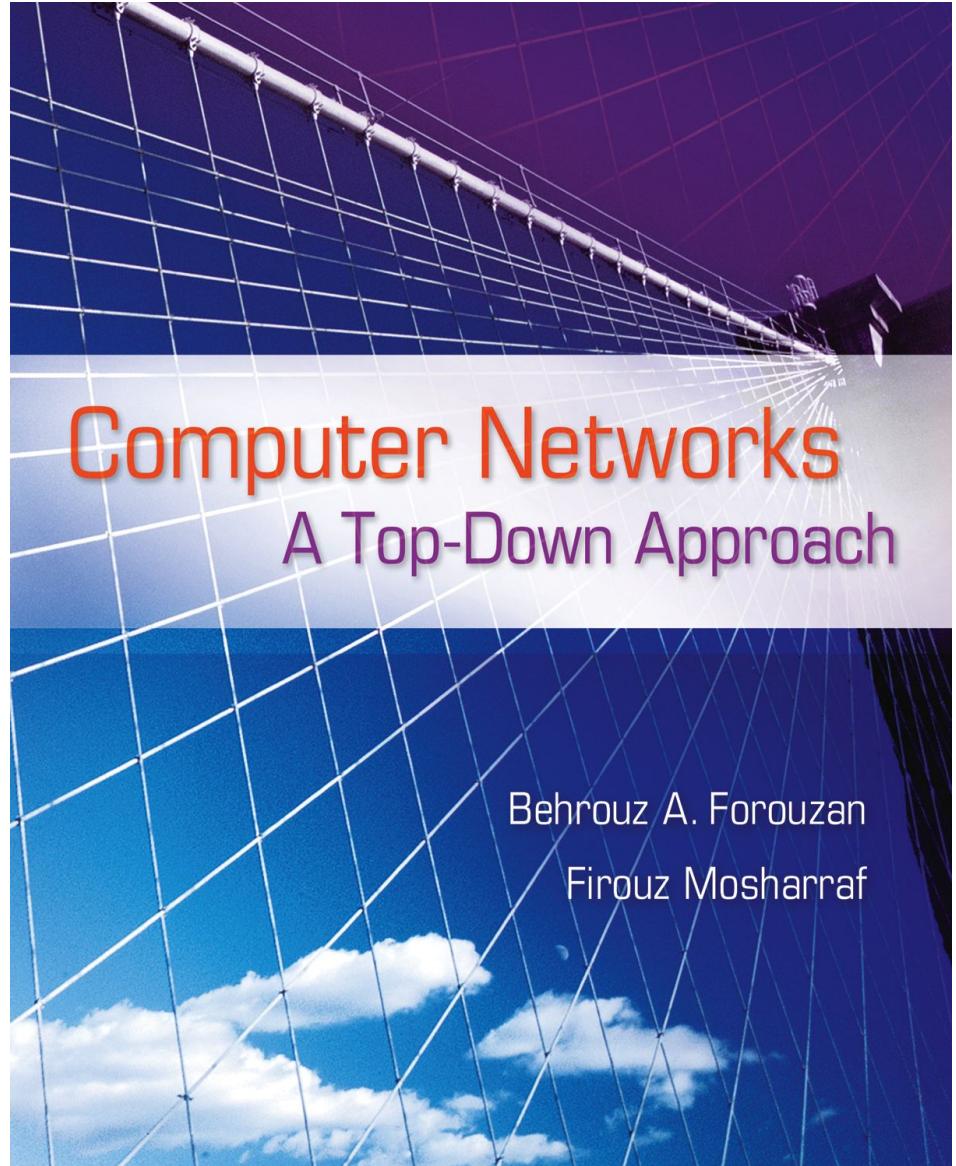
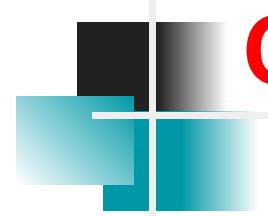


Chapter 7

Physical Layer and Transmission Media





Chapter 7: Outline

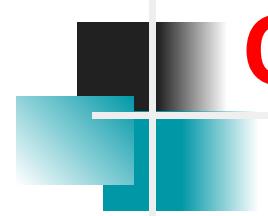
7.1 DATA AND SIGNAL

7.2 DIGITAL TRANSMISSION

7.3 ANALOG TRANSMISSION

7.4 BANDWIDTH UTILIZATION

7.5 TRANSMISSION MEDIA



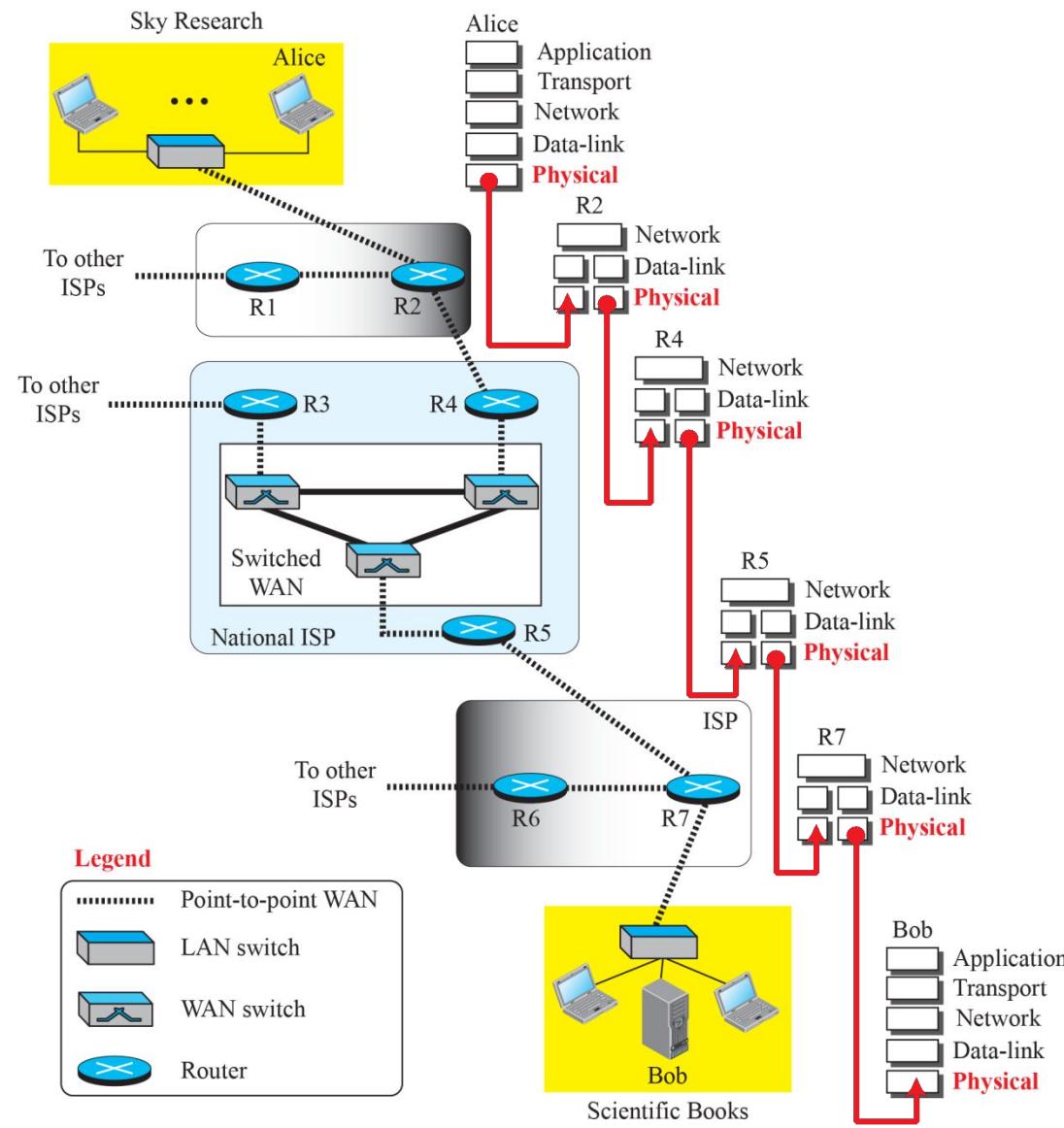
Chapter 7: Objective

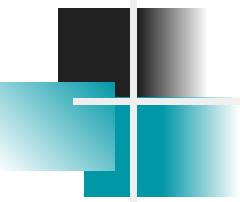
- *We first discuss the relationship between data and signals. We then show how data and signals can be both analog and digital.*
- *We then concentrate on digital transmission. We show how to convert digital and analog data to digital signals.*
- *Next, we concentrate on analog transmission. We show how to convert digital and analog data to analog signals.*
- *We then talk about multiplexing techniques and how they can combine several channels.*
- *Finally, we go below the physical layer and discuss the transmission media.*

7-1 DATA AND SIGNALS

At the physical layer, the communication is node-to-node, but the nodes exchange electromagnetic signals. Figure 7.1 uses the same scenario we showed in four earlier chapters, but the communication is now at the physical layer.

Figure 7.1: Communication at the physical layer





7.1.1 Analog and Digital

Data can be analog or digital. The term analog data refers to information that is continuous. Digital data take on discrete values.

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. 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.

7.1.1 (*continued*)

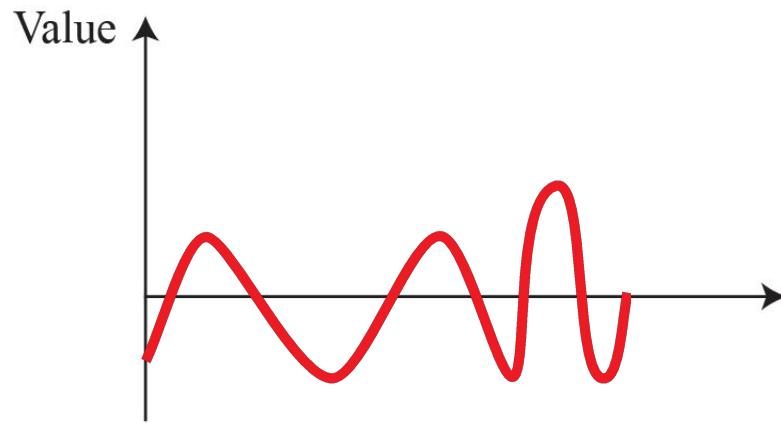
□ *Analog Signals*

- ◆ *Time and Frequency Domains*
- ◆ *Composite Signals*
- ◆ *Bandwidth*

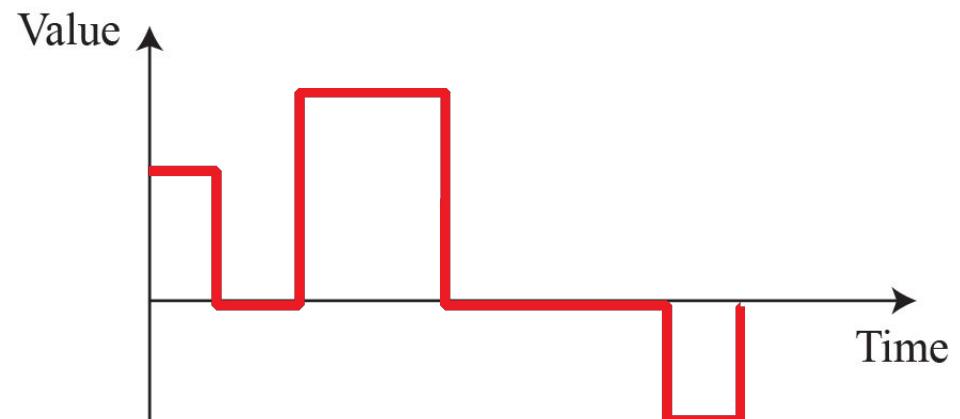
□ *Digital Signals*

- ◆ *Bit Rate*
- ◆ *Bit Length*
- ◆ *Digital Signal as a Composite Analog Signal*
- ◆ *Transmission of Digital Signals*
- ◆ *Baseband Transmission*
- ◆ *Broadband Transmission*

Figure 7.2: Comparison of analog and digital signals



a. Analog signal



b. Digital signal

Figure 7.3: A sine wave

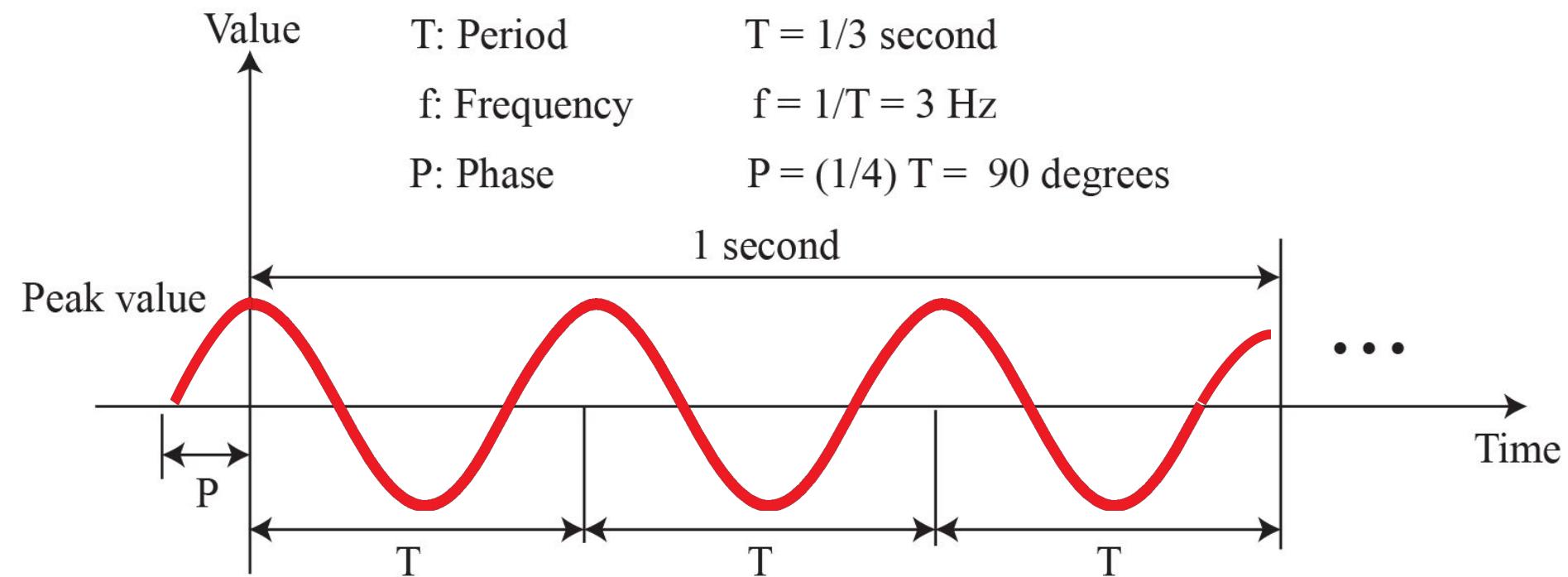
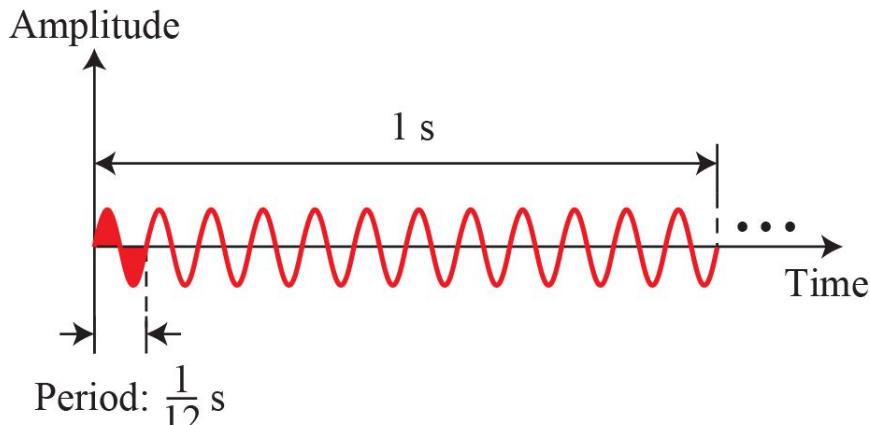


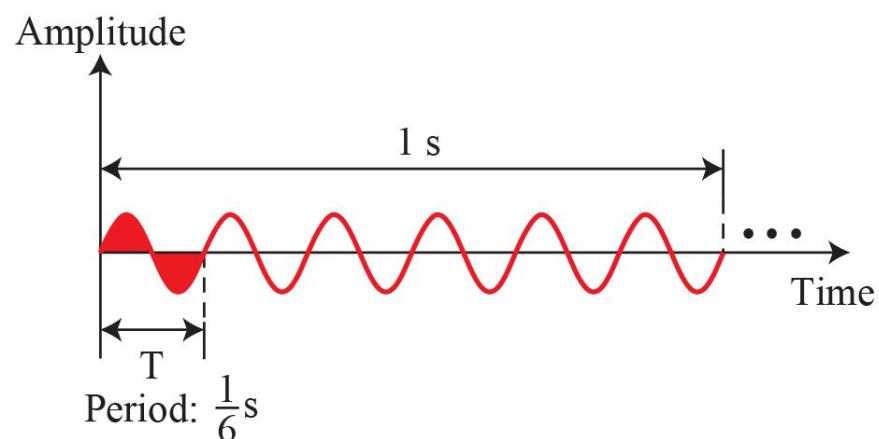
Figure 7.4: Wavelength and period

12 periods in 1 s → Frequency is 12 Hz



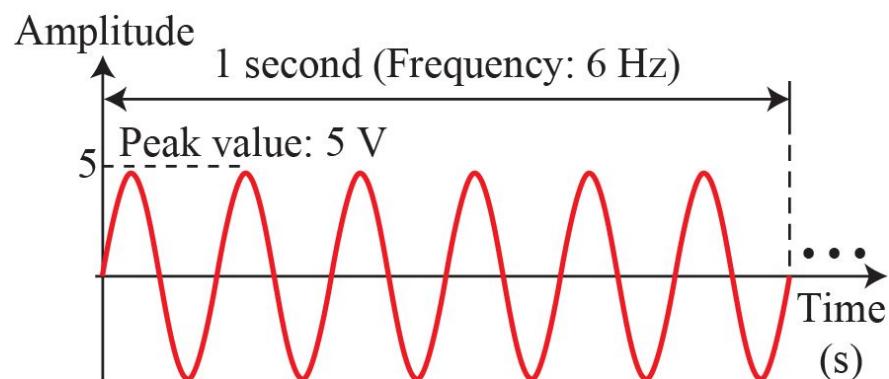
a. A signal with a frequency of 12 Hz

6 periods in 1 s → Frequency is 6 Hz

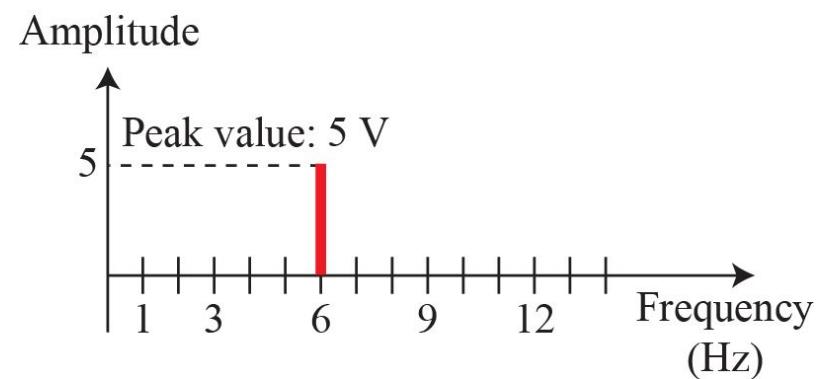


b. A signal with a frequency of 6 Hz

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

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

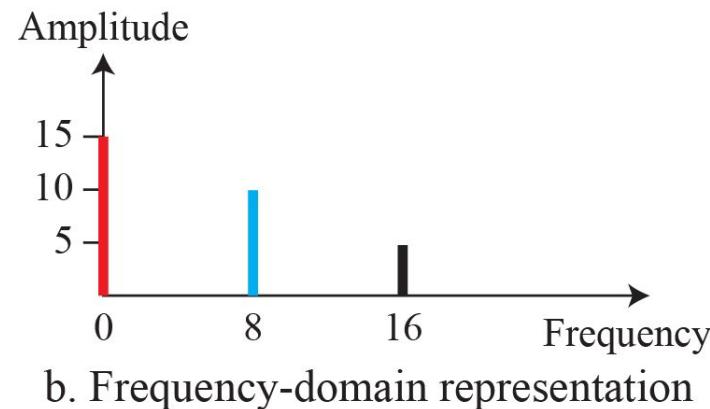
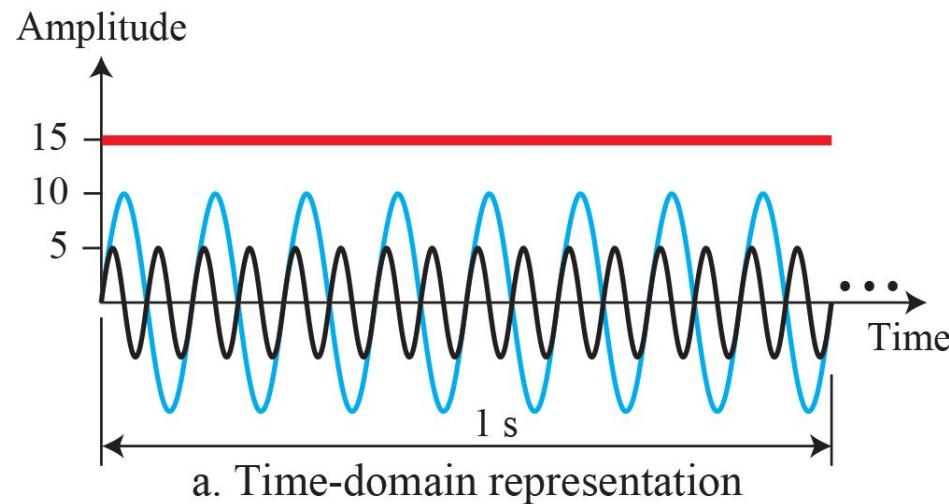
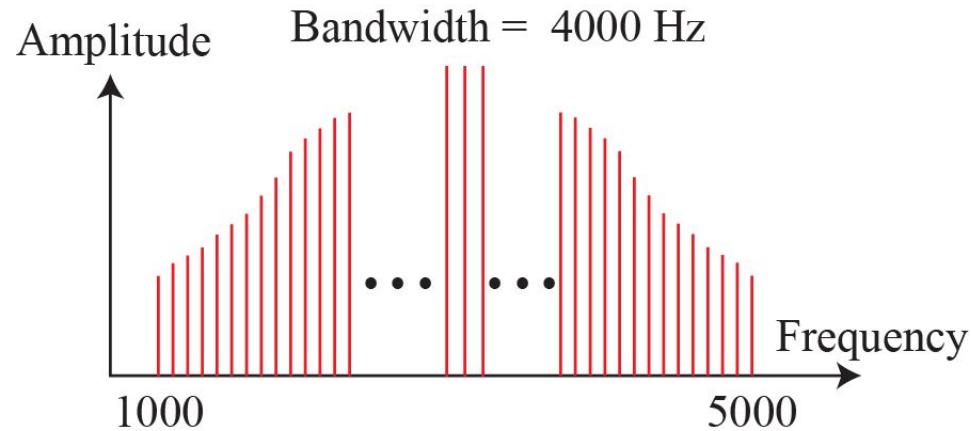
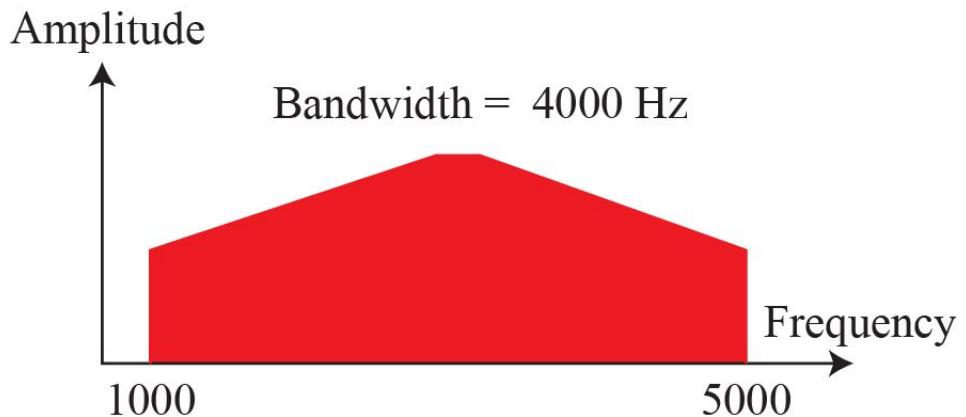


Figure 7.7: The bandwidth of periodic and nonperiodic composite signals

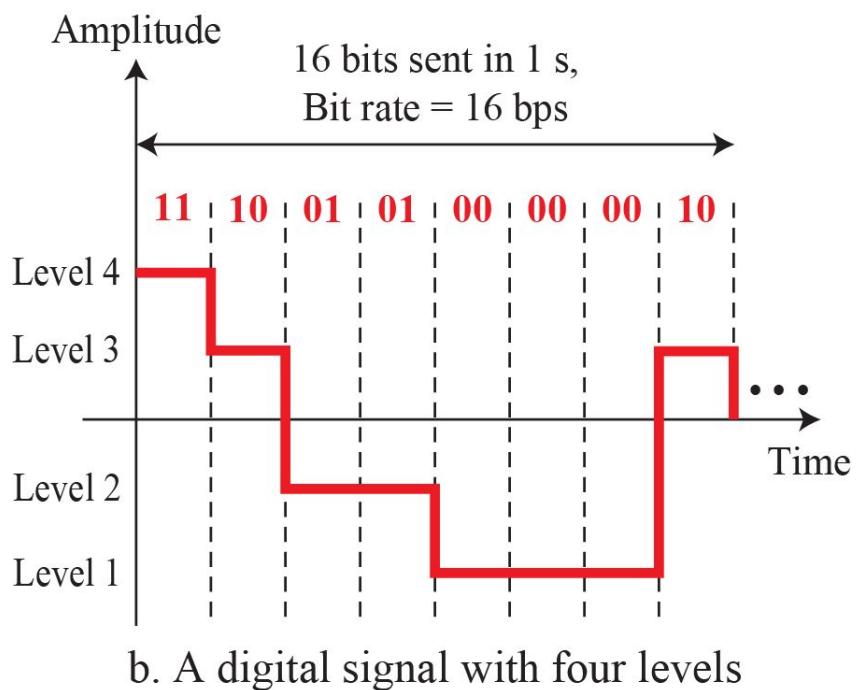
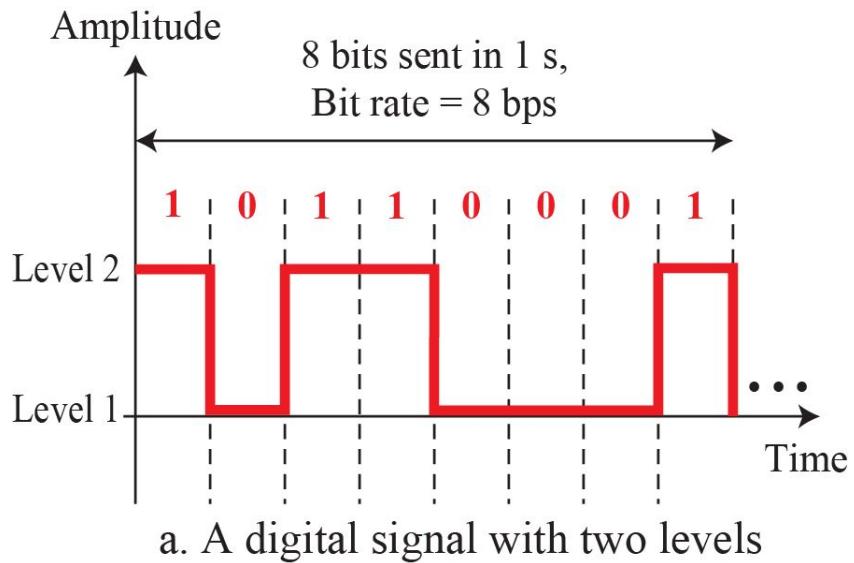


a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

Figure 7.8: Two digital signals: one with two signal levels and the other with four signal levels

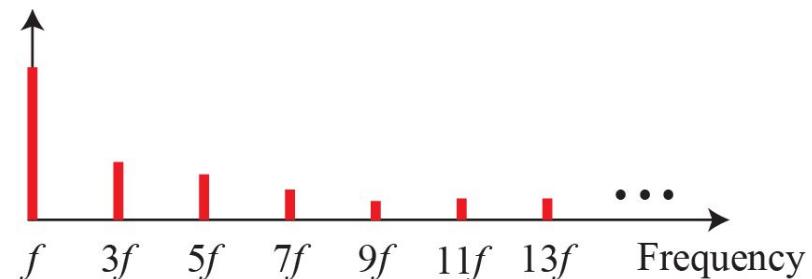
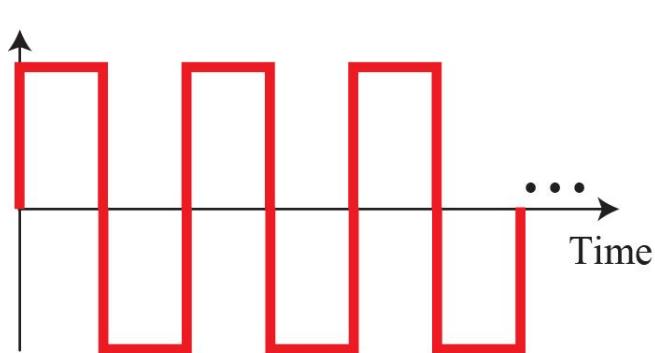


Example 7.2

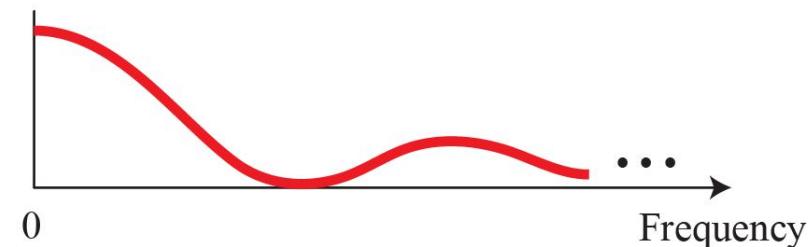
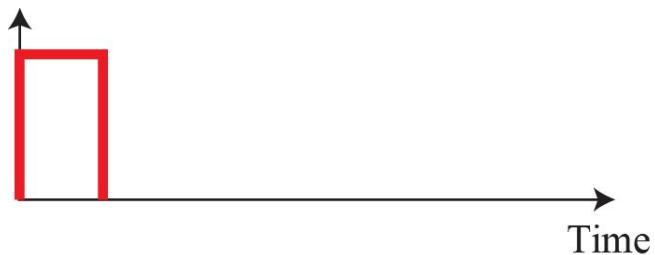
Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel? A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$100 \times 24 \times 80 \times 8 = 1,536,000 \text{ bps} = 1.536 \text{ Mbps.}$$

Figure 7.9: The time and frequency domains of periodic and nonperiodic digital signals

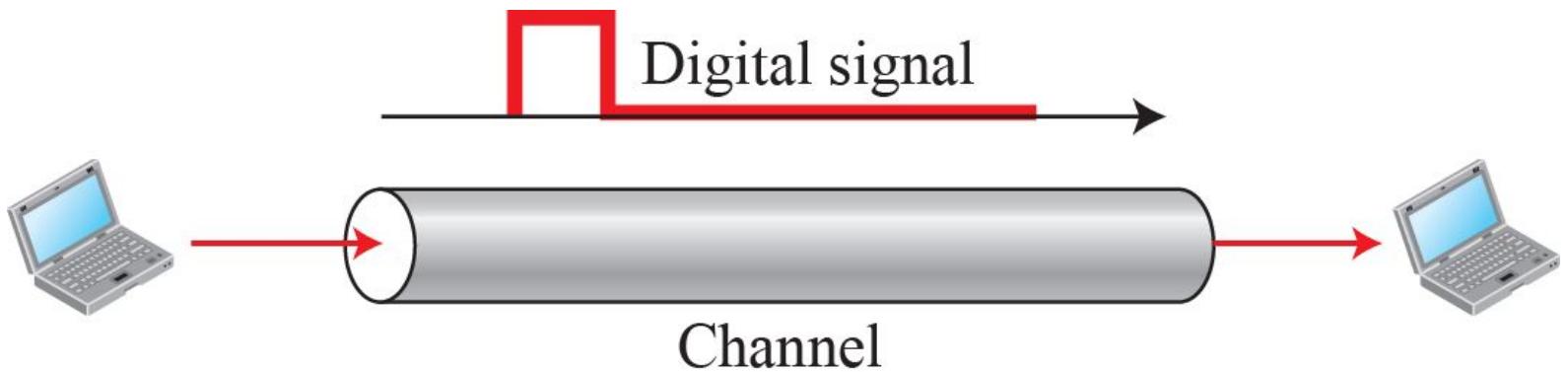


a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

Figure 7.10: Baseband transmission



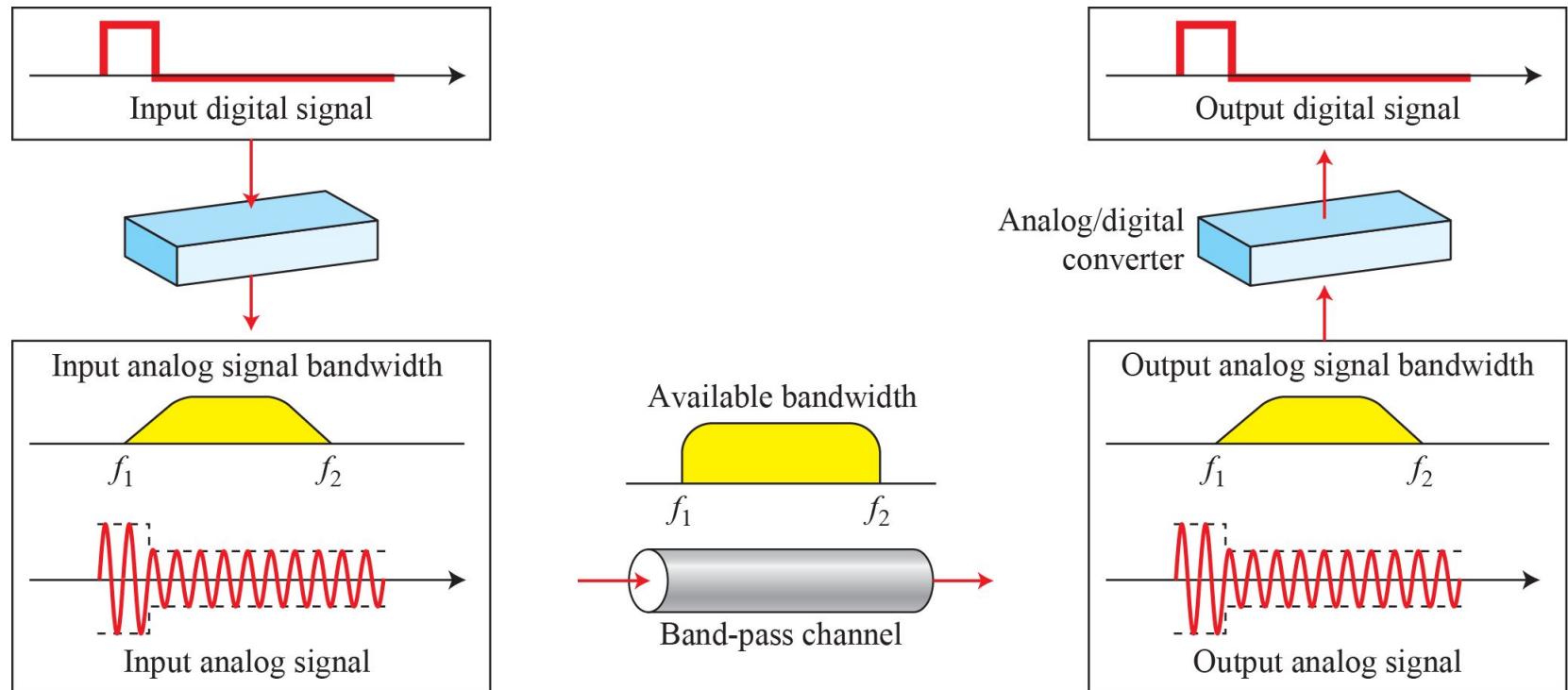
Example 7.3

An example of a dedicated channel where the entire bandwidth of the medium is used as one single channel is a LAN. Almost every wired LAN today uses a dedicated channel for two stations communicating with each other.

Figure 7.11: Bandwidth of a band-pass channel



Figure 7.12: Modulation of a digital signal for transmission on a band-pass channel

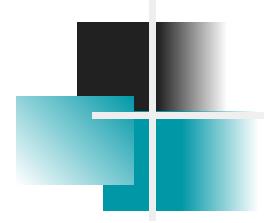


Example 7.4

An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office. Although this channel can be used as a low-pass channel, it is normally considered a band-pass channel. One reason is that the bandwidth is so narrow (4 kHz) that if we treat the channel as low-pass and use it for baseband transmission, the maximum bit rate can be only 8 kbps (explained later). The solution is to consider the channel a band-pass channel, convert the digital signal from the computer to an analog signal, and send the analog signal.

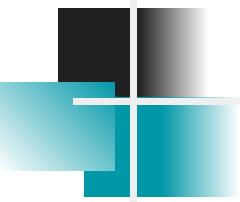
Example 7.5

A second example is the digital cellular telephone. For better reception, digital cellular phones digitize analog voice. Although the bandwidth allocated to a company providing digital cellular phone service is very wide, we still cannot send the digitized signal without conversion. The reason is that we have only a band-pass channel available between caller and callee. For example, if the available bandwidth is W and we allow 1000 couples to talk simultaneously, this means the available channel is $W/1000$, just part of the entire bandwidth. We need to convert the digitized voice to a composite analog signal before transmission.



7.1.2 Transmission Impairment

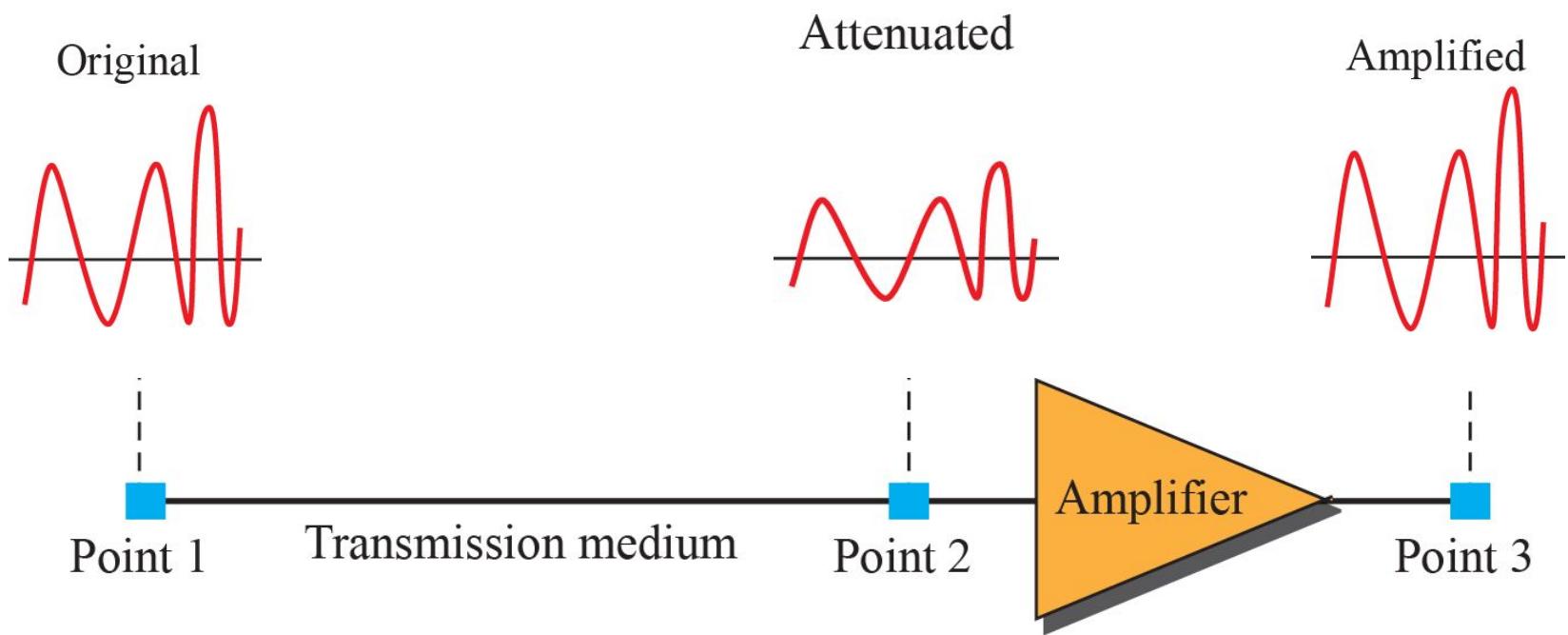
Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation,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



7.1.2 (*continued*)

- *Attenuation*
- *Distortion*
- *Noise*
- ◆ *Signal-to-Noise Ratio (SNR)*

Figure 7.13: Attenuation and amplification



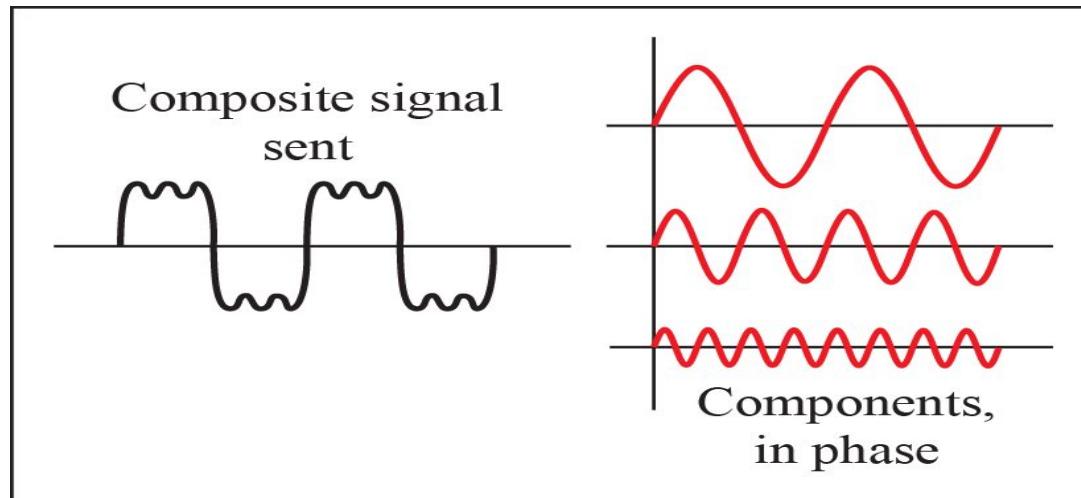
Example 7.6

Suppose a signal travels through a transmission medium and its power is reduced to one half. This means that $P_2 = 0.5 P_1$. In this case, the attenuation (loss of power) can be calculated as

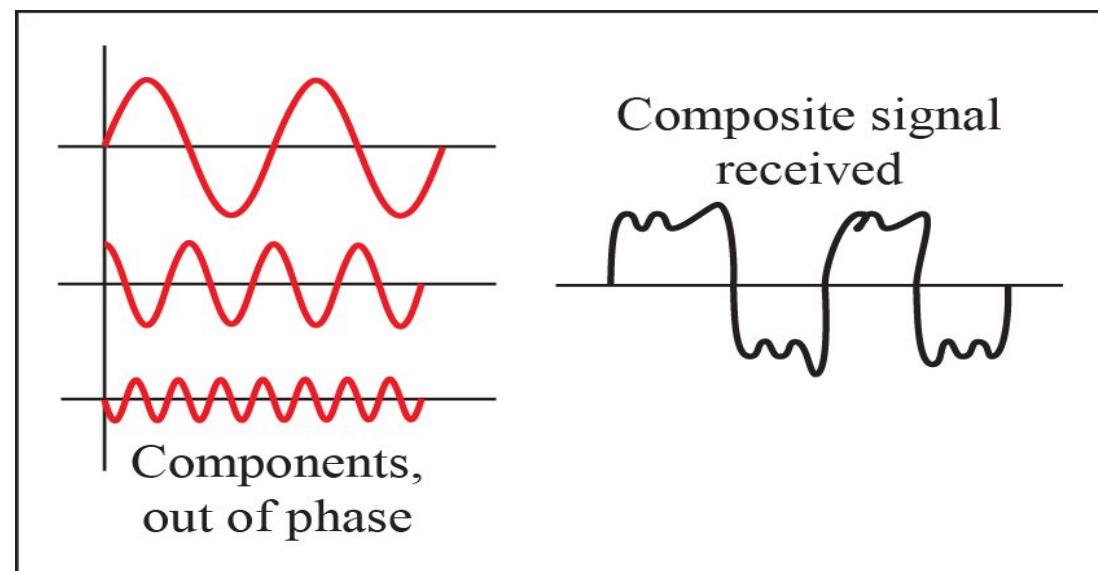
$$10 \log_{10} P_2/P_1 = 10 \log_{10} (0.5 P_1) /P_1 = 10 \log_{10} 0.5 = 10 \times (-0.3) = -3 \text{ dB.}$$

A loss of 3 dB (-3 dB) is equivalent to losing one-half the power.

Figure 7.14: Distortion



At the sender



At the receiver

Figure 7.15: Noise

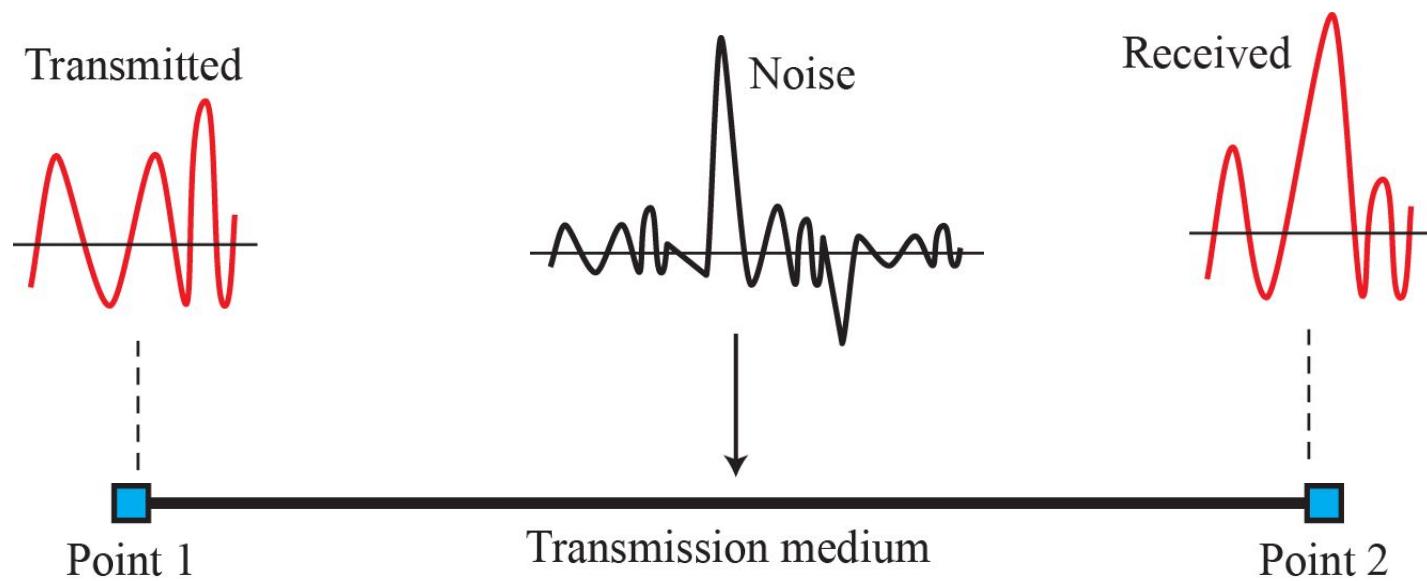
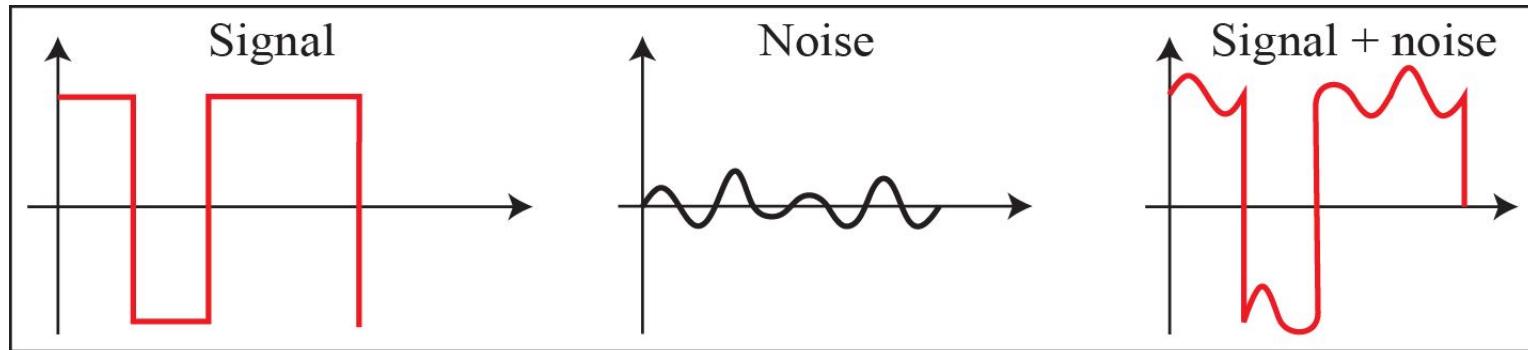
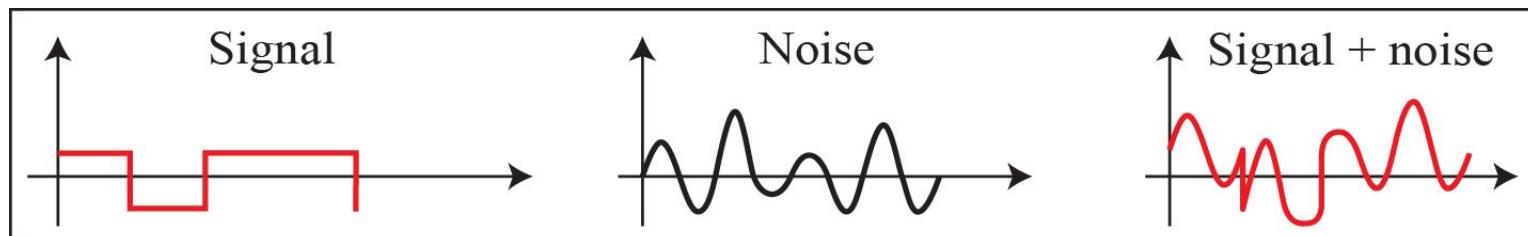


Figure 7.16: Two cases of SNR: a high SNR and a low SNR



a. High SNR



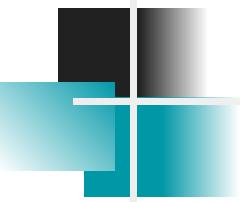
b. Low SNR

7.1.3 Data Rate Limits

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends 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.



7.1.3 (*continued*)

- *Noiseless Channel: Nyquist Bit Rate*
- *Noisy Channel: Shannon Capacity*
- *Using Both Limits*

Example 7.7

We need to send 265 kbps over a noiseless (ideal) channel with a bandwidth of 20 kHz. How many signal levels do we need? We can use the Nyquist formula as shown:

$$265,000 = 2 \times 20,000 \times \log_2 L \quad \rightarrow \quad \log_2 L = 6.625 \quad L = 2^{6.625} = 98.7 \text{ levels}$$

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

Example 7.8

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 shown below.

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

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, the data is so corrupted in this channel that it is useless when received.

Example 7.9

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as shown below.

$$C = B \log_2 (1 + SNR) = 3000 \log_2 (1 + 3162) = 34,881 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.881 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to noise ratio.

Example 7.10

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?

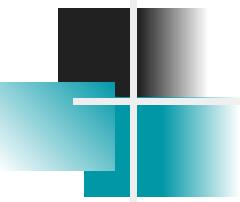
Solution

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

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

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \rightarrow \log_2 L = 2 \rightarrow L = 4$$



7.1.4 Performance

Up to now, we have discussed the tools of transmitting data (signals) over a network and how the data behave. One important issue in networking is the performance of the network—how good is it? We discuss quality of service, an overall measurement of network performance, in detail in Chapter 8.

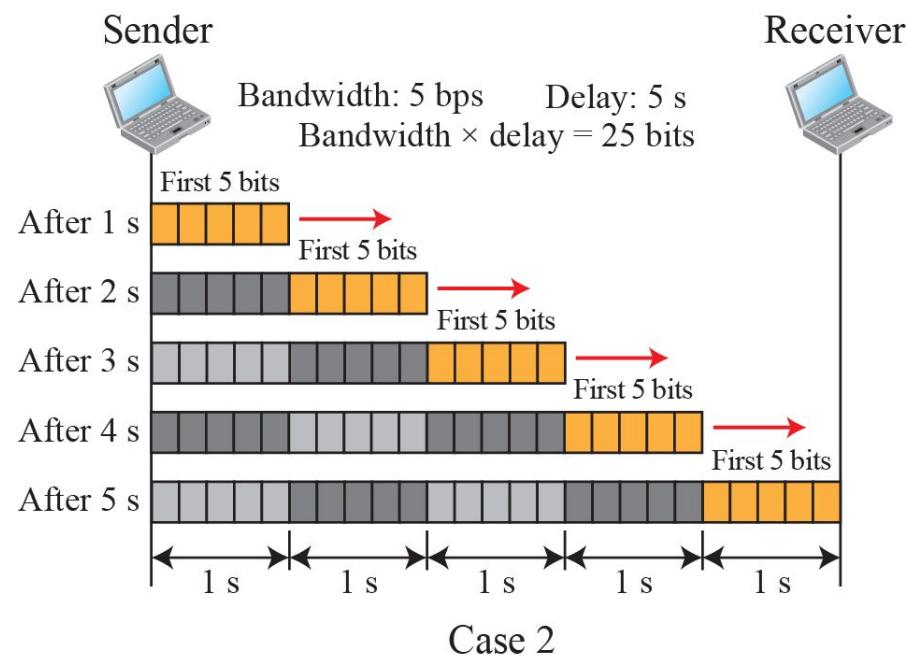
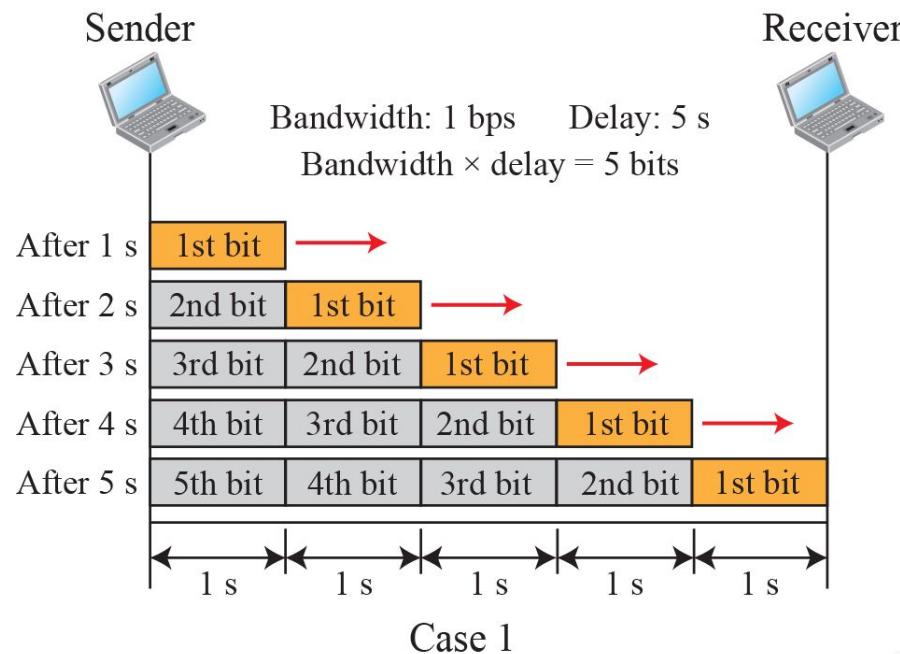
7.1.4 (*continued*)

- *Bandwidth*
 - ◆ *Bandwidth in Hertz*
 - ◆ *Bandwidth in Bits per Seconds*
 - ◆ *Relationship*
- *Throughput*
- *Latency (Delay)*
- *Bandwidth-Delay Product*
- *Jitter*

Example 7.11

The bandwidth of a subscriber line is 4 kHz for voice or data. The bandwidth of this line for data transmission can be up to 56 kbps, using a sophisticated modem to change the digital signal to analog. If the telephone company improves the quality of the line and increases the bandwidth to 8 kHz, we can send 112 kbps.

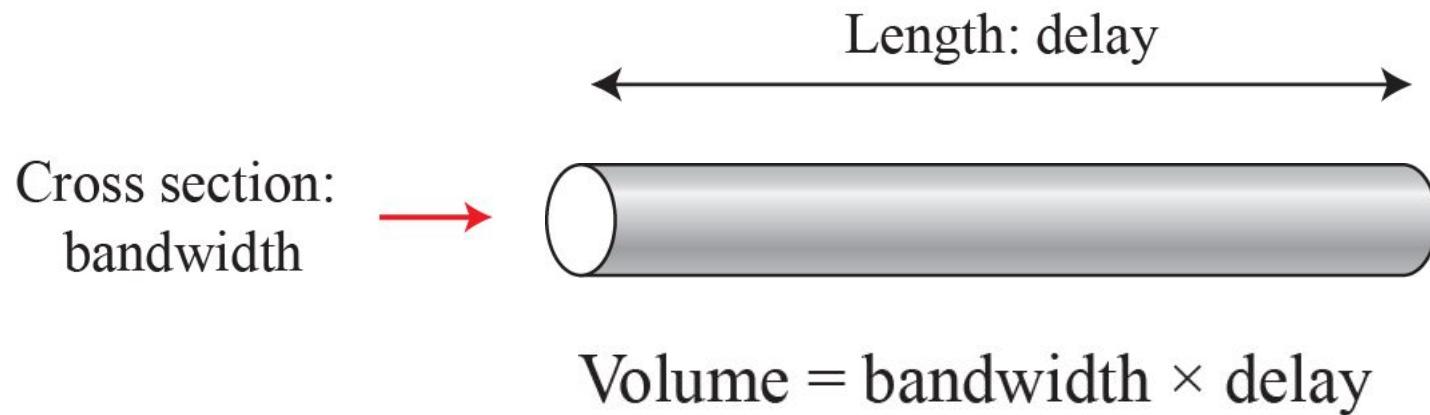
Figure 7.17: Filling the link with bits for cases 1 and 2



Example 7.12

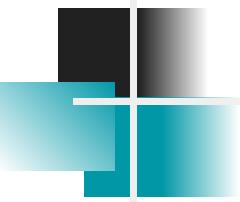
We can think about the link between two points as a pipe. The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay. We can say the volume of the pipe defines the bandwidth-delay product, as shown in Figure 7.18.

Figure 7.18: Concept of bandwidth-delay product



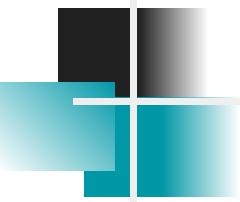
7-2 DIGITAL TRANSMISSION

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 this section, we discuss the first choice, conversion to digital signals; in the next section, we discuss the second choice, conversion to analog signals.



7.2.1 *Digital-to-Digital Conversion*

In this section, we see how we can represent digital data by using digital signals. The conversion involves three techniques: line coding, block coding, and scrambling. Line coding is always needed; block coding and scrambling may or may not be needed.



7.2.1 (*continued*)

□ *Line Coding*

- ◆ *Polar Schemes*
- ◆ *Bipolar Schemes*
- ◆ *Multilevel Schemes*

□ *Block Coding*

- ◆ *4B/5B Coding*
- ◆ *8B/10B Coding*

□ *Scrambling*

- ◆ *B8ZS Coding*
- ◆ *HDB3 Coding*

Figure 7.19: Line coding and decoding

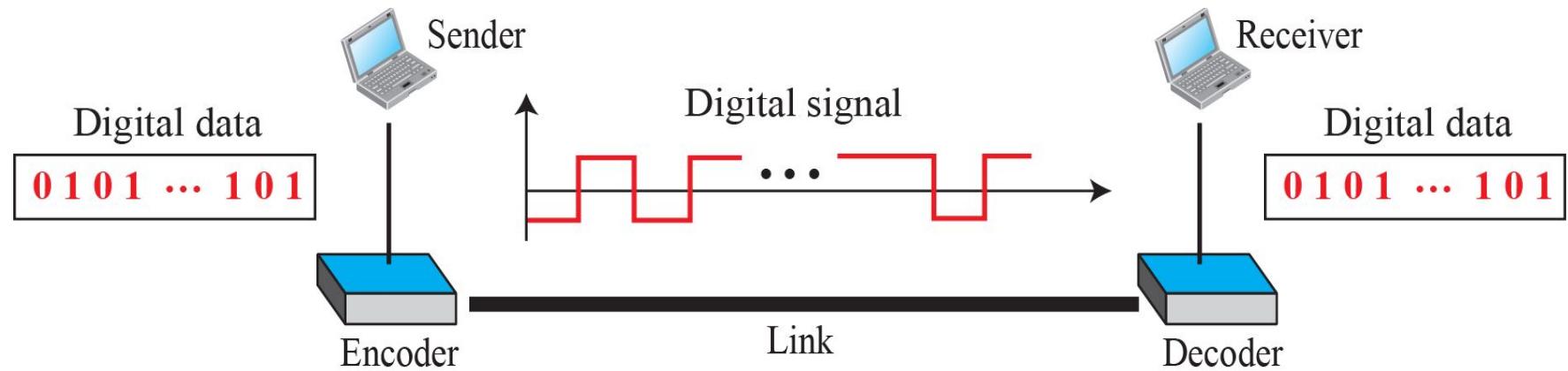


Figure 7.20: Polar schemes (Part I: NRZ)

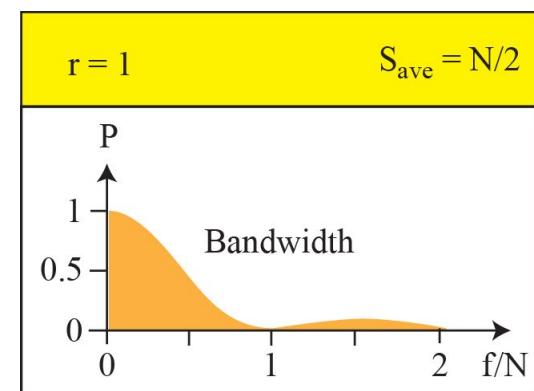
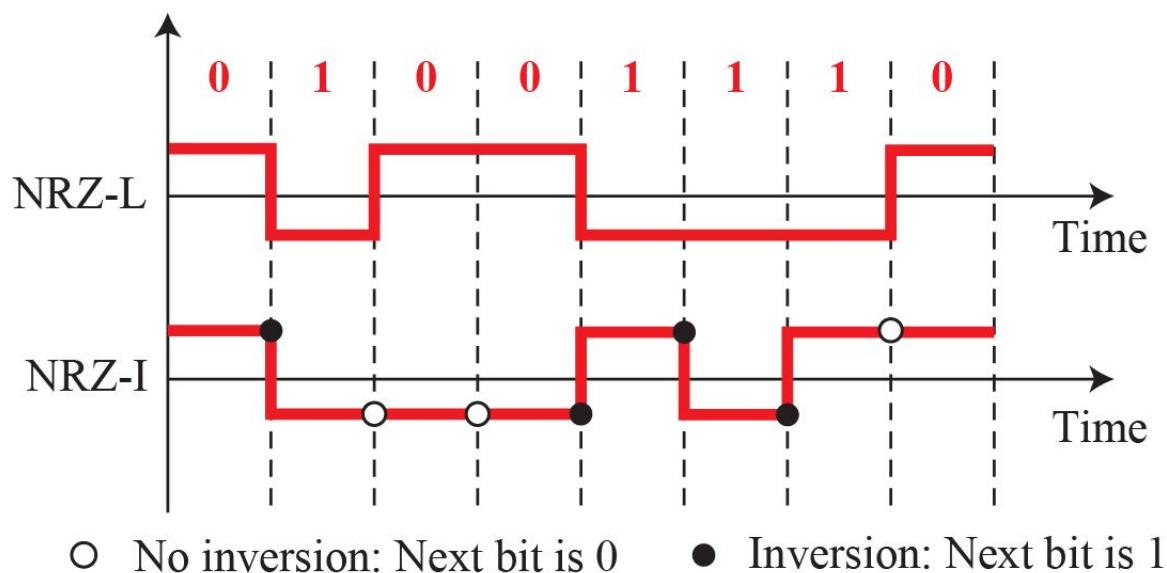


Figure 7.20: Polar schemes (Part II: RZ)

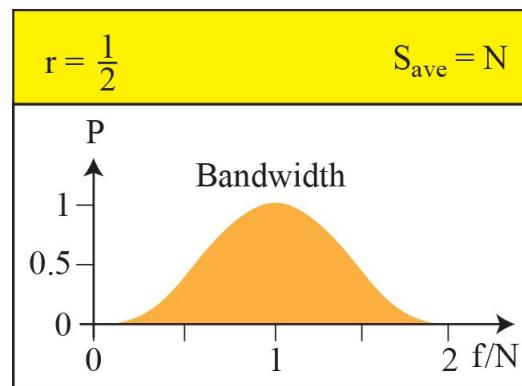
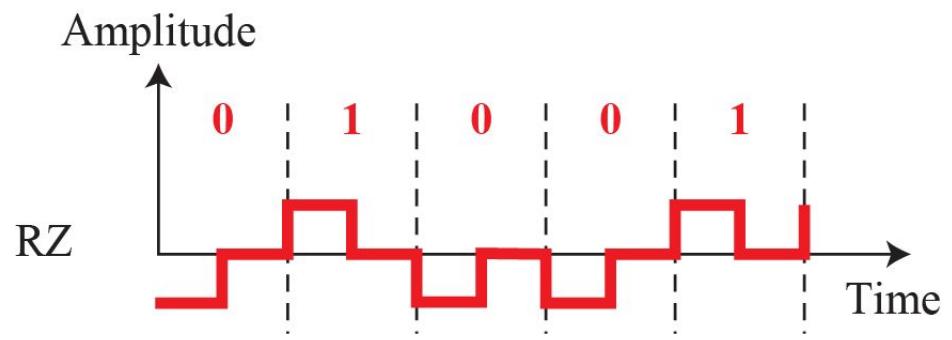
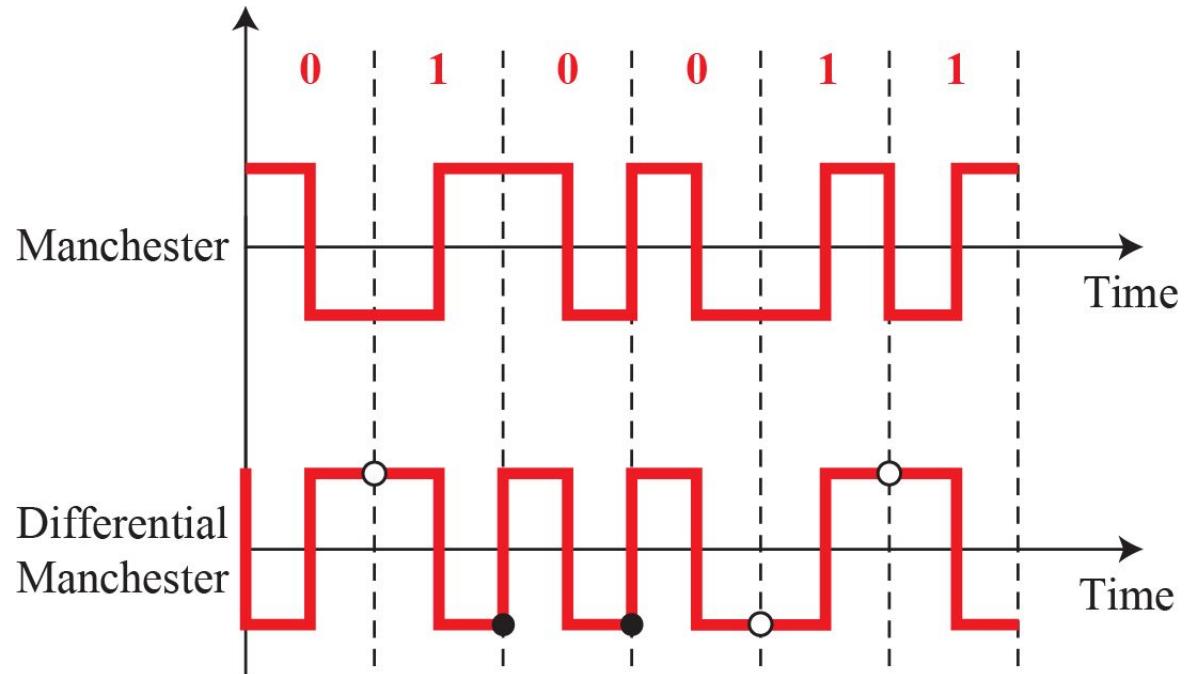


Figure 7.20: Polar schemes (Part III: Manchesters)



- No inversion: Next bit is 1
- Inversion: Next bit is 0

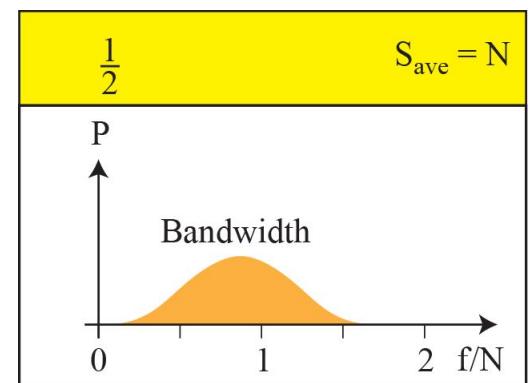


Figure 7.21: Bipolar schemes: AMI and pseudoternary

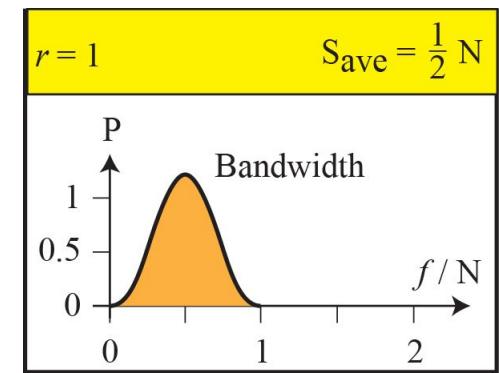
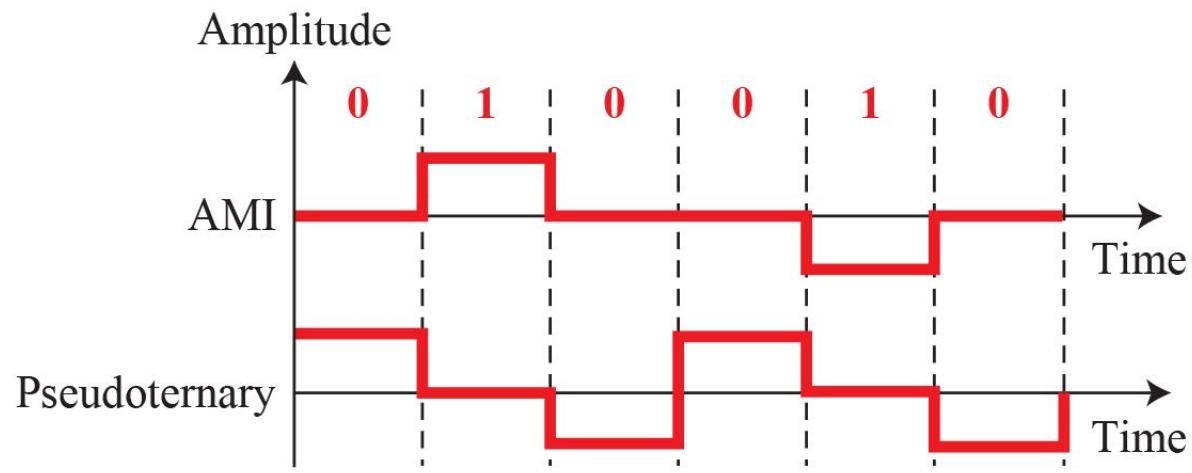


Figure 7.22: Multilevel: 2B1Q and 8B6T

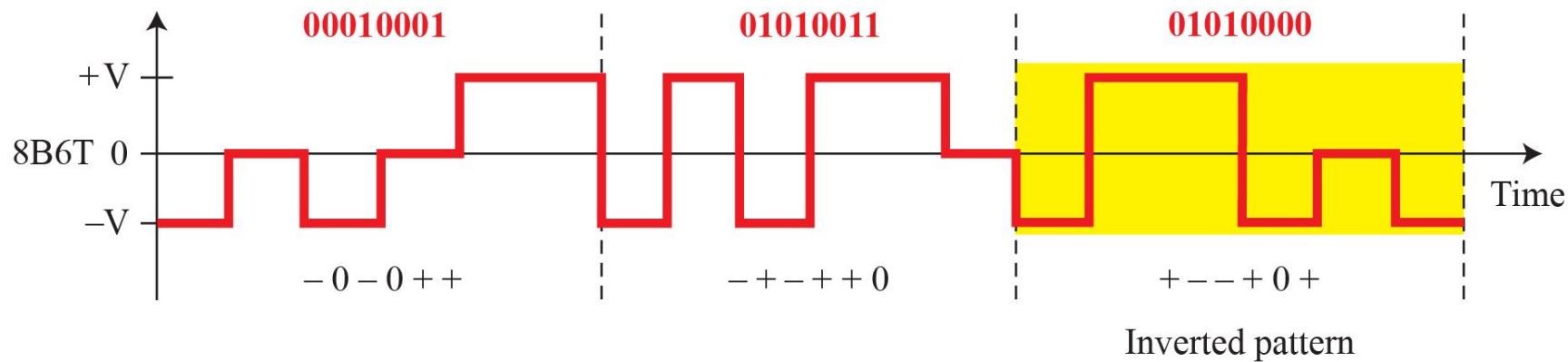
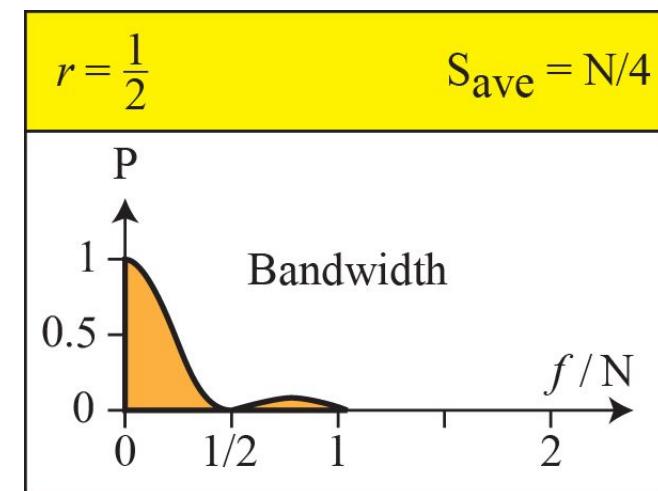
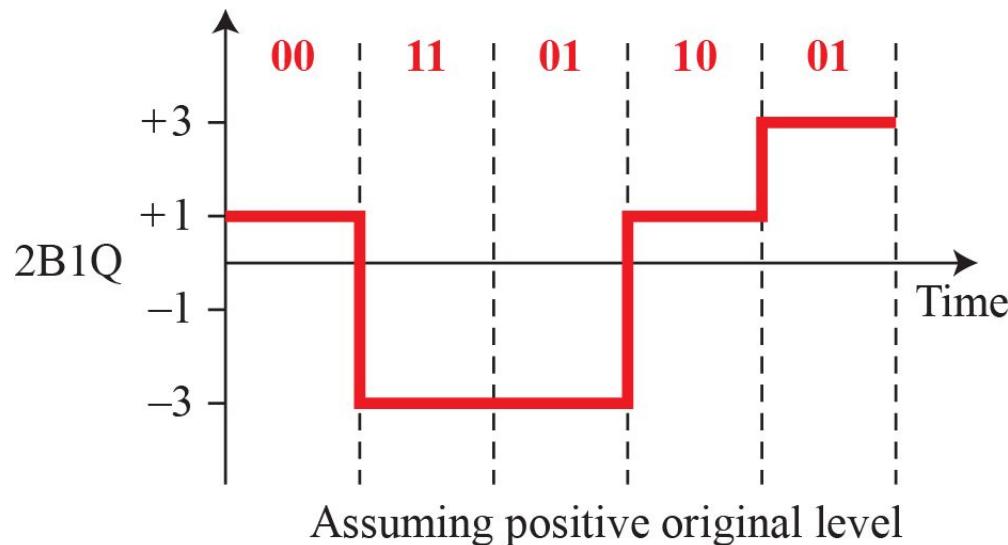


Figure 7.23: Block coding concept

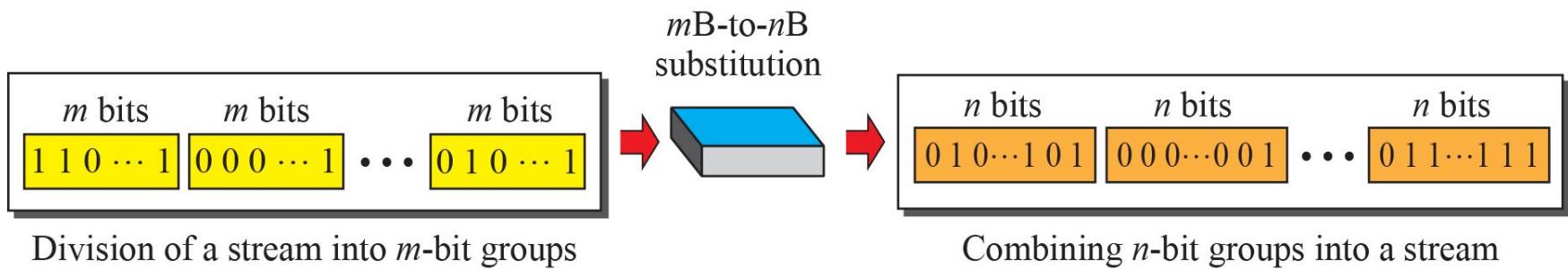


Figure 7.24: Using block coding 4B/5B with NRZ-I line coding scheme

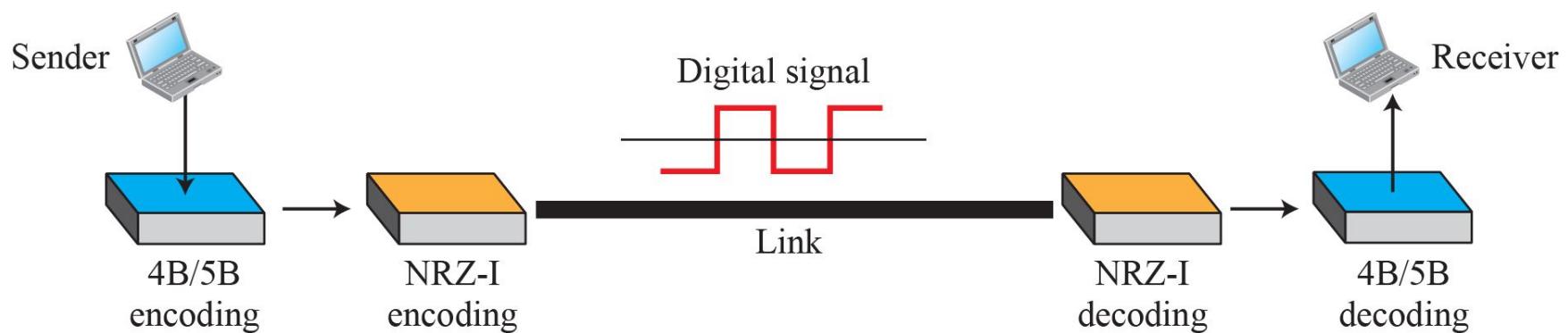


Figure 7.25: 8B/10B block encoding

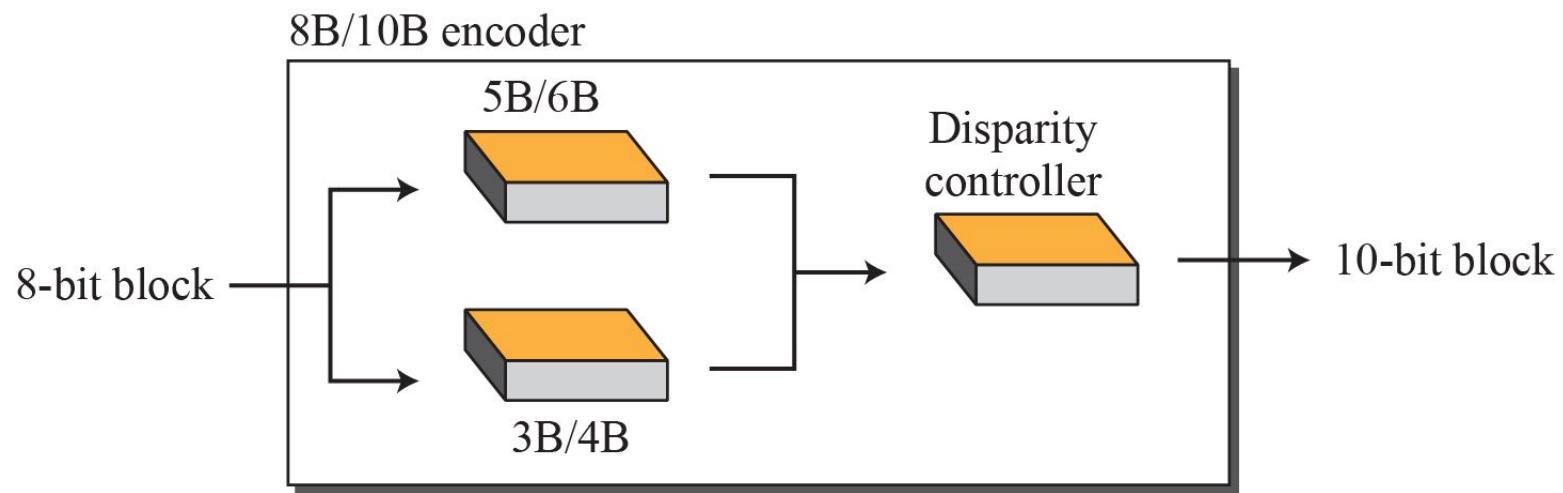


Figure 7.26: AMI used with scrambling

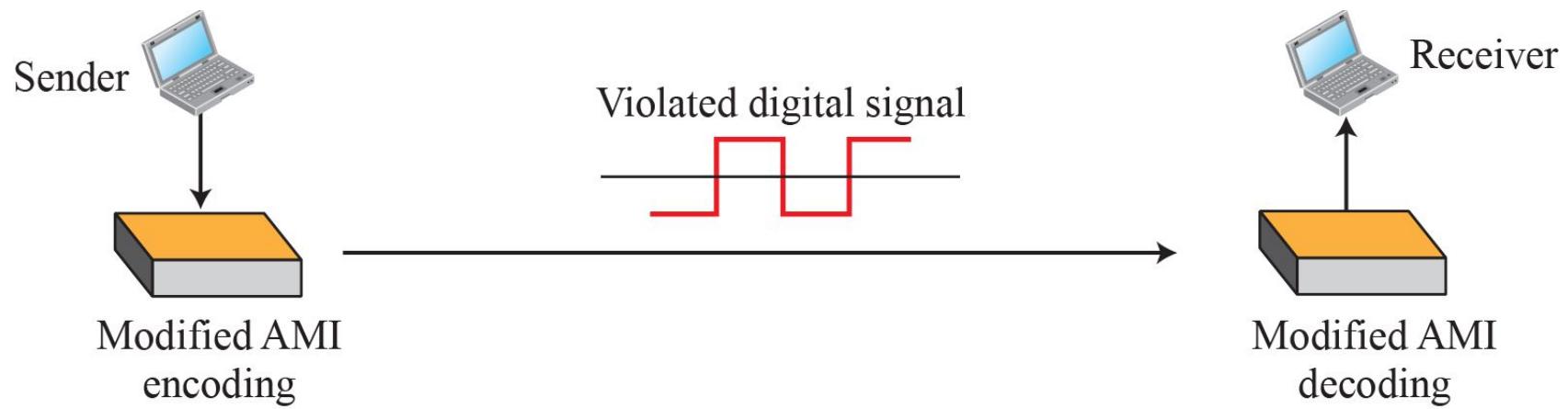
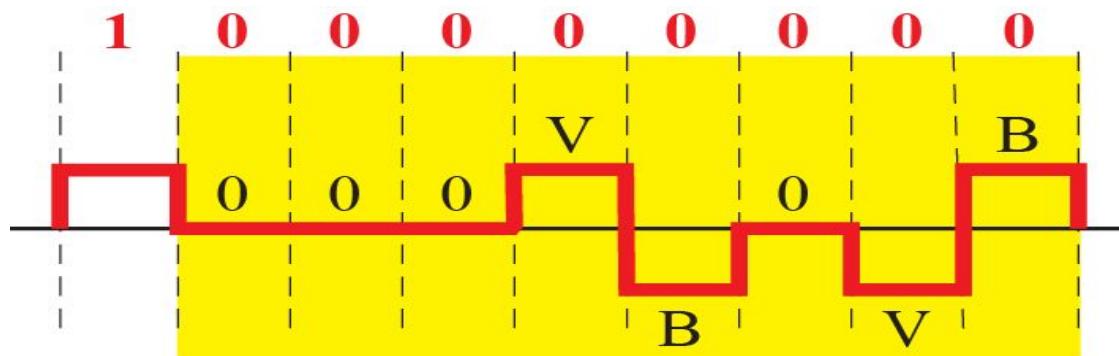
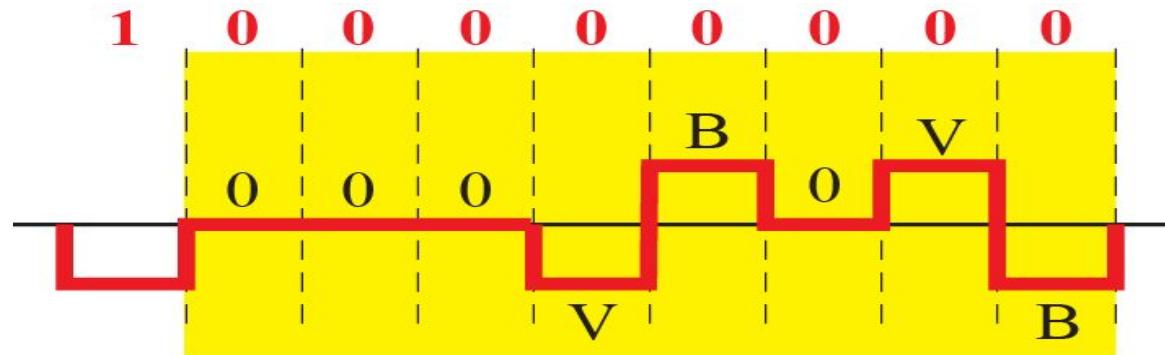


Figure 7.27: Two cases of B8ZS scrambling technique

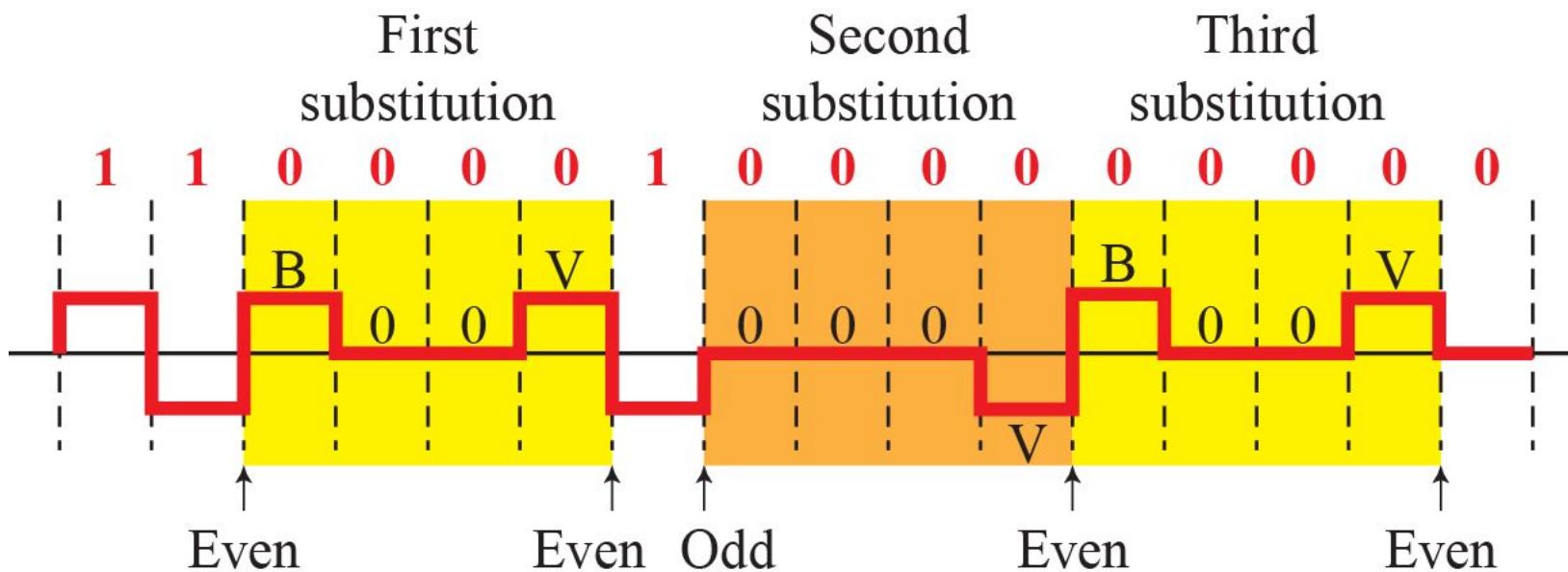


a. Previous level is positive.



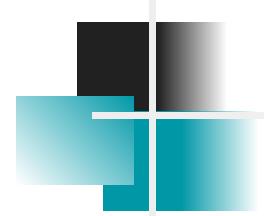
b. Previous level is negative.

Figure 7.28: Different situations in HDB3 scrambling technique



7.2.2 *Analog-to-Digital Conversion*

The techniques described in Section 7.2.1 convert digital data to digital signals. Sometimes, however, we have an analog signal such as one created by a microphone or camera. The tendency today is to change an analog signal to digital data because the digital signal is less susceptible to noise. In this section we describe two techniques, pulse code modulation and delta modulation. After the digital data are created (digitization),



7.2.2 (*continued*)

□ *Pulse Code Modulation (PCM)*

- ◆ *Sampling*
- ◆ *Quantization*
- ◆ *Encoding*
- ◆ *Original Signal Recovery*
- ◆ *PCM Bandwidth*

□ *Delta Modulation (DM)*

Figure 7.29: Components of PCM encoder

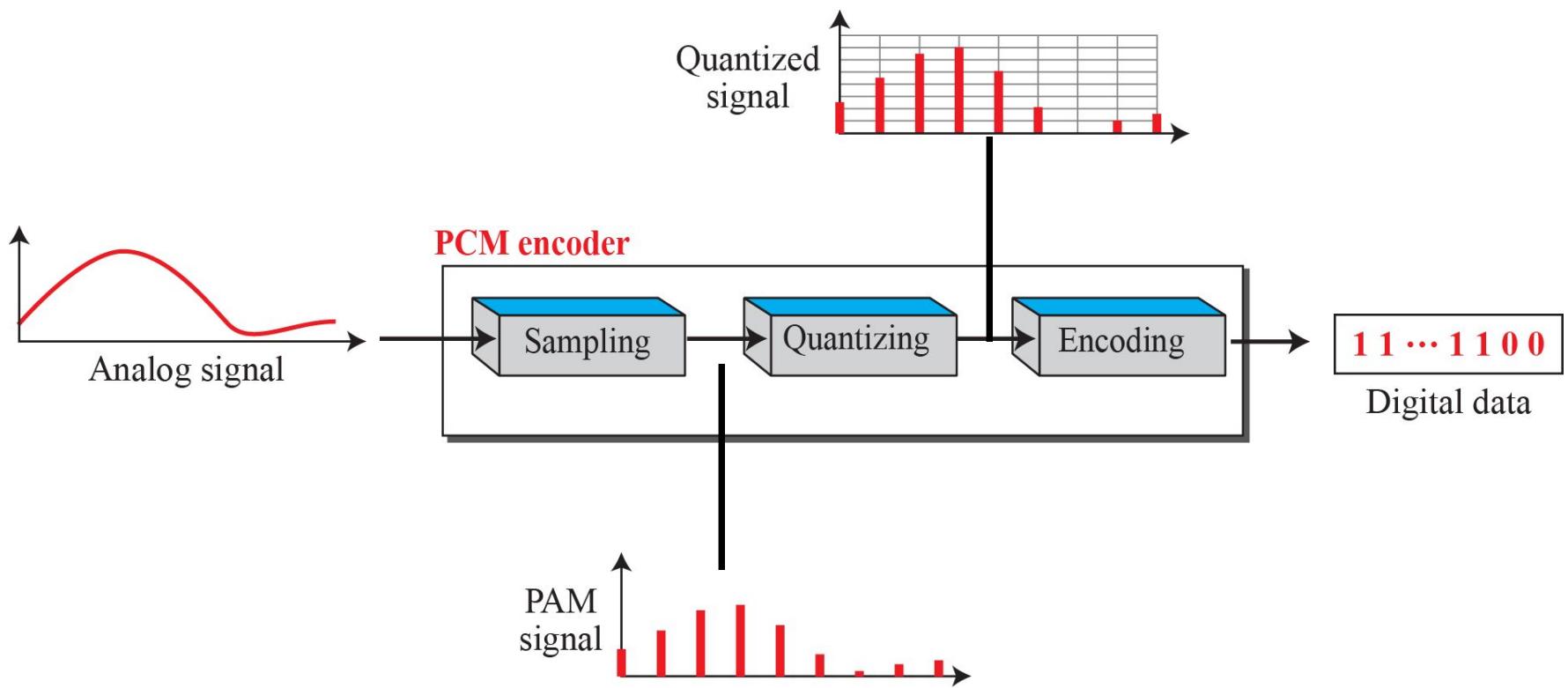
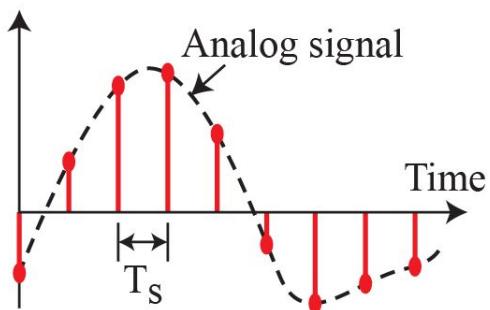


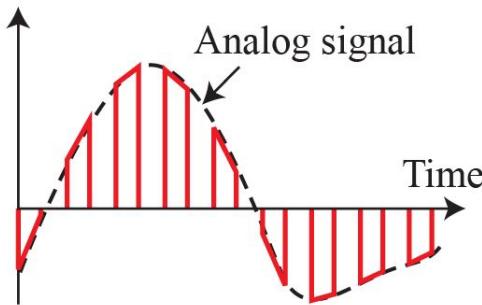
Figure 7.30: Three different sampling methods for PCM

Amplitude



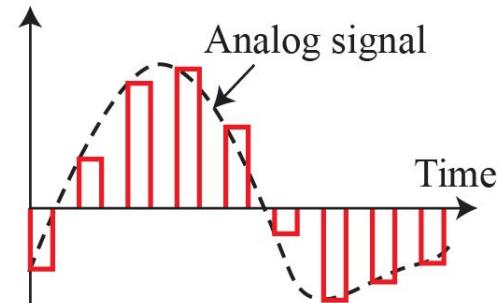
a. Ideal sampling

Amplitude



b. Natural sampling

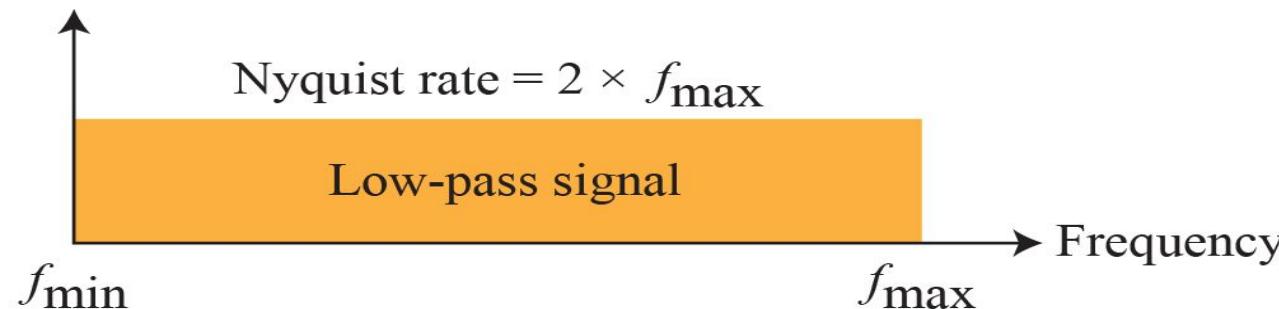
Amplitude



c. Flat-top sampling

Figure 7.30: Nyquist sampling rate for low-pass and bandpass signals

Amplitude



Amplitude

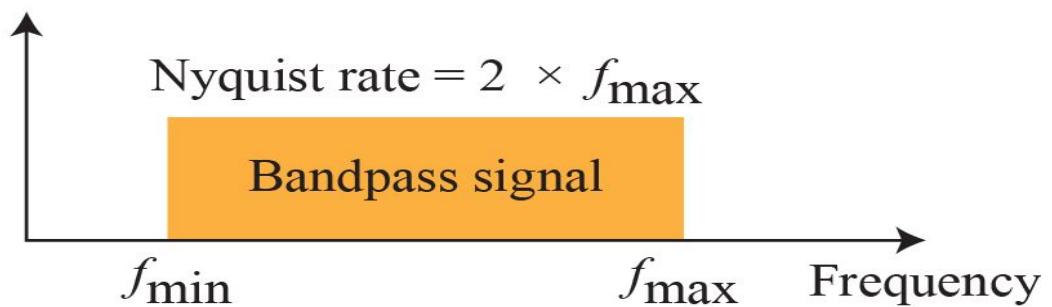
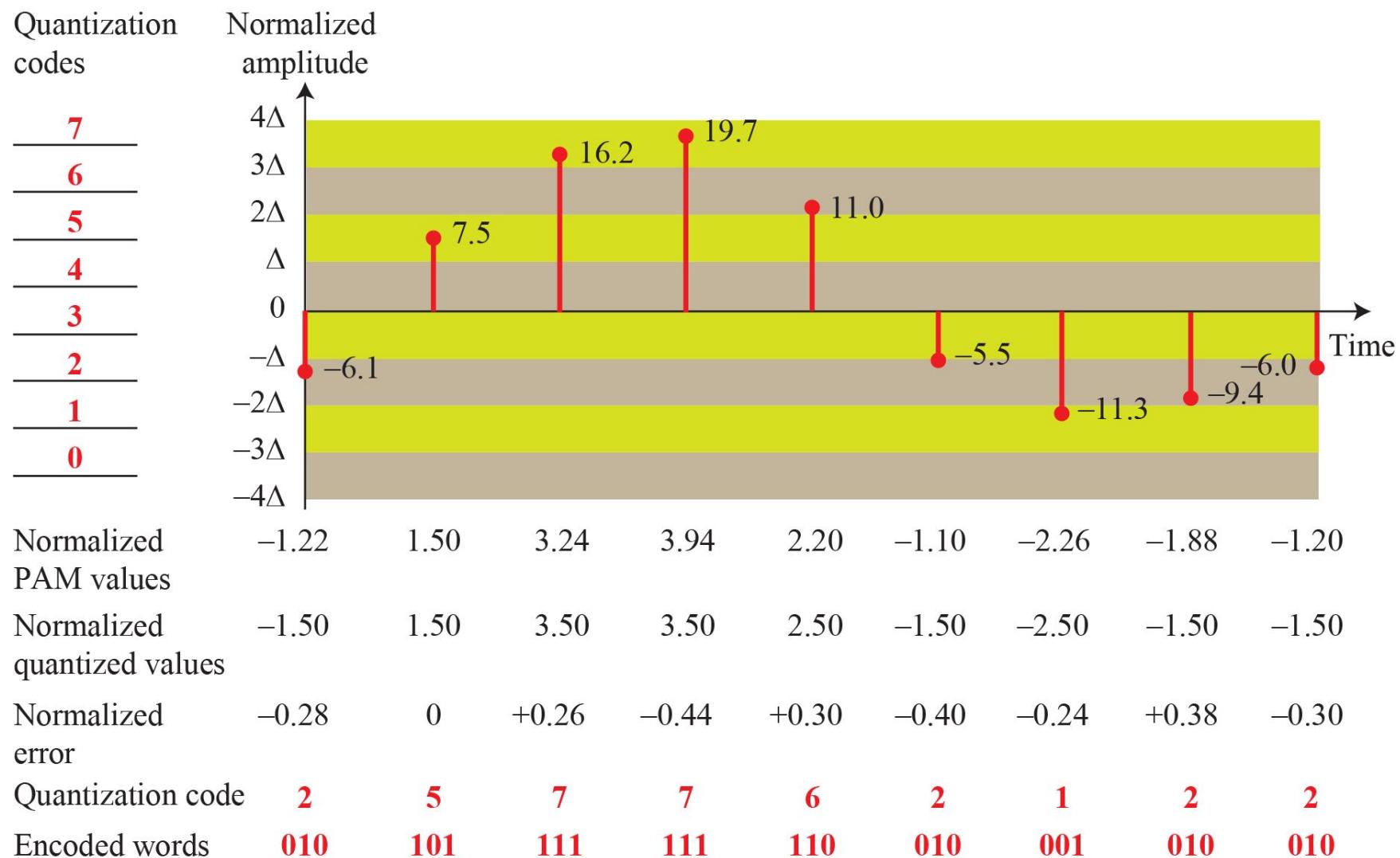


Figure 7.32: Quantization and encoding of a sampled signal



Example 7.13

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 follows.

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

Figure 7.33: Components of a PCM decoder

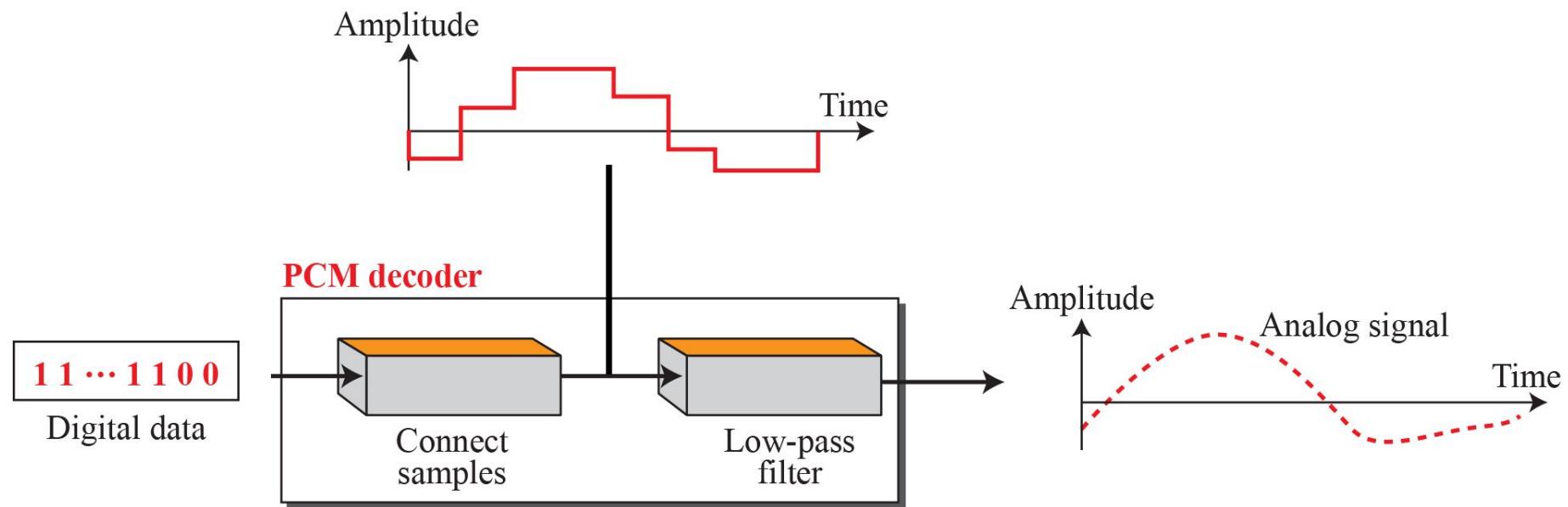
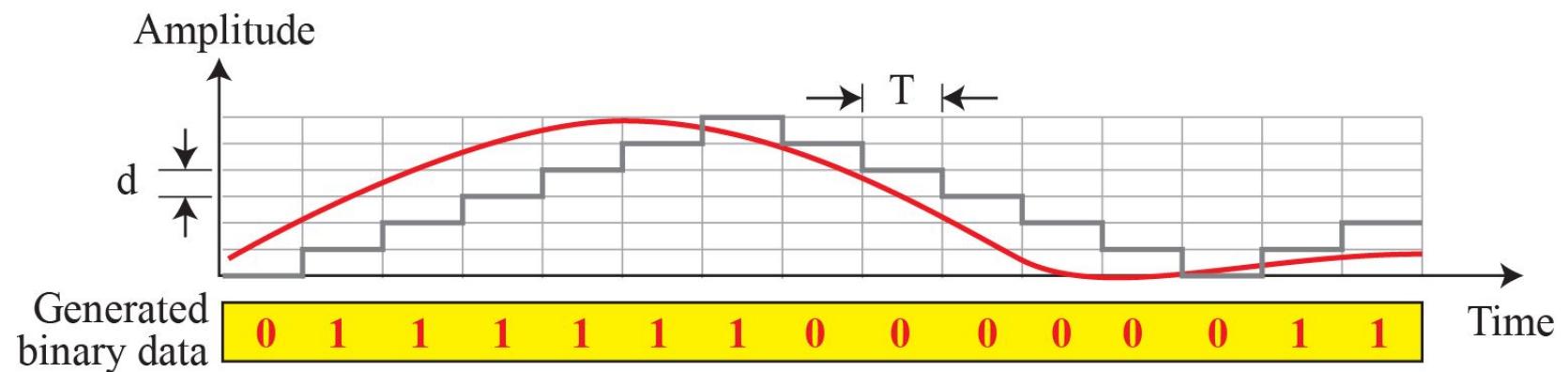


Figure 7.34: The process of delta modulation



7-3 ANALOG TRANSMISSION

While digital transmission is desirable, it needs a low-pass channel; analog transmission is the only choice if we have a bandpass channel. Converting digital data to a bandpass analog signal is traditionally called digital-to-analog conversion. Converting a low-pass analog signal to a bandpass analog signal is traditionally called analog-to-analog conversion.

7.3.1 *Digital-to-Analog Conversion*

Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data. Figure 7.35 shows the relationship between the digital information, the digital-to-analog modulating process, and the resultant analog signal.

7.3.1 (*continued*)

□ *Amplitude Shift Keying*

- ◆ *Binary ASK (BASK)*
- ◆ *Multilevel ASK*
- ◆ *Binary FSK (BFSK)*
- ◆ *Multilevel FSK*

□ *Phase Shift Keying*

- ◆ *Binary PSK (BPSK)*
- ◆ *Quadrature PSK (QPSK)*
- ◆ *Constellation Diagram*

□ *Quadrature Amplitude Modulation*

- ◆ *Bandwidth for QAM*

Figure 7.35: Digital-to-analog conversion

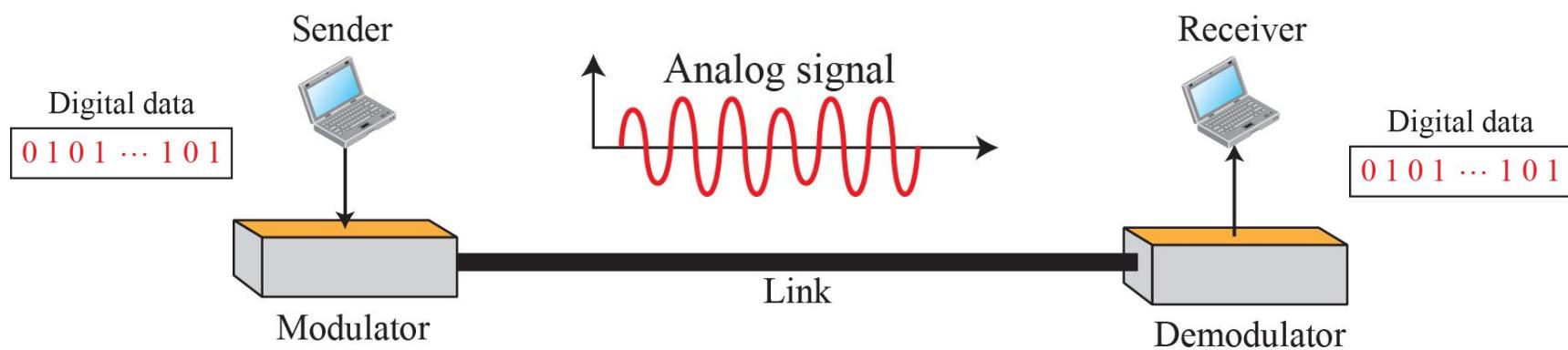


Figure 7.36: Binary amplitude shift keying

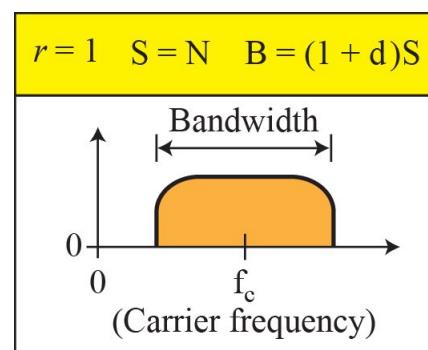
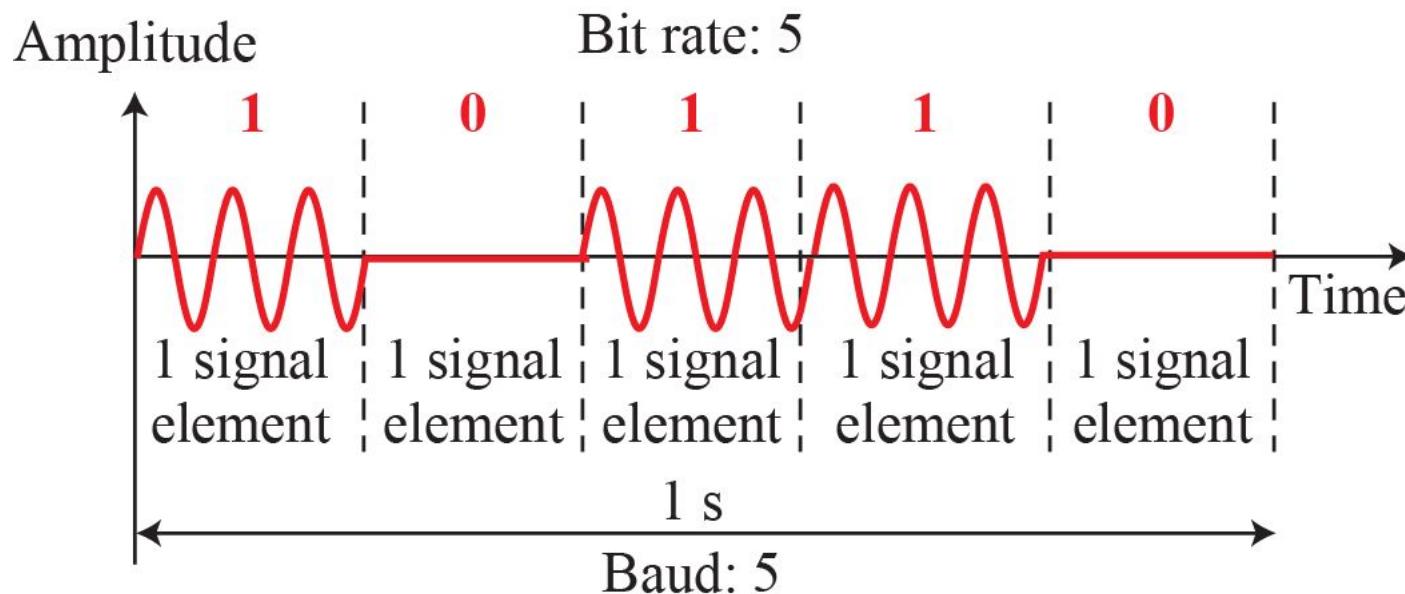


Figure 7.37: Binary frequency shift keying

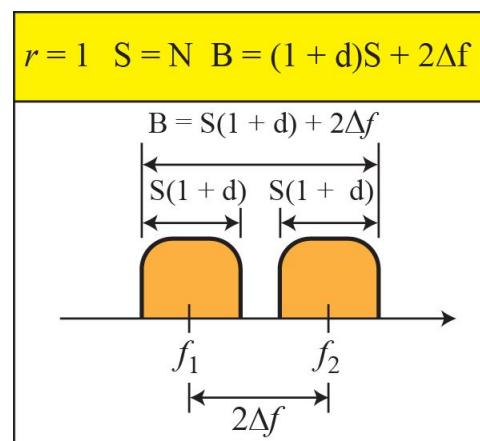
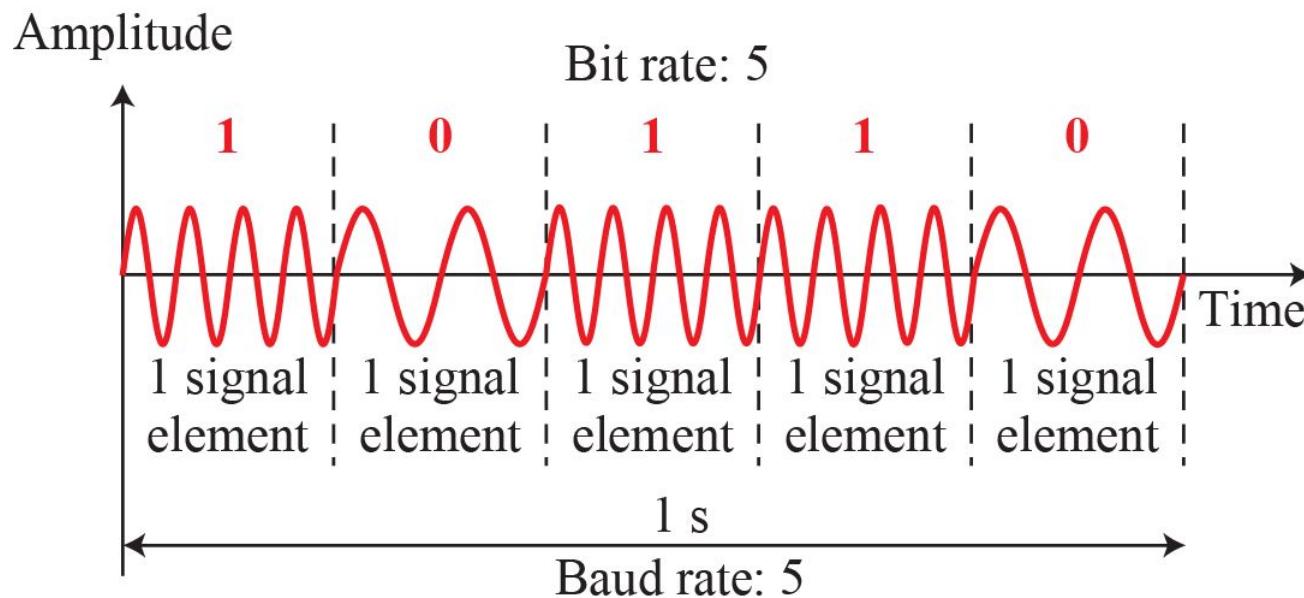


Figure 7.38: Binary phase shift keying

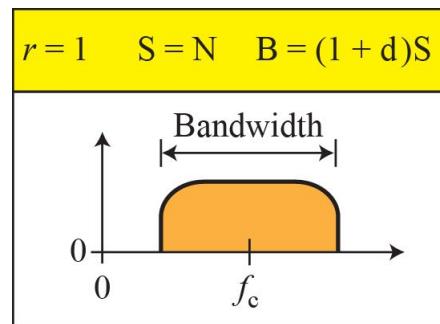
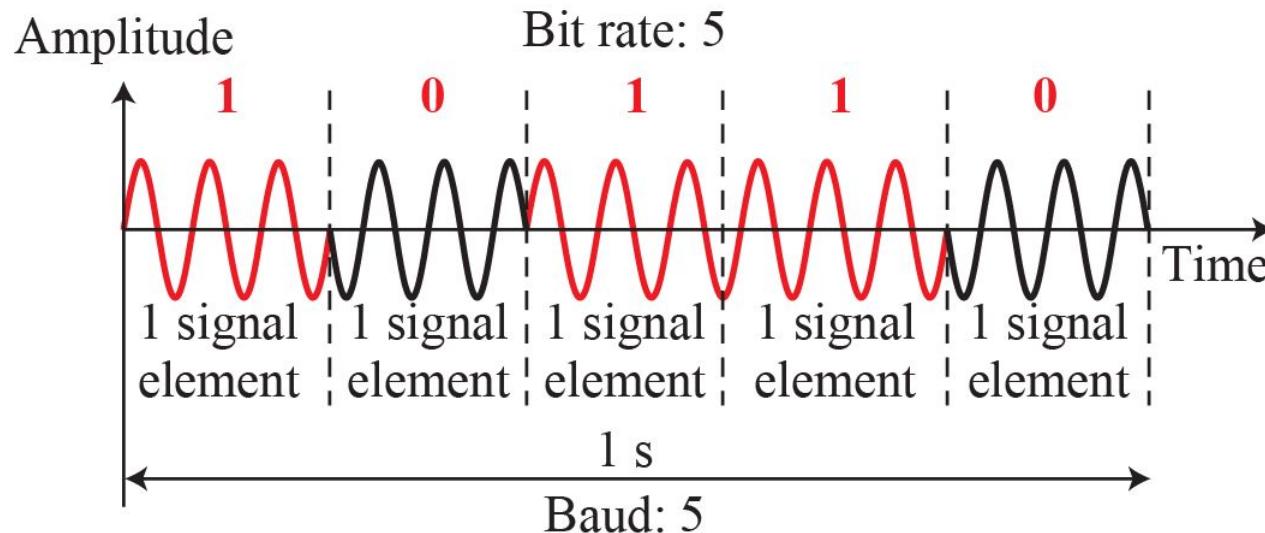


Figure 7.39: Concept of a constellation diagram

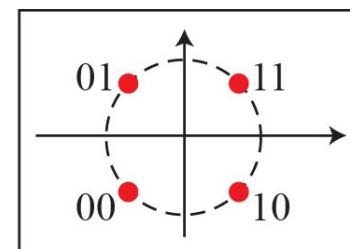
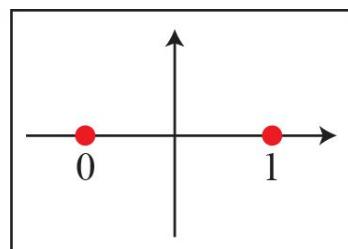
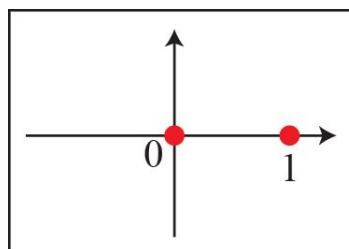
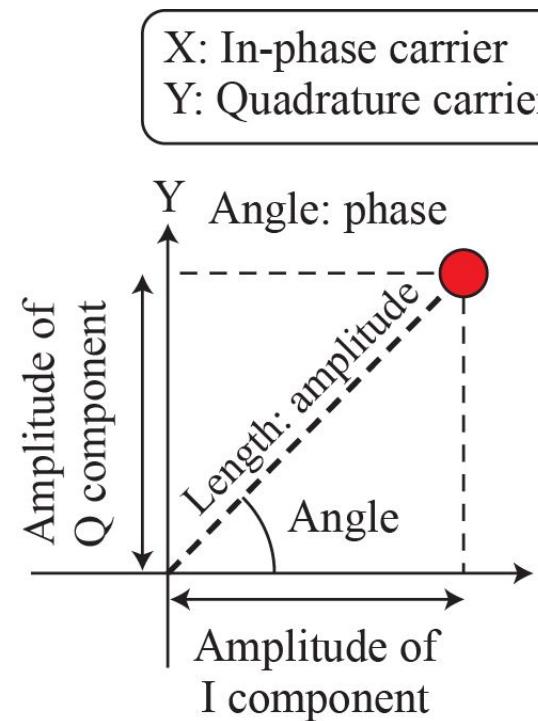
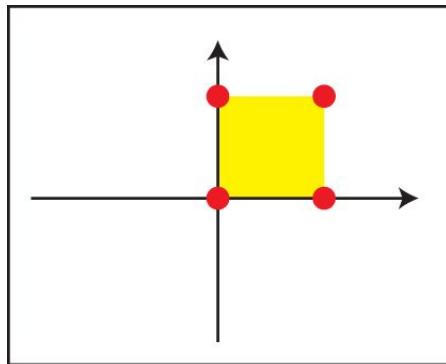
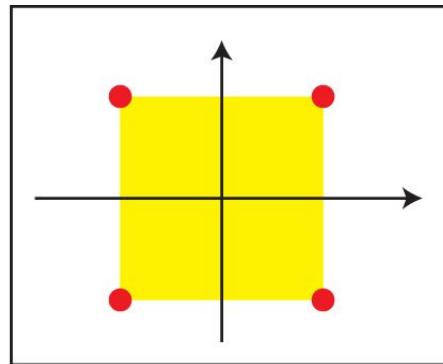


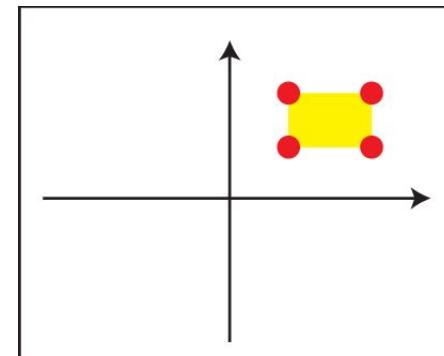
Figure 7.40: Constellation diagrams for some QAMs



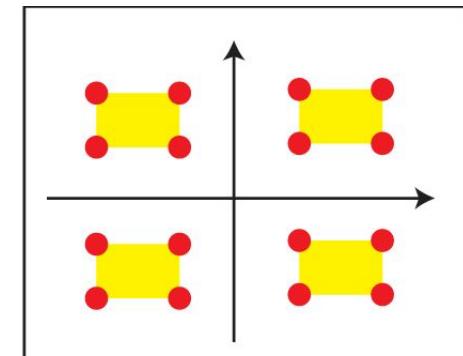
a. 4-QAM



b. 4-QAM



c. 4-QAM



d. 16-QAM

7.3.2 *Analog-to-Analog Conversion*

Analog-to-analog conversion, or analog modulation, is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us.

- Amplitude Modulation*
- Frequency Modulation*
- Phase Modulation*

Figure 7.41: Amplitude modulation

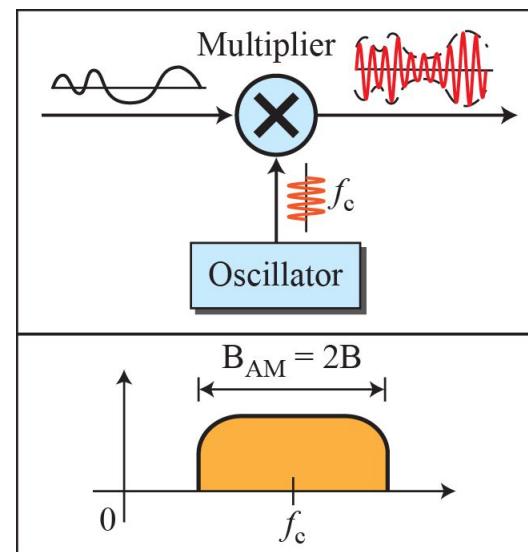
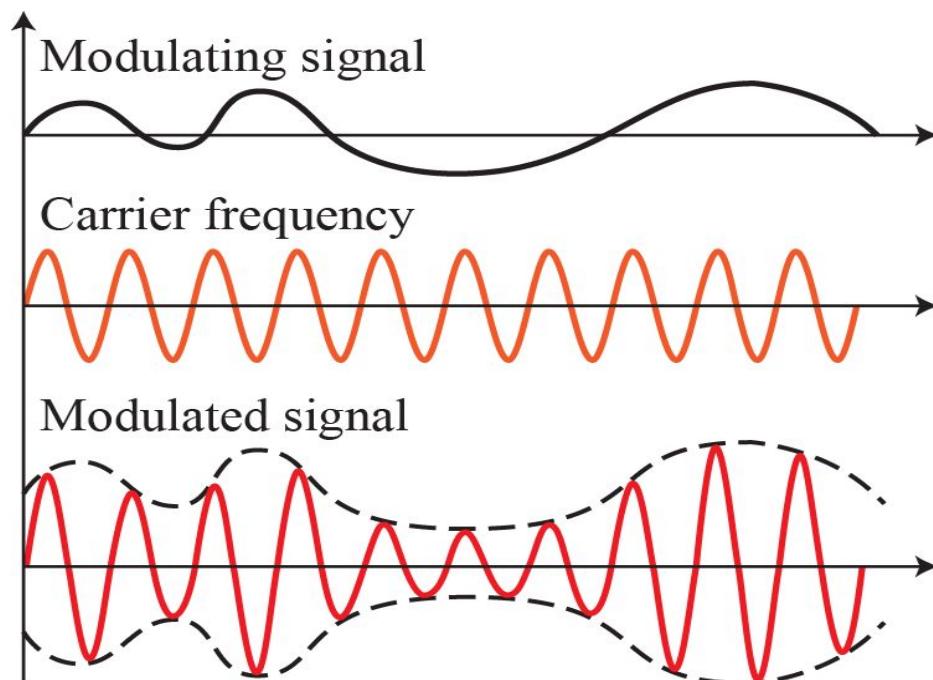


Figure 7.42: Frequency modulation

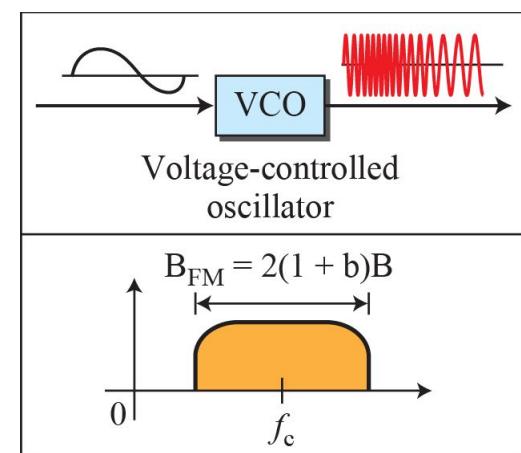
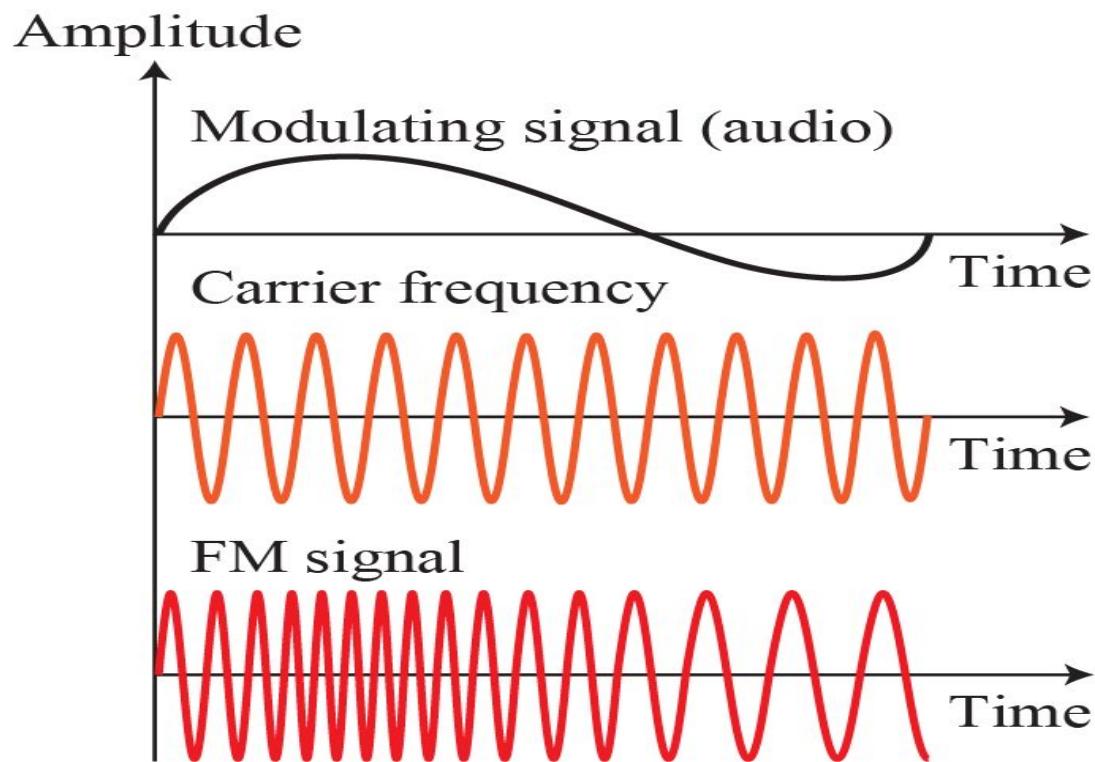
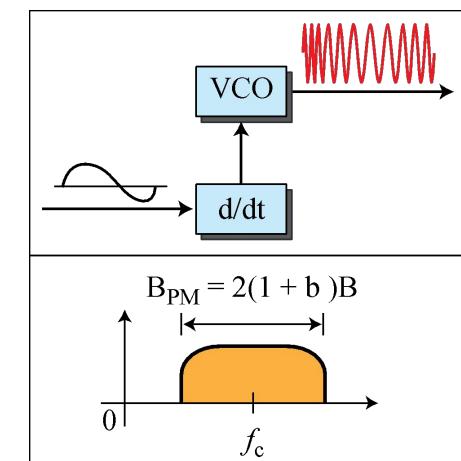
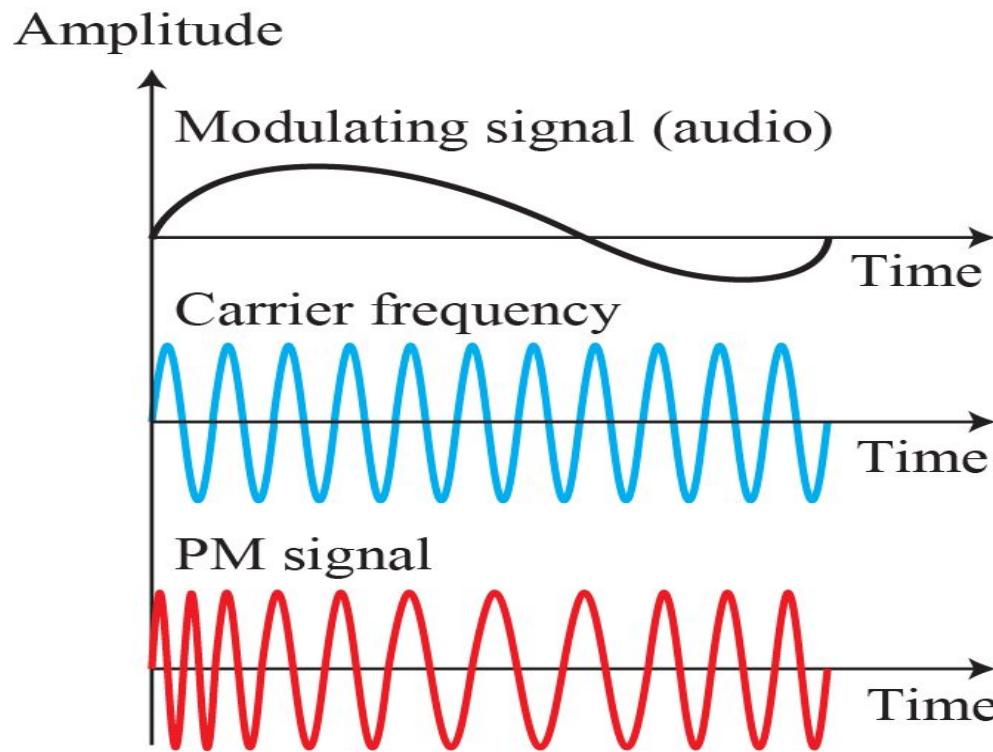
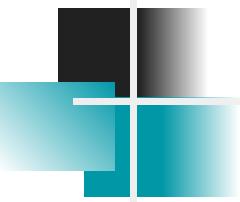


Figure 7.43: Phase modulation



7-4 BANDWIDTH UTILIZATION

In real life, we have links with limited bandwidths. Sometimes we need to combine several low-bandwidth channels to make use of one channel with a larger bandwidth. Sometimes we need to expand the bandwidth of a channel to achieve goals such as privacy and anti-jamming.



7.4.1 Multiplexing

Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic. We can accommodate this increase by continuing to add individual links each time a new channel is needed, or we can install higher-bandwidth links and use each to carry multiple signals.

7.4.1 (*continued*)

- *Frequency-Division Multiplexing*
- *Wavelength-Division Multiplexing*
- *Time-Division Multiplexing*
 - ❖ *Synchronous TDM*
 - ❖ *Statistical Time-Division Multiplexing*

Figure 7.44: Dividing a link into channels

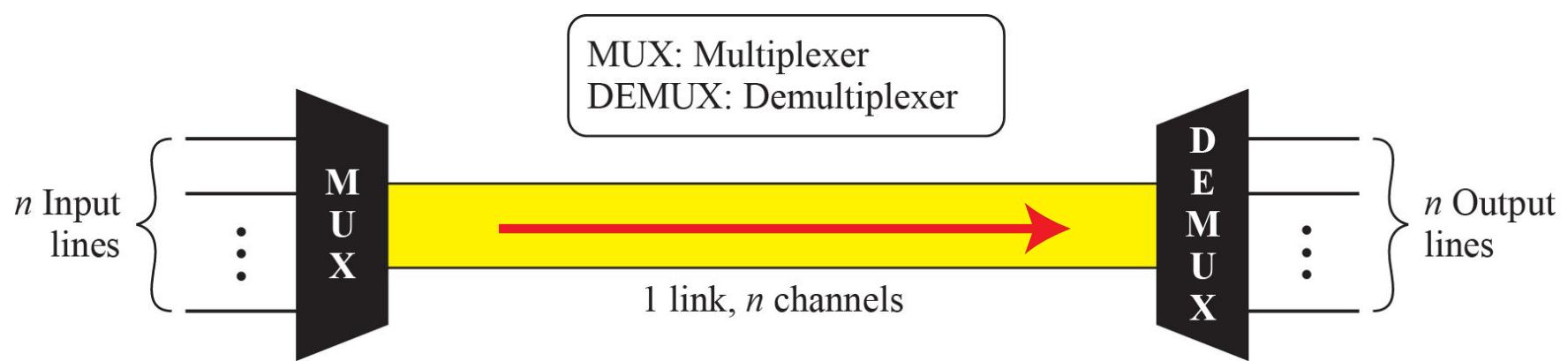
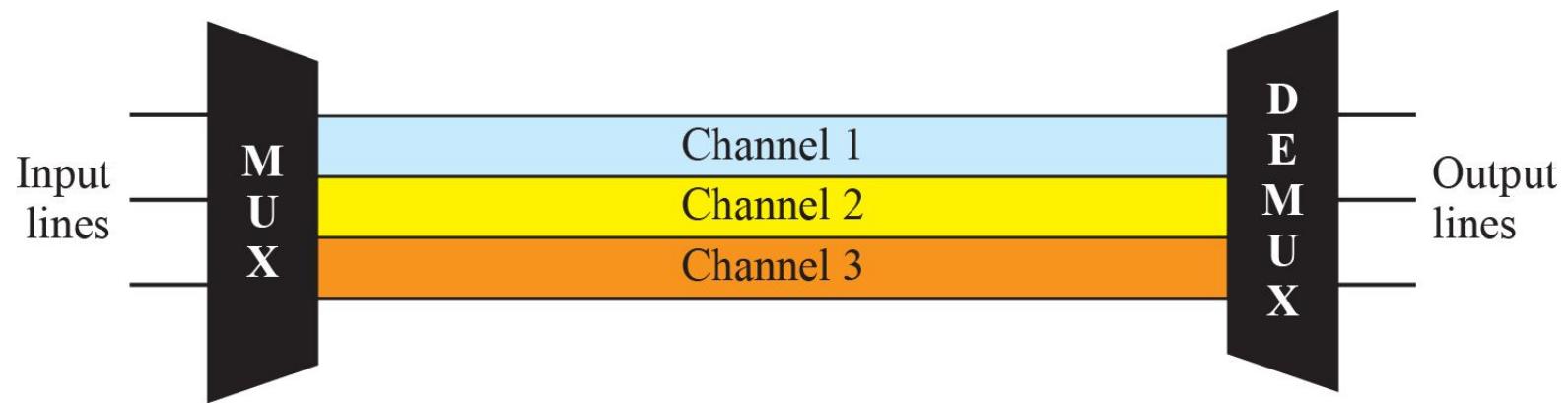


Figure 7.45: Frequency-division multiplexing



Example 7.14

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.

Solution

We shift (modulate) each of the three voice channels to a different bandwidth, as shown in Figure 7.46. We use the 20- to 24-kHz bandwidth for the first channel, the 24- to 28-kHz bandwidth for the second channel, and the 28- to 32-kHz bandwidth for the third one. Then we combine them as shown in Figure 7.46. At the receiver, each channel receives the entire signal, using a filter to separate out its own signal. The first channel uses a filter that passes frequencies between 20 and 24 kHz and filters out (discards) any other frequencies. The second channel uses a filter that passes frequencies between 24 and 28 kHz, and the third channel uses a filter that passes frequencies between 28 and 32 kHz. Each channel then shifts the frequency to start from zero.

Figure 7.46: Example 7.14

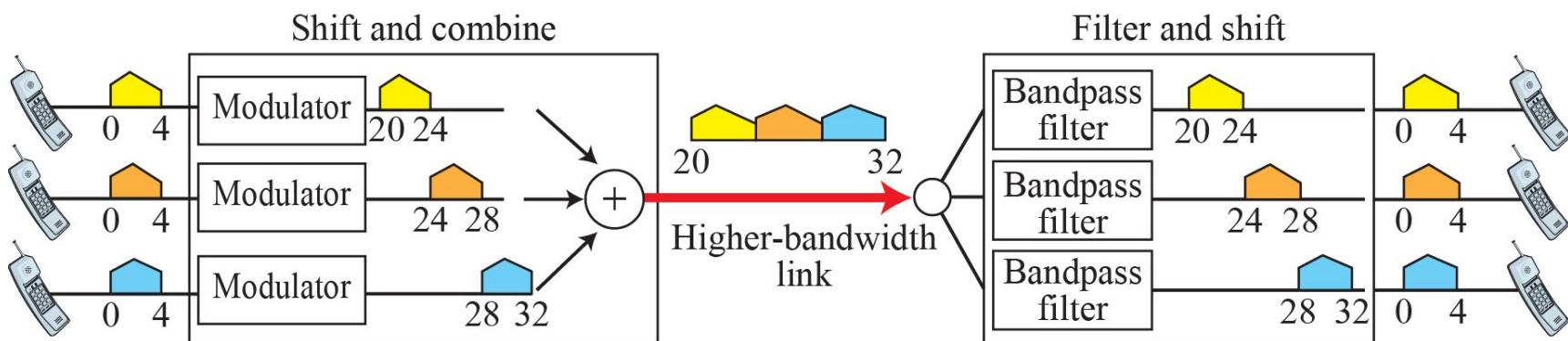


Figure 7.47: Wavelength-division multiplexing

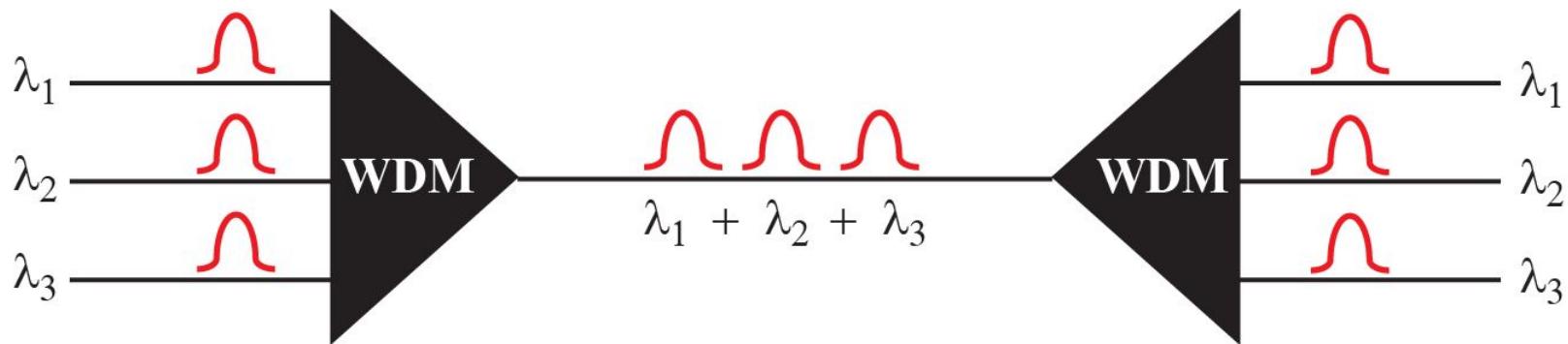


Figure 7.48: TDM

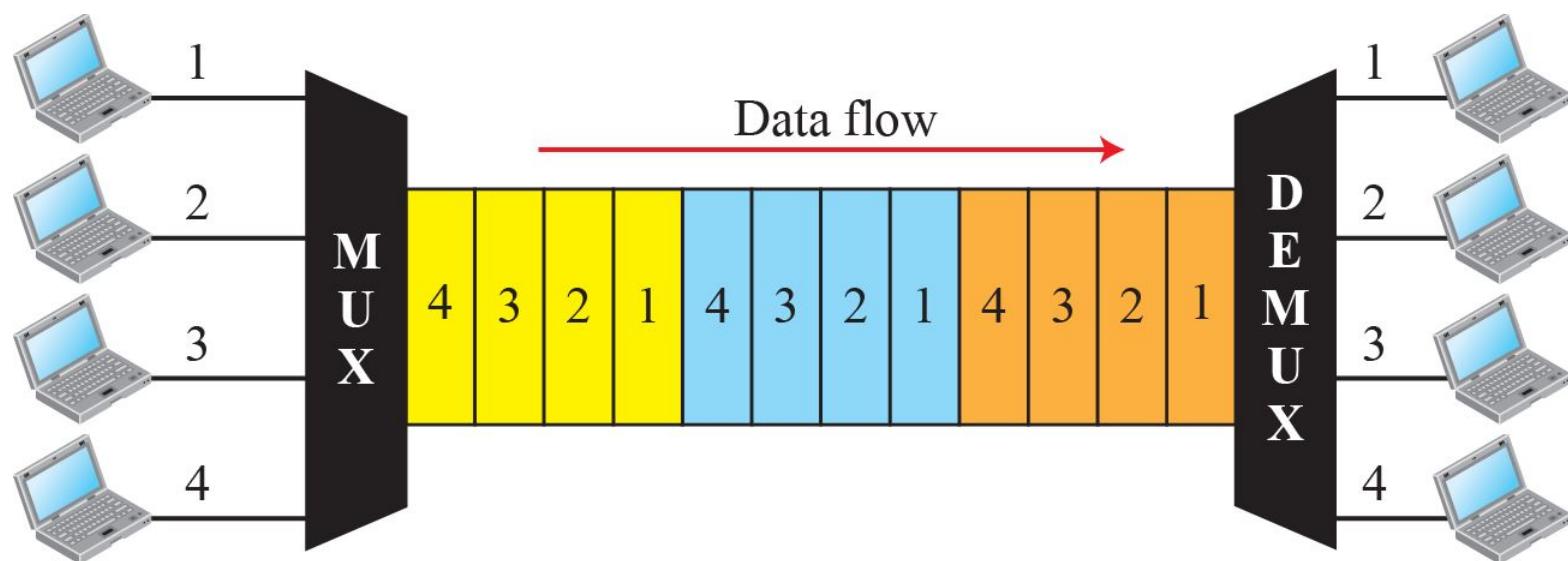
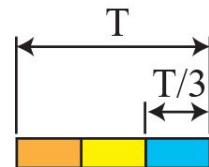
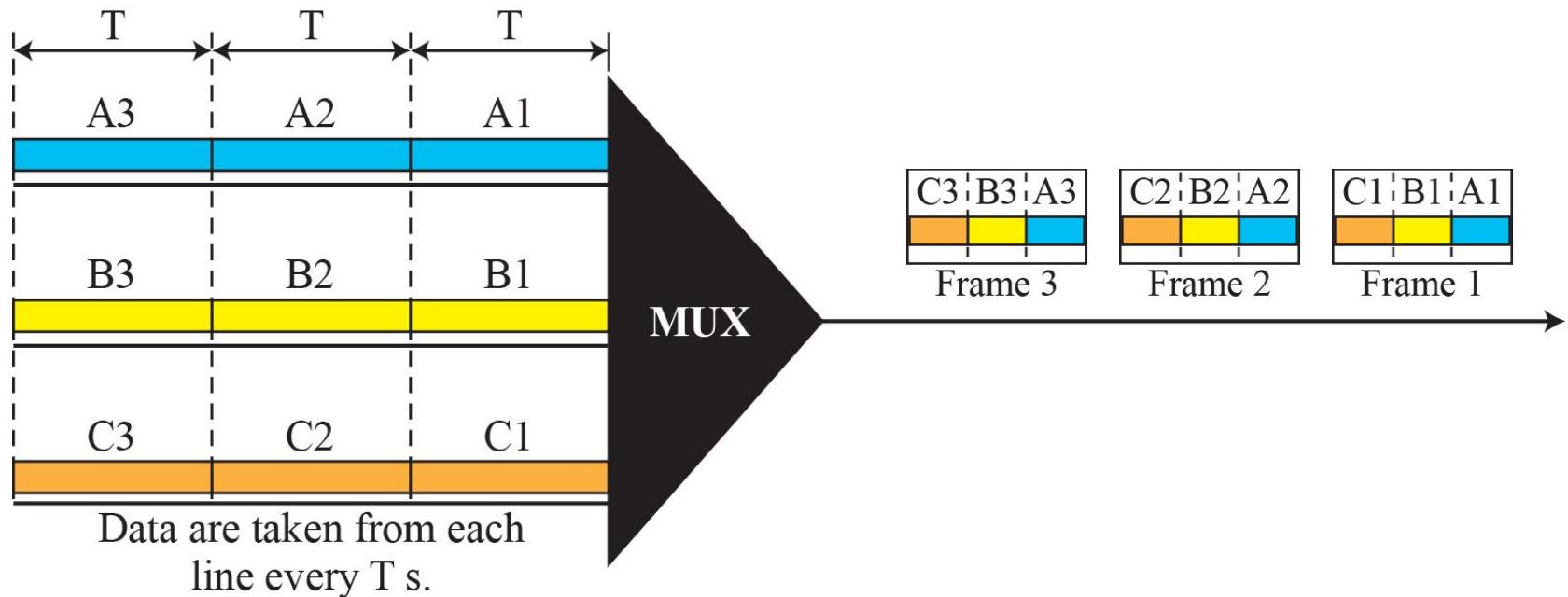


Figure 7.49: Synchronous time-division multiplexing



Each frame is 3 time slots.
Each time slot duration is $T/3$ s.

Example 7.15

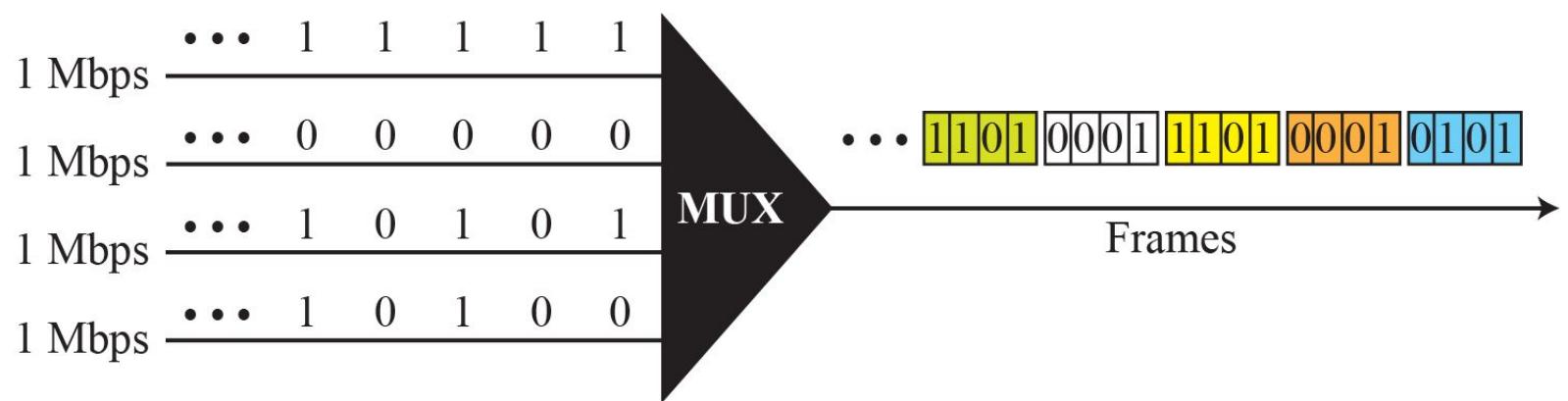
Figure 7.50 shows synchronous TDM with a data stream for each input and one data stream for the output. The unit of data is 1 bit. Find (a) the input bit duration, (b) the output bit duration, (c) the output bit rate, and (d) the output frame rate.

Solution

We can answer the questions as follows:

1. The input bit duration is the inverse of the bit rate: $1/1 \text{ Mbps} = 1 \mu\text{s}$.
2. The output bit duration is one-fourth of the input bit duration, or $1/4 \mu\text{s}$.
3. The output bit rate is the inverse of the output bit duration, or $1/(1/4) \mu\text{s}$ or 4 Mbps. This can also be deduced from the fact that the output rate is 4 times as fast as any input rate; so the output rate = $4 \times 1 \text{ Mbps} = 4 \text{ Mbps}$.
4. The frame rate is always the same as any input rate. So the frame rate is 1,000,000 frames per second. Because we are sending 4 bits in each frame, we can verify the result of the previous question by multiplying the frame rate by the number of bits per frame.

Figure 7.50: Example 7.15



Example 7.16

Telephone companies implement TDM through a hierarchy of digital signals, called digital signal (DS) service or digital hierarchy. Figure 7.51 shows the data rates supported by each level. The commercial implementations of these services are referred to as T lines.

- DS-0 service is a single digital channel of 64 kbps.**
- DS-1 is a 1.544-Mbps service.**
- DS-2 is a 6.312-Mbps service.**
- DS-3 is a 44.376-Mbps service.**
- DS-4 is a 274.176-Mbps service.**

Figure 7.51: Digital hierarchy

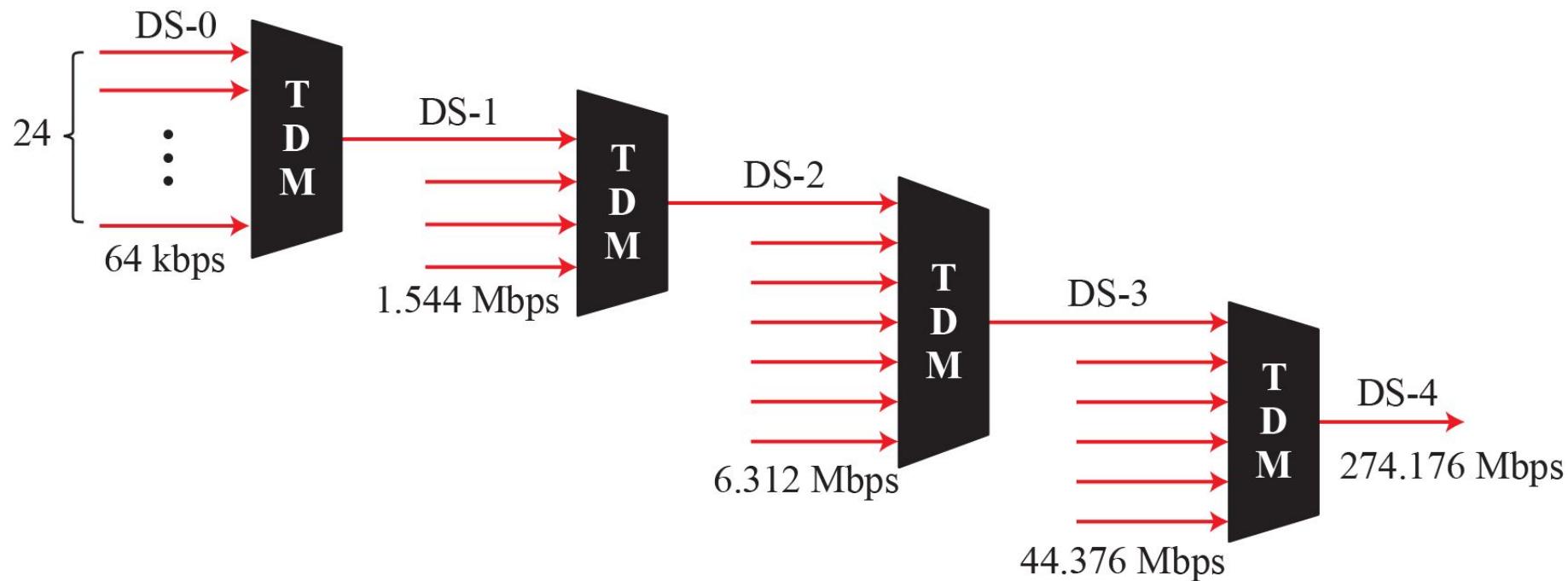
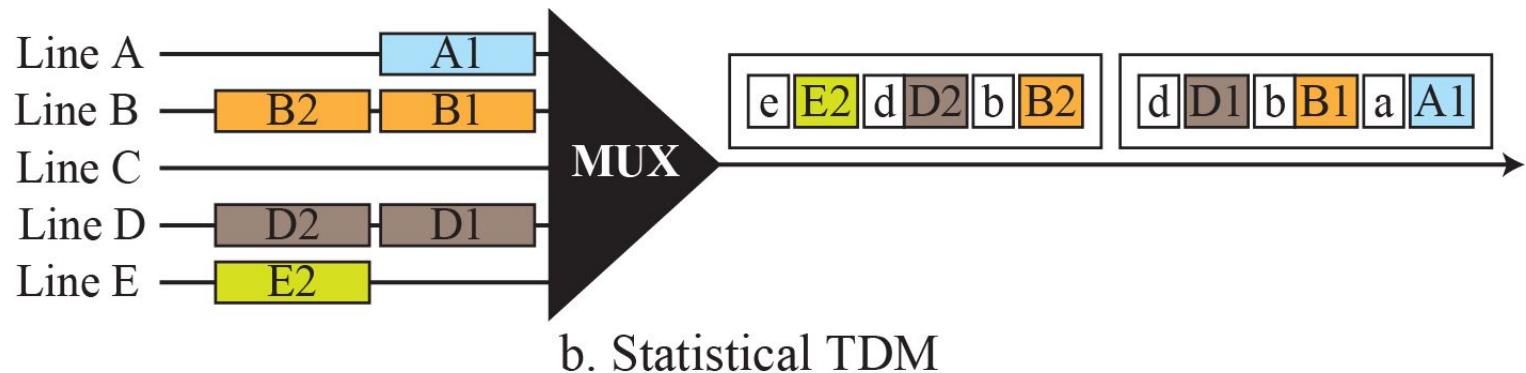
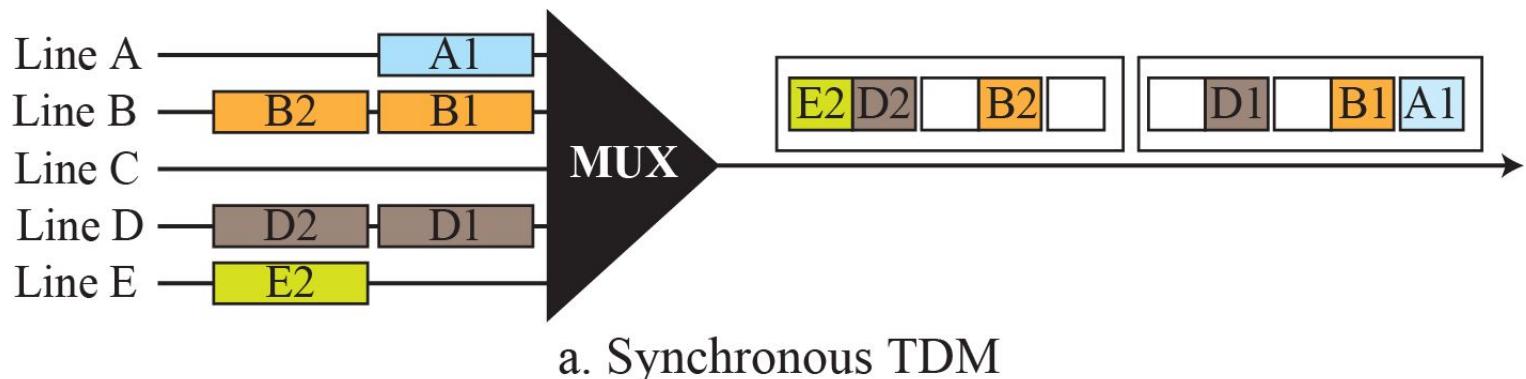
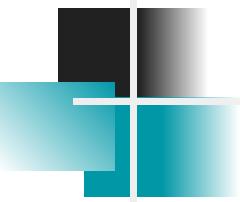


Figure 7.52: TDM slot comparison



7.4.2 *Spread Spectrum*

In spread spectrum, we also combine signals from different sources to fit into a larger bandwidth, but our goals are somewhat different. In these types of applications, we have some concerns that outweigh bandwidth efficiency. In wireless applications, all stations use air (or a vacuum) as the medium for communication. Stations must be able to share this medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder (in military operations, for example).



7.4.2 (*continued*)

- *Frequency Hopping Spread Spectrum (FHSS)*
 - ◆ *Bandwidth Sharing*
- *Direct Sequence Spread Spectrum*

Figure 7.53: Spread spectrum

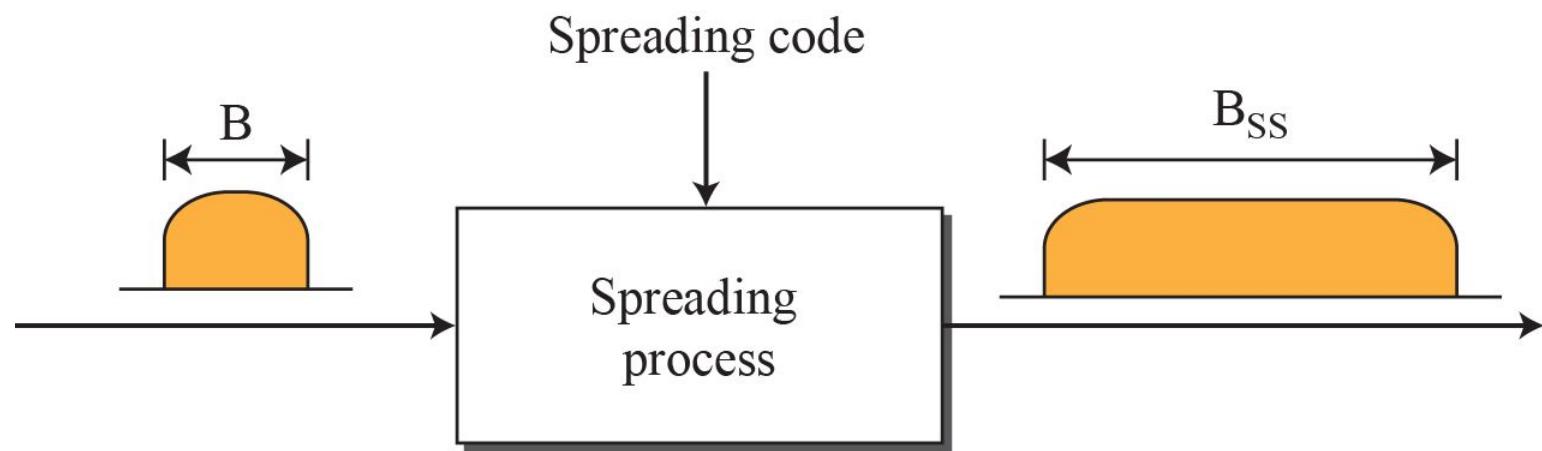


Figure 7.54: Frequency hopping spread spectrum (FHSS)

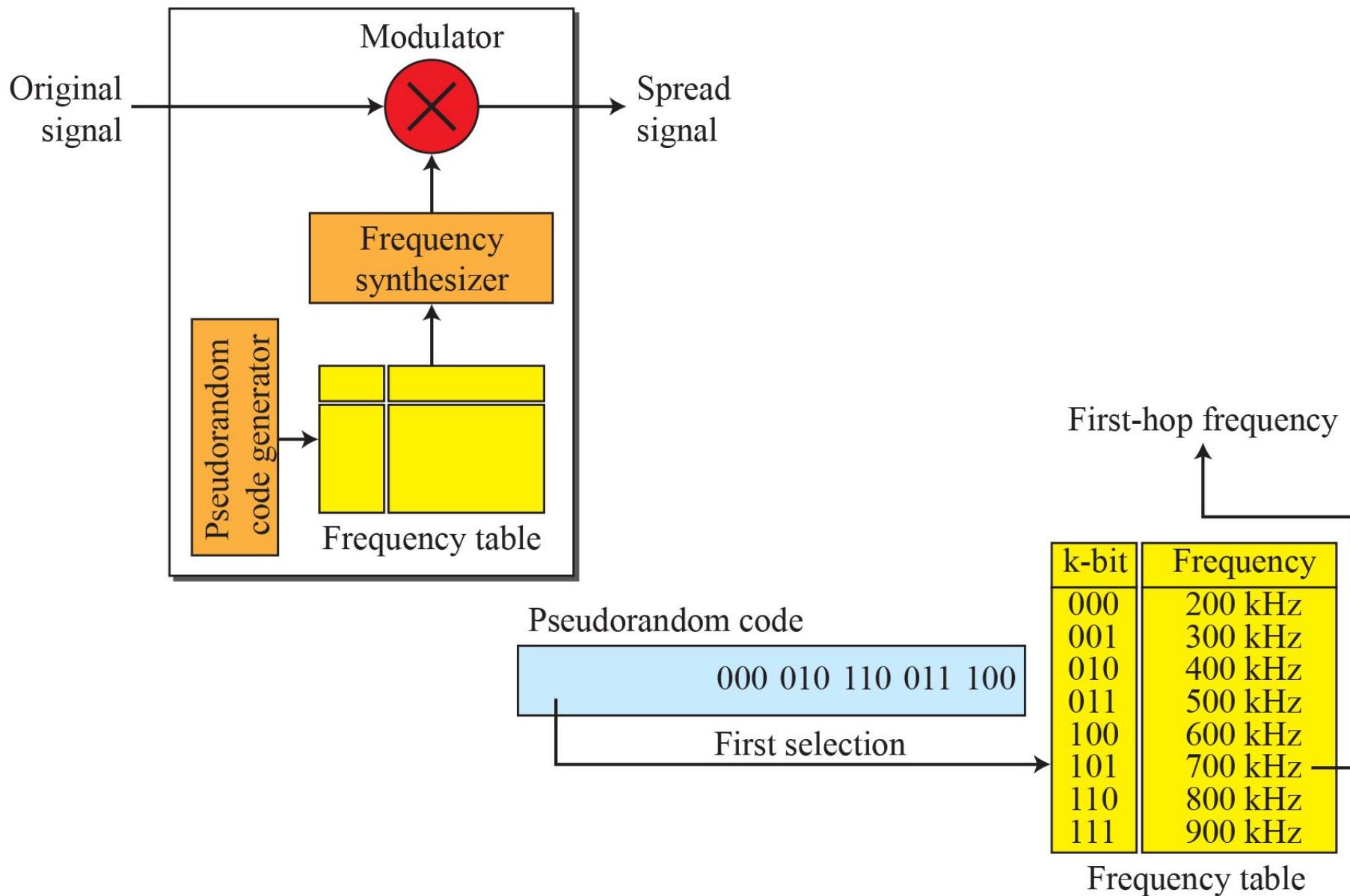


Figure 7.55: FHSS cycles

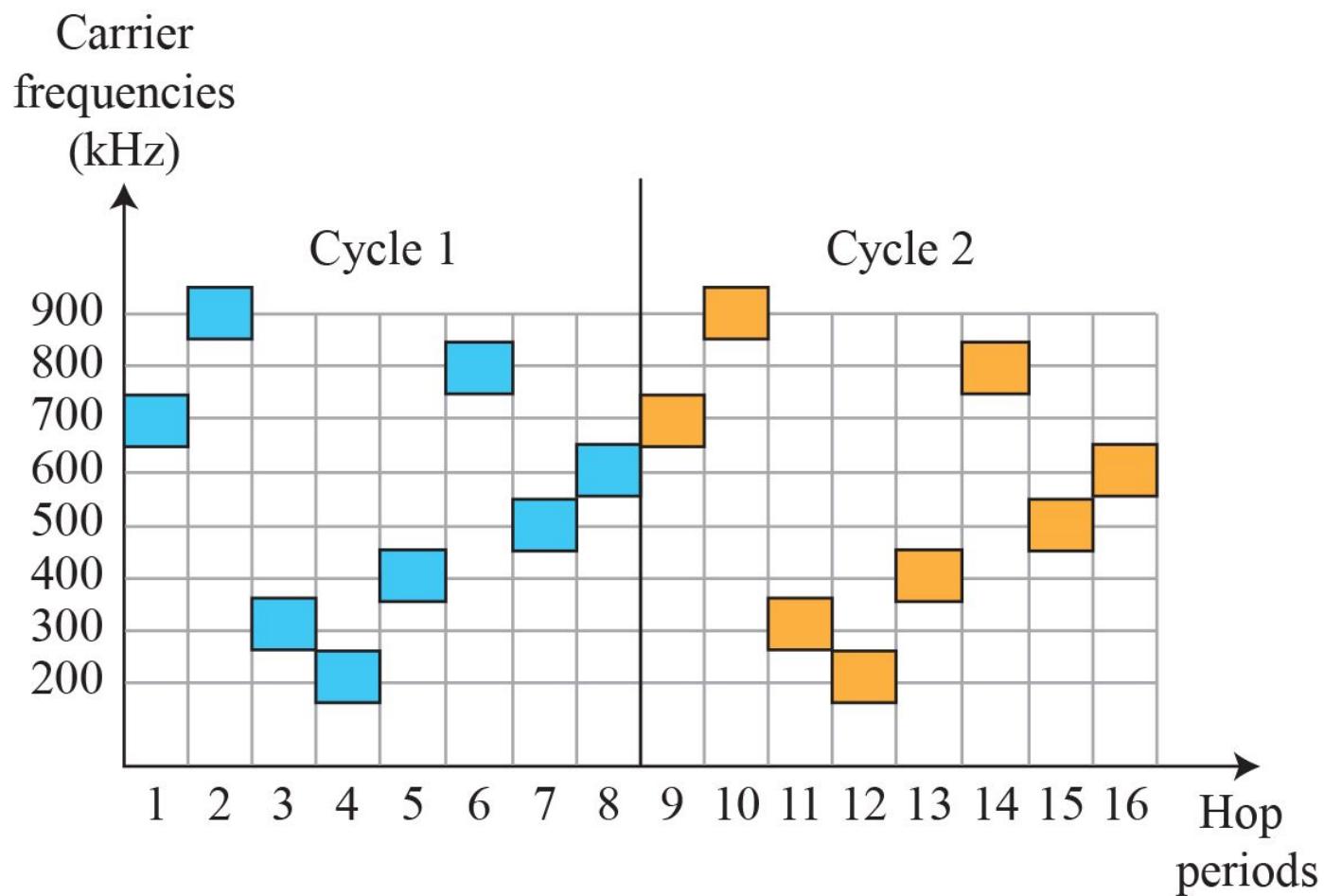


Figure 7.56: Bandwidth sharing

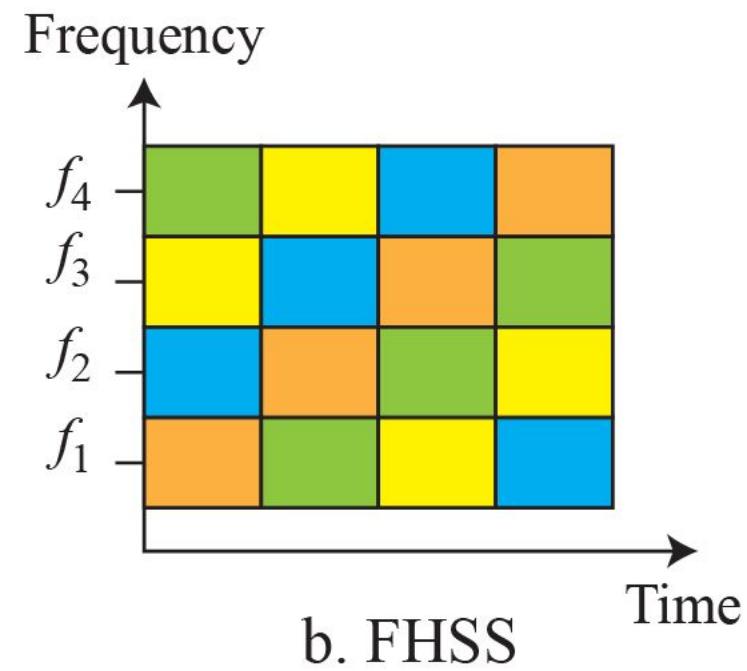
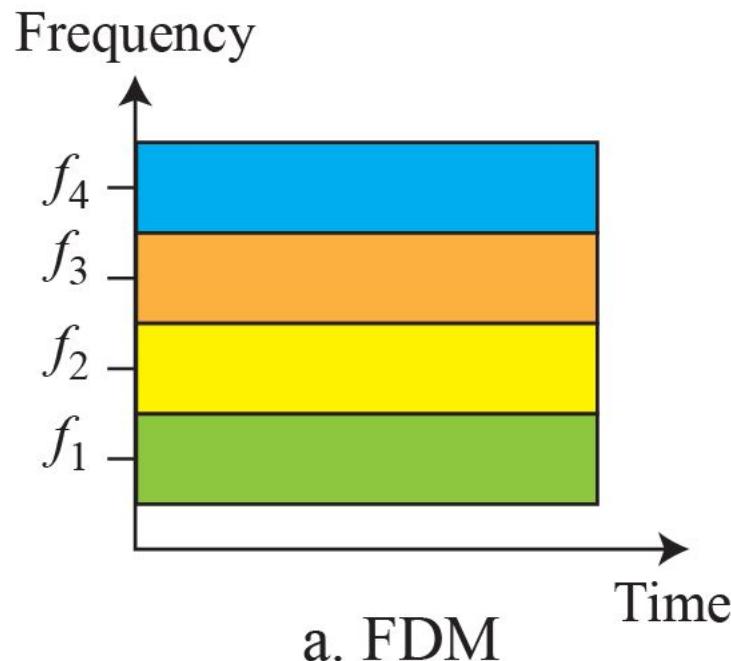
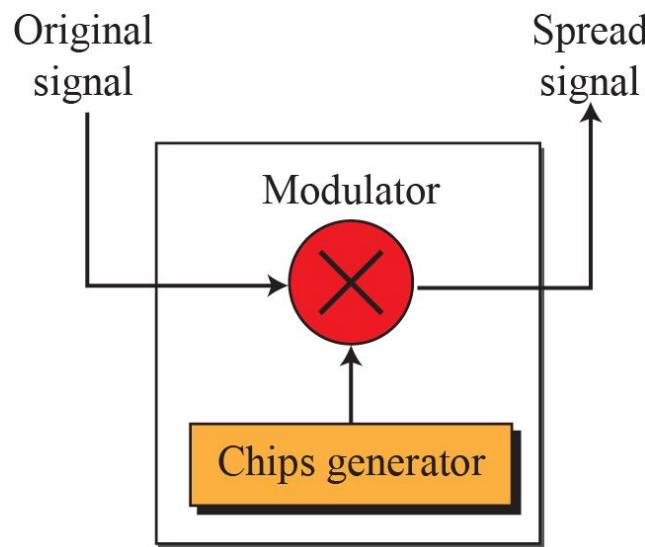
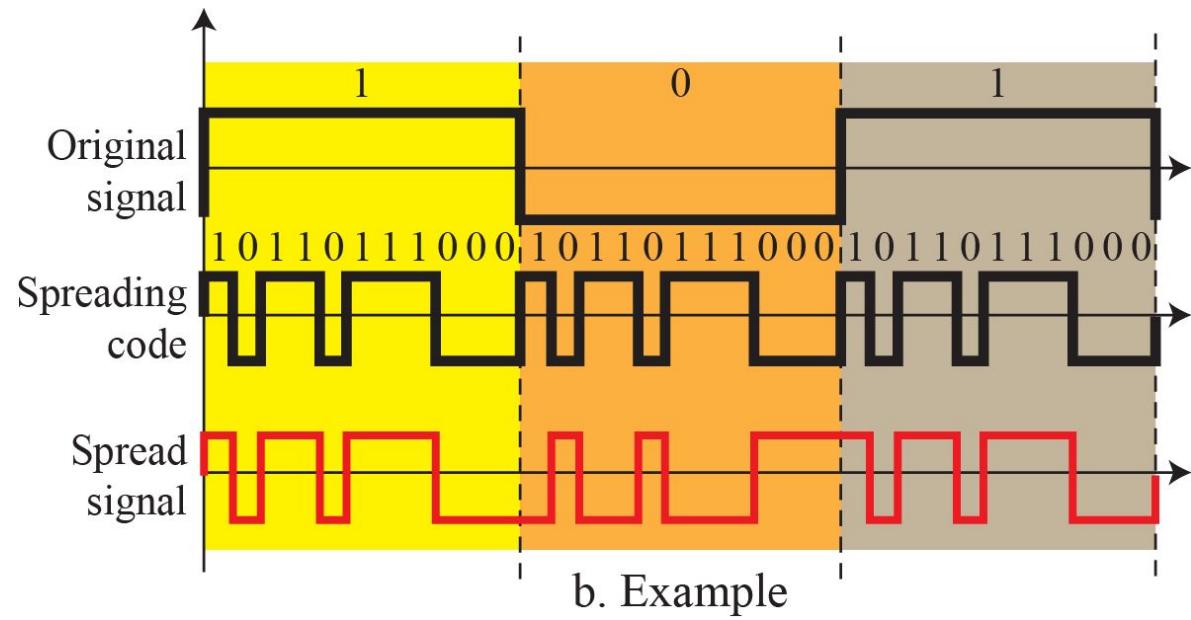


Figure 7.57: DSSS



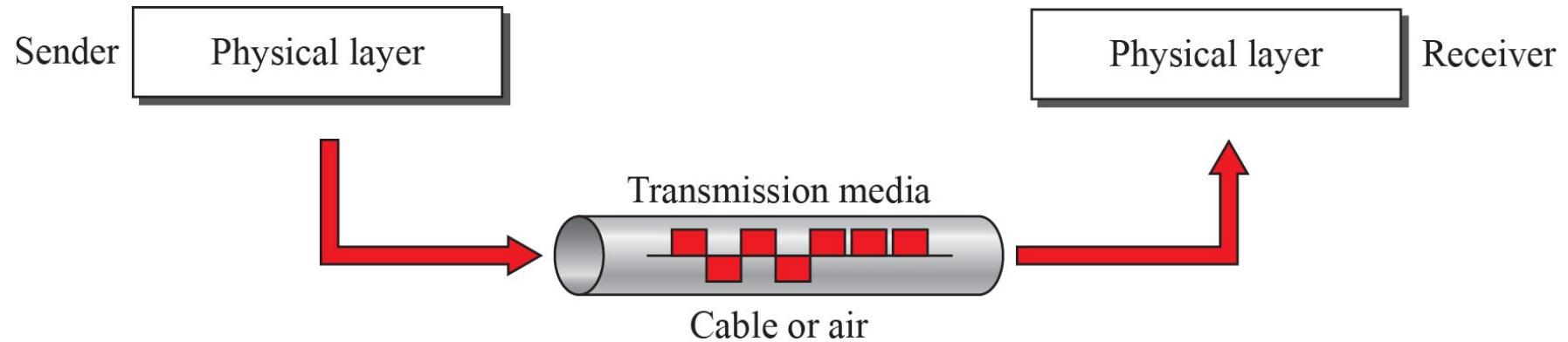
a. Concept

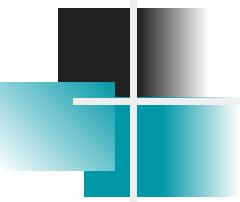


7-5 TRANSMISSION MEDIA

We discussed many issues related to the physical layer in this chapter. In this section, we discuss transmission media. Transmission media are actually located below the physical layer and are directly controlled by the physical layer. We could say that transmission media belong to layer zero.

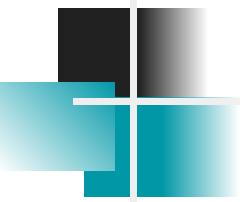
Figure 7.58: Transmission media and physical layer





7.5.1 *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.



7.5.1 (*continued*)

❑ *Twisted-Pair Cable*

- ❖ *Performance*
- ❖ *Applications*

❑ *Coaxial Cable*

- ❖ *Performance*
- ❖ *Applications*

❑ *Fiber-Optic Cable*

- ❖ *Propagation Modes*
- ❖ *Performance*
- ❖ *Applications*

Figure 7.59: Twisted-pair cable

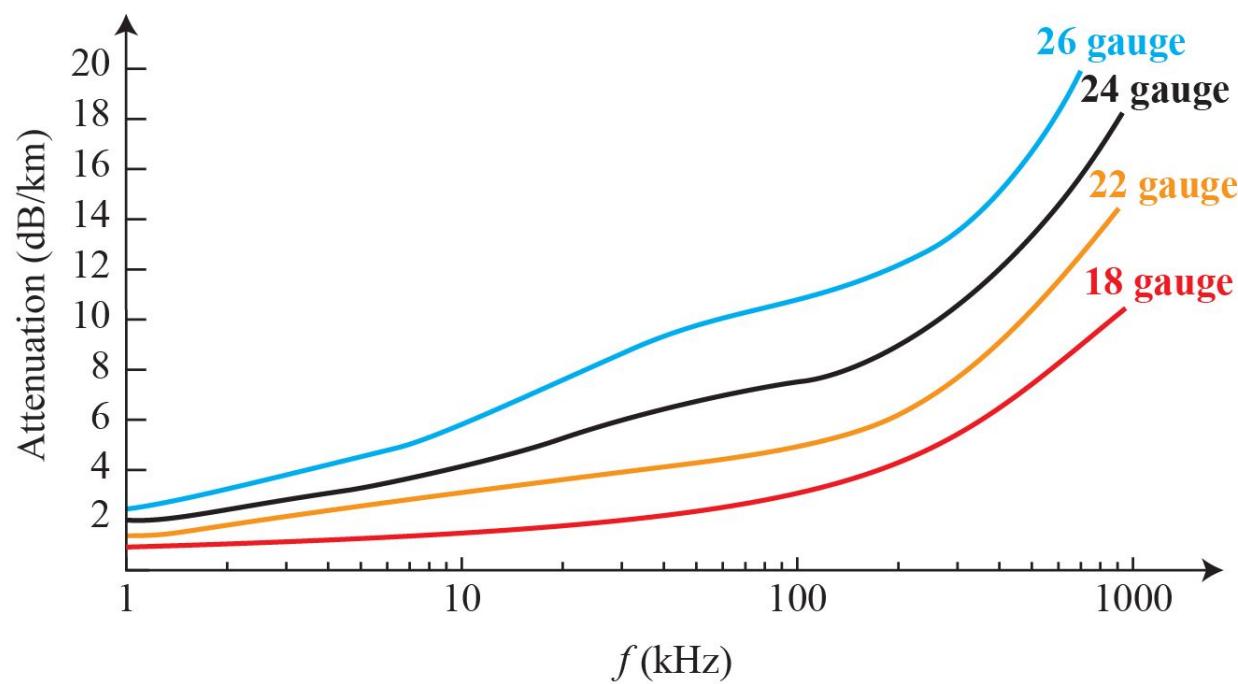
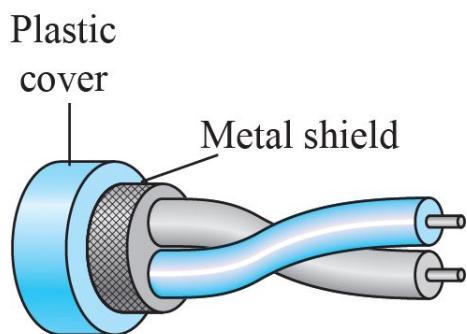
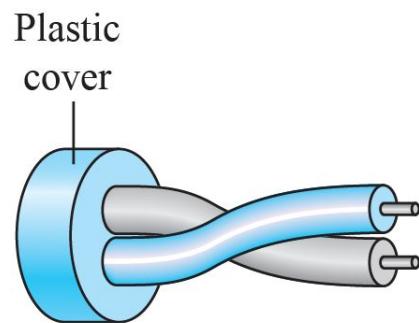


Figure 7.60: Coaxial cable

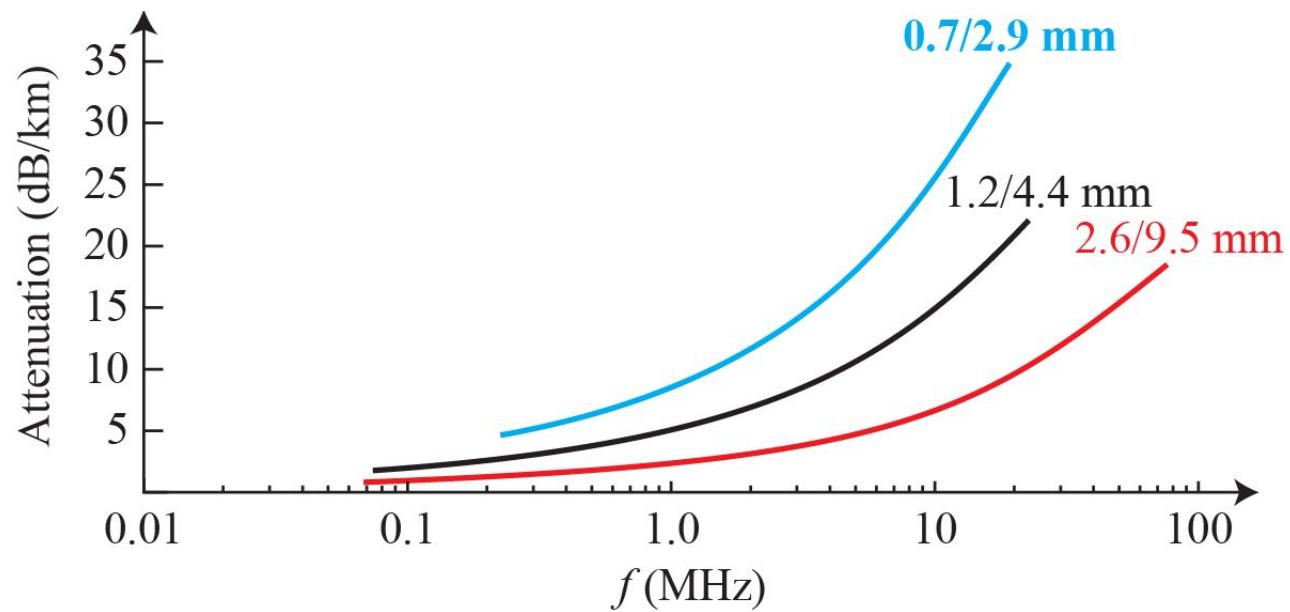
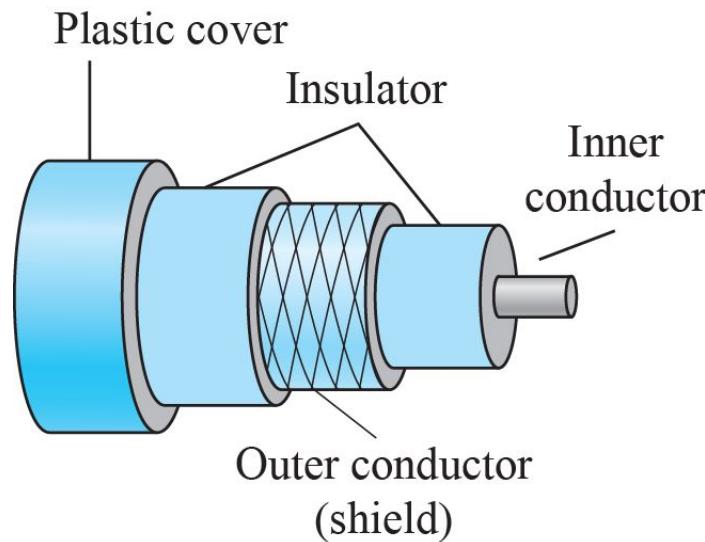
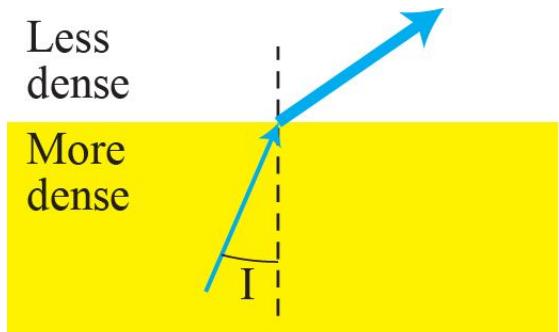
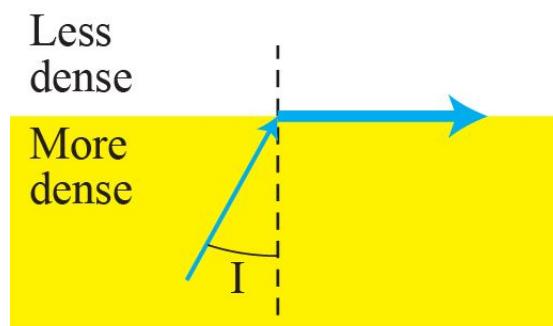


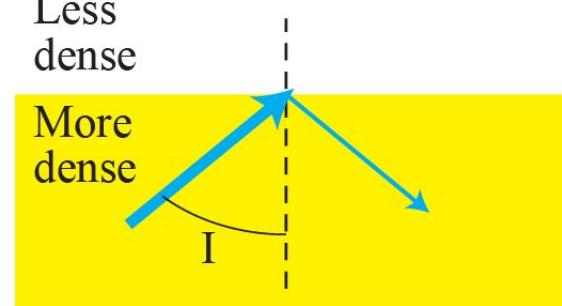
Figure 7.61: Bending of light ray



$I <$ critical angle,
refraction



$I =$ critical angle,
refraction



$I >$ critical angle,
reflection

Figure 7.62: Optical fiber

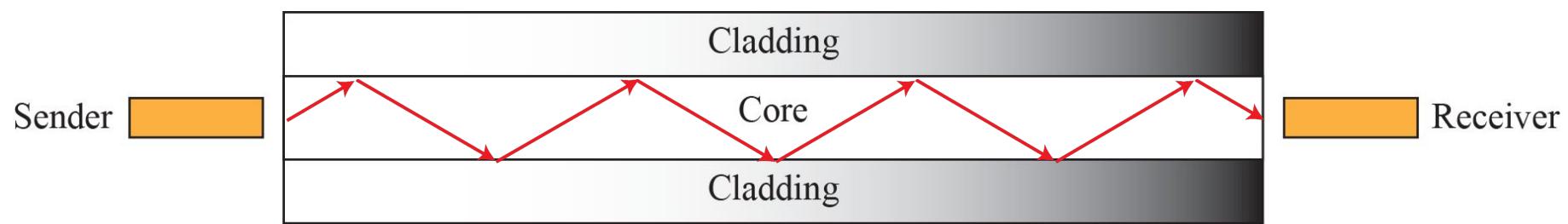
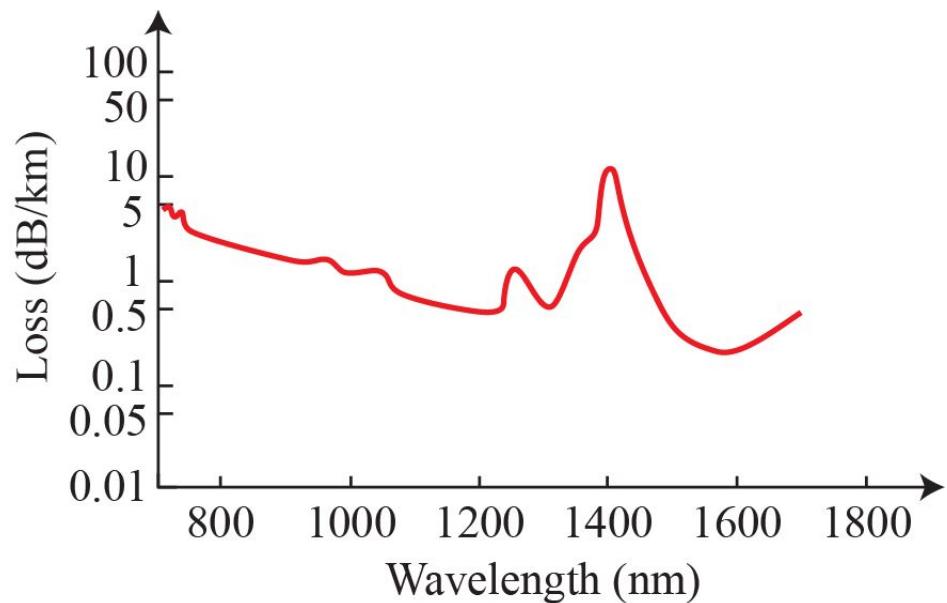
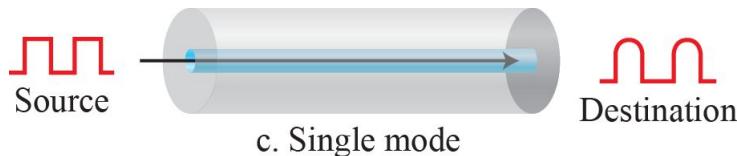
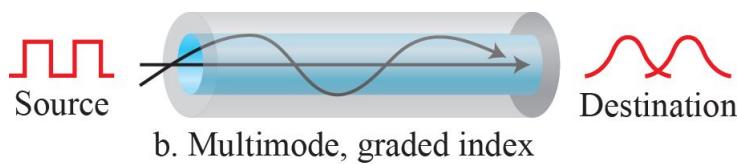
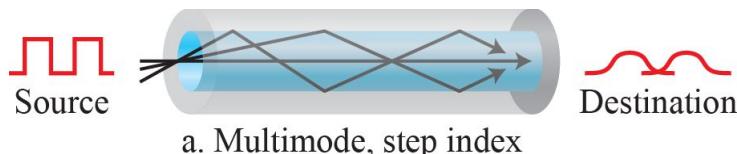


Figure 7.63: Modes

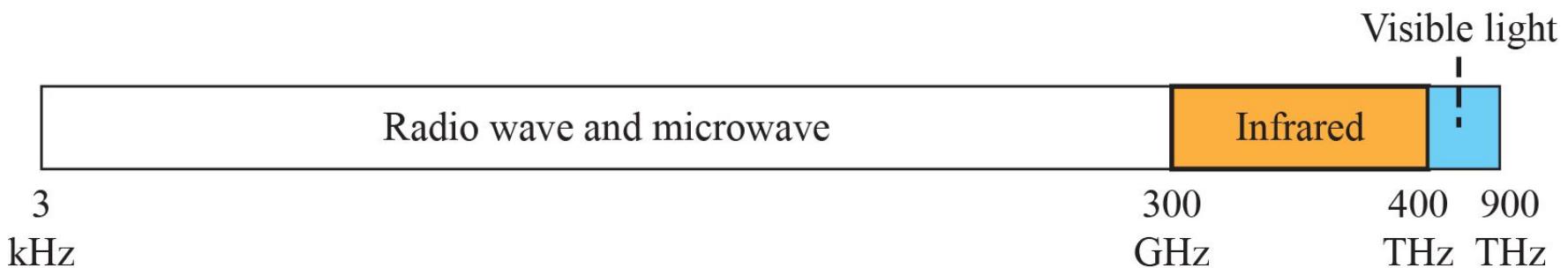


7.5.2 *Unguided Media*

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.

- Radio Waves*
- Microwaves*
- Infrared*

Figure 7.64: Electromagnetic spectrum for wireless communication



**Table 7.1: Bands**

<i>Band</i>	<i>Range</i>	<i>Propagation</i>	<i>Application</i>
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

Chapter 7: Summary

- *Data must be transformed to electromagnetic signals to be transmitted. Analog data are continuous and take continuous values. Digital data have discrete states and take discrete values. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values. In data communications, we commonly use periodic analog signals and non-periodic digital signals.*
- *Digital-to-digital conversion involves three techniques: line coding, block coding, and scrambling. The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM).*

Chapter 7: Summary (continued)

- *Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in the digital data. Digital-to-analog can be achieved in several ways: ASK, FSK, and PSK. QAM combines ASK and PSK. Analog-to-analog conversion can be accomplished in three ways: AM, FM), and PM.*
- *Bandwidth utilization is the use of available bandwidth to achieve specific goals. Efficiency can be achieved by using multiplexing; privacy and anti-jamming can be achieved by using spreading.*
- *Transmission media lie below the physical layer. We discussed guided and unguided media.*