SIGNAL ENCODING TECHNIQUES

Data transmission

Lecture#7

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Contents

- **Encoding techniques**
- **Digital Data, Digital Signals**
- **Digital Data, Analog Signals**

Why?!!

- To optimize the use of transmission media, i.e., conserve BW or minimize the errors.

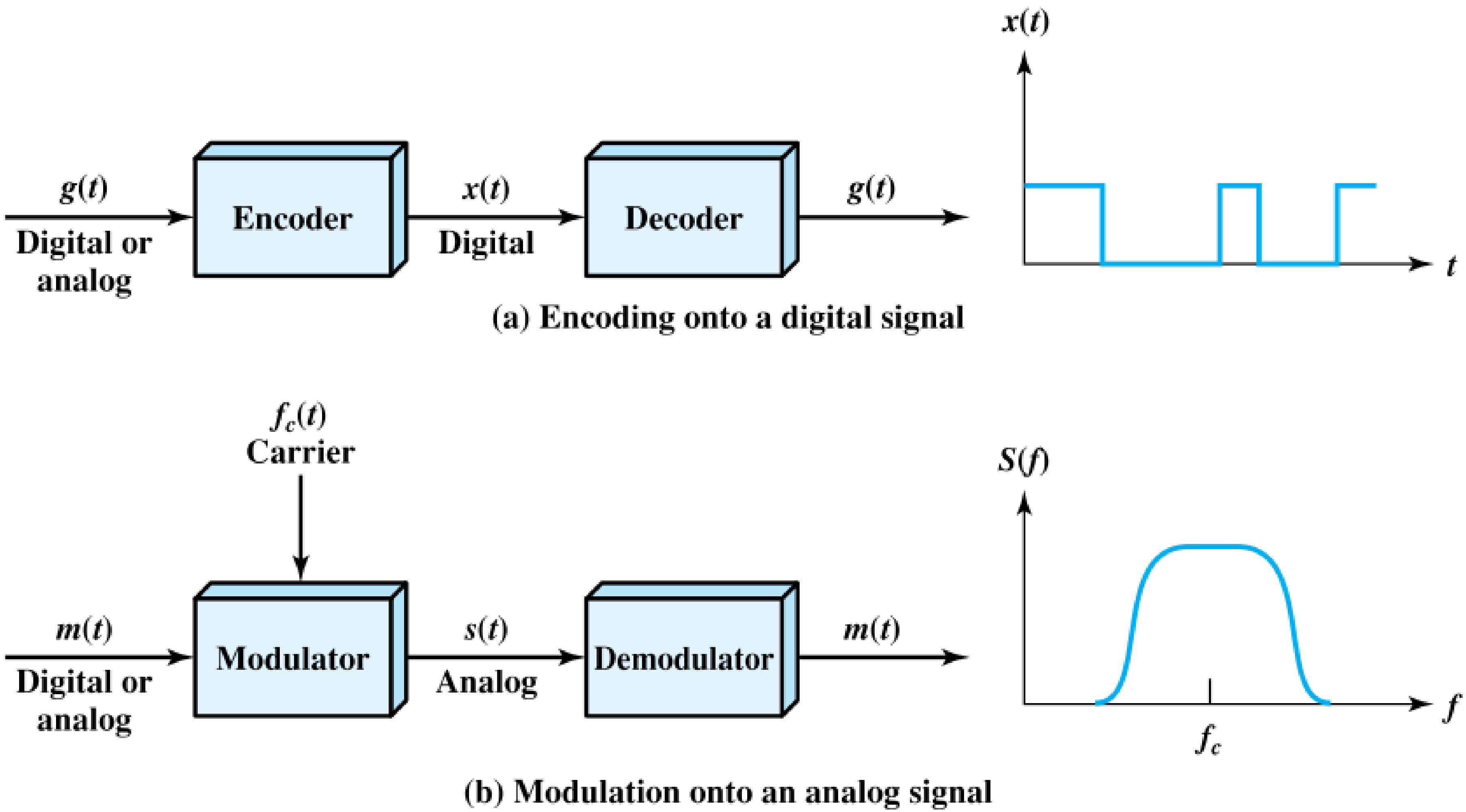
Choice of encoding techniques

- Depends on the specific requirements to be met and the media and communications facilities available.

Forms of encoding techniques

- Digital data, digital signals (line coding)
- Digital data, analog signal (ASK, FSK, PSK, …)
- Analog data, digital signals (PCM, DM)
- Analog data, analog signals (AM, FM, PM)

Digital and analog signaling



Reasons for choosing a particular technique

- Digital data, digital signal

  Equipment for encoding digital data into a digital signal is less complex and less expensive.

- Analog data, digital signal

  Permits the use of modern digital transmission and switching equipment.

- Digital data, analog signal

  Some transmission media, such as optical fiber and unguided media, will only propagate analog signals.

- Analog data, analog signal

  Frequency division multiplexing.

Data element and signal element

Term	Units	Definition
Data element	Bits	A single binary one or zero
Data rate	Bits per second (bps)	The rate at which data elements are transmitted
Signal element	Digital: a voltage pulse of constant amplitude Analog: a pulse of constant frequency, phase, and amplitude	That part of a signal that occupies the shortest interval of a signaling code
Signaling rate or modulation rate	Signal elements per second (baud)	The rate at which signal elements are transmitted

Unipolar and polar signaling

- Unipolar: If the signal elements all have the same algebraic sign, i.e., all positive or negative.

- Polar signaling, if one logic state is represented by a positive voltage level, and the other by a negative voltage level.

Tasks of receiver

- First, to know the timing of each bit.
- Second, to determine whether the signal level for each bit position is high or low.

Quality of receiving data

- For successful receiving, we are meant about:

1- SNR: increase in SNR decreases the bit error rate.

2- Data rate: increase in data rate increases the BER

3- BW: Increase in BW increases the data rate.

- Another factor that affects the transmission process is the encoding.
- **Encoding: is the mapping of the data bits to signal element.**

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

Encoding formats, cont.

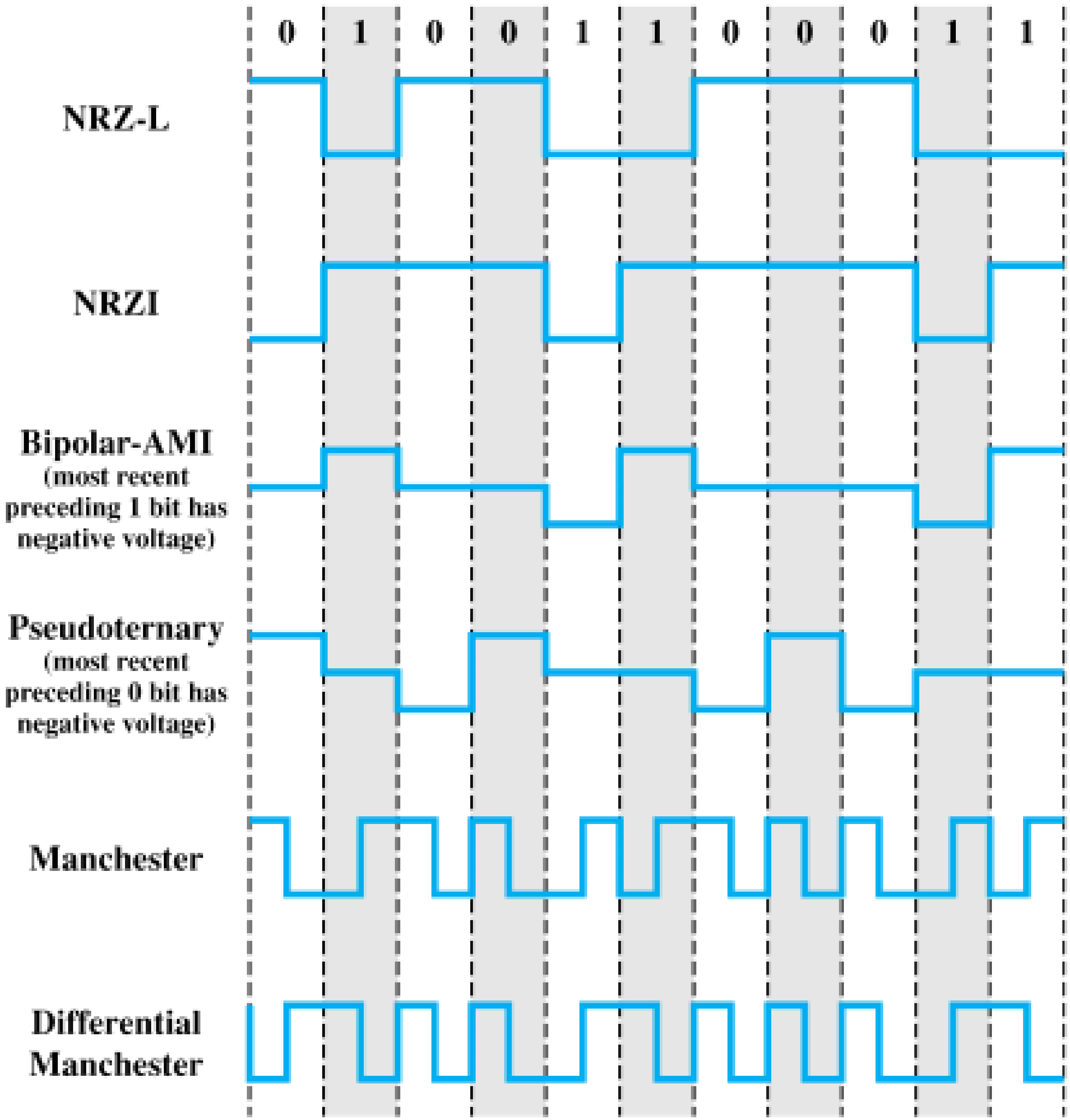


Figure 5.2 Digital Signal Encoding Formats

Signal spectrum

- <u>Important aspects:</u>

- Lack of high frequency components for low BW.
- No DC component make the ac coupling through transformers is possible. electrical isolation reduces the interference.
- Characteristics of the channel is worse near the edge, then, it is important to concentrate the power in the middle of the trans. BW.
- Codes are designed with the aim of shaping the spectrum of the signal.

To evaluate the coding techniques

- **Clocking:**

- The synchronization can be achieved using suitable encoding.

- **Error detection:**

- Make use of the encoding scheme.

- **Immunity to interference and noise :**

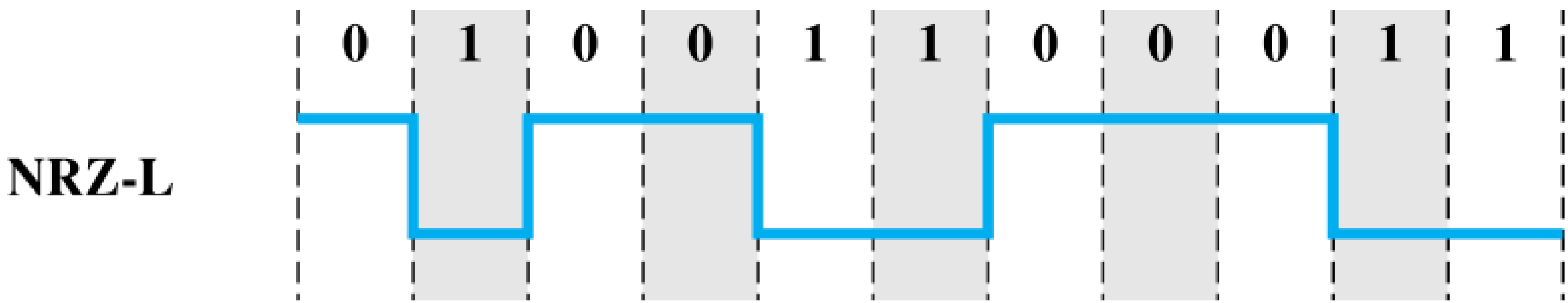
- Certain codes exhibit superior performance in the presence of noise.

- **Cost and complexity:**

- Some codes require a signaling rate that is greater than the actual data rate, increasing the cost and complexity.

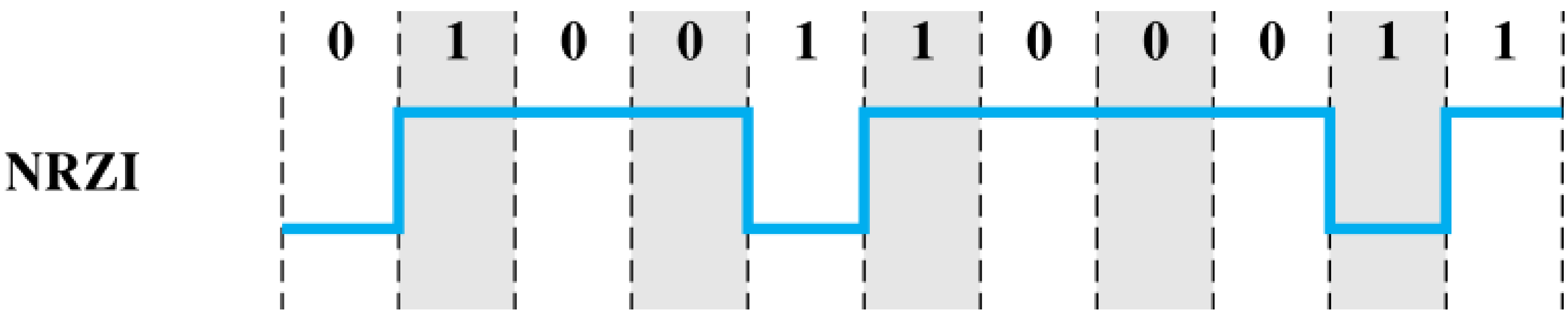
Nonreturn to Zero (NRZ)

- NRZL(Nonreturn to Zero-Level)
- NRZ makes efficient use of the BW. BW is between dc and half the bit rate.
- For simplicity is used in digital magnetic recording.



NRZI

- NRZI (Nonreturn to Zero, invert on ones)
- NRZI: an example of differential encoding
- In diff. encoding: represented in terms of the changes between successive signal elements rather than the signal elements themselves.



Benefits of diff. encoding

- More reliable to detect a transition in the presence of noise than to compare a value to a threshold.

- It is easy to lose the sense of the polarity of the signal without problems.

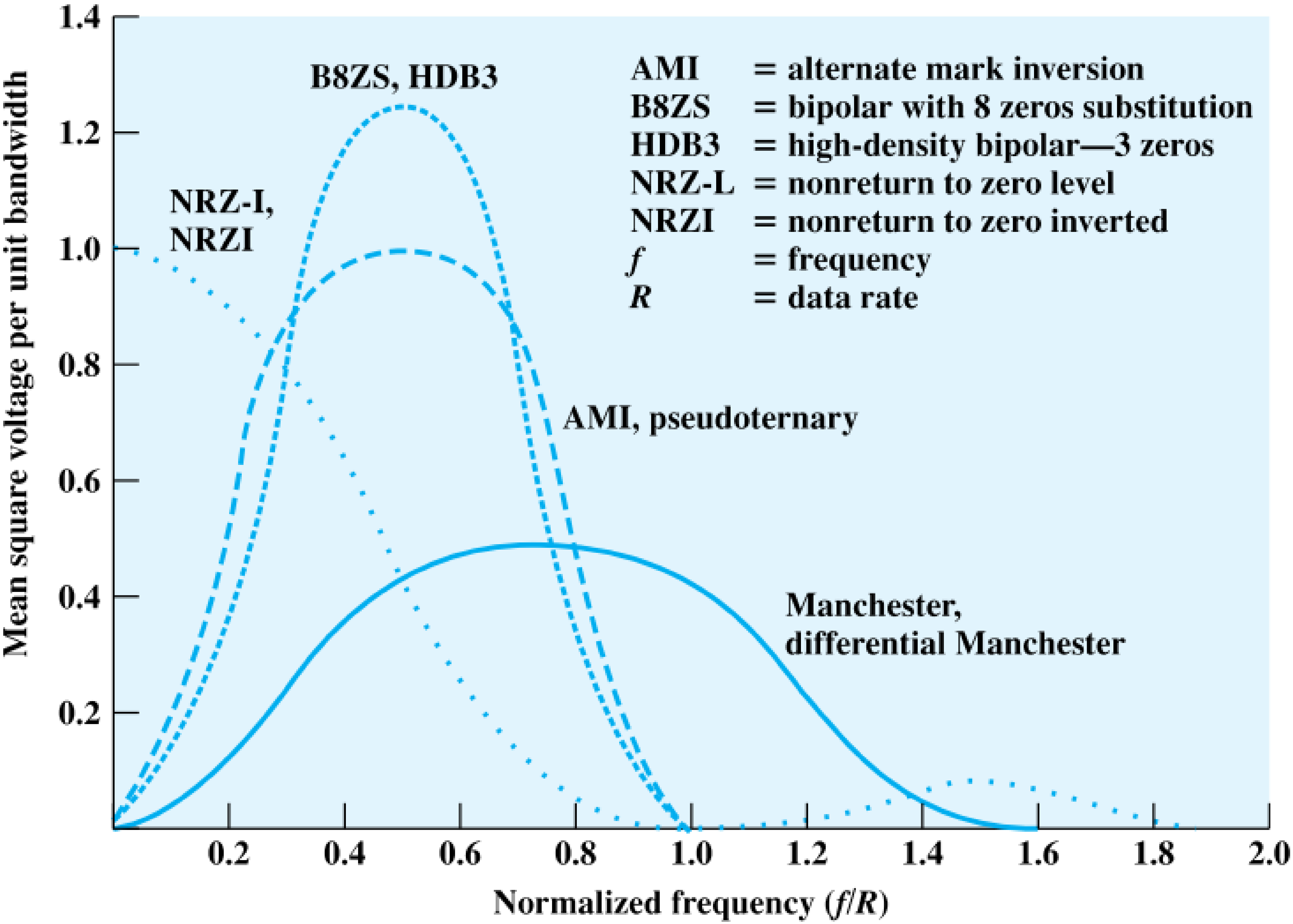
- Ex. Of twisted-pair polarity and comparison with NRZL.

Limitations of NRZ

- Presence of dc component.
- Lack of synchronization in case of long strings of 1s or 0s.

any drift between the clocks of transmitter and receiver will result in loss of synchronization between the two.

BW comparison of different encoding techniques



Multilevel Binary

- Use more than two signal levels.

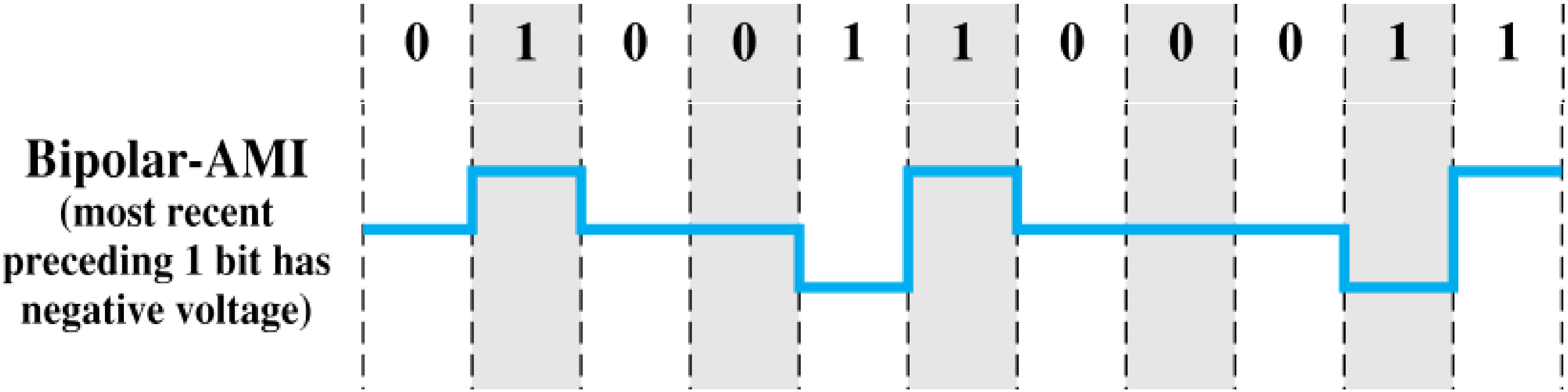
  no line signal and a positive or negative pulse.

- Bipolar-AMI (alternate mark inversion) and pseudoternary.

- Overcome the problems of NRZ codes.

Bipolar-AMI

- A binary 0 is represented by no line signal, and a binary 1 is represented by a positive or negative pulse. The binary 1 pulses must alternate in polarity.

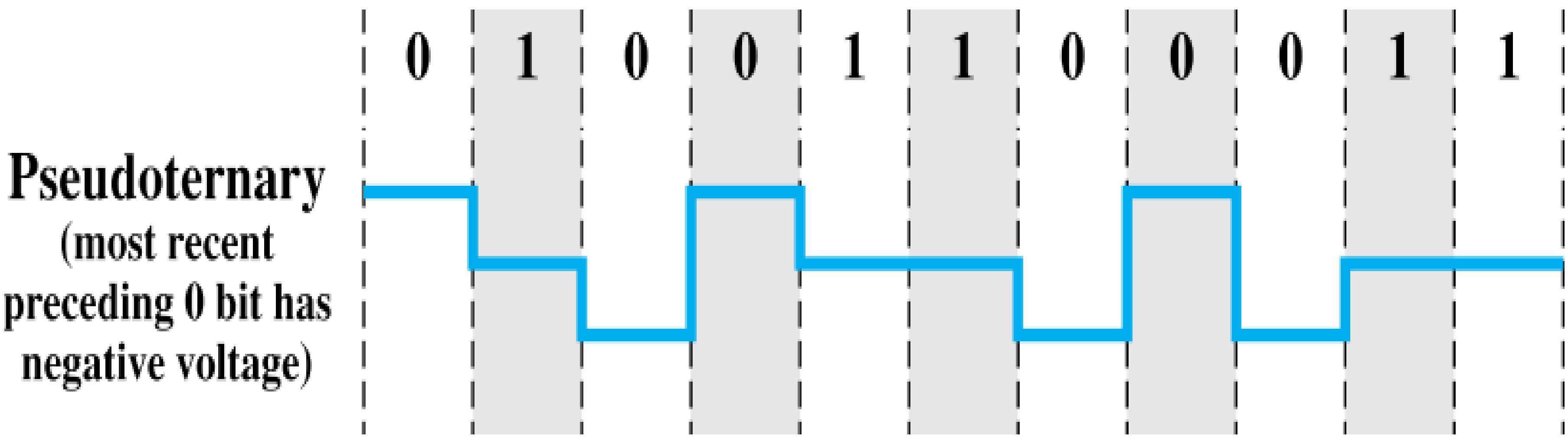


Advantages of bipolar-AMI

- No dc components.
- No loss of synchronization in case of long 1s, but long 0s is problematic.
- Lower BW than NRZ.
- Pulse alternation give good mean for error detection.

Pseudoternary

- Binary 1 is represented by the absence of a line signal, and the binary 0 by alternating positive and negative pulses.
- Problems of long strings of 1s in this case or 0s in the case of AMI can be solved by inserting additional bits for synch as in ISDN.



Disadvantages of multilevels encoding

- Multilevels in not efficient as the NRZ because
- i.e., 3levels…and each level represents only 1 bit
- More power than the two levels system.
- More BER than NRZ at the same SNR.

BER for encoding schemes

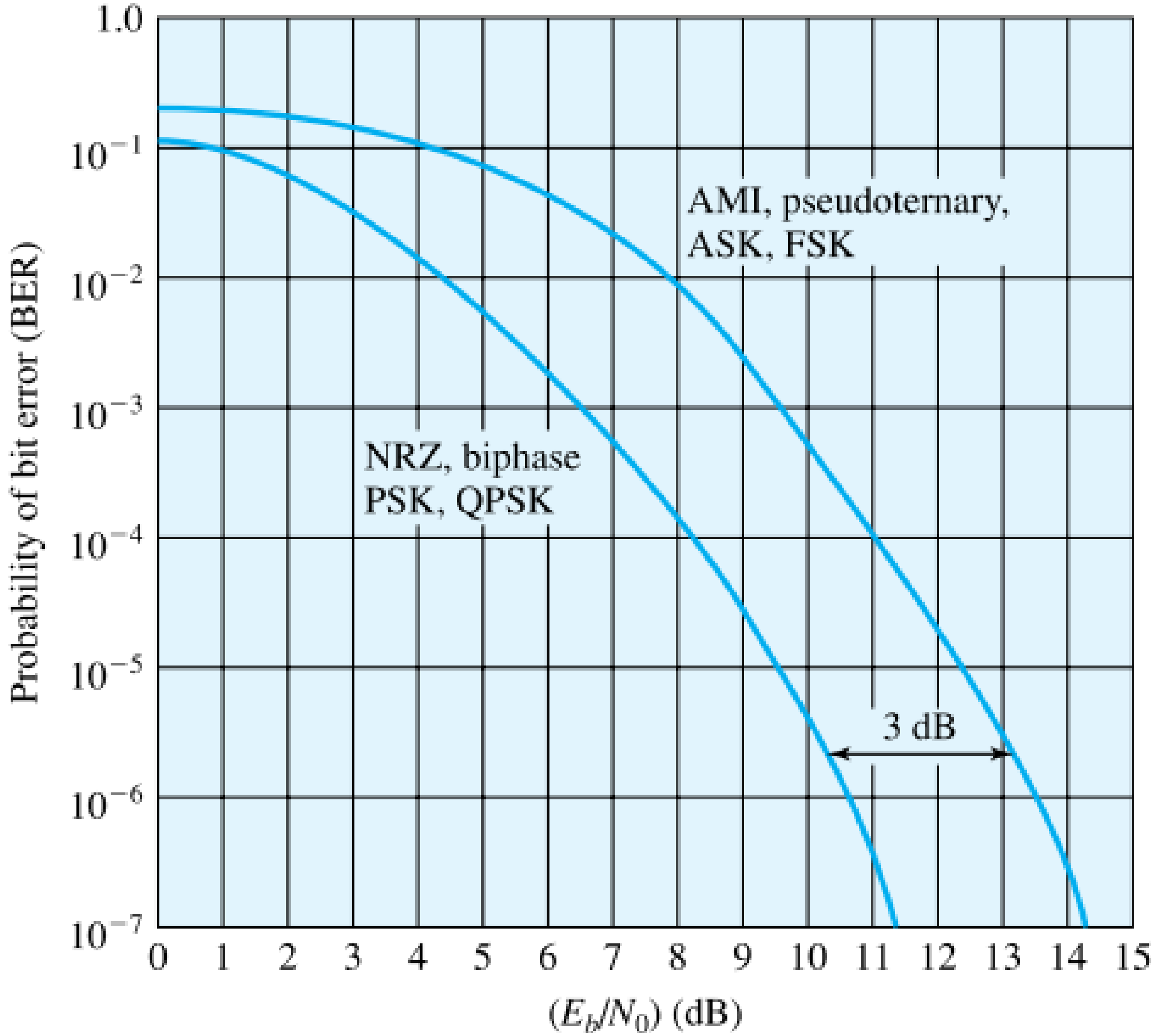
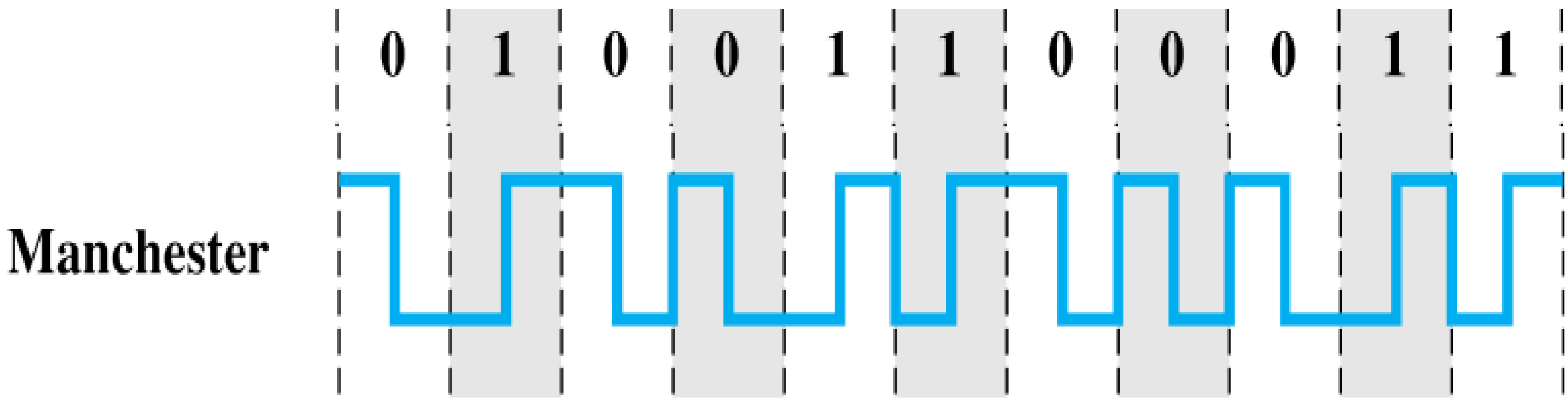


Figure 5.4 Theoretical Bit Error Rate for Various Encoding Schemes

Manchester

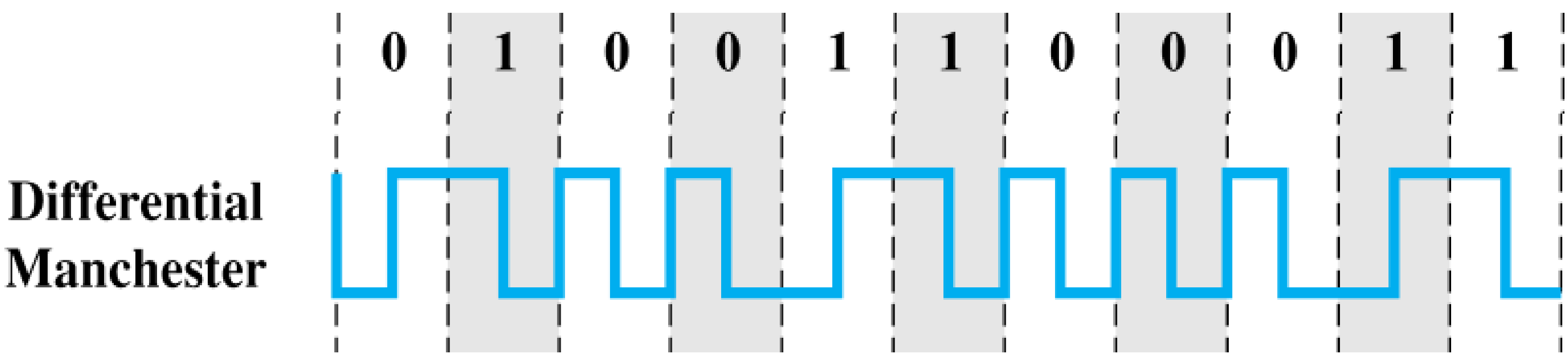
- It is a biphase encoding.

- Low-to-high transition represents a 1, and a high-to-low transition represents a 0.
- A transition at the middle of each bit period which serves as a clocking.
- Has been specified for the (Ethernet) standard for baseband coaxial cable and twisted-pair bus LANs.



Differential Manchester

- 0 is represented by the presence of a transition at the beginning of a bit period, and 1 is represented by the absence of a transition at the beginning of a bit period.
- Midbit transition is used only to provide clocking.
- Has been specified for the IEEE 802.5 token ring LAN, using shielded twisted-pair.



Biphase adv. and disadv.

- **Advantages:**

- Synchronization: using transitions (self-clocking code).
- No dc component
- Error detection: The absence of an expected transition can be used to detect errors.

- **Disadvantages:**

- Maximum modulation rate is twice that for NRZ; the bandwidth required is correspondingly greater.

Modulation Rate

- The modulation rate is the rate at which signal elements are generated.

$$D = \frac{R}{L} = \frac{R}{\log_2 M}$$

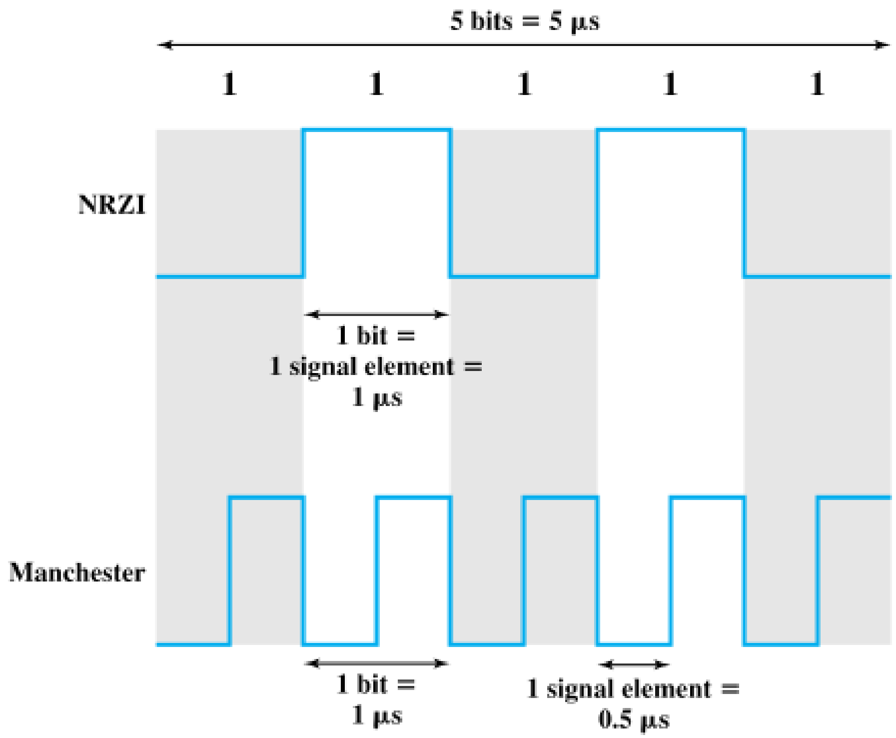


Figure 5.5 A Stream of Binary Ones at 1 Mbps

Scrambling Techniques

- Sequences that would result in a constant voltage level on the line are replaced by filling sequences that will provide sufficient transitions for the receiver’s clock to maintain synchronization.

- The filling sequence must be recognized by the receiver and replaced with the original data sequence.

Goals of scrambling

- No dc component
- No long sequences of zero-level line signals
- No reduction in data rate
- Error-detection capability

Bipolar with 8-zeros substitution (B8ZS)

- Commonly used in North America.
- Based on a bipolar-AMI.

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

High-density bipolar-3 zeros (HDB3)

- Used in Europe and Japan.
- Based on the use of AMI.
- It replaces strings of four zeros with sequences containing one or two pulses.

	Number of Bipolar Pulses (ones) since Last Substitution	
Polarity of Preceding Pulse	**Odd**	**Even**
−	0 0 0 −	+ 0 0 +
+	0 0 0 +	− 0 0 −

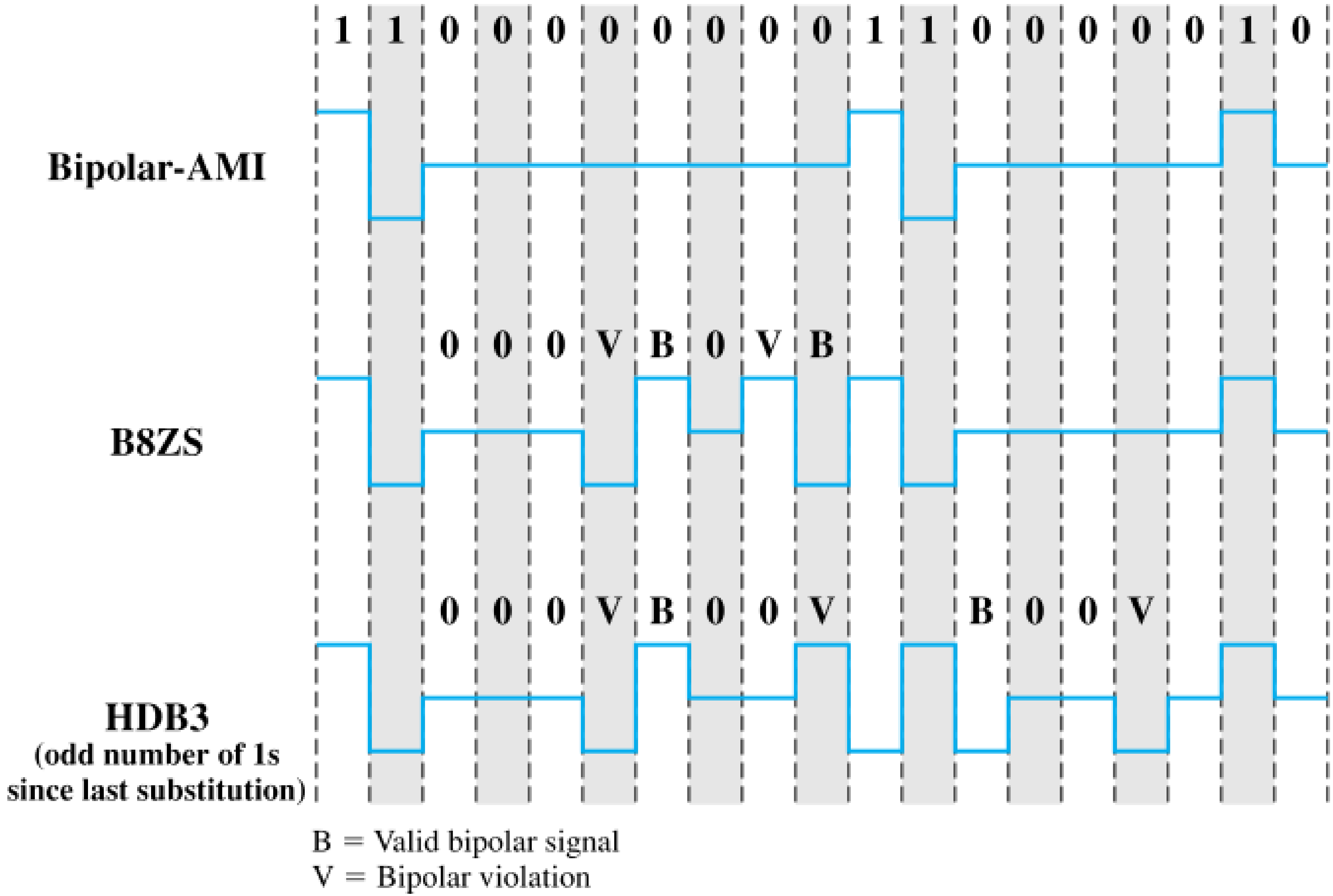


Figure 5.6 Encoding Rules for B8ZS and HDB3

Advantages of B8ZS and HDB3

- Neither has a dc component.
- Most of the energy is concentrated in a sharp spectrum around a frequency equal to one-half the data rate.
- Well suited to high data rate transmission.

Digital data, analog signals

- Used for transmitting digital data through the public telephone network.
  - Amplitude shift keying (ASK),
  - Frequency shift keying (FSK),
  - Phase shift keying (PSK).
- The resulting signal occupies a bandwidth centered on the carrier frequency.

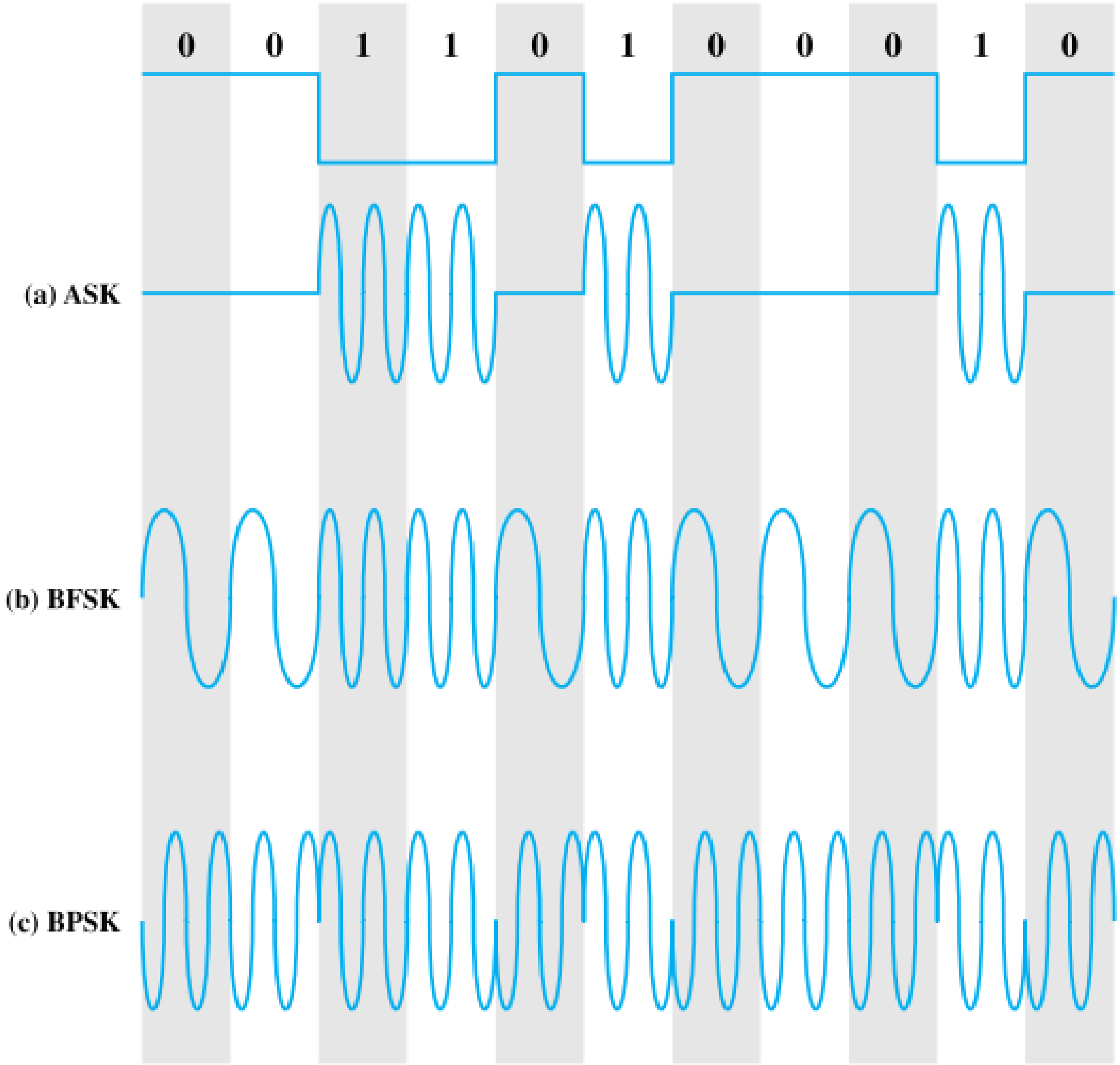


Figure 5.7 Modulation of Analog Signals for Digital Data

ASK

- Two binary values are represented by two different amplitudes.
- ASK is susceptible to sudden gain changes.
- Is a rather inefficient modulation technique.
- Is used to transmit digital data over optical fiber.

$$\textbf{ASK} \qquad s(t) = \begin{cases} A\cos(2\pi f_c t) & \text{binary } 1 \\ 0 & \text{binary } 0 \end{cases}$$

FSK

- The most common form of FSK is binary FSK (BFSK).
- In BFSK, the two binary values are represented by two different frequencies near the carrier frequency.

$$\textbf{BFSK} \qquad s(t) = \begin{cases} A\cos(2\pi f_1 t) & \text{binary 1} \\ A\cos(2\pi f_2 t) & \text{binary 0} \end{cases}$$

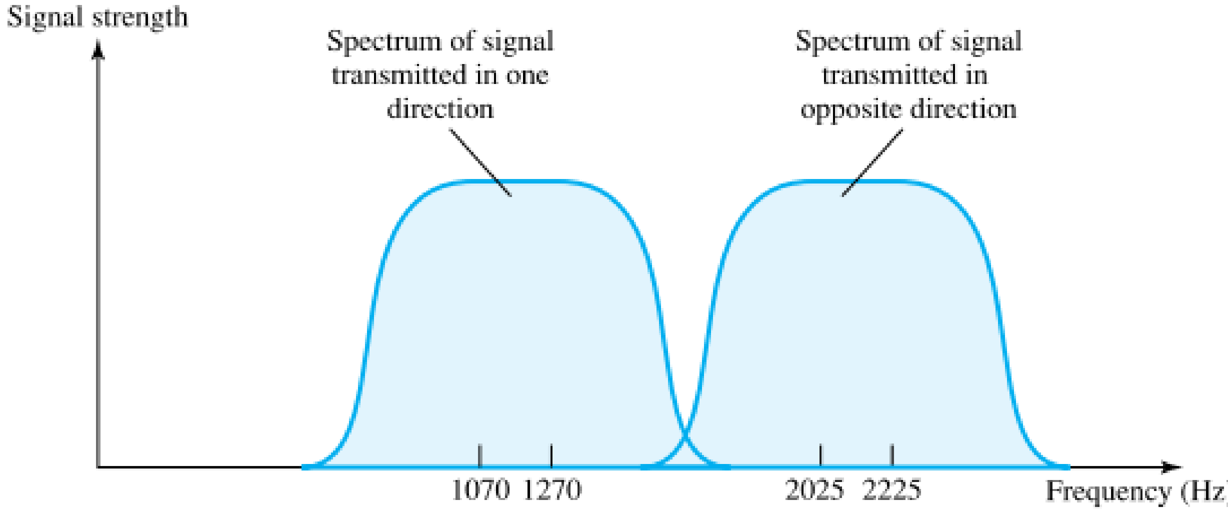


Figure 5.8 Full-Duplex FSK Transmission on a Voice-Grade Line

FSK, cont.

- BFSK is less susceptible to error than ASK.
- Used for high-frequency (3 to 30 MHz).
- More bandwidth efficient is the multiple FSK (MFSK).
- More than two frequencies can be used (Multiple FSK).

$$\textbf{MFSK} \qquad s_i(t) = A\cos 2\pi f_i t, \qquad 1 \le i \le M$$

$$f_i = f_c + (2i - 1 - M)f_d$$

f_c = the carrier frequency

f_d = the difference frequency

M = number of different signal elements = 2^L

L = number of bits per signal element

MFSK

- Each output signal element is held for a period Ts=LT of seconds.

- Total BW is ***$2Mf_d = M/Ts$***

  Where ***$2f_d=1/Ts$***

Example

EXAMPLE 5.2 Figure 5.9 shows an example of MFSK with $M = 4$. An input bit stream of 20 bits is encoded 2 bits at a time, with each of the four possible 2-bit combinations transmitted as a different frequency. The display in the figure shows the frequency transmitted (y-axis) as a function of time (x-axis). Each column represents a time unit T_s in which a single 2-bit signal element is transmitted. The shaded rectangle in the column indicates the frequency transmitted during that time unit.

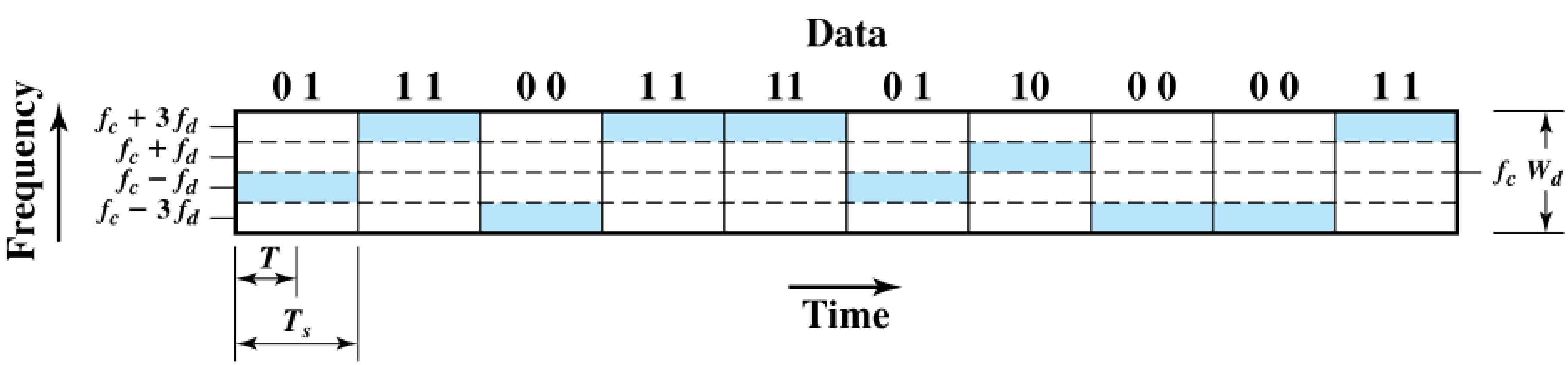


Figure 5.9 MFSK Frequency Use ($M = 4$)

Phase Shift Keying (PSK)

- The carrier signal is shifted to represent data.

- **Two-Level PSK:**

$$\textbf{BPSK} \qquad s(t) = \begin{cases} A\cos(2\pi f_c t) \\ A\cos(2\pi f_c t + \pi) \end{cases} = \begin{cases} A\cos(2\pi f_c t) & \text{binary 1} \\ -A\cos(2\pi f_c t) & \text{binary 0} \end{cases}$$

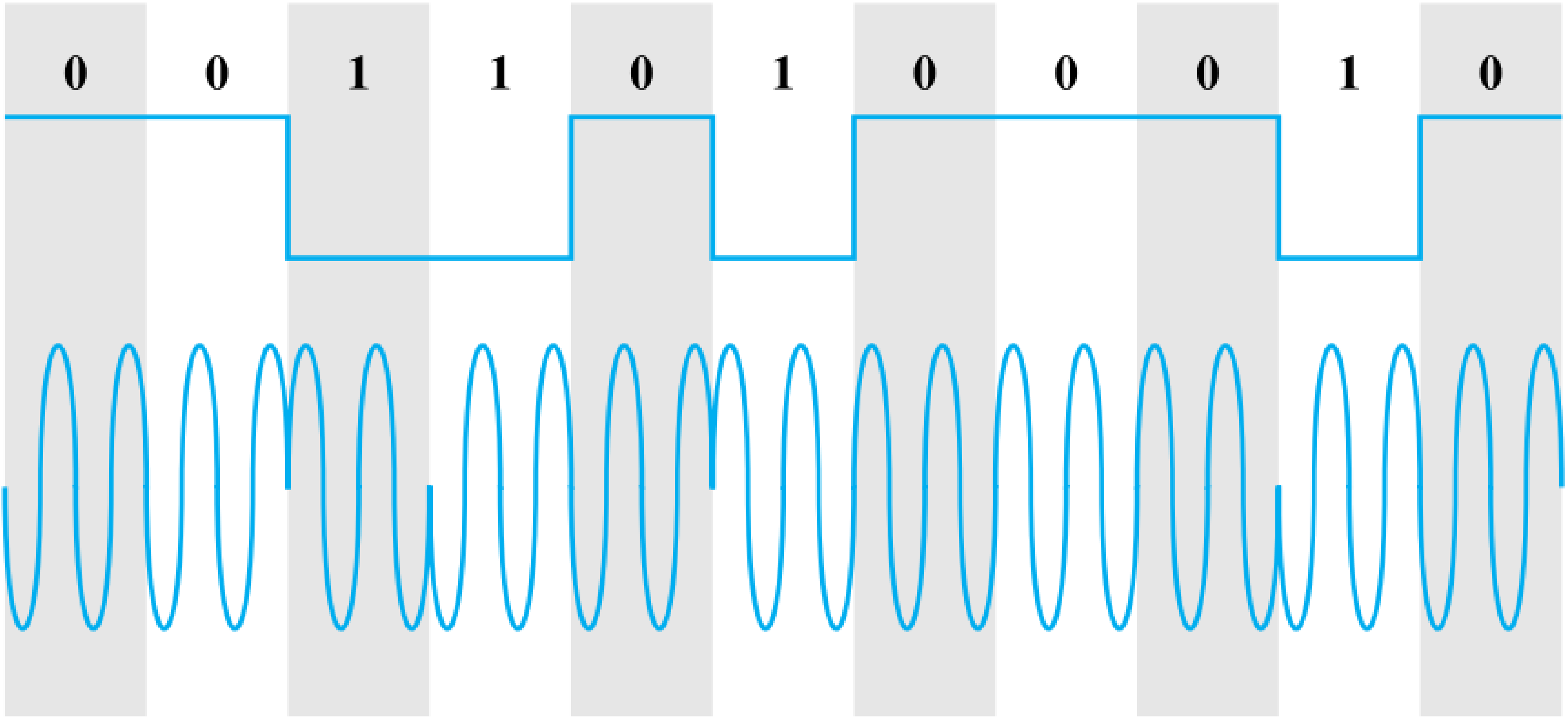
- We can define the transmitted signal as

$$\textbf{BPSK} \qquad s_d(t) = A\,d(t)\cos(2\pi f_c t)$$

Differential PSK (DPSK)

- A binary 0 is represented by sending a signal burst of the same phase as the previous signal burst sent.
- A binary 1 is represented by sending a signal burst of opposite phase to the preceding one.

Differential PSK (DPSK), cont.



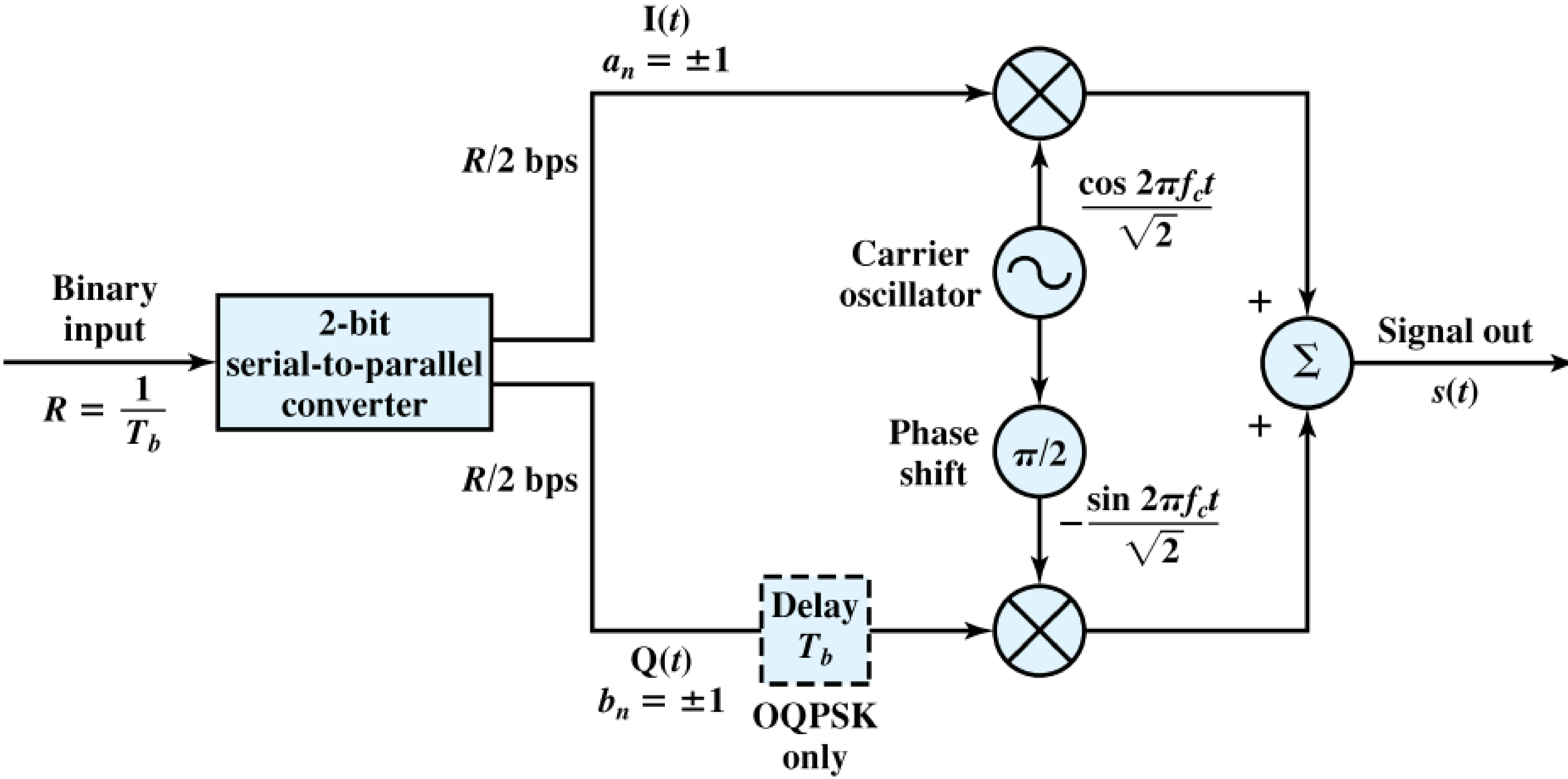
- DPSK avoids the requirement for an accurate local oscillator phase at the receiver that is matched with the transmitter.

Four-Level PSK

- known as quadrature phase shift keying (QPSK).
- Uses phase shifts separated by multiples of π/2.
- More efficient use of bandwidth can be achieved.

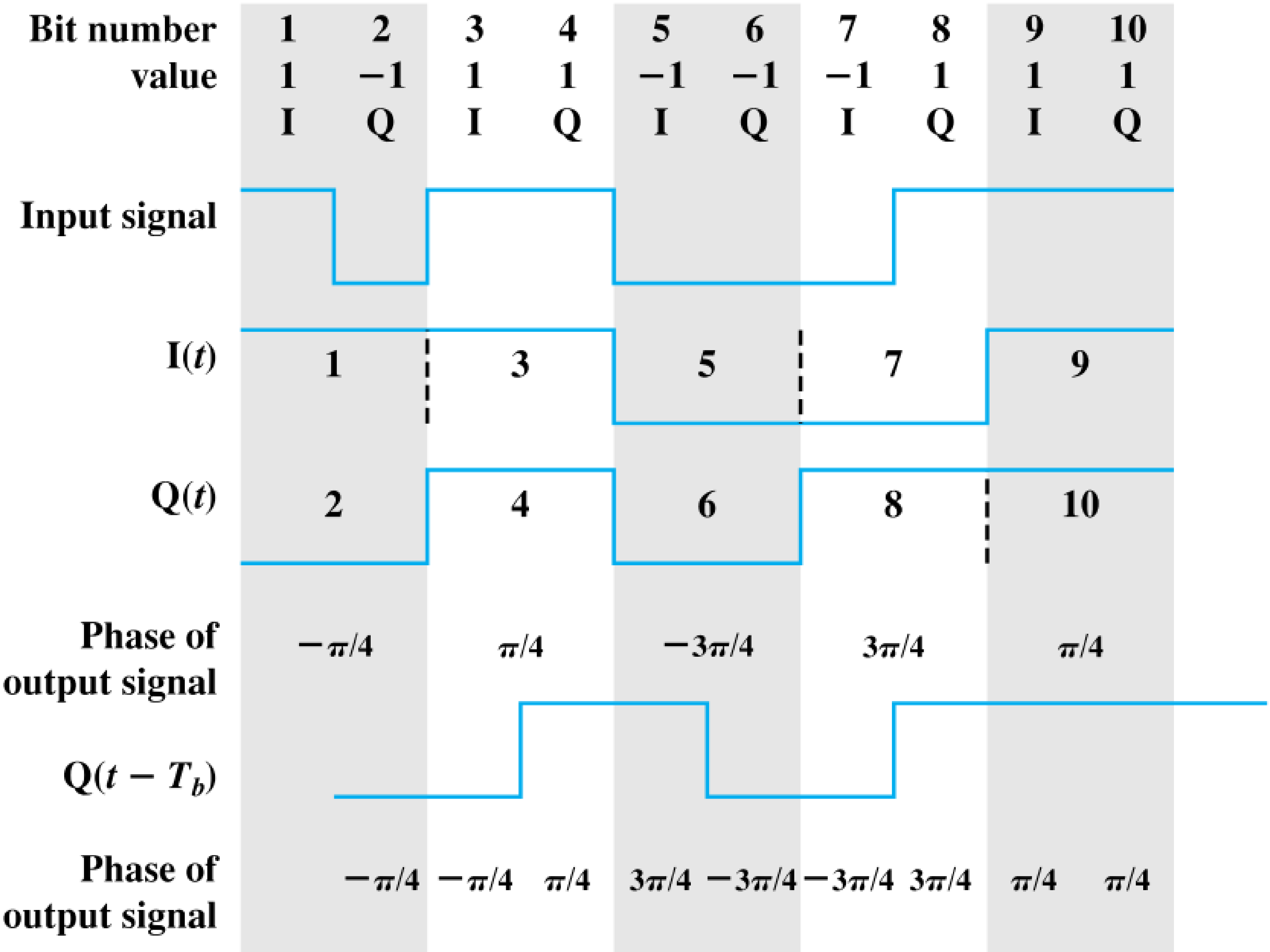
$$\textbf{QPSK} \qquad s(t) = \begin{cases} A\cos\left(2\pi f_c t + \dfrac{\pi}{4}\right) & 11 \\ A\cos\left(2\pi f_c t + \dfrac{3\pi}{4}\right) & 01 \\ A\cos\left(2\pi f_c t - \dfrac{3\pi}{4}\right) & 00 \\ A\cos\left(2\pi f_c t - \dfrac{\pi}{4}\right) & 10 \end{cases}$$

QPSK modulator



QPSK $$s(t) = \frac{1}{\sqrt{2}} I(t) \cos 2\pi f_c t - \frac{1}{\sqrt{2}} Q(t) \sin 2\pi f_c t$$

Example of QPSK and OQPSK



Advantage of OQPSK over QPSK

- Spectral characteristics and bit error performance are the same for the two.
- In OQPSK, only one of two bits in the pair can change sign at any time and thus the phase change in the combined signal never exceeds 90°
- Large phase shifts at high transition rates difficult to perform because physical limitations on phase modulators.
- It is easier to control the BW spreading if the phase changes are smaller.

Multilevel PSK

- It is possible to transmit number of bits at a time using different phases.
- Each angle can have more than one amplitude.
- For example, a standard 9600 bps modem uses 12 phase angles, four of which have two amplitude values, for a total of 16 different signal elements.

Performance

- **Bandwidth**

$$\textbf{ASK} \qquad B_T = (1 + r)R$$

$$\textbf{MPSK} \qquad B_T = \left(\frac{1 + r}{L}\right)R = \left(\frac{1 + r}{\log_2 M}\right)R$$

$$\textbf{MFSK} \qquad B_T = \left(\frac{(1 + r)M}{\log_2 M}\right)R$$

- Where R is the bit rate and r is related to the technique by which the signal is filtered to establish a bandwidth for transmission $0 < r < 1$
- L is the number of bits encoded per signal element and M is the number of different signal elements.

Bandwidth Efficiency (R/B_T)

	$r = 0$	$r = 0.5$	$r = 1$
ASK	1.0	0.67	0.5
FSK	0.5	0.33	0.25
Multilevel FSK			
$M = 4, L = 2$	0.5	0.33	0.25
$M = 8, L = 3$	0.375	0.25	0.1875
$M = 16, L = 4$	0.25	0.167	0.125
$M = 32, L = 5$	0.156	0.104	0.078
PSK	1.0	0.67	0.5
Multilevel PSK			
$M = 4, L = 2$	2.00	1.33	1.00
$M = 8, L = 3$	3.00	2.00	1.50
$M = 16, L = 4$	4.00	2.67	2.00
$M = 32, L = 5$	5.00	3.33	2.50

Quadrature Amplitude Modulation

- Is used in the asymmetric digital subscriber line (ADSL).
- Is a combination of ASK and PSK.
- Uses two copies of the carrier frequency, one shifted by 90° with respect to the other.
- For QAM, each carrier is ASK modulated.
- The two independent signals are simultaneously transmitted over the same medium.

QAM $$s(t) = d_1(t)\cos 2\pi f_c t + d_2(t)\sin 2\pi f_c t$$

QAM modulator