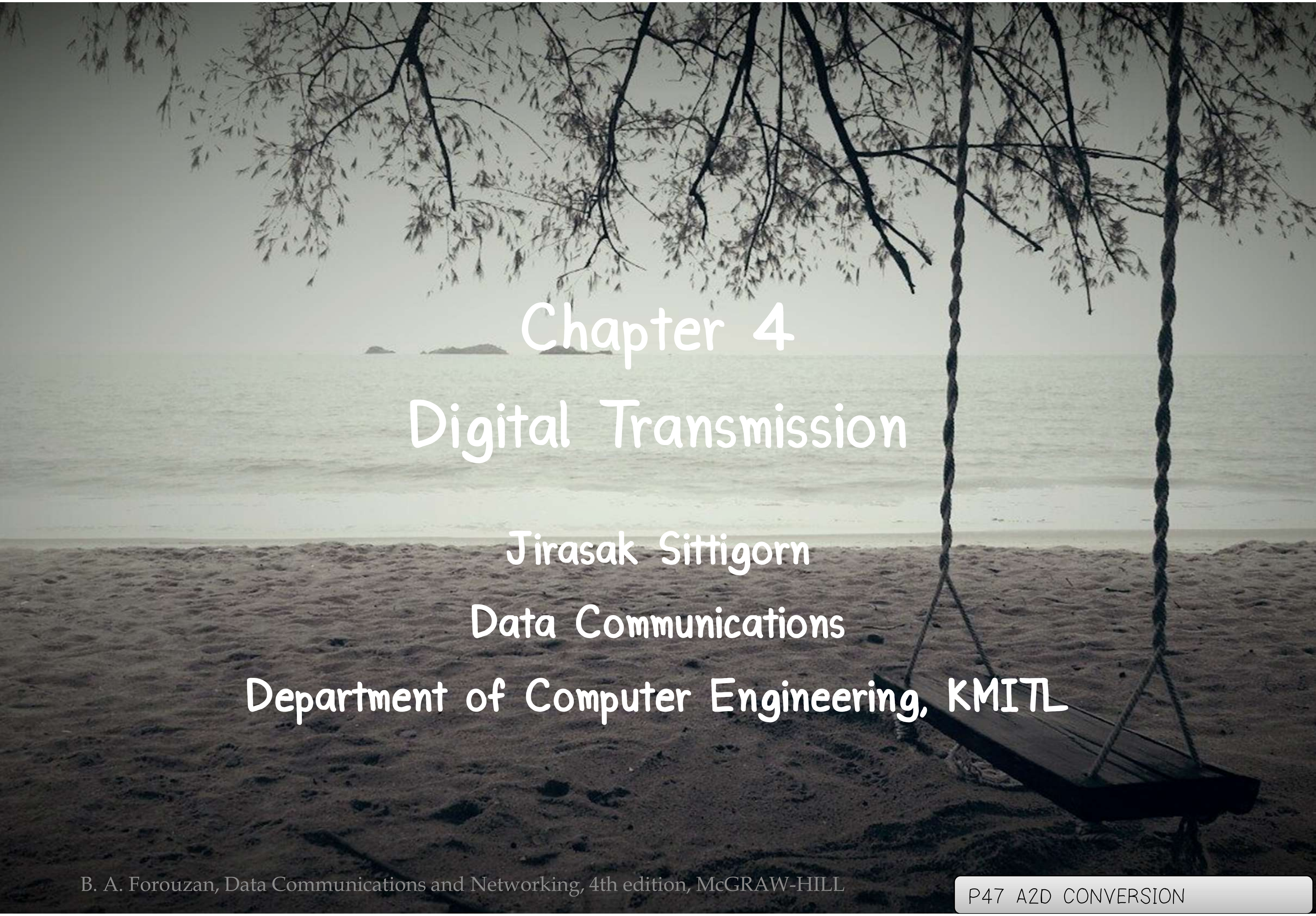

Chapter 4
Digital Transmission

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B. A. Forouzan, Data Communications and Networking, 4th edition, McGRAW-HILL

P47 A2D CONVERSION

Digital Transmission

- DIGITAL-TO-DIGITAL CONVERSION
  - Line Coding
  - Block Coding
  - Scrambling
- ANALOG-TO-DIGITAL CONVERSION
  - Pulse Code Modulation (PCM)
  - Delta Modulation (DM)

DIGITAL-TO-DIGITAL CONVERSION

- LINE CODING
- LINE CODING SCHEMES
- BLOCK CODING
- SCRAMBLING

Line Coding

- the process of converting digital data to digital signals
  - converts a sequence of bits to a digital signal

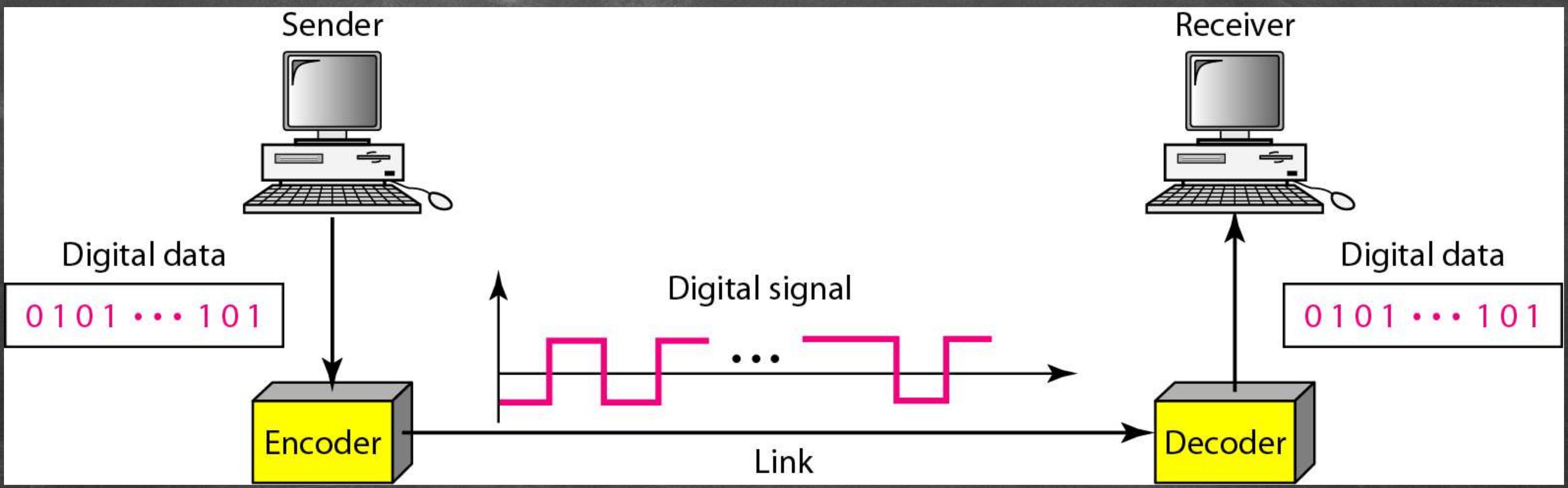
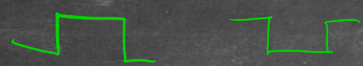


Figure 4.1 Line coding and decoding

Line Coding : Characteristics



- Signal Element are the carriers
- Data Element are being carried 0110

00 01 10

> a signal element carries data elements

- Ratio (r) is the number of data elements carried by each signal element

Data / Signal

- Data Rate (bit rate) defines the number of data elements (bits) sent in 1s : bits per second (bps)
- Signal Rate (pulse rate, modulation rate or baud rate) is the number of signal elements sent in 1s : baud

Line Coding : Characteristics

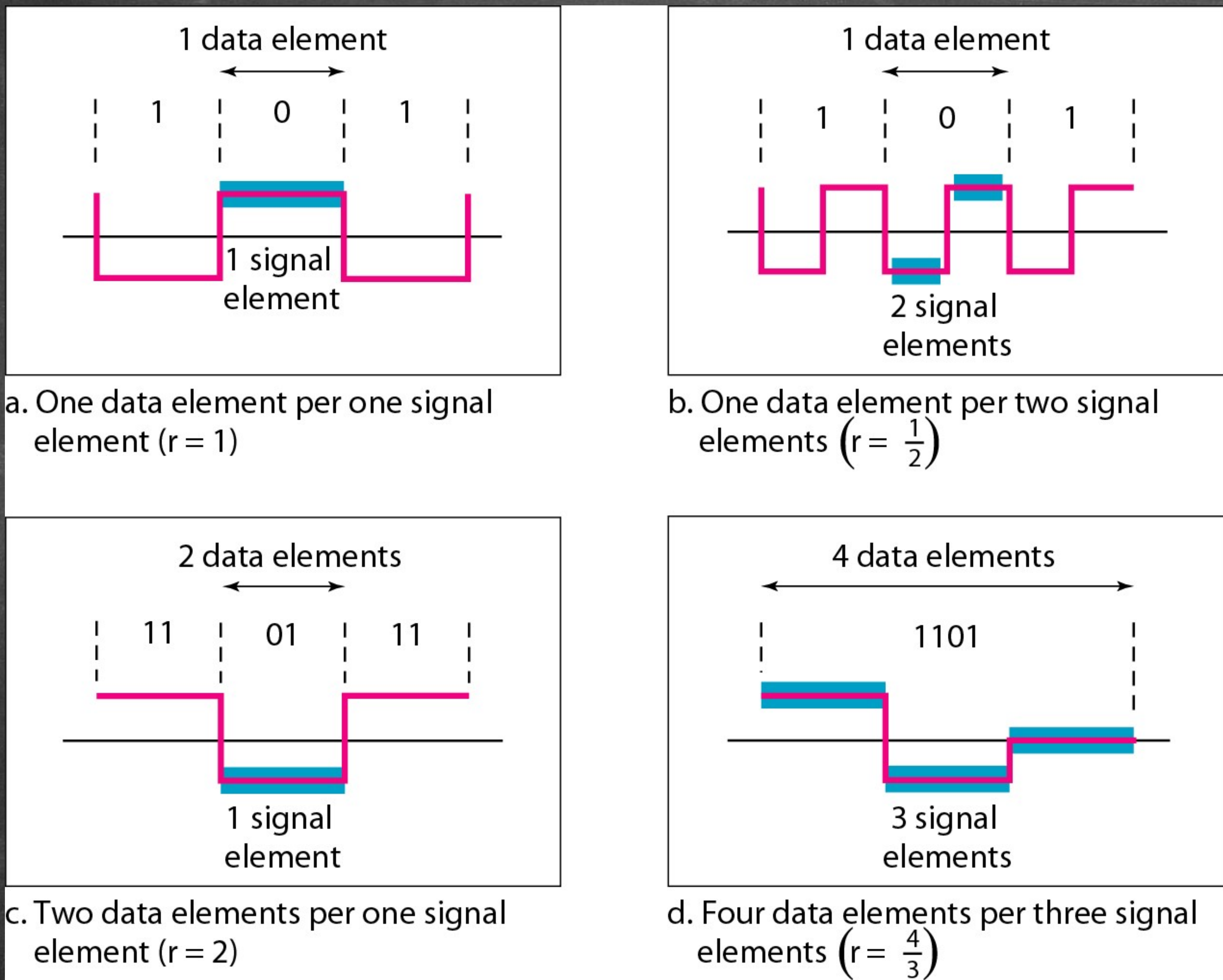


Figure 4.2 Signal element versus data element

$$S = c \times N \times \frac{1}{r}$$

N : data rate (bps)

c : case factor, which varies for each case

S : number of signal elements (baud)

r : previously defined factor

Example 4.1

$S = c \times N \times \frac{1}{r}$

- *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*

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

Line Coding : Characteristics

- Bandwidth : Although the actual bandwidth of a digital signal is infinite (Chapter 3), the effective bandwidth is finite

Example 4.2

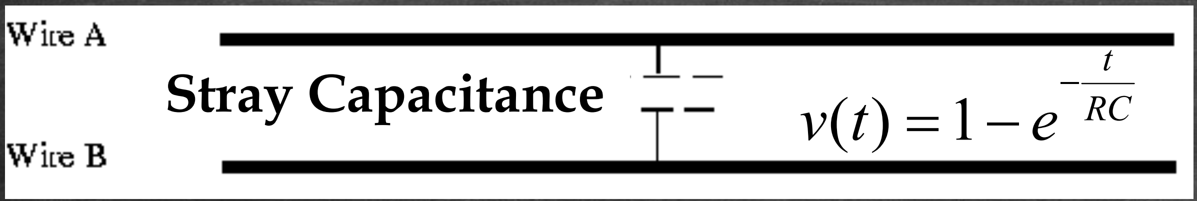
$$S = c \times N \times \frac{1}{r}$$

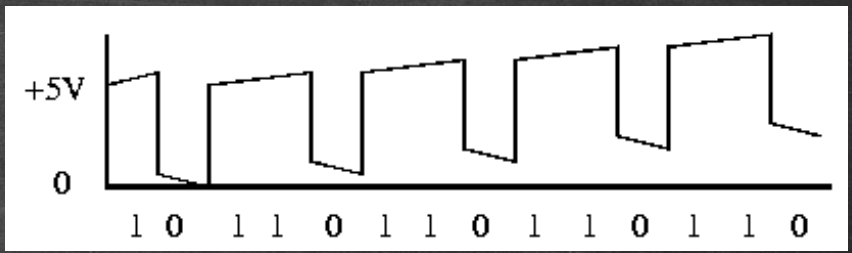
- *The maximum data rate of a channel (see Chapter 3) is Nmax = 2 × B × $\log_2$ L (defined by the Nyquist formula). Does this agree with the previous formula for N_{max}?*
- *Solution*
  - *A signal with L levels actually can carry $\log_2 L$ bits per level. If each level corresponds to one signal element and we assume the average case (c = 1/2), then we have*

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

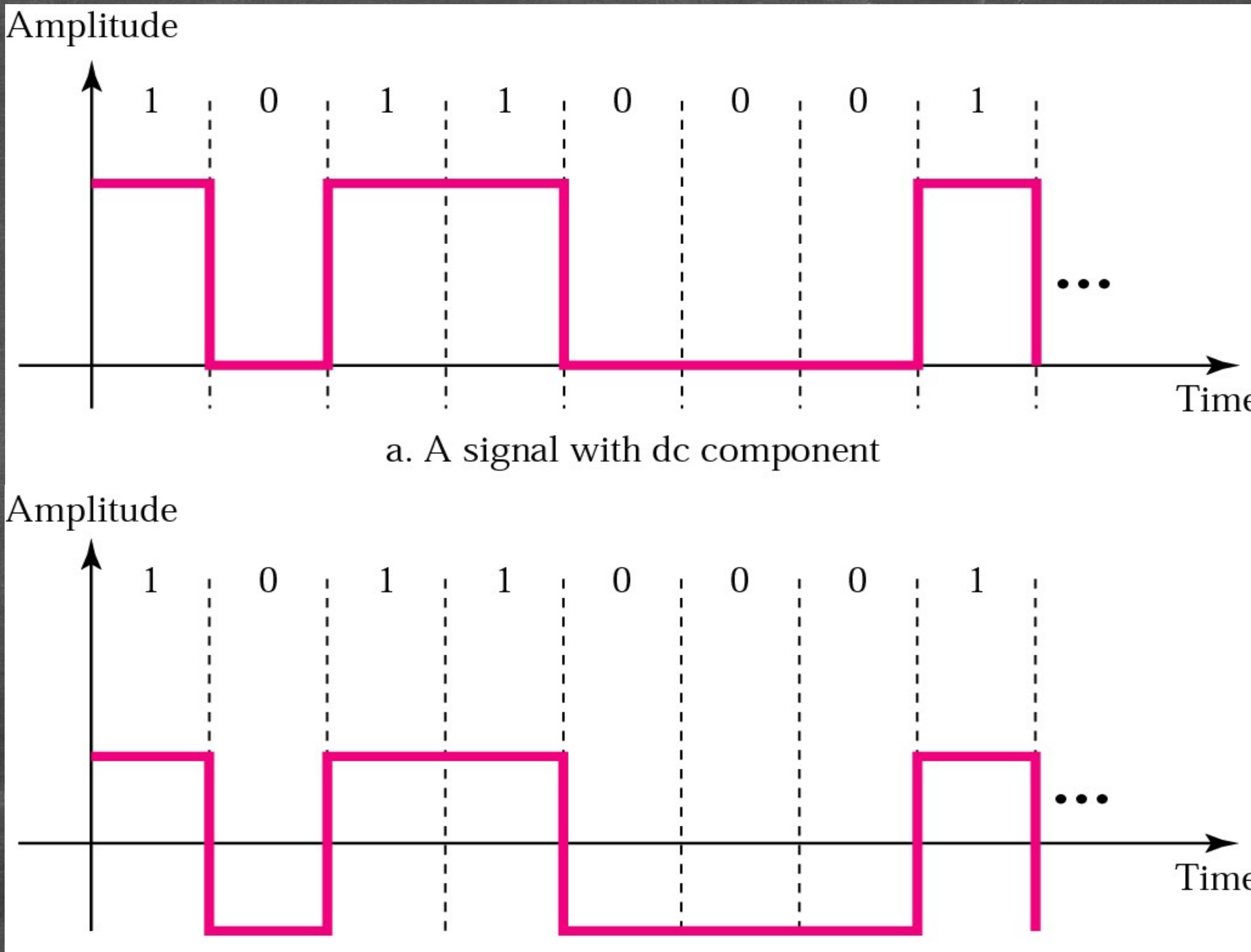
Line Coding : Characteristics

- Baseline Wandering
  - Baseline is average of the received signal power [0, 1]
  - A long string of 0 or 1 can cause a drift in the baseline
- DC Components
  - voltage level in a digital signal is constant : very low frequencies
  - Problems : cannot pass low frequencies or a system that uses electrical coupling (via a transformer)





Line Coding : Characteristics



a. A signal with dc component

b. A signal without dc component

Line Coding : Characteristics

- Self-synchronization

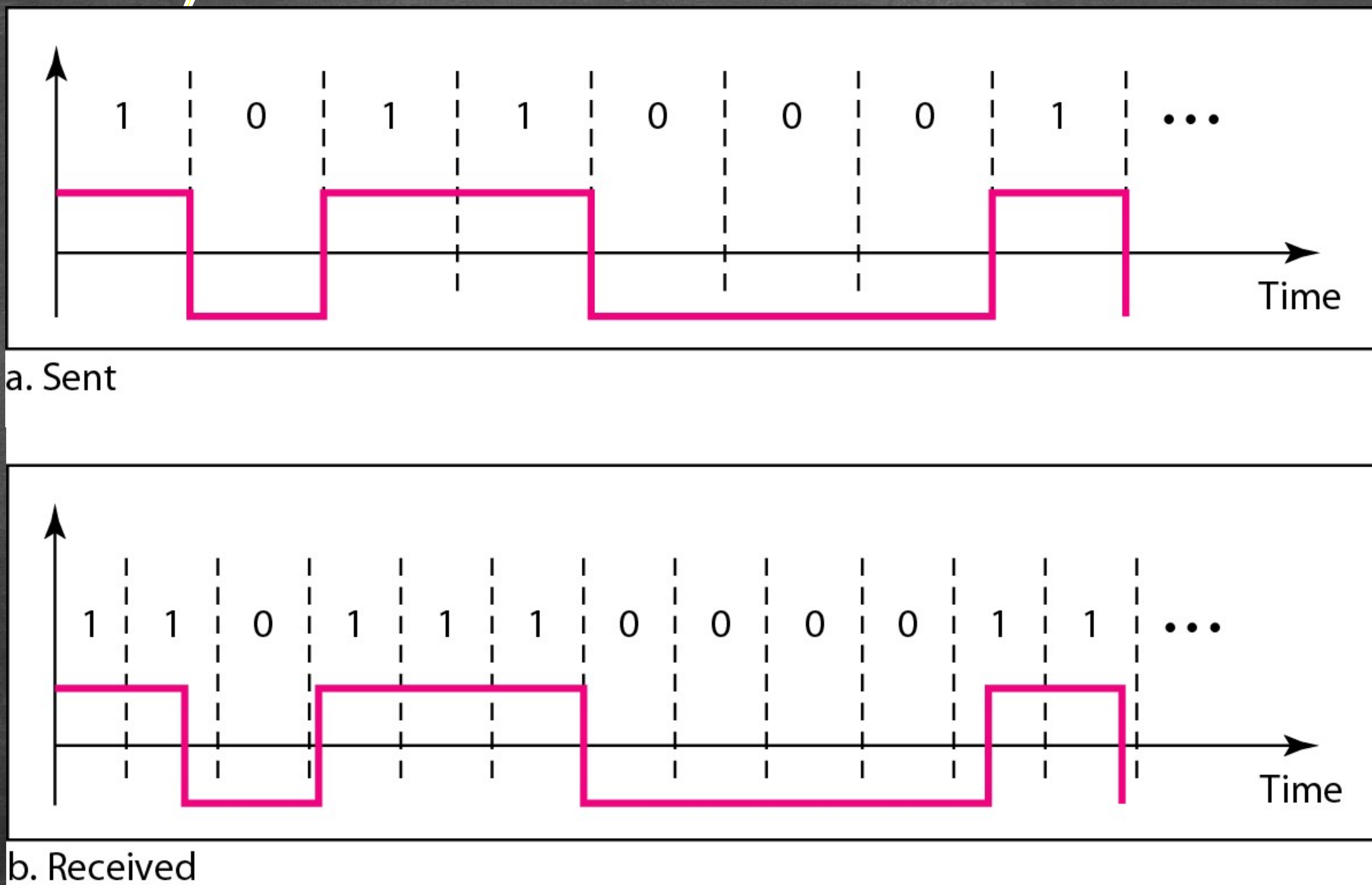


Figure 4.3 Effect of lack of synchronization

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

Line Coding Schemes

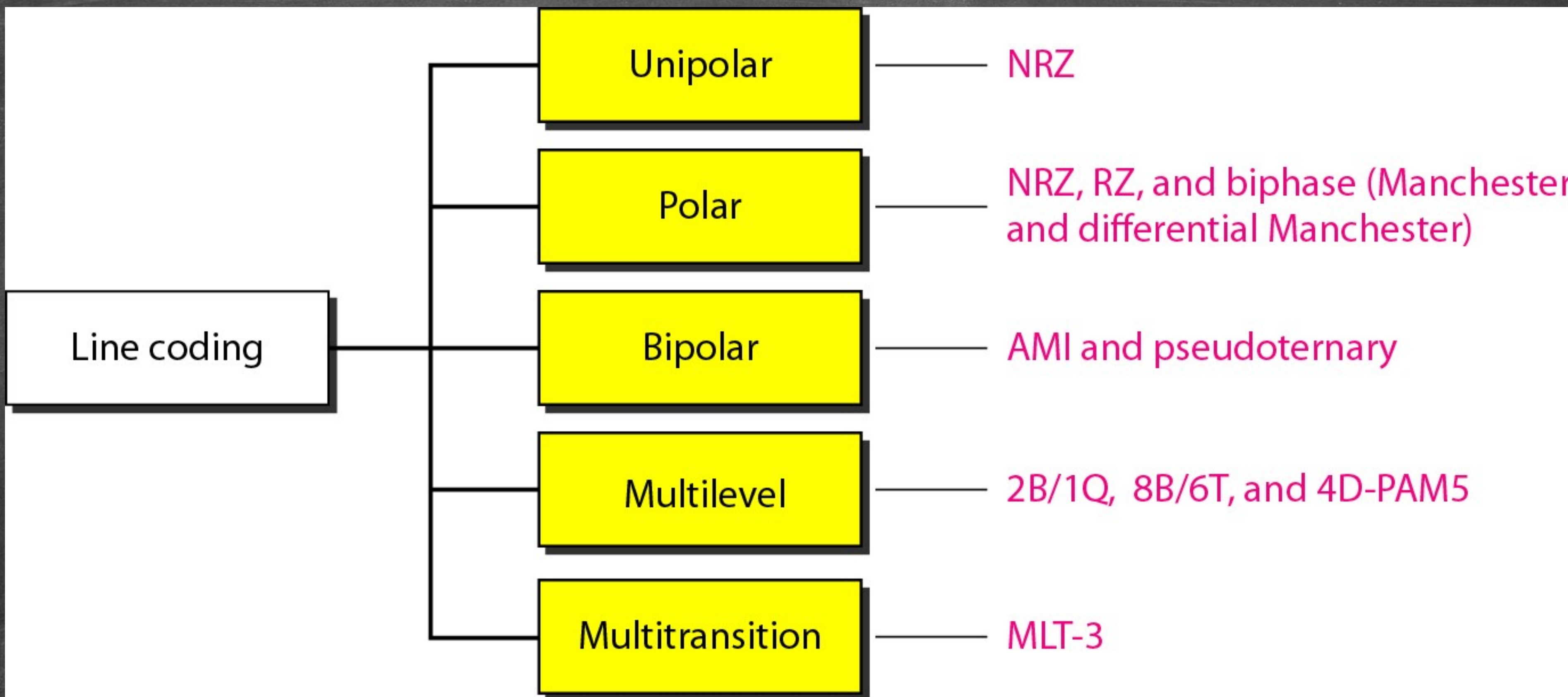


Figure 4.4 Line coding schemes

Line Coding Schemes

- Unipolar Scheme : all the signal levels are on one side of the time axis, either above or below.
  - NRZ (Non-Return-to-Zero)
    - bit 1 = positive voltage *(maybe or negative)* / bit 0 = zero voltage

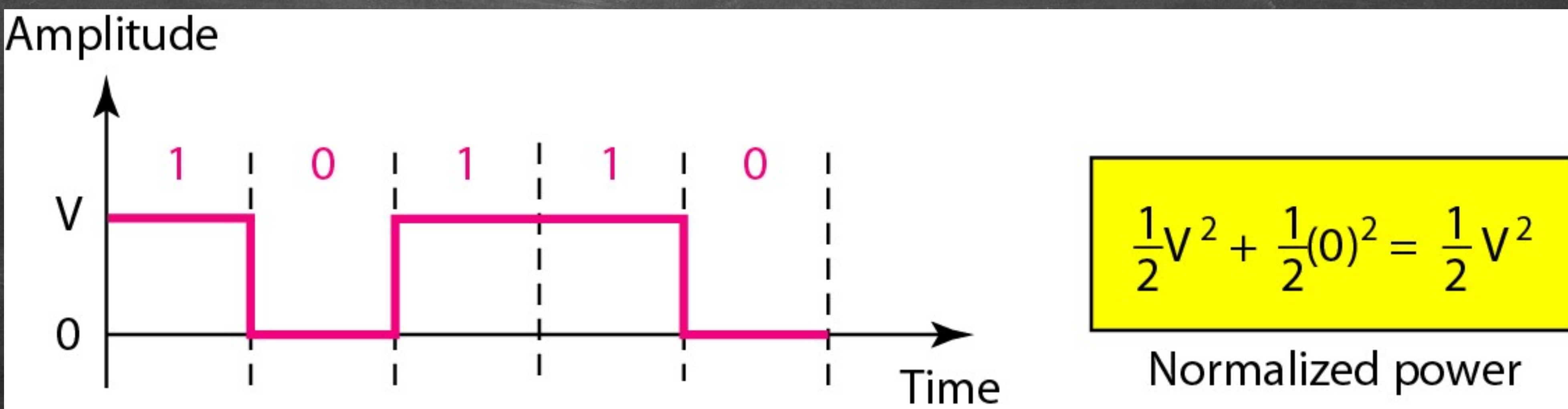
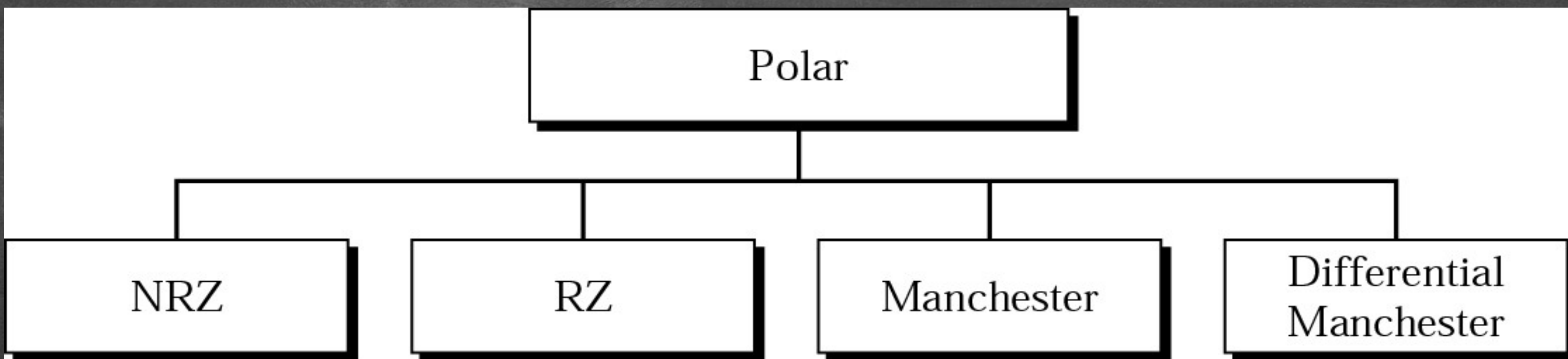


Figure 4.5 Unipolar NRZ scheme

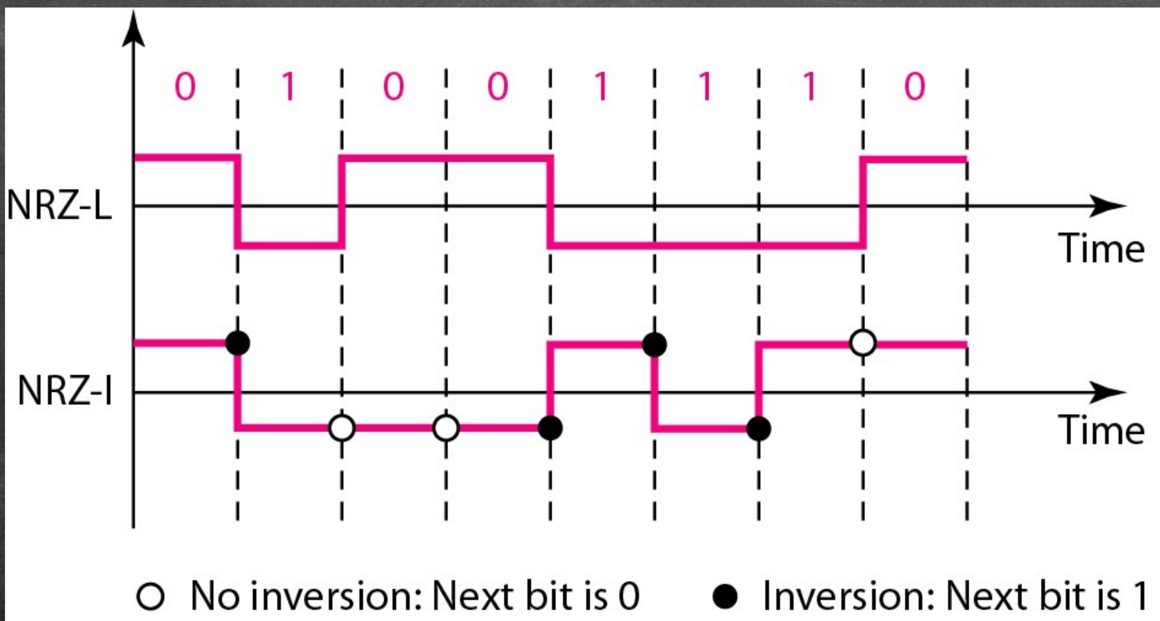
Line Coding Schemes

- Polar Schemes : the voltages are on the both sides of the time axis



Line Coding Schemes

- Polar Schemes (Cont.)
  - Non-Return-to-Zero (NRZ)
  - NRZ-I (NRZ-Invert)



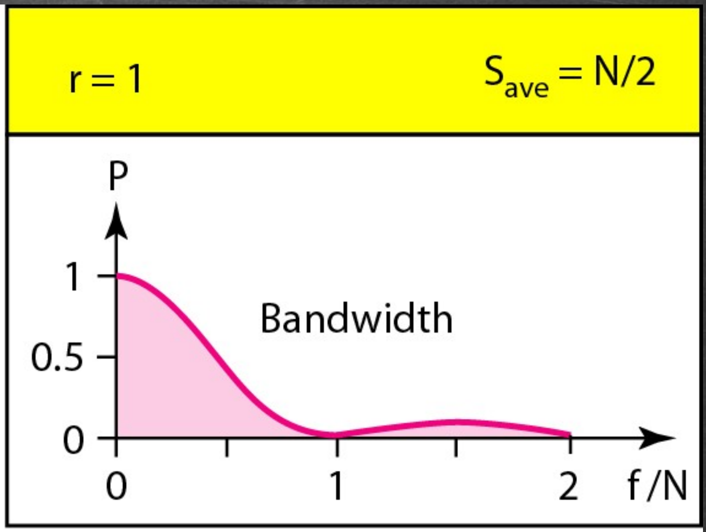


Figure 4.6 Polar NRZ-L and NRZ-I schemes

Line Coding Schemes

- In NRZ-L the level of the voltage determines the value of the bit.
- In NRZ-I the inversion or the lack of inversion determines the value of the bit.
- NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.
- NRZ-L and NRZ-I both have a DC component problem.

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 = 500 kbaud. The minimum bandwidth for this average baud rate is Bmin = S = 500 kHz.*

Line Coding Schemes

- Polar Schemes (Cont.)
  - Return to Zero (RZ)
    - A good encoded digital signal must contain a provision for synchronization.

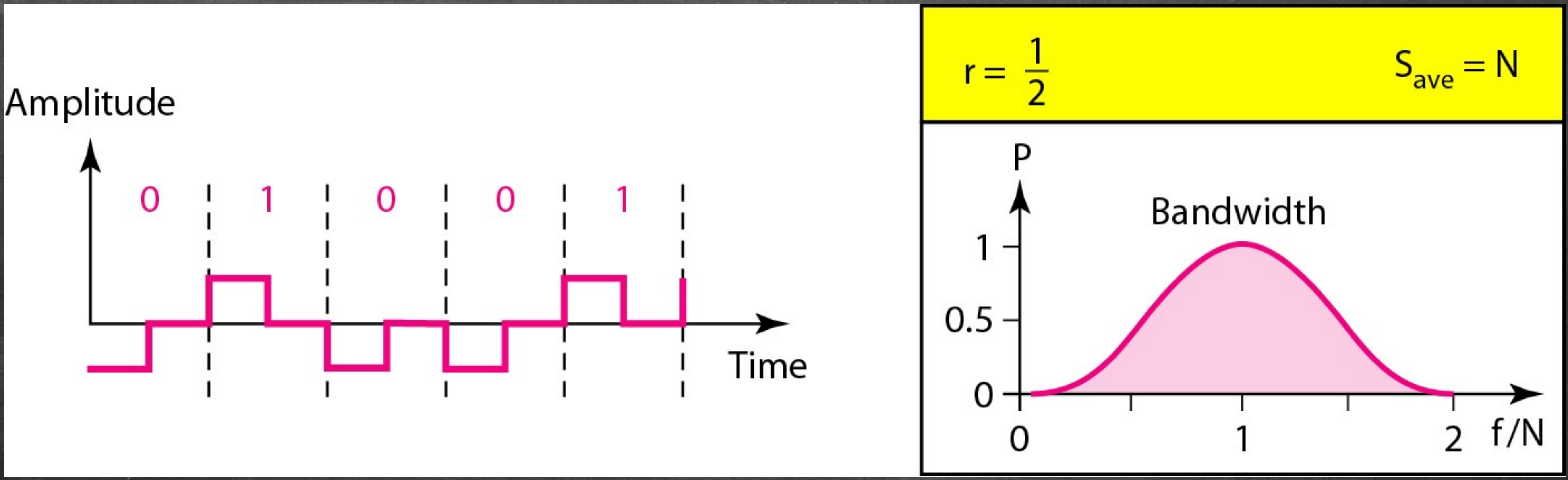


Figure 4.7 Polar RZ scheme

Line Coding Schemes

- Polar Schemes (Cont.)
  - Biphase : Manchester & Differential Manchester
    - the transition at the middle of the bit is used for synchronization.
    - The minimum bandwidth is 2 times that of NRZ.
    - In bipolar encoding, we use three levels: positive, zero, and negative.

Line Coding Schemes

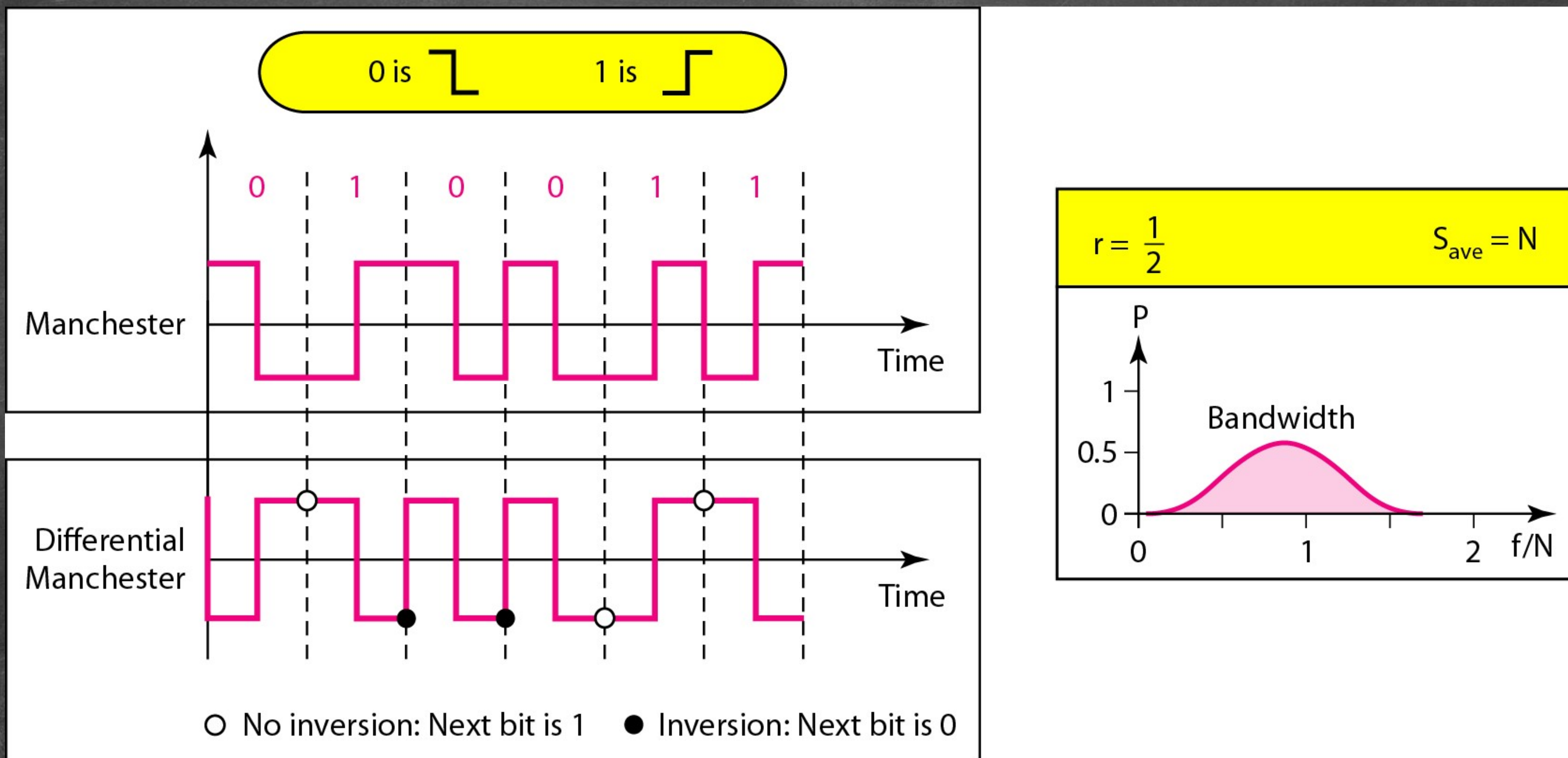


Figure 4.8 Polar biphase: Manchester and differential Manchester schemes

Line Coding Schemes

- Applications of Polar Schemes
  - NRZ encoding:
    - RS232 based protocols
  - Manchester encoding:
    - Ethernet networks
    - Hard drive
  - Differential Manchester encoding:
    - token-ring networks
  - NRZ-Inverted encoding:
    - Fiber Distributed Data Interface (FDDI)

Line Coding Schemes

- Bipolar Schemes : bipolar encoding (multilevel binary) / three voltage levels : positive, negative, and zero / voltage level for one data element is at zero
  - AMI (alternate mark inversion)
  - Pseudoternary

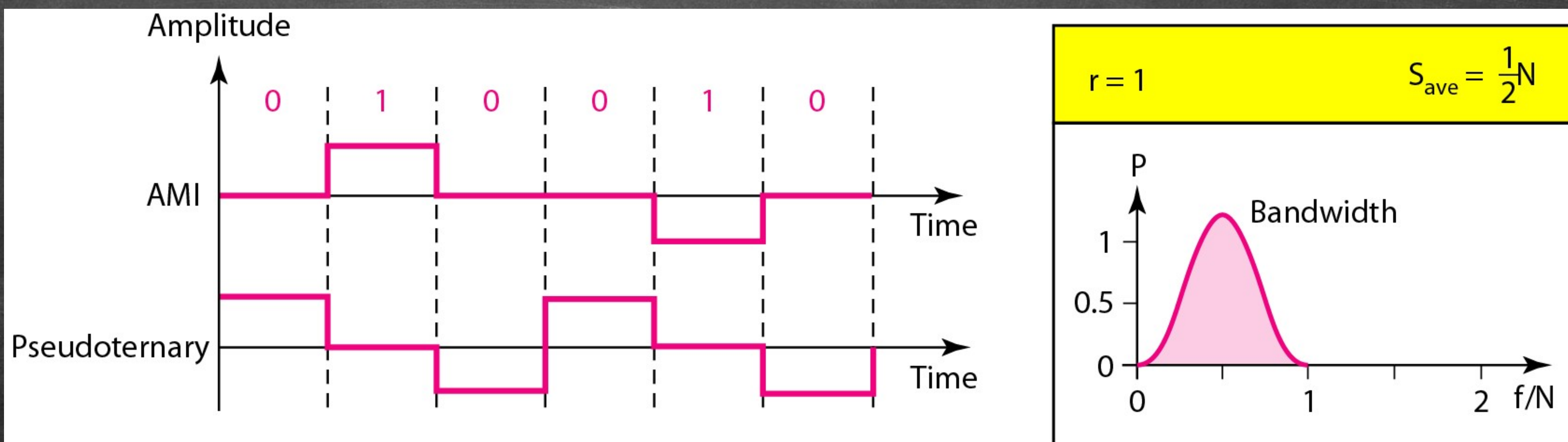


Figure 4.9 Bipolar schemes: AMI and pseudoternary

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Line Coding Schemes

- Multilevel Schemes : increase the number of bits per baud by encoding a pattern of *m* data elements into a pattern of *n* signal elements
  - data elements : combination of 2^m data patterns
  - signal elements : combinations of L_n signal patterns
- $2^m = L_n$: then each data pattern is encoded into one signal pattern
- $2^m < L_n$: data patterns occupy only a subset of signal patterns
- $2^m > L_n$ because some of the data patterns cannot be encoded

Line Coding Schemes

- Multilevel Schemes (Cont.)
  - mBnL : a pattern of m data elements is encoded as a pattern of n signal elements in which $2^m \leq L_n$
    - m : length of the binary pattern
    - B : binary data
    - n : length of the signal pattern
    - L : number of levels in the signaling

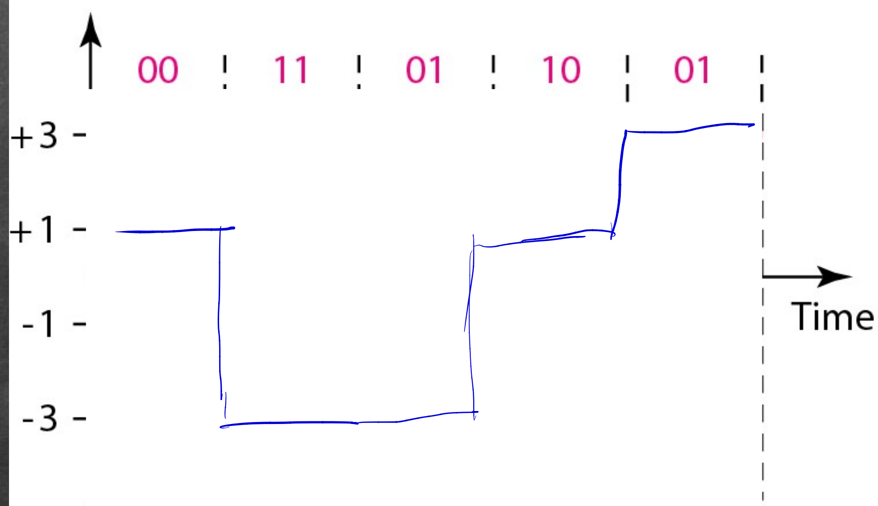
Line Coding Schemes

- Multilevel Schemes (Cont.)
  - 2B1Q (two binary, one quaternary)
    - uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal (m=2, n=1, and L=4)
    - used in DSL (Digital Subscriber Line)

Line Coding Schemes

	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

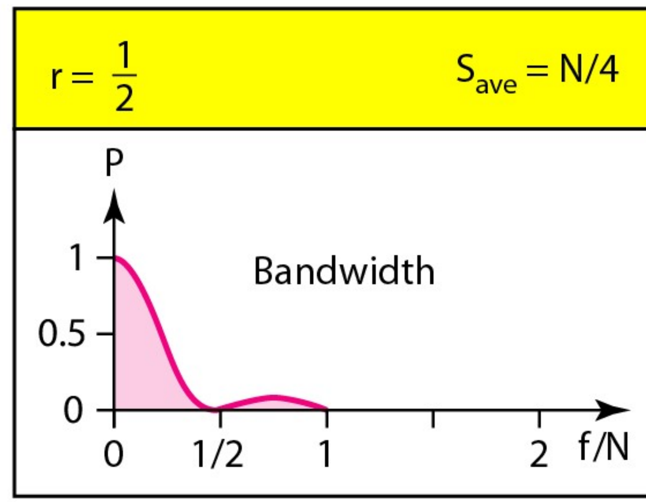
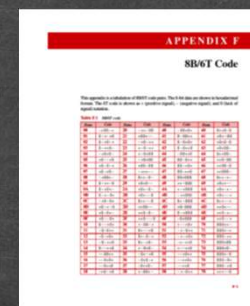


Figure 4.10 Multilevel: 2B1Q scheme

Line Coding Schemes

- Multilevel Schemes (Cont.)
  - 8B6T (eight binary, six ternary)
    - pattern of 8 bits as a pattern of 6 signal elements, where the signal has three levels (ternary)
      - 2^8=256 different data patterns
      - 3^6=478 different signal patterns
    - is used with 100BASE-4T cable



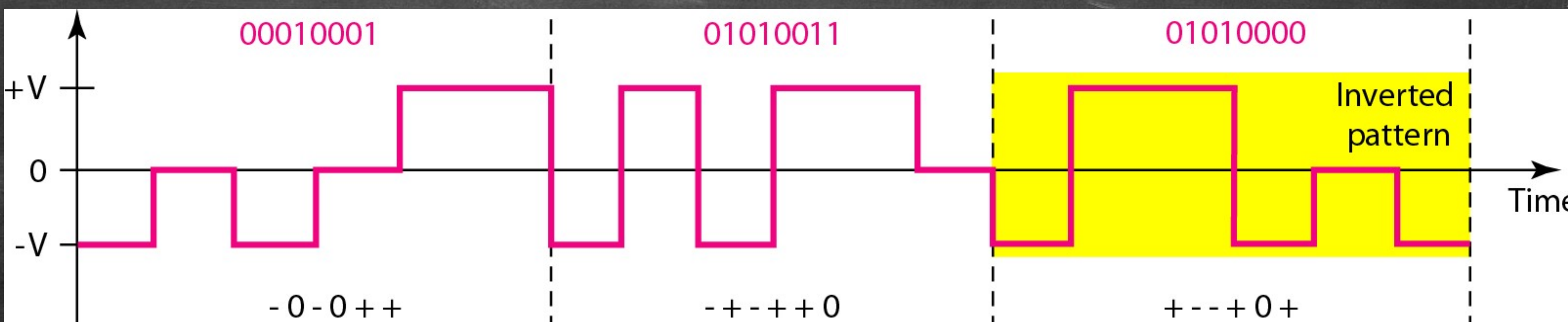


Figure 4.11 Multilevel: 8B6T scheme

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Line Coding Schemes

- Multilevel Schemes (Cont.)
  - 4D-PAMS (four dimensional five-level pulse amplitude modulation)
    - pattern of 8 bits as a pattern of 6 signal elements, where the signal has three levels (ternary)
      - 2^8=256 different data patterns
      - 3^6=478 different signal patterns
    - is used with 100BASE-4T cable

Line Coding Schemes

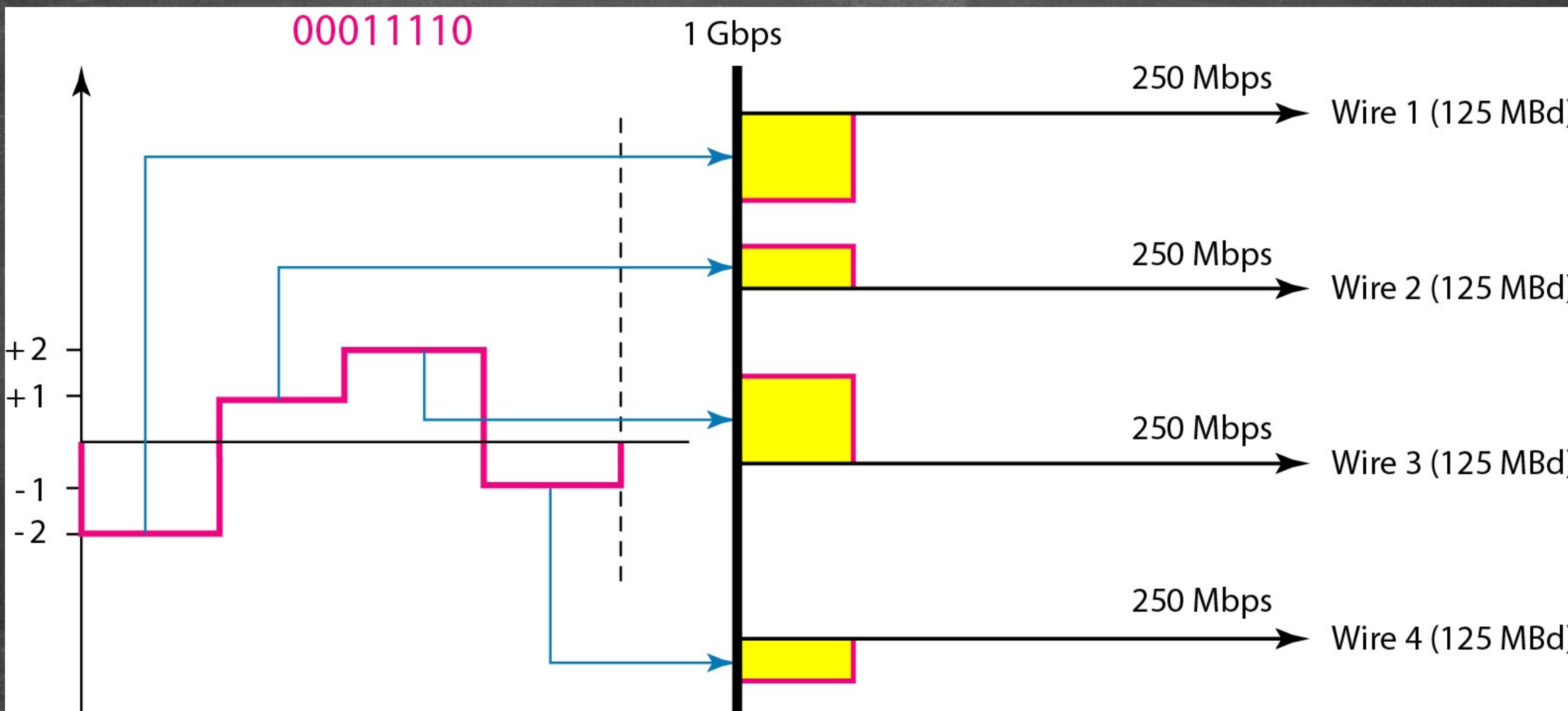


Figure 4.12 Multilevel: 4D-PAM5 scheme

Line Coding Schemes

- Multiline Transmission : three level (MLT-3) scheme uses three levels (+v, 0, and - V) and three transition rules to move between the levels
  - If the next bit is 0, there is no transition.
  - If the next bit is 1 and the current level is not 0, the next level is 0.
  - If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.
- First introduced by Cisco System for FDDI (Fiber Distributed Data Interface: Token Ring)
- Used in 100Base-TX (100 Mbit/s Ethernet)

Line Coding Schemes

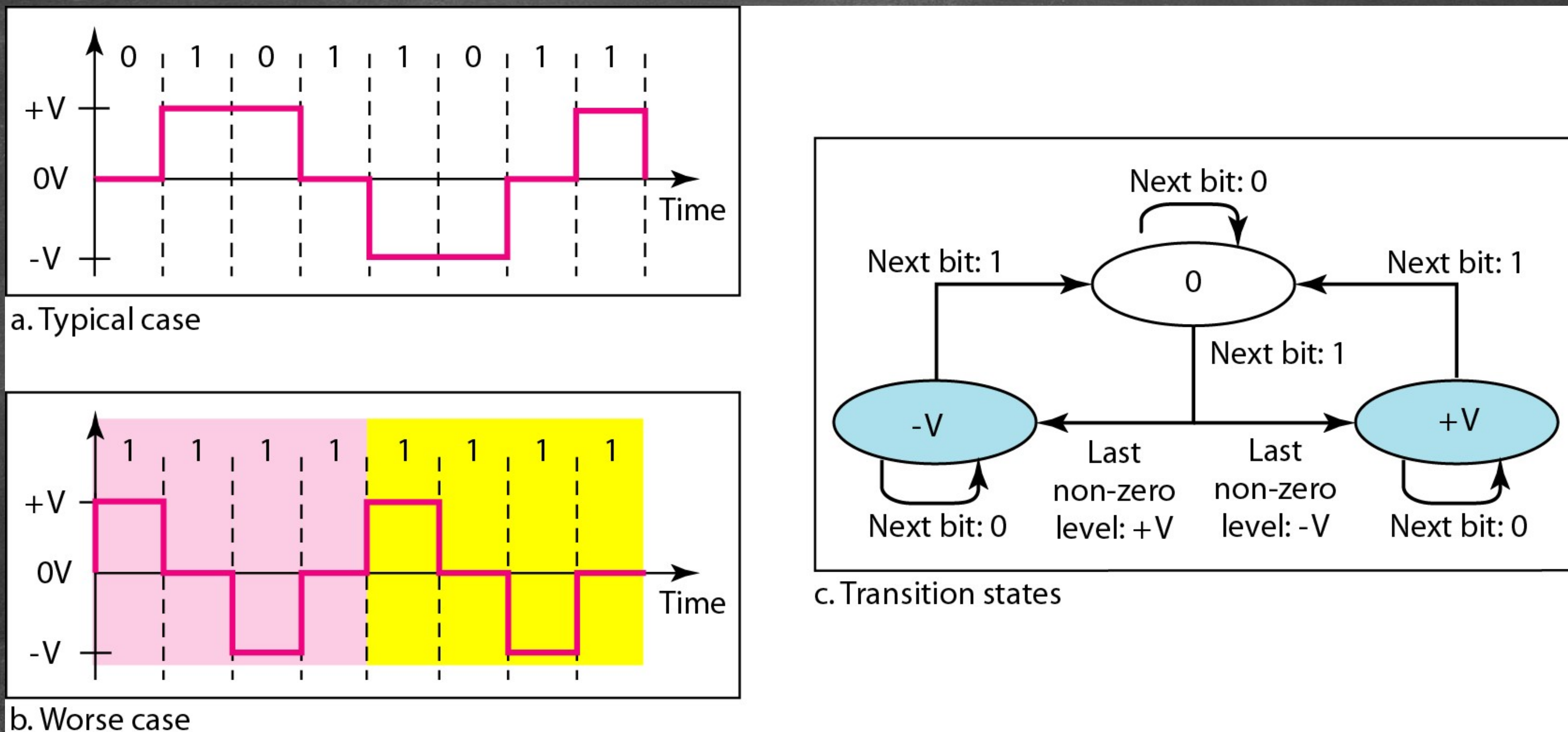


Figure 4.13 Multitransition: MLT-3 scheme

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

Table 4.1 Summary of line coding schemes

Block coding

- Block coding is normally referred to as mB/nB coding; it replaces each m-bit group with an n-bit group.

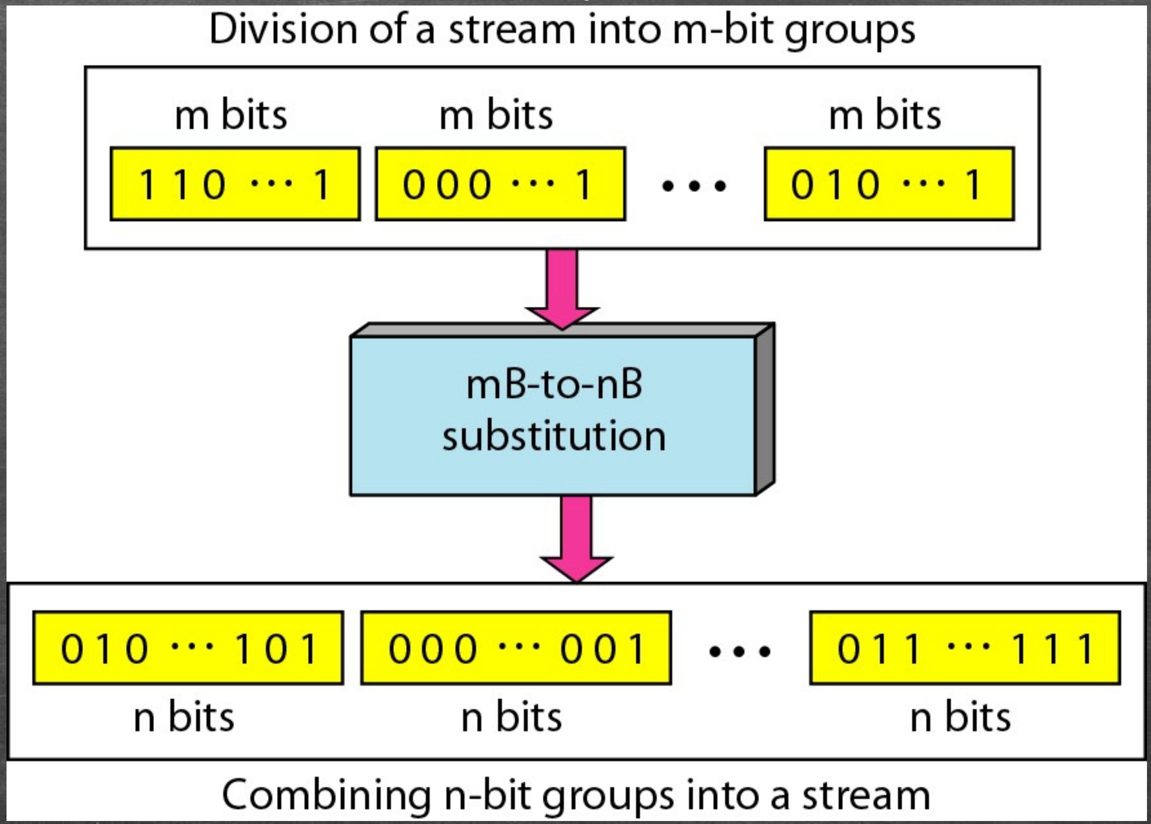


Figure 4.14 Block coding concept

Block coding

- 4B/5B
  - NRZ-I has a good signal rate : one-half that of the biphase, but it has a synchronization problem

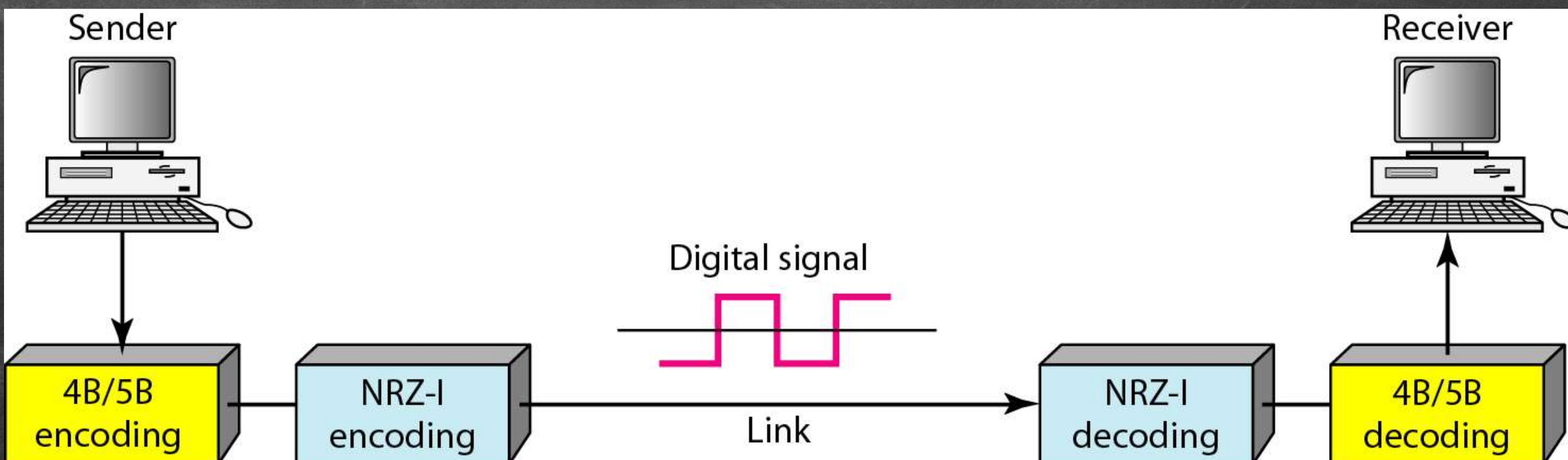


Figure 4.15 Using block coding 4B/5B with NRZ-I line coding scheme

Table 4.2 4B/5B mapping codes

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		
1001	10011		
1010	10110		
1011	10111		
1100	11010		
1101	11011		
1110	11100		
1111	11101		

Block coding

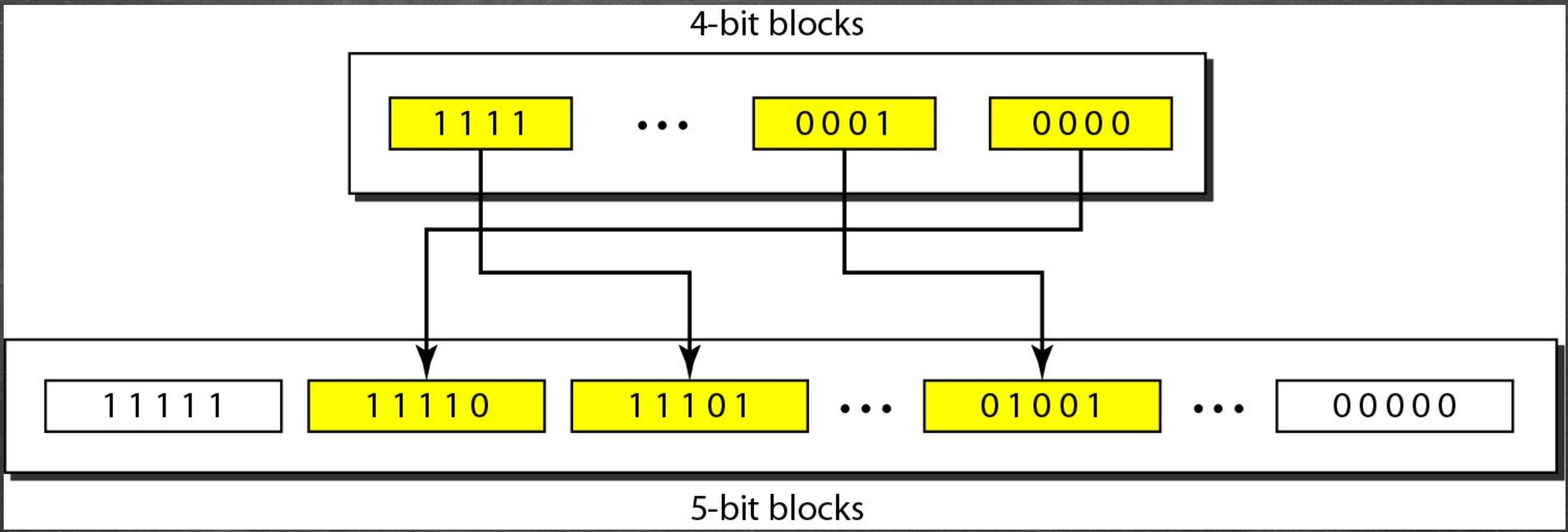


Figure 4.16 Substitution in 4B/5B block coding

Example 4.5

- ***We need to send data at a 1-Mbps rate. What is the minimum required bandwidth, using a combination of 4B/5B and NRZ-I or Manchester coding?***
- *Solution*
  - ***First 4B/5B block coding increases the bit rate to 1.25 Mbps. The minimum bandwidth using NRZ-I is N/2 or 625 kHz. The Manchester scheme needs a minimum bandwidth of 1 MHz. The first choice needs a lower bandwidth, but has a DC component problem; the second choice needs a higher bandwidth, but does not have a DC component problem.***

Block coding

- 8B/10B

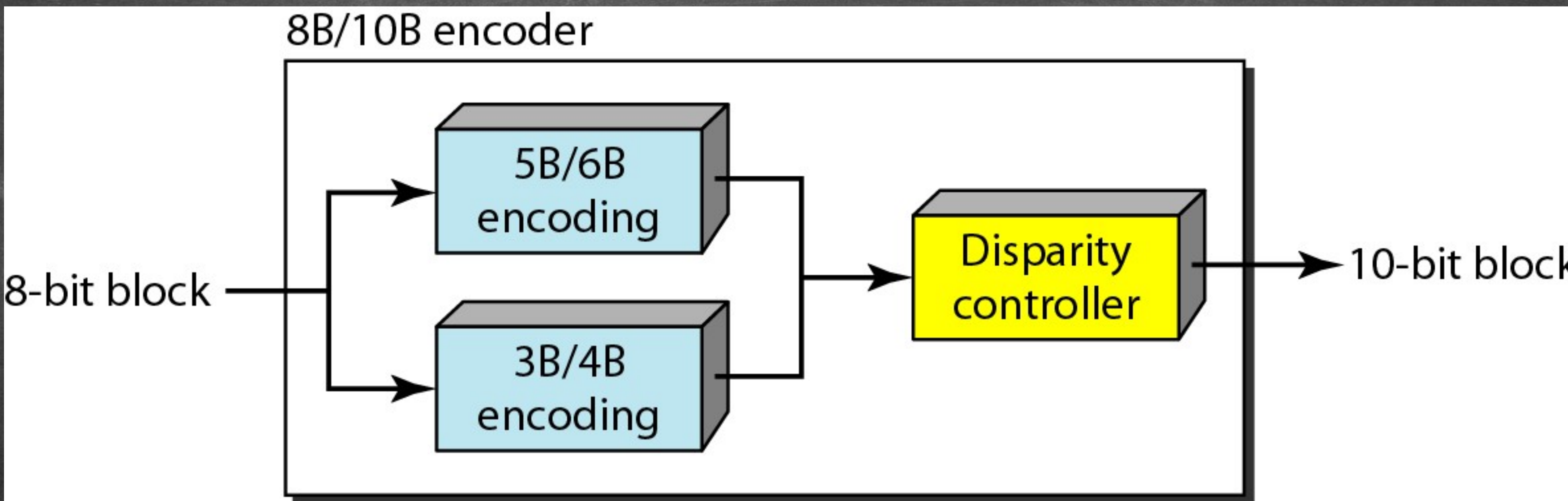


Figure 4.17 8B/10B block encoding

Scrambling

- Biphase schemes => LAN
  - Not suitable for long-distance communication (wide bandwidth requirement)
- Block coding and NRZ
  - Not suitable for long-distance encoding either (DC component)
- Bipolar AMI encoding ใช้น้อย
  - narrow bandwidth and does not create a DC component
  - void a long sequence of 0s 0 ติดกันยาว

Scrambling

0 ติดกัน 8 ตัว

- B8ZS substitutes eight consecutive zeros with 000VB0VB.

0 ติดกัน 4 ตัว

- HDB3 substitutes four consecutive zeros with 000V or B00V depending on the number of nonzero pulses after the last substitution.

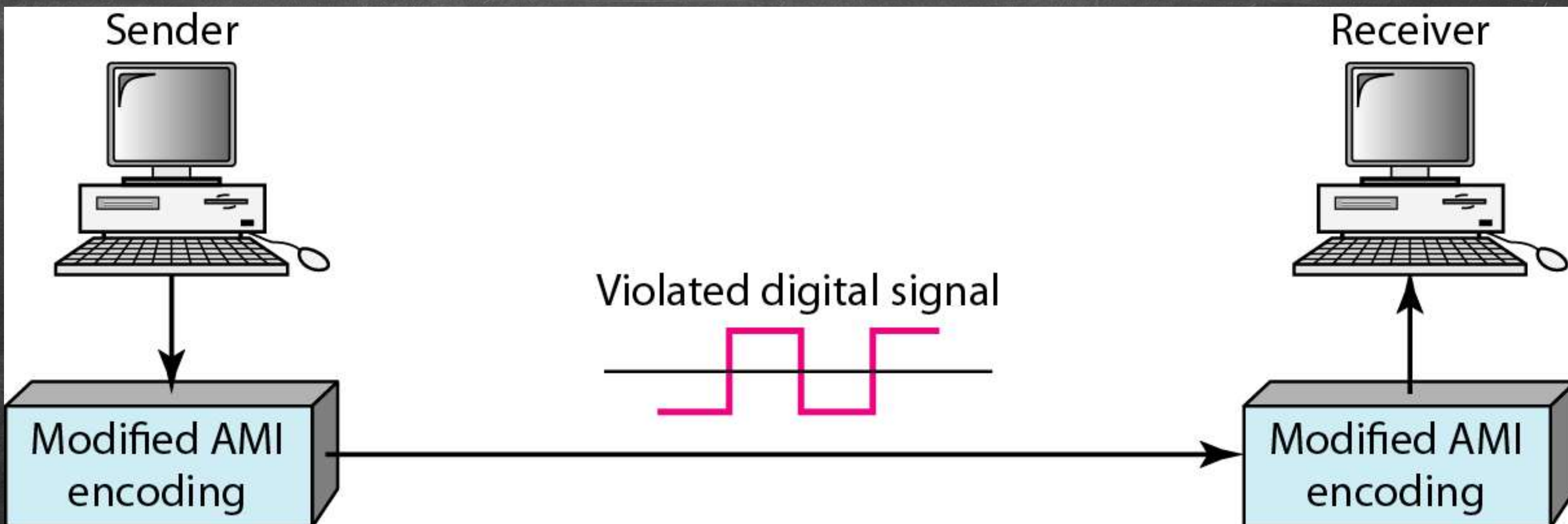
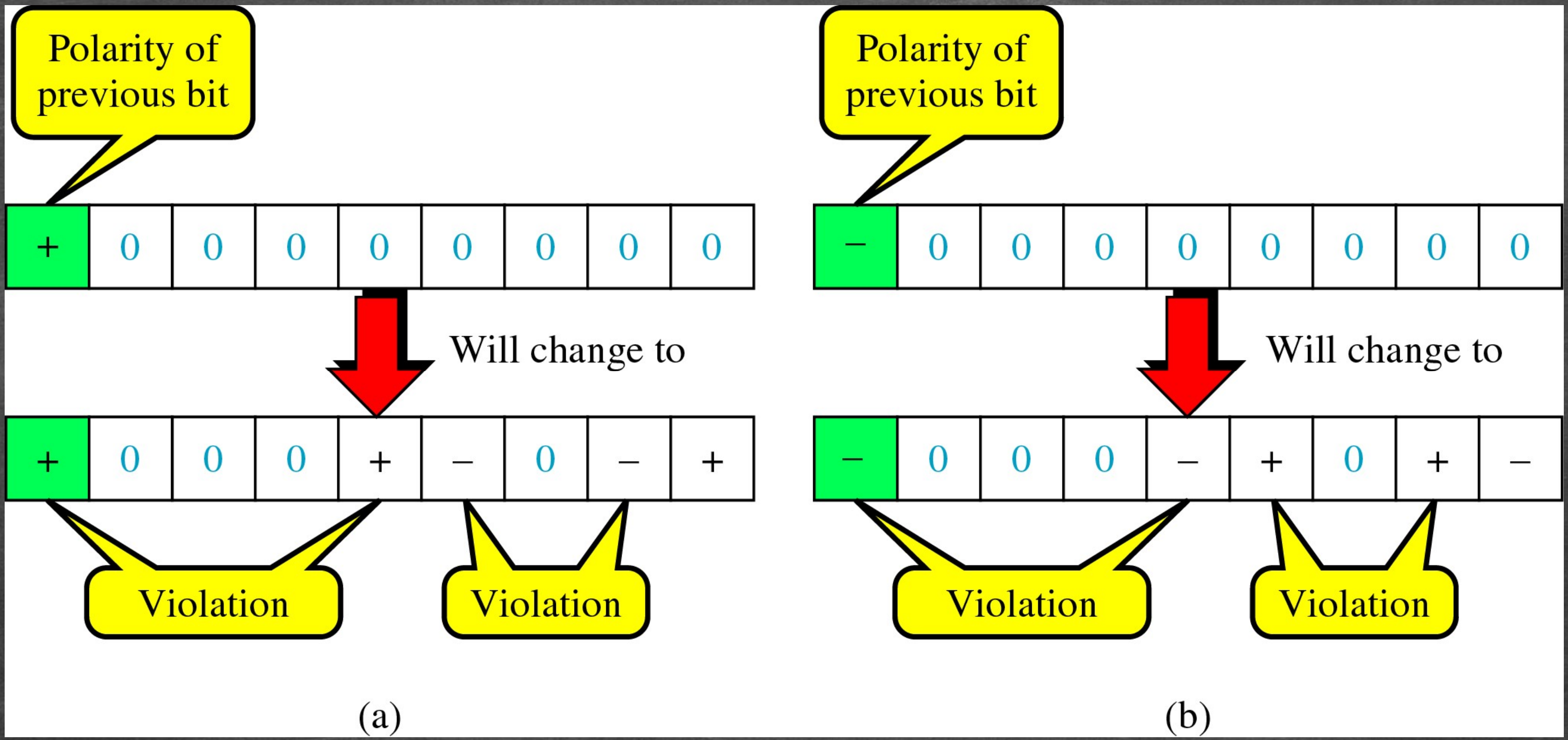


Figure 4.18 AMI used with scrambling

Scrambling

- B8ZS : Bipolar with 8-zero substitution



0 0 0 V B 0 V B

V = Violation, B = Bipolar

Scrambling

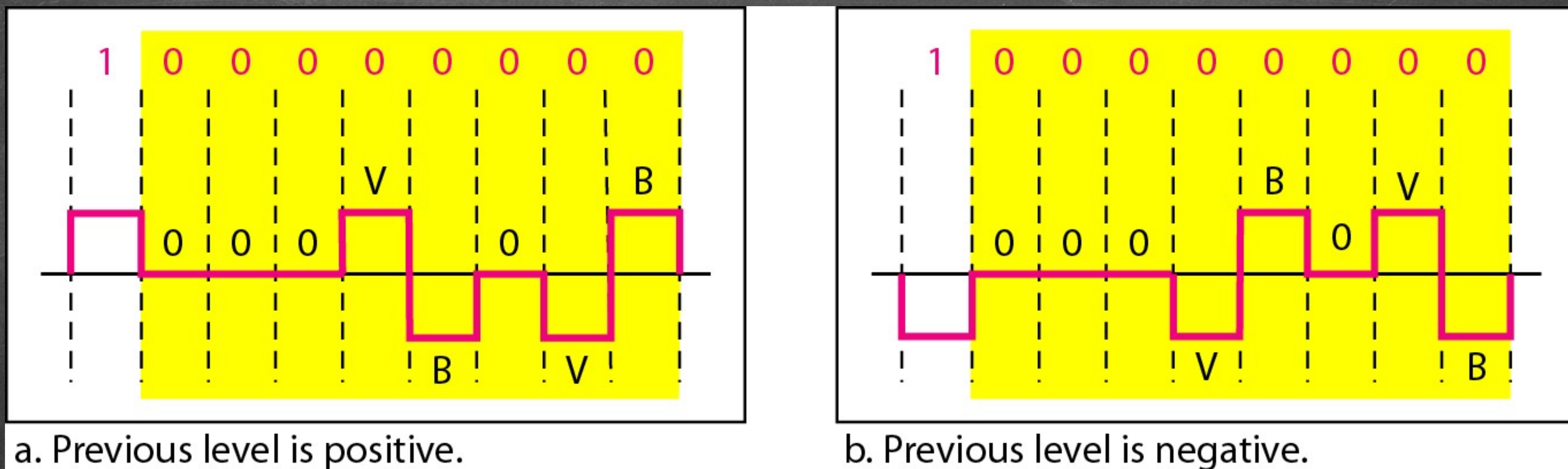
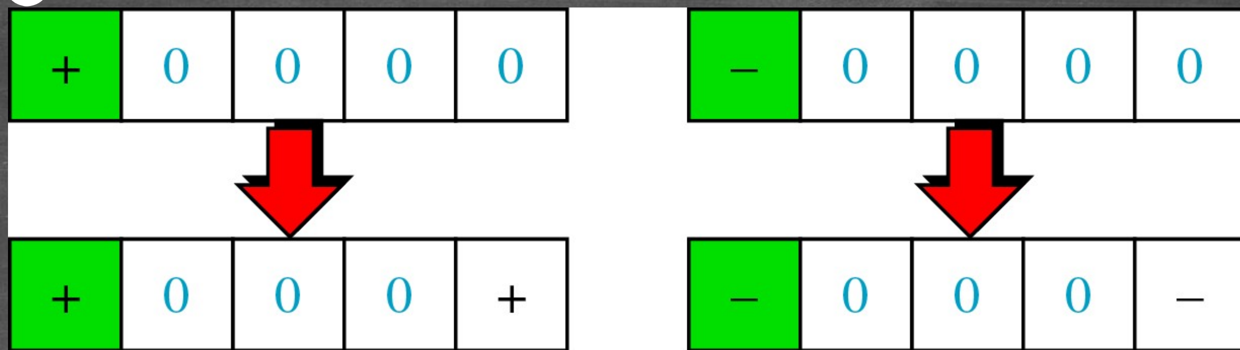


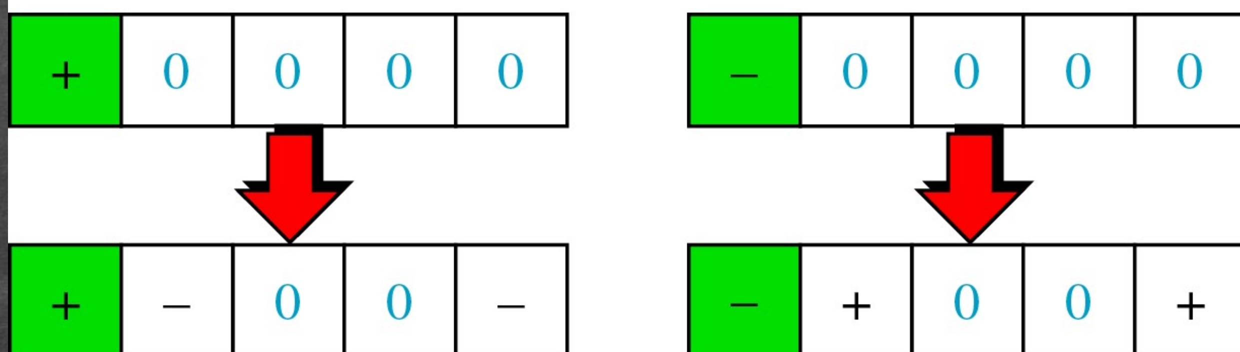
Figure 4.19 Two cases of B8ZS scrambling technique

Scrambling

- HDB3



(a) If the number of 1s since the last substitution is odd



(b) If the number of 1s since the last substitution is even

0 0 0 V or B 0 0 V

Scrambling

000V or B00V

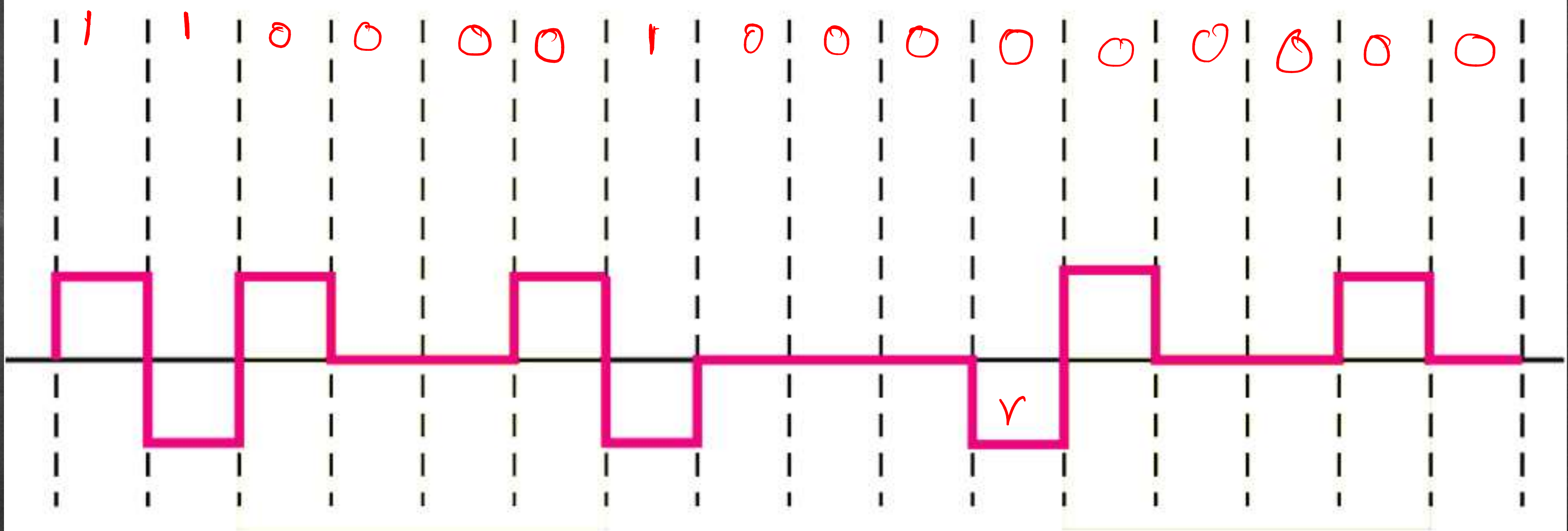


Figure 4.20 Different situations in HDB3 scrambling technique