Chapter 4

Digital Transmission

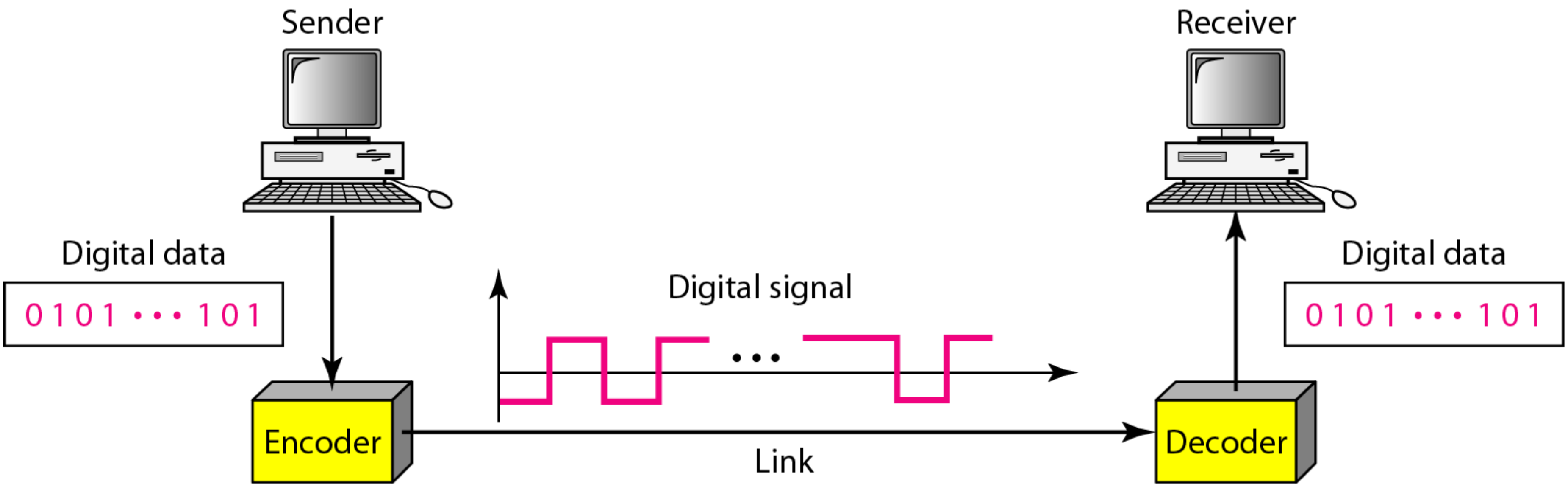
4-1 DIGITAL-TO-DIGITAL CONVERSION

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

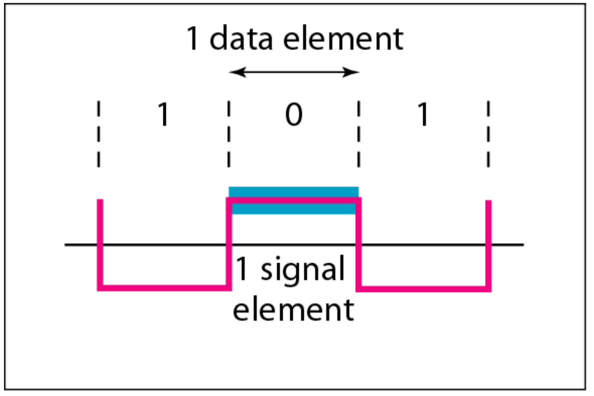
Figure 4.1 *Line coding and decoding*



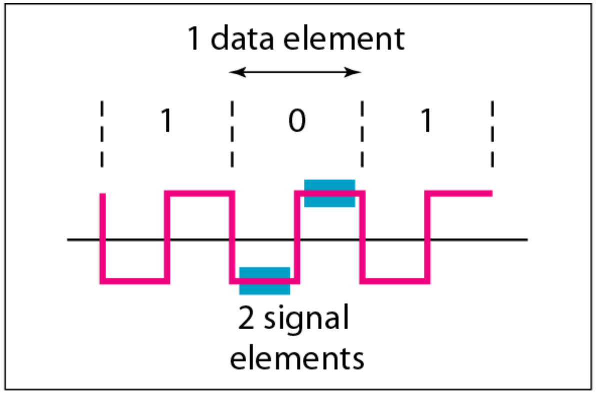
Line Coding Objective

- Improve Performance of Transmitting Digital Signals
  - **Data Rate**
  - Error Reduction
    - Distortion (DC Component)
    - Bit Synchronization
      - Lack of clk synchronization between Tx, Rx
      - Delay of signal

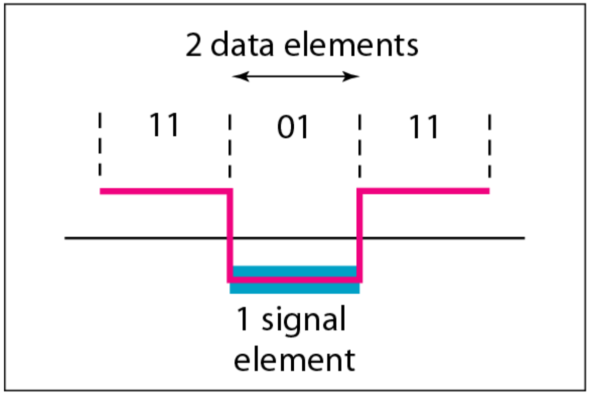
Figure 4.2 *Signal element versus data element*



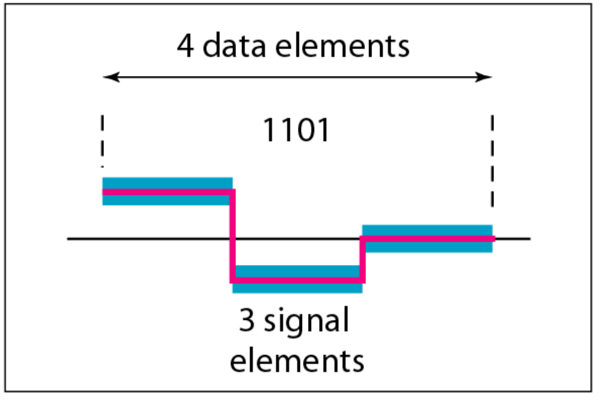
a. One data element per one signal element (r = 1)



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

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

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

Note

Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite.

Example 4.2

The maximum data rate of a channel (see Chapter 3) is $N_{max} = 2 \times B \times \log_2 L$ (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

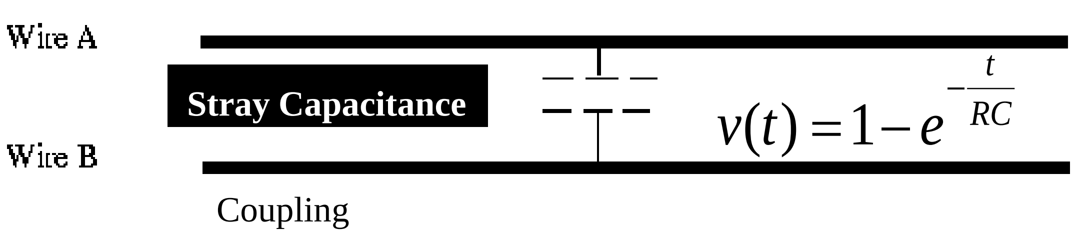
$$\boxed{N_{\max} = \frac{1}{c} \times B \times r = 2 \times B \times \log_2 L}$$

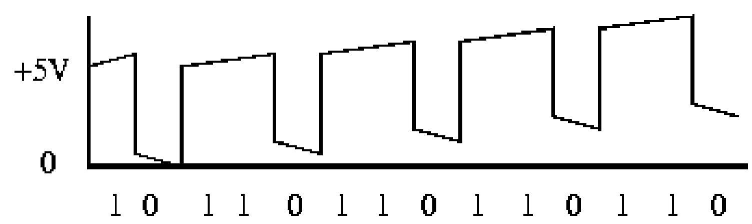
Line Coding Objective

- Improve Performance of Transmitting Digital Signals
  - Data Rate
  - Error Reduction
    - **Distortion (DC Component)**
    - Bit Synchronization
      - Lack of clk synchronization between Tx, Rx
      - Delay of signal

Line Coding : Characteristics

- **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)

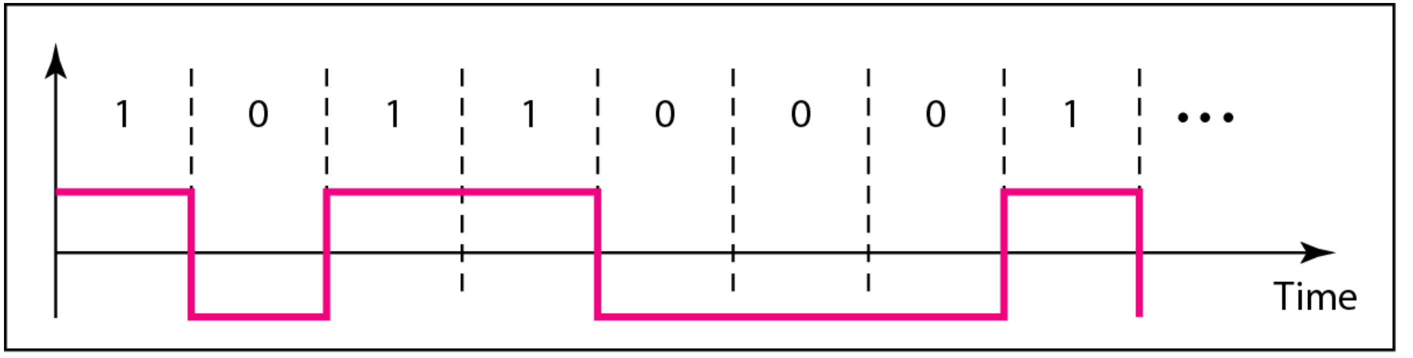




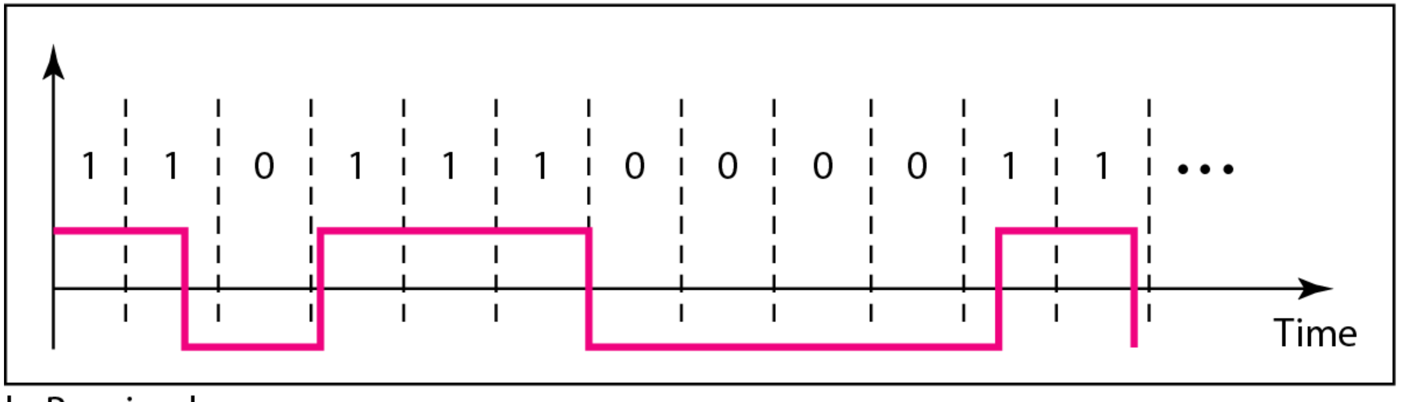
Line Coding Objective

- Improve Performance of Transmitting Digital Signals
  - Data Rate
  - Error Reduction
    - Distortion (DC Component)
    - Bit Synchronization
      - **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
      - Lack of clk synchronization between Tx, Rx
      - Delay of signal

Figure 4.3 *Effect of lack of 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

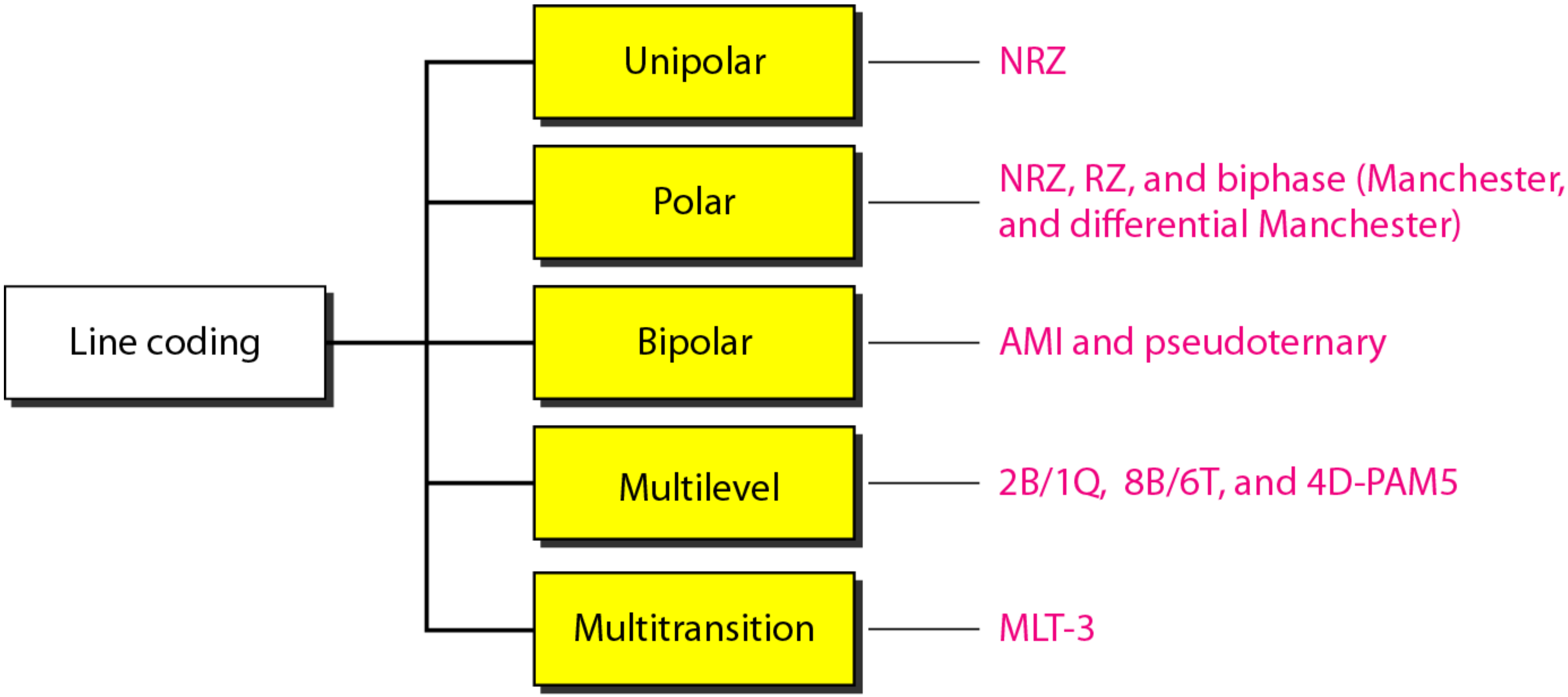
At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

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

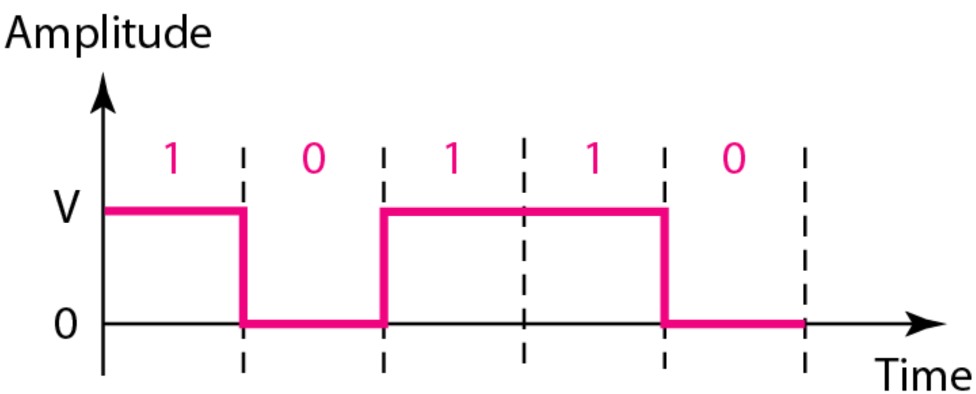
Figure 4.4 *Line coding schemes*



พยายามออกแบบข้อมูลเพื่อให้บรรลุวัตถุประสงค์ โดยใช้หลักการสร้างตัวแทนบิตข้อมูลในหลากหลายรูปแบบ เช่น ใช้ระดับความต่างศักดิ์ (signal level) หรือ ใช้การเปลี่ยนแปลงขั้วไฟฟ้า (inversion) เป็นตัวแทนข้อมูล

Figure 4.5 *Unipolar NRZ scheme*

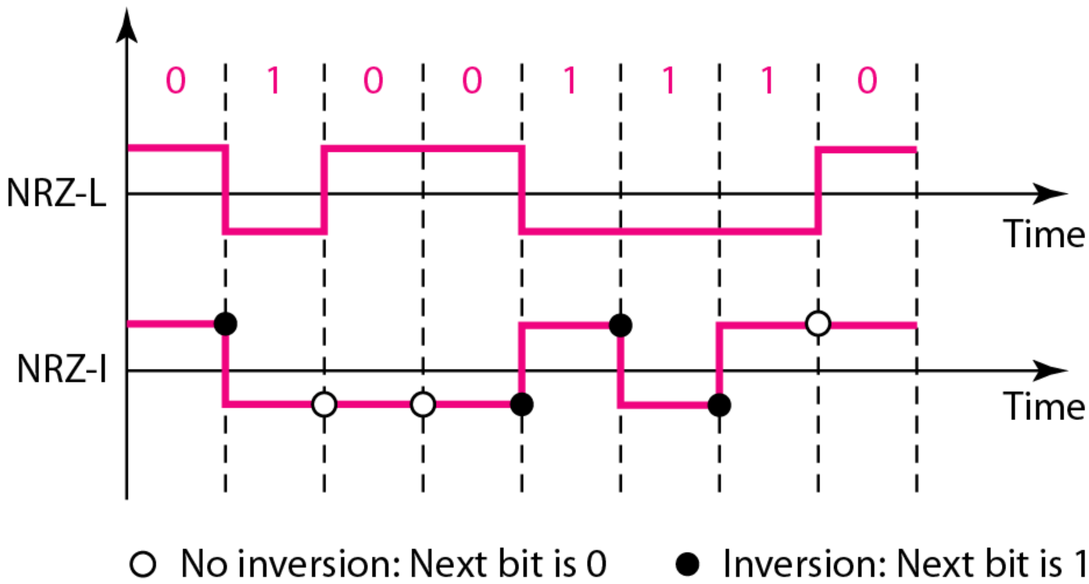
RS232 based protocols

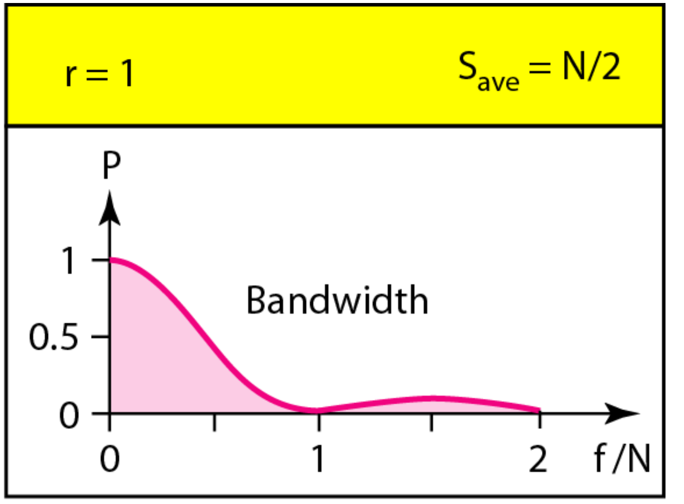


$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

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





Ethernet 100Mbps
FDDI Network

Note

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.

Note

NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.

Note

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 $B_{min} = S = 500$ kHz.

Figure 4.7 *Polar RZ scheme*

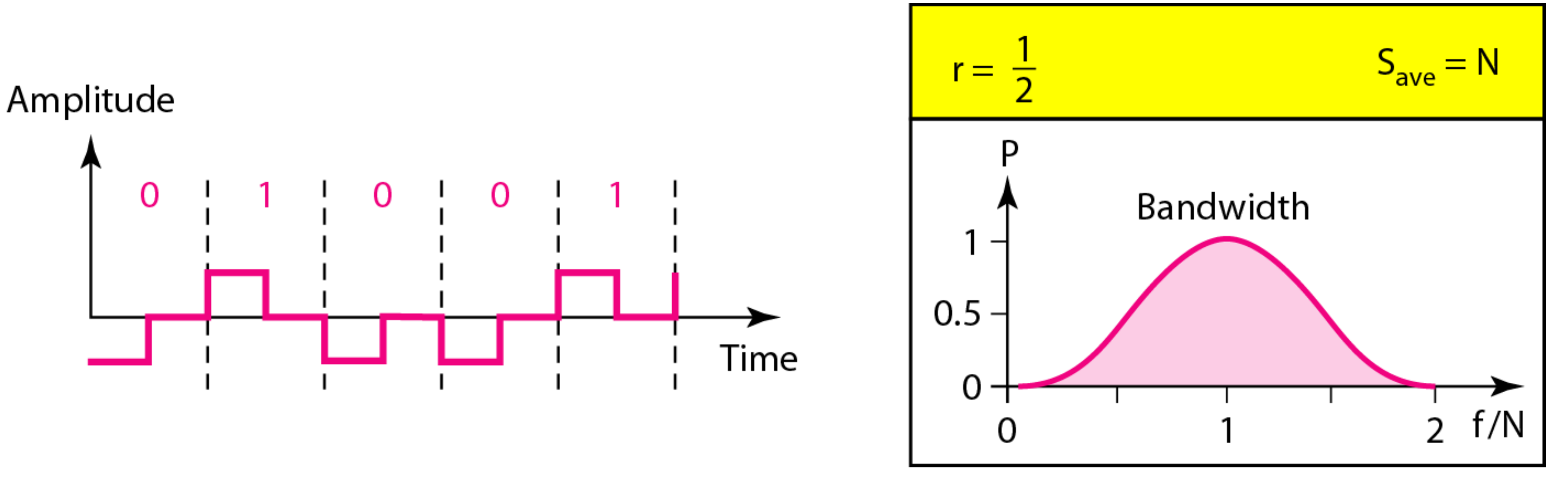
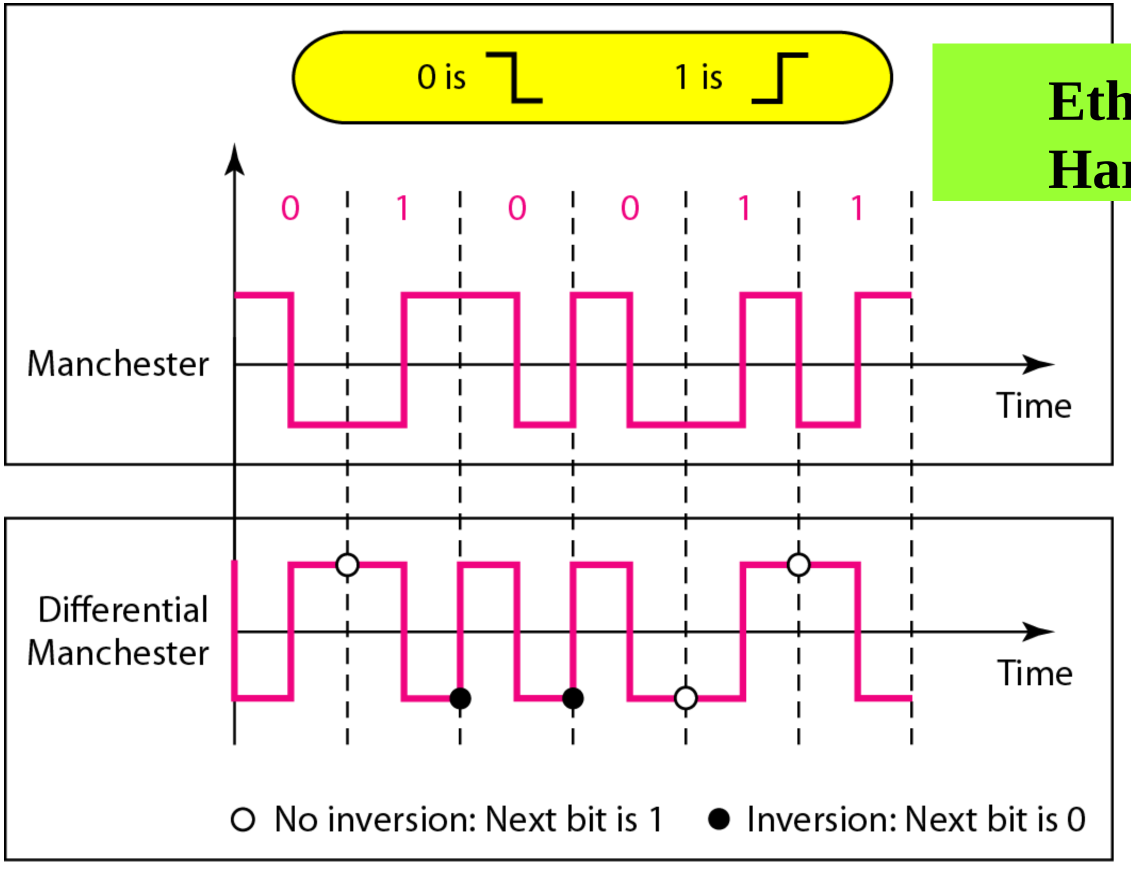
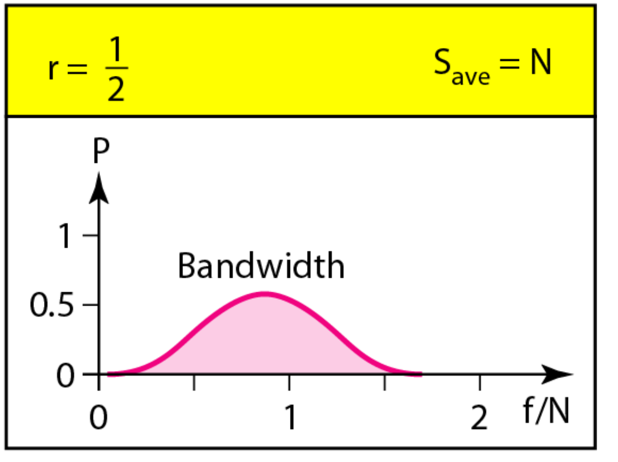


Figure 4.8 *Polar biphase: Manchester and differential Manchester schemes*



Ethernet networks
Hard drive



TOKEN Ring Network

Note

In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.

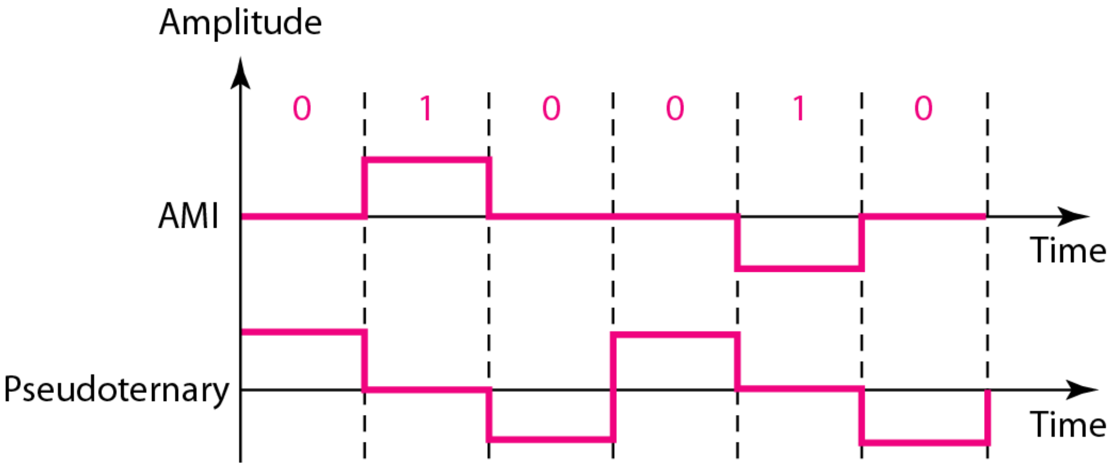
Note

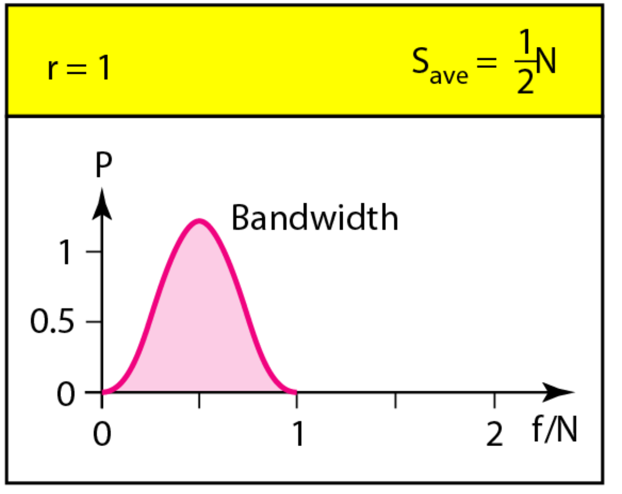
The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.

Note

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

Figure 4.9 *Bipolar schemes: AMI and pseudoternary*





T-1 and E-1 lines

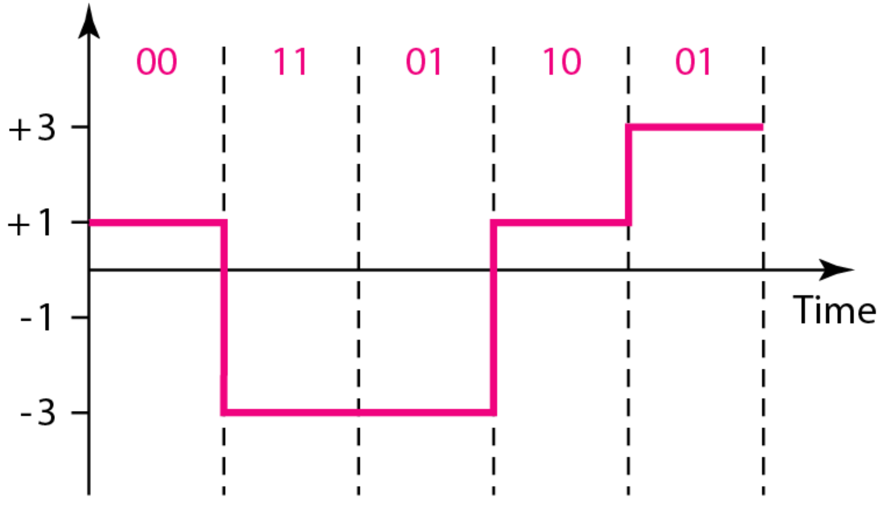
Note

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

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

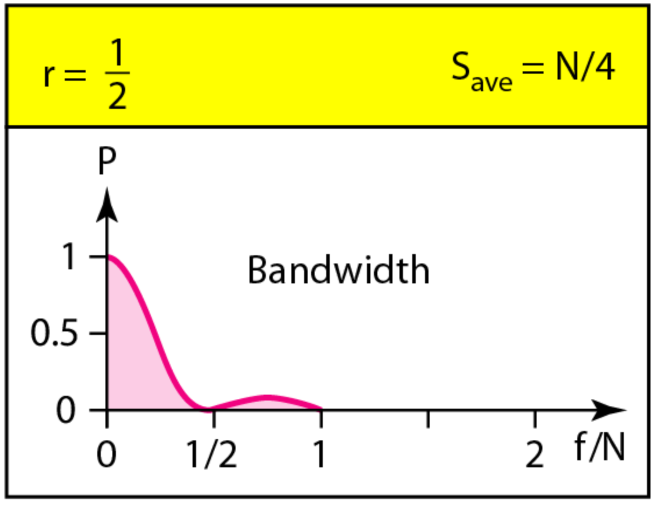


Figure 4.11 *Multilevel: 8B6T scheme*

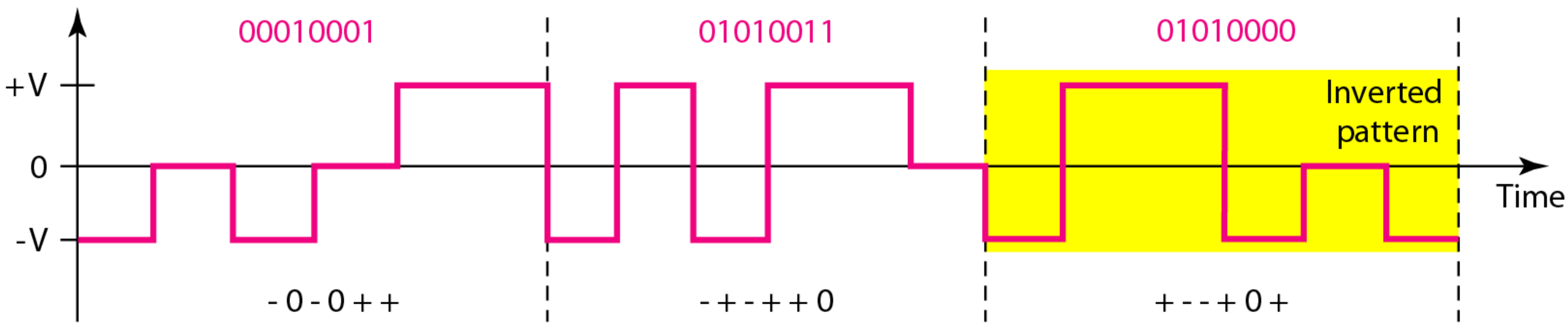


Figure 4.12 *Multilevel: 4D-PAM5 scheme*

(four dimensional five-level pulse amplitude modulation)

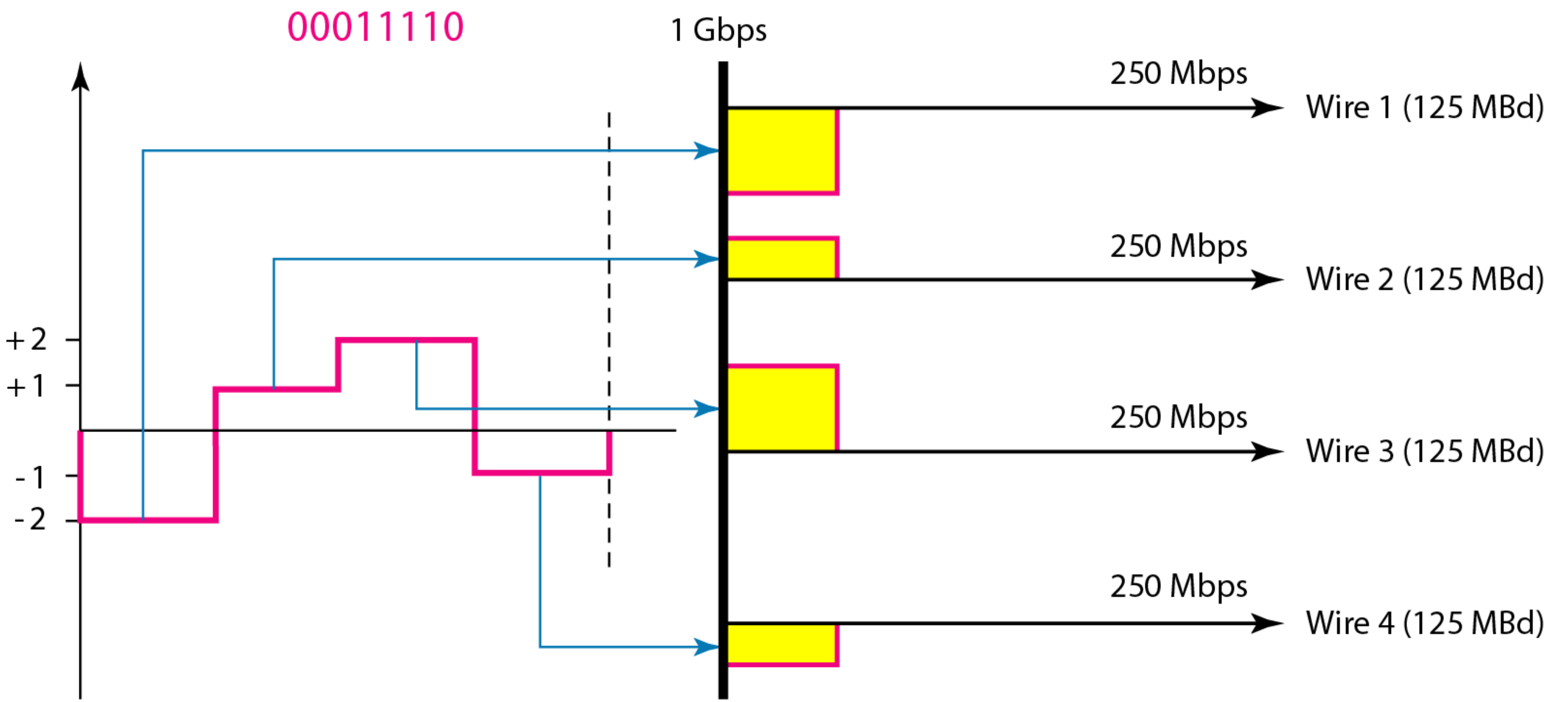
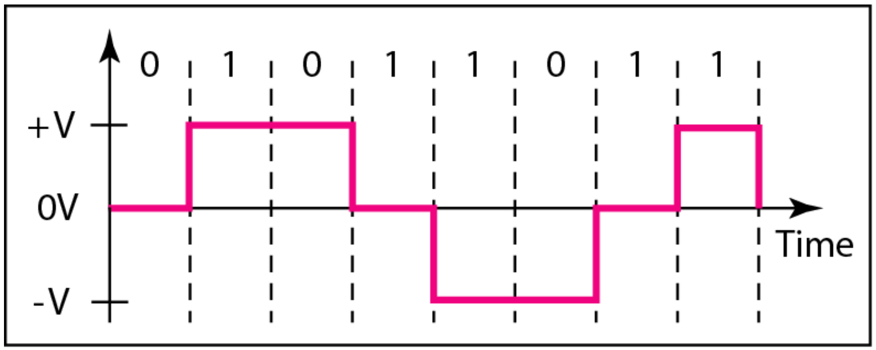
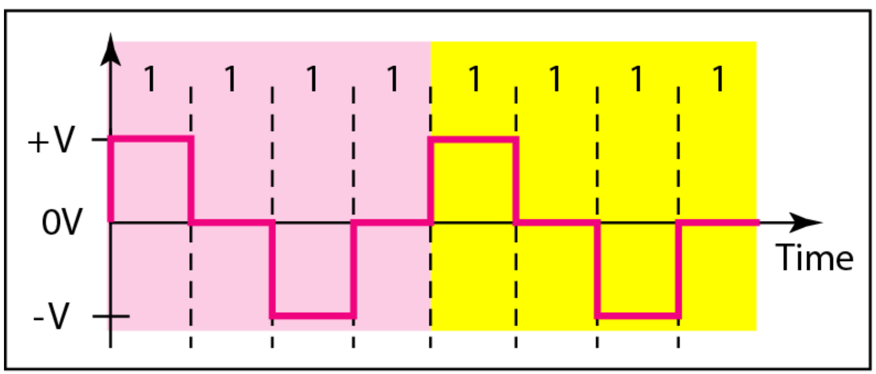


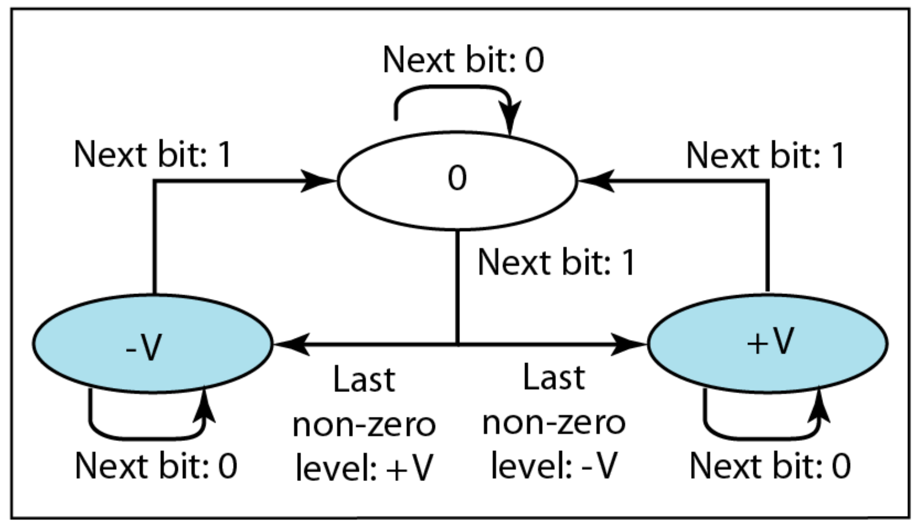
Figure 4.13 *Multitransition: MLT-3 scheme*



a. Typical case



b. Worse case



c. Transition states

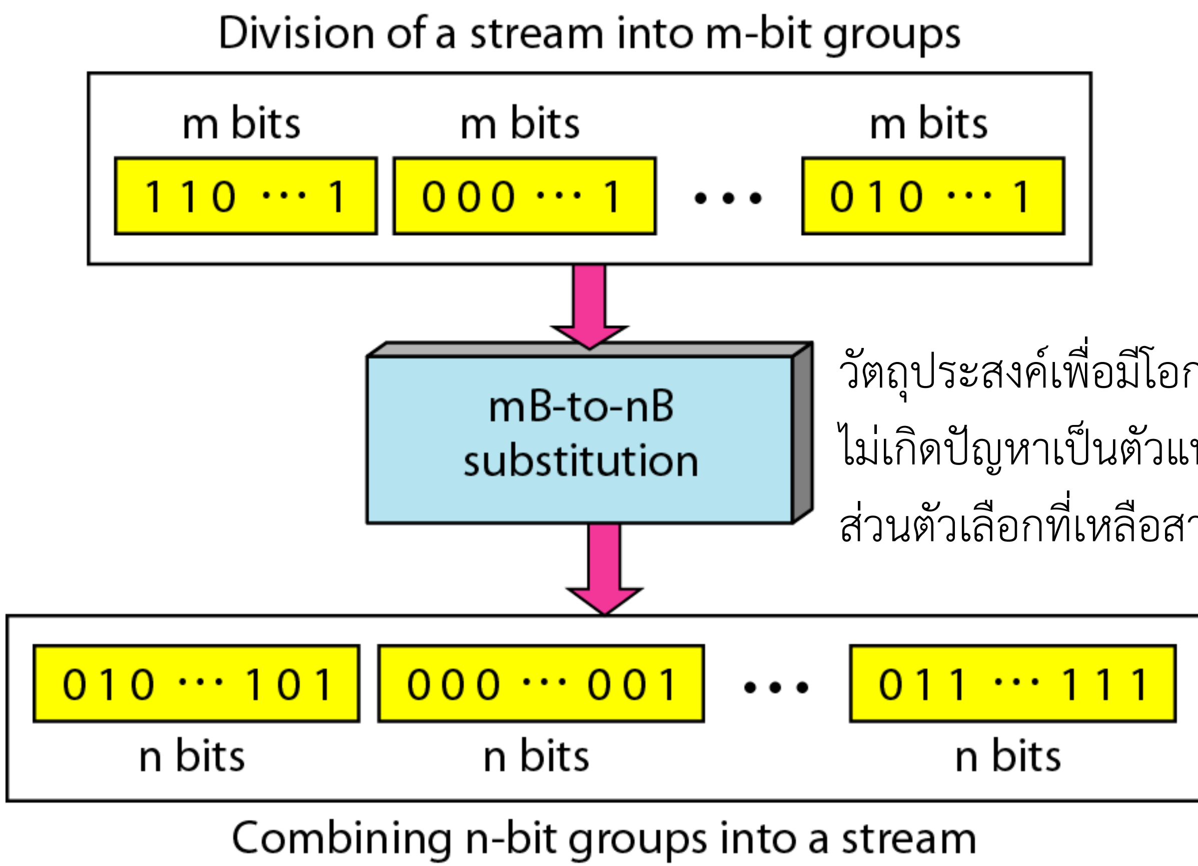
Table 4.1 ***Summary of line coding schemes***

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

Note

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

Figure 4.14 *Block coding concept*



วัตถุประสงค์เพื่อมีโอกาสเลือกตัวเลือกที่
ไม่เกิดปัญหาเป็นตัวแทนบิตข้อมูล
ส่วนตัวเลือกที่เหลือสามารถใช้เป็นคำสั่งได้อีก

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

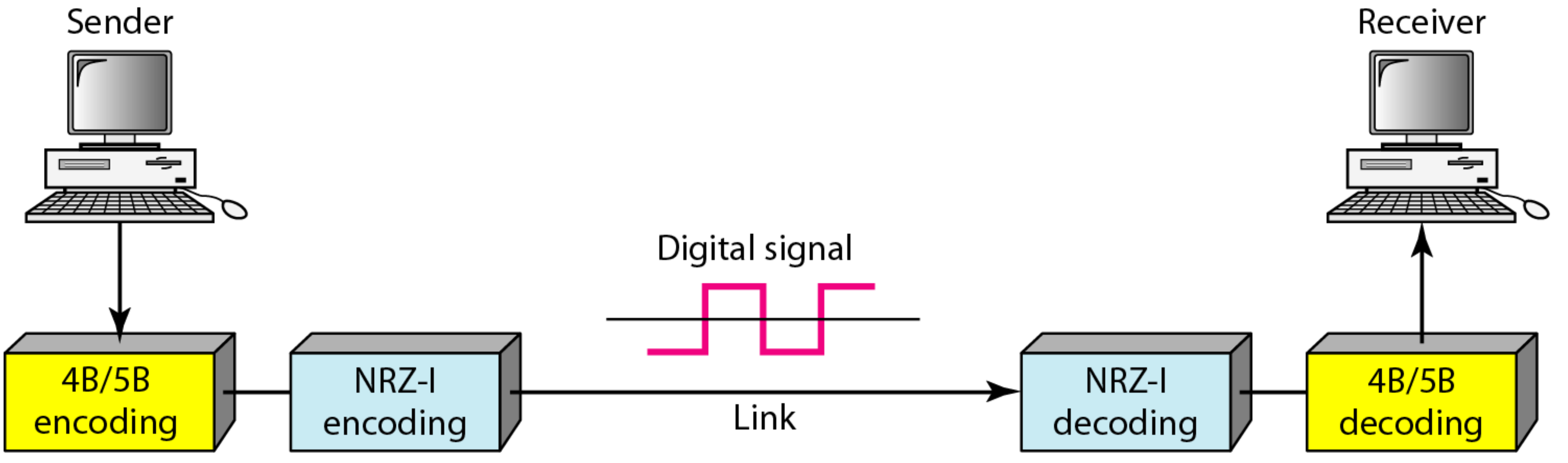
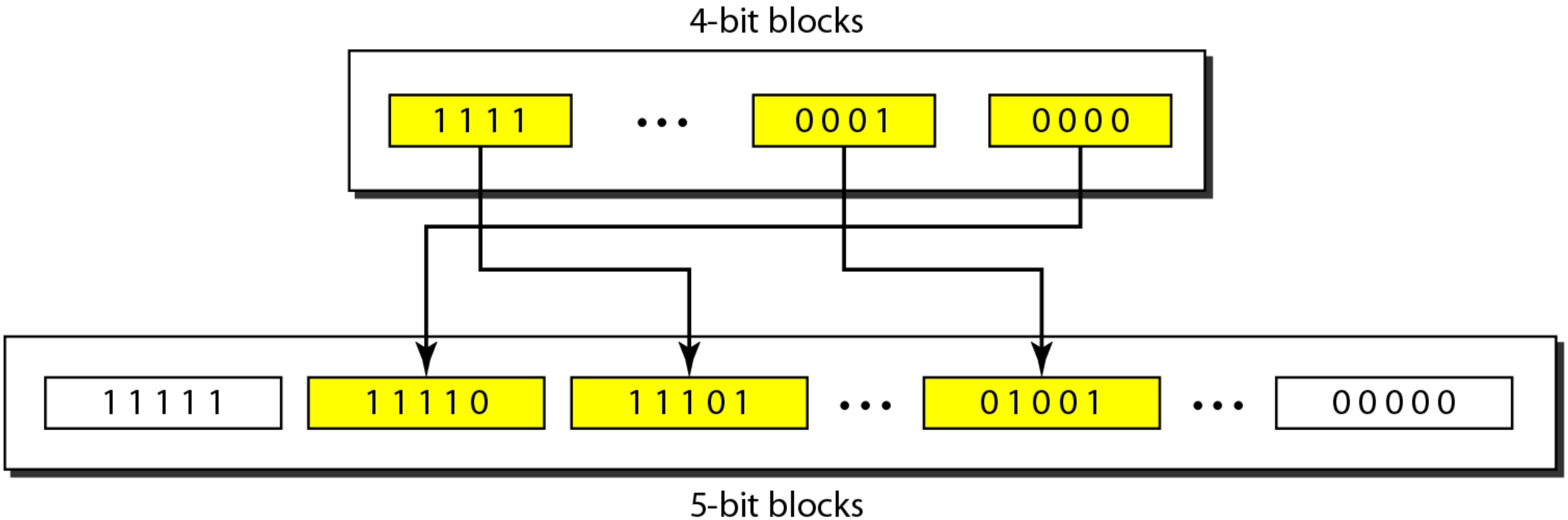


Table 4.2 *4B/5B mapping codes*

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		

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.

Figure 4.17 *8B/10B block encoding*

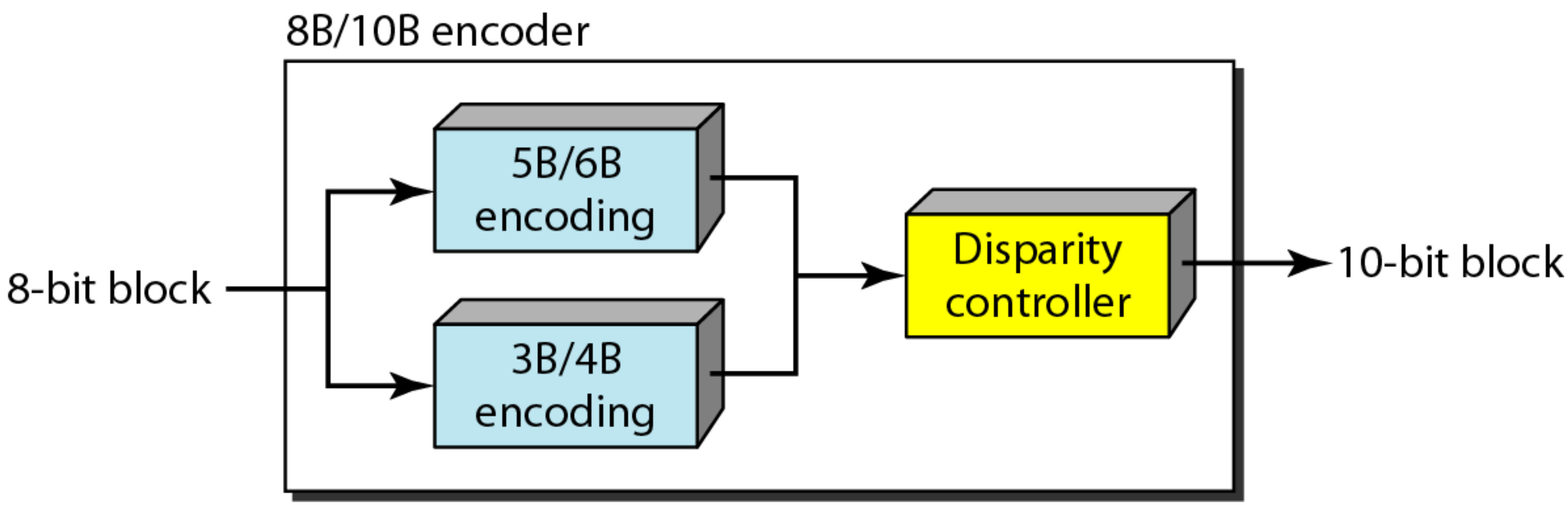


Figure 4.18 *AMI used with scrambling*

B8ZS substitutes eight consecutive zeros with 000VB0VB.
HDB3 substitutes four consecutive zeros with 000V or B00V depending on the number of nonzero pulses after the last substitution.

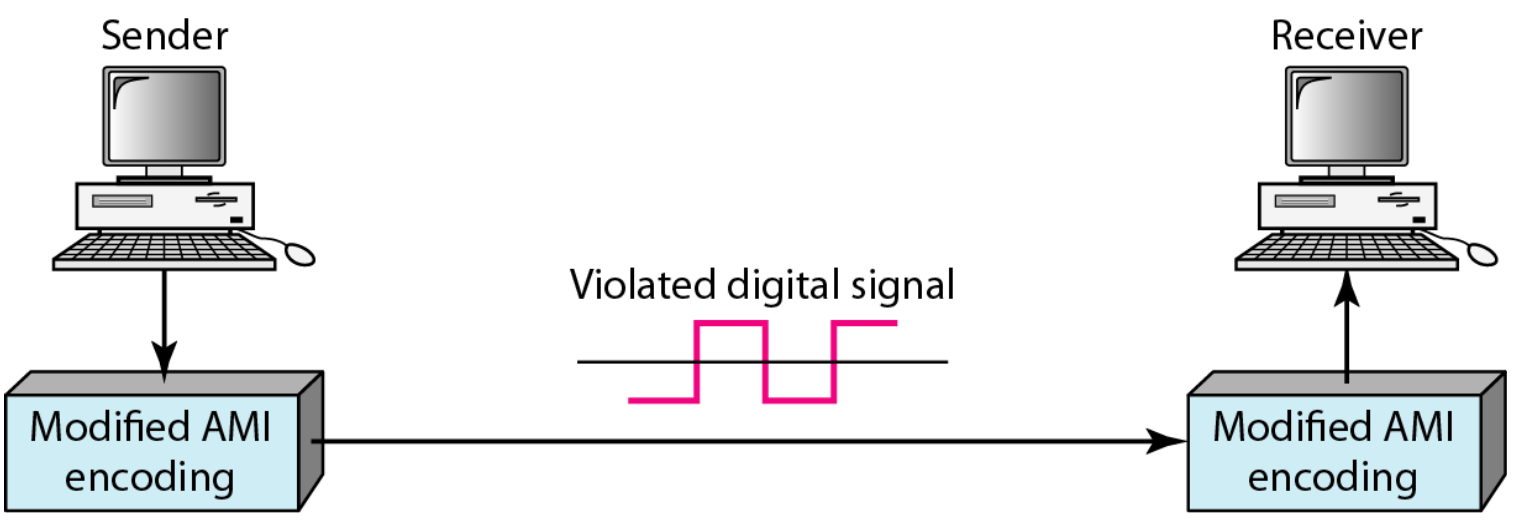
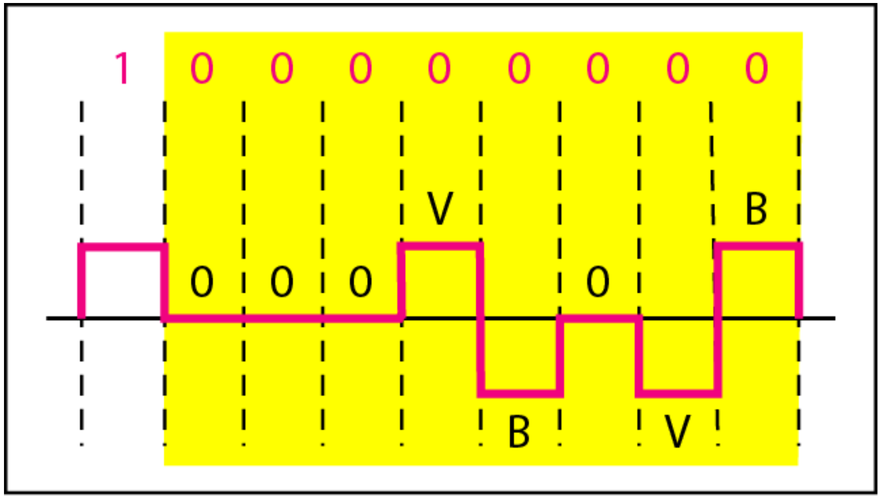
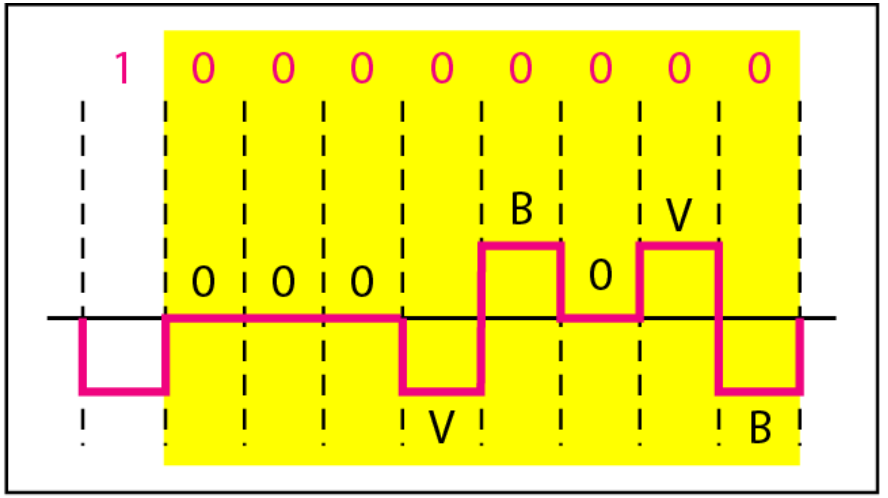


Figure 4.19 *Two cases of B8ZS scrambling technique*



a. Previous level is positive.

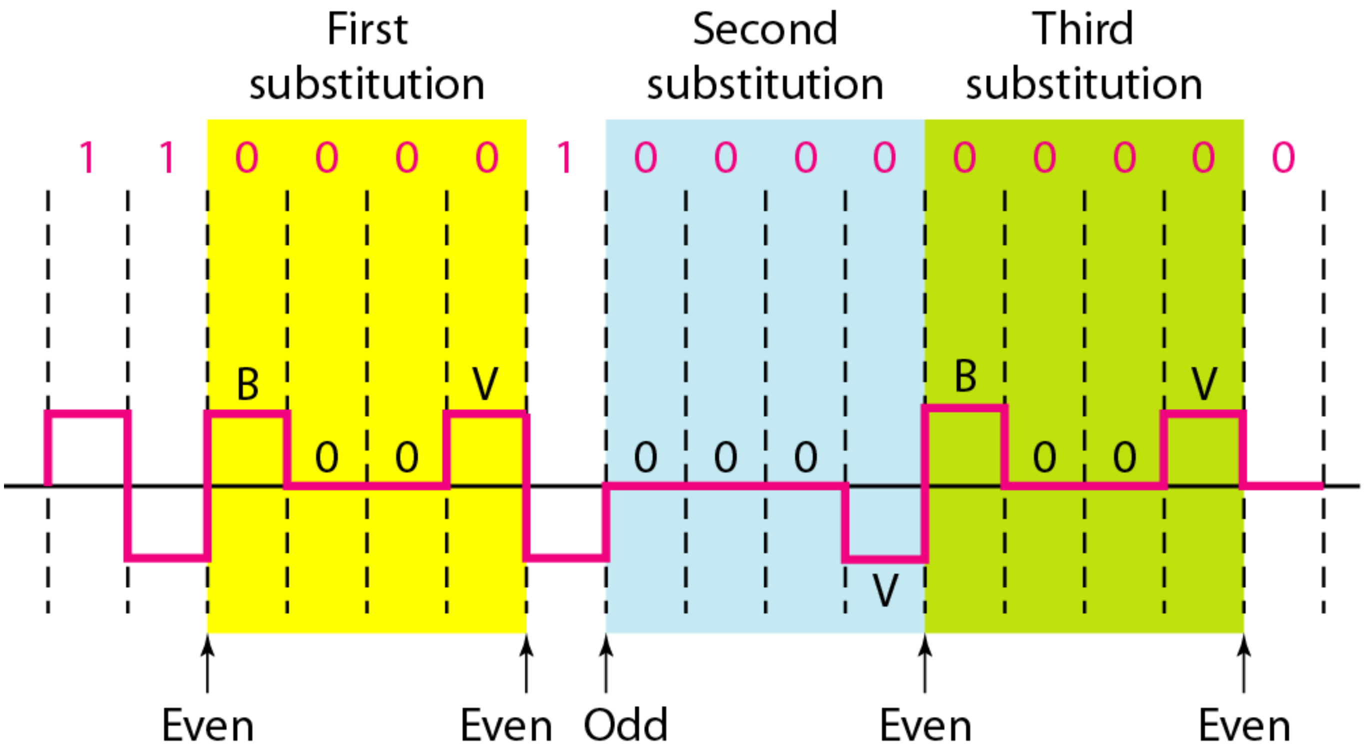


b. Previous level is negative.

Note

B8ZS substitutes eight consecutive zeros with 000VB0VB.

Figure 4.20 *Different situations in HDB3 scrambling technique*



Note

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

Applications of Line Coding

- NRZ encoding: RS232 based protocols
- Manchester encoding:
  - Ethernet networks (IEEE 802.3)
  - Hard drive
- Differential Manchester encoding:
  - token-ring networks (IEEE 802.5)
- NRZ-Inverted encoding:
  - USB
  - Fiber Distributed Data Interface (FDDI)
- 2B1Q: ISDN
- 8B6T: 100 Mbps Ethernet
- B8ZS and HDB3 : Fiber Optic
- 4B/5B NRZI: Ethernet 100 Mbps and FDDI
- 8B/10B: Gigabit Ethernet

Line Coding Summarize

Objective	Line Coding	Data rate
High Data rate	2B1Q 4D-PAM5	2 x Signal rate 4 channel of (2 x Signal rate)
No Error Sync Long ‘1’	NRZ-I, AMI, MLT-3	Signal rate
No Sync Error	RZ, Manchester, Differential Manchester 8B6T 4B/5B, 8B/10B B8ZS, HDB3 (AMI with Scrambling)	(1/2) x signal rate (4/3) x signal rate Require higher signal rate Data rate depends on chosen line coding technique Signal rate