CHAPTER-3
Data and Signals

Note

To be transmitted, data must be transformed to electromagnetic signals.

ANALOG DATA

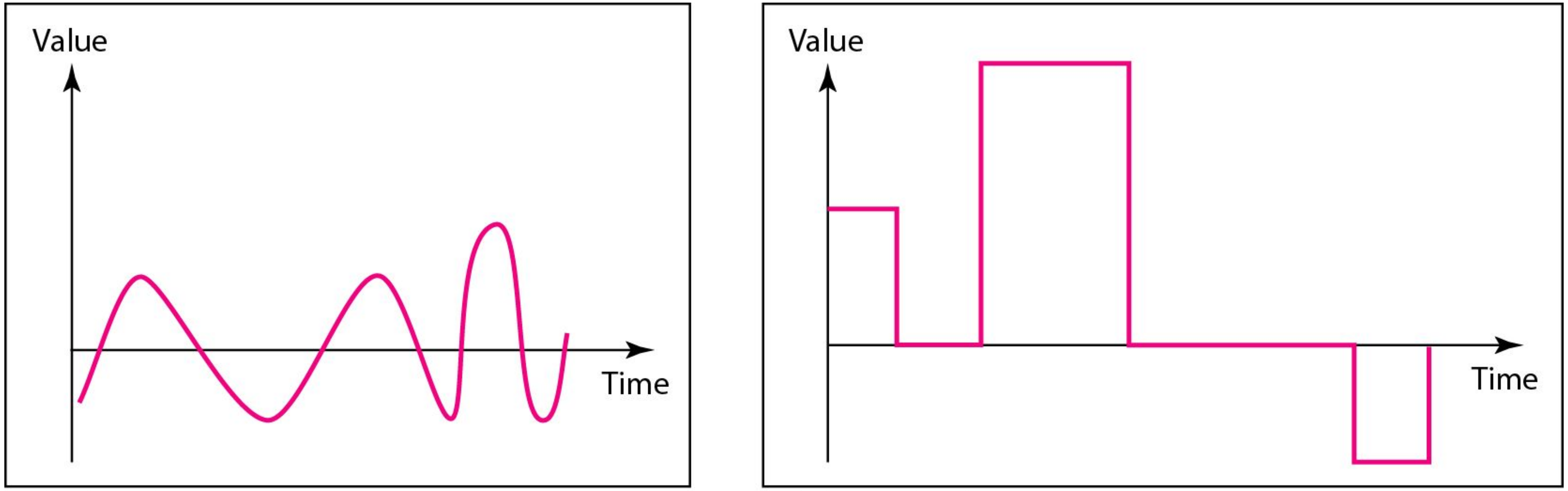
- ✔ The term **analog data** refers to information that is continuous.
- ✔ Analog data take on continuous values.
- ✔ Analog data, such as the sounds made by a human voice, take on continuous values.

DIGITAL DATA

- ✔ **Digital data** refers to information that has discrete states.
- ✔ It can take discrete values.
- ✔ Data are stored in computer memory in the form of 0's and 1's.

ANALOG AND DIGITAL SIGNALS

- An **analog signal** has infinitely many levels of intensity over a period of time.
- **Analog signals** can have an infinite number of values in a range.
- Digital signals can have only a limited number of values.



a. Analog signal b. Digital signal

Note

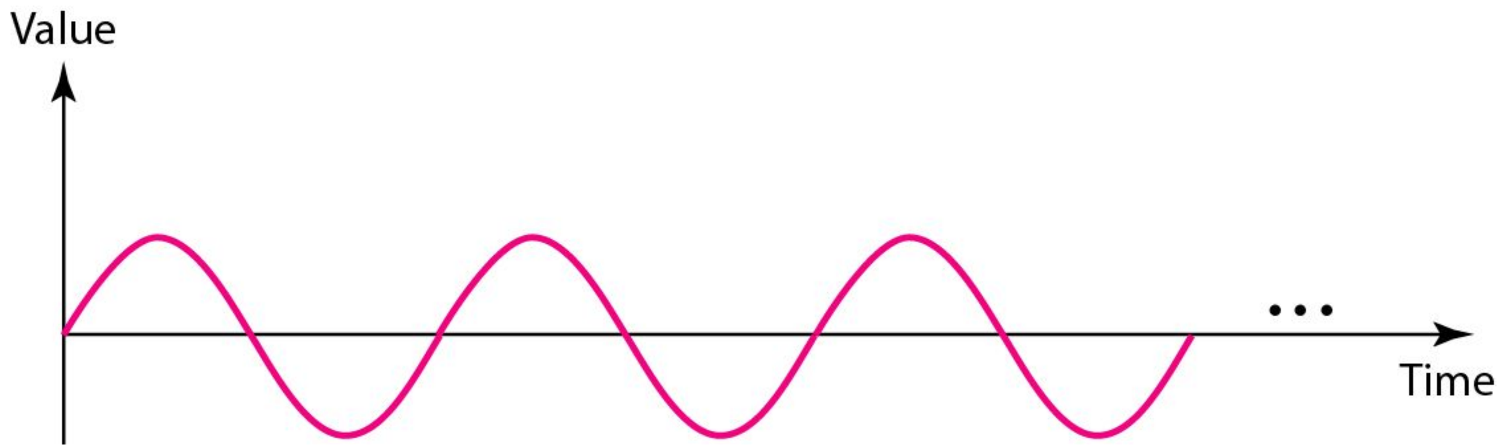
In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

PERIODIC AND NON-PERIODIC SIGNALS

- ✔ 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.
- ✔ A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.

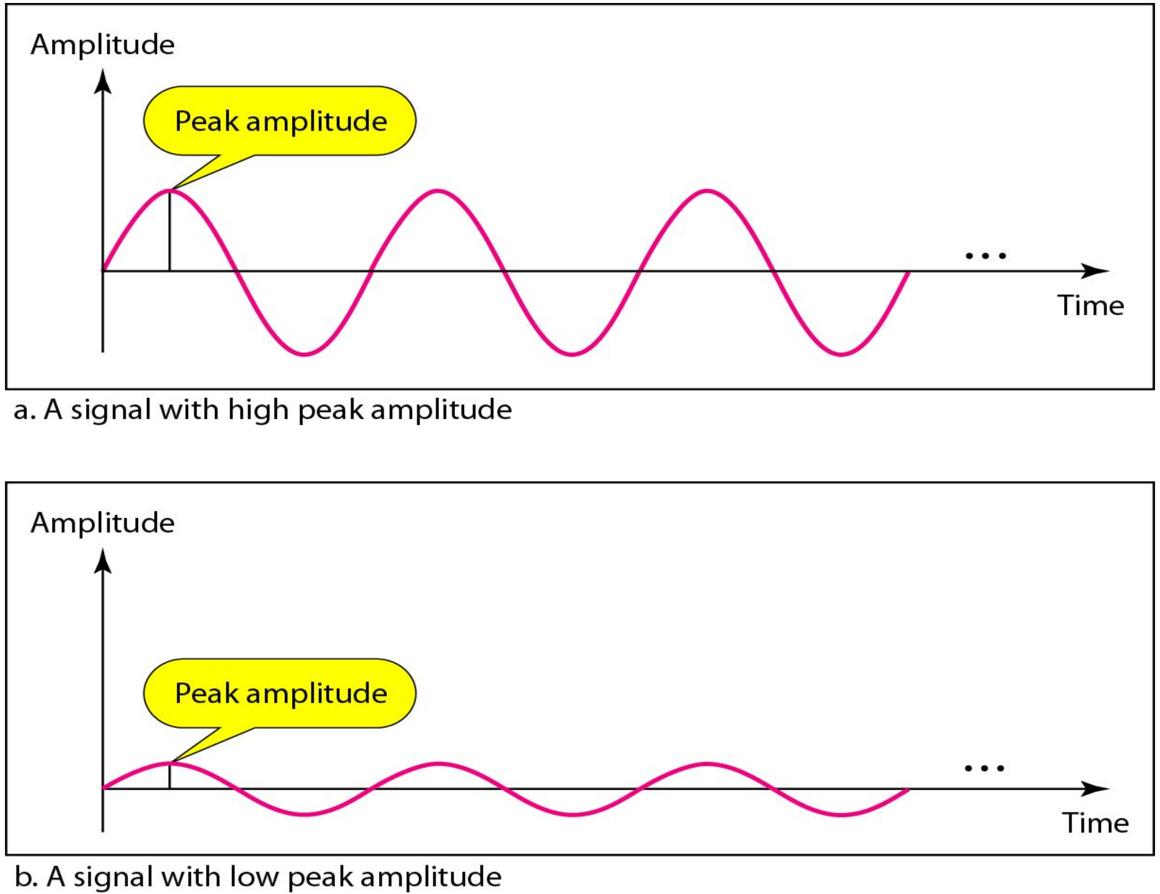
PERIODIC AND NON-PERIODIC SIGNALS

- **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.
- **Sine wave** is an example of a periodic analog signal. A sine wave can be represented by three parameters: the *peak amplitude*, the *frequency*, and the *phase*.



PERIODIC ANALOG SIGNALS

Peak Amplitude: The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries. The following figure presents two signals with same phase and frequency but different amplitudes.



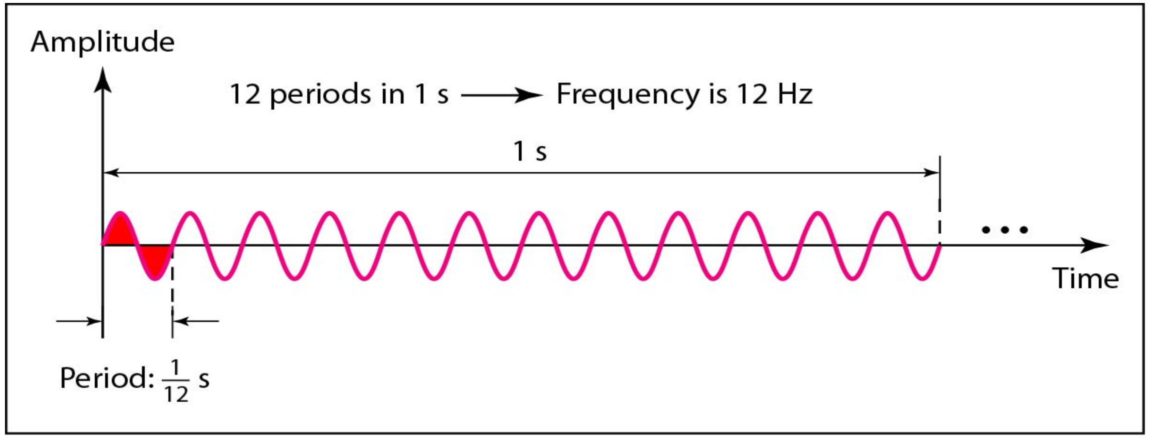
PERIODIC ANALOG SIGNALS

Period: Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle. Frequency refers to the number of periods in 1 s.

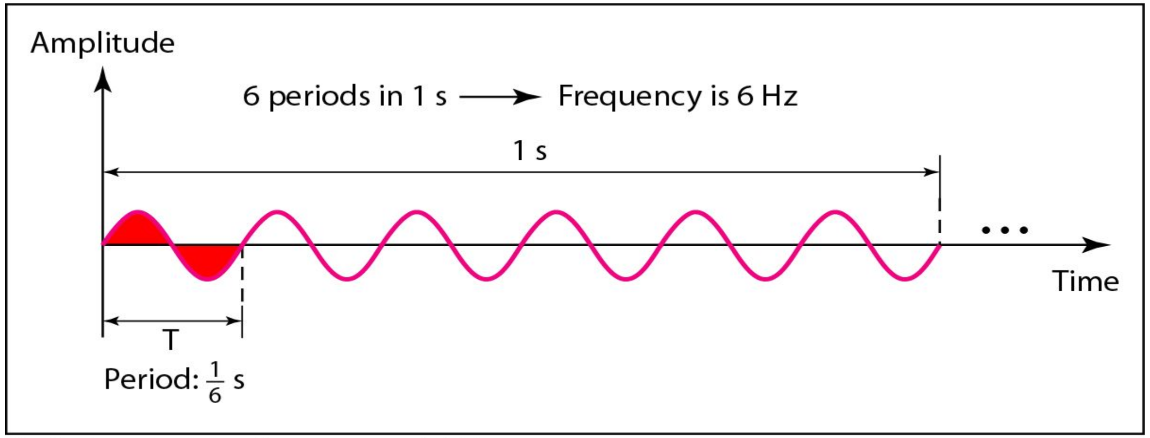
Frequency and period are the inverse of each other.

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

PERIODIC ANALOG SIGNALS



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Figure: Two signals with the same amplitude and phase but different frequencies

PERIODIC ANALOG SIGNALS

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

PERIODIC ANALOG SIGNALS

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

Solution:

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

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

PERIODIC ANALOG SIGNALS

❑ Frequency

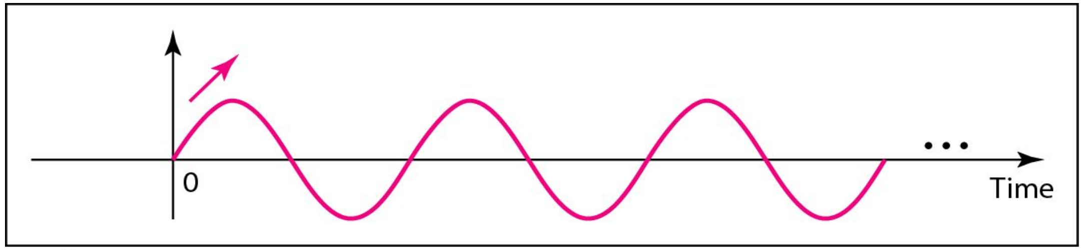
- ✔ Frequency is the rate of change with respect to time.
- ✔ Change in a short span of time means high frequency.
- ✔ Change over a long span of time means low frequency.
- ✔ If the value of a signal changes over a very short span of time, its frequency is high.
- ✔ If it changes over a long span of time, its frequency is low.

Note

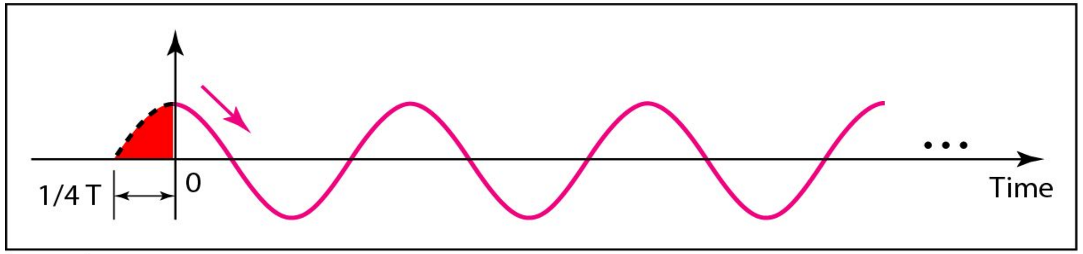
If a signal does not change at all, its frequency is zero. If a signal changes instantaneously, its frequency is infinite.

PERIODIC ANALOG SIGNALS

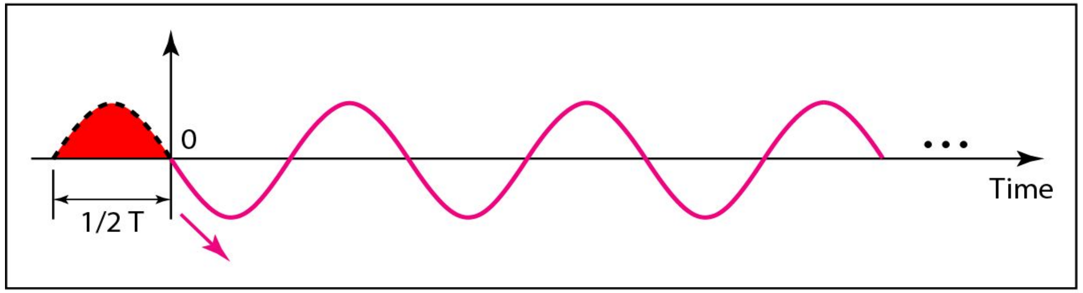
Phase: Phase describes the position of the waveform relative to time 0.



a. 0 degrees



b. 90 degrees



c. 180 degrees

PERIODIC ANALOG SIGNALS

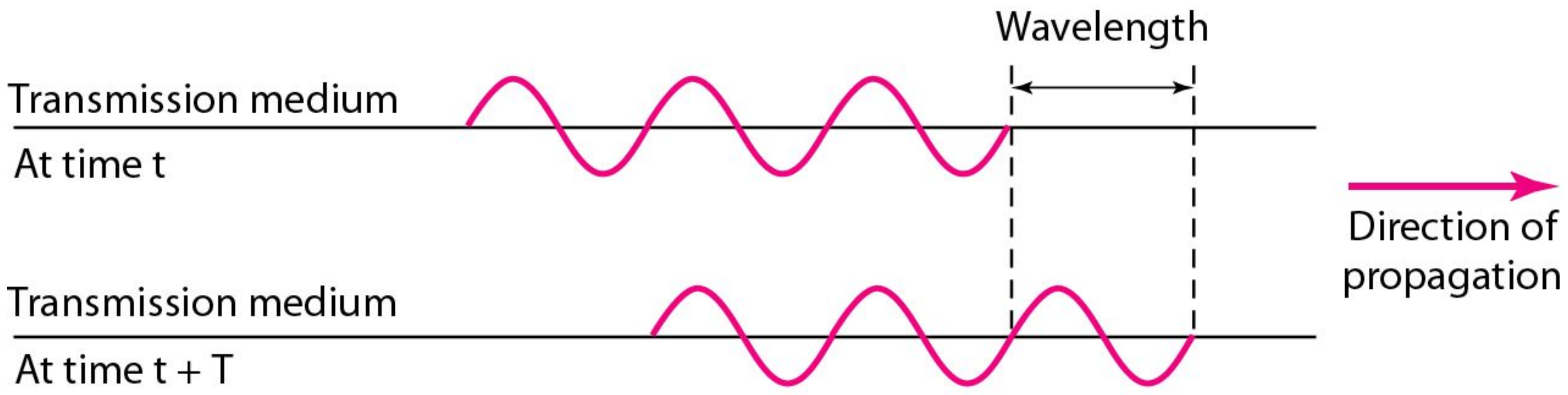
Example: A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians.

Solution: We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

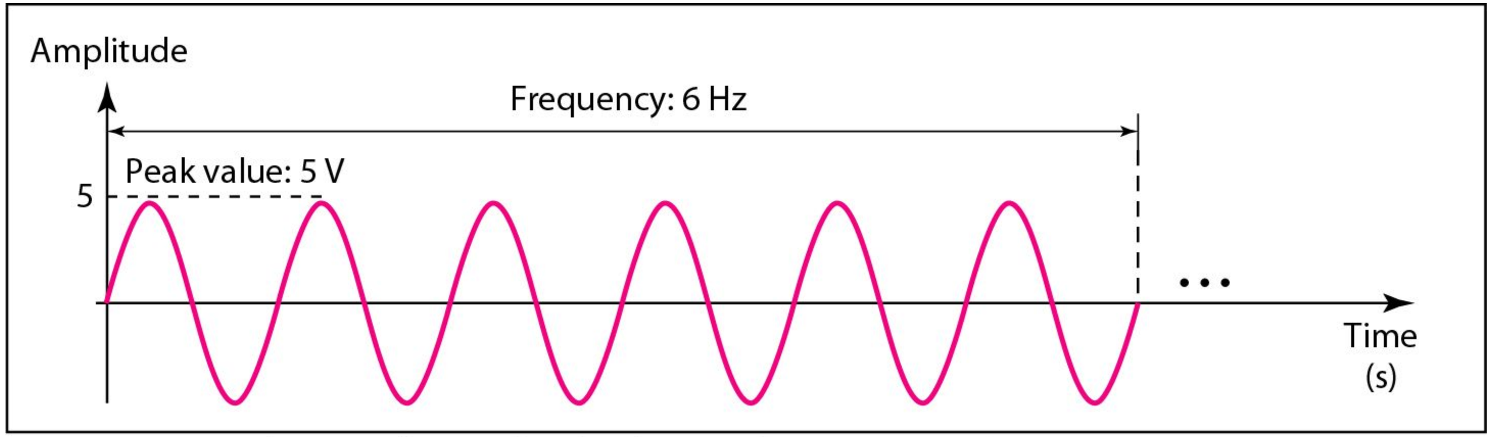
$$\boxed{\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}}$$

PERIODIC ANALOG SIGNALS

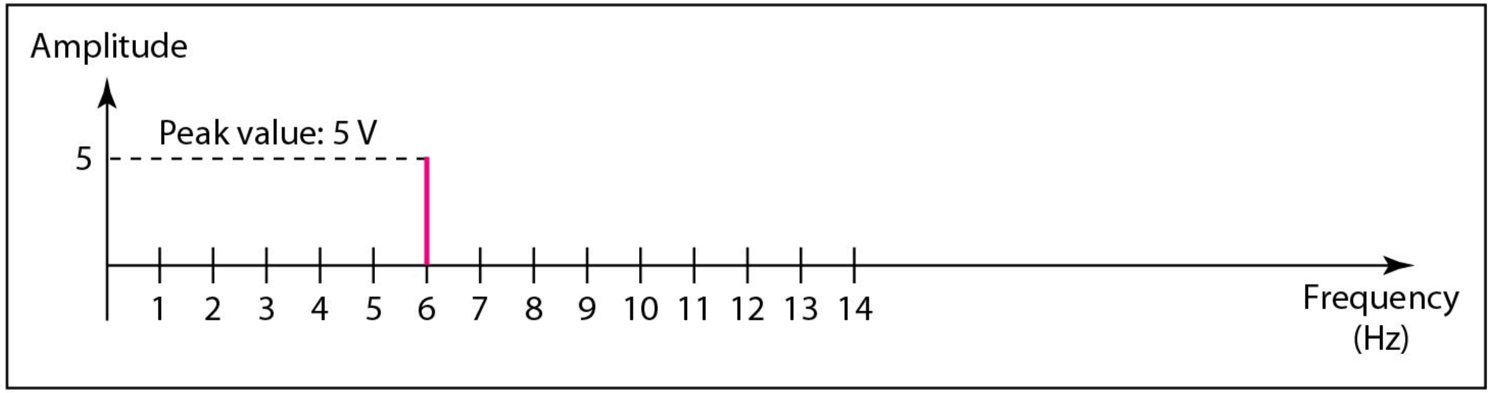
Wavelength: The wavelength is the distance a simple signal can travel in one period.



TIME DOMAIN AND FREQUENCY DOMAIN PLOT OF SINE WAVE



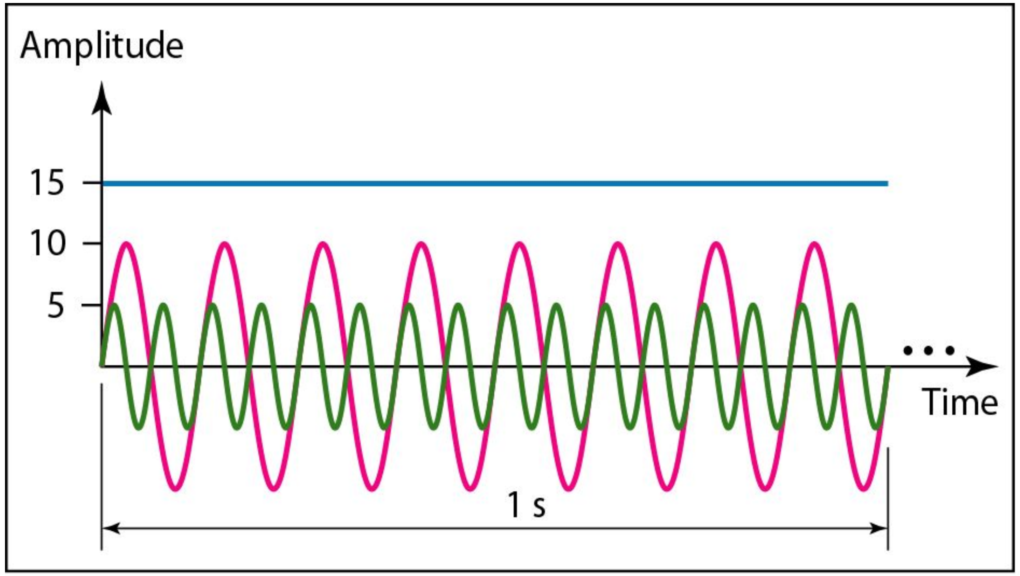
a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



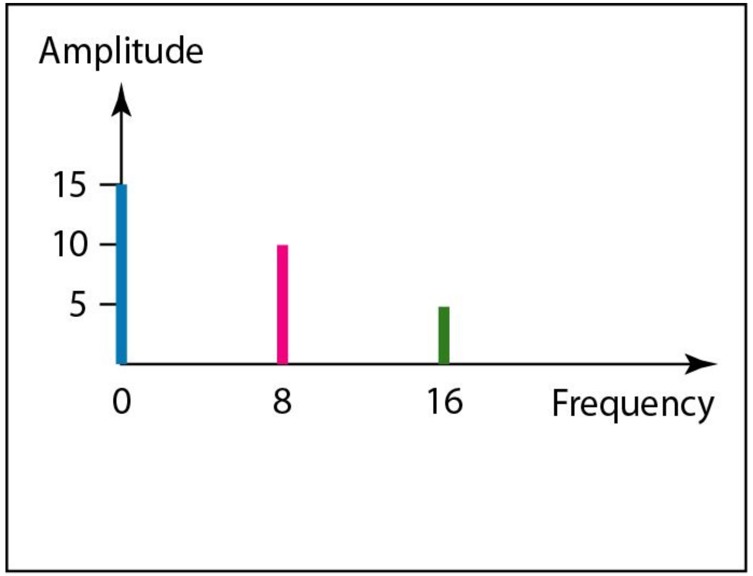
b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

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

TIME DOMAIN AND FREQUENCY DOMAIN PLOT OF THREE SINE WAVES

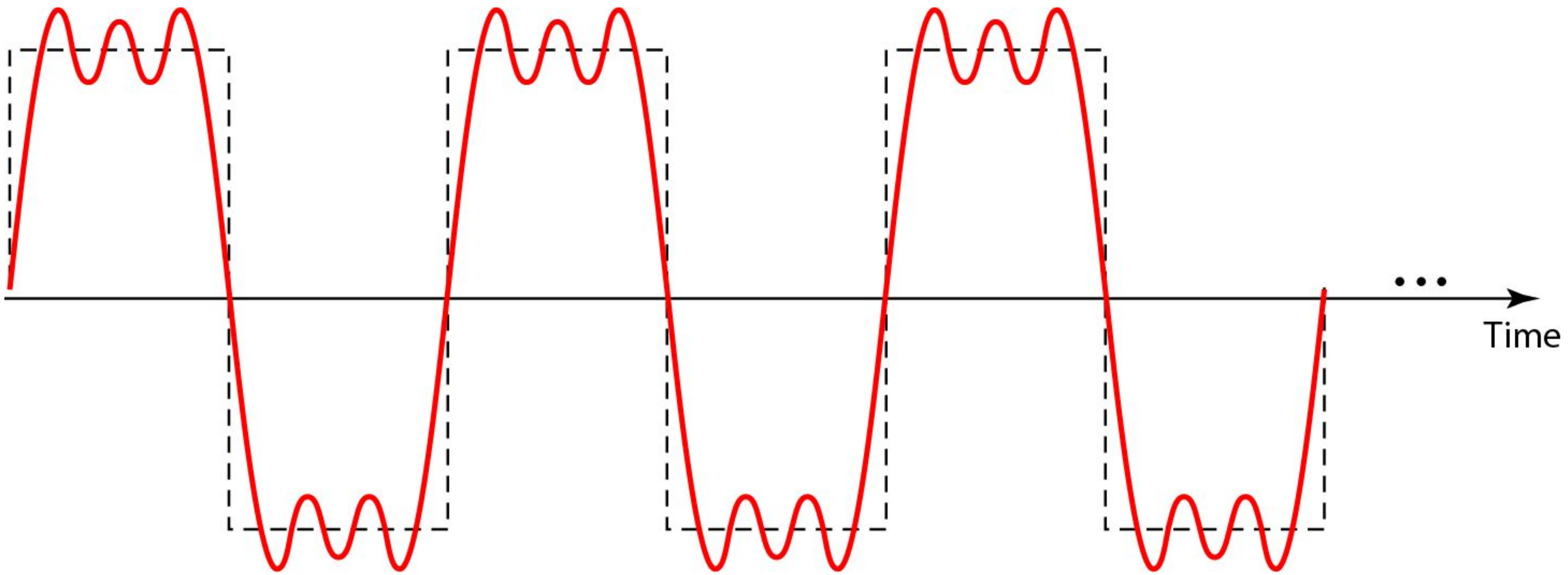


a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

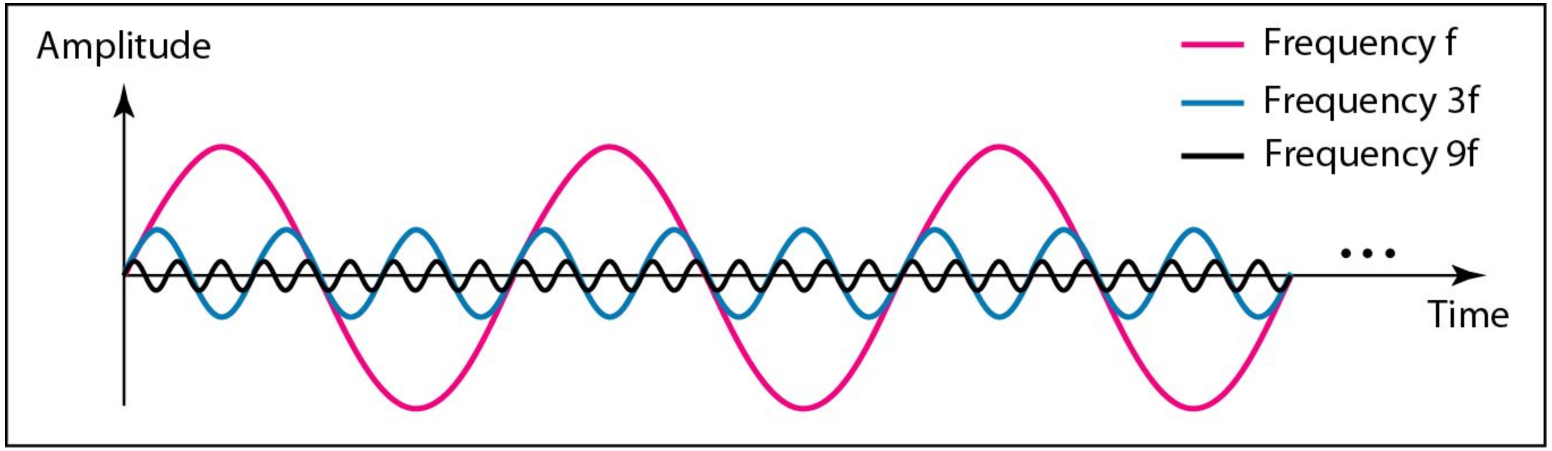


b. Frequency-domain representation of the same three signals

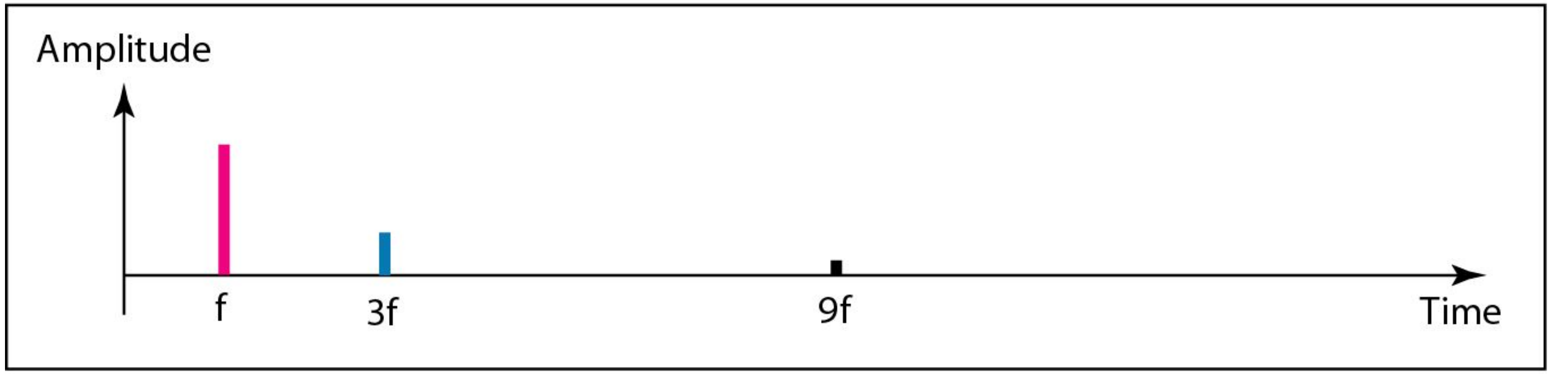
COMPOSITE PERIODIC SIGNAL



DECOMPOSITION OF A COMPOSITE PERIODIC SIGNAL IN THE TIME AND FREQUENCY DOMAINS



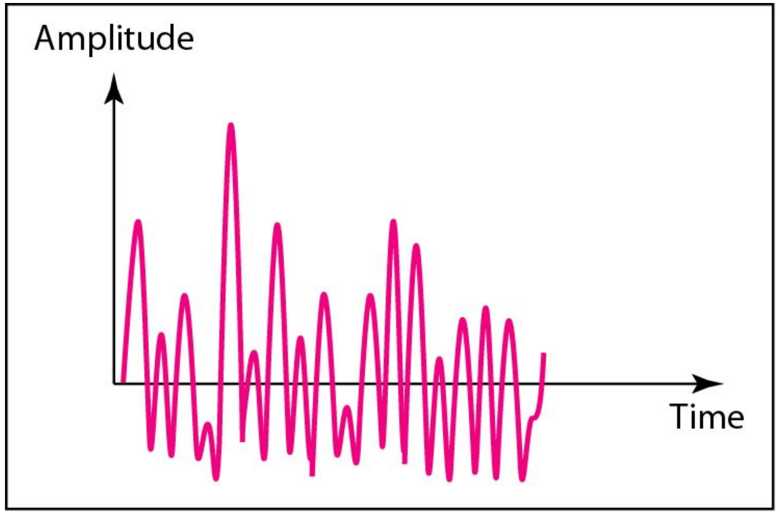
a. Time-domain decomposition of a composite signal



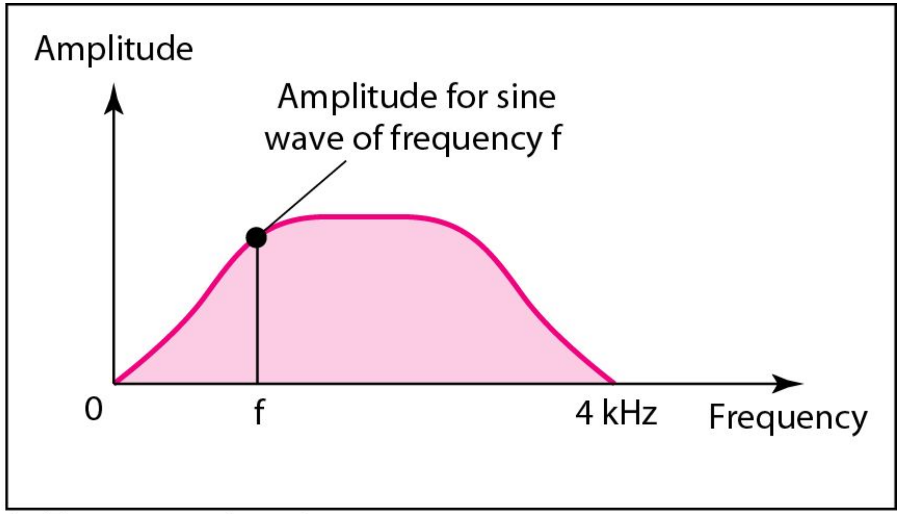
b. Frequency-domain decomposition of the composite signal

NON PERIODIC COMPOSITE SIGNAL

- ✔ It can be the signal created by a microphone or a telephone set when a word or two is pronounced.
- ✔ 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.



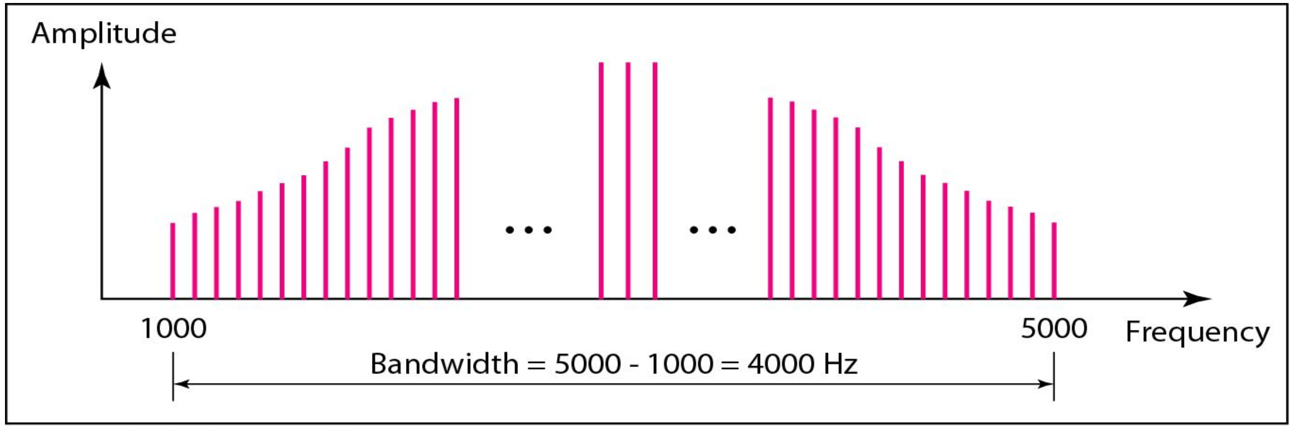
a. Time domain



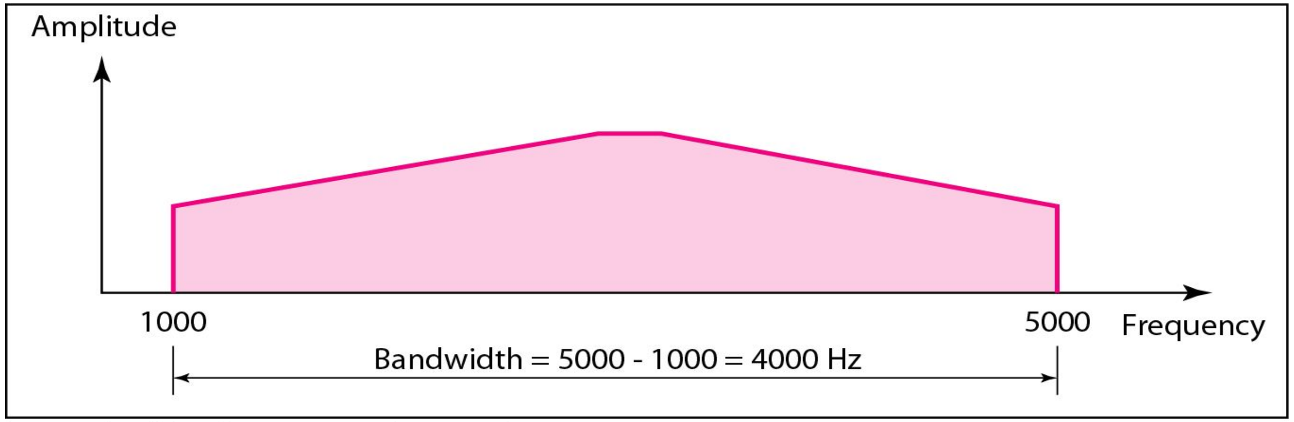
b. Frequency domain

BANDWIDTH

- 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

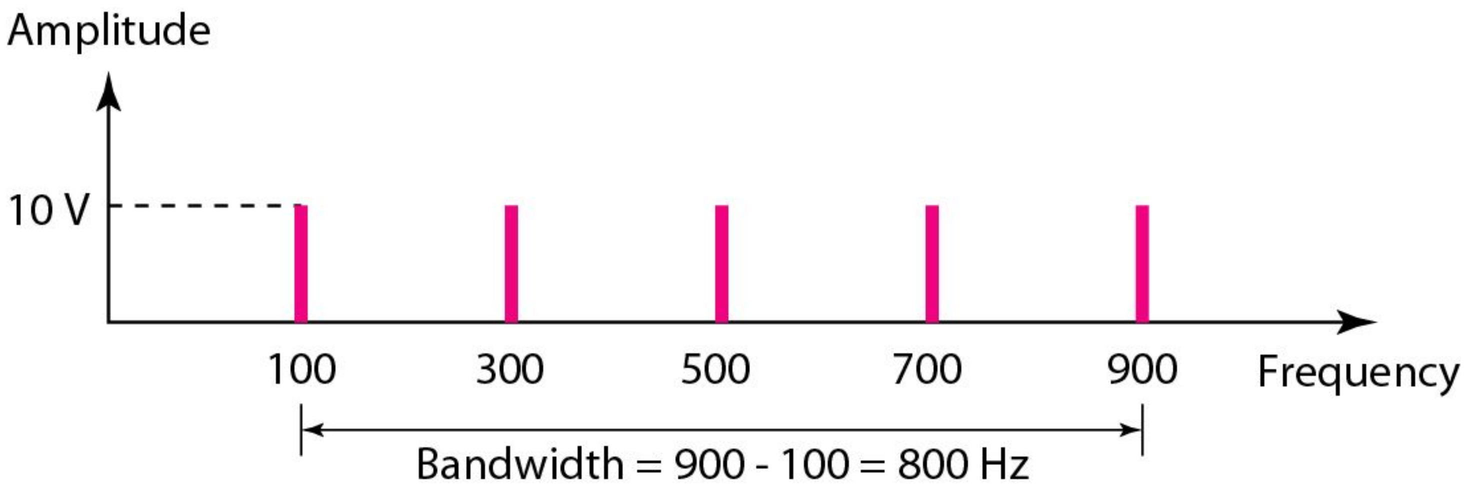


b. Bandwidth of a nonperiodic signal

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 f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

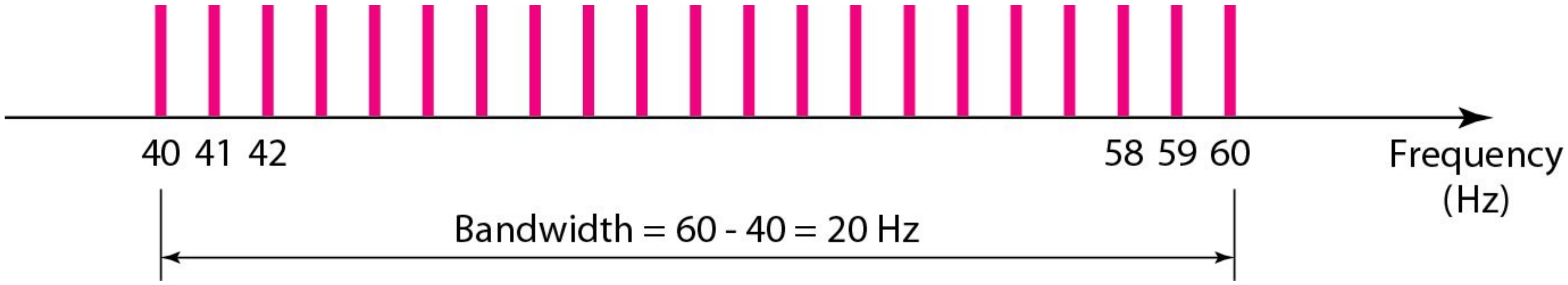
$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$



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.

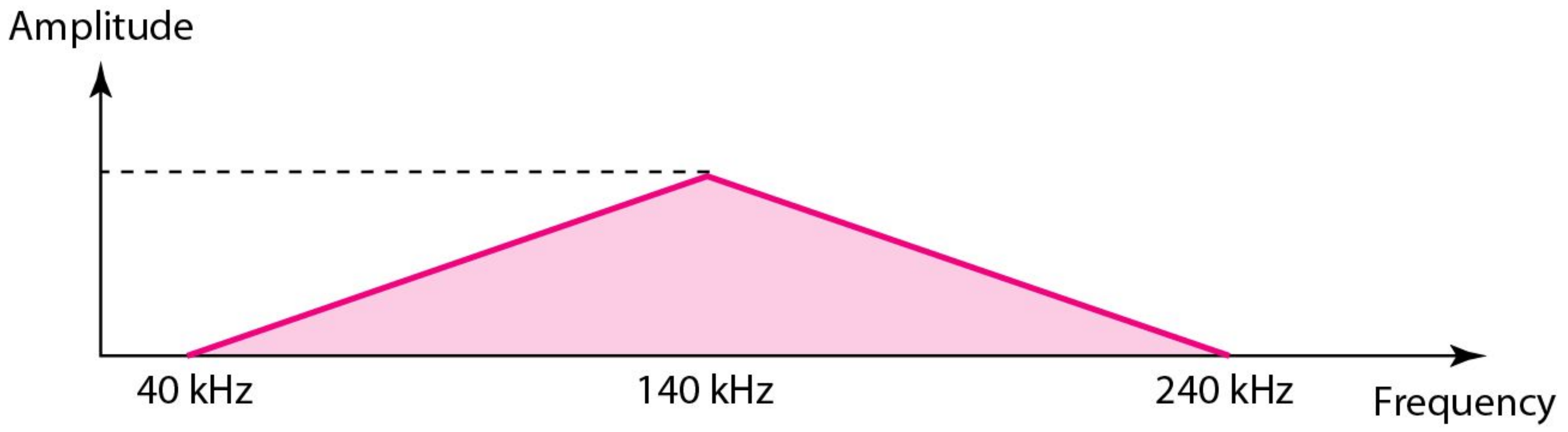
Solution: Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

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



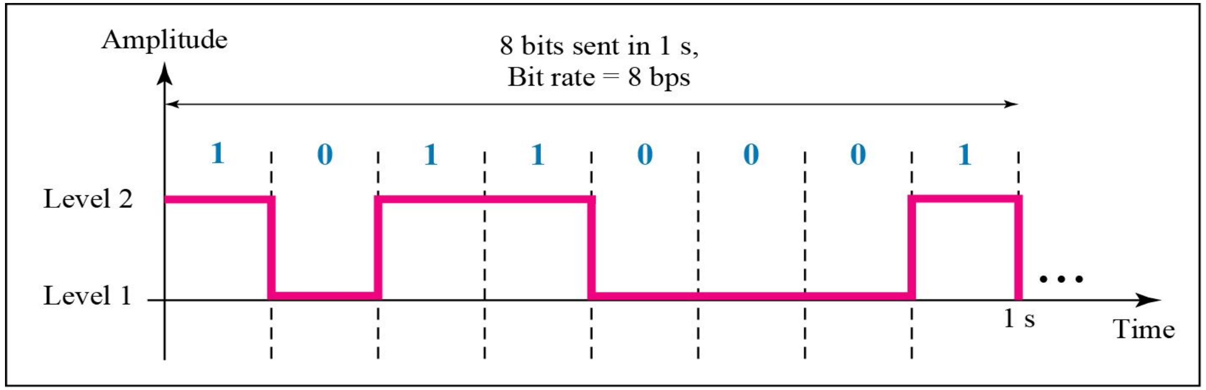
Example: A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

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

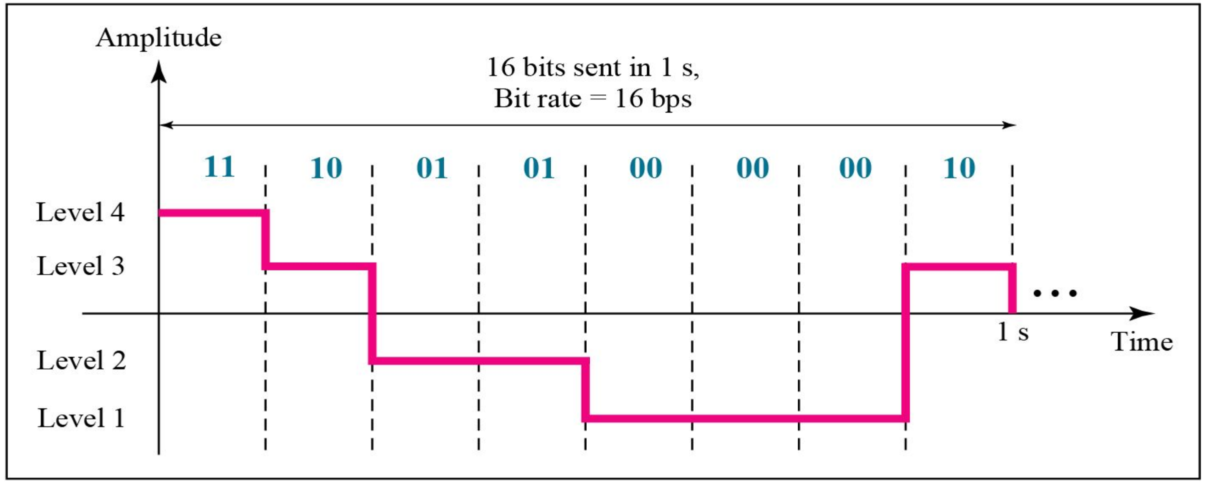


DIGITAL SIGNAL

- ‘1’ can be encoded as a 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.



a. A digital signal with two levels



b. A digital signal with four levels

DIGITAL SIGNAL

- 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.

- A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

DIGITAL SIGNAL

Example: Assume we need to download text documents at the rate of 100 pages per sec. 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 (ascii), the bit rate is

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

Example: A digitized voice channel, as we will see in Chapter 4, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution: The bit rate can be calculated as,

$$\boxed{2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}}$$

DIGITAL SIGNAL

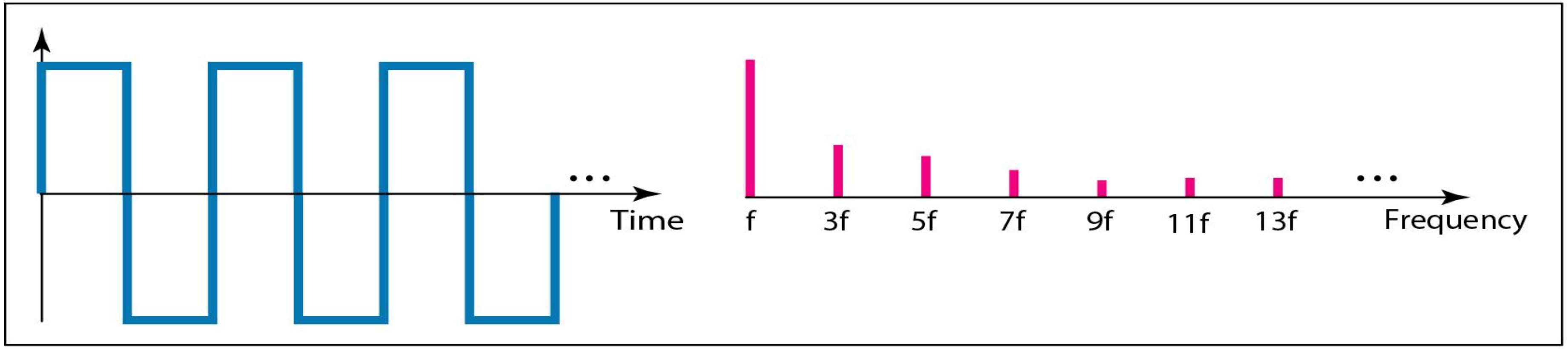
Example: What is the bit rate for high-definition TV (HDTV)?

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.

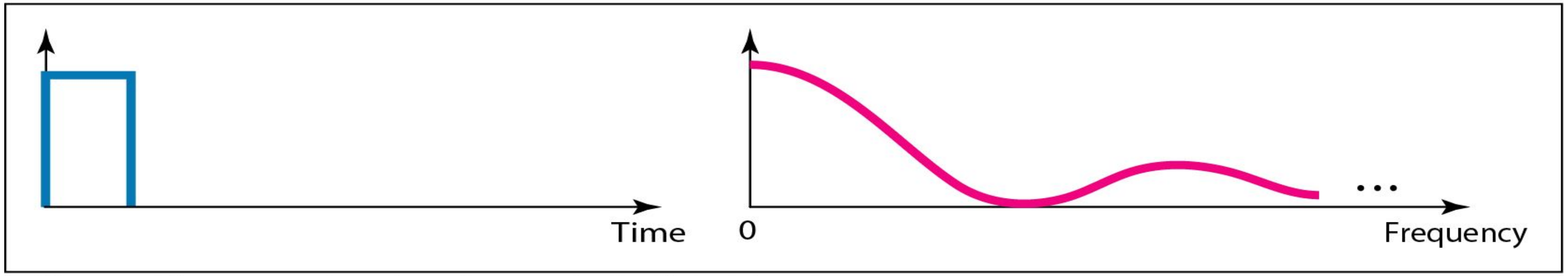
$$\boxed{1920 \times 1080 \times 30 \times 24 = 1{,}492{,}992{,}000 \text{ or } 1.5 \text{ Gbps}}$$

DIGITAL SIGNAL AS A COMPOSITE ANALOG SIGNAL

- If the digital signal is periodic, the decomposed signal has a frequency domain representation with an infinite bandwidth and discrete frequencies. If the digital signal is nonperiodic, the decomposed signal still has an infinite bandwidth, but the frequencies are continuous.



a. Time and frequency domains of periodic digital signal

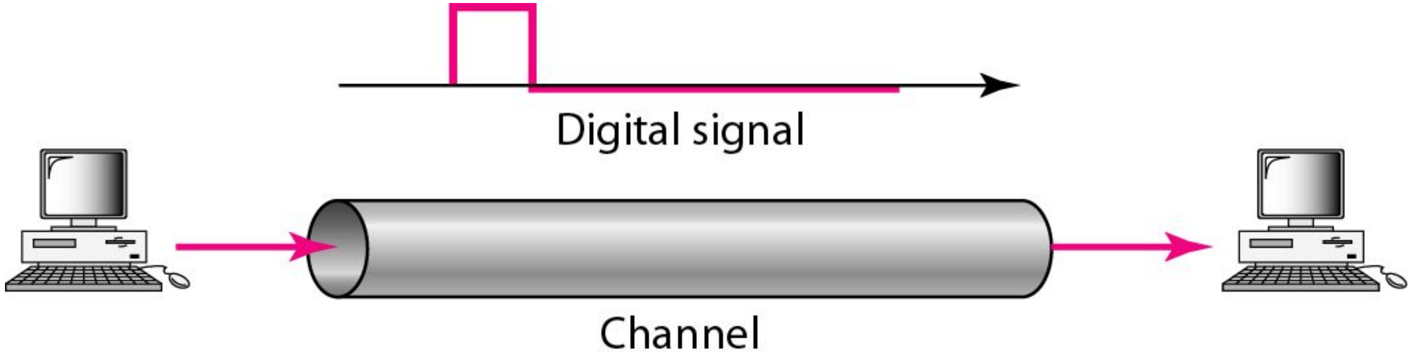


b. Time and frequency domains of nonperiodic digital signal

TRANSMISSION OF DIGITAL SIGNALS

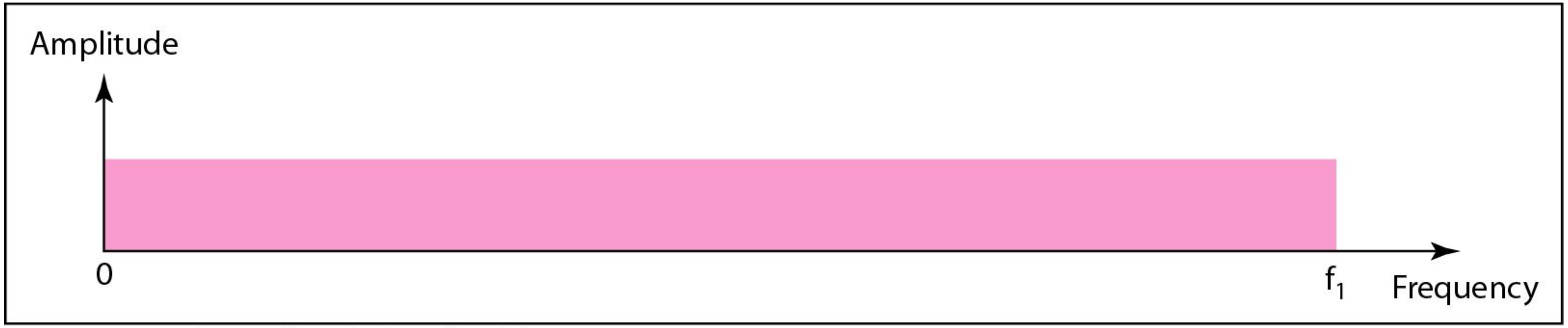
- ✔ Digital signal can be transmitted by using one of the two approaches:- **1) baseband transmission 2) broadband transmission (using modulation).**

1. **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.



TRANSMISSION OF DIGITAL SIGNALS

✔ Two cases of a **baseband transmission**: 1. Low pass channel with wide bandwidth 2. Low pass channel with limited bandwidth.



a. Low-pass channel, wide bandwidth

b. Low-pass channel, narrow bandwidth

TRANSMISSION OF DIGITAL SIGNALS

1. **Low pass channel with wide bandwidth:** Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.

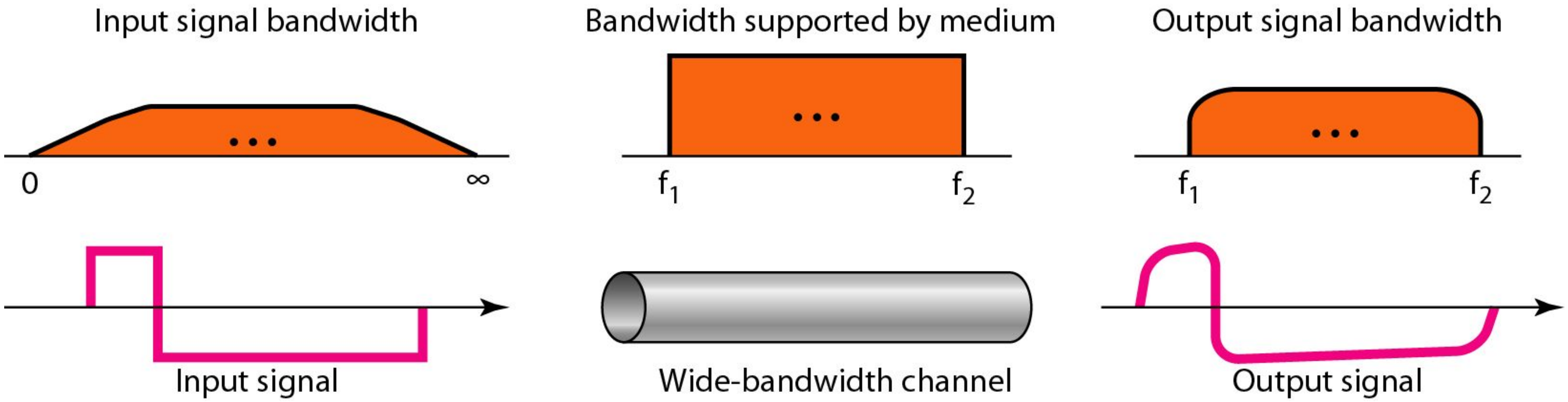


Figure: Baseband transmission using a dedicated medium

TRANSMISSION OF DIGITAL SIGNALS

2. **Broadband Transmission (Using Modulation):** Broadband transmission or modulation means changing the digital signal to an analog signal for transmission. Modulation allows us to use a bandpass channel-a channel with a bandwidth that does not start from zero. **Note that a low-pass channel can be considered a bandpass channel with the lower frequency starting at zero.**

TRANSMISSION OF DIGITAL SIGNALS

- ✔ Digital signal is converted to a composite analog signal. We have used a single-frequency analog signal the amplitude of the carrier has been changed to look like the digital signal.
- ✔ At the receiver, the received analog signal is converted to digital, and the result is a replica of what has been sent.

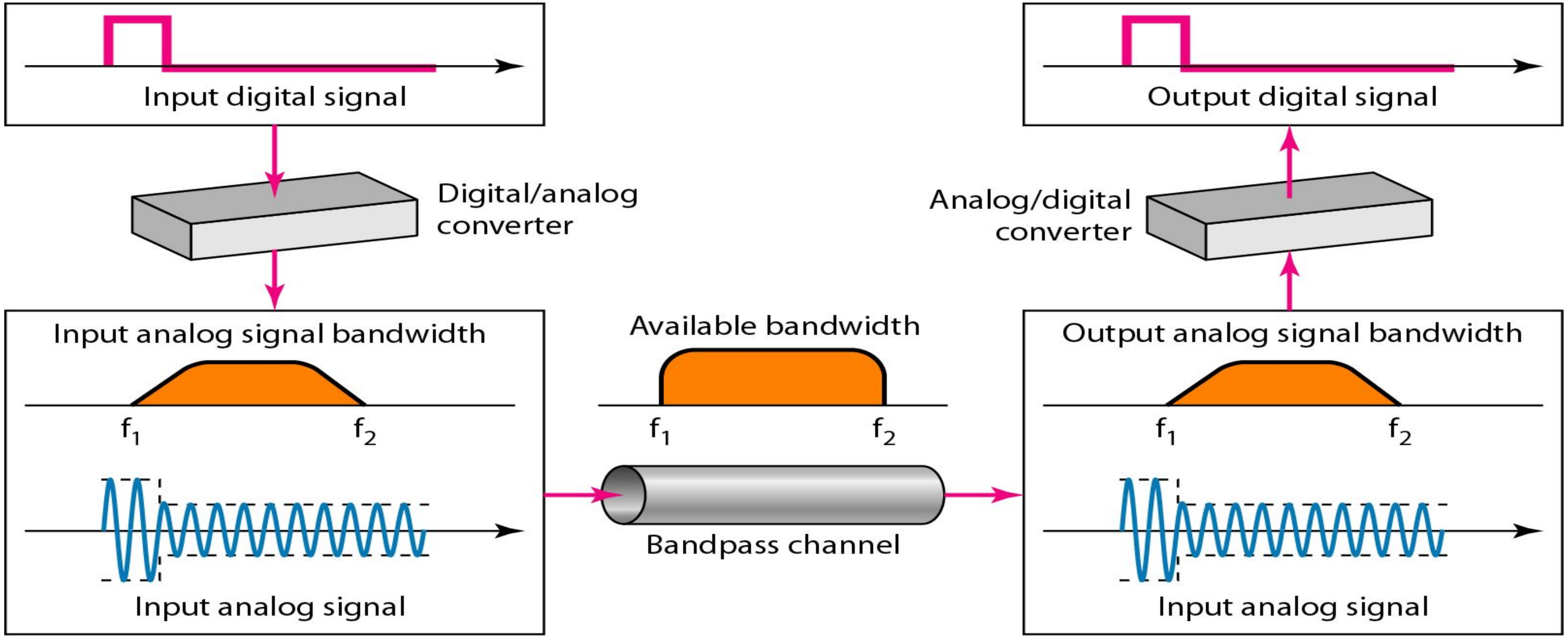


Figure: Modulation of a digital signal for transmission on a bandpass channel

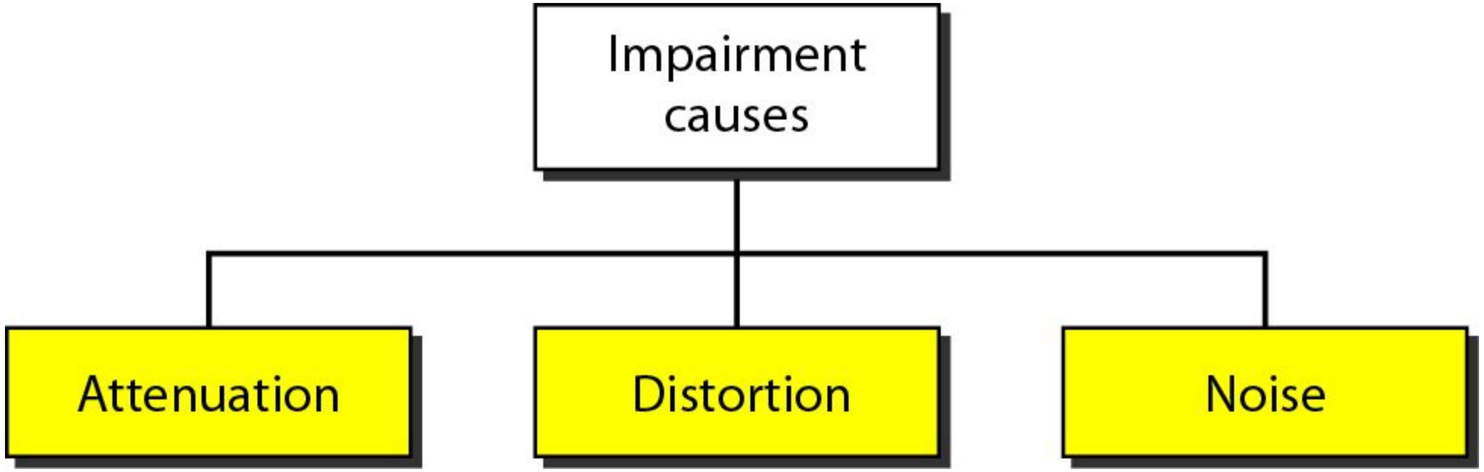
TRANSMISSION OF DIGITAL SIGNALS

Note

If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel, we need to convert the digital signal to an analog signal before transmission.

TRANSMISSION IMPAIRMENT

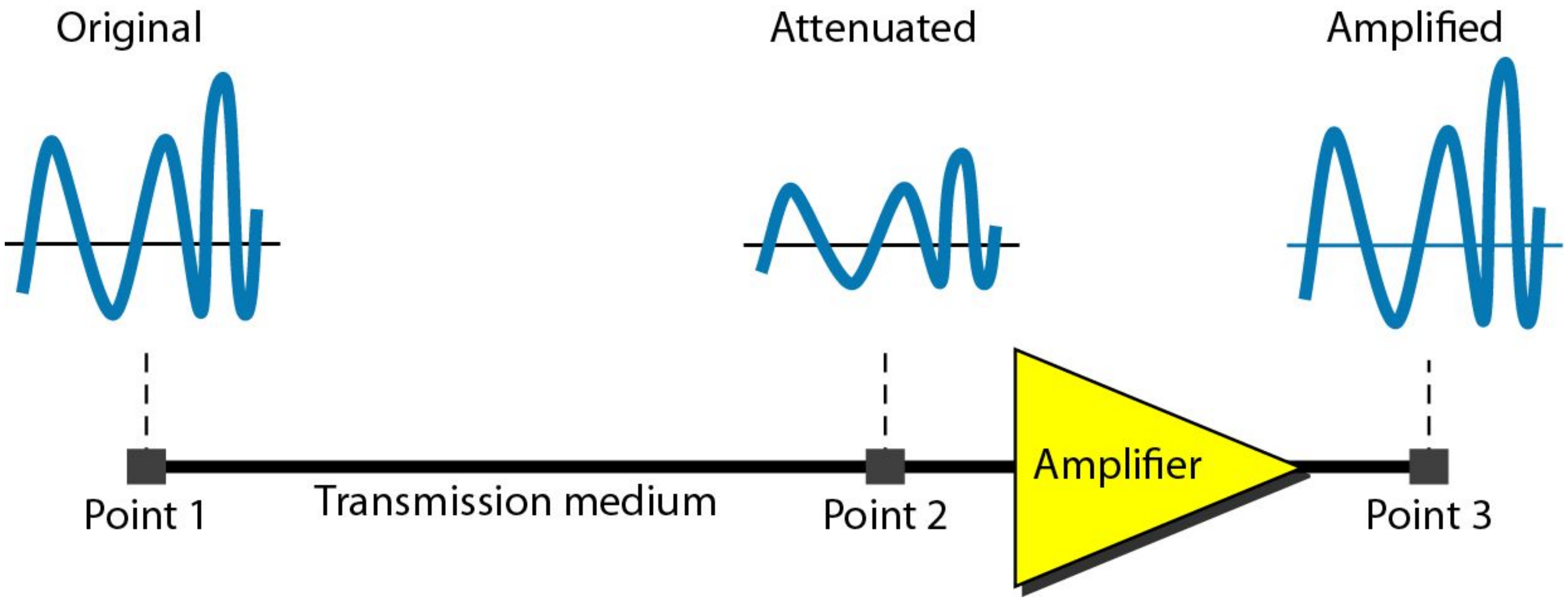
- Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are,



TRANSMISSION IMPAIRMENT

1) Attenuation

- ✔ Attenuation means a loss of energy.
- ✔ When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium.
- ✔ To compensate for this loss, amplifiers are used to amplify the signal.



TRANSMISSION IMPAIRMENT

- ✔ **Decibel** is used to show the gain or lost of strength in the signal. The decibel (dB) measures the relative strengths of two signals or one signal at two different points. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

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

P_1 - input signal

P_2 - output signal

Example: 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,

Solution:

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

Example: 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,

Solution:

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

$$= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

2. Distortion

- ✔ **Distortion** means that the signal changes its form or shape.
- ✔ Distortion can occur in a composite signal made of different frequencies.
- ✔ Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination.
- ✔ Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.
- ✔ In other words, signal components at the receiver have phases different from what they had at the sender.
- ✔ The shape of the composite signal is therefore not the same.

TRANSMISSION IMPAIRMENT

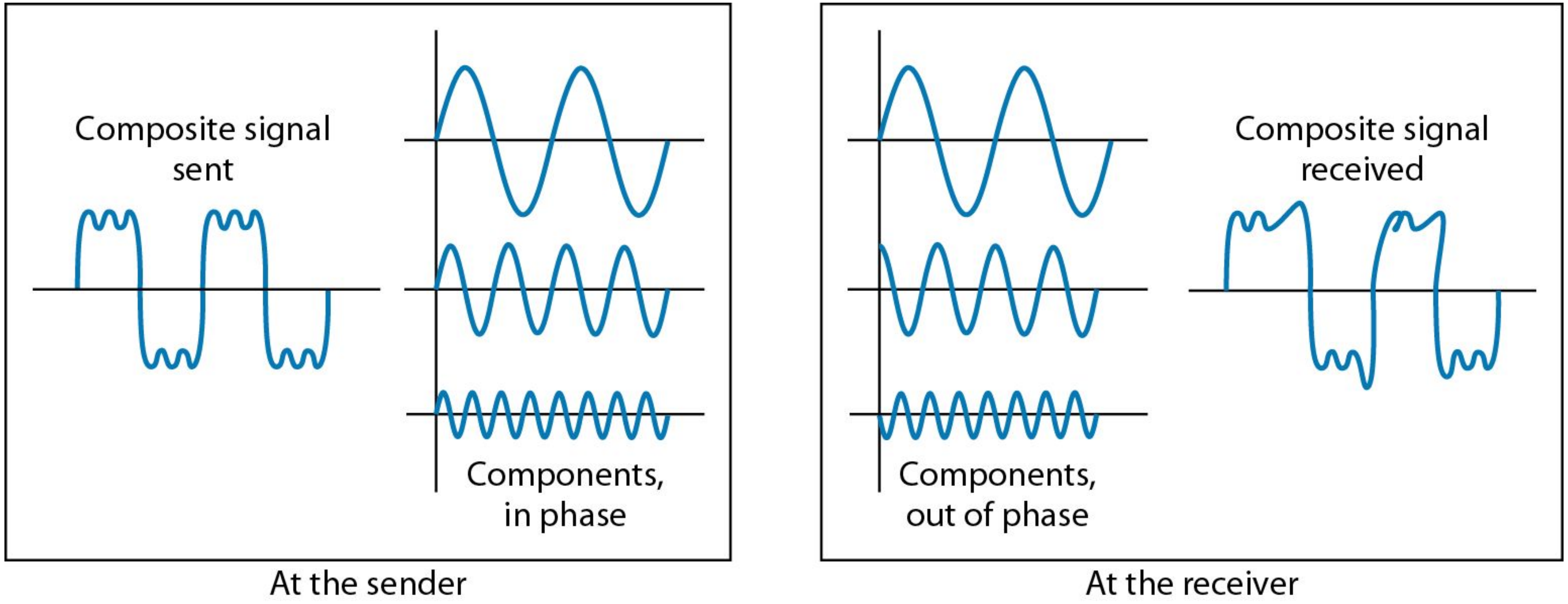
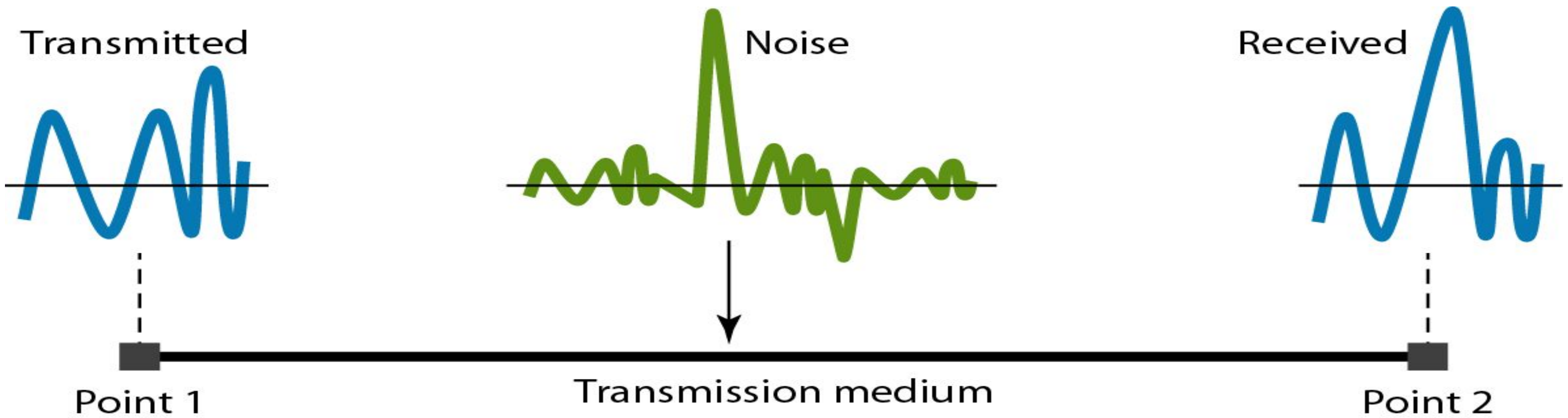


Figure: Distortion

3. Noise

- ✔ Noise is another cause of impairment.
- ✔ Several types of noise, such as **thermal noise, induced noise, crosstalk, and impulse noise.**
- ✔ **Thermal noise** is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter.
- ✔ **Induced noise** comes from sources such as motors and appliances.
- ✔ **Crosstalk** is the effect of one wire on the other.
- ✔ **Impulse noise** is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.



SIGNAL TO NOISE RATIO

- ✓ To measure the quality of a system the SNR is often used. It indicates the strength of the signal with respect to the noise power in the system.
- ✓ SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise).
- ✓ A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise.
- ✓ SNR is the ratio of two powers, it is often described in decibel units, $\boldsymbol{SNR_{DB} = 10log_{10}(SNR)}$
- ✓ Where, $\boldsymbol{SNR = {}^{average\ signal\ power}/_{average\ noise\ power}}$

SIGNAL TO NOISE RATIO

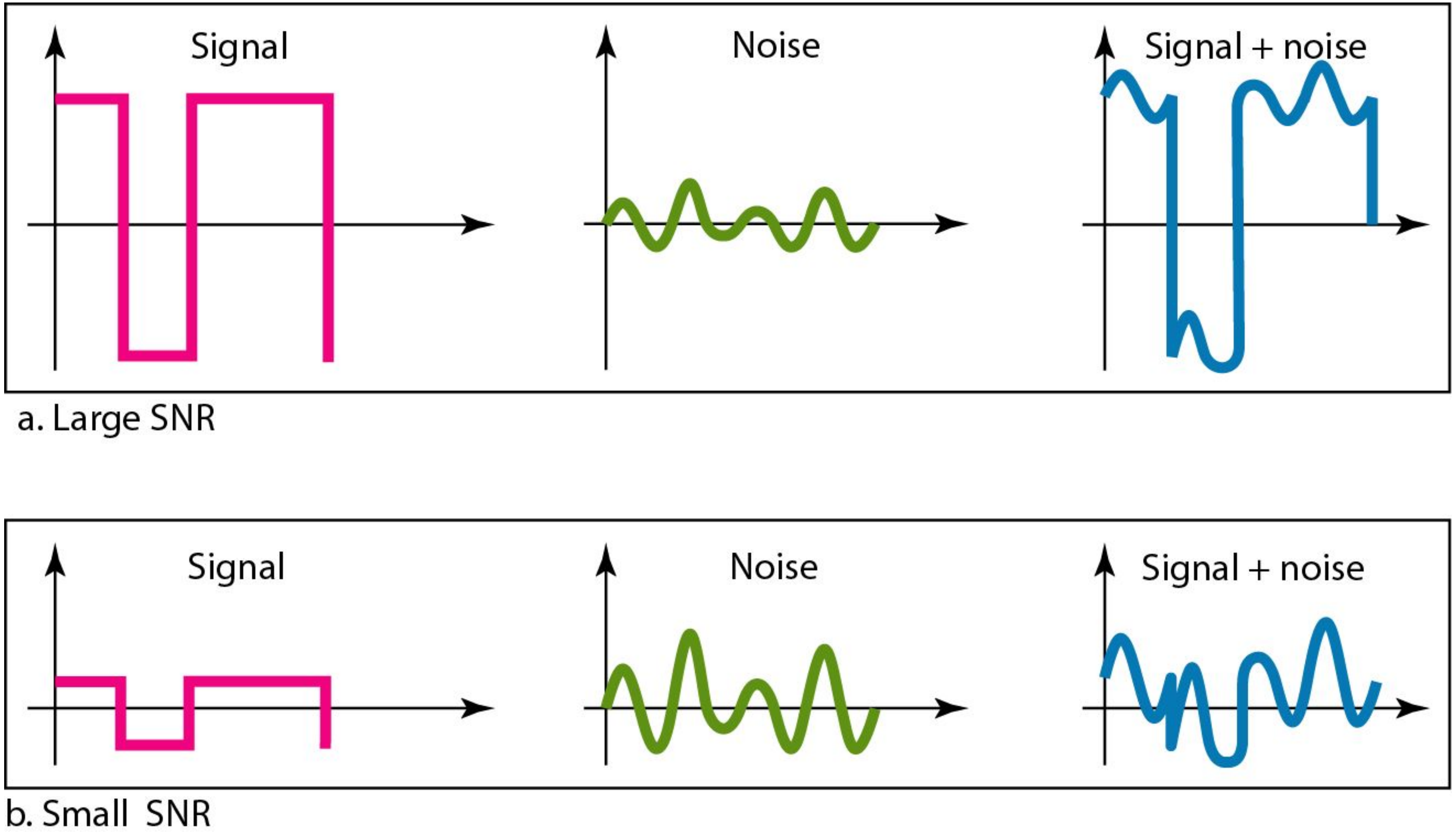


Figure: Two cases of SNR: a high SNR and a low SNR

SIGNAL TO NOISE RATIO

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:

$$\boxed{\begin{gathered} SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000 \\ SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40 \end{gathered}}$$

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

Solution:

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

Note: We can never achieve this ratio in real life, it is an ideal.

DATA RATE LIMITS

- Data rate defines how fast we can send data (bits per second) over a channel. **Data rate depends on three factors:-**

1. Bandwidth available.
2. The level of the signals.
3. The quality of the channel (level of noise).

- Two theoretical formulas were developed to calculate the data rate: 1) Nyquist for a noiseless channel 2) Shannon capacity for noisy channel.

DATA RATE LIMITS

❖ **Nyquist Bit Rate: Noiseless Channel**

For a noiseless channel, the Nyquist bit rate

$$\boldsymbol{Bit\ rate = 2 * B * Log_2 L}$$

Here, B is the bandwidth of the channel, L is the number of signal levels used to represent data, and Bit rate in bits per second.

- ✓ For a given bandwidth, any desired bit rate can be achieved by increasing the number of signal levels.
- ✓ If the number of levels in a signal is just 2, the receiver can easily distinguish between 0 and 1.
- ✓ If the level of a signal is 64, the receiver must be very sophisticated to distinguish between 64 different levels.
- ✓ **Therefore, increasing the level of signals, may reduce the reliability of the system.**

DATA RATE LIMITS

Example: Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as,

Solution:

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}}$$

Example: Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as,

Solution:

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}}$$

DATA RATE LIMITS

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:

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

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

Note: 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.

❖ Noisy Channel: Shannon Capacity

Shannon's theorem gives the capacity of a system in the presence of noise.

Capacity = B * $\log_2$(1 + SNR)

In this formula, bandwidth is the bandwidth of the channel, SNR is the signal-to noise ratio, and capacity is the capacity of the channel in bits per second.

Example: Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as,

$$\boxed{C = B \log_2 (1 + \mathrm{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0}$$

Note : This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

Example: A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as,

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

Example: Assume that $\text{SNR}_{\text{dB}} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as,

$$\text{SNR}_{\text{dB}} = 10 \log_{10} \text{SNR} \rightarrow \text{SNR} = 10^{\text{SNR}_{\text{dB}}/10} \rightarrow \text{SNR} = 10^{3.6} = 3981$$
$$C = B \log_2 (1 + \text{SNR}) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

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, we use the Shannon formula to find the upper limit.

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

Note

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

Measurement Of Network Performance

Network performance depends on some factors:-

❖ **Bandwidth**

✔ 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.

❖ **Throughput**

✔ The throughput is a measure of how fast we can actually send data through a network.

✔ For example, we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.

✔ Imagine a highway designed to transmit 1000 cars per minute from one point to another. However, if there is congestion on the road, this figure may be reduced to 100 cars per minute. The bandwidth is 1000 cars per minute; the throughput is 100 cars per minute.

Example: A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution: We can calculate the throughput as

$$\boxed{\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}}$$

Measurement Of Network Performance

- ❖ **Latency**
- ✔ The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.
- ✔ Latency is made of four components.
- ✔ **Latency = propagation time +transmission time + queuing time + processing delay**

Measurement Of Network Performance

1. **Propagation Time**

- ✔ Propagation time measures the time required for a bit to travel from the source to the destination.
- ✔ The propagation time is calculated by dividing the distance by the propagation speed.
- ✔ **Propagation Time = Distance / Propagation Speed**

Measurement Of Network Performance

Propagation speed: Speed at which a bit travels though the medium from source to destination.

Transmission speed: The speed at which all the bits in a message arrive at the destination. (difference in arrival time of first and last bit).

Example: What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 × 108 m/s in cable.

Solution: We can calculate the propagation time as

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^{8}} = 50 \text{ ms}$$

2. Transmission Time

- ✔ The **transmission time** is the amount of **time** from the beginning until the end of a message **transmission.**
- ✔ The time required for transmission of a message depends on the size of the message and the bandwidth of the channel.
- ✔ **Transmission time = Message size / Bandwidth**

Example: What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

Example: What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution:

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

- **Queuing Time**
- ✔ The time needed for each intermediate or end device to hold the message before it can be processed.
- ✔ When there is heavy traffic on the network, the queuing time increases.
- ✔ An intermediate device, such as a router, queues the arrived messages and processes them one by one.