Chapter 4

Digital Transmission

4-1 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.

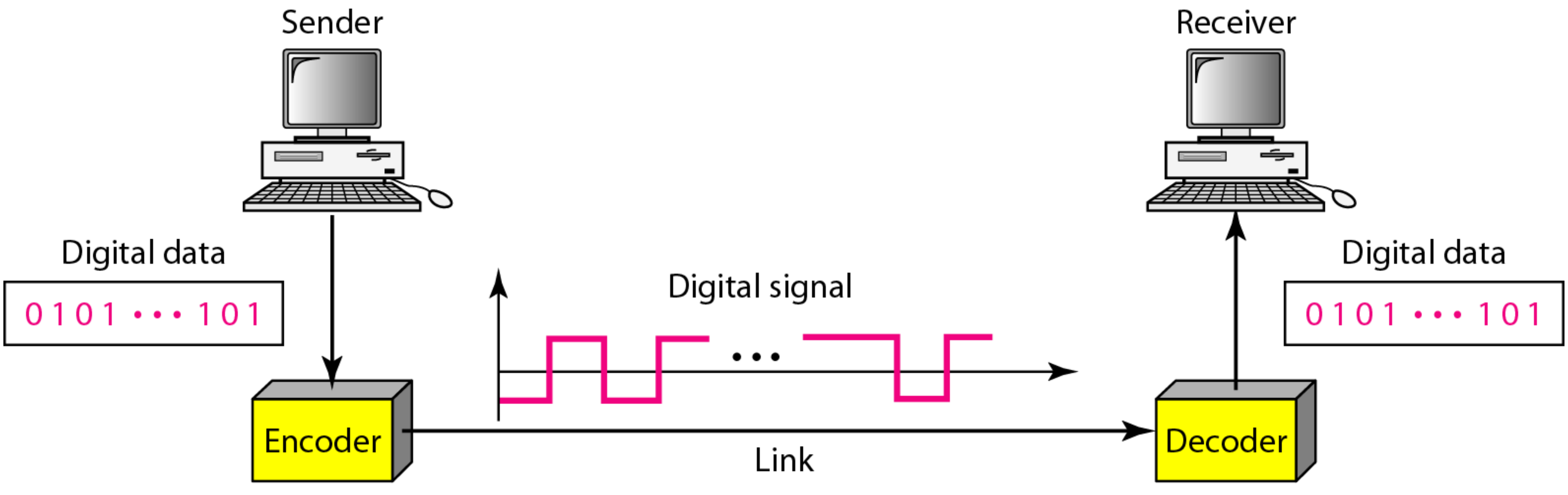
Topics discussed in this section:

Line Coding
Line Coding Schemes
Block Coding
Scrambling

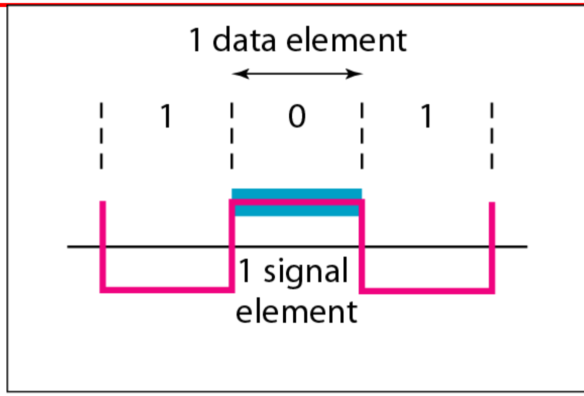
Data Elements and Signal Elements

- Data Element: Smallest entity that represent an information– a bit
- Signal Element: It is the shortest unit of digital signal
- Signals carry Data on the network
- Data Elements: We want to send
- Signal Elements: What actually moves on the wires

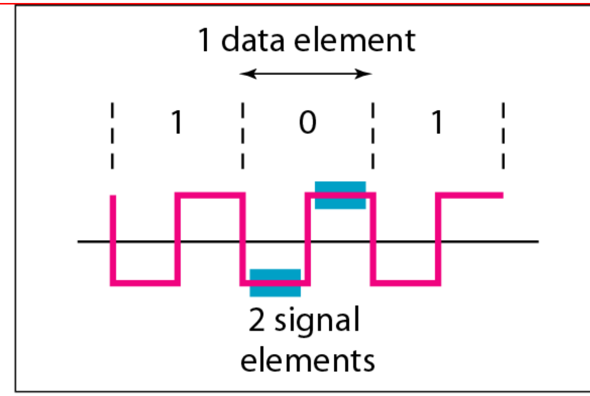
Figure 4.1 *Line coding and decoding*



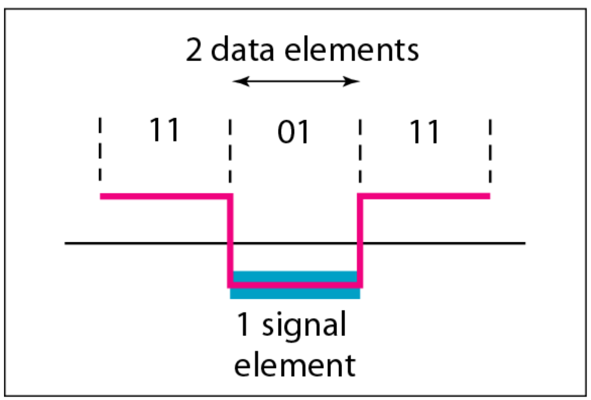
Signal element versus data element



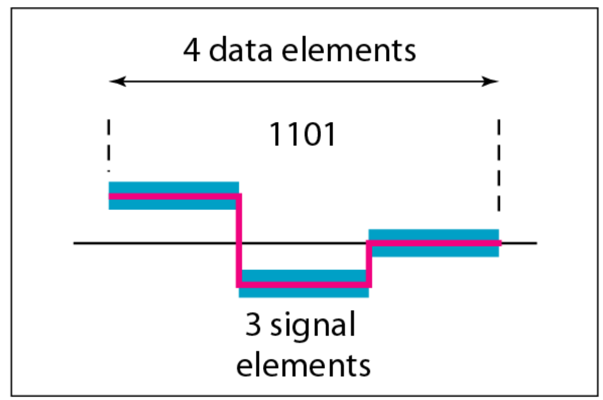
a. One data element per one signal element ($r = 1$)



b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$



c. Two data elements per one signal element ($r = 2$)



d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

r = No of Data Elements / No of Signal Elements

Digital Signals Bandwidth and Long Distance

- Required bandwidth to send a digital signal in perfect shape is infinite
- However digital signals can be sent in limited (finite) bandwidth over short distance
- Poor quality (shape) at destination when it travels beyond 100 m
- To send beyond 100m, use repeater (A switch) or use Broadband communication (convert to Analog)

Case Factor "C" in Digital Communication: No. of 1s and 0s

- **Case 0.** Our data can have all 1s 11111111 or all zero 00000000 that means no signal changes and we can send very large data in a limited bandwidth. We call this best case and define **C=0**
-
- **Case 1.** We can have data continuously changing, i.e. 10101010, worst case, that means there will be signal changes every bit. We say **C=1**

- **Case Average:** We assume data changes after every alternate bit, thus signal changes are half the number of bits. We say **C=1/2**

What is "r" in Data Communication

"r" is defined as number of bits that can be sent in each signal change

$$r = \frac{\text{No of Data Elements}}{\text{No of Signal Elements}} = \frac{\text{No of Bits Sent}}{\text{No of Signal Changes}}$$

r > 1 if more than 1 bit sent for every signal change
r = 1 if 1 bit sent for every signal change
r < 1 if less than 1 bit sent for every signal change

Example 4.1

Q. A signal is carrying data in which one data element is encoded as one signal element (r = 1). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1 (=1/2)?

Solution

We assume that the average value of c is 1/2 . The baud rate is then

$$\boxed{S = c \times N \times \frac{1}{r} = \frac{1}{2} \times 100{,}000 \times \frac{1}{1} = 50{,}000 = 50 \text{ kbaud}}$$

$$N = S \times r \times \; 1/c$$

Signal Levels vs Bits per Level

- **A signal with L levels carries $\log_2 L$ bits per level.**

- **More levels, more bits per signal change**

$N = S \times r \times 1/c = B \times r \times 1/c$

Bandwidth and Signal Rate

Larger the Bandwidth available, larger is the signal rate

Signal Rate S is measured in baud

- Bandwidth is Directly Proportional to Baud Rate.
- For higher data rate, larger bandwidth
- **Also more the number of levels, more bits carried per level**
- To get higher data rate, we make less signal changes by increasing the number of levels

Example 4.2

The maximum data rate of a channel is $N_{max} = 2 \times B \times \log_2 L$ (defined by the Nyquist formula).

Calculate N for C=1/2

Solution

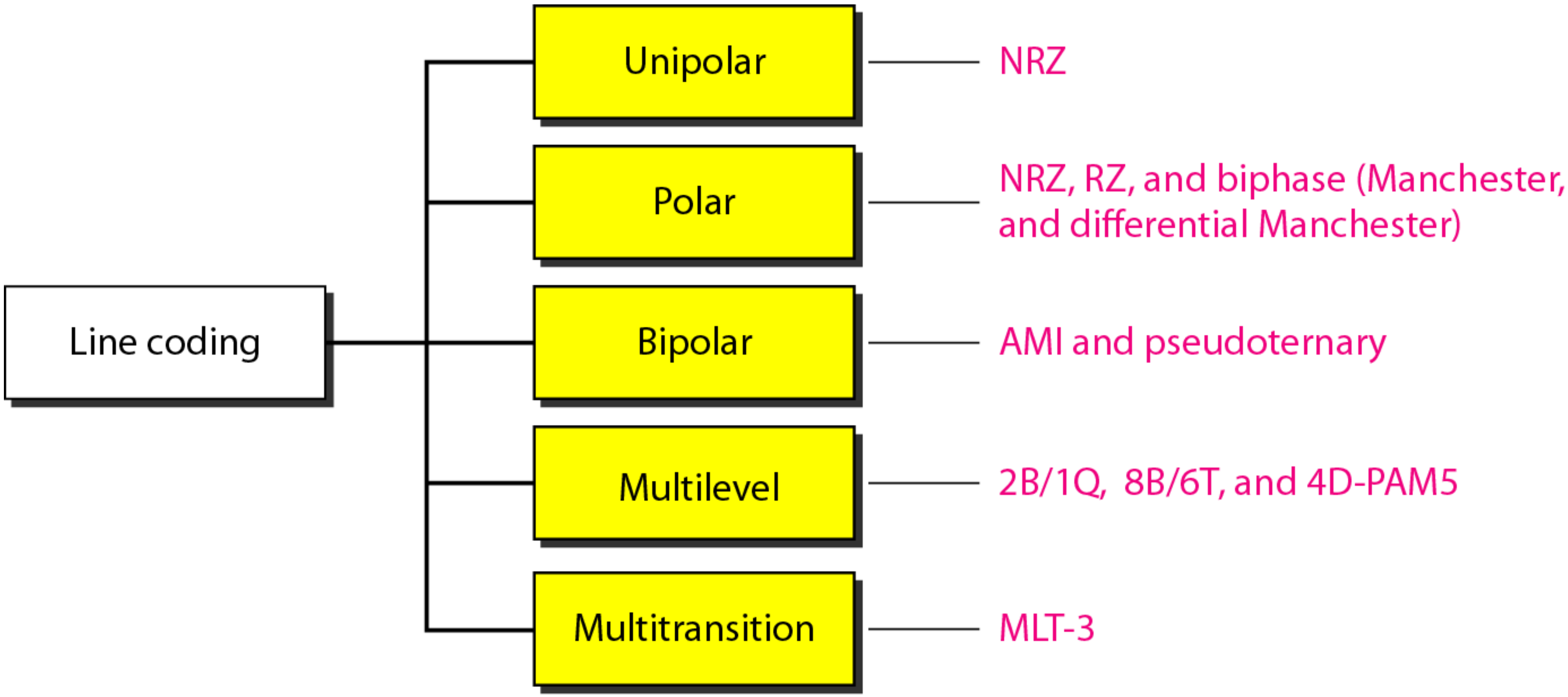
- *A signal with L levels actually can carry $\log_2 L$ bits per level.*
- *Every change in level results in a signal change (signal element)*
- *When c = 1/2, then we have*

$$N_{\max} = \frac{1}{c} \times B \times r = 2 \times B \times \log_2 L$$

Line Coding

1. Line Coding is the Process of converting digital data to digital signal
2. Data Could be Text, Numbers, Graphical Images, audio or video stored in memory as bits
3. At the sender the digital data is coded into digital signals
4. At the receiver the digital signals are decoded into digital data
5. There are lots of coding schemes, each one having very special characteristics and allow its use in very special situations

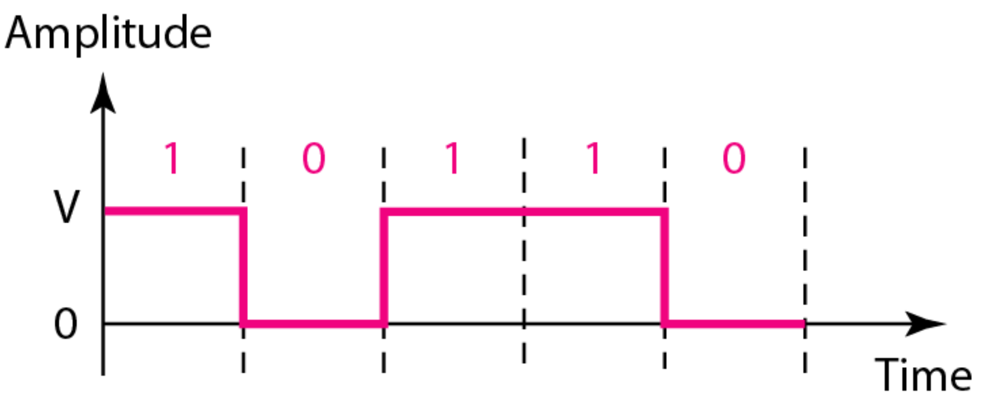
Line coding schemes



Characteristics of Line Coding Schemes

1. Relationship between Data Rate and Signal Rate
2. Bandwidth
3. Baseline Wandering
4. DC Component
5. Self Synchronization
6. Built-in Error Detection
7. Immunity to Noise and Interference
8. Complexity

Figure 4.5 *Unipolar NRZ scheme*

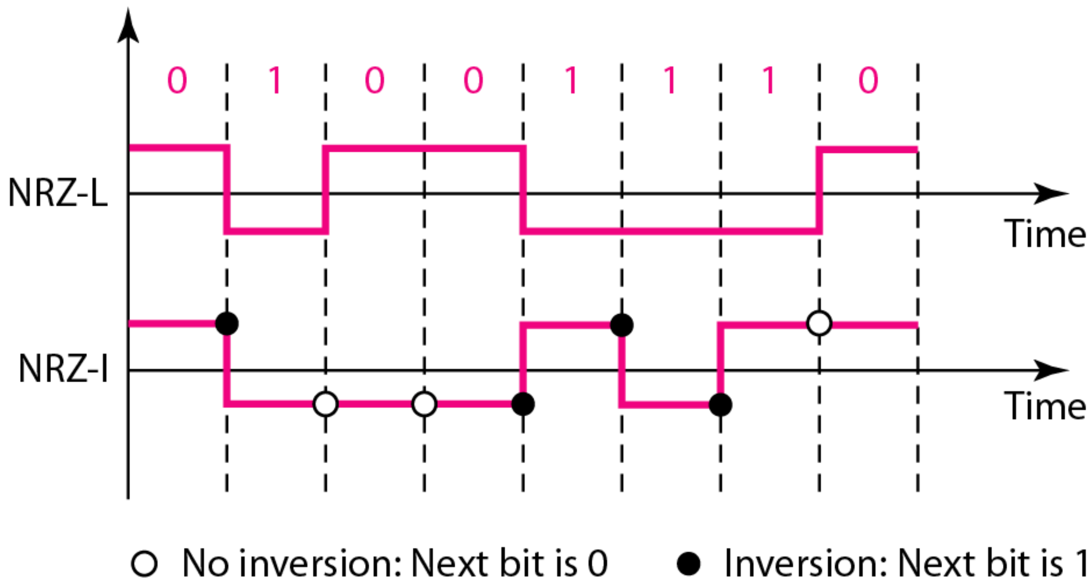


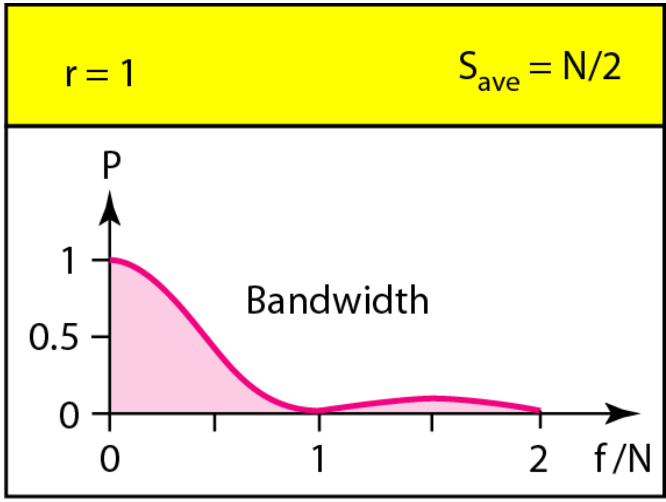
$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

Polar

NRZ-L and NRZ-I schemes





1. In NRZ-L the level of the voltage determines the value of the bit.
2. In NRZ-I the inversion or the lack of inversion determines the value of the bit.

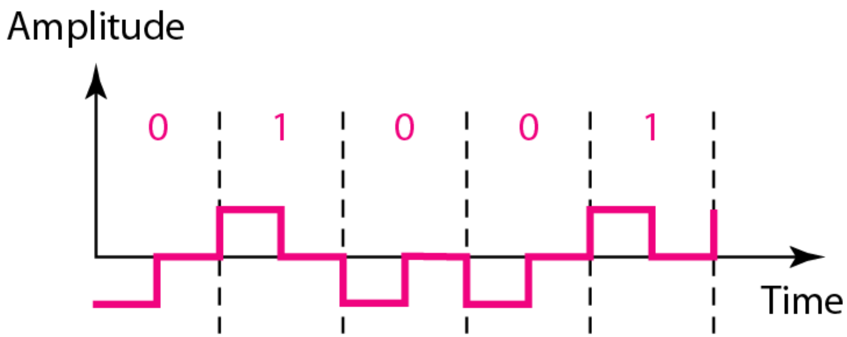
Example 4.4

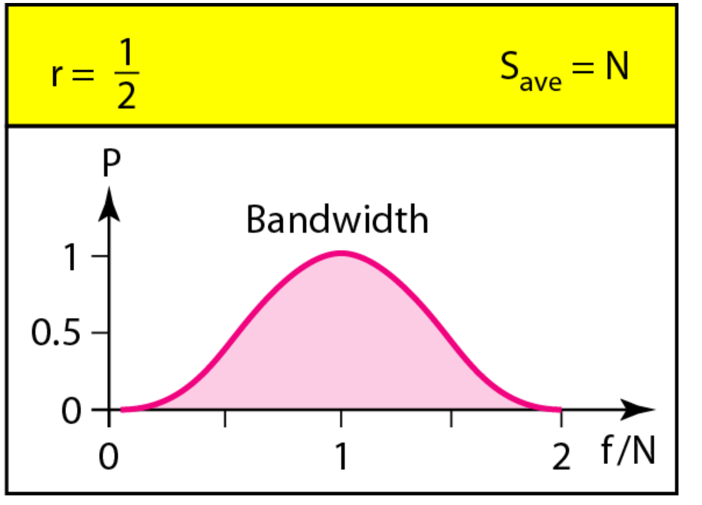
A system is using NRZ-I to transfer 1-Mbps data. What are the average signal rate and minimum required bandwidth? (In book it is written 10 Mbps by mistake)

Solution

The average signal rate is $S = N/2 = 500$ kbaud. The minimum bandwidth for this average baud rate is $B_{min} = S = 500$ kHz.

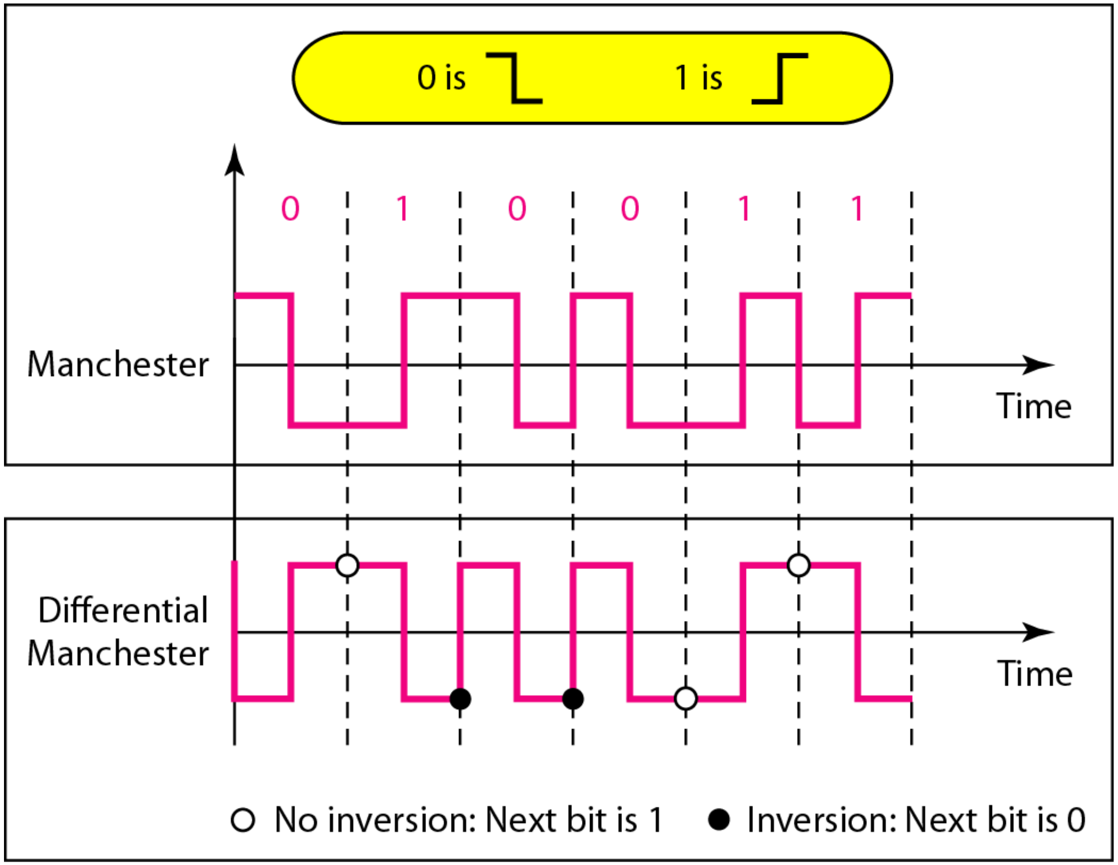
Polar RZ scheme

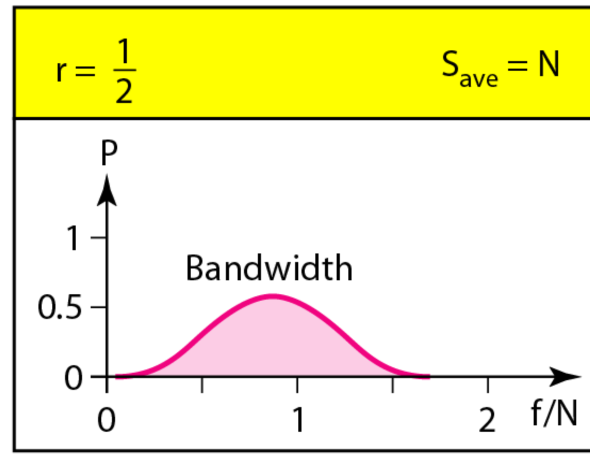




Polar

Manchester and differential Manchester schemes



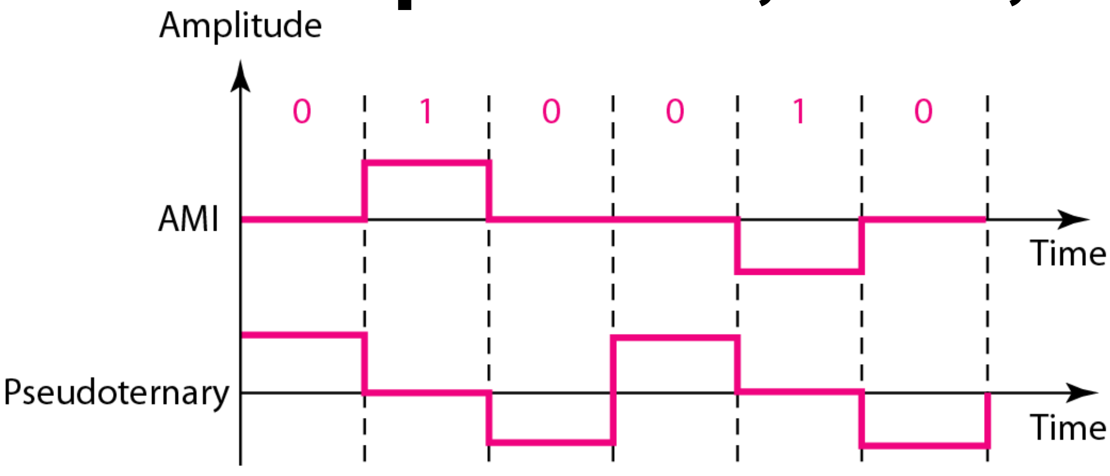


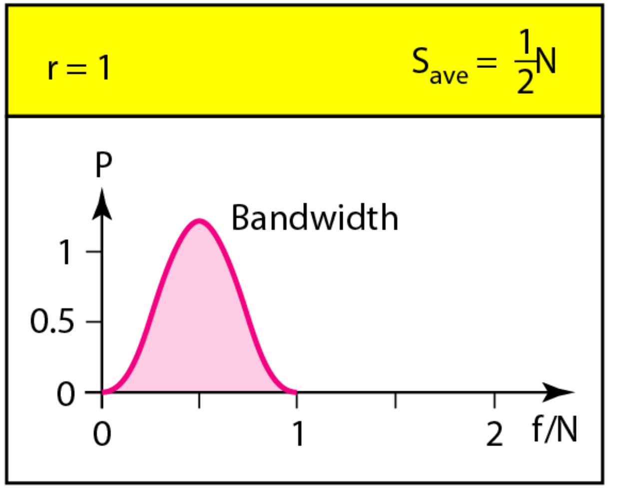
In Manchester and differential Manchester encoding, the change at the middle of the bit results in good synchronization. Also has no DC Component Problem

Bipolar schemes

AMI and Pseudoternary

In bipolar encoding, we use three levels: positive, zero, and negative.





Note

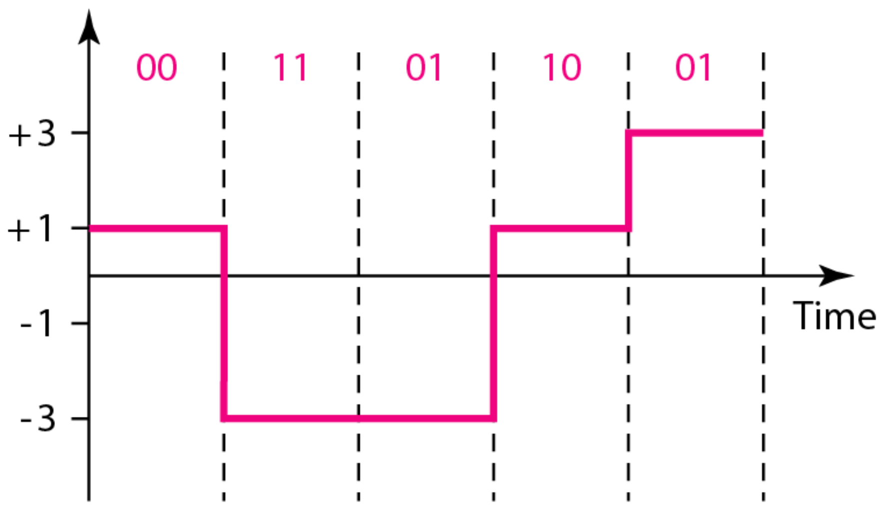
In *m*B*n*L schemes, a pattern of *m* data elements is encoded as a pattern of *n* signal elements in which $2^m \leq L^n$.

Multilevel Schemes: 2B1Q

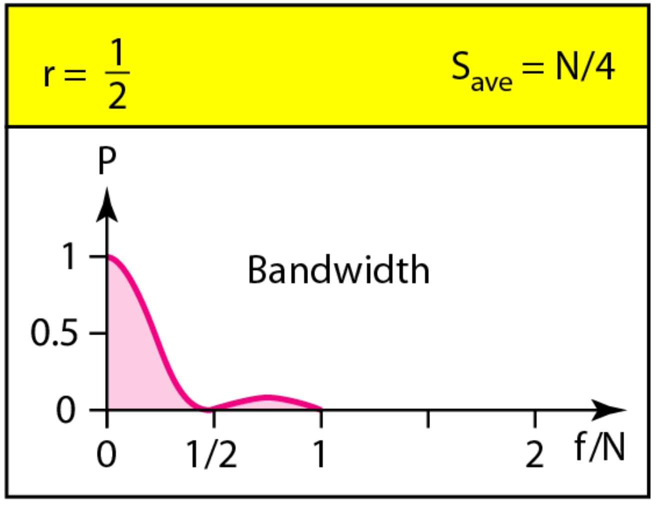
2B1Q: Two Binary, One Quaternary (Two bits one level)

	Previous level: positive	Previous level: negative
Next bits	Next level	Next level
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

Transition table

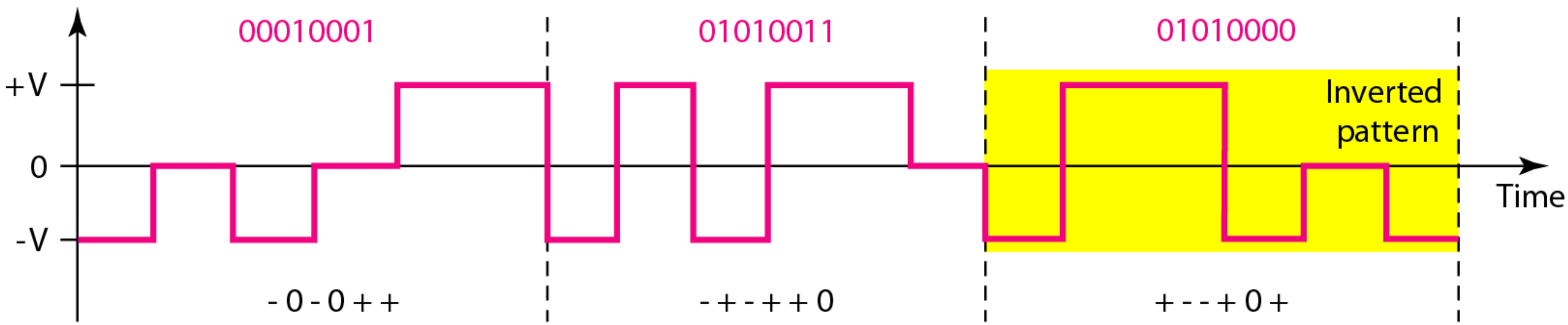


Assuming positive original level

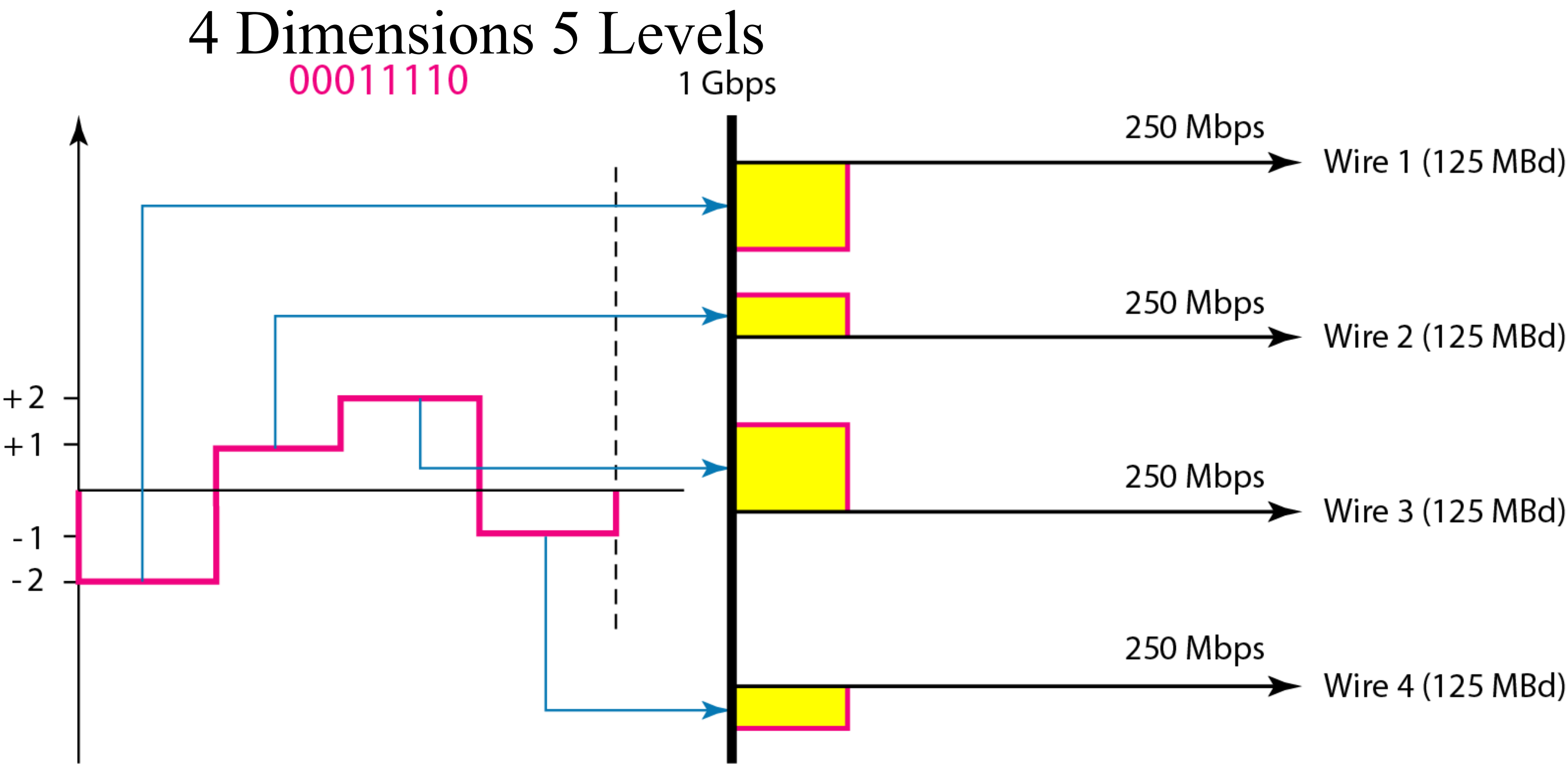


Multilevel Scheme : 8B6T

8B6T: 8 binary 6 Transitions



Multilevel: 4D-PAM5 scheme



Ethernet Coding Schemes

Ethernets use 10Base5, 10Base2, 10BaseT, 100BaseTX, 1000BaseT formats, they don’t use any carrier, but use baseband signaling, i.e. use signals with discrete values to encode either the **individual bits** or **groups of bits**.

1Gbps Ethernet uses 8B/10B code

100Mbps is using 4B/5B code.

10Mbps version (No more in use) did not use block coding

Ethernet

- The most commonly installed Ethernet systems are called 100 BASE-T .
- "BASE-T" means the systems use twisted-pair cabling), provide transmission speeds up to 100 mbps
- Gigabit Ethernet provides speeds of 1000 Mbps (1gbps)
- 10 GbE 10-Gigabit Ethernet, provides up to 10 Gbps.
- 100 BASE-T mostly for the connection of end-user computers, printers
- 1000 BASE-T for servers and Storage Area Networks SAN
- Higher speeds for network-backbone segments.
- Higher speeds are constantly under development for

4-2 ANALOG-TO-DIGITAL CONVERSION

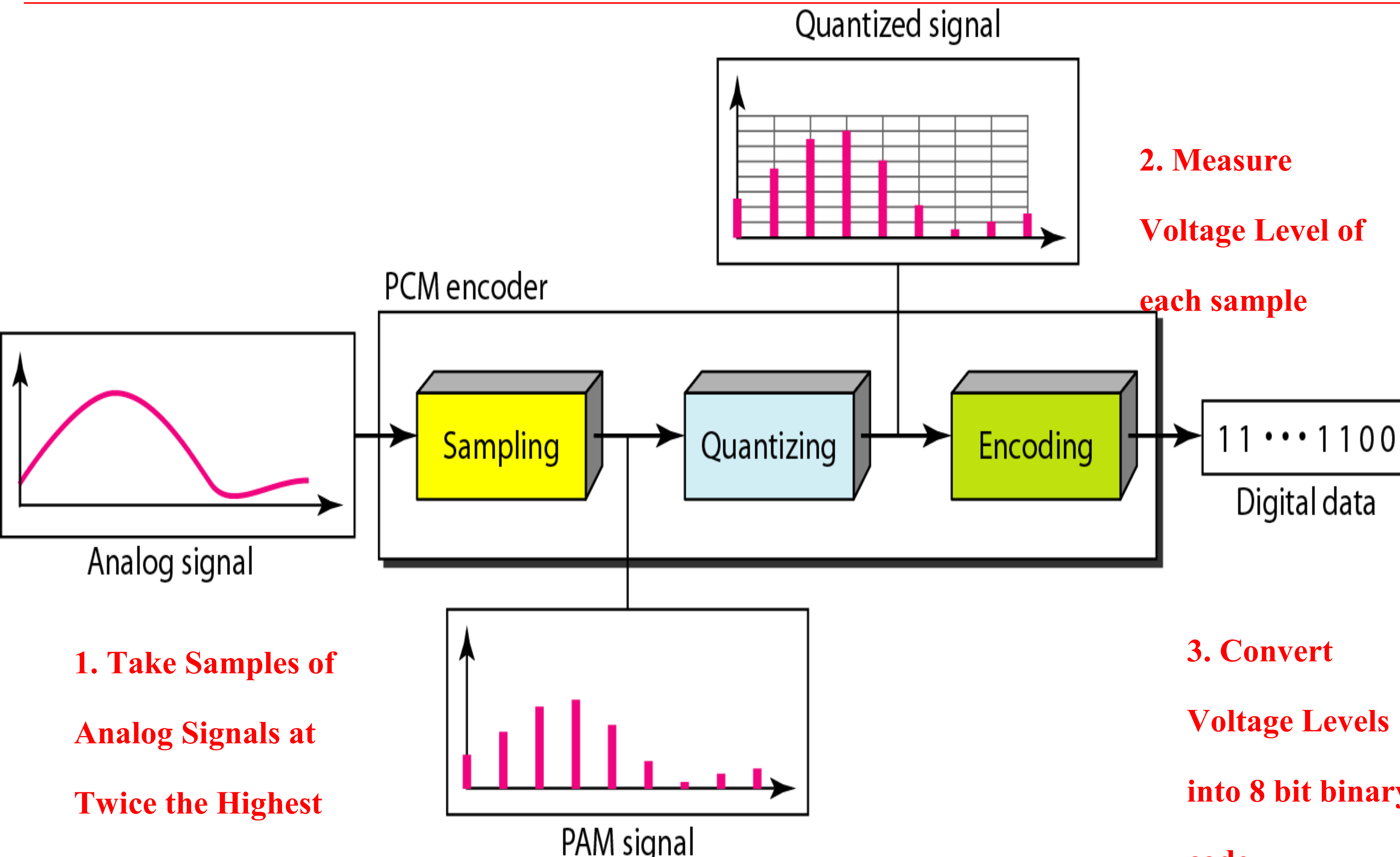
Transmission of digital signal is superior to an analog signal for quality transmission and better bandwidth utilization.

Thus changing an analog signal to digital data and then transmitting offers value

Two techniques used for converting Analog to Digital

1. **Pulse Code Modulation (PCM)**
2. **Delta Modulation (DM)**

Three Stages of PCM Encoder



2. Measure Voltage Level of each sample

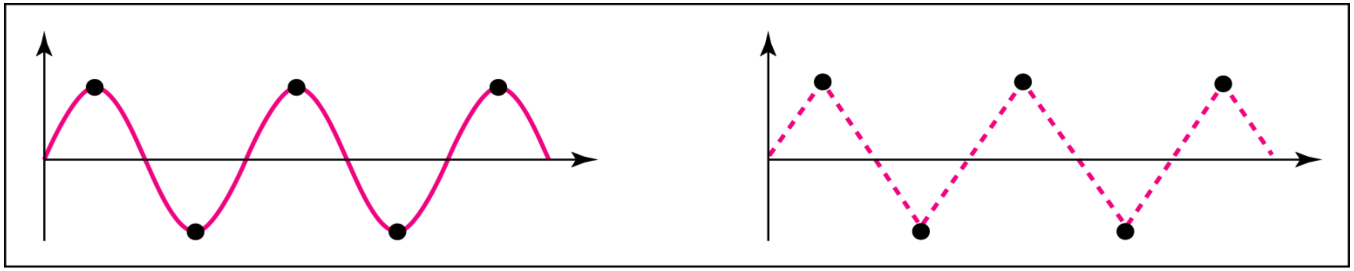
1. Take Samples of Analog Signals at Twice the Highest

3. Convert Voltage Levels into 8 bit binary code

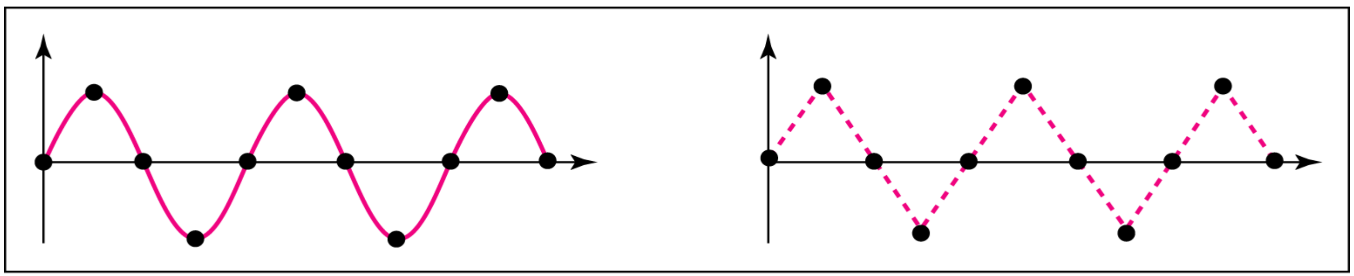
Note

According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.

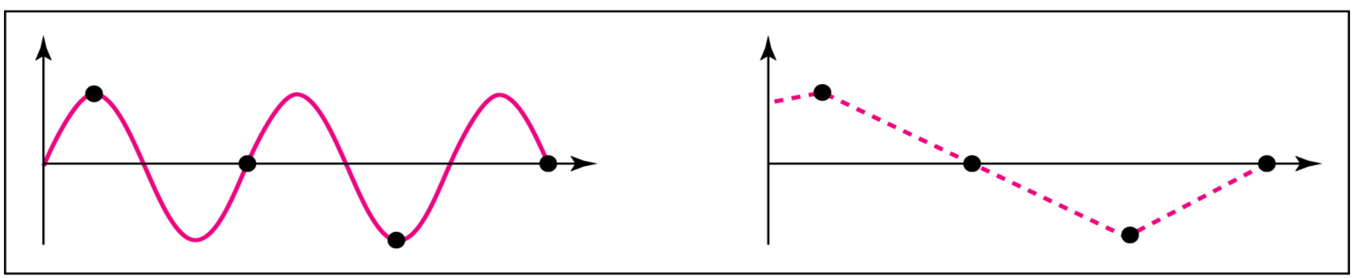
Figure 4.24 *Recovery of a sampled sine wave for different sampling rates*



a. Nyquist rate sampling: $f_s = 2f$



b. Oversampling: $f_s = 4f$



c. Undersampling: $f_s = f$

Example 4.9

Telephone companies digitize voice by assuming a maximum frequency of 4000 Hz. The sampling rate therefore is 8000 samples per second.

Example 4.10

A complex low-pass signal has a bandwidth of 200 kHz. What is the minimum sampling rate for this signal?

Solution

The bandwidth of a low-pass signal is between 0 and f, where f is the maximum frequency in the signal. Therefore, we can sample this signal at 2 times the highest frequency (200 kHz). The sampling rate is therefore 400,000 samples per second.

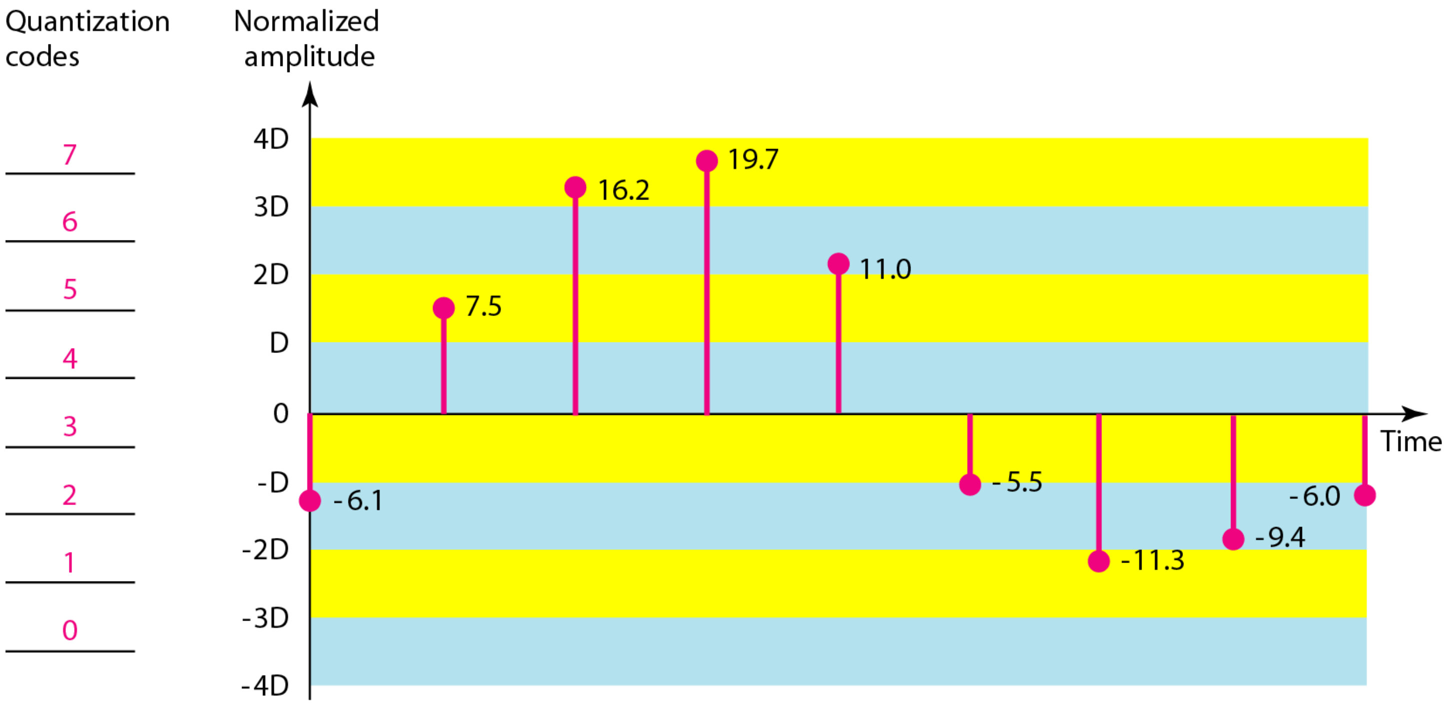
Example 4.11

A complex bandpass signal has a bandwidth of 200 kHz. What is the minimum sampling rate for this signal?

Solution

We cannot find the minimum sampling rate in this case because we do not know where the bandwidth starts or ends. We do not know the maximum frequency in the signal.

Quantization and encoding of a sampled signal using 8 Levels (3Bits)



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	-0.38	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

Example 4.14

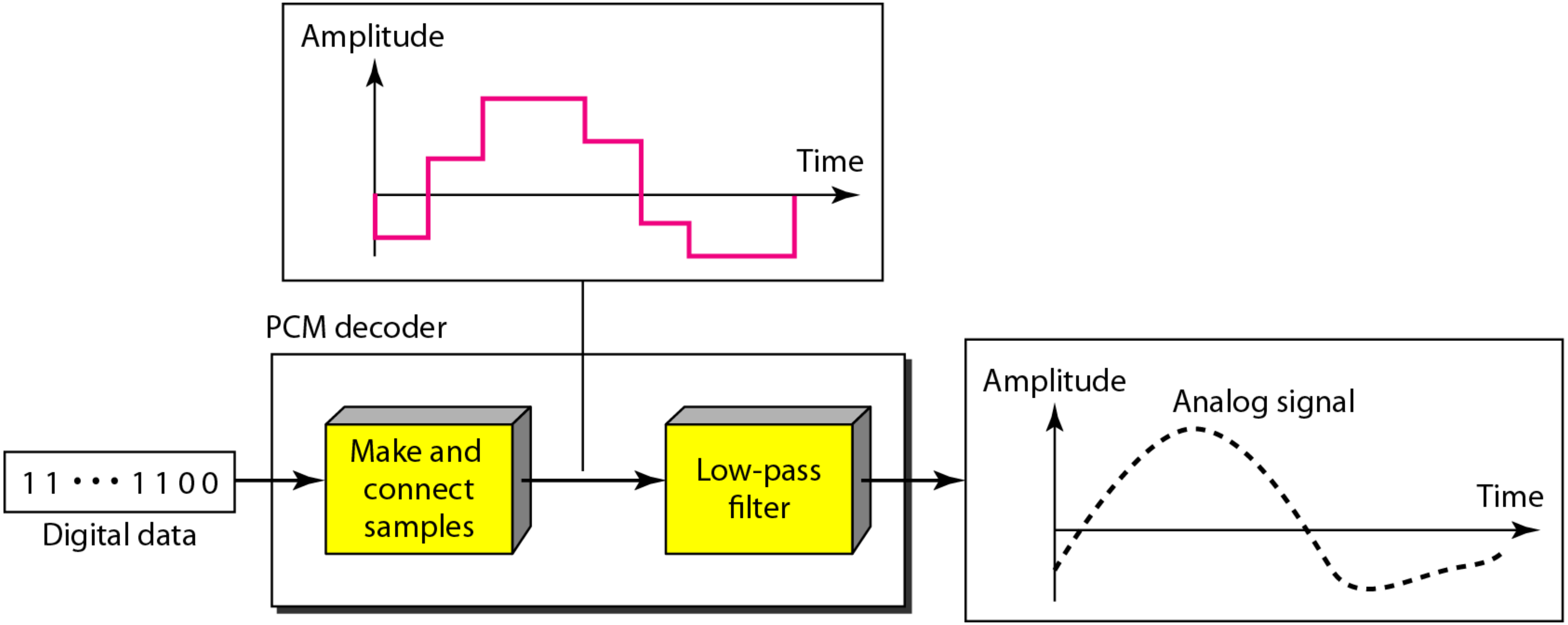
We want to digitize the human voice. What is the bit rate, assuming 256 Levels, 8 bits per sample?

Solution

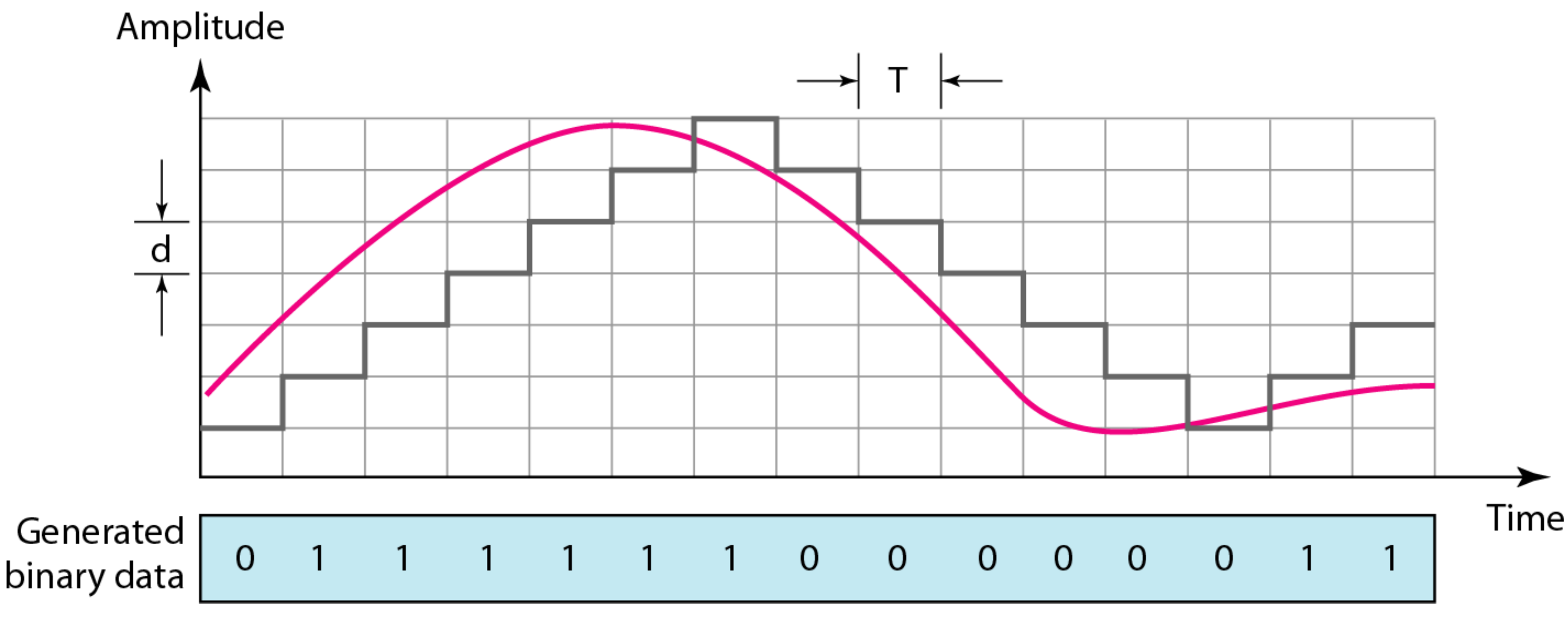
The human voice normally contains frequencies from 0 to 4000 Hz. So the sampling rate and bit rate are calculated as follows:

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

Components of a PCM decoder



Delta Modulation



Example 4.15

We have a low-pass analog signal of 4 kHz. If we send the analog signal, we need a channel with a minimum bandwidth of 4 kHz. If we digitize the signal and send 8 bits per sample, we need a channel with a minimum bandwidth of 8 × 4 kHz = 32 kHz.

Figure 4.29 *Delta modulation components*

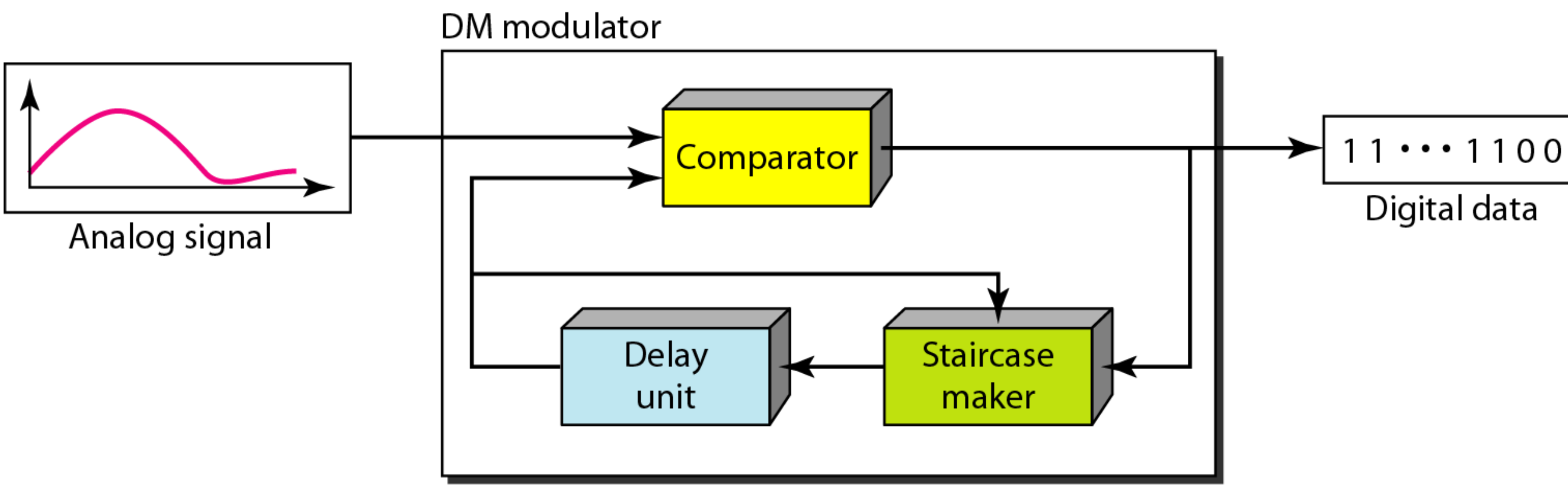
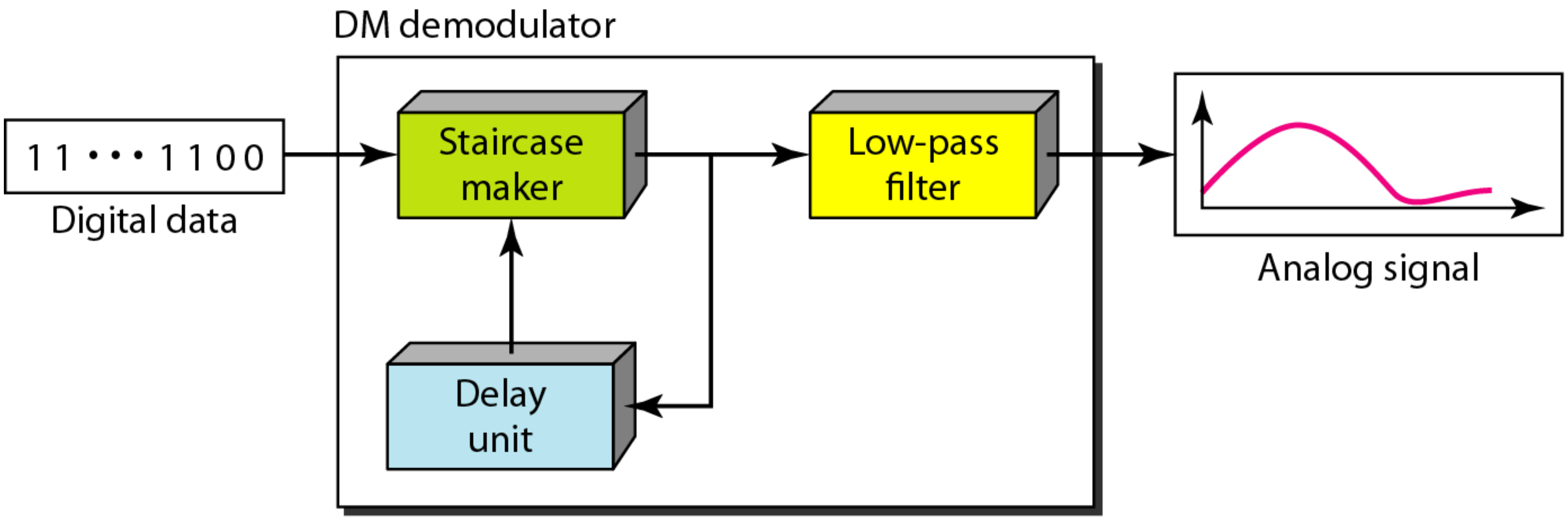


Figure 4.30 *Delta demodulation components*



4-3 TRANSMISSION MODES

Data across a link can be sent either parallel or serial mode.

In parallel mode, multiple bits are sent on multiple wires in parallel.

In serial mode, bits sent one after the other, There are three types of serial transmission:

1. ***Asynchronous***
2. ***Synchronous***
3. ***Isochronous.***

Figure 4.31 *Data transmission and modes*

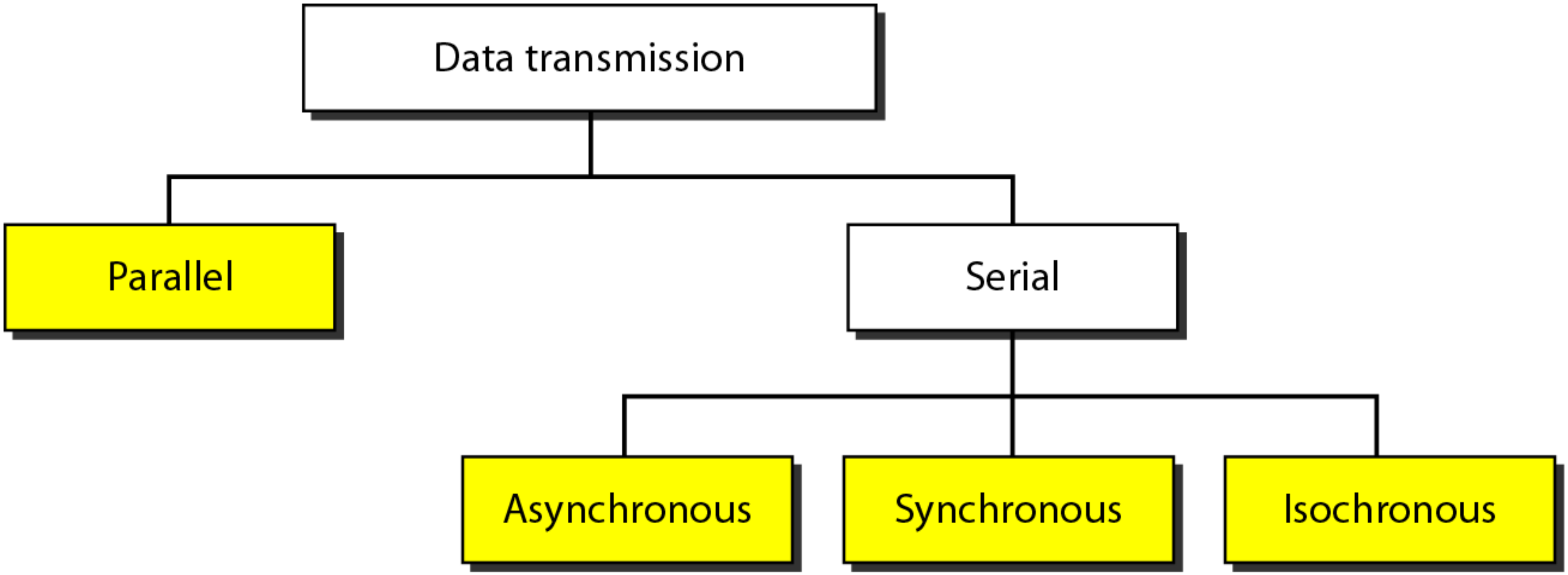


Figure 4.32 *Parallel transmission*

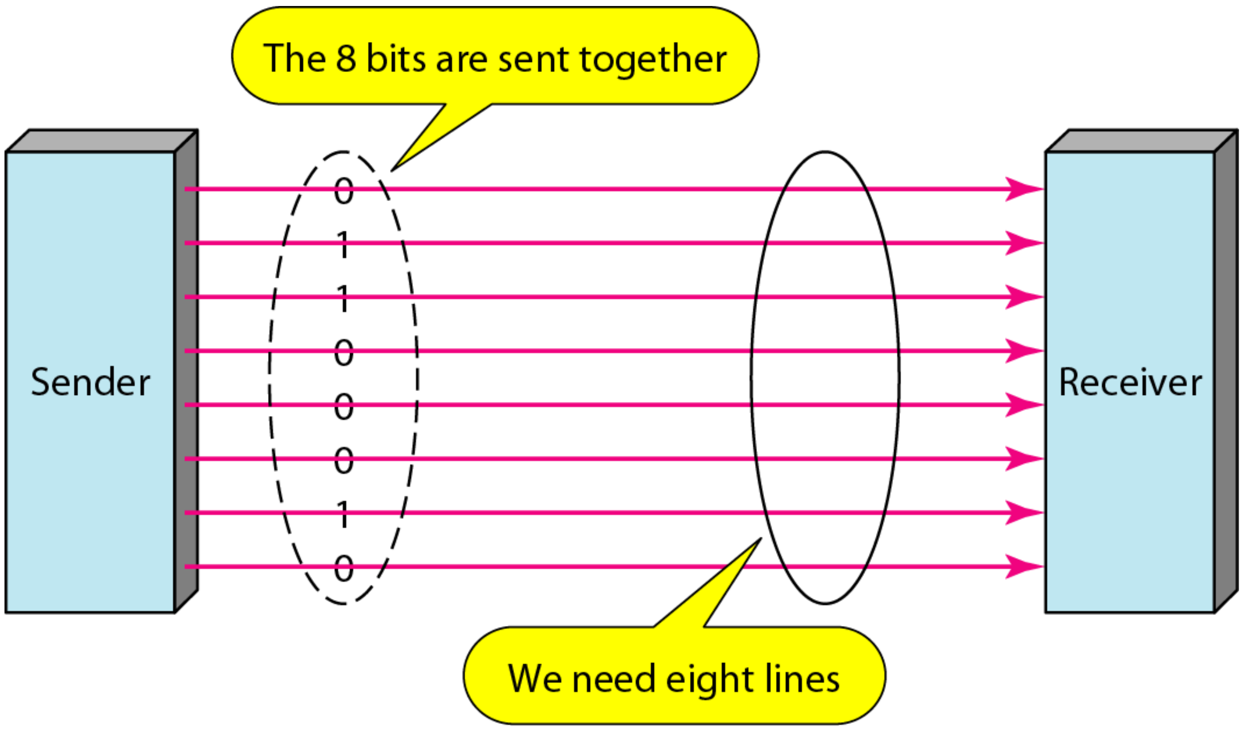
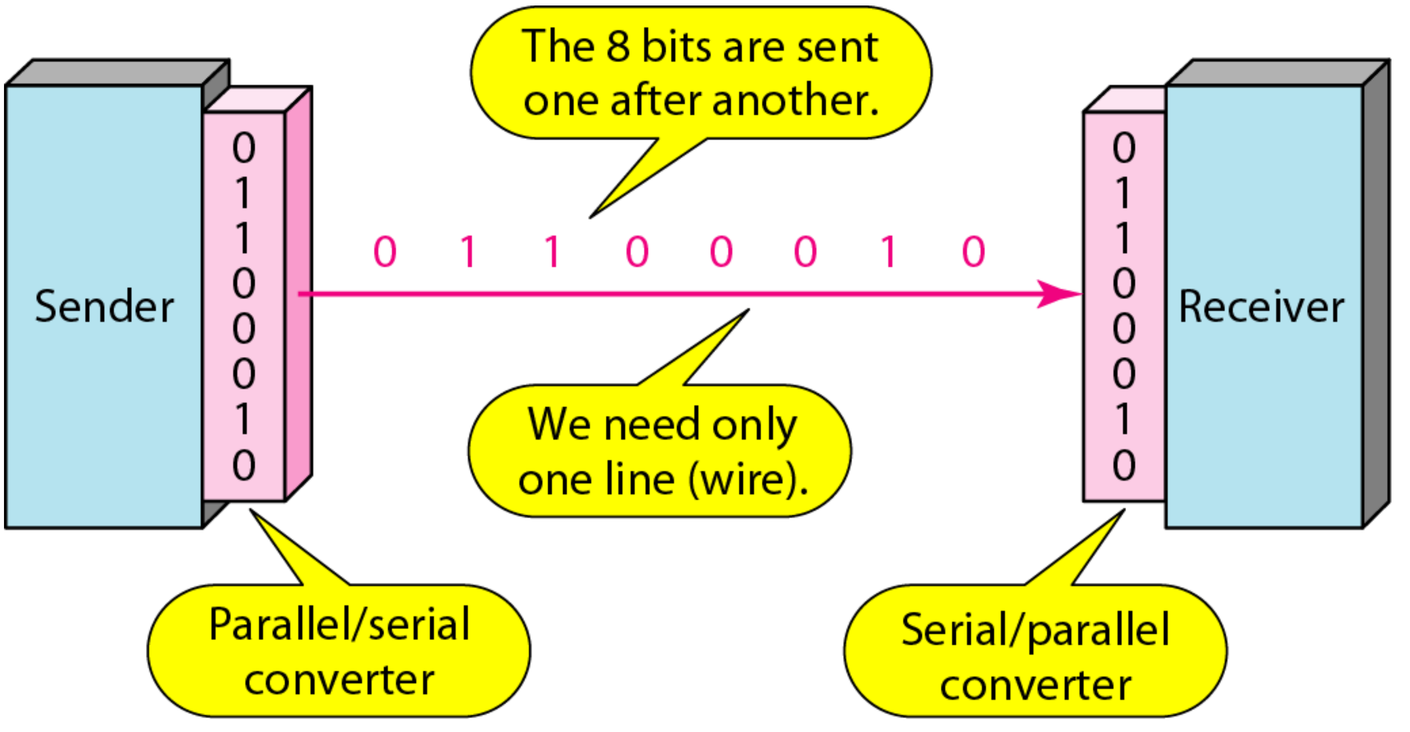
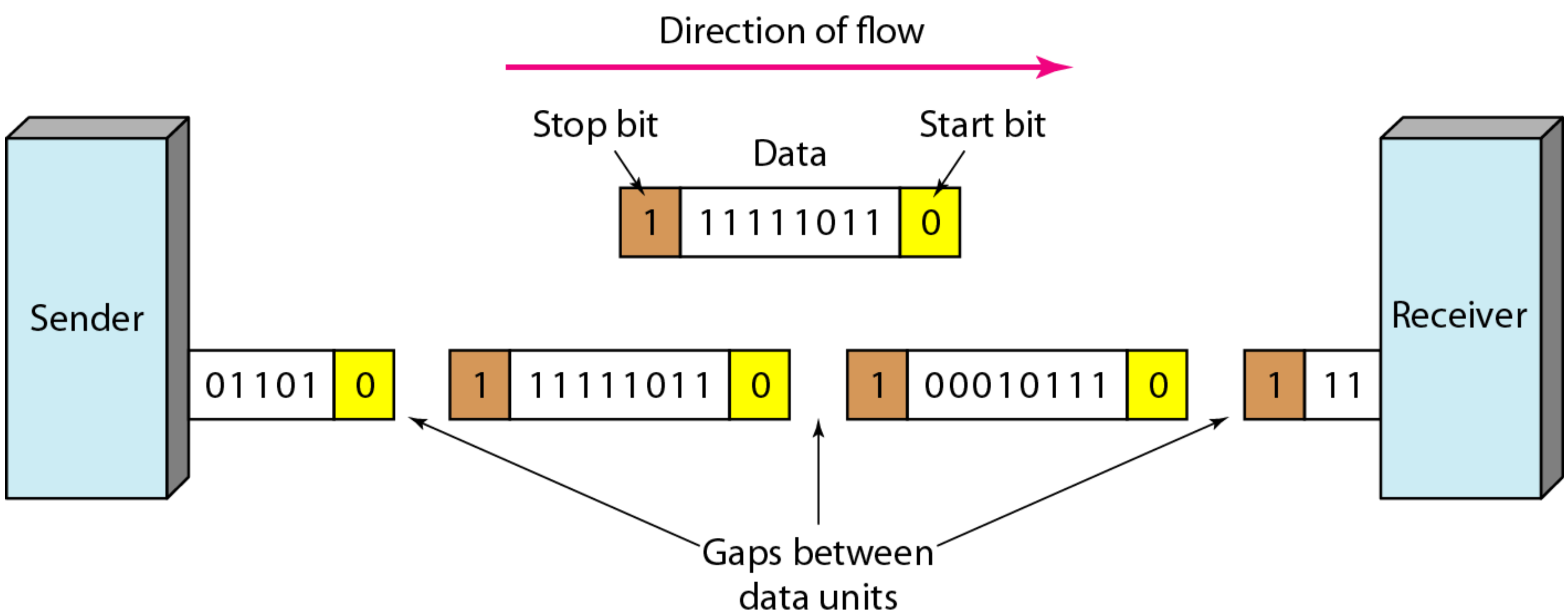


Figure 4.33 *Serial transmission*



Asynchronous Transmission

(Receiver synchronizes on Start and Stop Bits)

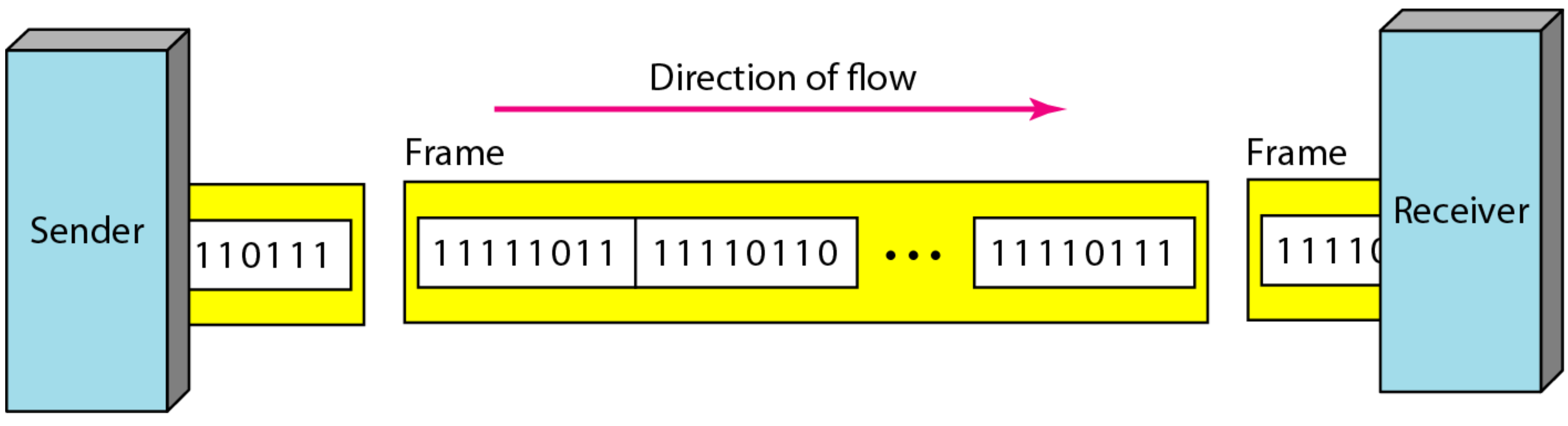


Synchronous Transmission

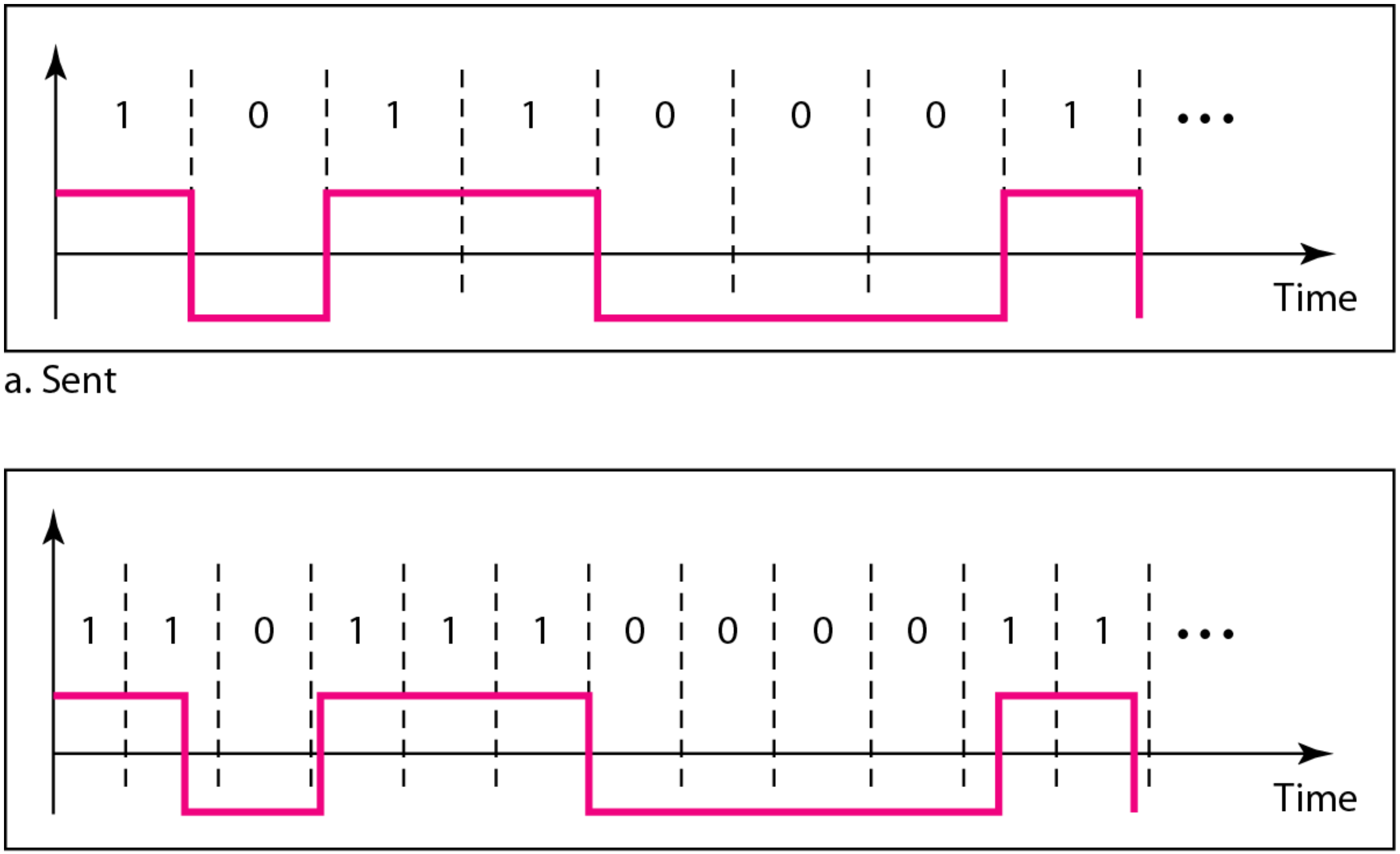
In synchronous transmission, we send bits one after another without ***start or stop bits or gaps***.

It is the responsibility of the receiver to group the bits.

Synchronous Transmission



Effect of Non Synchronization



a. Sent

b. Received

Example 4.3

In a digital transmission, the receiver clock is 0.1 percent faster than the sender clock. How many extra bits per second does the receiver receive if the data rate is 1 kbps? How many if the data rate is 1 Mbps?

Solution

At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

1000 bits sent	1001 bits received	1 extra bps

At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

1,000,000 bits sent	1,001,000 bits received	1000 extra bps

Typical Structure of Data Packets

Destination Address | Sender Address | Packet number | Total Packets | Data size | Data | Error Control Bits