Digital Transmission
Digital Encoding

Physical Layer

PSG COLLEGE OF TECHNOLOGY
DEPARTMENT OF APPLIED MATHEMATICS AND COMPUTATIONAL SCIENCES
COMPUTER NETWORKS
20XC42 & 20XW42 COMPUTER NETWORKS

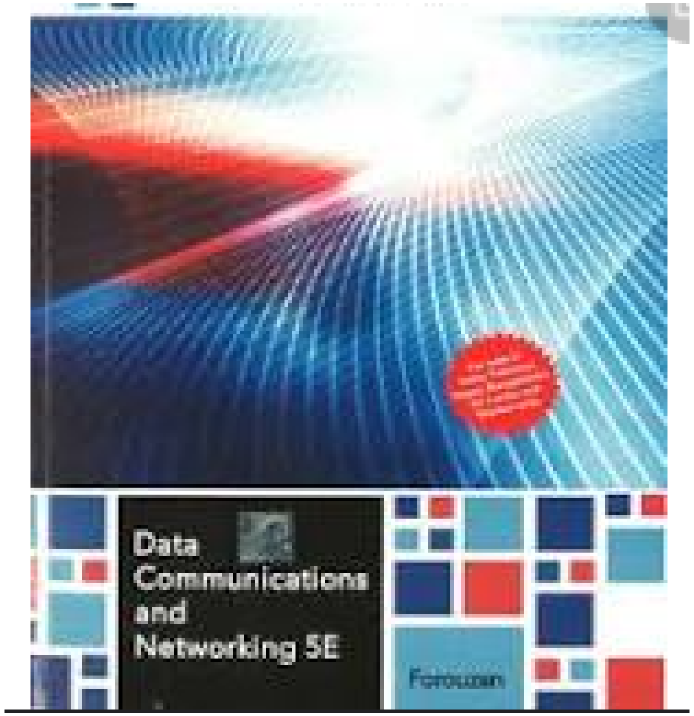
Text and Reference books

TEXT BOOKS:

1. **Behrouz A Forouzan, “Data Communications and Networking”, Tata McGraw Hill, 2013**

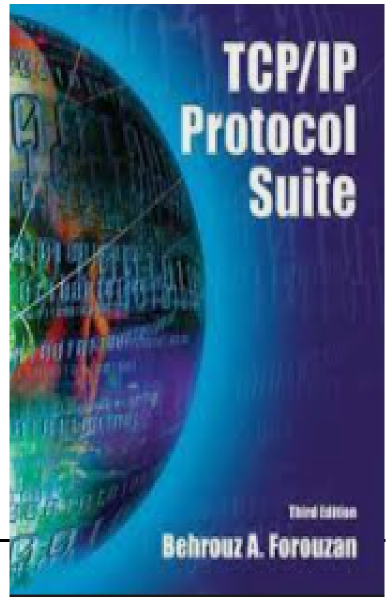
. 2. Behrouz A Forouzan, “TCP/ IP Protocol Suite”, Tata McGraw Hill, 2017.

3. **Peterson, Larry** L., and Bruce S. Davie. Computer networks: a systems approach. Elsevier, 2012.



REFERENCES:

1. Kevin Fall R and Richard Stevens W, "TCP/IP Illustrated, Volume 1: The Protocols”, Addison-Wesley, Ann Arbor, 2011.
2. James F. Kurose, Keith Ross, “Computer Networking: A Top-Down Approach”, Addison-Wesley, 2017.
3. Douglas Comer, “Internetworking with TCP/IP”, Prentice Hall, 2013.
4. **William Stallings**, "Data and Computer Communications”, Prentice Hall, 2007.



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

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**
- **Analog to Digital Conversion**

Digital to Digital Conversion

- The conversion involves three techniques:
- **line coding,**
    - **block coding**
    - **scrambling.**

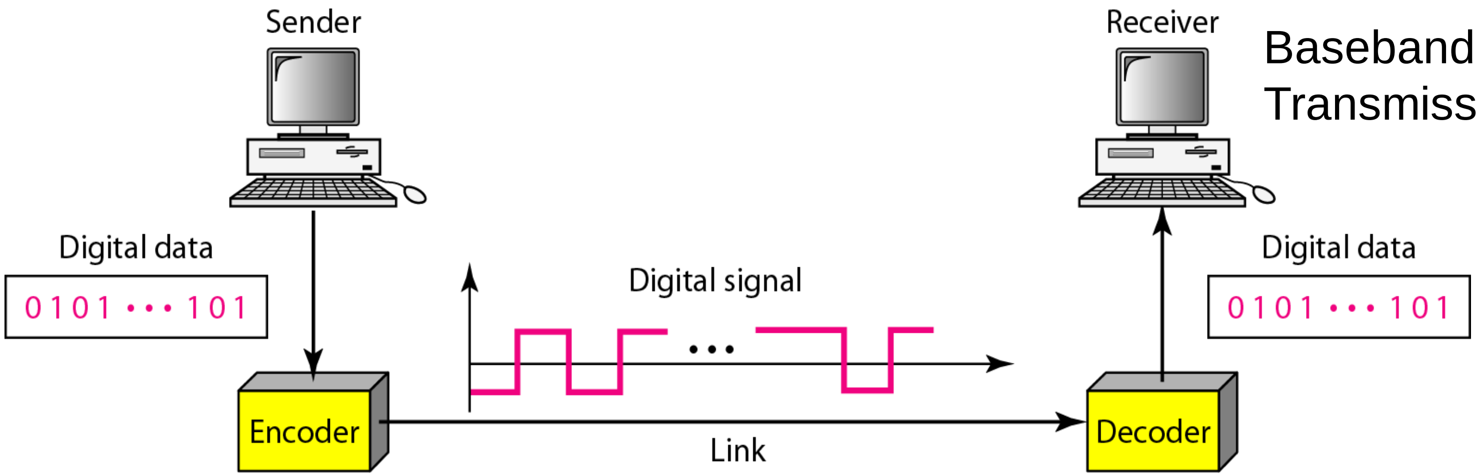
- Line coding is always needed;
  block coding and scrambling may or may not be needed.

Line Coding

Line coding is the process of converting digital data to digital signals.

- 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

Baseband Transmission



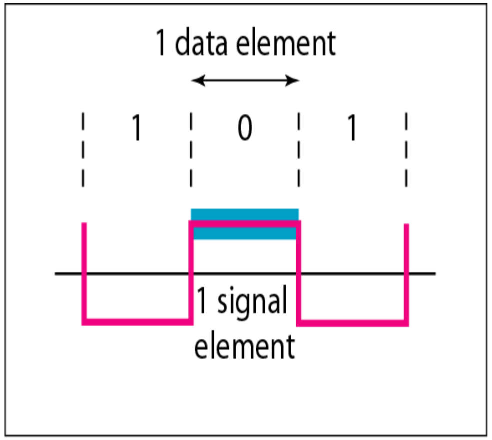
Data element: smallest entity representing a piece of information.

Signal element: shortest unit of a digital signal.

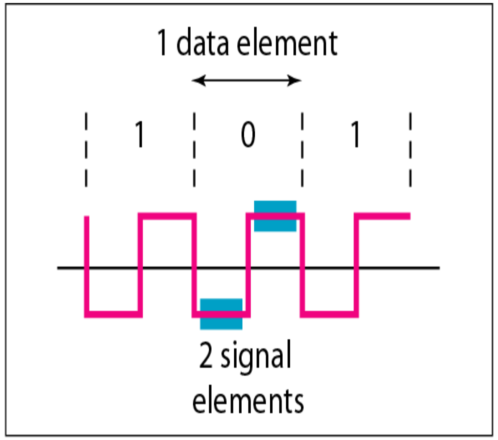
Signal Element vs Data Element

- In data communications, our goal is to send **data elements**.
- **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 (timewise) of a digital signal.**

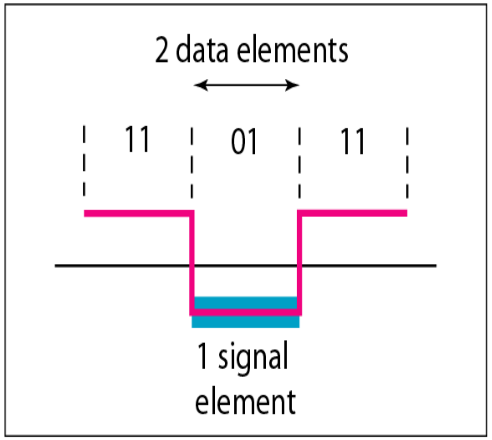
. In other words, **data elements are what we need to send**; **signal elements are what we can send**. Data elements are being carried; signal elements are the carriers.



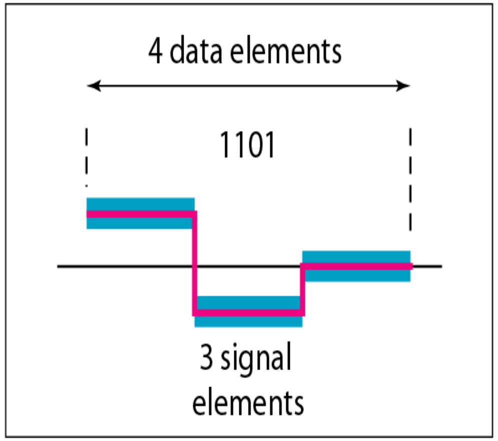
a. One data element per one signal element (r = 1)



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

Data Rate vs Signal Rate

The **data rate** defines the **number of data elements (bits) sent in 1s**. The unit is bits per second (**bps**).

The **signal rate** is the **number of signal elements sent in 1s.** The unit is the **baud. Rate at which the signal changes per second(mesurement of speed)**

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.

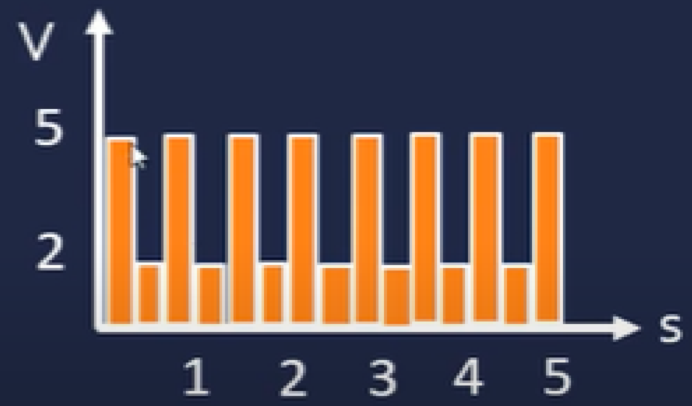
Relationship between data rate and signal rate as

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

where N is the data rate (bps); c is the case factor(0-1 ,worst, best, avg), which varies for each case; S is the number of signal elements; r is the ratio between data element & signal element

- The unit is the baud (Bd), and it is a measurement of **speed**

- This has a baud rate of 1 Bd, as the signal only changes once a second (taken to be the end)



- This has a baud rate of 3 Bd
- 3 pulses in 1 second

- This has a baud rate of 1 Bd, *and* a bit rate of 1 bps – only 2 voltage levels so only 1 bit per signal

- Baud rate still 1 Bd, but the bit rate is 2 bps – now each signal represents 2 bits

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 1?
- Solution

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

Example

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Solution

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

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

Note

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

The baud rate, not the bit rate, determines the required bandwidth for a digital signal

What is the bandwidth that s needed for a communication channel given the baud rate?

There is **a relationship between the baud rate (signal rate) and the bandwidth**.

What is the bandwidth of the digital signal if we know the baud rate?

Minimum bandwidth that we need is the baud rate

I need to have atleast a bandwidth of the channel equals to baud rate in order to the signal to pass through (minimum)

More bandwidth more accurately the signal will be received ..but minimum bandwidth

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

Maximum data rate if the bandwidth of the channel is given.(Same as Nyquist)

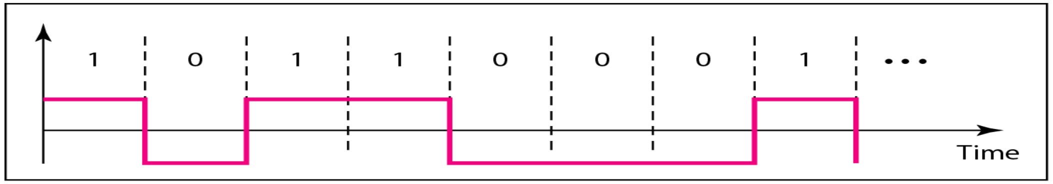
$$N_{max} = (1/c) \times B \times r$$

$C = 2 \text{ B } \log_2 2^n$

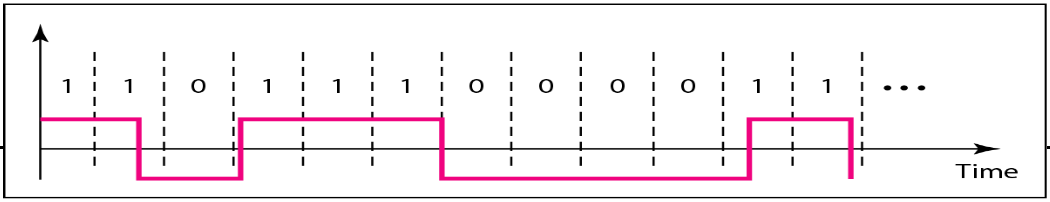
Self Synchronisation

- 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.
- Figure shows a situation in which the receiver has a shorter bit duration. The sender sends 10110001, while the receiver receives 110111000011.

Effect of lack of synchronisation



a. Sent



b. Received

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?
- 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

Evaluation consideration for a line encoding scheme

Baseline Wandering

- 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 Components

- 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, called 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. Also a long- distance link may use one or more transformers to isolate different parts of the line electrically. For these systems, we need a scheme with no DC component.

Self synchronization

- •To correctly interpret the signals, **receiver’s bit intervals should exactly match with the sender’s bit intervals**.
- • The ability to recover timing from the signal itself.
  • Long series of ones and zeros could cause a problem

Built in Error Detection

- It is desirable to have a built-in error-detecting capability in the generated code to detect some of or all the errors that occurred during transmission.

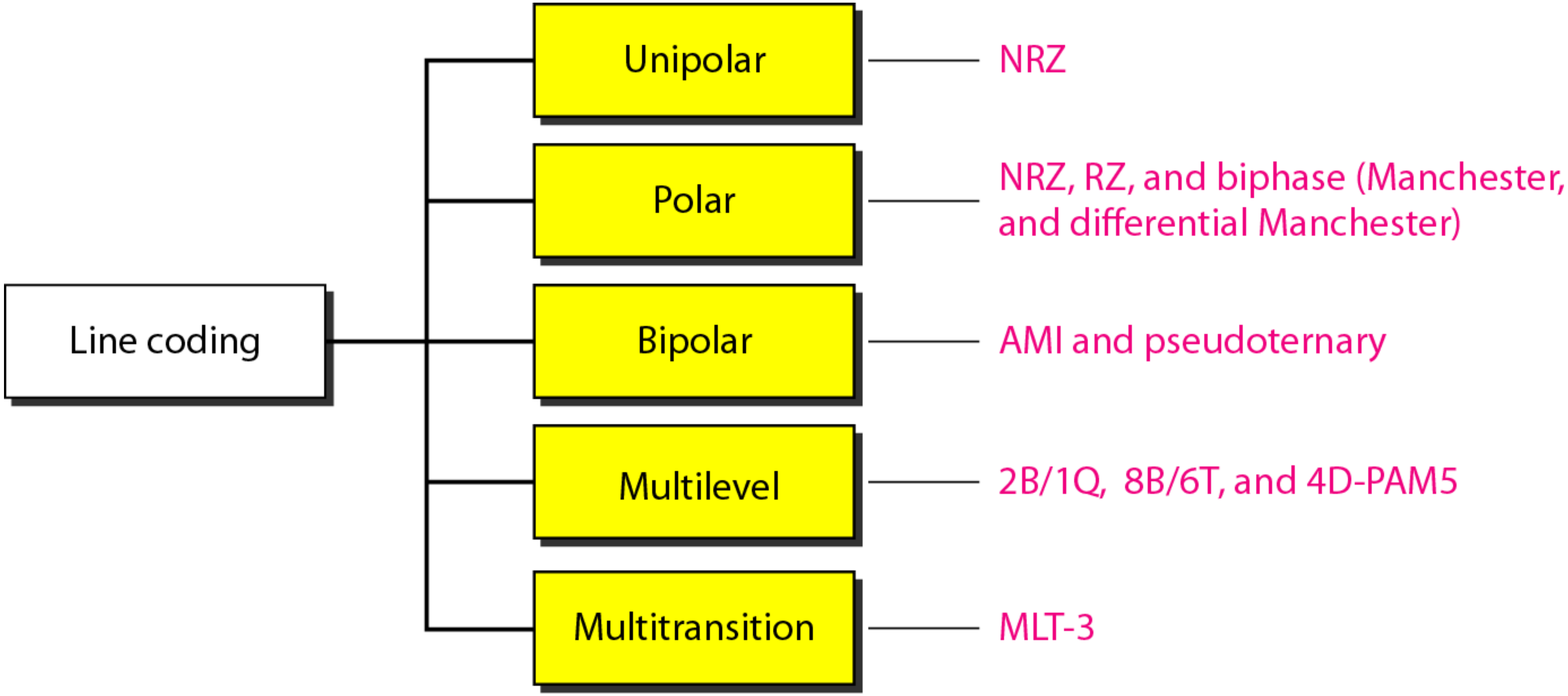
Immunity to Noise and Interference

- Another desirable code characteristic is a code that is immune to noise and other interferences.

Complexity

- A complex scheme is more costly to implement than a simple one.
- For example, a scheme that uses four signal levels is more difficult to interpret than one that uses only two levels.

Line Coding Schemes

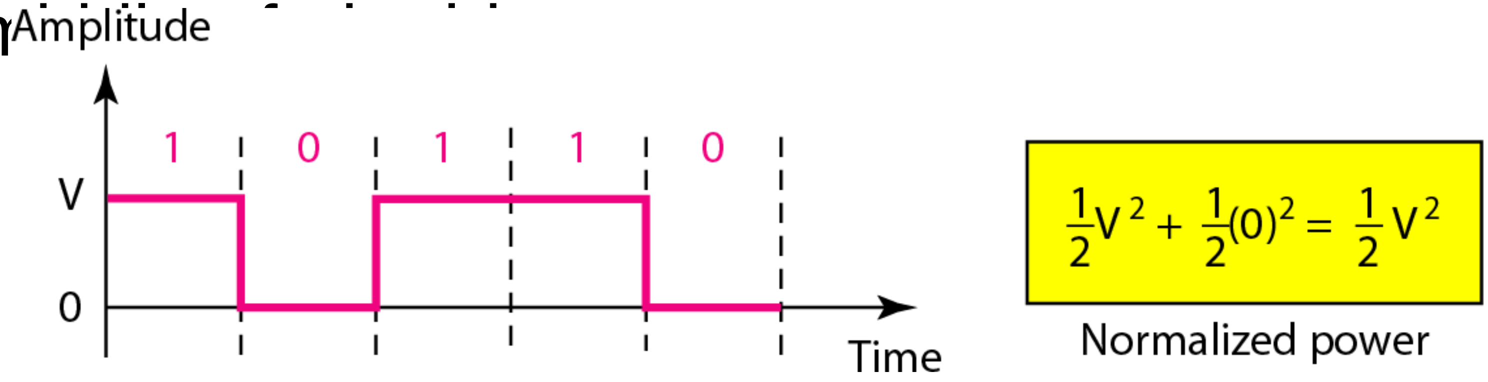


Unipolar Scheme

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

NRZ (Non-Return-to-Zero) 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 m



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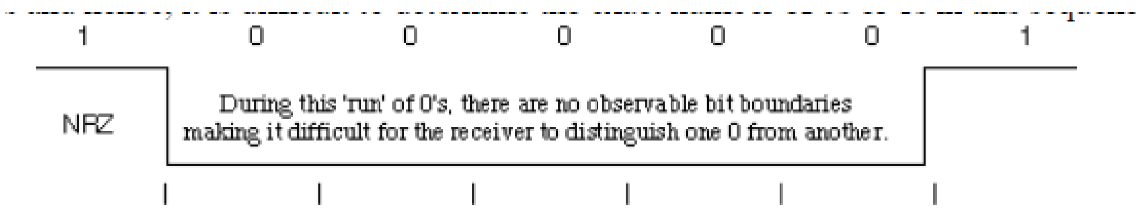
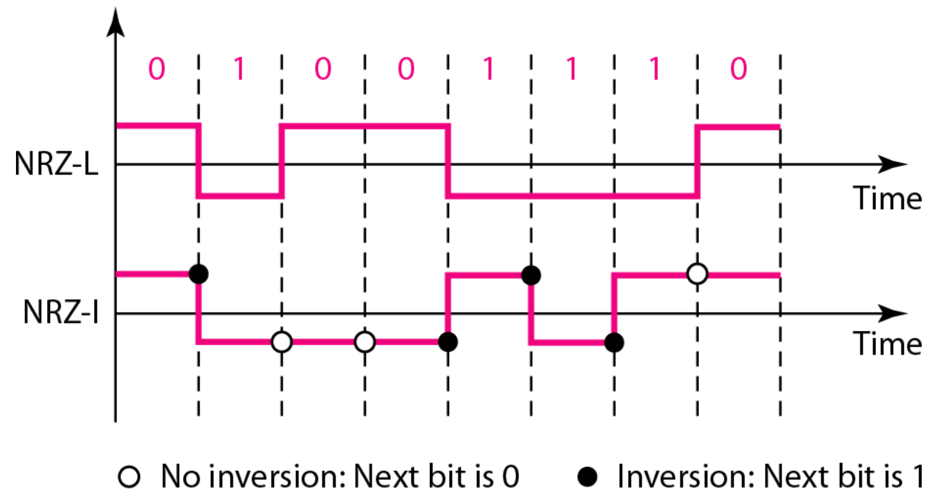
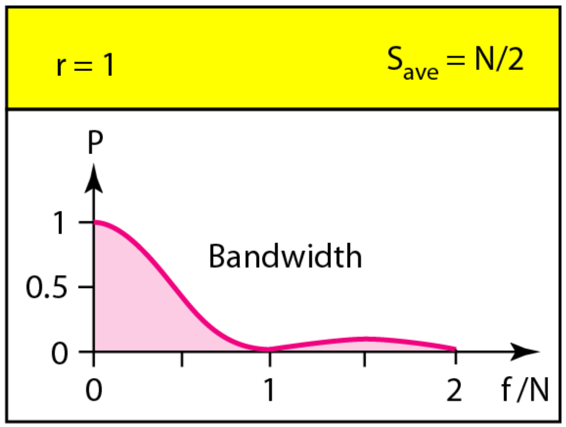


Polar Schemes

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.

- In **polar Non-Return-to-Zero (NRZ)** encoding, we use two levels of voltage amplitude. We can have two versions of polar NRZ: NRZ-Land NRZ-I, as shown in Figure. The figure also shows the value of r, the average baud rate, and the bandwidth.
- In the first variation, NRZ-L (NRZ-Level), the level of the voltage determines the value of the bit. In the second variation, **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.





Polar RZ

Use three level +,-,0

In RZ, the signal changes not between bits but during the bit. (0 does not carry data-extra signal level)

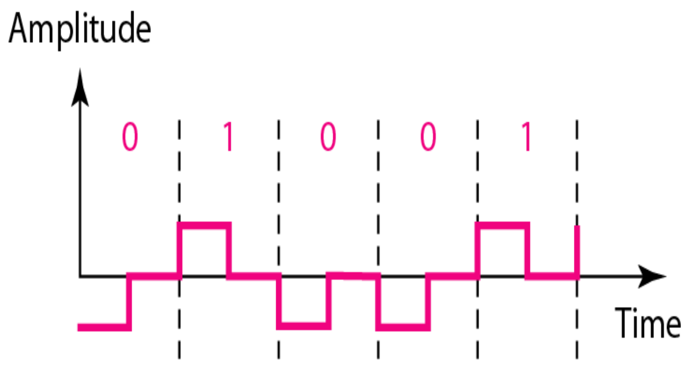
signal returns to 0 in the middle of each bit. It remains there until the beginning of the next bit.

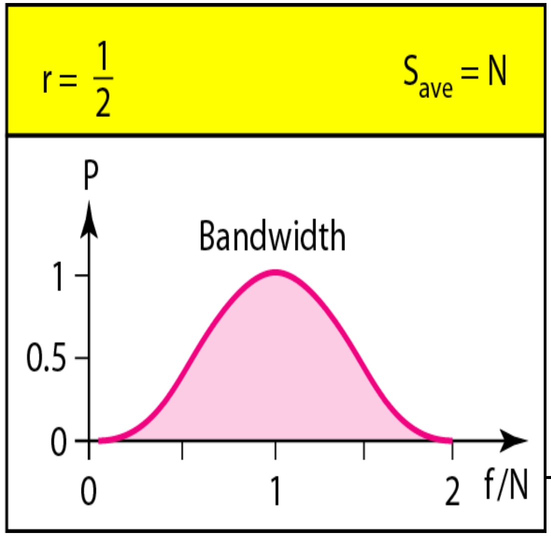
Timing information can be put in the middle of the bit

No constant voltage –no zero frequencies no dc component

The main disadvantage of RZ encoding is that it requires two signal changes to encode a bit and therefore occupies greater bandwidth.

The same problem we mentioned, a sudden change of polarity resulting in all as interpreted as 1s and all 1s interpreted as as, still exist here, but there is no DC component problem.





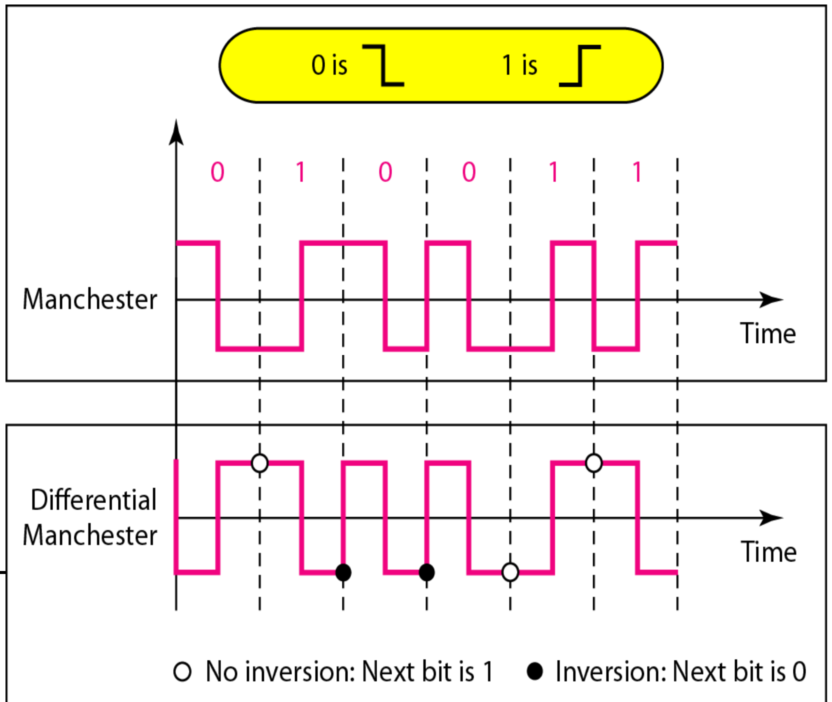
Biphase: Manchester and Differential Manchester

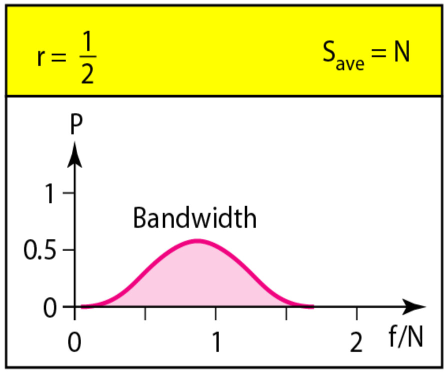
The idea of **RZ (transition in middle of the bit) and the idea of NRZ-L** are combined into the Manchester scheme

- 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. The transition at the middle of the bit provides synchronization.

Differential Manchester, on the other hand, 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.





Bipolar Schemes: AMI and Pseudoternary

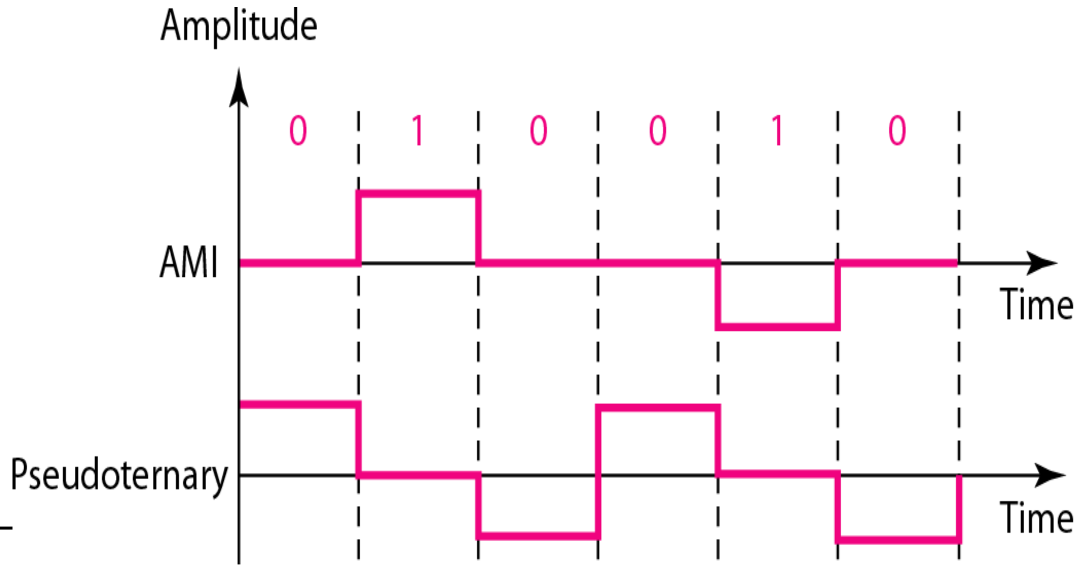
In bipolar encoding (sometimes called multilevel binary), there are **three voltage lev- els: positive, negative, and zero.** . 3 levels for data representation

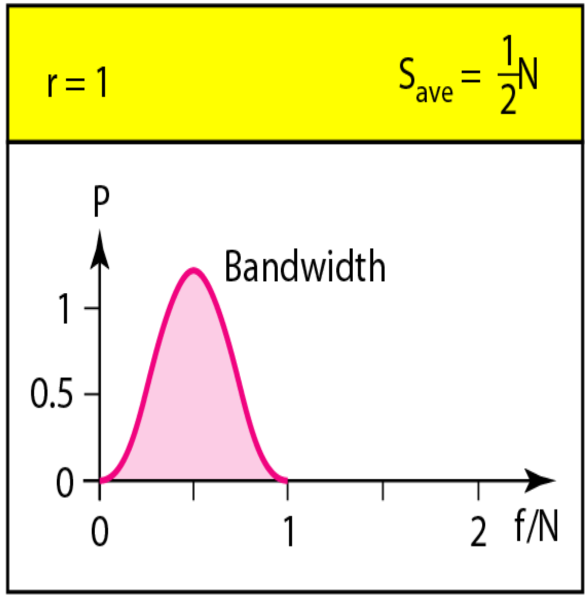
The voltage level for one data element is at zero, while the voltage level for the other element alternates between positive and negative.

A common bipolar encoding scheme is called bipolar alternate mark inversion (AMI). A neutral zero voltage represents binary 0.

Binary Is are represented by alternating positive and negative voltages.

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.





Multilevel Schemes

Group data bits and form data pattern then map them from a group of signal elements

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**.

Two types of data elements (0s and 1s), which means that a group of m data elements can produce a combination **of 2^m data patterns**.

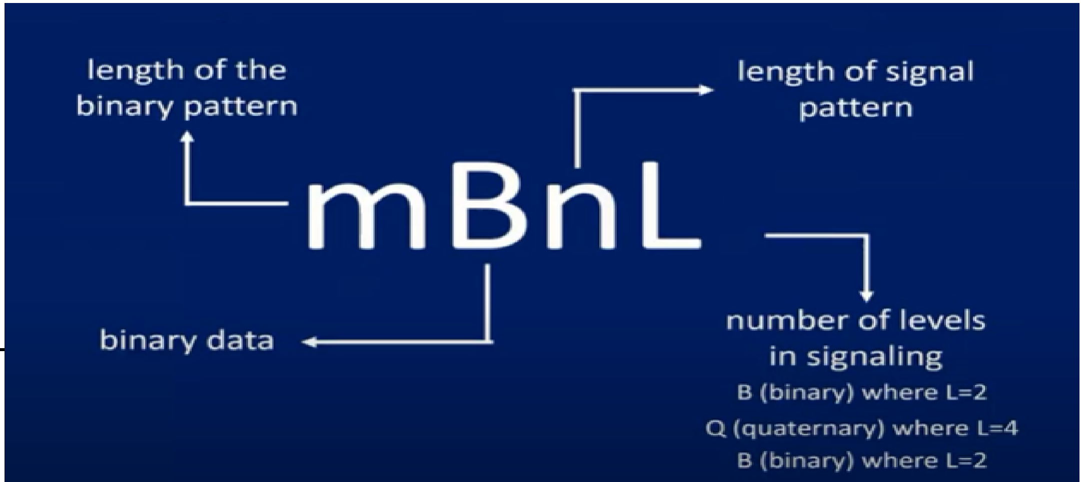
If we have **L different levels**, then we can produce L^n combinations of signal patterns.

If $2^m = L^n$, then each data pattern is encoded into one signal pattern.

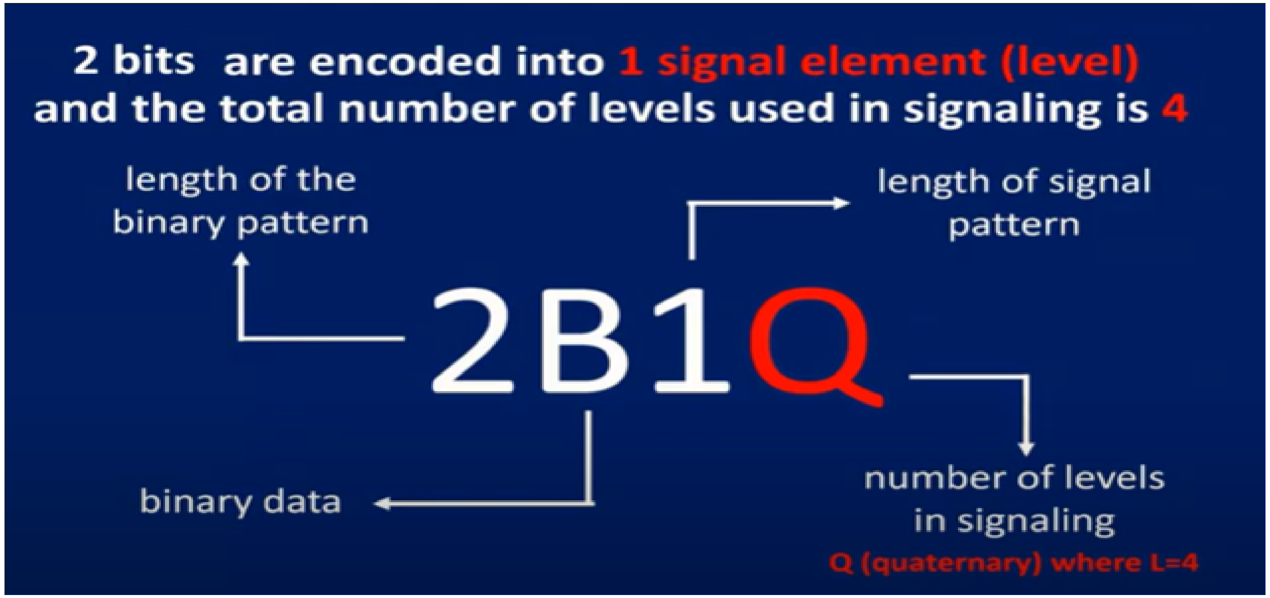
If $2^m < L^n$, data patterns occupy only a subset of signal patterns.

Data encoding is not possible if $2^m > L^n$ because some of the data patterns cannot be encoded.

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.



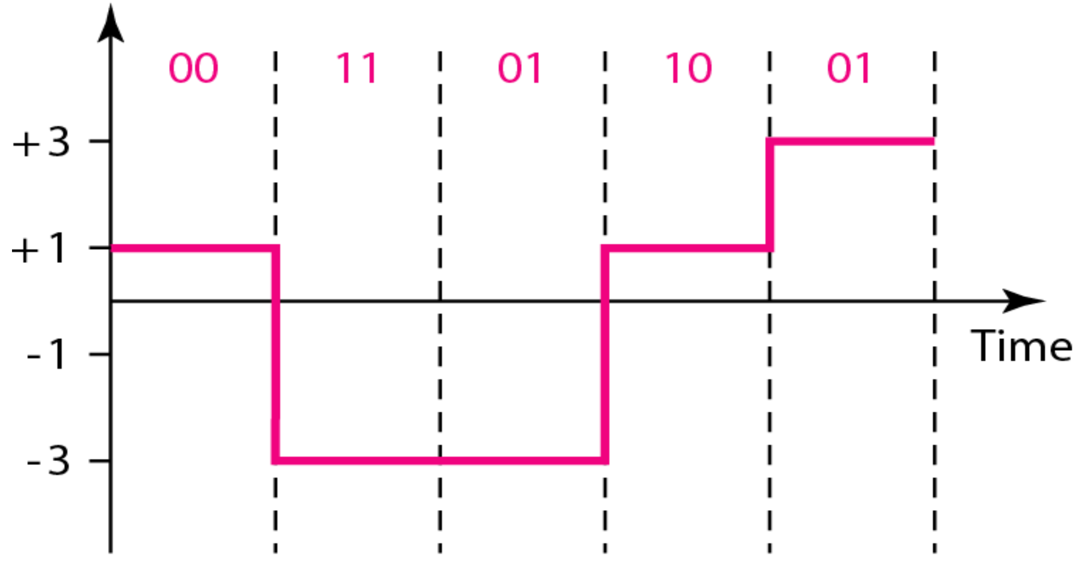
2B1Q Scheme



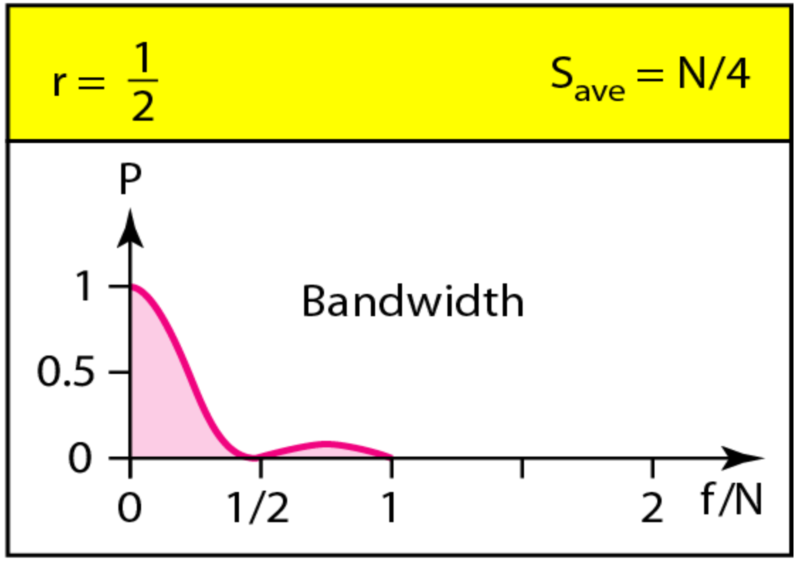
- The average signal rate of 2B1Q is S =N/4.
- This means that using 2B1Q, we can send data 2 times faster than by using NRZ-L. However, 2B1Q uses four different signal levels, which means the receiver has to discern four different thresholds.
- There are no redundant signal patterns in this scheme because $2^2 = 4^1$.

	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



8B6T Scheme

a pattern of **8 data elements** is encoded into a pattern of **6 signal elements** where the signal has **3 levels**

2 types of data elements
0 and 1

3 types of signal elements

Group of 8 data elements → 2^8 **data patterns**

Group of 6 signal elements → 3^6 **signal patterns**

Number of Redundant Signal Patterns

Number of data patterns = $2^8 = 256$

Number of signal patterns = $3^6 = 729$

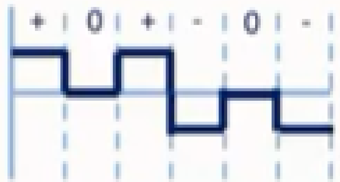
Number of redundant signal patterns = $729 - 256 = 473$

Mapping Table 8B6T (partial)

2A ⟶ 0010 1010

Data	Code	Data	Code	Data	Code	Data	Code
00	-+00-+	20	-++-00	40	-00+0+	60	0++0-0
01	0-+-+0	21	+00+--	41	0-00++	61	+0+-00
02	0-+0-+	22	-+0-++	42	0-0+0+	62	+0+0-0
03	0-++0-	23	+-0-++	43	0-0++0	63	+0+00-
04	-+0+0-	24	+-0+00	44	-00++0	64	0++00-
05	+0--+0	25	-+0+00	45	00-0++	65	++0-00
06	+0-0-+	26	+00-00	46	00-+0+	66	++00-0
07	+0-+0-	27	-+++--	47	00-++0	67	++000-
08	-+00+-	28	0++-0-	48	00+000	68	0++-+-
09	0-++-0	29	+0+0--	49	++-000	69	+0++--
0A	0-+0+-	2A	+0+-0-	4A	+-+000	6A	+0+-+-
0B	0-+-0+	2B	+0+--0	4B	-++000	6B	+0+--+
0C	-+0-0+	2C	0++--0	4C	0+-000	6C	0++--+
0D	+0-+-0	2D	++00--	4D	+0-000	6D	++0+--
0E	+0-0+-	2E	++0-0-	4E	0-+000	6E	++0-+-
0F	+0--0+	2F	++0- -0	4F	-0+000	6F	++0--+
10	0--+0+	30	+-00-+	50	+--+0+	70	000++-
11	-0-0++	31	0+--+0	51	-+-0++	71	000+-+
12	-0-+0+	32	0+-0-+	52	-+-+0+	72	000-++
13	-0-++0	33	0+-+0-	53	-+-++0	73	000+00
14	0--++0	34	+-0+0-	54	+--++0	74	000+0-
15	--00++	35	-0+-+0	55	--+0++	75	000+-0
16	--0+0+	36	-0+0-+	56	--++0+	76	000-0+
17	--0++0	37	-0++0-	57	--+++0	77	000-+0

+ 0 + - 0 -



8B6T Scheme

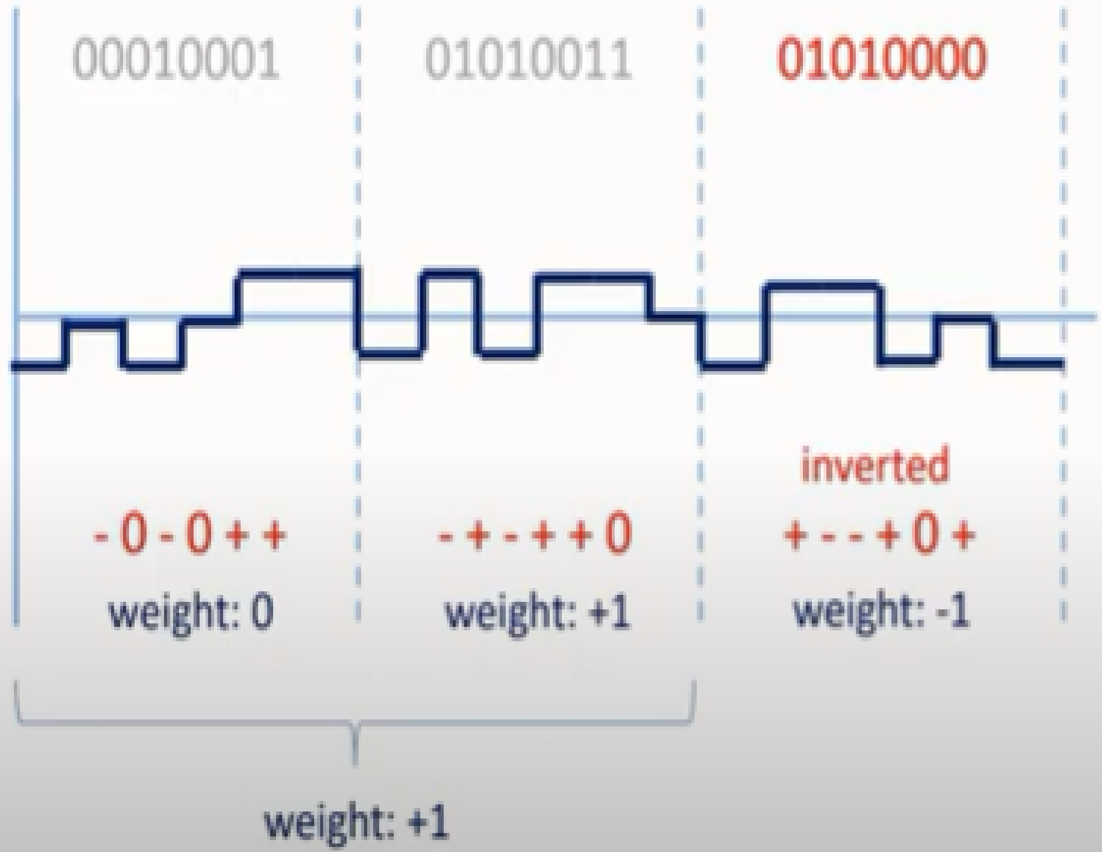
- This code is used with 100BASE-4T cable.
- Each signal pattern has a weight of 0 or +1 DC values. This means that there is no pattern with the weight -1.
- To make the whole stream **DC-balanced**, the sender keeps track of the weight.

  If two groups of weight 1 are encountered one after another, the first one is sent as is, while the next one is totally inverted to give a weight of -1.

DIGITAL DATA

000100010101001101010000

8B6T (partial)	
Data	**Code**
11	- 0 - 0 + +
50	+ - - + 0 +
53	- + - + + 0



01010000 → 50

inverted + - - + 0 + → - + + - 0 -

4D-PAM5(Four-dimensional five- level pulse amplitude modulation

- 4D means that data is sent over four wires at the same time.
- uses five voltage levels, such as -2, -1, 0, 1, and 2.
- one level, level 0, is used only for forward error detection

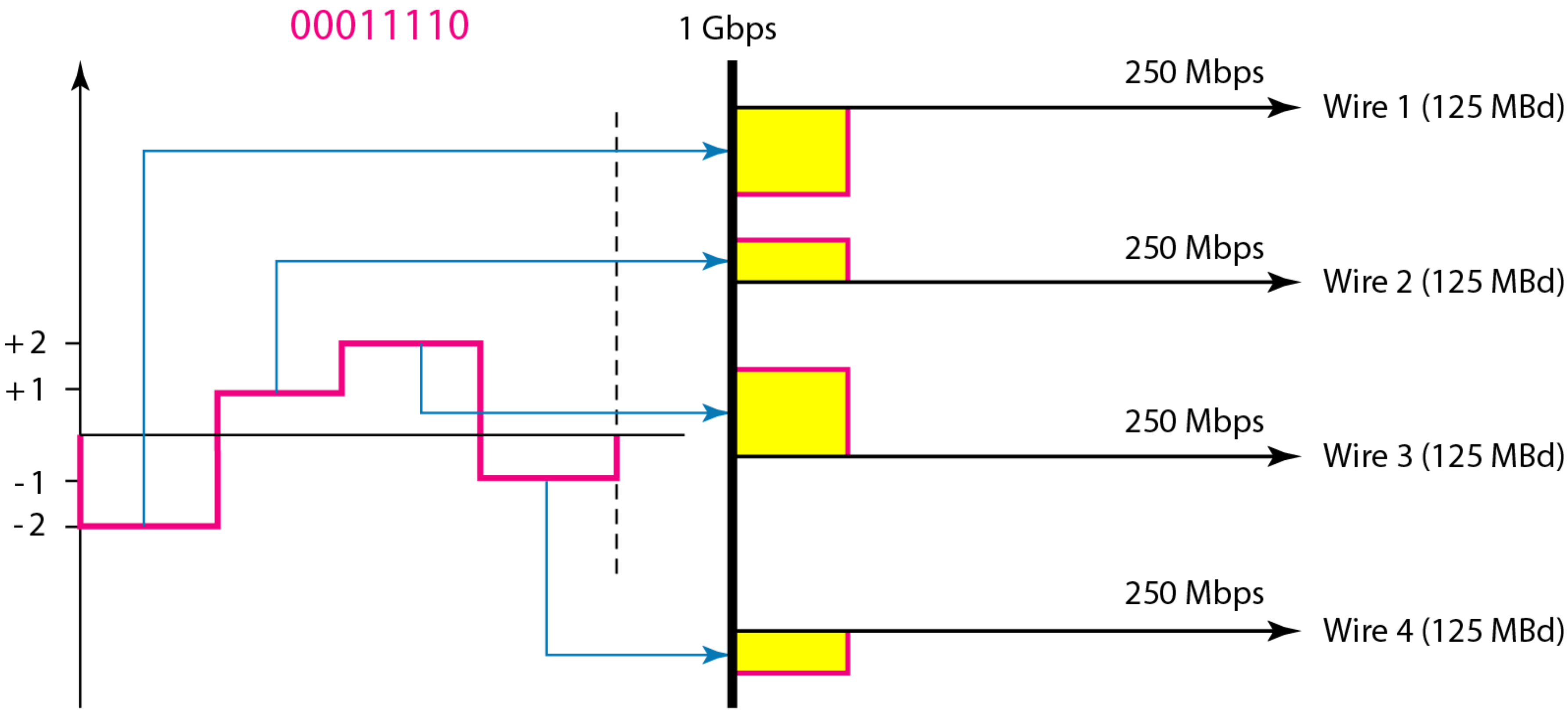
In other words, an 8-bit word is translated to a signal element of four different levels.

The technique is designed to send data over four channels (four wires).

All 8 bits can be fed into a wire simultaneously and sent by using one signal element.

- Gigabit LANs use this technique to send 1-Gbps data over four copper cables that can handle 125 Mbaud.

This scheme has a lot of redundancy in the signal pattern because 2^8 data patterns are matched to $4^4 = 256$ signal patterns. The extra signal patterns can be used for other purposes such as error detection.


00011110
1 Gbps
+2
+1
-1
-2
250 Mbps
Wire 1 (125 MBd)
250 Mbps
Wire 2 (125 MBd)
250 Mbps
Wire 3 (125 MBd)
250 Mbps
Wire 4 (125 MBd)

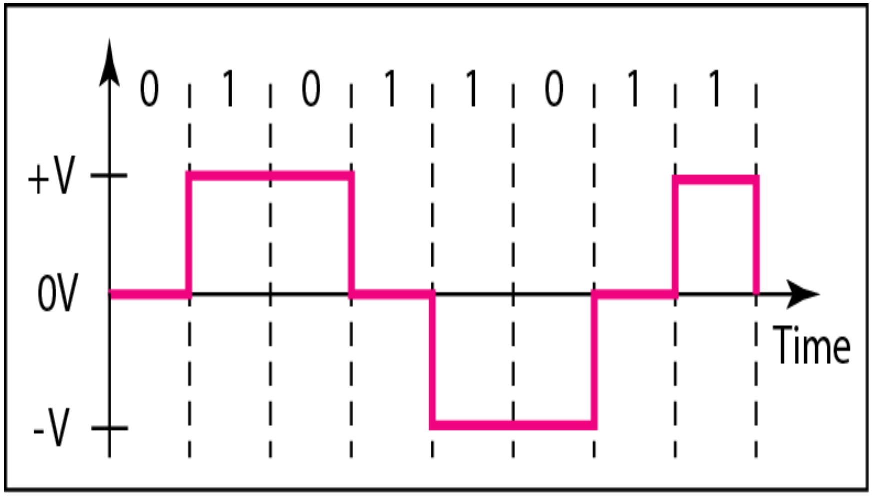
Multiline Transmission: MLT-3

- The multiline transmission, three level (MLT-3) scheme uses three levels (+V 0, and - V) and three transition rules to move between the levels.

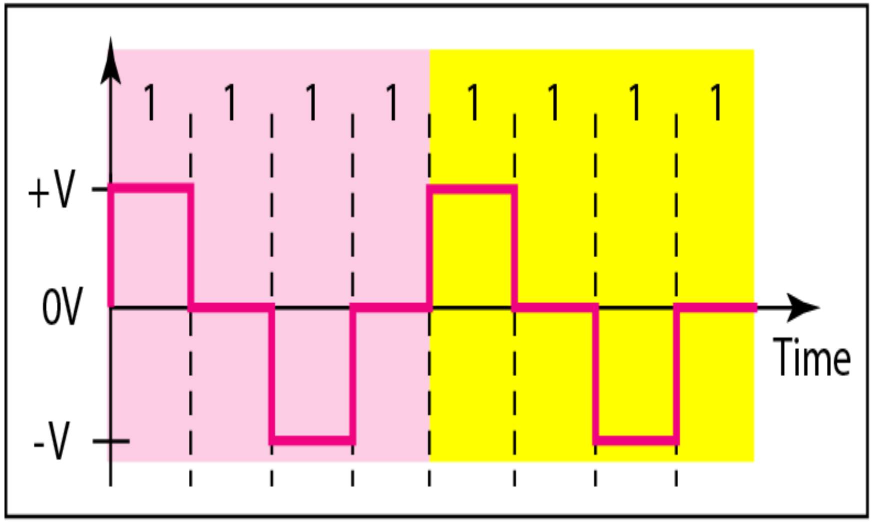
  1. If the next bit is 0, there is no transition.
  2. If the next bit is 1 and the current level is not 0, the next level is 0.
  3. If the next bit is 1 and the cutTent level is 0, the next level is the opposite of the last nonzero level.

- The behavior of MLT-3 can best be described by the state
- diagram

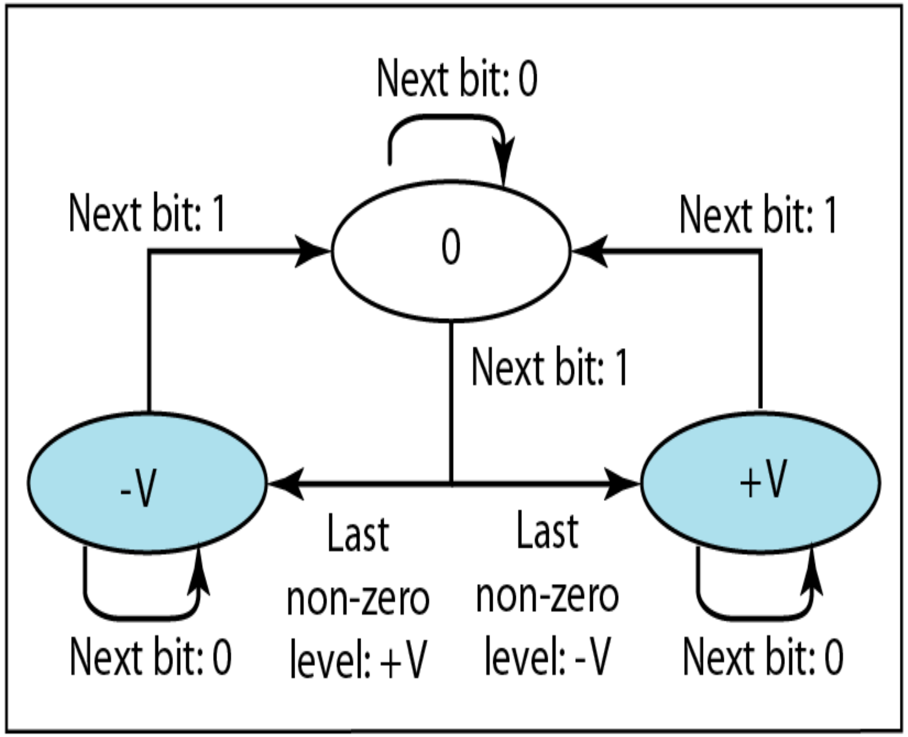
  MLT-3 a suitable choice when we need to send 100 Mbps on a copper wire



a. Typical case



b. Worse case



c. Transition states

Summary of Line Coding Schemes

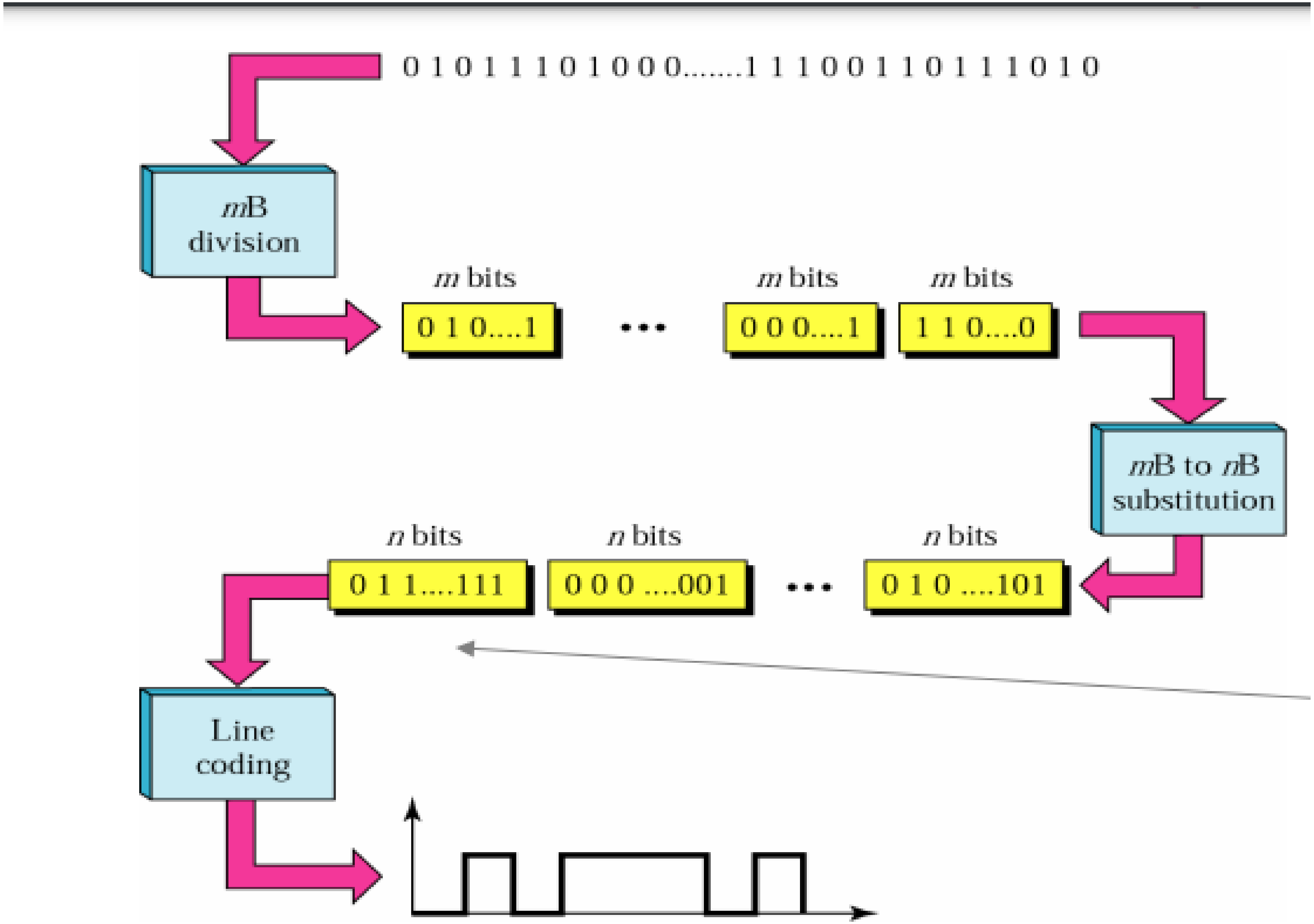
Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no 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

Block Coding

- We need redundancy to ensure synchronization and to provide some kind of inherent error detecting.
- 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.
- 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 concept

- 

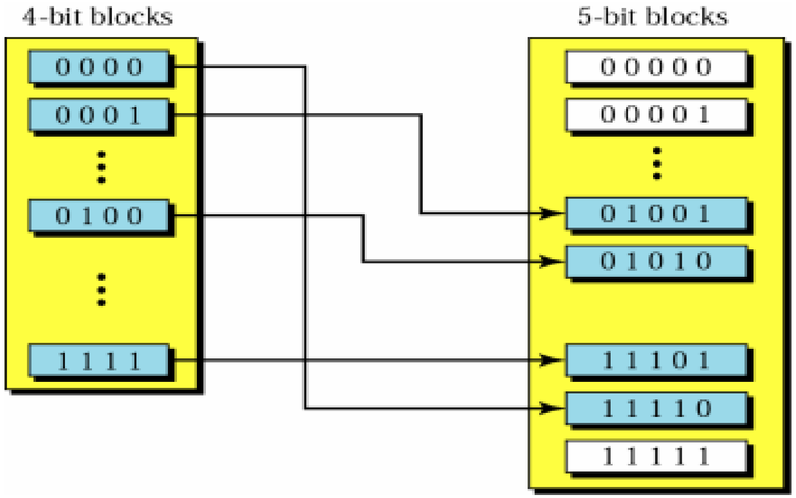
4B/5B

Every 4 bits of data is encoded into a 5-bit code.

The 5-bit codes are normally line coded using NRZ-invert (longer sequences of 1 are tolerated)!!!

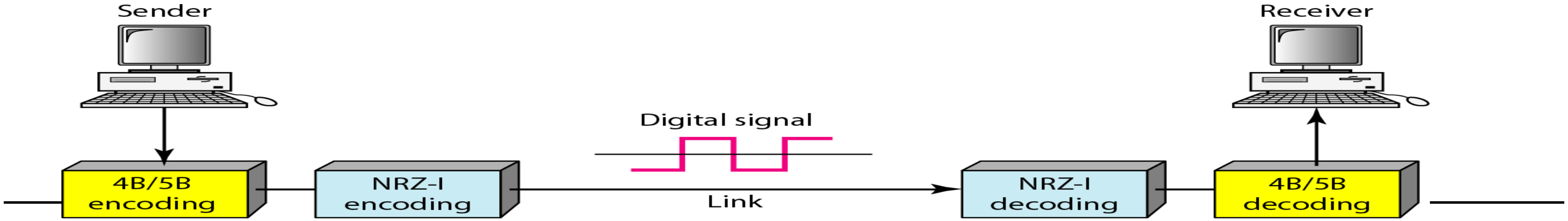
The selection of the 5-bit code is such that each code contains no more than one leading 0 and no more than two trailing 0s.

Therefore, when these 5-bit codes are sent in sequence, no more than three consecutive 0s are encountered.



Data	Code	Data	Code
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

4B/5B coding is used in the optical fiber transmission system (FDDI).

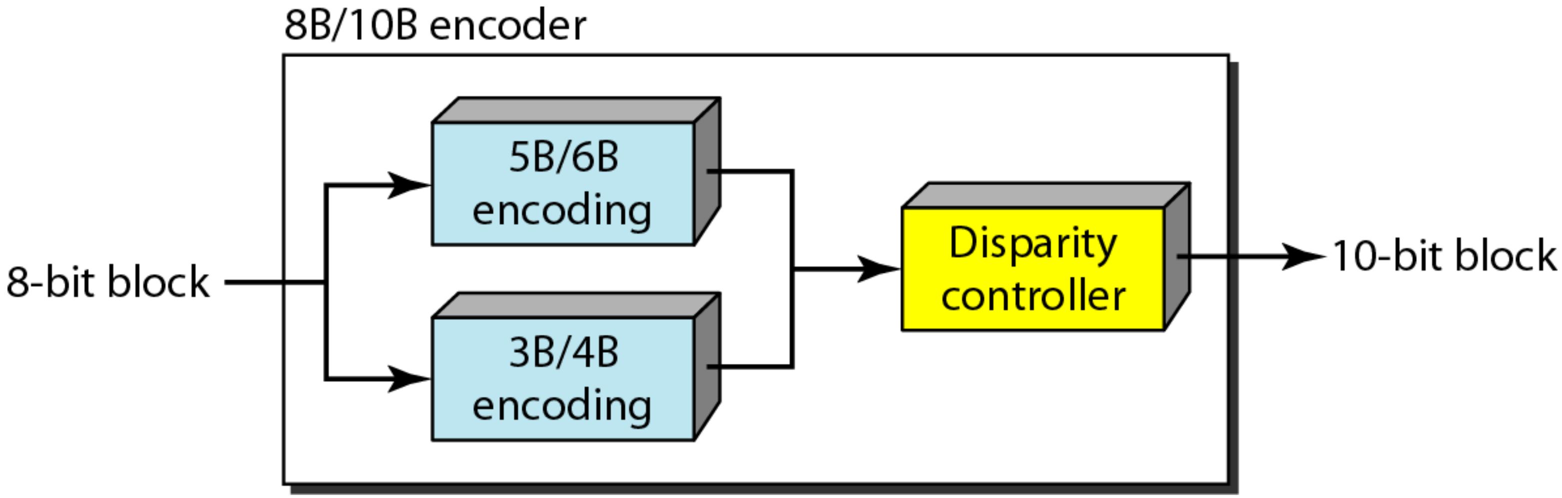


4B/5B Mapping Codes

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		

8B/10B

- The eight binary/ten binary (8B/10B) encoding is similar to 4B/5B encoding except that a group of 8 bits of data is now substituted by a 10-bit code.
- It provides greater error detection capability than 4B/5B.
- The 8B/10B block coding is actually a combination of 5B/6B and 3B/4B encoding



- In general, the technique is superior to 4B/5B because of better built-in error-checking capability and better synchronization.

Scrambling

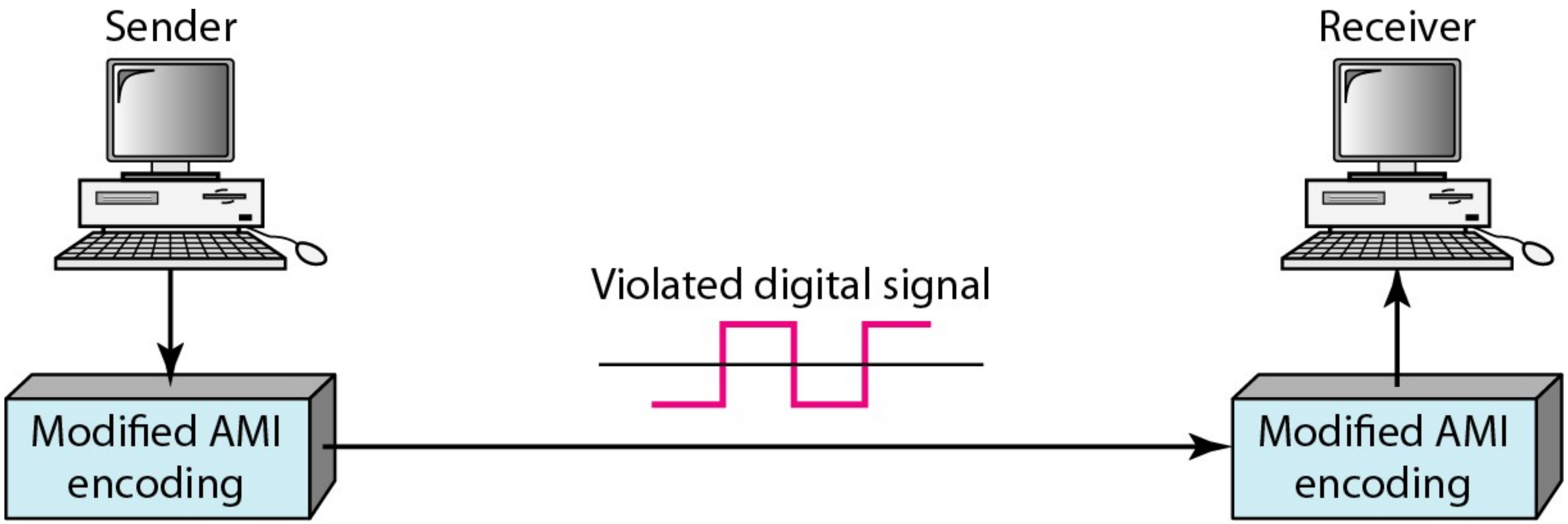
- Biphase schemes that are suitable for dedicated links between stations in a LAN are
- Not suitable for long-distance communication because of their wide bandwidth
- requirement.
- The combination of block coding and NRZ line coding is not suitable for long-distance encoding either, because of the DC component.
- Bipolar AMI encoding, on the other hand, has a narrow bandwidth and does not create a DC component.
- However, a long sequence of 0s upsets the synchronization.
- One solution is called scrambling. We modify part of the AMI rule to include scrambling.
- Note that scrambling, as opposed to block coding, is done at the same time as encoding. The system needs to insert the required pulses based on the defined scrambling rules.
- Two common scrambling techniques are **B8ZS** and **HDB3**.

Bipolar with 8-zero substitution (B8ZS)

- Bipolar with S-zero substitution (BSZS) is commonly used in North America. In this technique, eight consecutive zero-level voltages are replaced by the sequence 000VB0VB.

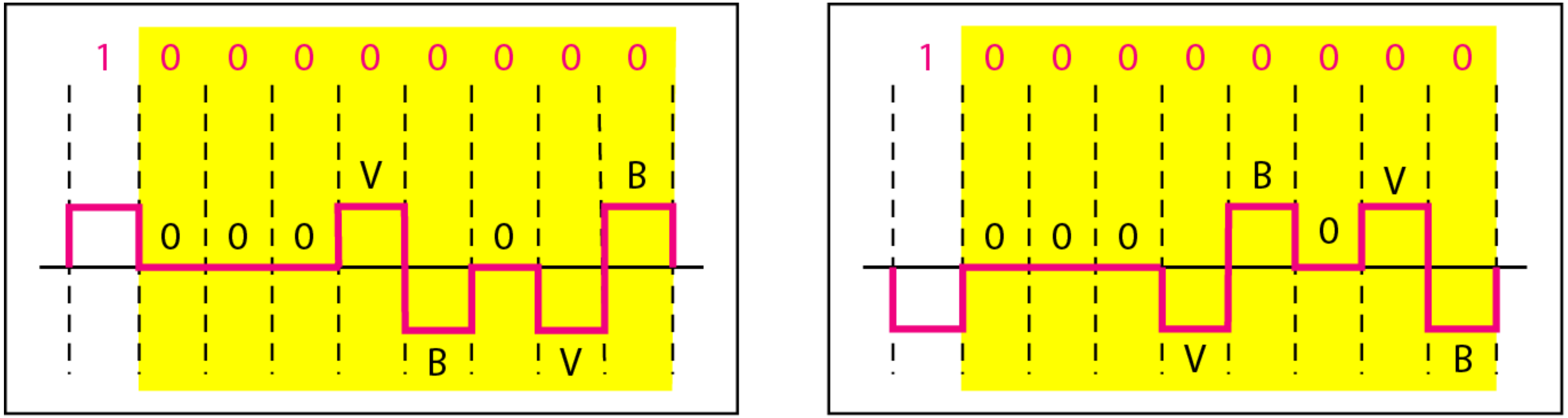
  The V in the sequence denotes violation; this is a nonzero voltage that breaks an AMI rule of encoding (opposite polarity from the previous).

  The B in the sequence denotes *bipolm*; which means a nonzero level voltage in accordance with the AMI rule.



B8ZS substitutes eight consecutive zeros with 000VB0VB.

- There are two cases, as shown in Figure



a. Previous level is positive.

b. Previous level is negative.

- One more point is worth mentioning. The letter V (violation) or B (bipolar) here is relative. The V means the same polarity as the polarity of the previous nonzero pulse; B means the polarity opposite to the polarity of the previous nonzero pulse.

High-density bipolar 3-zero (HDB3)

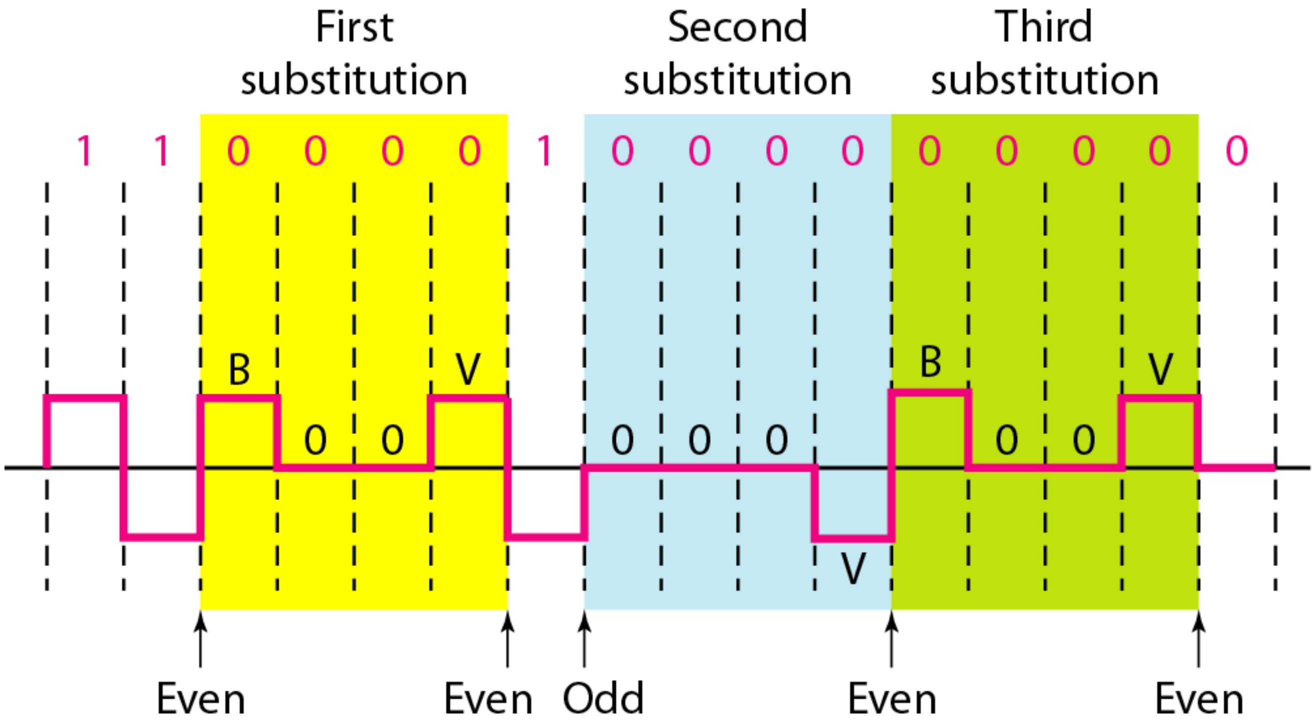
High-density bipolar 3-zero (HDB3) is commonly used outside of North America.

In this technique, which is more conservative than B8ZS, four consecutive zero-level voltages are replaced with a sequence of 000V or B00V.

The reason for two different substitutions is to maintain the even number of nonzero pulses after each substitution.

The two rules can be stated as follows:

1. If the number of nonzero pulses after the last substitution is odd, the substitution pattern will be 000V, which makes the total number of nonzero pulses even.
2. If the number of nonzero pulses after the last substitution is even, the substitution pattern will be B00V, which makes the total number of nonzero pulses even.



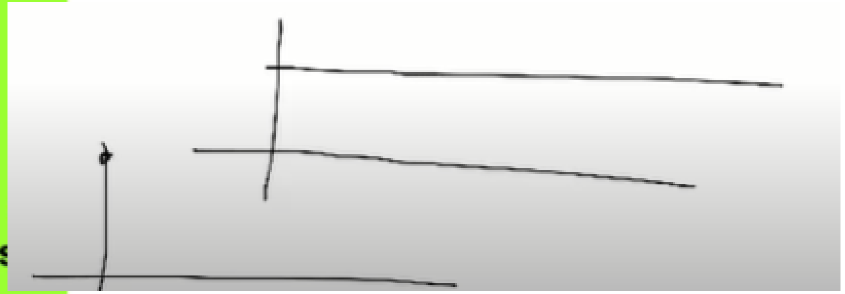
- There are several points we need to mention here. First, before the first substitution, the number of nonzero pulses is even, so the first substitution is B00V. After this substitution, the polarity of the 1 bit is changed because the AMI scheme, after each substitution, must follow its own rule. After this bit, we need another substitution, which is 000V because we have only one nonzero pulse (odd) after the last substitution. The third substitution is B00V because there are no nonzero pulses after the second substitution (even).

If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

In digital signal ,the signal changes from 0 to 1 immediately

In networking, we use the term bandwidth in two contexts.

- **The first, bandwidth in hertz, refers the range of frequencies in composite signal or the range frequencies that a channel can pas**



- **The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link.**