lecture 2 Physical Layer

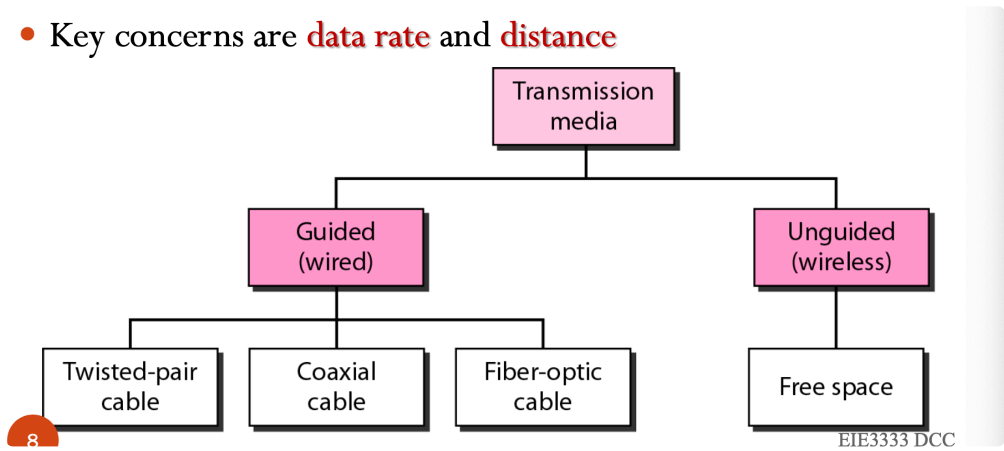
objectives

- different physical transmission medium and the impairments during transmission
- design factors when choosing an appropriate transmission medium
- estimate the maximum possible data rate
- different line coding techniques

Data Transmission

- Source Data
  - Digital data: discrete
  - Analog data: continuous
- Transmitted Signal:
  - Digital signal: sequence of voltage pulse transmitted over a medium
  - Analog signal: continuously varying electromagnetic wave
- four combination

Transmission Media



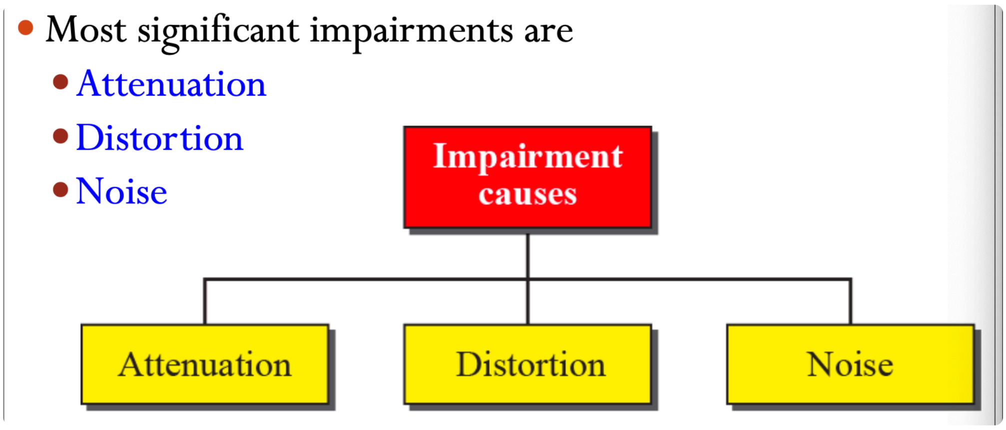
Design factors

- Bandwidth
  - gives higher data rate

- Transmission impairments
    - attenuation
- interference
- number of receivers

Transmission Impairments

- Analog - degradation of signal quality
- Digital - bit errors



Loss, Interference, and Electrical Noise

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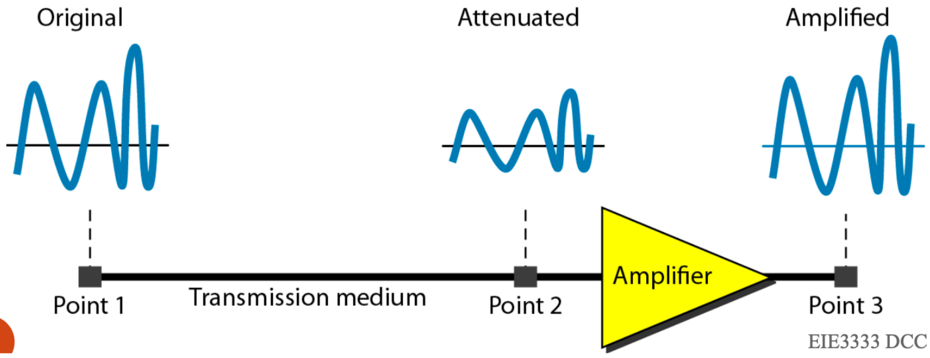
Transmission Impairments - Attenuation 衰减

- Attenuation means a loss of energy where signal strength falls off with distance
- Depends on medium
- Mainly resistance loss
- Received signal strength must be:
    - Strong enough to be detected
    - Sufficiently higher than noise to receive without error
    - Attenuation varies with frequency
- solution

- For the first and second problems, increase strength using amplifiers/repeaters
- For the third problem, equalize attenuation across a band of frequencies



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EIE3333 DCC

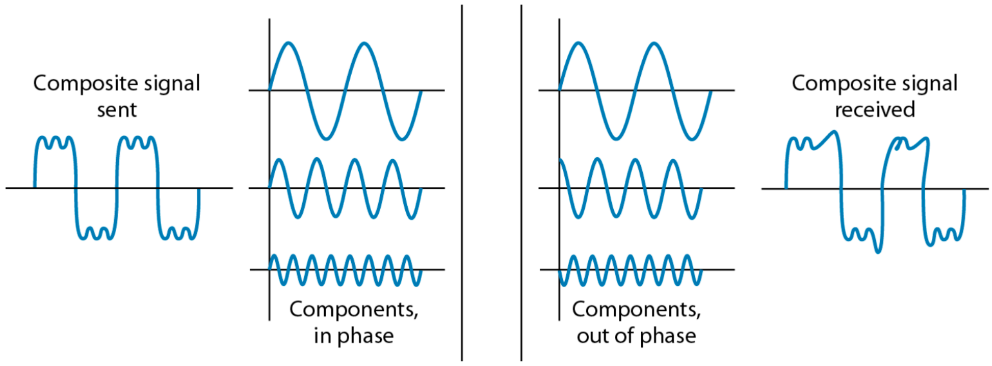
How to calculate the attenuation

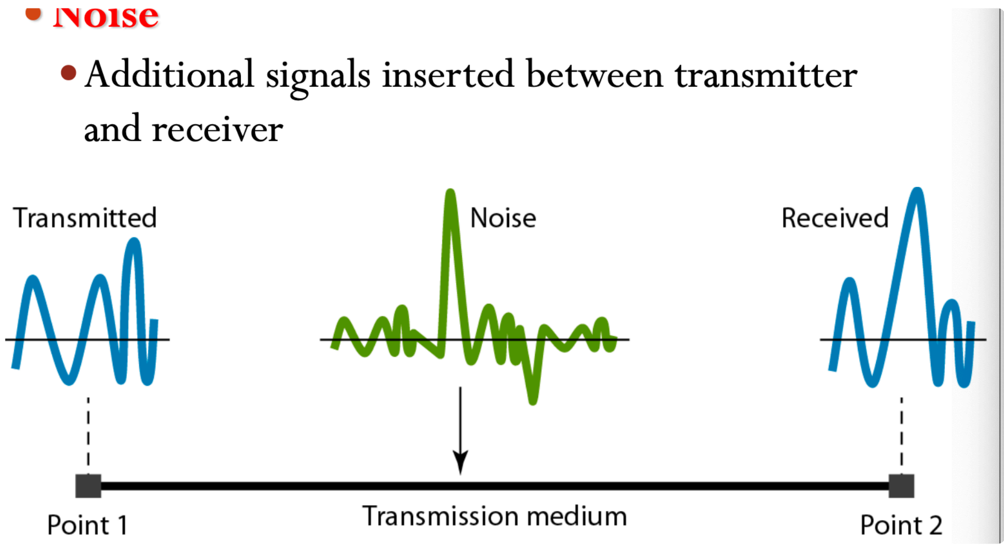
Suppose a signal travels through a transmission medium and its power is reduced to one half. This means that $P_2 = 0.5P_1$. In this case, the attenuation (loss of power) can be calculated as

$$\boxed{10 \log_{10} P_2/P_1 = 10 \log_{10} (0.5\, P_1)/P_1 = 10 \log_{10} 0.5 = 10 \times (-0.3) = -3 \text{ dB.}}$$

A loss of 3 dB (-3 dB) is equivalent to losing one-half of the power.

Transmission Impairments - Delay distortion 延迟失真 & Noise





Channel capacity

- Channel capacity = Maximum possible data rate on communications channel without error
- Channel capacity depends on three factors:
  - The bandwidth available
  - The level of the signals we use
  - The quality of the channel (the level of noise)

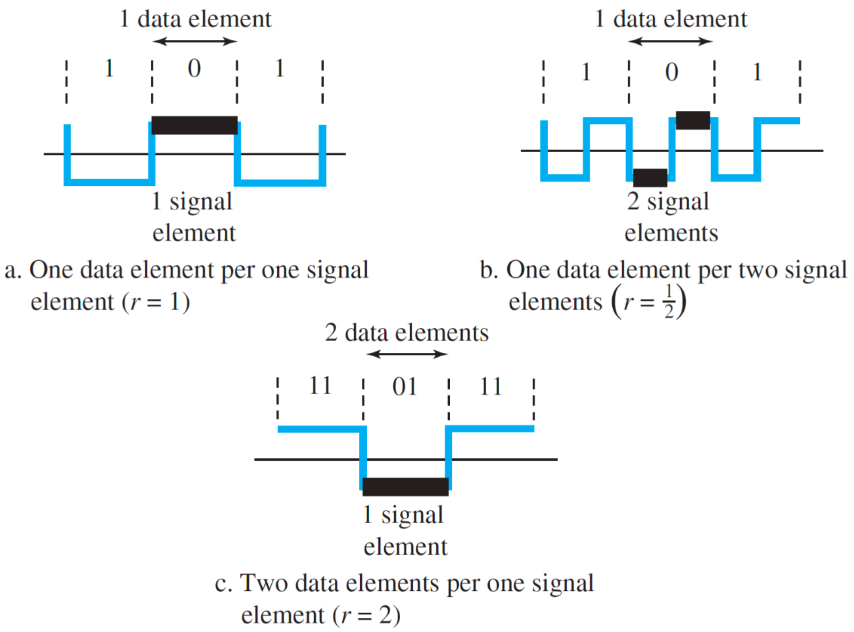
Bandwidth

Bandwidth in hertz (Hz), or cycles per second, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass

Signal Element versus Data Element

- A data element: this is the bit.
- the shortest unit (timewise) of a digital signal.

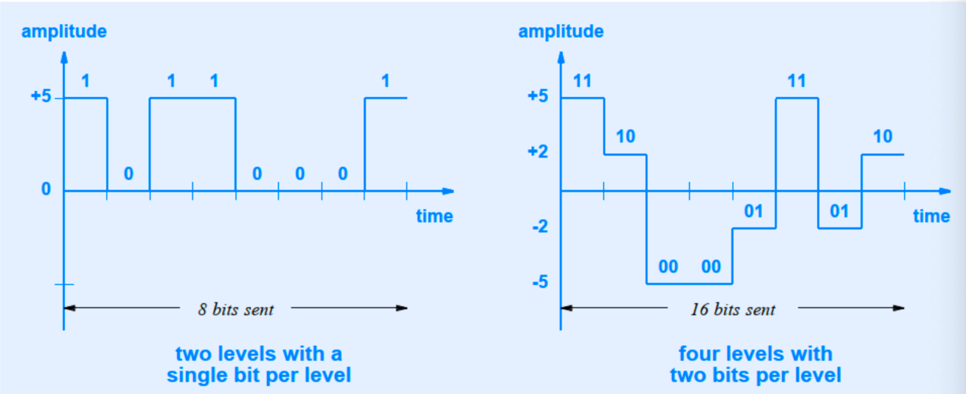
- a signal element carries data elements
- In other words, data elements are what we need to send; signal elements are what we can send
- define a ratio r



Data Rate Versus Signal Rate

- The signal rate is 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

- A digital signal level can represent multiple bits, says 2 bits
- In this case, bit rate = 2 × baud rate



Noiseless Channel - Nyquist Bandwidth

- Nyquist showed that maximum signaling rate is equal to 2 × bandwidth without inter-symbol interference.
- The Nyquist bit rate is given by

$$C = 2B \log_2 L \text{ bps}$$

where C = bit rate in bps
B = bandwidth in Hz
L = no. of levels per signaling element

Noisy Channel - Shannon Capacity Formula

$$C = B \log_2(1 + S/N) \text{ bps}$$

where C = information rate in bps
B = bandwidth in Hz
S/N = signal to noise ratio

$$= \frac{\text{Signal Power}}{\text{Noise Power}}$$

The signal-to-noise ratio is often given in decibels. Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Line Coding Schemes

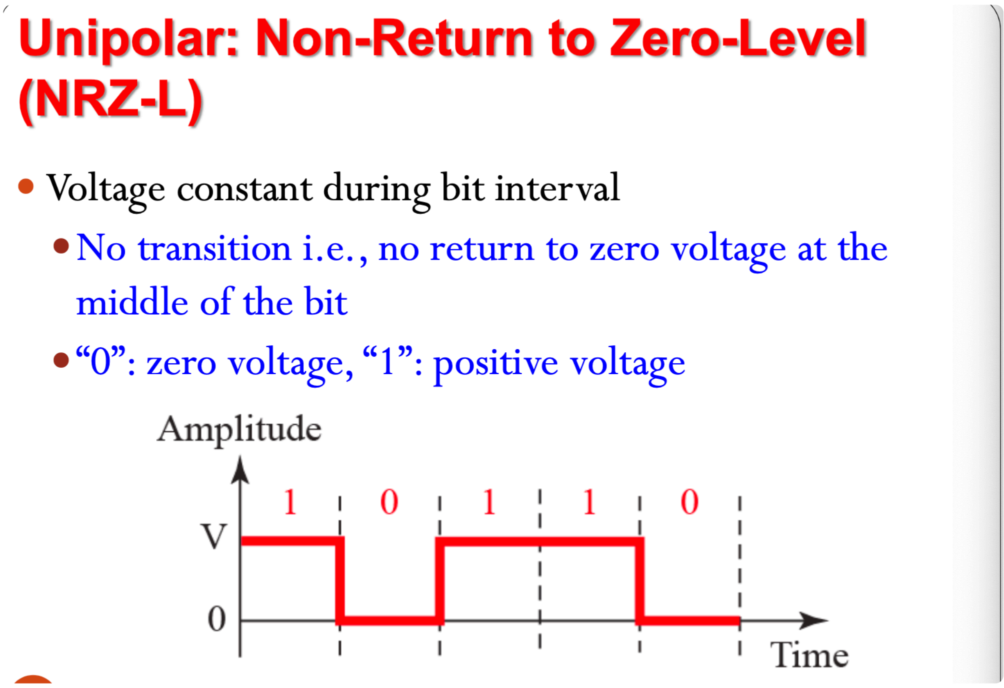
Requirements

- Small transmission bandwidth
- Power efficiency: as small as possible for required data rate and error probability
- Error detection/correction
- No DC component
- Timing information: clock can be extracted from data

A self-synchronizing digital signal:

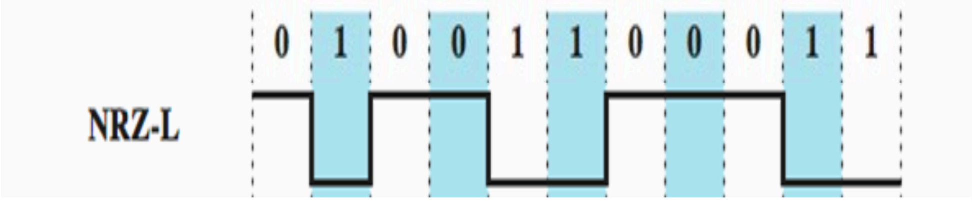
- A self-synchronizing digital signal includes timing information in the data being transmitted.
- there are transitions in the signal that alert the receiver to the beginning, middle, or end of the pulse.

Unipolar: Non-Return to Zero-Level (NRZ-L)



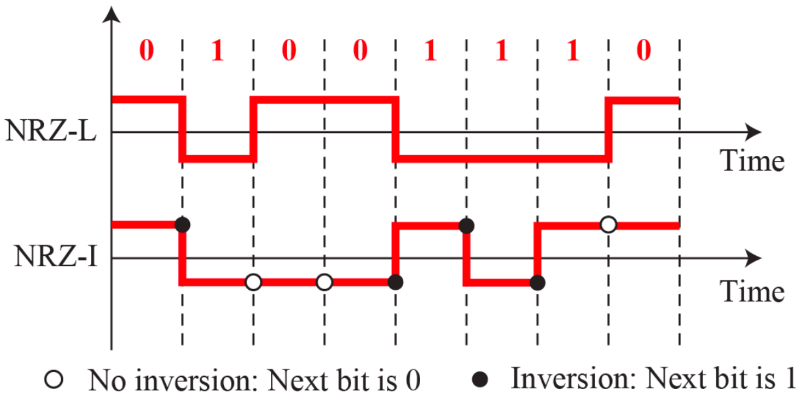
Polar: Non-Return to Zero-Level (NRZ-L)

- In polar schemes, the voltages are on both sides of the time axis (+Ve and –Ve)
- Two different voltages for 0 and 1 bits
- Voltage constant during bit interval
  - No transition i.e., no return to zero voltage
  - "0": positive voltage, "1": negative voltage



Polar: Non-Return to Zero, Inverted (NRZI)

- Non return to zero inverted on ones
- Constant voltage pulse for duration of bit
- Data encoded as presence or absence of signal transition at beginning of bit time
  - Transition denotes binary 1
  - Transition: low to high or high to low
  - No transition denotes binary 0
    - It is an example of differential encoding
      - Data represented by changes rather than levels
      - More reliable detection of transition rather than level
      - Easy to lose sense of polarity

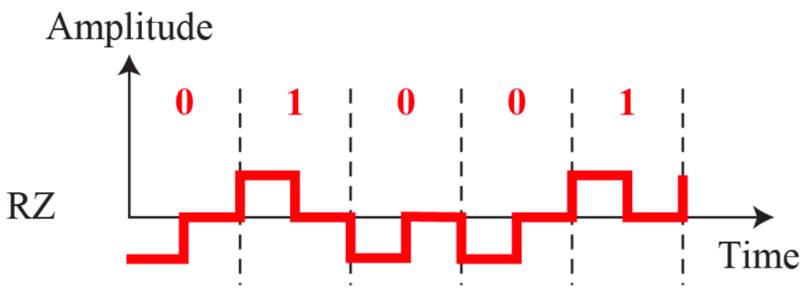


NRZ Pros & Cons

- Pros
  - Easy to engineer
  - Make good use of bandwidth
- Cons
  - DC component
  - Lack of synchronization capability
- Used for magnetic recording
- Not often used for signal transmission

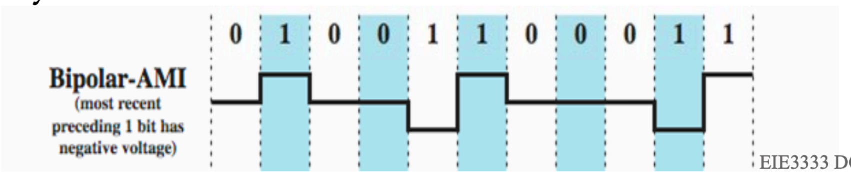
Polar: Return to Zero (RZ)

- In RZ, the signal changes not between bits but during the bit.
- The signal returns to zero in the middle of the bits.
- No DC component if numbers of "1" and "0" are the same



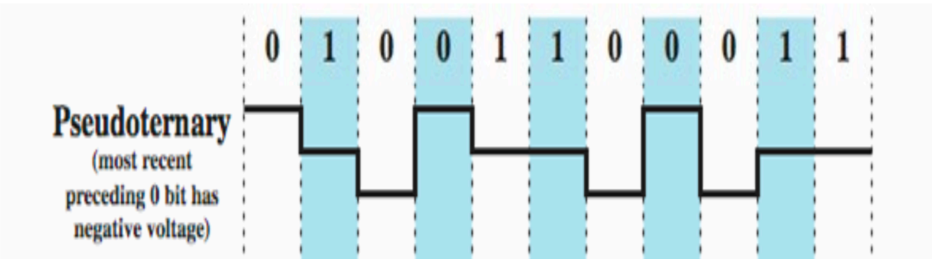
Bipolar - Alternate Mark Inversion (Bipolar-AMI) 双相交替标记反转

- Bipolar-AMI
  - Zero represented by no line signal
  - One represented by positive or negative pulse
  - One pulses alternate in polarity
- No loss of sync if a long string of ones (zeros still a problem)
- No net DC component
- Lower bandwidth
- Easy error detection



Pseudoternary

- One represented by absence of line signal
- Zero represented by alternating positive and negative
- Very similar to bipolar-AMI
- Each used in some applications



Bipolar Issues

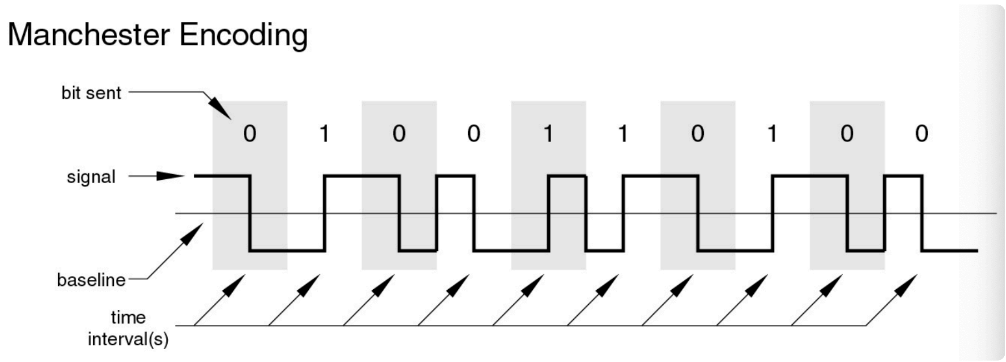
- Synchronization with long runs of 0's or 1's
- Not as efficient as NRZ
  - Each signal element only represents one bit
    - Receiver distinguishes between three levels: +A, -A, 0
  - A 3 level system could represent $\log_2 3 = 1.58$ bits
  - Requires approx. 3dB more signal power for same probability of bit error

Line Coding Schemes - Biphase Techniques

- Manchester encoding
- Differential Manchester encoding

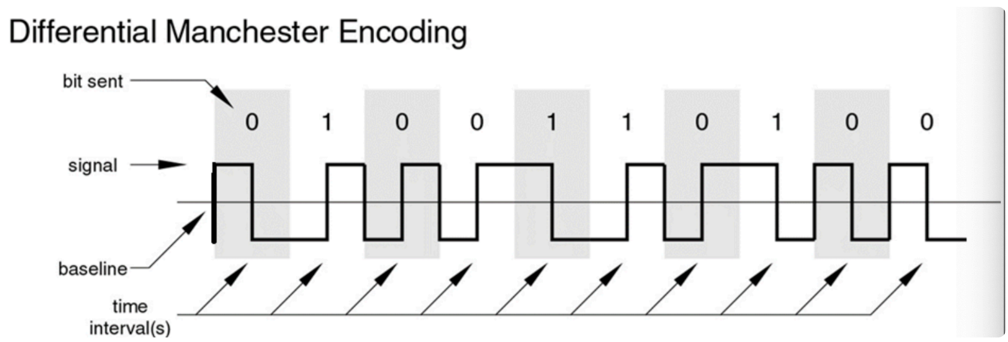
Manchester Encoding

- Has transition in middle of each bit period
- Transition serves as clock and data
- Low to high represents one
- High to low represents zero



Differential Manchester Encoding

- Midbit transition is clocking only
- Transition at start of bit period representing 0
- No transition at start of bit period representing 1
  - This is a differential encoding scheme



Biphase Pros and Cons

- 最大调制速率（modulation rate）是 NRZ 的两倍

- 在 NRZ 编码中，每个比特只需要一个符号（symbol），而 Biphase 需要两个符号，因此其调制速率是 NRZ 的两倍。

- Con
  - at least one transition per bit time and possibly two
  - maximum modulation rate is twice NRZ
  - requires more bandwidth
- Pros
  - synchronization on mid bit transition (self clocking)
  - has no DC component
  - has error detection (The absence of an expected transition can be used to detect errors)

Line Coding Schemes - 2B1Q & MLT-3

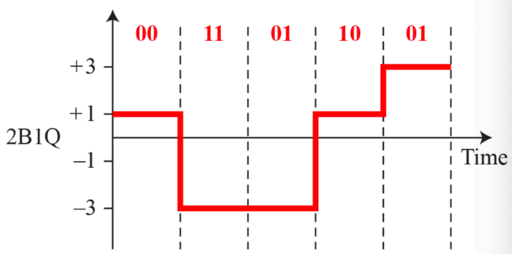
Multilevel: 2B1Q

Multilevel: 2B1Q

- Two binary, one quaternary (2B1Q)
- It uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal.
- 2B1Q is used in DSL (Digital Subscriber Line).

	Previous level: positive	Previous level: negative
Next bits	Next level	Next level
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

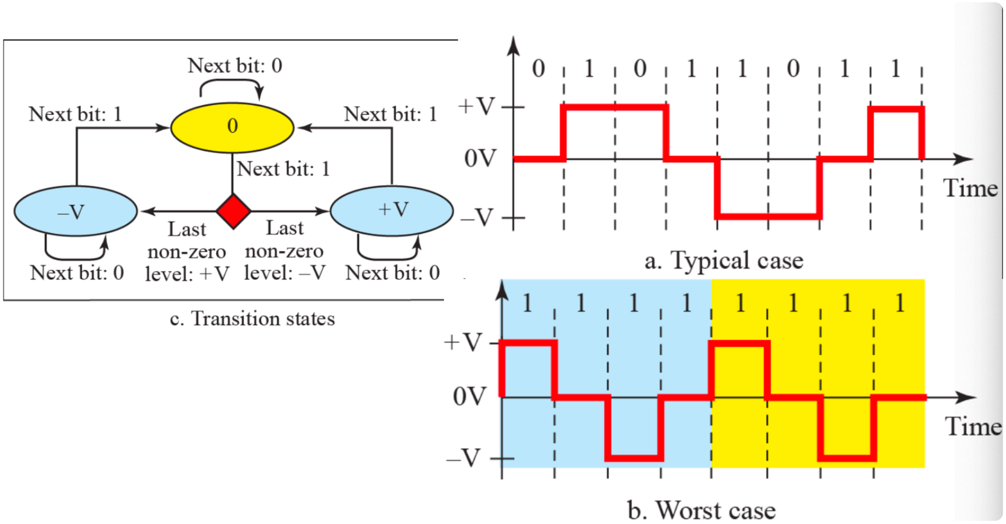
Transition table



Assuming positive original level

Multitransition: MLT-3

- Multiline transmission, three-level (MLT-3).
- It uses three levels (+V, 0 , -V) and three transition rules to move between 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 non-zero level.



Line Coding Schemes - Scrambling 扰码

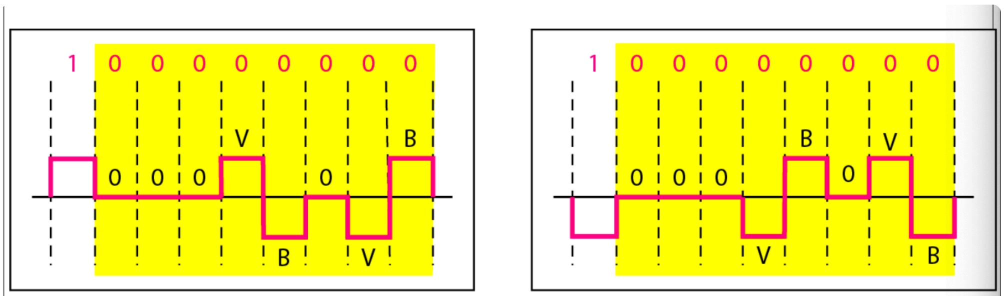
Scrambling

- Use scrambling to replace sequences that would produce constant voltage
- These filling sequences must
  - Produce enough transitions for synchronization
  - Be recognized by receiver & replaced with the original sequence
  - Be the same length as the original

Bipolar with 8-zeros Substitution (B8ZS)

- If an octet of all zeros occurs and the last voltage pulse preceding this octet was positive, then the eight zeros of the octets are encoded as 000+−0−+

- If an octet of all zeros occurs and the last voltage pulse preceding this octet was negative, then the eight zeros of the octets are encoded as 000−+0+−



a. Previous level is positive.

b. Previous level is negative.

High-density Bipolar-3 Zeros (HDB3)

- HDB3 substitutes four consecutive zeros with 000V or B00V depending on the number of nonzero pulses after the last substitution (commonly used outside of North America)
  - Even: B00V
  - Odd: 000V