COMP 3721
Introduction to Data Communications

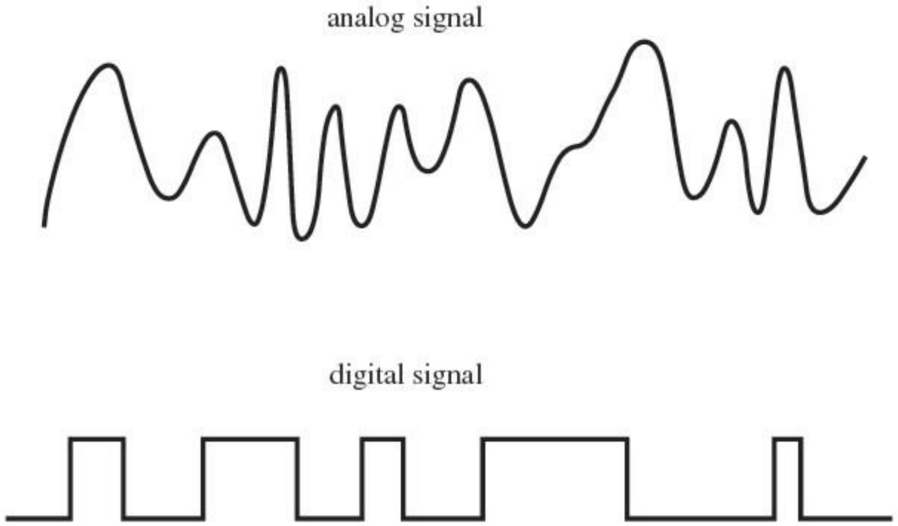
04. Week 4

Learning Outcomes

- By the end of this lecture, you will be able to:
  - Explain what is data rate and what is signal rate.
  - Compute the bandwidth of a digital signal.
  - Explain line coding schemes and their characteristics.

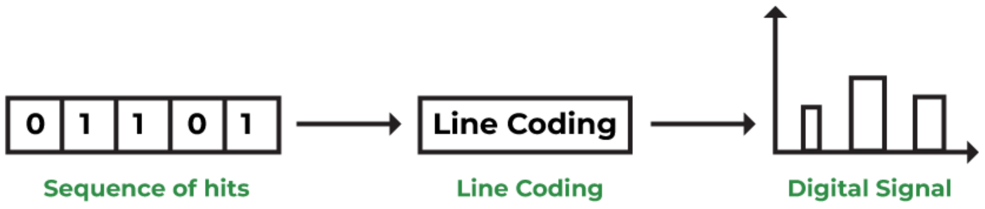
Introduction

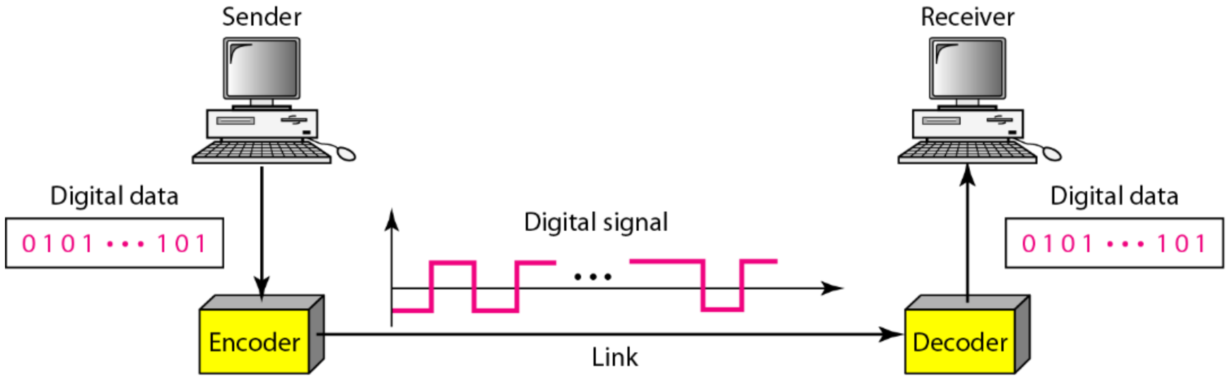
- A computer network is designed to send information from one point to another.
- This information needs to be converted to **either** a **digital signal** or an **analog signal** for transmission.
- This lecture: We will discuss **digital-to-digital conversion** (convert digital **data** to digital **signals**).



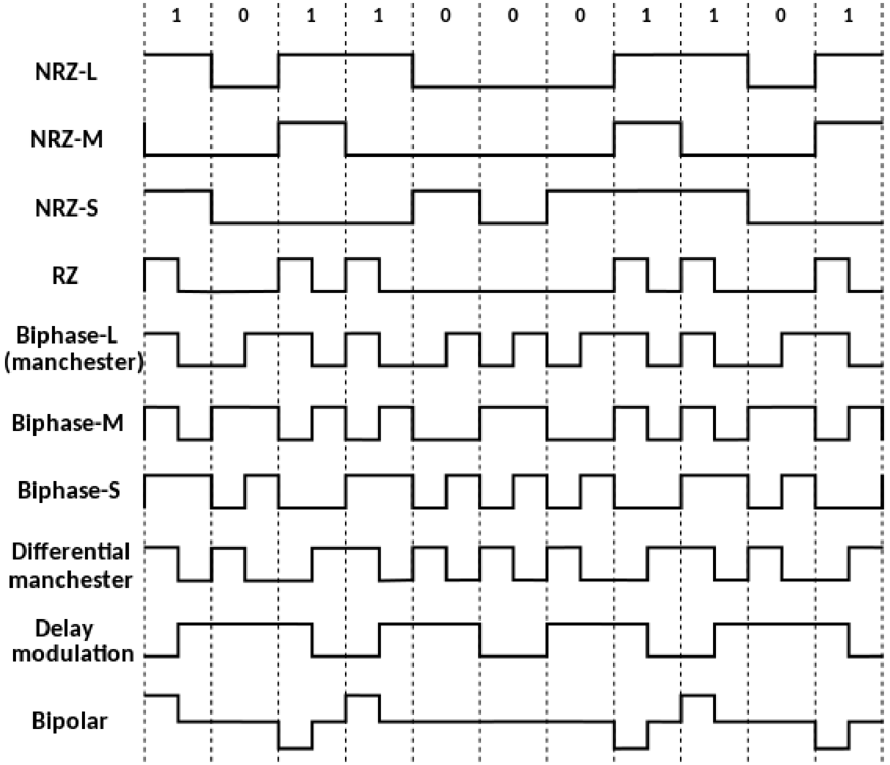
Digital-To-Digital Conversion

- Representing **digital data** by using **digital signals**.
- **Line coding**:
  - The process of **converting** digital data to digital signal.
  - A sequence of bits is converted to a digital signal.





Common Binary Line Code Formats



Some of the Common Characteristics of Line Coding Schemes

1. Signal element vs. Data element
2. Data rate vs. Signal rate
3. Bandwidth
4. Baseline wandering
5. Self-synchronization
6. DC components

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  - Data elements are what we need to send.
  - Two types: **0** and **1**

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Signal elements are what we **can** send (physically).

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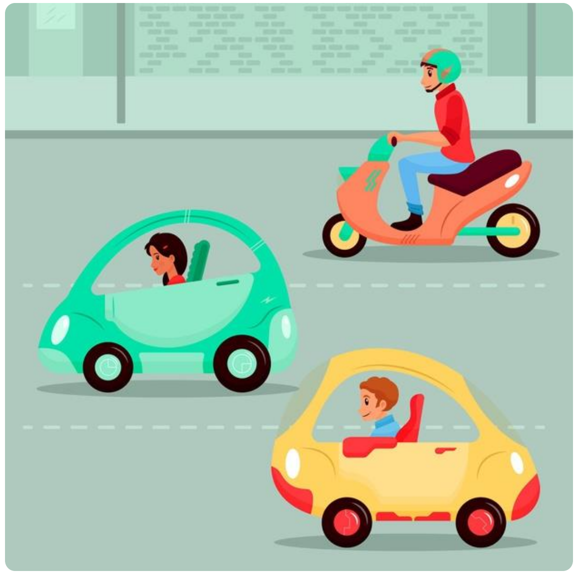
- **Ratio** (*r*)
  - The number of data elements carried by each signal element.
  - **Different** for each line coding scheme.

Data elements are what we **need** to send (logically).
Signal elements are what we **can** send (physically).

Signal Element vs. Data Element – Transportation Analogy

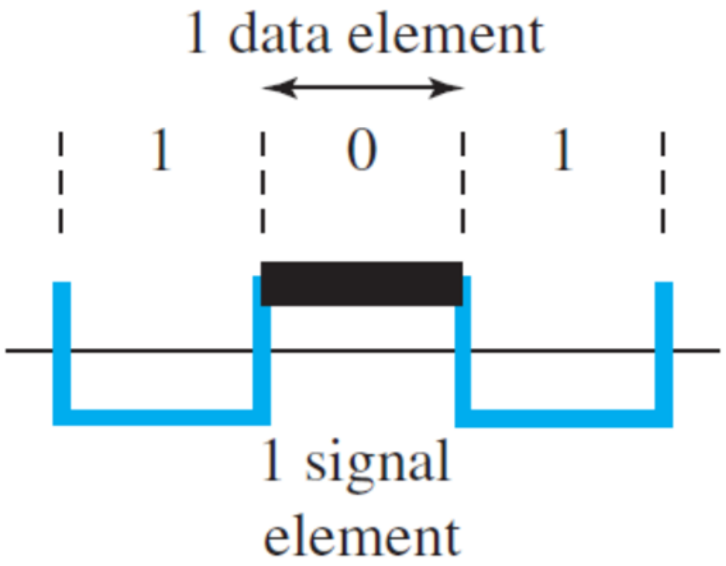
- An analogy: Suppose each **data** element is a **person** who needs to be carried from one place to another. We can think of a **signal** element as a **vehicle** that can carry **people**. When $r = 1$, it means **each person** is driving a **vehicle**. When $r > 1$, it means **more than one person** is travelling in a **vehicle** (a carpool, for example). We can also have the case where **one person** is driving **a car and a trailer** ($r = 1/2$).



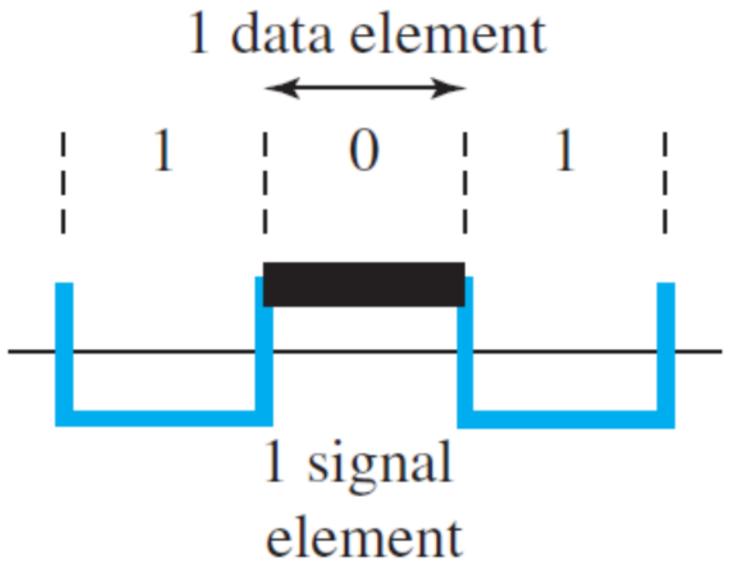
$r = 1$

$r > 1$

Signal Element vs. Data Element (Cont.)

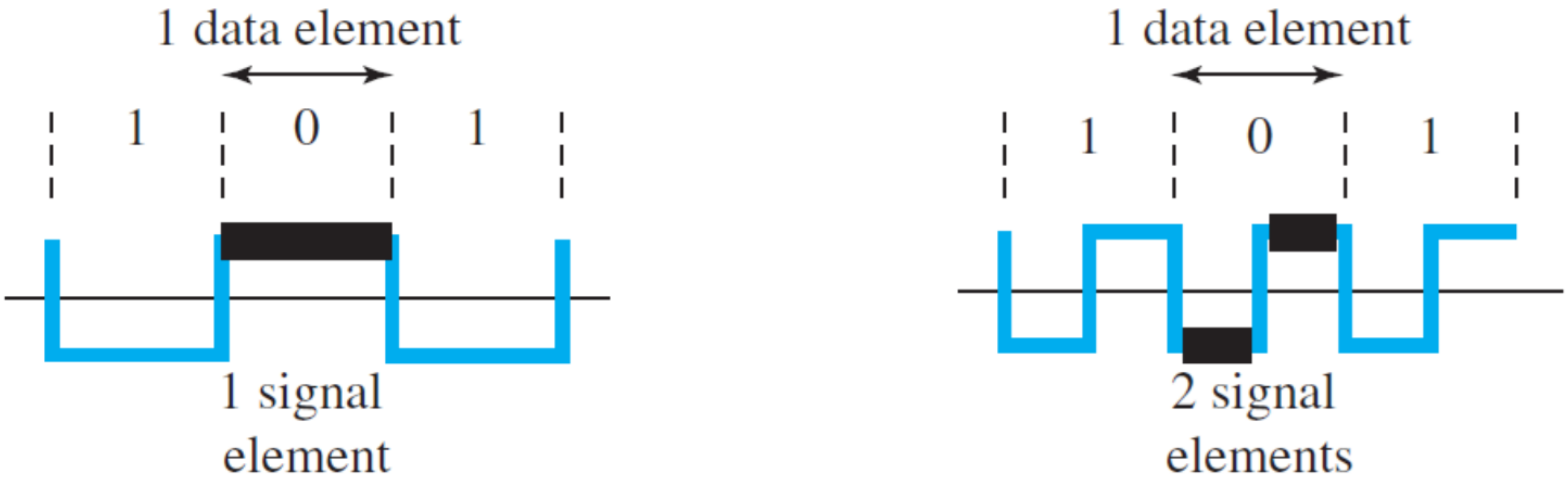


Signal Element vs. Data Element (Cont.)



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

Signal Element vs. Data Element (Cont.)



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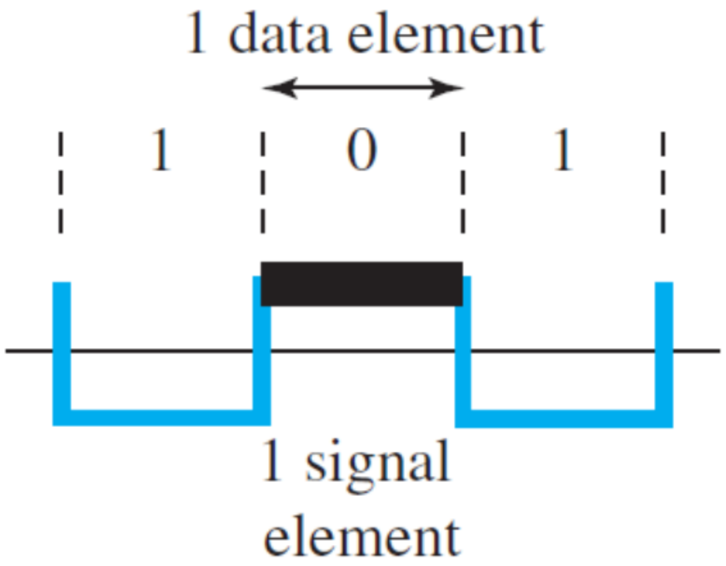

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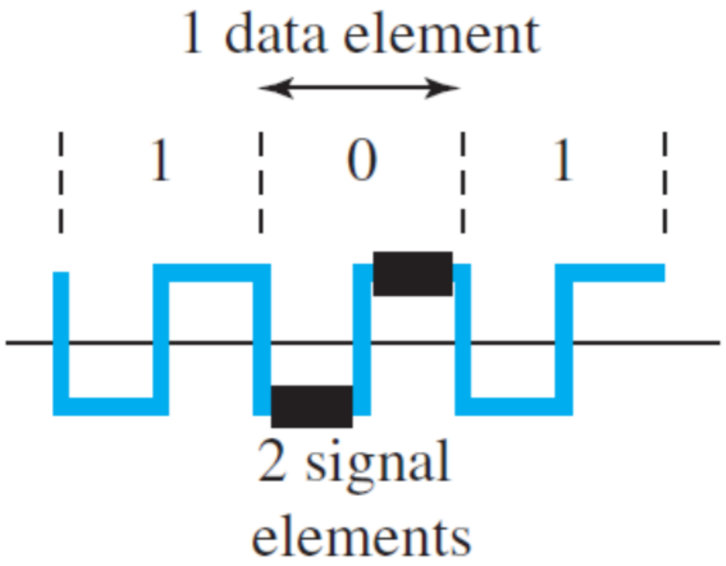
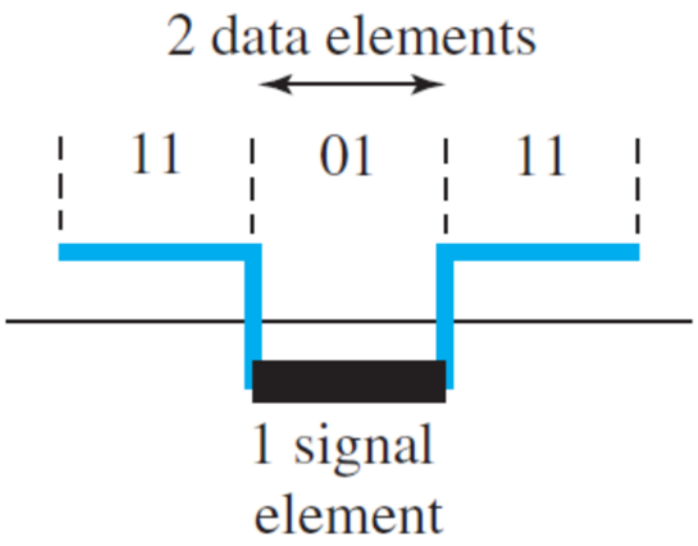
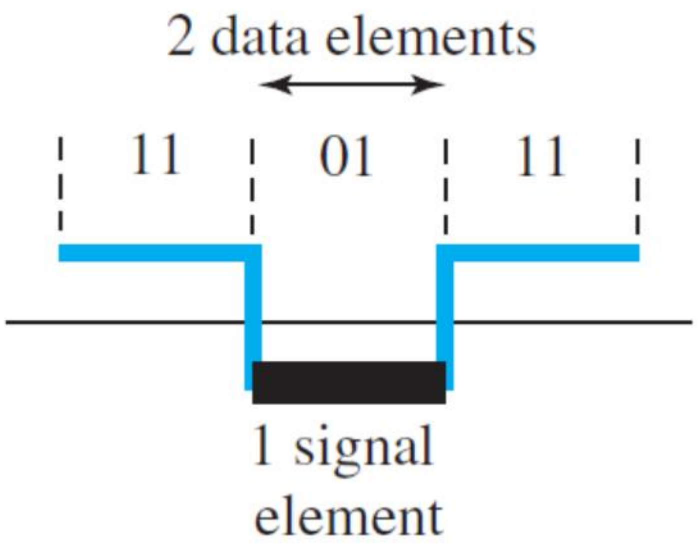


b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$

Signal Element vs. Data Element (Cont.)



Signal Element vs. Data Element (Cont.)



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

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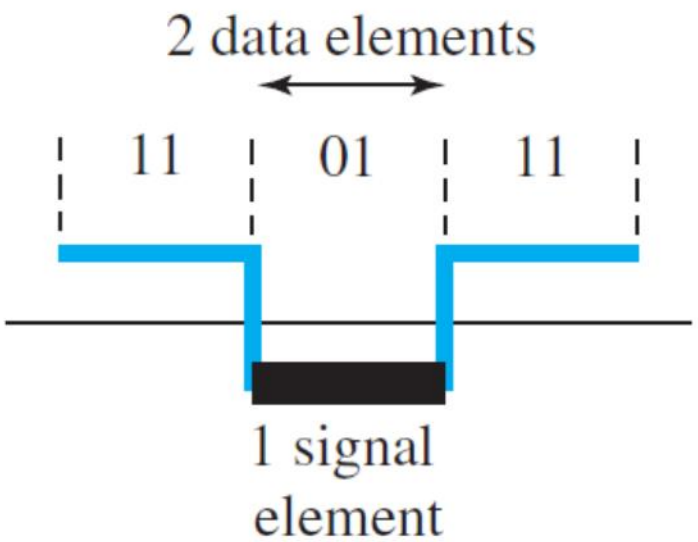

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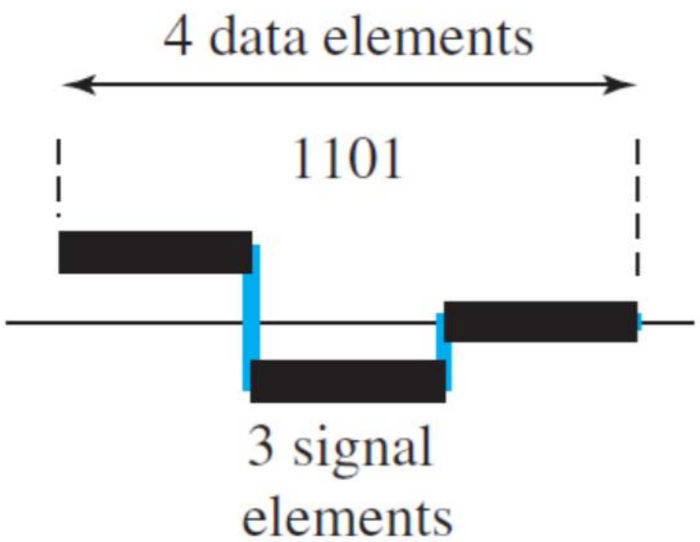

d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

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Data Rate vs. Signal Rate

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  - Unit is **bps**.
  - **Increase** in the data rate → **Increase** in the **speed** of transmission

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A goal in data communications is to **increase the data rate** while **decreasing the signal rate**.

Data Rate vs. Signal Rate

- The relationship between data rate (*N*) and signal rate (*S*):

$$\boxed{S = N/r}$$

- This relationship, of course, depends on the **value of *r*** and the **pattern of the data**.

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$$\boxed{S_{avg} = c \times N \times \frac{1}{r}}$$

Case factor (different for each case)

Data Rate vs. Signal Rate – Example

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- **Answer**:

$$r = 1$$

$$\boldsymbol{S} = c \times N \times \frac{1}{r} = \frac{1}{2} \times 100000 \times \frac{1}{1} = 50000 \text{ baud} = \mathbf{50\ kbaud}$$

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- The **baud rate**, not the bit rate, **determines** the required **bandwidth** for a digital signal.
- The bandwidth (**range of frequencies**) is proportional to the signal rate (**baud rate**).
  - We can replace *S* (signal rate) with *B* (bandwidth)

$$\boxed{B = c \times N \times \frac{1}{r}}$$

Bandwidth (Cont.)

- From the previous formula, we have the following,

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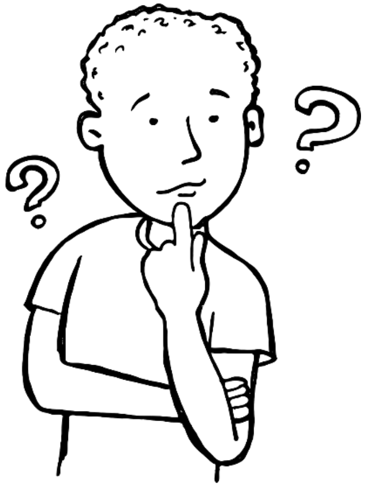
- Does the above formula agree with the **Nyquist formula** for $N_{\max}$?



Bandwidth (Cont.)

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Date rate of a channel

- Does the above formula agree with the **Nyquist formula** for $N_{\max}$?
  - A signal with ***L*** levels can carry **$\log_2 L$** bits (data elements) **per level**.
  - If **each level corresponds to one signal element** and we assume the average case (c = 1/2), we have the following,

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

Maximum date rate of a channel

Nyquist formula

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Baseline Wandering

- **Baseline**
  - 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.

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A **good line coding scheme** needs to **prevent baseline wandering**.

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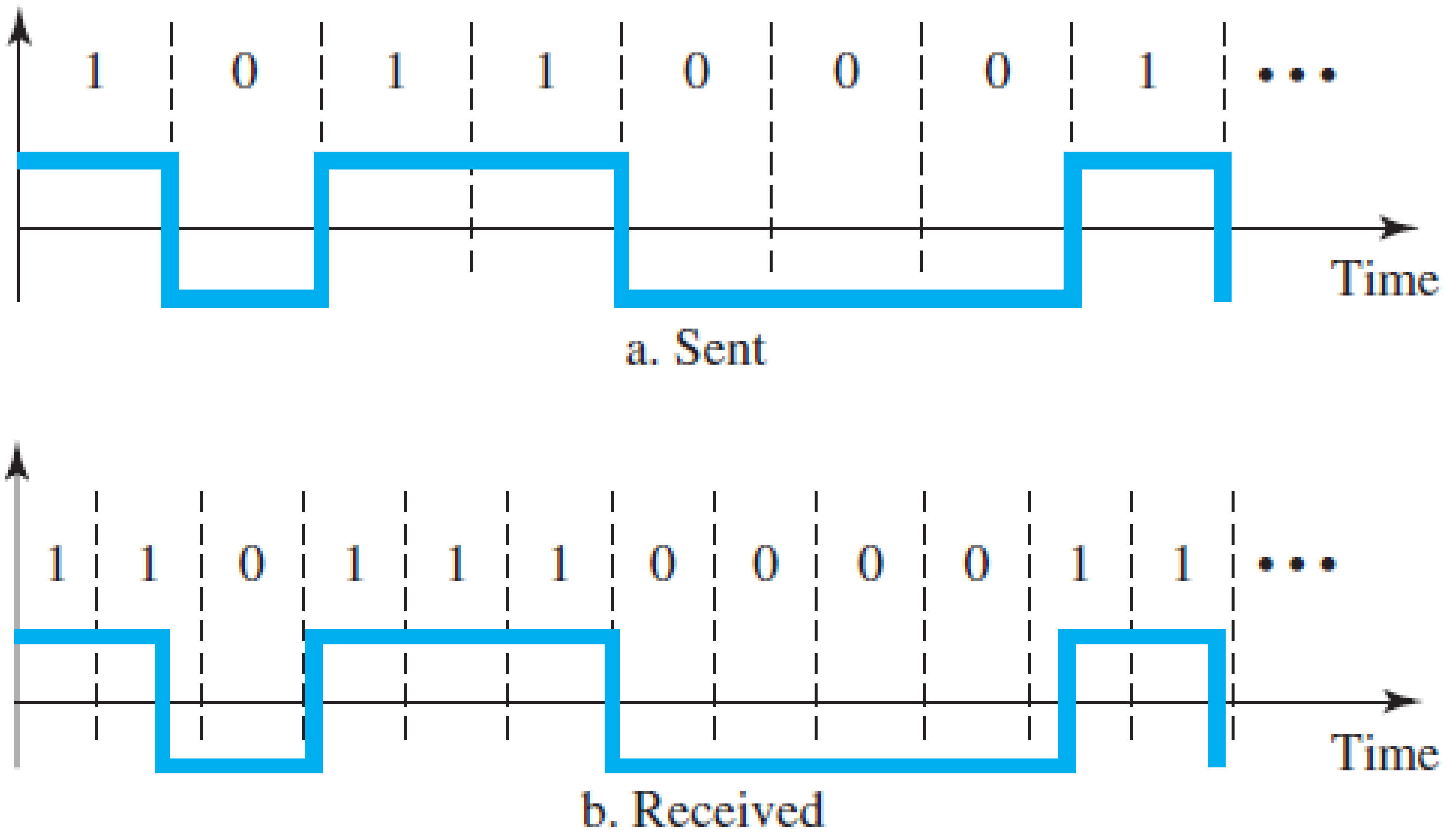
Self-Synchronization

- The receiver clock must be synchronized with the sender clock (**the receiver's bit intervals must correspond exactly to the sender's bit intervals**).
  - To correctly interpret the received signals.
- **Self-synchronization**
  - Self-synchronizing digital signal includes **timing information** in the **data being transmitted**.
  - Transitions (**changes in voltage level**) in the signal that **alert the receiver** to the beginning, middle, or end of the pulse (if the receiver's clock is out of synchronization, these points can reset the clock).

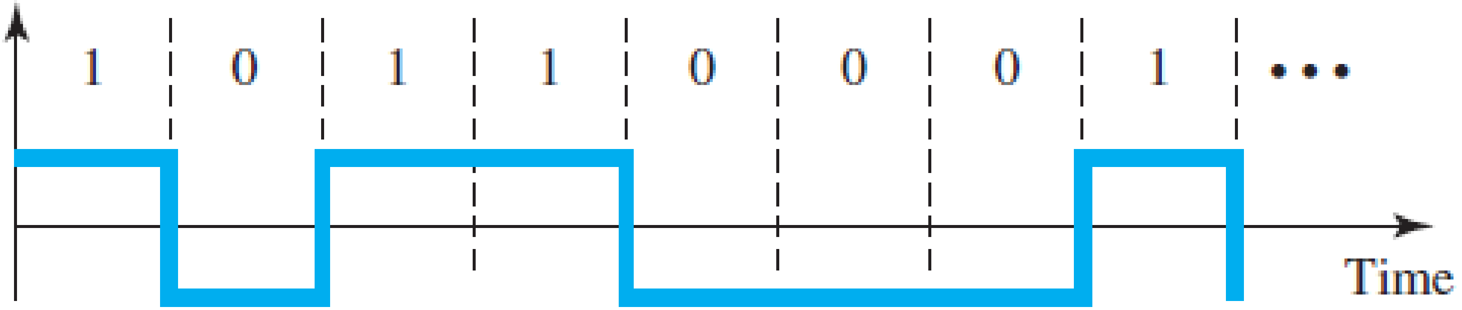
Self-Synchronization (Cont.)

- If the receiver clock is **faster** or **slower**, the bit intervals are not matched, and the receiver might **misinterpret** the signals.
- Figure in the next slide shows a situation in which the receiver has a shorter bit duration.
- The sender sends 10110001, while the receiver receives 110111000011.

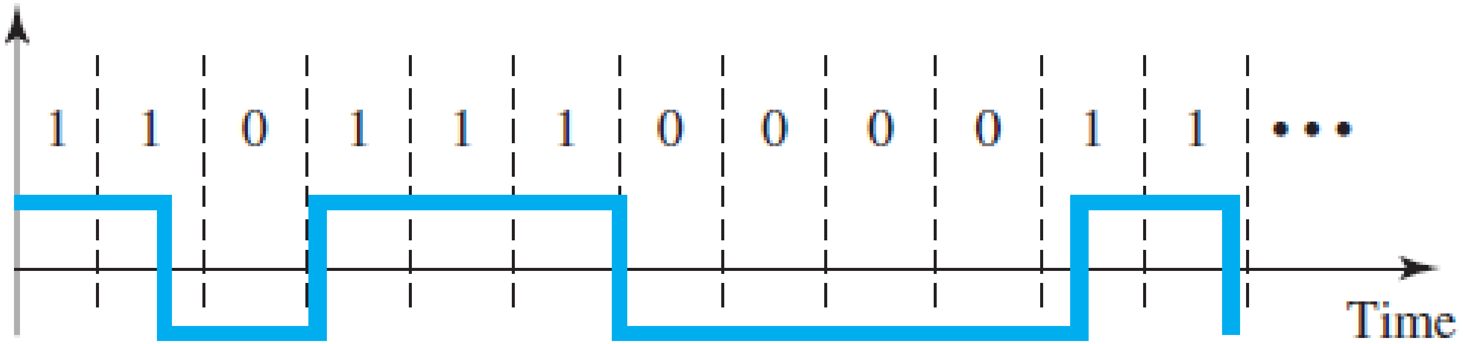
Self-Synchronization (Cont.)



Self-Synchronization (Cont.)



a. Sent



b. Received

Receiver has a shorter **bit duration** than the sender.

Self-Synchronization – Example

- 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?

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- **Answer**:
- **1 kbps** → 1000 bits sent in 1 s
  $1000 \times (1 + 0.1\%)$ bits received in 1 s = 1001 bits received in 1 s
  → **1 extra bps**
- **1 Mbps** → 1000000 bits sent in 1 s
  $1000000 \times (1 + 0.1\%)$ bits received in 1 s = 1001000 bits received in 1 s
  → **1000 extra bps**

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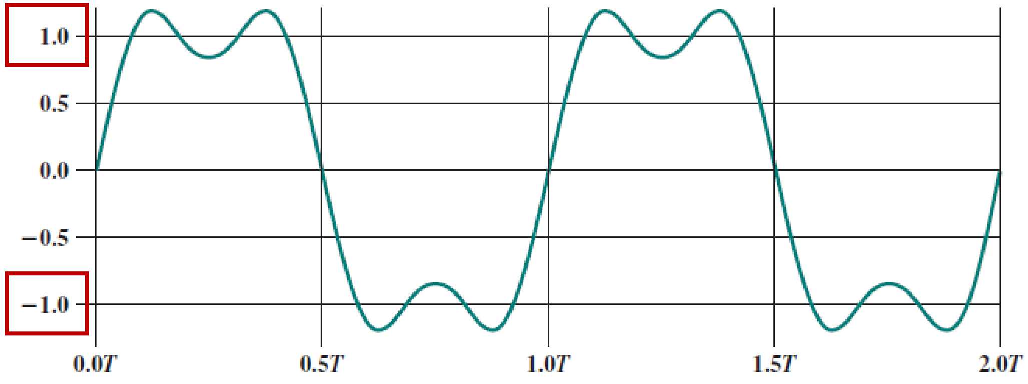
DC Components

- The **very low frequencies** (around zero) that are created by the **spectrum** as a result of a duration of **fixed voltage level in a digital signal** are called Direct Current (DC) Components (or constant components).
- Causes problems for a system that cannot pass low frequencies or uses electrical coupling.
  - e.g., A line that cannot pass frequencies below 200 Hz.
    (For these systems, we need a line coding scheme with no DC component.)
- With **no DC component**, a signal has an **average amplitude of 0**.

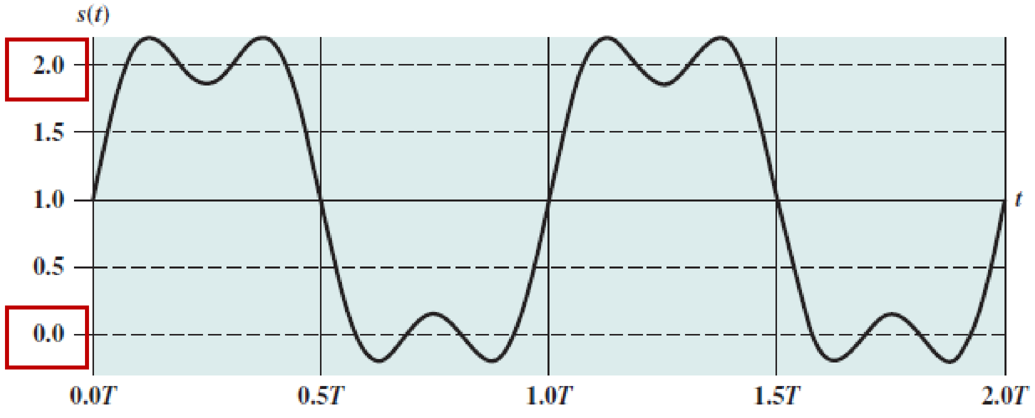
DC component (**bias**): The **mean amplitude** of the waveform.
If the mean amplitude is zero, there is no DC bias (DC balanced or DC free waveform).

DC Components – Example

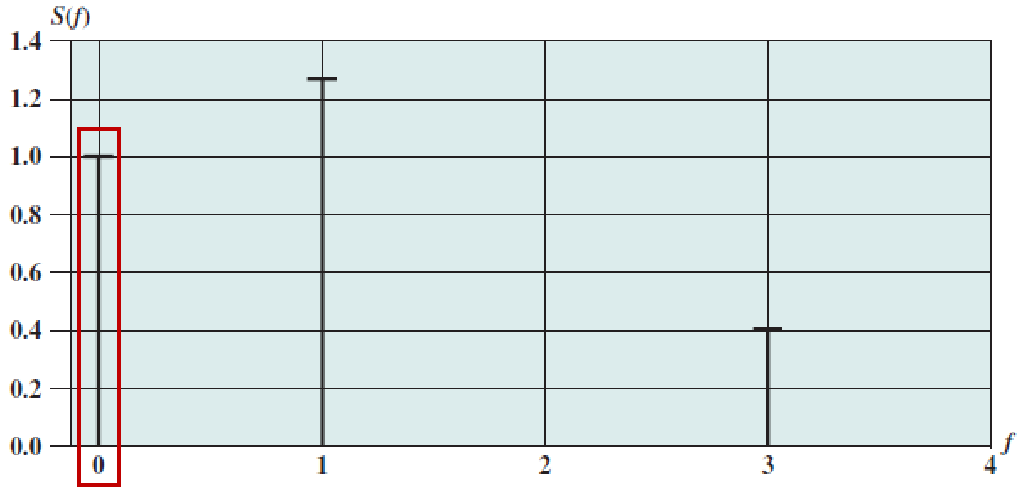
A composite analog signal.



Same signal with added DC component.



Time-domain Plot



Frequency-domain Plot

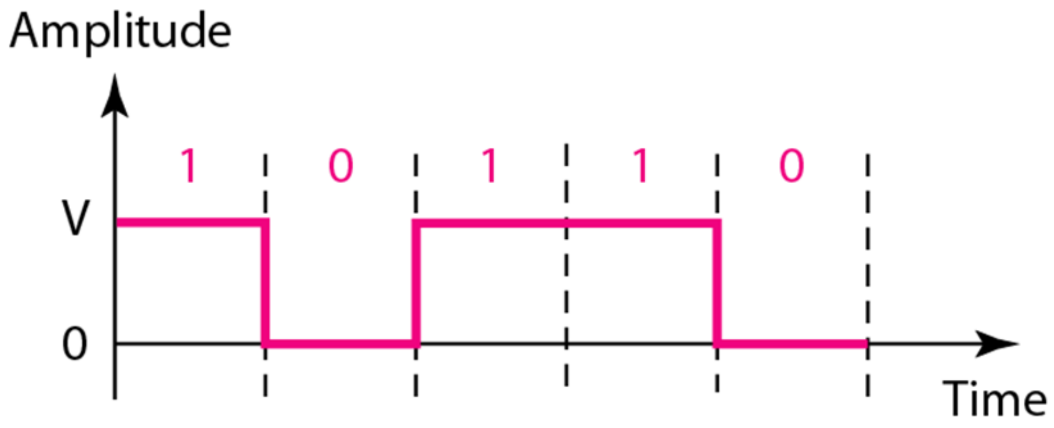
Some of the Line Coding Schemes (Techniques)

Line Coding

- **Unipolar**
  - NRZ
- **Polar**
  - NRZ, RZ, and biphase (Manchester, and differential Manchester)
- **Bipolar**
  - AMI

Unipolar (On-Off Keying) Schemes

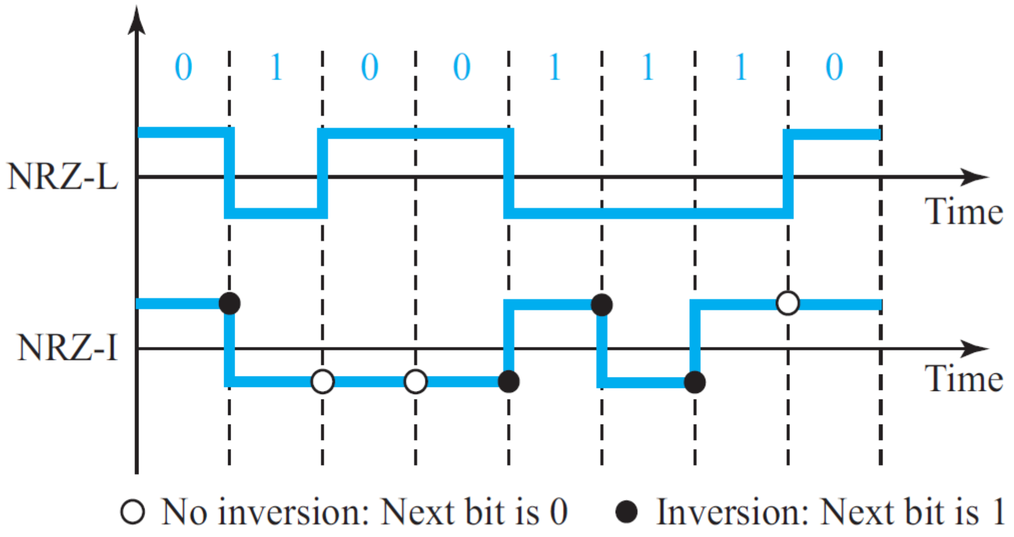
- All the **signal levels** are on **one side of the time axis**, either above or below.
- Traditionally, a unipolar scheme was designed as a **non-return-to-zero** (**NRZ**) scheme
  - NRZ because the signal **does not return** to zero at the middle of the bit.
- **Positive** voltage defines **bit 1** and the **zero** voltage defines **bit 0**.



Polar Schemes – NRZ-L and NRZ-I

- The voltages are on **both sides of the time axis**.
- **NRZ-L** (Level)
  - Two levels of voltage amplitude.
  - **Positive** voltage level for **0** and **negative** voltage level for **1**.
- **NRZ-I** (Invert)
  - The change or lack of change in the level of the voltage determines the value of the bit.
  - **No change** for **0** and **change** for **1**.

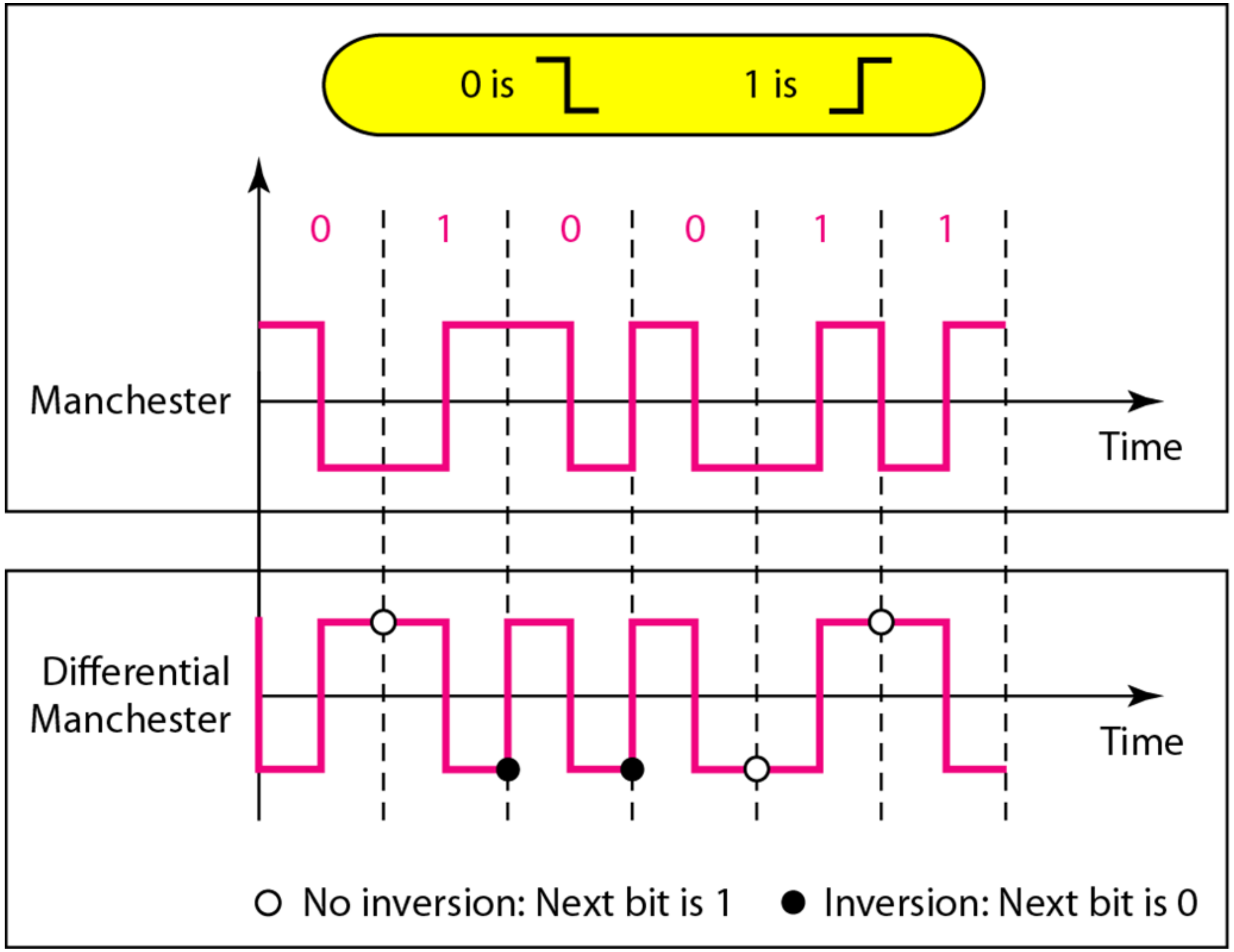
Figure 4.6 *Polar NRZ-L and NRZ-I schemes*



Polar Schemes – Problems

- **DC components**
  - Power density is very high around frequencies close to zero.
- **Baseline wandering**
  - A long sequence of 0s or 1s
- **No self-synchronization**
  - A long sequence of 0s or 1s

Polar Schemes – Manchester and Differential Manchester



Popular techniques for data transmission.

It is used for IR protocols, RFID, and NFC system.

NRZ-I and differential Manchester are classified as differential encoding

Used in 802.5 with Twisted Pair.

Polar Schemes – Manchester and Differential Manchester (Cont.)

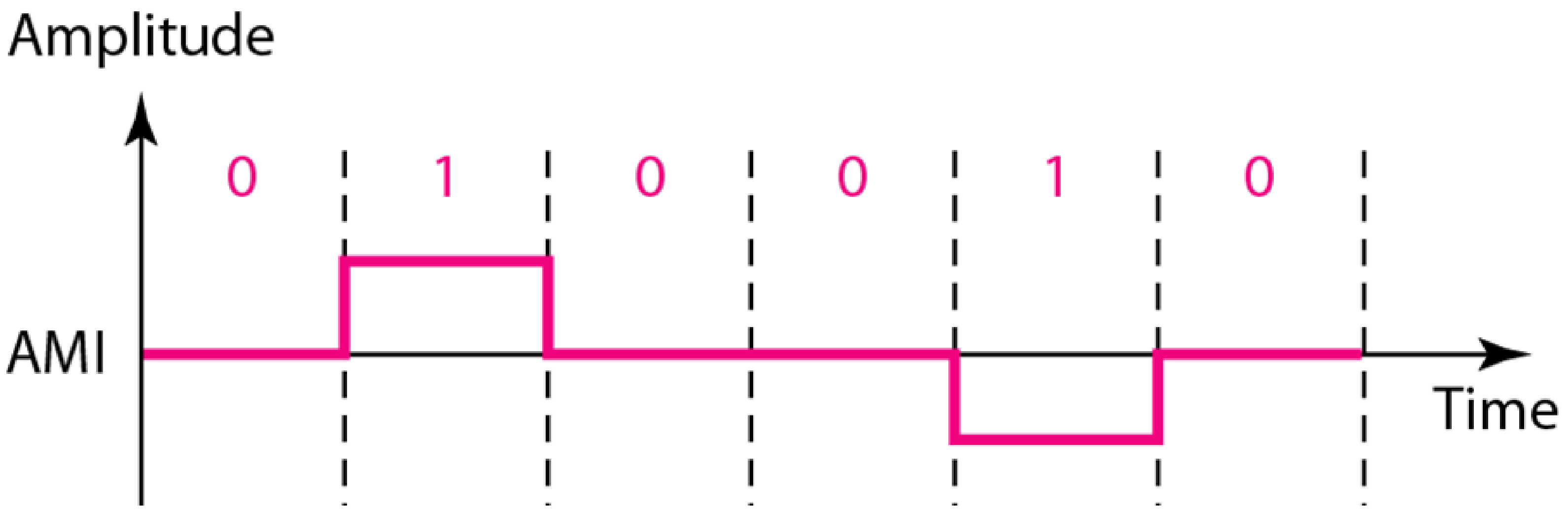
- **Have Self-Synchronization**
  - Provided by the transition at the middle of the bit.
- **No baseline wandering**
- **No DC component**
  - Each bit has a positive and negative voltage contribution.
- **Drawback**
  - The signal rate for Manchester and differential Manchester is higher compared with some other polar schemes, e.g., NRZ-L.

Bipolar (Multilevel Binary) Schemes

- Three voltage levels: **positive**, **negative**, **zero**.
  - The voltage level for one data element (**bit**) is at zero.
  - The voltage level for the other element alternates between positive and negative.

Bipolar (Multilevel Binary) Schemes – AMI

- **Alternate Mark Inversion (AMI)** – alternate 1 inversion
  - **0** → a neutral zero voltage
  - **1** → alternating positive and negative voltages



Summary

- Line coding schemes (for **digital-to-digital** conversion) and their common characteristics.
  - Unipolar, polar, and bipolar schemes.

References

[1] Behrouz A.Forouzan, Data Communications & Networking with TCP/IP Protocol Suite, 6th Ed, 2022, McGraw-Hill companies.

Reading

- Chapter 2 of the textbook, section 2.3.1.
- Chapter 2 of the textbook, section 2.8 (Practice Test)