CSCS 311

Data Communications and Networking

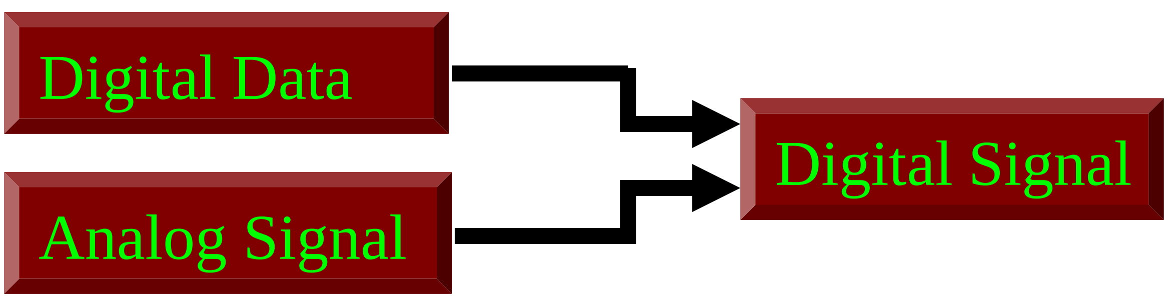
Lecture 15

Lecture Focus:

- Digital Transmission

Digital Transmission

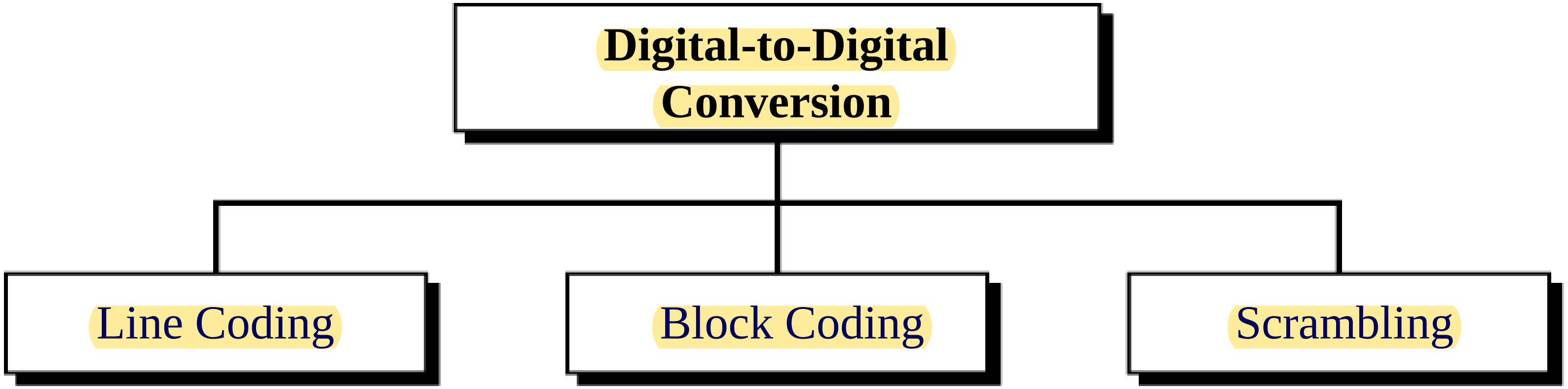
- A computer network is designed to send information from one point to another.
- This information needs to be converted to either a digital signal or an analog signal for transmission.
- Here, we study the schemes and techniques used to transmit data digitally.
  - First, we discuss digital-to-digital conversion techniques, methods which convert digital data to digital signals.
  - Second, we discuss analog-to-digital conversion techniques, methods which change an analog signal to a digital signal.



DIGITAL-TO-DIGITAL CONVERSION

- Data can be either digital or analog. Signals that represent data can also be digital or analog.
- Here. we study how we can represent digital data by using digital signals.
- The conversion involves three techniques:
  - Line coding
  - Block coding
  - Scrambling
- Line coding is always needed.
- Block coding and scrambling may or may not be needed.

Digital-to-Digital Conversion



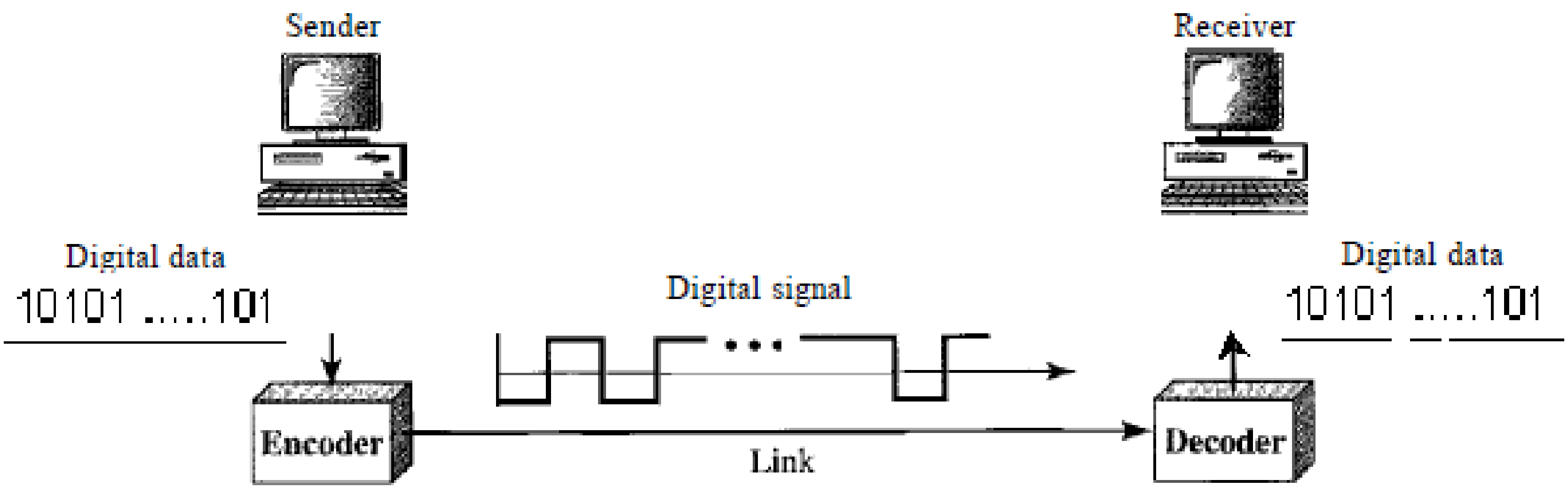
Digital-to-Digital Conversion

Line Coding

- Line coding is the process of converting digital data to digital signals.
- We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits.
- Line coding converts a sequence of bits to a digital signal.
  - At the sender, digital data are encoded into a digital signal;
  - At the receiver, the digital data are recreated by decoding the digital signal.

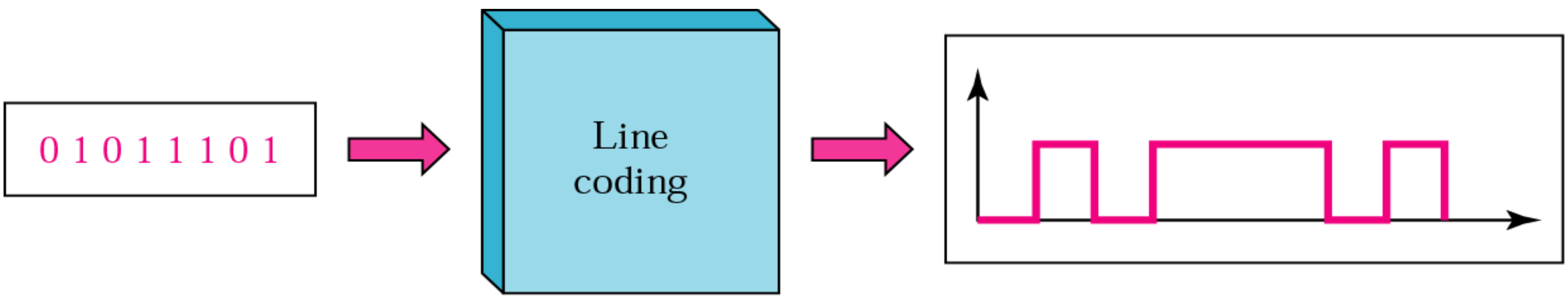
Digital-to-Digital Conversion

Line Coding Process



Digital-to-Digital Conversion

Line Coding Process



Line coding and decoding

Characteristics of Line Coding Schemes

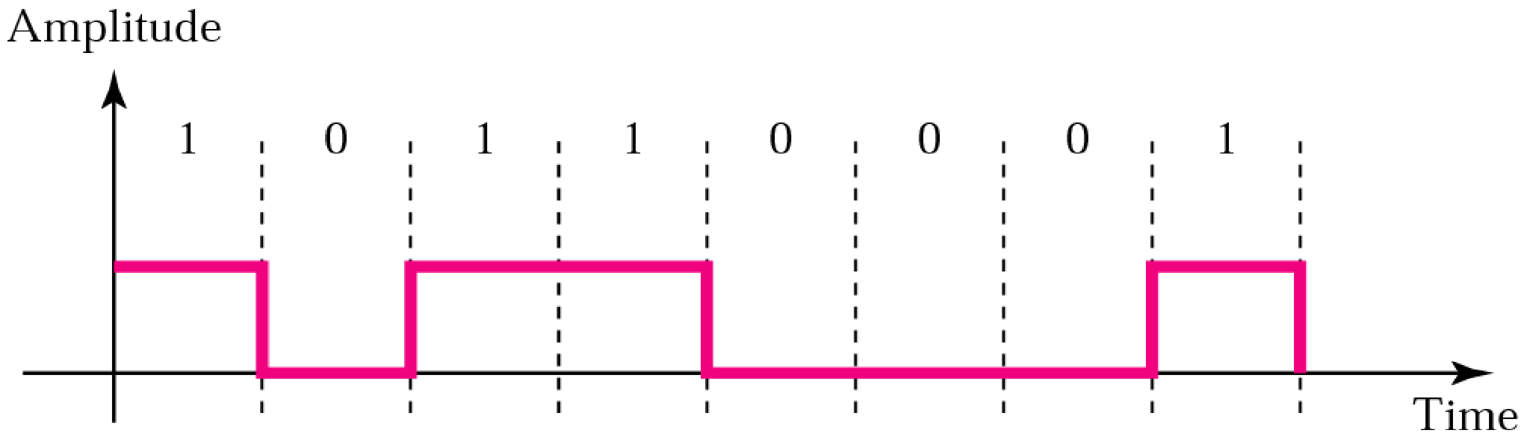
Signal Element Versus Data Element

- A data element is the smallest entity that can represent a piece of information: this is the bit.
- In digital data communications, a signal element carries data elements.
- A signal element is the shortest unit (time wise) of a digital signal.
- In other words, data elements are what we need to send; signal elements are what we can send.
- Data elements are being carried; signal elements are the carriers.

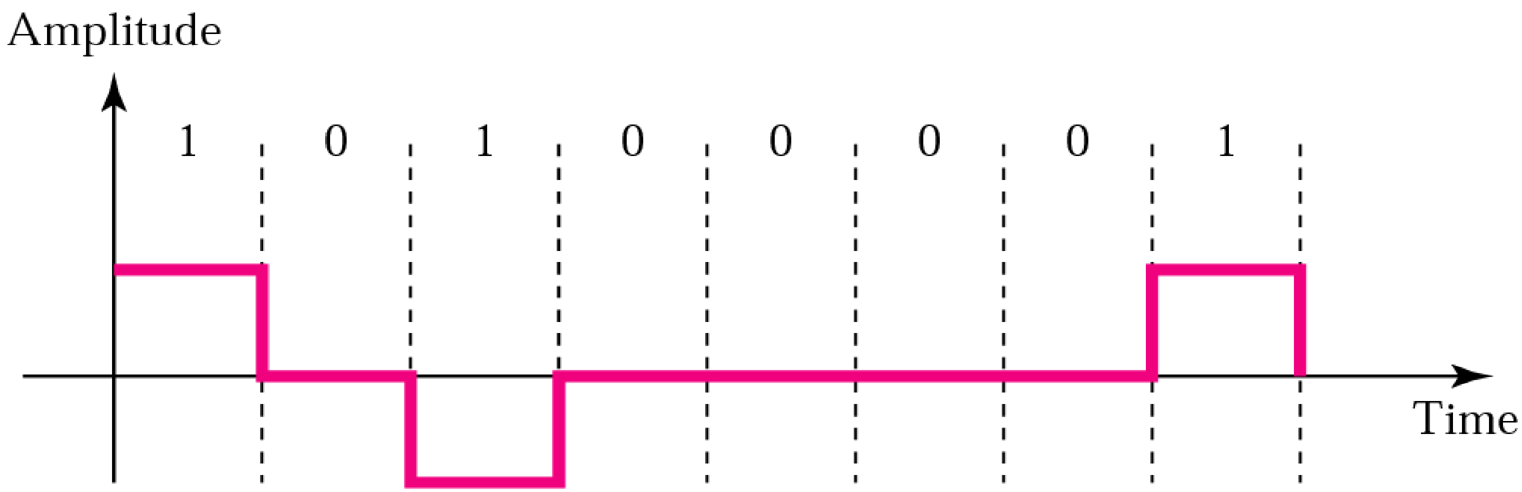
- We define a ratio r which is the number of data elements carried by each signal element.
- Figure shows several situations with different values of r.

Characteristics of Line Coding Schemes

Signal Element Versus Data Element



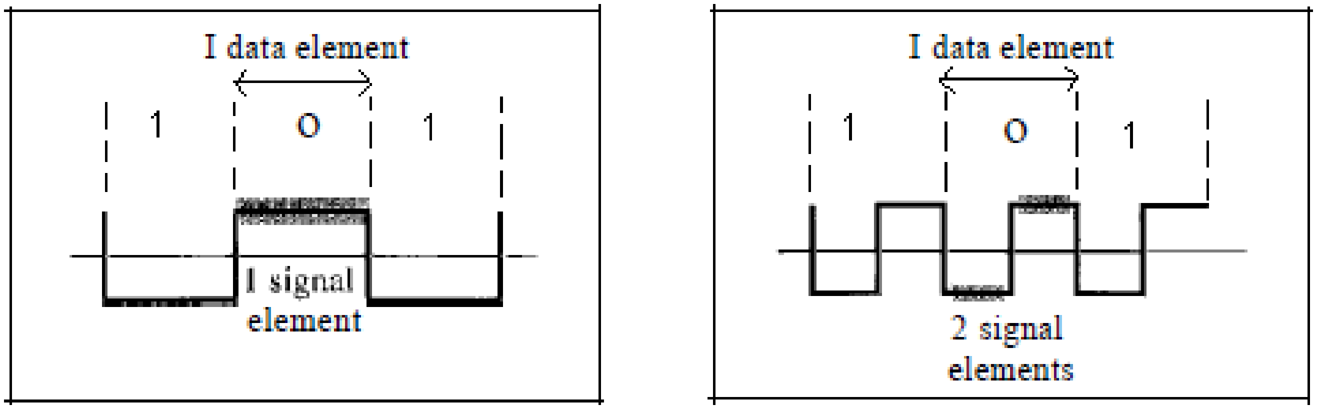
a. Two signal levels, two data levels



b. Three signal levels, three data levels

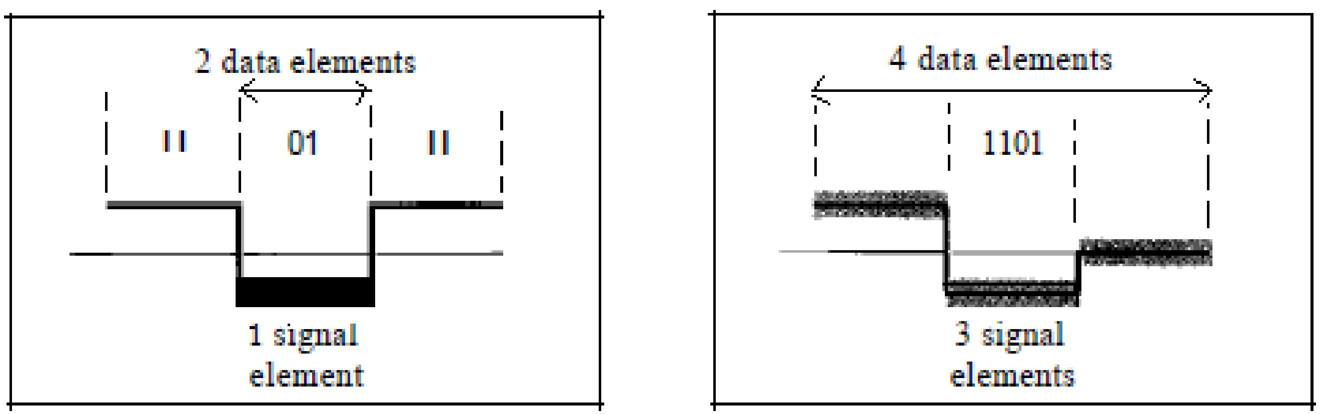
Characteristics of Line Coding Schemes

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

We need two signal elements (two transitions) to carry each data element.

Characteristics of Line Coding Schemes

Data Rate Versus Signal Rate

- **Data rate:**
  - The number of data elements (bits) sent in 1s.
  - The unit is bits per second (bps).
- **Signal rate:**
  - The number of signal elements sent in 1s.
  - The unit is the baud.
- The data rate is sometimes called the bit rate.
- The signal rate is sometimes called the pulse rate, the modulation rate, or the baud rate.

Characteristics of Line Coding Schemes

Data Rate Versus Signal Rate

- One goal in data communications is to:
  - Increase the data rate, and
  - Decrease the signal rate
- Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement.
- We need to carry more people in fewer vehicles to prevent traffic jams. We have a limited bandwidth in our transportation system.

Characteristics of Line Coding Schemes

Relationship between Data Rate and Signal Rate

- This relationship depends on the value of r.
- It also depends on the data pattern.
  - If a data pattern consists of all 1s or all 0s, the signal rate may be different from a data pattern of alternating 0s and 1s.
- To derive a formula for the relationship, we need to define three cases: the worst, the best, and the average.
  - The worst case is when we need the maximum signal rate.
  - The best case is when we need the minimum signal rate.
- We are usually interested in the average case.

Characteristics of Line Coding Schemes

Relationship between Data Rate and Signal Rate

- We can formulate the relationship between data rate and signal rate as:

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

Where:

N is the data rate (bps);

c is the case factor, which varies for each case;

S is the number of signal elements; and

r is the previously defined factor.

Characteristics of Line Coding Schemes

Relationship between Data Rate and Signal Rate

Example

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 l?

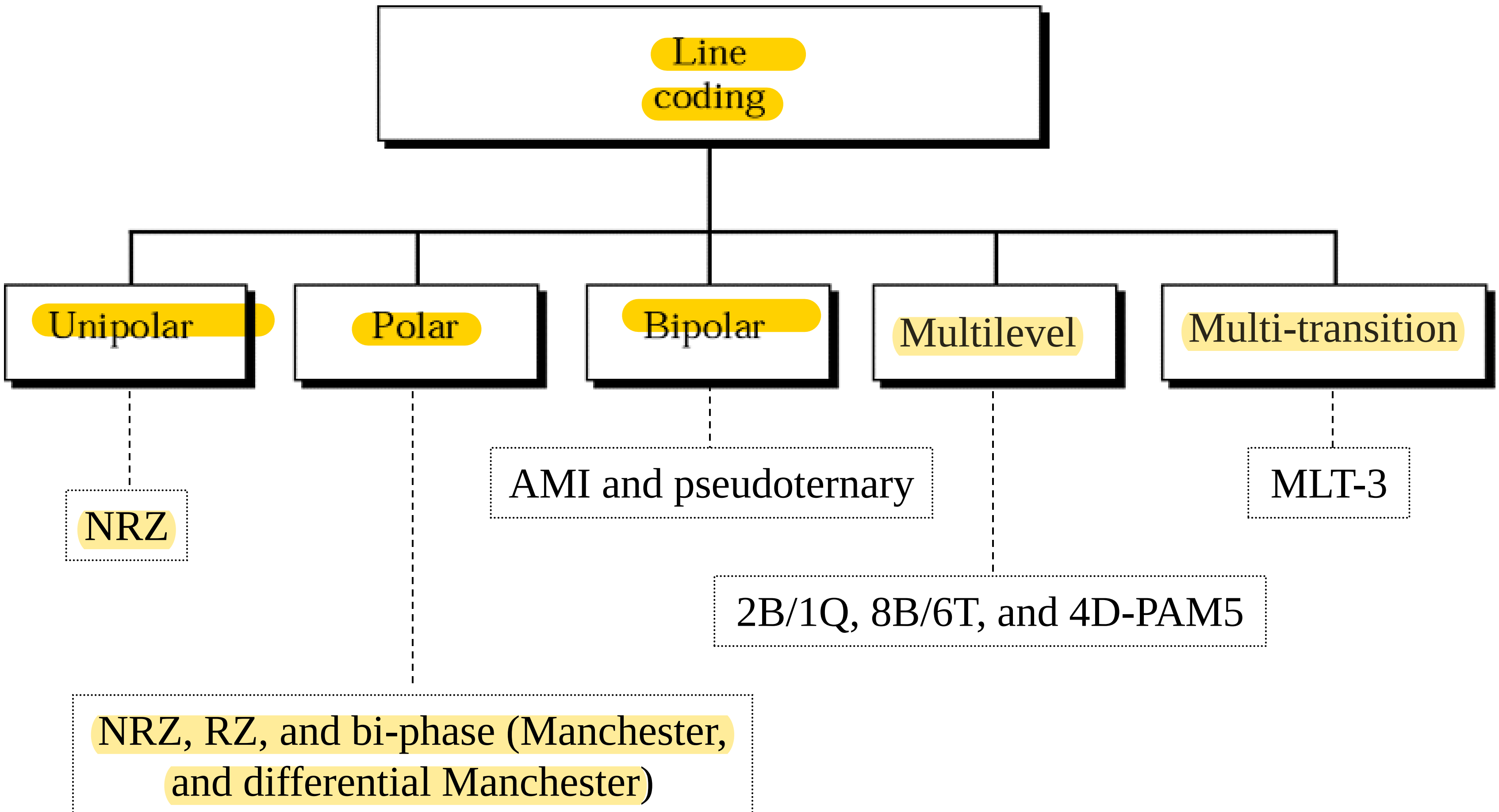
Solution

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

$$
\begin{aligned}
S &= c \times N \times 1/r \\
&= 1/2 \times 100{,}000 \times 1/1 \\
&= 50{,}000 \text{ bauds} \\
&= 50 \text{ kbaud}
\end{aligned}
$$

Line Coding Schemes

Five categories



There are several schemes in each category.

Line Coding Schemes

UNIPOLAR

In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.

Unipolar encoding uses only one voltage level.

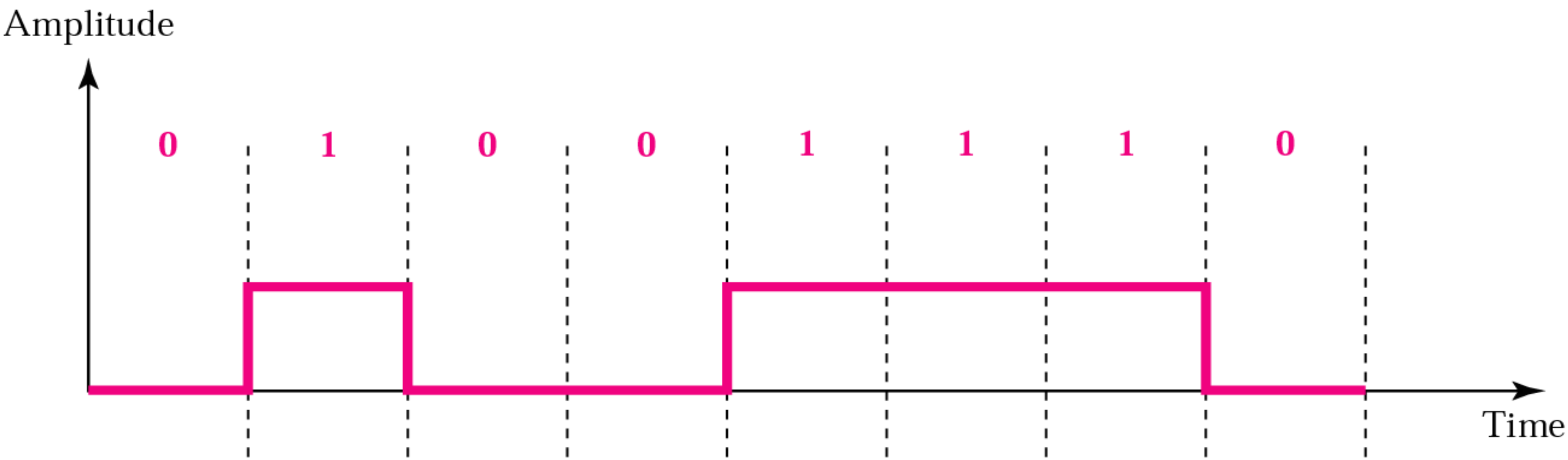
UNI = Single

Line Coding Schemes

UNIPOLAR

NRZ (Non-Return-to-Zero)

- Unipolar scheme was designed as a non-return-to-zero (NRZ) scheme in which the positive voltage defines bit 1 and the zero voltage defines bit 0.
- It is called NRZ because the signal does not return to zero at the middle of the bit.



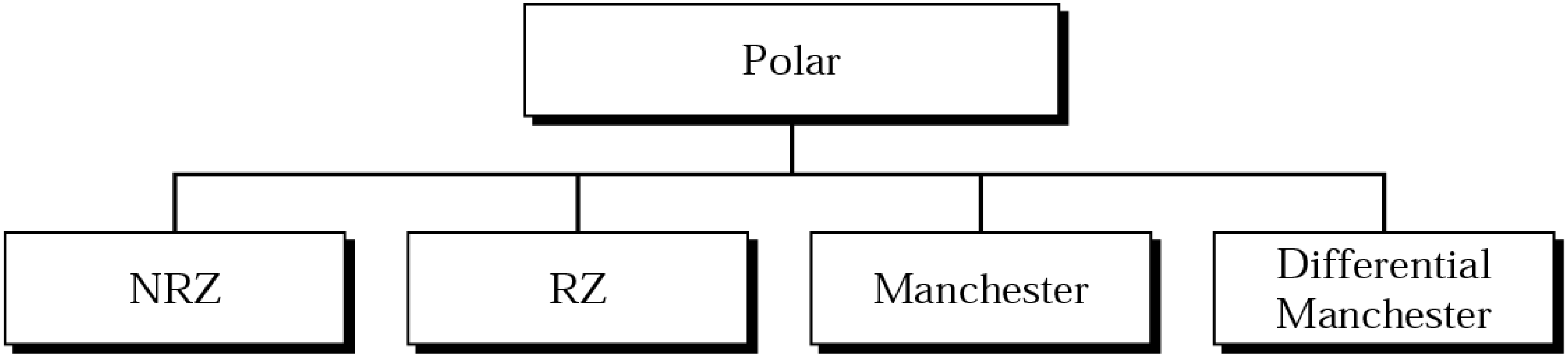
Line Coding Schemes

POLAR SCHEMES

- In polar schemes, the voltages are on the both sides of the time axis.
- For example, the voltage level for 0 can be positive and the voltage level for 1 can be negative.

Polar encoding uses two voltage levels (positive and negative).

Types of polar encoding

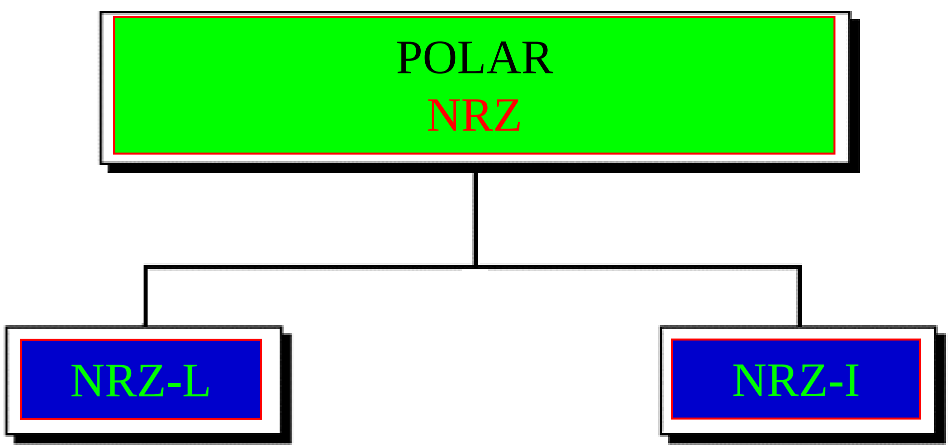


Line Coding Schemes

POLAR SCHEMES

NRZ (Non-Return-to-Zero)

- In polar NRZ encoding, we use two levels of voltage amplitude.
- We have two versions of polar NRZ:
  - NRZ-L
  - NRZ-I



Line Coding Schemes

POLAR SCHEMES

NRZ (Non-Return-to-Zero)

- In NRZ-L (NRZ-Level), the level of the voltage determines the value of the bit.

In NRZ-L the level of the signal is dependent upon the state of the bit.

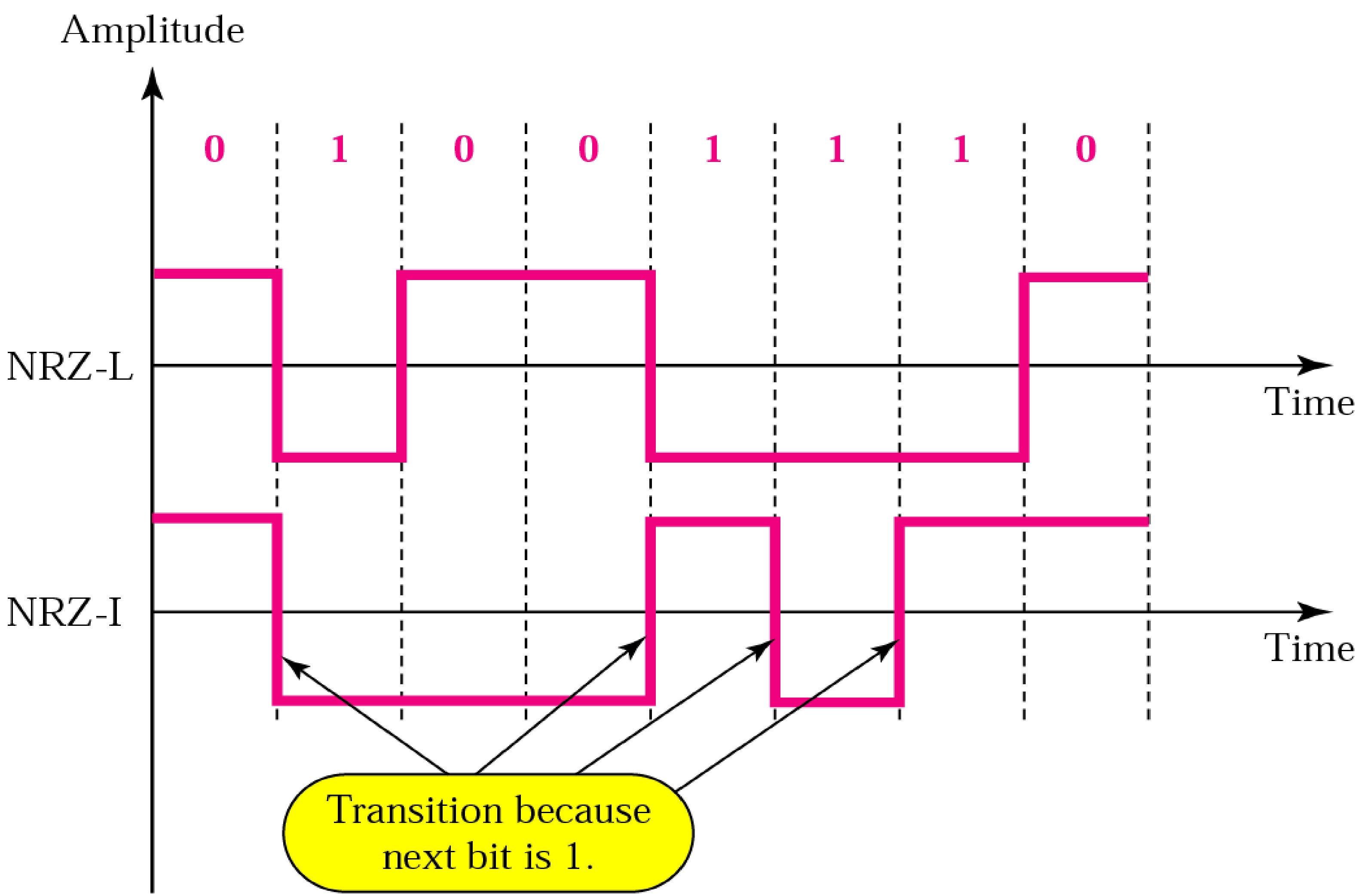
- In NRZ-I (NRZ-Invert), the change or lack of change in the level of the voltage determines the value of the bit.
  - If there is no change, the bit is 0.
  - If there is a change, the bit is 1.

In NRZ-I the signal is inverted if a 1 is encountered.

Line Coding Schemes

POLAR SCHEMES

NRZ (Non-Return-to-Zero)



Line Coding Schemes

POLAR SCHEMES

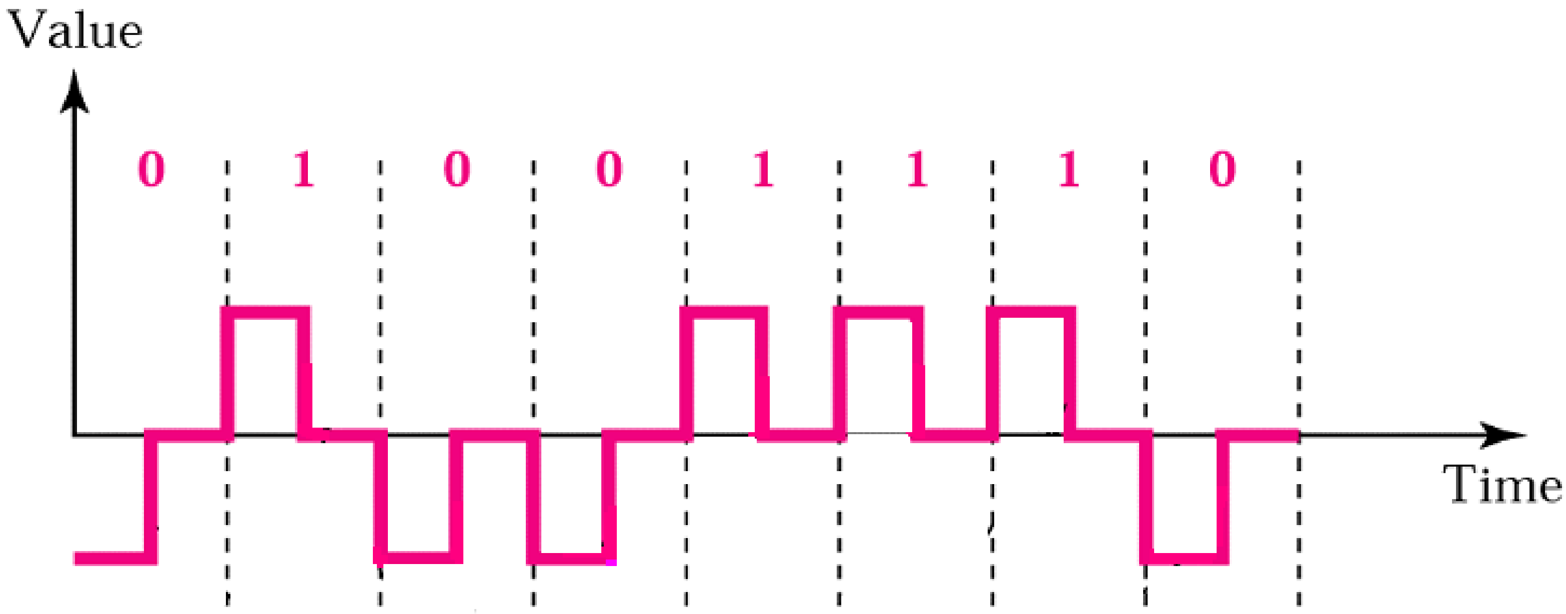
RZ (Return-to-Zero)

- This scheme uses three values: positive, negative, and zero.
- In RZ, the signal changes not between bits but during the bit.
- Signal goes to 0 in the middle of each bit. It remains there until the beginning of the next bit.
- The main disadvantage of RZ encoding is that it requires two signal changes to encode a bit and therefore occupies greater bandwidth.
- Another problem is the complexity: RZ uses three levels of voltage, which is more complex to create and discern.
- As a result of all these deficiencies, the scheme is not used today.
  - It has been replaced by the better-performing Manchester and differential Manchester schemes.

Line Coding Schemes

POLAR SCHEMES

RZ (Return-to-Zero)

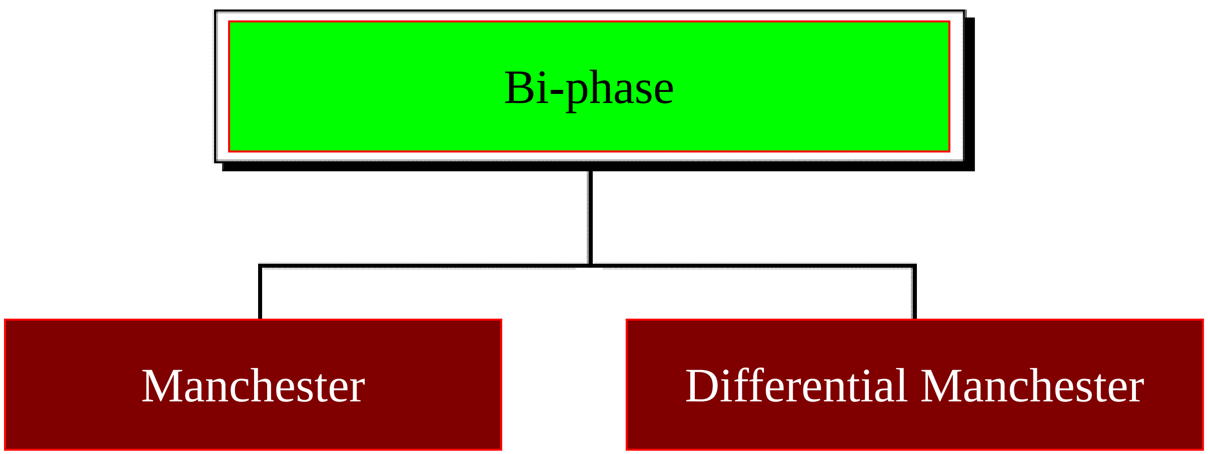


Line Coding Schemes

POLAR SCHEMES

Bi-phase

- Manchester
- Differential Manchester



Line Coding Schemes

POLAR SCHEMES

Bi-phase: Manchester

- The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme.
- In Manchester encoding, the duration of the bit is divided into two halves.
  - The voltage remains at one level during the first half and moves to the other level in the second half.

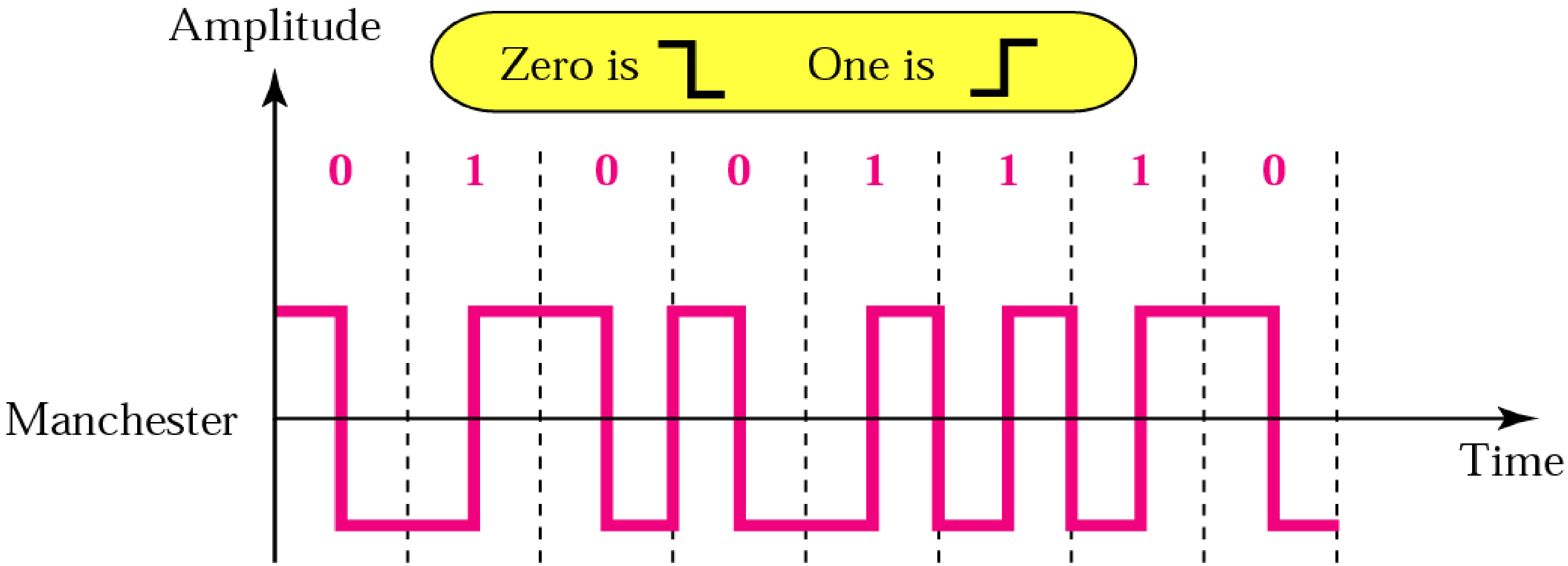
Bi-phase: Differential Manchester

- This scheme combines the ideas of RZ and NRZ-I.
- There is always a transition at the middle of the bit, but the bit values are determined at the beginning of the bit.
  - If the next bit is 0, there is a transition.
  - If the next bit is 1, there is none.

Line Coding Schemes

POLAR SCHEMES

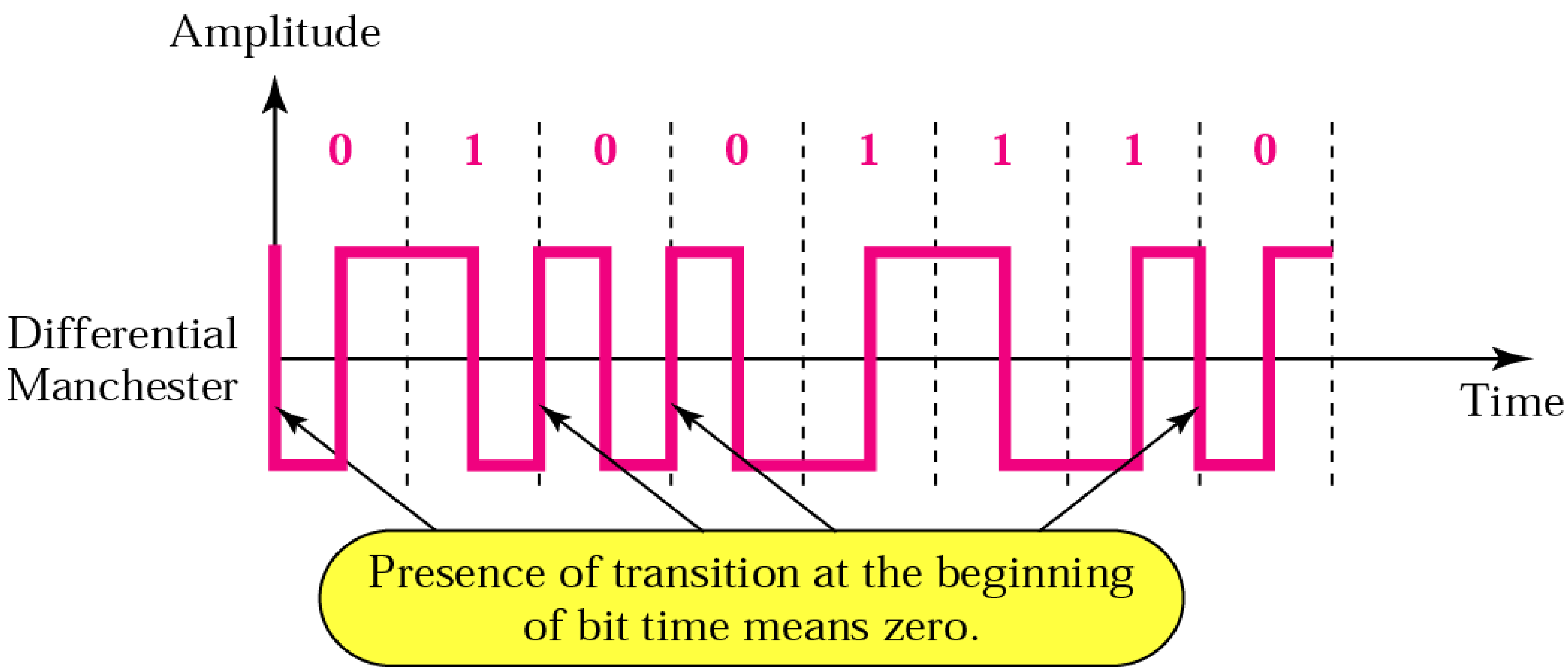
Manchester encoding



Line Coding Schemes

POLAR SCHEMES

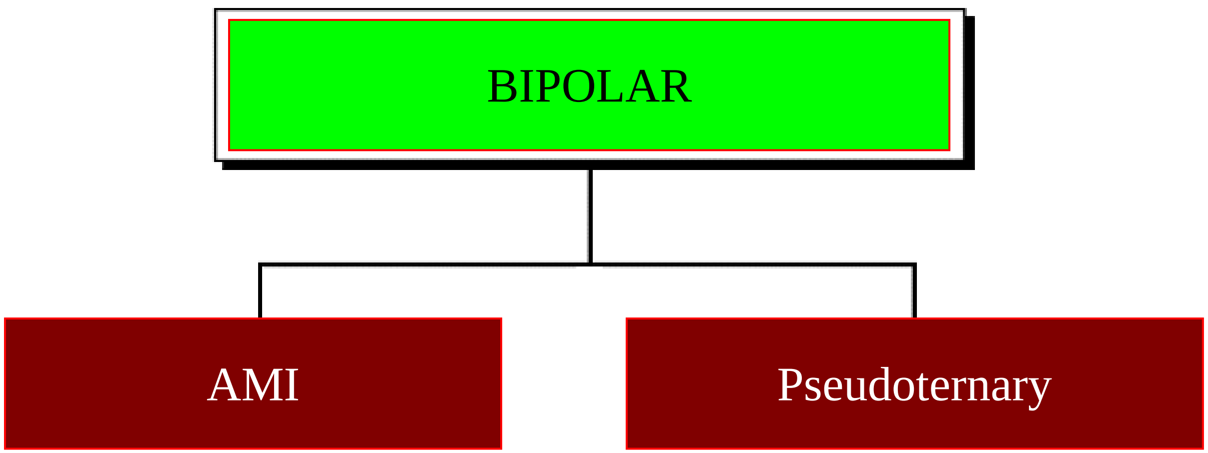
Differential Manchester encoding



Line Coding Schemes

BIPOLAR SCHEMES

- In bipolar encoding (sometimes called multilevel binary), there are three voltage levels: positive, negative, and zero.
  - The voltage level for one data element is at zero.
  - The voltage level for the other element alternates between positive and negative.



Line Coding Schemes

BIPOLAR SCHEMES

AMI: Alternate Mark Inversion

- In the term alternate mark inversion, the word mark comes from telegraphy and means 1. So AMI means alternate 1 inversion.
- A neutral zero voltage represents binary 0.
- Binary 1s are represented by alternating positive and negative voltages.

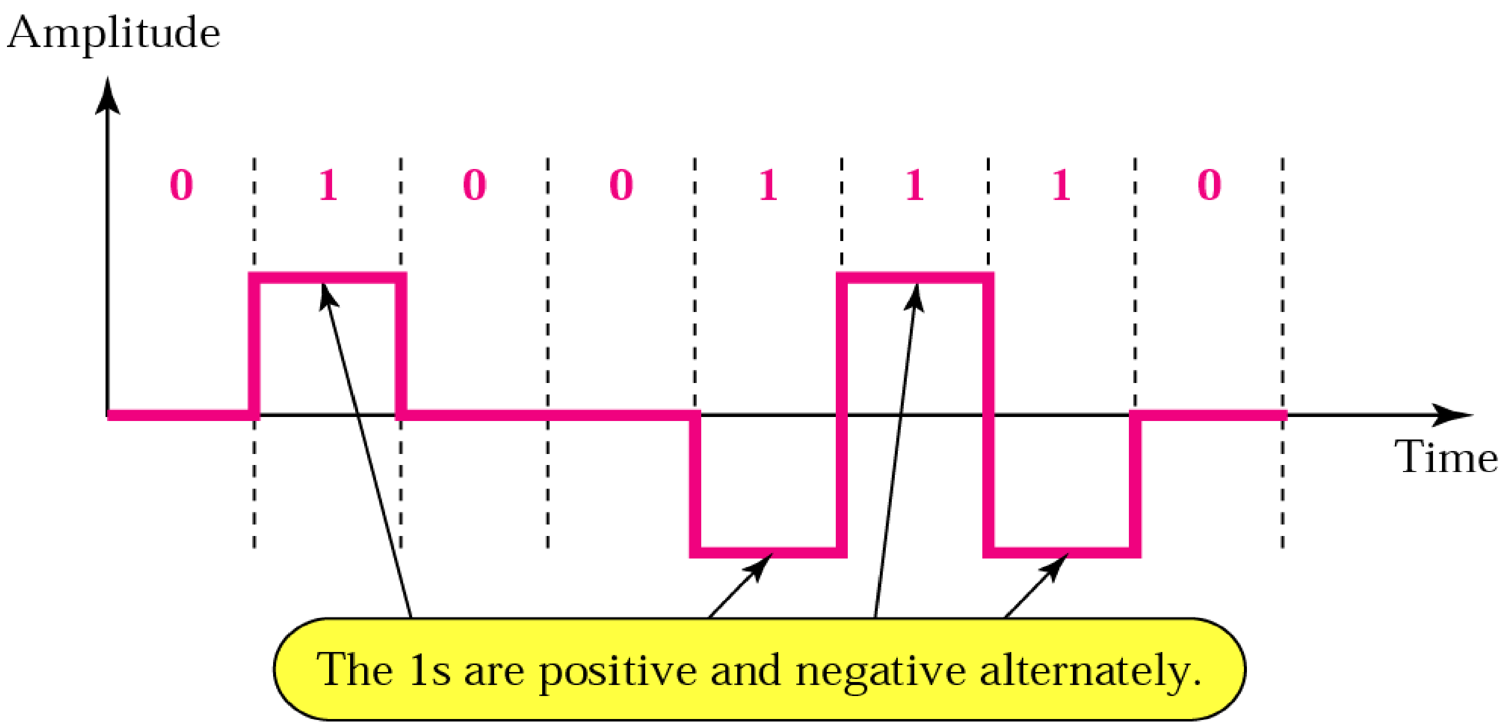
Pseudoternary

- A variation of AMI encoding is called pseudoternary in which the 1 bit is encoded as a zero voltage and the 0 bit is encoded as alternating positive and negative voltages.

Line Coding Schemes

BIPOLAR SCHEMES

AMI: Alternate Mark Inversion

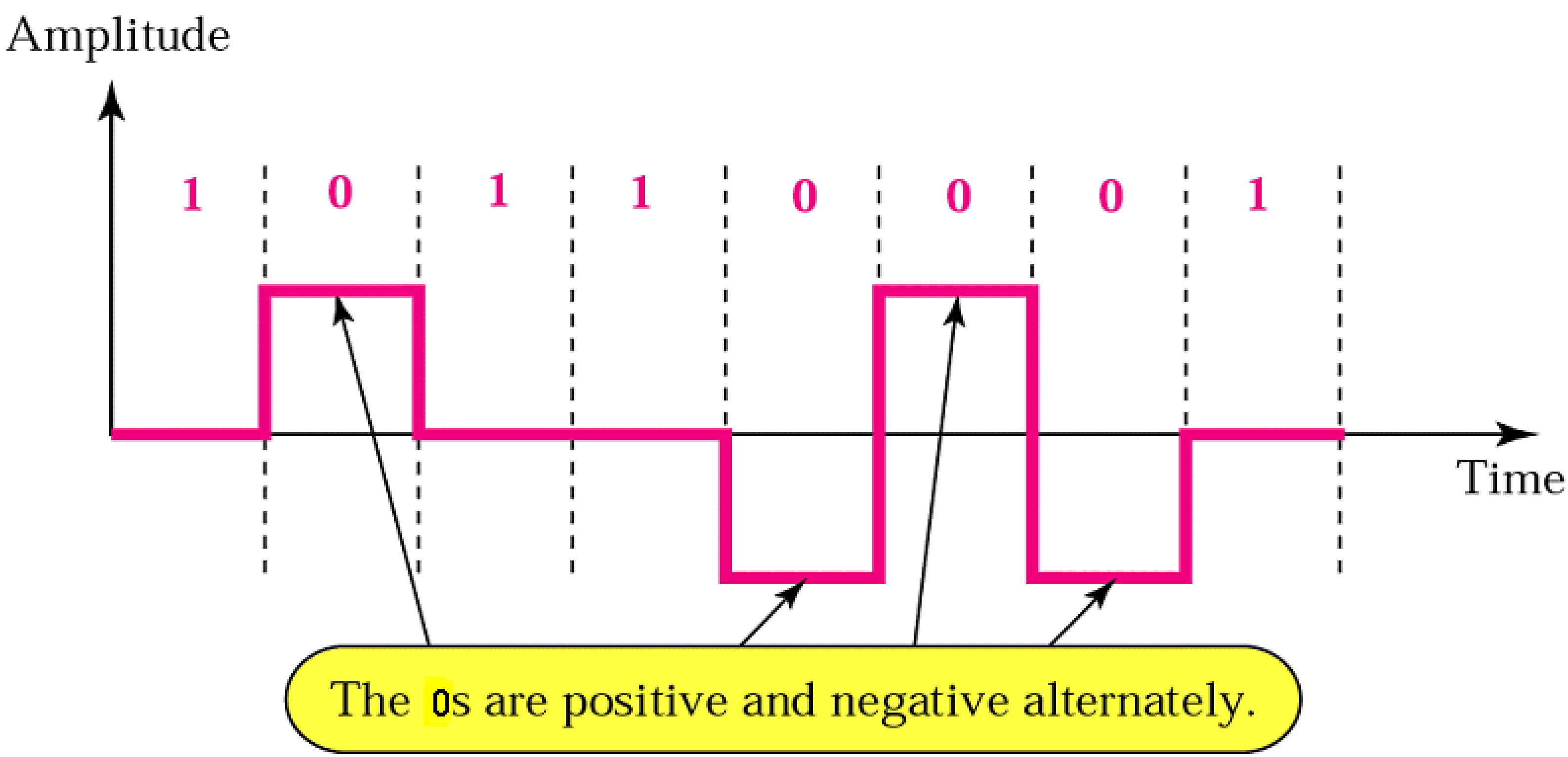


Bipolar AMI encoding

Line Coding Schemes

BIPOLAR SCHEMES

Pseudoternary



Bipolar Pseudoternary encoding

Line Coding Schemes

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.
- We only have two types of data elements (0s and 1s).
  - It means that a group of m data elements can produce a combination of 2^m data patterns.
- We can have different types of signal elements by allowing different signal levels.
  - If we have L different levels, we can produce L^n combinations of signal patterns.

- If $2^m = L^n$, then each data pattern is encoded into one signal pattern.
- If $2^m < L^n$, data patterns occupy only a subset of signal patterns.
- Data encoding is not possible if $2^m > L^n$ because some of the data patterns cannot be encoded.

Line Coding Schemes

MULTILEVEL SCHEMES

- The code designers have classified these types of coding as mBnL, 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.
- A letter is often used in place of L:
  - B (binary) for L =2,
  - T (ternary) for L =3, and
  - Q (quaternary) for L =4.
- Note that:
- The first two letters define the data pattern, and
- The second two define the signal pattern.

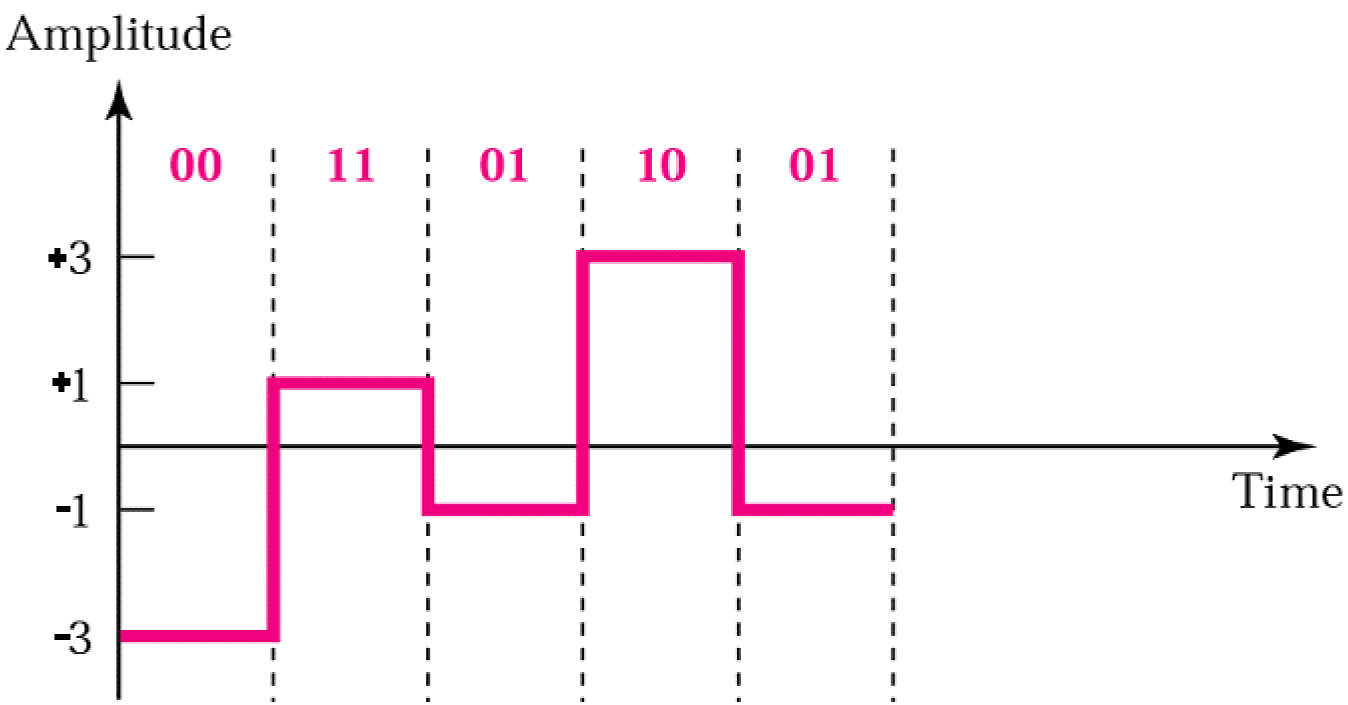
In mBnL schemes, a pattern of m data elements is encoded as a pattern of n signal elements in which $2^m \le L^n$.

Line Coding Schemes

MULTILEVEL SCHEMES

2B1Q

- The first mBnL scheme, two binary, one quaternary (2B1Q), uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal.
- In this type of encoding m =2, n =1, and L =4 (quaternary).
- Figure below shows an example of a 2B1Q signal.

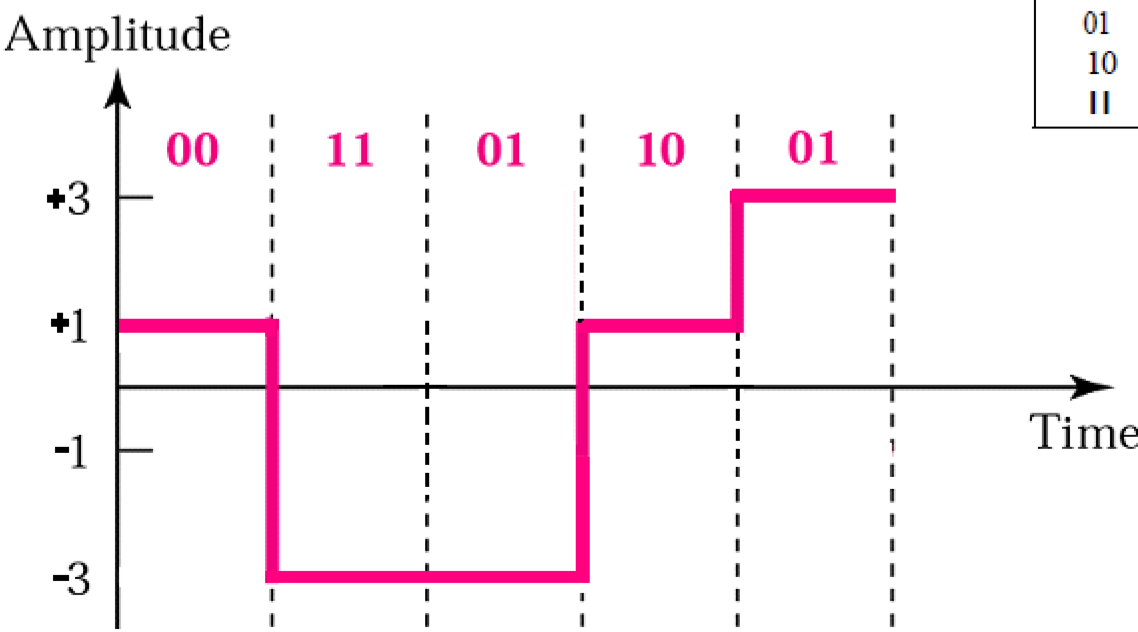


Line Coding Schemes

MULTILEVEL SCHEMES 2B1Q

	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



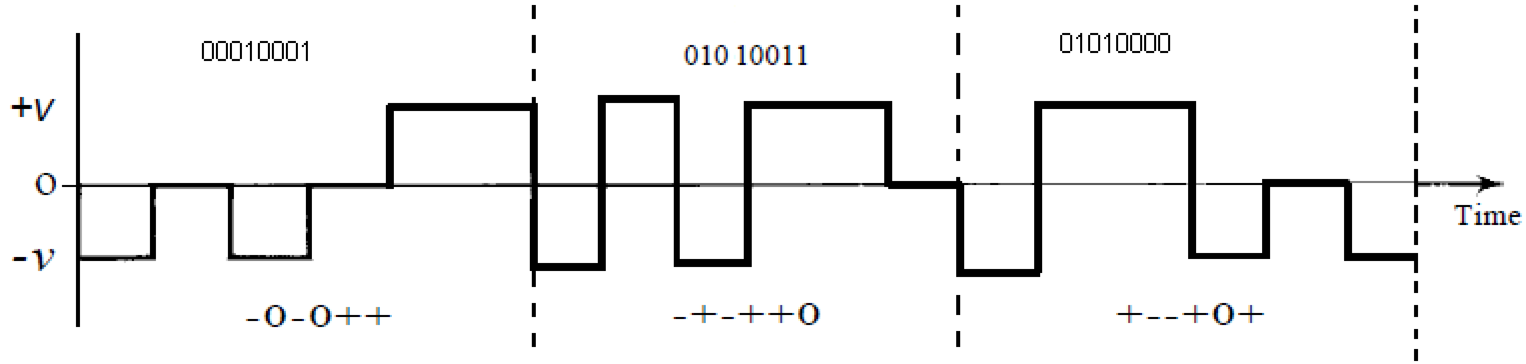
Assuming positive original level

Line Coding Schemes

MULTILEVEL SCHEMES

8B6T : Eight binary, six ternary

- The idea is to encode a pattern of 8 bits as a pattern of 6 signal elements, where the signal has three levels (ternary).
- In this type of scheme, we can have 2^8 =256 different data patterns and 3^6 =478 different signal patterns.
- There are 478 - 256 =222 redundant signal elements that provide synchronization and error detection.



Line Coding Schemes

Multi-Transition Schemes

Multiline Transmission: MLT-3

- NRZ-I and differential Manchester are classified as differential encoding but use two transition rules to encode binary data (no inversion, inversion).
- If we have a signal with more than two levels, we can design a differential encoding scheme with more than two transition rules.
- Multiline transmission, three level (MLT-3) scheme uses three levels (+V, 0, and -V) and three transition rules to move between the levels.
  1. If the next bit is 0, there is no transition.
  2. If the next bit is 1 and the current level is not 0, the next level is 0.
  3. If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.

Line Coding Schemes

Multi-Transition Schemes

Multiline Transmission: MLT-3

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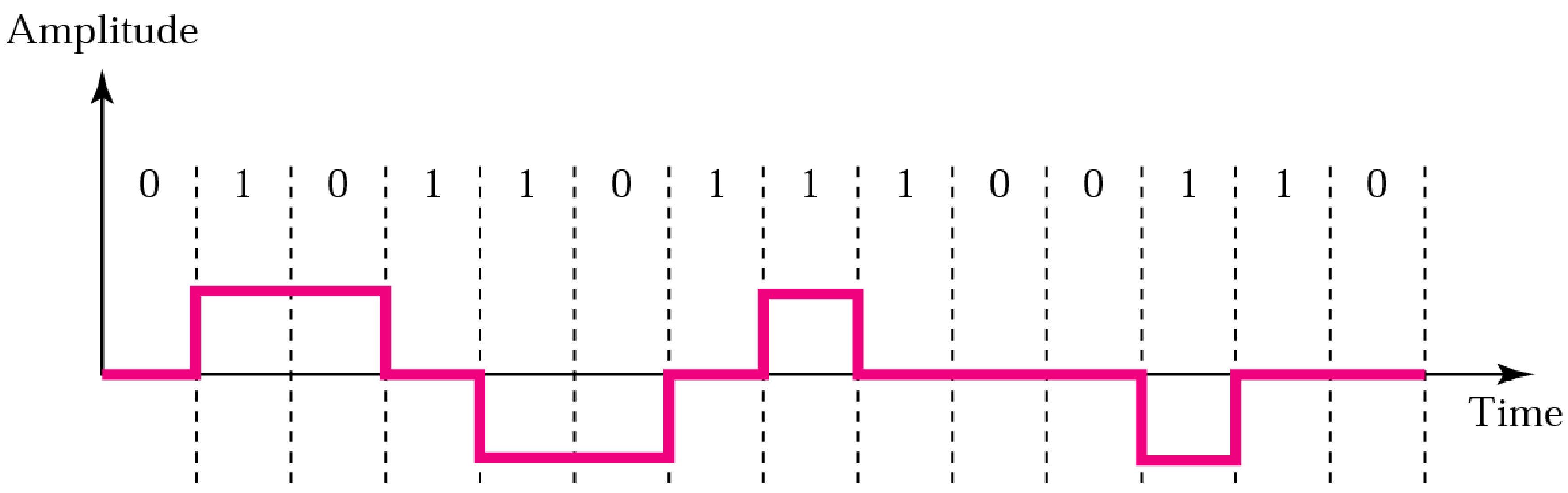

Line Coding Schemes

Multi-Transition Schemes

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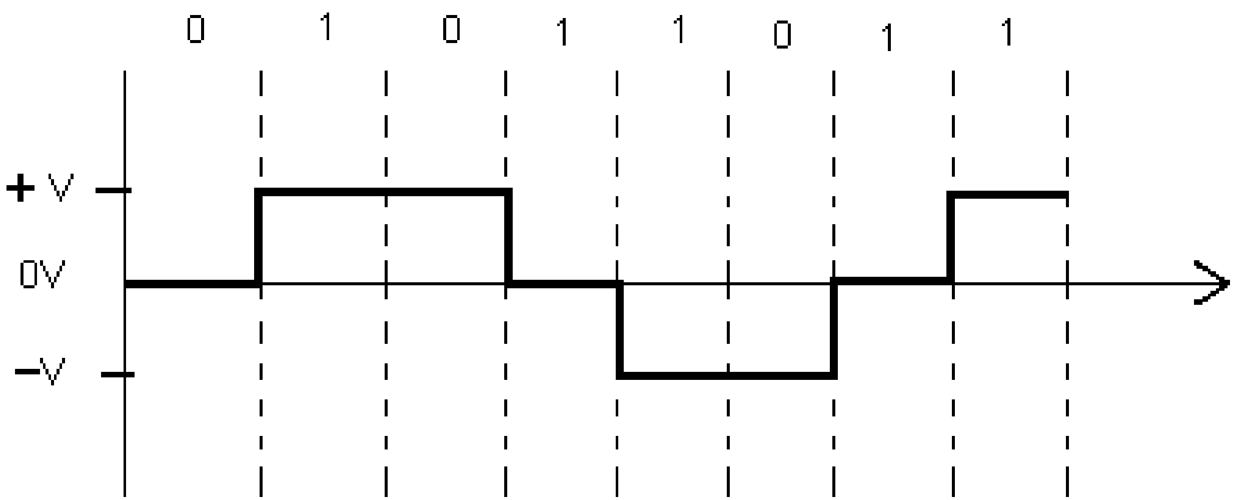

Line Coding Schemes

Multi-Transition Schemes

Multiline Transmission: MLT-3

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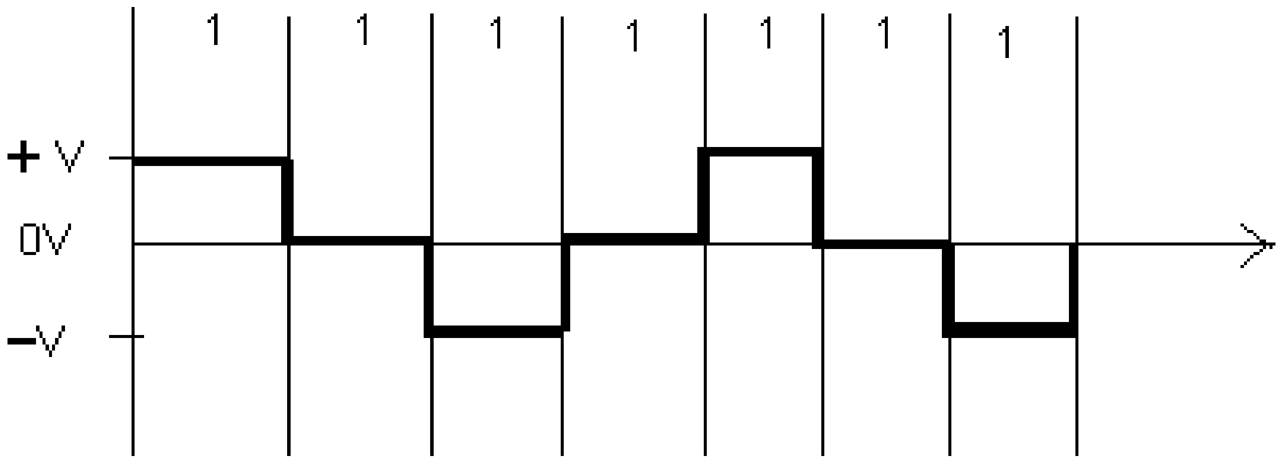


WORST CASE

Line Coding Schemes

Draw the graph of the NRZ-L, NRZ-I, Manchester, Differential Manchester schemes using each of the following data streams, assuming that the last signal level has been positive.

a. 00000000

b. 11111111

c. 01010101

d. 00110011

2B1Q scheme:

a. 0000000000000000

b. 1111111111111111

c. 0101010101010101

d. 0011001100110011

MLT-3 scheme:

a. 00000000

b. 11111111

c. 01010101

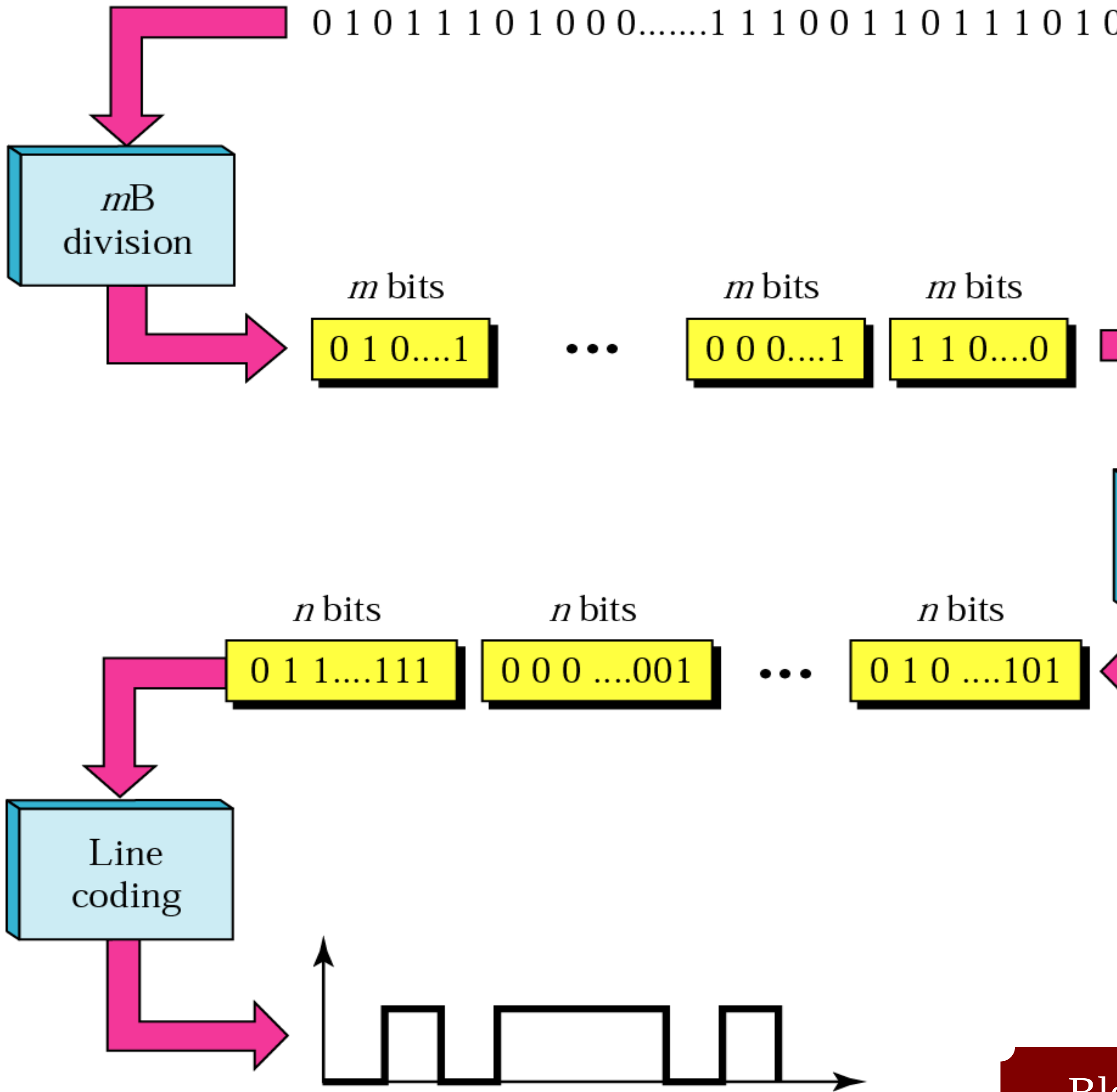
d. 00011000

Block Coding

- Block coding changes a block of m bits into a block of n bits, where n is larger than m.
- Block coding is referred to as an mB/nB encoding technique.
  - It replaces each m-bit group with an n-bit group.

- Block coding normally involves three steps:
  - Division, Substitution, and Combination.
- In the division step, a sequence of bits is divided into groups of m bits.
  - For example, in 4B/5B encoding, the original bit sequence is divided into 4-bit groups.
- The heart of block coding is the substitution step.
  - In this step, we substitute an m-bit group for an n-bit group.
  - For example, in 4B/5B encoding we substitute a 4-bit code for a 5-bit group.
- Finally, the n-bit groups are combined together to form a stream. The new stream has more bits than the original bits.

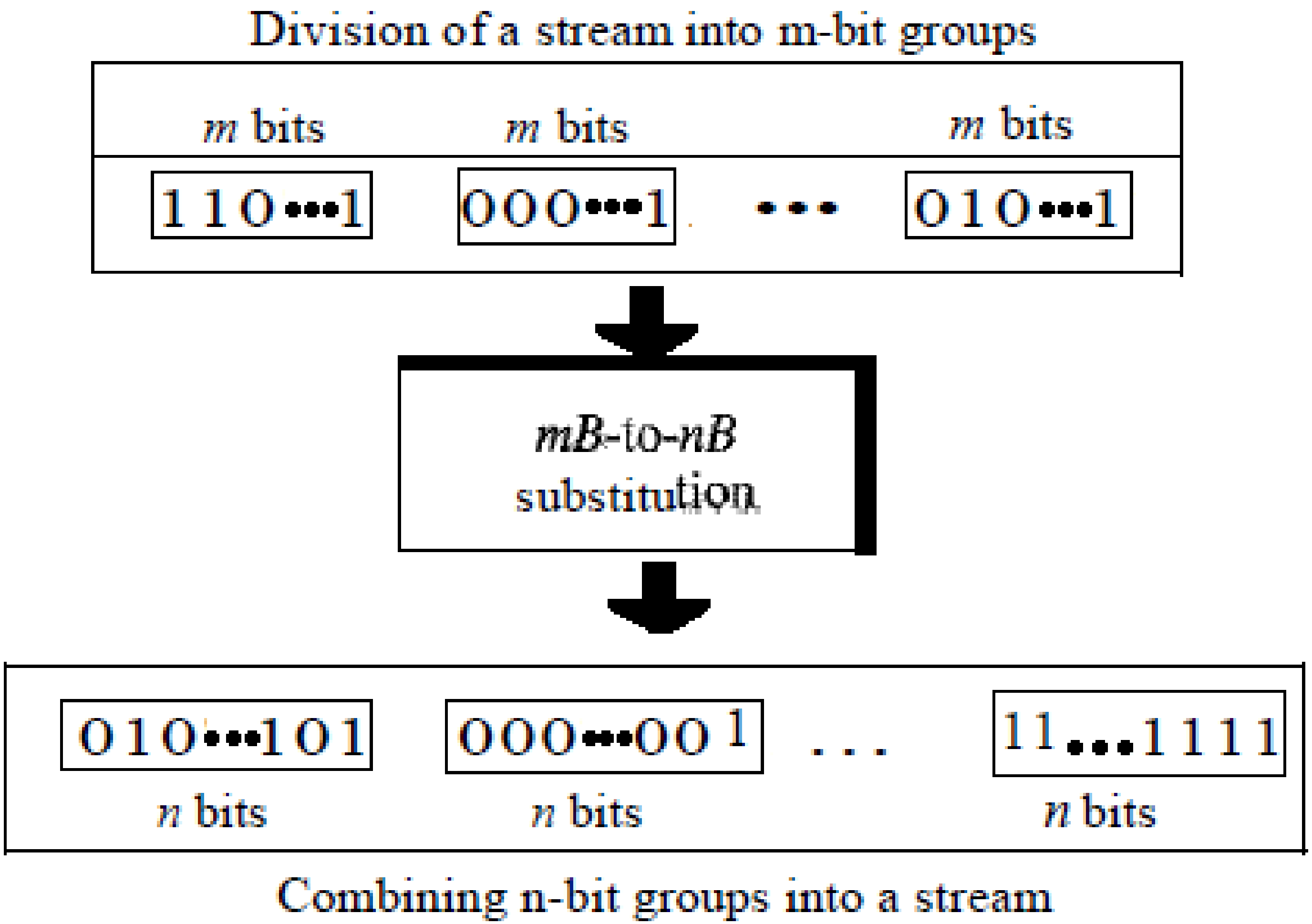
Block Coding



Block coding concept

Block Coding

Block coding concept

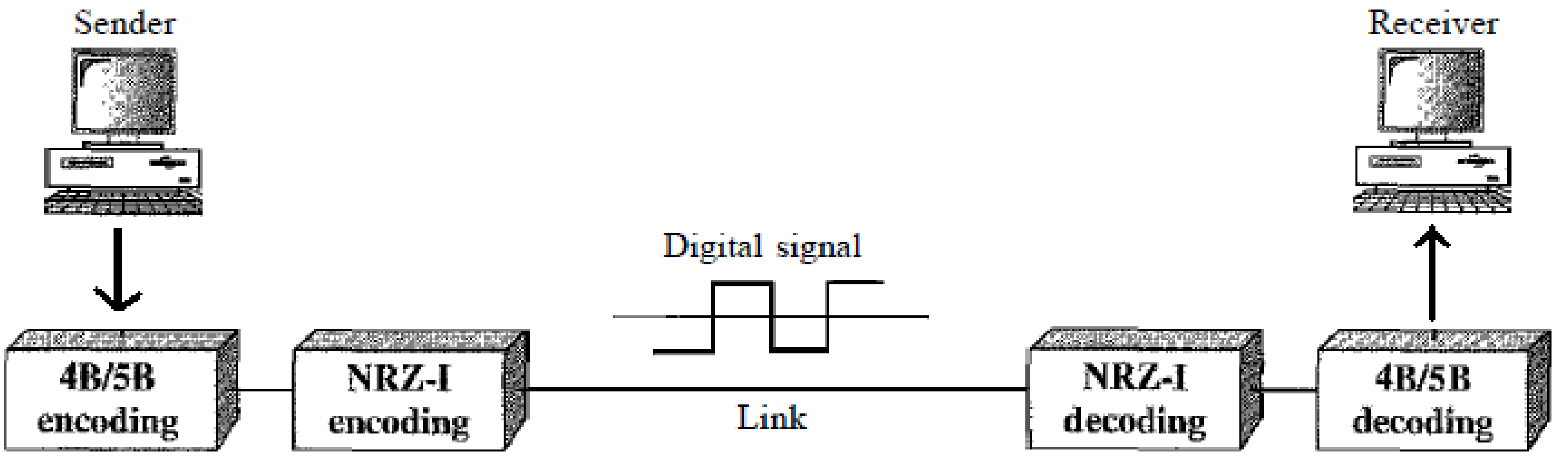


Block Coding

4B/5B

- The four binary/five binary (4B/5B) coding scheme was designed to be used in combination with NRZ-I.

- Steps:
  - At the sender side, change the bit stream, prior to encoding with NRZ-I.
  - At the receiver, the NRZ-I encoded digital signal is first decoded into a stream of bits and then decoded.

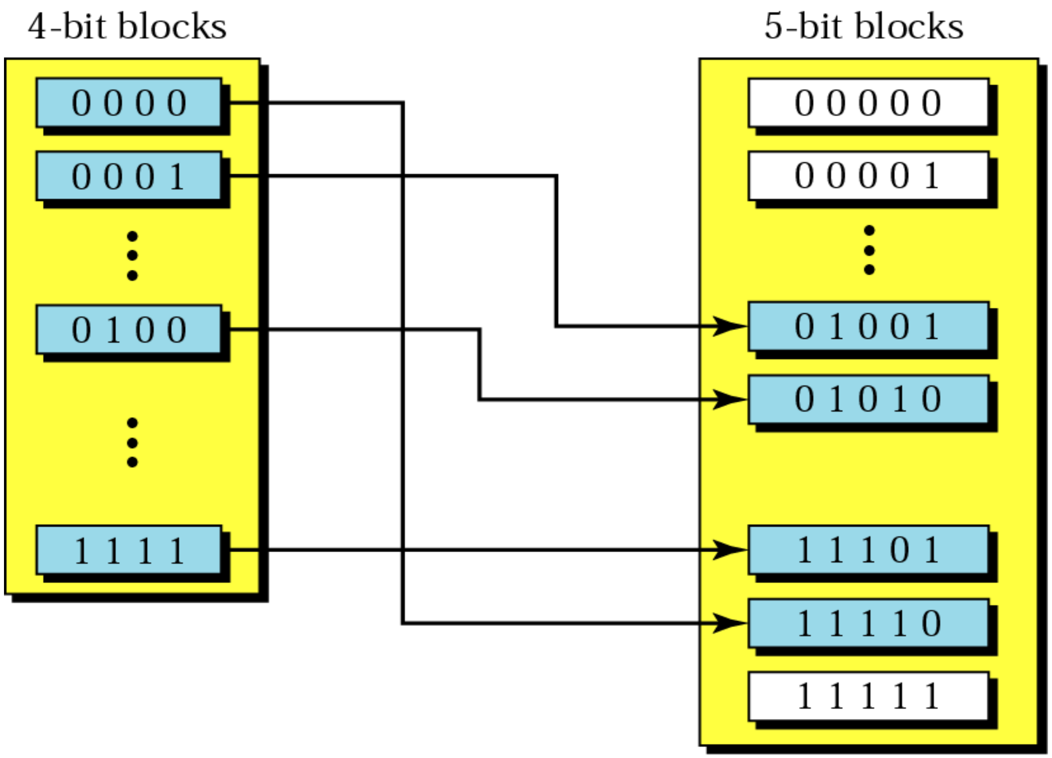


Using block coding 4B/5B with NRZ-I line coding scheme

Block Coding

4B/5B

- In 4B/5B, the 5-bit output that replaces the 4-bit input has no more than one leading zero (left bit) and no more than two trailing zeros (right bits).
- So when different groups are combined to make a new sequence, there are never more than three consecutive 0s.



Block Coding

4B/5B

- A group of 4 bits can have only 16 different combinations while a group of 5 bits can have 32 different combinations.
  - This means that there are 16 groups that are not used for 4B/5B encoding.
  - Some of these unused groups are used for control purposes; the others are not used at all. The latter provide a kind of error detection.
- If a 5-bit group arrives that belongs to the unused portion of the table, the receiver knows that there is an error in the transmission.

Block Coding 4B/5B

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	11 010		
1101	11011		
1110	11100		
1111	11101		

Digital-to-Digital Conversion