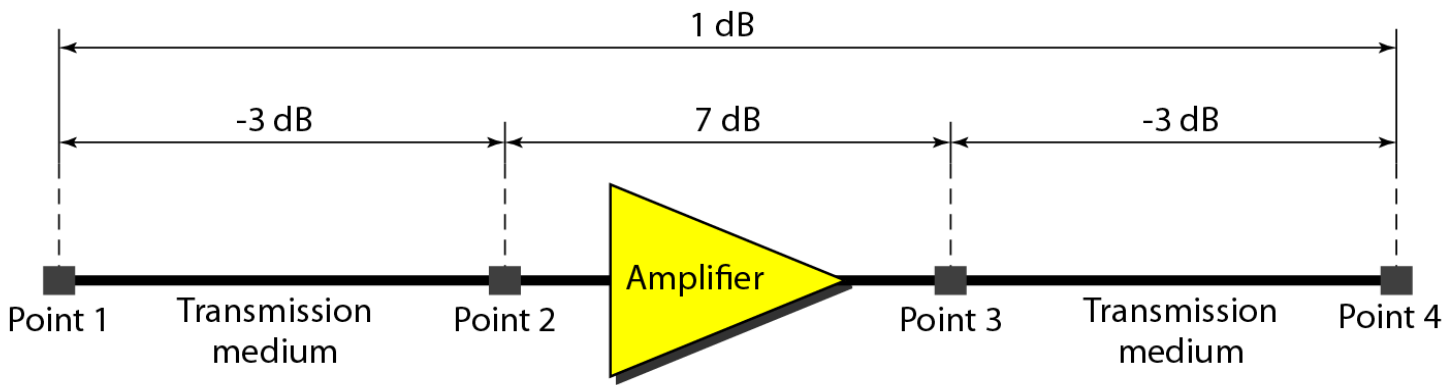
$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}}$$

- A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10 P_1}{P_1}} \quad \boxed{= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}}$$

MEASUREMENT OF ATTENUATION (EXAMPLES)

- One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two.



$$dB = -3 + 7 - 3 = +1$$

Measurement of Attenuation (Examples)

- The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

- Solution The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as

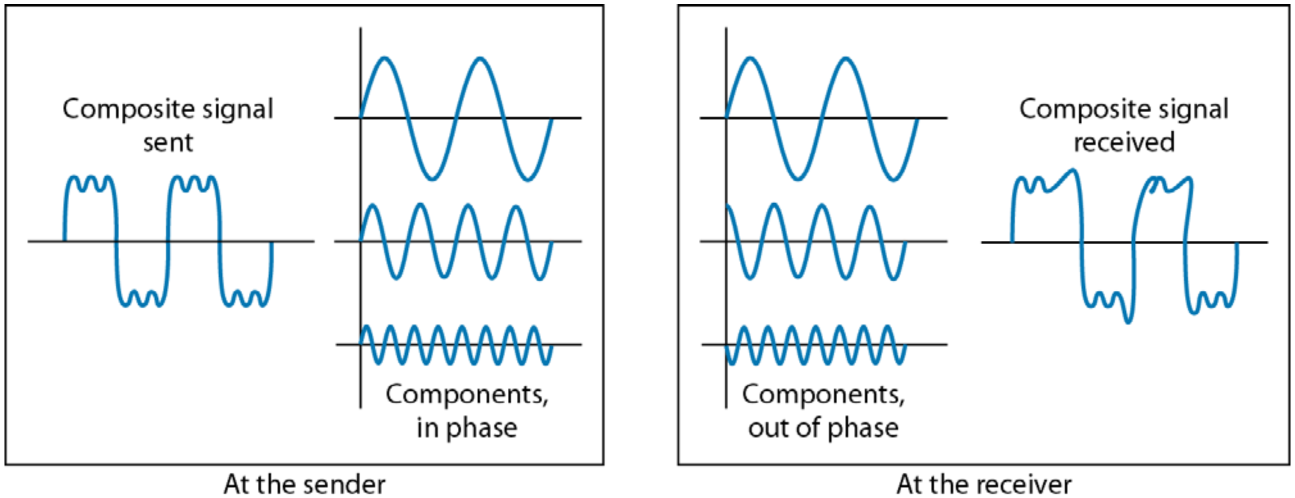
$$\mathrm{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

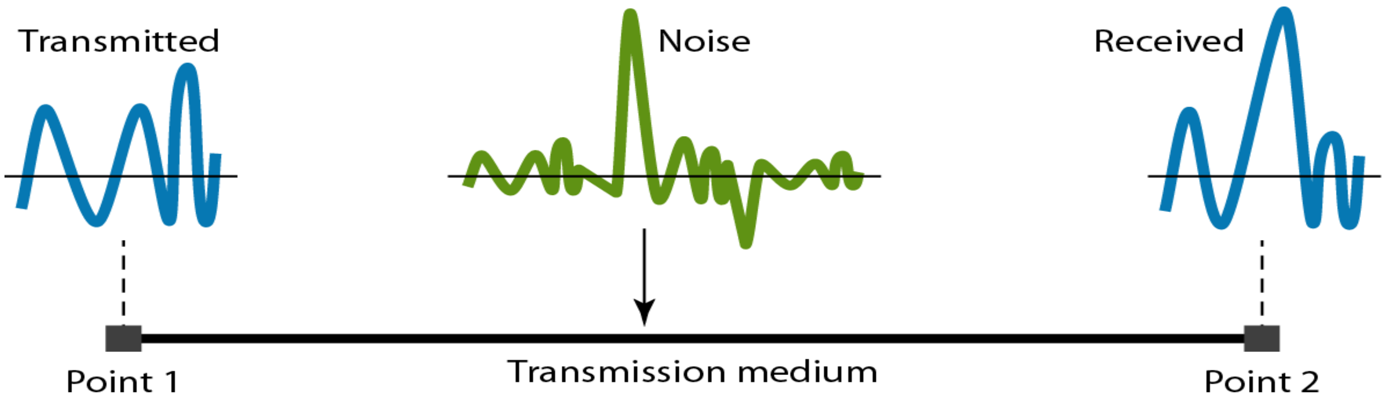
DISTORTION

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.



Noise

- There are different types of noise
  - Thermal - random noise of electrons in the wire creates an extra signal
  - Induced - from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
  - Crosstalk - same as above but between two wires.
  - Impulse - Spikes that result from power lines, lightning, etc.



Signal to Noise Ratio (SNR)

- It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.

$$SNR = \frac{average\ signal\ power}{average\ noise\ power}$$

- A high SNR means the signal is less corrupt by noise and vice versa.
- Since SNR is the ratio of two powers, it is usually given in dB and referred to as $\mathrm{SNR}_{\mathrm{dB.}}$

$$SNR_{db} = 10\log_{10} SNR$$

Signal to Noise Ratio (SNR) (Example)

- The values of SNR and SNR_{dB} for a noiseless channel are

$$\boxed{\begin{aligned} SNR &= \frac{\text{signal power}}{0} = \infty \\ SNR_{dB} &= 10 \log_{10} \infty = \infty \end{aligned}}$$

- We can never achieve this ratio in real life; it is an ideal.