Communication PH Layer

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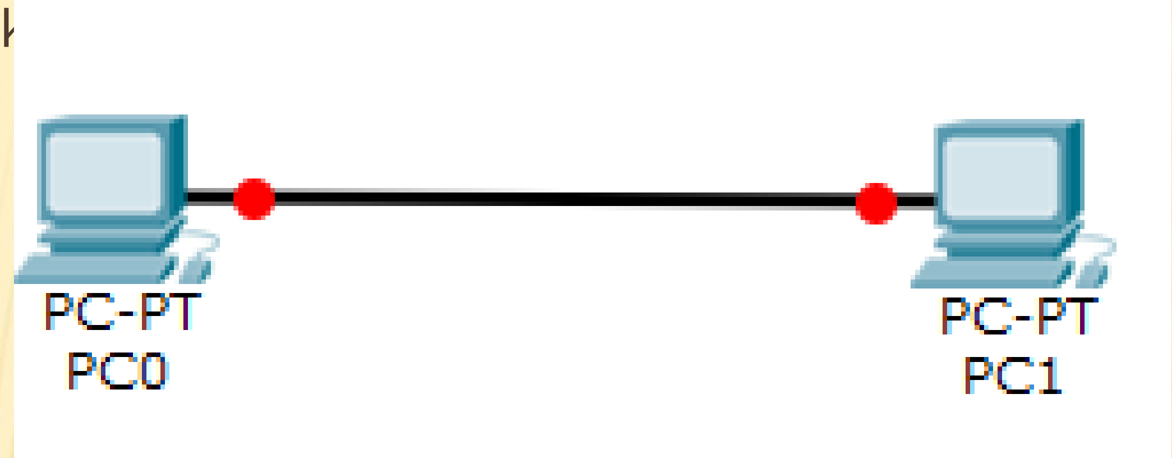
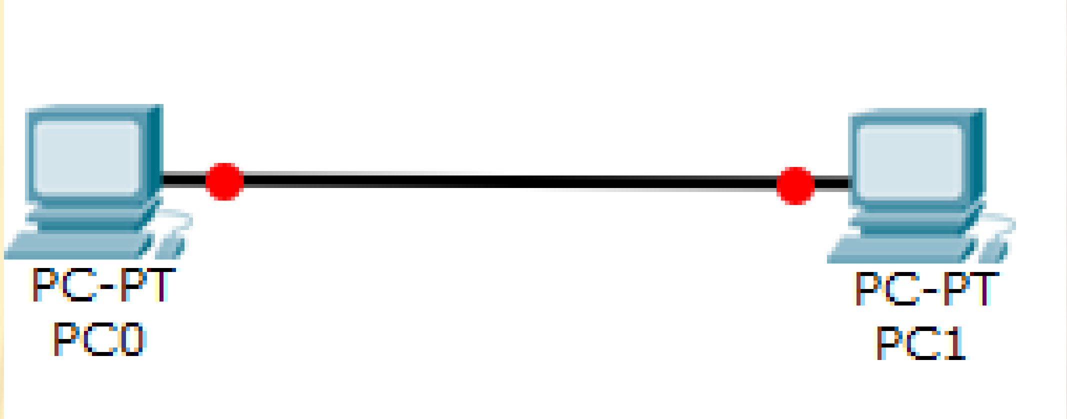
NETWORK TOPOLOGY

- Characteristic of Network
  - Two Computers
  - Connected with Cable
    - Wires ??
  - Topology
    - Point-to-point
  - Distance between two machine
    - <100 mtr: LAN
    - <40,000 and >100 mtr: LAN
    - >40,000: WAN
  - Distance is 5 Mtr
    - What kind of network?
  - Names of the machine.
    - PC0 and PC1



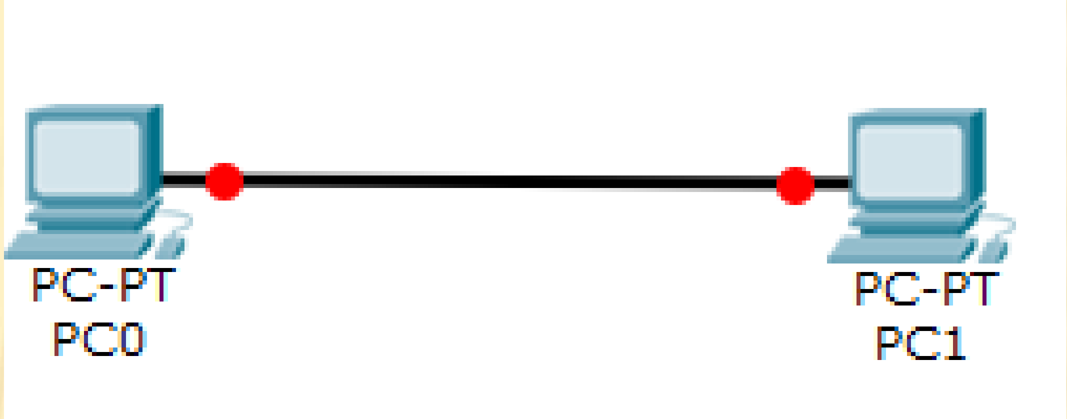
SENDER PROGRAM (PC0)

```
#define Port 33
Main()
    {
     //Variable declarations…
           Send("Hello world");

   }

Send(Char s[])
 {
 for(i=0;i<strlen(s);i++)
     transfer(Port,s[i]);
}
```

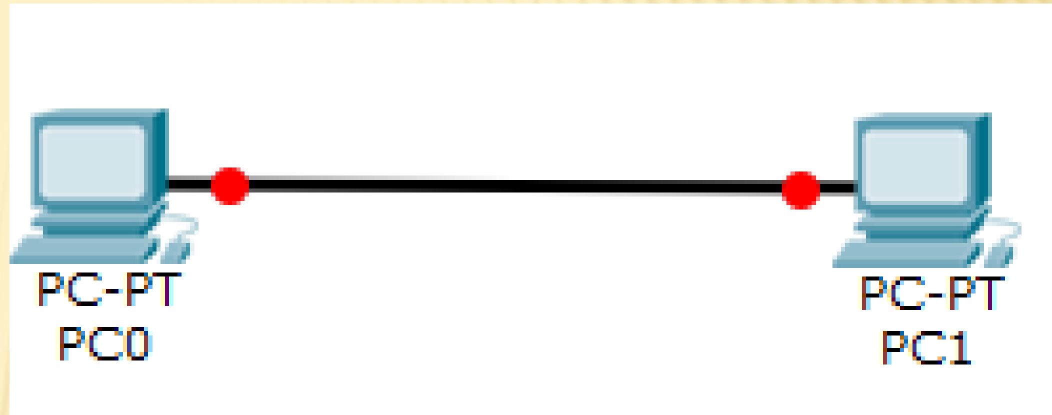


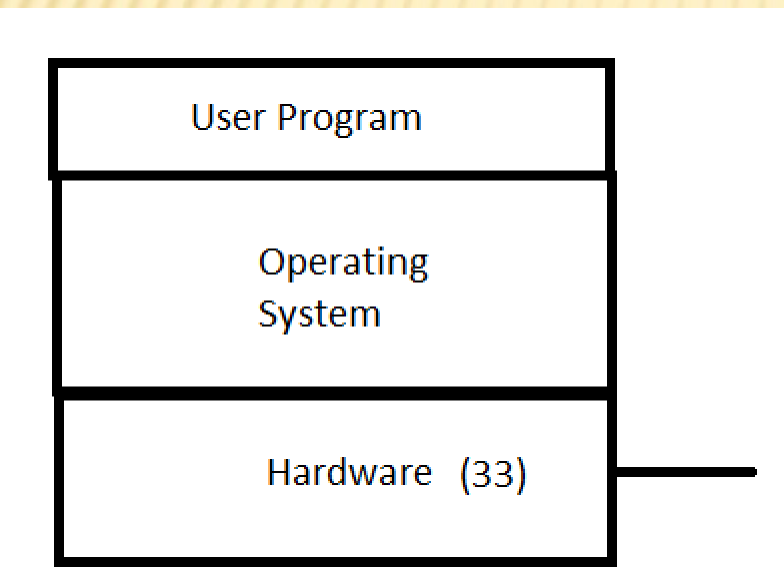
RECEIVER PROGRAM(PC1)

```
#define Port 33
Main()
    {
     //Variable declarations…
     char recv[100];
     char recv=receive();
     printf("Received string: %s",recv)

   }

Receive()
 {
 Char s[100];
 While(Port==NULL)
     s[i]=accept(Port,1);
  return(s)
}
```

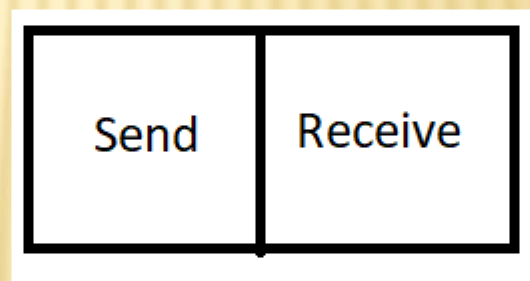


FLOW OF INFORMATION

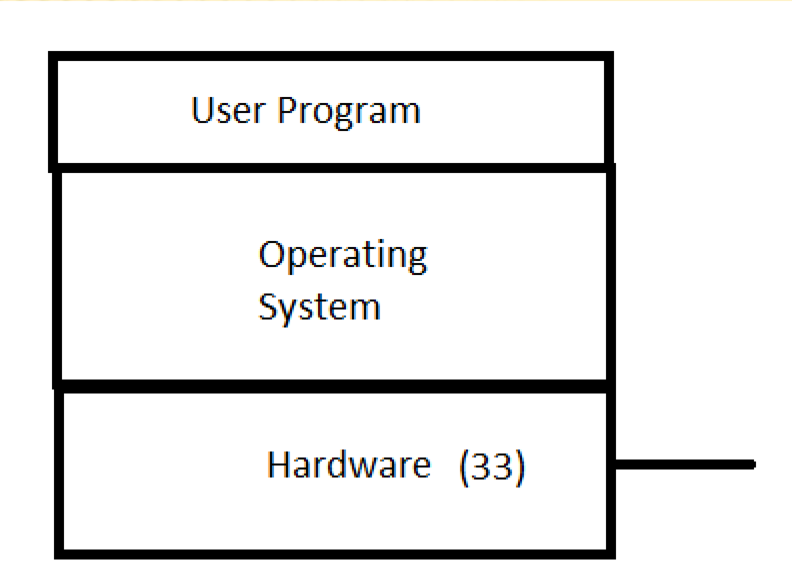




Transfer Accept



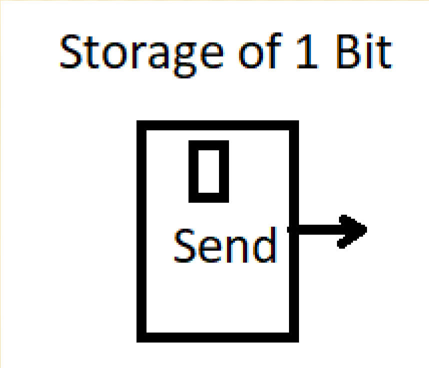
SENDER HARDWARE



Hello World

48 65 6C 6C 6F 20 57 ...

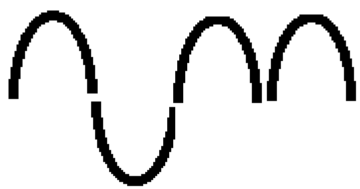
010010000110010101101100..



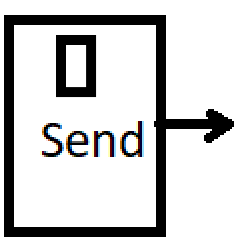
If hardware takes 1 sec to transfer 1 bit
How much time it take to transfer Hello world?
Data rate is 1 bits/sec
If hardware takes 100 milli second to transfer 1 bit
How much time it take=??
What is data rate: ??
If hardware takes 1 microsecond to transfer 1 bit ??
How much time it take=??
What is data rate: ??

SENDING FLOW

Sending: 1011

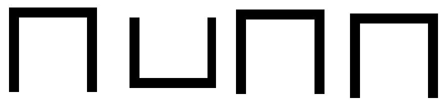


Storage of 1 Bit

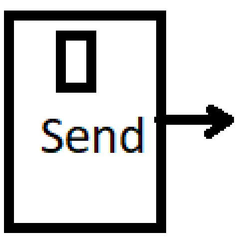


SENDING FLOW

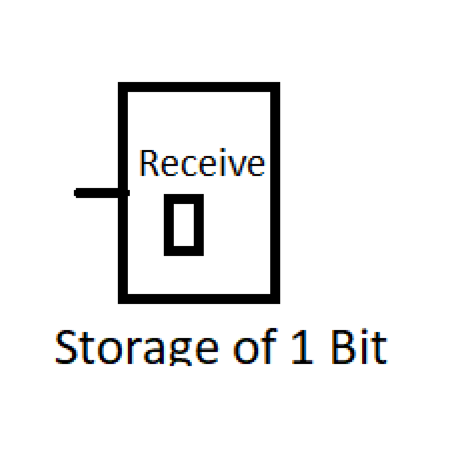
Sending: 1011

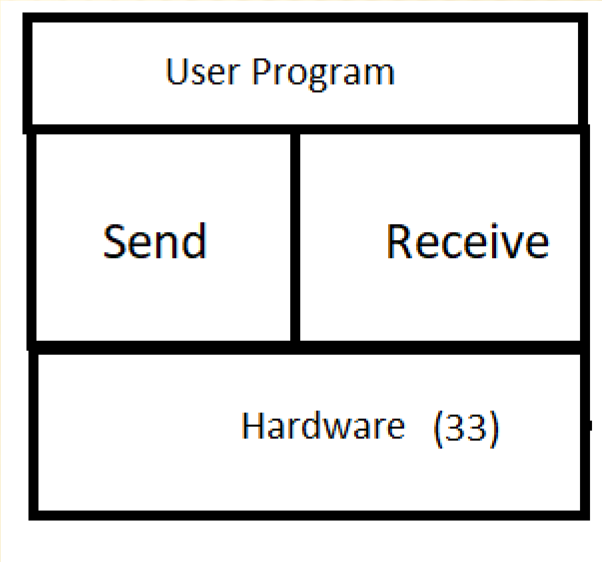


Storage of 1 Bit



RECEIVER HARDWARE



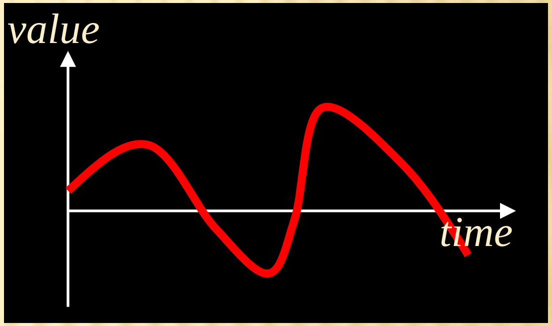


ANALOG VS. DIGITAL DATA

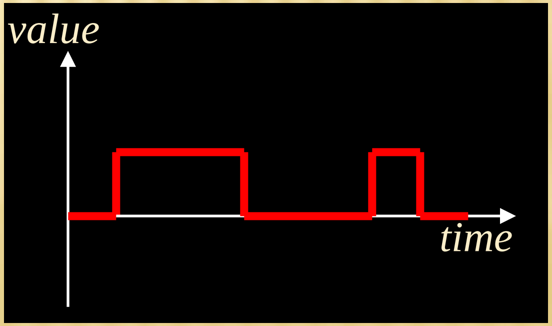
- Analog data
  - Data take on continuous values
  - E.g., human voice, temperature reading
- Digital data
  - Data take on discrete values
  - E.g., text, integers

ANALOG VS. DIGITAL SIGNALS

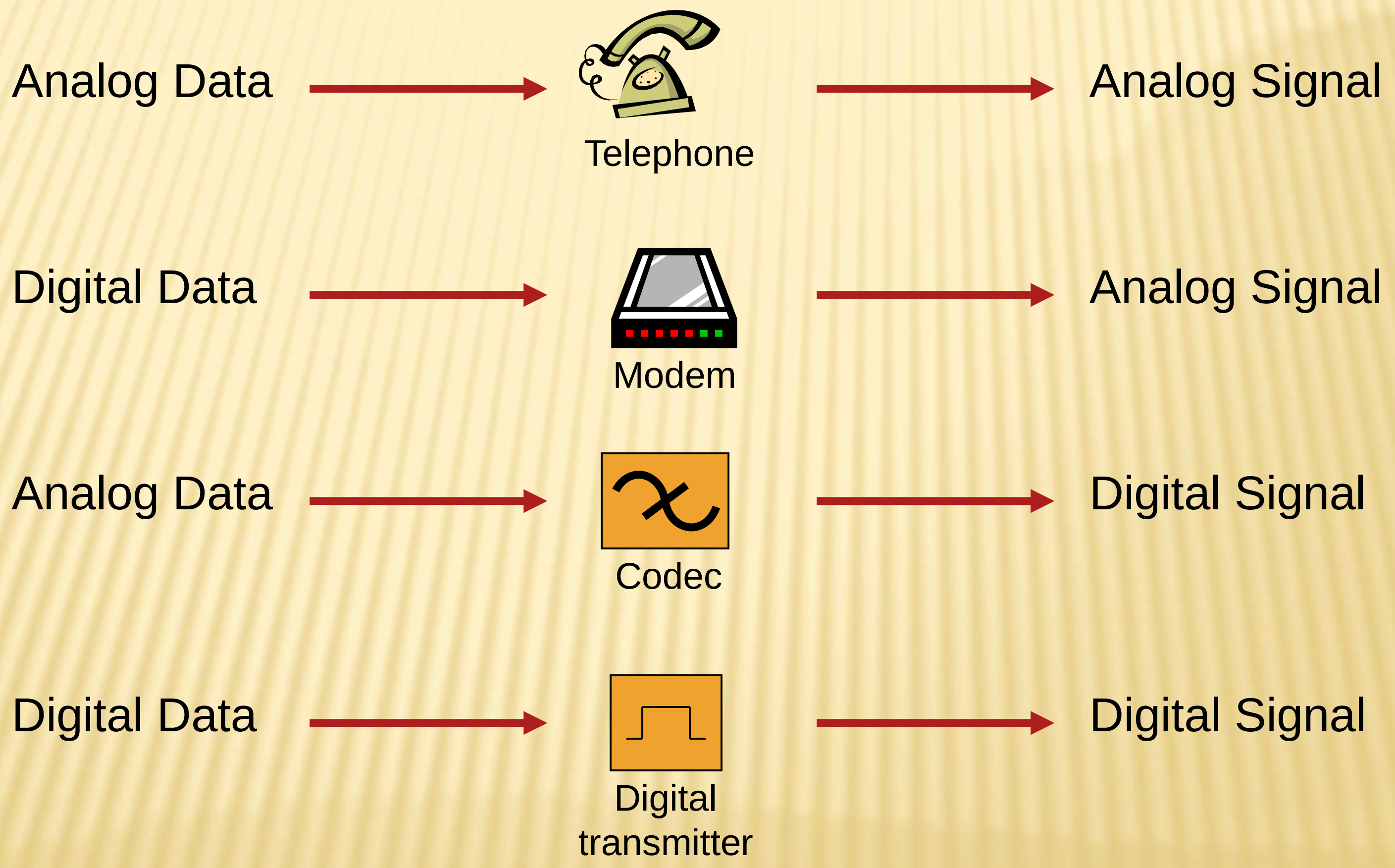
- Analog signals
  - have an infinite number of values in a range



- Digital signals
  - Have a limited number of values



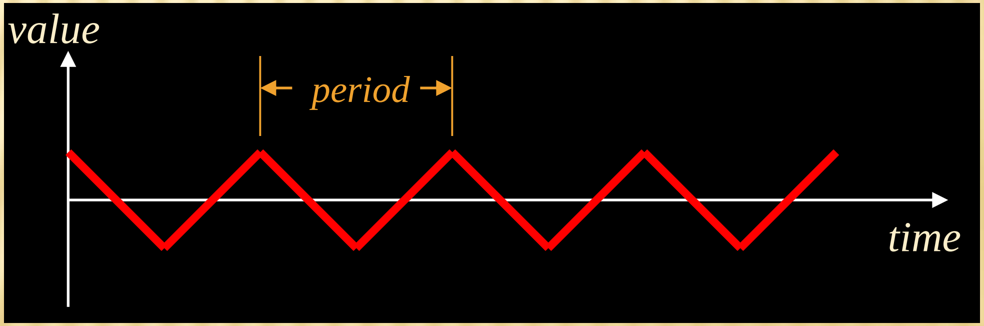
DATA AND SIGNALS



PERIODIC SIGNALS

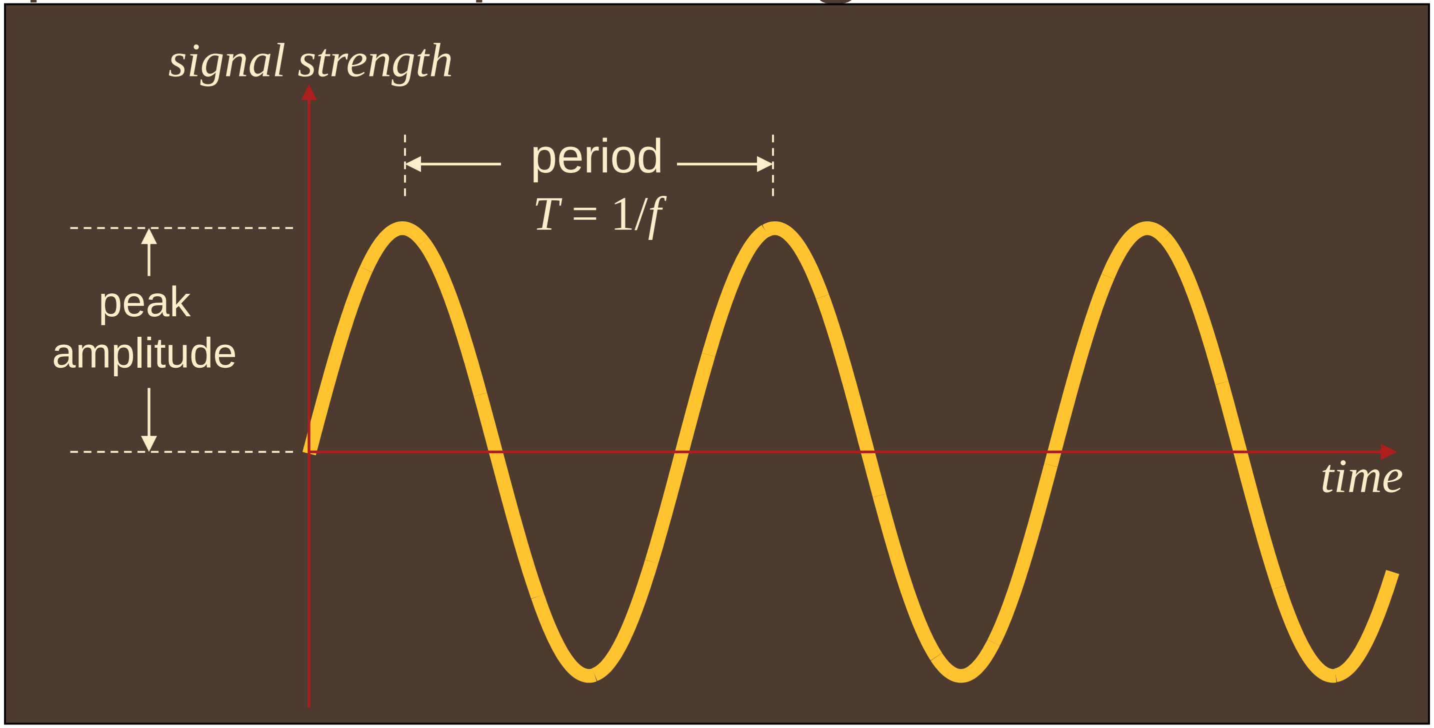
- A *periodic signal* completes a pattern within a timeframe, called a *period*
- A signal $x(t)$ is periodic if and only if

$$x(t) = x(t+T) \quad -\infty < t < \infty$$



SINE WAVES

- Simplest form of periodic signal



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

phase / phase shift

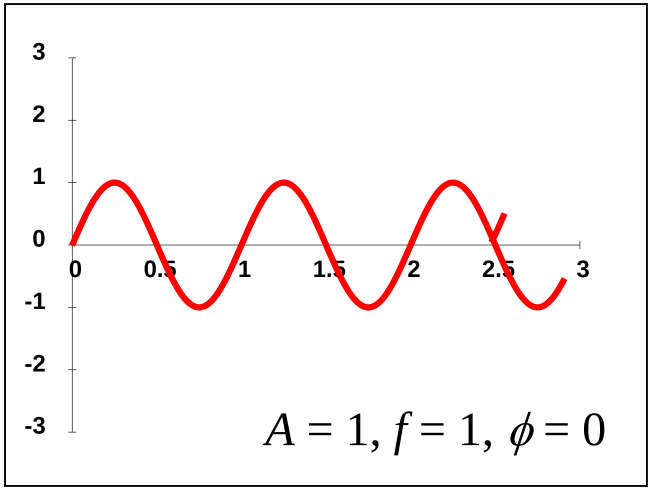
CONCLUSION

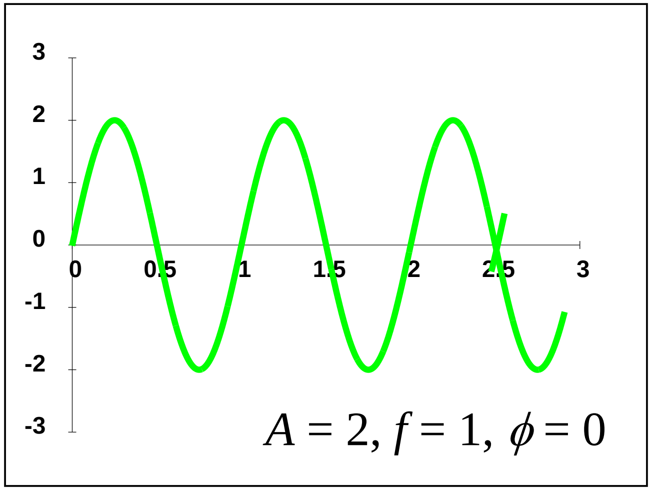
- High frequency, low range, (potentially) high bandwidth.
- Low frequency, high range, low bandwidth.
- As frequency increases, the signal is absorbed more by physical objects (atmospheric moisture, trees, buildings, etc). Hence you need more power to make up for the signal loss

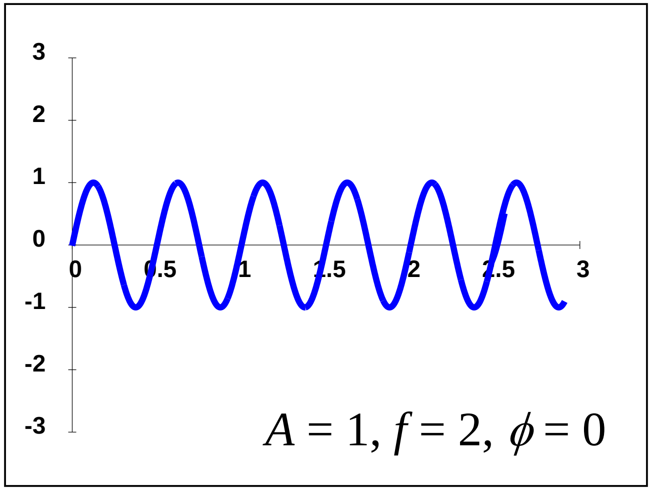
CONCLUSION

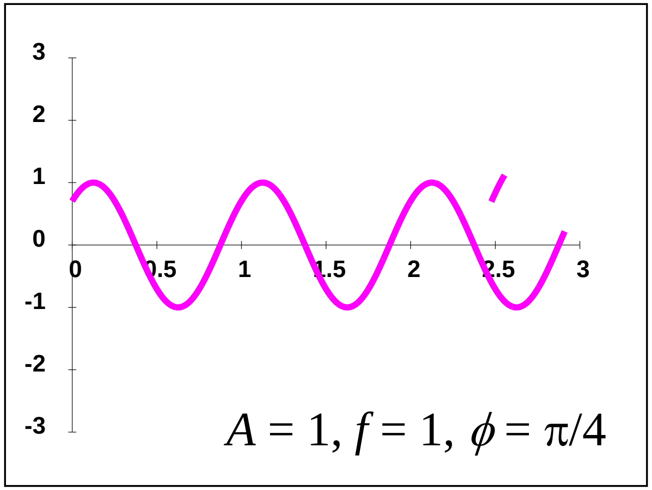
- Low frequency(LF) is longer than High Frequency (HF) signals, hence it has less penetration power. So, when it comes to sending information signals to larger distance, LF fails. (Which means LF can carry less information).
- While HF has high penetration power, thus it can easily send information to large distance. (Which means HF carries more information).

VARYING SINE WAVES





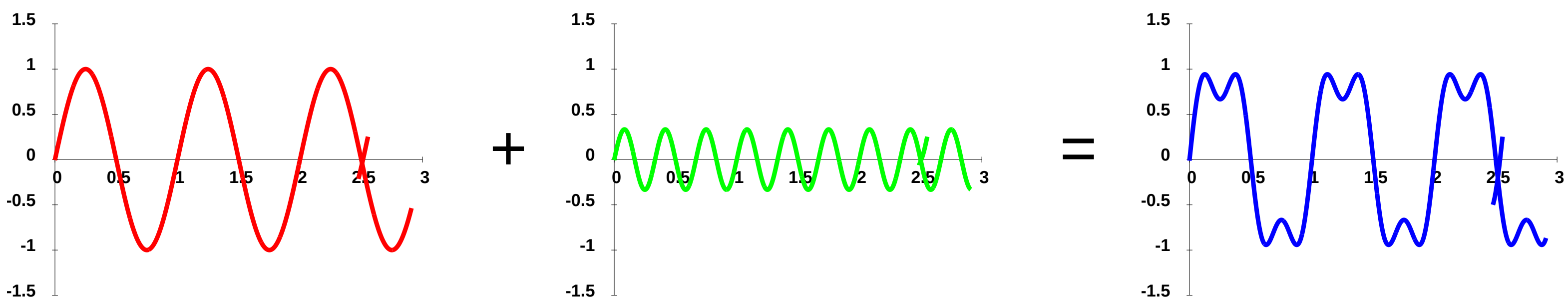




TIME VS. FREQUENCY DOMAINS

- Consider the signal

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



Demo: sine.py

LINE CODING

- Process of converting binary data to digital signal

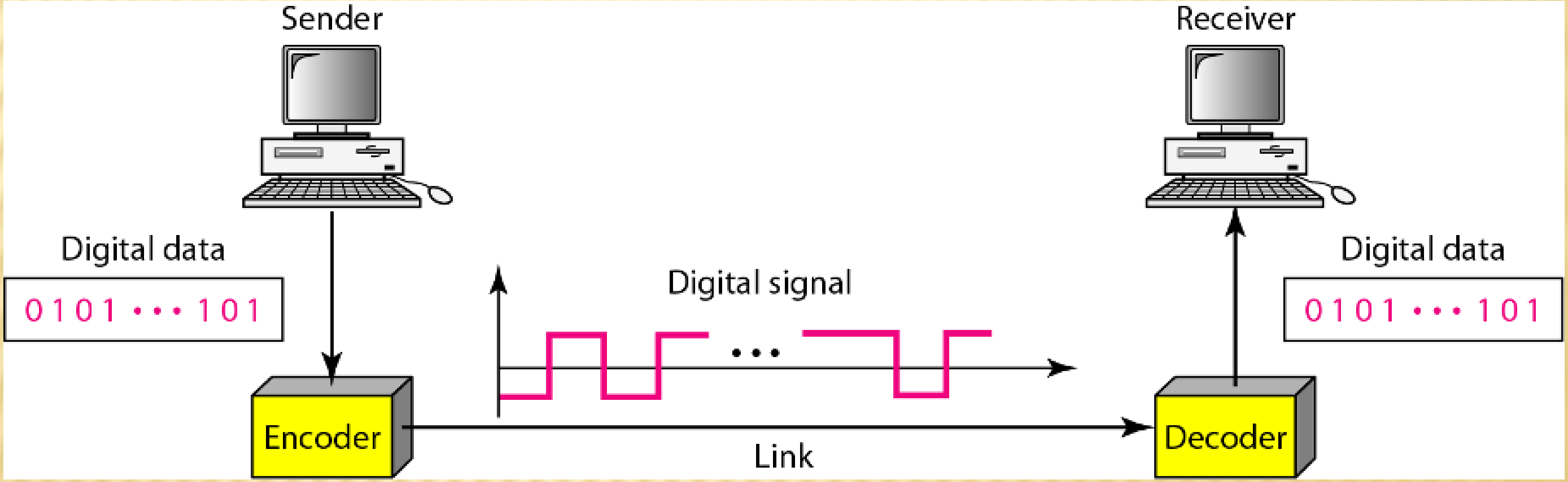


Figure *A sine wave*

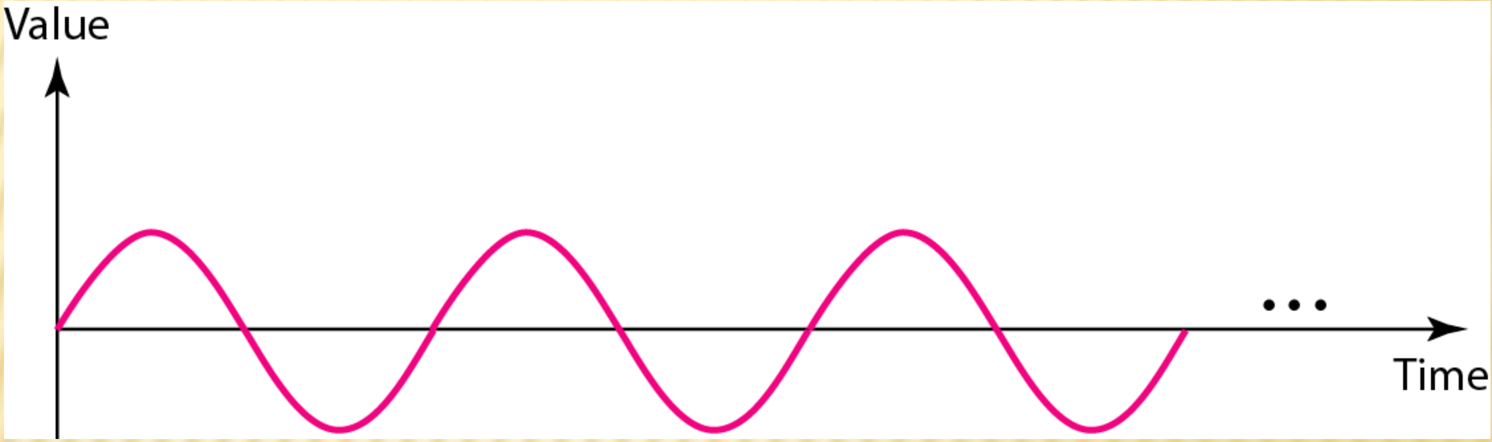
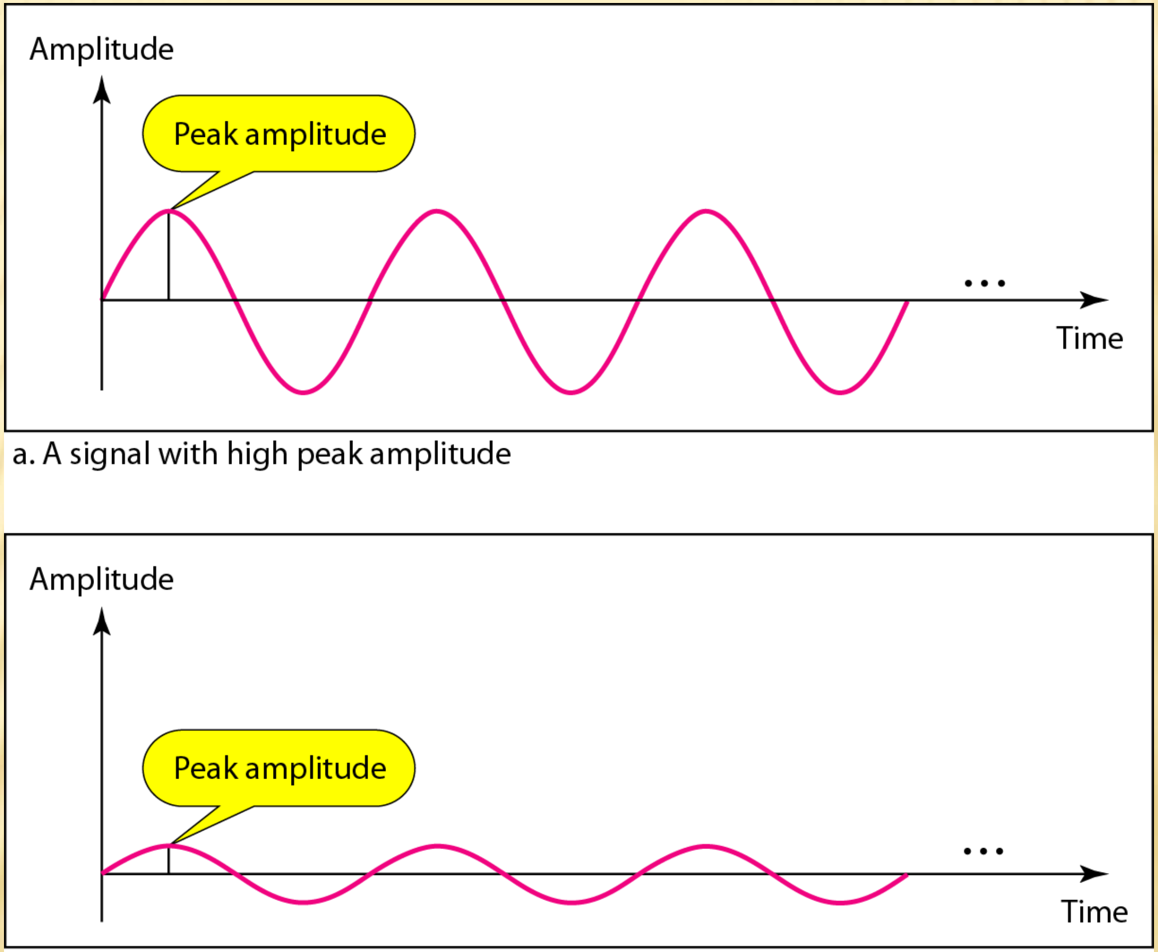


Figure ***Two signals with the same phase and frequency, but different amplitudes***



a. A signal with high peak amplitude

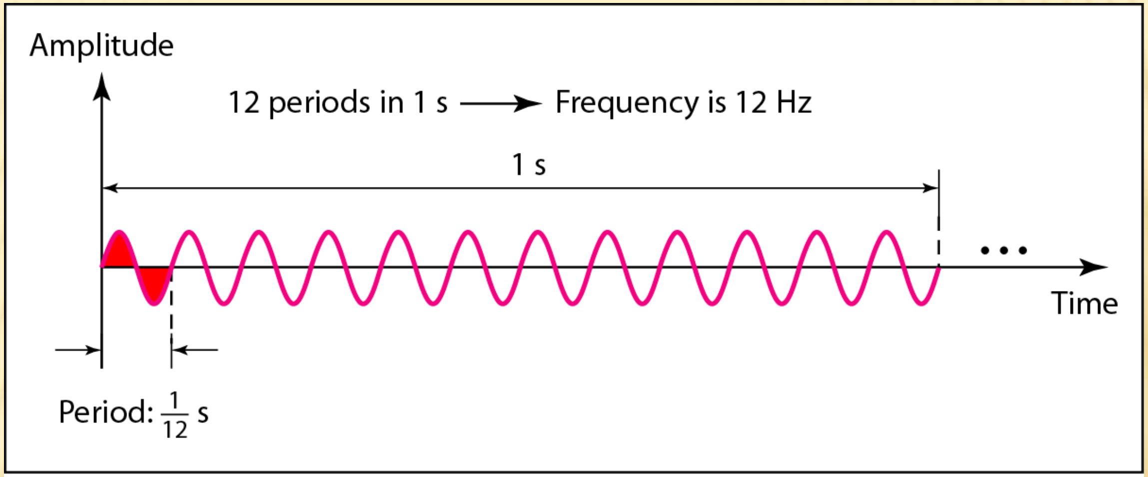
b. A signal with low peak amplitude

Note

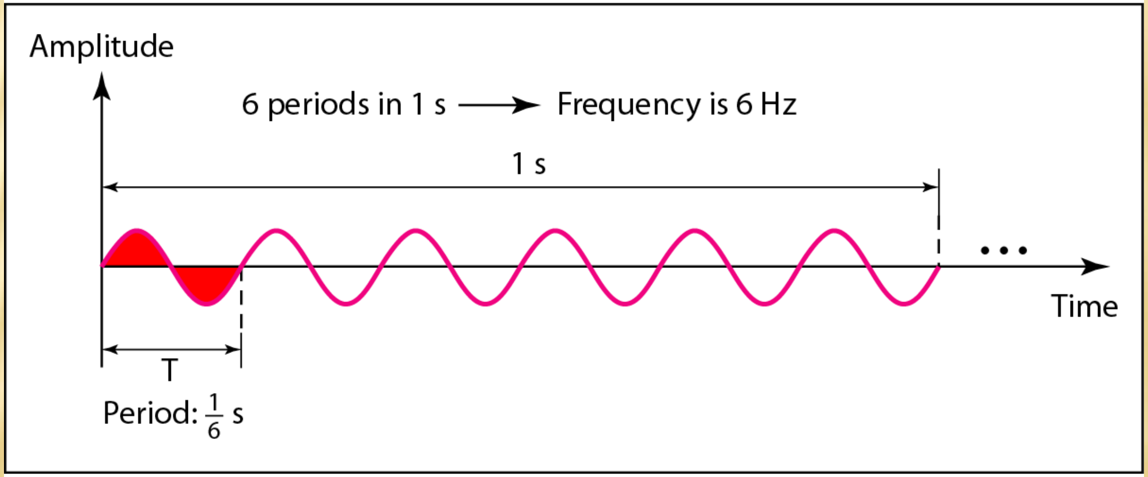
Frequency and period are the inverse of each other.

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

Figure *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 ***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 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 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).

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

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

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.

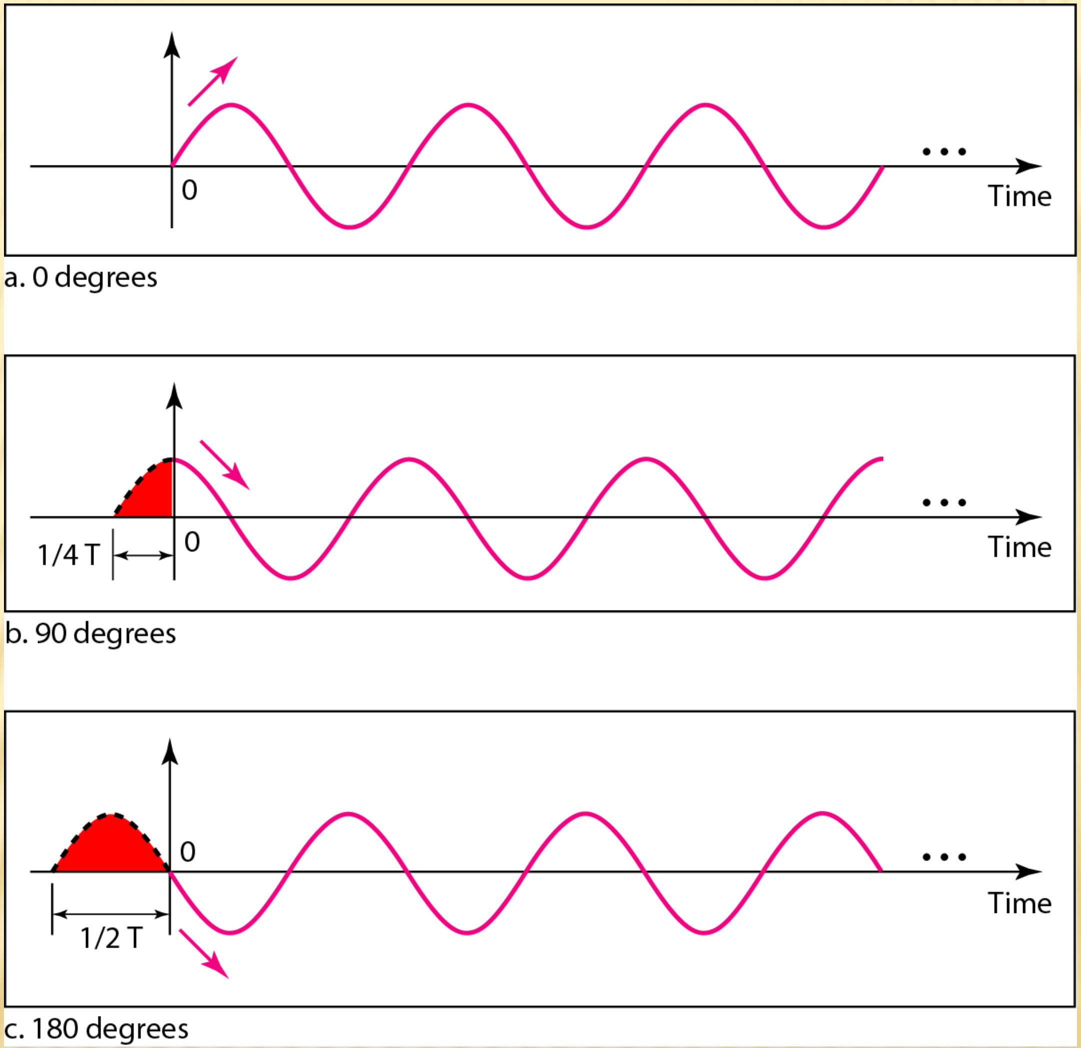
Note

If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

Note

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

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



Example 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

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

Figure *Wavelength and period*

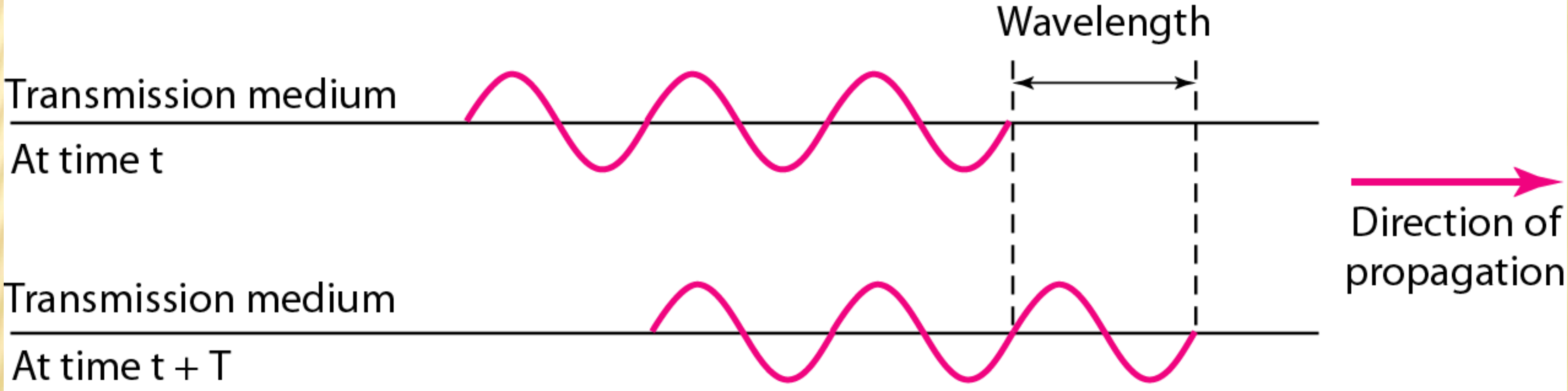
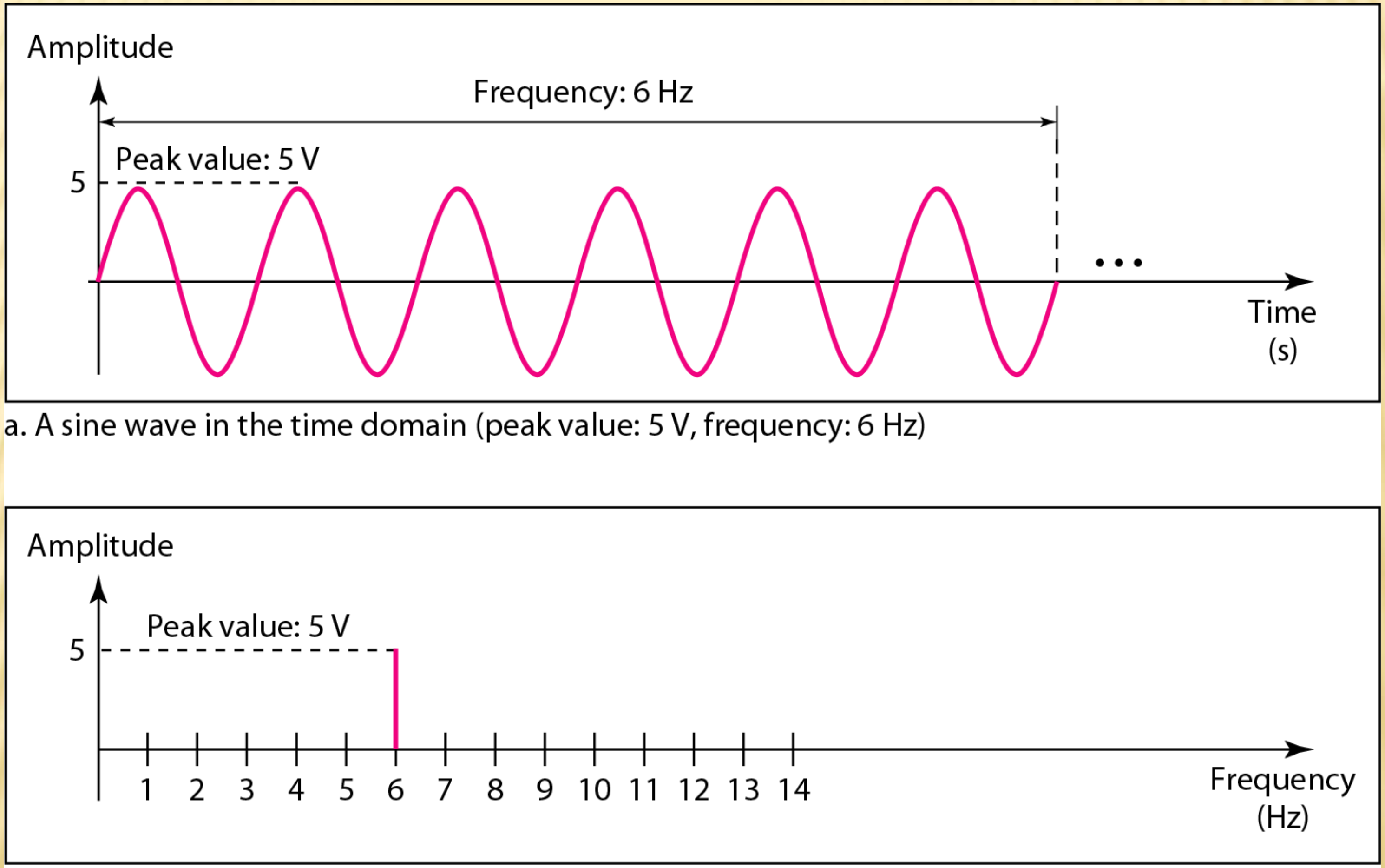


Figure *The time-domain and frequency-domain plots of a sine wave*



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)

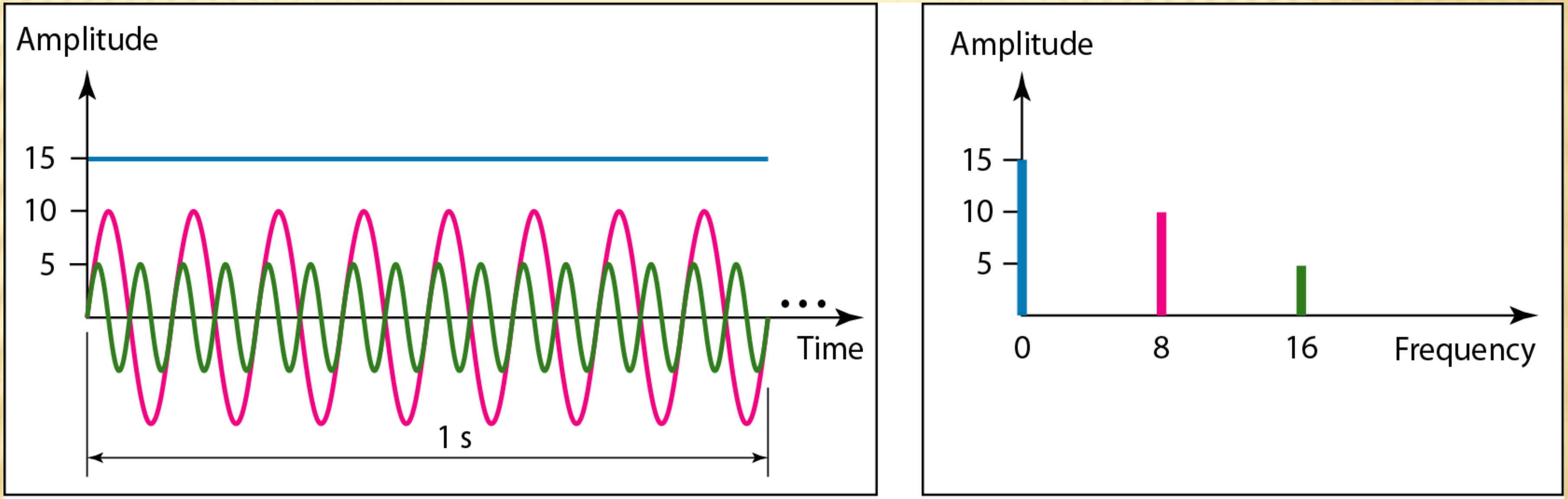
Note

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

Example 7

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

Figure 3 *The time domain and frequency domain of three sine waves*



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

b. Frequency-domain representation of the same three signals

SIGNALS AND COMMUNICATION

- 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.

COMPOSITE SIGNALS AND PERIODICITY

- 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.

Example 4

Next Page Figure 3 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.

Figure 3.9 *A composite periodic signal*

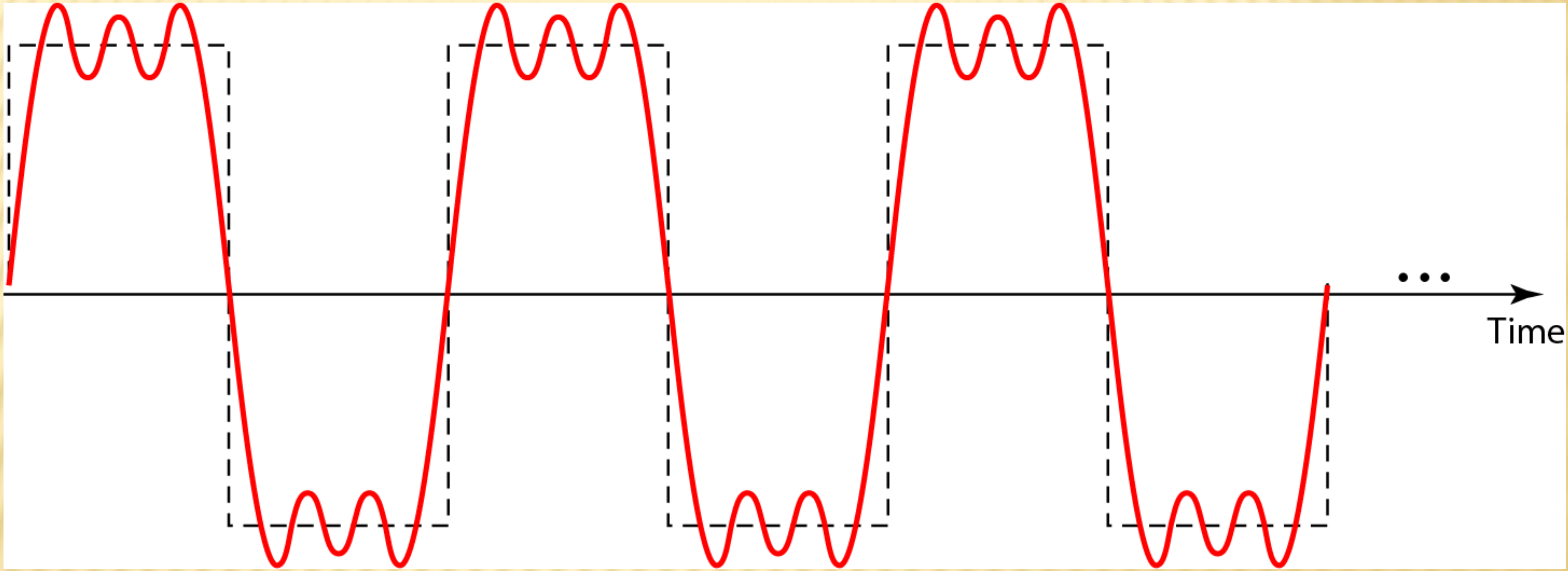
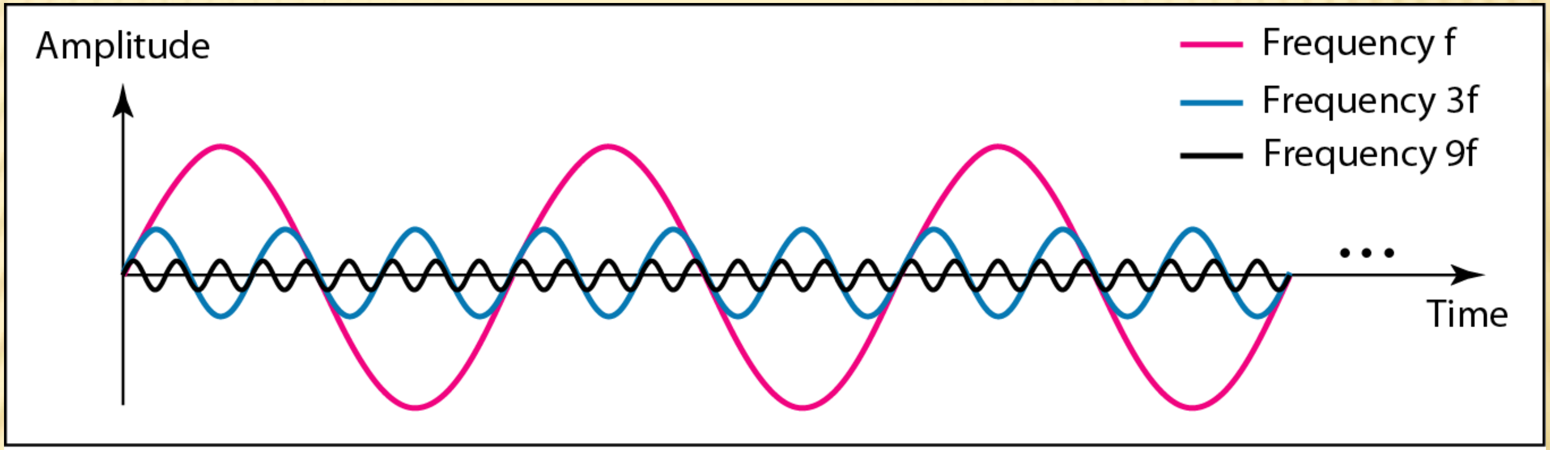
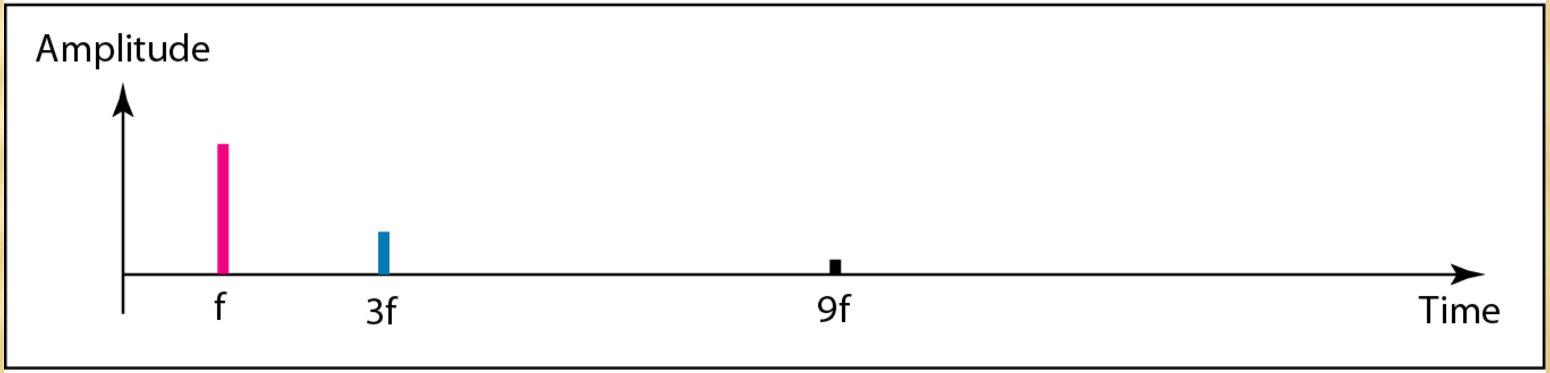


Figure 3.10 *Decomposition of a composite periodic signal in the time and frequency domains*

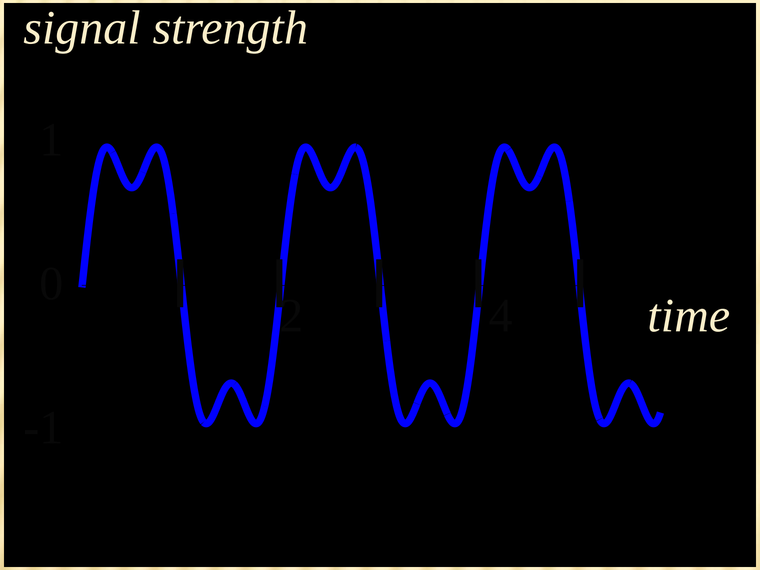


a. Time-domain decomposition of a composite signal

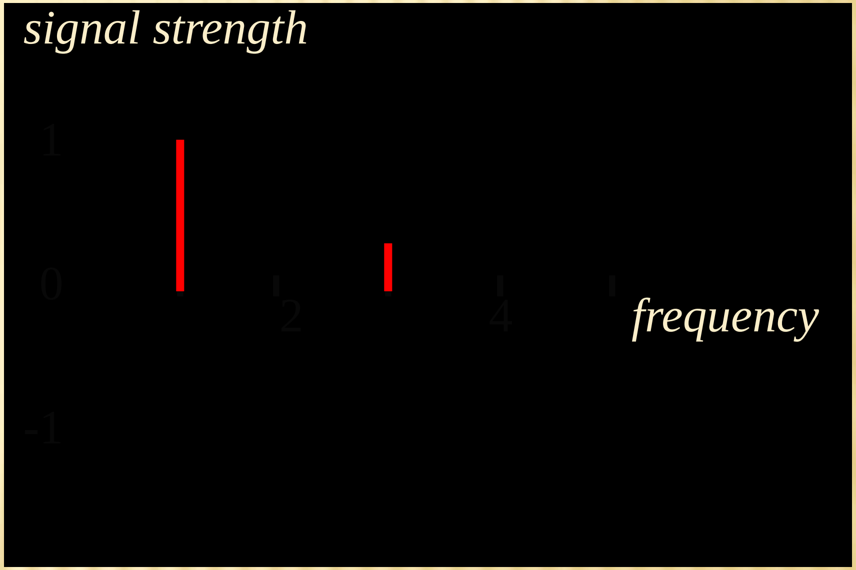


b. Frequency-domain decomposition of the composite signal

TIME VS. FREQUENCY DOMAINS



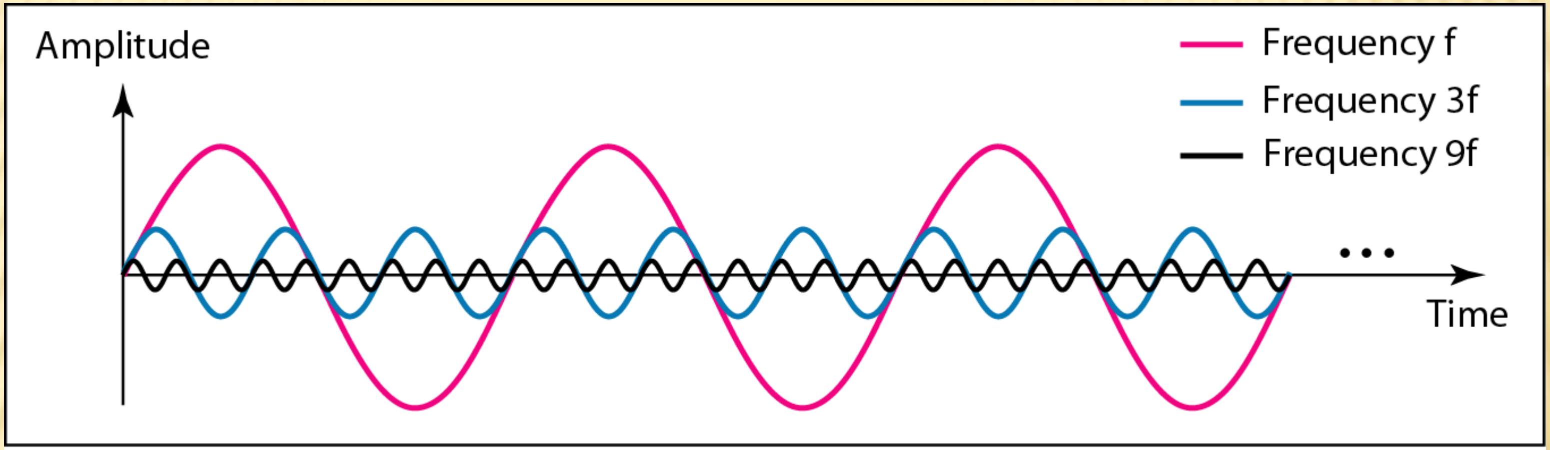
Time Domain Representation
→ *plots amplitude as a function of time*



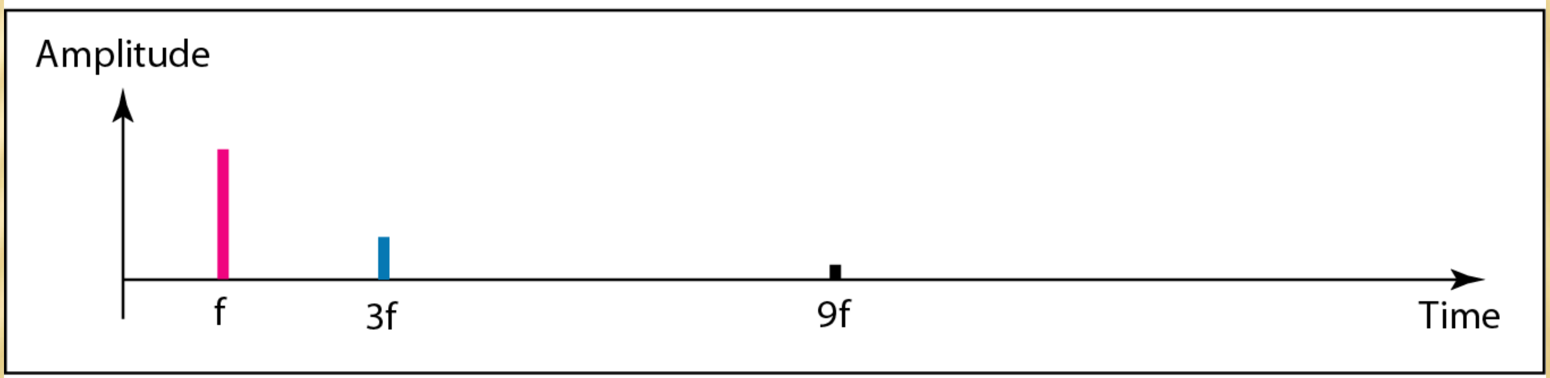
Frequency Domain Representation
→ *plots each sine wave's peak amplitude against its frequency*

Demo: Equalizer

Figure 3.10 *Decomposition of a composite periodic signal in the time and frequency domains*



a. Time-domain decomposition of a composite signal

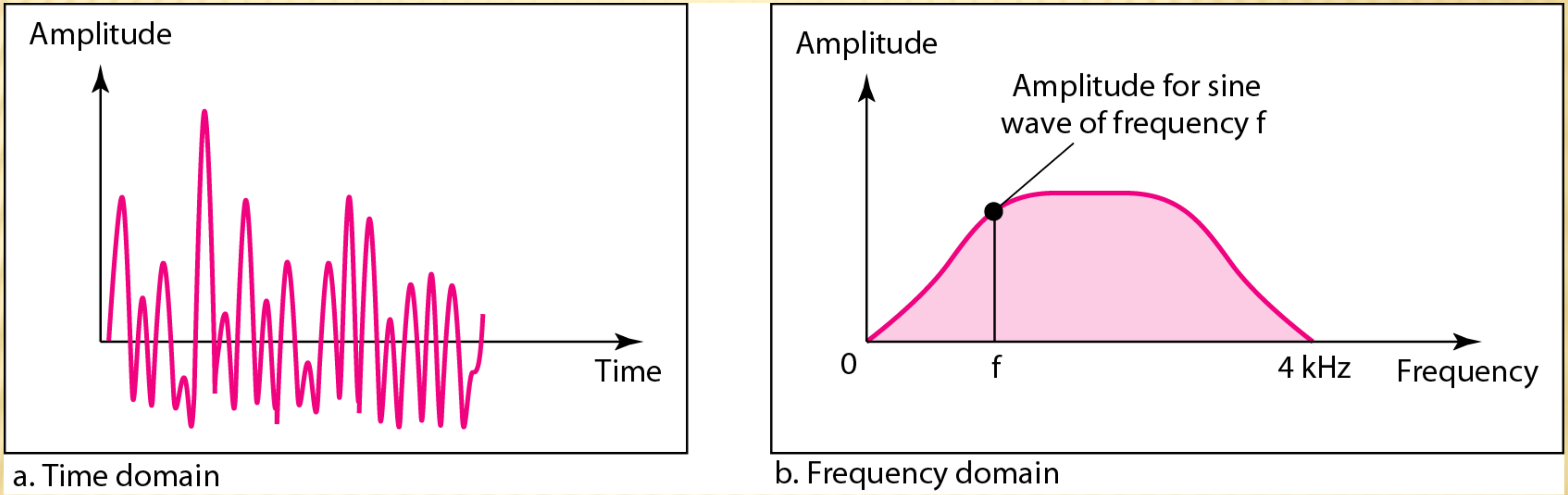


b. Frequency-domain decomposition of the composite signal

Example

Figure on next page 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.

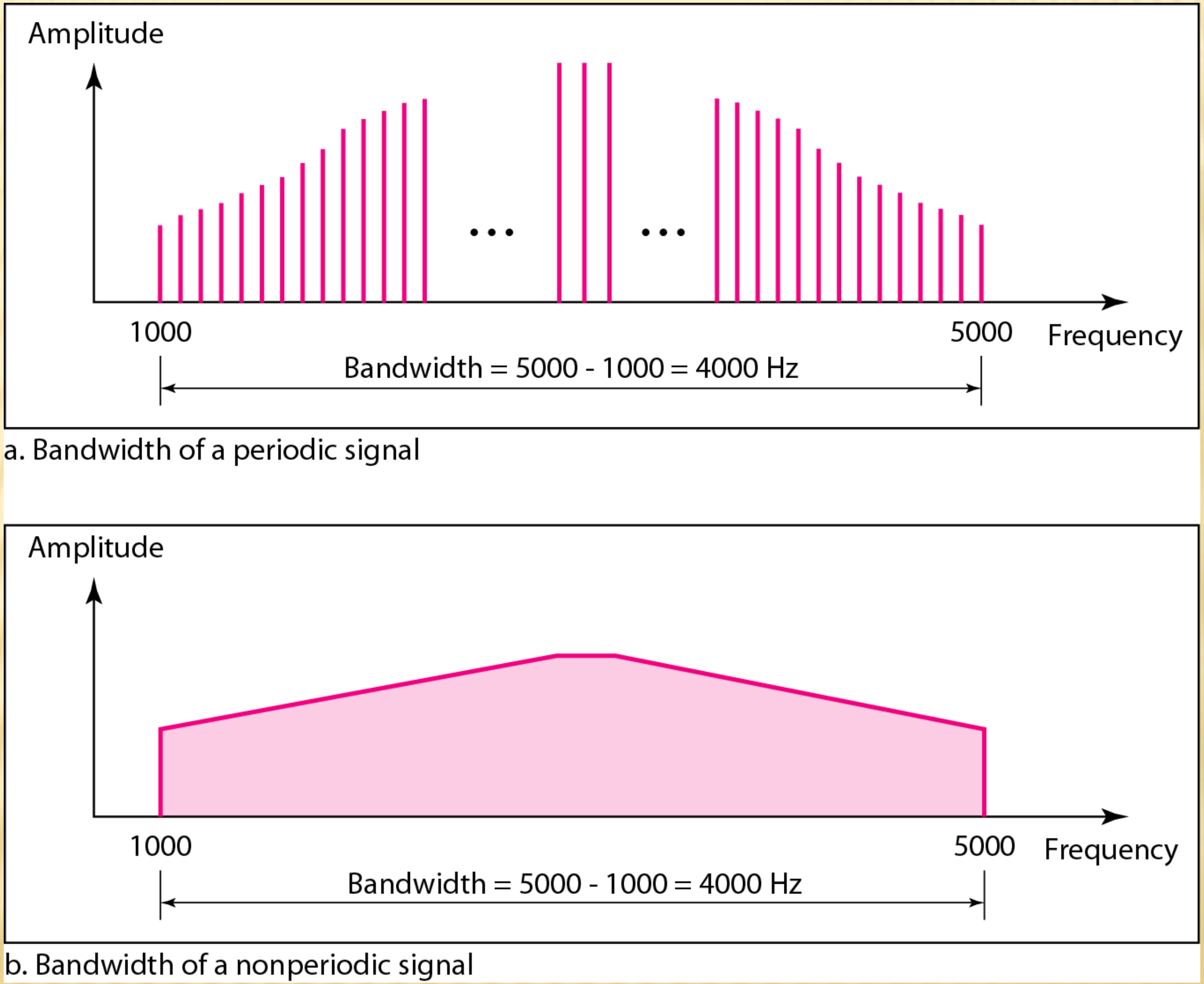
Figure ***The time and frequency domains of a nonperiodic signal***



BANDWIDTH AND SIGNAL FREQUENCY

- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

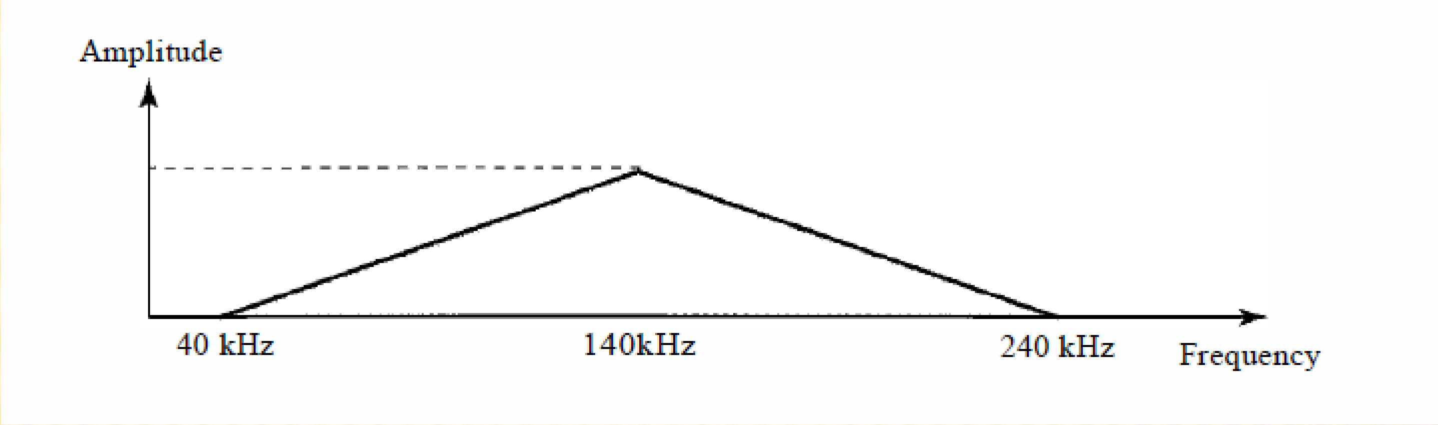
Figure *The bandwidth of periodic and nonperiodic composite signals*



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.

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.

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.



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.

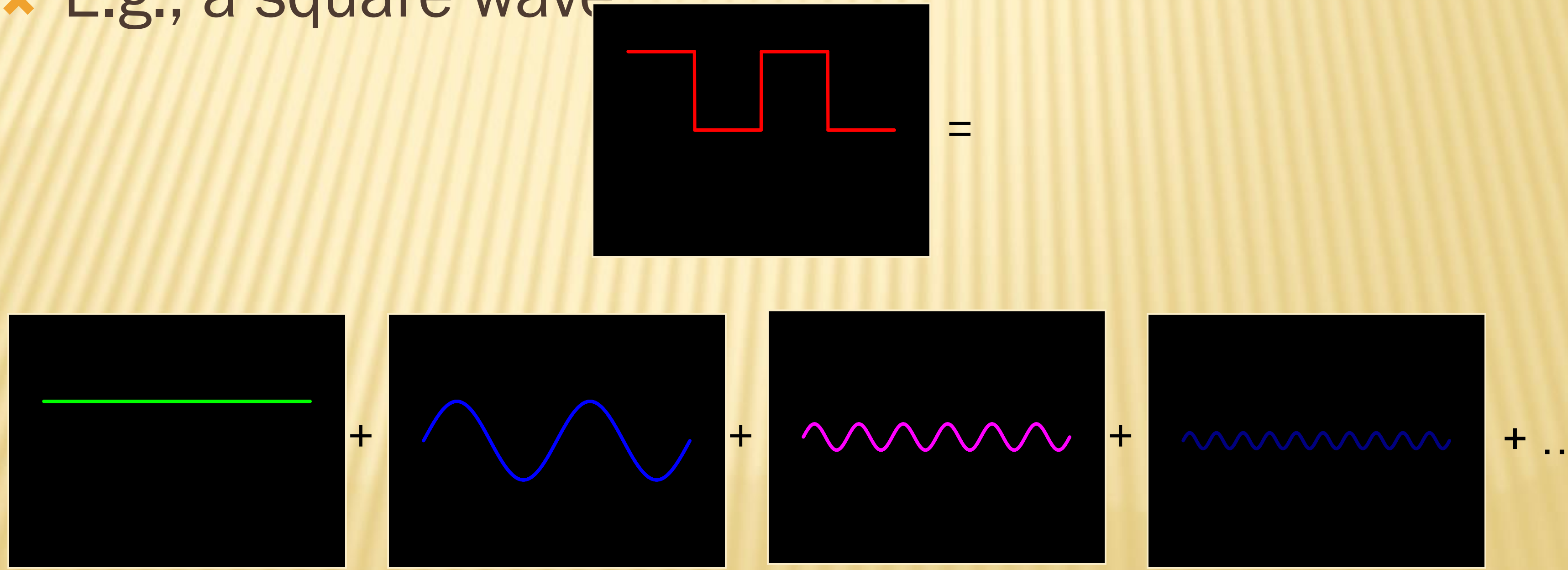
Example of a nonperiodic composite signal is the signal received by an old-fashioned analog black-and-white TV. A TV screen is made up of pixels (picture elements) with each pixel being either white or black. The screen is scanned 30 times per second. (Scanning is actually 60 times per second, but odd lines are scanned in one round and even lines in the next and then interleaved.) If we assume a resolution of 525 x 700 (525 vertical lines and 700 horizontal lines), which is a ratio of 3: 4, we have 367,500 pixels per screen. If we scan the screen 30 times per second, this is 367,500 x 30 = 11,025,000 pixels per second.

The worst-case scenario is alternating black and white pixels. In this case, we need to represent one color by the minimum amplitude and the other color by the maximum amplitude. 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 5.5124 MHz. This worst-case scenario has such a low probability of occurrence that the assumption is that we need only 70 percent of this bandwidth, which is 3.85 MHz. Since audio and synchronization signals are also needed, a 4-MHz bandwidth has been set aside for each black and white TV channel. An analog color TV channel has a 6-MHz bandwidth.

FOURIER ANALYSIS

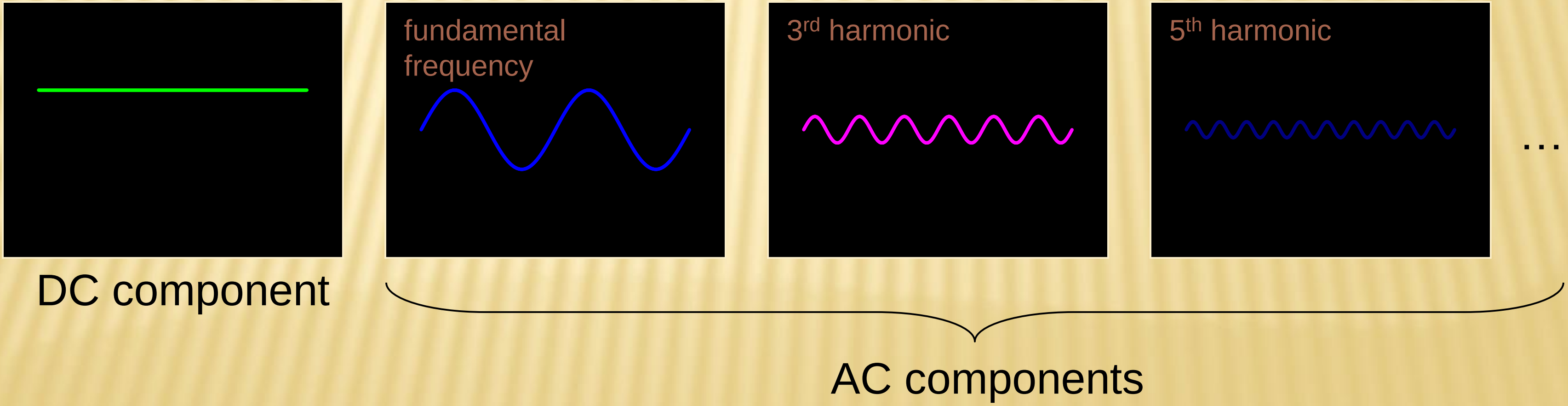
Joseph Fourier
(1768-1830)

- Any periodic signal can be represented as a sum of sinusoids
  - known as a *Fourier Series*
- E.g., a square wave:

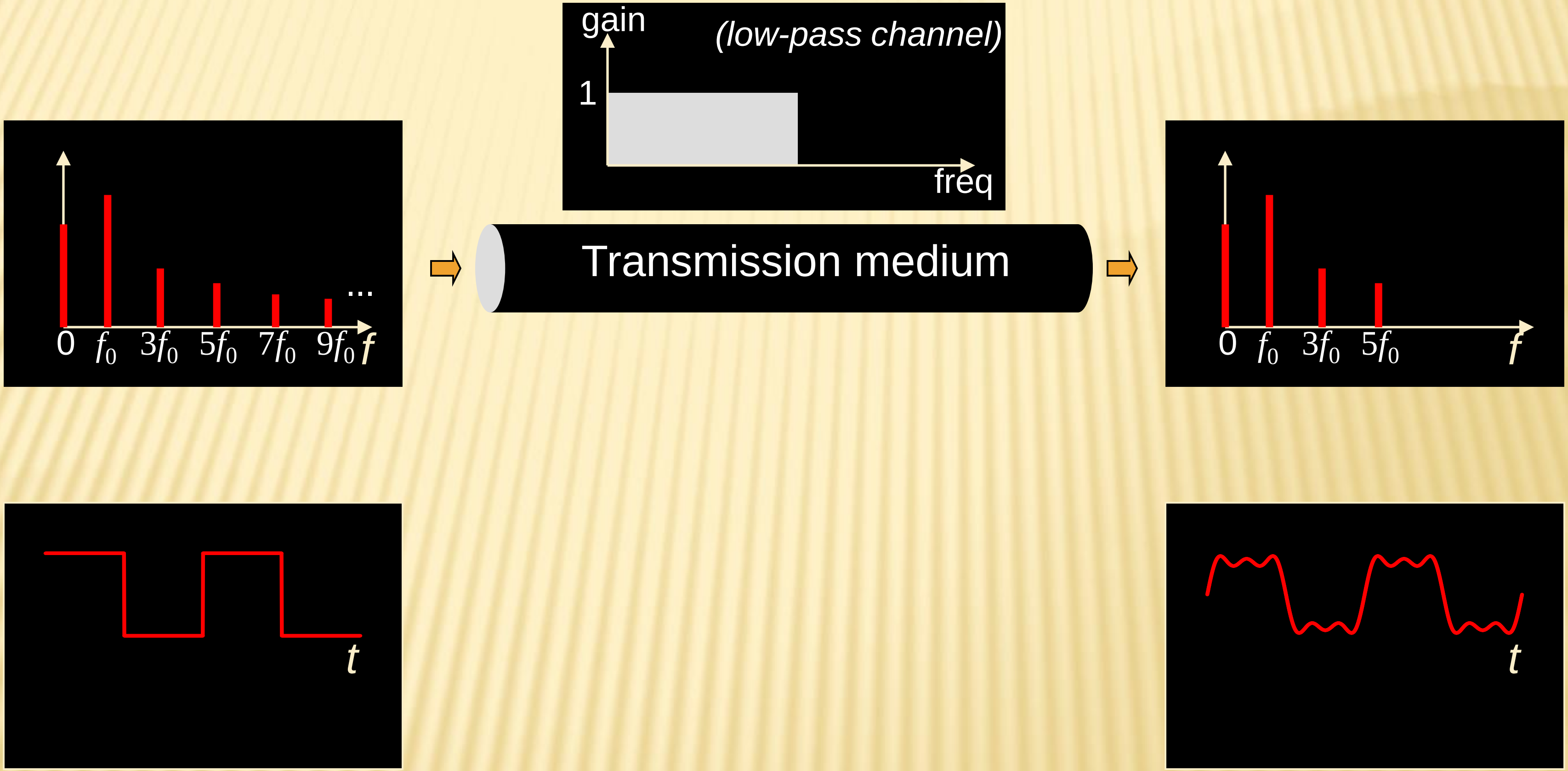


FOURIER ANALYSIS

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

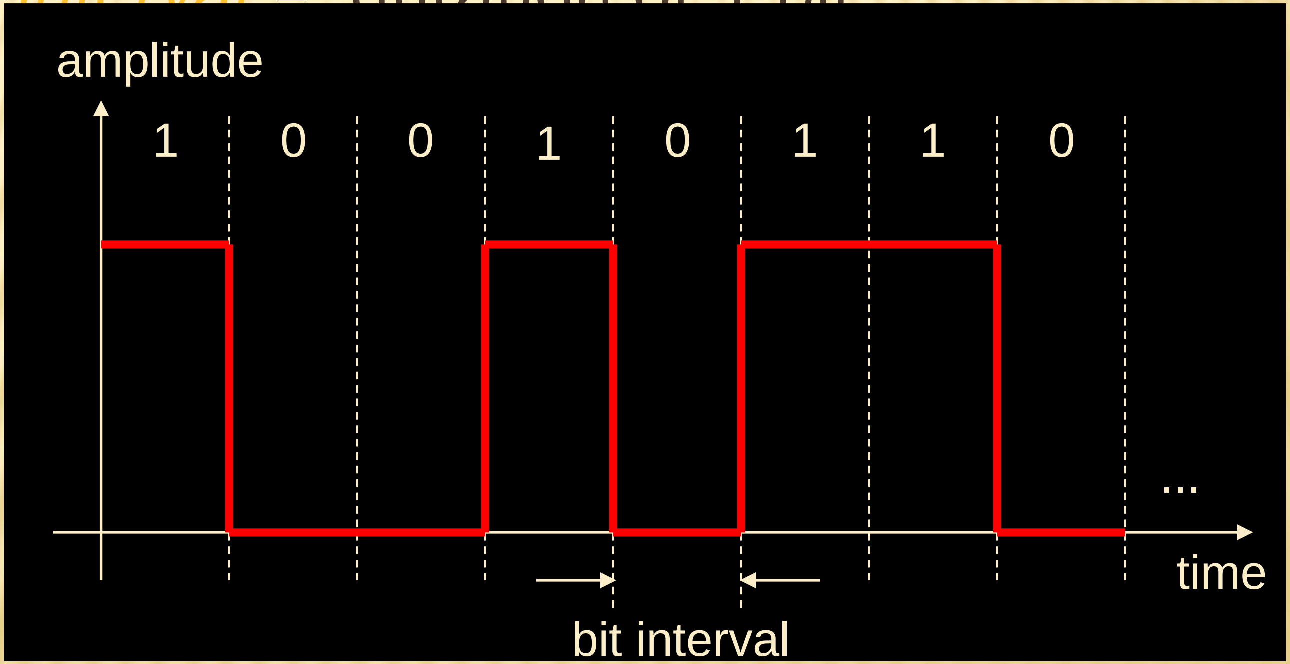


BANDWIDTH OF A MEDIUM

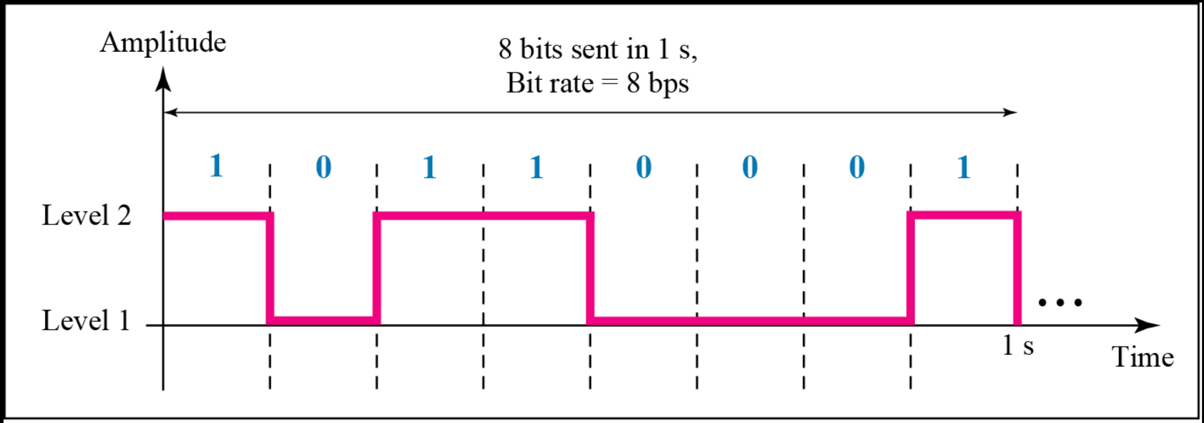


DIGITAL SIGNALS

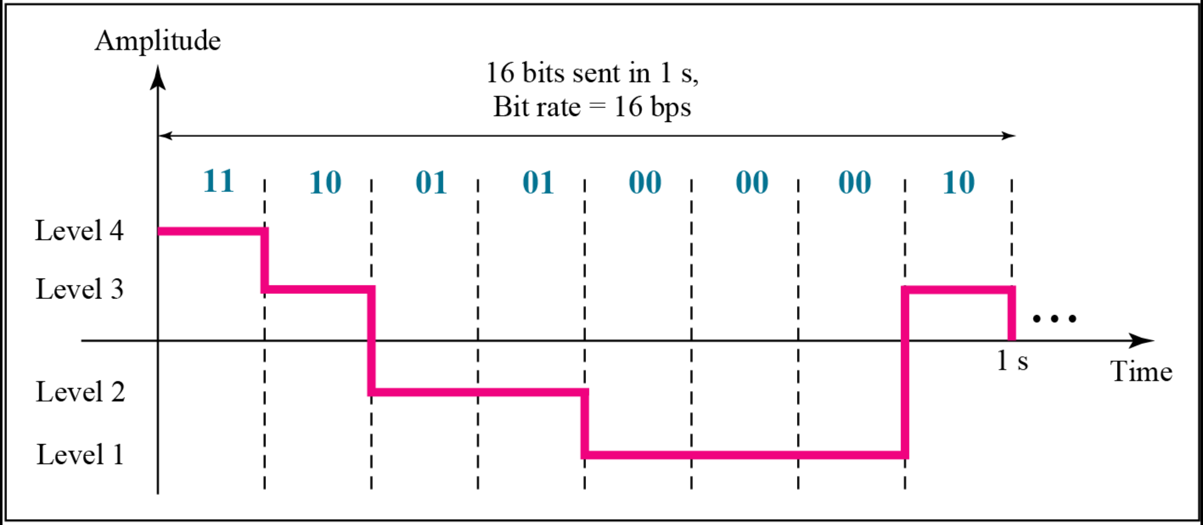
- Properties:
  - *Bit rate* – number of bits per second
  - *Bit interval* – duration of 1 bit



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

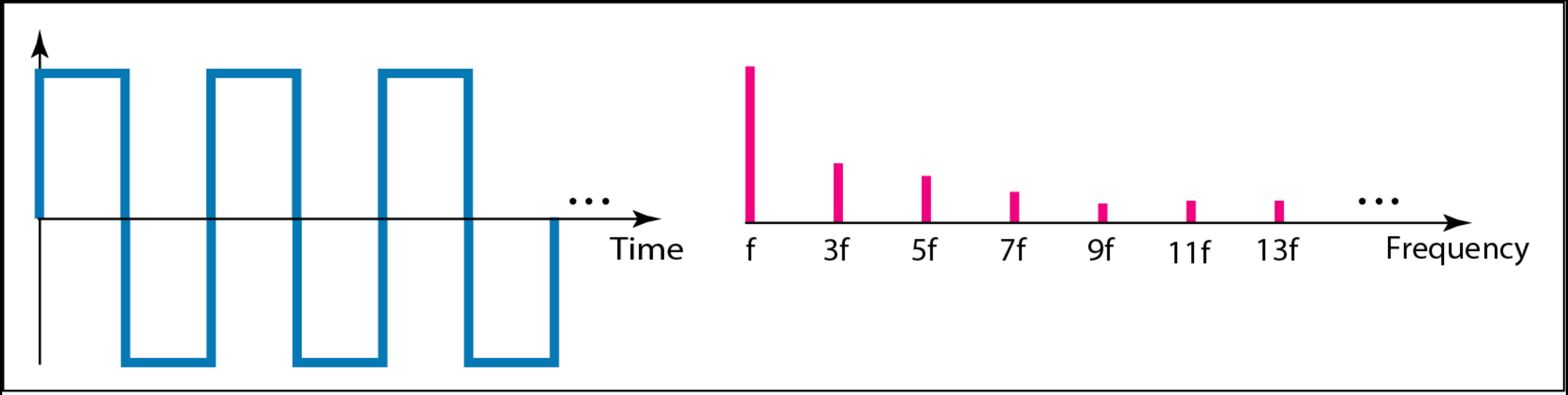


a. A digital signal with two levels

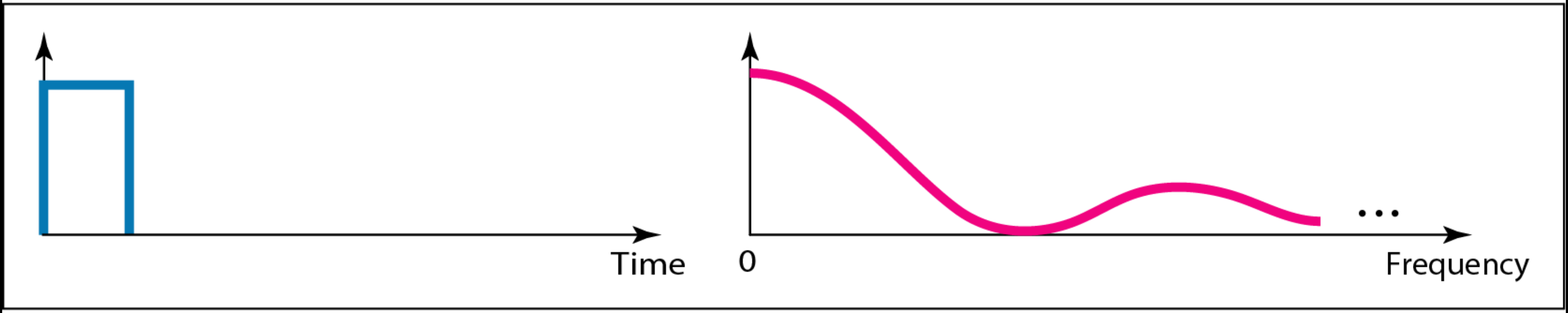


b. A digital signal with four levels

The time and frequency domains of periodic and nonperiodic digital signals

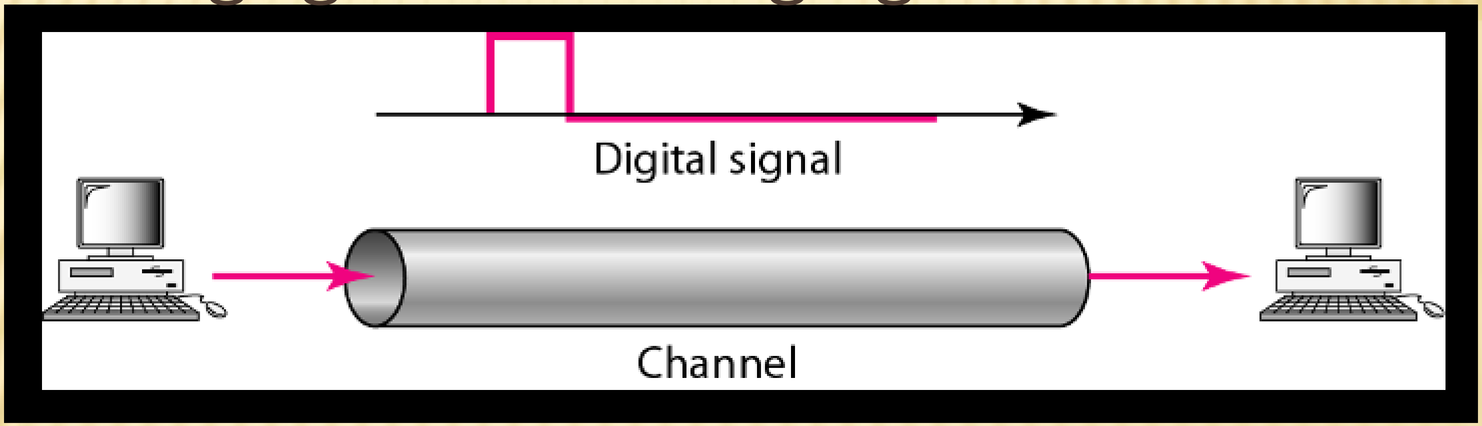


a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

- *Baseband transmission*
  → Sending a digital signal over a channel without changing it to an analog signal

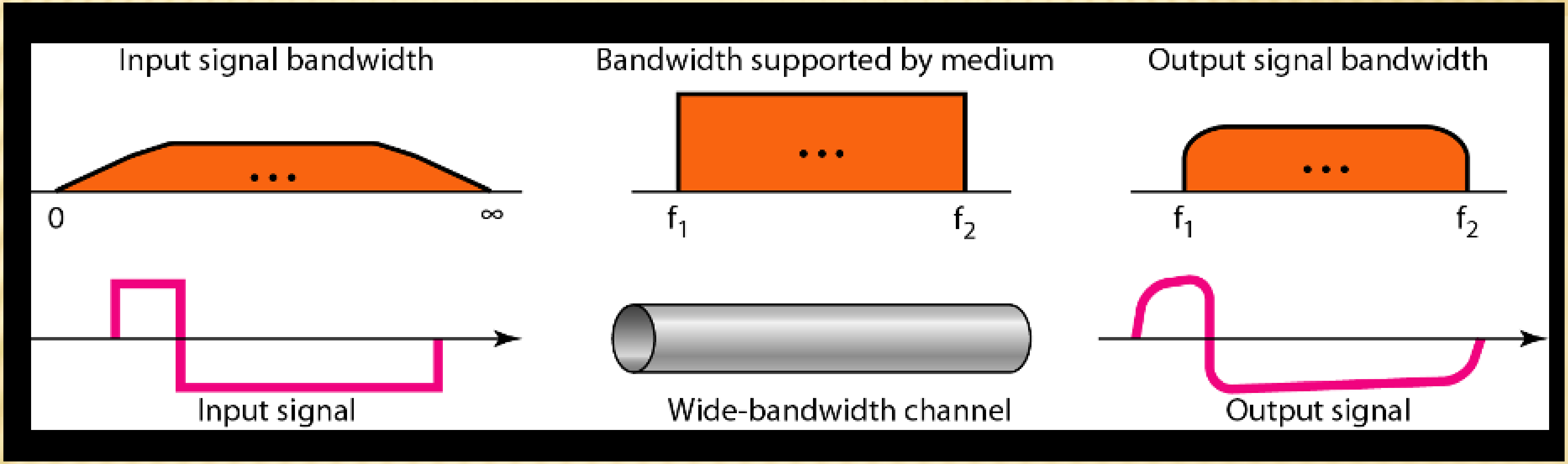


- Baseband transmission requires a low-pass channel

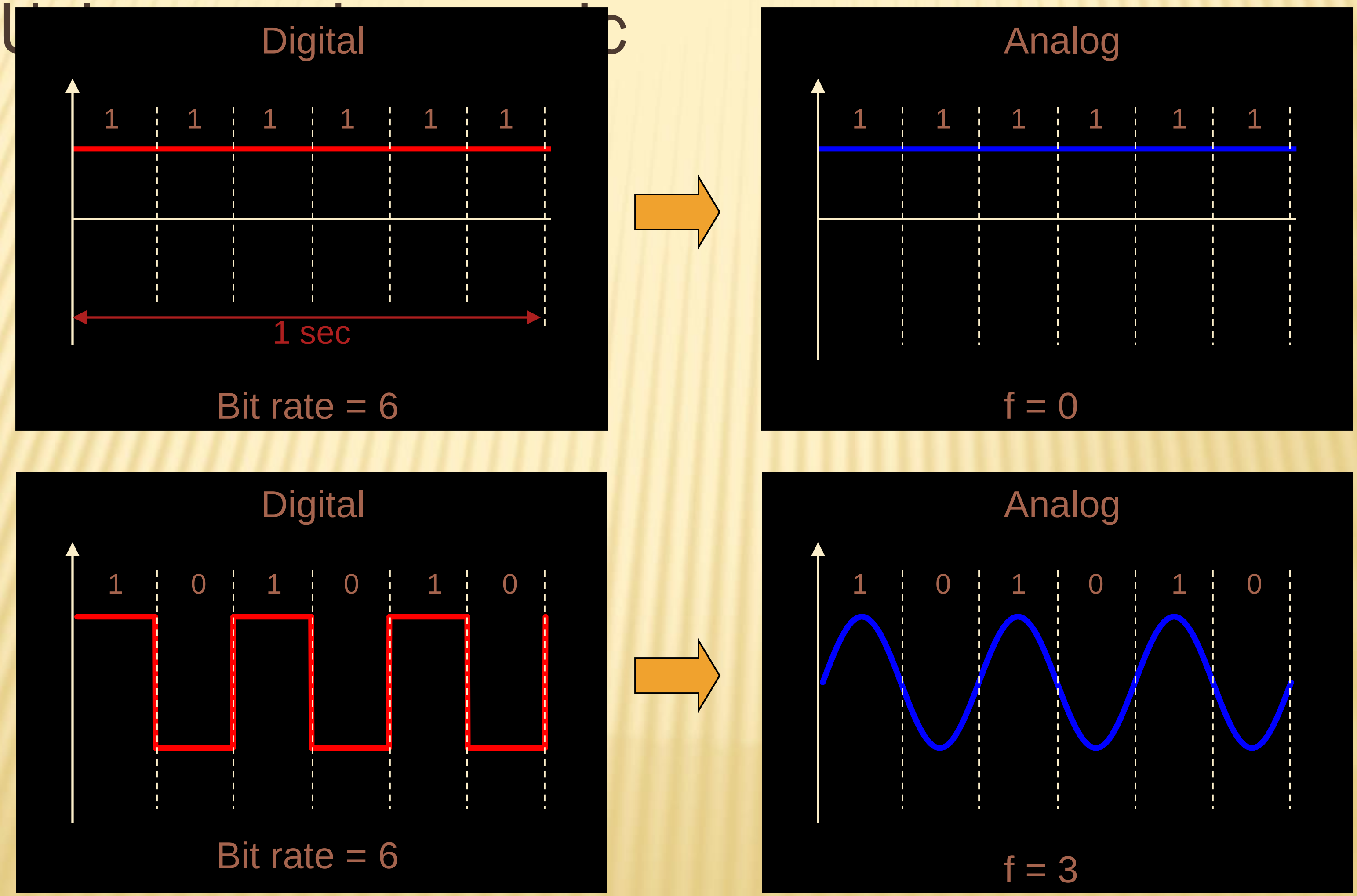
Note

A digital signal is a composite analog signal with an infinite bandwidth.

Baseband transmission using a dedicated medium

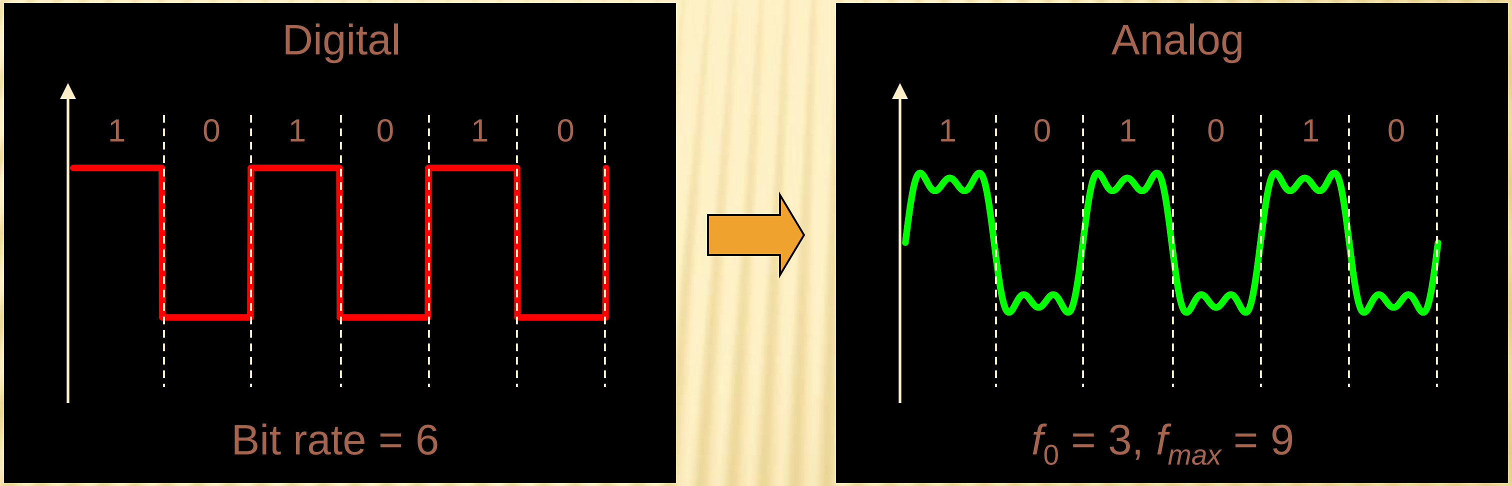


DIGITAL VS. ANALOG



DIGITAL VS. ANALOG

- Using more harmonics
  - Adding 3rd harmonic to improve quality



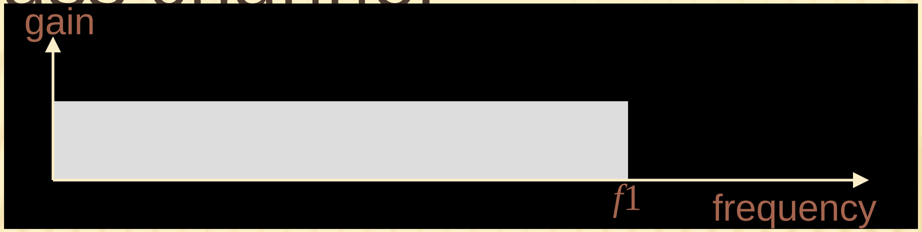
DIGITAL VS. ANALOG BANDWIDTH

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

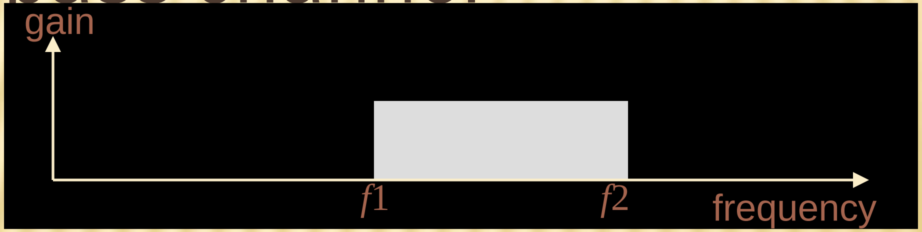
Bit rate and bandwidth are proportional to each other

LOW-PASS AND BAND-PASS CHANNELS

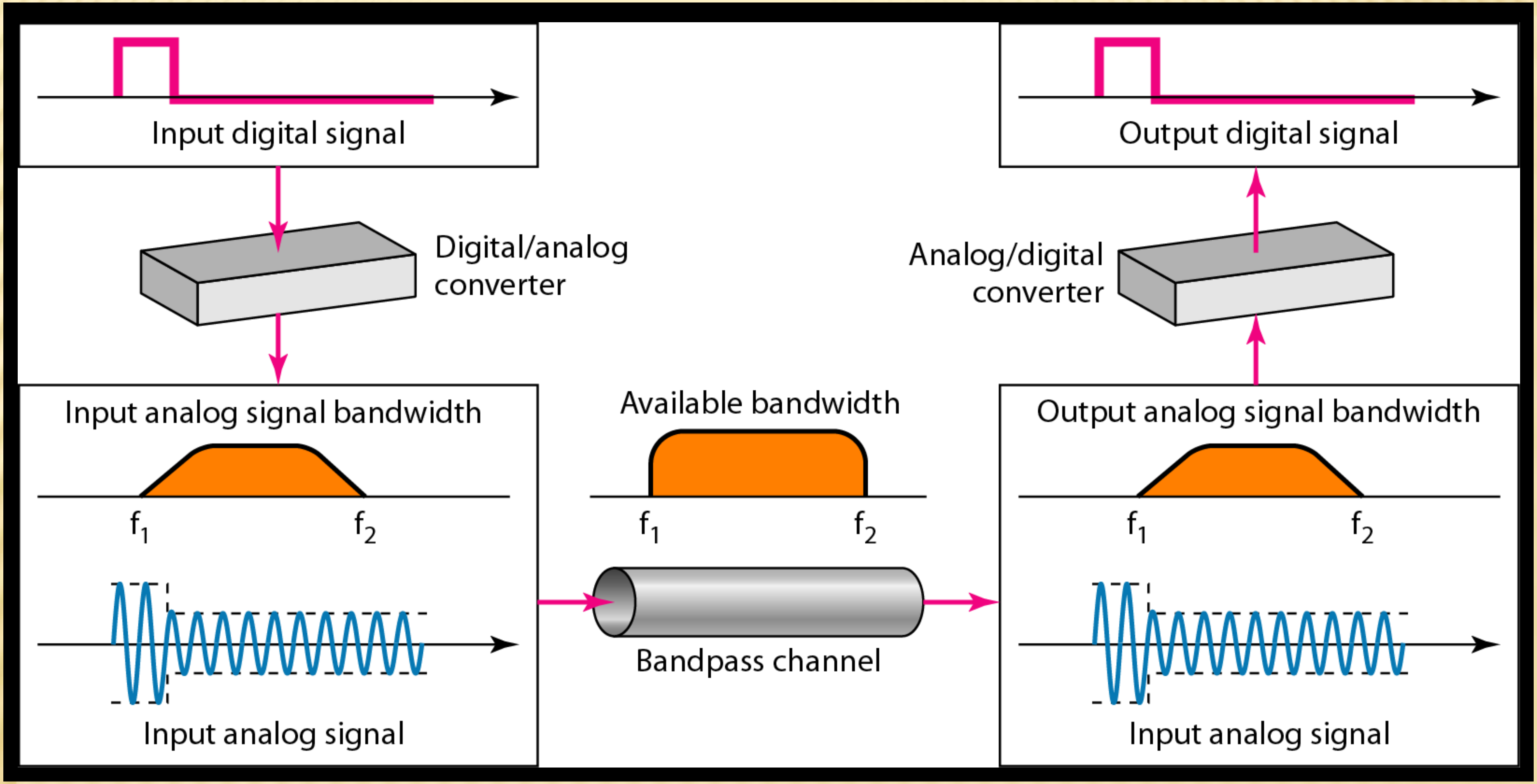
- Low-pass channel



- Band-pass channel



Modulation of a digital signal for transmission on a bandpass channel

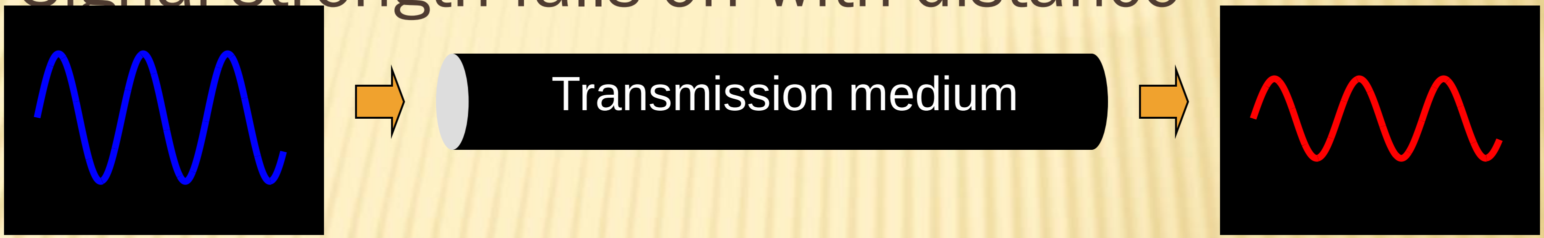


TRANSMISSION IMPAIRMENT

- 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)*

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

  - 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)

Example

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dBm and is calculated as dB_m = 10 log10 P_m, where P_m is the power in milliwatts. Calculate the power of a signal with dBm = −30.

Solution

We can calculate the power in the signal as

$$\mathrm{dB_m} = 10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW}$$

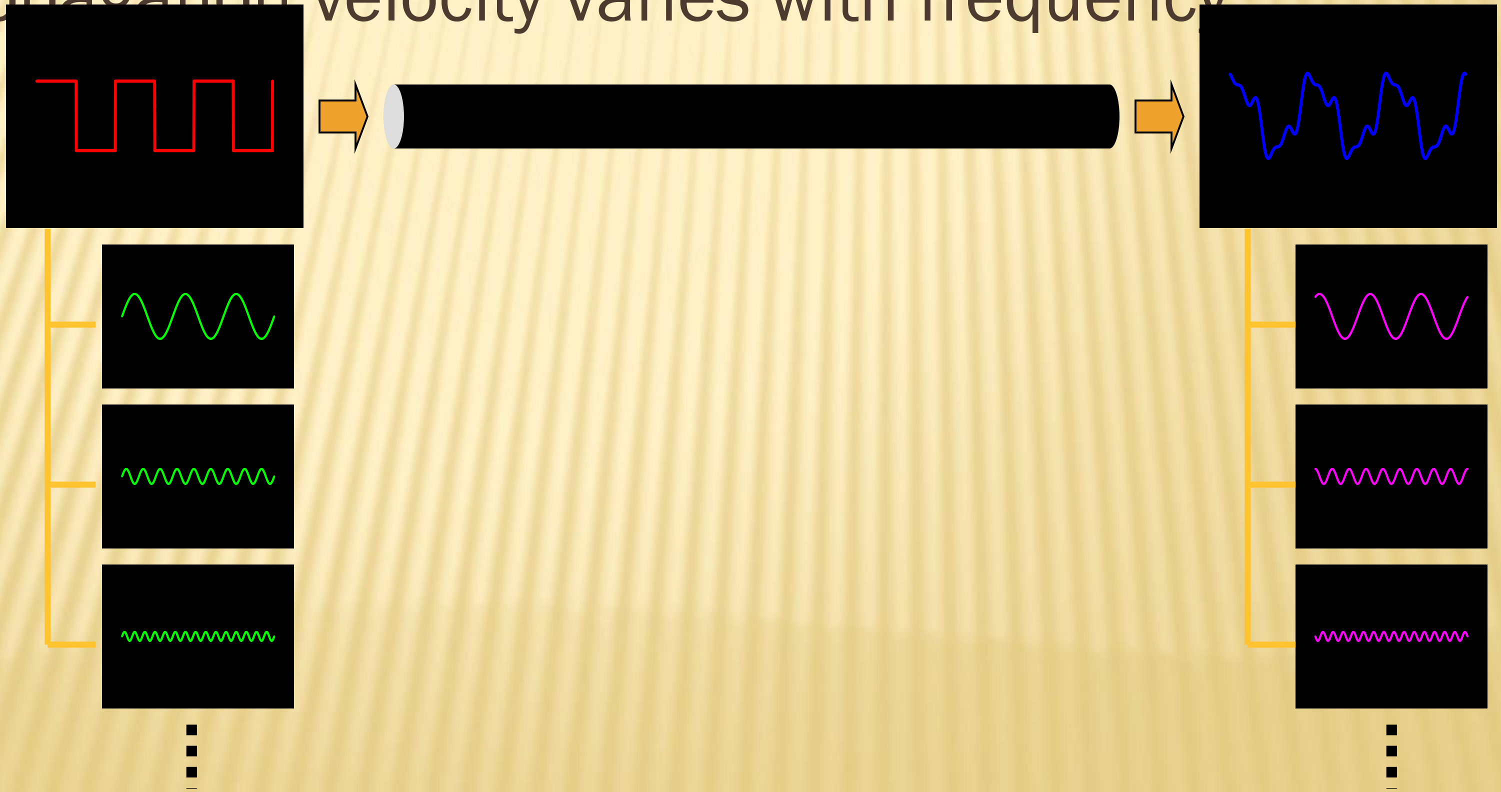
Example

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?

[redacted]

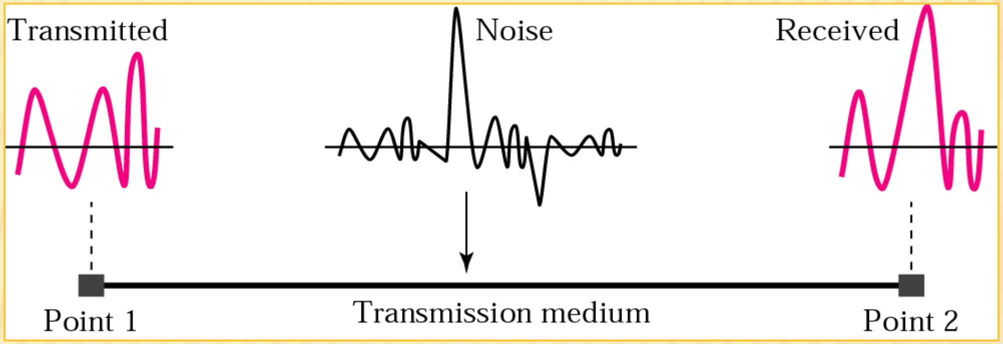
SIGNAL DISTORTION

- Distortion ⇨ Change in signal shape
  - Only happens in guided media
- Propagation velocity varies with frequency



NOISE

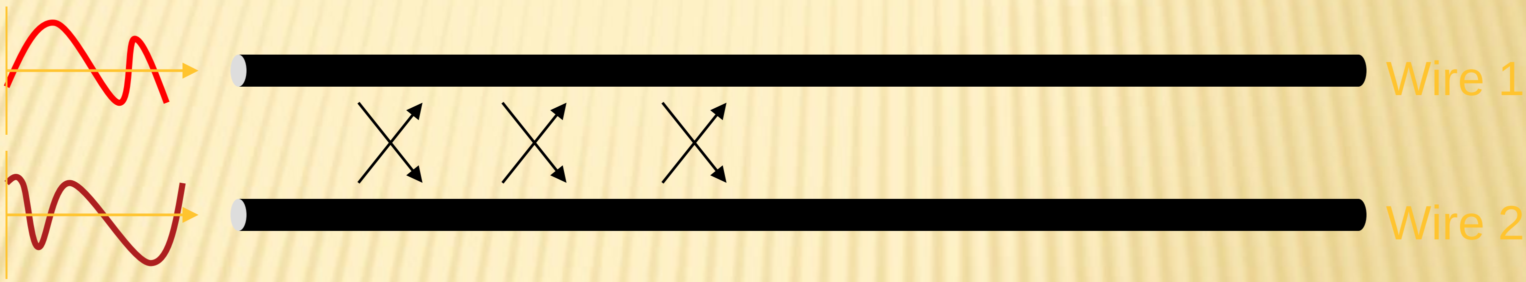
- Noise ⇨ Undesirable signals added between the transmitter and the receiver



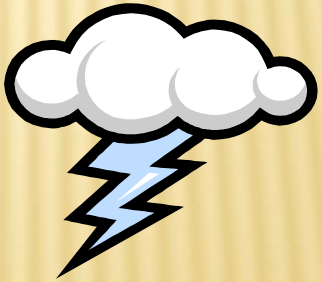
- Types of noise
  - Thermal
    - Due to random motion of electrons in a wire

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



SIGNAL-TO-NOISE RATIO

- Signal-to-Noise Ratio (SNR)

$$SNR = \frac{Power_{signal}}{Power_{noise}}$$

Example

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

Solution

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

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

$$\text{SNR}_{\text{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

DATA RATE: NOISELESS CHANNELS

- *Nyquist Theorem*

$$\text{Bit Rate} = 2 \times \text{Bandwidth} \times \log_2 L$$

Harry Nyquist
(1889-1976)

  - Bit rate in bps
  - Bandwidth in Hz
  - L – number of signal levels

Example

We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

DATA RATE: NOISY CHANNELS

- *Shannon Capacity*

$$\text{Capacity} = \text{Bandwidth} \times \log_2(1+\text{SNR})$$

  - Capacity (maximum bit rate) in bps
  - Bandwidth in Hz
  - SNR – Signal-to-Noise Ratio

Claude Elwood Shannon (1916-2001)

Example

A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. Calculate the theoretical highest bit rate of a regular telephone line.

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Example

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, use the Shannon capacity

$$C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}$$

followed by the Nyquist formula

[redacted] $\text{Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \quad \longrightarrow \quad L =$ [redacted]

Note

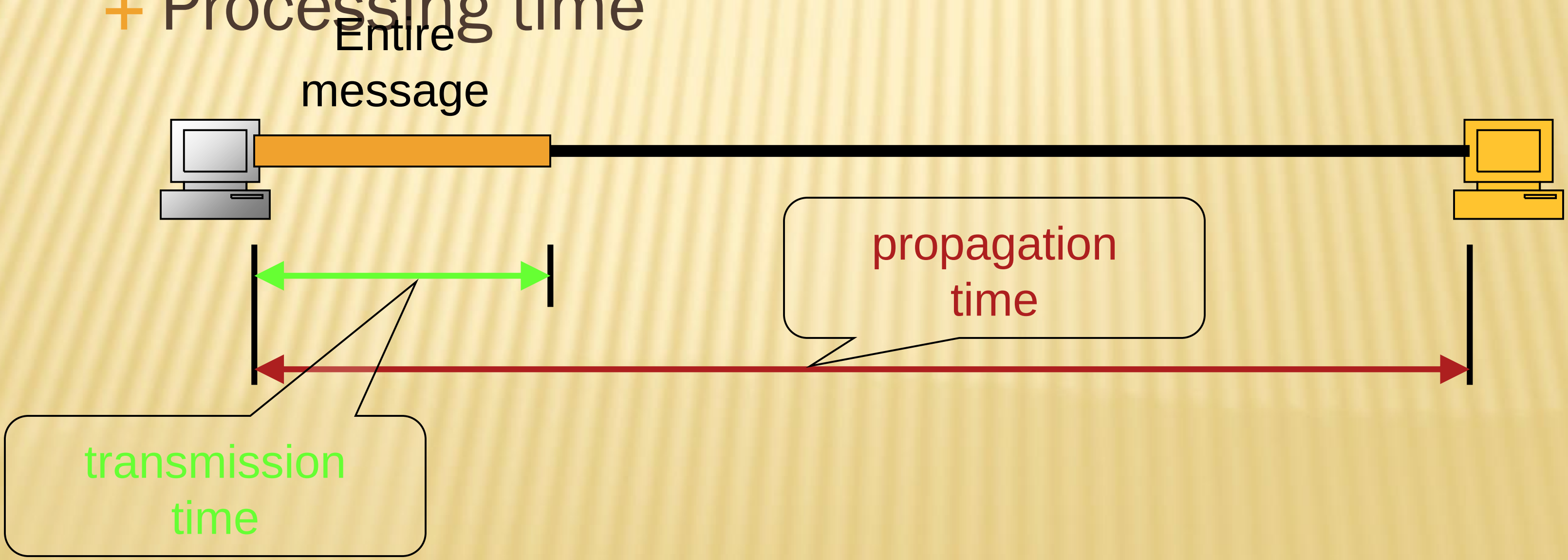
The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

NETWORK PERFORMANCE

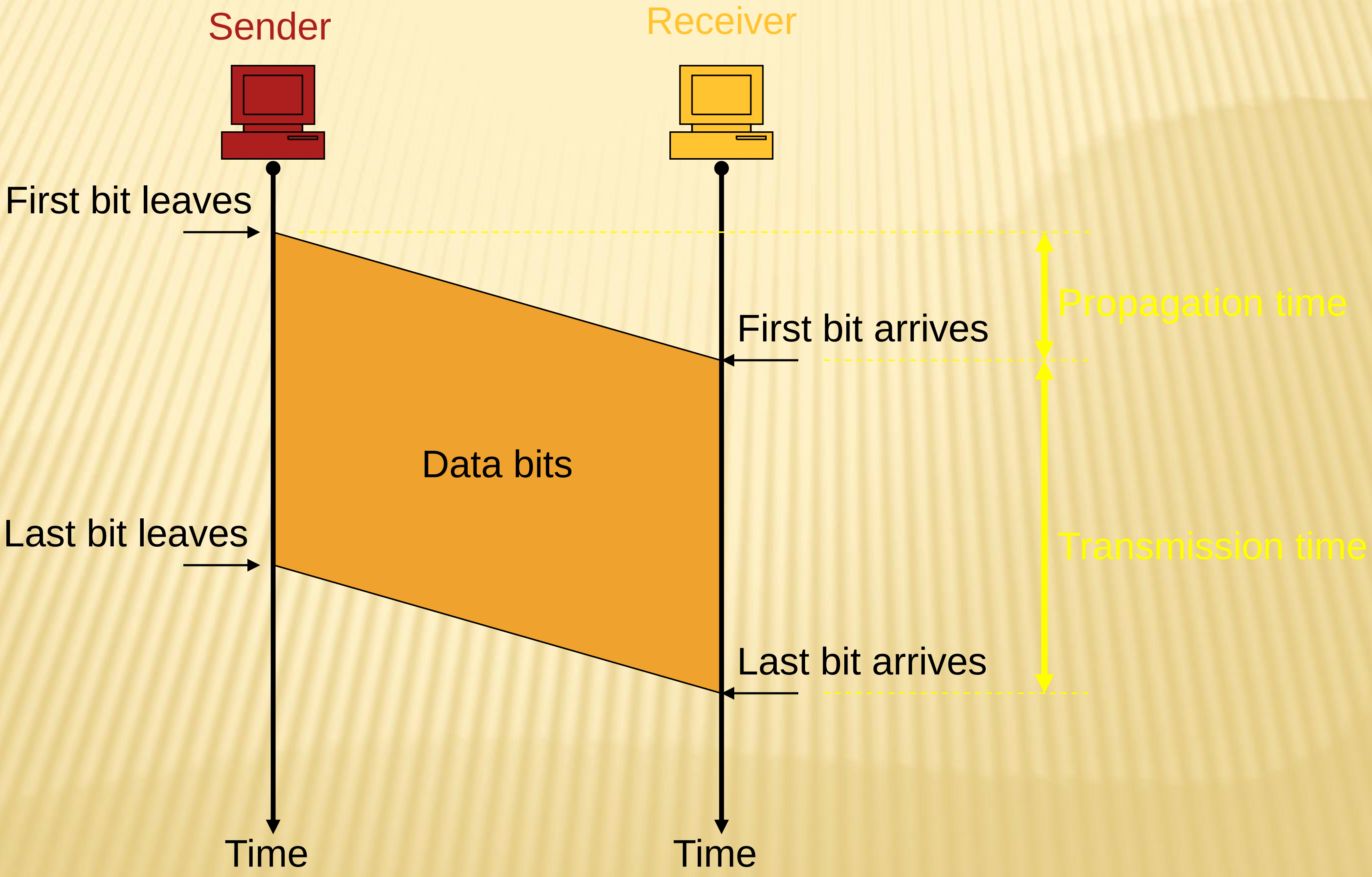
- Bandwidth
  - Hertz
  - Bits per second (bps)
- Throughput
  - Actual data rate
- Latency (delay)
  - Time it takes for an entire message to completely arrive at the destination

LATENCY

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



LATENCY



Sender
Receiver
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

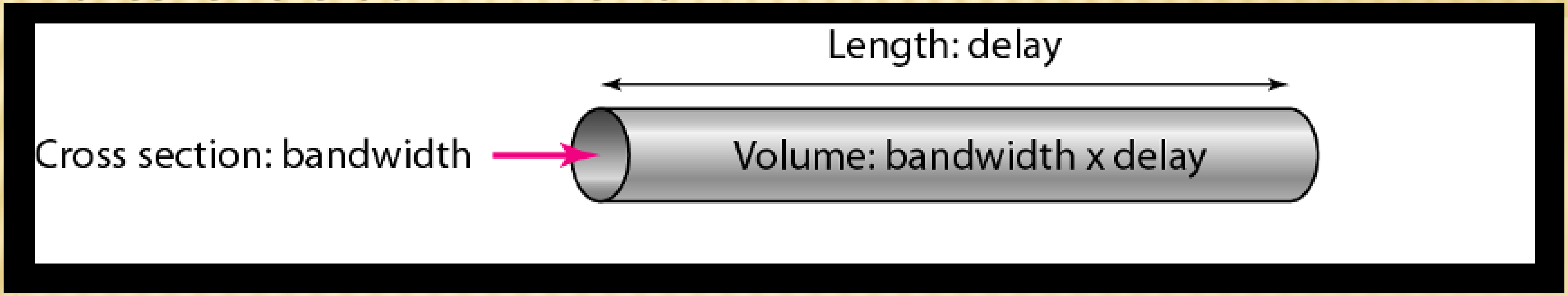
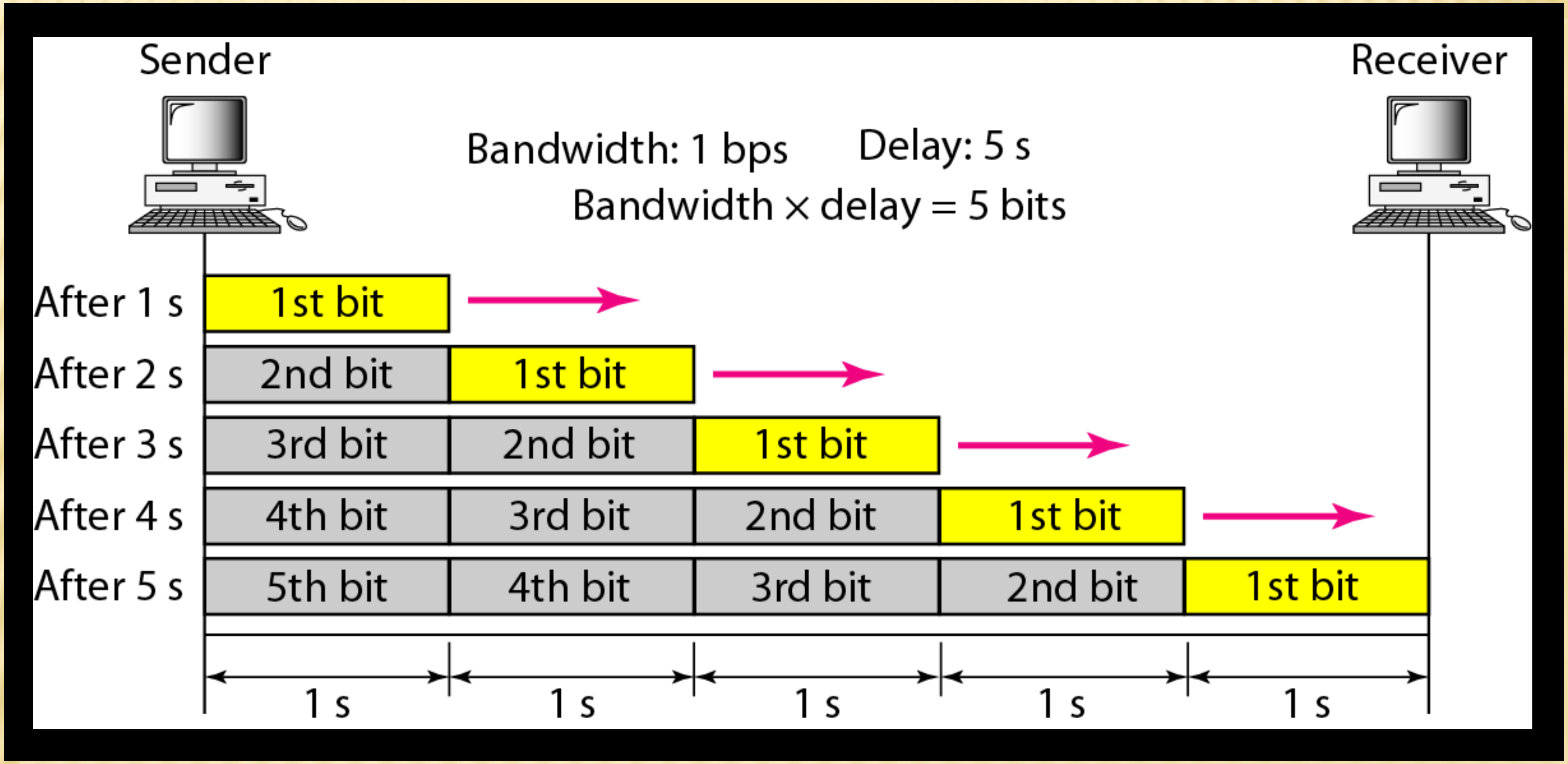


Figure *Filling the link with bits for case 1*



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

Thank you