Lecture #4

Encoding,
Modulation, Signal Encoding

Instructor:
Dr. Mahmoud Elkhouly

Agenda

- Modulation
- Signal Encoding
- Error Detection
- Error Control

Different Conversion Schemes

Both analog and digital information can be encoded as either analog or digital signals. The particular encoding that is chosen depends on the specific requirements to be met and the media and communications facilities available.

Digital Data

Digital data, digital signals: The simplest form of digital encoding of digital data is to assign one voltage level to binary one and another to binary zero. More complex encoding schemes are used to improve performance, by altering the spectrum of the signal and providing synchronization capability.

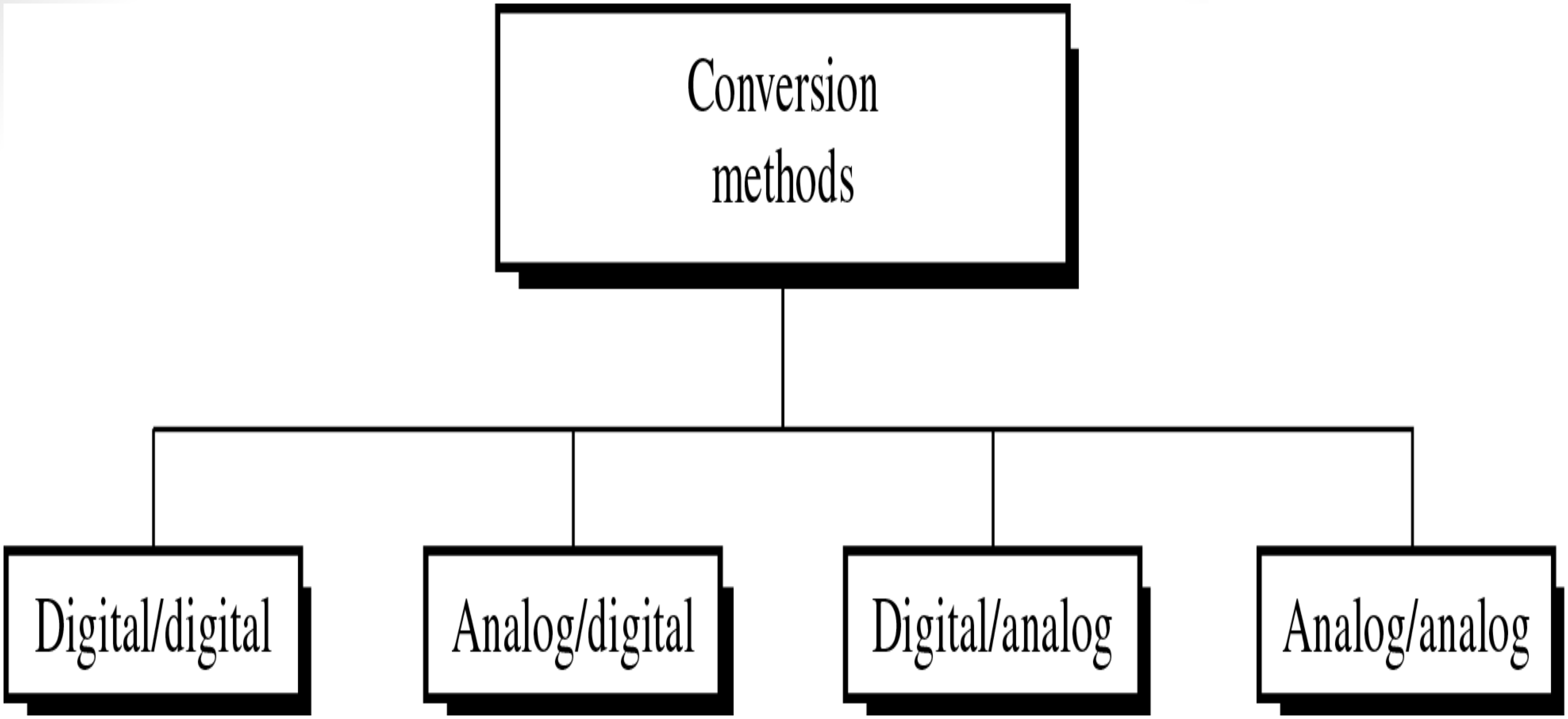
- **Digital data, analog signal:** A modem converts digital data to an analog signal so that it can be transmitted over an analog line. The basic techniques are amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). All involve altering one or more characteristics of a carrier frequency to represent binary data.

Analog Data

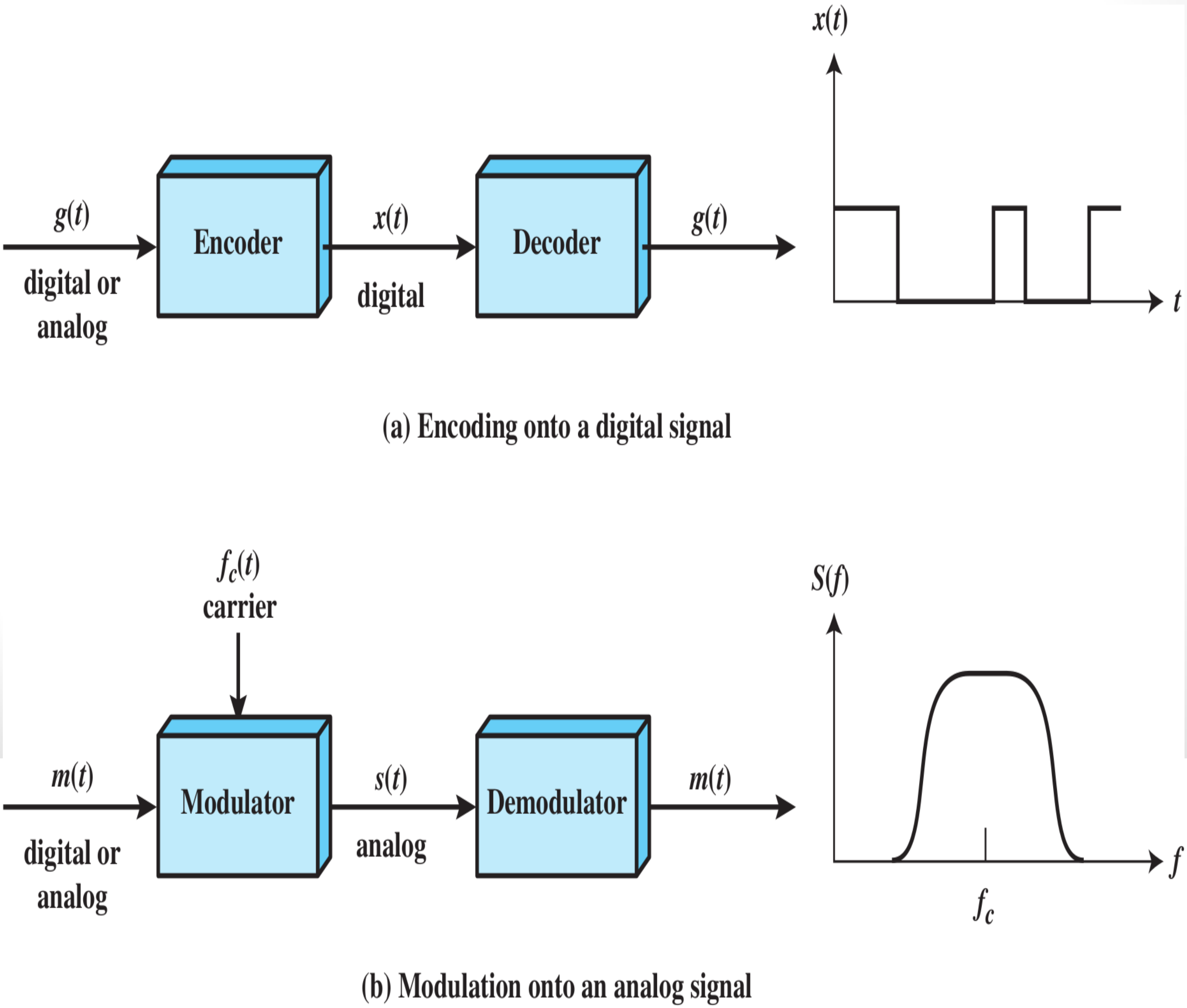
Analog data, digital signals: Analog data, such as voice and video, are often digitized to be able to use digital transmission facilities.The simplest technique is pulse code modulation (PCM), which involves sampling the analog data periodically and quantizing the samples.

- **Analog data, analog signals:** Analog data are modulated by a carrier frequency to produce an analog signal in a different frequency band, which can be utilized on an analog transmission system. The basic techniques are amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM).

Different Conversion Schemes

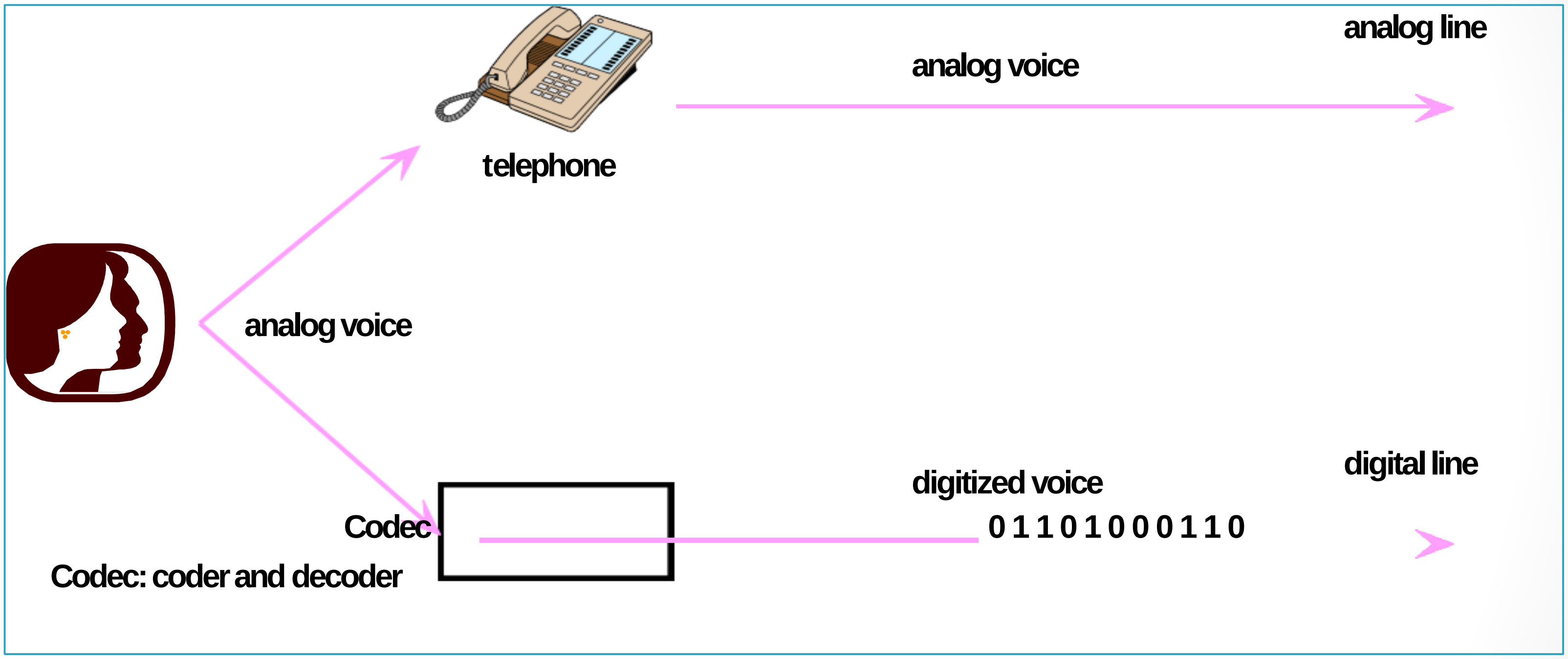


Encoding and Modulation Techniques

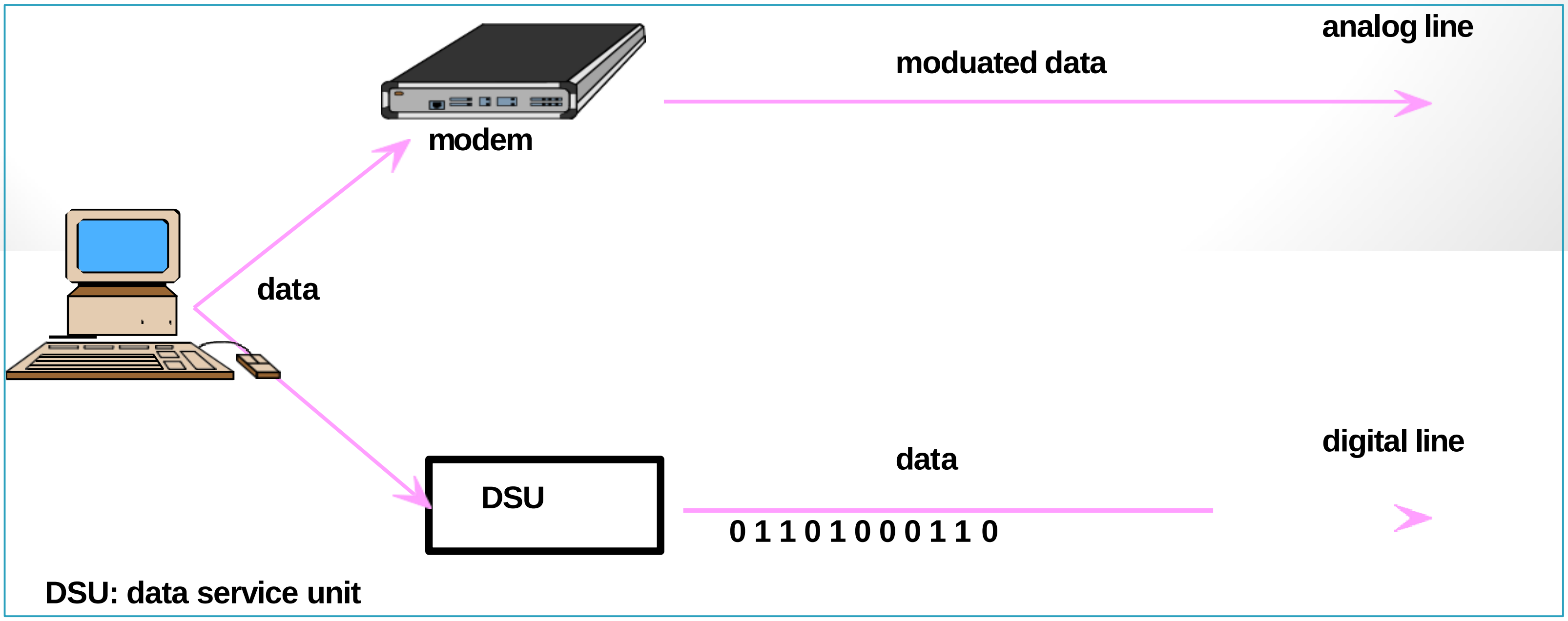


Data Communication Basics

- Analog Data Choices



- Digital Data Choices



Reasons for Using Different Techniques

Digital data, digital signal: Equipment less complex/expensive than digital-to-analog modulation equipment

Analog data, digital signal: Permits use of digital transmission equipment

Digital data, analog signal: Some media only propagate analog signals, e.g. optical fibre, wireless

Analog data, analog signal: Some analog data can easily be transmitted as baseband signals, e.g. voice; enables multiple signals at different positions in spectrum to share transmission media

Digital Transmission Advantages

- The signal is exact
- Signals can be checked for errors
- Noise/interference are easily filtered out
- A variety of services can be offered over one line
- Higher bandwidth is possible with data compression

Analog Encoding of Digital Data

- data encoding and decoding to represent data using the properties of analog waves
- modulation: the conversion of digital signals to analog form
- demodulation: the conversion of analog data signals back to digital form

Modem

- an acronym for modulator-demodulator
- uses a constant-frequency signal known as a carrier signal
- converts a series of binary voltage pulses into an analog signal by modulating the carrier signal
- the receiving modem translates the analog signal back into digital data

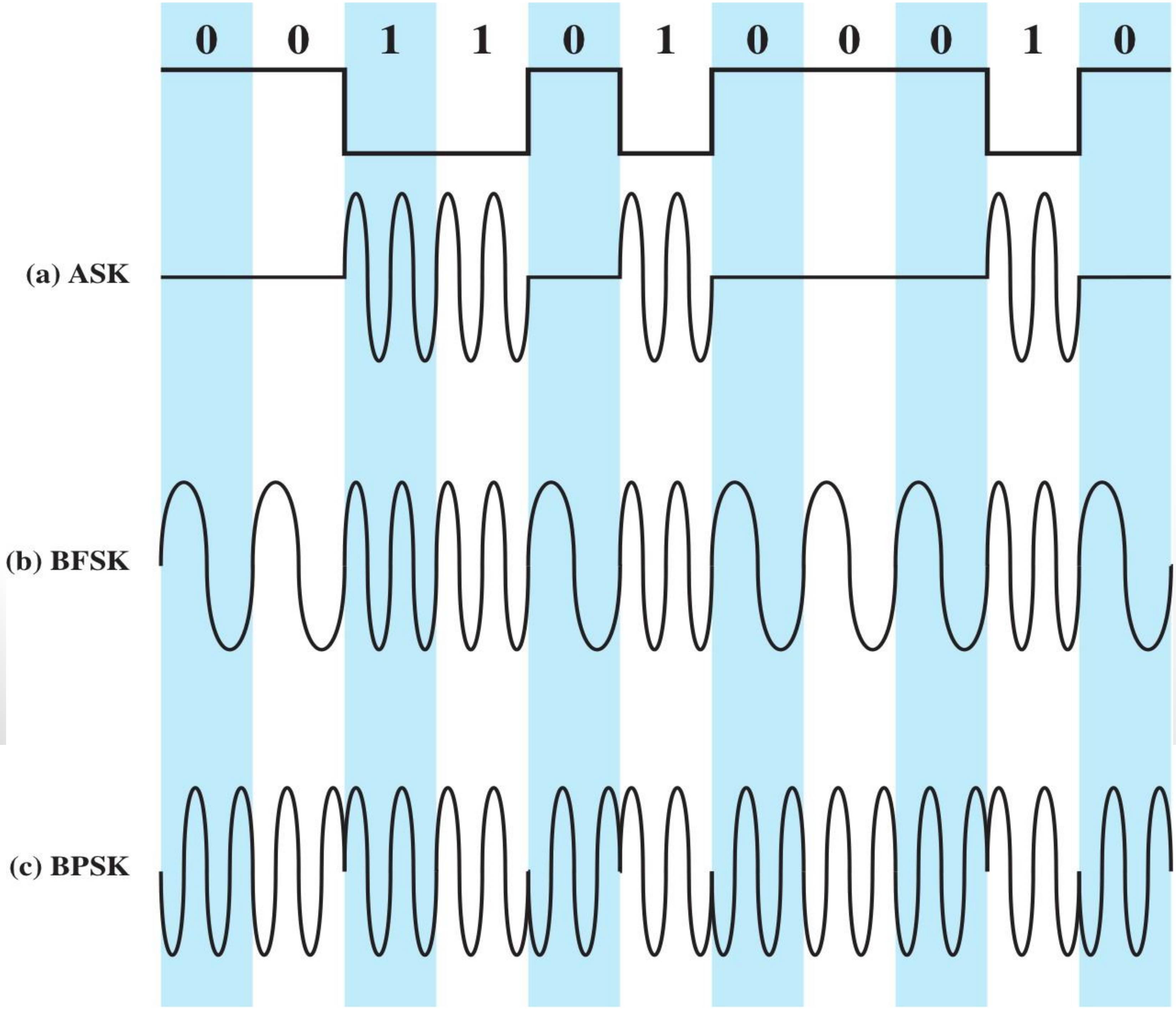
Digital Data, Analog Signals

- Transmit digital data over media that only support analog signals, e.g. telephone network, microwave systems
  - Telephone network designed to transmit signals in voice-frequency (300 to 3400 Hz)
  - Modems(modulator-demodulator) convert digital data to signals in this frequency range

Methods of Modulation

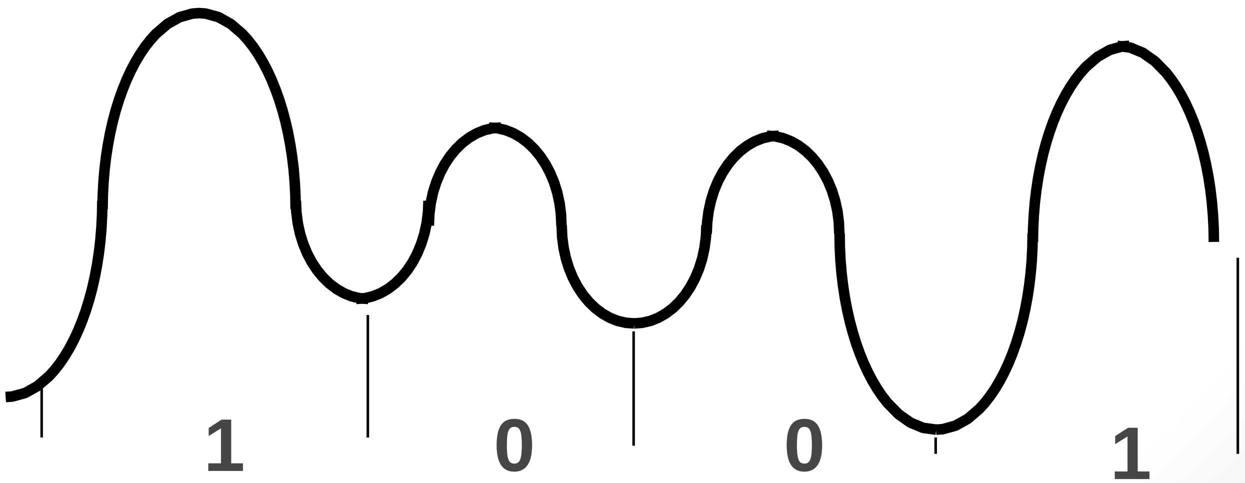
- amplitude modulation (AM) or amplitude shift keying (ASK)
- frequency modulation (FM) or frequency shift keying (FSK)
- phase modulation (PM) or phase shift keying (PSK)

Modulation of Analog Signals for Digital Data



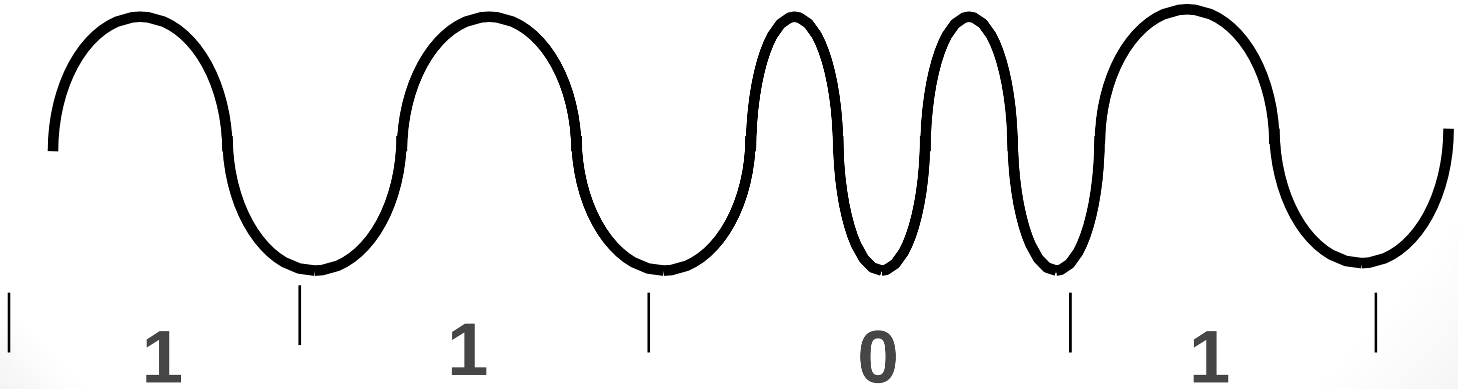
Amplitude Shift Keying (ASK)

- In radio transmission, known as amplitude modulation (AM)
- the amplitude (or height) of the sine wave varies to transmit the ones and zeros
- Up to 1200 bps over voice-grade lines
- major disadvantage
  - telephone lines are very susceptible to variations in transmission quality that affect amplitude



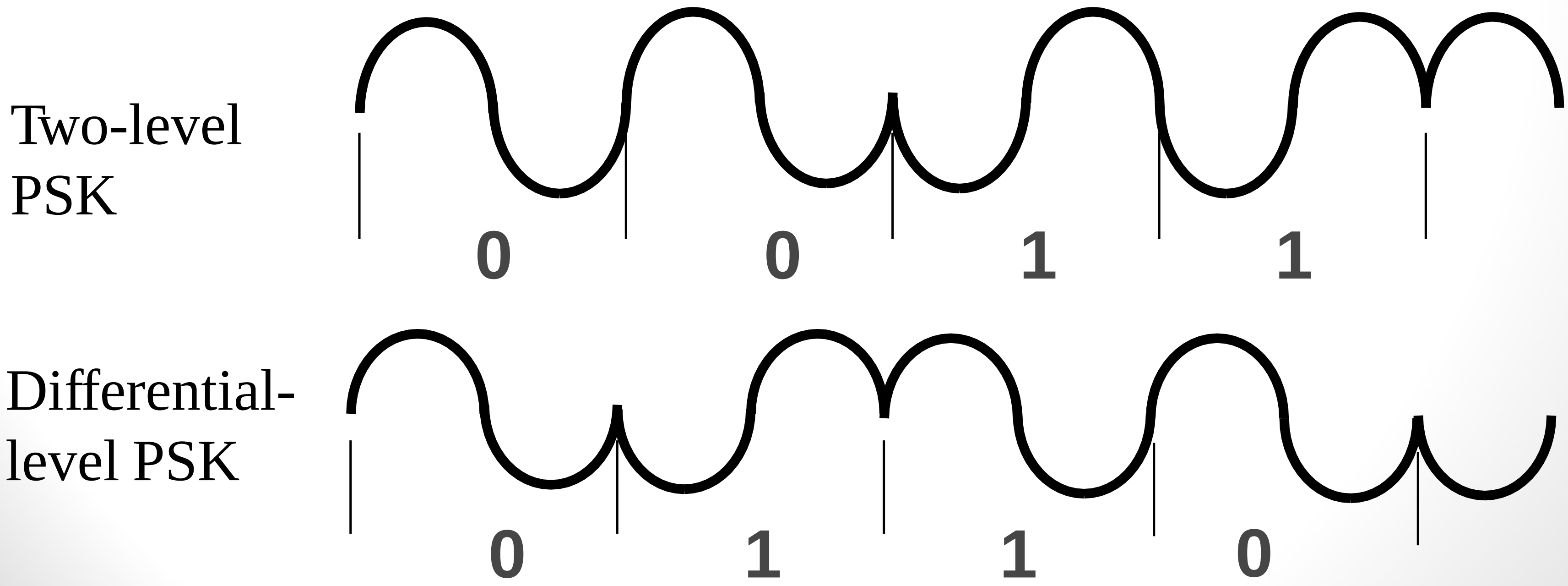
Frequency Shift Keying (FSK)

- in radio transmission, known as frequency modulation (FM)
- the frequency of the carrier wave varies in accordance with the signal to be sent
- signal is transmitted at constant amplitude
- more immune to noise than ASK
- requires more analog bandwidth than ASK
- still up to 1200 bps on voice-grade lines



Phase Shift Keying (PSK)

- also known as phase modulation (PM)
- frequency and amplitude of the carrier signal are kept constant
- the carrier is shifted in phase according to the input data stream
- each phase can have a constant value, or value can be based on whether or not phase changes (differential keying)



Comparing the Shift Keying Schemes

Amplitude Shift Keying (ASK)

- Inefficient modulation technique
- Used on voice lines $<$ 1200 bps and optical fibre

Frequency Shift Keying (FSK)

- Used on voice lines, coaxial cable, HF radio systems
- Extended with M frequencies: improve efficiency, higher error rate

Phase Shift Keying (PSK)

- Used in wireless transmission systems
- Extended with M phases, e.g. QPSK ($M = 4$),
- Combined with ASK: Quadrature Amplitude Modulation (QAM); used in ADSL and wireless systems

Multilevel PSK

- Can extend levels beyond one bit at a time
- 9600 bps modem
  - 12 different phase angles
  - 4 of them use two different amplitude values (ASK)
  - 16 different signal types – 4 bits per signal type
  - 9600 bps modem / 4 bits per signal type
  - 2400 baud modem (signaling speed)

Digital Encoding of Analog Data

- Uses pulse-code modulation (PCM)
- The sampling theorem:
  - If a signal *f*(*t*) is sampled at regular intervals of time and at a rate higher than twice the highest signal frequency, the samples contain all the information of the original signal.
- 8000 samples/sec sufficient for 4000 Hz

Converting Samples to Bits

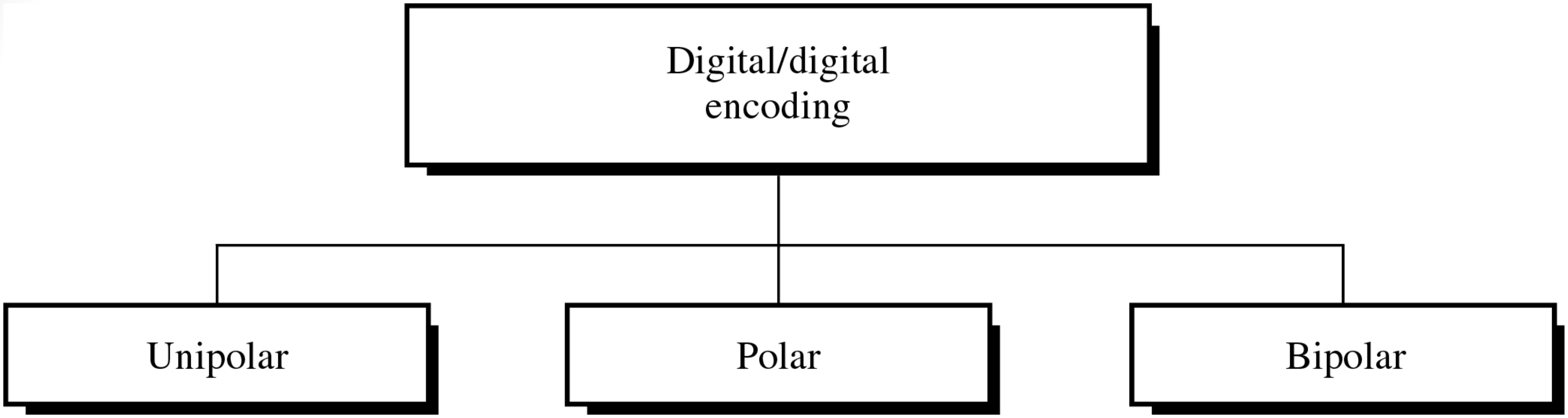
- Quantizing (similar concept to pixelization)
- Breaks wave into pieces, samples it, and assigns a value in
  a particular range
- More bits per sample means greater detail, fewer bits means less detail
- 8-bit range allows for 256 possible sample levels
  - Quality of recovered voice comparable to analog
- 8000 samples/sec * 8 bits/sample = 64 kbps

Codec

- Coder/Decoder
- converts analog signals into a digital form and converts it back to analog signals
- e.g. television
  - 4.6 MHz bandwidth signal (9.2 M samples per sec)
  - 10-bit codes
  - 92 Mbps data
- Repeaters instead of amplifiers
  - No cumulative noise

-3

Types of Digital to Digital Encoding



Digital Signals

* Unipolar (positive voltage for 1, no voltage for 0)
* Bipolar, nonreturn-to zero (NRZ)

  Manchester coding (low-to-high is 1, high-to- low is 0)

  Differential Manchester (no transition at the beginning of the bit period is 1, second transition at the beginning of the bit period is 0)

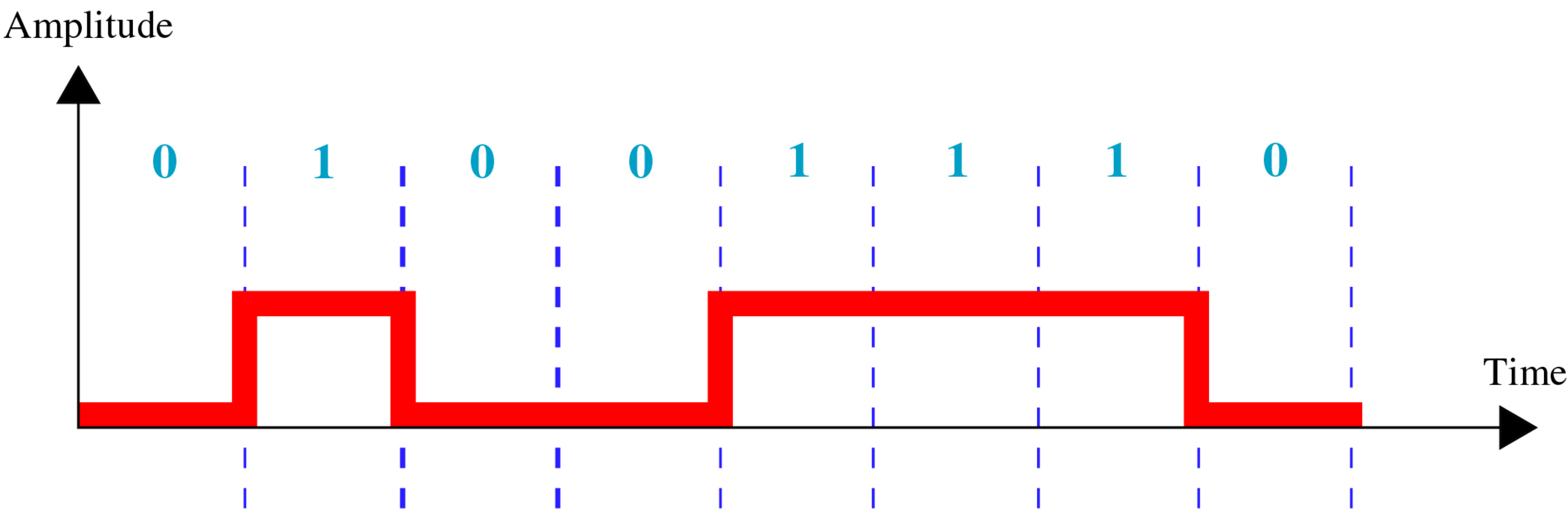
  Benefits: self-clocking, and error detection
* Bipolar, return-to-zero

Benefits of Digital Transmission

- Better data integrity (detect & correct error)
- Higher capacity cables (fiber-optic)
- Easier integration (voice, data, video, etc.)
- Better security and privacy (encrypt data)
- Lower cost (large-scale integrated circuitry)

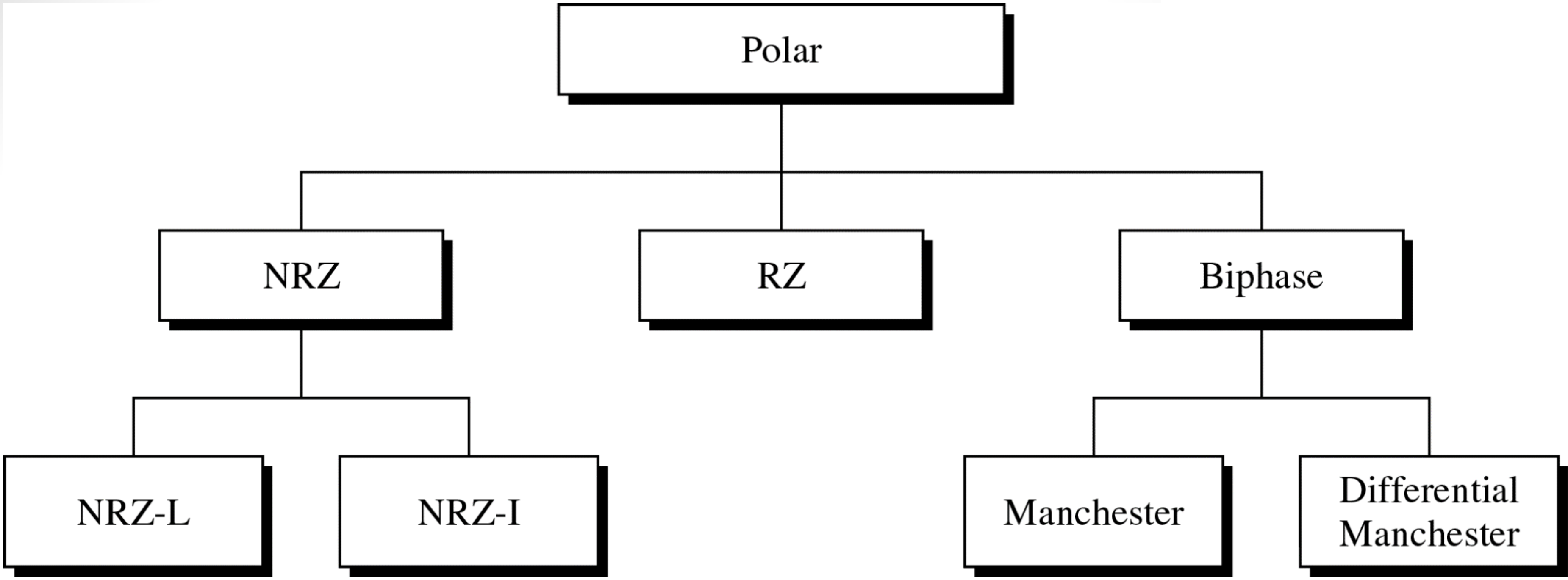
-4

Unipolar Encoding



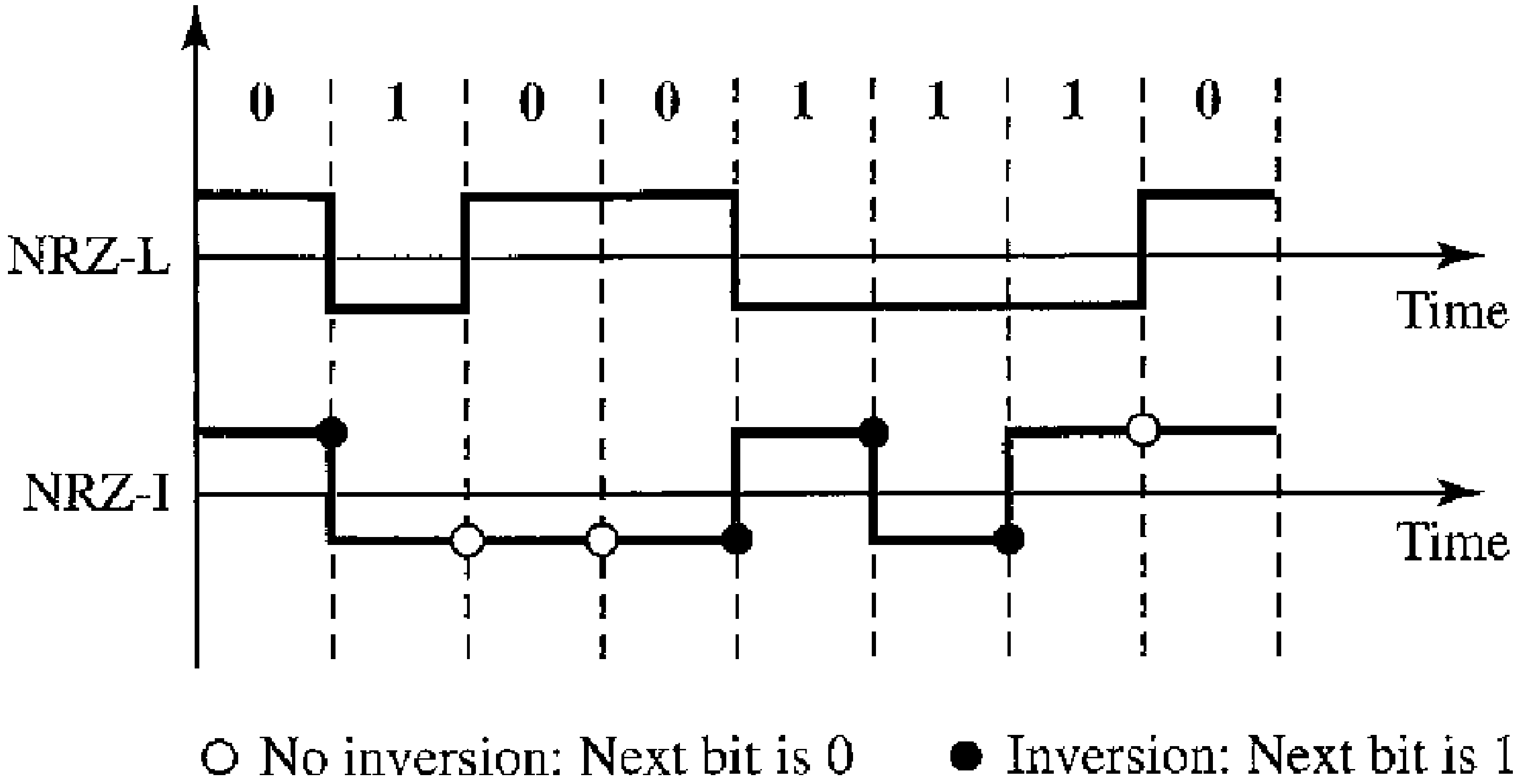
In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.

Types of Polar Encoding



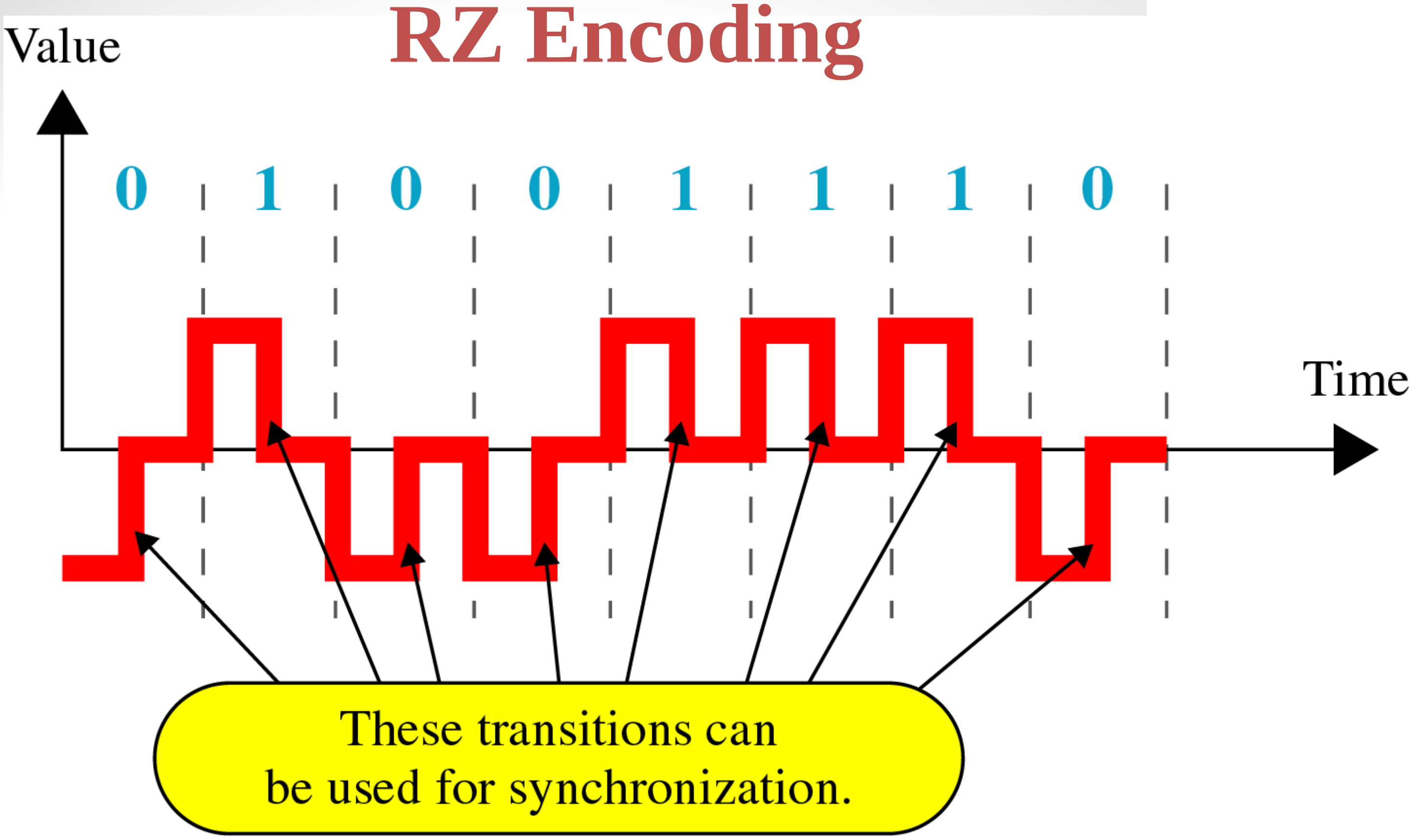
non-return-to-zero (NRZ) scheme in which the positive voltage defines bit 1 and the zero voltage defines bit 0. It is called NRZ because the signal does not return to zero at the middle of the bit. Figure 4.5 show a unipolar NRZ scheme.

NRZ-L and NRZ-I Encoding



width. 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.

RZ Encoding



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. In Figure 4.7 we see that the 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. The same problem we mentioned, a sudden change of

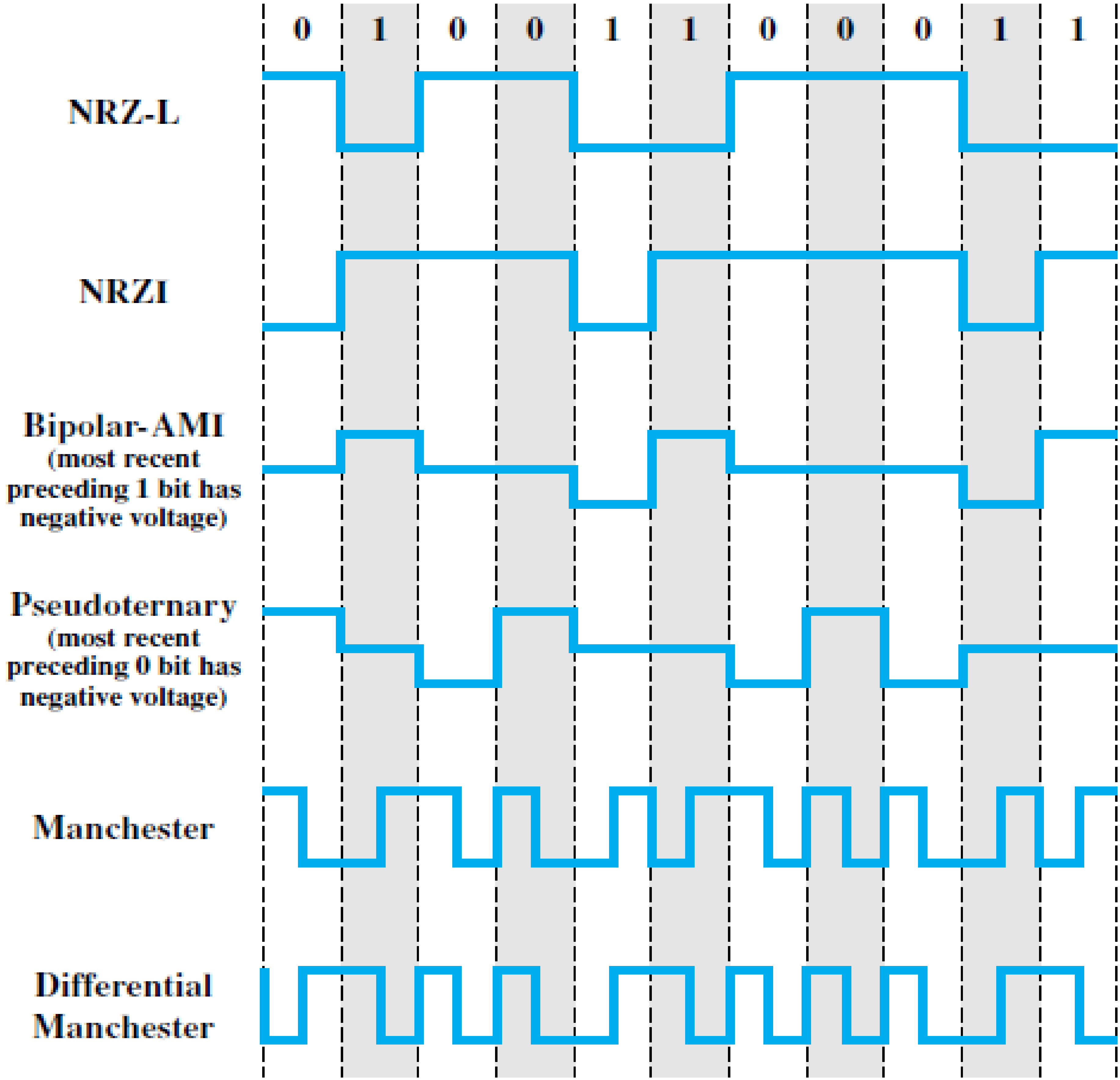


Figure Digital Signal Encoding Formats

Digital Encoding of Digital Data

- Most common, easiest method is different voltage levels for the two binary digits
- Typically, negative=1 and positive=0
- Known as NRZ-L, or non-return-to-zero level
  - signal never returns to zero, and the voltage during a bit transmission is level (constant)

Table Definition of Digital Signal Encoding Formats

Nonreturn to Zero-Level (NRZ-L)

0 = high level

1 = low level

Nonreturn to Zero Inverted (NRZI)

0 = no transition at beginning of interval (one bit time)

1 = transition at beginning of interval

Bipolar-AMI

0 = no line signal

1 = positive or negative level, alternating for successive ones

Pseudoternary

0 = positive or negative level, alternating for successive zeros

1 = no line signal

Manchester

0 = transition from high to low in middle of interval

1 = transition from low to high in middle of interval

Differential Manchester

Always a transition in middle of interval

0 = transition at beginning of interval

1 = no transition at beginning of interval

B8ZS

Same as bipolar AMI, except that any string of eight zeros is replaced by a string with two code violations

HDB3

Same as bipolar AMI, except that any string of four zeros is replaced by a string with one code violation

Differential NRZ

- Differential version is NRZI (NRZ, invert on ones)
- Change=1, no change=0
- Advantage of differential encoding is that it is more reliable to detect a change in polarity than it is to accurately detect a specific level

Problems With NRZ:

- Difficult to determine where one bit ends and the next begins
- In NRZ-L, long strings of ones and zeroes would appear as constant voltage pulses
- Timing is critical, because any drift results in lack of synchronization and incorrect bit values being transmitted

Biphase Alternatives to NRZ

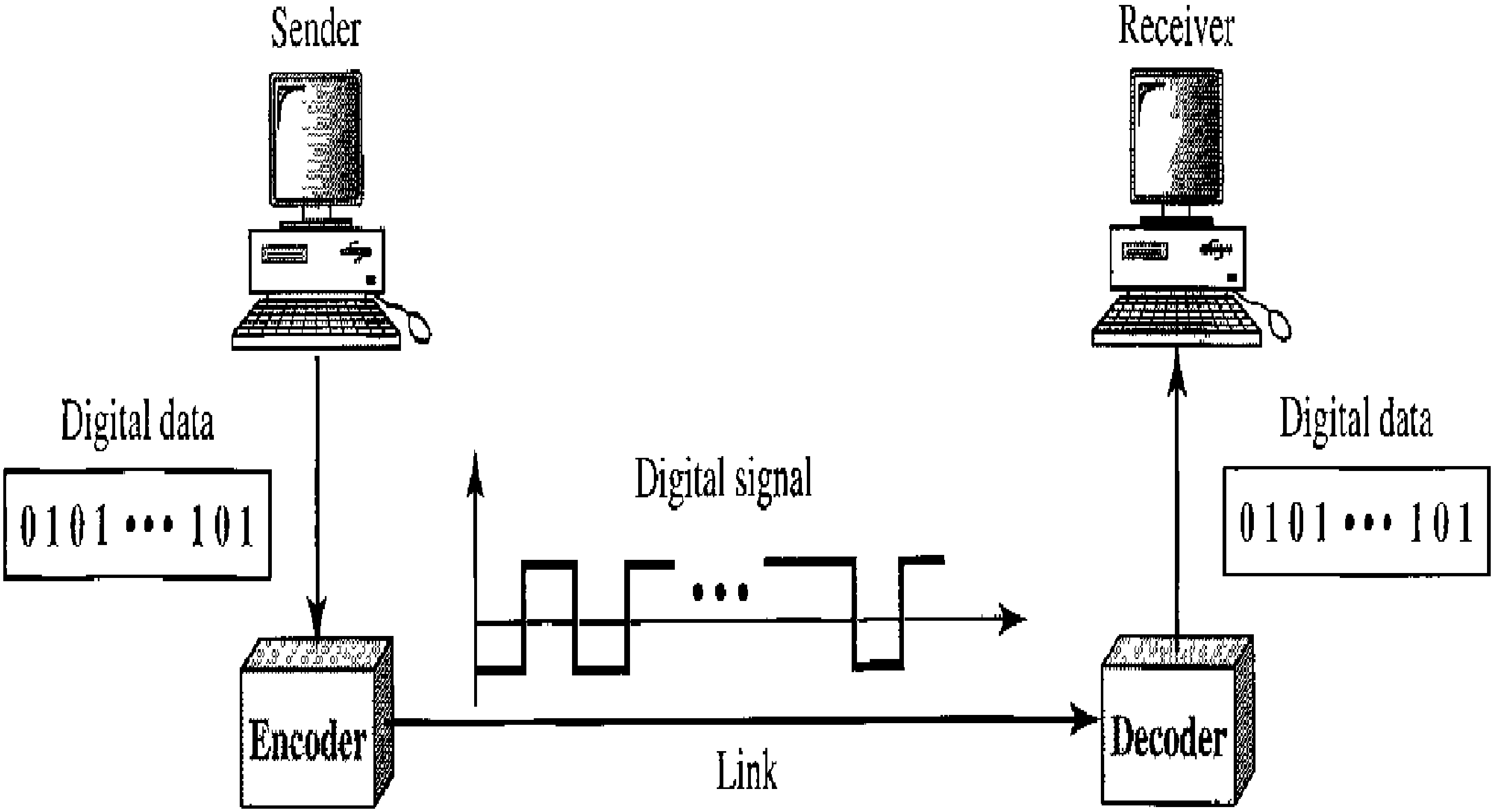
- Require at least one transition per bit time, and may even have two
- Modulation rate is greater, so bandwidth requirements are higher
- Advantages
  - Synchronization due to predictable transitions
  - Error detection based on absence of a transition

Manchester Code

- Transition in the middle of each bit period
- Transition provides clocking and data
- Low-to-high=1 , high-to-low=0
- Used in Ethernet

Differential Manchester:

- Midbit transition is only for clocking
- Transition at beginning of bit period=0
- Transition absent at beginning=1
- Used in token-ring


Sender
Receiver
Digital data
0101 ••• 101
Digital signal
•••
Digital data
0101 ••• 101
Encoder
Link
Decoder

Example Technologies using Encoding Schemes

- NRZ/NRZI: RS-232, HDLC, USB, . . .
- Manchester: Ethernet, Token Ring, . . .
- Multilevel Binary: US T-carrier and European E-carrier telecommunication systems