Data Communications and Networking

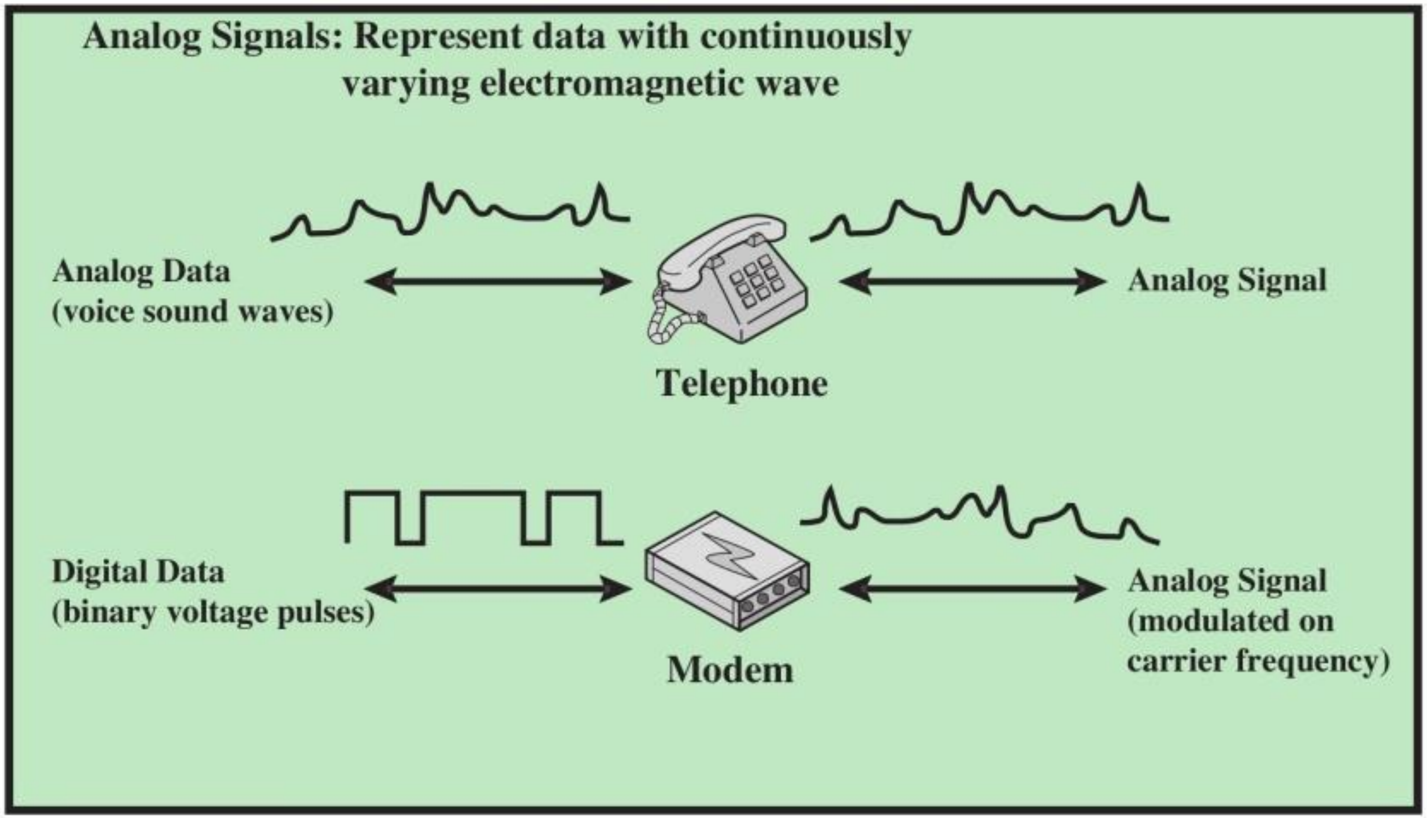
Chapter 5
Signal Encoding Techniques:Part1

References:
Book Chapter 5
Data and Computer Communications, 8th edition, by William Stallings

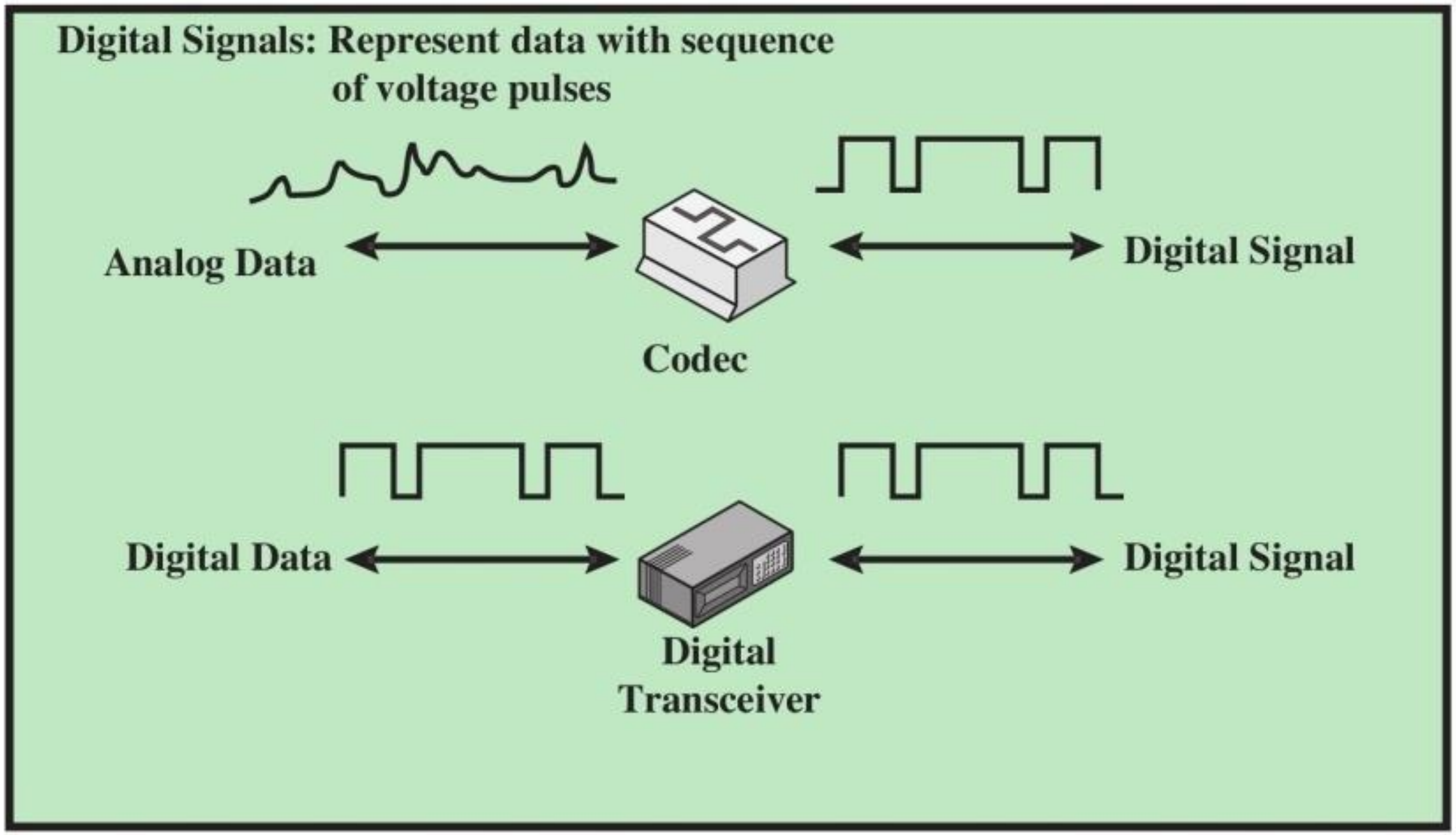
Outline

- Overview
  - Encoding and Modulation
- Digital data, digital signal
- Digital data, analog signal
- Analog data, digital signal
- Analog data, analog signal

Analog Signaling of Analog and Digital Data



Digital Signaling of Analog and Digital Data



(a) Data and Signals

	Analog Signal	Digital Signal
Analog Data	Two alternatives: (1) signal occupies the same spectrum as the analog data; (2) analog data are encoded to occupy a different portion of spectrum.	Analog data are encoded using a codec to produce a digital bit stream.
Digital Data	Digital data are encoded using a modem to produce analog signal.	Two alternatives: (1) signal consists of two voltage levels to represent the two binary values; (2) digital data are encoded to produce a digital signal with desir ed properties.

Shift Keying

Line Encoding Techniques

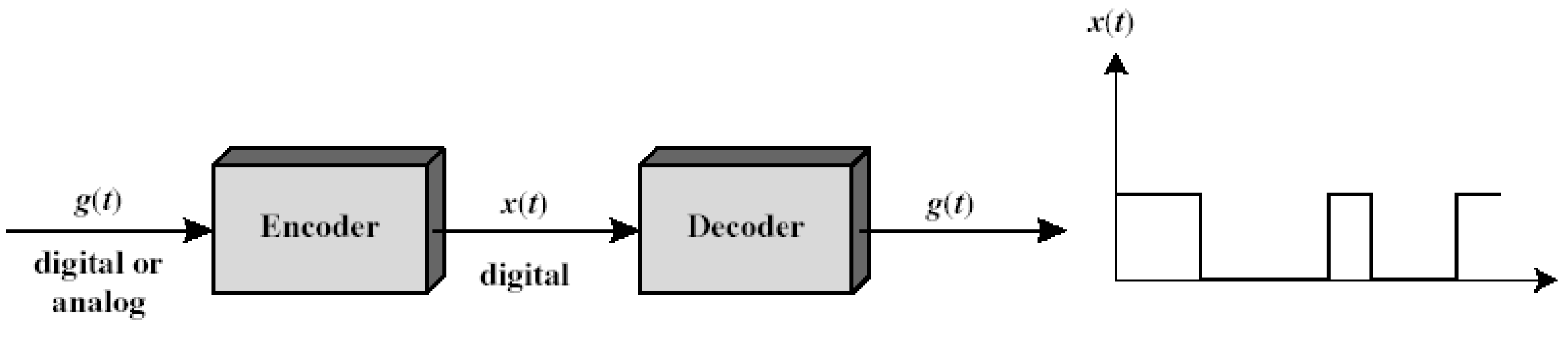
(b) Treatment of Signals

	Analog Transmission	Digital Transmission
Analog Signal	Is propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data.	Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal.
Digital Signal	Not used	Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 1s and 0s is recovered from inbound signal and used to generate a new digital outbound signal.

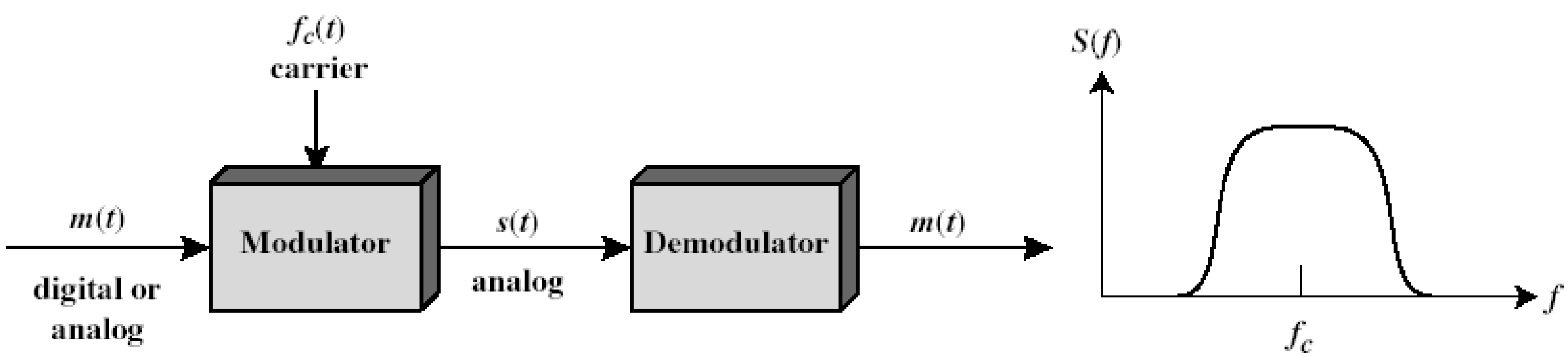
Treatment of Signals

Treatment of Signals	Analog Transmissions	Digital Transmissions
Analog Signals	Amplifiers	May use repeaters
Digital Signals	Not used	Repeaters

Encoding and Modulation



(a) Encoding onto a digital signal



(b) Modulation onto an analog signal

Modulation

- Modulation is the process of encoding source data onto a carrier signal with frequency f_c.
  - The frequency of the carrier signal is chosen to be compatible with the transmission medium being used.
  - Modulation techniques involve operation on one or more of the three parameters: ***amplitude, frequency, and phase***
- According to the input source signal m(t) (either analog or digital), which is called baseband signal (or modulating signal) , the carrier signal $f_c(t)$ will be modulated into modulated signal s(t).

Encoding/modulation Techniques

- **Digital data, digital signal**
  - The equipment for encoding digital data into a digital signal is less complex and less expensive than digital-to-analog modulation equipment.
- Analog data, digital signal
  - Conversion of analog data (e.g., voice, video) to digital form permits the use of modern digital transmission & switching.
- **Digital data, analog signal**
  - Optical system and unguided media (wireless system) only propagate analog signals.
- Analog data, analog signal
  - Baseband: easy and cheap, e.g., in voice-grade telephone lines, voice signals are transmitted over telephone lines at their original spectrum
  - Modulation permits frequency division multiplexing, e.g., AM/FM radios

(I) Digital Data, Digital Signal

- Digital signal is a sequence of discrete, discontinuous **voltage pulses**.
- Each pulse is a **signal element**.
- Binary data are transmitted by encoding the bit stream into signal elements.
- In the simplest case, one bit is represented by one signal element.
  - E.g., 1 is represented by a lower voltage level, and 0 is represented by a higher voltage level

Terminologies

- Unipolar
  - If all signal elements have the same algebraic sign (all positive or all negative), then the signal is unipolar.
- Polar
  - One logic state represented by positive voltage, the other by negative voltage
- Data rate
  - Rate of data transmission measured in **bps**: **bits per second**
- Duration or length of a bit
  - Time taken for transmitter to emit the bit
- Modulation rate/Signalling rate
  - Rate at which the signal level changes
  - Measured in **baud**: **signal elements per second**

How are they related?

Interpreting Signals at the Receiver

- The receiver needs to know
  - The timing of each signal element, i.e., when a signal element begins and ends
  - signal levels
  - These tasks are performed by sampling each element position in the middle of the interval and comparing the value to a threshold.
- Factors affecting successful interpreting of signals
  - Signal-to-noise ratio (SNR)
  - Data rate
  - Bandwidth
- Some principles:
  - An increase in data rate increases bit error rate (BER)
  - An increase in SNR decreases BER
  - An increase in bandwidth allows an increase in data rate
- Another factor that can improve performance:
  - Encoding scheme: the mapping from data bits to signal elements

Evaluation of Encoding Schemes (1)

- Signal Spectrum
  - Lack of high frequencies reduces required bandwidth
  - Lack of dc component allows ac coupling via transformer, providing electrical isolation and reducing interference
  - Concentrate power in the middle of the bandwidth
- Clocking
  - Need to determine the beginning and end of each bit
  - Synchronizing transmitter and receiver
    1. Use external clock, which is expensive; or
    2. Synchronization mechanism based on the transmitted signal

Comparison of Encoding Schemes (2)

- Error detection
  - Various error-detection techniques will be covered in Chapter 9
  - Some error detection capability can be built into signal encoding scheme
- Signal interference and noise immunity
  - Some codes are better than others in the presence of noise
  - Performance is usually expressed in terms of BER
- Cost and complexity
  - Higher signal rate (thus data rate) leads to higher cost
  - Some codes require a signal rate greater than the actual data rate

Basic categories

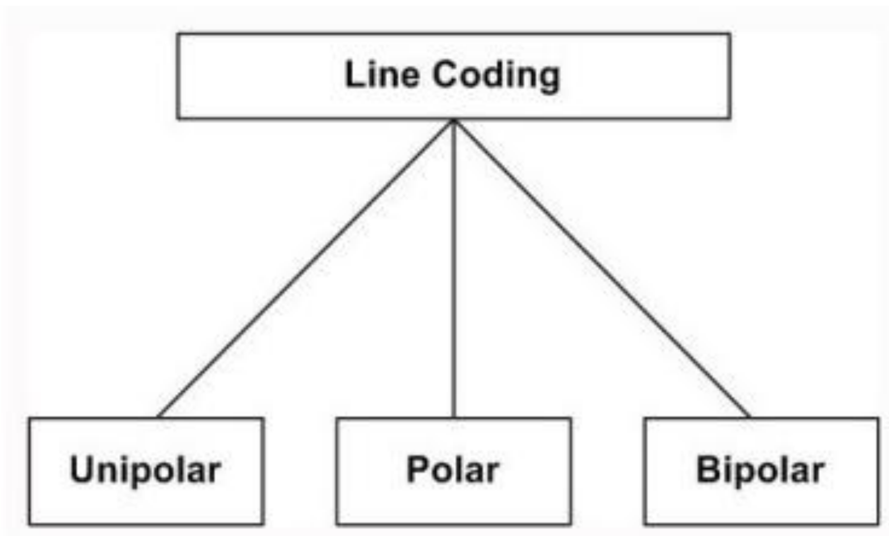
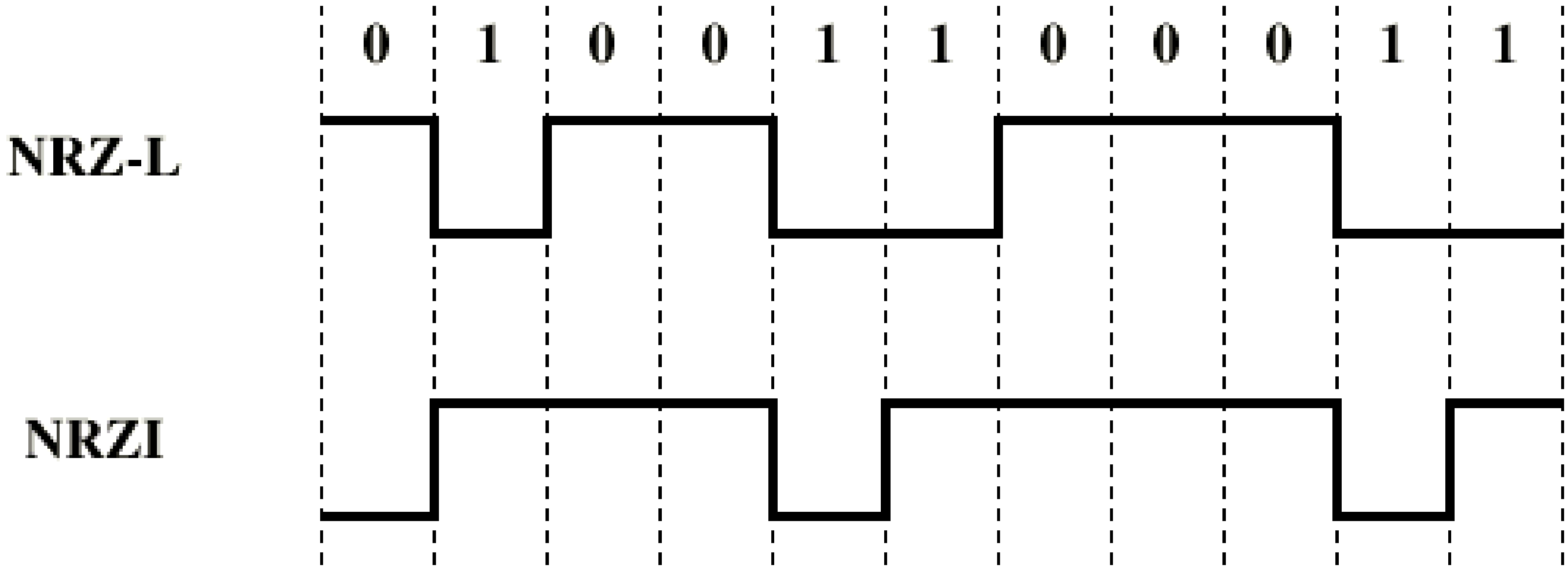


Figure 2.4.4 *Three basic categories of line coding techniques*

Encoding Schemes

- Nonreturn to Zero (NRZ)
  - Nonreturn to Zero-Level (NRZ-L)
  - Nonreturn to Zero Inverted (NRZI)
- Multilevel Binary
  - Bipolar-AMI
  - Pseudoternary
- Biphase
  - Manchester
  - Differential Manchester
- Scrambling techniques
  - B8ZS
  - HDB3

NRZ



Nonreturn to Zero-Level (NRZ-L)

- Two different voltages for 0 and 1 bits
- Voltage is constant during a bit interval
  - no transition, i.e. no return to zero voltage
- E.g. absence of voltage for zero, constant positive voltage for one
- More often, negative voltage for one value and positive for the other
- This is known as NRZ-L

Nonreturn to Zero Inverted

- NRZI: Nonreturn to zero, invert on ones
- Constant voltage pulse for duration of bit
- Data are encoded as presence or absence of signal transition at the beginning of the bit time
- A transition (low to high or high to low) denotes a binary 1
- No transition denotes binary 0
- NRZI is an example of differential encoding technique

Differential Encoding

- Data are represented in terms of the changes between successive signal elements, rather than the signal elements themselves.
- It is more reliable to detect a transition in the presence of noise than to compare a value to a threshold.
- With a complex transmission layouts, it is easy to lose the sense of the polarity of the signal.

NRZ pros and cons

- Pros
  - Easy to engineer
  - Make efficient use of bandwidth
- Cons
  - The presence of dc component
  - The lack of synchronization capability
- NRZ codes are commonly used for digital magnetic recording, but not often used for signal transmission.

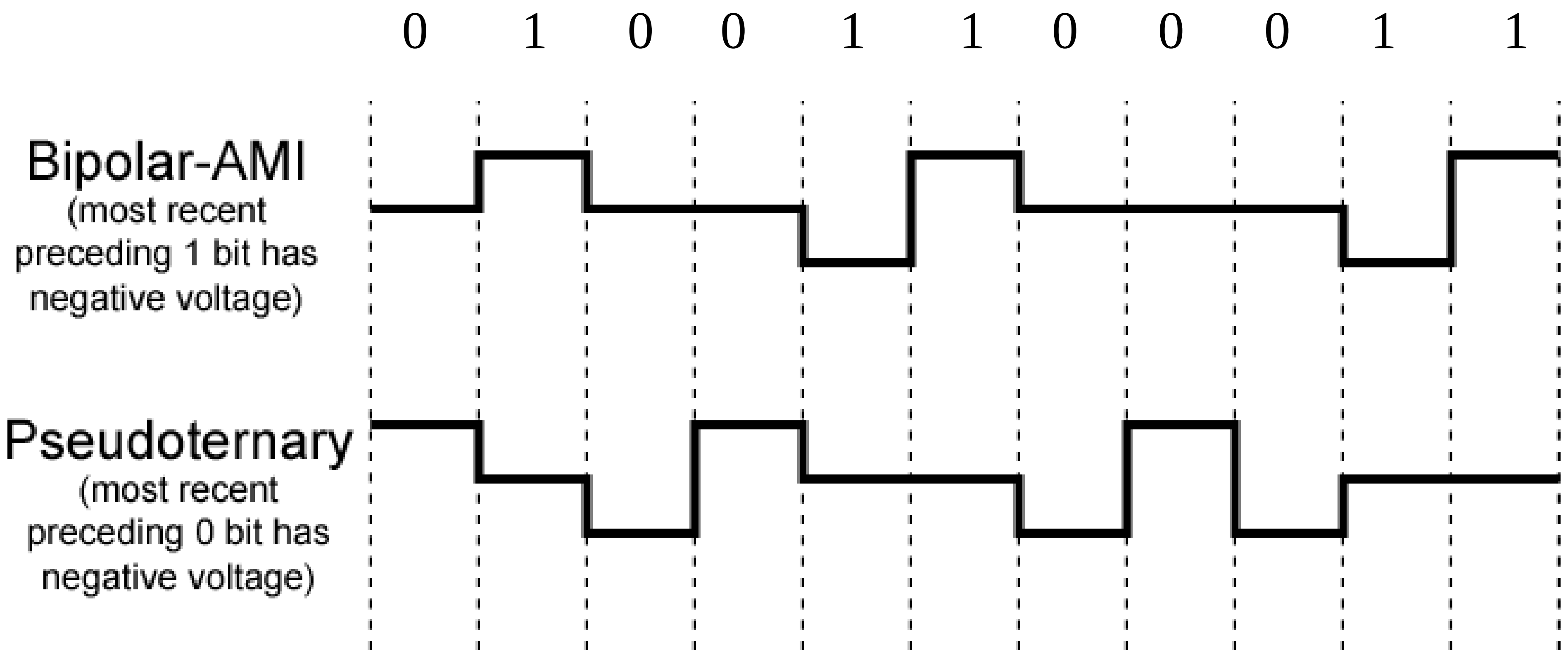
Multilevel Binary

- Use more than two levels
- Bipolar-AMI: alternate mark inversion
  - zero represented by no line signal
  - one represented by a positive or negative pulse
  - one pulses must alternate in polarity
  - Advantages:
    - No loss of synchronization if a long string of 1s occurs (0s still be a problem)
    - No net dc component
    - Provides a simple means of error detection

Pseudoternary

- 1 represented by the absence of line signal
- 0 represented by alternating positive and negative pulses
- No advantage or disadvantage over bipolar-AMI

Bipolar-AMI and Pseudoternary



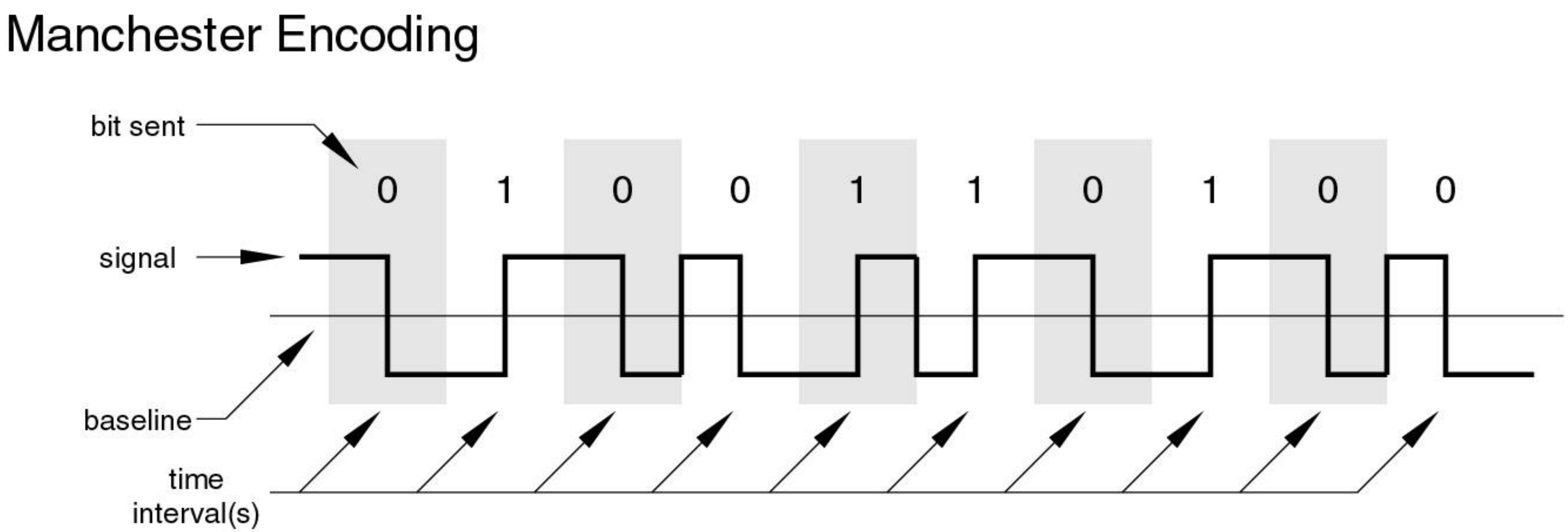
Trade-off for Multilevel Binary

- Not as efficient as NRZ
  - —However, in bipolar-AMI & pseudoternary, each signal element only represents one bit
  - —Receiver must distinguish between three levels (+A, -A, 0)
  - —Requires approx. 3dB more signal power for same probability of bit error, or
  - —The BER for NRZ codes, at a given SNR, is significantly less than for mulitlevel binary.

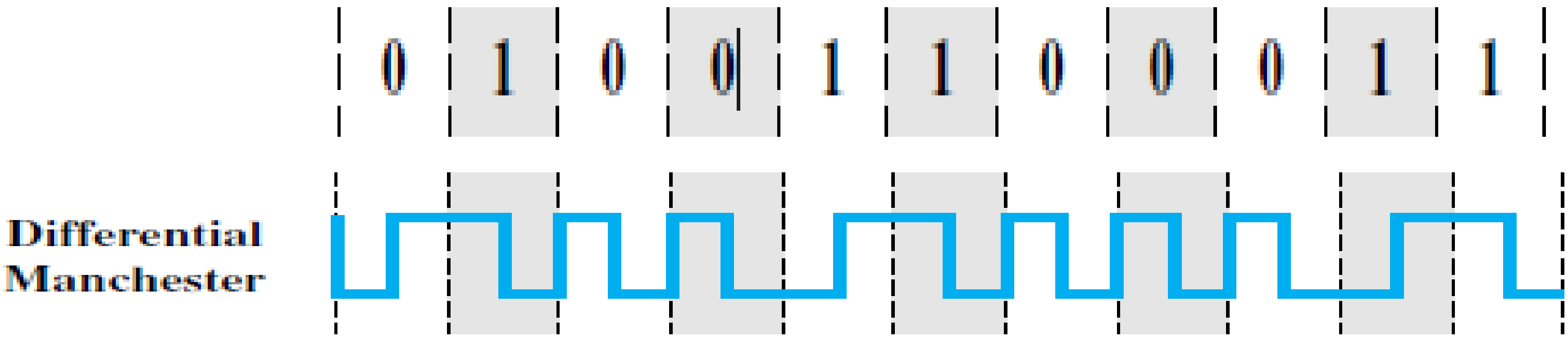
Biphase

- Manchester
  - There is a transition at the middle of each bit period.
  - The midbit transition serves as a clock mechanism and also as data: low to high represents 1, high to low represents 0
  - Used by IEEE 802.3 Ethernet LAN
- Differential Manchester
  - The midbit transition is used only to provide clocking.
  - 0 is represented by the presence of a transition at the beginning of a bit period.
  - 1 is represented by the absence of a transition at the beginning of a bit period.
  - Note: this is a differential encoding scheme
  - Used by IEEE 802.5 token ring LAN

Manchester Encoding



Differential Manchester Encoding



Biphase Pros and Cons

- Pros
  - Self-clocking: Because there is a predictable transition during each bit time, the receiver can synchronize on that transition.
  - No dc component
  - Error detection: the absence of an expected transition can be used to detect errors
- Con
  - Requires at least one transition per bit time and may have as many as two transitions, thus,
  - The maximum modulation rate is twice that for NRZ
  - Requires more bandwidth

Scrambling

- Use scrambling to replace sequences that would produce constant voltage
- Main idea:
  - Sequences that would result in a constant voltage are replaced by filling sequences that will provide sufficient transitions for the receiver's clock to maintain synchronization.
  - Filling sequences must be recognized by receiver and replaced with original data sequence.
  - Filling sequence is the same length as original sequence.
- Design goals:
  - No dc component
  - No long sequences of zero-level line signals
  - No reduction in data rate
  - Error detection capability

B8ZS

- Bipolar With 8-Zeros Substitution
- Based on bipolar-AMI, whose drawback is a long string of zeros may result in loss of synchronization.
- If octet of all zeros occurs and the last voltage pulse preceding this octet was positive, encode as 000+-0-+
- If octet of all zeros occurs and the last voltage pulse preceding this octet was negative, encode as 000-+0+-

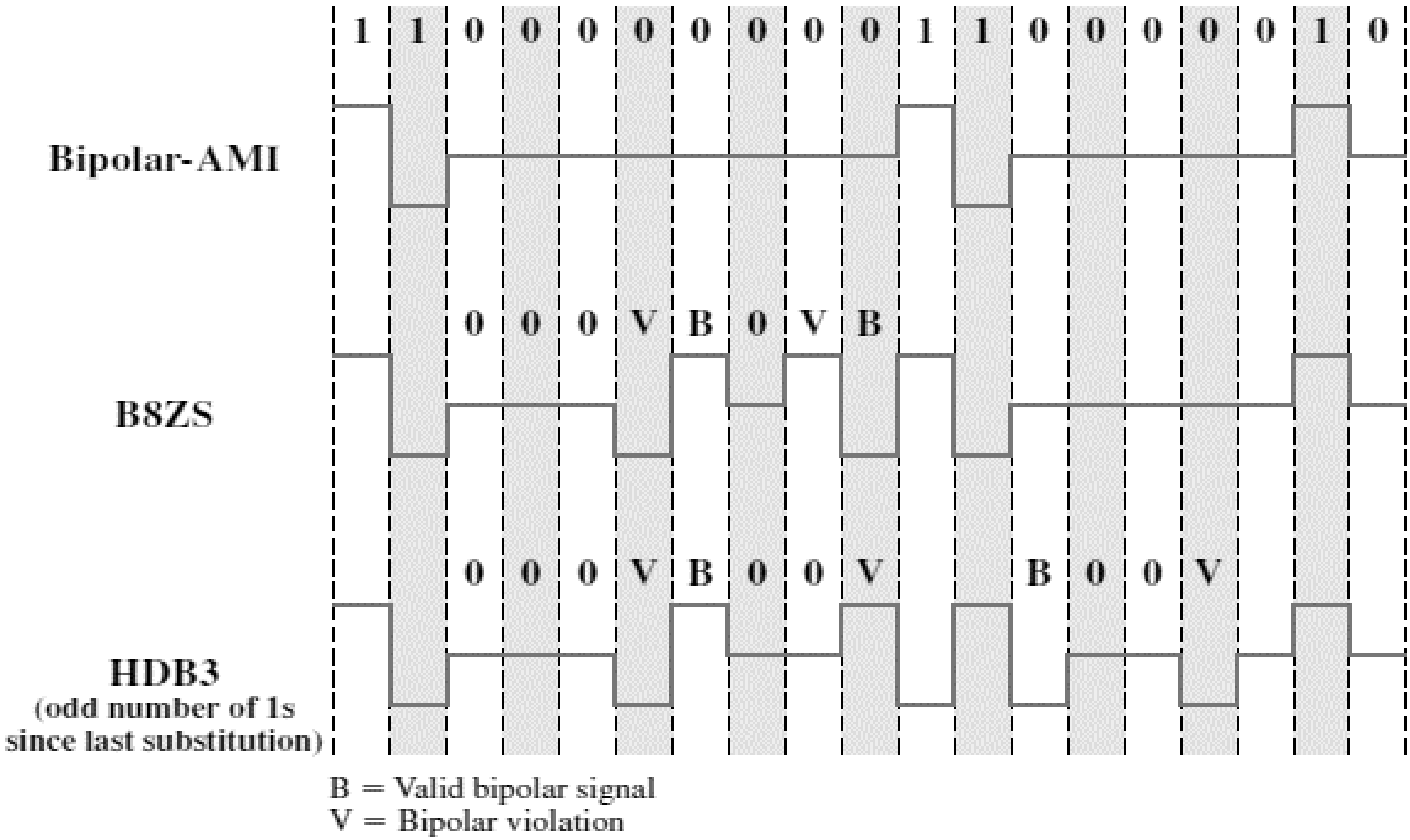
- Unlikely to occur as a result of noise
- Receiver recognizes the pattern and interprets the octet as consisting of all zeros.

HDB3

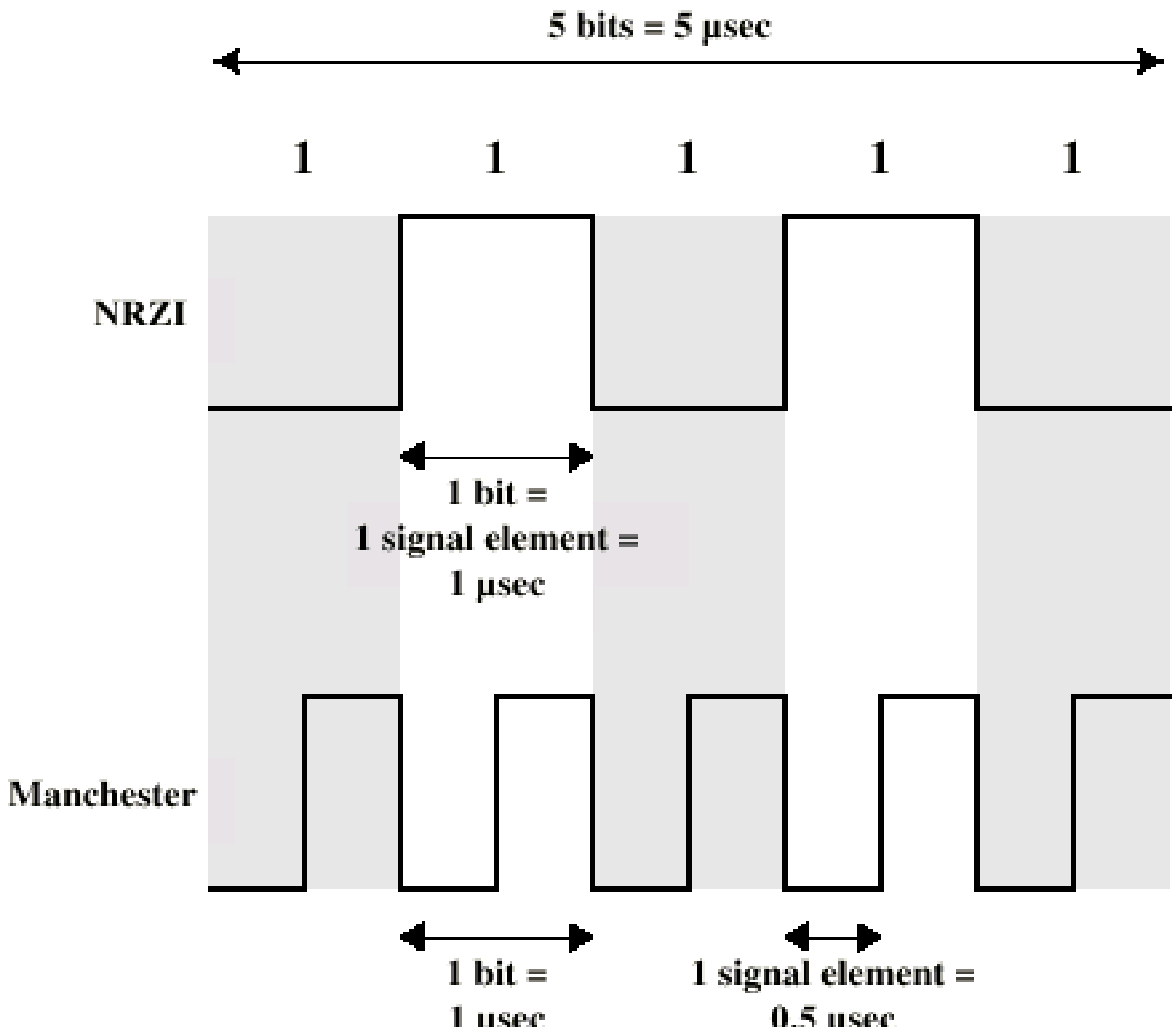
- High-Density Bipolar-3 Zeros
- Based on bipolar-AMI
- String of four zeros is replaced with sequences containing one or two pulses.

	Number of Bipolar Pulses since last substitution	
Polarity of Preceding Pulse	Odd	Even
-	000-	+00+
+	000+	-00-

B8ZS and HDB3



Modulation Rate



Tutorial Question

- For the bit stream 01001110, sketch the waveforms for each of the line coding technique: NRZL,NRZI,Manchester,Differential Manchester.
- Assume that the signal level for the preceding bit for NRZI was high;
- the most recent preceding 1 bit (AMI) has a negative voltage;
- and the most recent preceding 0 bit(pseudoternary) has a negative voltage.