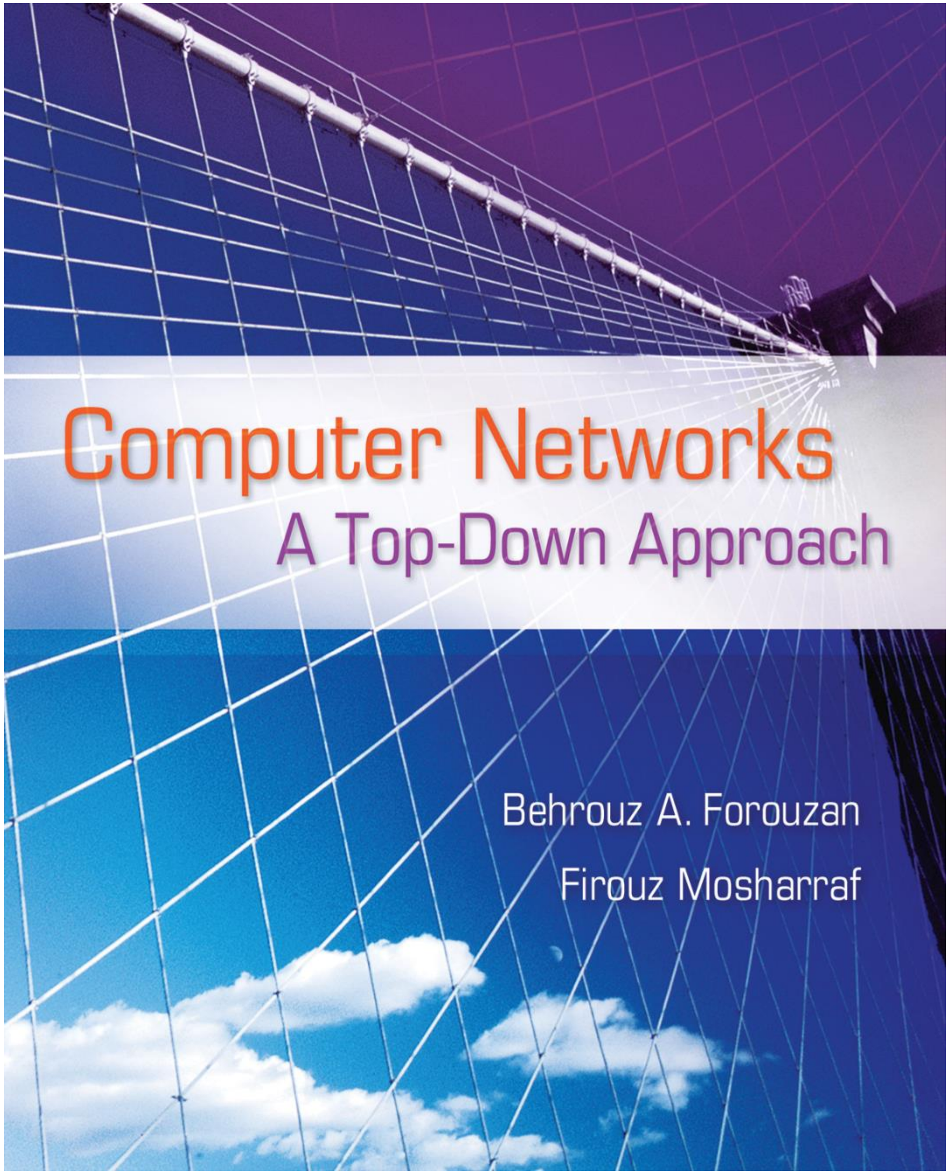
Chapter 7

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.*

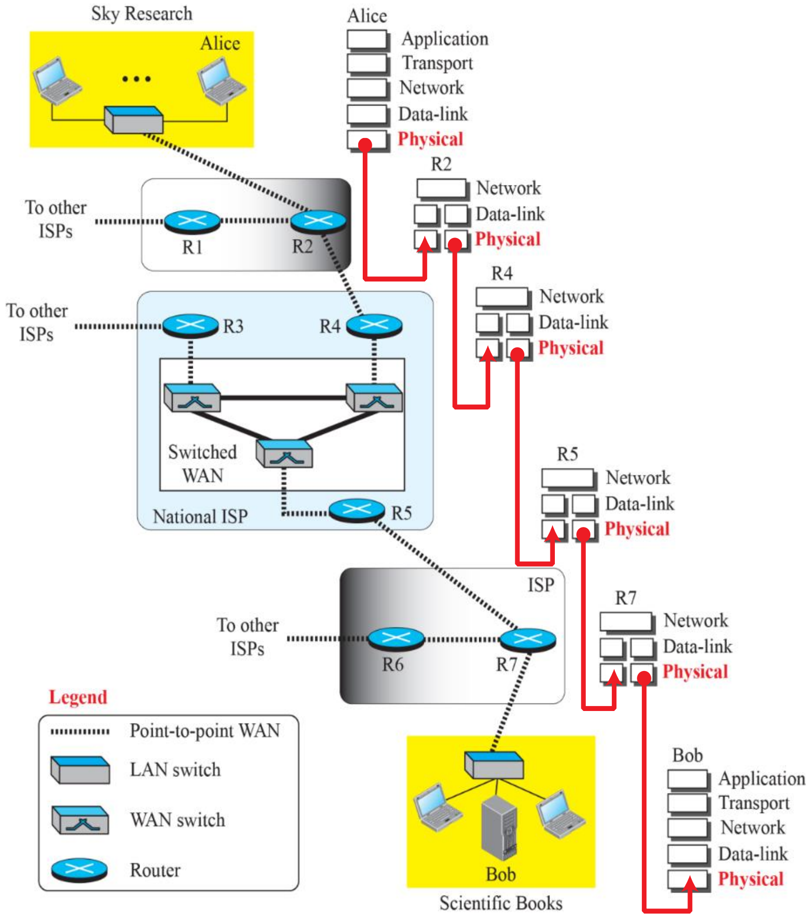


***Figure 7.1:* Communication at the physical layer**

7.1.1 Analog and Digital

- ***Data can be analog or digital.***
  - *Analog data is continuous.*
  - *Digital data take on discrete values.*
- ***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.*

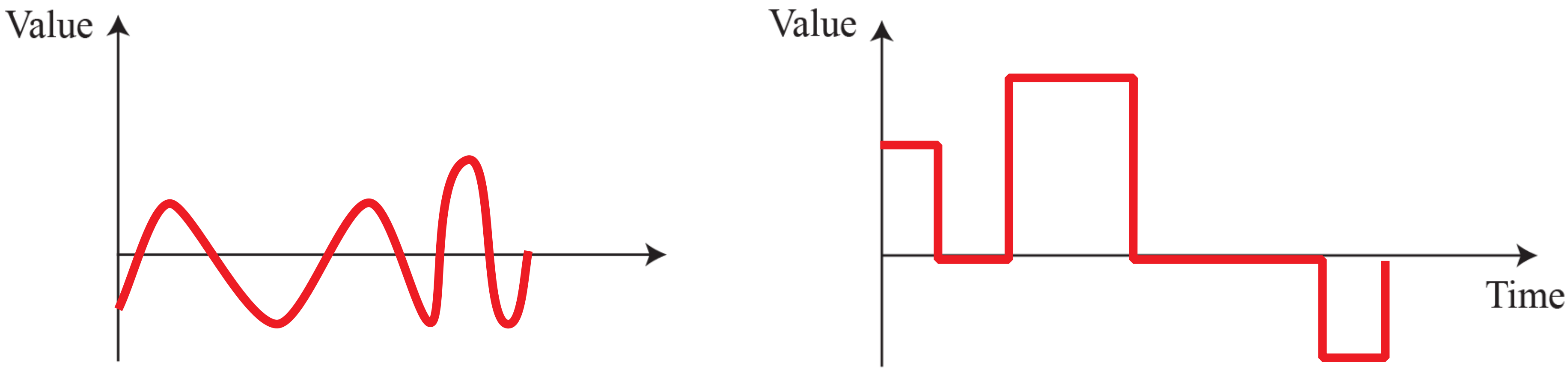
Analog Signals

- *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*

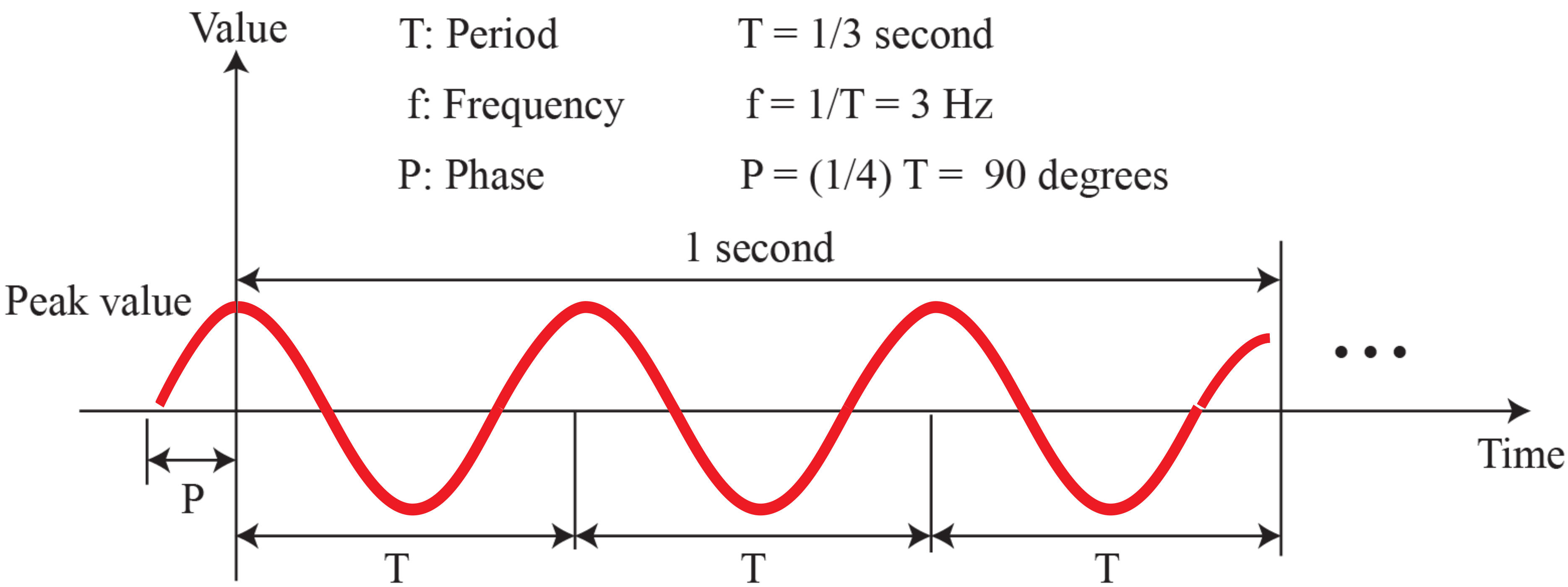
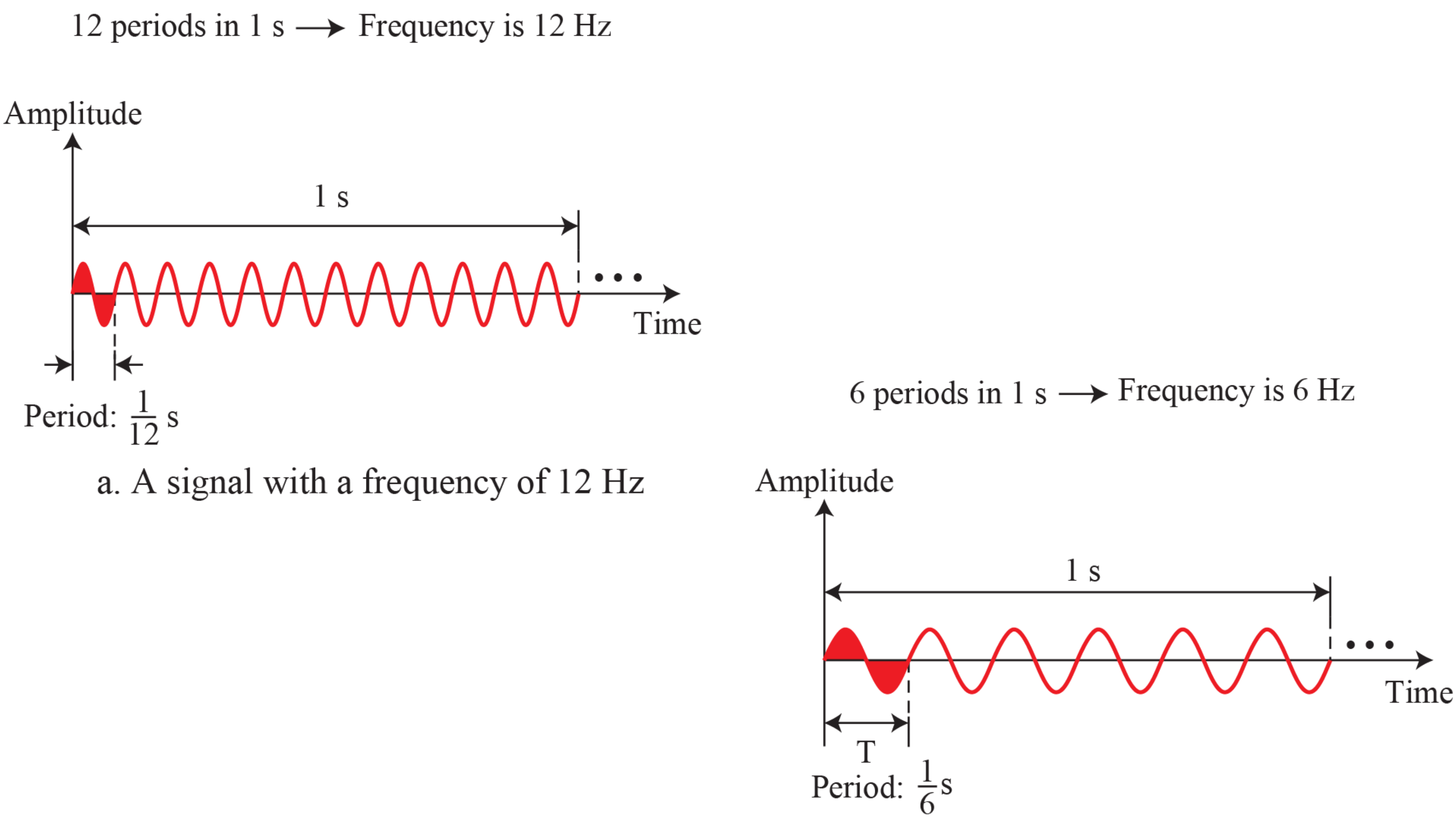


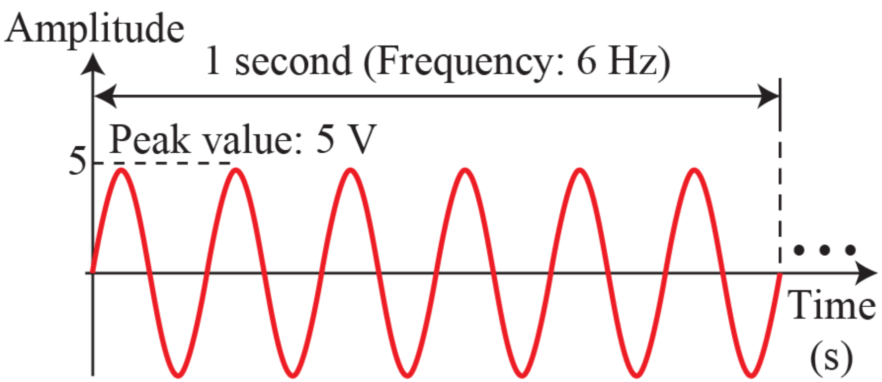
Figure 7.4: Wavelength and period



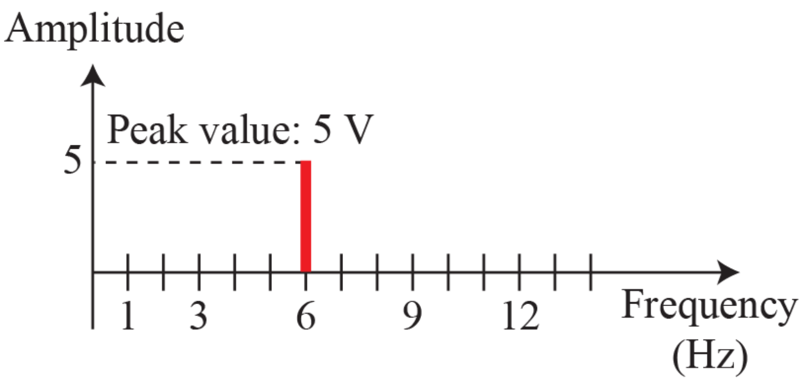
a. A signal with a frequency of 12 Hz

b. A signal with a frequency of 6 Hz

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

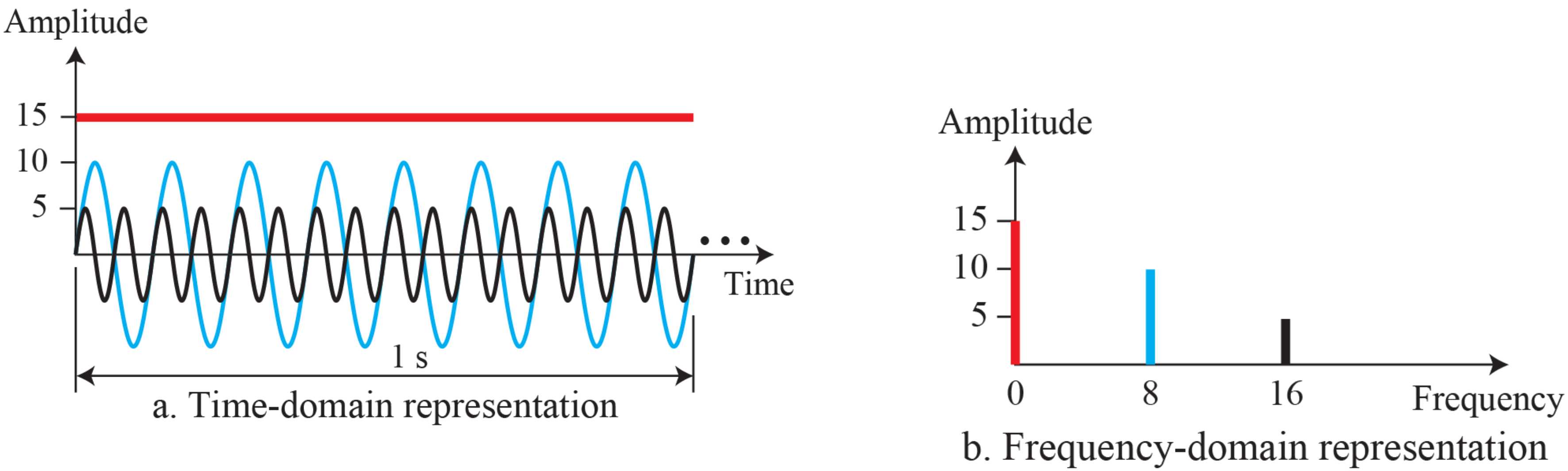


a. A sine wave in the time domain



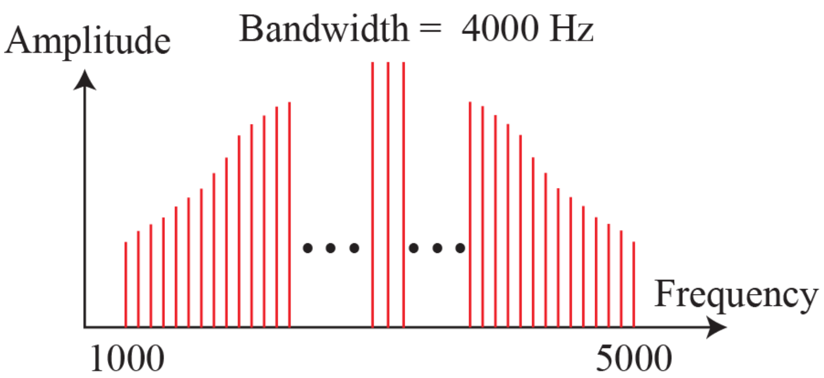
b. The same sine wave in the frequency domain

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

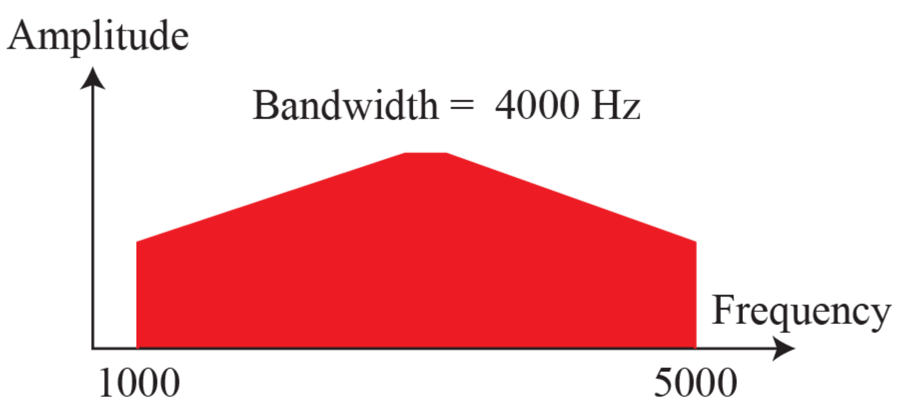


Example 7.1: *The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example,* ***Figure 7.6*** *shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.*

Figure 7.7: The bandwidth of periodic and nonperiodic composite signals

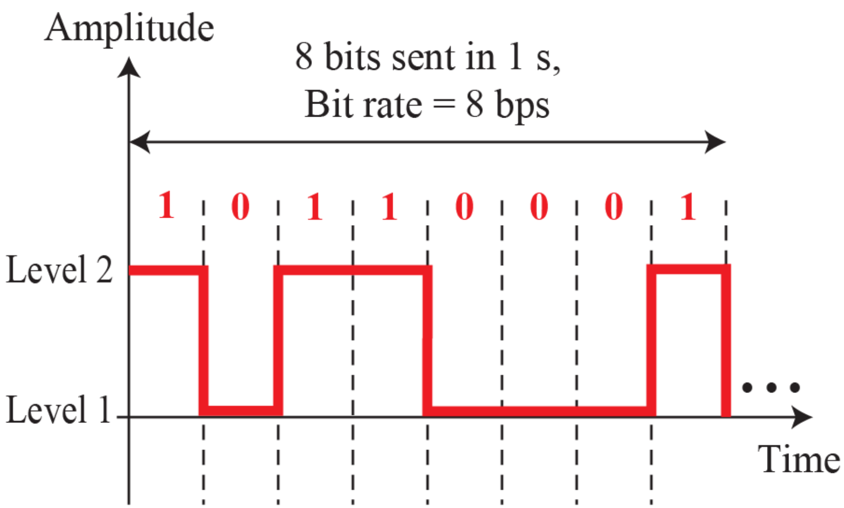


a. Bandwidth of a periodic signal

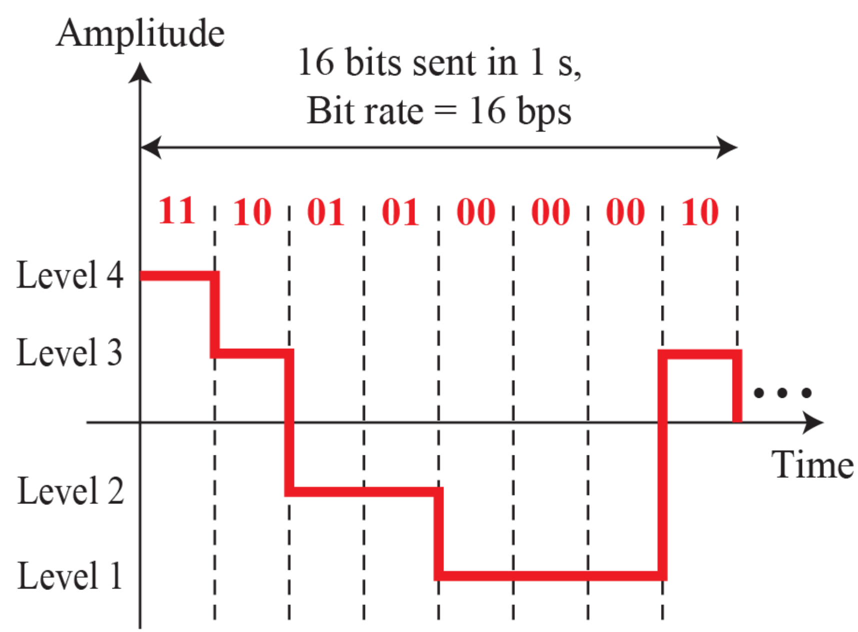


b. Bandwidth of a nonperiodic signal

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

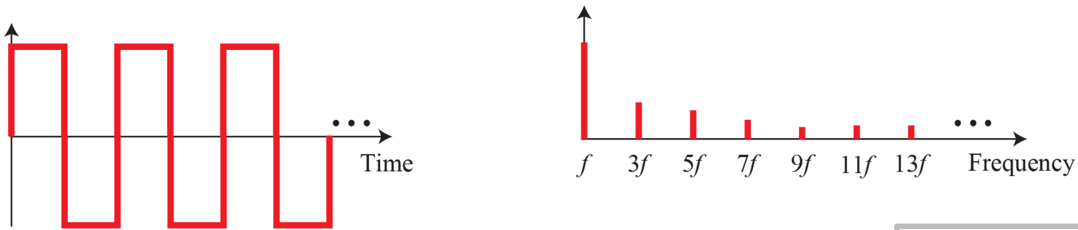


a. A digital signal with two levels



b. A digital signal with four levels

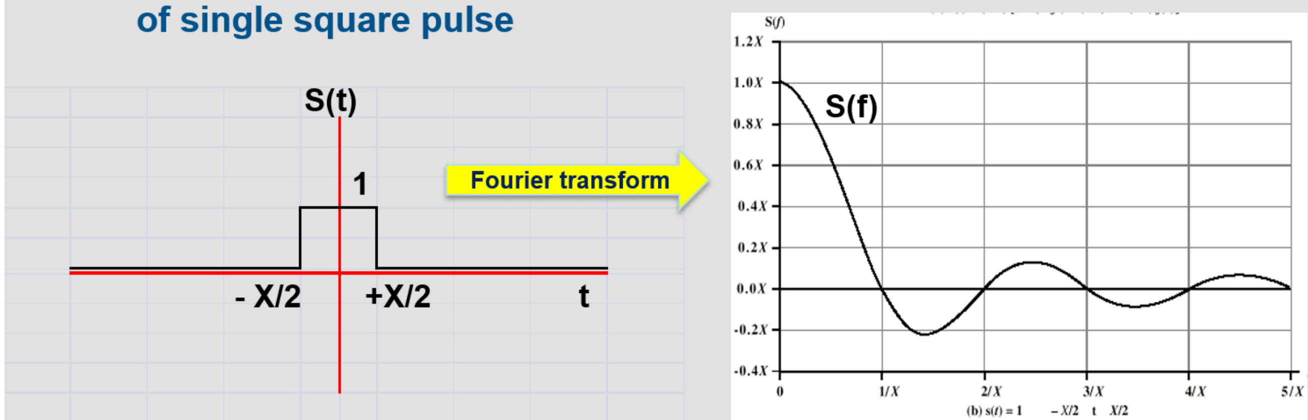
Figure 7.9: The time and frequency domains of periodic and nonperiodic digital signals



a. Time and frequency domains of periodic digital signal

$$s(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} \left(A_n \cos(2\pi n f_0\ t) + b_n \sin(2\pi n f_0\ t) \right)$$

- **Frequency domain function of single square pulse**



S(t) = 1 for time period -X/2 to +X/2
= 0 elsewhere

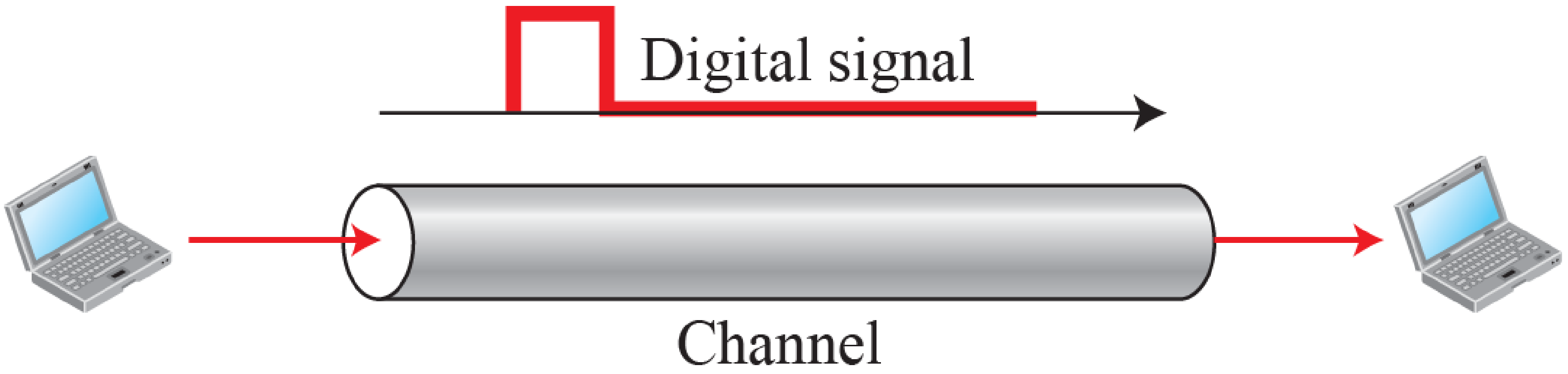
Fourier transform

S(f) = 1 X sin(π f X)

π f X

reference Page-839 William Stallings

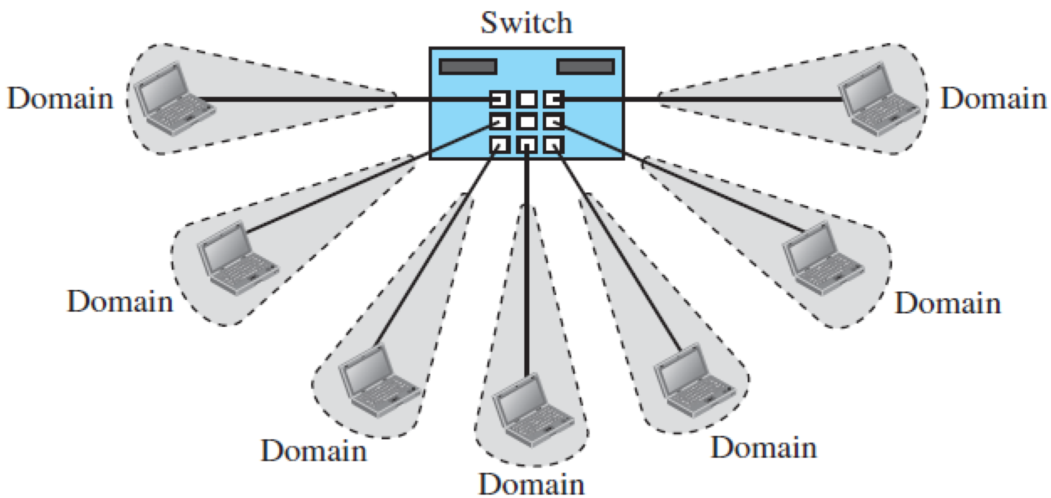
Figure 7.10: Baseband transmission



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.*

Switched Ethernet

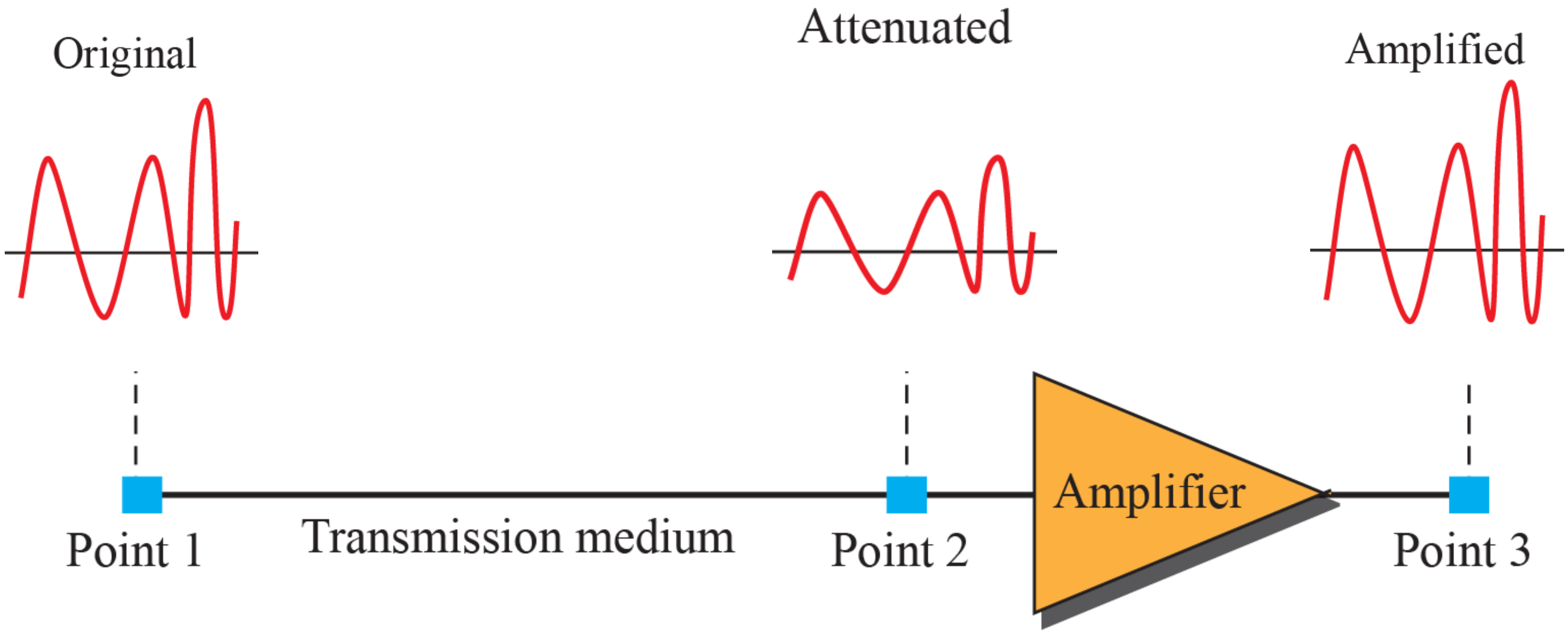


7.1.2 Transmission Impairment

- *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****.*

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

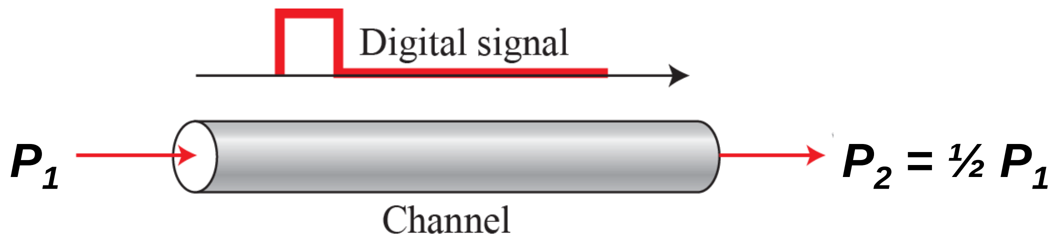
Figure 7.13: Attenuation and amplification



Signal Strength

- During propagation of signal, there is attenuation. Compensation is possible using **amplifiers** or **repeaters** at regular intervals
- We use **deciBELs (dB)** to measure gains, losses and relative levels
  - *Logarithmic representation is best where losses are exponential, as in transmission media*
  - *Gains and losses can be cascaded using simple addition of units in dB*

$$G_{db} = 10 \log_{10} \frac{P_{out}}{P_{in}}$$

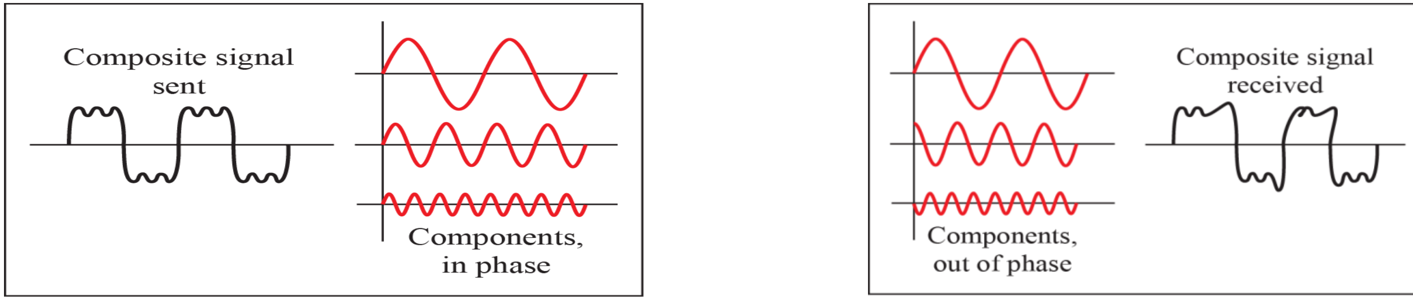


Example 7.6: Suppose a signal travels through a transmission medium and its power is **reduced to one half**. This means that P2 = 0.5 P1. In this case, the attenuation (loss of power) can be calculated as

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

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***

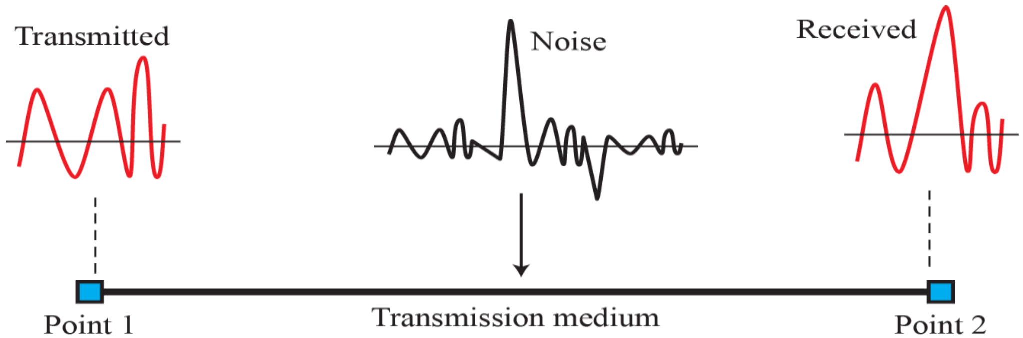
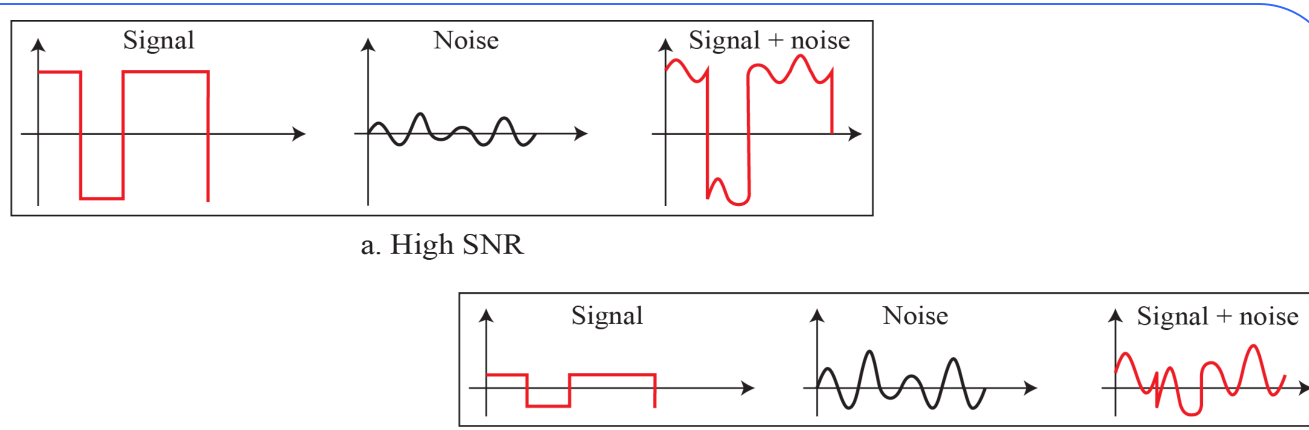


Figure 7.16: ***Two cases of SNR: a high SNR and a low SNR***



b. Low SNR

7.1.3 Data Rate Limits

A very important consideration in data communications is how fast we can send data called capacity in bits per second, over a channel. Data rate depends on <u>three</u> factors:

- ***The bandwidth available***
- ***The levels of the signals we use***
- ***The quality of the channel (the level of noise)***

Two theoretical formulas were developed to calculate the data Capacity:

- ***one by Nyquist for a <u>noiseless</u> channel(Nyquist Equation)***

$$C = 2\,B\,\mathrm{Log}_2\,L$$

- ***another by Shannon for a <u>noisy</u> channel (Shannon's Equation)***

$$C = B\,\mathrm{Log}_2\,(1 + SNR)$$

Where:

- **C = Capacity of the channel in bps**
- **B = Bandwidth of the channel in Hz**
- **L = Number of voltage levels in digital signal**
- **SNR = Signal to noise ratio**

Logarithms formulas / rules

$$A = Log_b N$$
$$N = b^A$$

$$Log_b (A B) = Log_b(A) + Log_b(B)$$

$$Log_b (A / B) = Log_b(A) - Log_b(B)$$

$$b^{Log_b x} = x$$

$$Log_b 1 = 0 \text{ for any base } b$$

$$Log_b (A) = \frac{Log_n(A)}{Log_n(b)}$$

$$Log_b b = 1 \text{ for any base } b$$

$$Log_b (A^n) = n \, Log_b(A)$$

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:

Nyquist for a noiseless channel(Nyquist Equation)

$$C = 2\ B\ Log_2\ L$$

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

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

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.

Shannon for a noisy channel (Shannon's Equation)

$$C = B \, Log_2 \, (1 + SNR)$$

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

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.

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

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.

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

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.

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

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?*

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

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.

B = 4000 Hz
C = 56,000 bps

Shannon for a noisy channel (Shannon's Equation) $C = B \, Log_2 \, (1 + SNR)$
$56000 = 4000 \times Log_2 \, (1 + SNR)$
$SNR = 16383$

$112000 = 8000 \times Log_2 \, (1 + SNR)$
$SNR = 16383$

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, coding, and scrambling. Line coding is always needed; block coding and scrambling may or may not be needed.*

- ***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

- **Line Coding**
  - ***Polar Schemes***
  - ***Bipolar Schemes***
  - ***Multilevel Schemes***

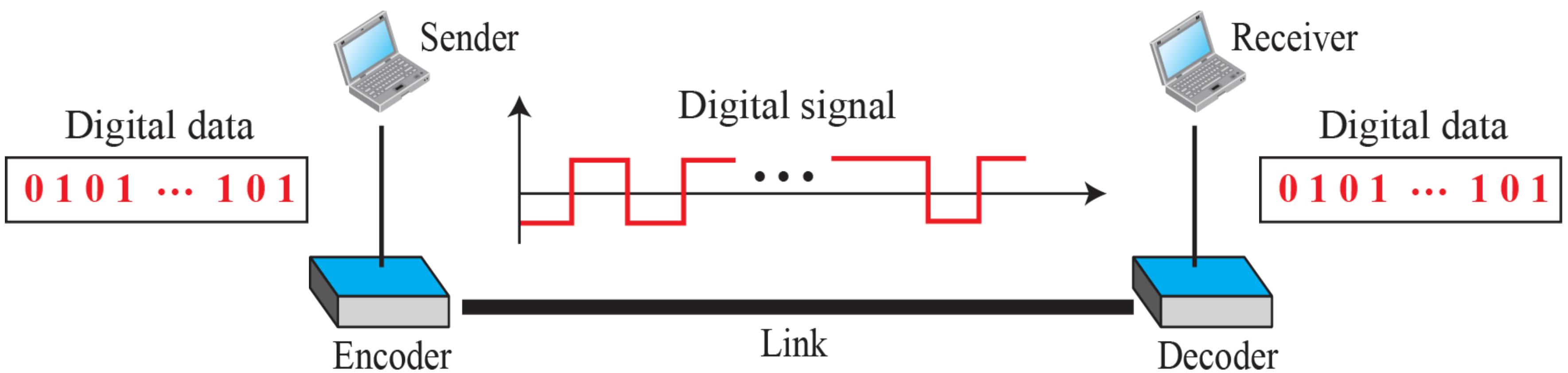
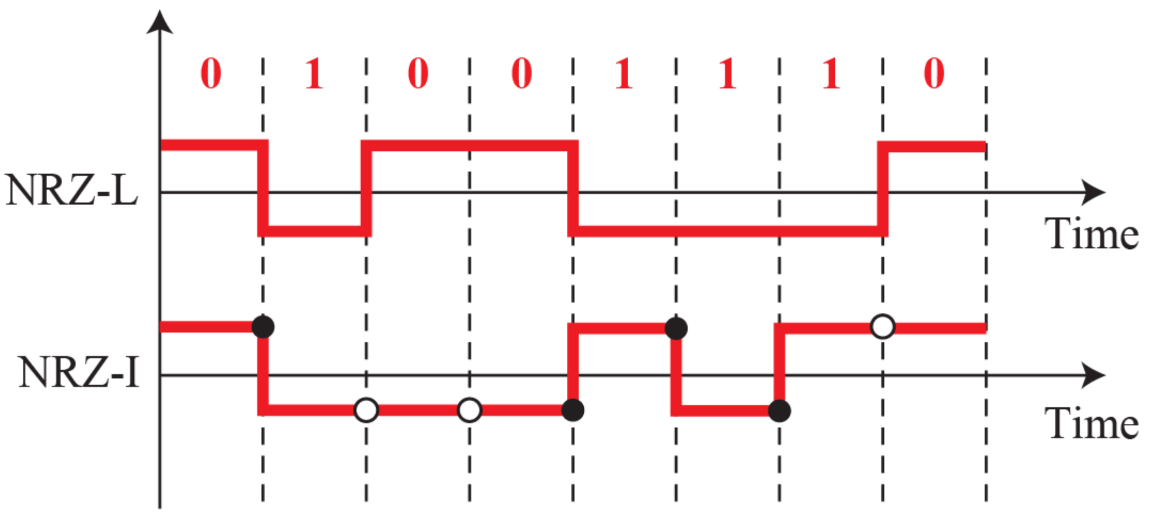


Figure 7.20: Polar schemes (Part I: NRZ)

- **Line Coding**
  - *Polar Schemes*
  - *Bipolar Schemes*
  - *Multilevel Schemes*



○ No inversion: Next bit is 0 ● Inversion: Next bit is 1

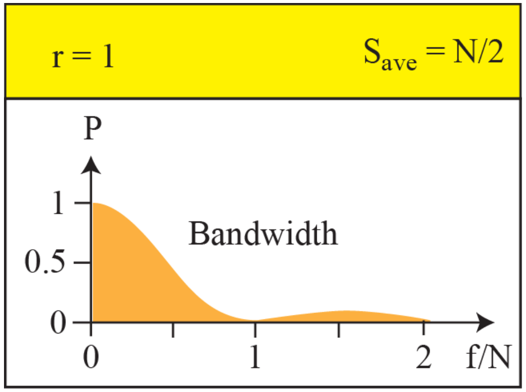


Figure 7.20: Polar schemes (Part II: RZ)

❑ Line Coding

- ❖ ***Polar Schemes***
- ❖ ***Bipolar Schemes***
- ❖ ***Multilevel Schemes***

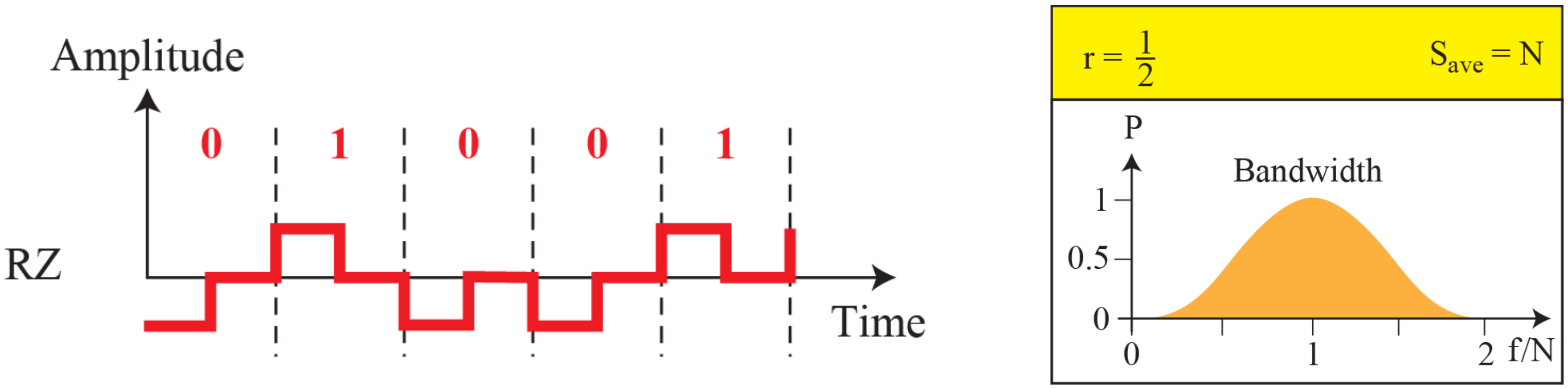
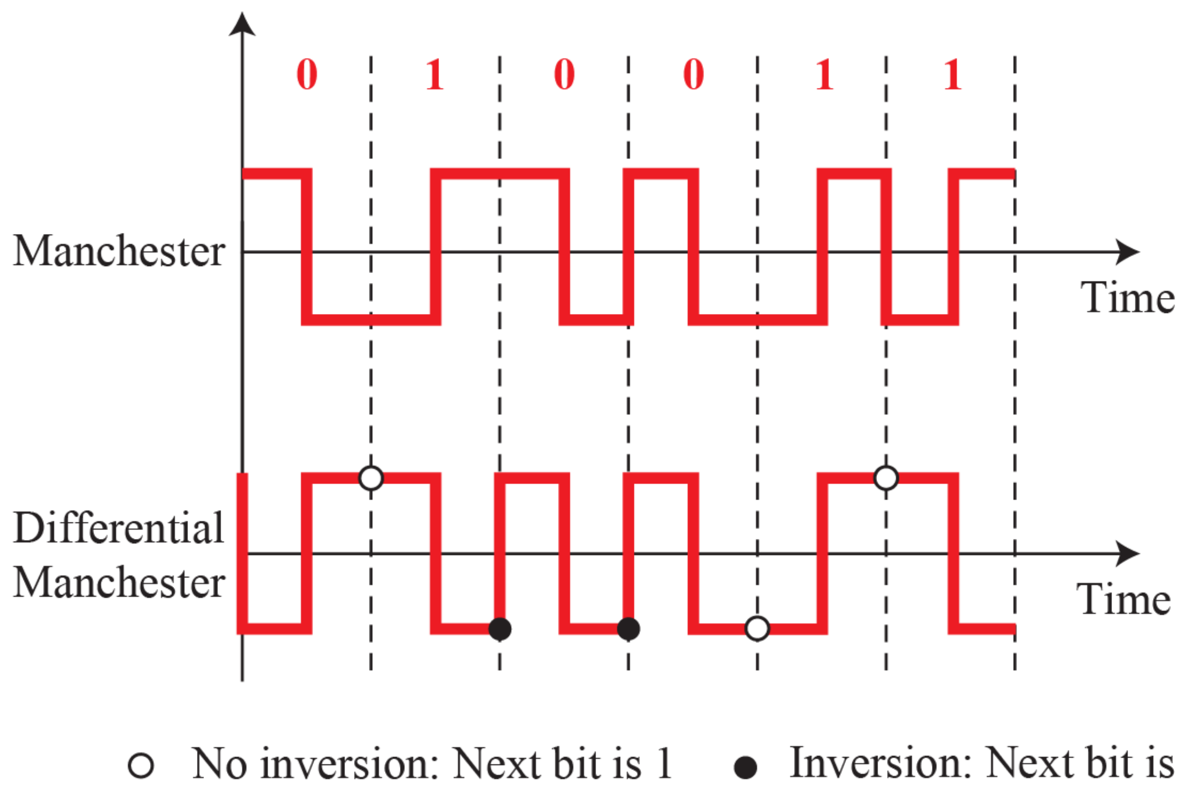


Figure 7.20: ***Polar schemes (Part III: Manchesters)***

- ***Line Coding***
  - ***Polar Schemes***
  - ***Bipolar Schemes***
  - ***Multilevel Schemes***



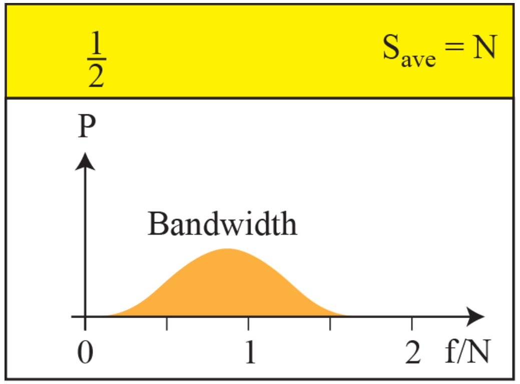


Figure 7.21: Bipolar schemes: AMI and pseudoternary

- **Line Coding**
  - *Polar Schemes*
  - *Bipolar Schemes*
  - *Multilevel Schemes*

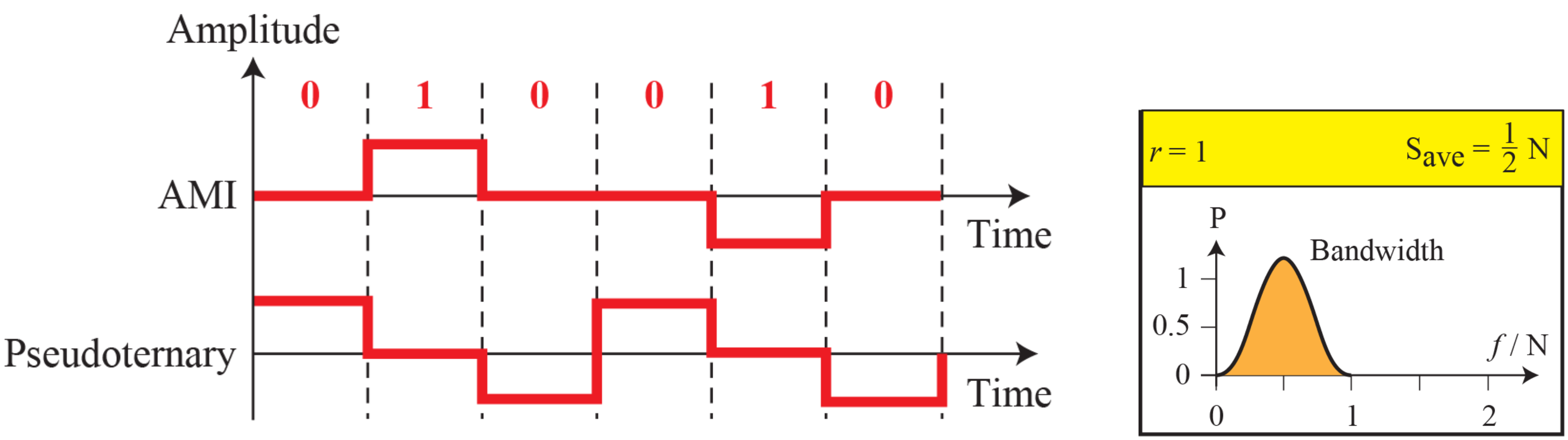
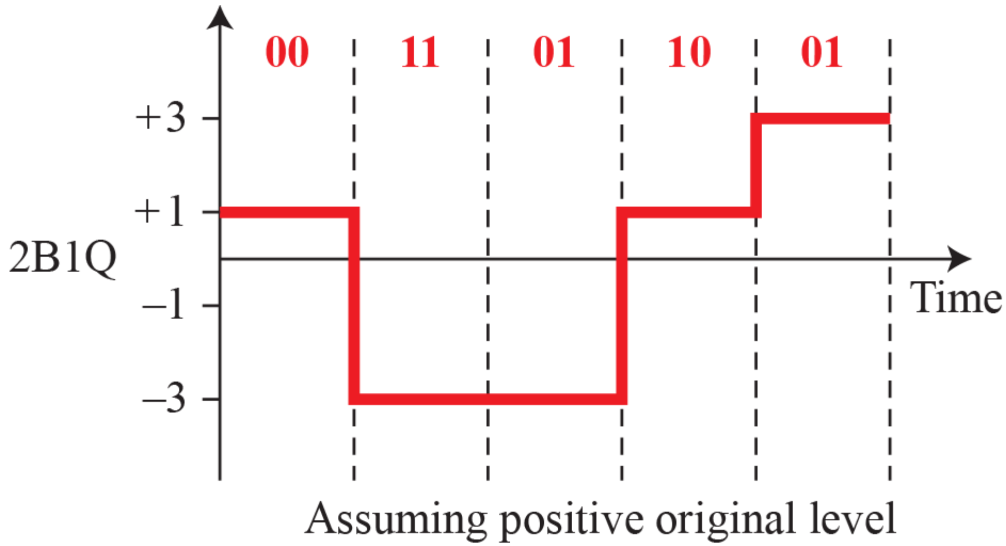
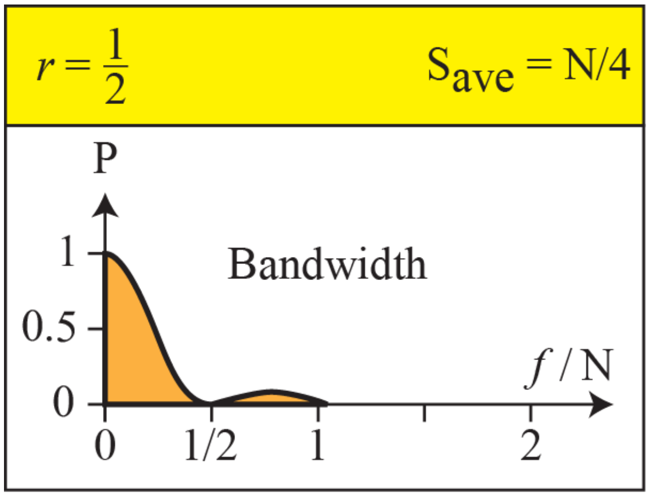


Figure 7.22: Multilevel: 2B1Q and 8B6T

- **Line Coding**
  - *Polar Schemes*
  - *Bipolar Schemes*
  - *Multilevel Schemes*





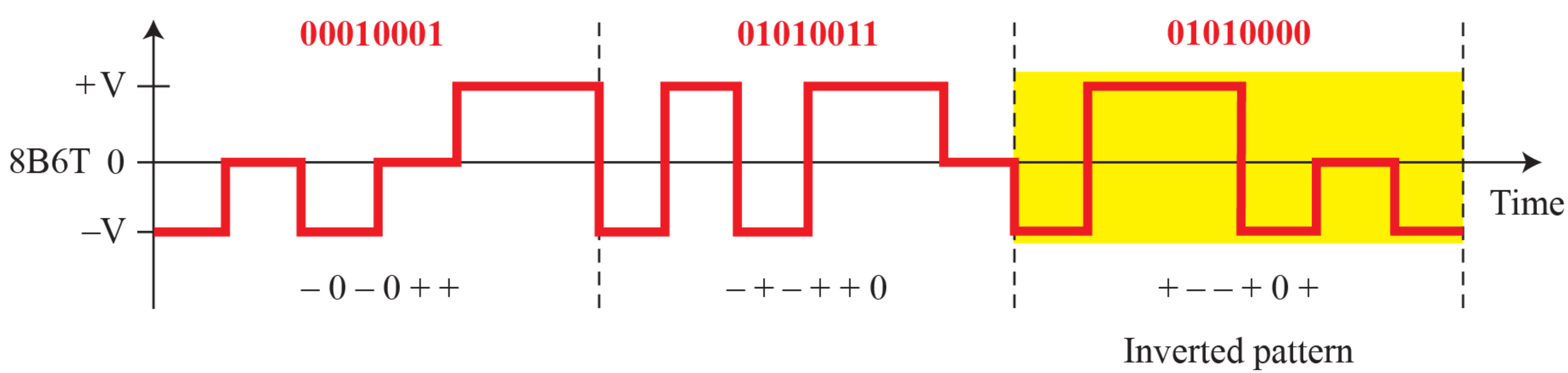


Figure 7.23: Block coding concept

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

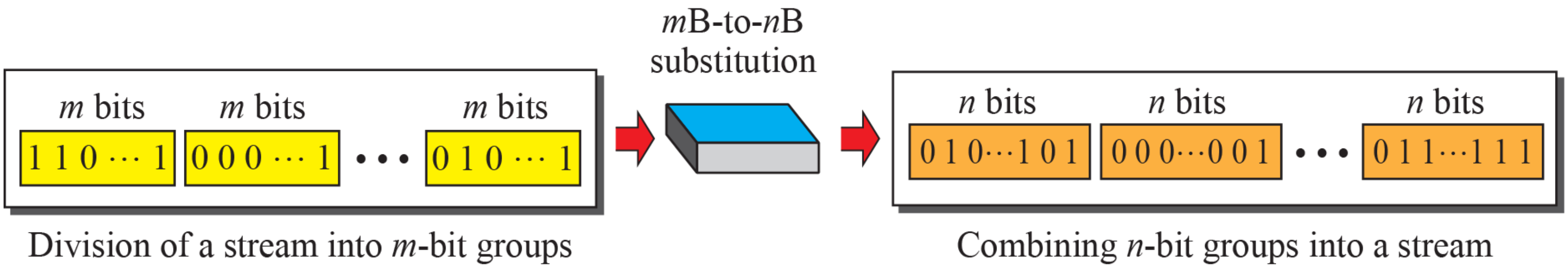


Figure 7.24: Using block coding 4B/5B with NRZ-I line coding scheme

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

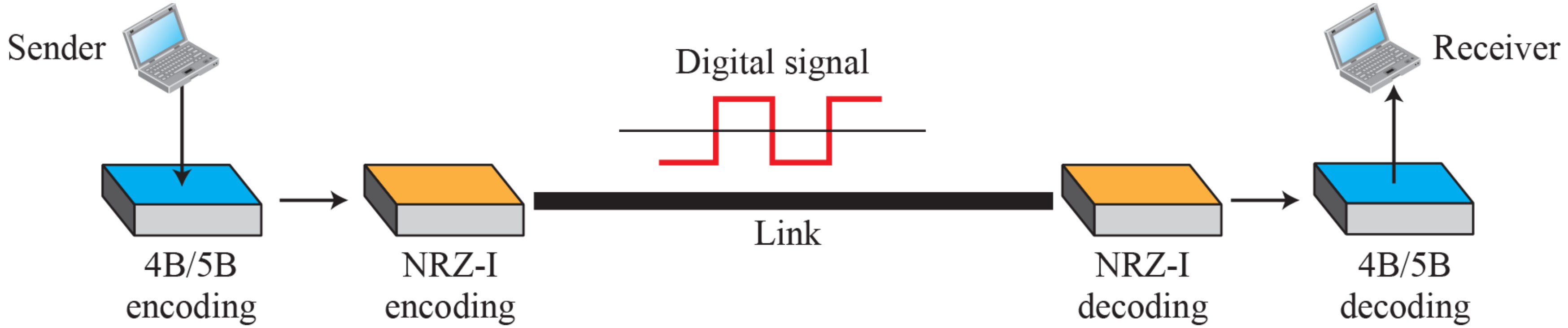


Figure 7.25: *8B/10B block encoding*

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

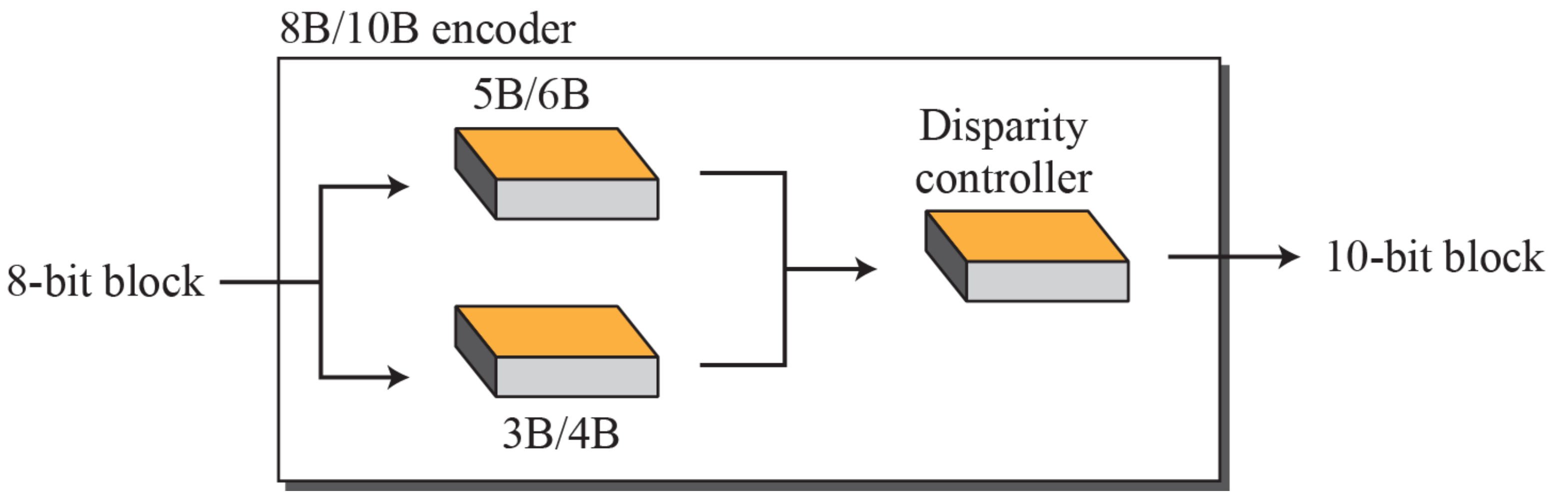


Figure 7.26: AMI used with scrambling

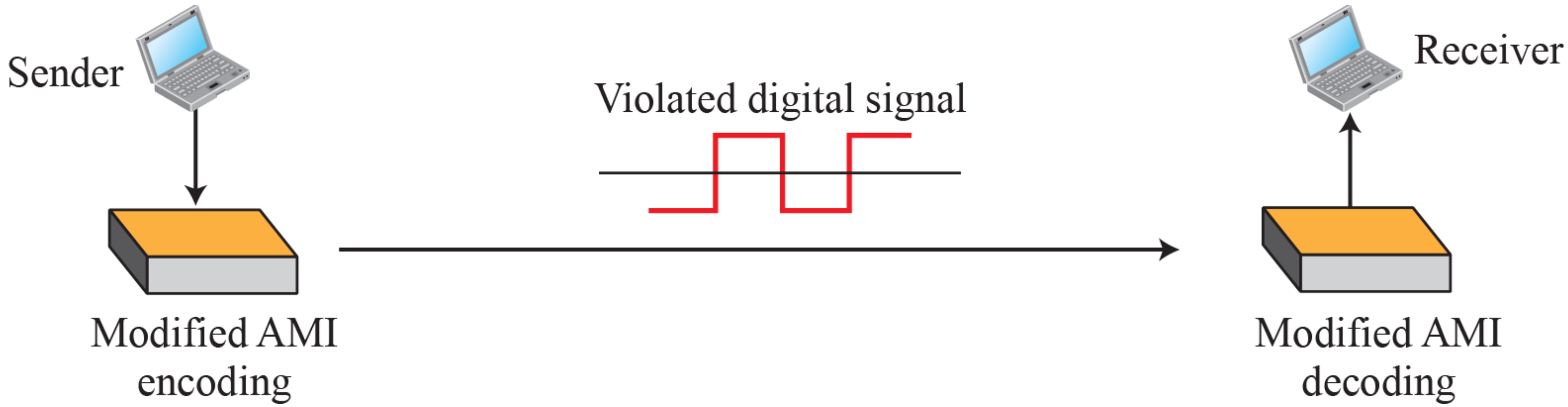
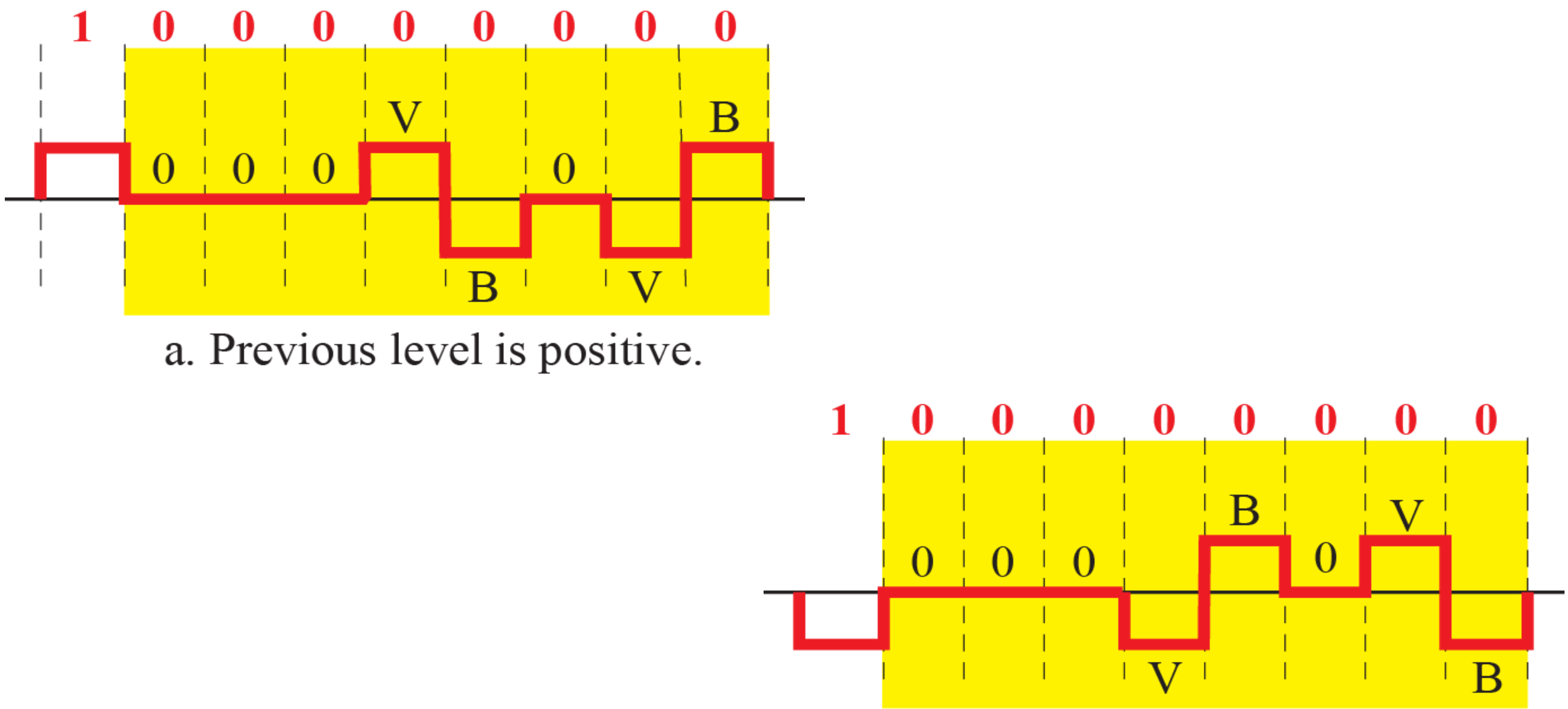


Figure 7.27: Two cases of B8ZS scrambling technique

- ***Scrambling***
  - ***B8ZS Coding***
  - ***HDB3 Coding***

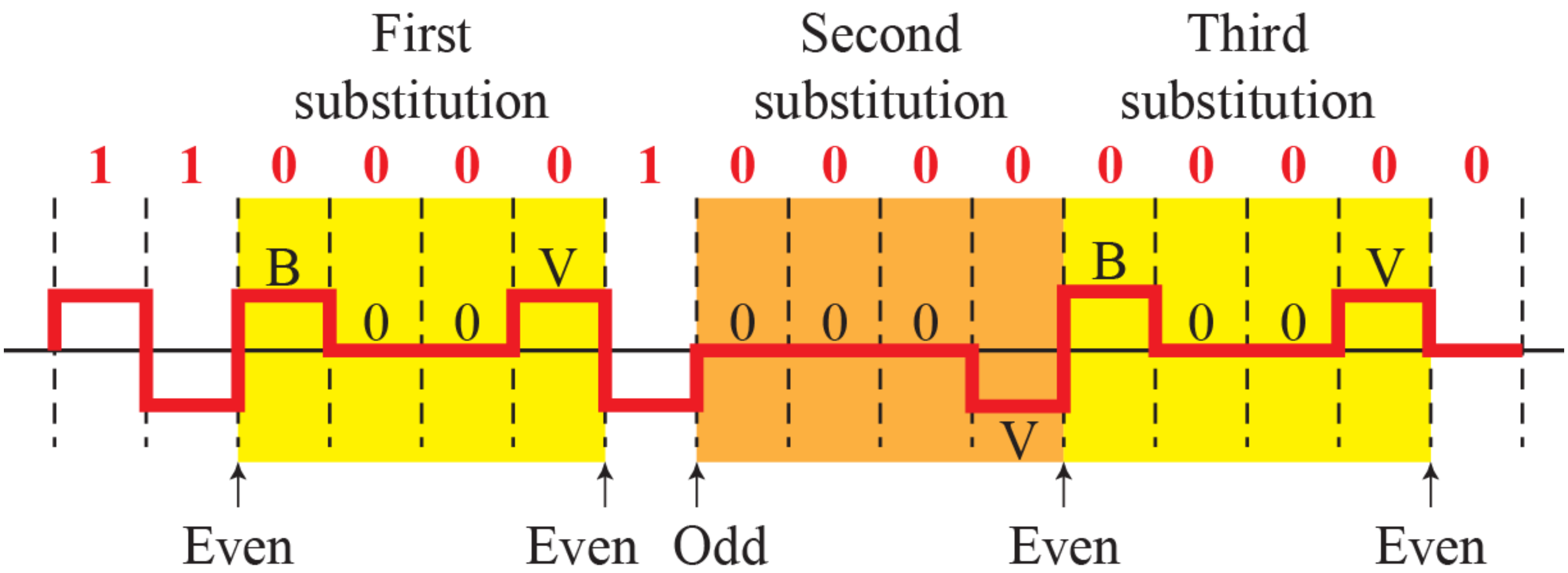


a. Previous level is positive.

b. Previous level is negative.

Figure 7.28: Different situations in HDB3 scrambling technique

- ***Scrambling***
  - ***B8ZS Coding***
  - ***HDB3 Coding***



7.2.2 Analog-to-Digital Conversion

The techniques described in Section 7.2.1 convert digital data to digital signals.

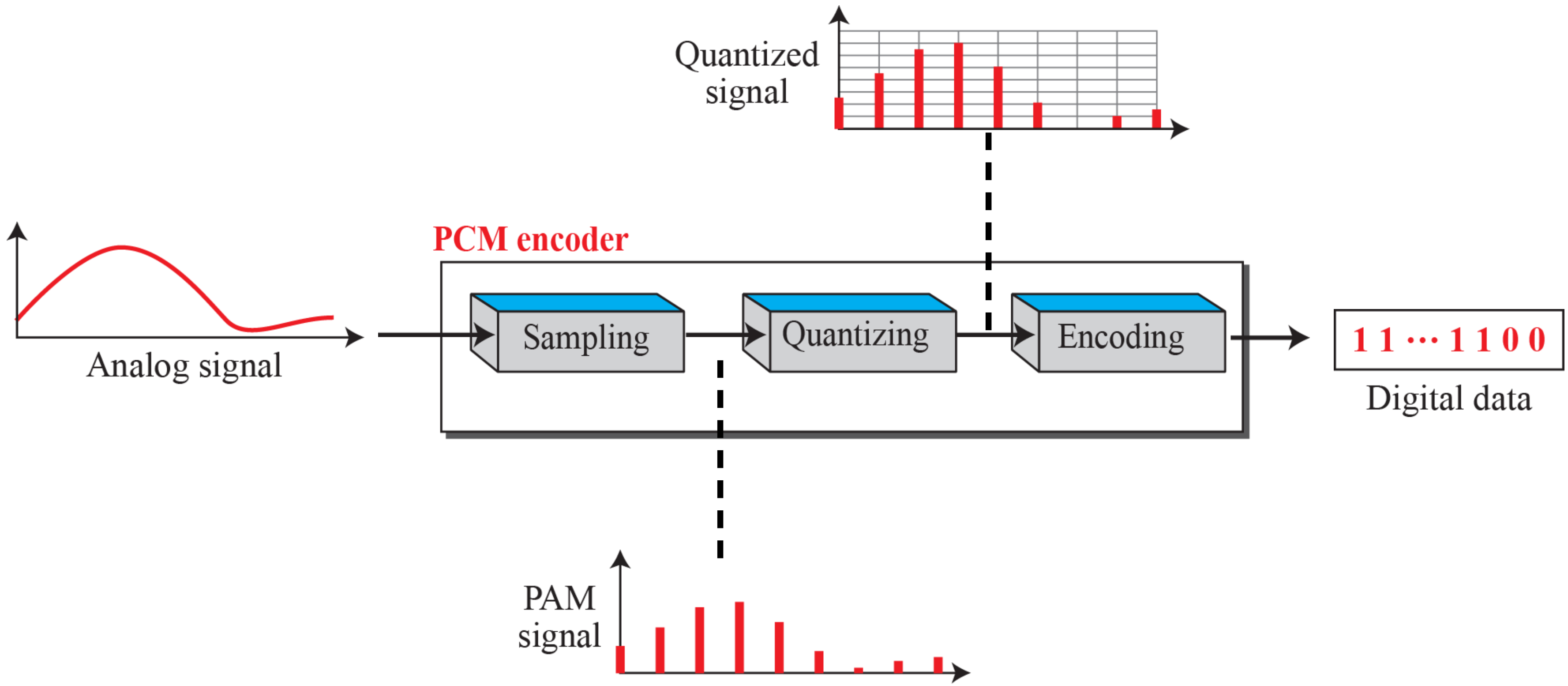
- *Sometimes, however, we have an analog signal such as one created by a microphone or camera. The tendency today is to change an analog signal to digital data because the digital signal is less susceptible to noise.*
- *In this section we describe two techniques,*
  - ***Pulse code modulation*** *and*
  - ***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



$$SNR_{dB} = 6.02\ n_b + 1.76\ ; \quad n_b = \text{Quantization encoded words - levels}$$

Figure 7.30: *Three different sampling methods for PCM*

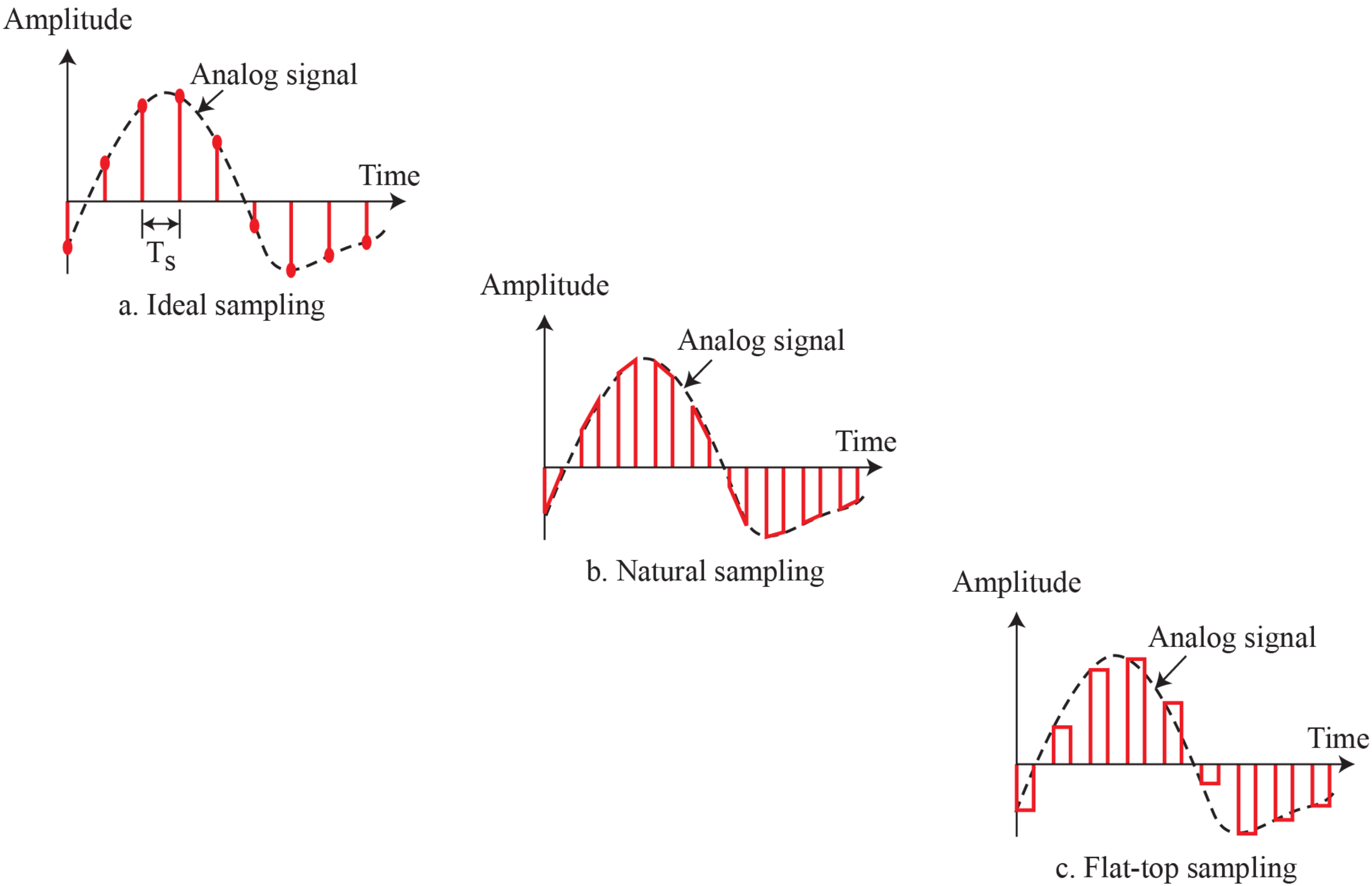
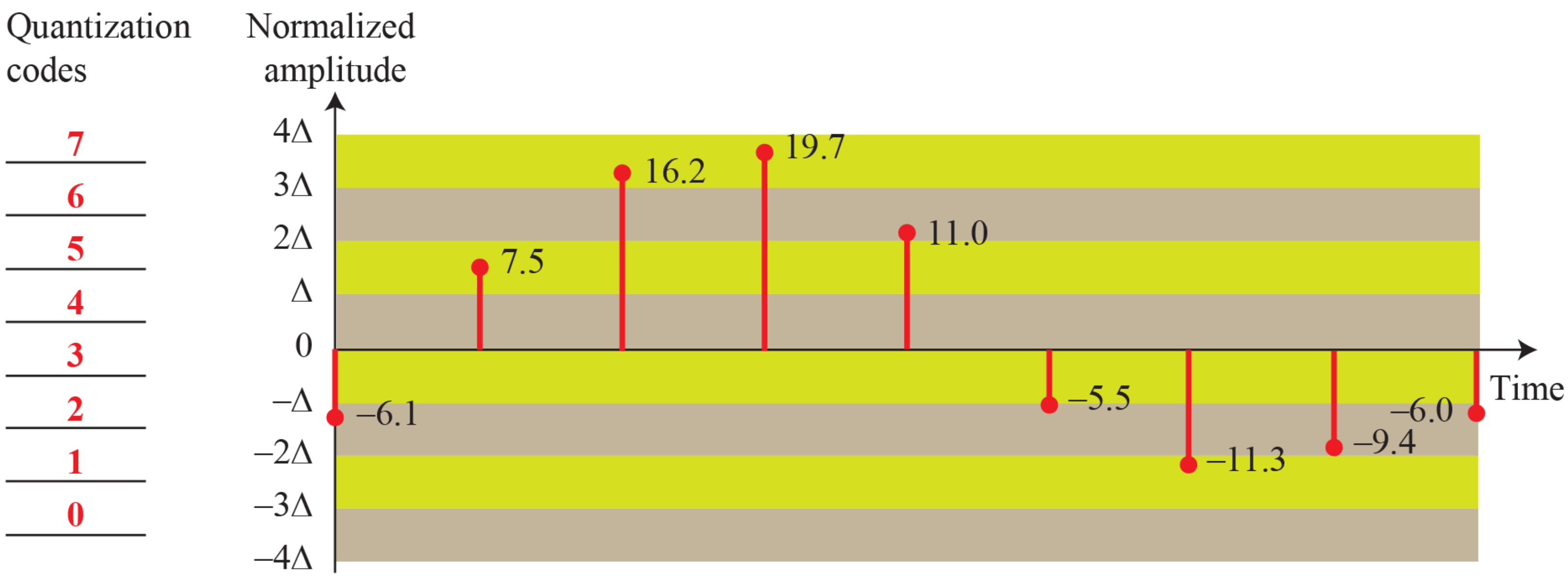


Figure 7.32: *Quantization and encoding of a sampled signal*



Normalized PAM values	–1.22	1.50	3.24	3.94	2.20	–1.10	–2.26	–1.88	–1.20
Normalized quantized values	–1.50	1.50	3.50	3.50	2.50	–1.50	–2.50	–1.50	–1.50
Normalized error	–0.28	0	+0.26	–0.44	+0.30	–0.40	–0.24	+0.38	–0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

$$SNR_{dB} = 6.02\ n_b + 1.76\ ;$$ n_b = *Quantization encoded words - levels*

Example 7.13

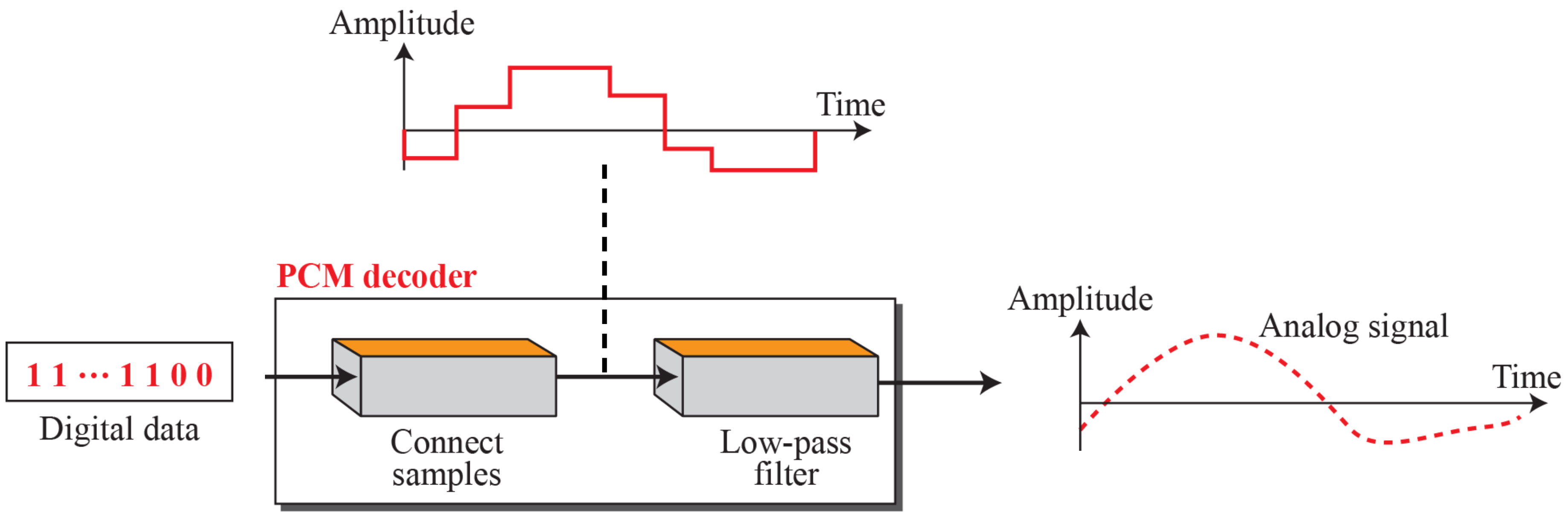
We want to digitize the human voice. What is the bit rate, assuming 8 bits per sample?

Solution

The human voice normally contains frequencies from 0 to 4000 Hz. So the sampling rate and bit rate are calculated as follows.

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

Figure 7.33: Components of a PCM decoder

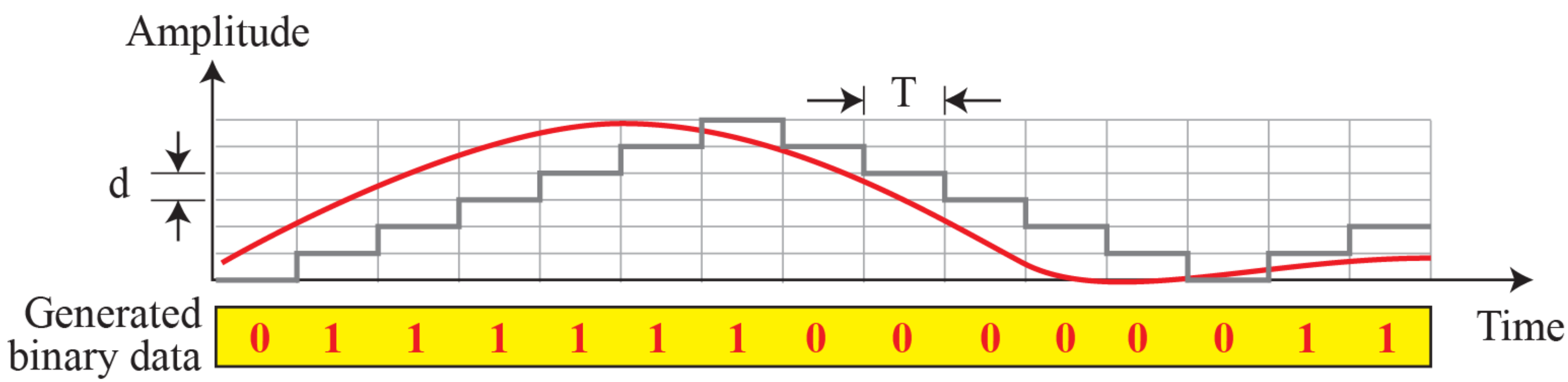


$$SNR_{dB} = 6.02\ n_b + 1.76$$

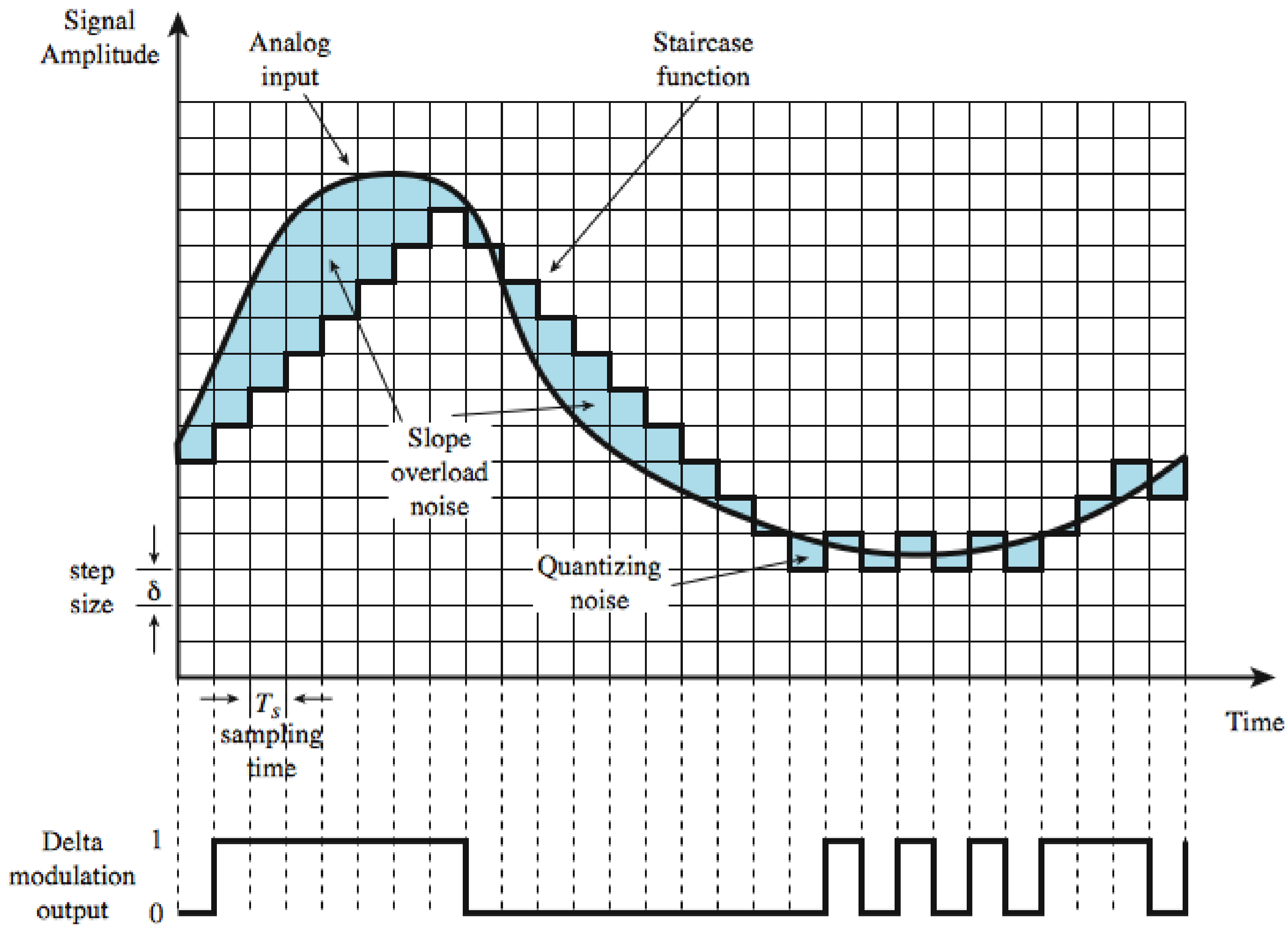
n_b = *Quantization encoded word - levels*

Figure 7.34: The process of delta modulation

- analog input is approximated by a staircase function
  - can move up or down one level (δ) at each sample interval
- has binary behavior
  - since function only moves up or down at each sample interval
  - hence can encode each sample as single bit
  - 1 for up or 0 for down



Delta Modulation Example



7-3 ANALOG TRANSMISSION

- *If digital transmission is desirable, it needs a low-pass channel;*
- *If 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 shows the relationship between the digital information, the digital-to-analog modulating process, and the resultant analog signal.*

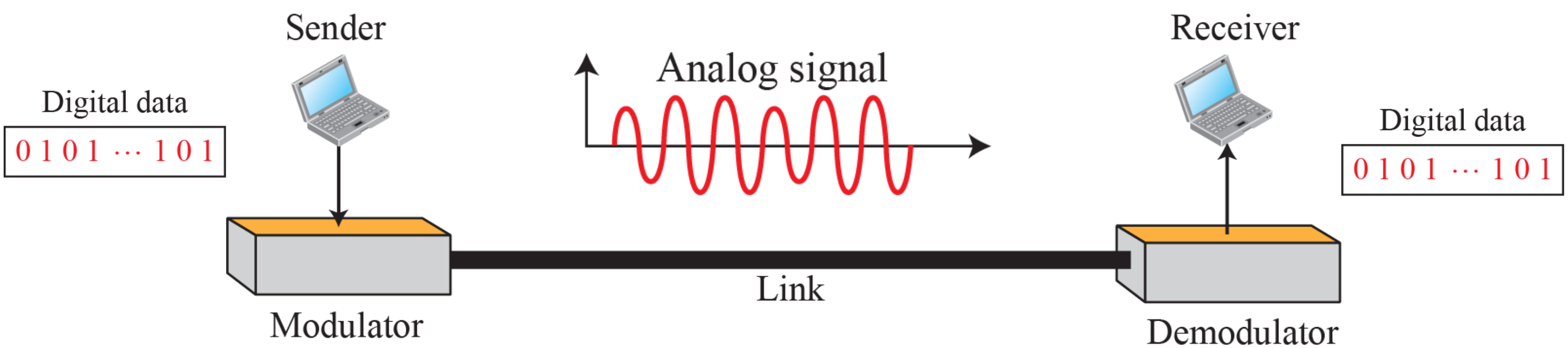


Figure 7.35: ***Digital-to-analog conversion***

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*

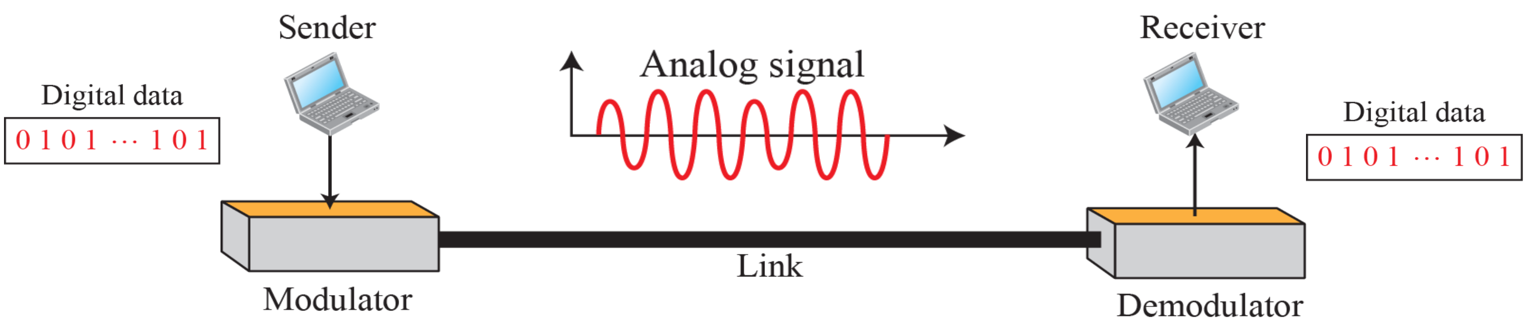
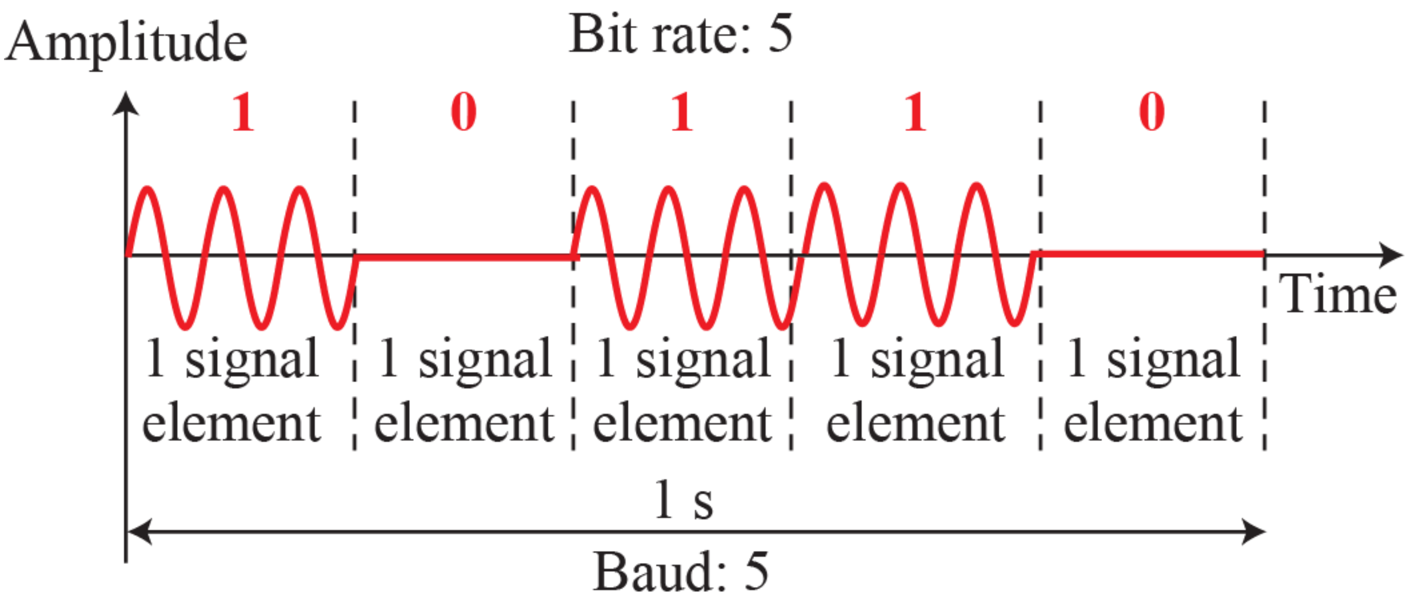
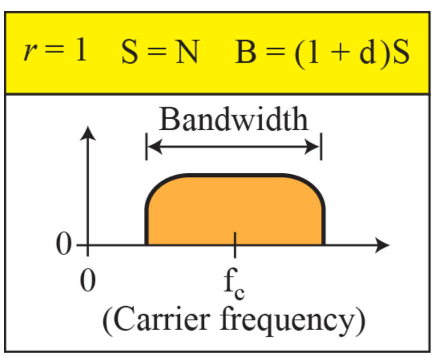


***Figure 7.35:* Digital-to-analog conversion**

Figure 7.36: Binary amplitude shift keying





$$s(t) = A * Sin\,(2\pi\, f\, t + \theta)$$

A = Amplitude

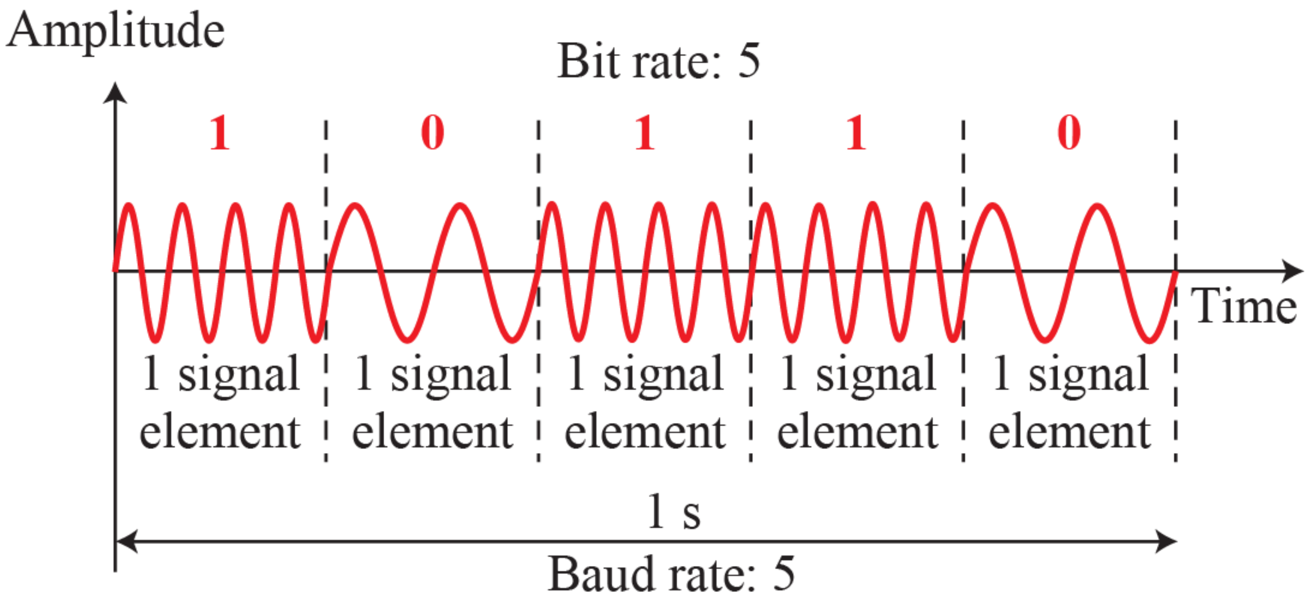
f = carrier frequency

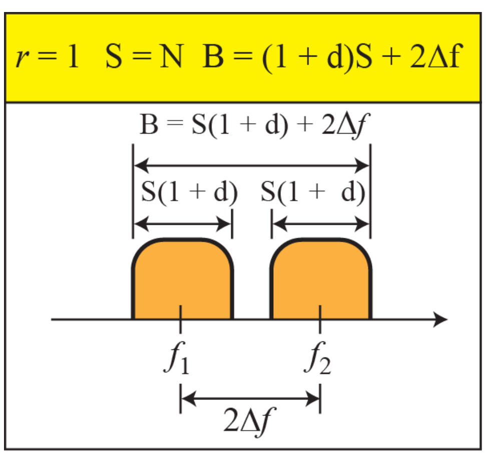
θ = Phase Angle

$$\text{“0”} = 0 * Sin\,(2\pi\, f\, t + 0)$$

$$\text{“1”} = A * Sin\,(2\pi\, f\, t + 0)$$

Figure 7.37: *Binary frequency shift keying*



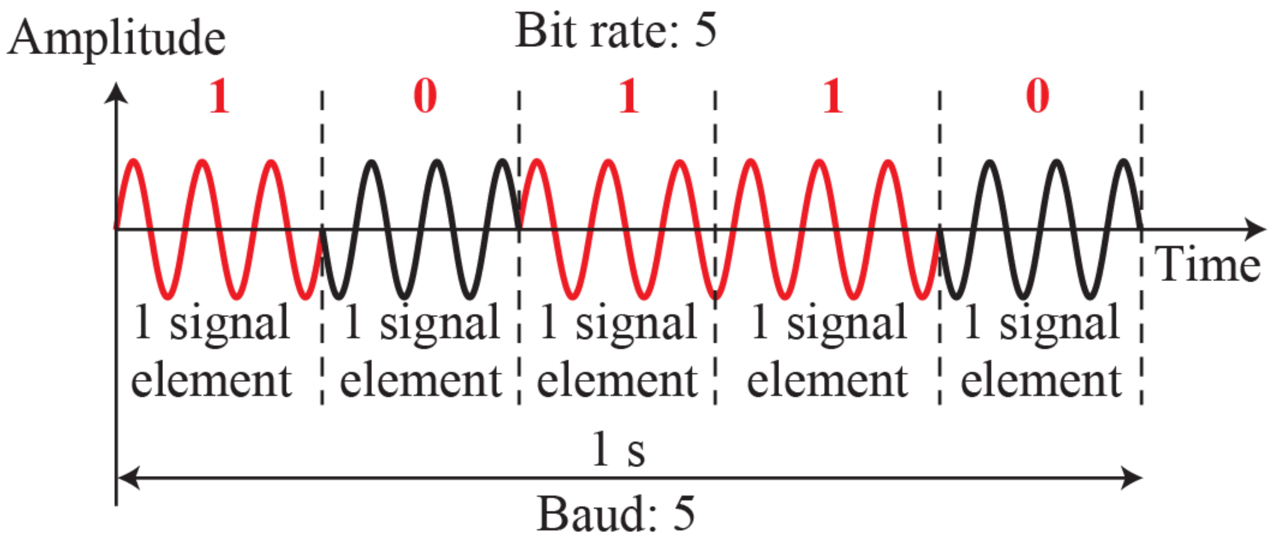


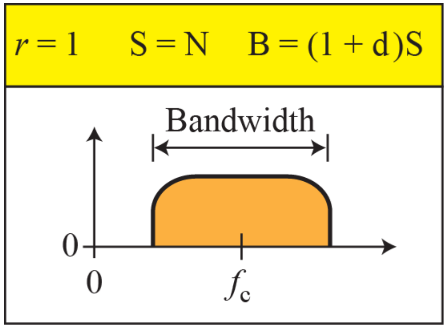
s(t) = A * Sin (2π f t + θ)
A = Amplitude
f = carrier frequency
θ = Phase Angle

"0" = A * Sin (2π f_1 t + 0)

"1" = A * Sin (2π f_2 t + 0)

Figure 7.38: *Binary phase shift keying*





$s(t) = A * Sin\ (2\pi\ f\ t + \theta)$

A = Amplitude

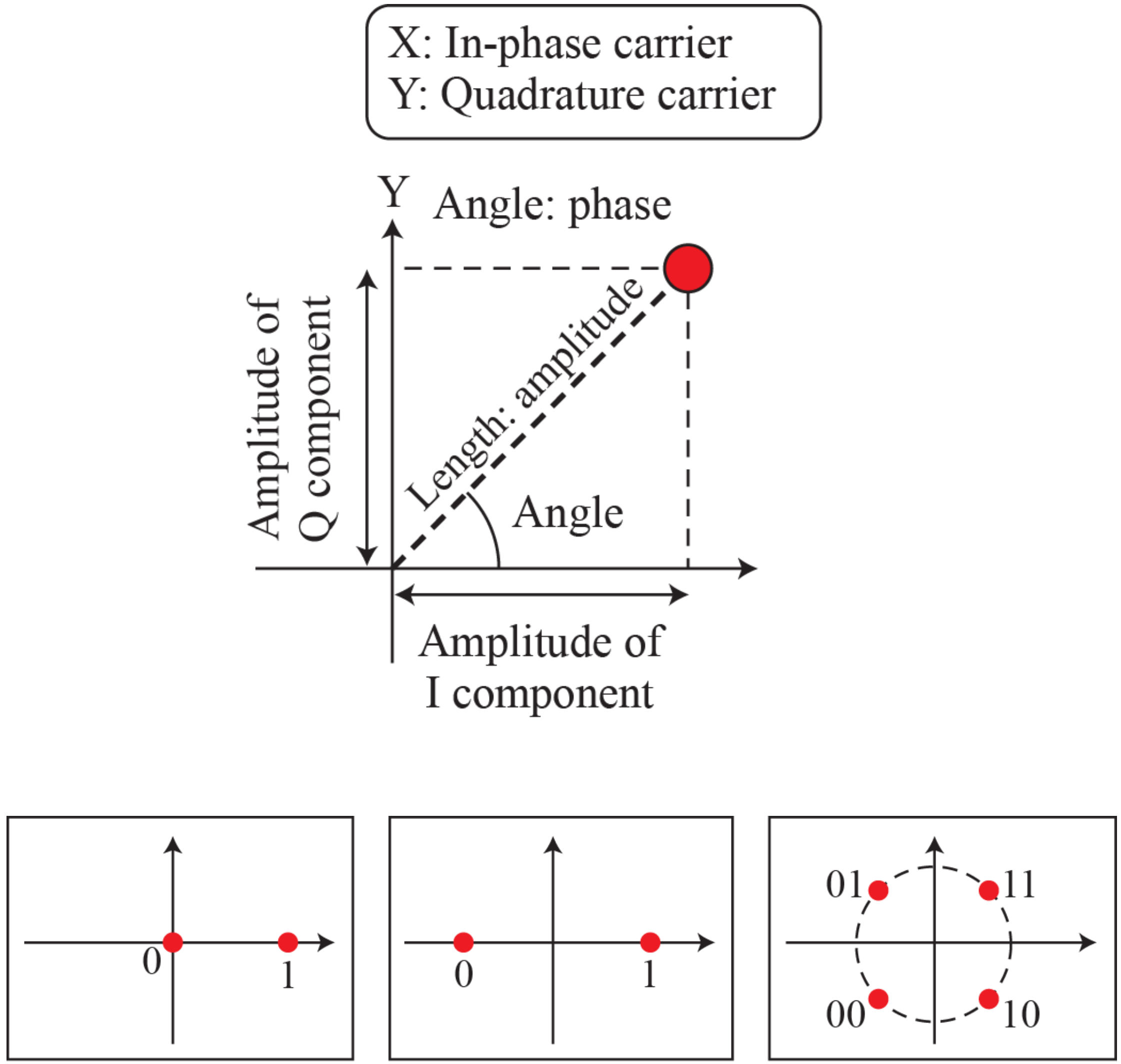
f = carrier frequency

θ = Phase Angle

"0" $= A * Sin\ (2\pi\ f_1\ t + 0)$

"1" $= A * Sin\ (2\pi\ f_1\ t + 180)$

Figure 7.39: Concept of a constellation diagram

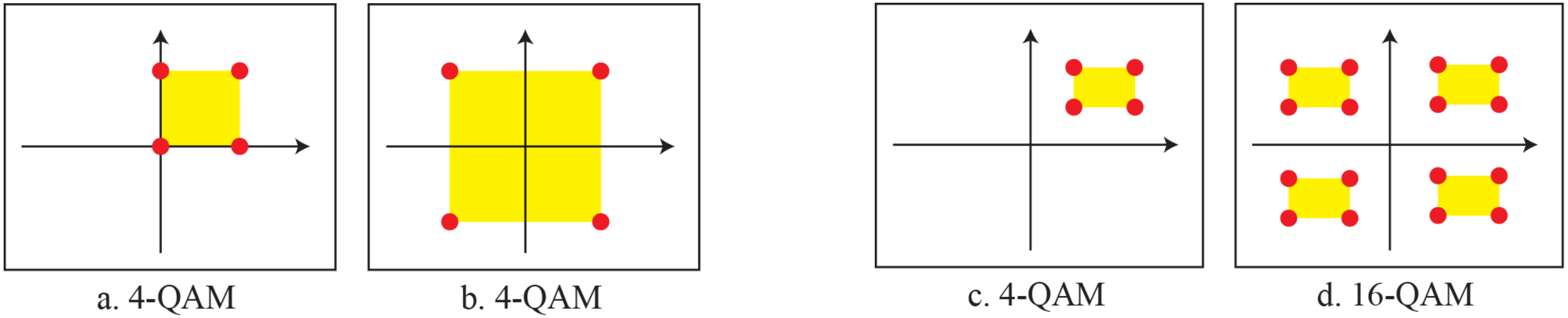


a. BASK (OOK)

b. BPSK

c. QPSK

Figure 7.40: Constellation diagrams for some QAMs



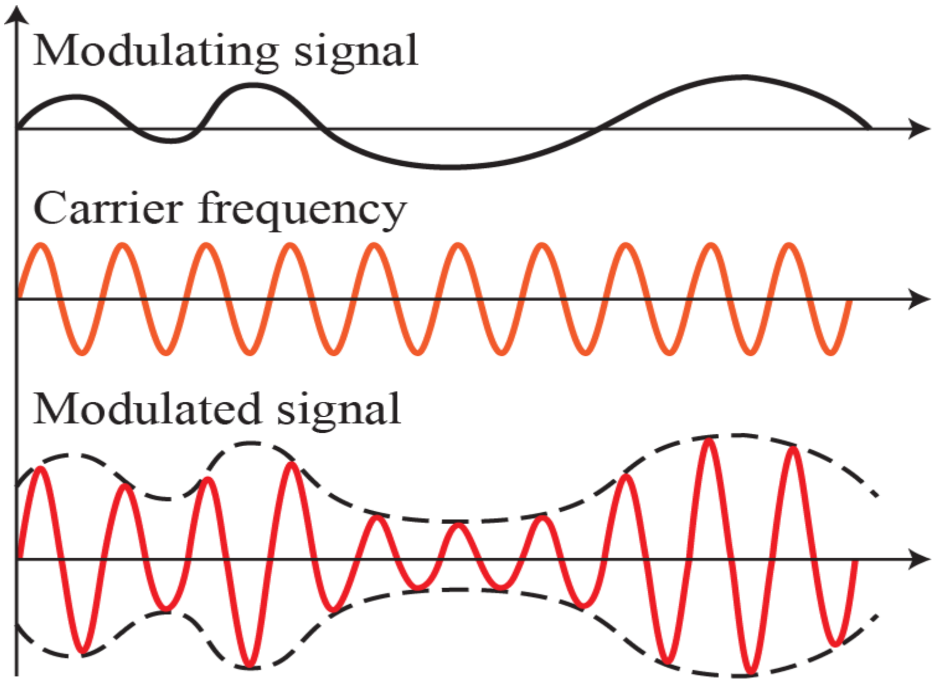
- QAM used in asymmetric digital subscriber line (ADSL) and some wireless communication
- combination of ASK and PSK
- logical extension of QPSK
- send two different signals simultaneously on same carrier frequency
  - uses two copies of carrier f_c, one shifted by a phase angle of 90°
  - each carrier is ASK modulated
  - two independent signals over same medium
  - demodulate and combine for original binary output

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 for communication wirelessly*

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

Figure 7.41: Amplitude modulation



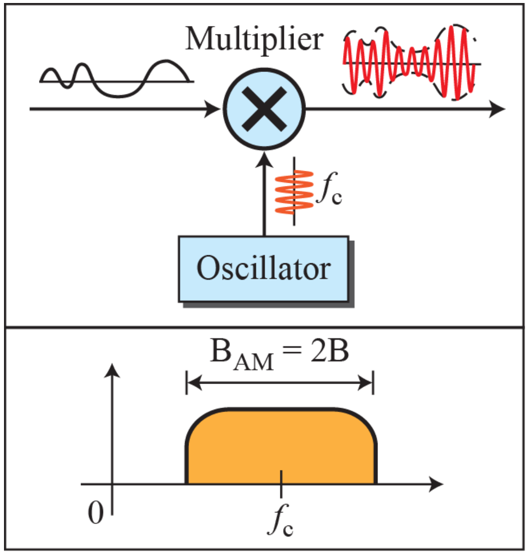
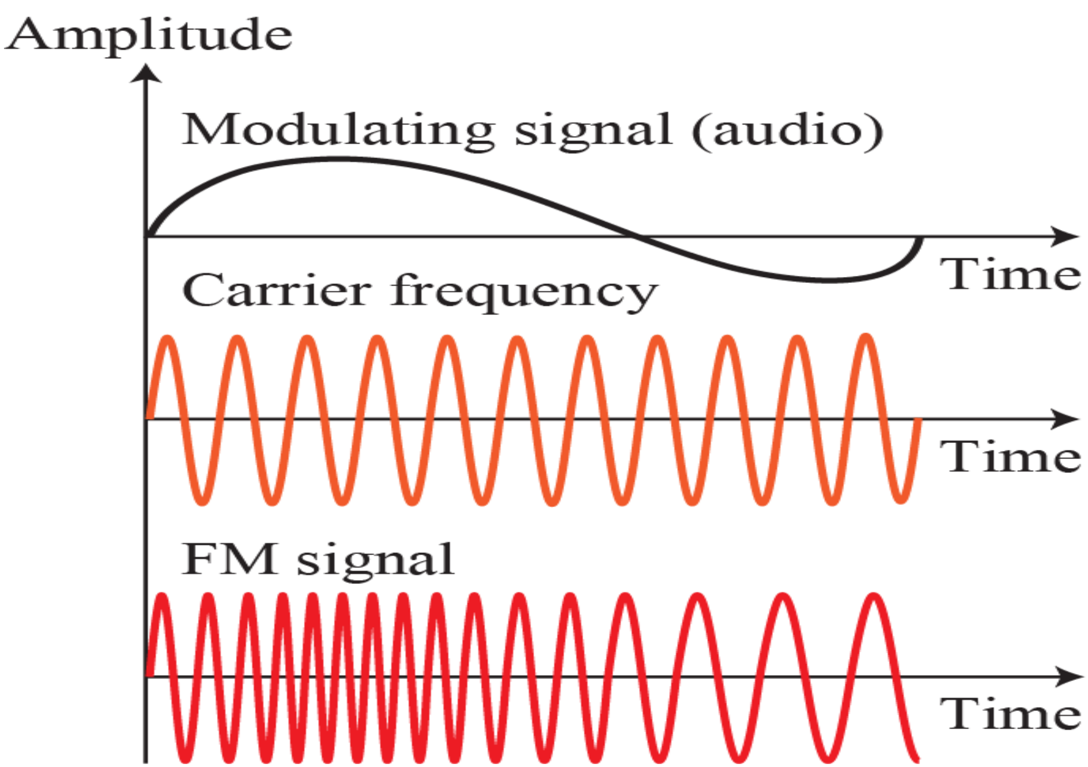


Figure 7.42: Frequency modulation



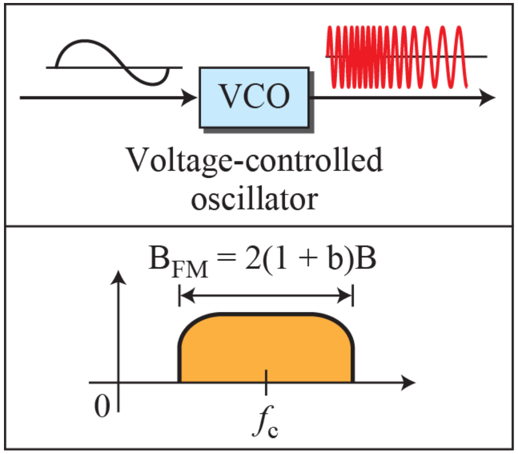
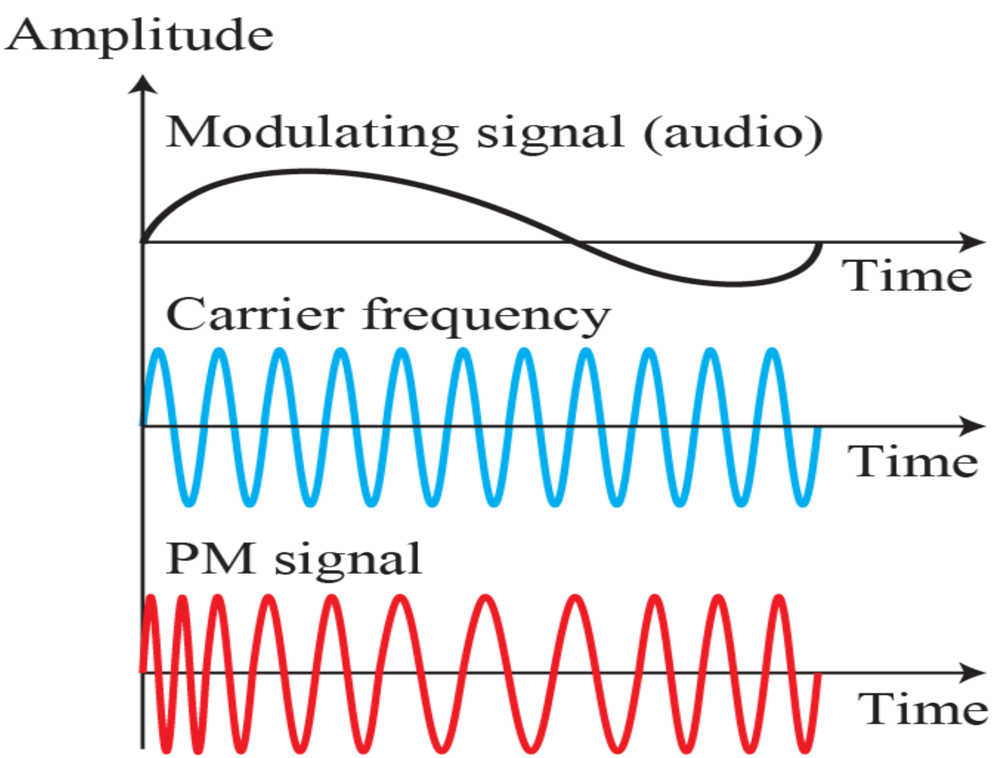
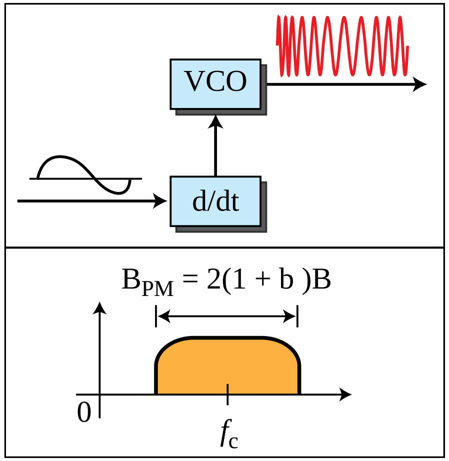


Figure 7.43: Phase modulation





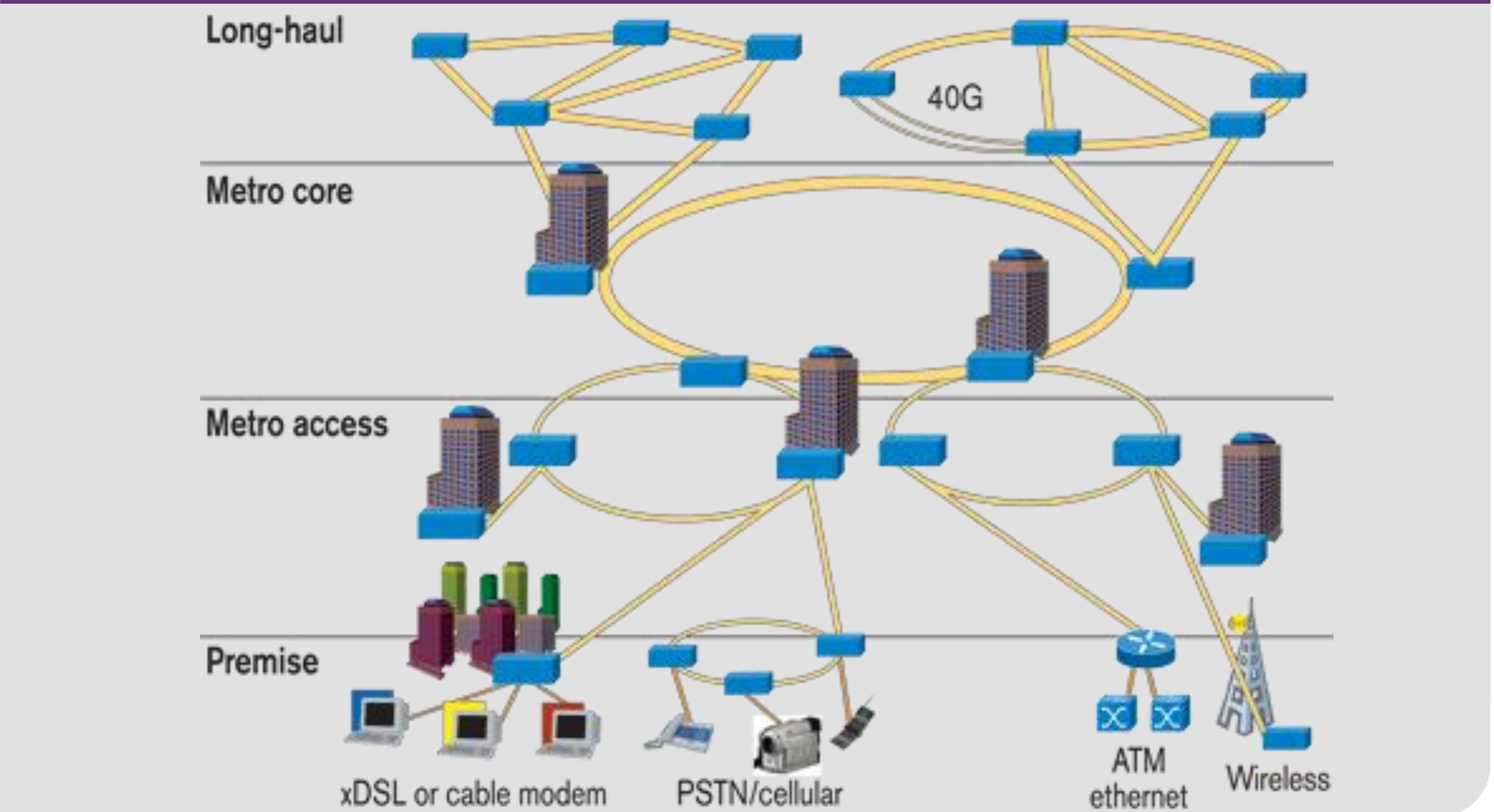
7-4 BANDWIDTH UTILIZATION

- *In real life, we have links/communication channels with limited bandwidths.*
- *Hence, at times we need to combine several low-bandwidth channels to make use of one channel with a larger bandwidth.*

Multiplexing

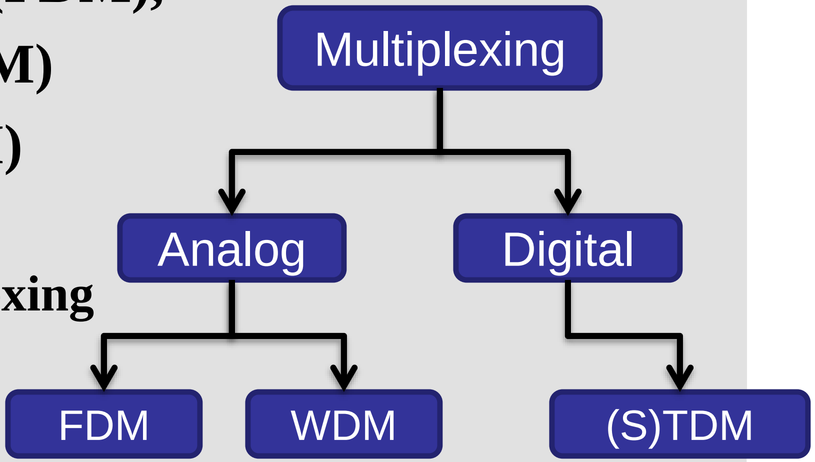
- Multiplexing is the process where multiple channels are combined for transmission over a common transmission path.
- Full capacity of data transmission links are not always fully utilized
- To make efficient use of high-speed telecommunications lines, some form of multiplexing is used
- common application of multiplexing is done in long-haul communications.

Multiplexing – in long-haul communications.



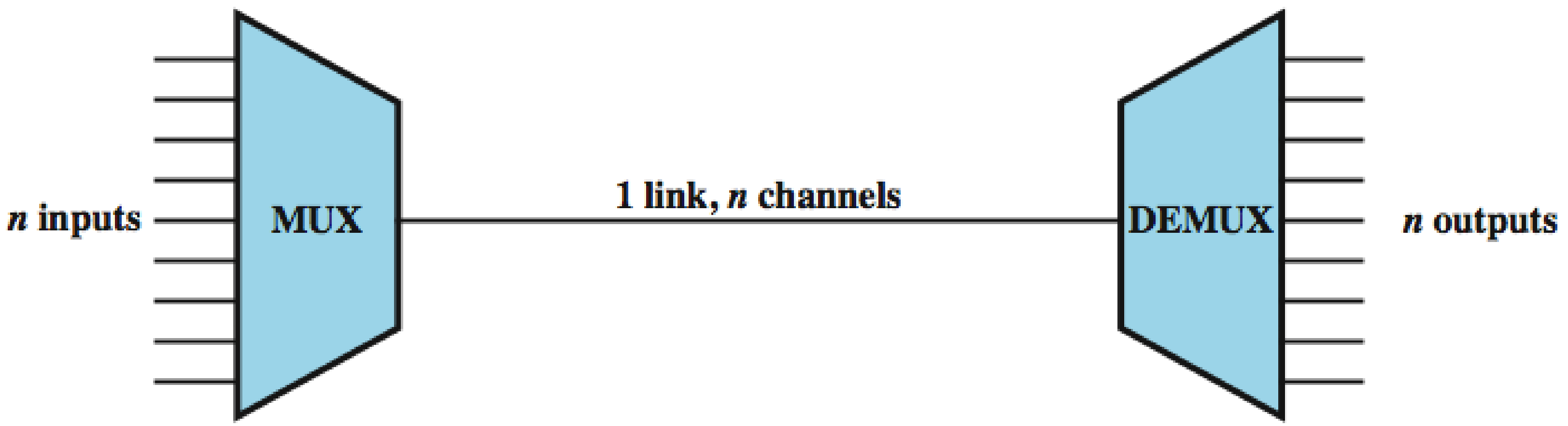
Multiplexing

- Trunks on long-haul networks are high-capacity fiber, coaxial, or microwave links.
- These links can carry large numbers of voice and data transmissions simultaneously using multiplexing.
- Common forms of multiplexing are:
  - Frequency Division Multiplexing (FDM),
  - Wave Division Multiplexing (WDM)
  - Time Division Multiplexing (TDM)
    - Synchronous TDM
    - Statistical Time-Division Multiplexing



Multiplexing

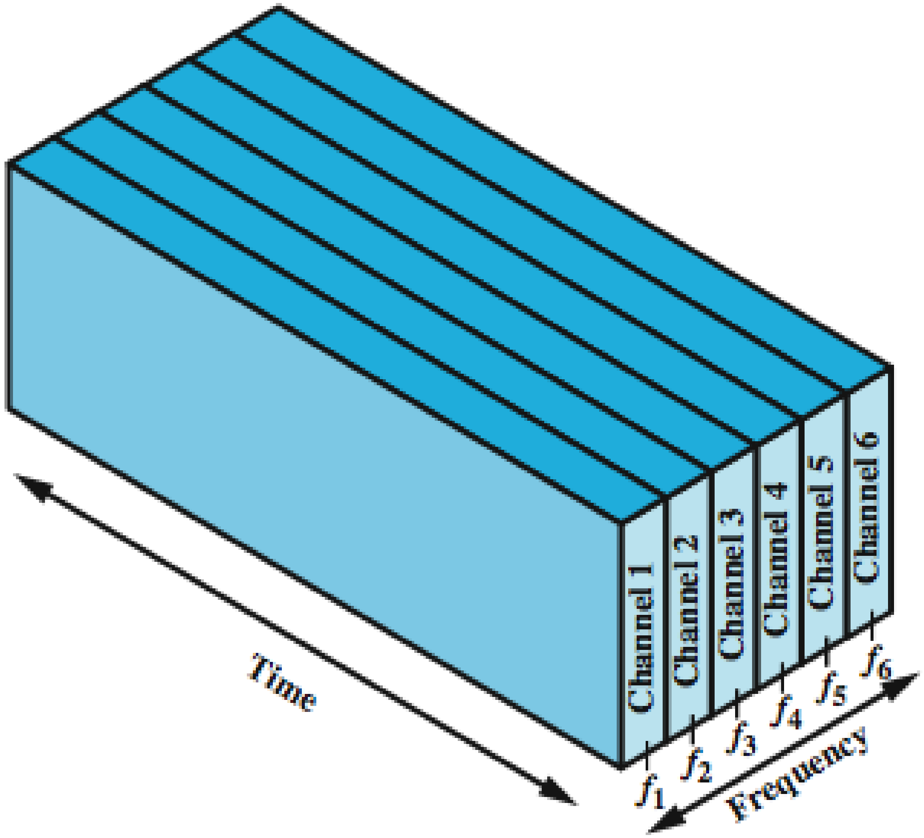
- multiple *n inputs* / *1 outputs* on 1 physical line
- multiplexing allows several transmission sources to share a larger transmission capacity
- the link can carry multiple channels of data
- common on long-haul, high capacity, links



Frequency Division Multiplexing

- Division of a transmission link into multiple channels by splitting the frequency band into multiple slots.
- Used when useful bandwidth of the link is greater than required bandwidth of individual signals to be transmitted.
- Each signal is modulated on a different carrier frequency.
- Carrier frequencies are centered at each signal BW and typically separated by guard bands so that signals do not overlap.
- An FDM receiver uses filters, one per slot, to separate the individual channels, each of which is separately demodulated to extract the signal.

Frequency Division Multiplexing



(a) 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.

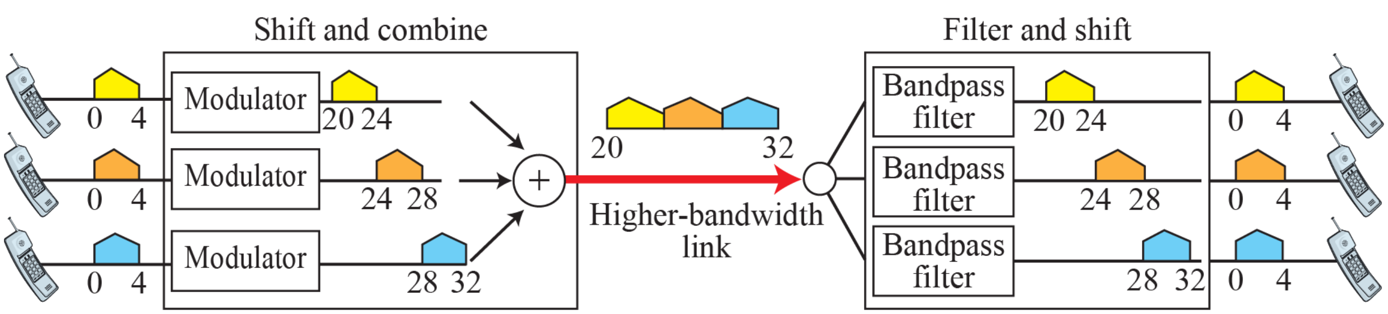
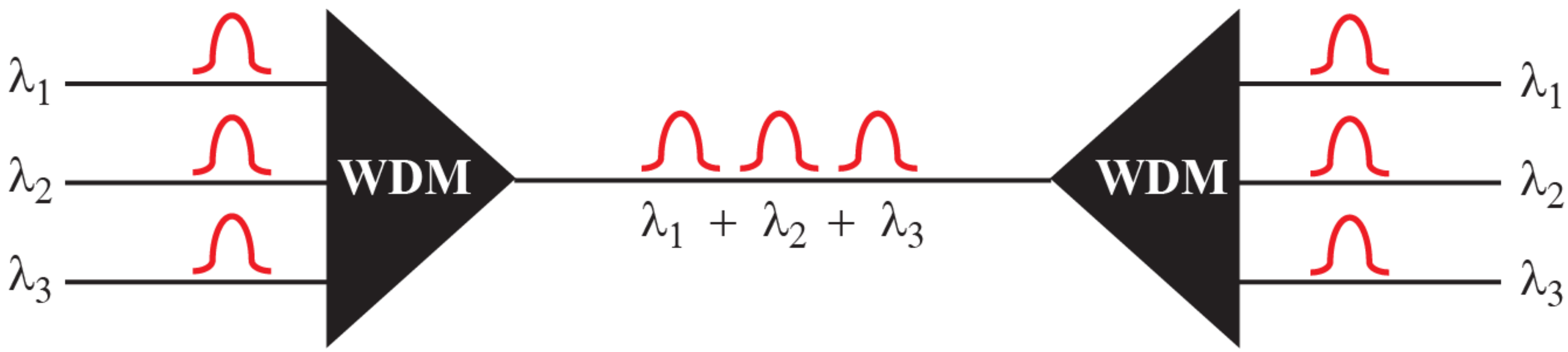


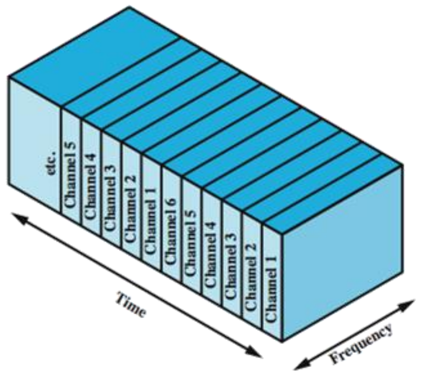
Figure 7.46: Example 7.14

Figure 7.47: Wavelength-division multiplexing



Synchronous Time Division Multiplexing

- **Time slots on a shared medium are assigned to devices on a fixed, predetermined basis**



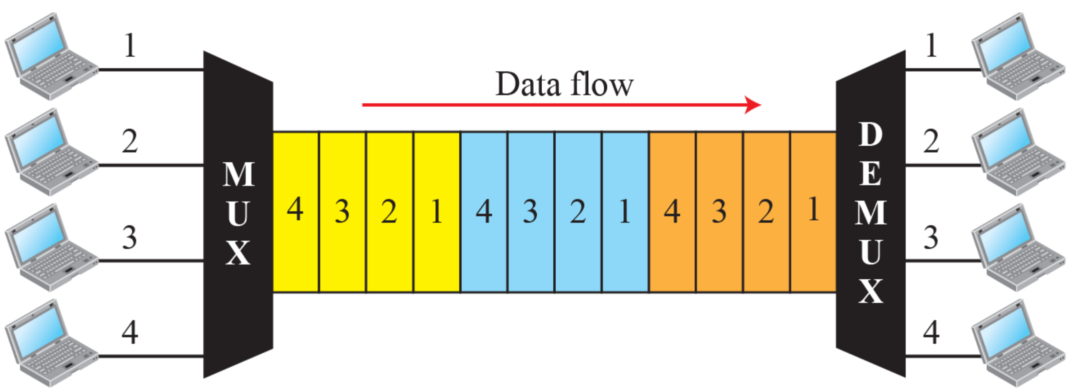


Figure 7.49: Synchronous time-division multiplexing

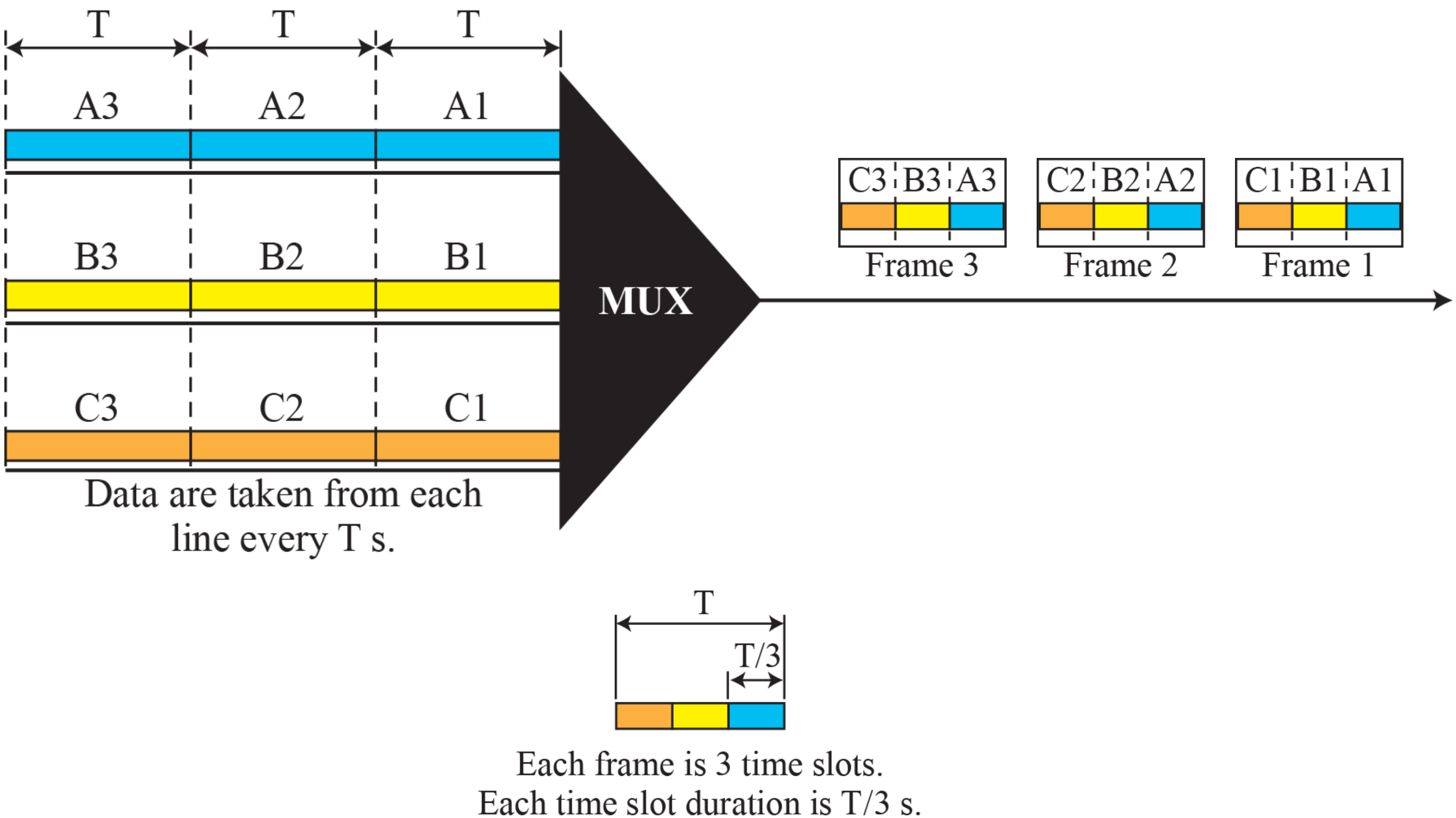
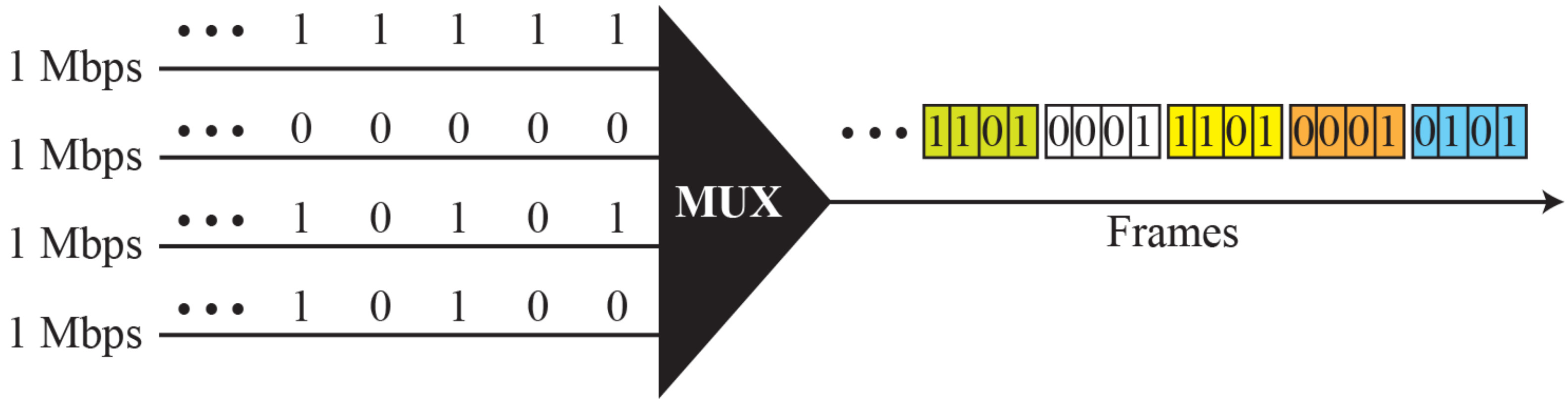


Figure 7.50: Example 7.15



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

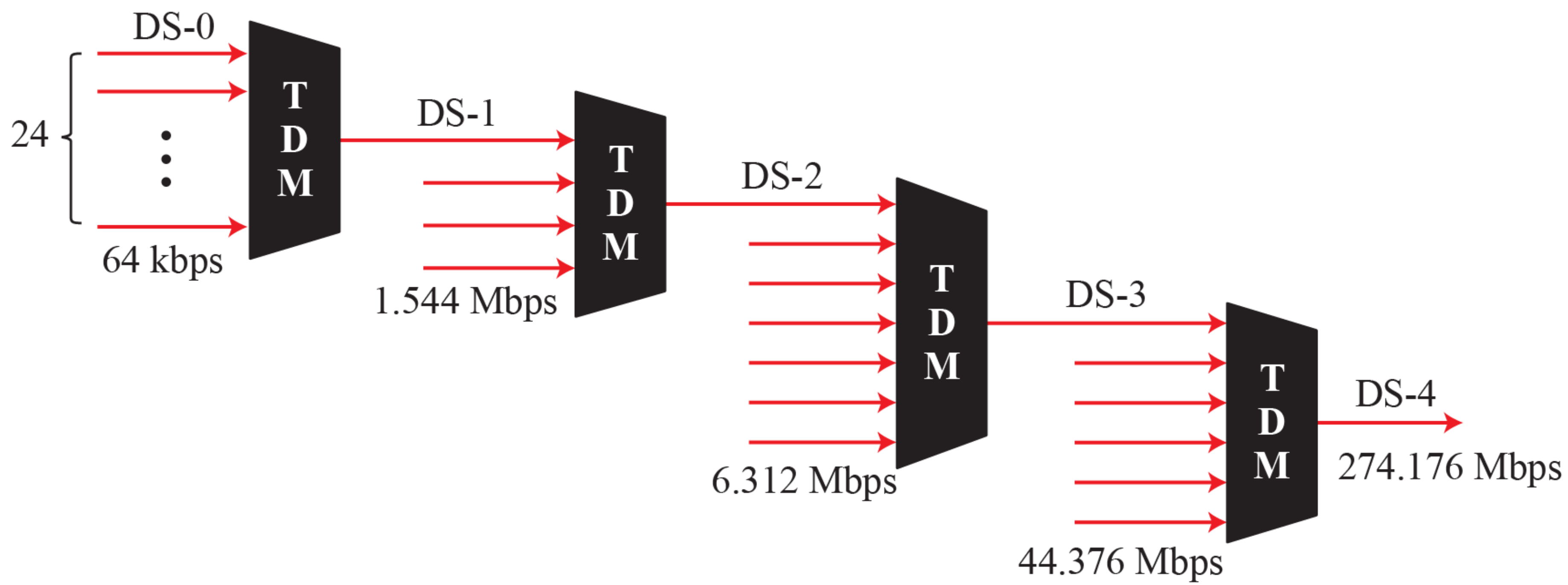
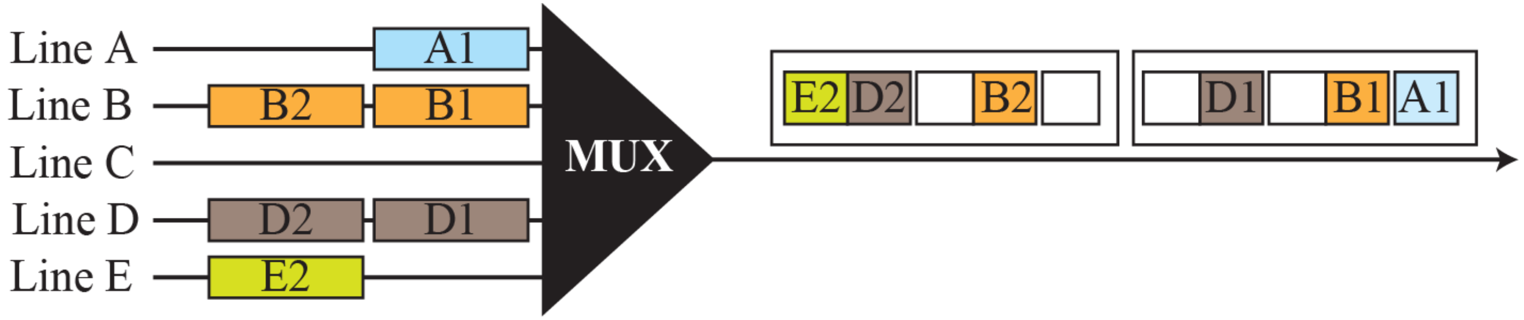
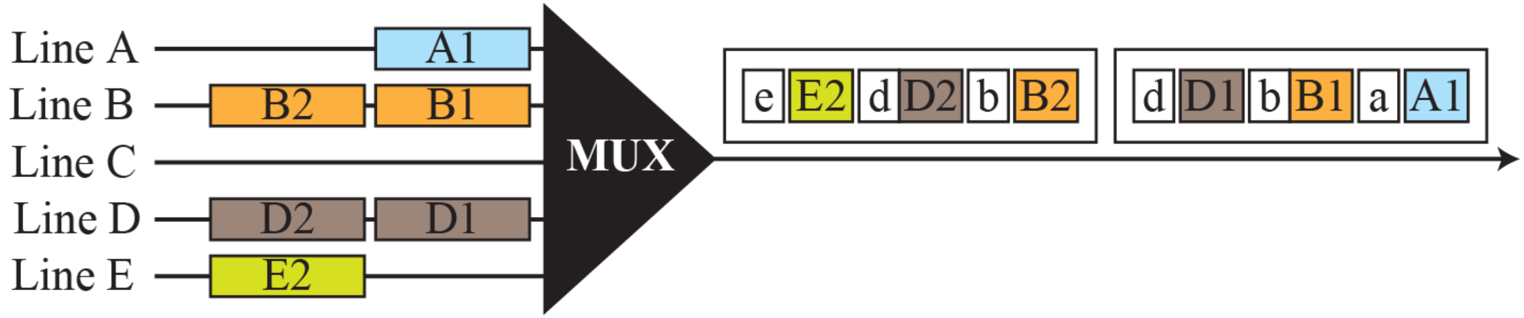


Figure 7.52: TDM slot comparison



a. Synchronous TDM



b. Statistical TDM

Wavelength Division Multiplexing

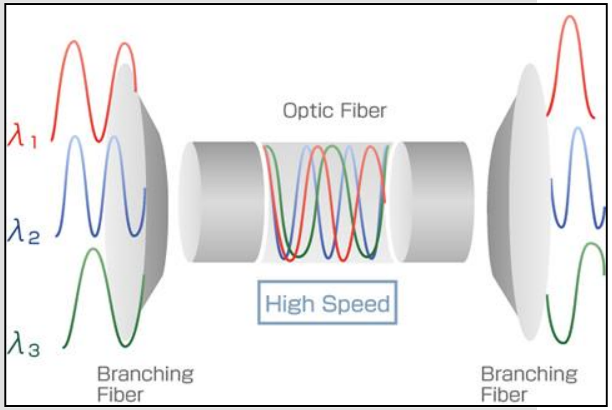
- **FDM with multiple beams of light at different frequencies**

$$f\ (Frequency) = \frac{c\ (speed\ of\ light)}{\lambda\ (wavelength)}$$

- **WDM carried over optical fiber links uses λ wavelength**
  - commercial systems with 160 channels of 10 Gbps
  - lab demo of 256 channels 39.8 Gbps

$$\lambda = \frac{c\ (speed\ of\ light)}{f\ (Frequency)}$$

- **Architecture similar to other FDM systems**
  - multiplexer consolidates laser sources (1550nm) of different λ 's for transmission over single fiber
  - Optical amplifiers amplify all wavelengths
  - Demux separates channels at the destination



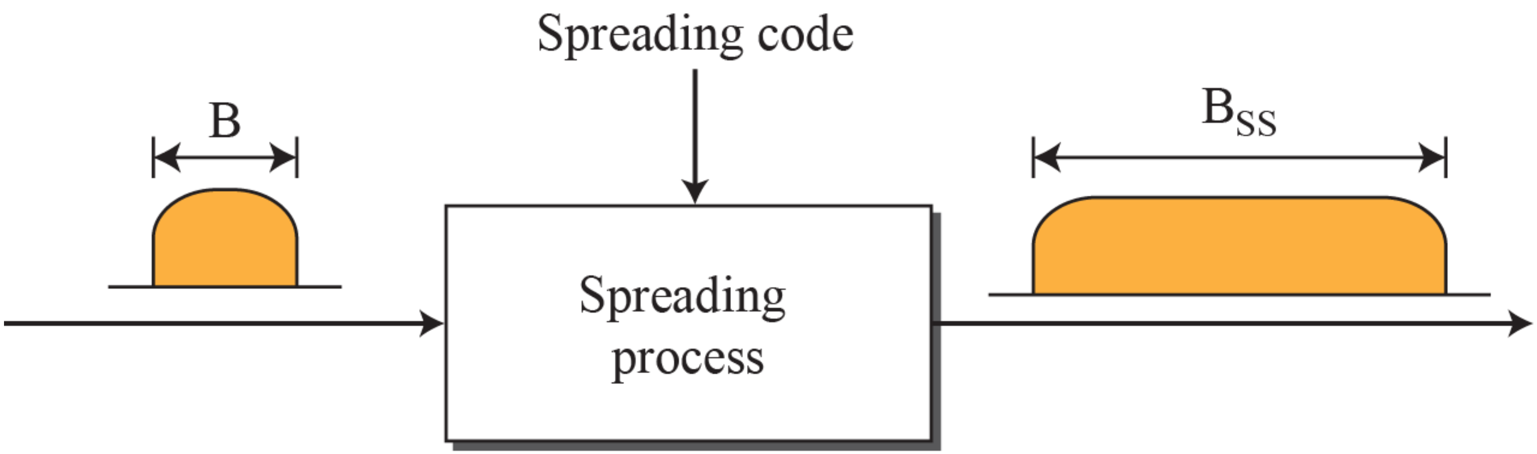
- **There are two types of WDM, namely:**
  - **Coarse WDM (CWDM)** - here the wavelengths are spaced **well apart**
  - **Dense WDM (DWDM)** - here larger number of **closely spaced** wavelengths

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).*

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

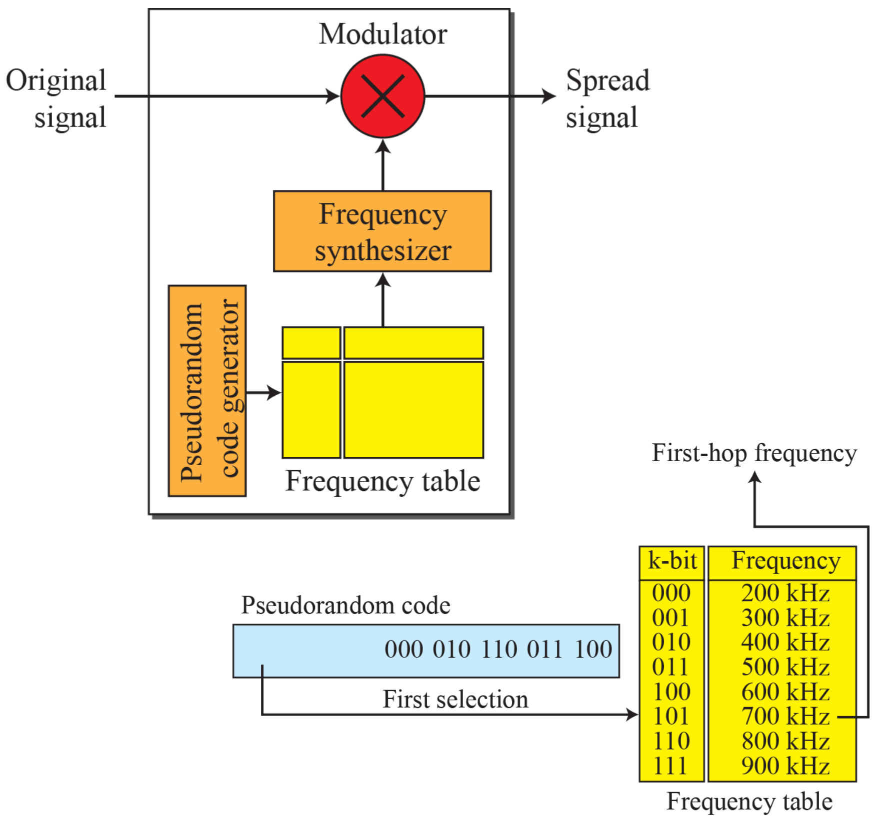
Figure 7.53: Spread spectrum



- *spread-spectrum techniques are methods by which a communicating signal generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth.*
- *The practice of spreading the transmitted signal is done to occupy the frequency spectrum available for transmission.*
- *The spread spectrum transmission uses spreading codes to spread the signal out over a wider bandwidth then would normally be required.*

Figure 7.54: *Frequency hopping spread spectrum (FHSS)*

- *Frequency-hopping spread spectrum (FHSS) is a method of transmitting radio signals by rapidly switching a carrier among many frequency channels, using a pseudorandom sequence known to both transmitter and receiver.*
- *FHSS is a wireless technology that spreads its signal over rapidly changing frequencies.*



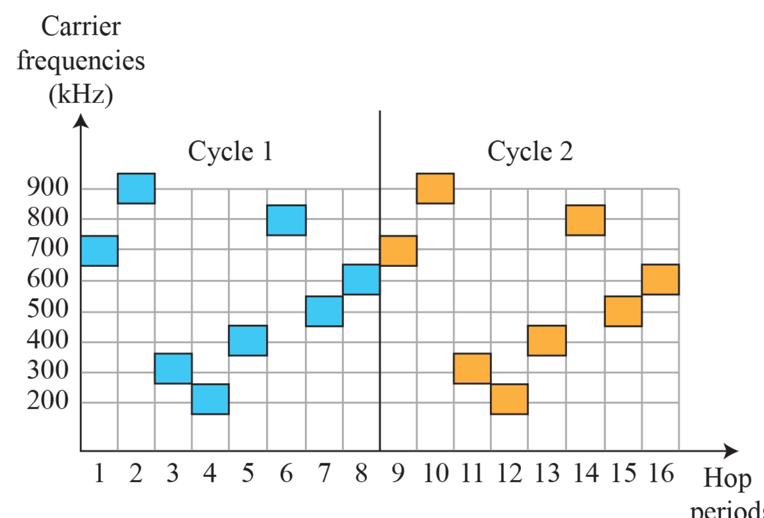


Figure 7.55: ***FHSS cycles***

Figure 7.56: ***Bandwidth sharing***

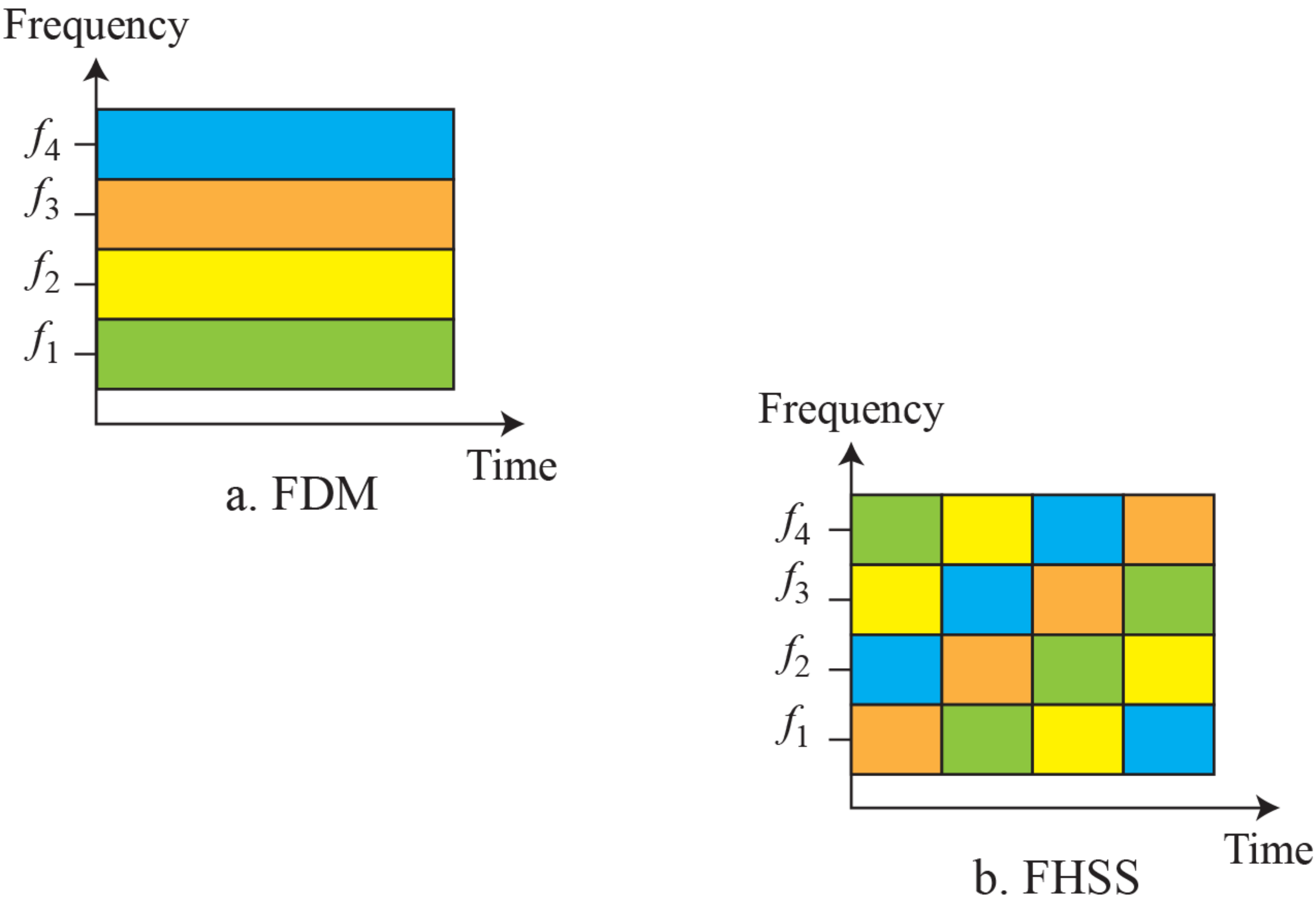
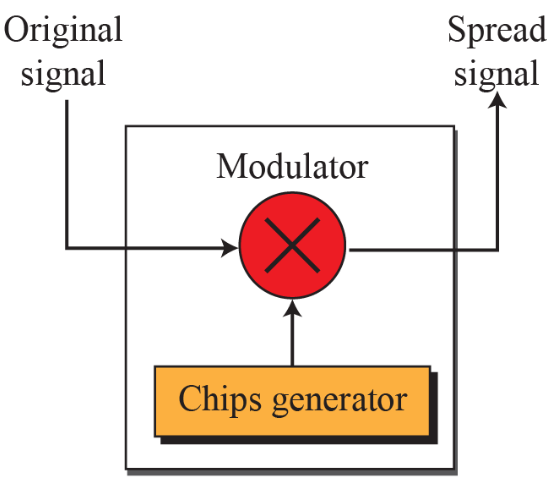
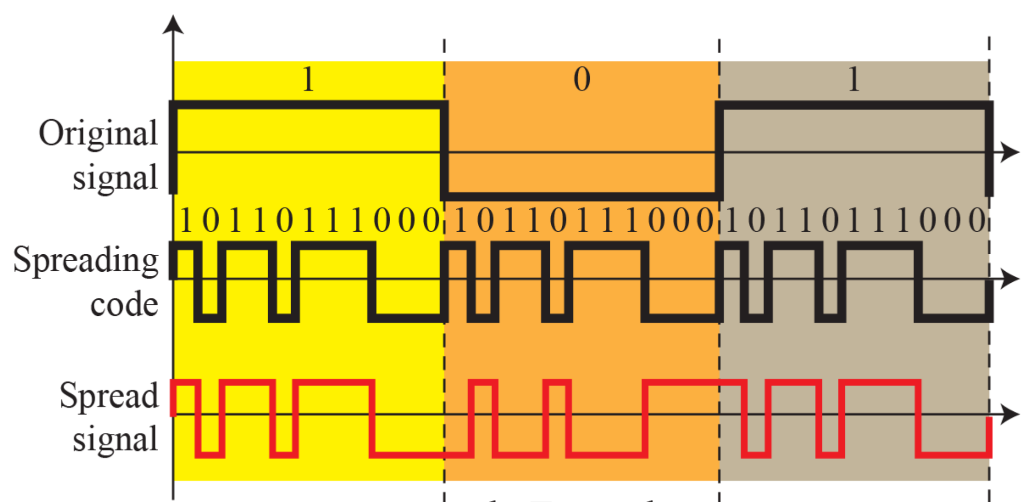


Figure 7.57: DSSS

- ***Direct Sequence Spread Spectrum (DSSS)*** *is a spread spectrum technique whereby the original data signal is* ***multiplied with a pseudo random noise spreading code****. This spreading code has a higher chip rate (this the bitrate of the code), which results in a wideband time continuous scrambled signal.*
- *DSSS significantly* ***improves protection against interfering (or jamming)*** *signals, especially narrowband and makes the signal less noticeable.*
- *It also provides* ***security*** *of transmission if the code is not known to the public.*



a. Concept



b. Example

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.*

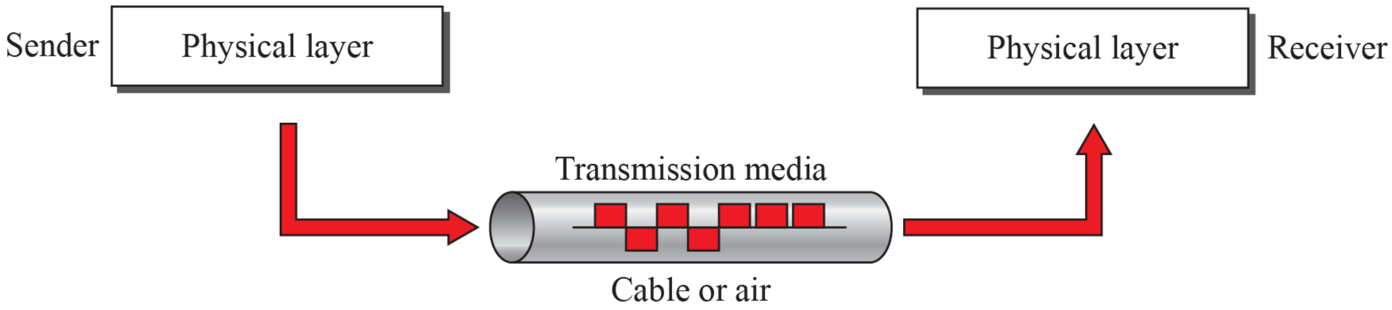


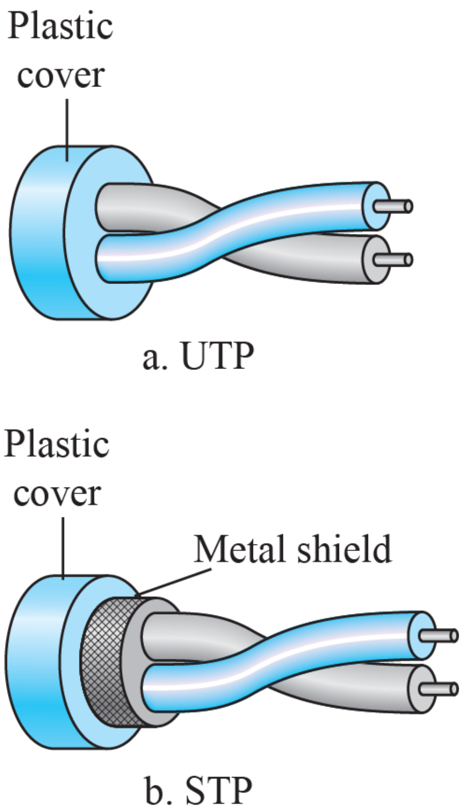
Figure 7.58: ***Transmission media and physical layer***

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****.*

- ***Twisted-Pair Cable***
  - ***Performance***
  - ***Applications***
- ***Coaxial Cable***
  - ***Performance***
  - ***Applications***
- ***Fiber-Optic Cable***
  - ***Propagation Modes***
  - ***Performance***
  - ***Applications***

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



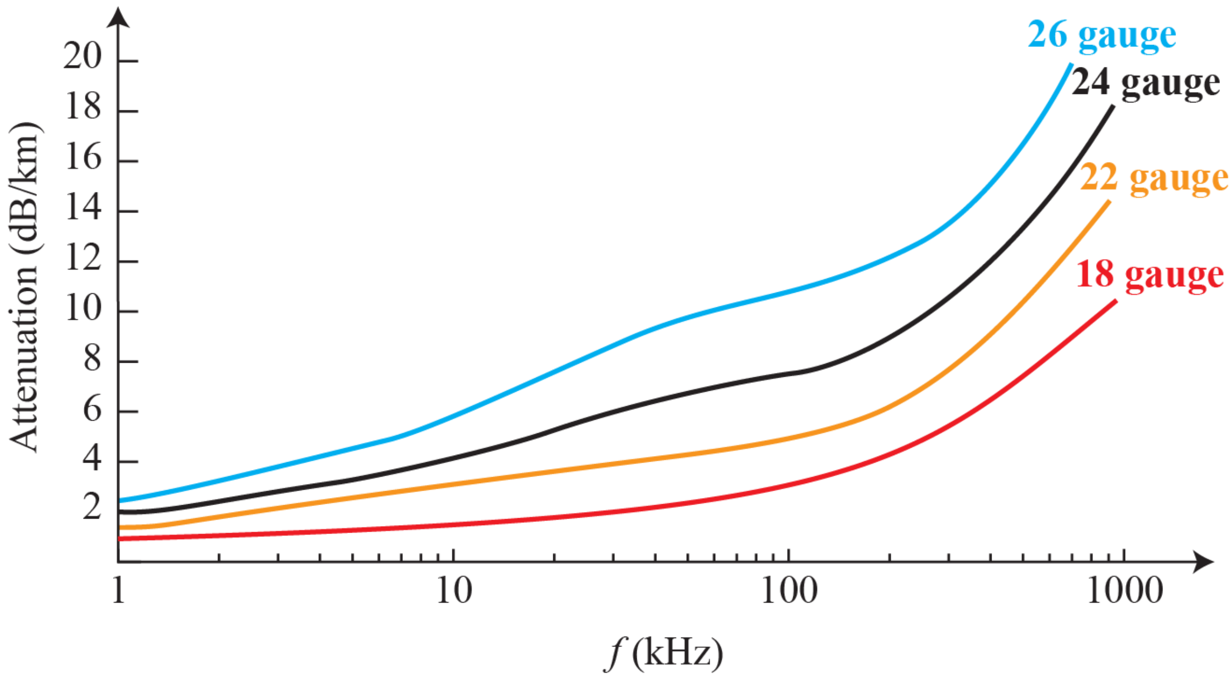
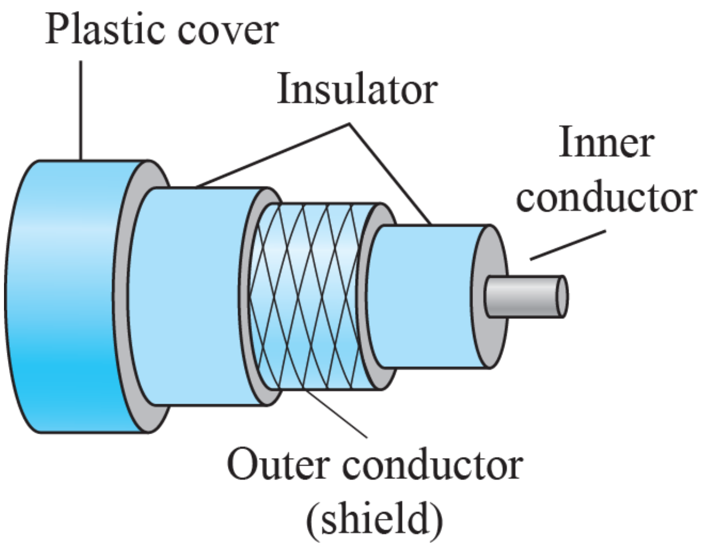


Figure 7.60: Coaxial cable



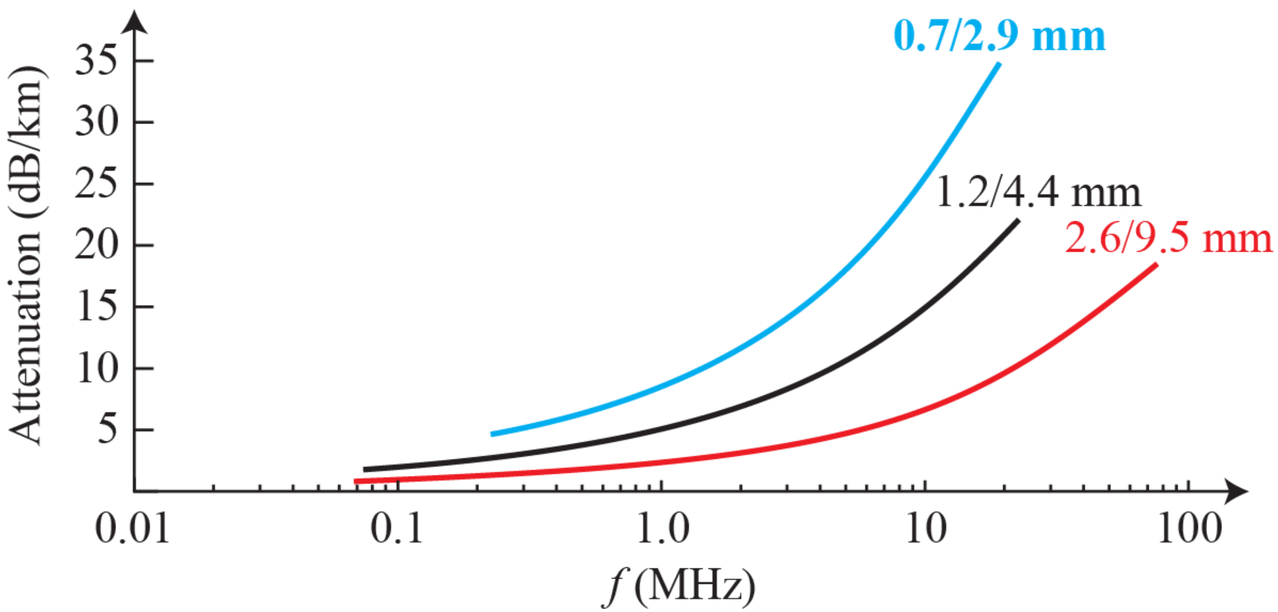


Figure 7.61: Bending of light ray

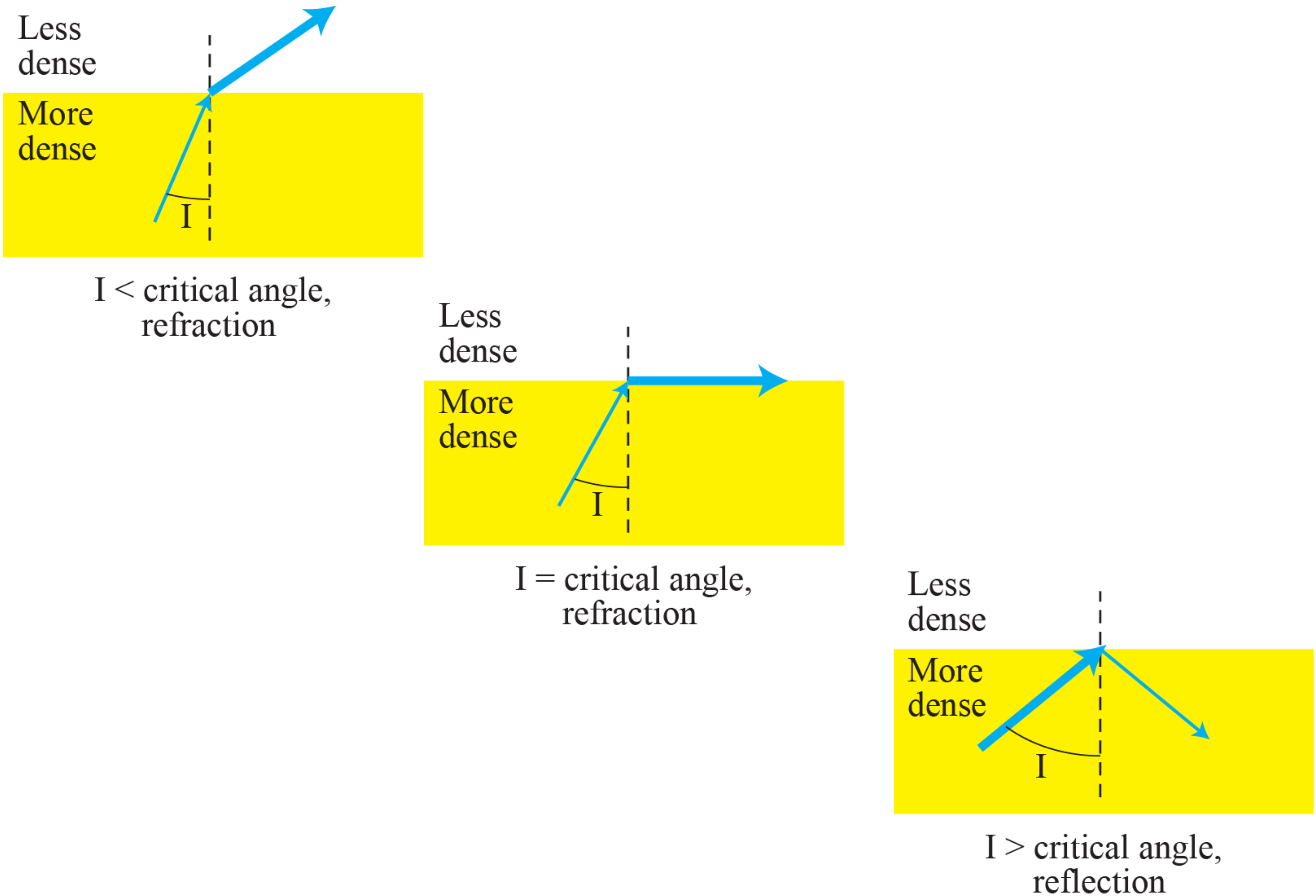


Figure 7.62: Optical fiber

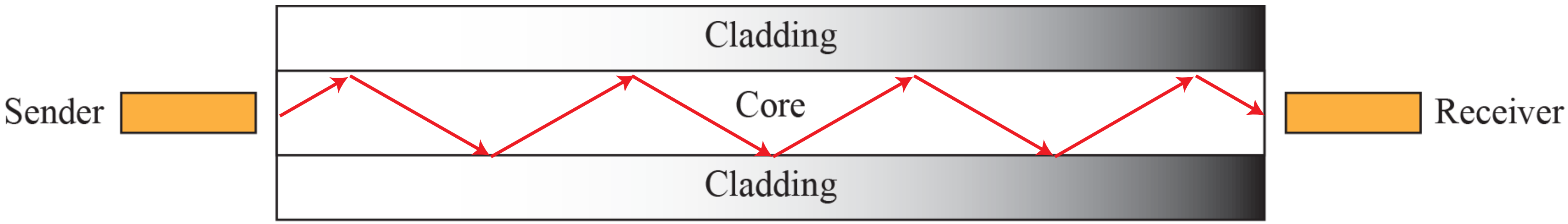
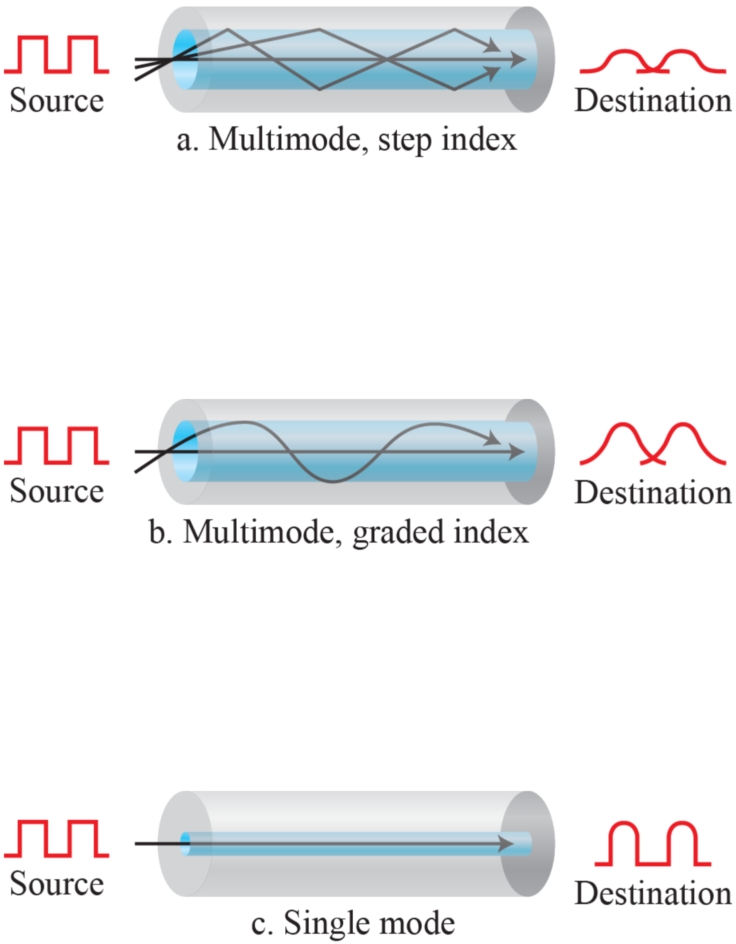
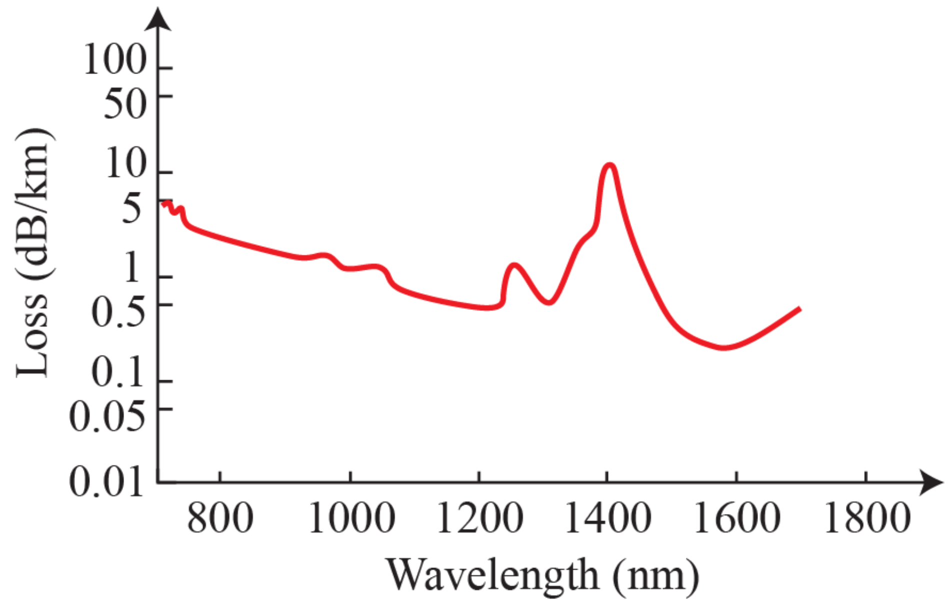


Figure 7.63: Modes





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***

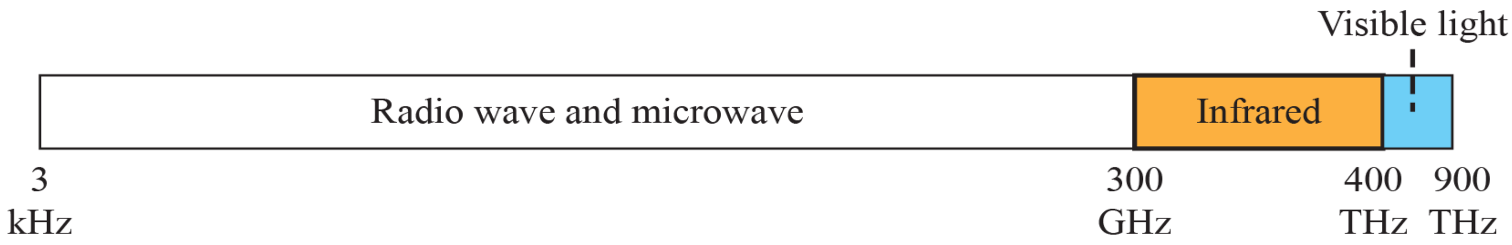


Figure 7.64: ***Electromagnetic spectrum for wireless communication***

Table 7.1: Bands

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

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 (guided and unguided media)***