Data & Signals (Part 1)

Course Code: COE 3201 Course Title: Data Communication

Dept. of Computer Engineering
Faculty of Engineering

Lecture No:	**5**	**Week No:**	**5**	**Semester:**	
Lecturer:					

Lecture Outline

1. Digital to Digital Conversion
2. Signal Element vs Data Element
3. Signal Rate vs Data Rate
4. Baseline Wandering
5. DC Component
6. Synchronization
7. Line Coding:
    a) Unipolar
    b) Polar
    c) Bipolar
    d) Multilevel
    e) Multitransition

Digital to Digital Conversion

- Digital to digital conversion is the way of representing digital data by using digital signals. The conversion involves three techniques: line coding, block coding, and scrambling.

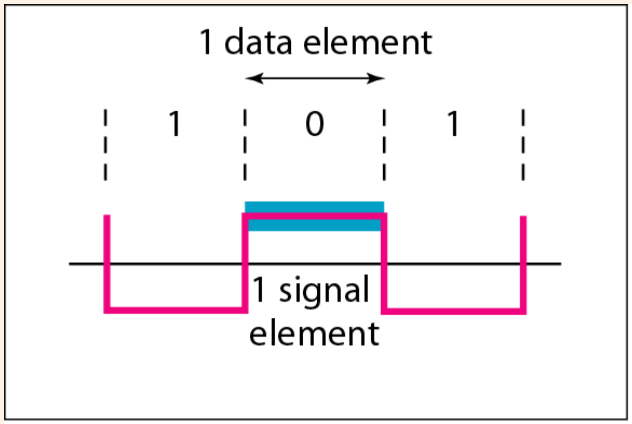
- Line coding is always needed. We will mainly discuss line coding in this lecture.

- Block coding and scrambling may or may not be needed.

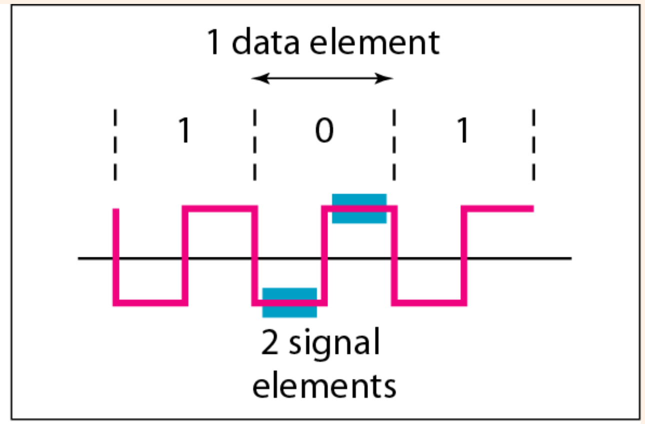
Signal Element vs Data Element

- **Signal element**
  - The shortest unit (timewise) of a **digital signal**.
- **Data element**
  - The smallest entity that can represent a piece of information: this is **bit**.
- In other words
  - Data elements are what we need to send.
  - Signal elements are what we can send.

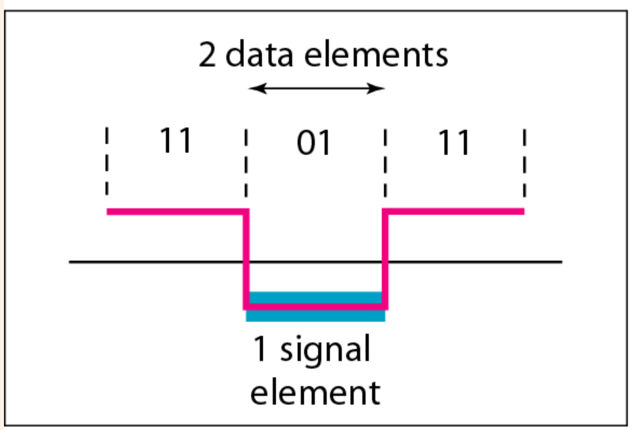
Signal Element vs Data Element



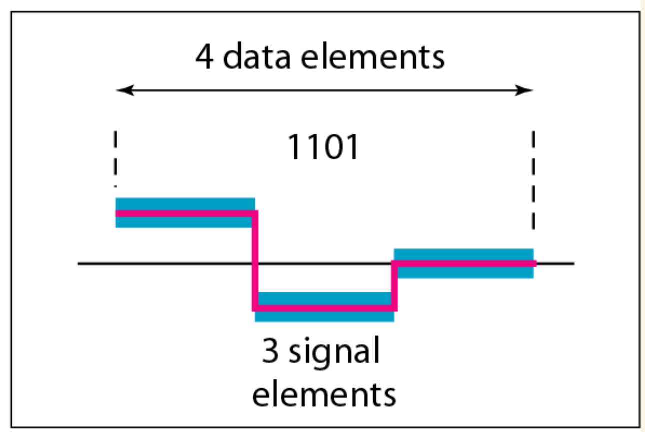
a. One data element per one signal element (r = 1)



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

Signal Rate vs Data Rate

- **Signal rate**
  - The number of signal elements sent in 1s
  - The unit is **baud**
- **Data rate**
  - The number of data elements (bits) sent in 1s
  - The unit is bits per second (**bps**)
- Relationship between data rate and signal rate

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

- S: signal rate (baud), c: case factor, N: data rate (bps), r: data elements per signal elements

Signal Rate vs Data Rate

Problem:

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 assumed to vary between 0 and 1?

Solution:

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

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

Signal Rate vs Data Rate

Problem:

The maximum data rate of a channel 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 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

$$N_{max} = (1/c) \times B \times r = 2 \times B \times \log_2 L$$

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.

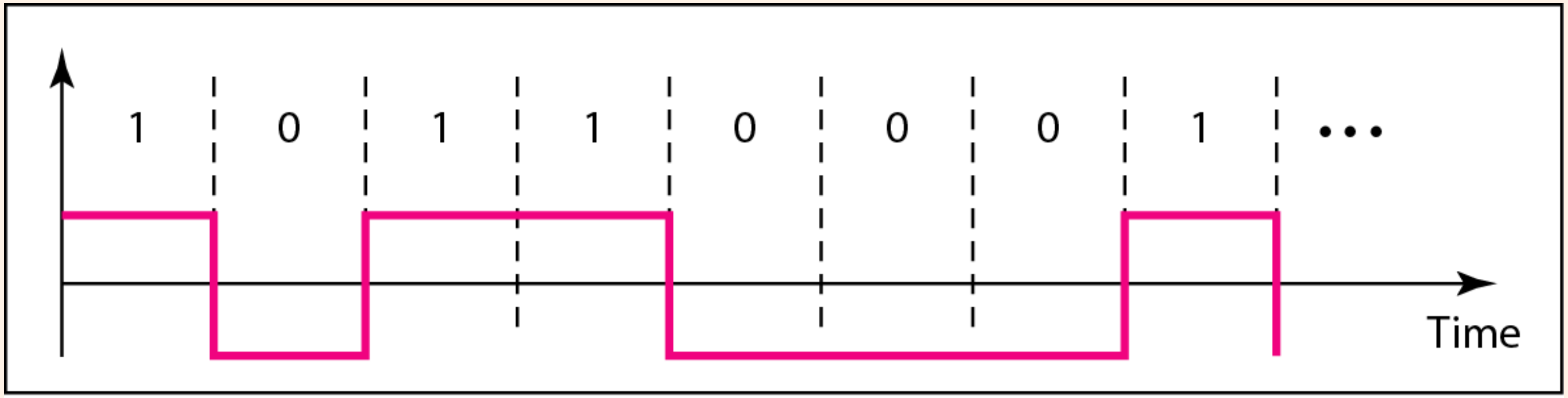
DC Component

- 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, call DC (direct-current) components, present problems for a system that cannot pass low frequencies or a system that uses electrical coupling (via a transformer).
- For example, a telephone line cannot pass frequencies below 200 Hz.

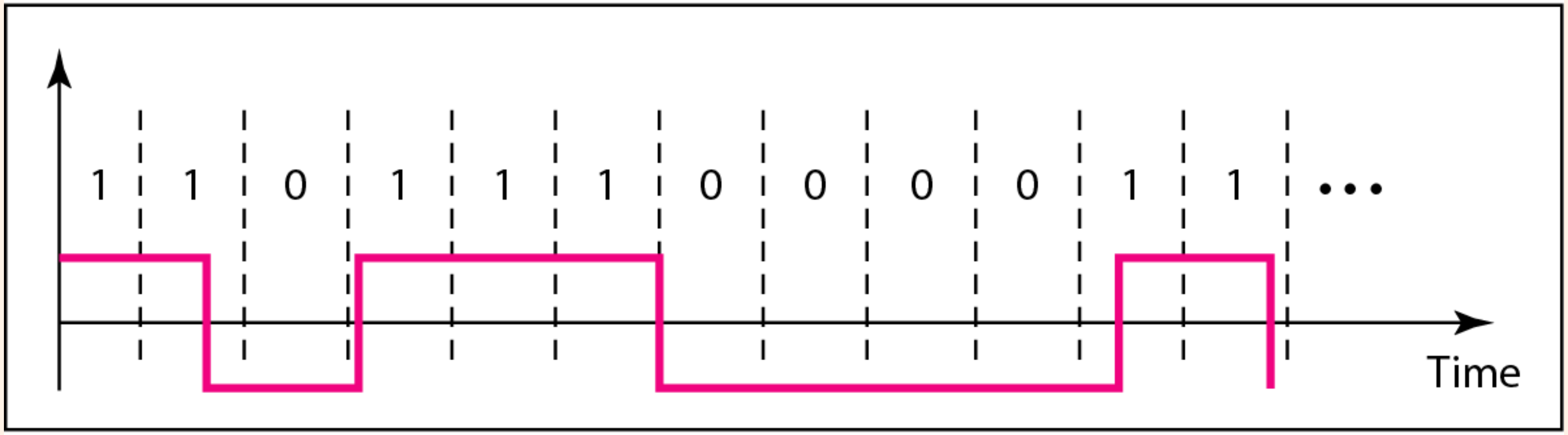
Synchronization

- To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals. If the receiver clock is faster or slower, the bit intervals are not matched, and the receiver might misinterpret the signals.
- Self-synchronization
  - 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.

Effect of Lack of Synchronization



a. Sent



b. Received

Effect of Lack of Synchronization

Problem:

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.

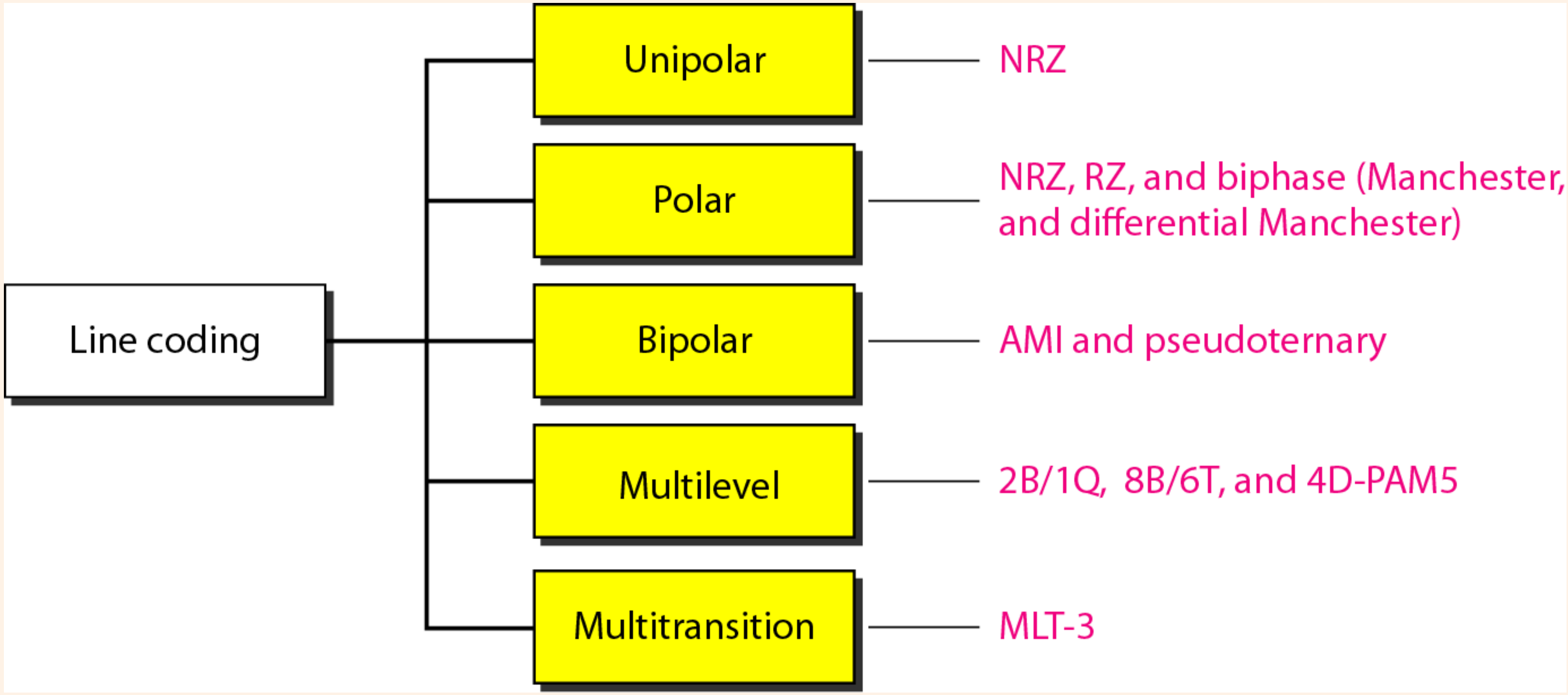
$$1000 \text{ bits sent} \quad \rightarrow \quad 1001 \text{ bits received} \quad \rightarrow \quad 1 \text{ extra bps}$$

At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

$$1{,}000{,}000 \text{ bits sent} \quad \rightarrow \quad 1{,}001{,}000 \text{ bits received} \quad \rightarrow \quad 1000 \text{ extra bps}$$

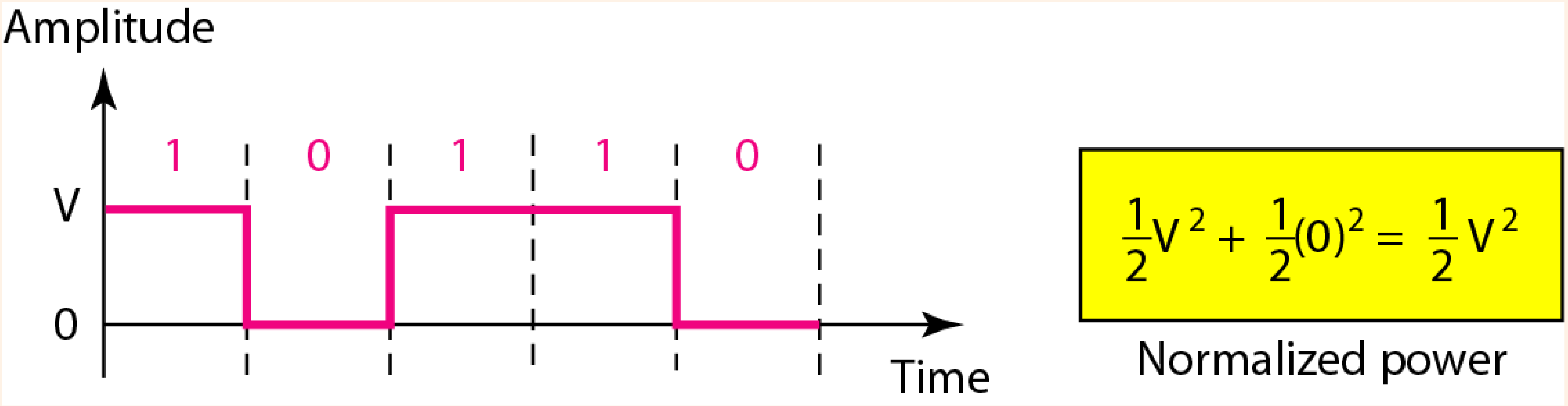
Line Coding

Line coding schemes



Unipolar

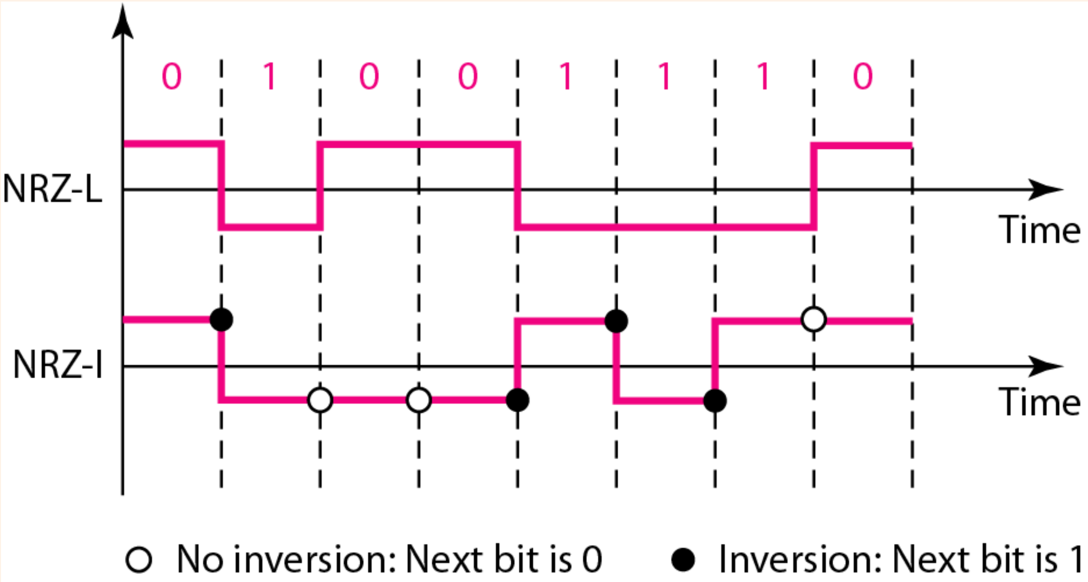
Non-Return to Zero

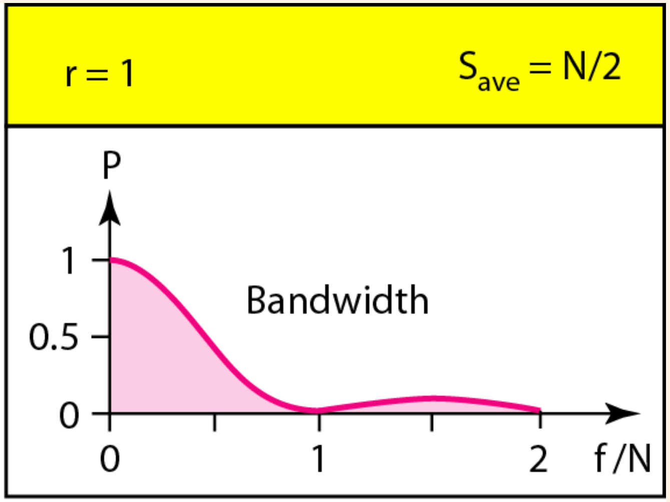


It is called NRZ because the signal does not return to zero at the middle of the bit.

Polar

NRZ-L (NRZ-Level), NRZ-I (NRZ-Invert)





Polar: NRZ-L (NRZ-Level), NRZ-I (NRZ-Invert)

- 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 Baud.
- NRZ-L and NRZ-I both have a DC component problem.

Polar: NRZ-L (NRZ-Level), NRZ-I (NRZ-Invert)

Problem:

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,

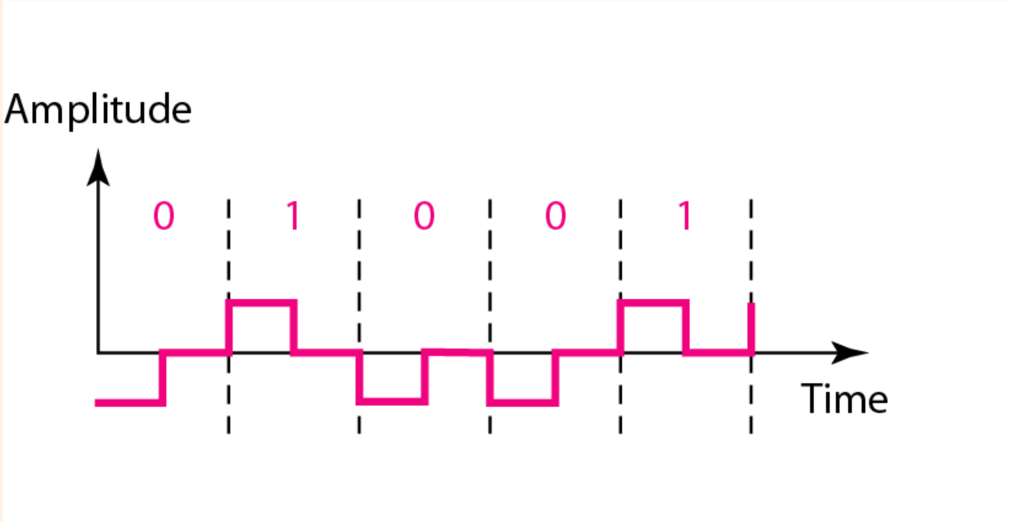
$S = N/2 = 5000$ kbaud

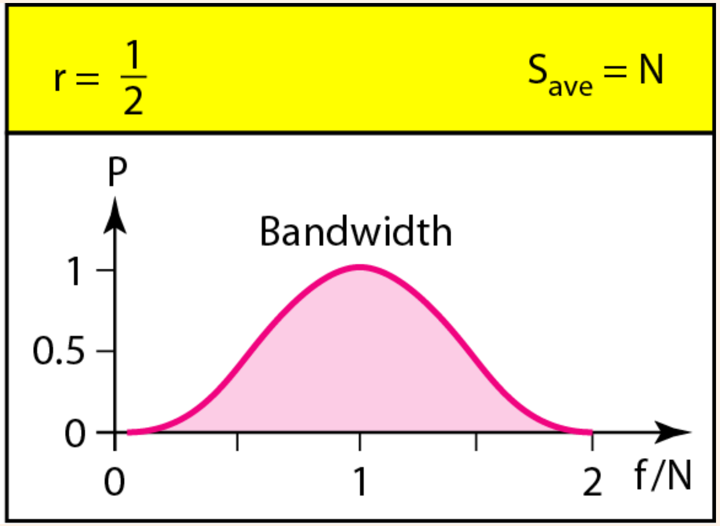
The minimum bandwidth for this average baud rate,

$B_{min} = S = 5000$ kHz.

Polar

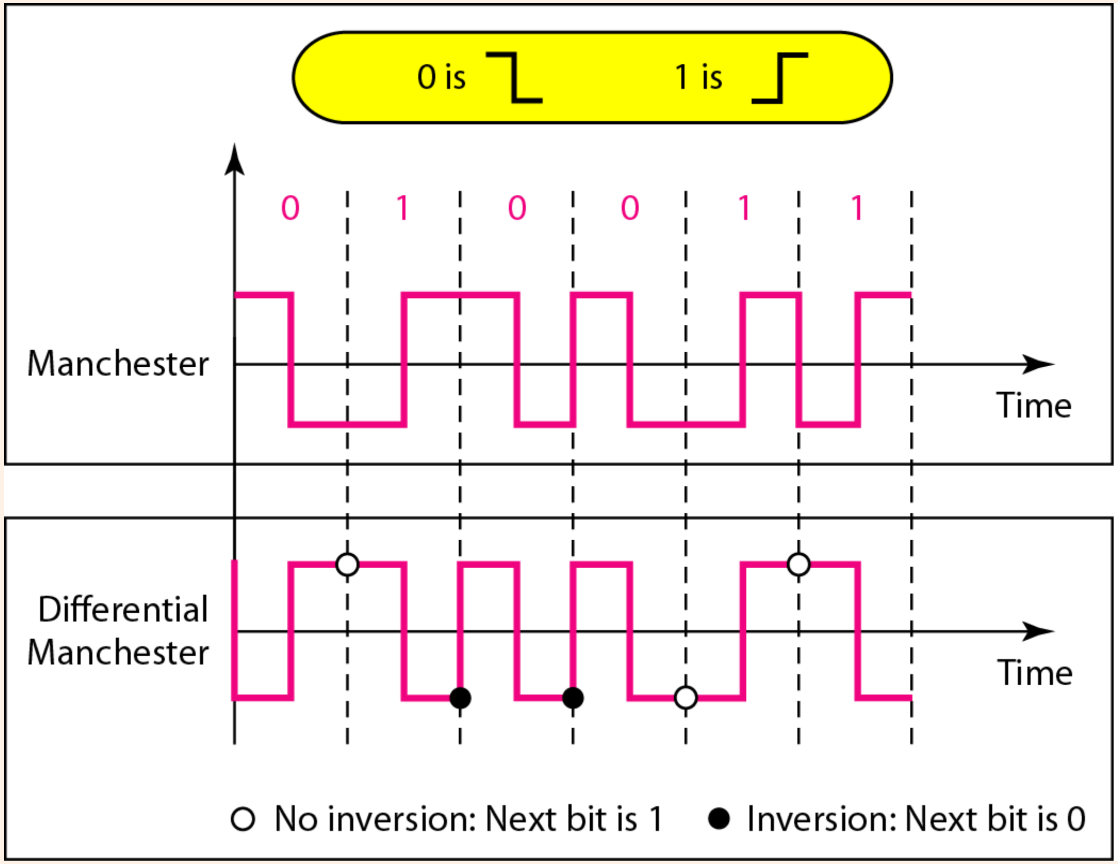
RZ: Return-to-Zero Scheme

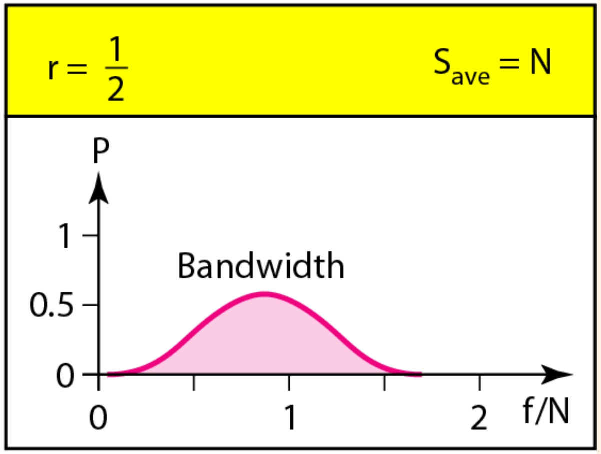




Polar Biphase

Manchester and Differential Manchester Schemes





Manchester and differential Manchester schemes

- In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.
- The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.

Bipolar Schemes

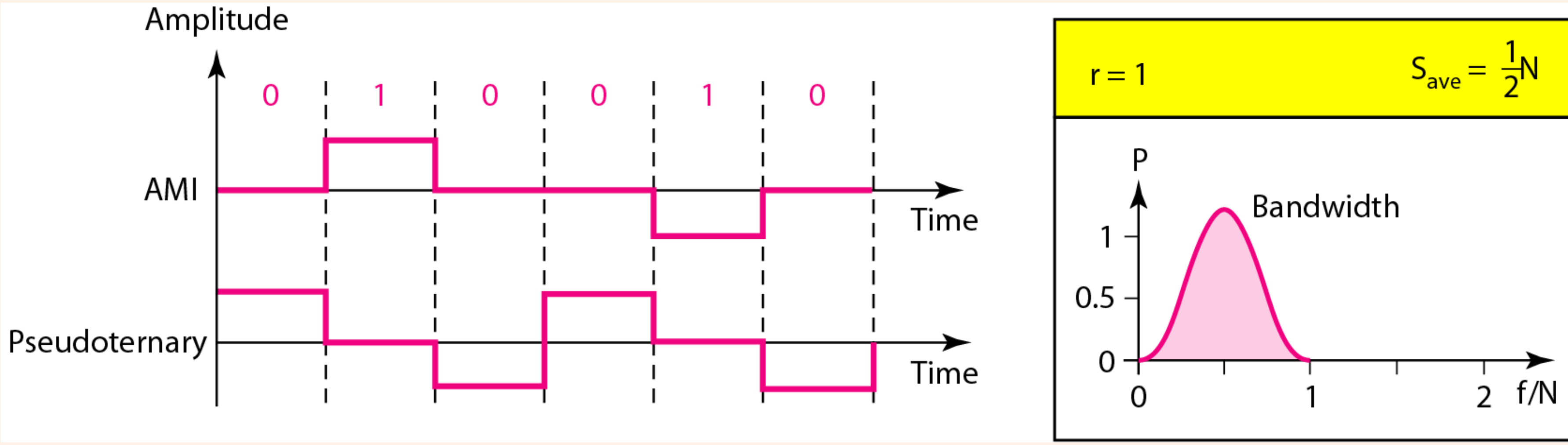
AMI and Pseudoternary

- Bipolar encoding (sometimes called multilevel binary)
  - Three voltage levels: positive, negative, and zero
- Two variations of bipolar encoding
  - AMI (alternate mark inversion)
    - 0: neutral zero voltage
    - 1: alternating positive and negative voltages
  - Pseudoternary
    - 1: neutral zero voltage
    - 0: alternating positive and negative voltages
- Bipolar schemes have **no** DC component problem
- In bipolar encoding, we use three levels: positive, zero, and negative.

AMI and Pseudoternary

- **AMI** (alternate mark inversion)
  - The word mark comes from telegraphy and means 1
  - AMI means alternate 1 inversion
  - The neutral zero voltage represents binary 0
  - Binary 1s are represented by alternating positive and negative voltages
- **Pesudoternary**
  - Same as AMI, but 1 bit is encoded as a zero voltage and the 0 bit is encoded as alternating positive and negative voltages.

AMI and Pseudoternary



Multilevel Schemes

- The desire to increase the data speed or decrease the required bandwidth has resulted in the creation of many schemes.

- The goal is to increase the number of bits per baud by encoding a pattern of **m** data elements into a pattern of **n** signal elements.

- Different types of signal elements can be allowed for different signal levels.

Multilevel Schemes

- If we have L different levels, then we can produce L^n combinations of signal patterns.

- The data element and signal element relation is

- mBnL coding, 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.

- B (binary, L=2), T (tenary, L=3), and Q (quaternary, L=4).

Multilevel: 2B1Q scheme

- 2B1Q (two binary, one quaternary)
  - m=2, n=1, and L=4
  - The signal rate (baud rate)

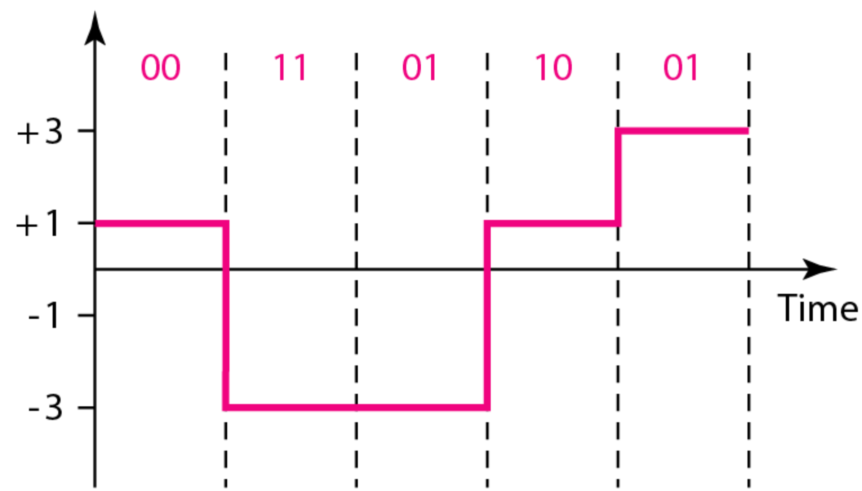
$$S = cN\frac{1}{r} = \frac{1}{2}\times N\times\frac{1}{2} = \frac{N}{4}$$

- 2B1Q is used in DSL (digital subscriber line) technology to provide a high-speed connection to the Internet by using subscriber telephone lines.

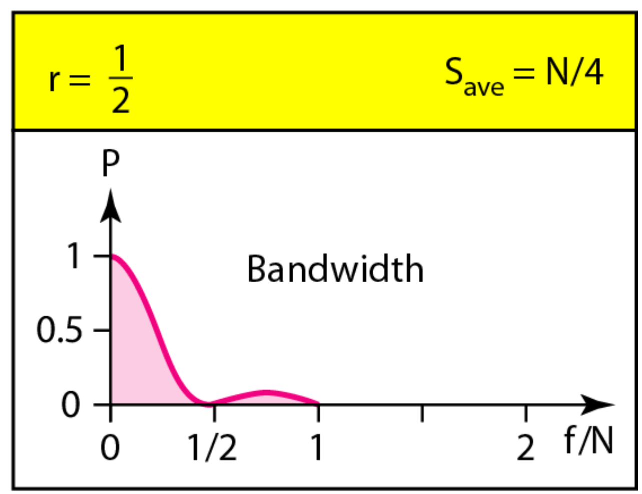
Multilevel: 2B1Q scheme

	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



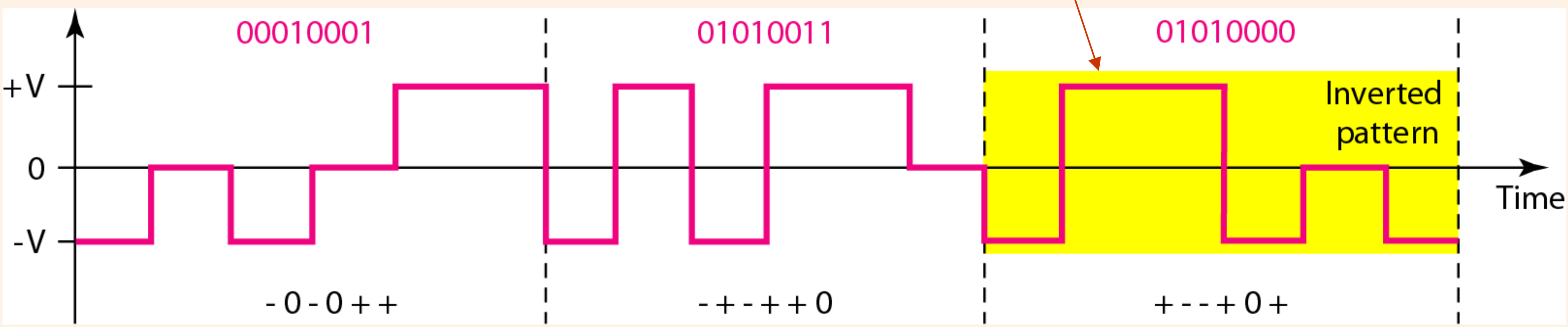
Multilevel: 8B6T scheme

- This code is used with 100BASE-4T cable.
- Encode a pattern of 8 bits as a pattern of 6 signal elements, where the signal has three levels (ternary).
- 2^8=256 different data patterns and 3^6=729 different signal patterns. (The mapping is shown in Appendix D.)
- There are 729-256=473 redundant signal elements that provide synchronization and error detection.
- Part of the redundancy is also used to provide **DC (direct-current) balance**.

Multilevel: 8B6T scheme

- + (positive signal), - (negative signal), and 0 (lack of signal) notation.
- To make whole stream DC-balanced, the sender keeps track of the weight

Invert - + + - 0 - = -1



Multiline Transmission: MLT-3

Three levels (+V, 0, and –V) and three transition rules to move the levels

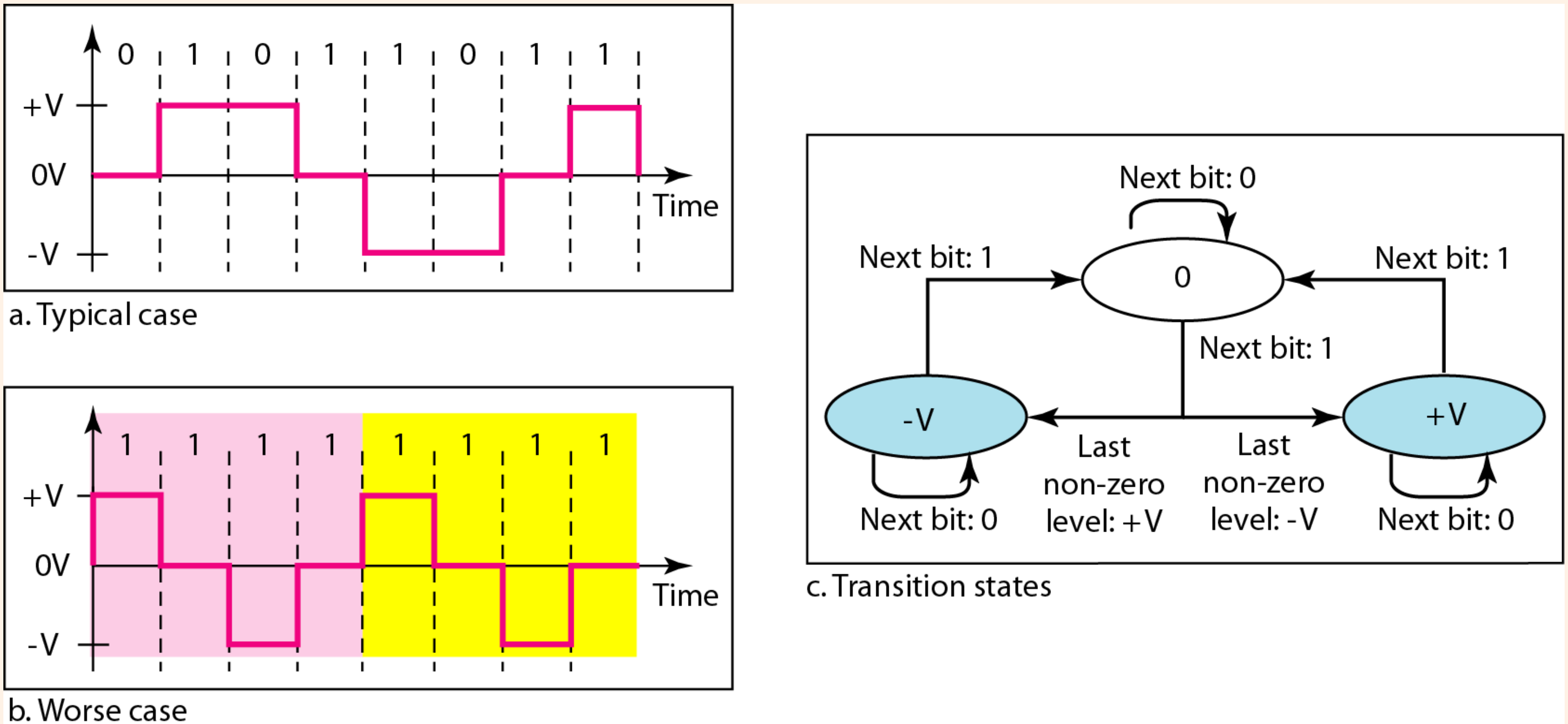
- If the next bit is 0, there is no transition
- If the next bit is 1 and the current level is not 0, the next level is 0.
- If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.

Multiline Transmission: MLT-3

Why do we need to use MLT-3?

- The signal rate for MLT-3 is one-fourth the bit rate (N/4).
- This makes MLT-3 a suitable choice when we need to send 100 Mbps on a copper wire that cannot support more than 32 MHz (frequencies above this level create electromagnetic emission).

Multiline Transmission: MLT-3



Summary

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

Books

1. Forouzan, B. A. "Data Communication and Networking. Tata McGraw." (2005).

References

1. Prakash C. Gupta, “Data communications”, Prentice Hall India Pvt.
2. William Stallings, "Data and Computer Communications”, Pearson
3. Forouzan, B. A. "Data Communication and Networking. Tata McGraw." (2005).