Signal Encoding Techniques

Line Coding Characteristics

- **Line Coding**: (process of converting digital data to digita l signals)
- Signal Element Versus Data Element
- Data Rate Versus Signal Rate
- the relationship between data rate and signal rate as

$$S = c \; x N x \; \frac{1}{r} \qquad \text{baud}$$

- where N is the data rate (bps); c is the case factor, which varies for each case; S is the number of signal elements; a nd r is the previously defined factor.
- Minimum bandwidth: $B_{min} = c \times N \times \frac{1}{r}$
- Maximum data rate: $N_{max} = \frac{1}{c} \, x B x r$

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?

We assume that the average value of c is $\frac{1}{2}$. The baud rate is then

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

The maximum data rate of a channel (see Chapter 3) is $N_{max} = 2 \times B \times \log2L$ (defined by the Nyquist formula). Does this agree with the previous formula for N_{max}?

A signal with L levels actually can carry log2 L bits per level. If each level corresponds to one signal element and we assume the average case ($c = \frac{1}{2}$), then we have

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

Introduction

- A distinction was made between analog and digital data and analog and digital signals in chap.3
- Either form of data could be encoded into either form of signal.
- **A data source g(t), which may be either digital or analog, is** encoded into a digital signal *x(t)*.
- The actual form of x(t) depends on the encoding technique and is chosen to optimize use of the transmi -ssion medium.
- For example, the encoding may be chosen to conserve bandwidth or to minimize errors.

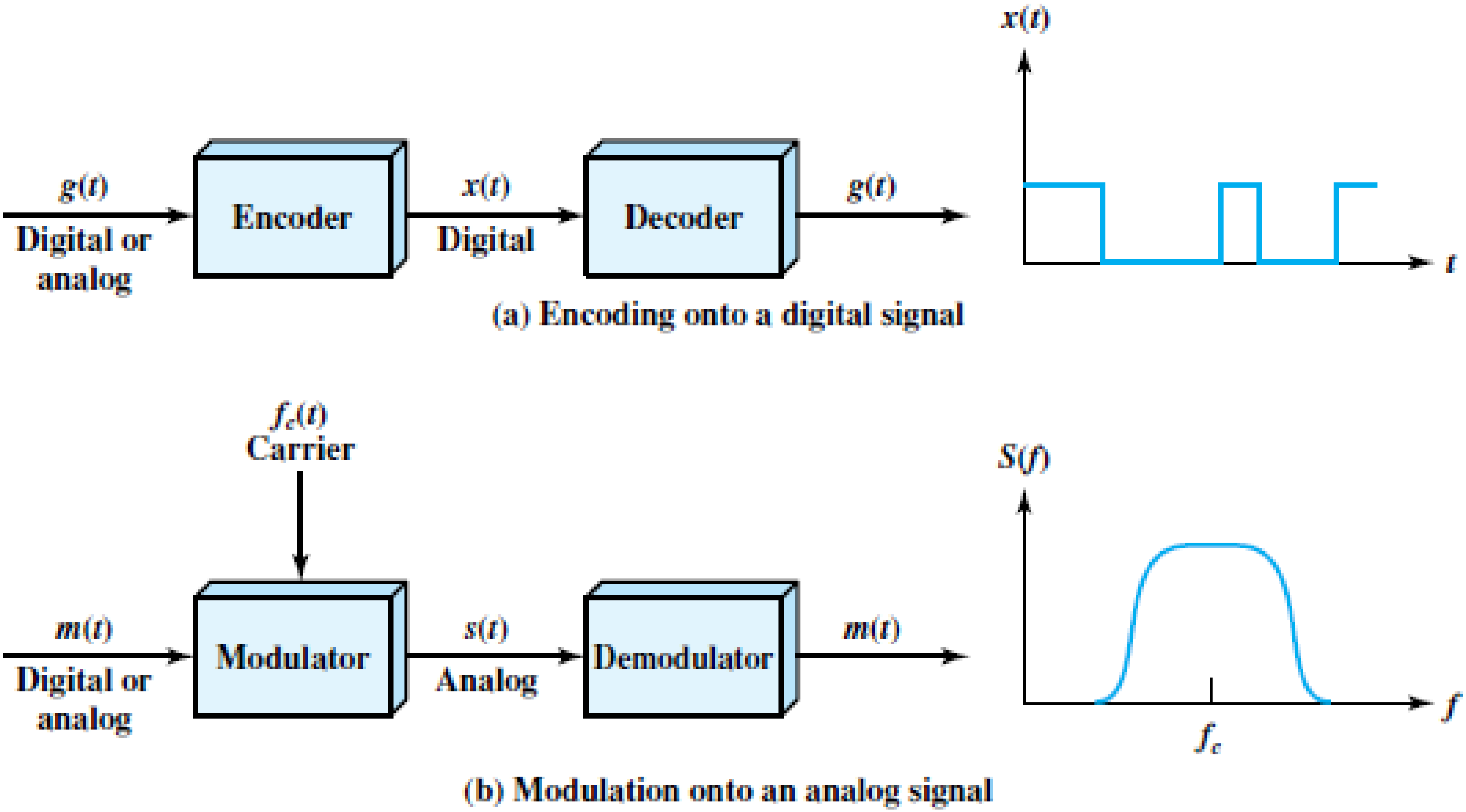


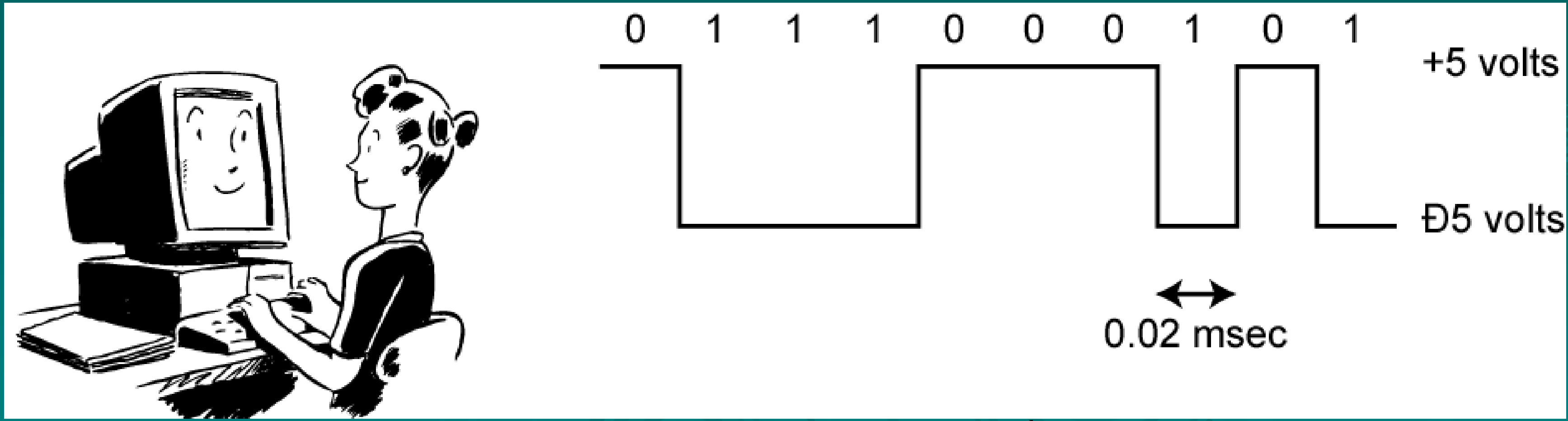
Figure 5.1 Encoding and Modulation Techniques

Introduction ….

- All modulation techniques involve operation on one or m ore of the three fundamental frequency domain parame- ters: amplitude, frequency, and phase.
- ♦ **Digital data, digital signals:** simplest form of digital encoding of digital data
- ♦ **Digital data, analog signal:** A modem converts digital data to an a nalog signal so that it can be transmitted over an analog line.
- ♦ **Analog data, digital signals:** Analog data, such as voice and video , are often digitized to be able to use digital transmission facilities
- ♦ **Analog data, analog signals:** Analog data are modulated by a carri er frequency to produce an analog signal in a different frequency ba nd, which can be utilized on an analog transmission system

Digital Data, Digital Signal

- Digital signal
  - discrete, discontinuous voltage pulses
  - each pulse is a signal element
  - binary data encoded into signal elements



Some Terms

- unipolar
- polar
- data rate
- duration or length of a bit
- modulation rate
- mark and space

Interpreting Signals

- need to know
  - timing of bits - when they start and end
  - signal levels
- factors affecting signal interpretation
  - signal to noise ratio
  - data rate
  - bandwidth
  - encoding scheme

Comparison of Encoding Schemes

- signal spectrum
- clocking
- error detection
- signal interference and noise immunity
- cost and complexity

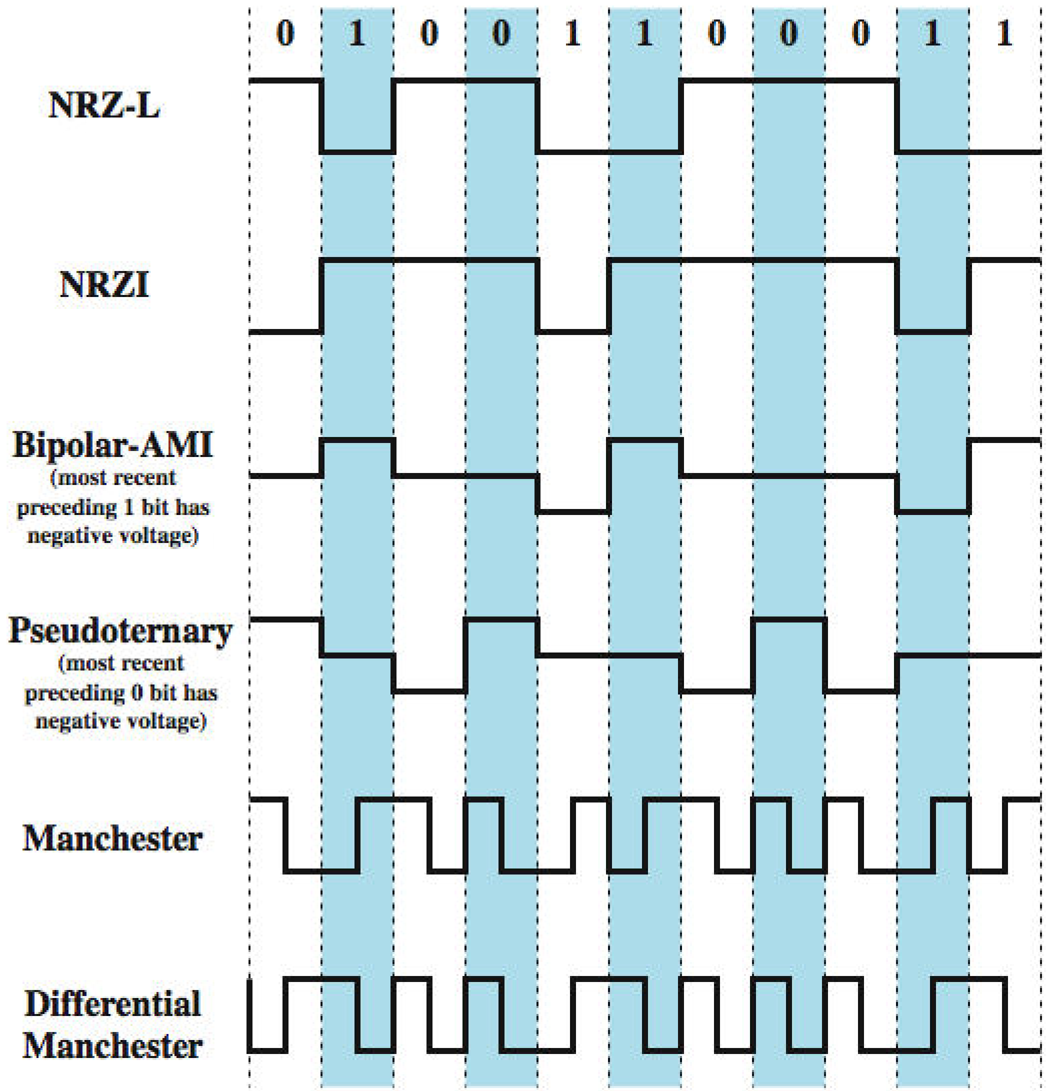
Comparison (1)

- Signal Spectrum
  - Lack of high frequencies reduces required bandwidth
  - Concentrate power in the middle of the bandwidth
- Clocking
  - Synchronizing transmitter and receiver
  - External clock
  - Sync mechanism based on signal

Comparison (2)

- Error detection
  - Can be built in to signal encoding
- Signal interference and noise immunity
  - Some codes are better than others
- Cost and complexity
  - Higher signal rate (& thus data rate) lead to higher costs
  - Some codes require signal rate greater than data rate

Encoding Schemes



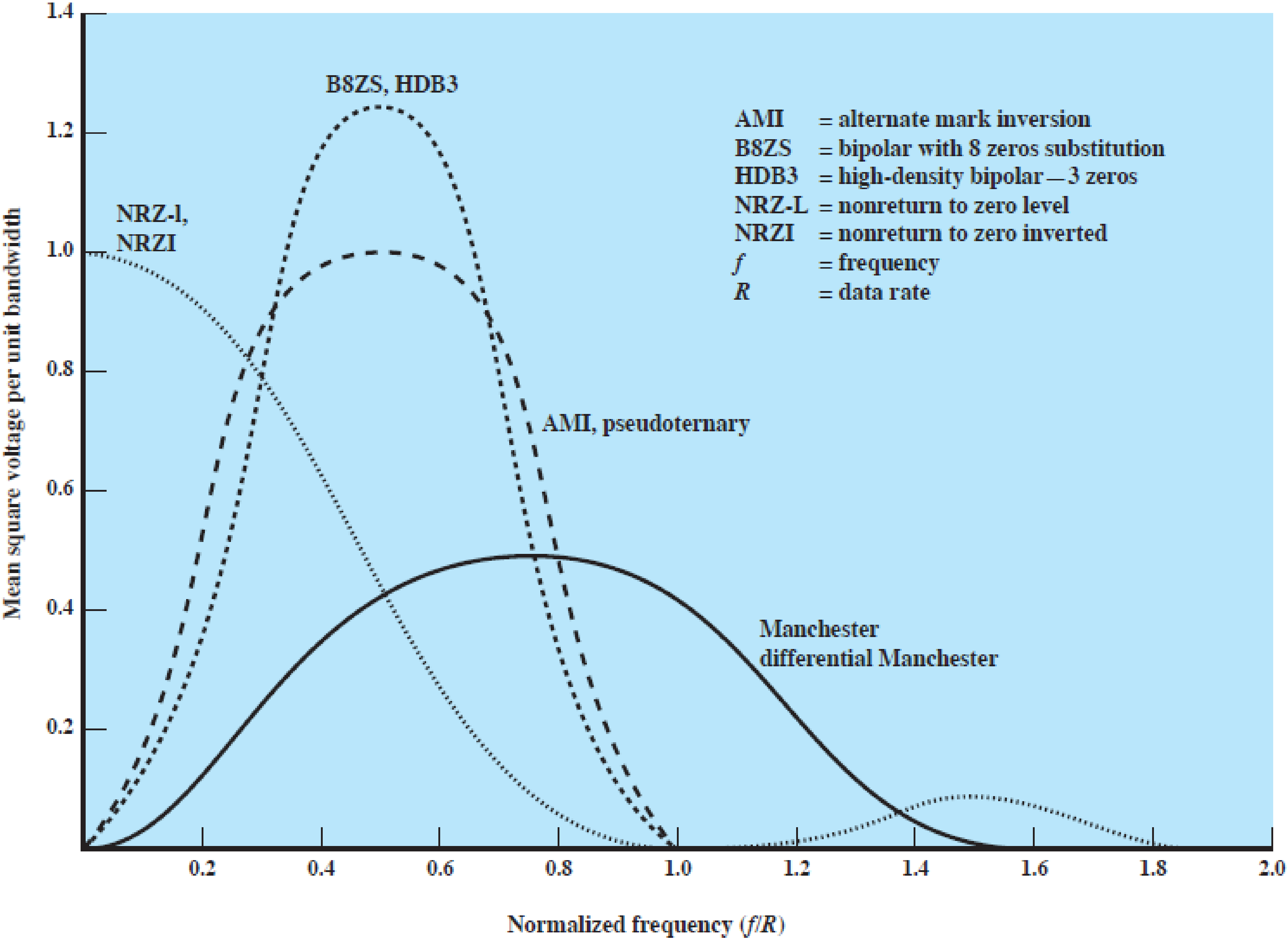
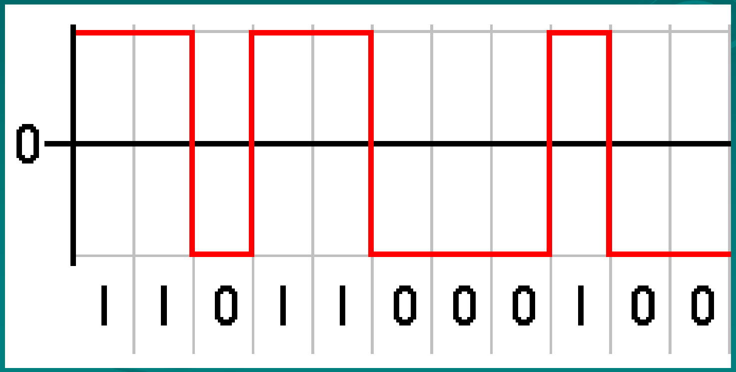


Figure 5.3 Spectral Density of Various Signal Encoding Schemes

Nonreturn to Zero-Level (NRZ-L)

- two different voltages for 0 and 1 bits
- voltage constant during bit interval
  - no transition I.e. no return to zero voltage
  - such as absence of voltage for zero, constant positive voltage for one
  - more often, negative voltage for one value and positive for the other



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.

Nonreturn to Zero Inverted

- nonreturn 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 (low to high or high to low) denotes binary 1
  - no transition denotes binary 0
- example of differential encoding since have
  - 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

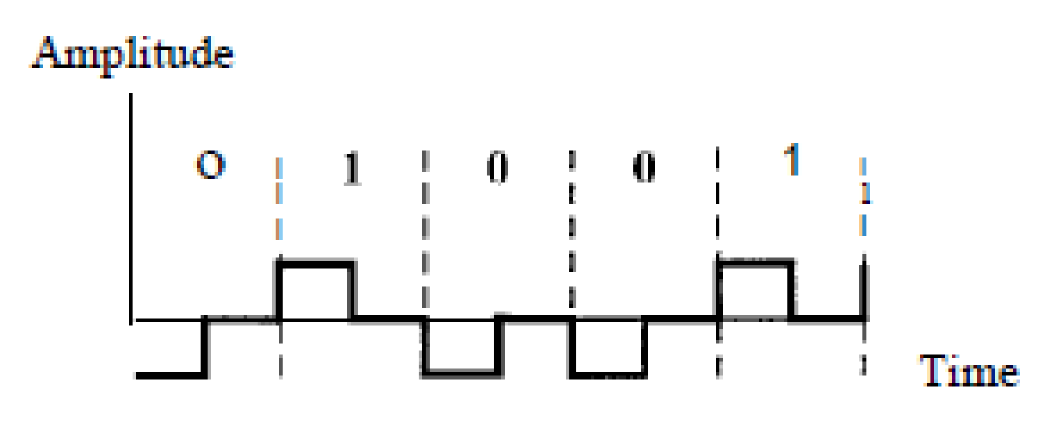
Return to Zero (RZ)

- The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized.
- The receiver does not know when one bit has ended and the next bit is starting.

One solution is the return-to-zero (RZ) scheme, which uses three values: positive, negative, and zero.

- In RZ, the signal changes not between bits but during the 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



Multilevel Binary - Bipolar-AMI

- Use more than two levels
- Bipolar-AMI
- In the term *alternate mark inversion,* the word *mark* comes from telegraphy and means 1
  - zero represented by no line signal
  - one represented by positive or negative pulse
  - Binary one pulses alternate in polarity
  - no loss of sync if a long string of ones
  - long runs of zeros still a problem
  - no net dc component
  - lower bandwidth
  - easy error detection

Multilevel Binary Pseudoternary

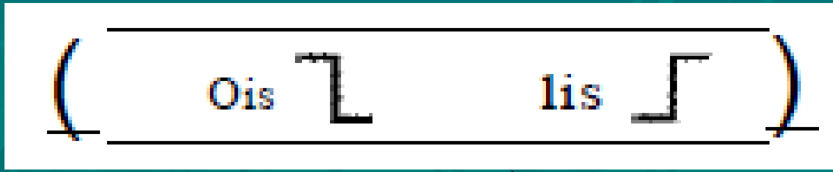
- one represented by absence of line signal
- zero represented by alternating positive and negative
- no advantage or disadvantage over bipolar-AMI
- each used in some applications

Multilevel Binary Issues

- synchronization with long runs of 0's or 1's
  - can insert additional bits, cf ISDN
  - scramble data (later)
- not as efficient as NRZ
  - each signal element only represents one bit
    - receiver distinguishes between 3 levels: +A, -A, 0
  - 3 level system could represent $\log_2 3 = 1.58$ bits
  - requires approx. 3dB more signal power for same probability of bit error

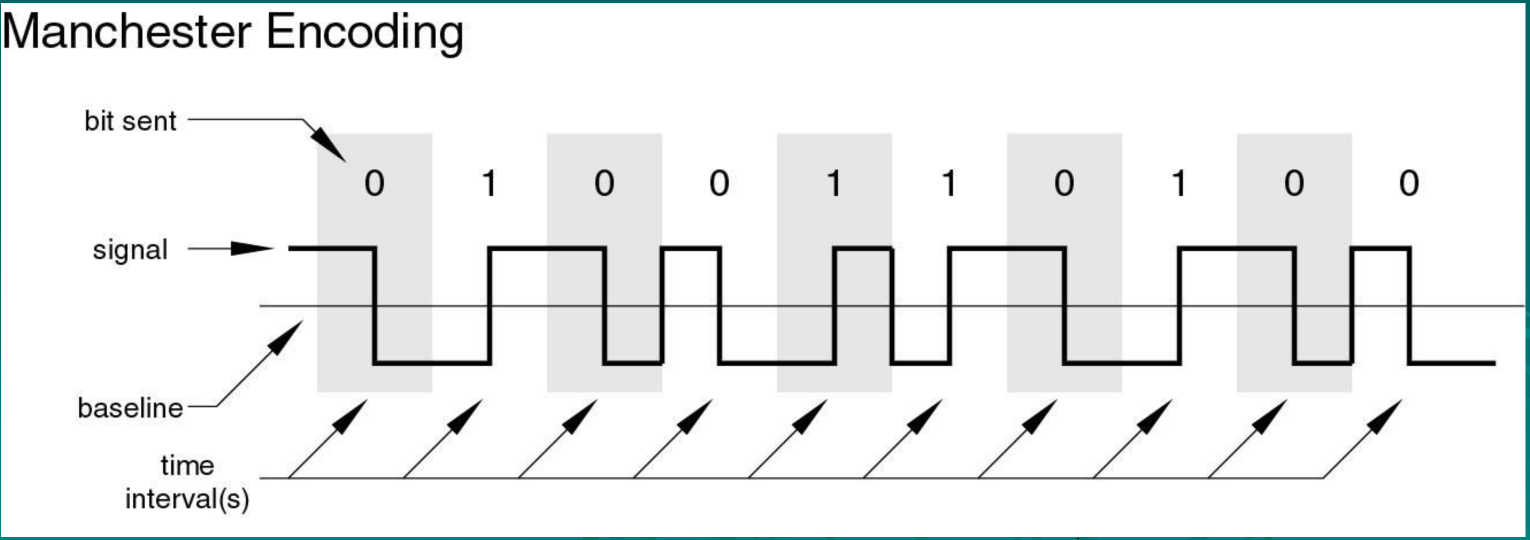
Manchester Encoding

- RZ and NRZ-L are combined into the Manchester scheme
- 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
- Signal does not stop at zero but continues to the other level.



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
- used by IEEE 802.3

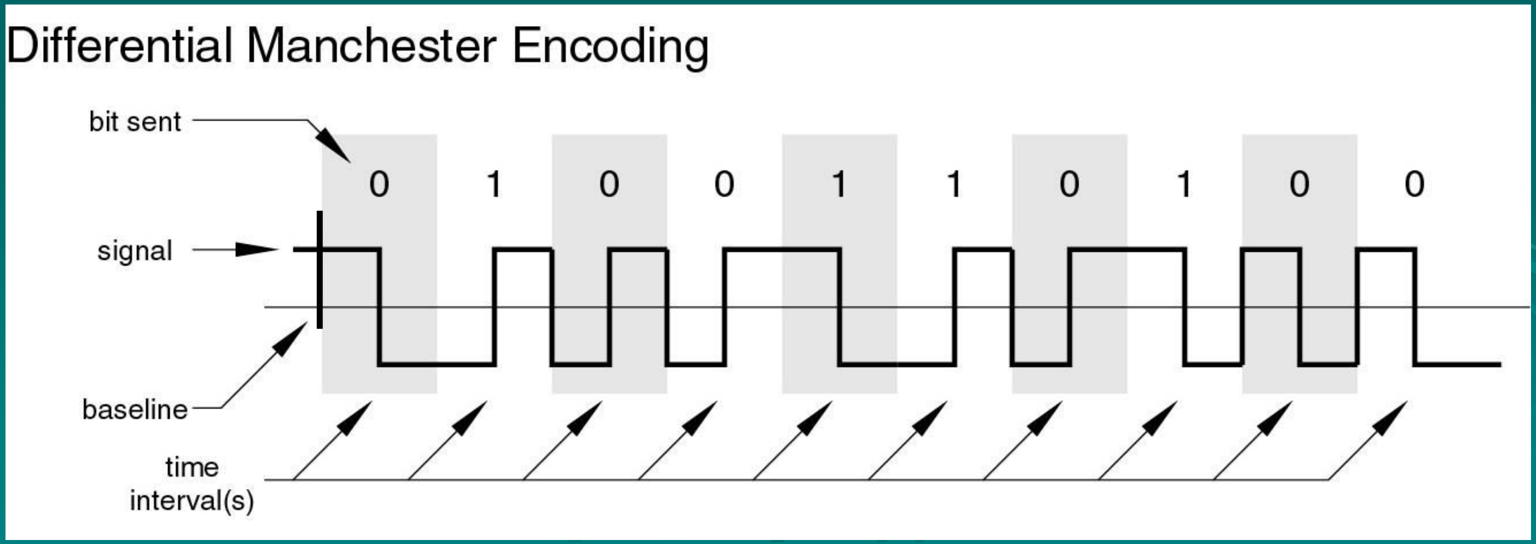


Differential Manchester Encoding

- 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.

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
- used by IEEE 802.5
- Inversion of the middle of the bit is used for syn.



Biphase Pros and Cons

- 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

Modulation Rate