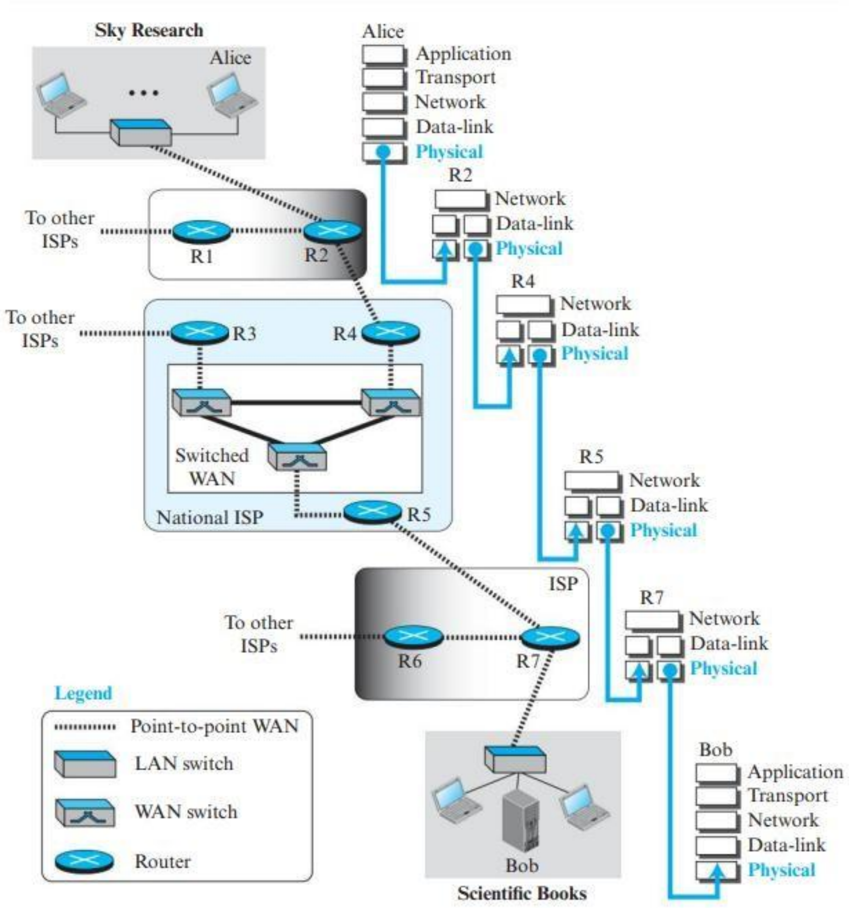
# Chapter - 6

Physical Layer

# Topics

- Analog Signals and Digital Signals
- Data Transmission and Multiplexing
- Transmission Media

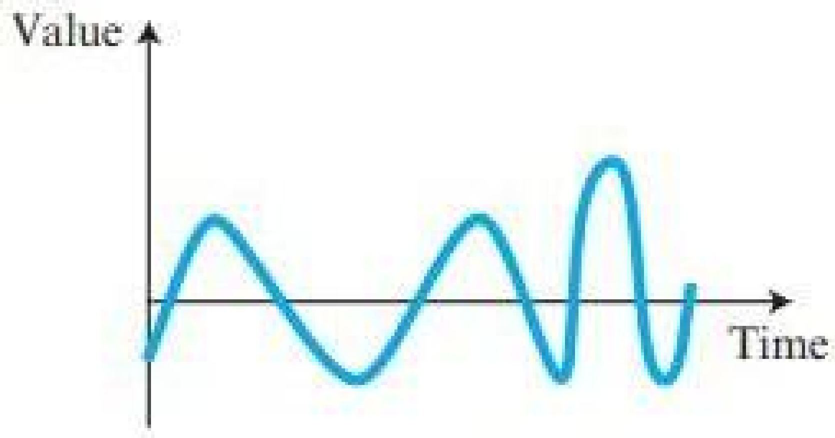
# DATA AND SIGNALS



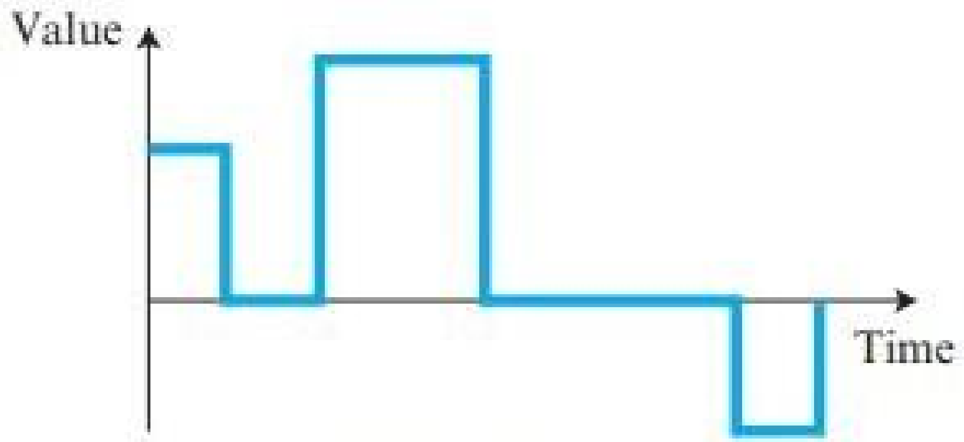
# Analog and Digital

- **Analog data** refers to information that is continuous. Analog data, such as the sounds made by a human voice, take on continuous values.
- When someone speaks, an analog wave is created in the air. This can becaptured by a microphone and converted to an analog signal or sampled and converted to a digital signal.
- **Digital data** take on discrete values. For example, data are stored in computer memory in the form of 0s and 1s. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.

Like the data they represent, signals can be either analog or digital. An analog signal has infinitely many levels of intensity over a period of time. As the wave moves from value A to value B, it passes through and includes an infinite number of values along its path. A digital signal, on the other hand, can have only a limited number of defined values. Although each value can be any number, it is often as simple as 1 and 0. The simplest way to show signals is by plotting them on a pair of perpendicular axes. The vertical axis represents the value or strength of a signal. The horizontal axis represents time.




a. Analog signal

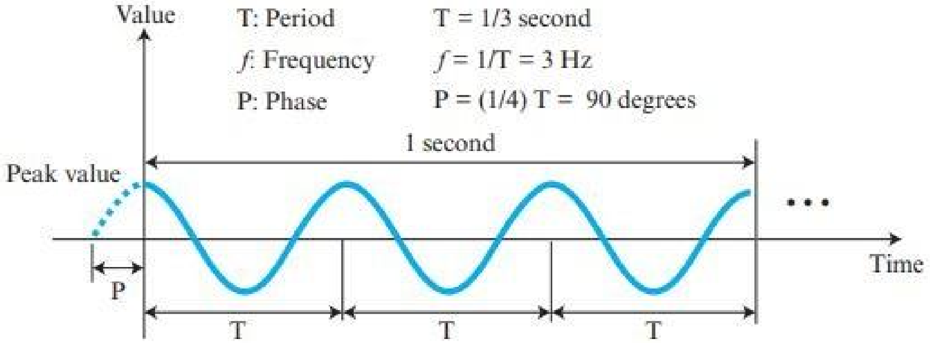



b. Digital signal

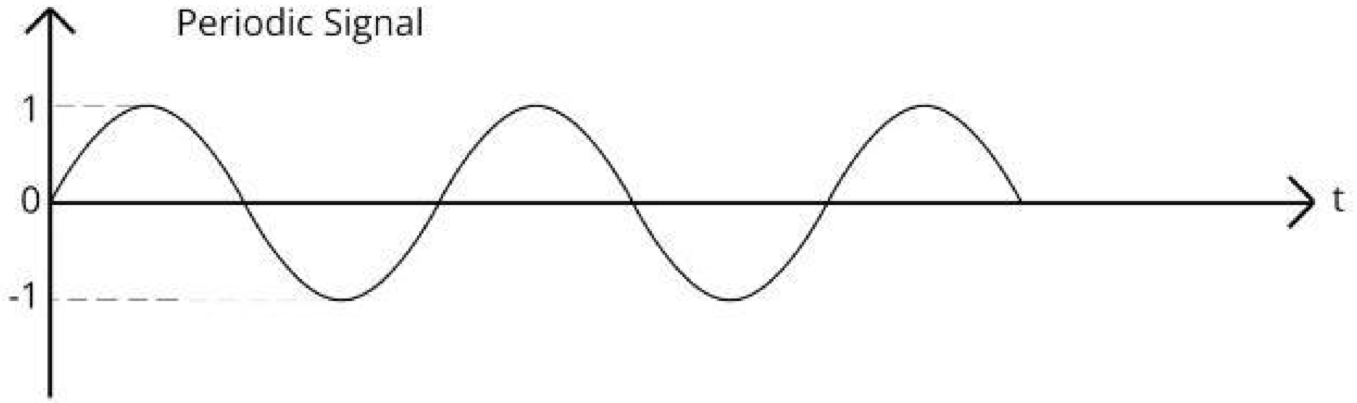
# Analog Signals

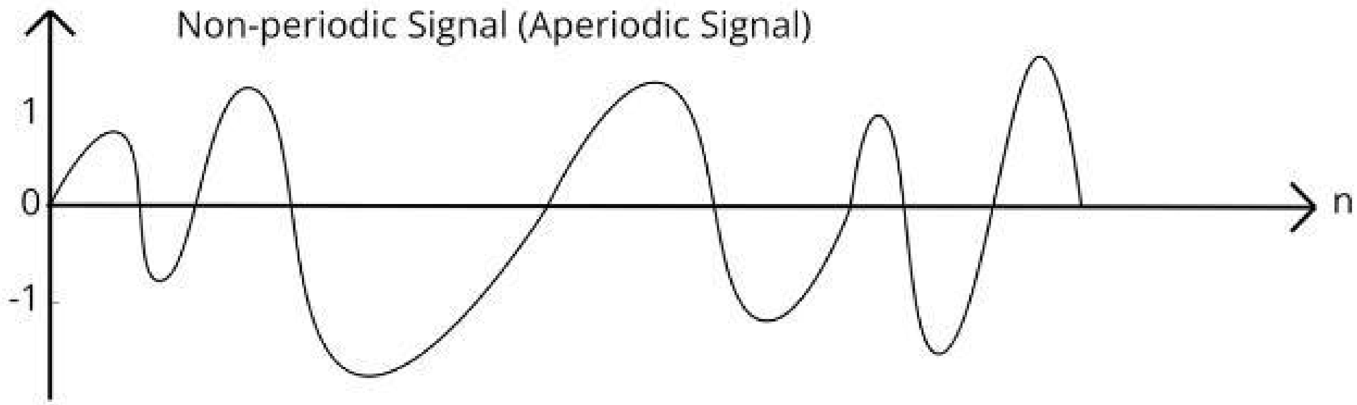
Let's first focus on analog signals, which can be either periodic or nonperiodic (aperiodic). A periodic analog signal completes a pattern within a measurable timeframe, called a **period**, and repeats this pattern over subsequent periods. Each full pattern is called a **cycle**. Conversely, a **nonperiodic analog signal does not exhibit a repeating pattern over time.**

In data communications, periodic analog signals are commonly used and can be classified as simple or composite. **A simple periodic analog signal, such as a sine wave, cannot be broken down into simpler signals**. A composite periodic analog signal comprises multiple sine waves. The sine wave is the most fundamental form of a periodic analog signal, characterized by a smooth, continuous oscillating curve. Each cycle of a sine wave consists of one arc above the time axis followed by one arc below it.

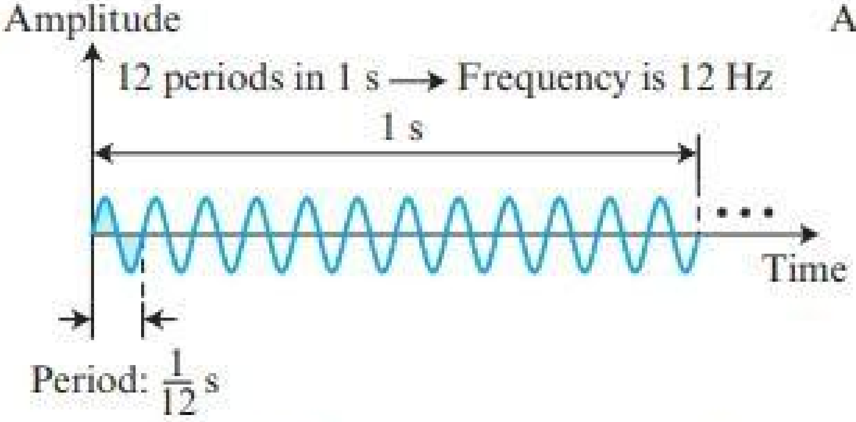


# Periodic and Non-Periodic Signals

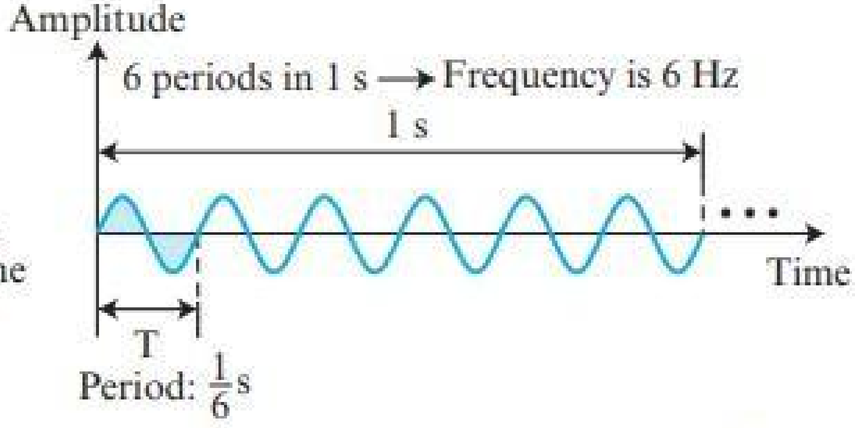


A sine wave can be described by three parameters: **peak amplitude, frequency(rate of change), and phase.** The peak amplitude is the a**bsolute value of the wave's highest intensity**, usually measured in volts for electric signals, and indicates the energy the wave carries. **Period refers to the time needed to complete one cycle**, measured in seconds, while **frequency, measured in Hertz (Hz), indicates the number of cycles per second.** Period and frequency are inversely related (f = 1/T).

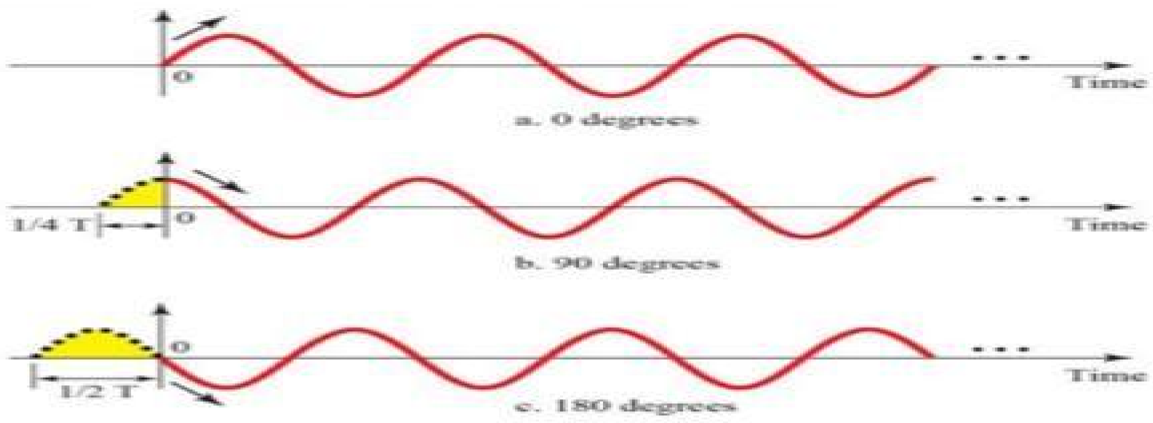



a. A signal with a frequency of 12 Hz

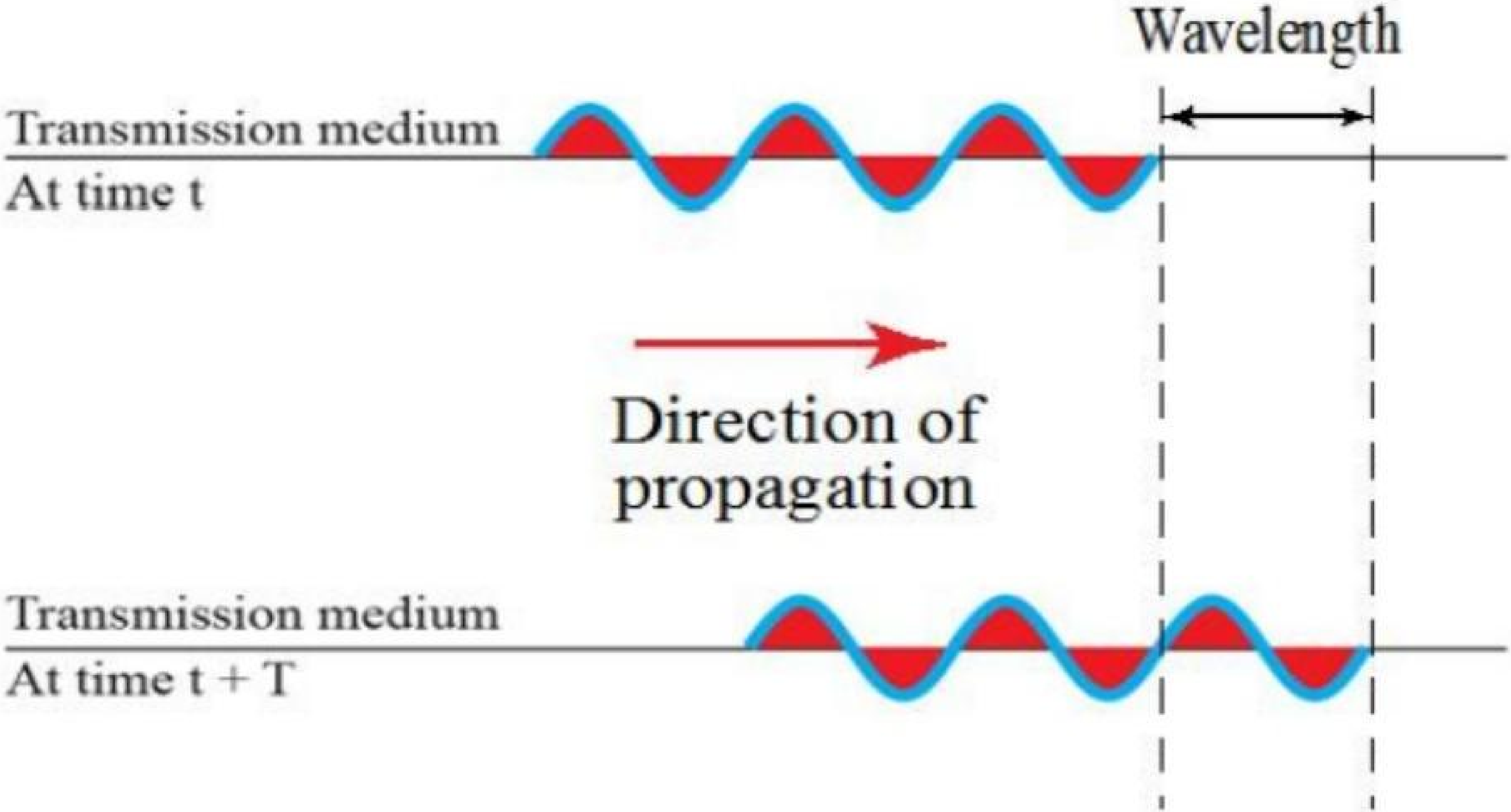



b. A signal with a frequency of 6 Hz

the position of a waveform relative to time 0, indicating the amount of shift along the time axis and the status of the first cycle. It is measured in degrees or radians (360° = 2π radians).




**Wavelength is the distance a signal travels in one period**, linking the period or frequency of a sine wave to the propagation speed of the medium. While frequency is independent of the medium, wavelength depends on both frequency and the medium. Wavelength is often used to describe light transmission in optical fibers. It can be calculated using the formula **λ = c / f, where λ is the wavelength, c is the propagation speed, and f is the frequency.**


Wavelength
Transmission medium
At time t
Direction of
propagation
Transmission medium
At time t + T

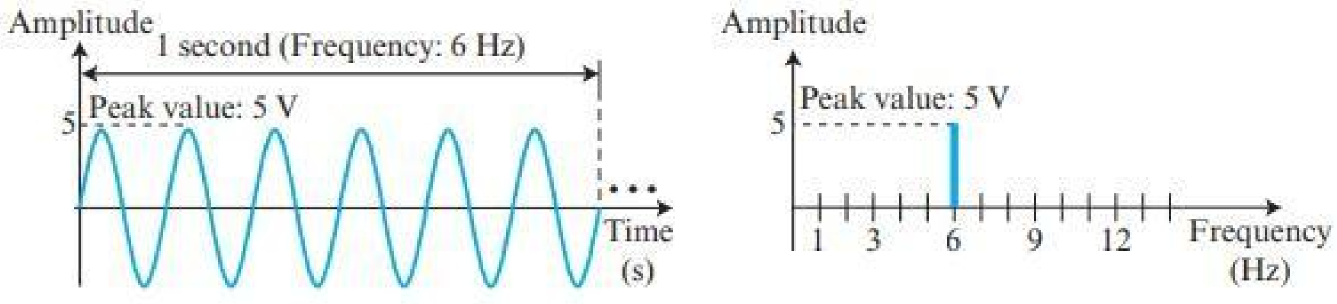
# Signal Attributes

| Property | Definition | Symbol | Measured in | Extra Information |
|---|---|---|---|---|
| Displacement | Distance a particle has moved from its equilibrium position | | Meters(m) | |
| Amplitude | Maximum displacement | | Meters(m) | |
| Wavelength | Length of one full wave(cycle) | λ | Meters(m) | |
| Frequency | Number of full cycles per second | f | Hz | |
| Time Period | Time to complete one full cycle | T | Seconds | F=1/T |
| Phase | Position of waveform relative to time 0 | φ | Degree/Radian | |

# Time and Frequency Domains

A sine wave is comprehensively defined by its amplitude, frequency, and phase. We have been showing a sine wave by using what is called a time-domain plot, which shows changes in signal amplitude with respect to time. **To show the relationship between amplitude and frequency, we can use a frequency-domain plot.** Figure 7.5 shows a signal in both the time and frequency domains.

Figure 7.5 *The time-domain and frequency-domain plots of a sine wave*




a. A sine wave in the time domain

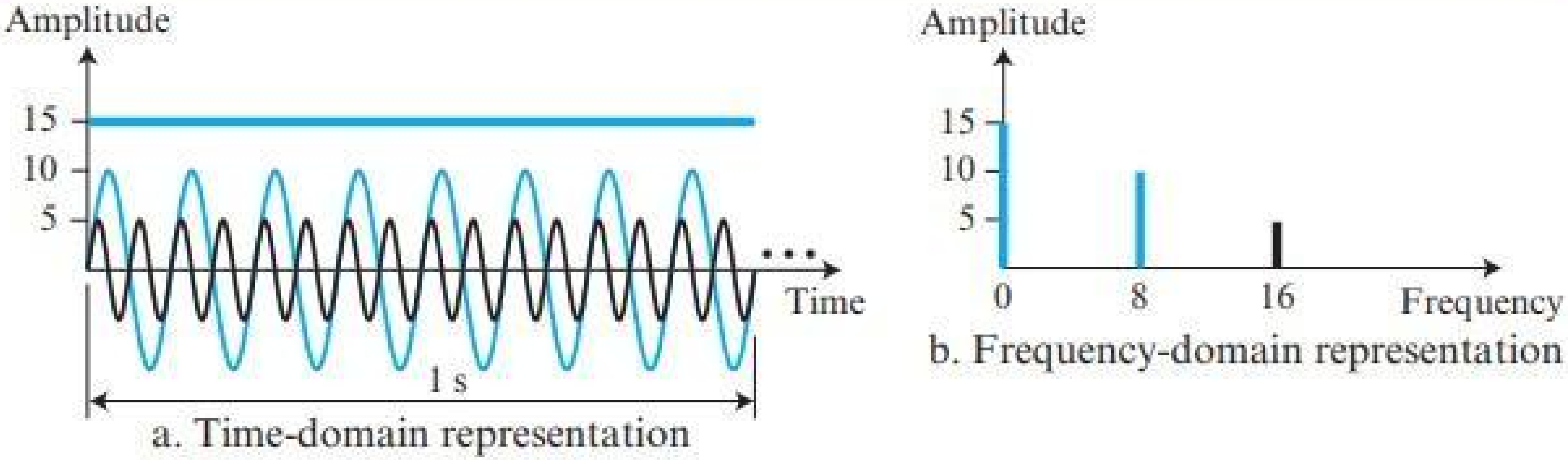
b. The same sine wave in the frequency domain

In the frequency domain, a sine wave is represented by one spike. The position of the spike shows the frequency; its height shows the peak amplitude.

### Example 7.1

The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, Figure 7.6 shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.

**Figure 7.6** *The time domain and frequency domain of three sine waves*

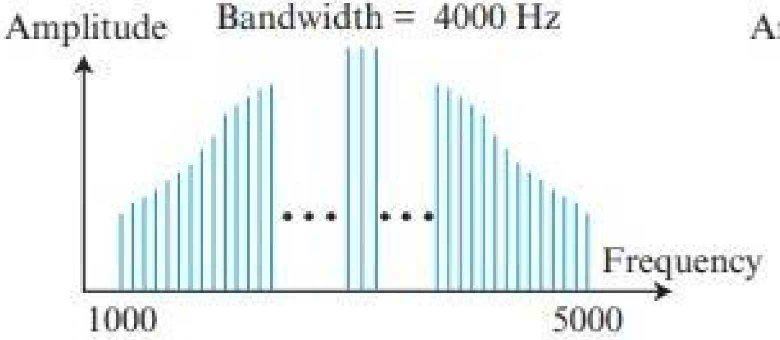


**Composite Signals**

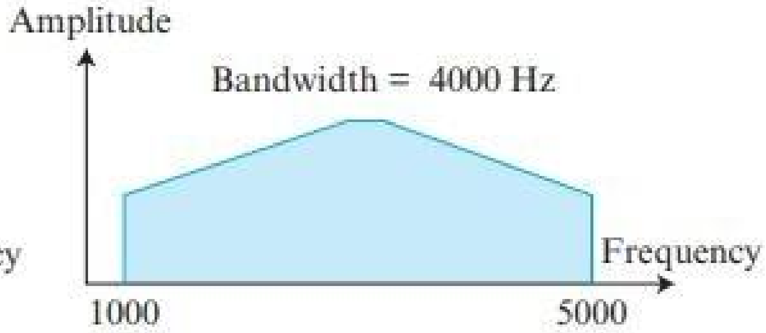
a single sine wave can't convey meaningful information, such as a conversation over the phone. Instead, we use composite signals, made of many simple sine waves. In the early 1900s, mathematician Jean-Baptiste Fourier demonstrated that any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases. Composite signals can be periodic or nonperiodic. **A periodic composite signal can be decomposed into simple sine waves with discrete frequencies, which are integral multiples of the fundamental frequency. A nonperiodic composite signal can be decomposed into an infinite number of simple sine waves with continuous, real-valued frequencies.**

**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

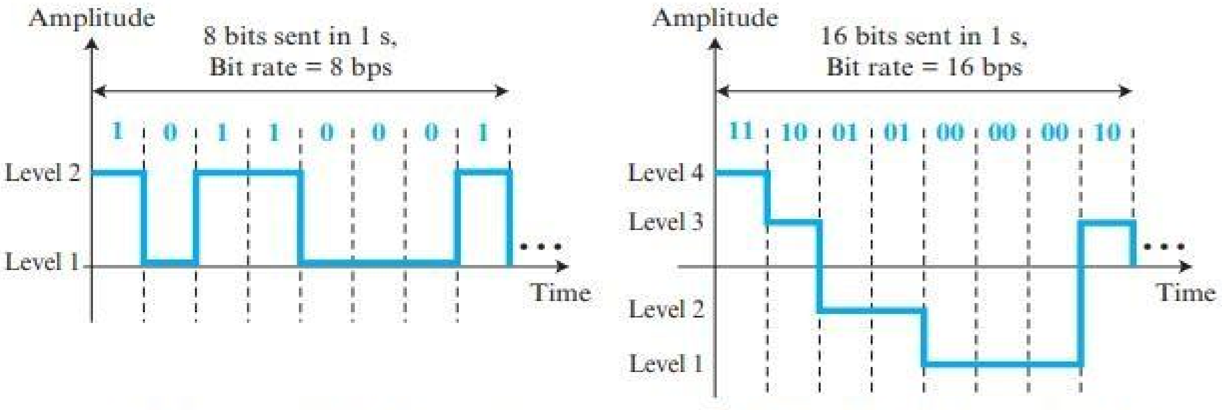


b. Bandwidth of a nonperiodic signal

# Digital Signals

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 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. Figure 7.8 shows two signals, one with two levels and the other with four. We send 1 bit per level in part a of the figure and 2 bits per level in part b of the figure. In general, if a signal has L levels, each level needs log2L bits.

**Figure 7.8** *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

**Bit Rate**

Most digital signals are nonperiodic, making period and frequency inappropriate characteristics. Instead, we use the term bit rate to describe digital signals, which is the number of bits sent in one second, expressed in bits per second (bps).

**Bit Length**

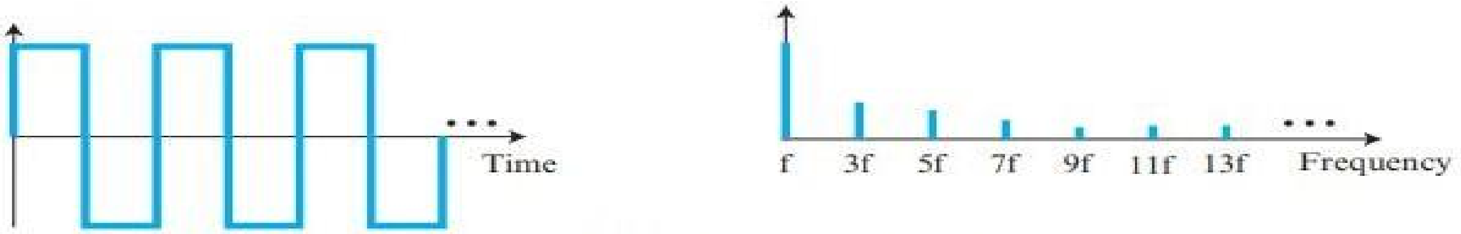
The bit length is the distance one bit occupies on the transmission medium.

Bit length = propagation speed × bit duration

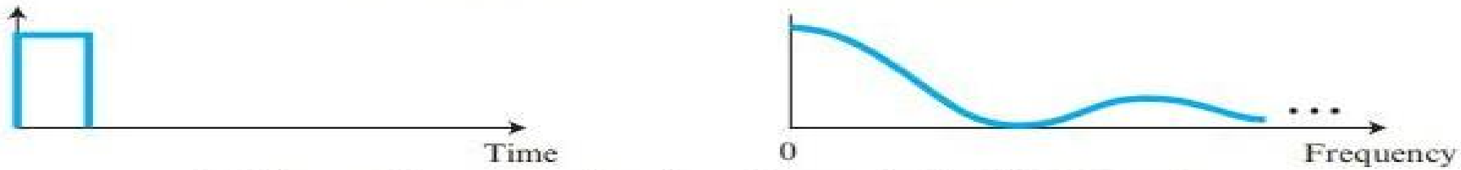
***bit length = 1 / bit rate***

# Digital Signal as a Composite Analog Signal

- **a digital signal is a composite analog signal with infinite bandwidth.** In the time domain, a digital signal consists of connected vertical and horizontal line segments. **A vertical line indicates an infinite frequency (sudden change), while a horizontal line indicates a frequency of zero (no change). This implies all frequencies between zero and infinity are present.**
- Fourier analysis can decompose a digital signal. For a periodic digital signal (rare in data communications), the decomposed signal has an infinite bandwidth with discrete frequencies. For a nonperiodic digital signal, the decomposed signal also has infinite bandwidth, but with continuous frequencies.




a. Time and frequency domains of periodic digital signal




b. Time and frequency domains of nonperiodic digital signal

**Transmission of Digital Signals**

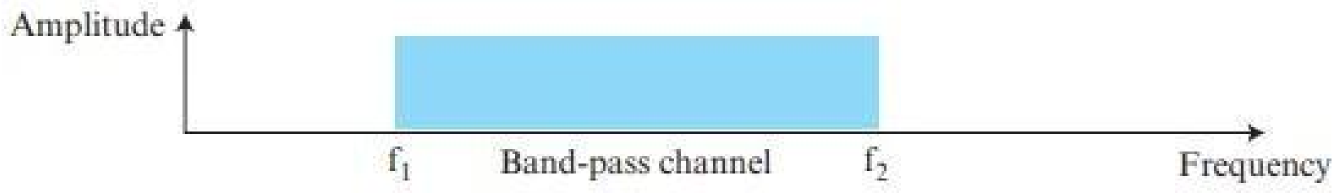
A digital signal, **whether periodic or nonperiodic, is a composite analog signal with frequencies ranging from zero to infinity.** For our discussion, we'll focus on nonperiodic digital signals common in data communications. The key question is how to transmit a digital signal from point A to point B. There are two approaches: baseband transmission or broadband transmission (using modulation).

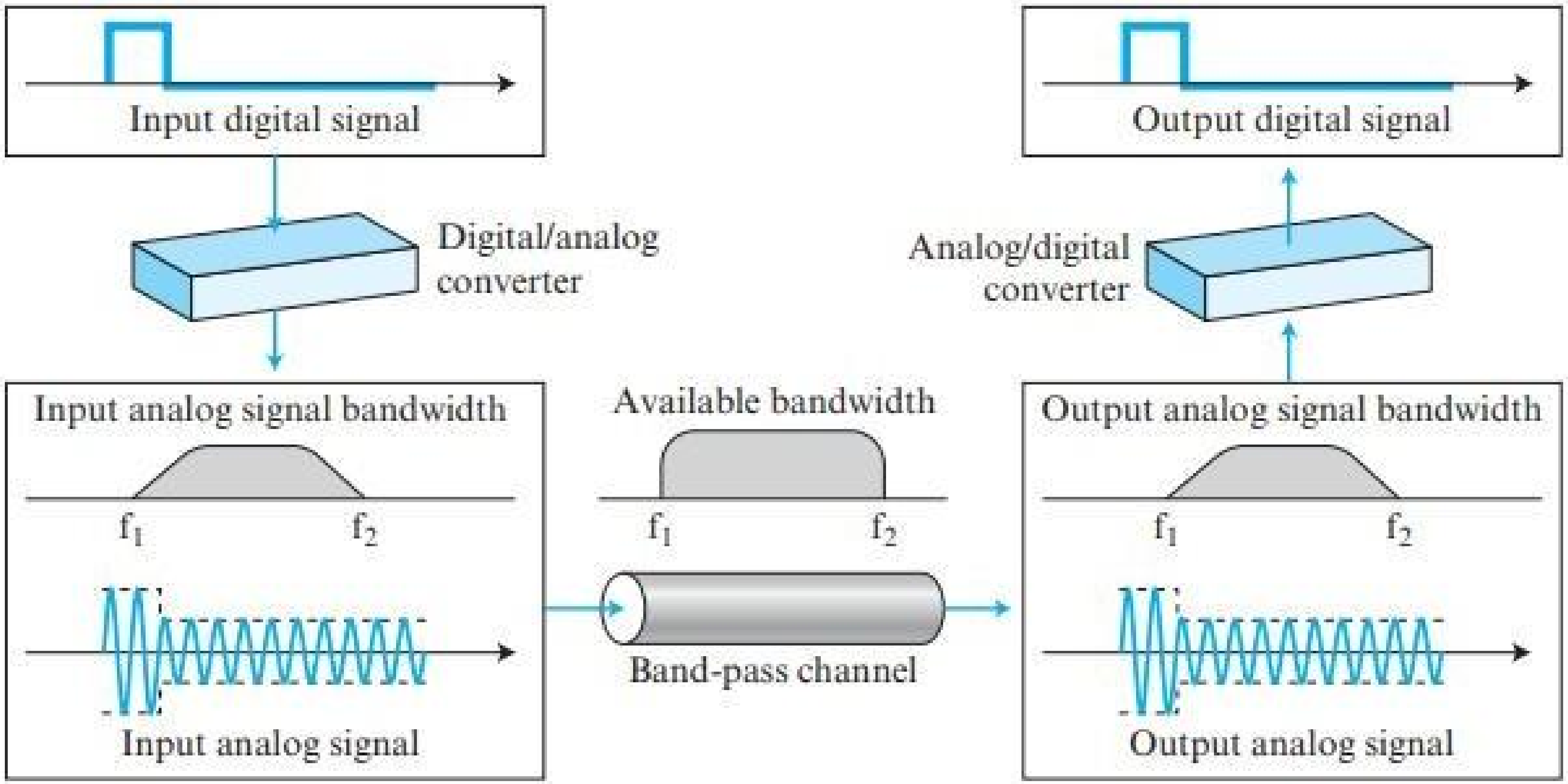
**Baseband Transmission**

Baseband transmission involves **sending a digital signal over a channel without converting it to an analog signal**. This method requires a low-pass channel, which has a **bandwidth starting from zero**. Examples include a **dedicated cable** connecting two computers or a medium where only two stations communicate at a time. In both cases, the entire bandwidth constitutes a single channel suitable for baseband communication.

## Broadband Transmission

Broadband transmission, or modulation, **involves converting a digital signal to an analog signal for transmission.** This method uses a band-pass channel, **which has a bandwidth that doesn't start from zero** and is more commonly available than a low-pass channel. **In modulation, a digital signal is converted to a composite analog signal using a carrier frequency.** The carrier's amplitude is varied to match the digital signal, resulting in a composite signal. At the receiver end, the analog signal is converted back to digital, replicating the original signal sent.



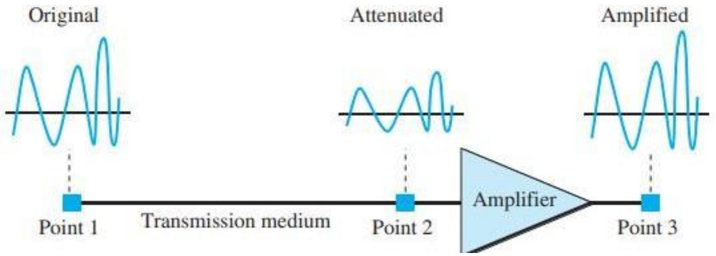

Input digital signal
Digital/analog converter
Input analog signal bandwidth
f1
f2
Input analog signal
Available bandwidth
f1
f2
Band-pass channel
Output digital signal
Analog/digital converter
Output analog signal bandwidth
f1
f2
Output analog signal

# Signal 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
  - ***attenuation***
  - ***distortion***
  - ***noise***.

# Attenuation and Amplification

- 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, we need amplification.

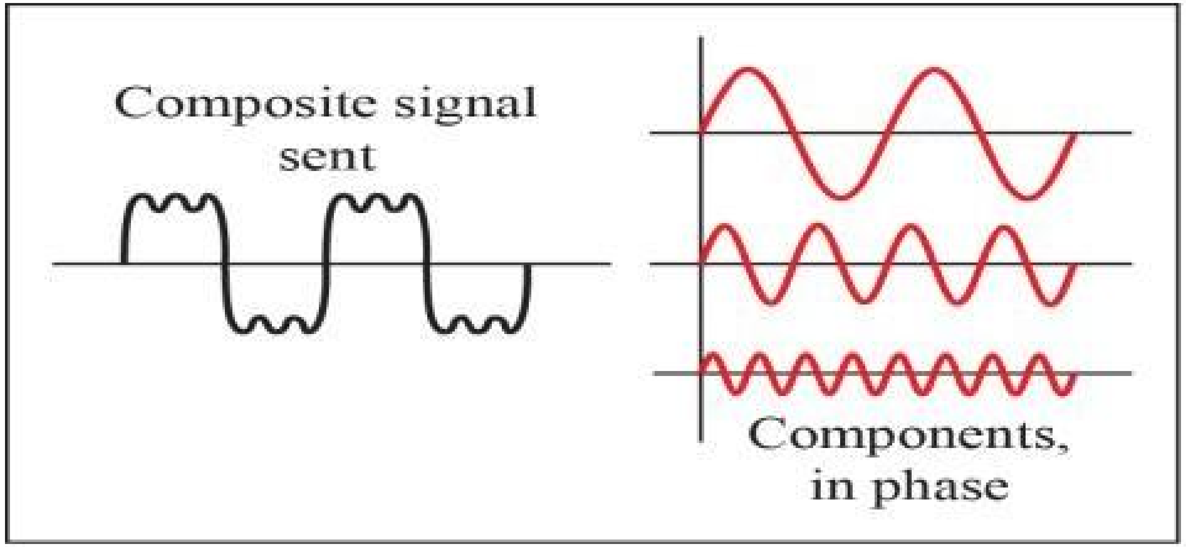



- The **decibel (dB)** measures the relative strength of two signals or one signal at two different points. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified. Variables P1 and P2 are the powers of a signal at points 1 and 2, respectively.

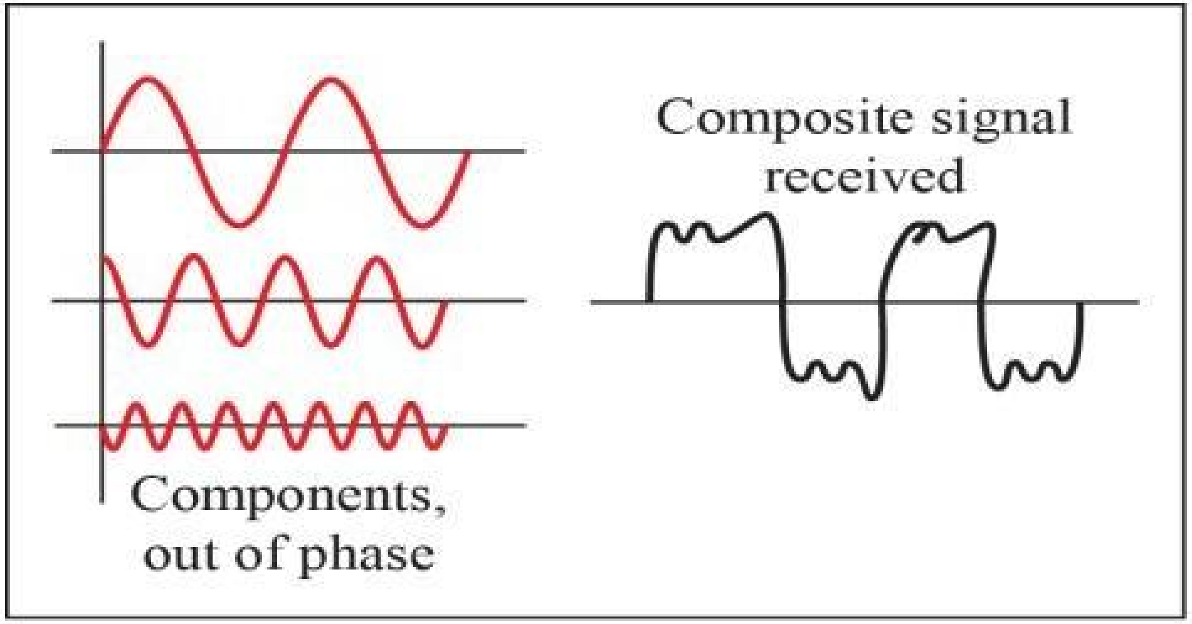
$$\mathrm{dB} = 10 \log_{10} (P_2/P_1)$$

# Distortion

- Distortion means that the signal changes its form or shape. Distortion can occur in a composite signal made up 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.



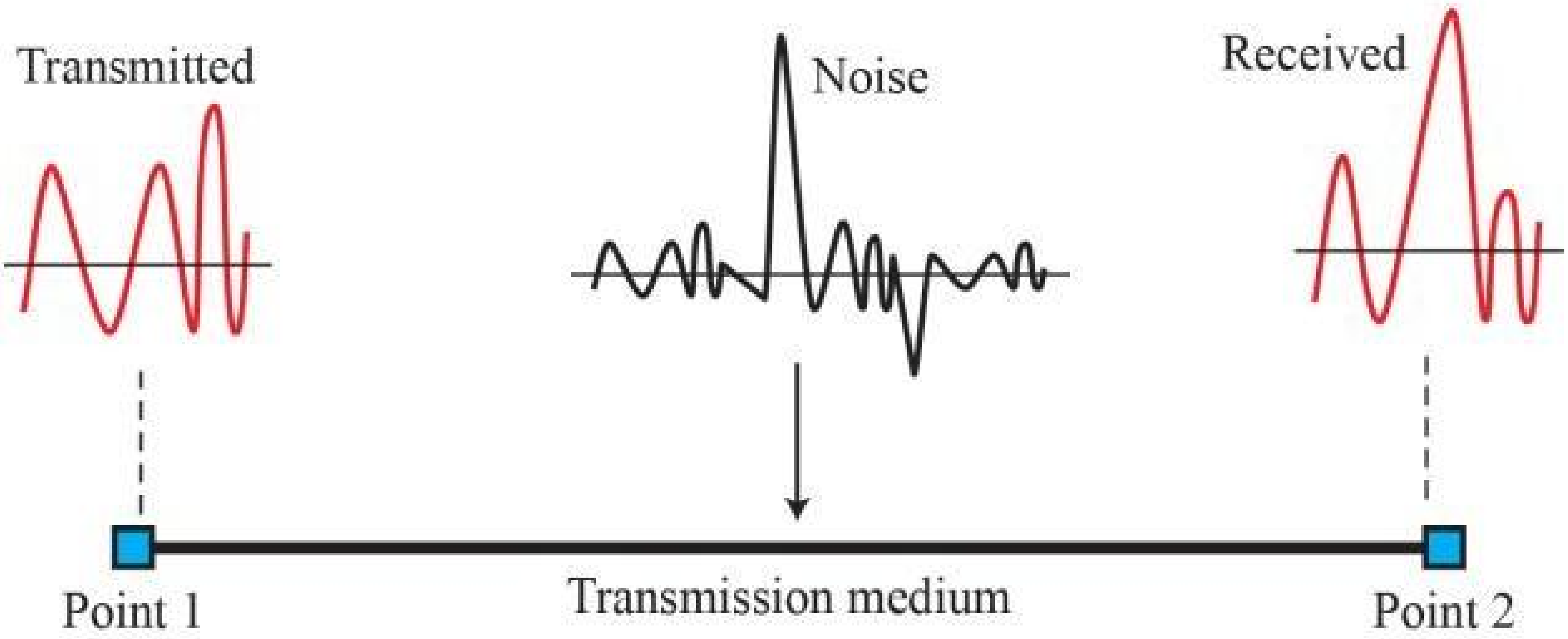
At the sender



At the receiver

# Noise

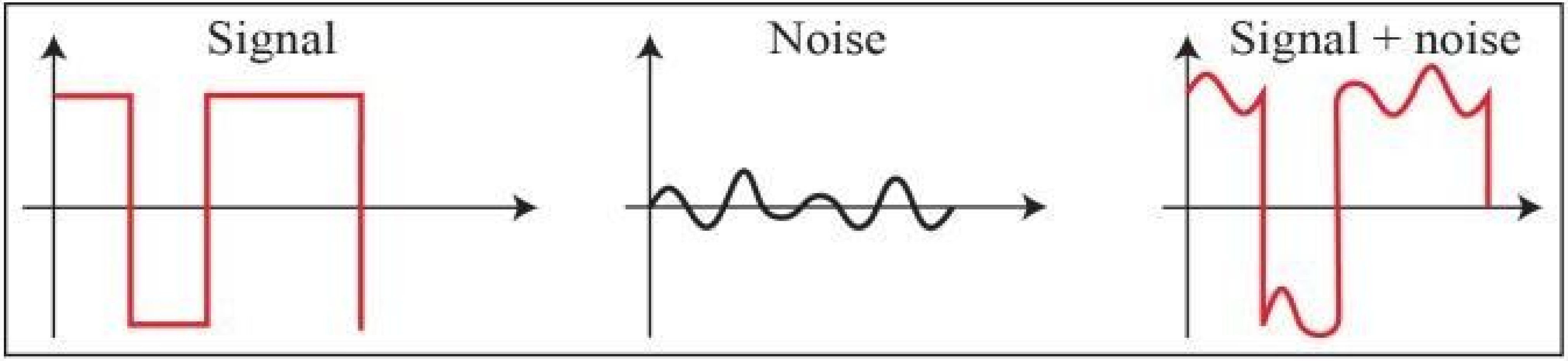
- Noise is another cause of impairment. Several types of noise, such as *thermal noise, induced noise, crosstalk, and impulse noise*, may corrupt the signal.
- ***Thermal noise*** is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter.
- ***Induced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



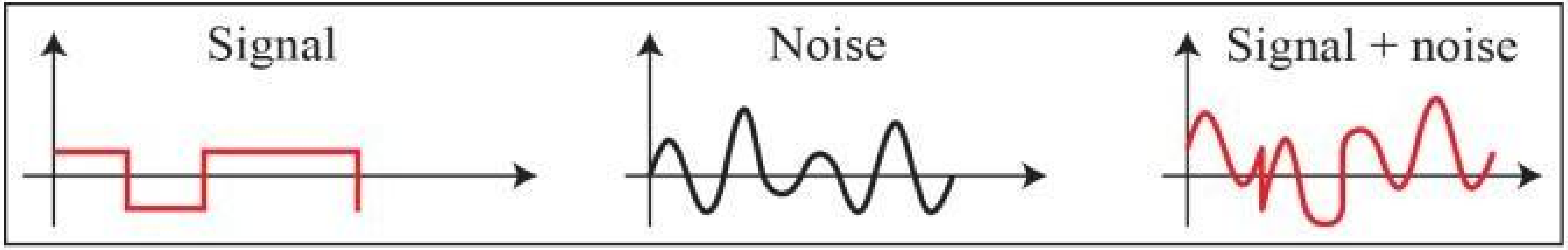
Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

# Noise

- To find the theoretical bit-rate limit, we need to know the ratio of the signal power to the noise power. The **signal-to-noise ratio** is defined as -
  - ***SNR = average signal power / average noise power***
- Because SNR is the ratio of two powers, it is often described in decibel units, $SNR_{dB}$ as -
  - **$SNR_{dB} = 10 \log_{10} SNR$**




a. High SNR




b. Low SNR

# Data Rate Limits

- Data Rate Limit is how fast we can send data over a channel. It is measured in bits per second.
- Data rate depends on three factors:
  - The bandwidth available
  - The level of the signals we use
  - The quality of the channel (the level of noise)
- For a noiseless channel, the **Nyquist bit rate** formula defines the theoretical maximum bit rate
  - **BitRate = 2 x B x $\log_2$ L** where B is bandwidth of the channel and L is signal level
- For a noisy channel, the **Shannon capacity** formula to determine the theoretical highest bit rate -
- **C = B x $\log_2$ (1 + SNR)** defines the capacity of channel where ***SNR = average signal power / average noise power***

# Performance Metrics

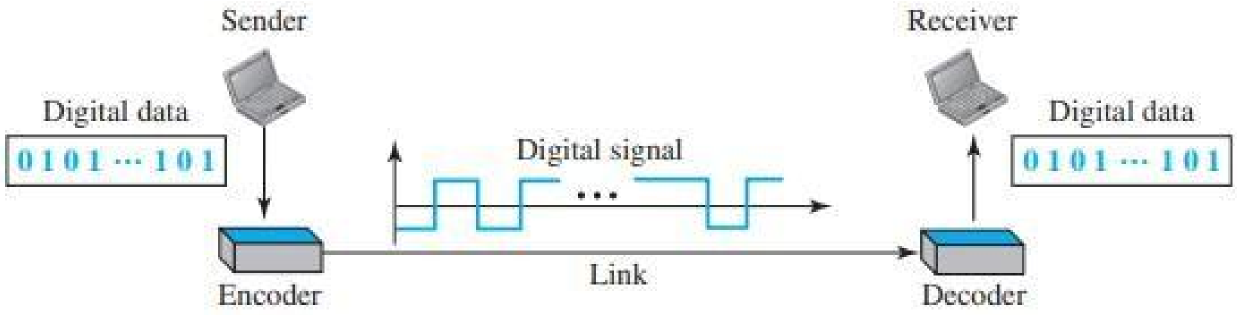
- Bandwidth
- Throughput
- Latency (Delay)
- **Jitter** - It is the variation in the time delay between received signals compared to the expected time intervals.

# Digital Transmission

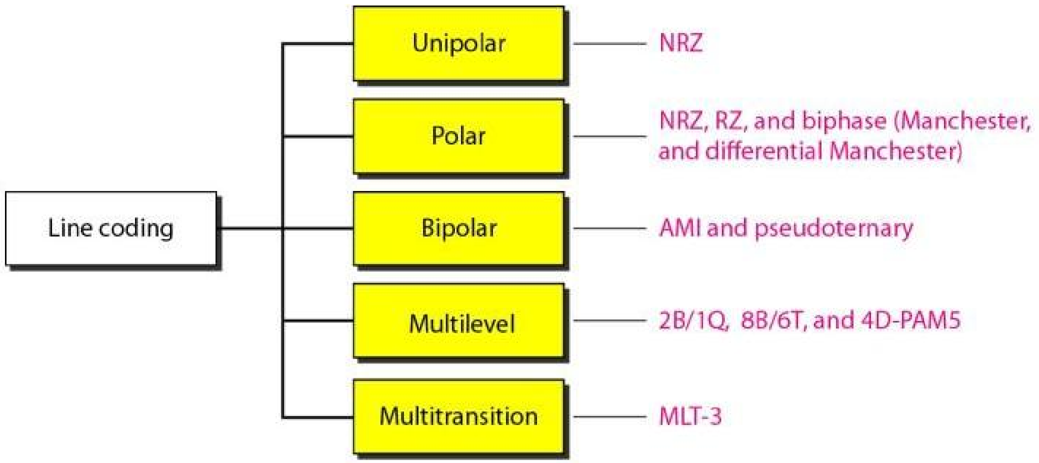
- A computer network is designed to send information from one point to another. This information needs to be converted to either a digital signal or an analog signal for transmission.
- In digital transmission, we transmit data using digital signals.
- If our data is in digital form (discrete data like text, images, etc.) then we need ***digital-to-digital encoding techniques.***
- If our data is in analog form (continuous data like temperature, etc.) then we need ***analog-to-digital encoding techniques.***

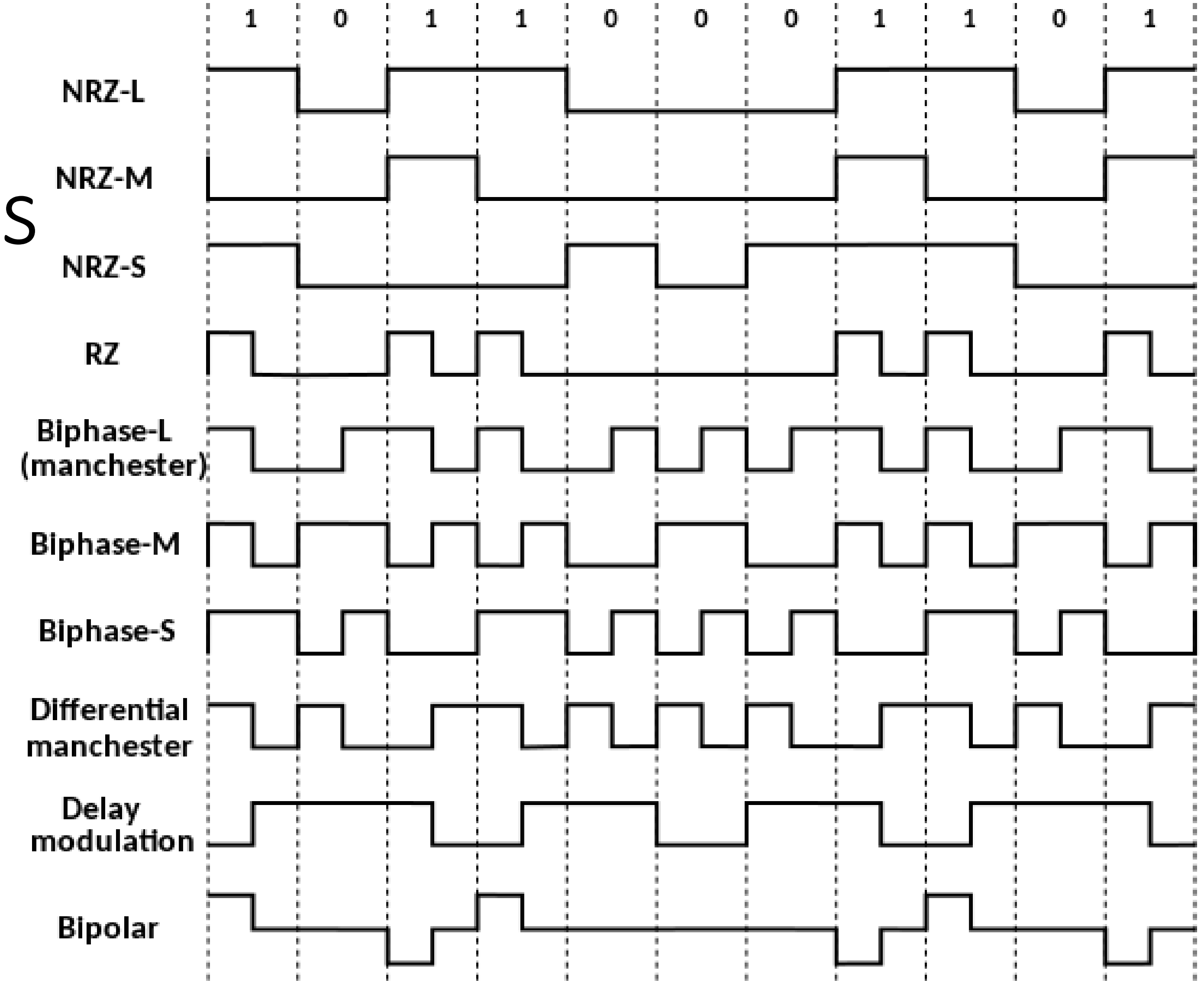
# Digital-to-Digital Conversion

- For digital transmission of digital data, digital-to-digital conversion is necessary, involving line coding, block coding, and scrambling. Line coding is always required, while block coding and scrambling are optional.
- **Line Coding**
- Line coding converts digital data into digital signals. Data stored as sequences of bits (e.g., text, numbers, images, audio, video) are encoded into a digital signal by the sender and decoded back into digital data by the receiver.



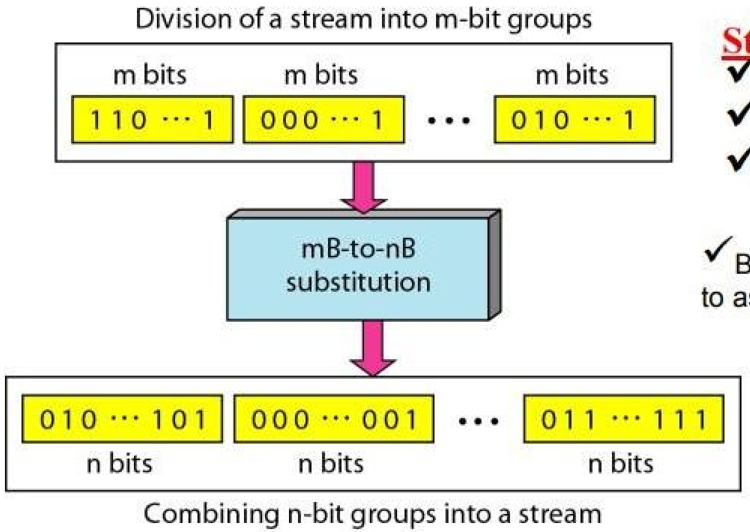
# Line Coding Schemes

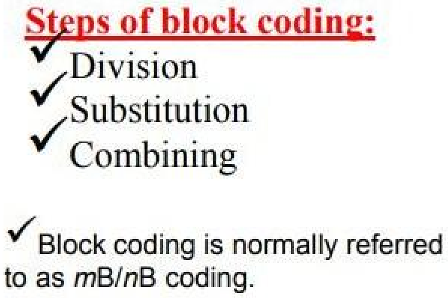


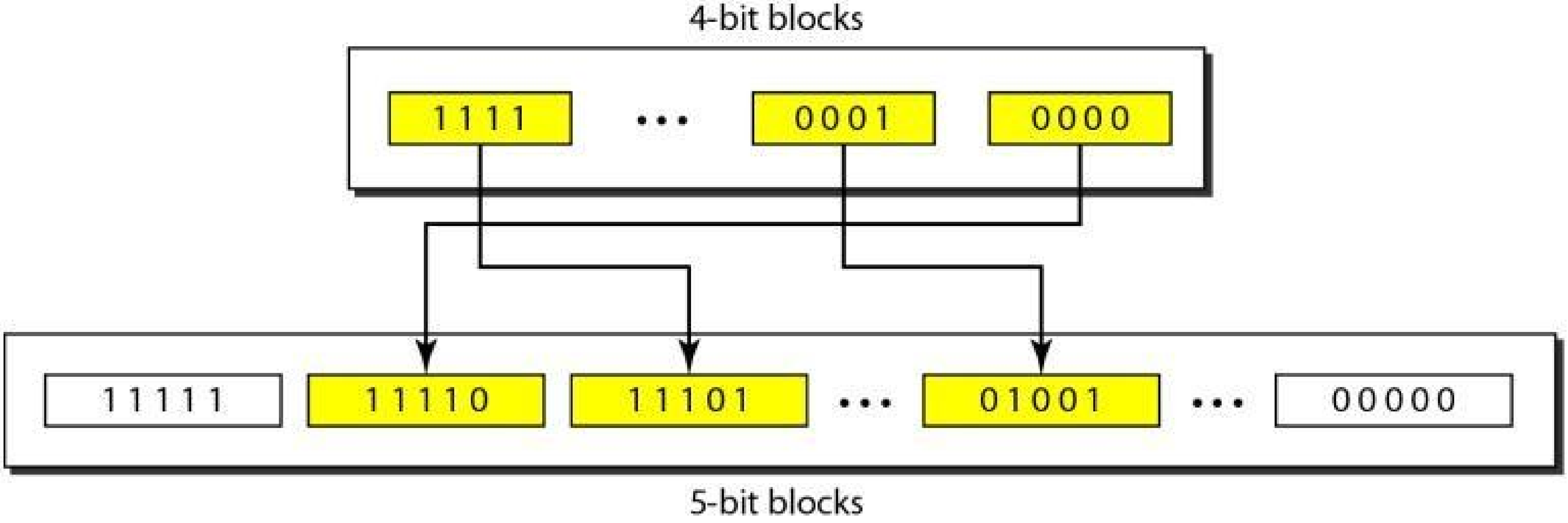
# Block Coding

- Block coding changes a block of **m bits** into a block of **n bits**, where n is larger than m. That's block coding is also known as ***mB/nB*** **coding**.
- Extra bits (redundancy bits) are added to ensure synchronization and to provide error detection.
- Block coding involves three steps - Division, Substitution, Combining



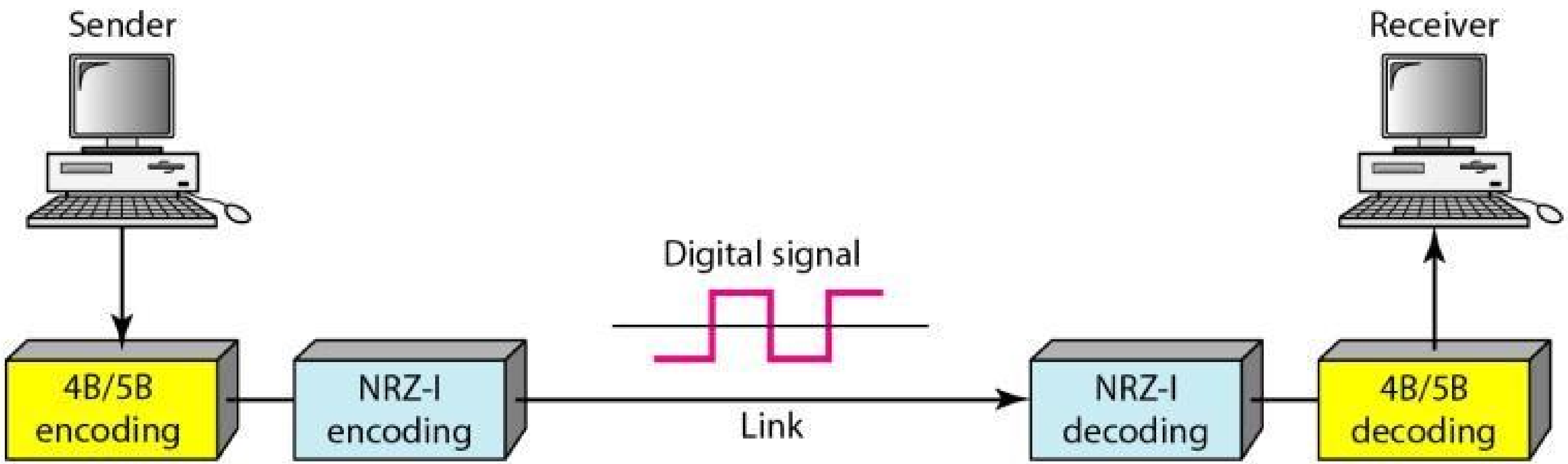



# Block Coding



# Block coding with line coding

**Figure 4.15** *Using block coding 4B/5B with NRZ-I line coding scheme*



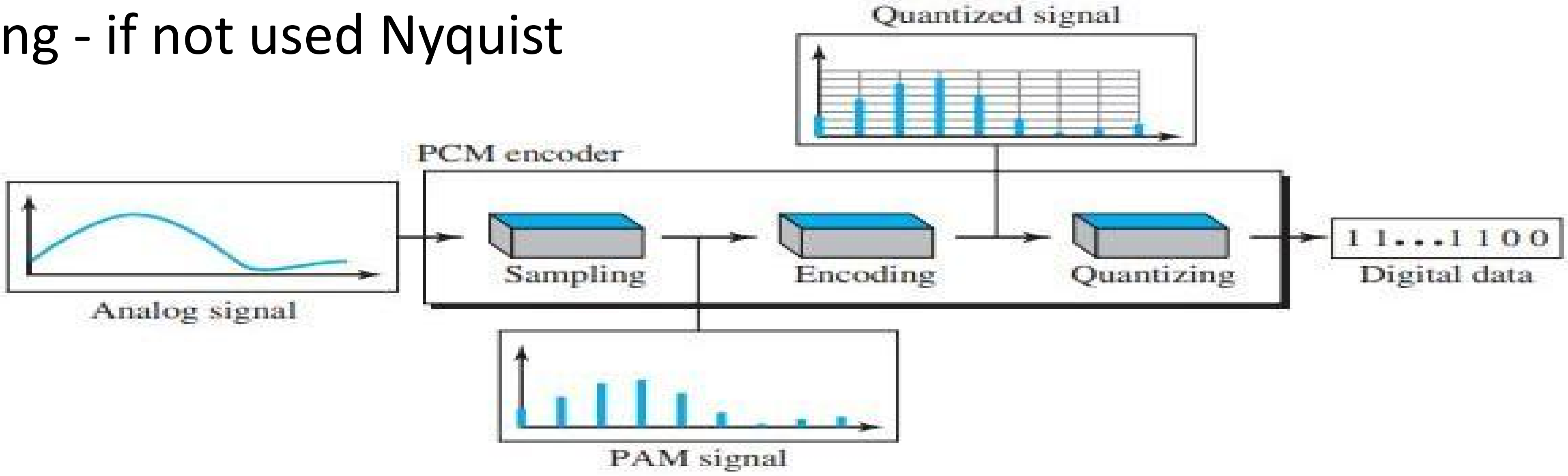
# Analog-to-Digital Conversion

- Analog signals from devices like microphones or cameras are often converted to digital data to reduce noise susceptibility. This section covers two digitization techniques: pulse code modulation and delta modulation. Once digitized, the data can be converted to a digital signal using methods from futher sections.

**Pulse Code Modulation (PCM)**

The most common technique used to change an analog signal to digital data (digitization) is called pulse code modulation (PCM). A PCM encoder has three processes, as shown in next page

- Nyquist - no. of sample required
- aliasing - if not used Nyquist




The three processes are:

1. The analog signal is sampled every $T$ s.
2. The sampled signal is quantized, which means every sample is considered as a pulse.
3. The quantized values (pulses) are encoded as streams of bits.

# Example

- We want to digitize the human voice. What is the bit rate, assuming 8 bits per sample?
- **Solution** - The human voice normally contains frequencies from 0 to 4000 Hz. So the sampling rate and bit rate are calculated as

$$\text{Sampling rate} = 4000 \times 2 = 8000 \text{ samples/s}$$
$$\text{Bit rate} = 8000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$

***PCM Bandwidth***

It can be proved that the minimum bandwidth of the digital signal is

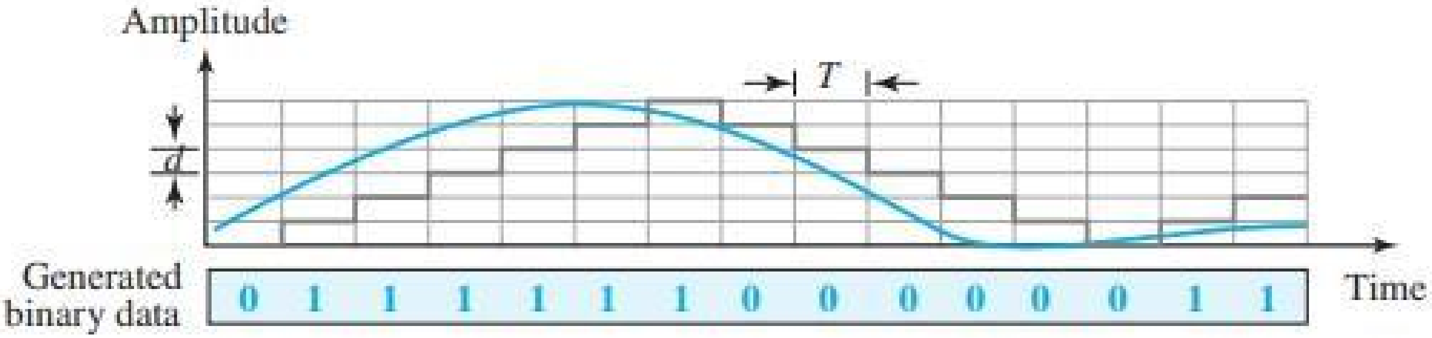
$$B_{min} = n_b \times B_{analog}$$

This means the minimum bandwidth of the digital signal is $n_b$ times greater than the bandwidth of the analog signal. This is the price we pay for digitization.

**Delta Modulation (DM)**

PCM is a complex technique, while delta modulation (DM) is simpler. PCM measures the signal amplitude for each sample, whereas DM measures the change from the previous sample. Figure 2.10 illustrates this process, where bits are sent sequentially without code words.

**Figure 2.10** *The process of delta modulation*



# Analog Transmission

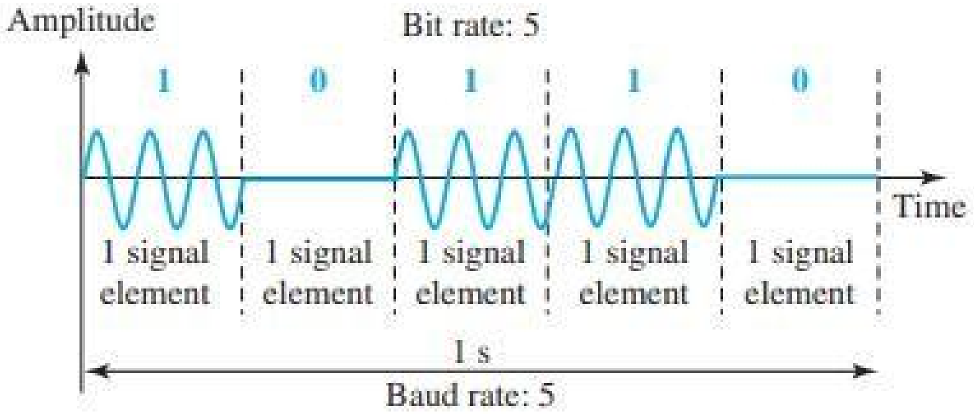
Digital transmission requires a low-pass channel (starting from 0), whereas analog transmission is necessary for a bandpass channel (not starting from 0). **Digital-to-analog conversion converts digital data to a bandpass analog signal, while analog-to-analog conversion changes a low-pass analog signal to a bandpass analog signal.** This section covers both conversion types.

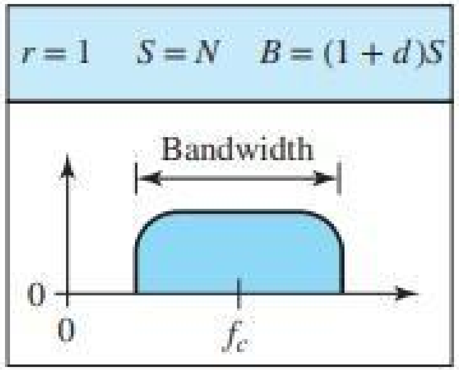
# Digital-to-Analog Conversion

- Digital-to-analog conversion modifies one characteristic of an analog signal based on digital data. This involves altering amplitude, frequency, or phase, resulting in three modulation methods: amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). A more efficient method, quadrature amplitude modulation (QAM), combines changes in both amplitude and phase and is the most commonly used technique today.
- **Amplitude Shift Keying**
- In amplitude shift keying (ASK), the carrier signal's amplitude is varied to create signal elements, while frequency and phase remain constant.

ASK typically uses two levels, known as binary amplitude shift keying (BASK) or on-off keying (OOK). One signal level's peak amplitude is 0, and the other matches the carrier frequency's amplitude. The modulation creates a nonperiodic composite signal with a continuous set of frequencies. The bandwidth, proportional to the signal rate (S), is influenced by a factor $d$ (0 to 1), giving the bandwidth formula $B = (1 + d)S$. Thus, the required bandwidth ranges from $S$ to $2S$. The carrier frequency $f_c$ is at the center of this bandwidth, allowing the modulated signal to fit available bandpass channels, which is a key advantage of digital-to-analog conversion.

Baud rate :
Baud rate is the **rate at which the number of signal elements or changes to the signal occurs per second** when it passes through a transmission medium.
The higher a baud rate is the faster the data is sent/received.
**Baud rate = number of signal elements/total time (in seconds)**




The Baud rate refers to the total number of signal units transmitted in one second. The Bit rate refers to the total Bits transmitted in one unit time.

**Multilevel ASK**

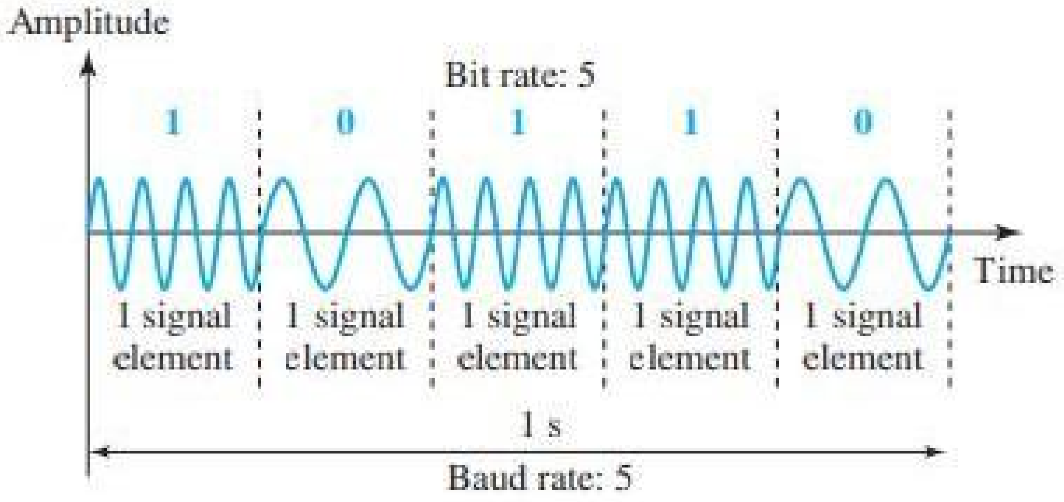
Multilevel ASK uses more than two amplitude levels, such as 4, 8, or 16, to modulate data using 2, 3, 4, or more bits at a time. This is commonly implemented with QAM rather than pure ASK.

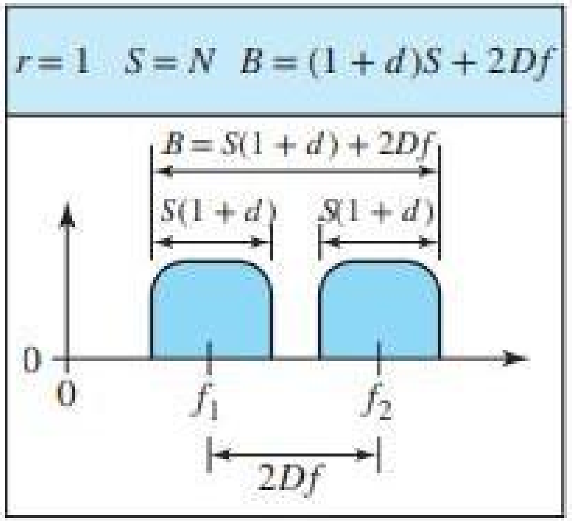
# Frequency Shift Keying (FSK)

In frequency shift keying (FSK), the carrier signal's frequency is varied to represent data, while its amplitude and phase remain constant. The frequency stays the same for each signal element and changes only if the data element changes.

# Binary FSK (BFSK)

Binary FSK (BFSK) uses two carrier frequencies: $f_1$ for data element 0 and $f_2$ for data element 1. Typically, these carrier frequencies are very high, and the difference between them is minimal. Figure 2.12 illustrates this concept for demonstration purposes.



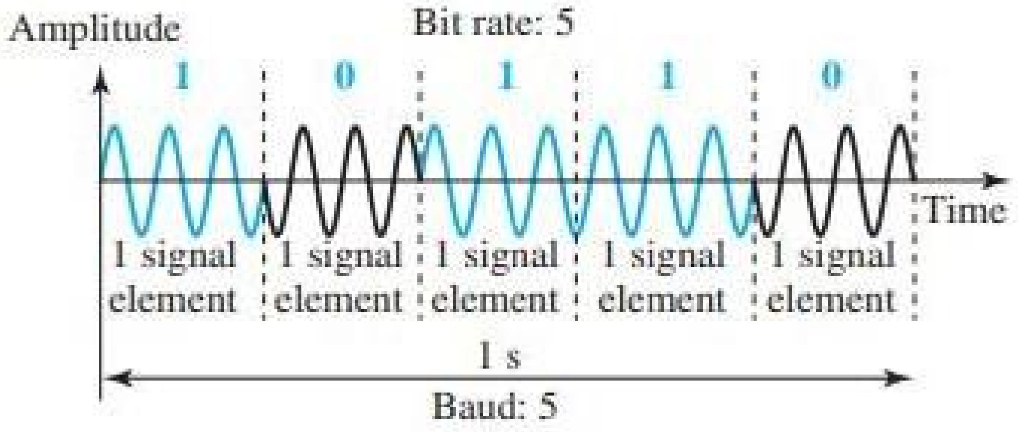



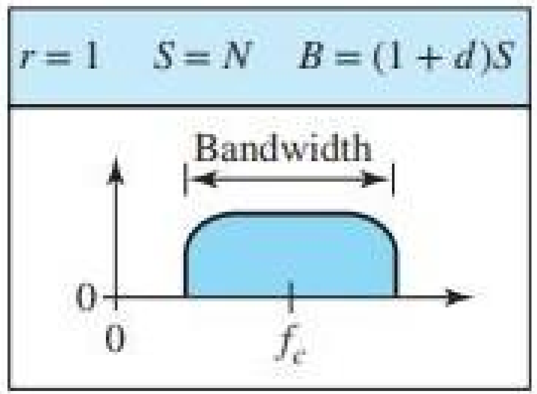
## Phase Shift Keying

In phase shift keying (PSK), the carrier's phase is varied to represent different signal elements, while amplitude and frequency remain constant. PSK is more common than ASK or FSK, but QAM, which combines ASK and PSK, is the dominant digital-to-analog modulation method.

## Binary PSK (BPSK)

Binary PSK (BPSK) is the simplest form of PSK, using two signal elements with phases of 0° and 180°. As shown in Figure 2.13, BPSK is as simple as binary ASK but has the advantage of being less susceptible to noise.



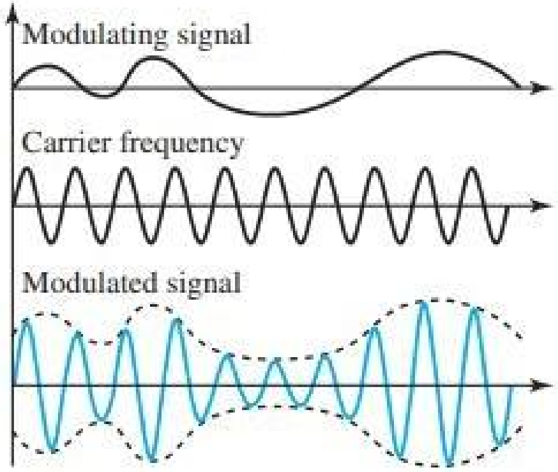



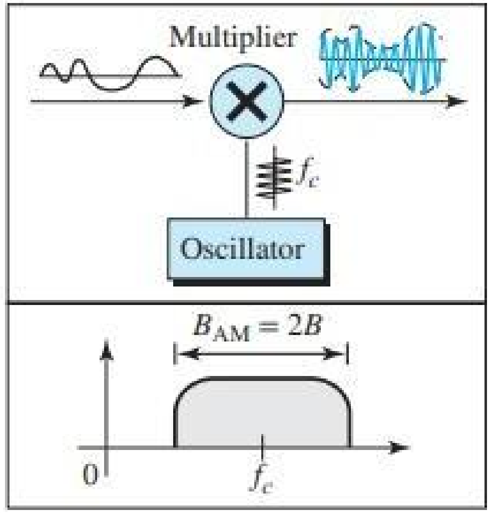
# Analog-to-Analog Conversion

Analog-to-analog conversion, or analog modulation, represents analog information with an analog signal. It is necessary when using a bandpass medium or channel, such as radio, where each station is assigned a narrow bandwidth. Low-pass signals from different stations need to be shifted to different ranges for clear reception. This conversion can be done through amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM), with FM and PM often grouped together.

## Amplitude Modulation

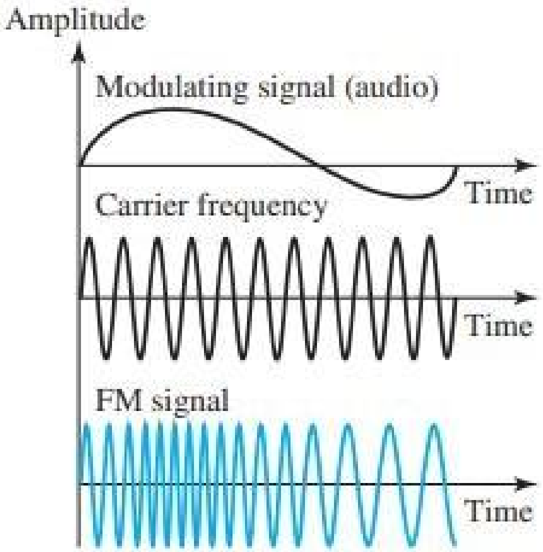
In AM transmission, the carrier signal's amplitude varies with the modulating signal's amplitude, while its frequency and phase remain constant. The modulating signal shapes the carrier's envelope. AM is typically implemented using a multiplier to adjust the carrier's amplitude. The bandwidth of an AM signal is twice that of the modulating signal and is centered on the carrier frequency. Since the upper and lower bands carry identical information, some implementations discard one-half of the signal to reduce bandwidth.

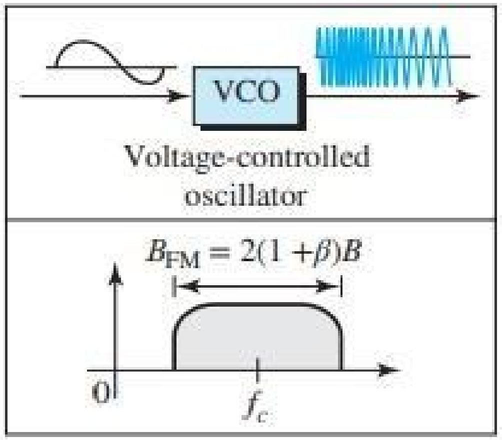


# Frequency Modulation

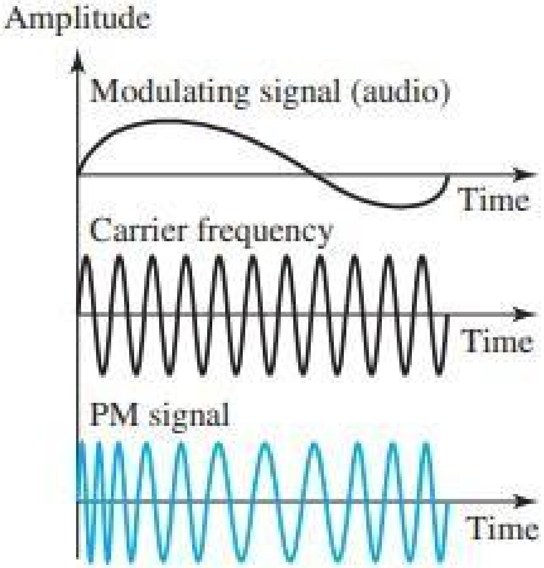
In FM transmission, the carrier signal's frequency varies with the modulating signal's amplitude, while its peak amplitude and phase remain constant. The frequency changes according to the input voltage from the modulating signal. FM is typically implemented using a voltage-controlled oscillator. The bandwidth of an FM signal is given by $B_{FM} = 2(1+\beta)B$, where $\beta$ is a modulation factor, often around 4.

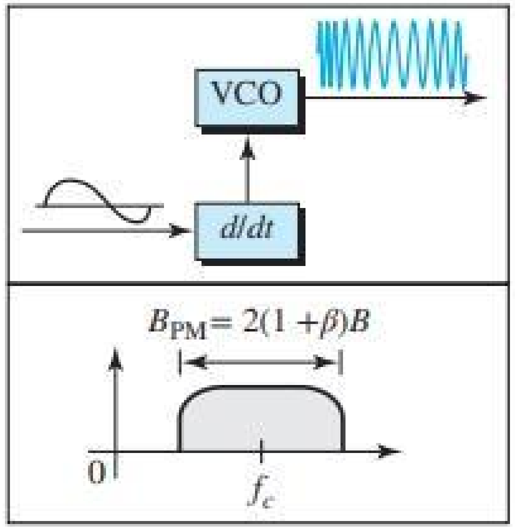


# Phase Modulation

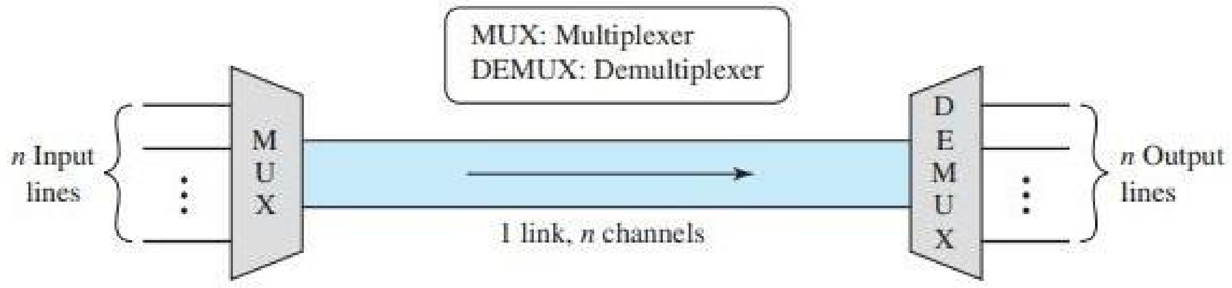
In PM transmission, the carrier signal's phase varies with the modulating signal's amplitude, while its peak amplitude and frequency remain constant. The phase changes as the modulating signal's amplitude changes. PM is similar to FM, but in FM, the frequency change is proportional to the modulating signal's amplitude, whereas in PM, it is proportional to the derivative of the amplitude. PM is typically implemented using a voltage-controlled oscillator and a derivative. The bandwidth of a PM signal is empirically several times that of the analog signal, with the modulation factor $\beta$ being lower (around 1 for narrowband and 3 for wideband).



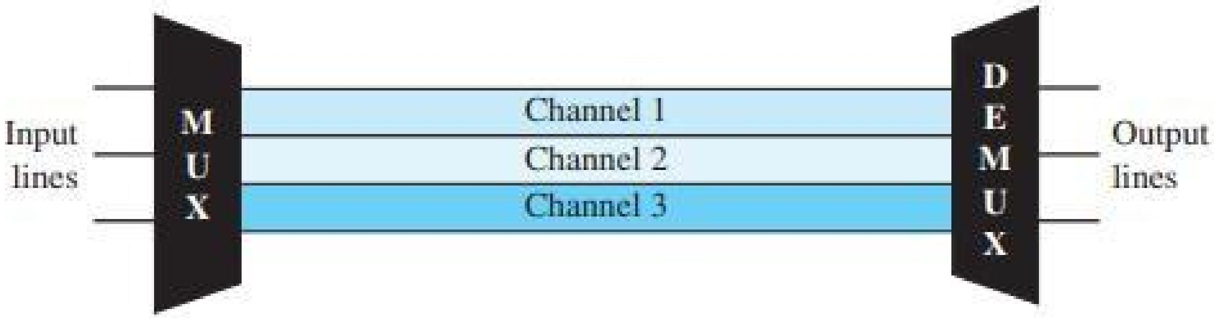
# MULTIPLEXING

When the bandwidth of a medium linking two devices exceeds their bandwidth needs, the link can be shared using multiplexing techniques. Multiplexing allows multiple signals to be transmitted simultaneously across a single data link. This is essential as data and telecommunications traffic increases. Instead of adding individual links for each new channel, higher-bandwidth links can be installed to carry multiple signals. High-bandwidth media such as optical fiber and microwave technologies support this. In a multiplexed system, multiple lines share the bandwidth of one link, combining streams into a single one via a multiplexer and then separating them at the receiving end with a demultiplexer. The physical path is called a link, and each transmission path within it is a channel. The three basic multiplexing techniques are frequency-division multiplexing (FDM) and wavelength-division multiplexing (WDM) for analog signals, and time-division multiplexing (TDM) for digital signals.



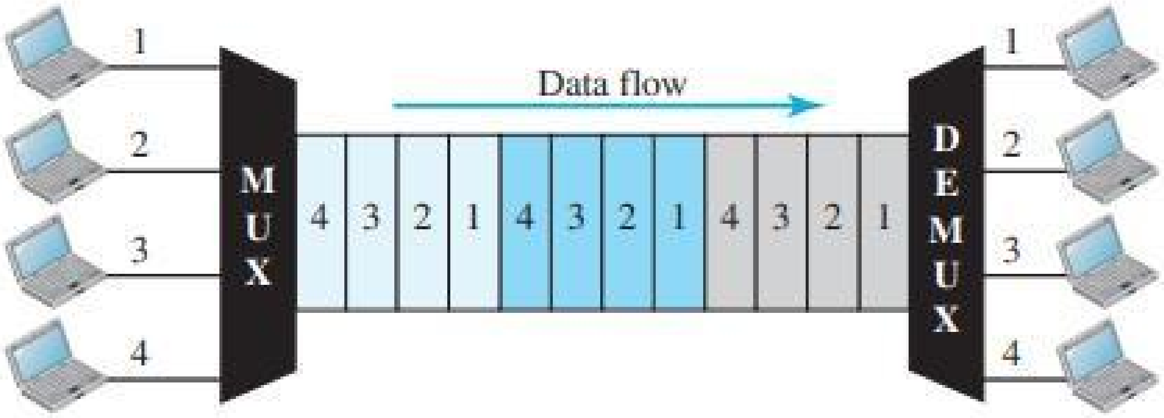
## Frequency-Division Multiplexing

Frequency-division multiplexing (FDM) is an analog technique used when a link's bandwidth (in hertz) exceeds the combined bandwidths of the signals to be transmitted. Each signal modulates a different carrier frequency, and these modulated signals are combined into a single composite signal for transmission. Carrier frequencies are separated by sufficient bandwidth to avoid overlap, with guard bands used to prevent interference. Carrier frequencies must also avoid interfering with the original data frequencies. Although FDM is an analog technique, it can be used for digital signals by converting them to analog before multiplexing.



## Time-Division Multiplexing

Time-division multiplexing (TDM) is a digital technique that allows multiple connections to share a high-bandwidth link by dividing time rather than bandwidth. Each connection uses a portion of the link's time sequentially. In TDM, data from different sources are combined into a single time-shared link, with each source's data occupying the link in turns. Unlike switching, TDM ensures fixed and unvarying delivery to specific destinations. Although primarily digital, TDM can also handle analog data by converting it to digital before multiplexing.



# Transmission Media

Transmission media are actually located below the physical layer and are directly controlled by the physical layer.

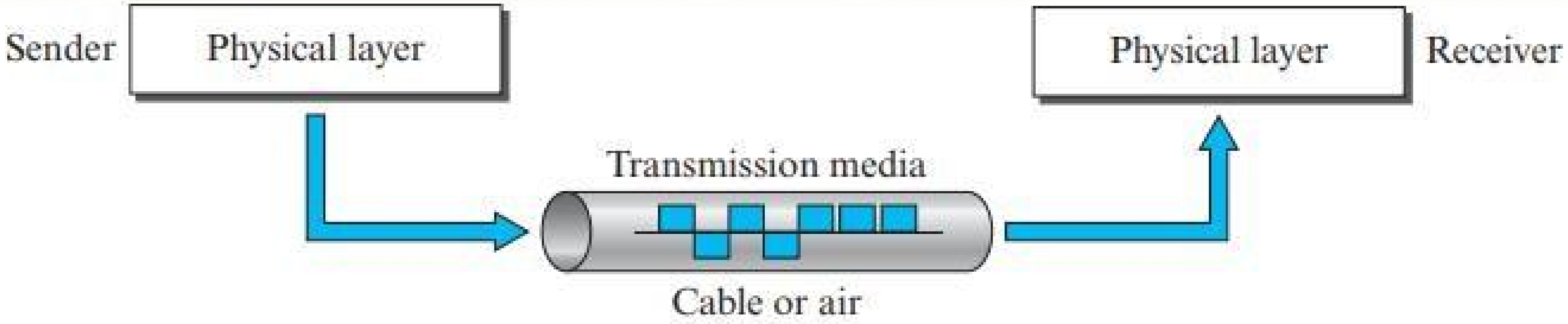
A transmission medium can be broadly defined as anything that can carry information from a source to a destination

In data communications the definition of the information and the transmission medium is more specific. The transmission medium is usually free space, metallic cable, or fiber-optic cable. The information is usually a signal that is the result of a conversion of data from another form.

In telecommunications, transmission media can be divided into two broad categories: guided and unguided. Guided media include twisted-pair cable, coaxial cable, and fiber-optic cable. Unguided medium is free space.

# Transmission Media

**Figure 7.58** *Transmission media and physical layer*



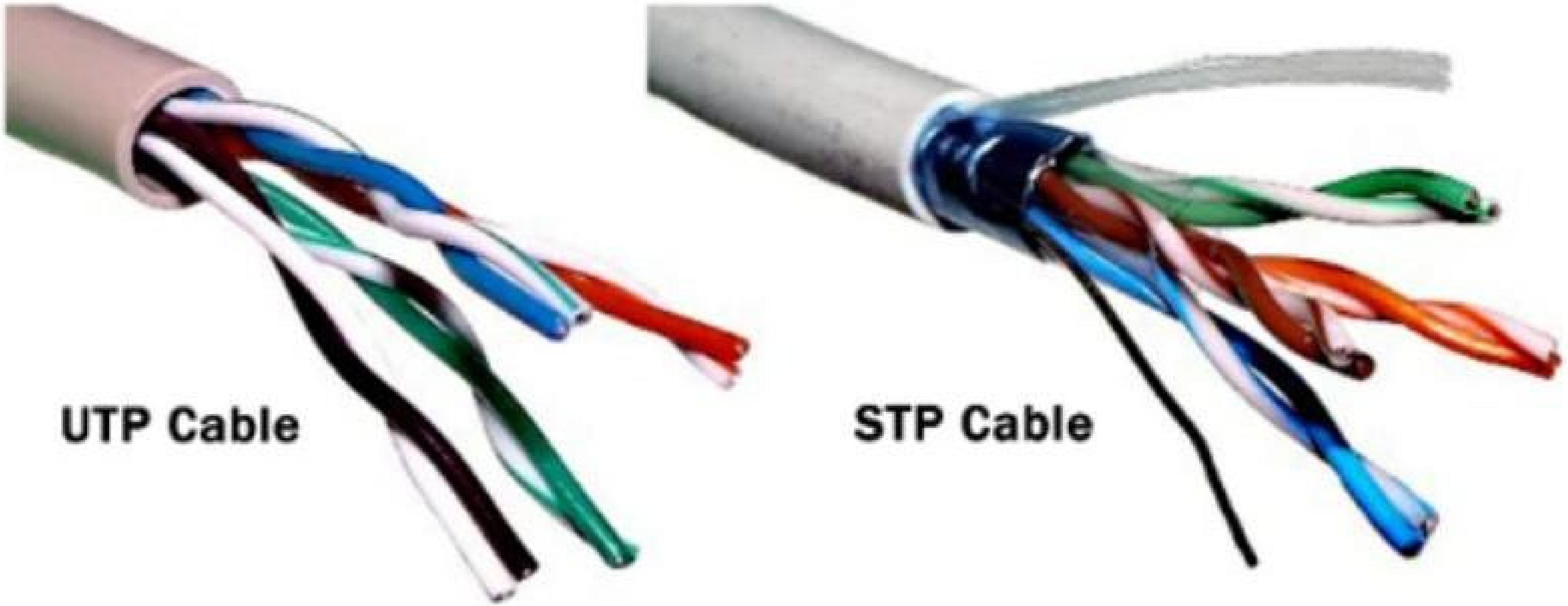
# Guided Media

Guided media, which are those that provide a conduit from one device to another, include twisted-pair cable, coaxial cable, and fiber-optic cable.
A signal traveling along any of these media is directed and contained by the physical limits of the medium.
Twisted-pair and coaxial cable use metallic (copper) conductors that accept and transport signals in the form of electric current.
Fiber-optic cable is a cable that accepts and transports signals in the form of light.

# Twisted-Pair Cable

A twisted pair consists of two conductors (normally copper), each with its own plastic insulation, twisted together.
One of the wires is used to carry signals to the receiver, and the other is used only as a ground reference. The receiver uses the difference between the two.
In addition to the signal from the sender, interference (noise) and crosstalk may affect both wires and create unwanted signals.
If the two wires are parallel, the effect of these unwanted signals is not the same in both wires because they are at different locations relative to the noise or crosstalk sources. This results in a difference at the receiver. By twisting the pairs, a balance is maintained.
The most common twisted-pair cable used in communications is referred to as unshielded twisted-pair (UTP). IBM has also produced a version of twisted-pair cable for its use called shielded twisted-pair (STP).

# Twisted-Pair Cable



# Twisted Pair Cables

## Performance

One way to measure the performance of twisted-pair cable is to compare attenuation versus frequency and distance. A twisted-pair cable can pass a wide range of frequencies.

However, Figure 7.59 also shows that with increasing frequency, the attenuation, measured in decibels per kilometer (dB/km), sharply increases with frequencies above 100 kHz. Note that gauge is a measure of the thickness of the wire (inversely).

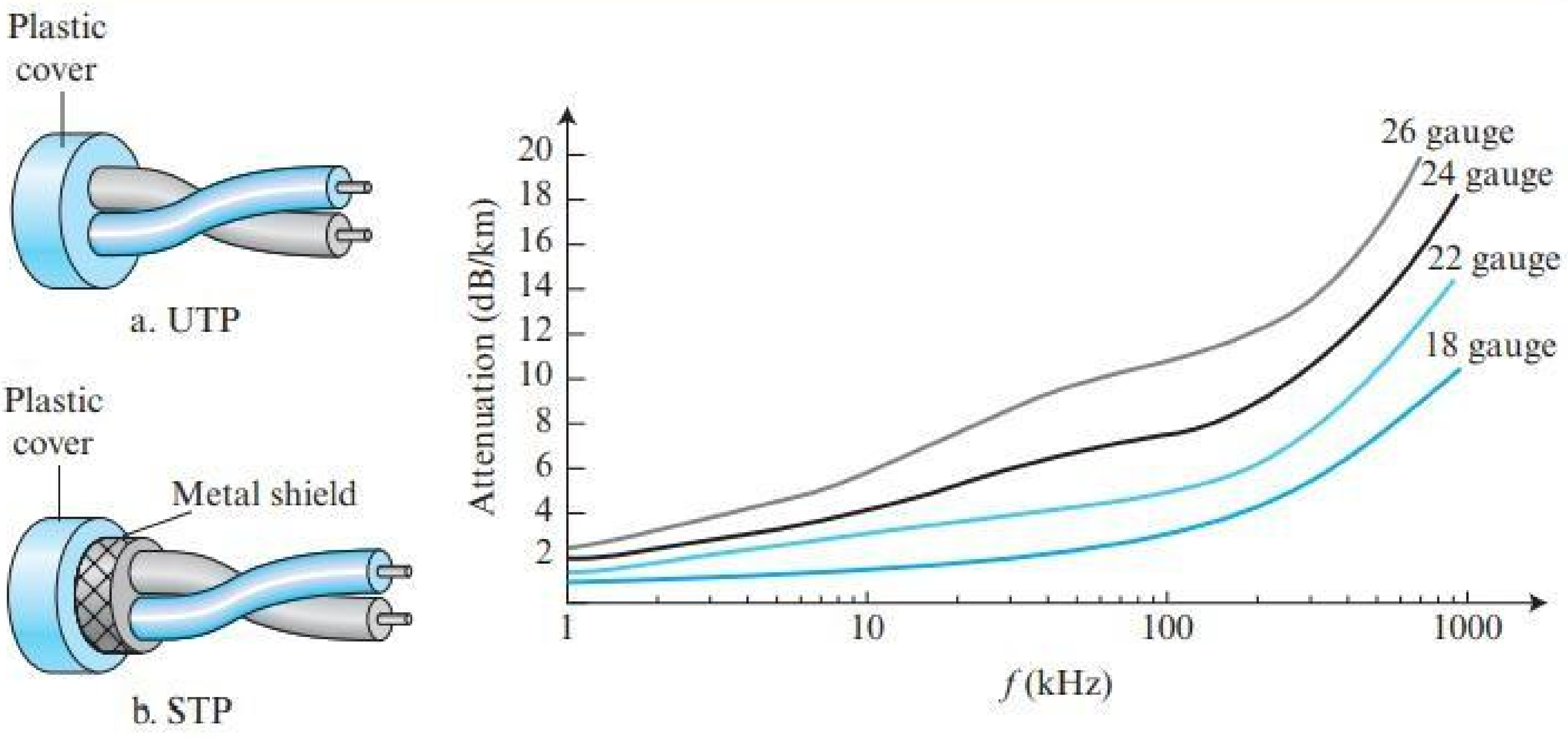
## Applications

Twisted-pair cables are used in telephone lines to provide voice and data channels. The local loop—the line that connects subscribers to the central telephone office—commonly consists of unshielded twisted-pair cables.

The DSL lines that are used by the telephone companies to provide high-data-rate connections also use the high-bandwidth capability of unshielded twisted-pair cables

# Twisted Pair Cables

**Figure 7.59** *Twisted-pair cable*



# Coaxial Cable

Coaxial cable (or coax) carries signals of higher frequency ranges than those in twistedpair cable, in part because the two media are constructed quite differently. Instead of having two wires, coax has a central core conductor of solid or stranded wire (usually copper) enclosed in an insulating sheath, which is, in turn, encased in an outer conductor of metal foil, braid, or a combination of the two.

The outer metallic wrapping serves both as a shield against noise and as the second conductor, which completes the circuit. This outer conductor is also enclosed in an insulating sheath, and the whole cable is protected by a plastic cover

# Coaxial Cable

## Performance

As we did with twisted-pair cables, we can measure the performance of a coaxial cable. We notice in Figure 7.60 that the attenuation is much higher in coaxial cable than in twisted-pair cable.

In other words, although coaxial cable has a much higher bandwidth, the signal weakens rapidly and requires the frequent use of repeaters.

## Applications

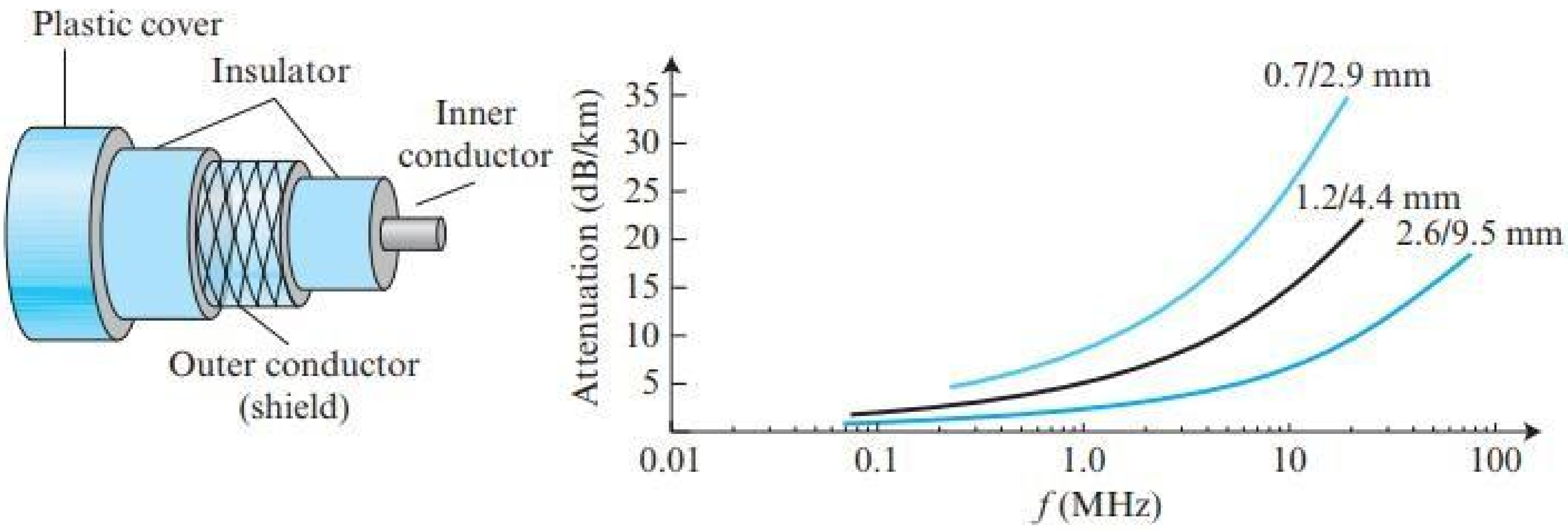
Coaxial cable was widely used in analog telephone networks where a single coaxial network could carry 10,000 voice signals.

Cable TV networks also use coaxial cable. In the traditional cable TV network, the entire network used coaxial cable. Later, however, cable TV providers replaced most of the media with fiber-optic cable.

Another common application of coaxial cable is in traditional Ethernet LANs. Because of its high bandwidth, and consequently high data rate, coaxial cable was chosen for digital transmission in early Ethernet LANs. Thick Ethernet has specialized connectors.

# Coaxial Cable

**Figure 7.60** *Coaxial cable*



# Fiber-Optic Cable

A fiber-optic cable is made of glass or plastic and transmits signals in the form of light.
To understand optical fiber, we first need to explore several aspects of the nature of light.
Light travels in a straight line as long as it is moving through a single uniform substance. If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction.
Optical fibers use reflection to guide light through a channel. A glass or plastic core is surrounded by a cladding of less dense glass or plastic. The difference in density of the two materials must be such that a beam of light moving through the core is reflected off the cladding instead of being refracted into it.

# Fiber-Optic Cable

**Figure 7.61** *Bending of light ray*

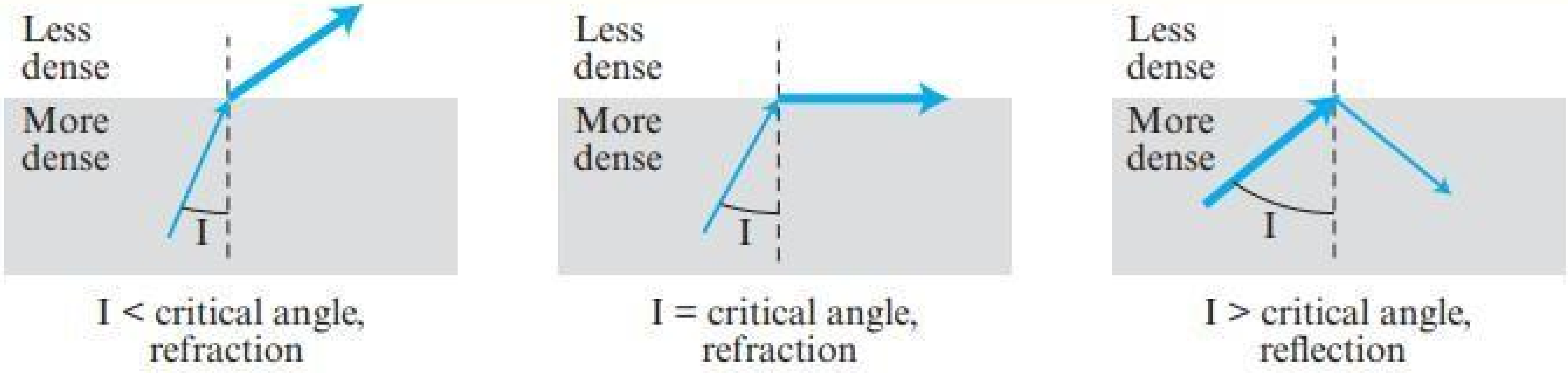
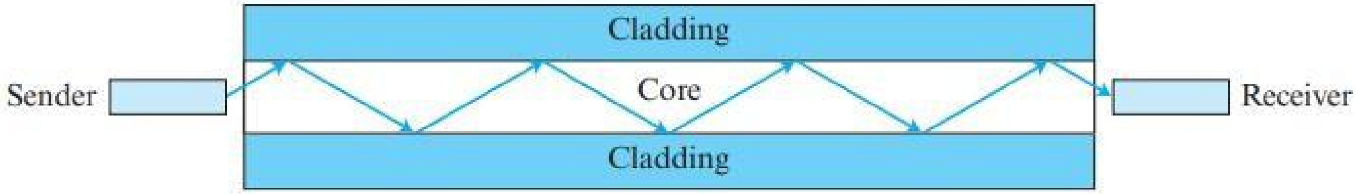



**Figure 7.62** *Optical fiber*

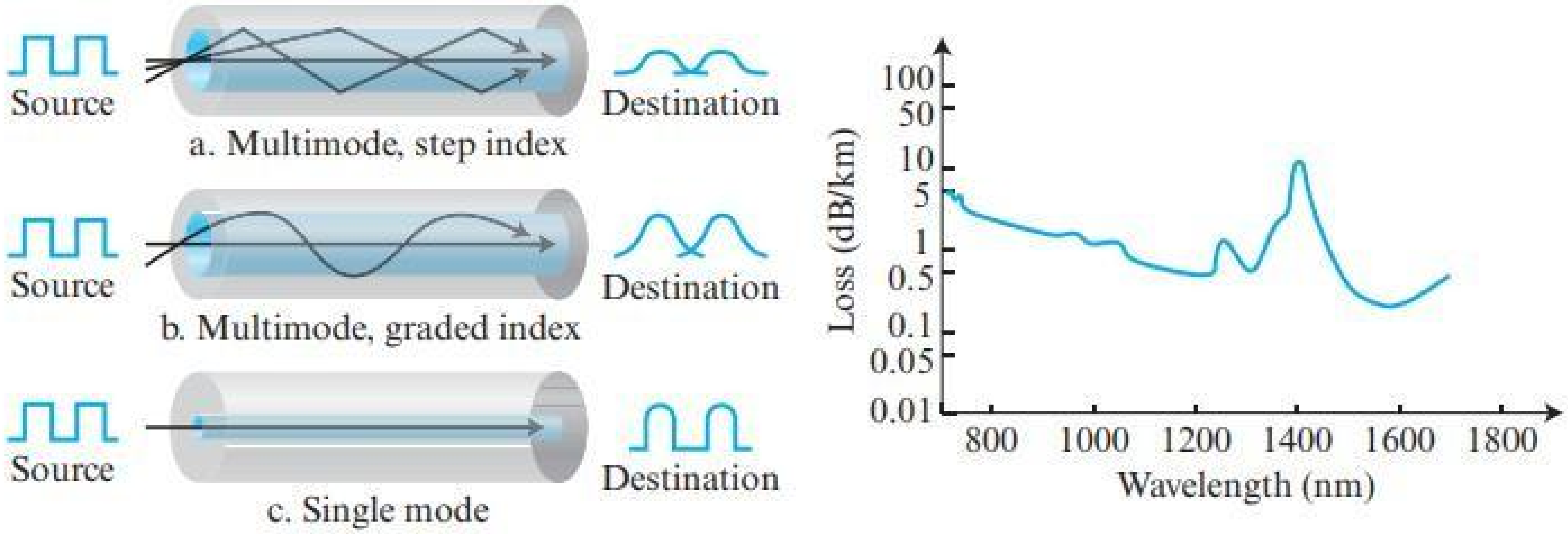


# Propagation Modes

Current technology supports two modes (multimode and single mode) for propagating light along optical channels, each requiring fiber with different physical characteristics.
Multimode is so named because multiple beams from a light source move through the core in different paths. How these beams move within the cable depends on the structure of the core.
Multimode can be implemented in two forms: step-index or graded-index.

# Propagation Modes

**Figure 7.63** *Modes*



# Propagation Modes

In multimode step-index fiber, the density of the core remains constant from the center to the edges. A beam of light moves through this constant density in a straight line until it reaches the interface of the core and the cladding. At the interface, there is an abrupt change due to a lower density; this alters the angle of the beam's motion. The term step index refers to the suddenness of this change, which contributes to the distortion of the signal as it passes through the fiber.

A second type of fiber, called multimode graded-index fiber, decreases this distortion of the signal through the cable. The word index here refers to the index of refraction. As we saw above, the index of refraction is related to density. A graded-index fiber, therefore, is one with varying densities. Density is highest at the center of the core and decreases gradually to its lowest at the edge.

# Propagation Modes

Single-mode uses step-index fiber and a highly focused source of light that limits beams to a small range of angles, all close to the horizontal. The single-mode fiber itself is manufactured with a much smaller diameter than that of multimode fiber, and with substantially lower density (index of refraction). The decrease in density results in a critical angle that is close enough to 90° to make the propagation of beams almost horizontal. In this case, propagation of different beams is almost identical, and delays are negligible. All the beams arrive at the destination "together" and can be recombined with little distortion to the signal.

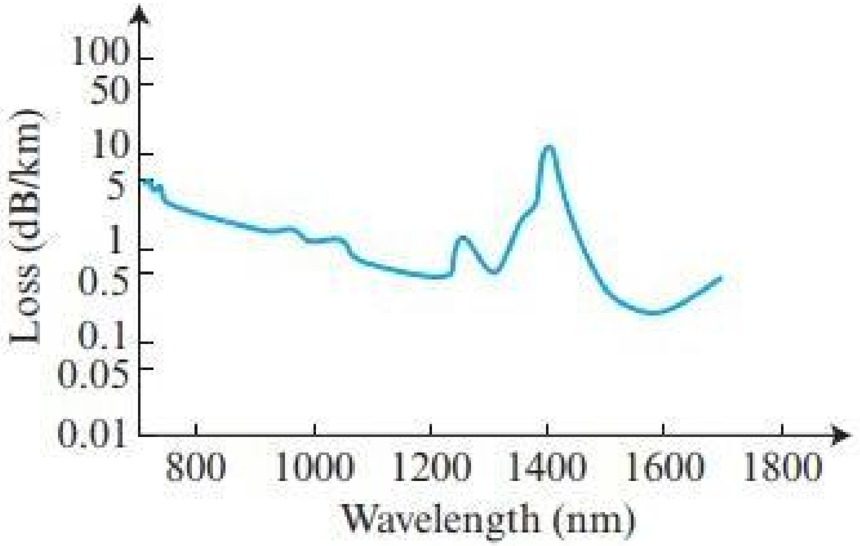
# Fibel-Optic Cables

## Performance

The plot of attenuation versus wavelength in Figure 7.63 also shows a very interesting phenomenon in fiber-optic cable. Attenuation is flatter than in the case of twisted-pair cable and coaxial cable. The performance is such that we need fewer (actually 10 times fewer) repeaters when we use fiber-optic cable.

## Applications

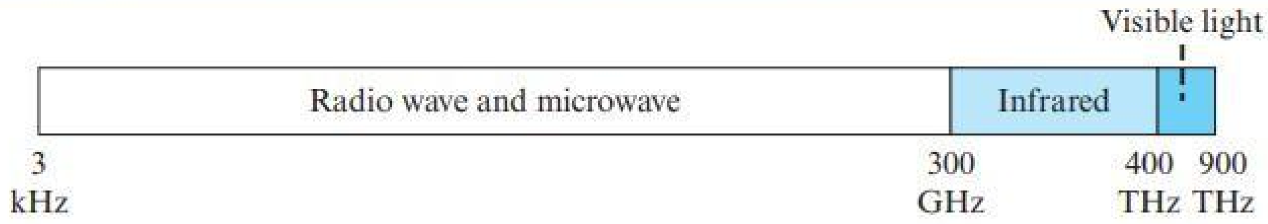
Fiber-optic cable is often found in backbone networks because its wide bandwidth is cost-effective. Today, with wavelength-division multiplexing (WDM), we can transfer data at a rate of 1600 Gbps. Some cable TV companies use a combination of optical fiber and coaxial cable, thus creating a hybrid network.



# Unguided Media: Wireless

Unguided media transport electromagnetic waves without using a physical conductor.
This type of communication is often referred to as wireless communication.
Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them.

**Figure 7.64** *Electromagnetic spectrum for wireless communication*



# Unguided Media

Unguided signals can travel from source to destination in several ways: ground propagation, sky propagation, and line-of-sight propagation.

In ground propagation, radio waves travel through the lowest portion of the atmosphere, hugging the earth. These low-frequency signals emanate in all directions from the transmitting antenna and follow the curvature of the planet. Distance depends on the amount of power in the signal: The greater the power, the greater the distance.

In sky propagation, higher-frequency radio waves radiate upward into the ionosphere (the layer of atmosphere where particles exist as ions) where they are reflected back to earth. This type of transmission allows for greater distances with lower output power.

# Unguided Media

In line-of-sight propagation, very high-frequency signals are transmitted in straight lines directly from antenna to antenna. Antennas must be directional, facing each other, and either tall enough or close enough together not to be affected by the curvature of the earth. Line-of-sight propagation is tricky because radio transmissions cannot be completely focused.

The section of the electromagnetic spectrum defined as radio waves and microwaves is divided into eight ranges, called bands, each regulated by government authorities. These bands are rated from very low frequency (VLF) to extremely high frequency (EHF).

We can divide wireless transmission into three broad groups: radio waves, microwaves, and infrared waves.

# Unguided Media

Table 7.1 *Bands*

| *Band* | *Range* | *Propagation* | *Application* |
|---|---|---|---|
| VLF (very low frequency) | 3–30 kHz | Ground | Long-range radio |
| LF (low frequency) | 30–300 kHz | Ground | Radio beacons |
| MF (middle frequency) | 300 kHz–3 MHz | Sky | AM radio |
| HF (high frequency) | 3–30 MHz | Sky | Citizens band (CB), ship/aircraft communication |
| VHF (very high frequency) | 30–300 MHz | Sky and line-of-sight | VHF TV, FM radio |
| UHF (ultrahigh frequency) | 300 MHz–3 GHz | Line-of-sight | UHF TV, cellular phones, paging, satellite |
| SHF (superhigh frequency) | 3–30 GHz | Line-of-sight | Satellite communication |
| EHF (extremely high frequency) | 30–300 GHz | Line-of-sight | Radar, satellite |

# Radio Waves

Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves; waves ranging in frequencies between 1 and 300 GHz are called microwaves. However, the behavior of the waves, rather than the frequencies, is a better criterion for classification.

Radio waves, for the most part, are omnidirectional. When an antenna transmits radio waves, they are propagated in all directions. This means that the sending and receiving antennas do not have to be aligned.

The omnidirectional property has a disadvantage, too. The radio waves transmitted by one antenna are susceptible to interference by another antenna that may send signals using the same frequency or band.

Radio waves, particularly those waves that propagate in the sky mode, can travel long distances. This makes radio waves a good candidate for long-distance broadcasting such as AM radio.

# Radio Waves

Radio waves, particularly those of low and medium frequencies, can penetrate walls. This characteristic can be both an advantage and a disadvantage. It is an advantage because, for example, an AM radio can receive signals inside a building. It is a disadvantage because we cannot isolate a communication to just inside or outside a building.

The radio wave band is relatively narrow, just under 1 GHz, compared to the microwave band. When this band is divided into subbands, the subbands are also narrow, leading to a low data rate for digital communications.

Almost the entire band is regulated by authorities. Using any part of the band requires permission from the authorities.

# Microwaves

Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves.

Microwaves are unidirectional. When an antenna transmits microwaves, they can be narrowly focused. This means that the sending and receiving antennas need to be aligned.

The unidirectional property has an obvious advantage. A pair of antennas can be aligned without interfering with another pair of aligned antennas.

# Microwaves

## The following describes some characteristics of microwave propagation:

Microwave propagation is line-of-sight. Since the towers with the mounted antennas need to be in direct sight of each other, towers that are far apart need to be very tall. The curvature of the earth as well as other blocking obstacles do not allow two short towers to communicate by using microwaves. Repeaters are often needed for longdistance communication.

Very high-frequency microwaves cannot penetrate walls. This characteristic can be a disadvantage if receivers are inside buildings.

The microwave band is relatively wide, almost 299 GHz. Therefore wider subbands can be assigned, and a high data rate is possible.

Use of certain portions of the band requires permission from authorities.

# Microwaves

networks, and wireless LANs.

## Applications

Microwaves, due to their unidirectional properties, are very useful when unicast (oneto-one) communication is needed between the sender and the receiver. They are used in cellular phones, satellite

# Infrared Waves

Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mm to 770 nm), can be used for short-range communication.
Infrared waves, having high frequencies, cannot penetrate walls. This advantageous characteristic prevents interference between one system and another; a short-range communication system in one room cannot be affected by another system in the next room.
When we use our infrared remote control, we do not interfere with the use of the remote by our neighbors. However, this same characteristic makes infrared signals useless for long-range communication.
In addition, we cannot use infrared waves outside a building because the sun's rays contain infrared waves that can interfere with the communication.