Department of Computer science and Information Technology

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

- **Line coding is the process of converting digital data to digital signals. It converts a sequence of bits to a digital signal.**

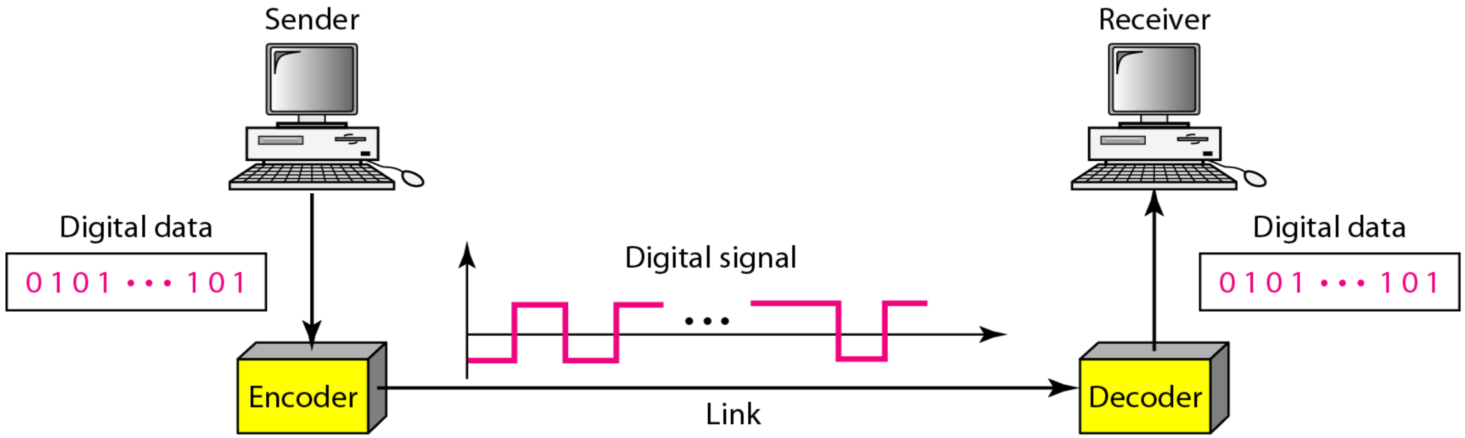


Figure 4.1 ***Line coding and decoding***

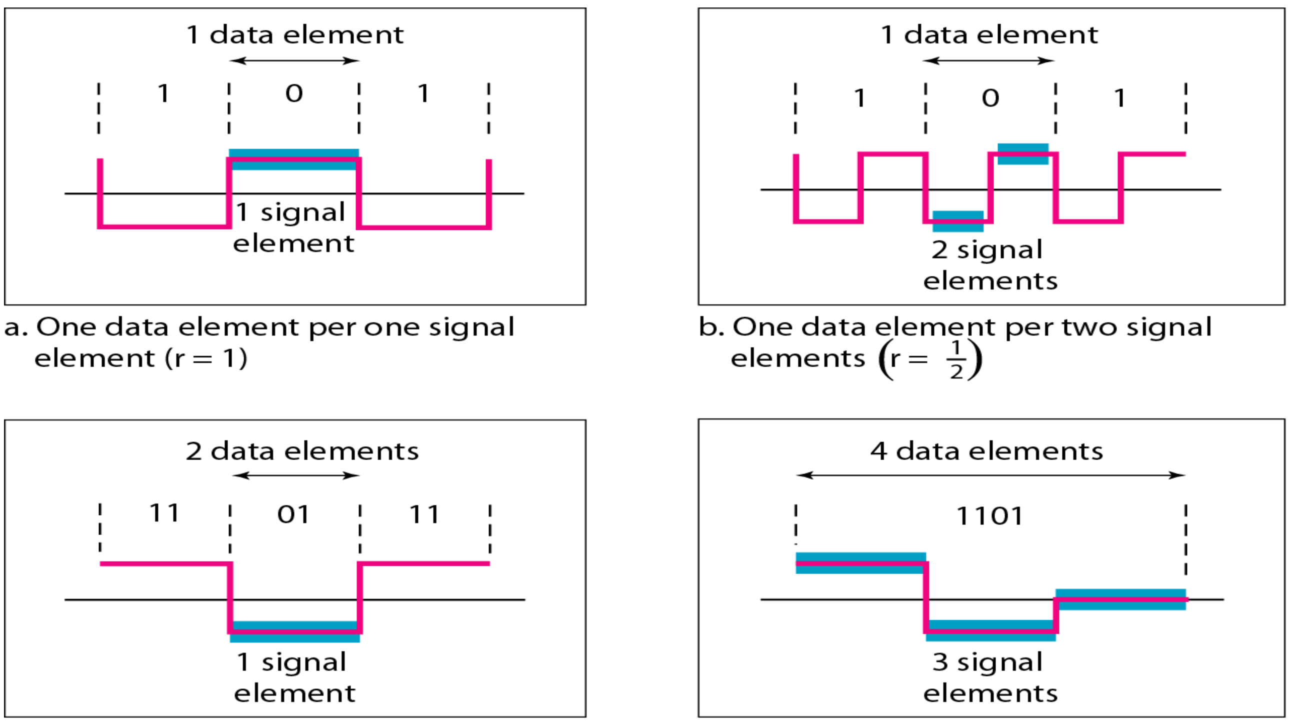
Characteristics of Line Coding

1. Signal Element Versus Data Element

	Signal Element	Data Element
1.	shortest unit (timewise) of a digital signal.	smallest entity that can represent a piece of information i.e bit
2.	Are what we can send.	are what we need to send
3.	signal elements are the carriers.	Data elements are being carried

Figure 4.2 *Signal element versus data element*

A ratio r is the number of data elements carried by each signal 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 $\left(r = \frac{4}{3}\right)$

Continue..

2. Data Rate Versus Signal Rate

	Data Rate	Signal Rate
1.	number of data elements (bits) sent in 1s.	number of signal elements sent in 1s.
2.	The unit is bits per second (bps).	The unit is the baud.
3.	sometimes called the bit rate	sometimes called the pulse rate, the modulation rate, or the baud rate.
4.	Increasing the data rate increases the speed of transmission	decreasing the signal rate decreases the bandwidth requirement.

Continue..

- Relationship between data rate (N) and signal rate (S)
    - $S_{ave} = c * N * (1/r)$
- Where,
- N= Data rate (bps)
- C = Case factor
- S= Number of signal elements per second

Example 4.1

- **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

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

Bandwidth

- Digital signal that carries information is nonperiodic.
- The bandwidth of a nonperiodic signal is continuous with an infinite range.
- Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite.
- baud rate, not the bit rate, determines the required bandwidth for a digital signal.
- The bandwidth reflects the range of frequencies we need.
- The bandwidth (range of frequencies) is proportional to the signal rate (baud rate). The minimum bandwidth can be given as:
- $B_{min} = c * N * (1 / r)$
- We can solve for the maximum data rate if the bandwidth of the channel is given.
- $Nmax = (1 / c) * B * r$

Baseline Wandering

- In decoding a digital signal, the receiver calculates a running average of the received signal power. This average is called the baseline.
- The incoming signal power is evaluated against this baseline to determine the value of the data element.
- A long string of 0s or 1s can cause a drift in the baseline (baseline wandering) and make it difficult for the receiver to decode correctly.
- A good line coding scheme needs to prevent baseline wandering.

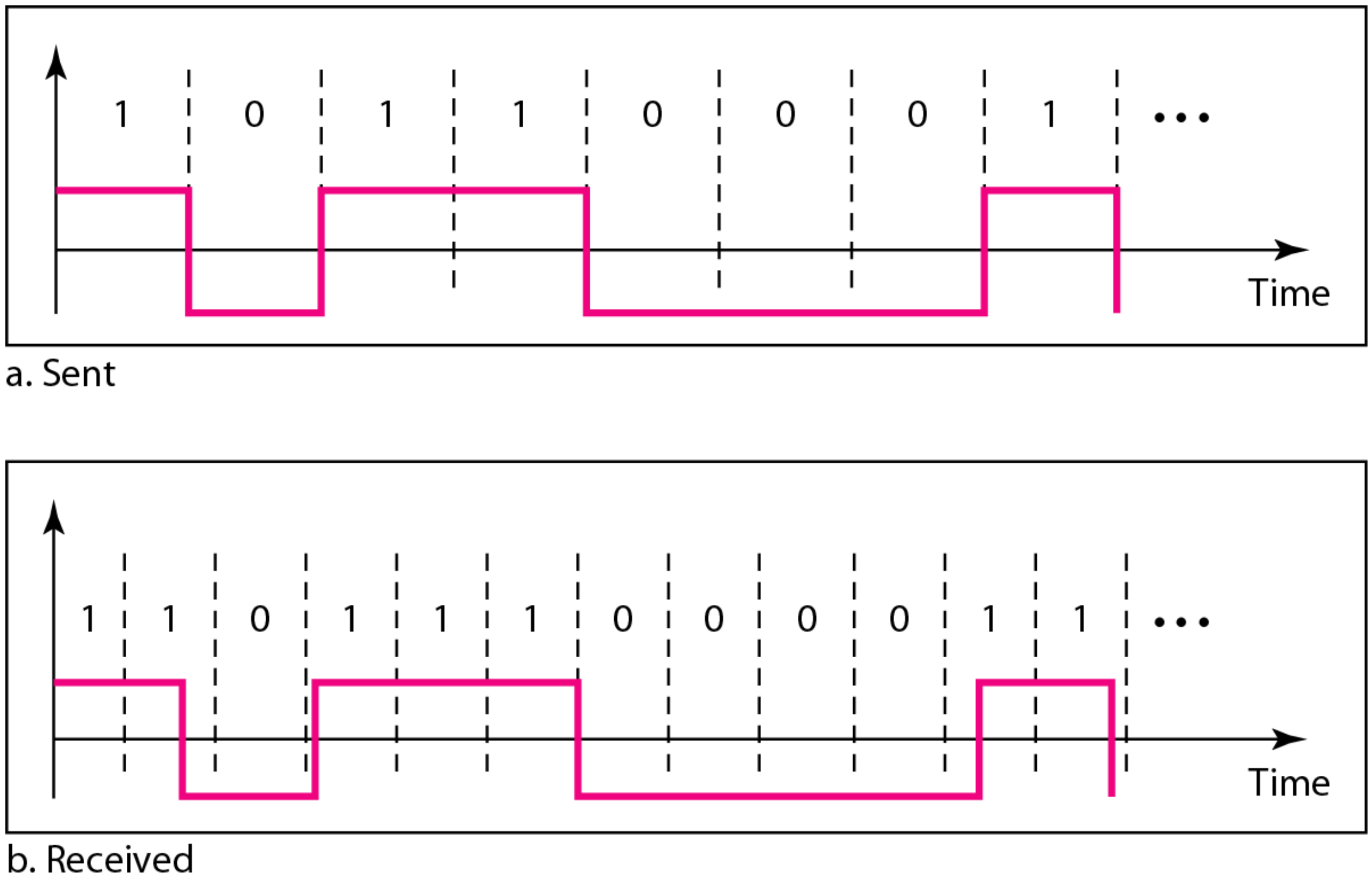
DC Components

- **When the voltage level in a digital signal is constant for a while, the spectrum creates very low frequencies (results of Fourier analysis). These frequencies around zero, called DC (direct-current) components**
- **They present problems for a system that cannot pass low frequencies or a system that uses electrical coupling.**
- **For example, a telephone line cannot pass frequencies below 200 Hz.**

Self-synchronization

- To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals.
- A self-synchronizing digital signal includes timing information in the data being transmitted.
- This can be achieved if there are transitions in the signal that alert the receiver to the beginning, middle, or end of the pulse.

Figure 4.3 *Effect of lack of synchronization*



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

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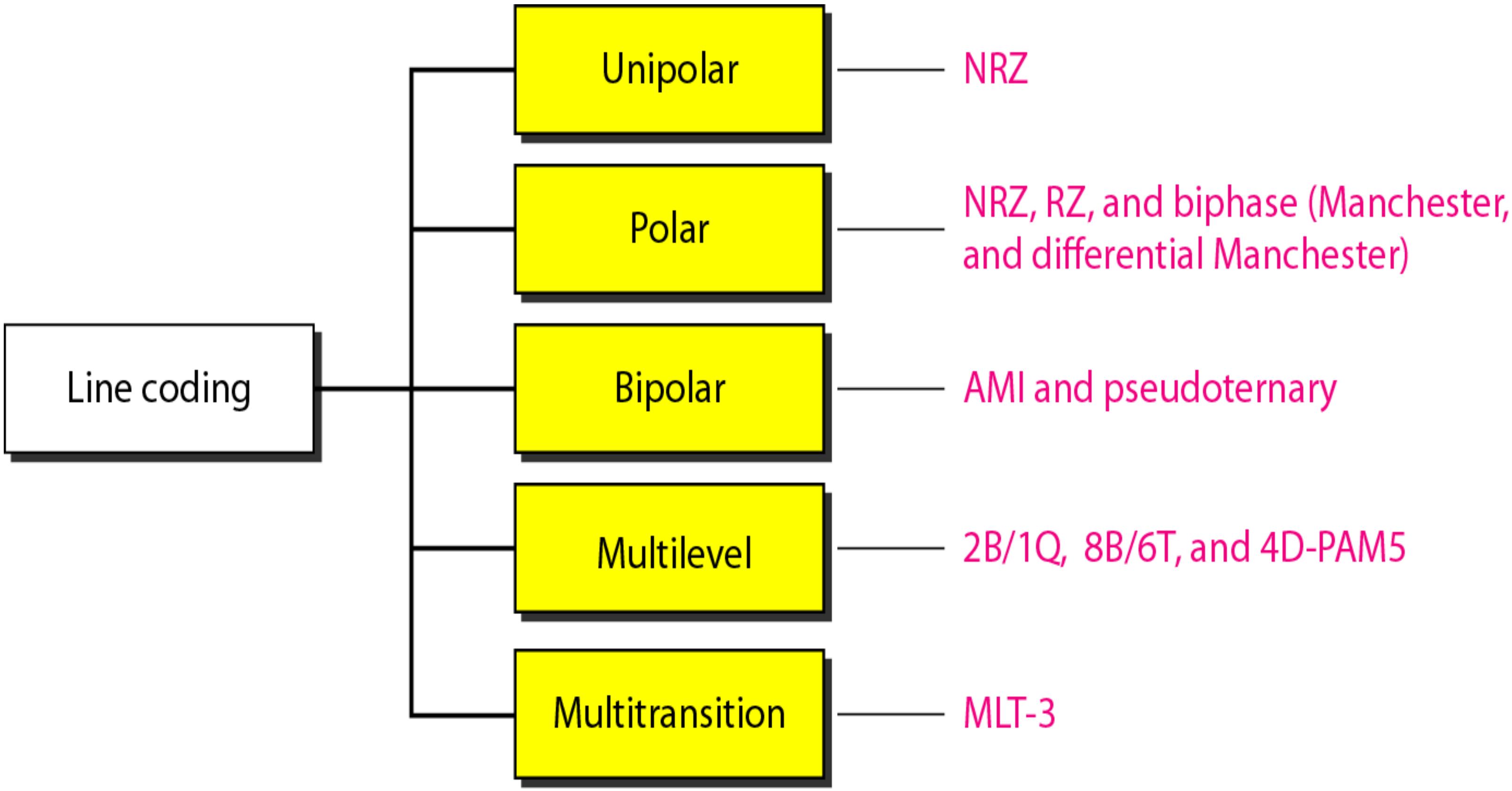
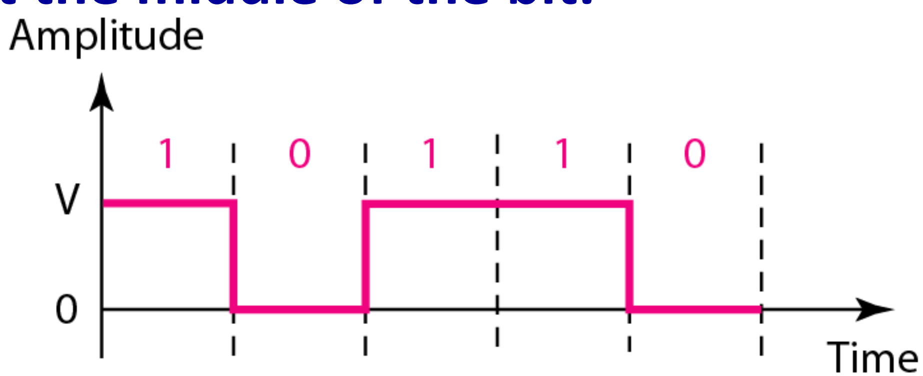
Figure 4.4 *Line coding schemes*



Unipolar NRZ 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):**
- **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.**



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

Normalized power

Figure 4.5 ***Unipolar NRZ scheme***

Polar NRZ-L and NRZ-I 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 **NRZ-L(NRZ-Level)**, the level of the voltage determines the value of the bit. **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.*

Continue…

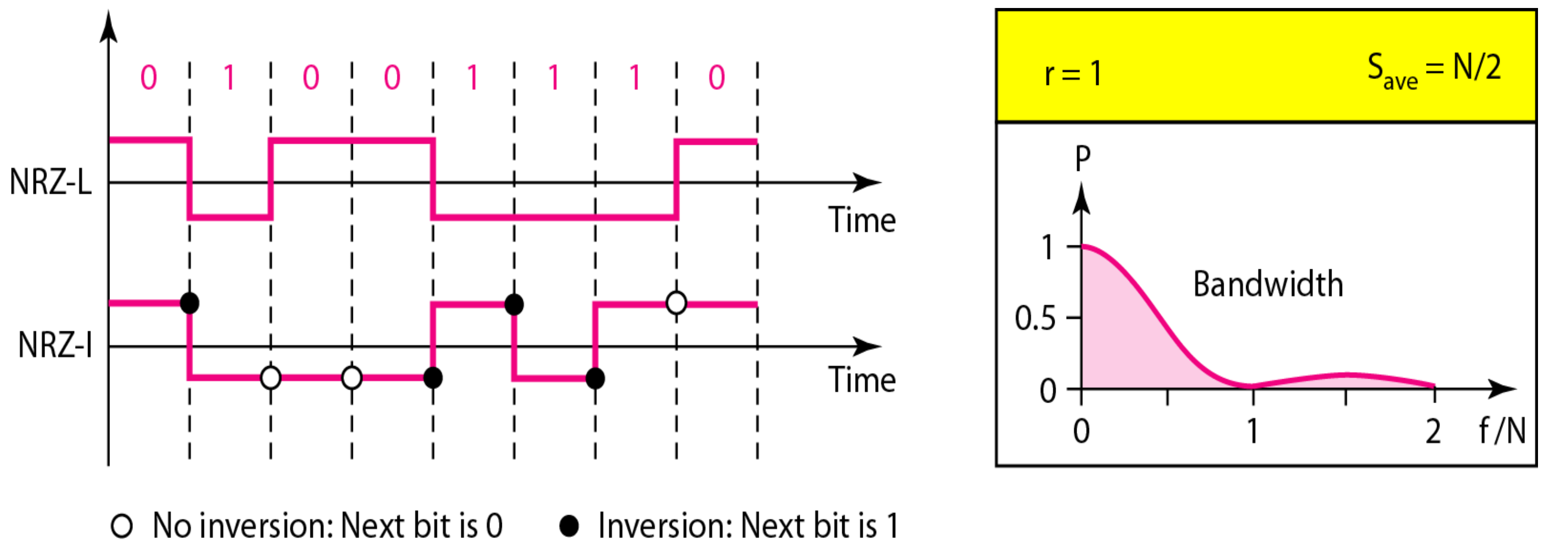


Figure 4.6 ***Polar NRZ-L and NRZ-I schemes***

Comparison between NRZ-L and NRZ-I

- **Although baseline wandering is a problem for both variations, it is twice as severe in NRZ-L.**
- **The synchronization problem also exists in both schemes. 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.**
- **NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.**

Example 4.4

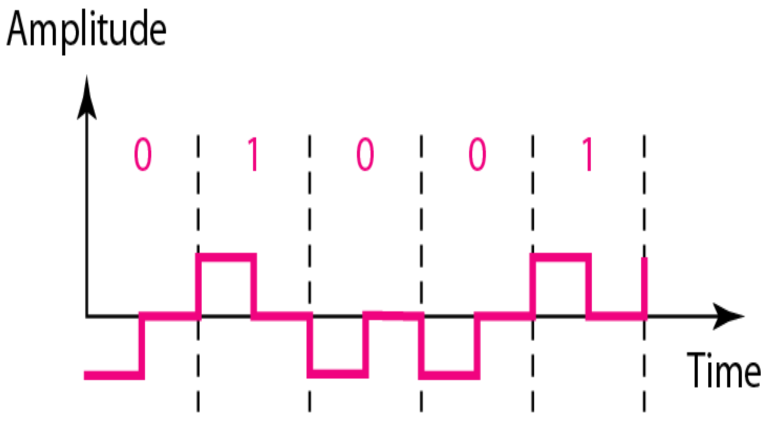
- ***A system is using NRZ-I to transfer 10-Mbps data. What are the average signal rate and minimum bandwidth?***

- **Solution**
- **The average signal rate is S = N/2 = 5000 kbaud. The minimum bandwidth for this average baud rate is Bmin = S = 5000 kHz.**

Return-to-Zero (RZ)

- The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized.
- 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.
- The main disadvantage of RZ encoding is that it requires two signal changes to encode a bit and therefore occupies greater bandwidth.
- a sudden change of polarity resulting in all 0s interpreted as 1s and all 1s interpreted as 0s, still exists here, but there is no DC component problem.
- Another problem is the complexity: RZ uses three levels of voltage, which is more complex to create and discern.

Continue..



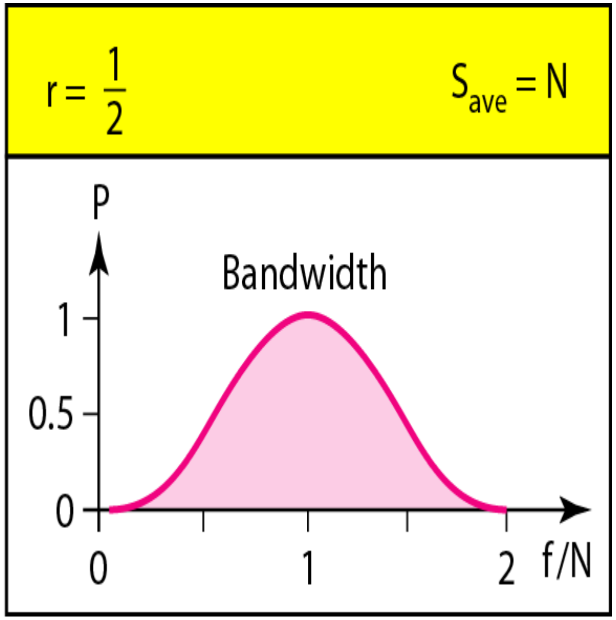


Figure 4.7 ***Polar RZ scheme***

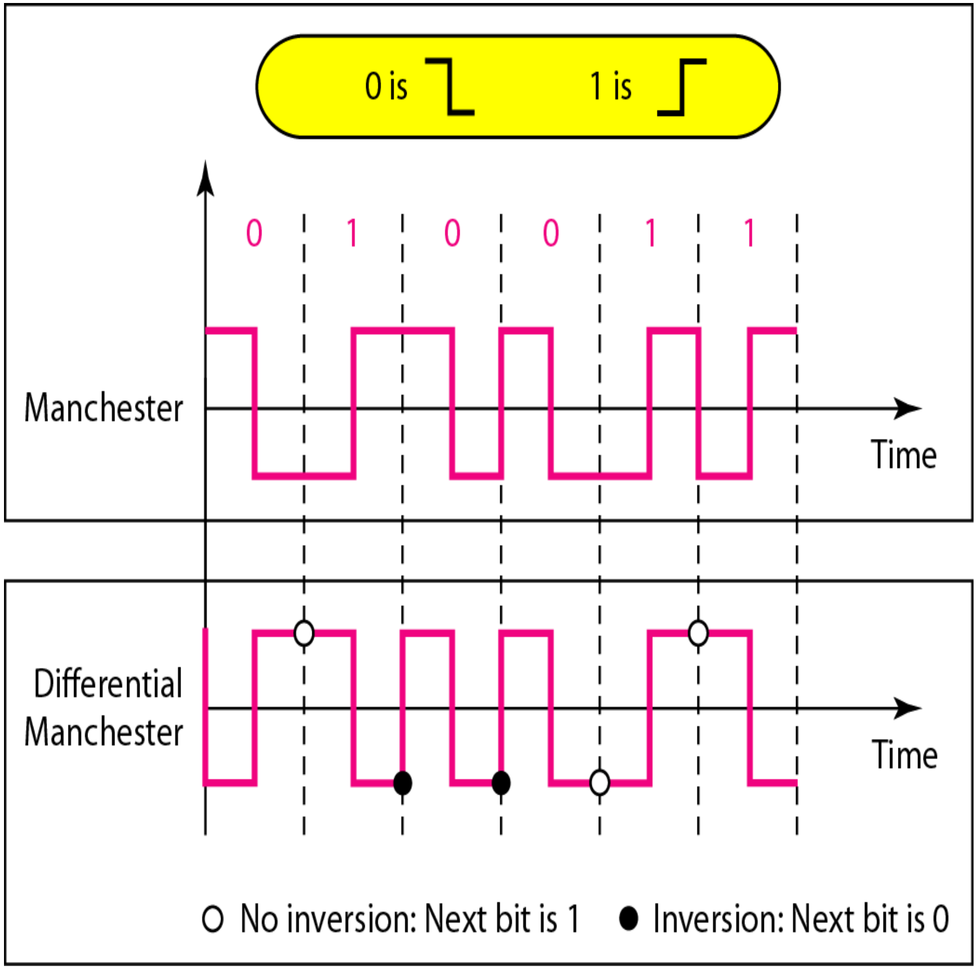
Biphase: Manchester and Differential Manchester

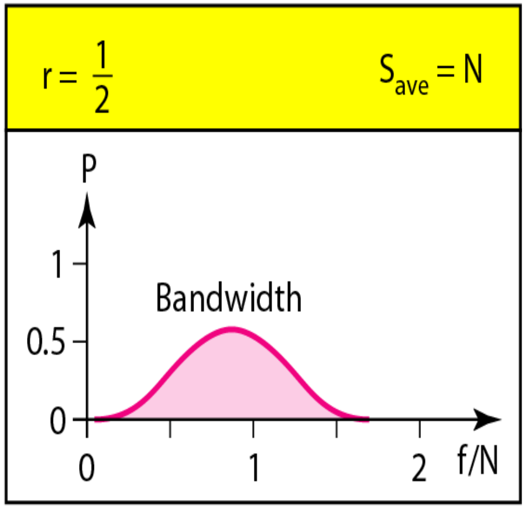
- The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme.
- The voltage remains at one level during the first half and moves to the other level in the second half. The transition at the middle of the bit provides synchronization.
- Differential 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.

Continue..

- The Manchester scheme overcomes several problems associated with NRZ-L
- Differential Manchester overcomes several problems associated with NRZ-I.
- There is no baseline wandering.
- There is no DC component because each bit has a positive and negative voltage contribution.
- The only drawback is the signal rate as it is double that for NRZ.
- Manchester and differential Manchester schemes are also called biphase schemes.

Figure 4.8 *Polar biphase: Manchester and differential Manchester schemes*





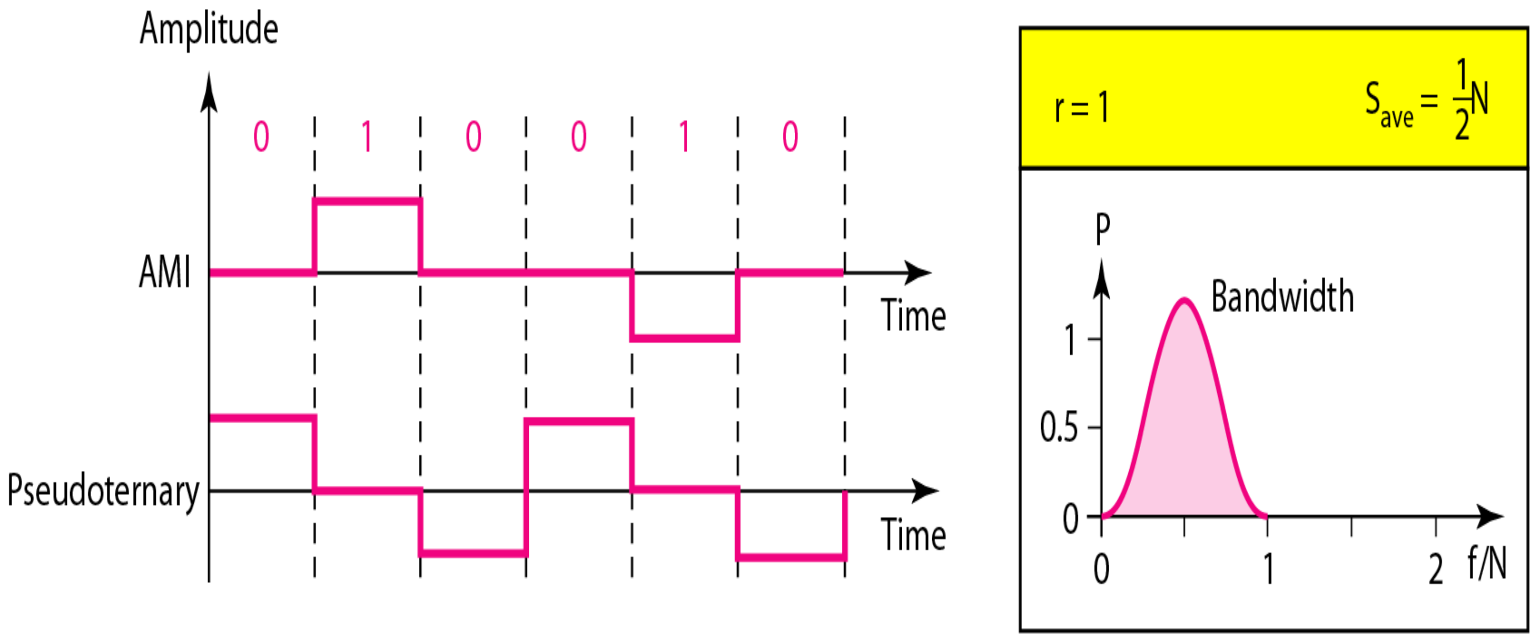
Bipolar Schemes

- In bipolar encoding (sometimes called multilevel binary), there are three voltage levels: positive, negative, and zero.
- AMI and Pseudoternary
- A common bipolar encoding scheme is called bipolar alternate mark inversion (AMI).
- AMI means alternate 1 inversion.
- neutral zero voltage represents binary 0. Binary 1s are represented by alternating positive and negative voltages.
- A variation of AMI encoding is called pseudoternary in which the 1 bit is encoded as a zero voltage and the 0 bit is encoded as alternating positive and negative voltages.

Continue..

- **The bipolar scheme was developed as an alternative to NRZ.**
- **bipolar scheme has the same signal rate as NRZ, but there is no DC component.**
- **The concentration of the energy in bipolar encoding is around frequency N/2.**
- **AMI is commonly used for long-distance communication, but it has a synchronization problem when a long sequence of 0s is present in the data.**

Figure 4.9 ***Bipolar schemes: AMI and pseudoternary***



Multilevel Schemes

- The goal of the scheme is to increase the number of bits per baud by encoding a pattern of **m** data elements into a pattern of **n** signal elements.
- We only have two types of data elements (0s and 1s), which means that a group of m data elements can produce a combination of 2^m data patterns.
- If we have L different Signal levels, then we can produce L^n combinations of signal patterns.
- If $2^m = L^n$, then each data pattern is encoded into one signal pattern.
- If $2^m < L^n$, data patterns occupy only a subset of signal patterns.
- Data encoding is not possible if $2^m > L^n$

Continue..

- **The code designers have classified these types of coding as mBnL, where m is the length of the binary pattern, B means binary data, n is the length of the signal pattern, and L is the number of levels in the signaling.**
- **A letter is often used in place of L: B (binary) for L = 2, T (ternary) for L = 3, and Q (quaternary) for L = 4.**
- **the first two letters define the data pattern, and the second two define the signal pattern.**

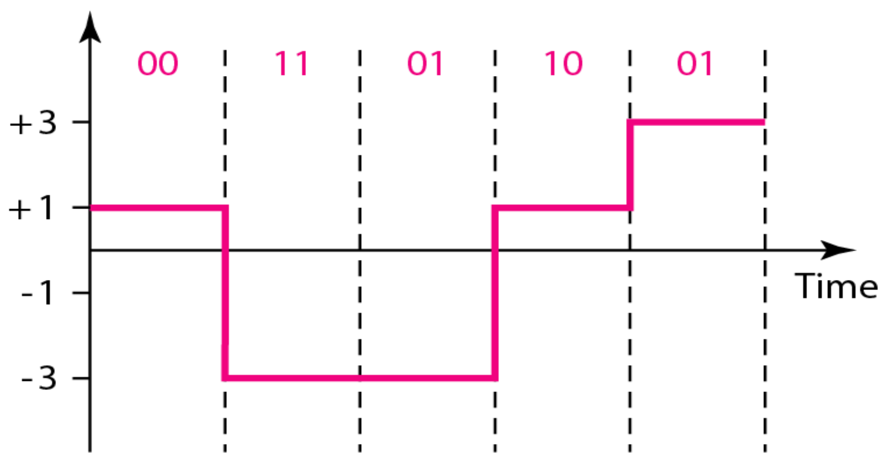
2B1Q

- ***The first mBnL scheme we discuss, two binary, one quaternary (2B1Q), uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal. In this type of encoding m = 2, n = 1, and L = 4 (quaternary).***
- ***The average signal rate of 2B1Q is S = N/4. This means that using 2B1Q, we can send data 2 times faster than by using NRZ-L.***
- ***2B1Q uses four different signal levels, which means the receiver has to discern four different thresholds.***

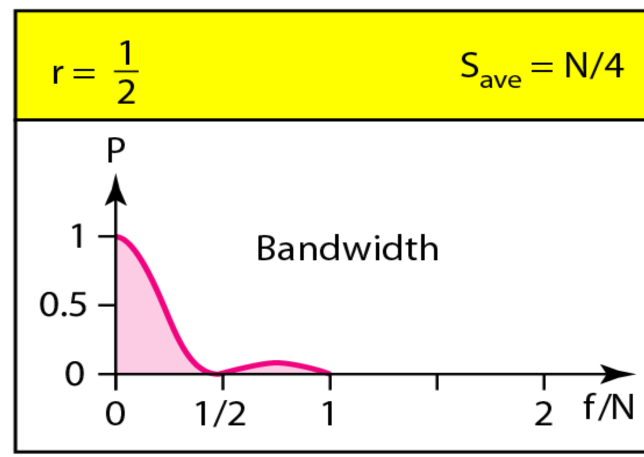
Figure 4.10 *Multilevel: 2B1Q scheme*

	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



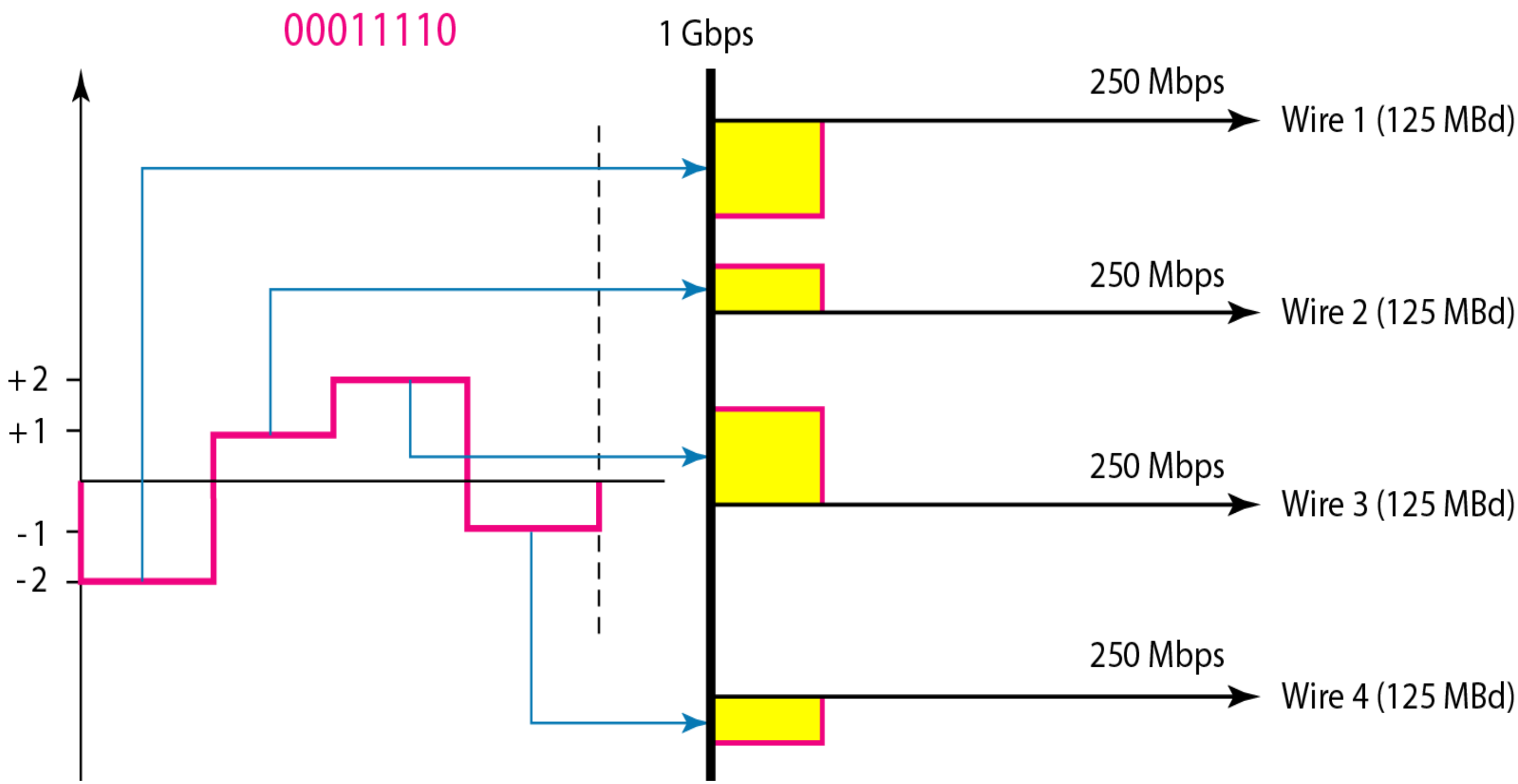
8B6T

- **Eight binary, six ternary (8B6T). This code is used with 100BASE-4T cable**
- **The idea is to encode a pattern of 8 bits as a pattern of six signal elements, where the signal has three levels (ternary).**
- **we can have $2^8 = 256$ different data patterns and $3^6 = 729$ different signal patterns.**
- **The average signal rate of the scheme is theoretically $S_{ave} = (½) \times N \times (6/8)$; in practice**
- **the minimum bandwidth is very close to 6N/8.**

4D-PAM5

- **four-dimensional five level pulse amplitude modulation (4D-PAM5).**
- **The 4D means that data is sent over four wires at the same time. It uses five voltage levels, such as −2, −1, 0, 1, and 2.**
- **The technique is designed to send data over four channels (four wires). This means the signal rate can be reduced to N/8. All 8 bits can be fed into a wire simultaneously and sent by using one signal element.**

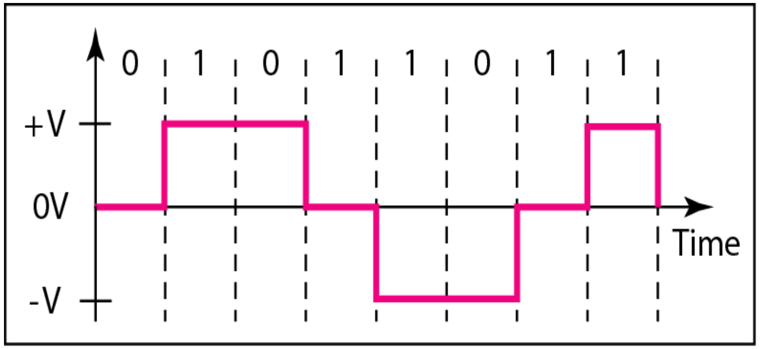
Figure 4.12 *Multilevel: 4D-PAM5 scheme*



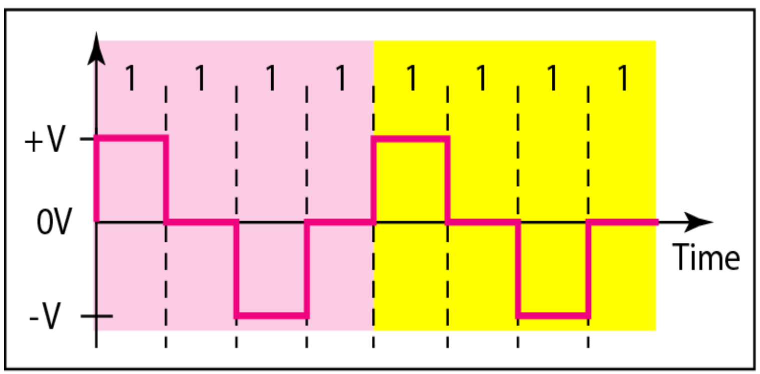
Multitransition: MLT-3

- The multiline transmission, three-level (MLT-3) scheme uses three levels (+V, 0, and –V) and three transition rules to move between the levels.
- 1. If the next bit is 0, there is no transition.
- 2. If the next bit is 1 and the current level is not 0, the next level is 0.
- 3. If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.
- This is a scheme that maps one bit to one signal element.
- The signal rate is the same as that for NRZ-I, but with greater complexity.
- the shape of the signal in this scheme helps to reduce the required bandwidth.
- the signal rate for MLT-3 is one-fourth the bit rate

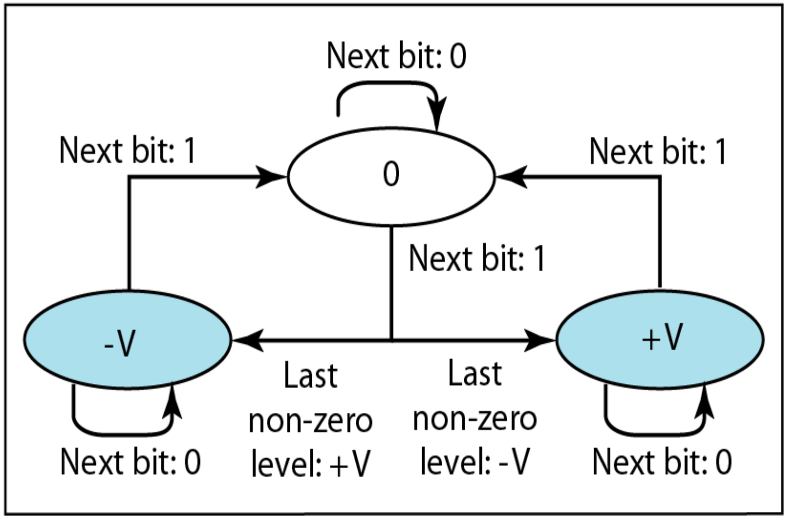
Figure 4.13 *Multitransition: MLT-3 scheme*



a. Typical case



b. Worse case



c. Transition states

Table 4.1 *Summary of line coding schemes*

Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multiline	MLT-3	$B = N/3$	No self-synchronization for long 0s

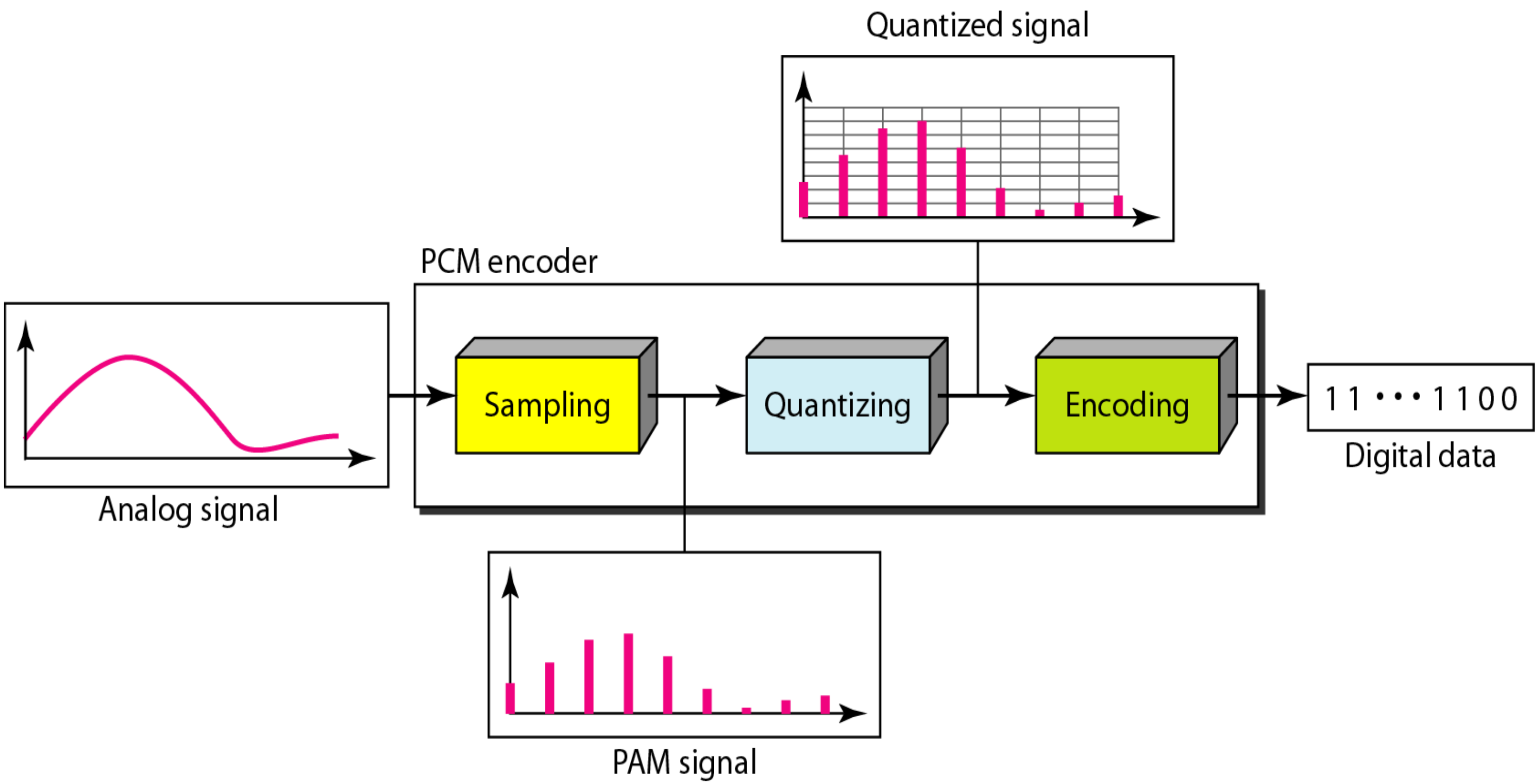
4-2 ANALOG-TO-DIGITAL CONVERSION

- **Digital signal is superior to an analog signal. The tendency today is to change an analog signal to digital data.**

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

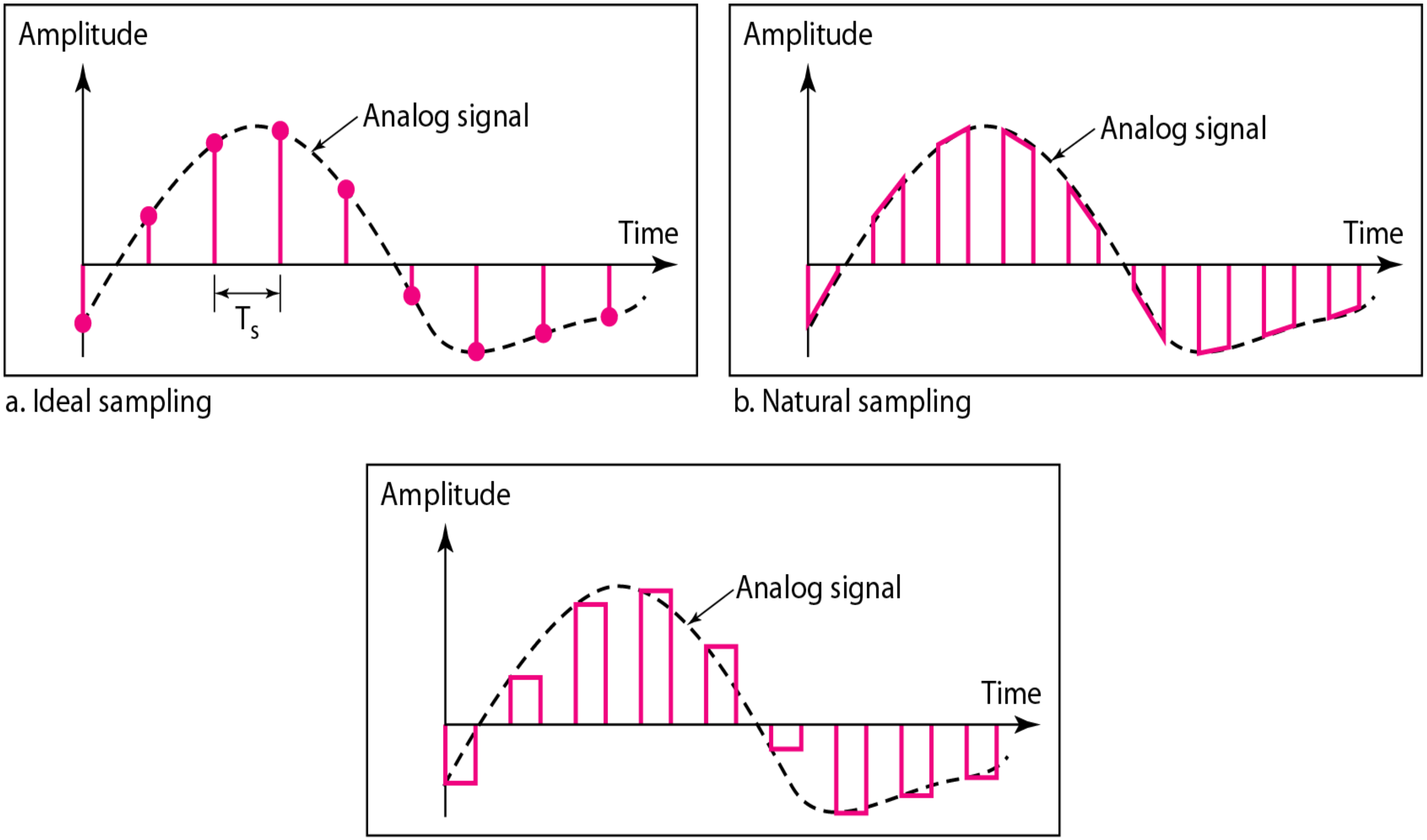
Figure 4.21 *Components of PCM encoder*



1. Sampling

- The analog signal is sampled every T_s *s, where* T_s *is* the sample interval or period. The inverse of the sampling interval is called the ***sampling rate or sampling frequency and denoted by*** f_s***, where*** $f_s = 1/T_s$***.***
- There are three sampling methods—ideal, natural, and flat-top
- In ideal sampling, pulses from the analog signal are sampled.
- In natural sampling, a high-speed switch is turned on for only the small period of time when the sampling occurs.
- common sampling method, called ***sample and hold, however, creates flat-top samples*** by using a circuit.

Figure 4.22 *Three different sampling methods for PCM*



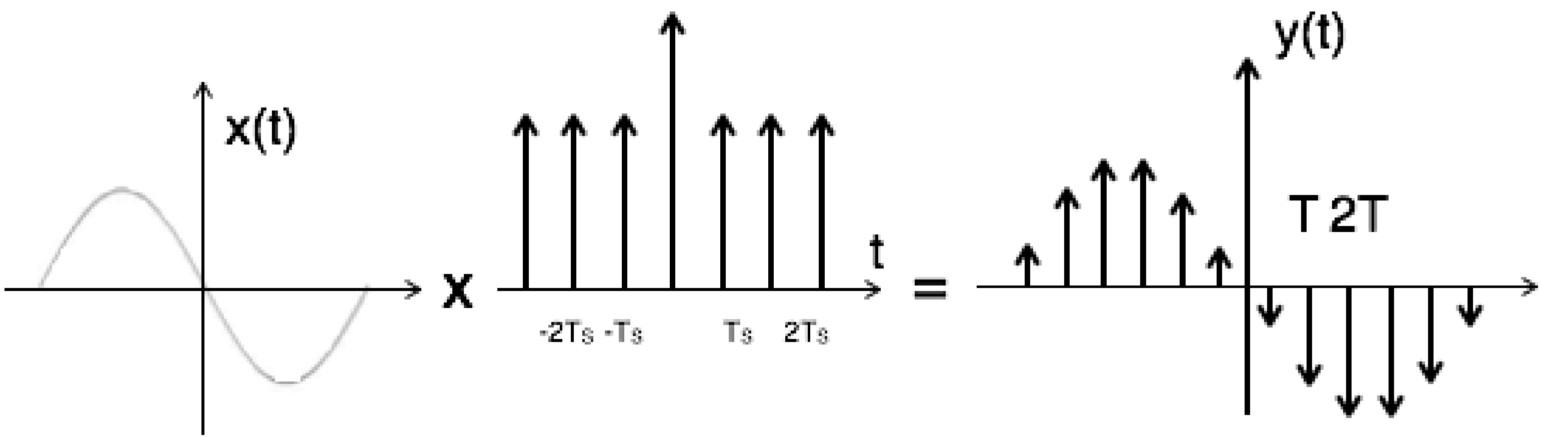
a. Ideal sampling

b. Natural sampling

c. Flat-top sampling

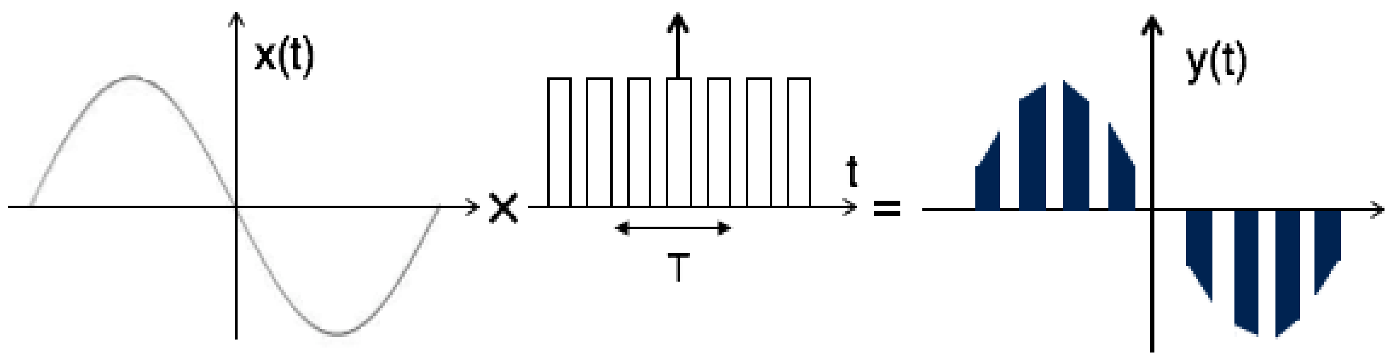
Impulse Sampling

- Impulse sampling can be performed by multiplying input signal x(t) with impulse train of period 'T'. Here, the amplitude of impulse changes with respect to amplitude of input signal x(t).



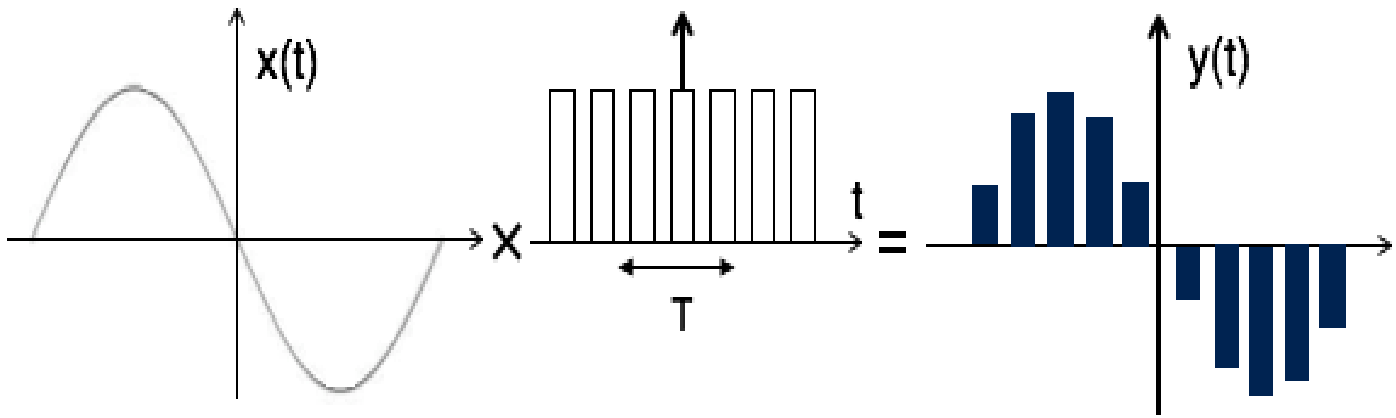
Natural Sampling

- Natural sampling is similar to impulse sampling, except the impulse train is replaced by pulse train of period T. i.e. you multiply input signal x(t) to pulse train



Flat Top Sampling

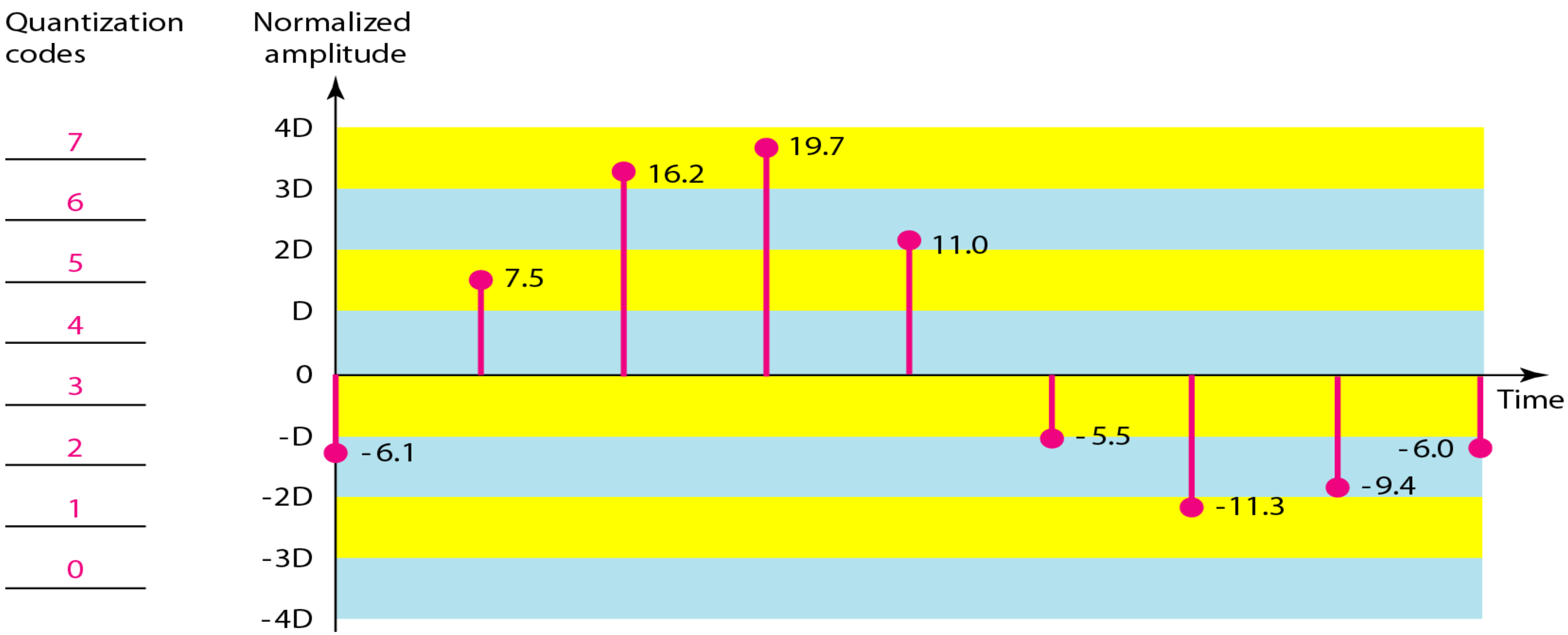
- During transmission, noise is introduced at top of the transmission pulse which can be easily removed if the pulse is in the form of flat top. Here, the top of the samples are flat i.e. they have constant amplitude. Hence, it is called as flat top sampling or practical sampling.



Example 4.9

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

Figure 4.26 *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	-0.38	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

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Example 4.12

- ***What is the SNRdB in the example of Figure 4.26?***
- ***Solution***
- ***We can use the formula to find the quantization. We have eight* levels *and 3 bits per sample, so***

    - ***SNRdB = 6.02(3) + 1.76 = 19.82 dB***

- ***Increasing the number of levels increases the SNR.***

Example 4.13

- **A telephone subscriber line must have an SNRdB above 40. What is the minimum number of bits per sample?**
- **Solution**
- **We can calculate the number of bits as**

$$\boxed{SNR_{dB} = 6.02n_b + 1.76 = 40 \quad \longrightarrow \quad n = 6.35}$$

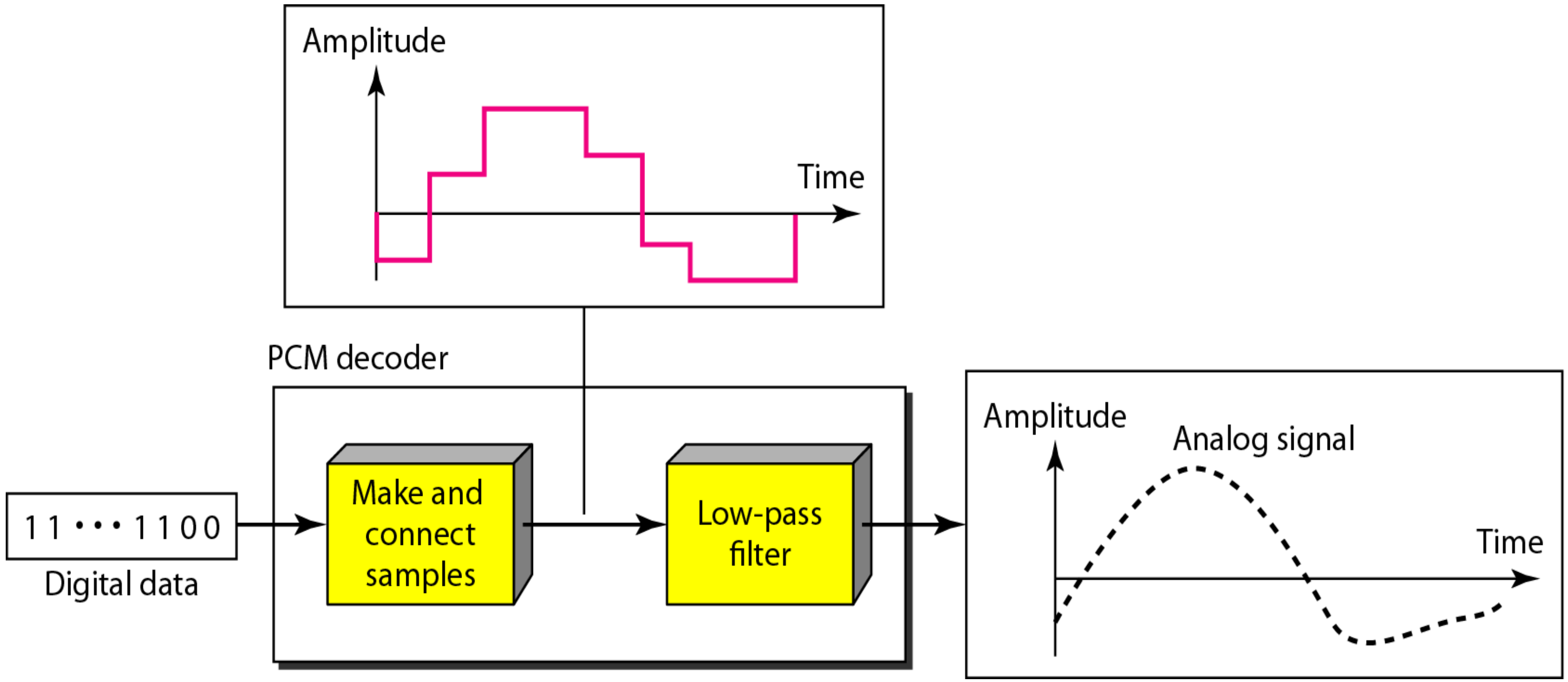
- **Telephone companies usually assign 7 or 8 bits per sample.**

Example 4.14

- 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:

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

Figure 4.27 ***Components of a PCM decoder***



4-3 TRANSMISSION MODES

- 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**.

Figure 4.31 *Data transmission and modes*

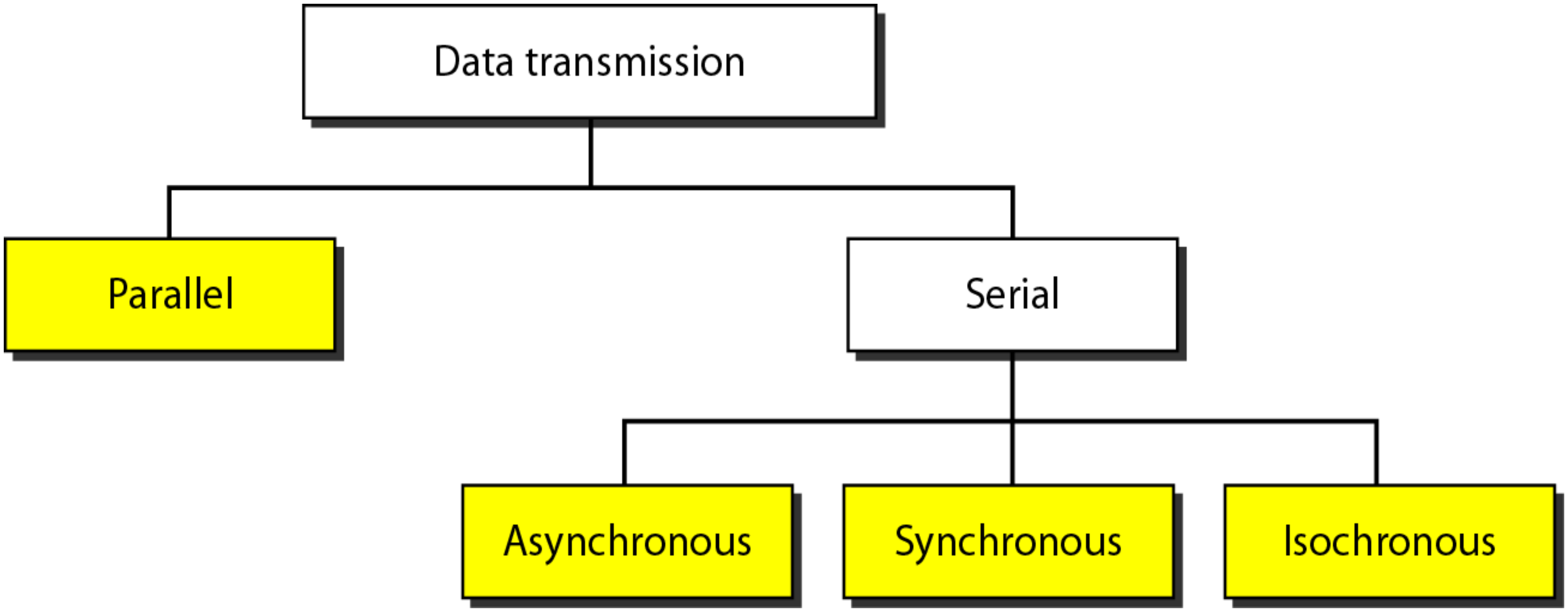


Figure 4.32 *Parallel transmission*

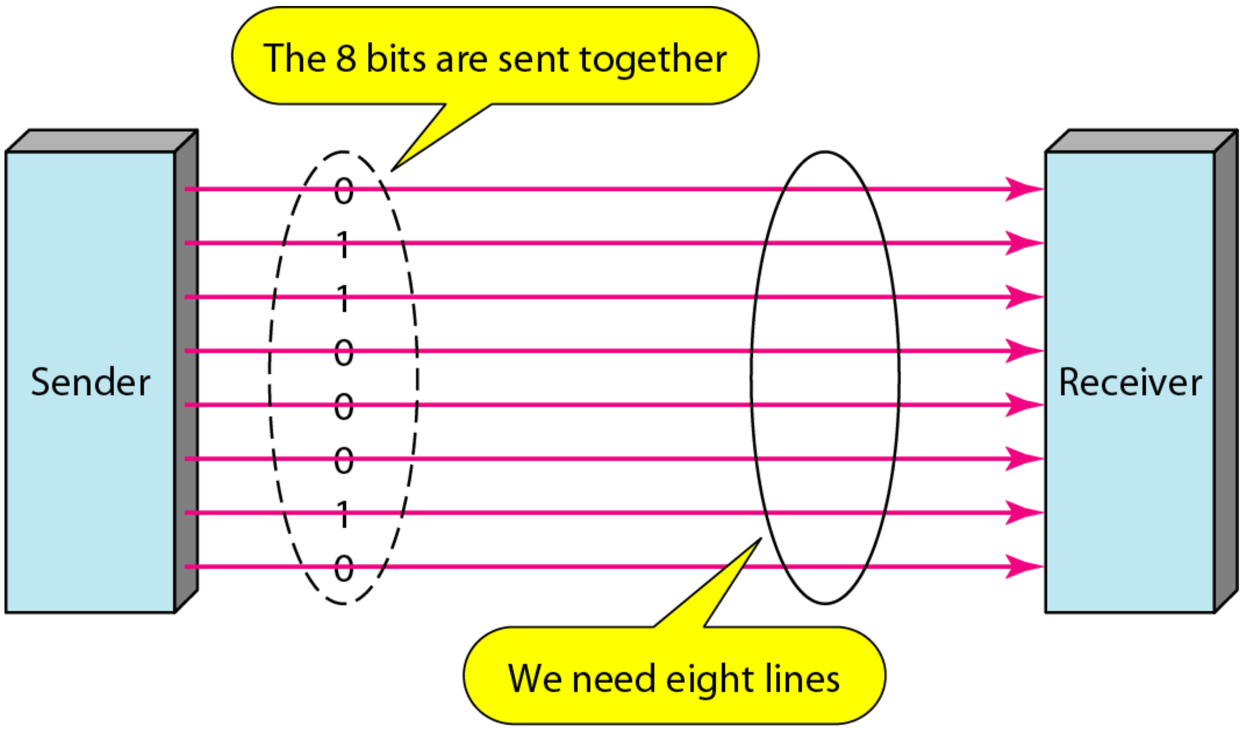


Figure 4.33 *Serial transmission*

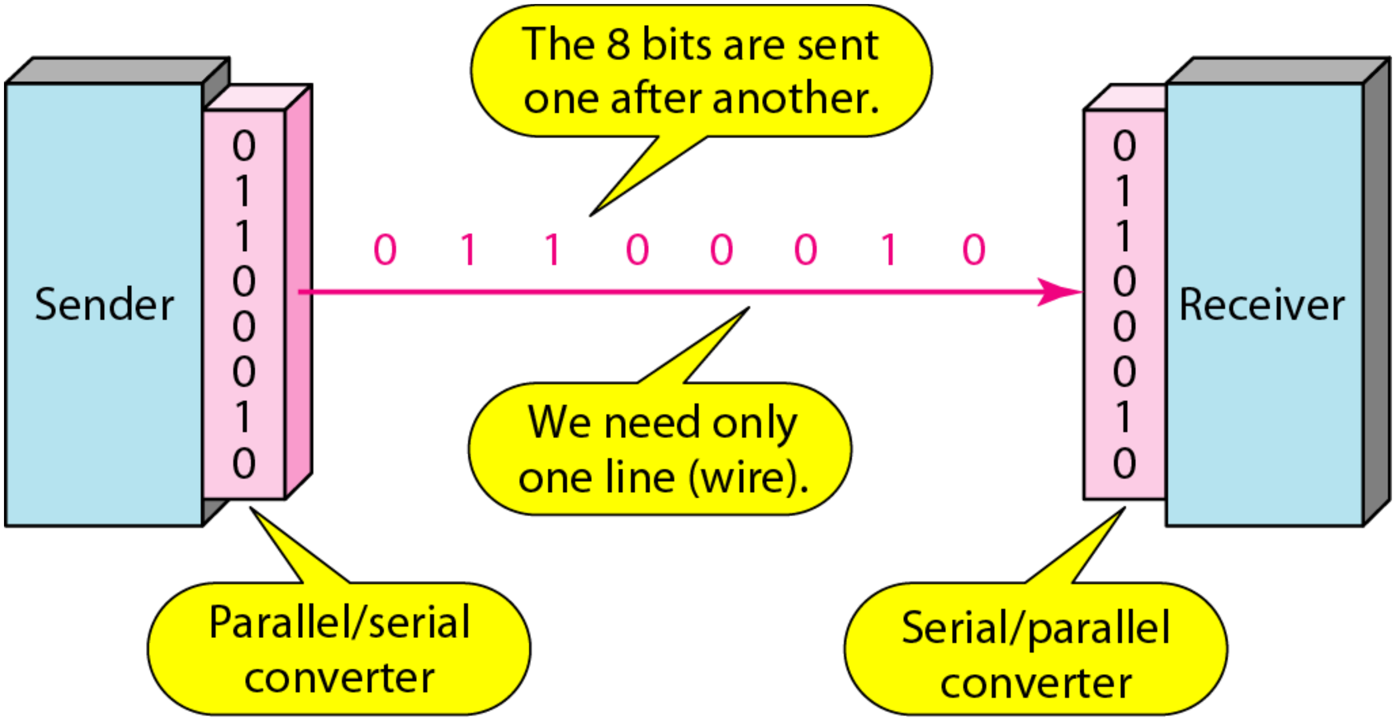


Figure 4.34 *Asynchronous transmission*

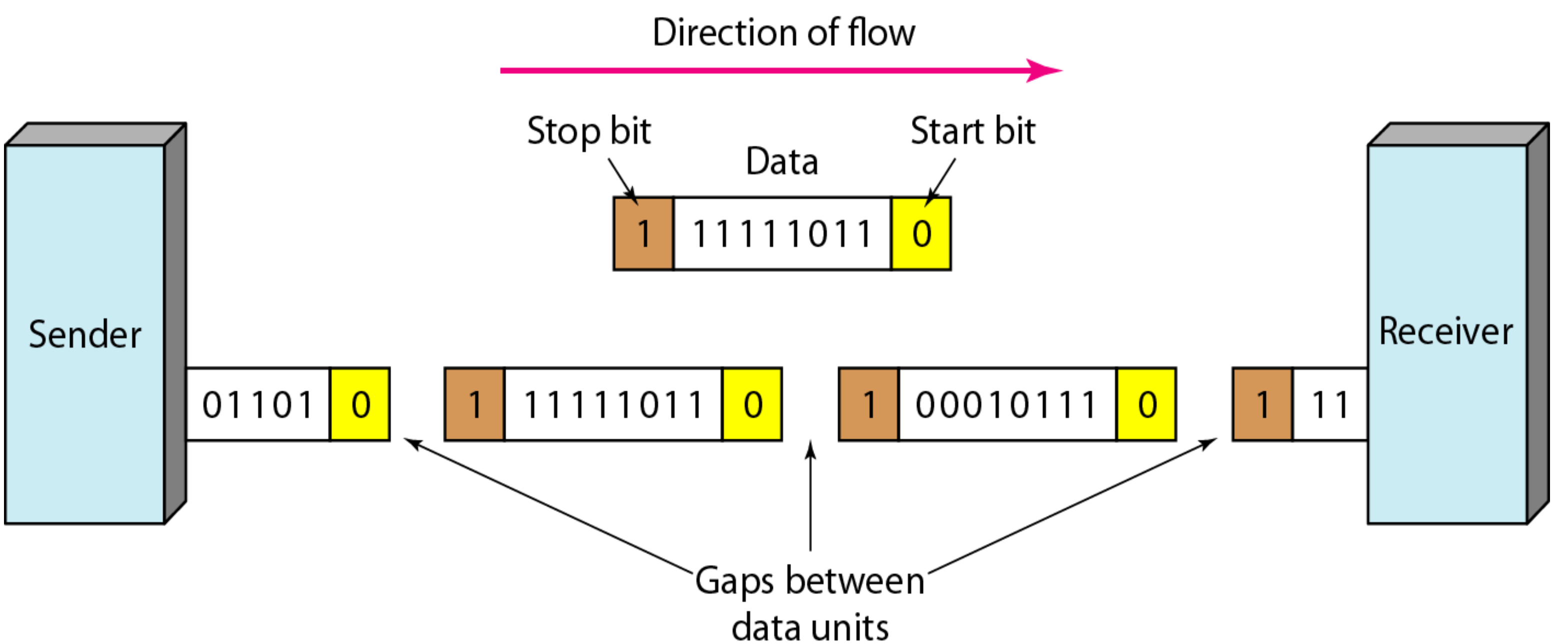
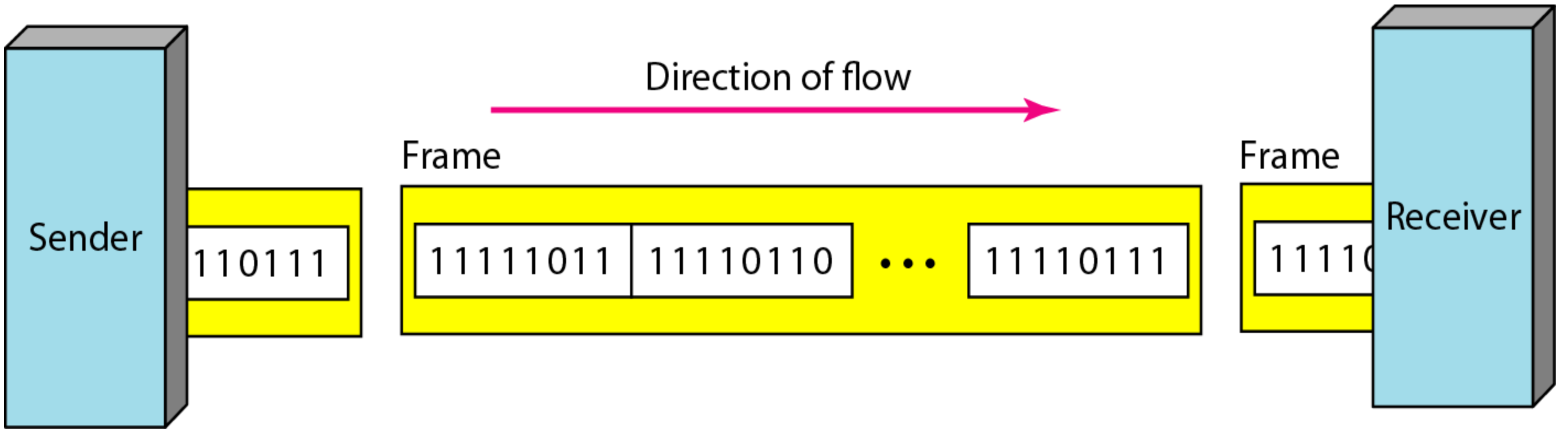


Figure 4.35 *Synchronous transmission*



Reference

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