Digital Transmission

DIGITAL-TO-DIGITAL CONVERSION

-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.

Line Coding

-Line coding is the process of converting digital data to digital signals.

- We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits

- Line coding converts a sequence of bits to a digital signal.

- At the sender, digital data are encoded into a digital signal; at the receiver, the digital data are recreated by decoding the digital signal. Figure 4.1 shows the process.

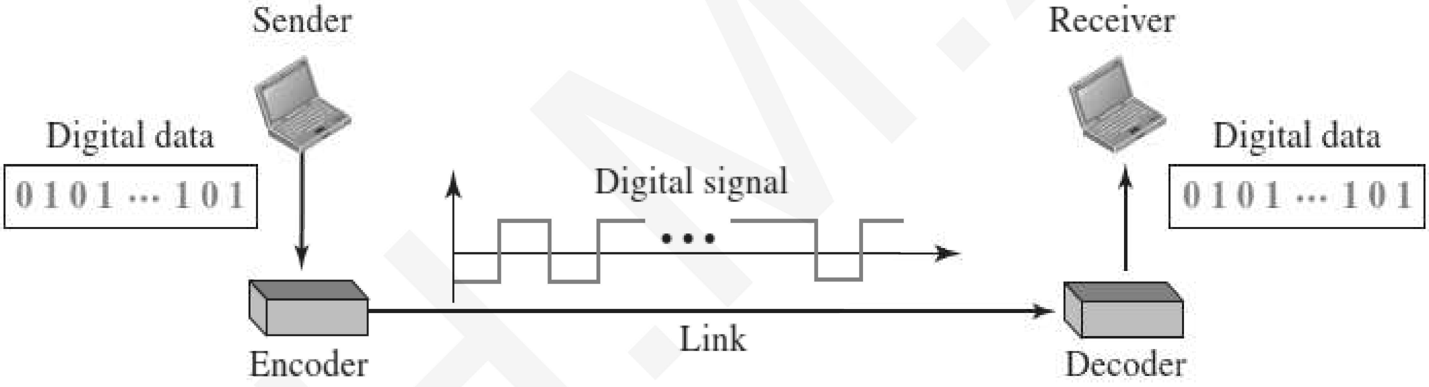


Figure 4.1 Line coding and decoding

Characteristics

Before discussing different line coding schemes, we address their common characteristics.

Signal Element Versus Data Element

- In data communications, our goal is to send data elements.

- A data element is the smallest entity that can represent a piece of information: this is the bit.

- In digital data communications, a signal element carries data elements.

- A signal element is the shortest unit (timewise) of a digital signal.

- In other words, data elements are what we need to send; signal elements are what we can send. Data elements are being carried; signal elements are the carriers.

- We define a ratio r which is the number of data elements carried by each signal element. Figure 4.2 shows several situations with different values of r.

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 $\left(r = \frac{4}{3}\right)$

Figure 4.2 Signal element versus data element

Data Rate Versus Signal Rate

- The data rate defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps).

-The signal rate is the number of signal elements sent in 1s. The unit is the baud.

- The data rate is sometimes called the bit rate; the signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.

- One goal in data communications is to increase the data rate while decreasing the signal rate. Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement.

- We can formulate the relationship between data rate and signal rate as

$S_{ave} = c \times N \times (1/r)$ baud where N is the data rate (bps); c is the case factor, which varies for each case; S is the number of signal elements per second; and r is the previously defined factor.

Example

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?

Solution

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

$S = c \times N \times 1/r = \frac{1}{2} \times 100,000 \times 1 = 50,000 = 50$ Kbaud

Line Coding Schemes

We can roughly divide line coding schemes into five broad categories, as shown in Figure 4.4. There are several schemes in each category.

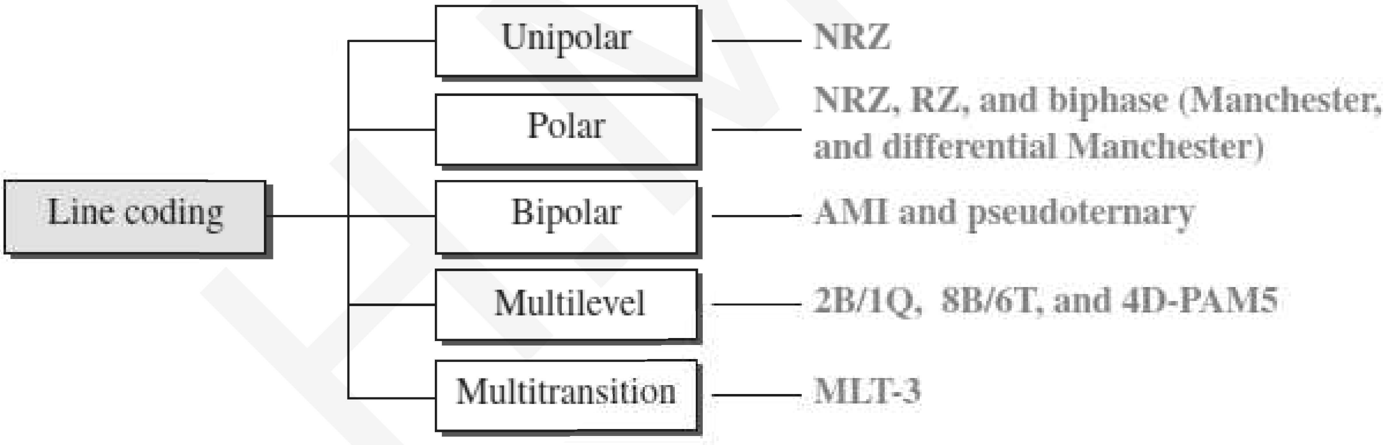


Figure 4.4 Line coding schemes

Unipolar Scheme

-In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.

NRZ (Non-Return-to-Zero)

Traditionally, a unipolar scheme was designed as a non-return-to-zero (NRZ) scheme in which the positive voltage defines bit 1 and the zero voltage defines bit 0. It is called NRZ because the signal does not return to zero at the middle of the bit. Figure 4.5 shows a unipolar NRZ scheme.

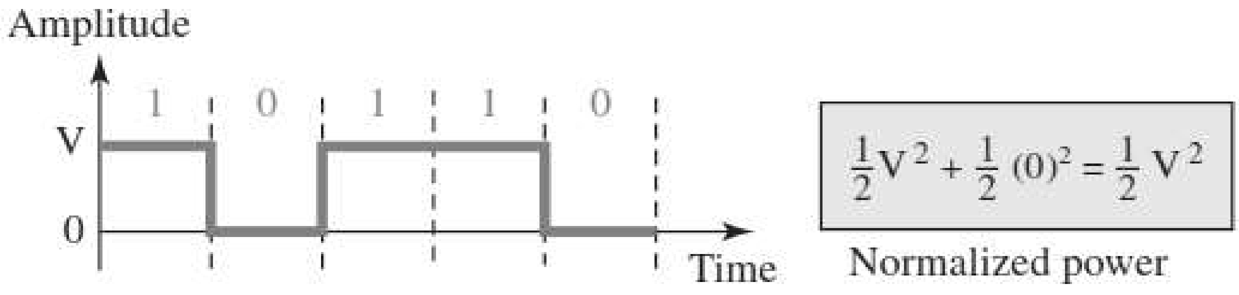


Figure 4.5 Unipolar NRZ scheme

Polar Schemes

In polar schemes, the voltages are on both sides of the time axis. For example, the voltage level for 0 can be positive and the voltage level for 1 can be negative.

Non-Return-to-Zero (NRZ)

In polar NRZ encoding, we use two levels of voltage amplitude. We can have two versions of polar NRZ: NRZ-L and NRZ-I, as shown in Figure 4.6. The figure also shows the value of r, the average baud rate, and the bandwidth.

-In the first variation, NRZ-L (NRZ-Level), the level of the voltage determines the value of the bit.

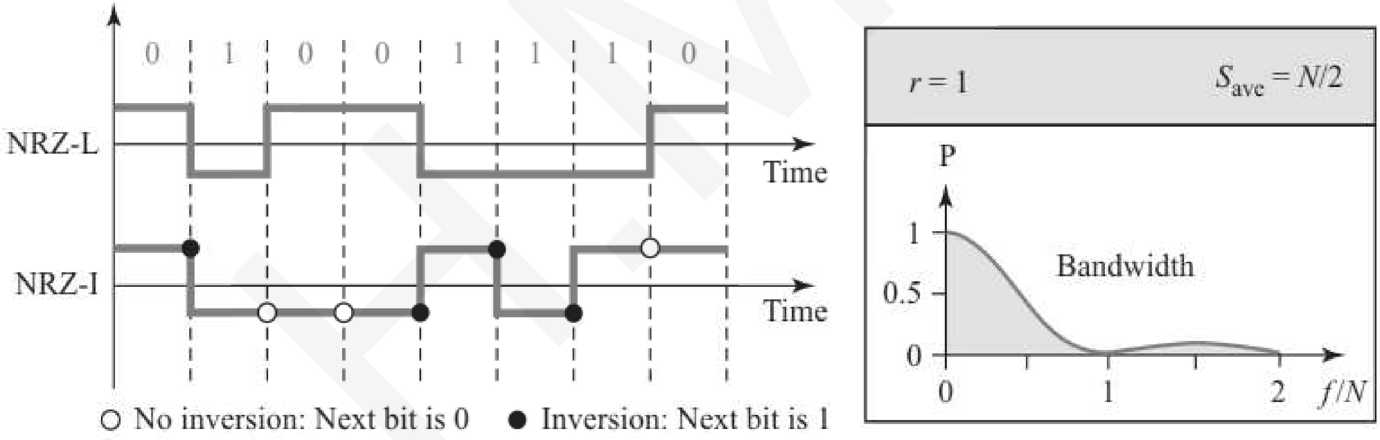


Figure 4.6 Polar NRZ-L and NRZ-I schemes

-In the second variation, NRZ-I (NRZ-Invert), the change or lack of change in the level of the voltage determines the value of the bit. If there is no change, the bit is 0; if there is a change, the bit is 1.

- The synchronization problem (sender and receiver clocks are not synchronized) also exists in both schemes. Again, this problem is more serious in NRZ-L than in NRZ-I. While a long sequence of 0s can cause a problem in both schemes, a long sequence of 1s affects only NRZ-L.

- Another problem with NRZ-L occurs when there is a sudden change of polarity in the system.

- For example, if twisted-pair cable is the medium, a change in the polarity of the wire results in all 0s interpreted as 1s and all 1s interpreted as 0s. NRZ-I does not have this problem. Both schemes (NRZ-L and NRZ-I)have an average signal rate of N/2 Bd

Example

A system is using NRZ-I to transfer 10-Mbps data. What are the average signal rate and minimum bandwidth?

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.

Return-to-Zero (RZ)

The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized. The receiver does not know when one bit has ended and the next bit is starting. One solution is the return-to-zero (RZ) scheme which uses three values: positive, negative, and zero. In RZ, the signal changes not between bits but during the bit.

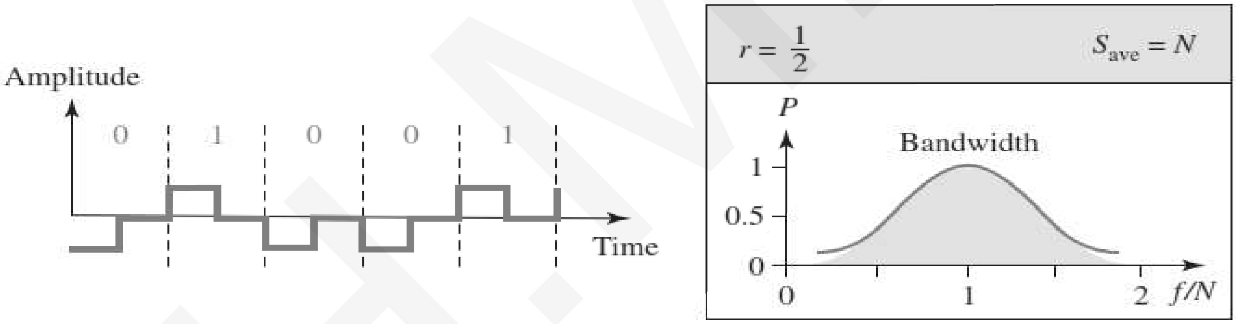


Figure 4.7 Polar RZ scheme

Biphase: Manchester and Differential Manchester

- The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme.

-In **Manchester encoding**, the duration of the bit is divided into two halves. The voltage remains at one level during the first half and moves to the other level in the second half. The transition at the middle of the bit provides synchronization.

-Differential Manchester, on the other hand, combines the ideas of RZ and NRZ-I. There is always a transition at the middle of the bit, but the bit values are determined at the beginning of the bit. If the next bit is 0, there is a transition; if the next bit is 1, there is none.

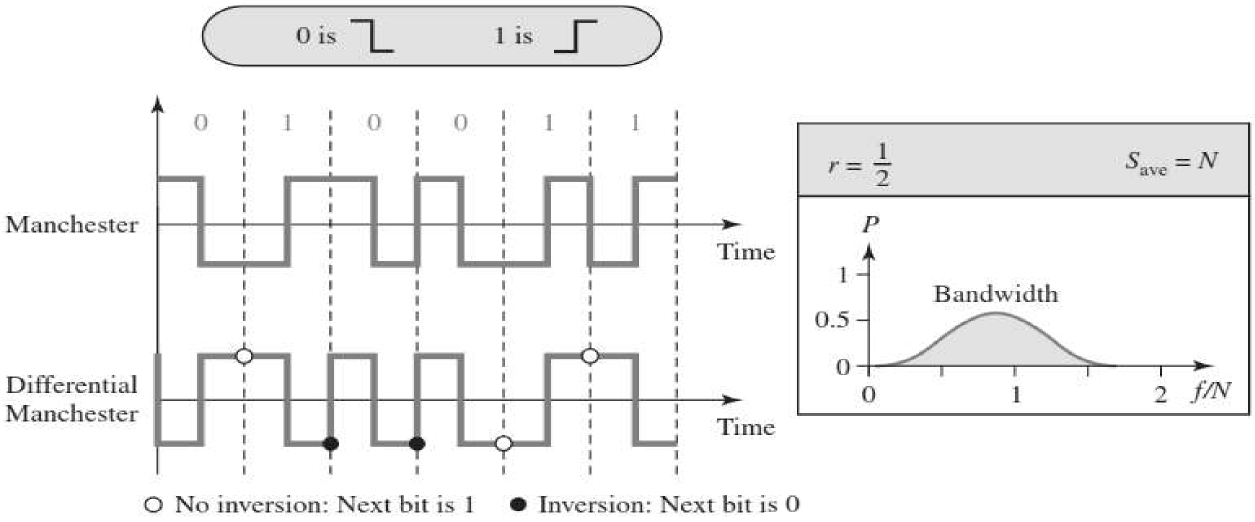


Figure 4.8 Polar biphase: Manchester and differential Manchester schemes

Block Coding

We need redundancy to ensure synchronization and to provide some kind of inherent error detecting. Block coding can give us this redundancy and improve the performance of line coding. In general, block coding changes a block of m bits into a block of n bits, where n is larger than m. Block coding is referred to as an mB/nB encoding technique.

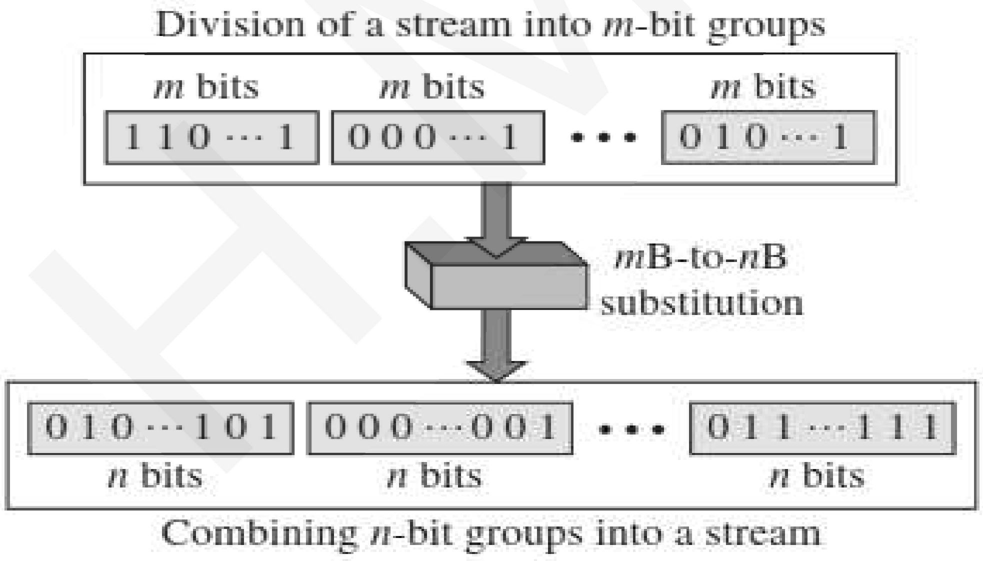


Figure 4.9 Block coding concept

ANALOG-TO-DIGITAL CONVERSION

The tendency today is to change an analog signal to digital data. In this section we describe two techniques, pulse code modulation and delta modulation.

Pulse Code Modulation (PCM)

The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM). A PCM encoder has three processes, as shown in Figure 4.10.

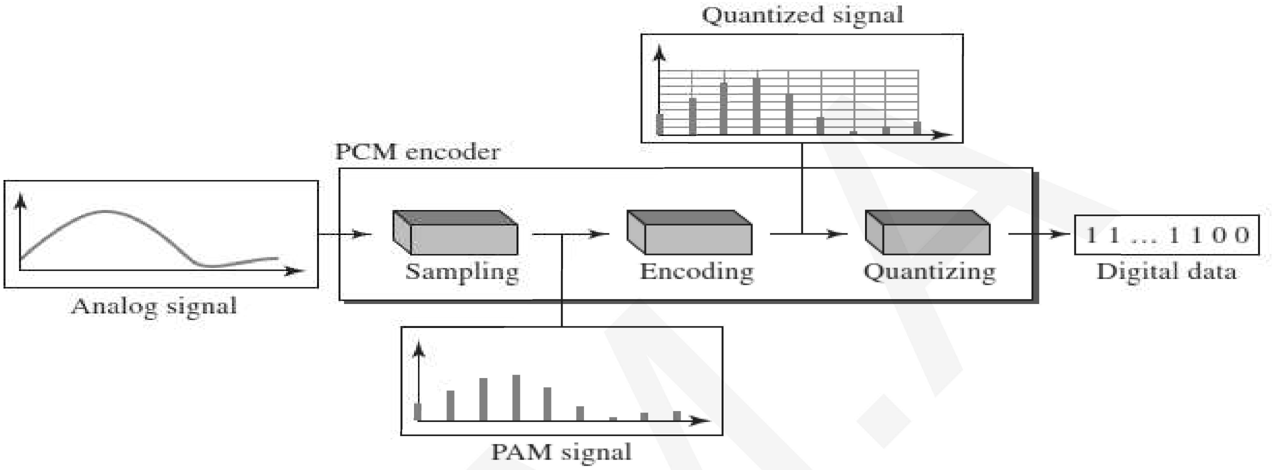


Figure 4.10 Components of PCM encoder

1. The analog signal is sampled.
2. The sampled signal is quantized.
3. The quantized values are encoded as streams of bits.

Sampling

-Analog signal is sampled every TS secs.

-Ts is referred to as the sampling interval and fs = 1/Ts is called the sampling rate or sampling frequency.

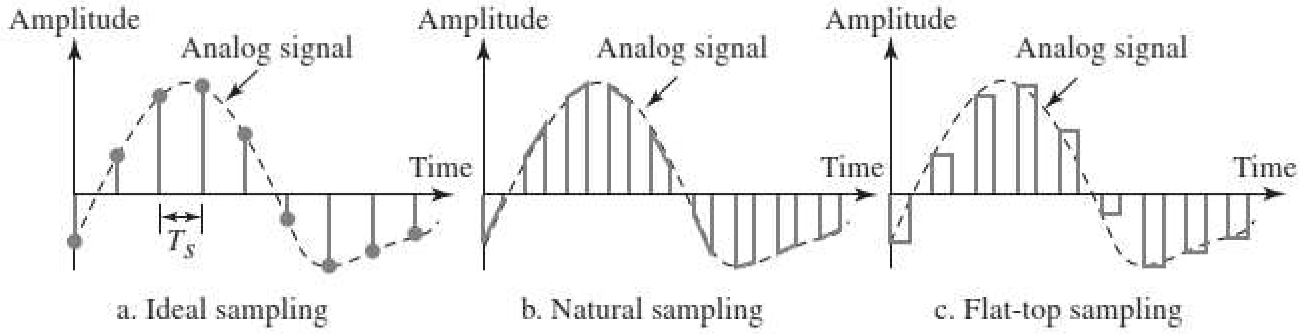
There are 3 sampling methods:

Ideal - an impulse at each sampling instant

Natural - a pulse of short width with varying amplitude

Flattop - sample and hold, like natural but with single amplitude value

The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values



a. Ideal sampling b. Natural sampling c. Flat-top sampling

Figure 4.11 Three different sampling methods for PCM

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

Quantization

-Sampling results in a series of pulses of varying amplitude values ranging between two limits: a min and a max.

-The amplitude values are infinite between the two limits.

-We need to map the infinite amplitude values onto a finite set of known values.

-This is achieved by dividing the distance between min and max into L zones, each of height Δ

Δ= (max - min)/L

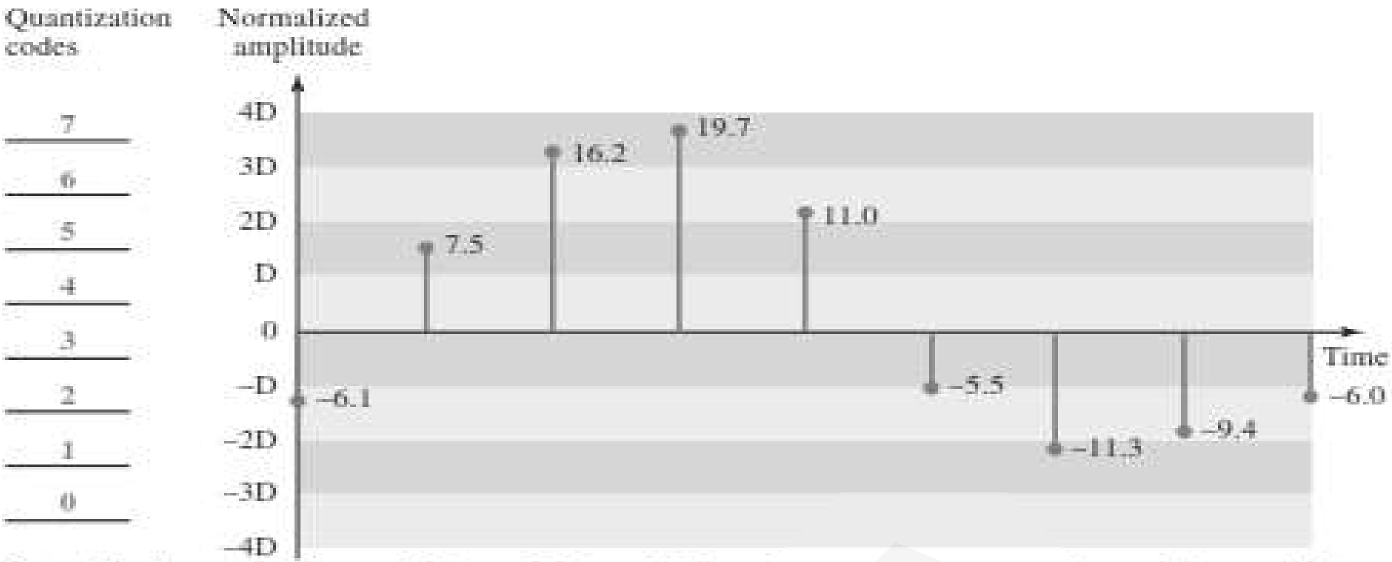
-The midpoint of each zone is assigned a value from 0 to L-1 (resulting in L values)

-Each sample falling in a zone is then approximated to the value of the midpoint.

- Assume we have a voltage signal with amplitutes Vmin=-20V and Vmax=+20V.

We want to use L=8 quantization levels.

Zone width Δ = (20 - -20)/8 = 5



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

Figure 4.12 Quantization and encoding of a sampled signal

Encoding

The last step in PCM is encoding. After each sample is quantized and the number of bits per sample is decided, each sample can be changed to an n_b-bit code word.

Delta Modulation (DM)

PCM is a very complex technique. Other techniques have been developed to reduce the complexity of PCM. The simplest is delta modulation. PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample. Figure 4.13 shows the process. Note that there are no code words here; bits are sent one after another.

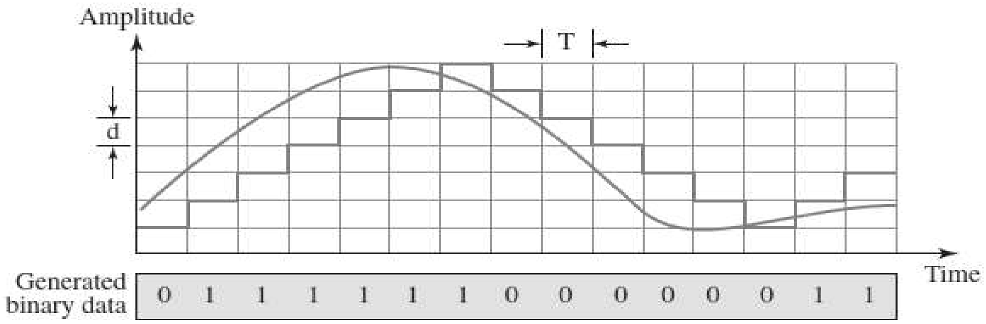


Figure 4.13 The process of delta modulation

TRANSMISSION MODES

Of primary concern when we are considering the transmission of data from one device to another is the wiring, and of primary concern when we are considering the wiring is the data stream. Do we send 1 bit at a time; or do we group bits into larger groups and, if so, how? The transmission of binary data across a link can be accomplished in either parallel or serial mode. In parallel mode, multiple bits are sent with each clock tick. In serial mode, 1 bit is sent with each clock tick. While there is only one way to send parallel data, there are three subclasses of serial transmission: asynchronous, synchronous, and isochronous (see Figure 4.14).

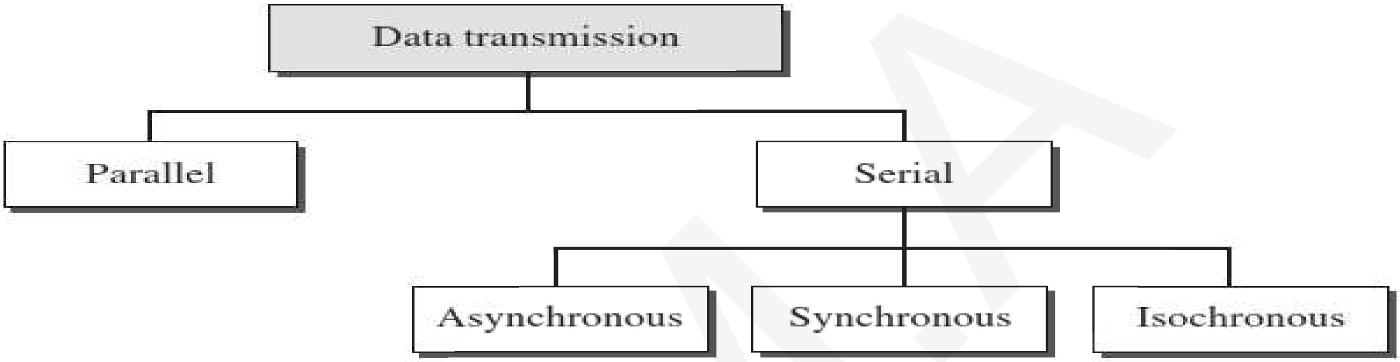


Figure 4.14 Data transmission and modes

Parallel Transmission

Binary data, consisting of 1s and 0s, may be organized into groups of n bits each. Computers produce and consume data in groups of bits much as we conceive of and use spoken language in the form of words rather than letters. By grouping, we can send data n bits at a time instead of 1. This is called parallel transmission.

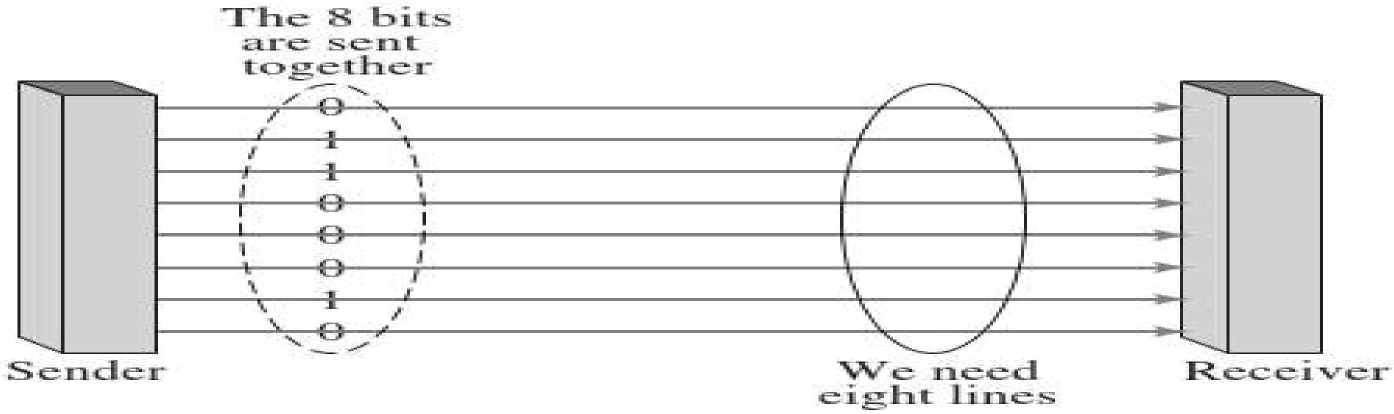


Figure 4.15 Parallel transmission

-The advantage of parallel transmission is speed. All else being equal, parallel transmission can increase the transfer speed by a factor of n over serial transmission.

--The Disadvantage of Parallel transmission requires n communication lines just to transmit the data stream. Because this is expensive, parallel transmission is usually limited to short distances.

Serial Transmission

-In serial transmission one bit follows another, so we need only one communication channel rather than n to transmit data between two communicating devices (see Figure 4.16).

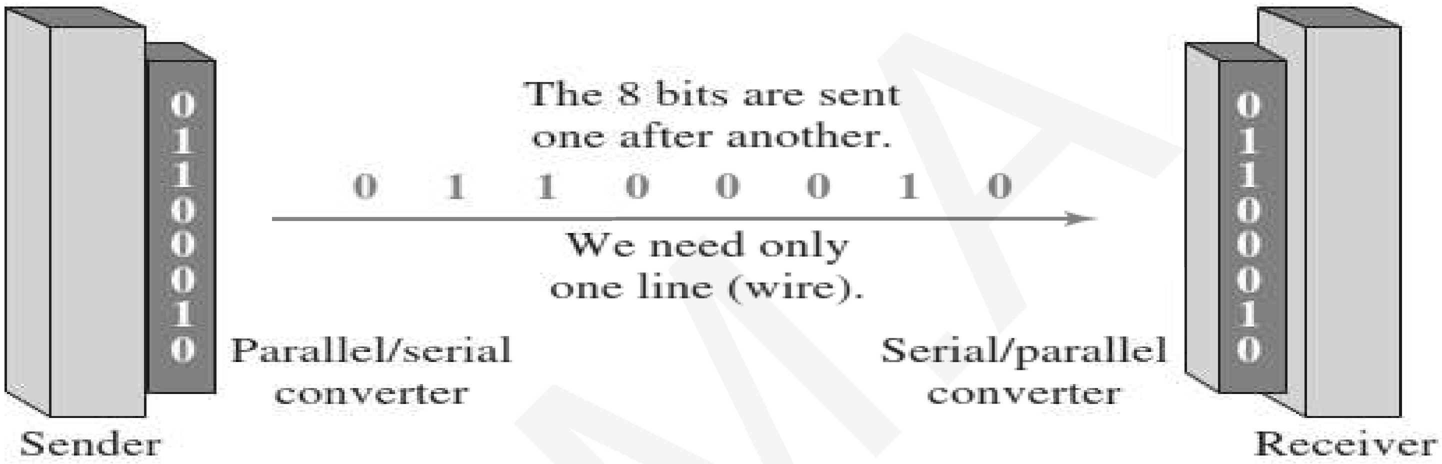


Figure 4.16 Serial transmission

-The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission over parallel by roughly a factor of n.

-Since communication within devices is parallel, conversion devices are required at the interface between the sender and the line (parallel-to-serial) and between the line and the receiver (serial-to-parallel).

-Serial transmission occurs in one of three ways: asynchronous, synchronous, and isochronous.

Asynchronous Transmission

In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte. There may be a gap between bytes.

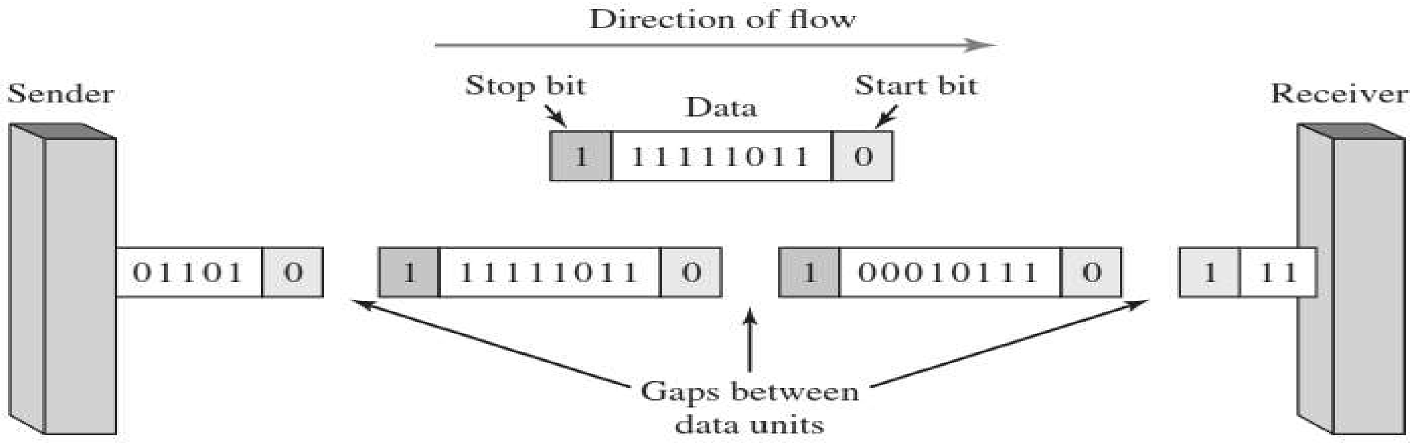


Figure 4.17 Asynchronous transmission

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.

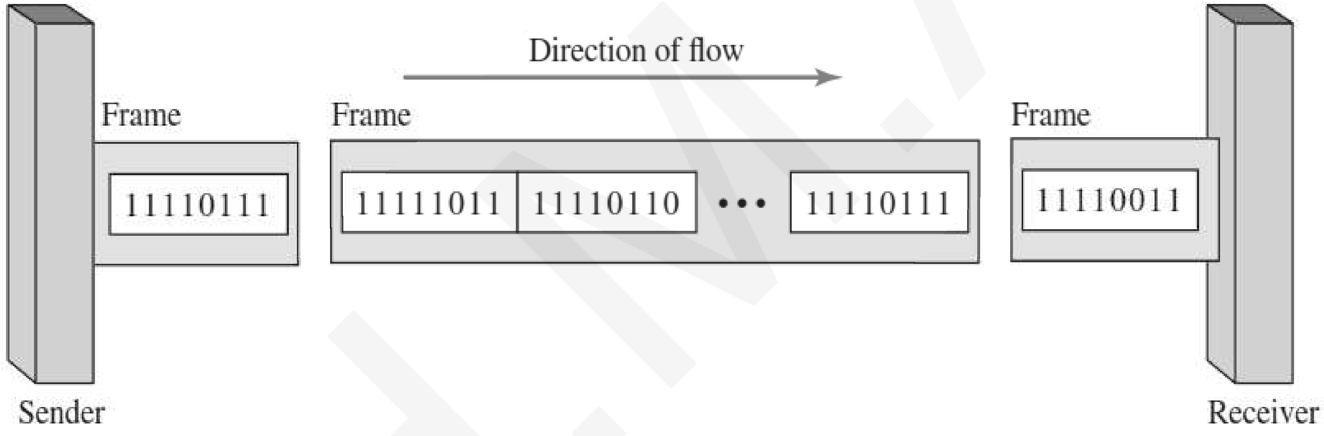


Figure 4.35 Synchronous transmission

Isochronous

The isochronous transmission guarantees that the data arrive at a fixed rate. In real-time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails. For example, TV images are broadcast at the rate of 30 images per second; they must be viewed at the same rate. If each image is sent by using one or more frames, there should be no delays between frames.