វិទ្យាស្ថានបច្ចេកវិទ្យាកម្ពុជា
INSTITUTE OF TECHNOLOGY OF CAMBODIA

Department of Information and Communication Engineering

DIGITAL AND ANALOG TRANSMISSION

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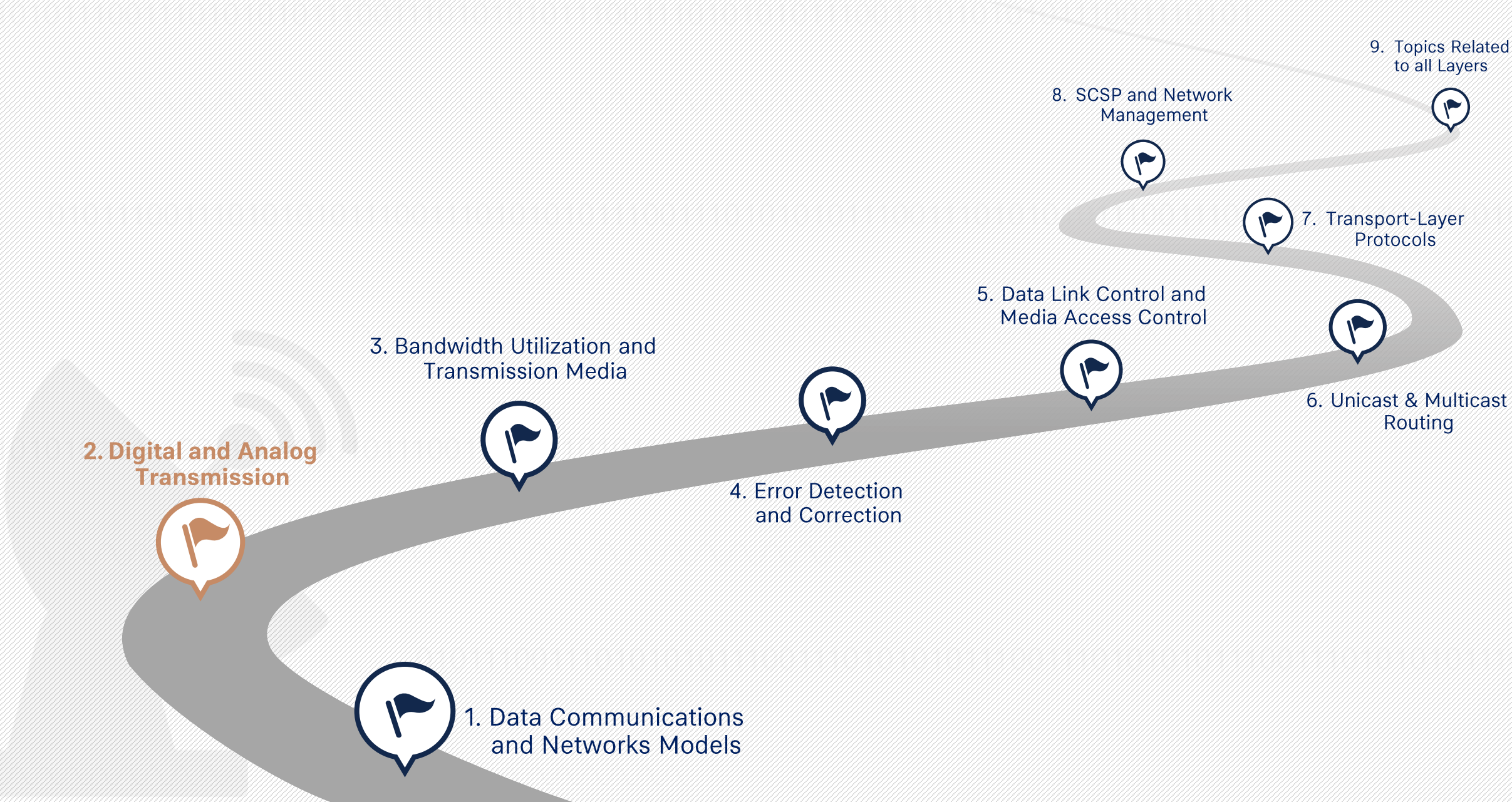
LEARNING MAP



INTRODUCTION TO PHYSICAL LAYER

PART-I

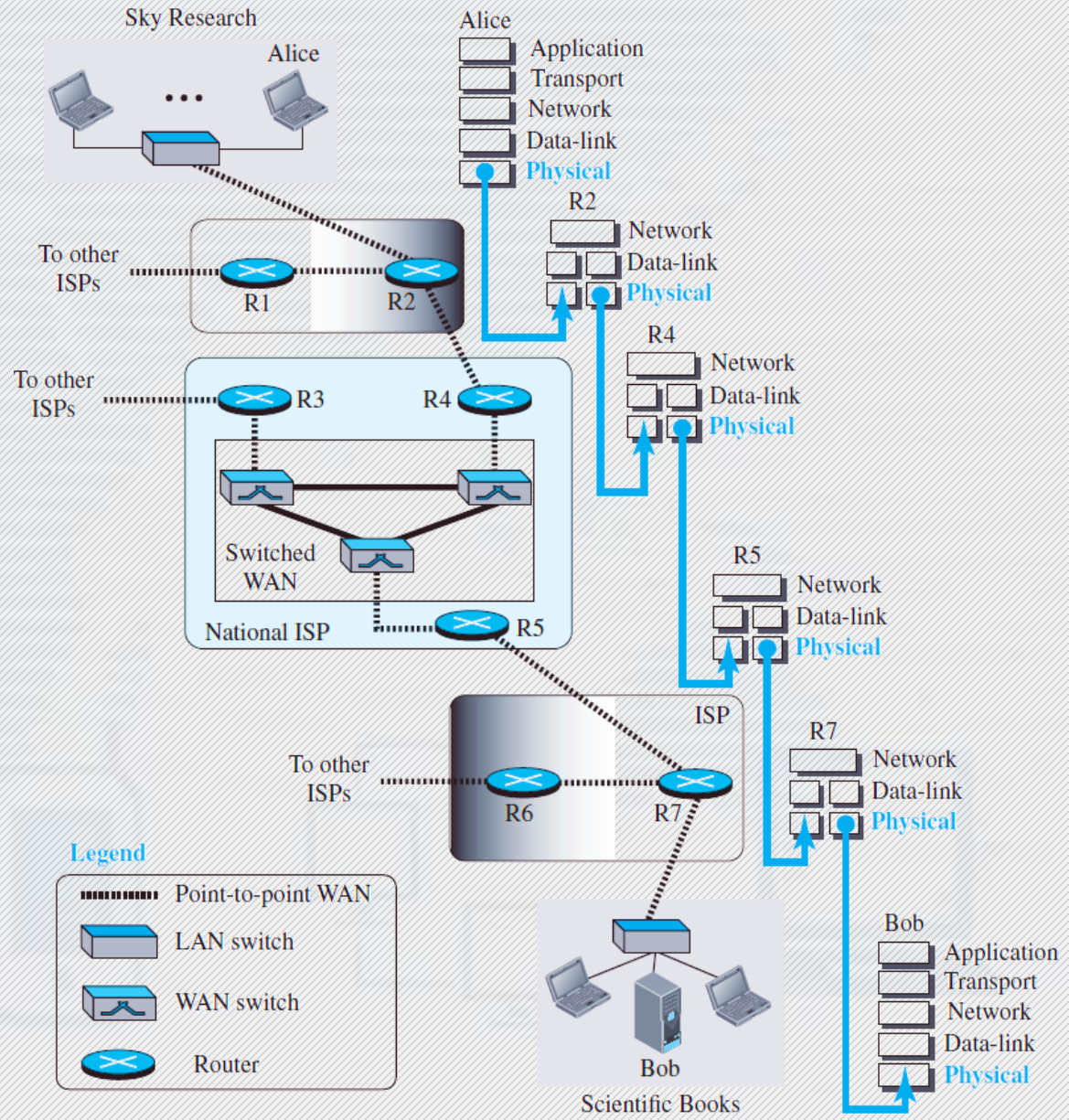
LEARNING OBJECTIVES

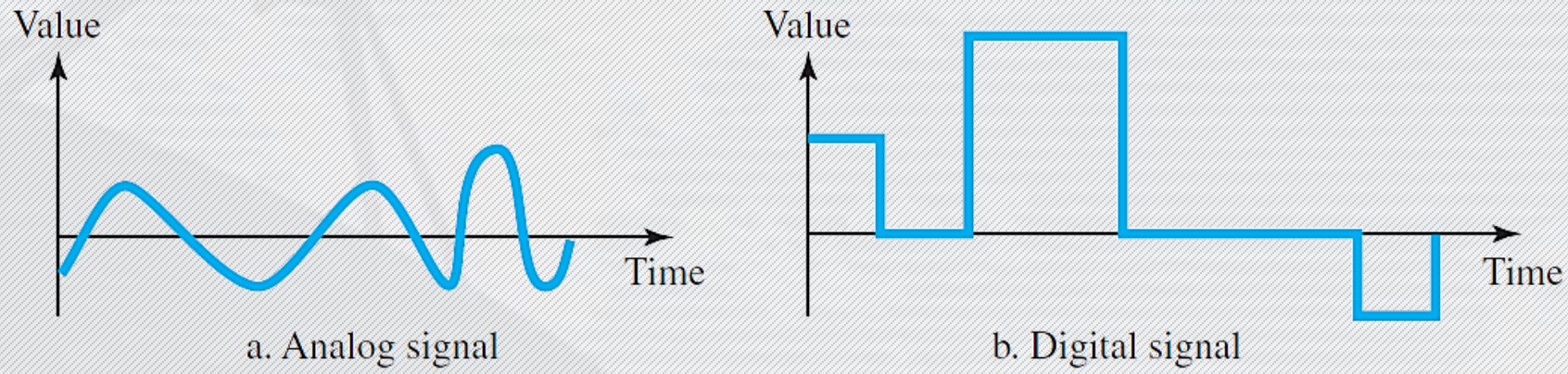
- Shows how data and signals can be either analog or digital.
- Shows periodic and nonperiodic signals can be used in data communication.
- Briefly discusses on transmission impairment: attenuation, distortion, and noise.
- Discusses data rate limit; how many bps can send with the available channel.
- Discusses the performance of data transmission including bandwidth, throughput, latency, jitter.

LECTURE CONTENTS

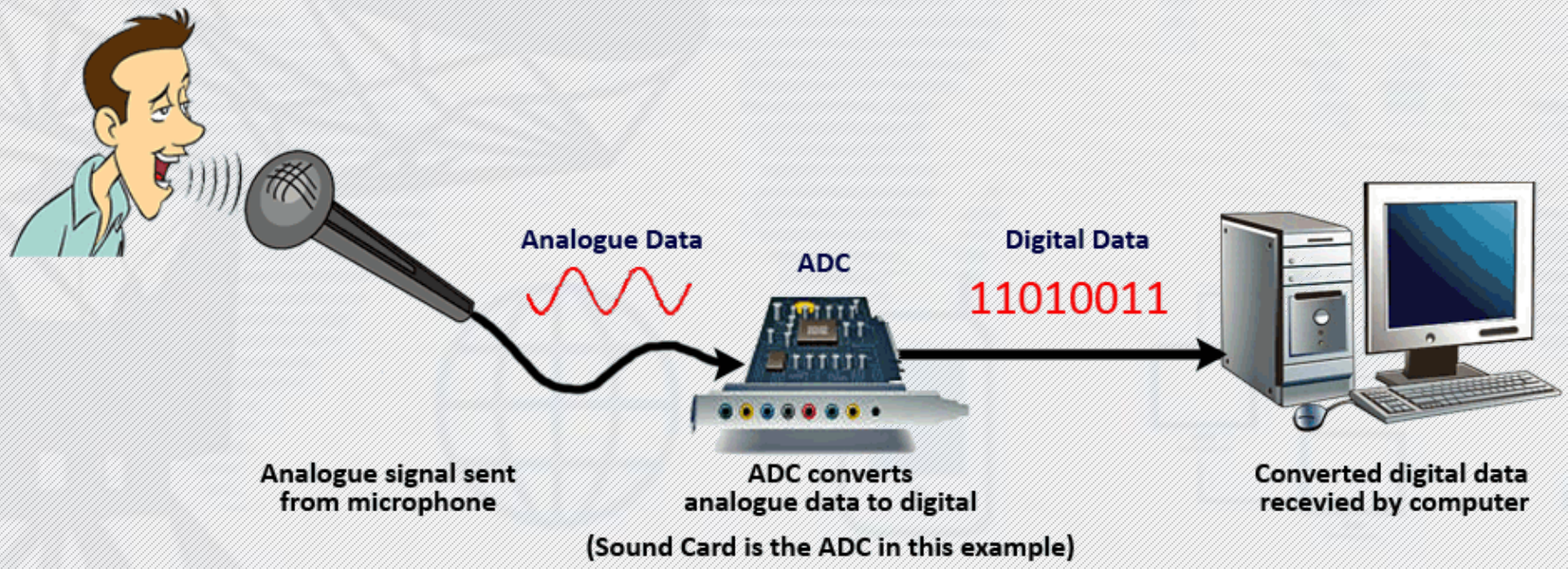
Data and Signal

- Five different levels of communication between Alice and Bob. Communication at application, transport, network, or data link is logical; at physical layer is physical.
- Although they need to exchange the data, communication at the physical layer means exchanging signals.
- Data need to be transmitted and received, but the media have to change data to signals.
- Both data and the signals that represent them can be either analog or digital in form.





Analog and Digital Signal



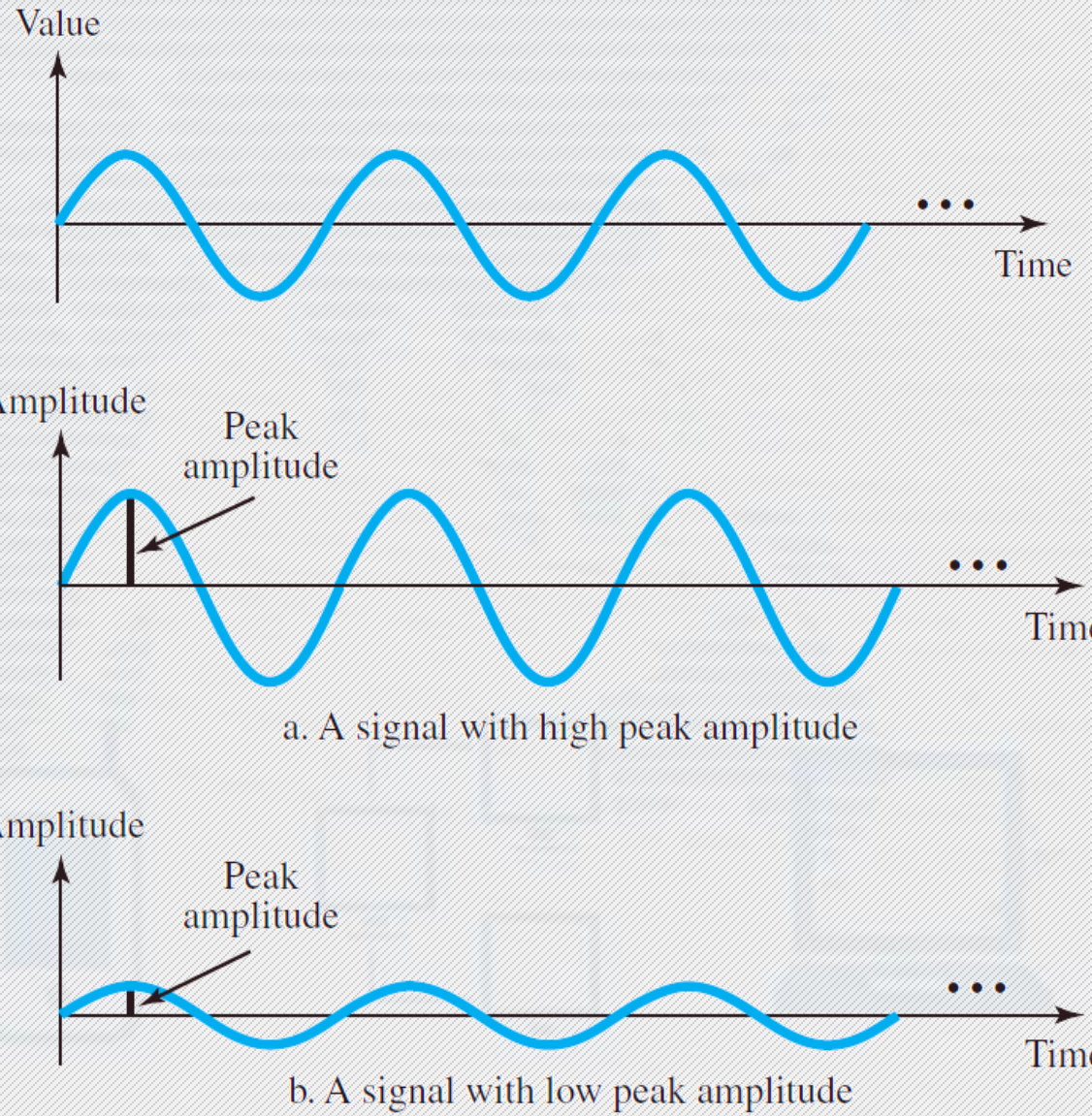
Analog and Digital Data

Sine Wave

- A sine wave can be represented by three parameters: **peak amplitude**, **frequency**, and **phase**.

Peak Amplitude

- The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries. For the electrical signals, peak amplitude is normally measured in *volts*.

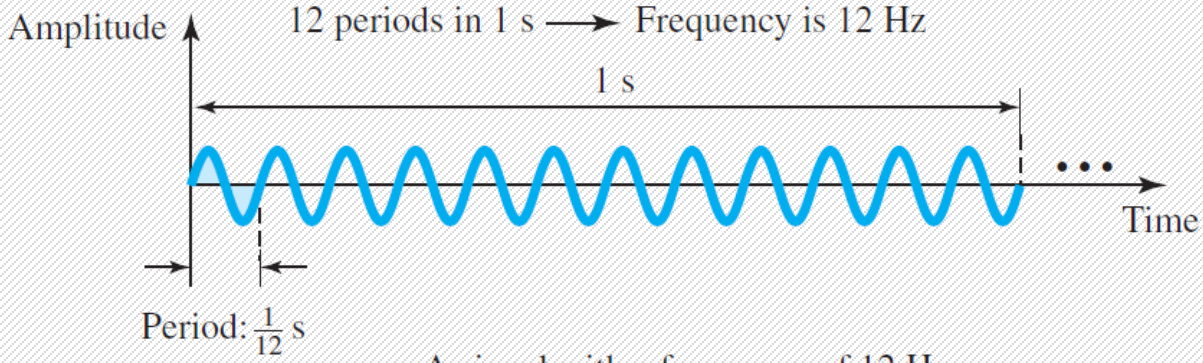


Period and Frequency

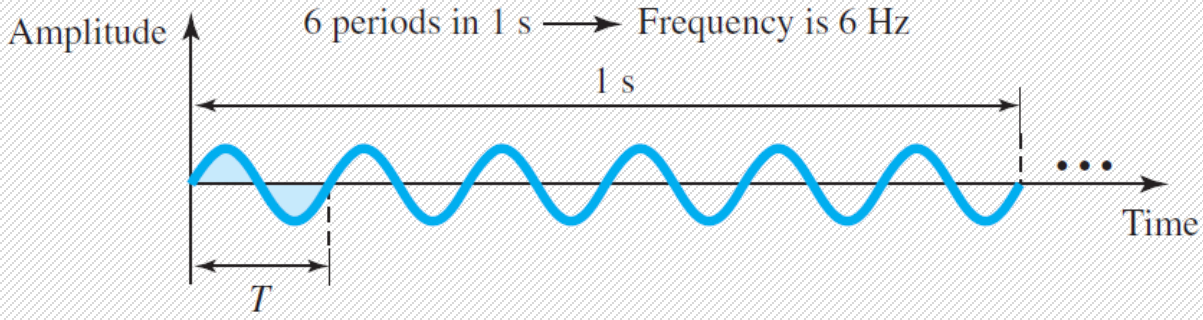
- Period refers to the amount of time, in second, a signal needs to complete 1 cycle.
- Frequency refers to the number of periods in 1s. Frequency and period are the inverse of each other.

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

- Frequency is the rate of change with respect to time. Change is a short span of time means high frequency. Change over a long span of time mean low frequency.



a. A signal with a frequency of 12 Hz

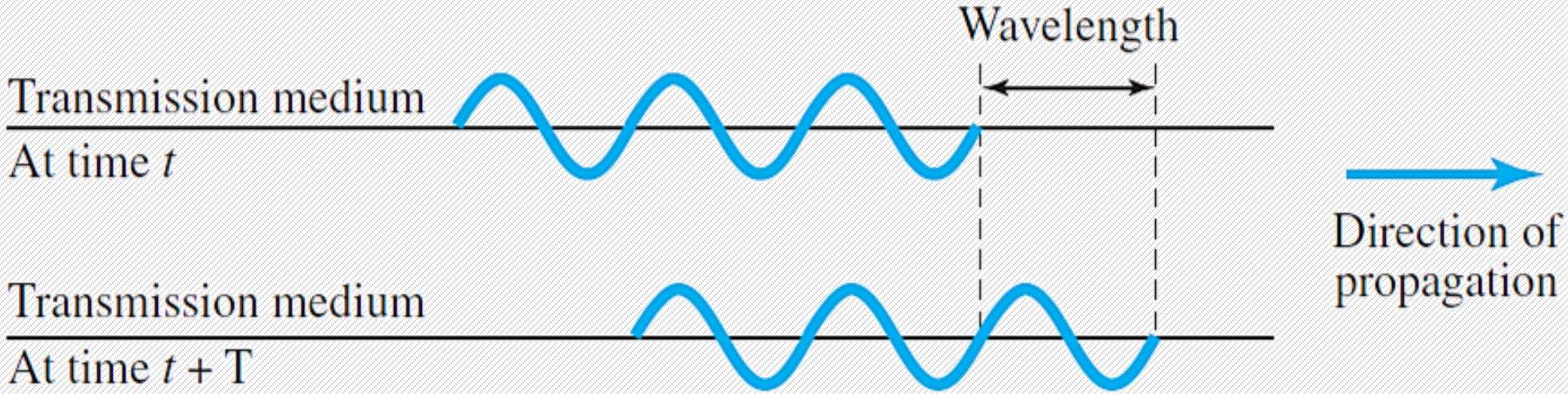


b. A signal with a frequency of 6 Hz

Period		*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

Wavelength

- Wavelength is another characteristic of a signal traveling through a transmission medium; which binds the period or the frequency of a simple sine wave to the propagation speed of the medium.



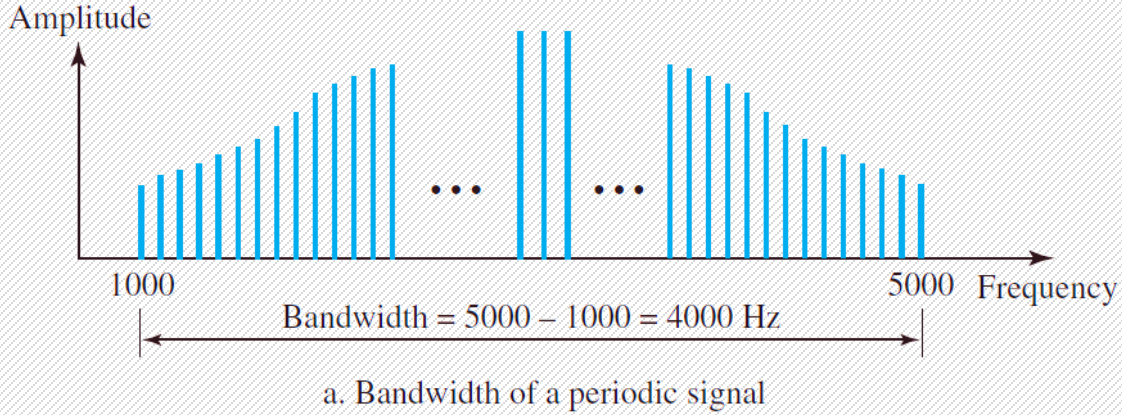
$$\text{Wavelength} = \text{propagation speed} \times \text{period} = \frac{\text{propagation speed}}{\text{frequency}}$$

$$\lambda = \frac{c}{f} \quad where \quad c = 3 \times 10^8 m/s$$

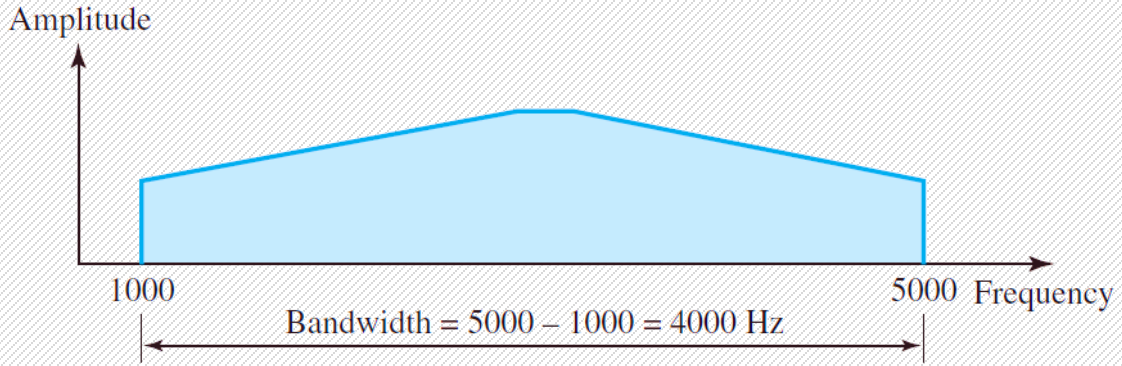
Bandwidth

- The range of frequencies contained in a composite signals is its **bandwidth**.
- The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.
- Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

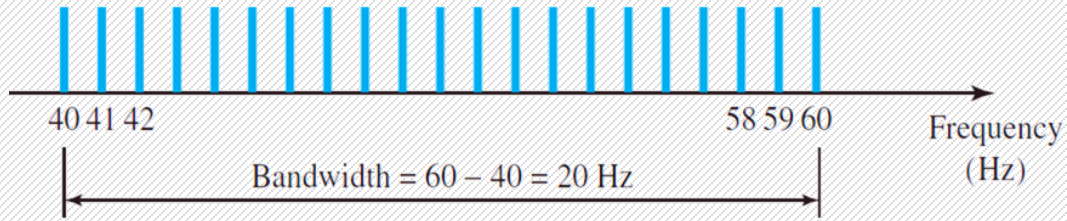
$$B = f_h - f_l$$



a. Bandwidth of a periodic signal



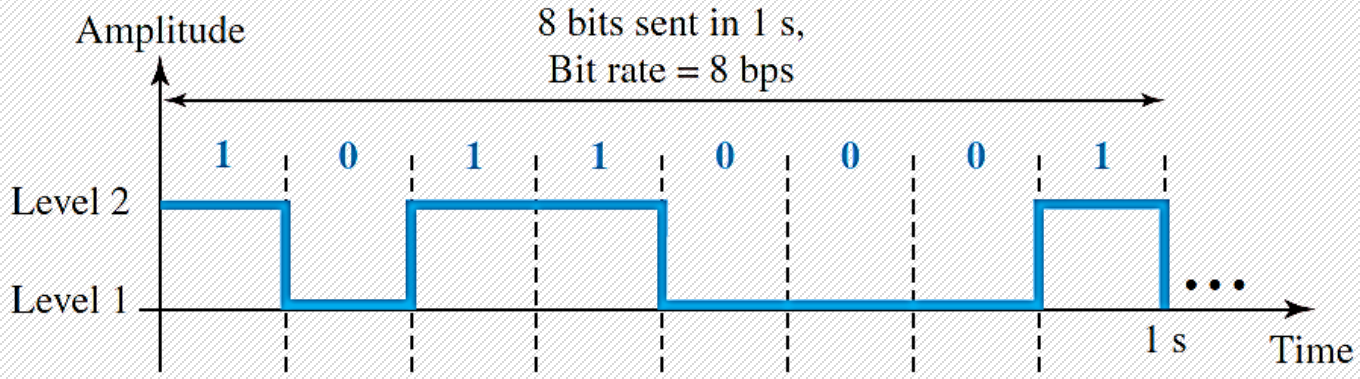
b. Bandwidth of a nonperiodic signal



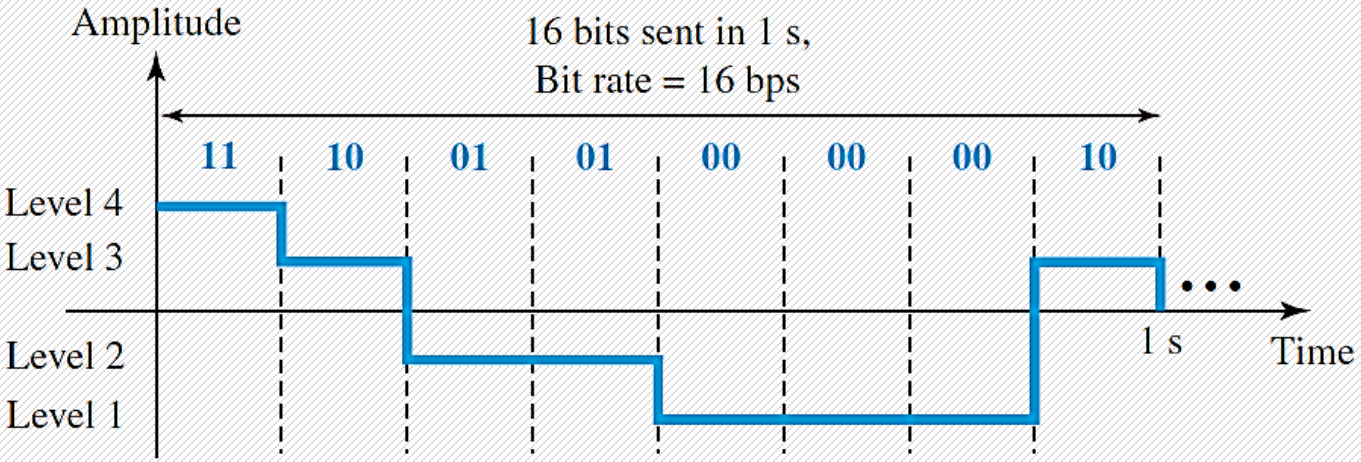
Digital Signals

- In digital signal, 1 can be encoded as a positive voltage and 0 as zero voltage.
- A digital signal can have more than two level and also can send more than 1 bit for each level.
- In general, if a signal has L levels, each level needs:

$$\text{Number of bits per level} = \log_2 L$$



a. A digital signal with two levels



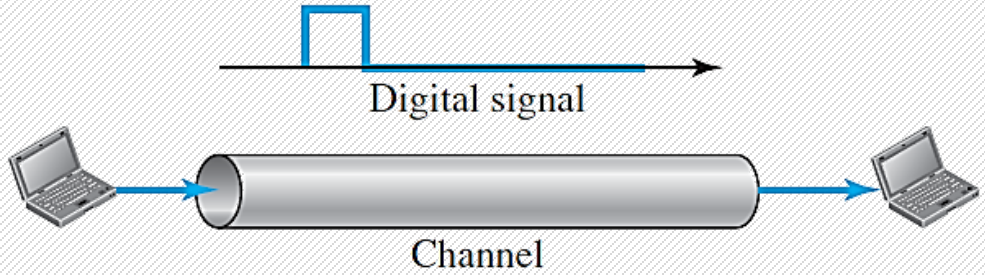
b. A digital signal with four levels

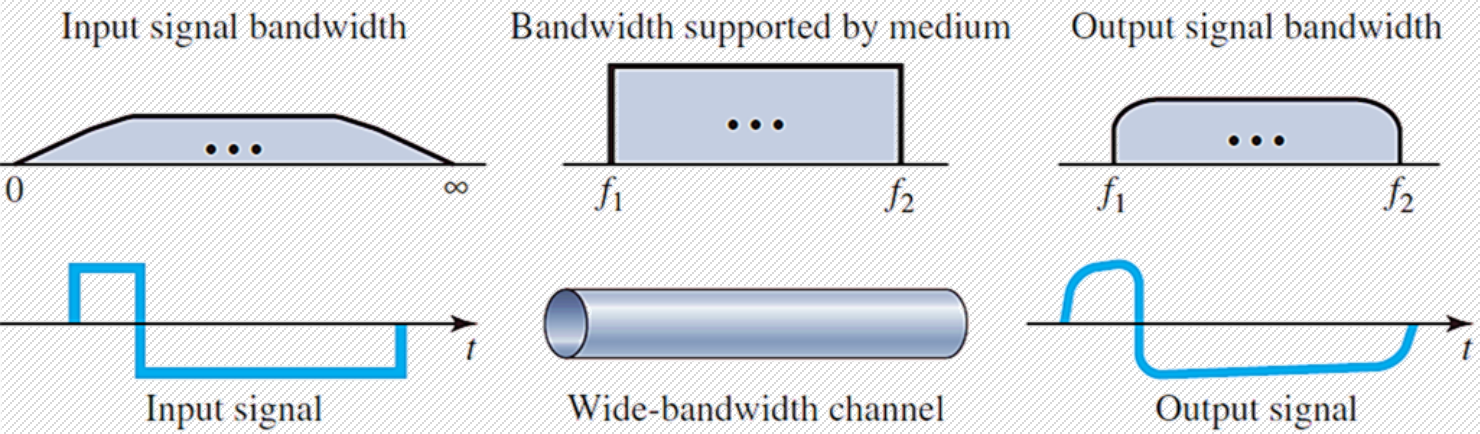
Transmission of Digital Signals

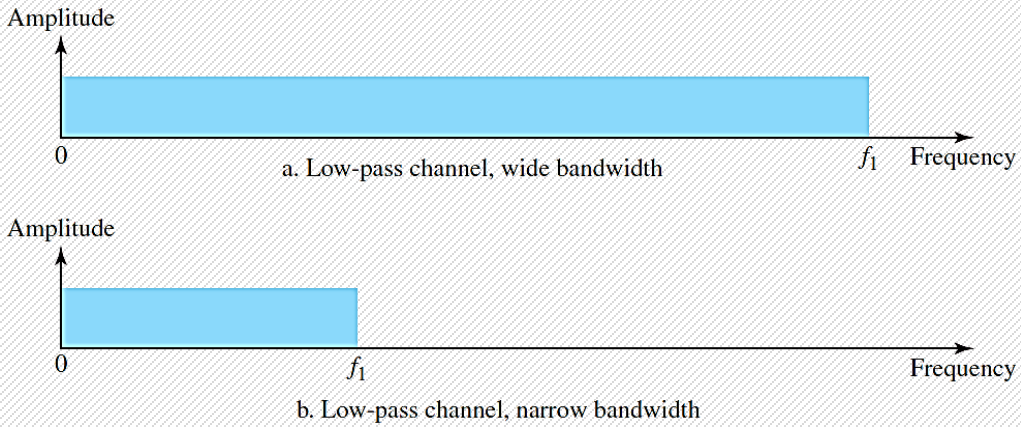
- To transmit a digital signal, we can use one of two different approaches: baseband transmission or broadband transmission.

Baseband Transmission

- Sending a digital signal over a channel without changing the digital signal to analog signal.
- It requires the low-pass channel with two cases: a wide bandwidth and a narrow bandwidth.

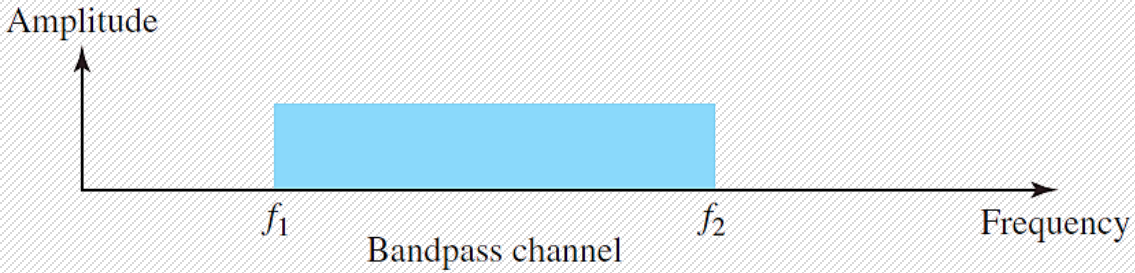


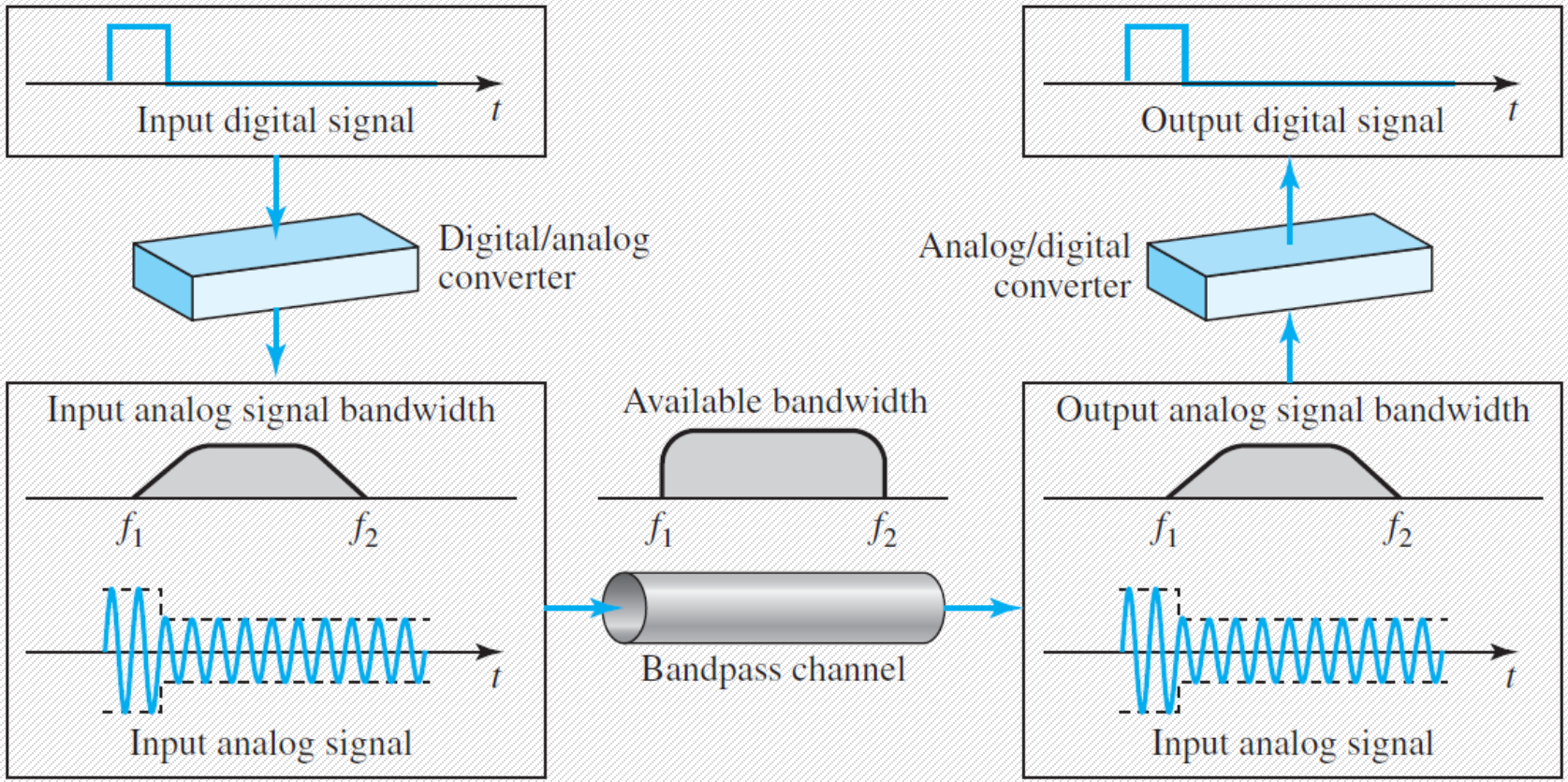




Broadband Transmission

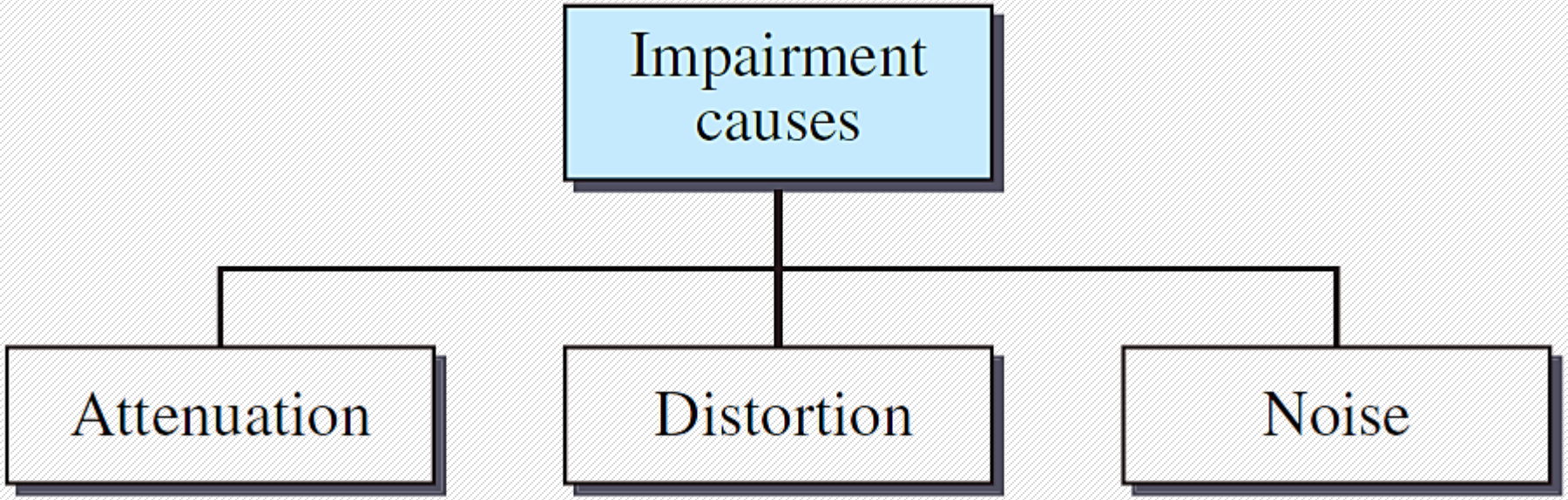
- Broadband transmission means changing the digital signal to analog signal for transmission. It allows to use a Bandpass channel.





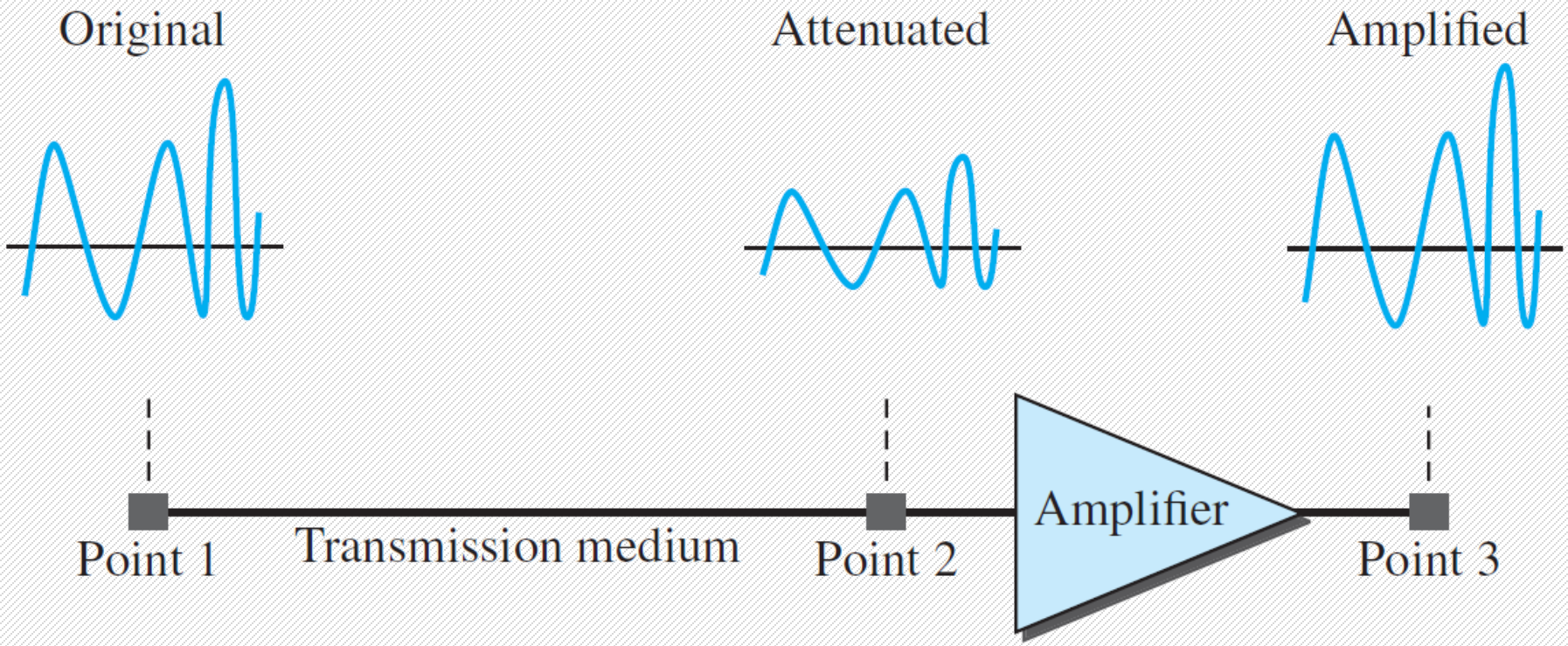
4. TRANSMISSION IMPAIRMENT

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



Attenuation

- Attenuation means a loss of energy, when a signal travels through a medium it losses some of its energy in overcoming the resistance of the medium. To compensate for this loss, amplifier are used to amplify the signal.

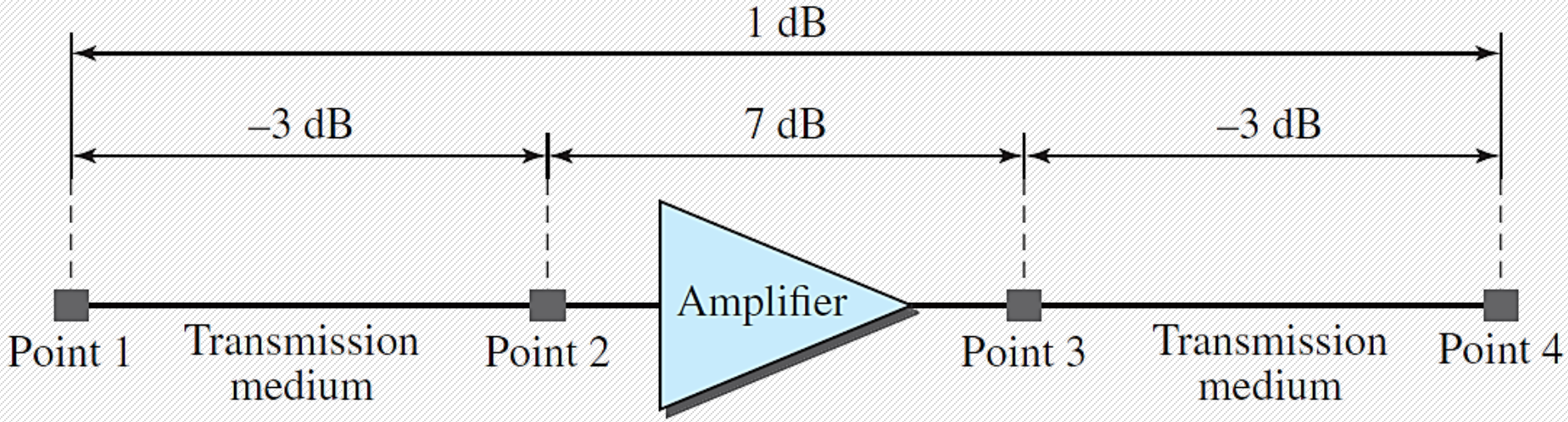


Decibel

- 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.

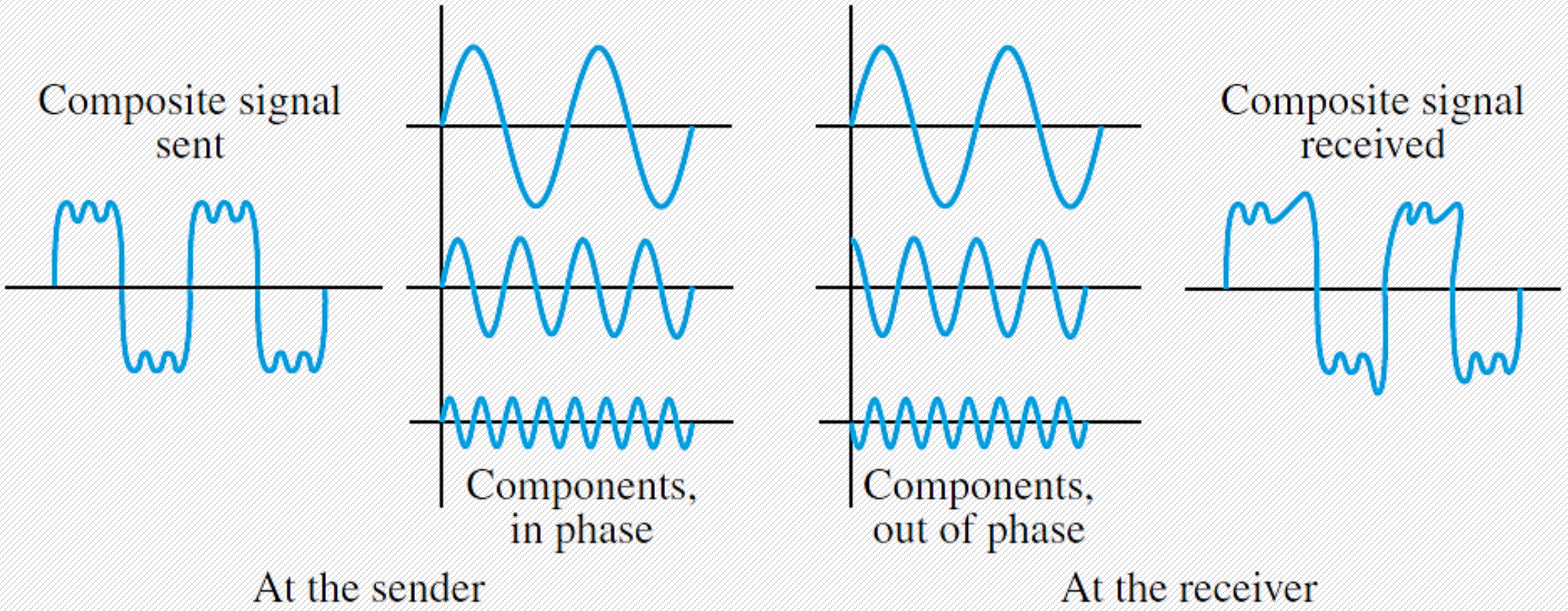
$$dB = 10 \log_{10} \frac{P_2}{P_1} \quad \text{or} \quad dB = 20 \log_{10} \frac{V_2}{V_1}$$

- P_1 and P_2 are the powers of a signal at point 1 and 2, respectively. Decibel can also define in term of voltage instead of power.



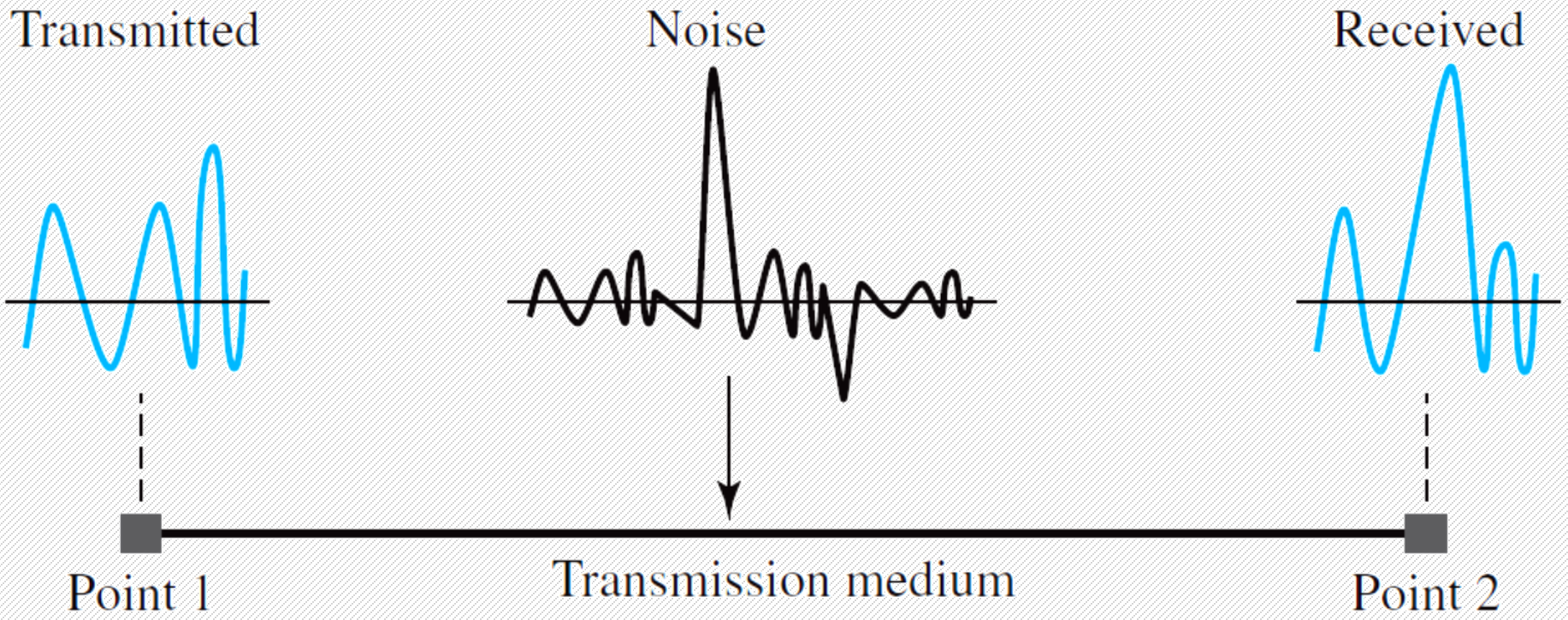
Distortion

- Distortion means that the signal changes its form or shape, which occur in a composite signal made of different frequencies.



Noise

- Noise is another cause of impairment; which has several types such as: thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.

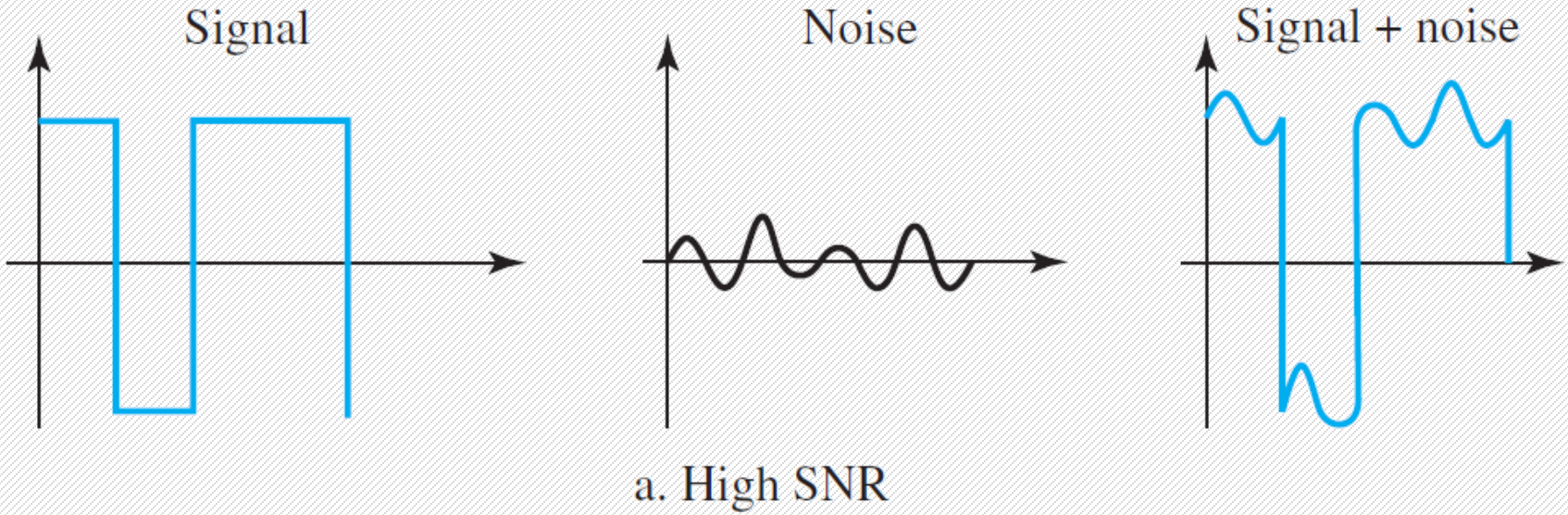


Signal-To-Noise Ratio (SNR)

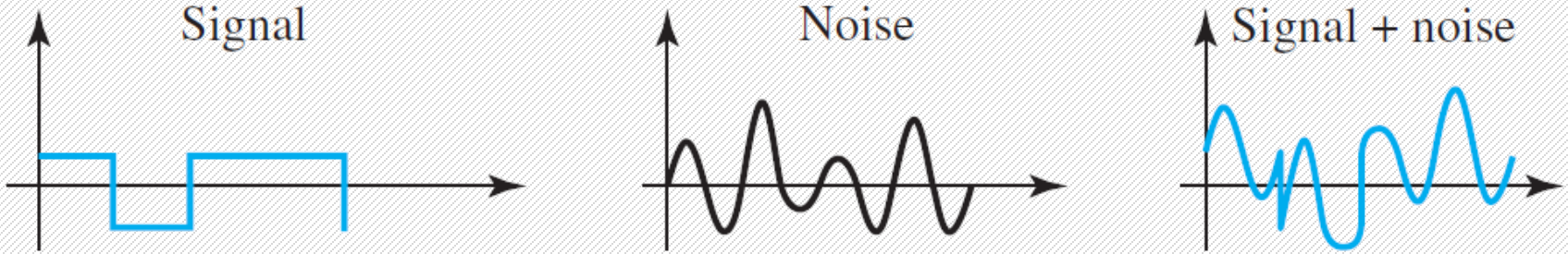
- SNR is used to measure the quality of system. SNR is defined as:

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

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



a. High SNR



b. Low SNR

- A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depend on three factors:
  1. The bandwidth available
  2. The level of the signals we use
  3. The quality of the channel (the level of noise)
- Two theoretical formulas were developed to calculate the data rate: one by Nyquist for a noiseless channel, another by Shannon for a noisy channel.

Noiseless Channel: Nyquist Bit Rate

- For a noiseless channel, the Nyquist bit rate formula defined the theoretical max bit rate.

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

  - Bandwidth is the bandwidth of the channel, L is the number of signal levels, Bit Rate in the bit rate (bps)

- Increasing the levels of a signal may reduce the reliability of the system.

Noisy Channel: Shannon Capacity

- Shannon capacity formula determine the theoretical highest data rate for a noisy channel:

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

  - Bandwidth is the bandwidth of the channel, SNR is the signal-to-noise ratio, and capacity is in bps.

Note: in Shannon capacity there is no indication of the signal level, which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of channel.

Using Both Limits

- In practical, we need to use both methods to find the limits and signal levels.
- The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

Example

1. Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. Calculate the maximum bit rate?
2. We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?
3. A regular telephone line is a noisy channel and normally has a bandwidth of 3000 Hz assigned for data communications. The signal to noise ratio is usually 3162. Calculate the capacity of this channel?
4. The signal-to-noise ratio is often given in decibels. Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. Then, calculate the channel capacity?
5. 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?

6. NETWORK PERFORMANCE

One important issue in networking is the performance of the network – how good is it?

- **Bandwidth**: bandwidth in hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass; bandwidth in bits per second refers to the speed of bit transmission in channel or link.
- **Throughput** is a measure of how fast we can actually send data through a network.
- **Latency (Delay)** defines how long it takes for an entire message to completely arrive at destination from the time the first bit is sent out from the source. Latency is made of four components: propagation time, transmission time, queuing time and processing delay.
- **Bandwidth-Delay Product** defines the number of bits that can fill the link.
- **Jitter** is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive.

7. SUMMARY

Data must be transformed to electromagnetic signals to be transmitted; it can be analog or digital. Analog data are continuous and take continuous values, digital data have discrete states and take discrete values.

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

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

For a noiseless channel, Nyquist bit rate formula defines the theoretical maximum bit rate. For a noisy channel, we need to use the Shannon capacity to find the maximum bit rate.

8. HOMEWORK

1. What is the relationship between period and frequency?
2. Distinguish between baseband transmission and broadband transmission.
3. A line has a signal-to-noise ratio of 1000 and a bandwidth of 4000 KHz. What is the maximum data rate supported by this line?
4. A signal with 200 milliwatts power passes through 10 devices, each with an average noise of 2 microwatts. What is the SNR? What is the SNR in dB?
5. We have a channel with 4 KHz bandwidth. If we want to send data at 100 Kbps, what is the minimum SNR in dB? What is the SNR?

DIGITAL TRANSMISSION

PART-II

Thank you!

Any Question?