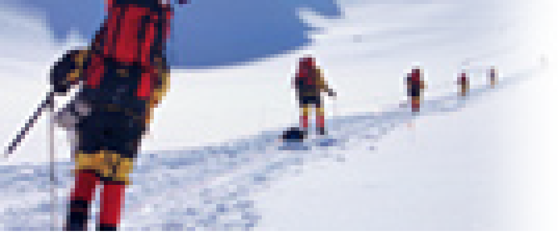


Data Communications and Networking Fourth Edition

Forouzan

Chapter 4

Digital Transmission

Review of Analog and Digital Signals

- Analog Signal
  - An continuously varying electromagnetic wave that may be propagated over a variety of media (e.g., twisted pair or coaxial cable, atmosphere), depending on spectrum.
- Digital Signal
  - An sequence of voltage pulses that may be transmitted over a wire medium, e.g., a constant positive voltage level may represent binary 0 and a constant negative voltage level may represent binary 1.
- Advantages of digital signal over analog signal
  - Cheaper in price
  - Less susceptible to noise interference
- Disadvantages of digital signal over analog signal
  - Suffer more from attenuation
    - Pulses become rounded and smaller
    - Leads to loss of information

Review Q: Why we have to convert information

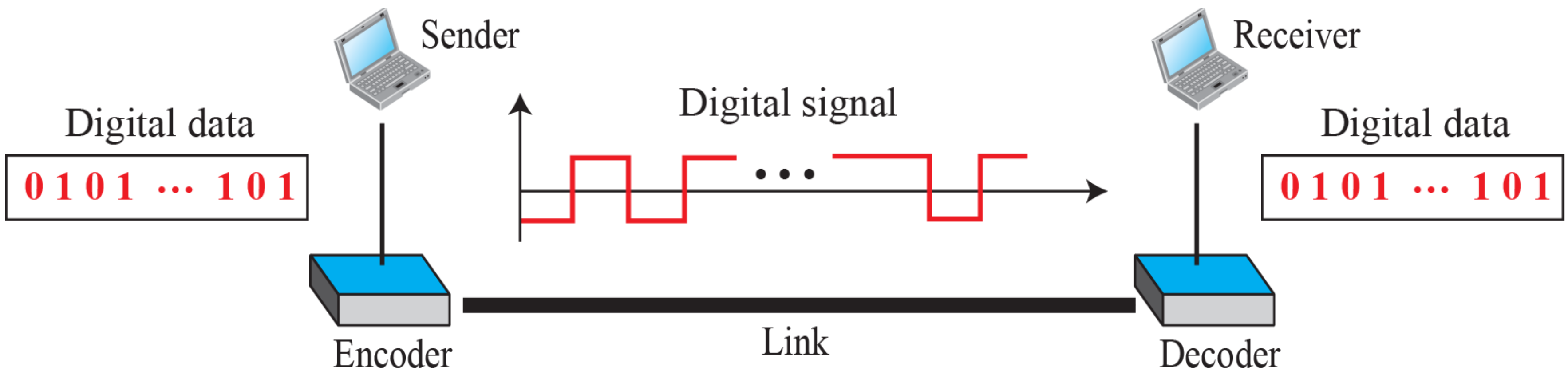
to either a digital signal or an analog signal?

Figure 4.1 *Line coding*

Q: Why we have to convert data to digital signal for transmission?

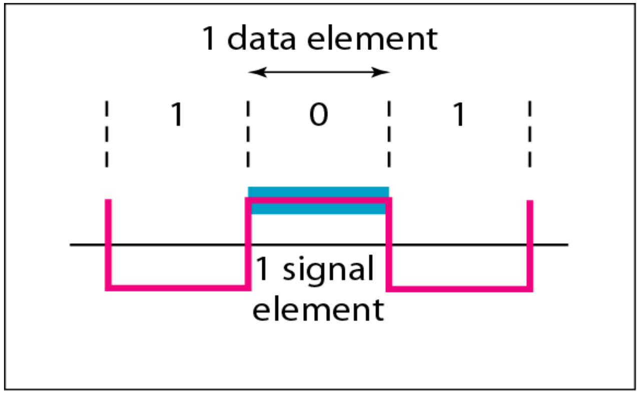
- **Line Coding?**

  Line coding is the process of converting binary data, a sequence of bits, to a digital signal.

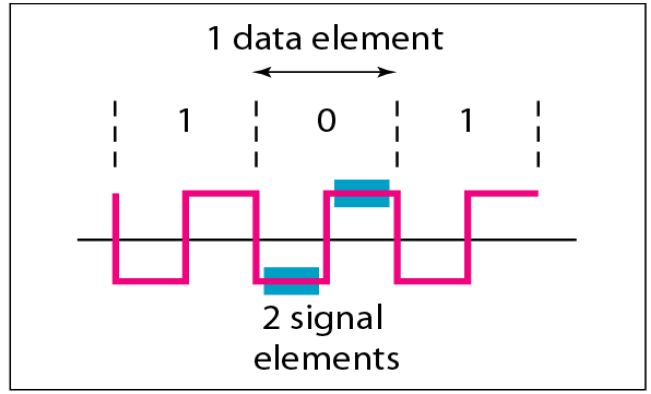


- **Considering points: signal level versus data level, dc components, self-synchronization**

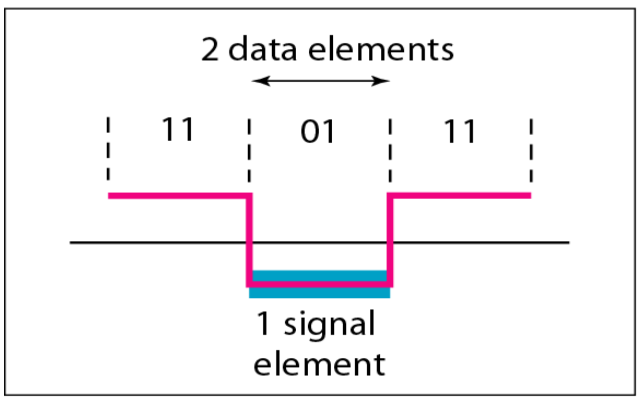
Figure 4.2 *Signal element versus data element*



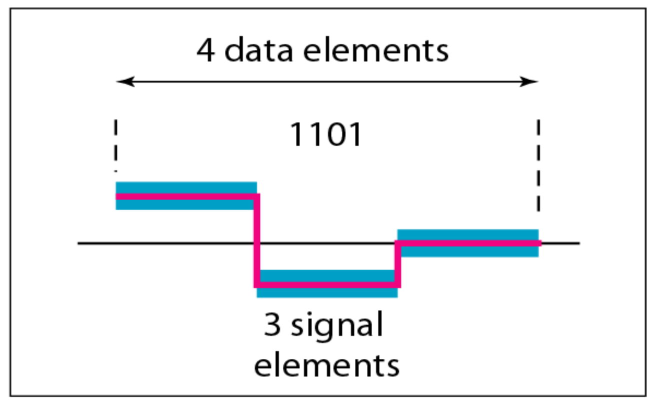
a. One data element per one signal element (r = 1)



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

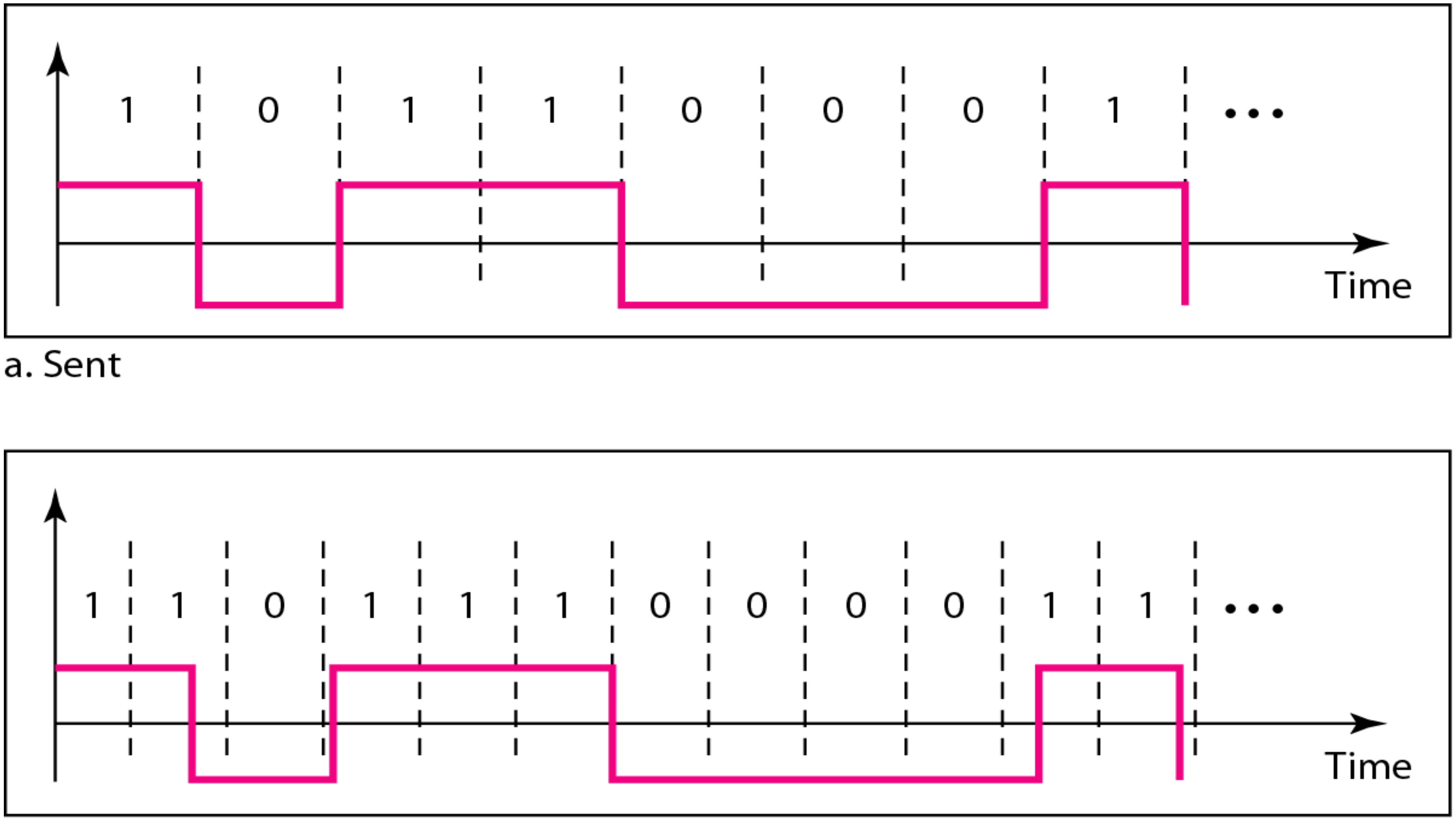


c. Two data elements per one signal element (r = 2)



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

Figure 4.3 *Effect of lack of synchronization*



a. Sent

b. Received

Figure 4.4 *Line coding schemes*

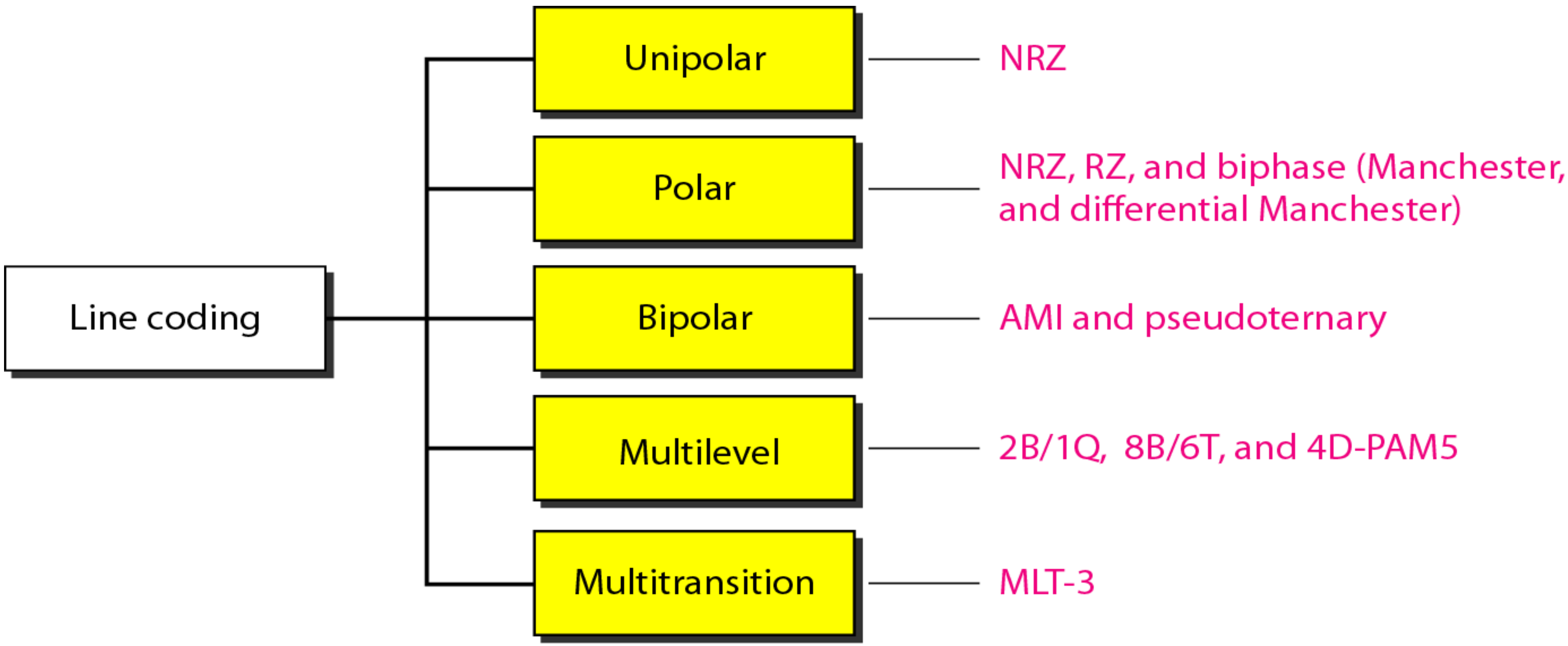
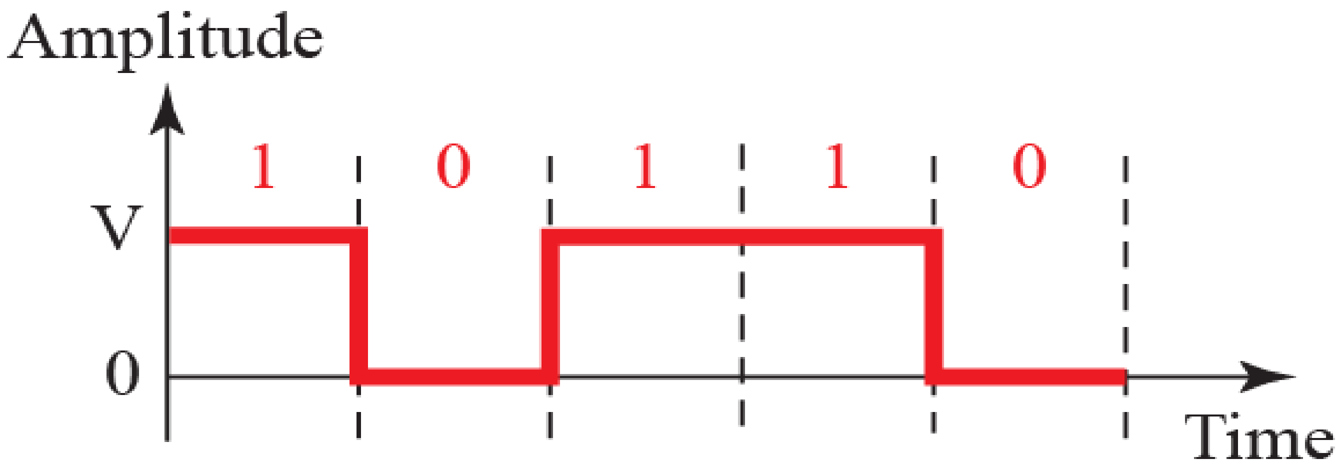


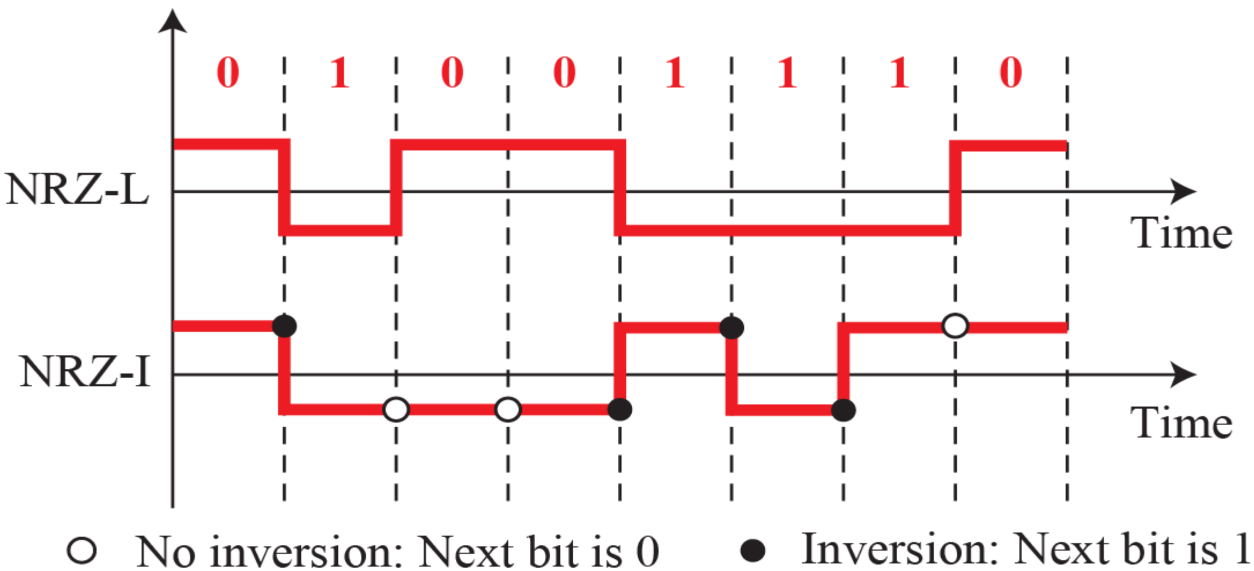
Figure 4.5: Unipolar NRZ scheme



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

Normalized power

Figure 4.6: Polar schemes (NRZ-L and NRZ-I)



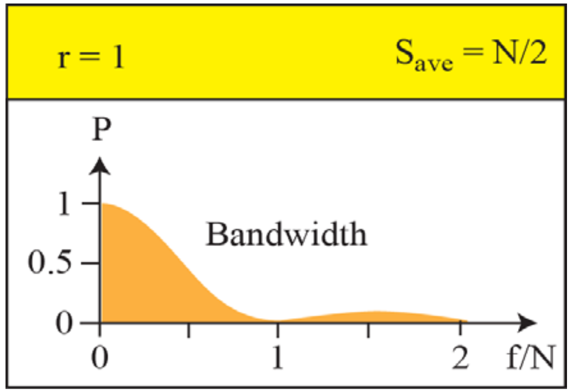
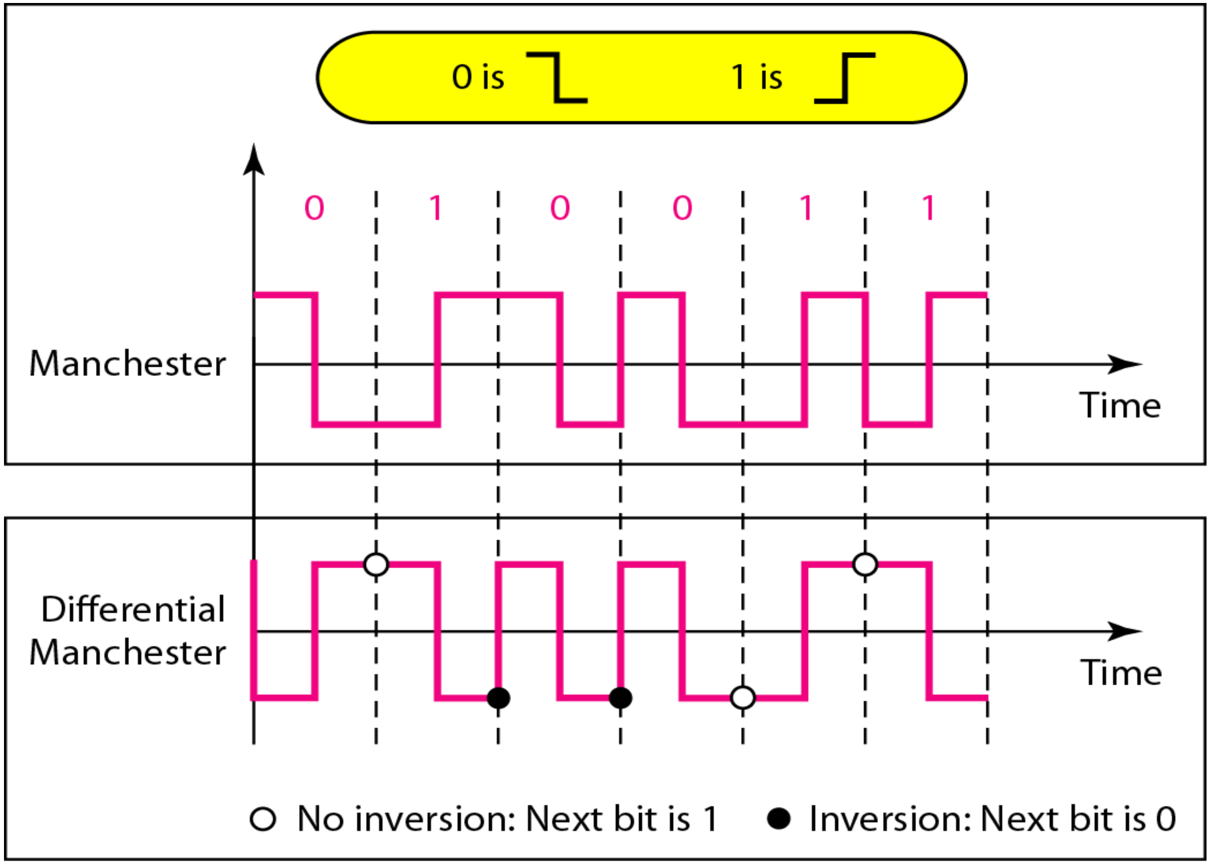


Figure 4.8 *Polar biphase: Manchester and differential Manchester schemes*



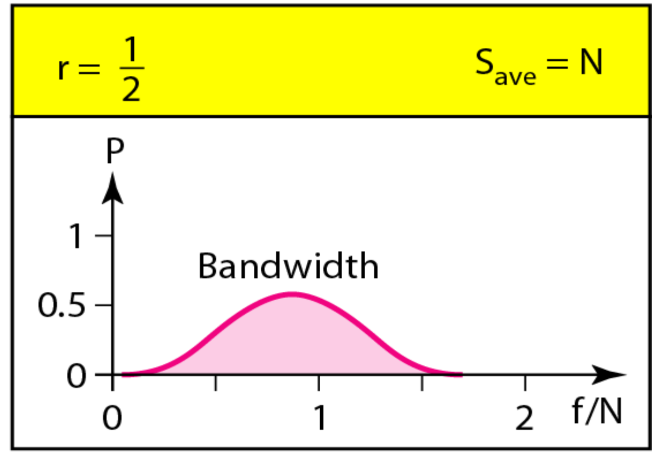
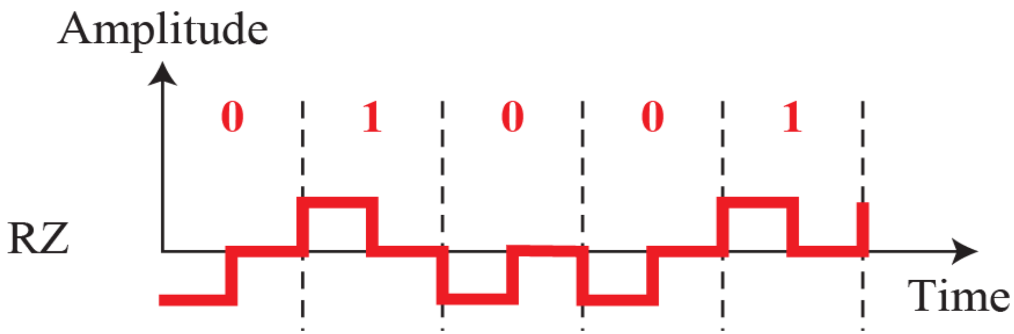


Figure 4.7: Polar schemes (RZ)



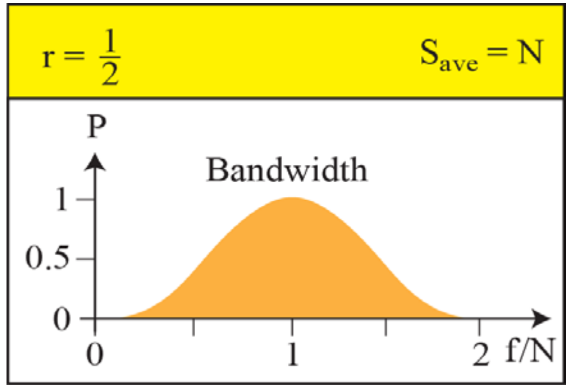
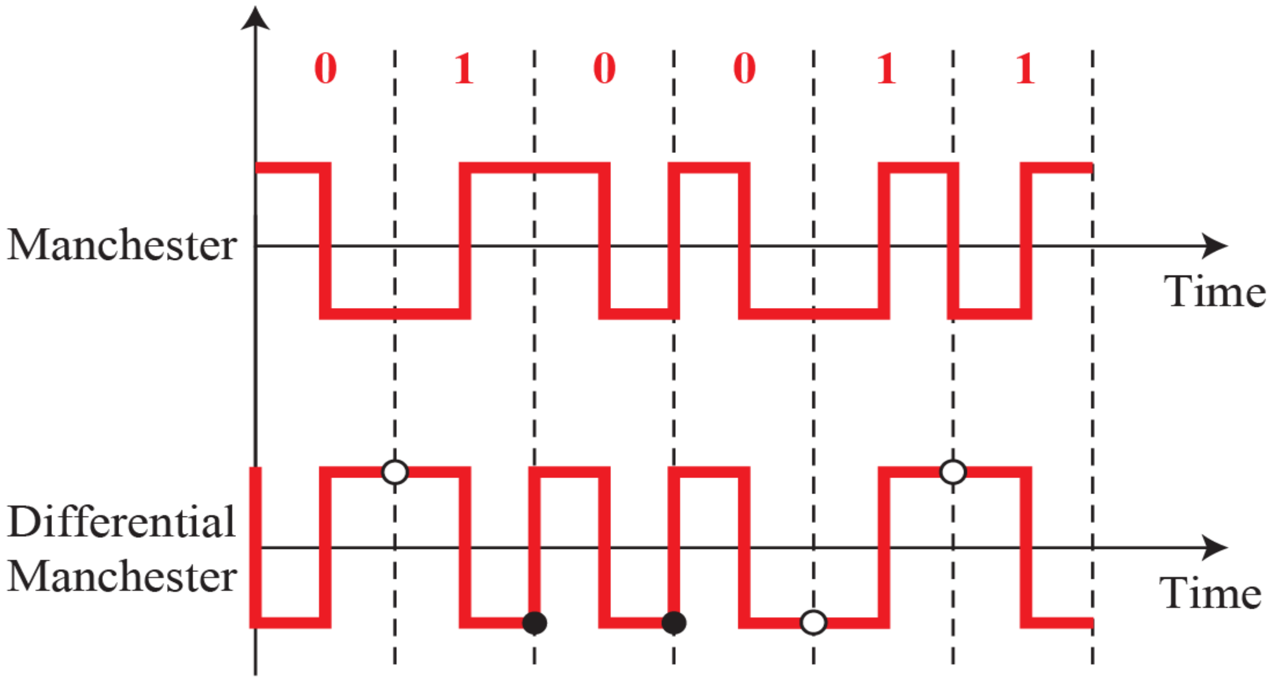
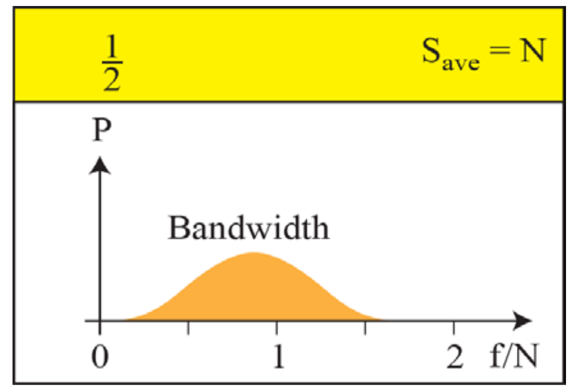


Figure 4.8: Polar biphase





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

Figure 4.9: Bipolar schemes: AMI and pseudoternary

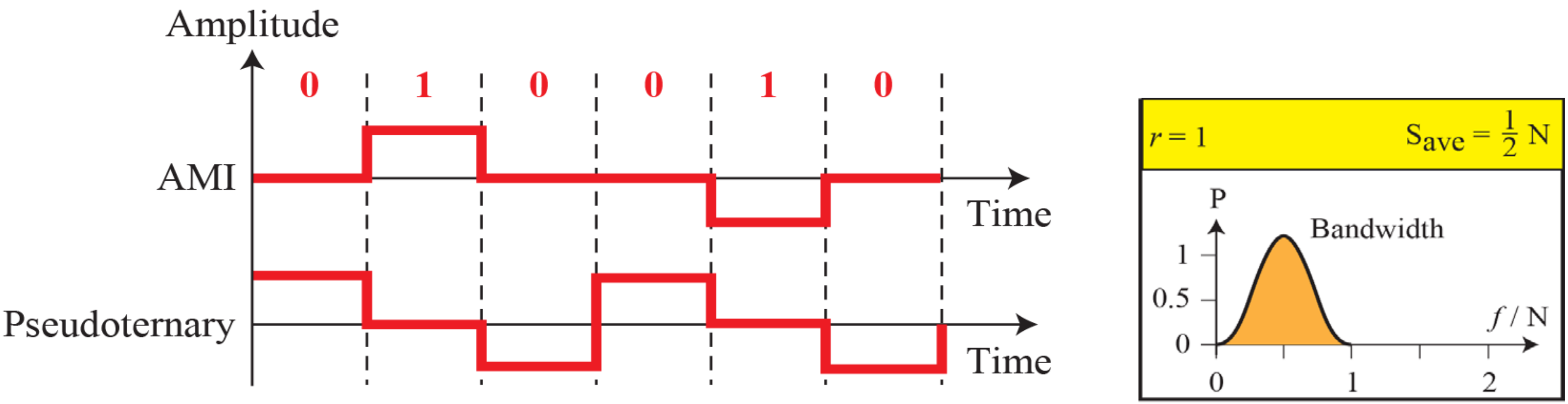


Figure 4.10: Multilevel: 2B1Q

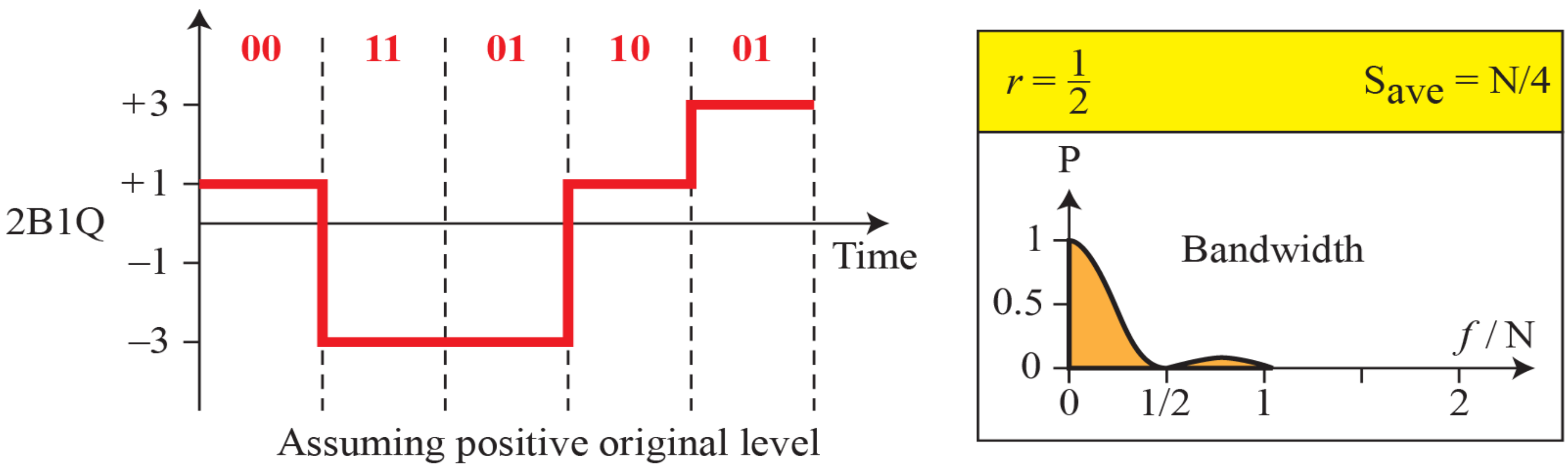


Figure 4.11: Multilevel: 8B6T

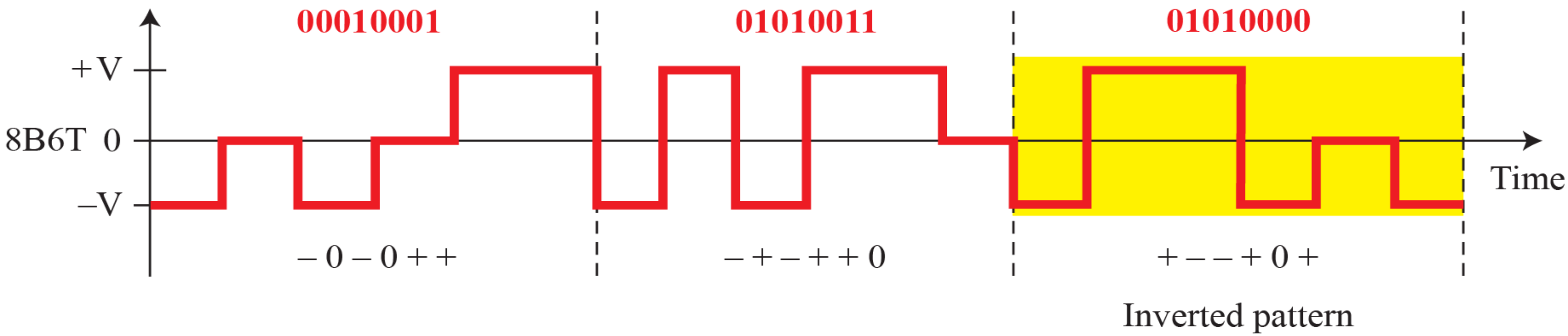


Figure 4.12: Multilevel: 4D-PAMS scheme

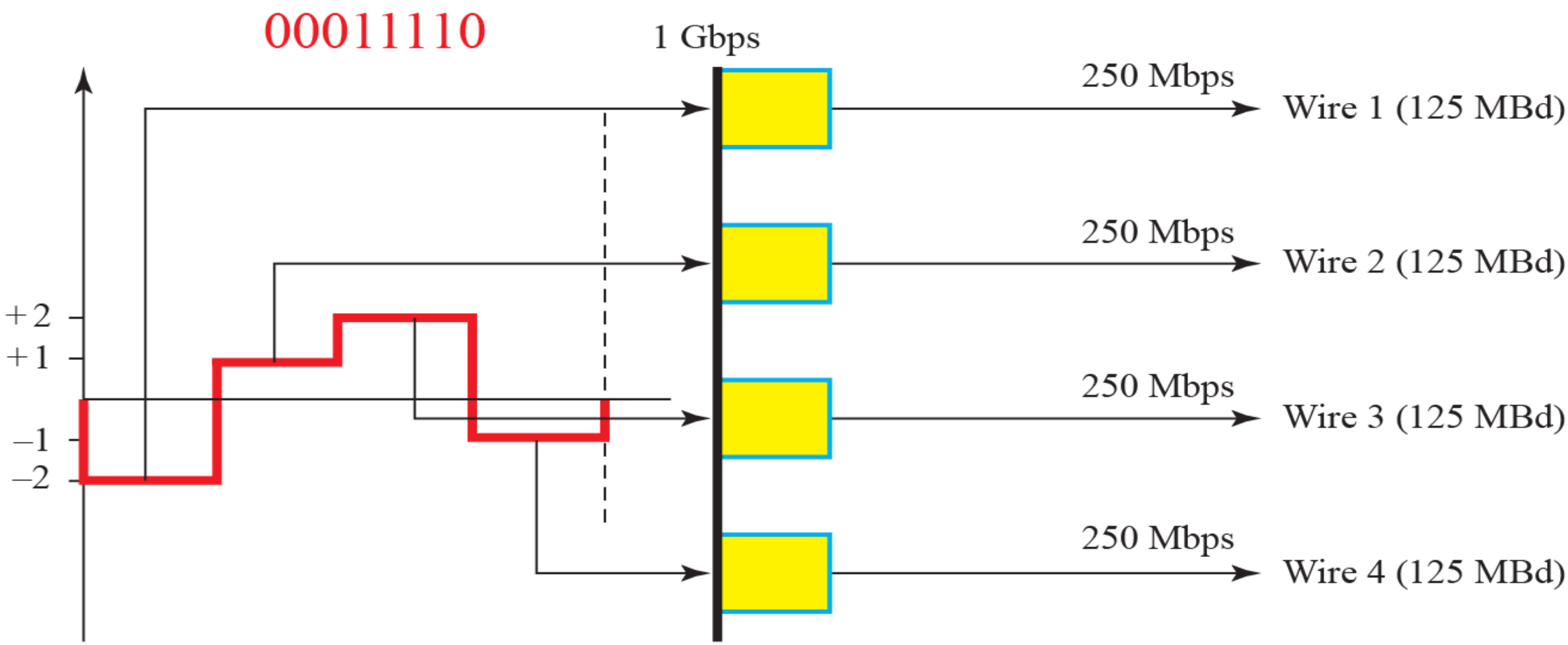


Figure 4.13: Multi-transition MLT-3 scheme

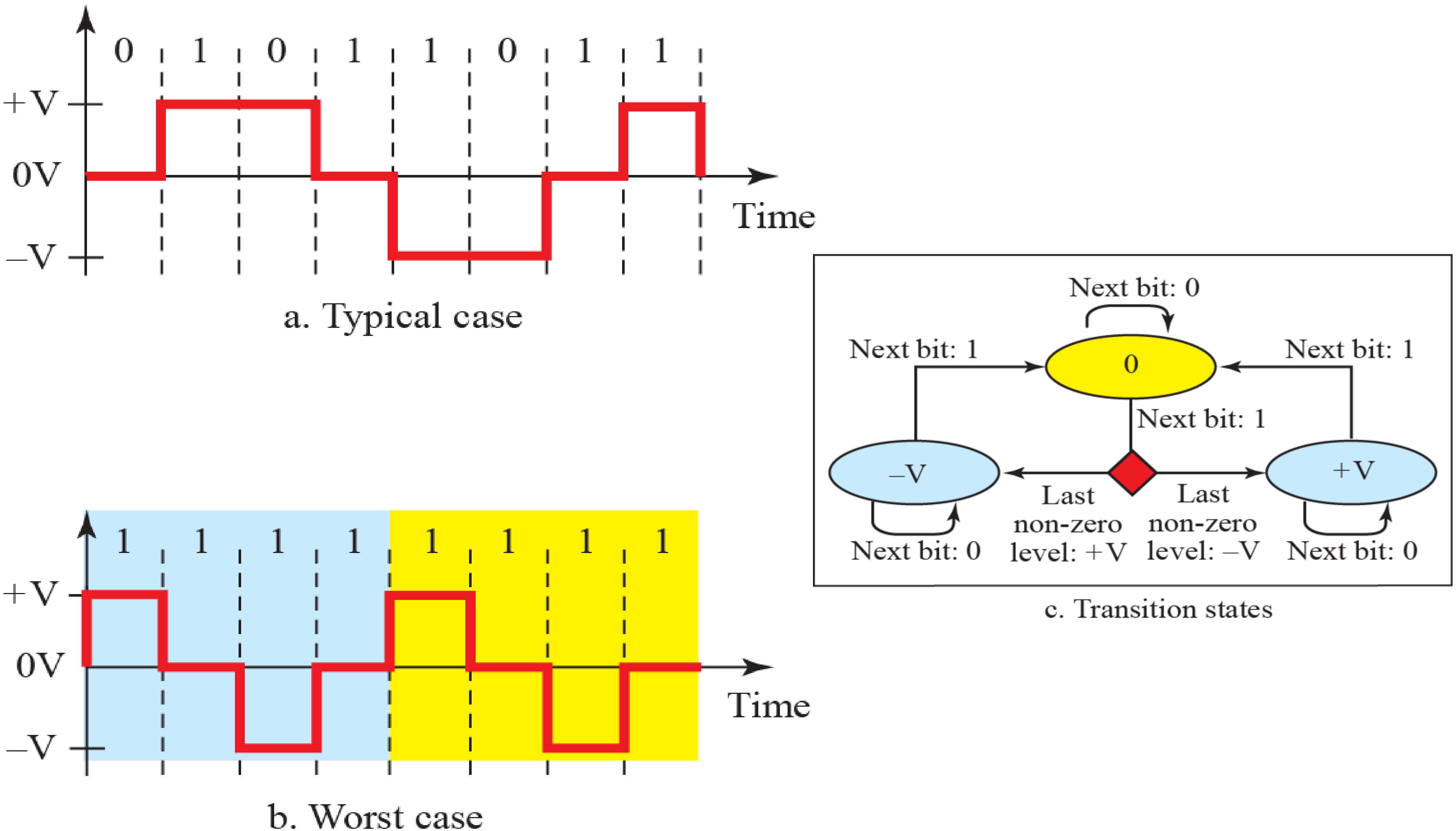
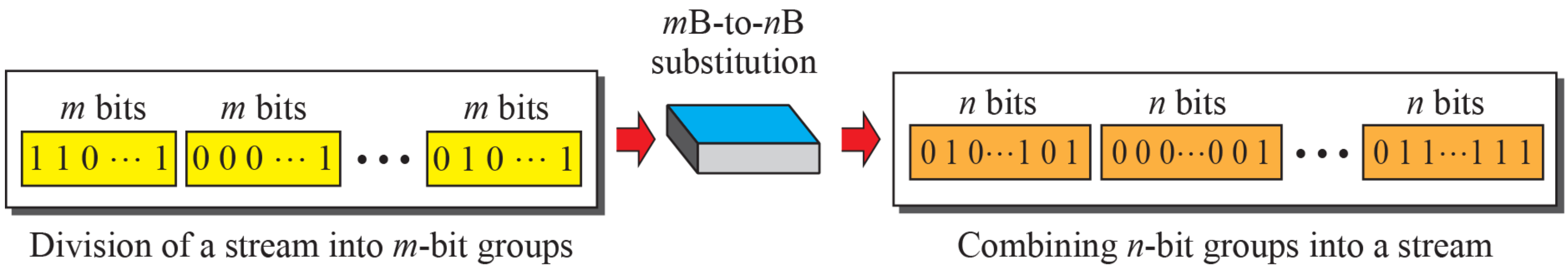


Table 4.1: Summary of line coding schemes

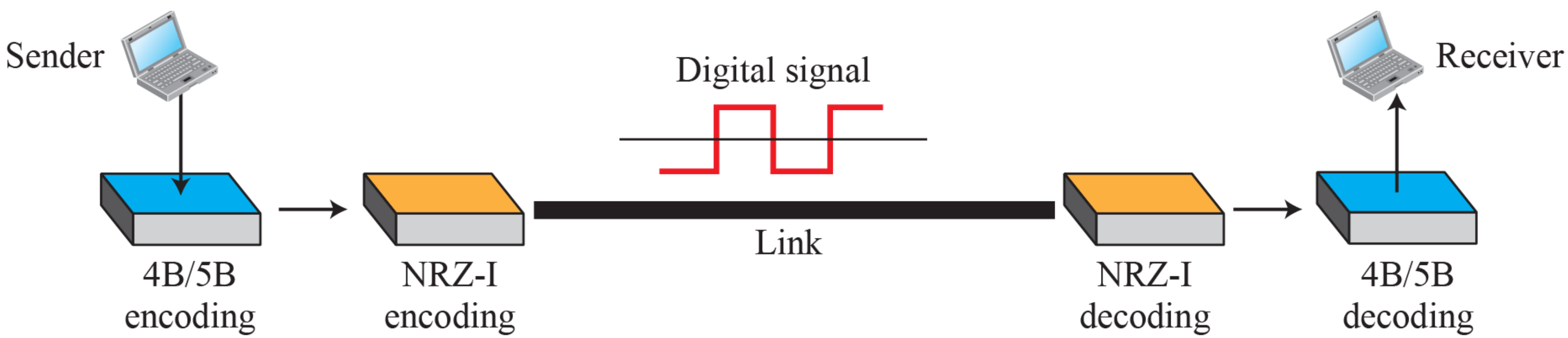
Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Polar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, 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
Multitransition	MLT-3	$B = N/3$	No self-synchronization for long 0s

Block Coding

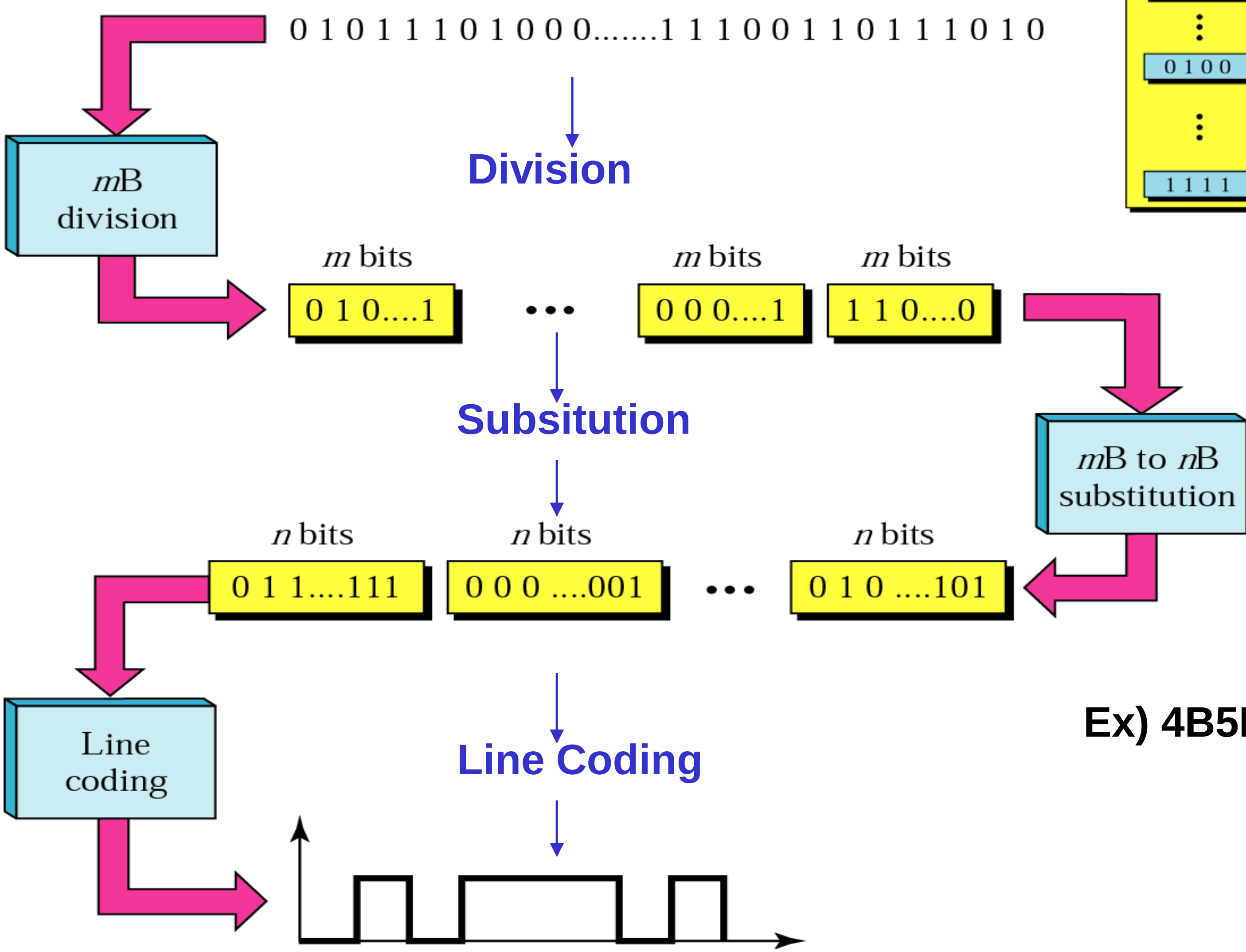
- Figure 4.14: Block coding concept

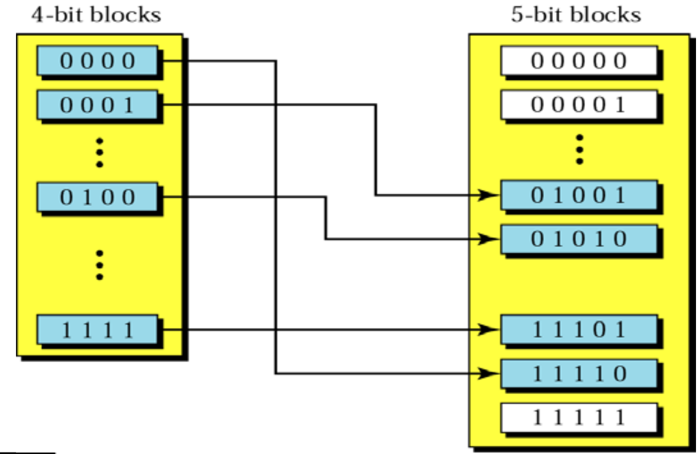


- Figure 4.15: Using block coding 4B/5B with NRZ-I line coding scheme



Block Coding 예





Ex) 4B5B: Fast Ethernet & FDDI

Table 4.2 *4B/5B mapping codes*

Invalid code

Data Sequence	*Encoded Sequence*	*Control Sequence*	*Encoded Sequence*
0000	11110	Q (Quiet)	00000
0001	01001	I (Idle)	11111
0010	10100	H (Halt)	00100
0011	10101	J (Start delimiter)	11000
0100	01010	K (Start delimiter)	10001
0101	01011	T (End delimiter)	01101
0110	01110	S (Set)	11001
0111	01111	R (Reset)	00111
1000	10010	**Invalid code**	
1001	10011		
1010	10110		
1011	10111		
1100	11010		
1101	11011		
1110	11100		
1111	11101		

Figure 4.16 *Substitution in 4B/5B block coding*

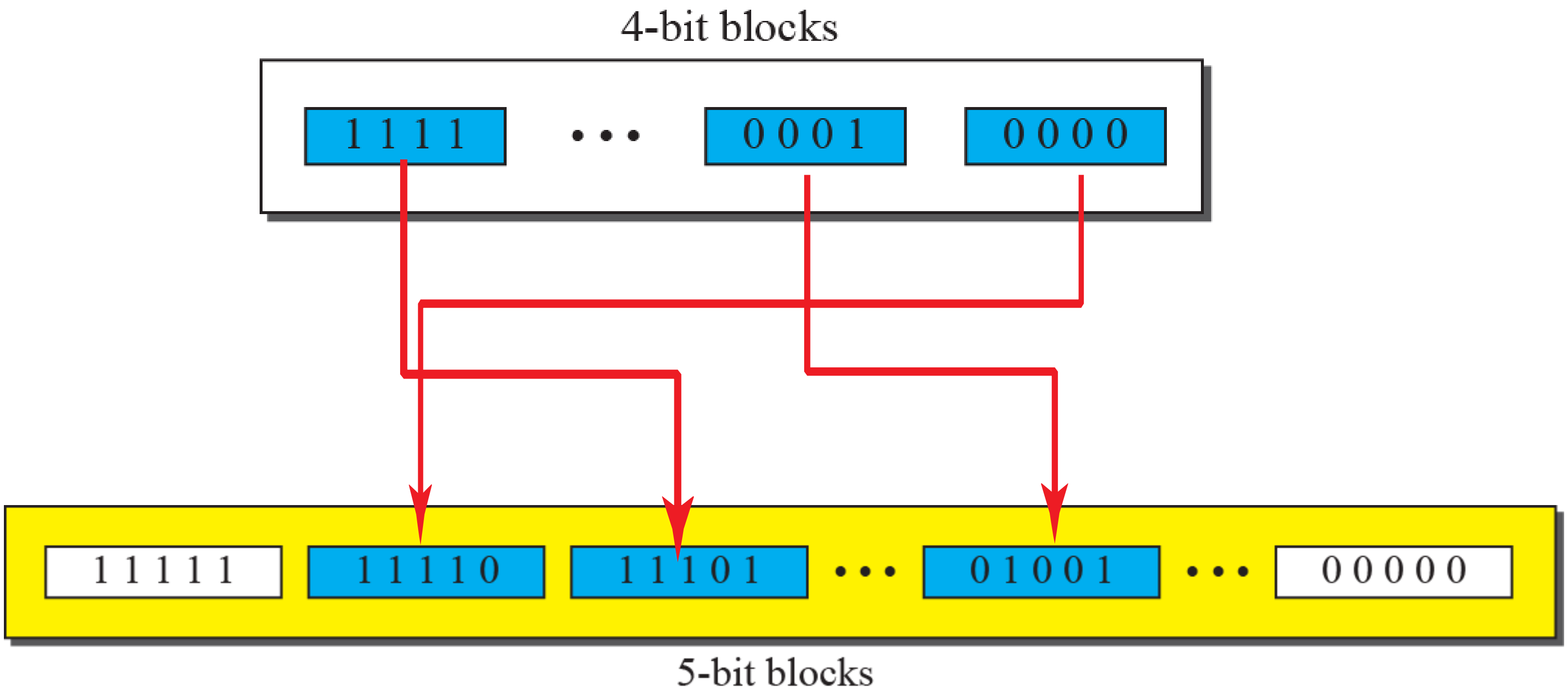
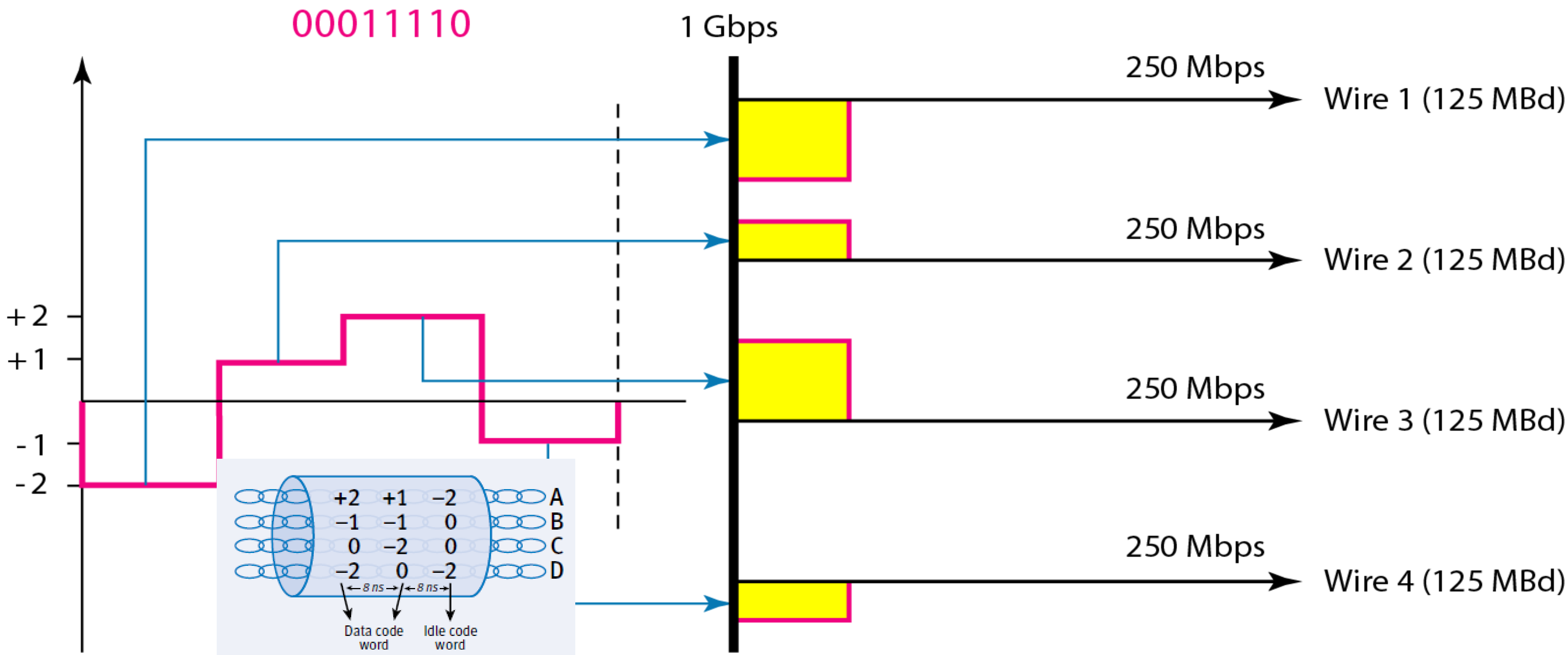


Figure 4.12 *Multilevel: 4D-PAM5 scheme*

기가비트 LAN 용



4-Dimensional 5-level Pulse Amplitude Modulation (PAM)

Symbol	Mapped voltage level (volts)
−2	−1
−1	−0.5
0	0
+1	+0.5
+2	+1

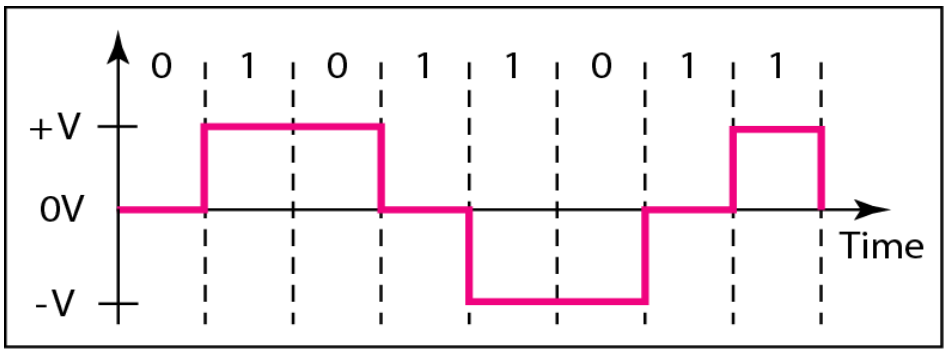
Figure 4.13 *Multitransition: MLT-3 scheme*

3 레벨의 신호 (+, 0, -) 과 3 가지 규칙을 사용하여 부호화

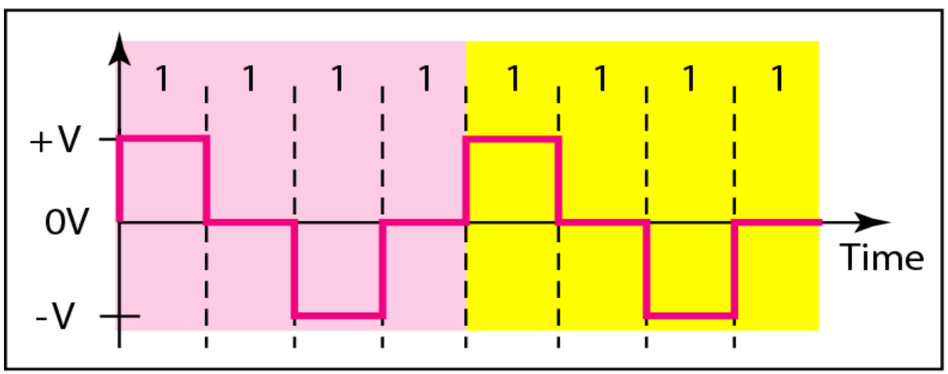
다음 비트가 0 이면 레벨 변화가 없다

다음 비트가 1 이고 현재 레벨이 0 이 아니면 다음 레벨은 0

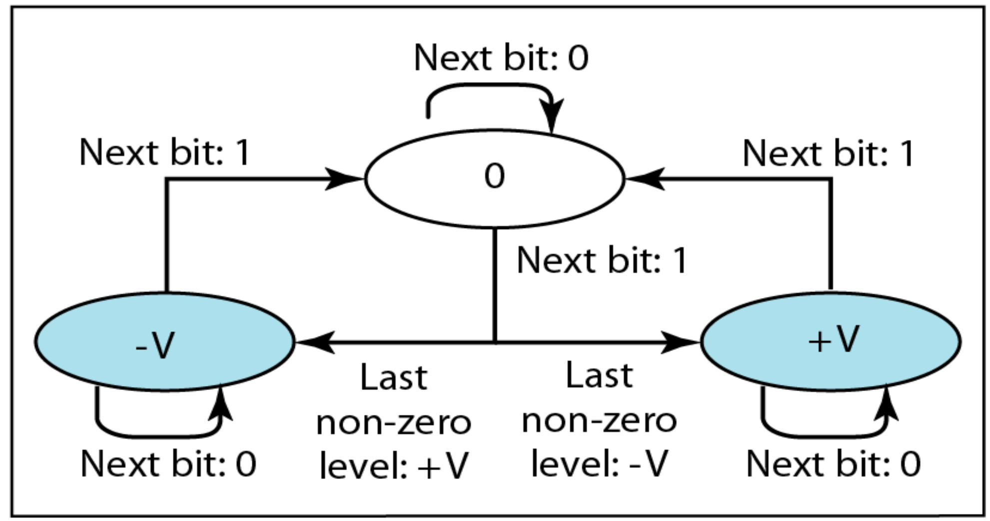
다음 비트가 1 이고 현재 레벨이 0 이면 다음 레벨은 최근 0 이 아니었던 레벨의 역



a. Typical case



b. Worse case

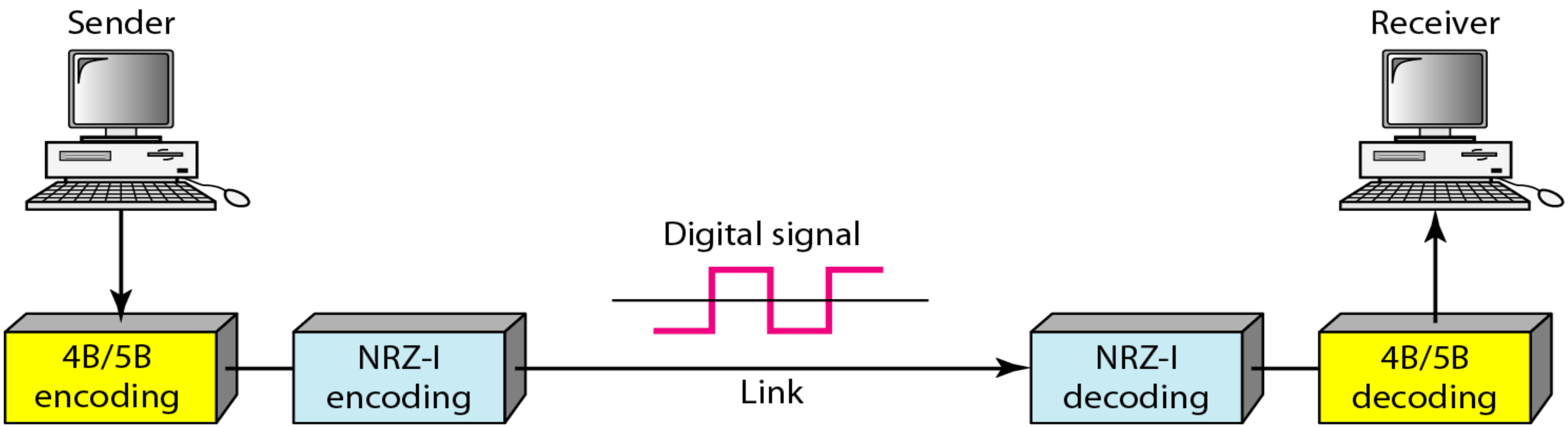


c. Transition states

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

Figure 4.15 *Using block coding 4B/5B with NRZ-I line coding scheme*



4-2 ANALOG-TO-DIGITAL CONVERSION

We have seen in Chapter 3 that a digital signal is superior to an analog signal. 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.

Topics discussed in this section:

Pulse Code Modulation (PCM)
Delta Modulation (DM)

Figure 4.21 *Components of PCM encoder*

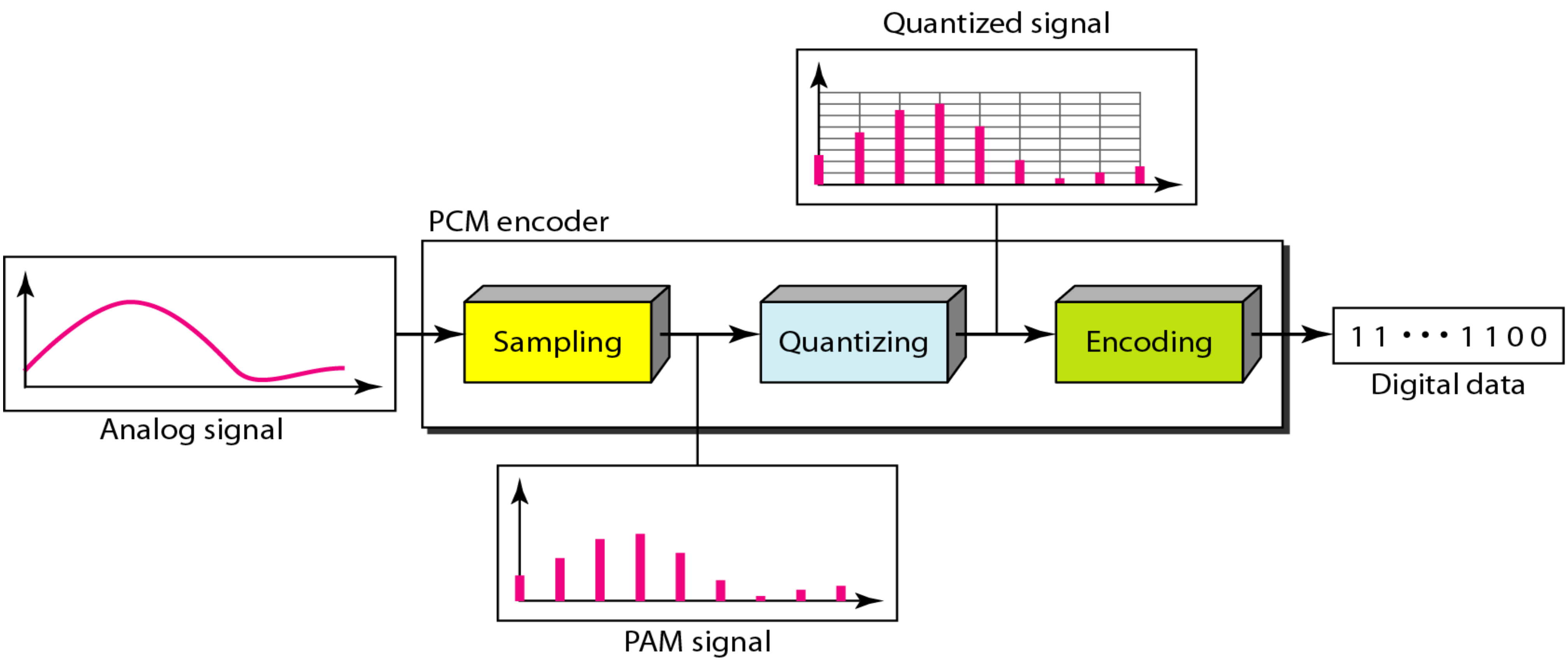


Figure 4.27: Components of a PCM decoder

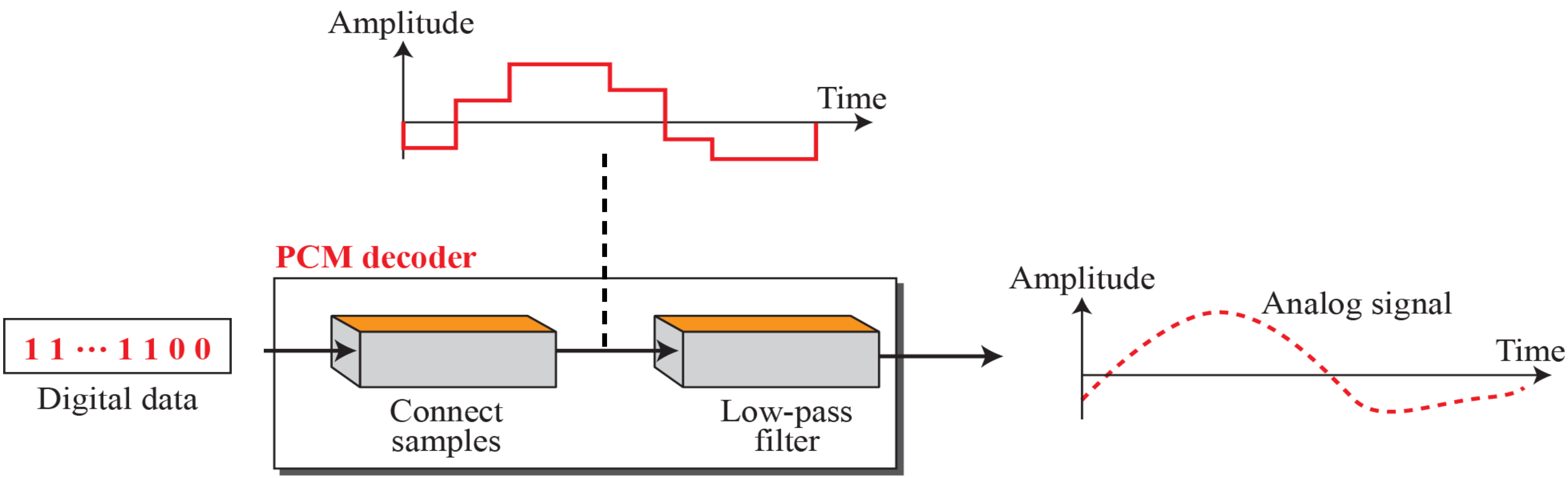
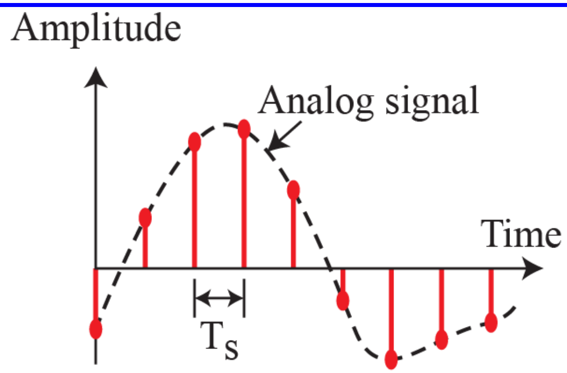
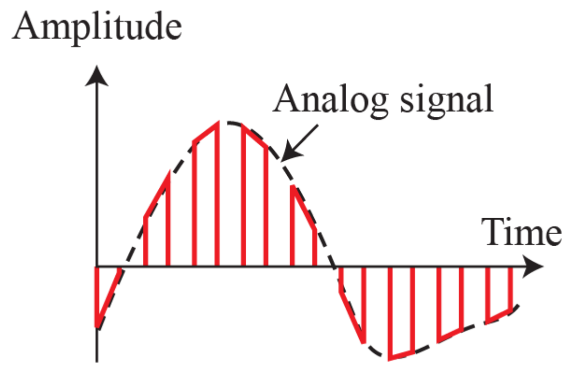


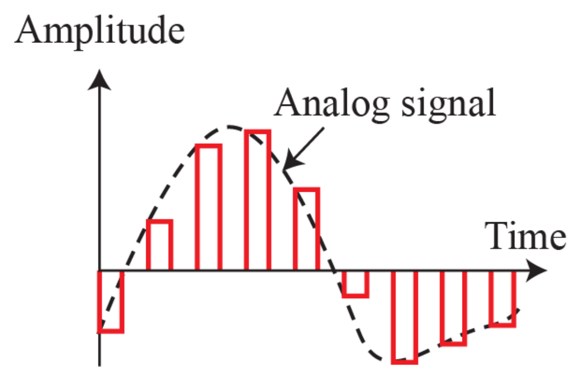
Figure 4.22 *Three different sampling methods for PCM*



a. Ideal sampling



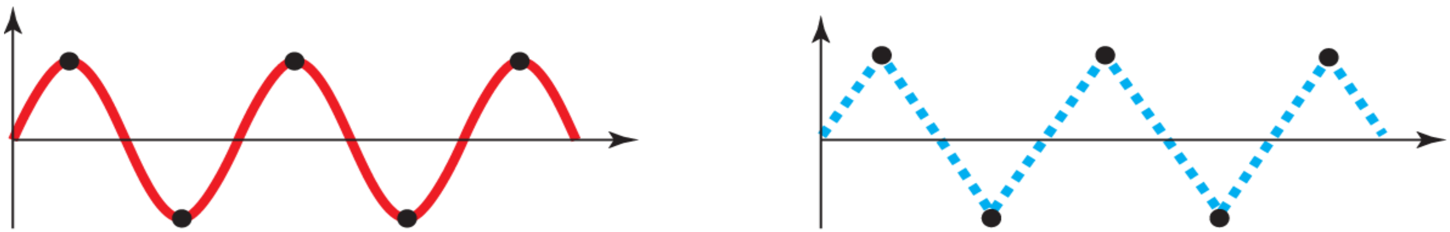
b. Natural sampling



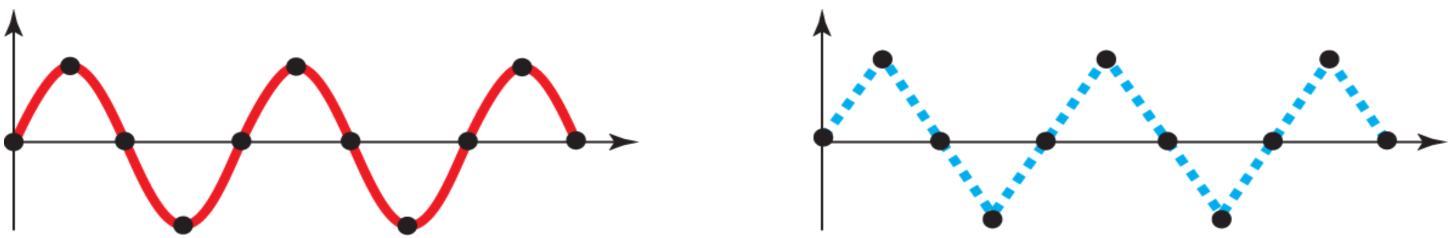
c. Flat-top sampling

the Nyquist theorem → $f_s = 2f$ (Nyquist rate)
the sampling and the subsequent recovery of the signal

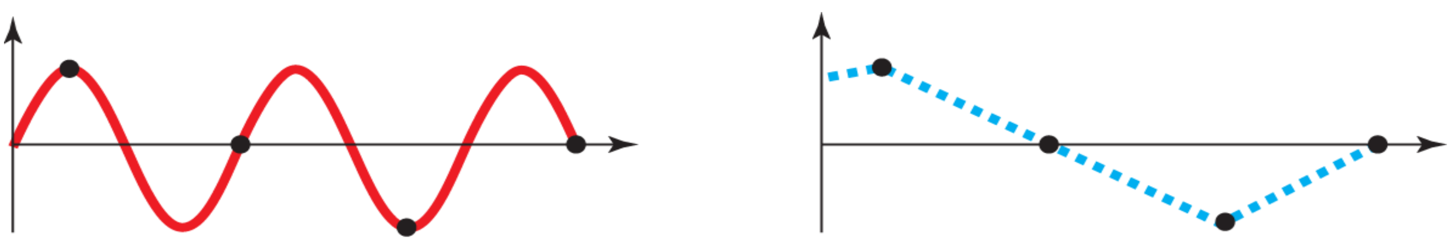
Figure 4.24: Recovery of a sine wave with different sampling rates.



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



b. Oversampling: $f_s = 4\ f$



c. Undersampling: $f_s = \ f$

4.3 Transmission Mode

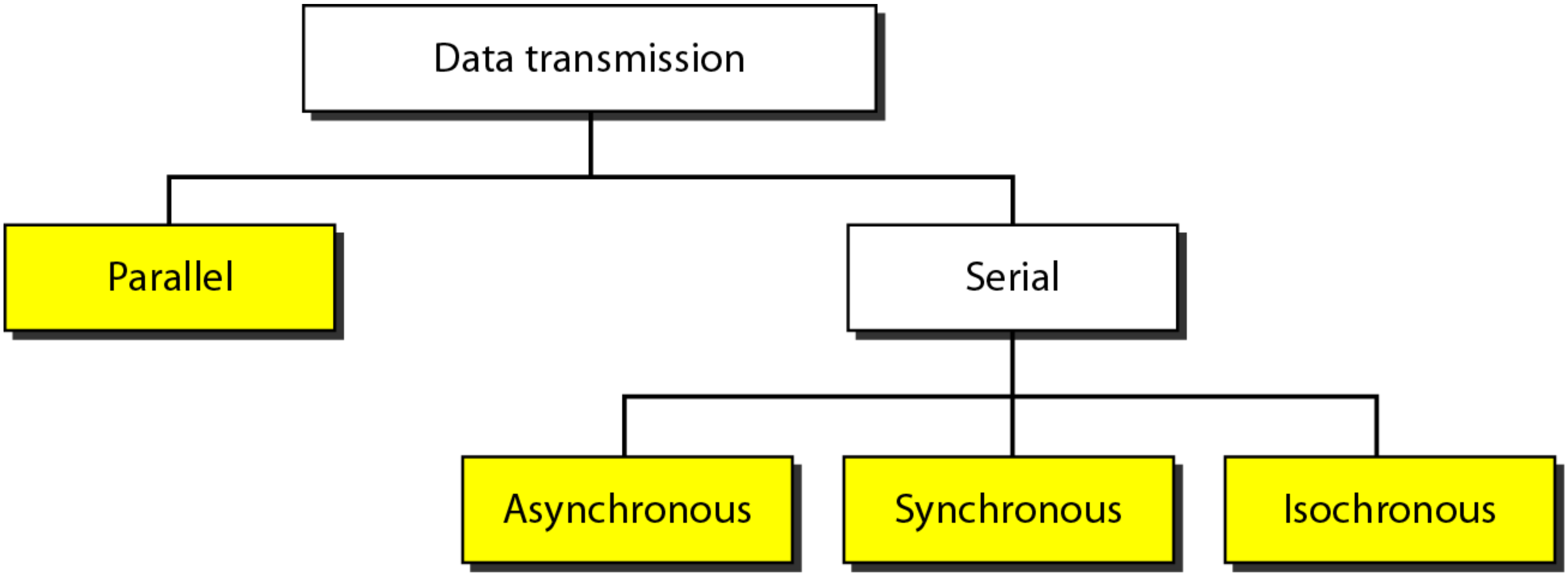


Figure 4.32-33 *Parallel and Serial transmission*

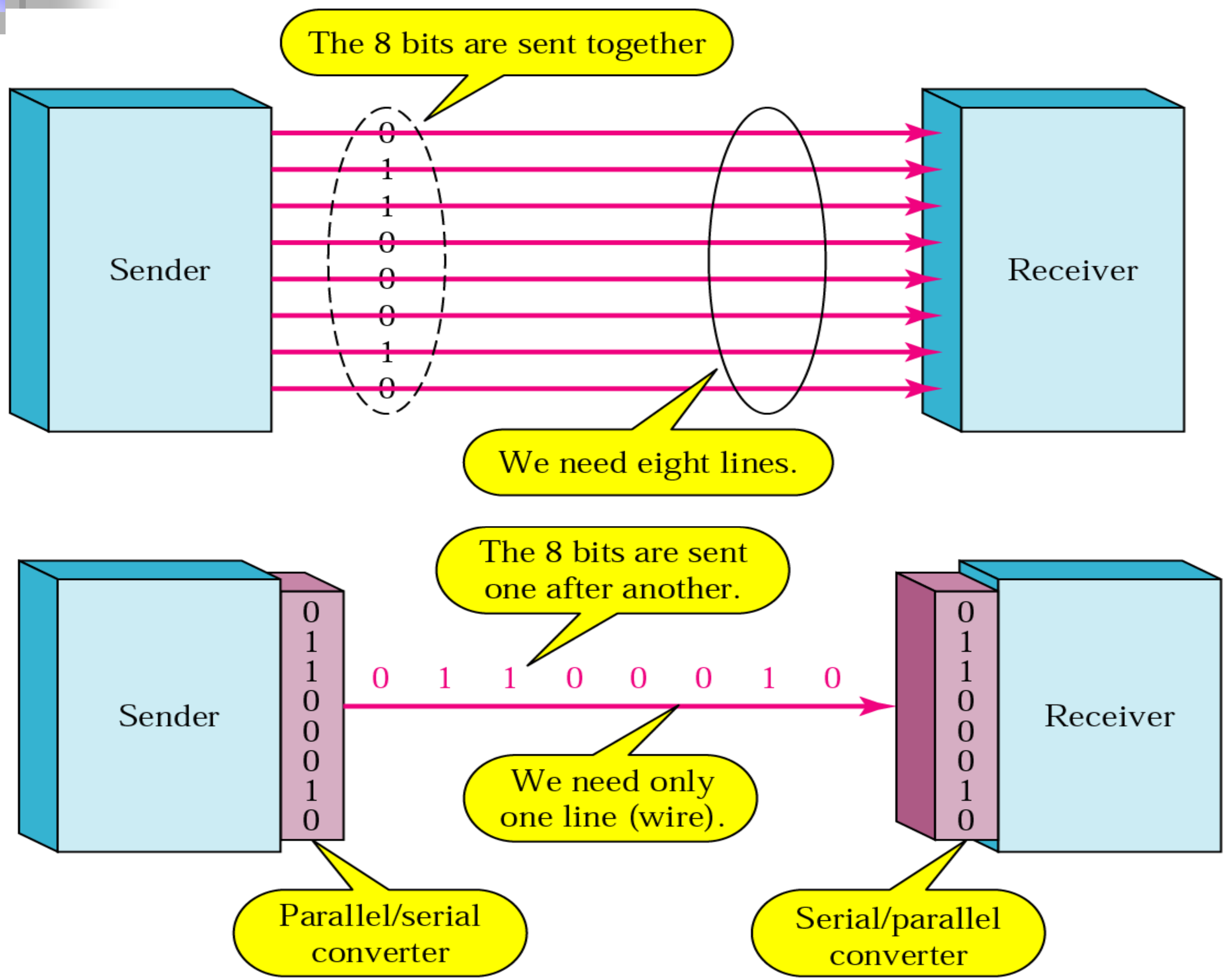
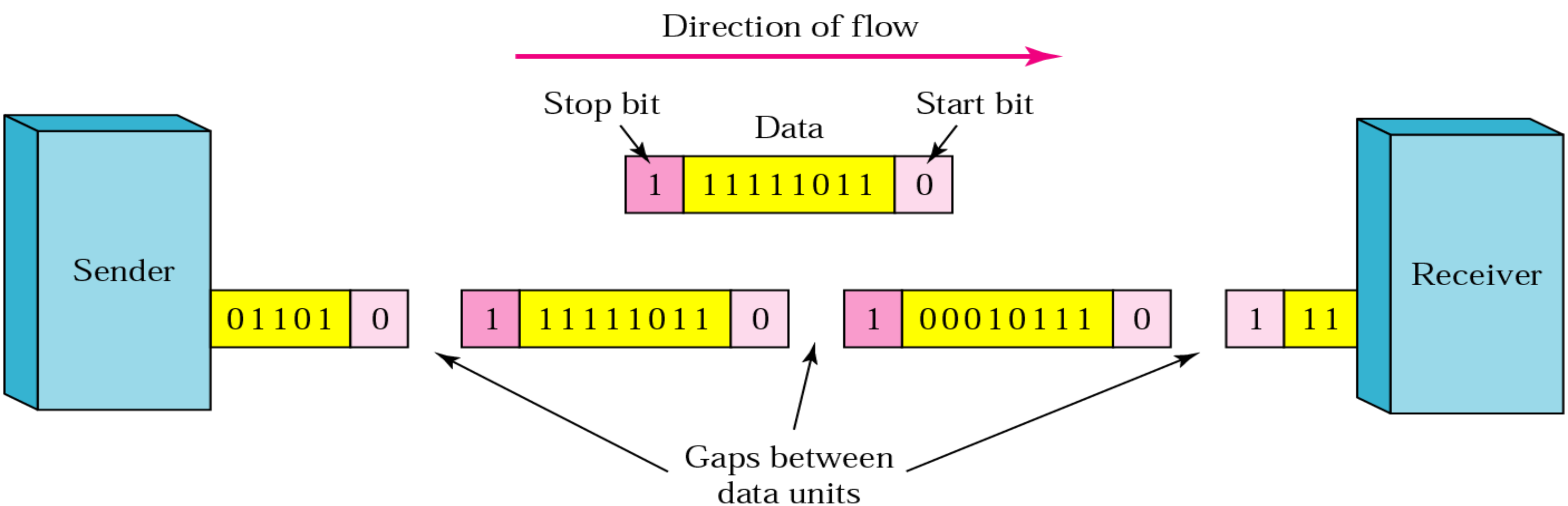
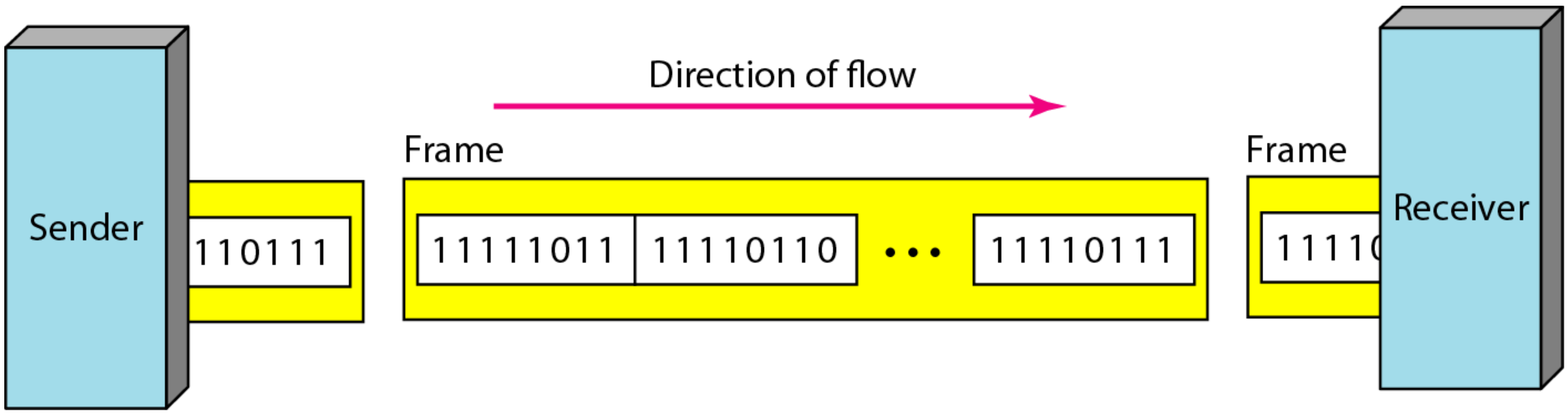


Figure 4.34 *Asynchronous transmission*



Asynchronous here means "asynchronous at the byte level," but the bits are still synchronized; their durations are the same.

Figure 4.35 *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.