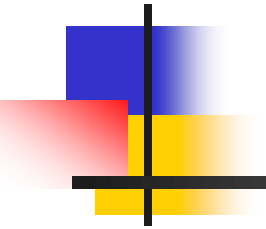
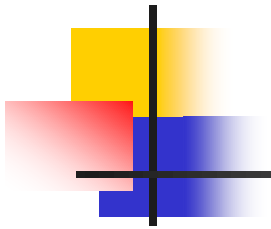


CH3: Physical Layer

Data and Signals



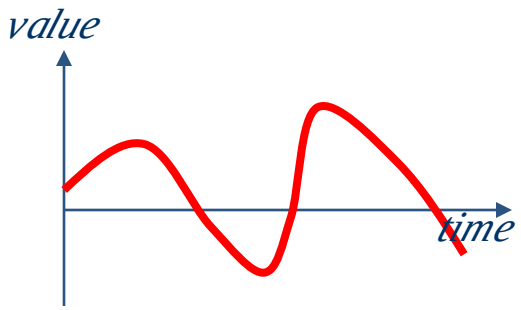
Analog vs. Digital Data

- Analog data
  - Data take on continuous values
  - E.g., human voice, temperature reading
- Digital data
  - Data take on discrete values
  - E.g., text, integers

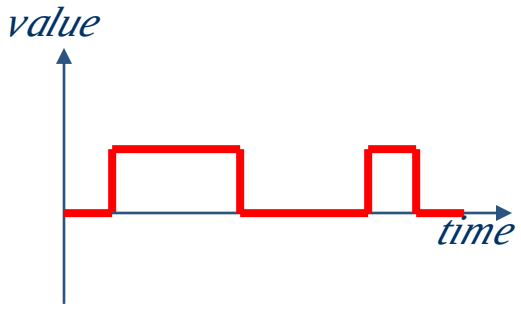
Analog vs. Digital Signals

To be transmitted, data must be transformed to electromagnetic signals

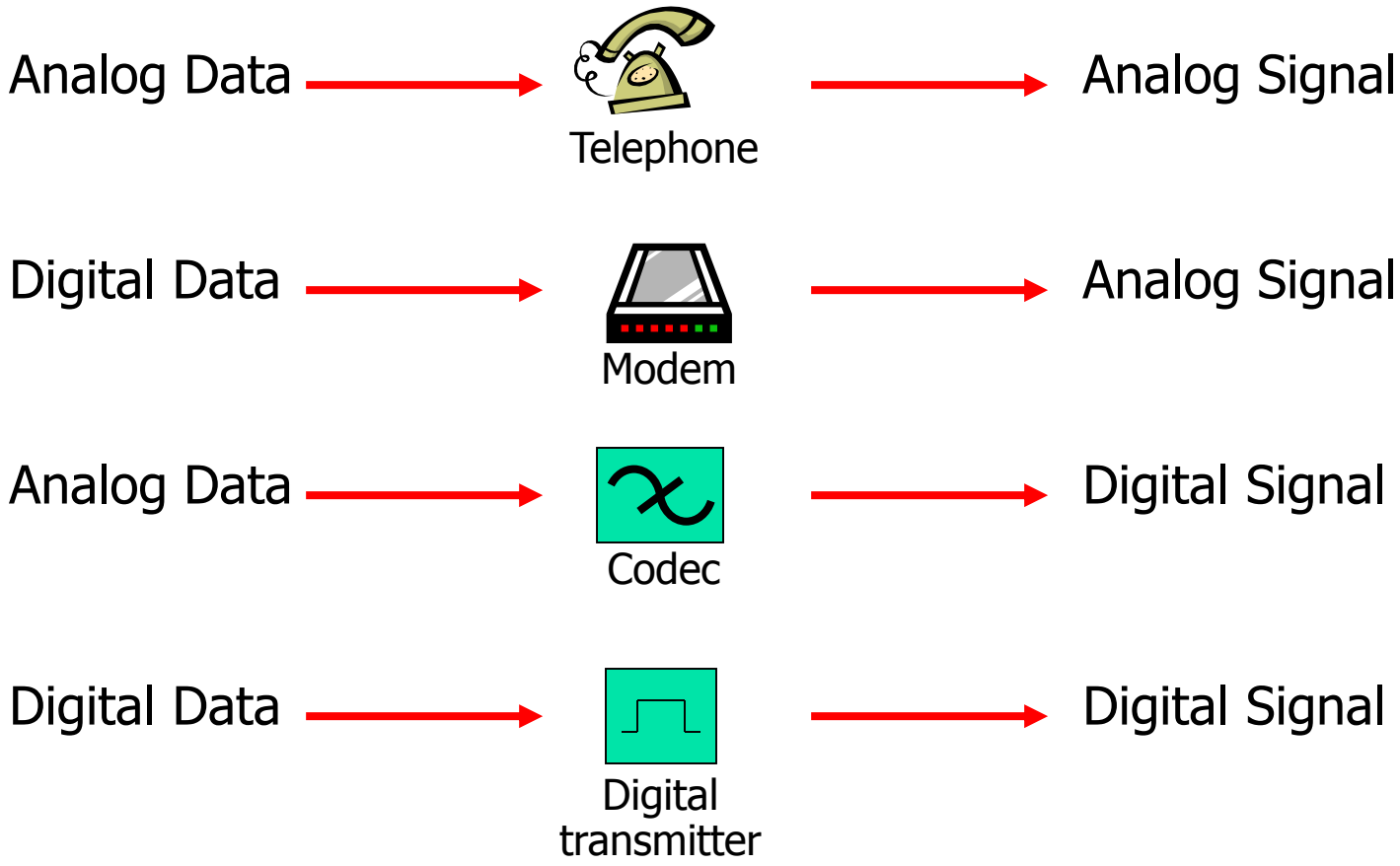
- Analog signals
  - have an infinite number of values in a range



- Digital signals
  - Have a limited number of values

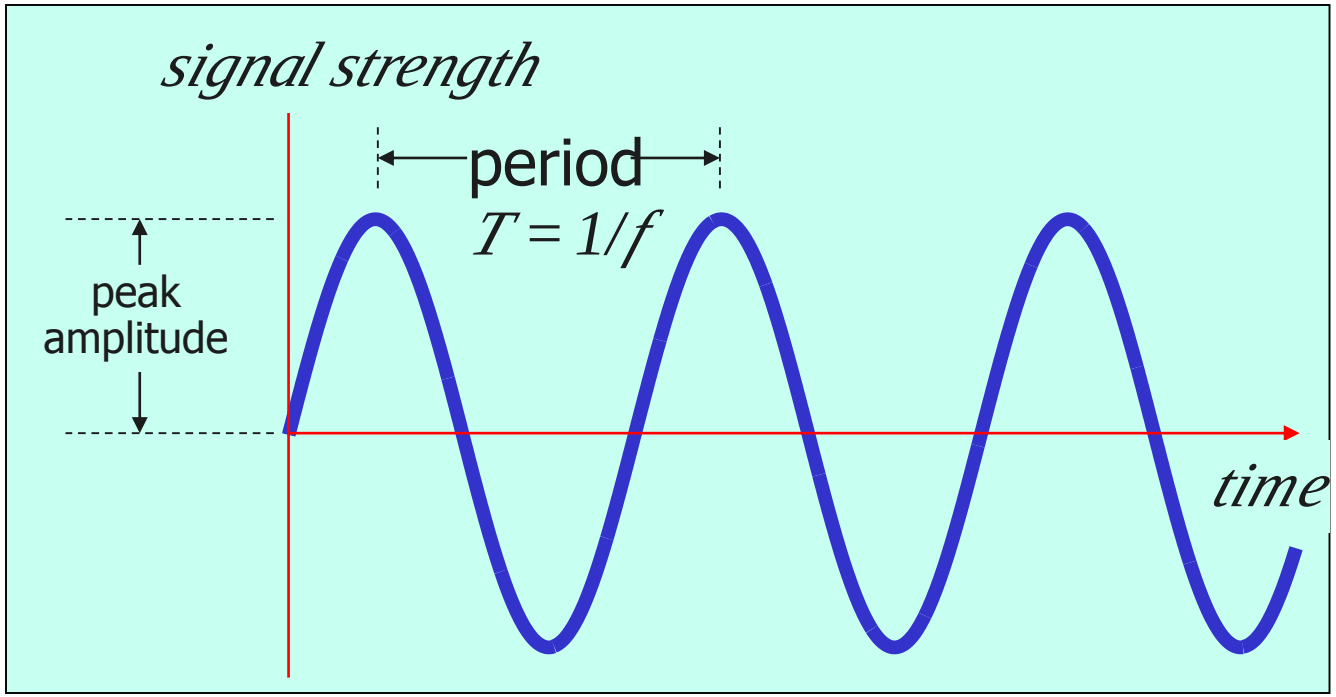


Data and Signals



Sine Waves

- Simplest form of periodic signal



- General form: $x(t) = A \times \sin(2\pi ft + \phi)$

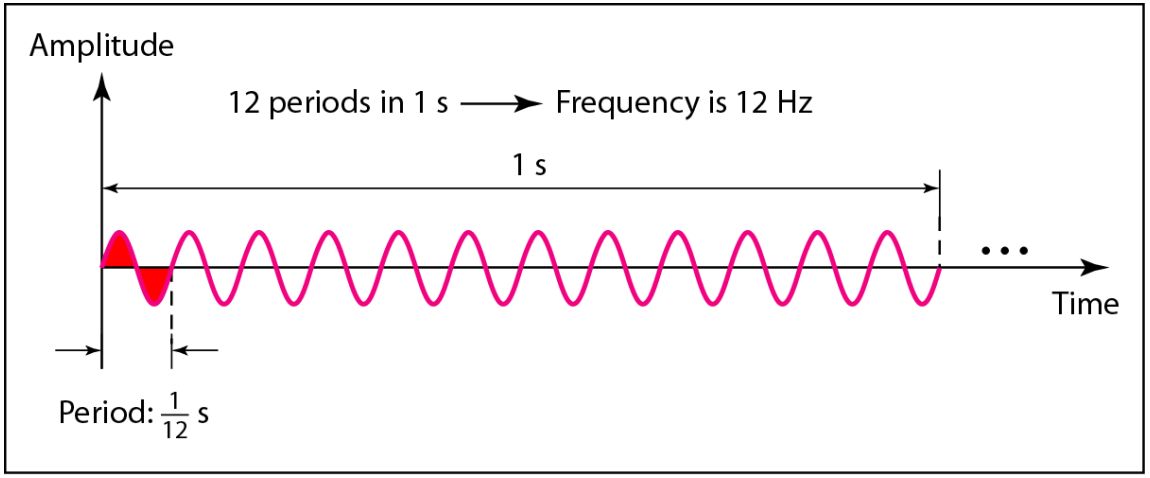
phase / phase shift

Note

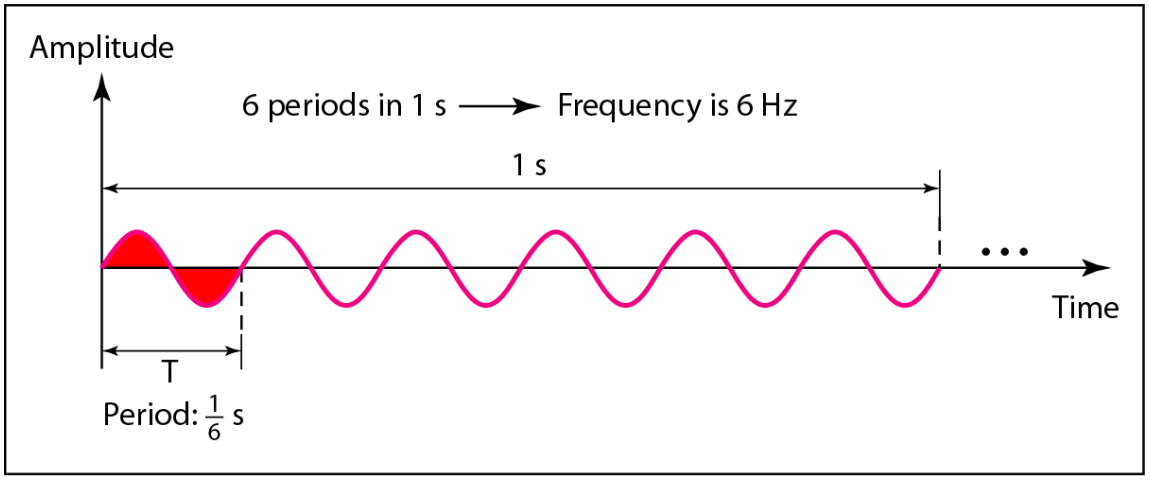
Frequency and period are the inverse of each other.

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

Figure 3.4 *Two signals with the same amplitude and phase, but different frequencies*



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

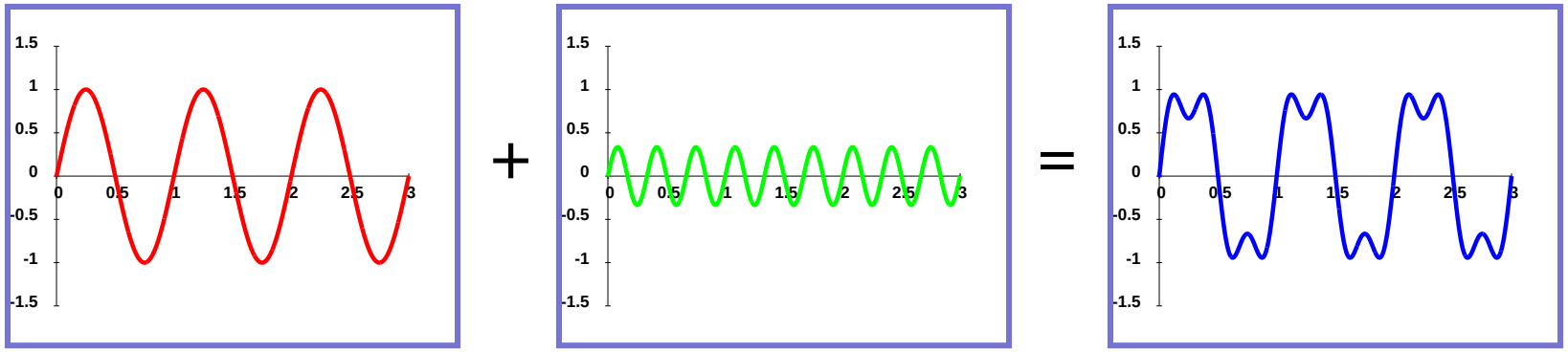
Table 3.1 *Units of period and frequency*

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

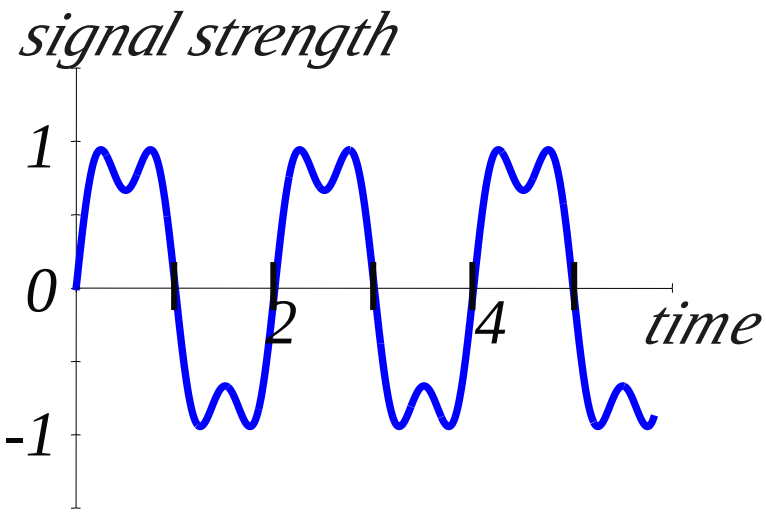
Time vs. Frequency Domains

- Consider the signal

$$x(t) = \sin(2\pi \times t) + \frac{1}{3}\sin(2\pi \times 3t)$$

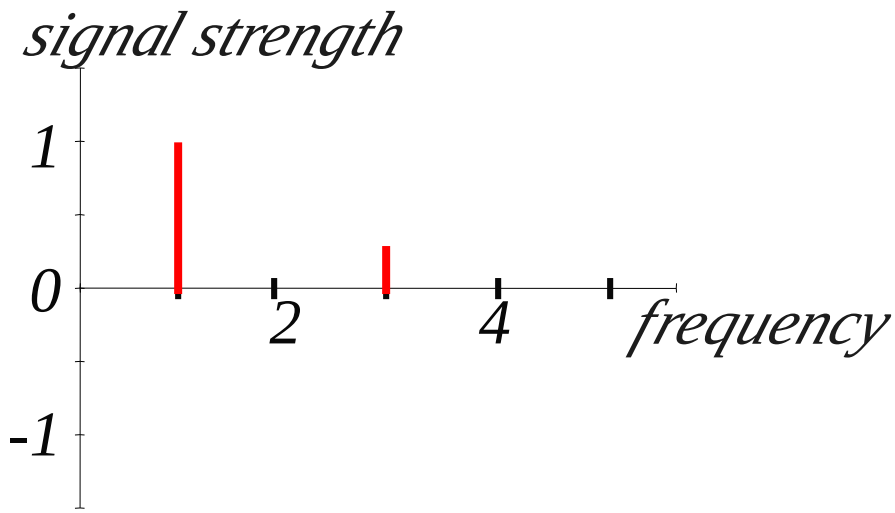


Time vs. Frequency Domains



Time Domain Representation

→ *plots amplitude as a function of time*

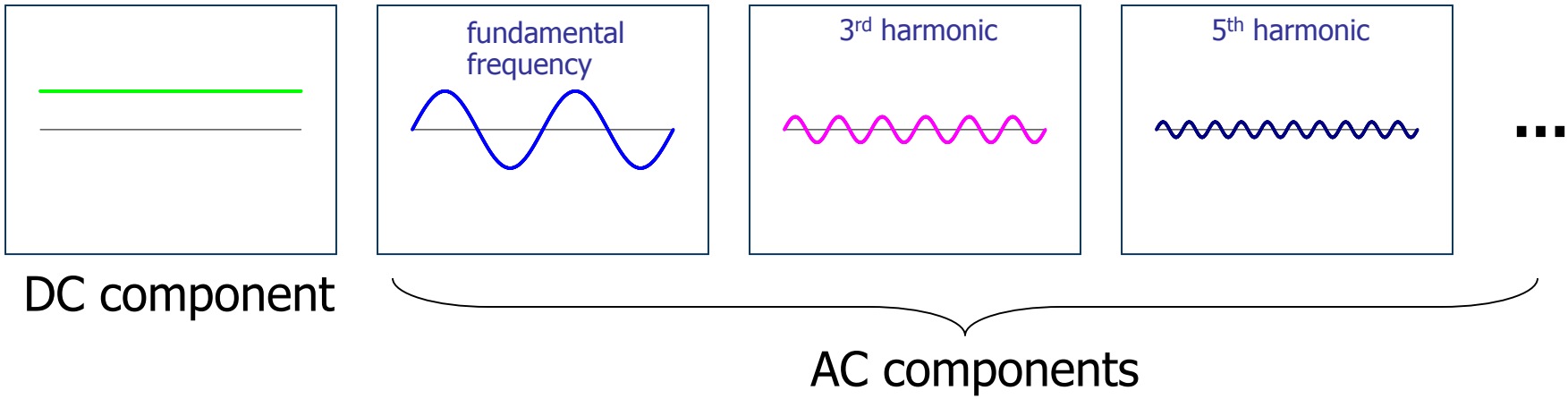


Frequency Domain Representation

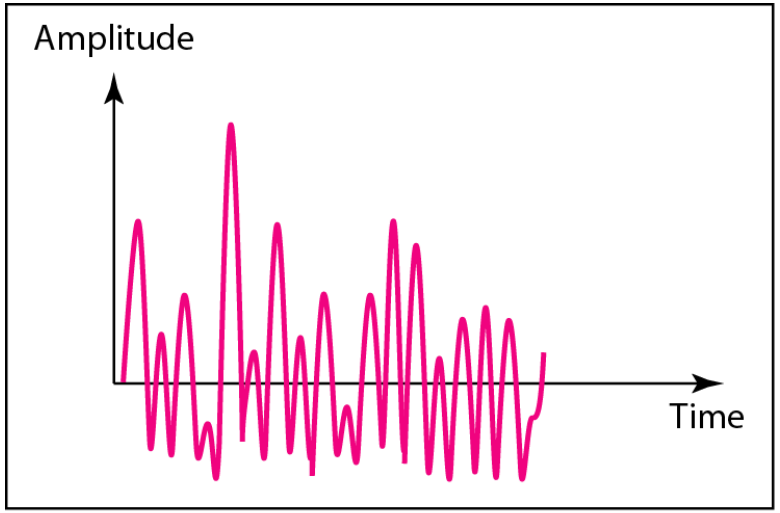
→ *plots each sine wave's peak amplitude against its frequency*

Fourier Analysis

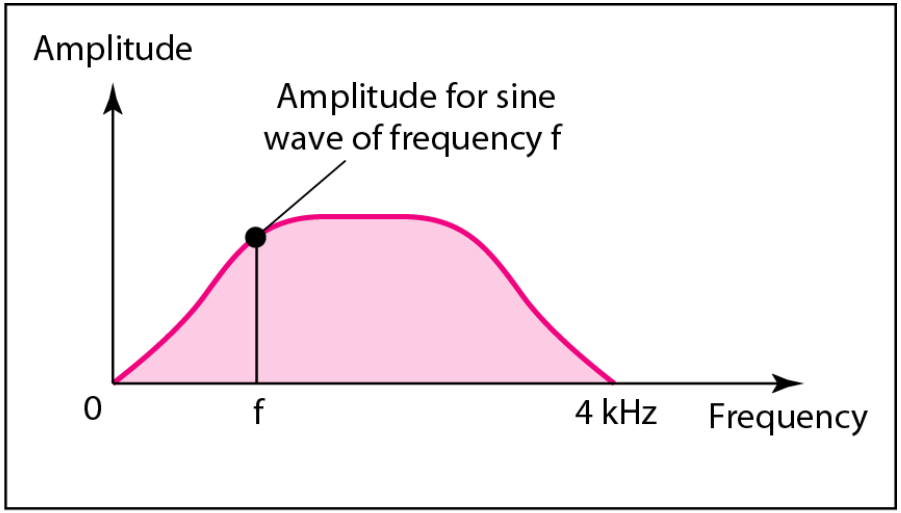
- Every periodic signal consists of
  - DC component
  - AC components
    - Fundamental frequency (f_0)
    - Harmonics (multiples of f_0)



The time and frequency domains of a nonperiodic signal



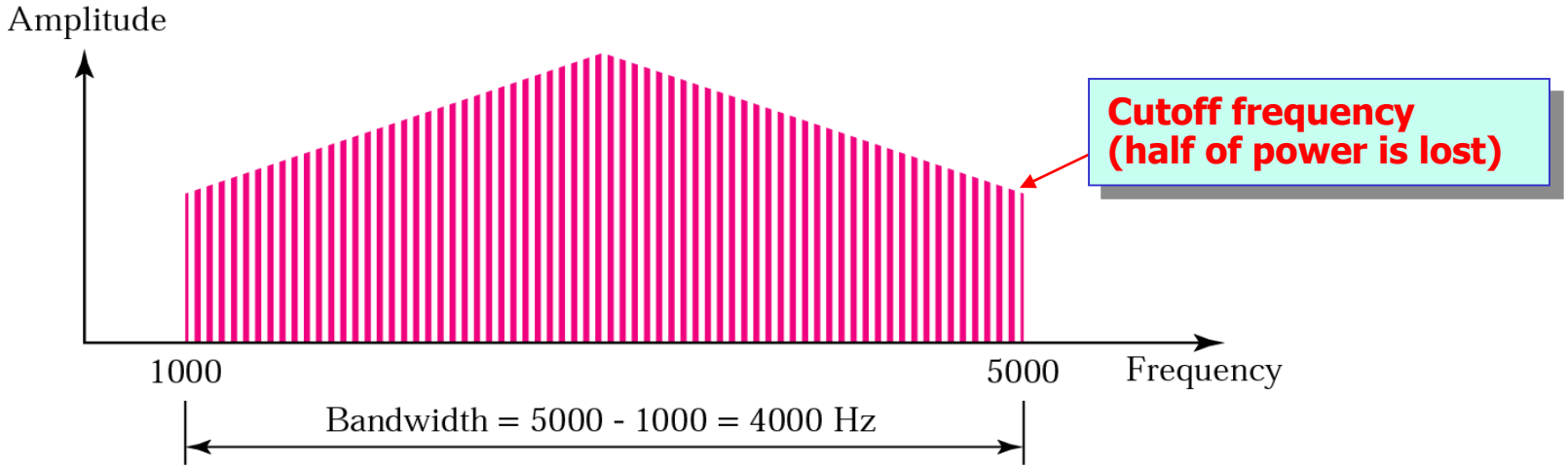
a. Time domain



b. Frequency domain

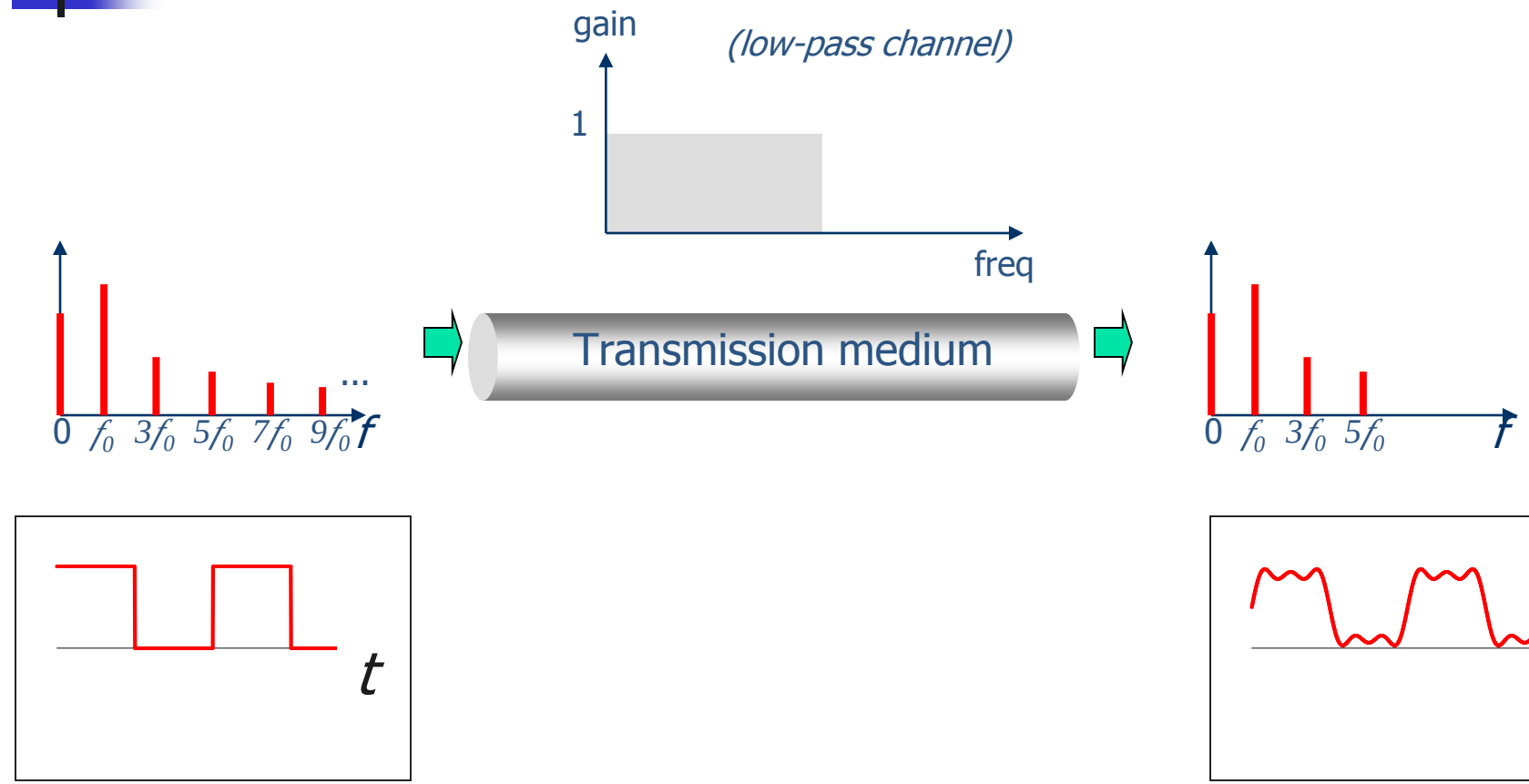
Bandwidth

- A property of a medium
  - Indicates the difference between the highest and the lowest frequencies allowed to pass
  - *<highest freq allowed> – <lowest freq allowed>*



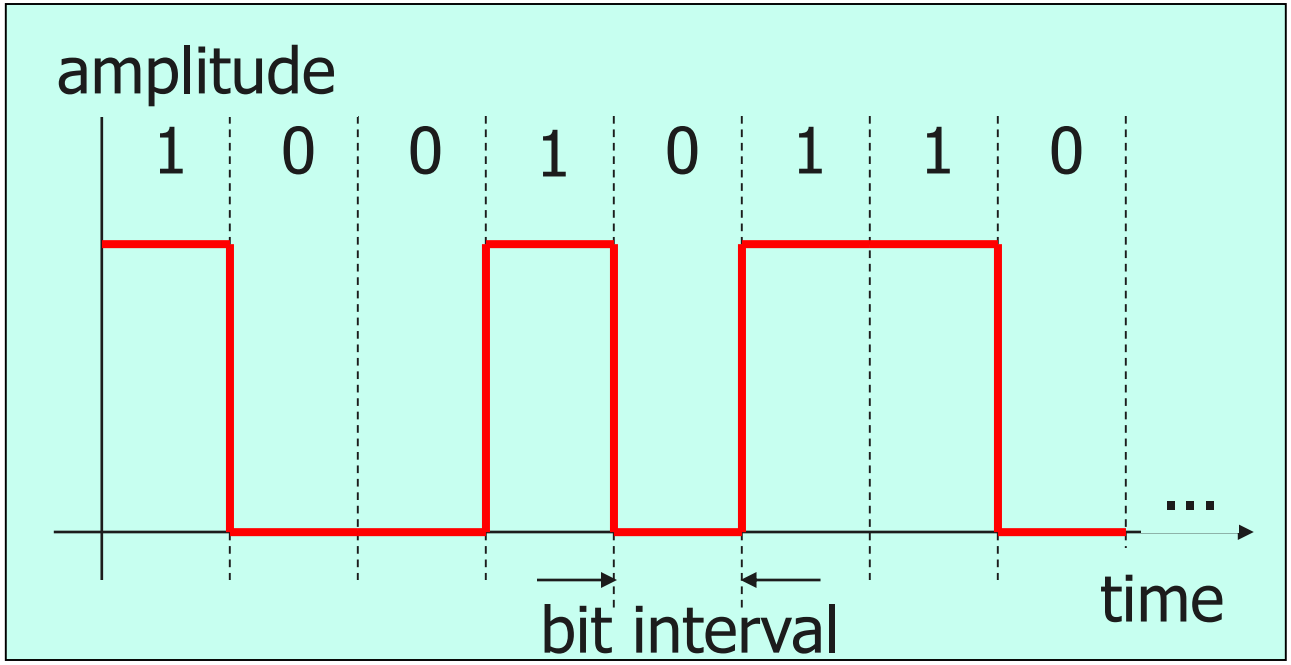
- Also a property of a single spectrum

Bandwidth of a Medium

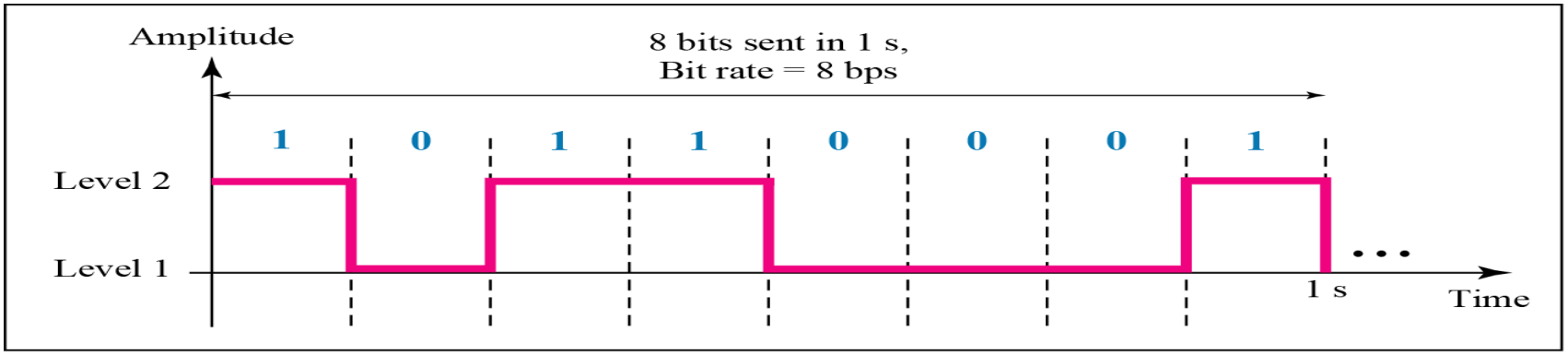


Digital Signals

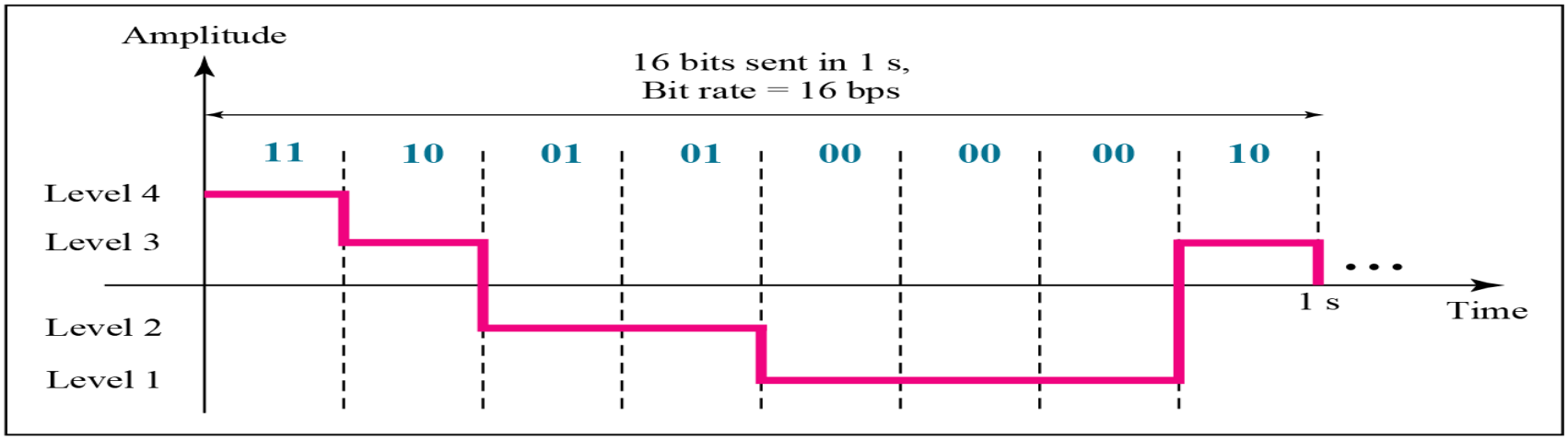
- Properties:
  - *Bit rate* – number of bits per second
  - *Bit interval* – duration of 1 bit



Two digital signals: one with two signal levels and the other with four signal levels



a. A digital signal with two levels

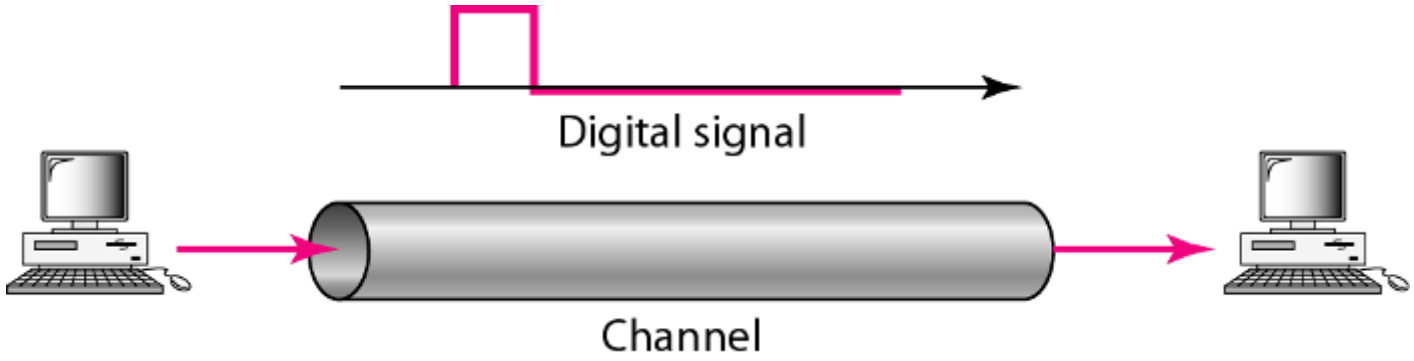


b. A digital signal with four levels

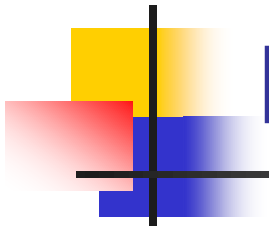
Baseband transmission

- *Baseband transmission*

  → Sending a digital signal over a channel without changing it to an analog signal



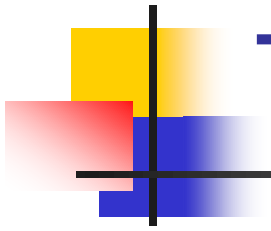
- Baseband transmission requires a low-pass channel



Digital vs. Analog Bandwidth

- Digital bandwidth
  - Expressed in bits per second (bps)
- Analog bandwidth
  - Expressed in Hertz (Hz)

Bit rate and bandwidth are proportional to each other



Transmission Impairment

- Attenuation
- Distortion
- Noise

Signal Attenuation

- Attenuation ⇨ Loss of energy
  - Signal strength falls off with distance

- Attenuation depends on medium
- Attenuation is an increasing function of frequency

Relative Signal Strength

- Measured in *Decibel (dB)*

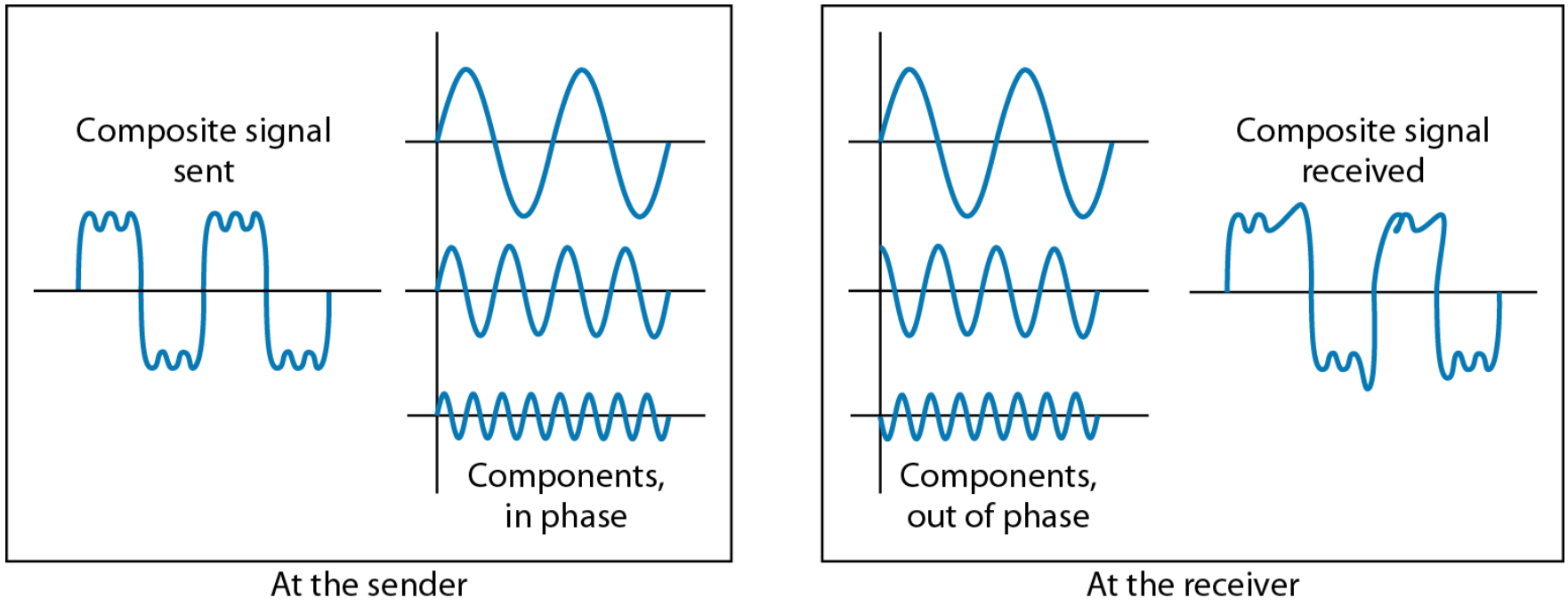
$$dB = 10 \log_{10} (P_2/P_1)$$

  - P_1 and P_2 are signal powers at points 1 and 2, respectively

  - Positive dB → signal is amplified (gains strength)
  - Negative dB → signal is attenuated (loses strength)

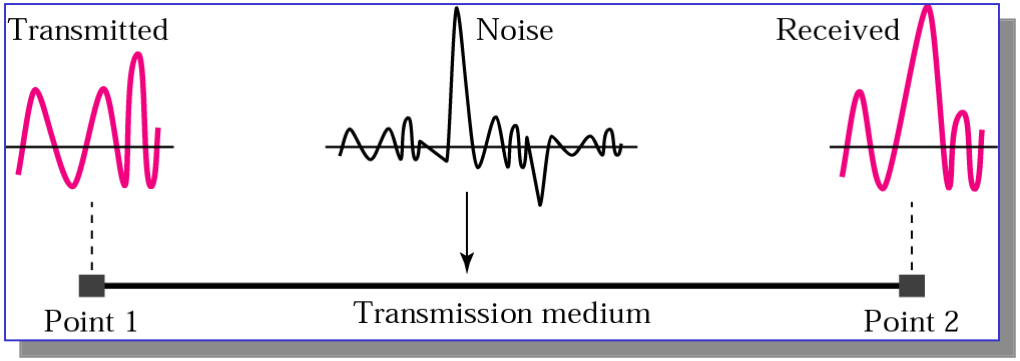
Figure 3.28 *Distortion*

- Distortion ⇨ Change in signal shape



Noise

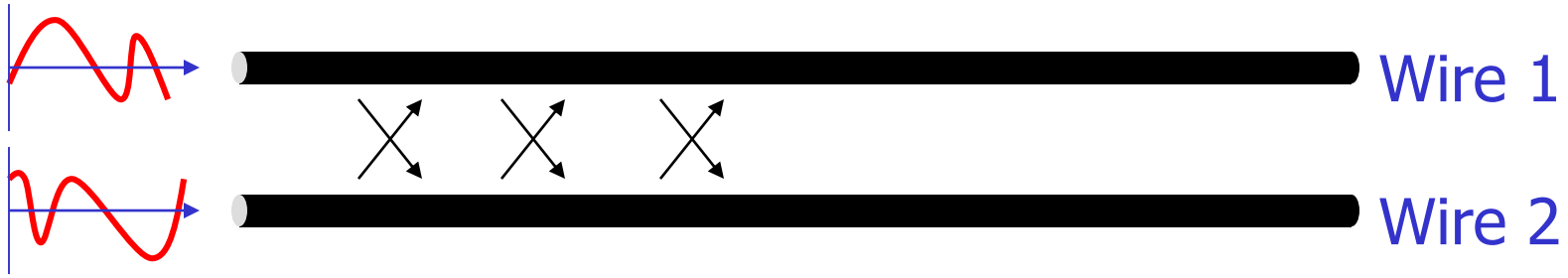
- Noise ⇨ Undesirable signals added between the transmitter and the receiver



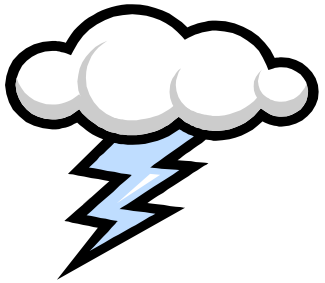
- Types of noise
  - Thermal
    - Due to random motion of electrons in a wire

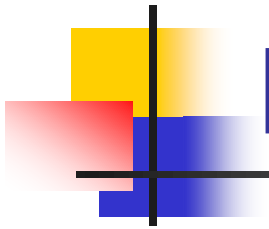
Noise

- Types of noise (cont'd)
  - Crosstalk
    - Signal from one line picked up by another



  - Impulse
    - Irregular pulses or spikes
    - E.g., lightning
      - Short duration
      - High amplitude



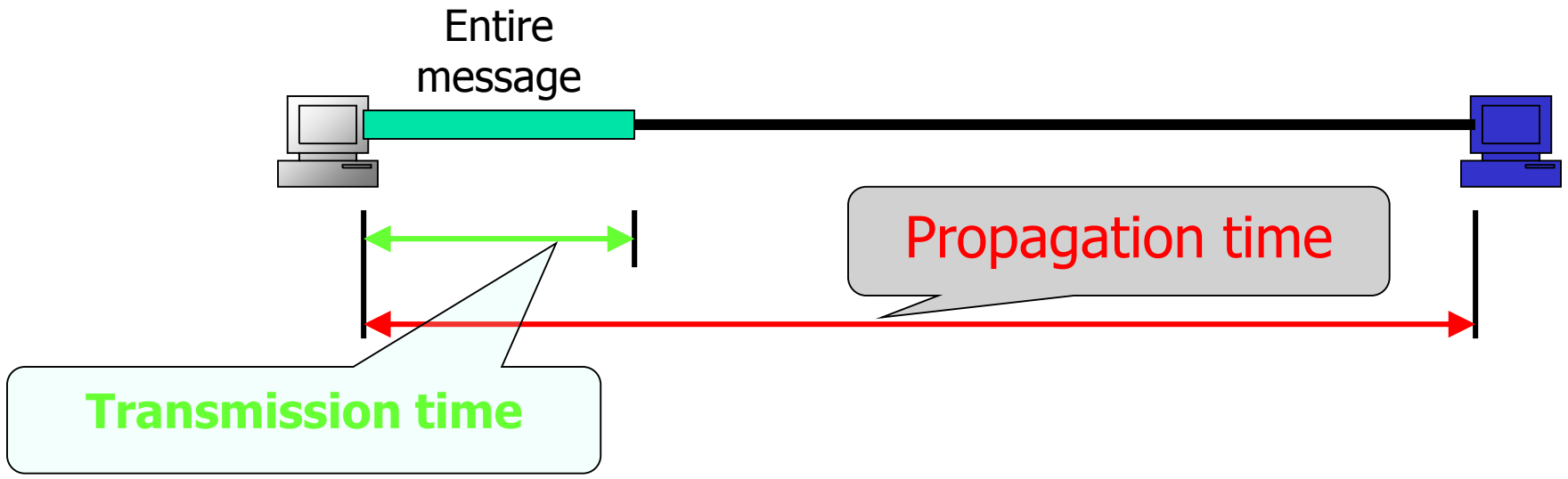


Network Performance

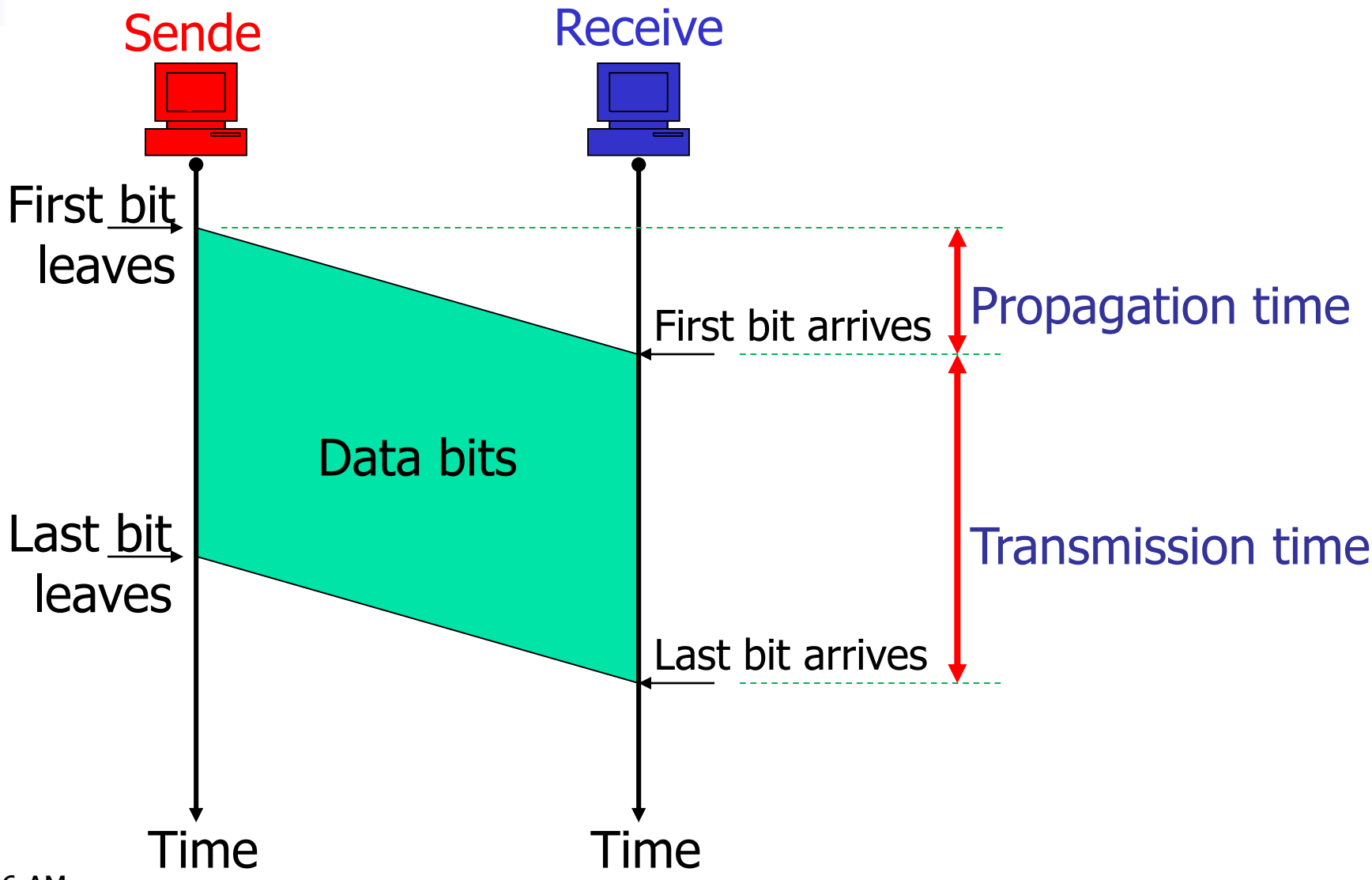
- Bandwidth
  - Hertz
  - Bits per second (bps)
- Throughput
  - Actual data rate
- Latency (delay)
  - Time it takes for an entire message to completely arrive at the destination

Latency

- Composed of
  - Propagation time
  - Transmission time
  - Queuing time
  - Processing time



Latency


Sende
Receive
First bit leaves
First bit arrives
Propagation time
Data bits
Last bit leaves
Transmission time
Last bit arrives
Time
Time

Bandwidth-Delay Product

- The link is seen as a pipe
  - Cross section = bandwidth
  - Length = delay
- Bandwidth-delay product defines the number of bits that can fill the link

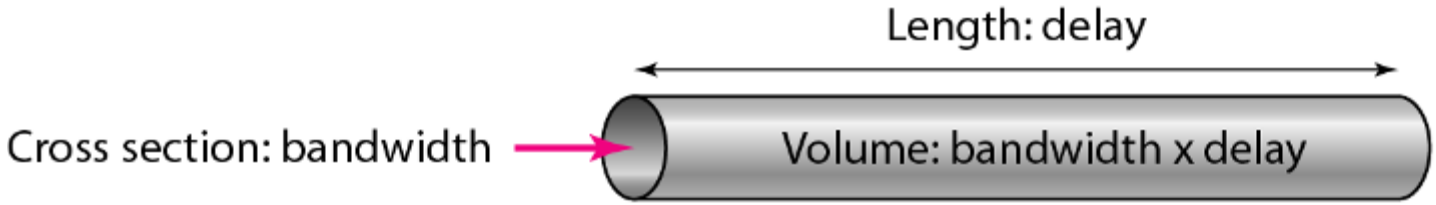


Figure: *Filling the link with bits for case 1*

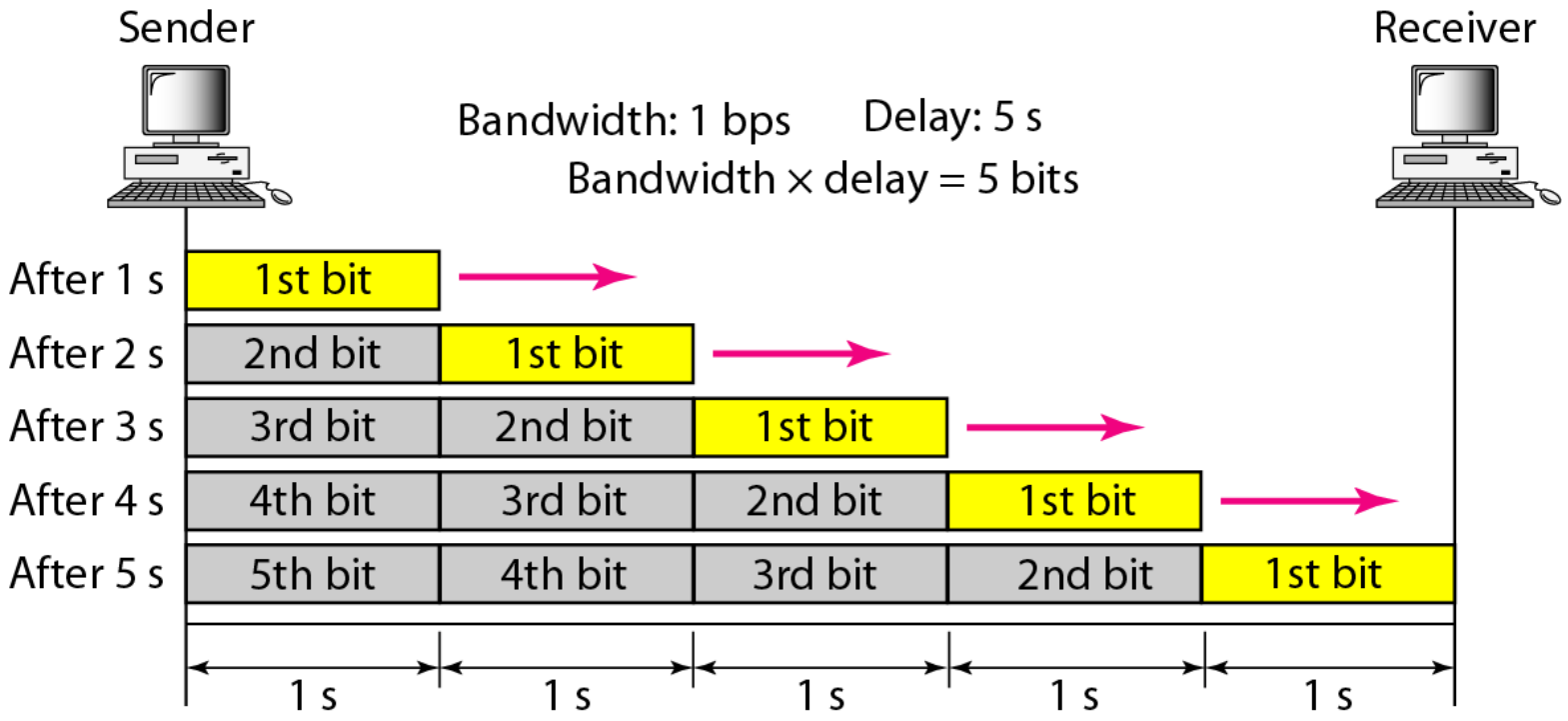
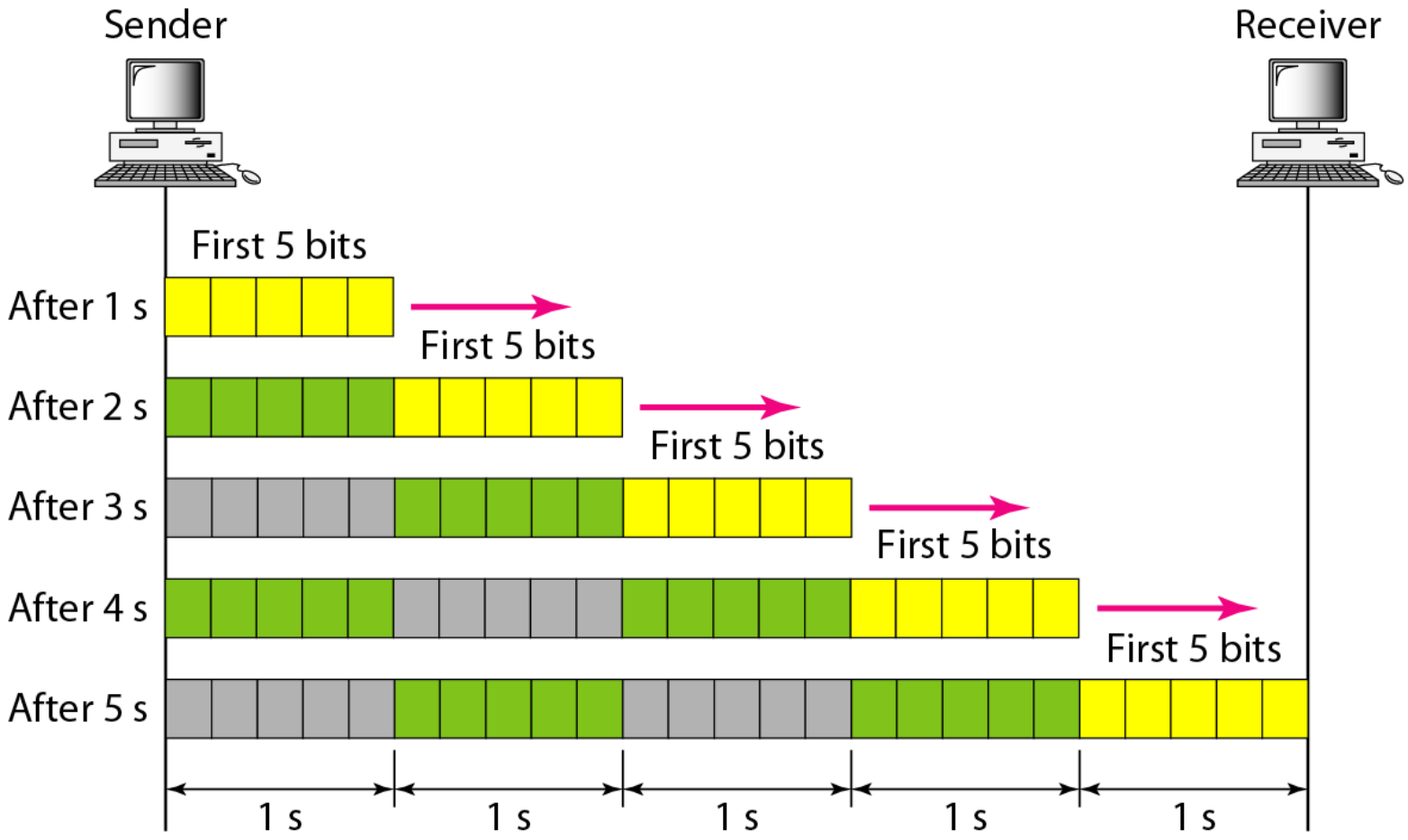
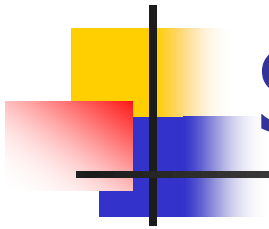


Figure 3.32 *Filling the link with bits in case 2*





Summary

- Data need to take form of signal to be transmitted
- Frequency domain representation of signal allows easier analysis
  - Fourier analysis
- Medium's bandwidth limits certain frequencies to pass
- Bit rate is proportional to bandwidth
- Signals get impaired by attenuation, distortion, and noise