Chapter 4

Digital Transmission

DIGITAL-TO-DIGITAL CONVERSION

Data

- ***Digital***
- ***Analog***

Signals

- ***Digital***
- ***Analog***

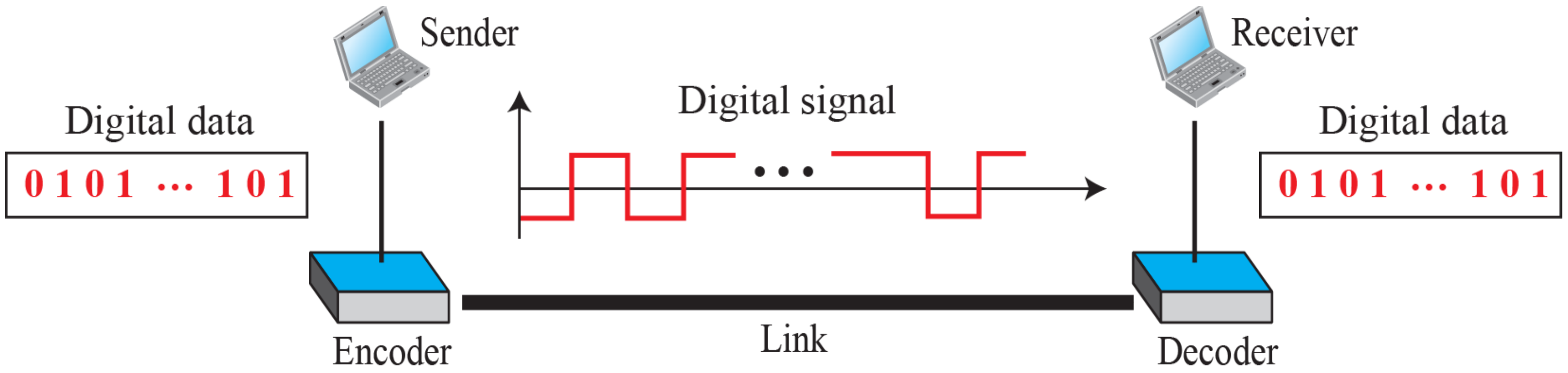
Line Coding

- ***The process of converting a sequence of bits to digital signals.***

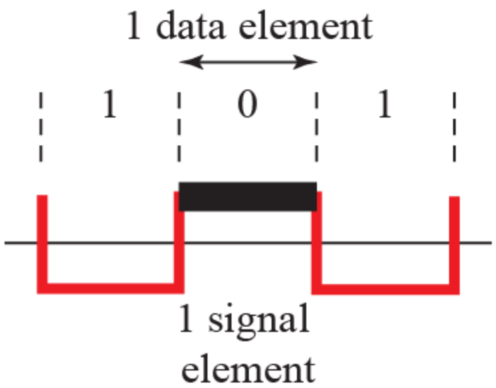
- ***At the sender, digital data are encoded into a digital signal***

- ***at the receiver, the digital data are recreated by decoding the digital signal.***

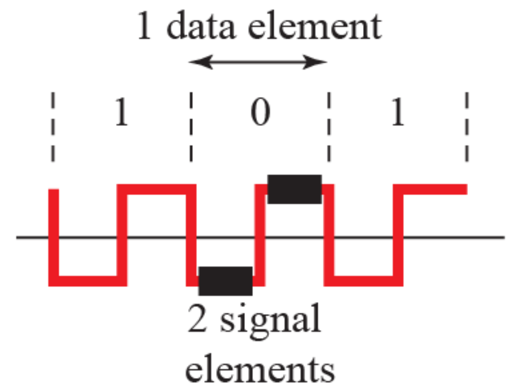
Line coding and decoding



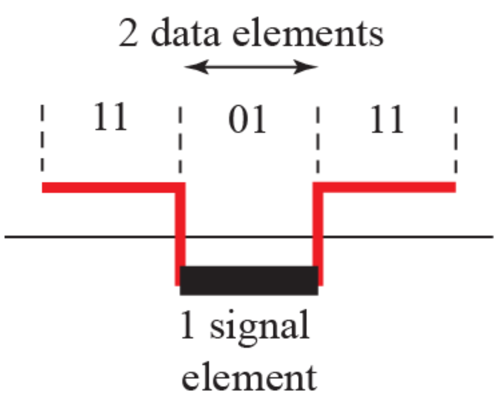
Signal elements versus data elements



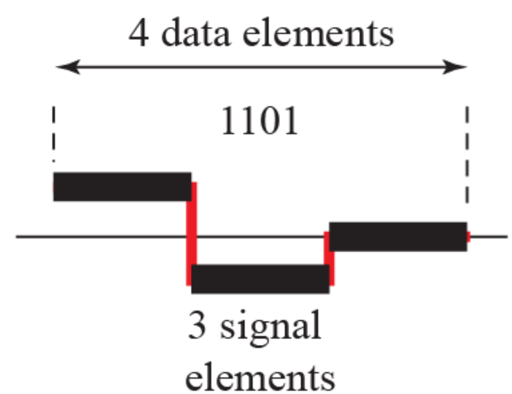
a. One data element per one signal element (r = 1)



b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$



c. Two data elements per one signal element (r = 2)



d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

Example

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?

Solution

We assume that the average value of c is 1/2. The baud rate is then

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

Example

The maximum data rate of a channel is
$N_{max} = 2 \times B \times \log2 L$ (defined by the Nyquist formula).
Does this agree with the previous formula for N_{max}?

Solution

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 = 1/2), then we have

$$N_{max} = (1/c) \times B \times r = 2 \times B \times \log_2 L$$

Example

In a digital transmission, the receiver clock is 0.1 percent faster than the sender clock. How many extra bits per second does the receiver receive if the data rate is 1 kbps? How many if the data rate is 1 Mbps?

Solution

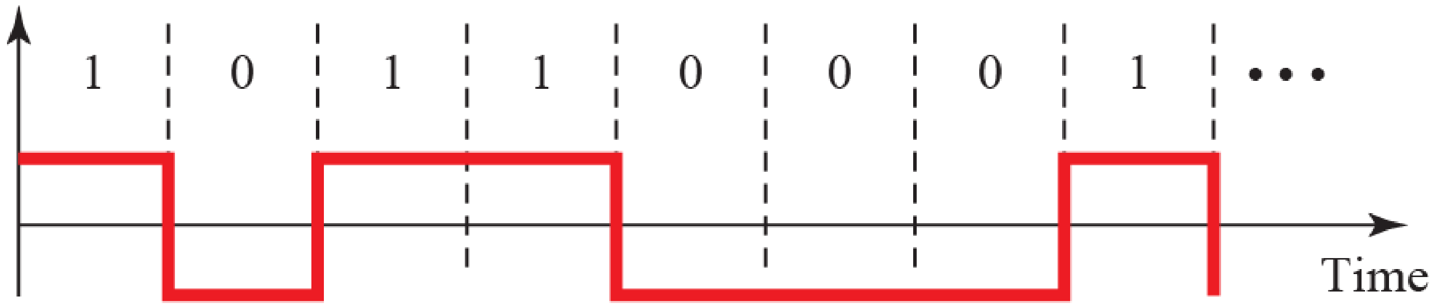
At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

1000 bits sent → 1001 bits received → 1 extra bps

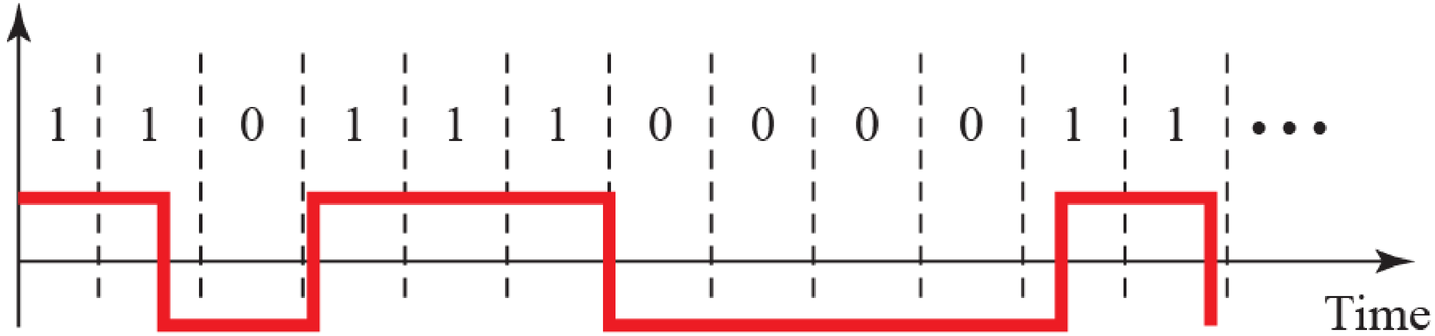
At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

1,000,000 bits sent → 1,001,000 bits received → 1000 extra bps

Effect of lack of synchronization

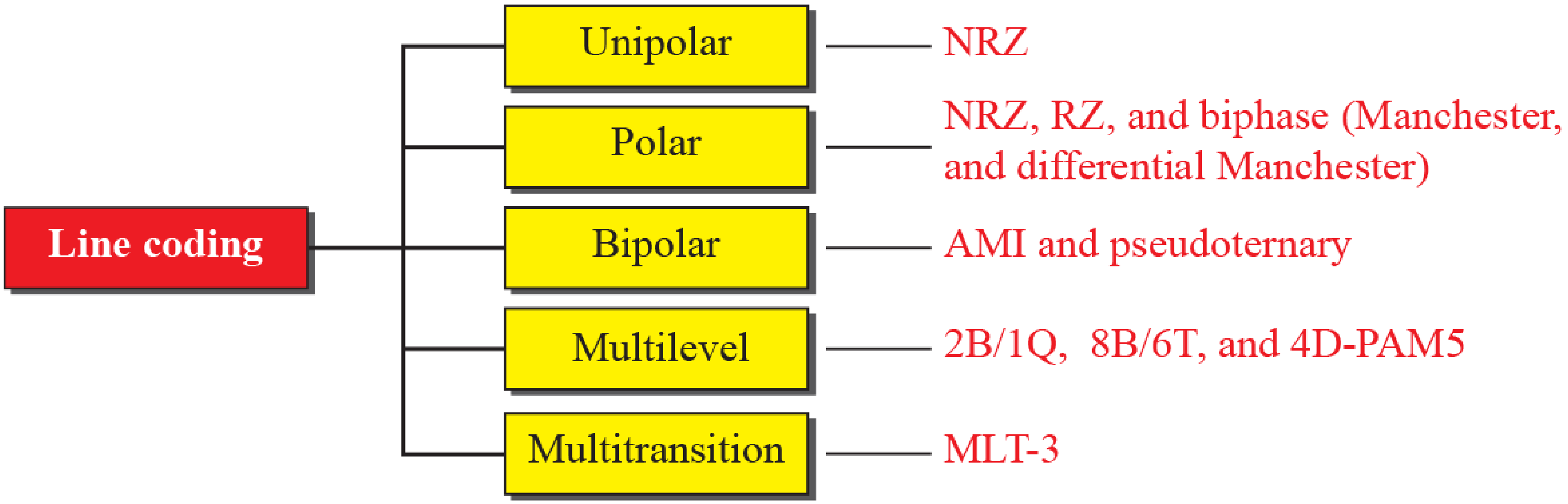


a. Sent

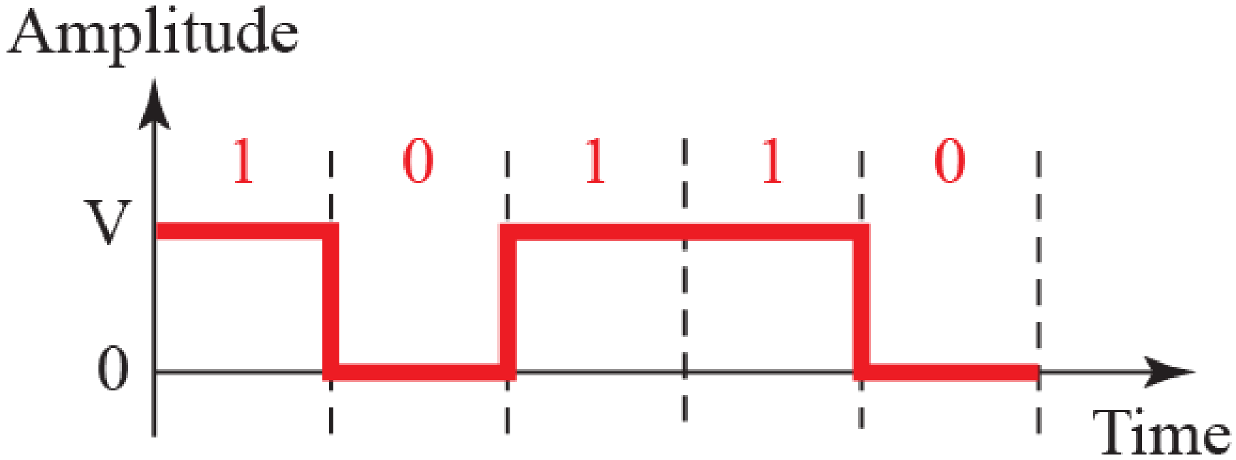


b. Received

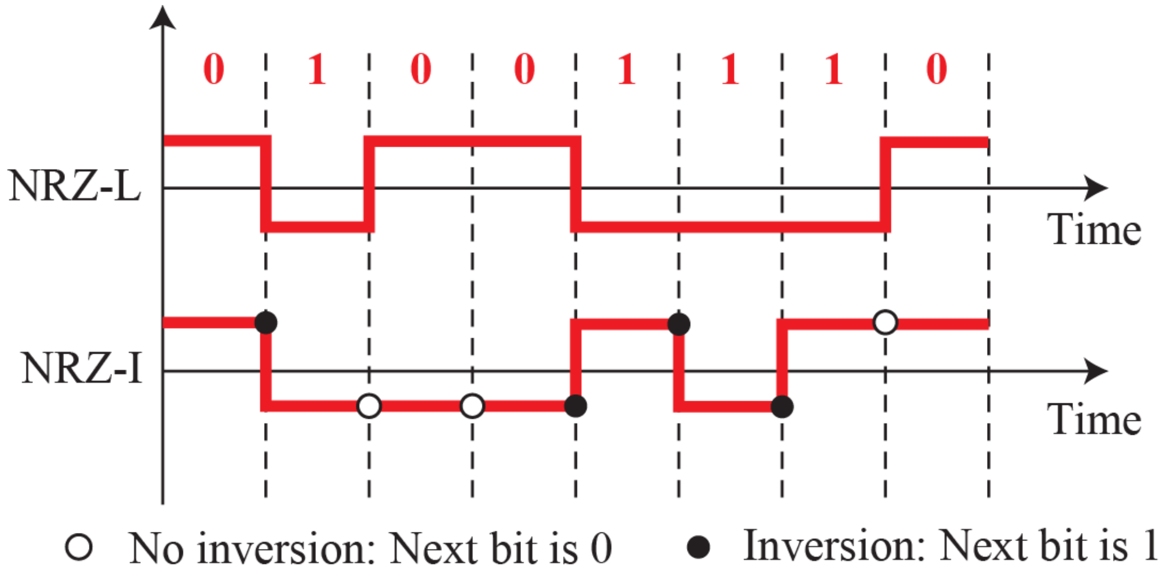
Line coding scheme



Unipolar scheme



Polar schemes (NRZ-L and NRZ-I)



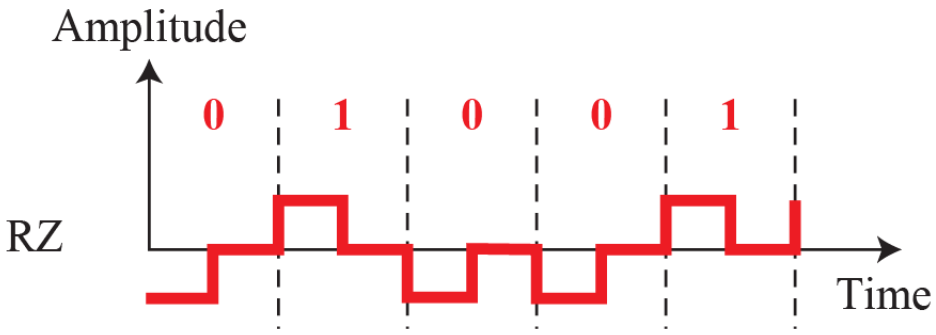
Example

A system is using NRZ-I to transfer 10-Mbps data. What are the average signal rate and minimum bandwidth?

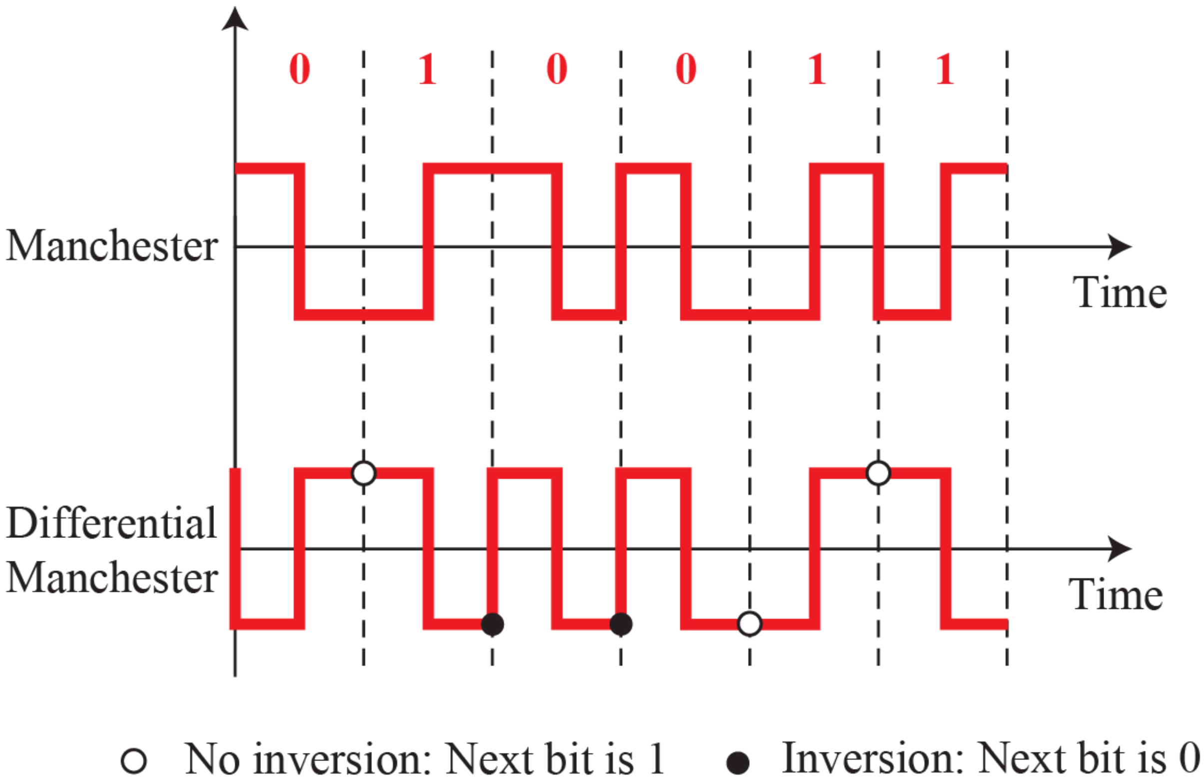
Solution

The average signal rate is S = N/2 = 500 kbaud. The minimum bandwidth for this average baud rate is B_{min} = S = 500 kHz.

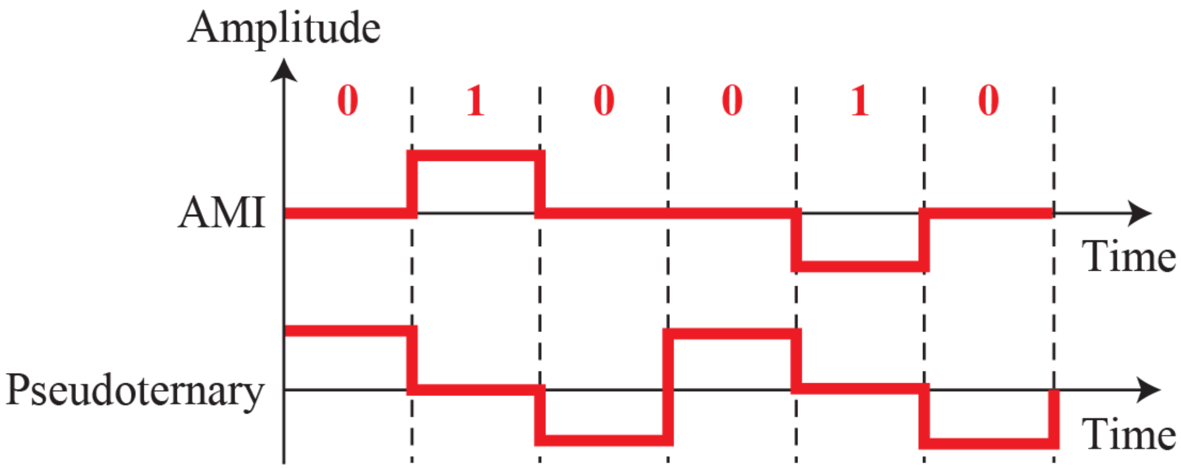
Polar schemes (RZ)



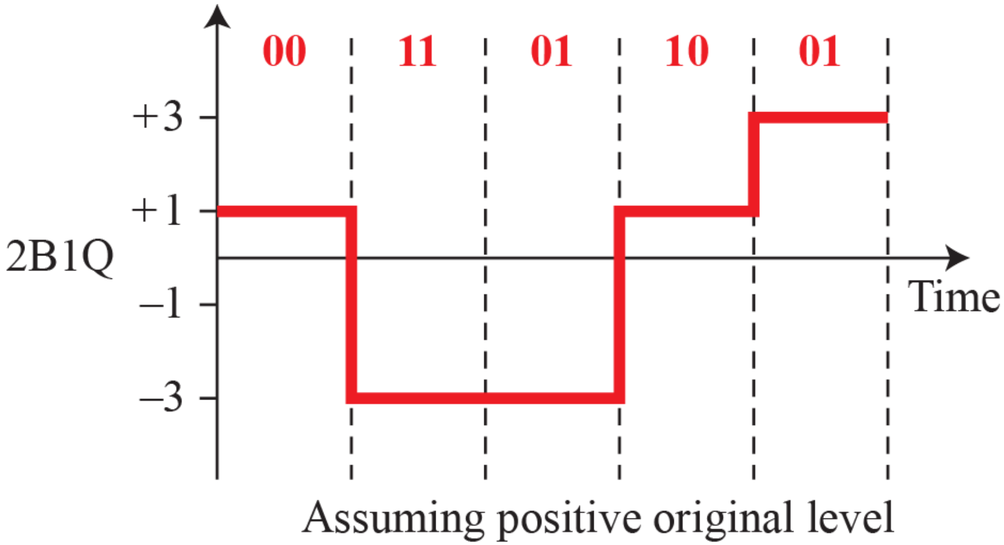
Polar biphase



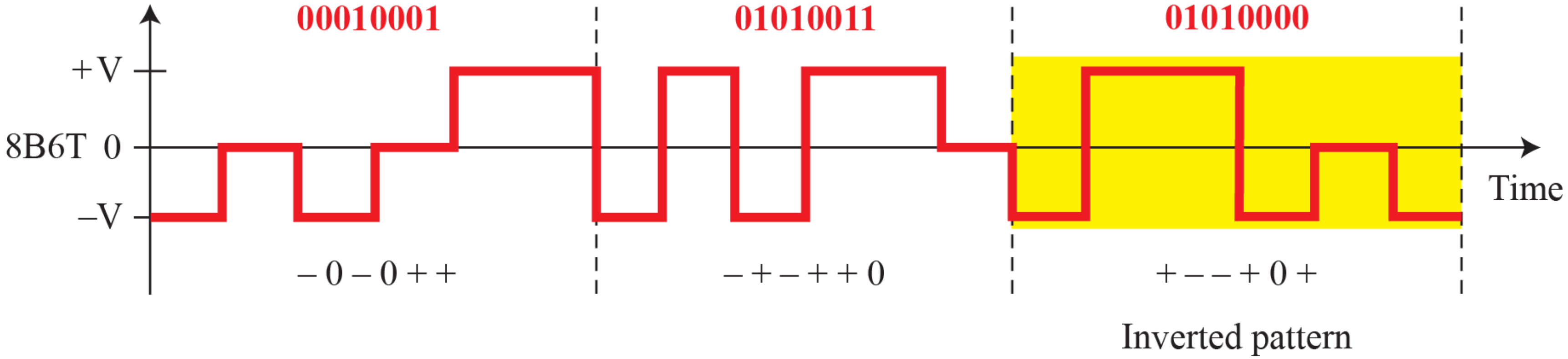
Polar schemes: AMI and pseudoternary



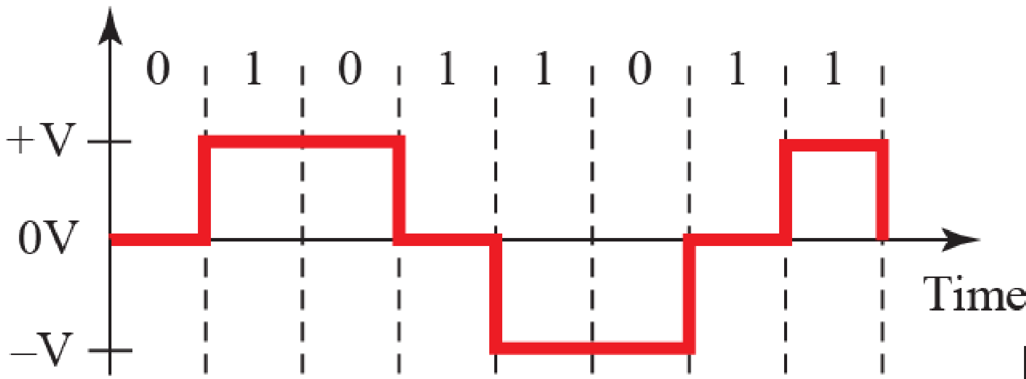
Multilevel: 2B1Q



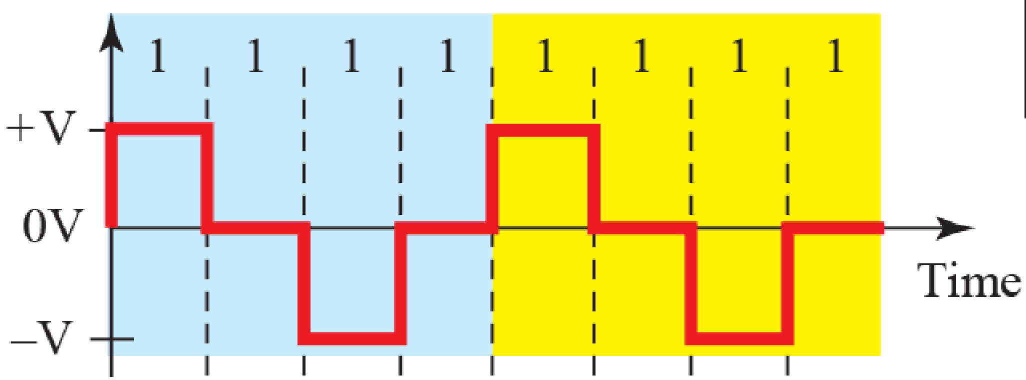
Multilevel: 8B6T



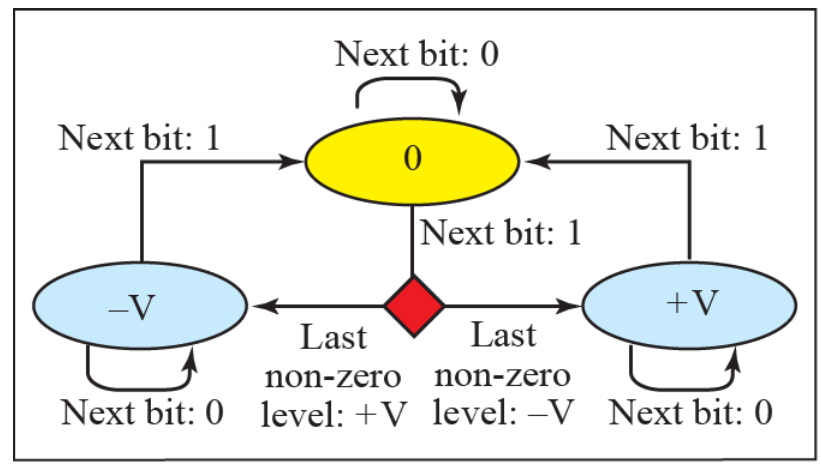
Multi-transition MLT-3 scheme



a. Typical case



b. Worst case



c. Transition states

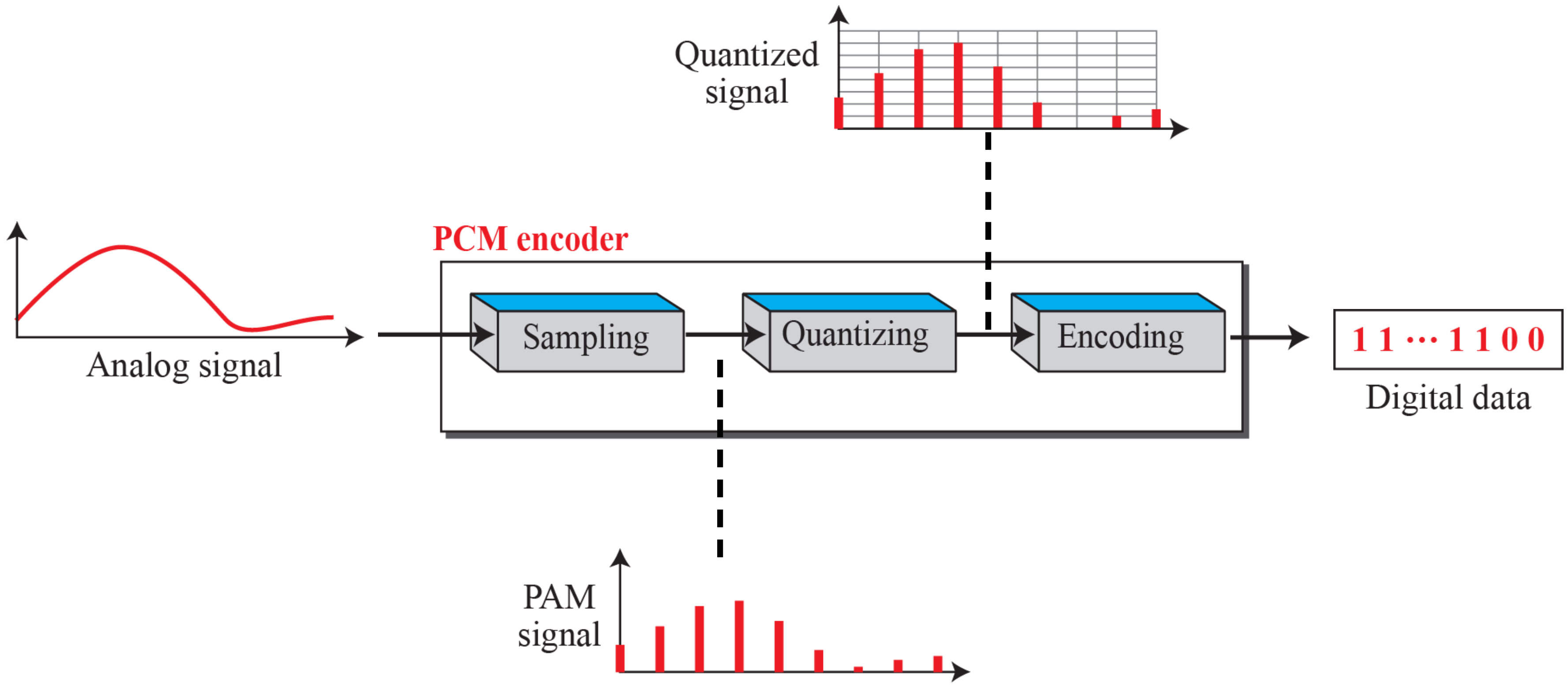
ANALOG-TO-DIGITAL CONVERSION

- to change an analog signal to digital data

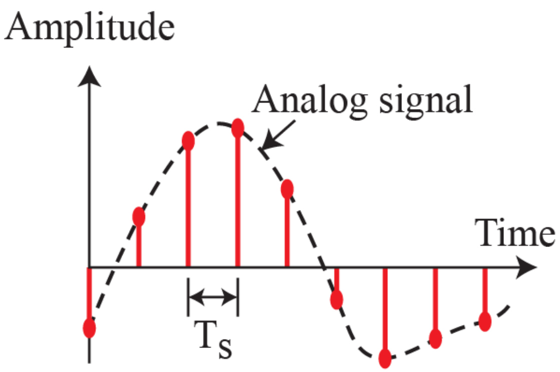
Pulse Code Modulation (PCM)

The most common technique to change an analog signal to digital data (digitization)

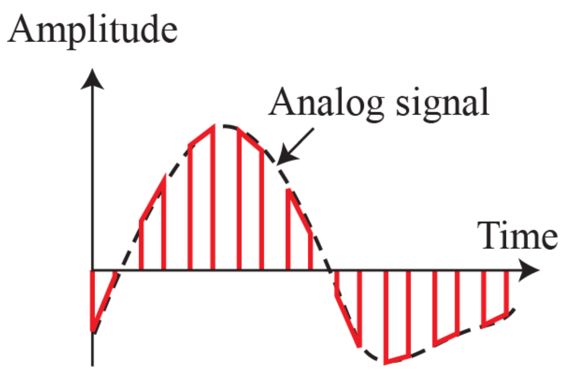
Components of PCM encoder



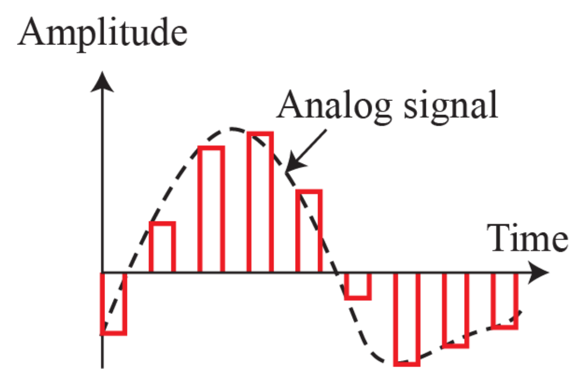
Three different sampling methods for PCM



a. Ideal sampling

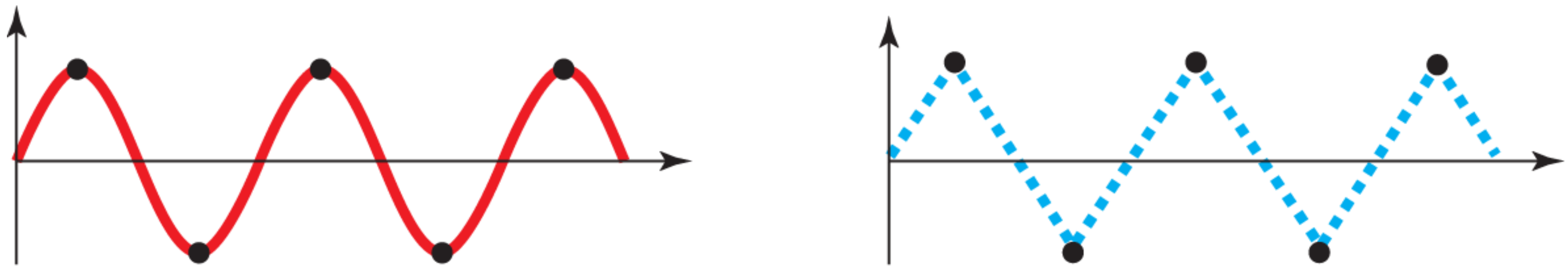


b. Natural sampling

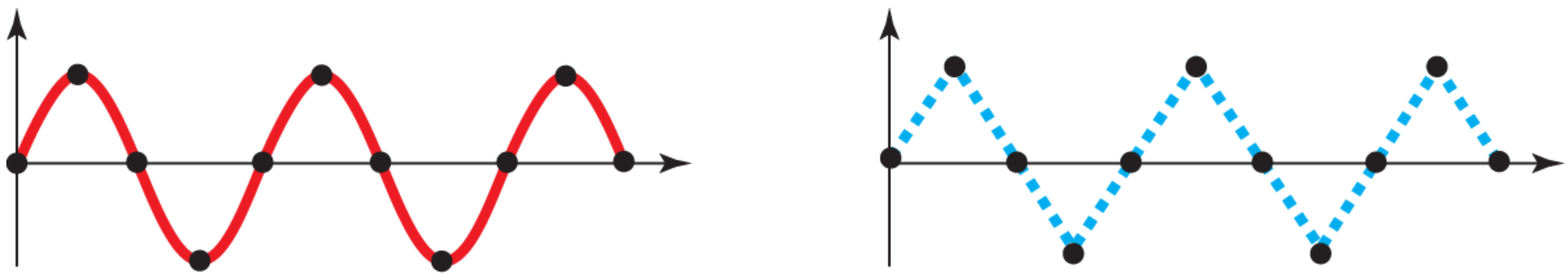


c. Flat-top sampling

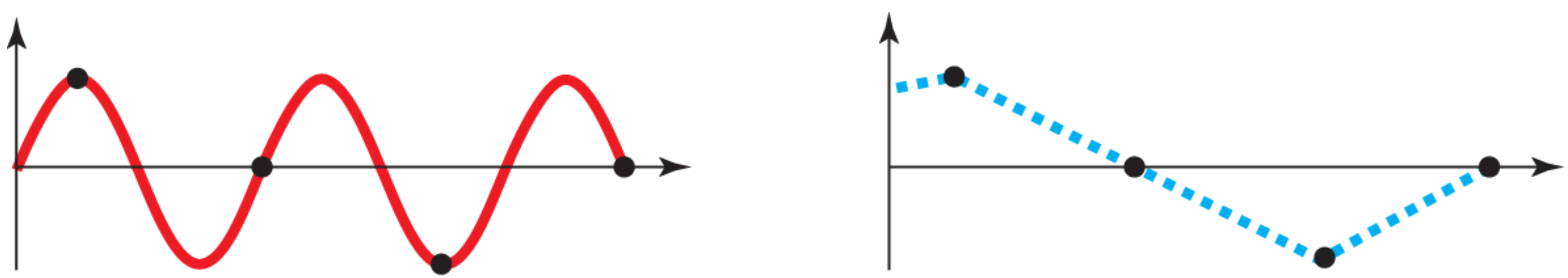
Recovery of a sine wave with different sampling rates.



a. Nyquist rate sampling: $f_s = 2\ f$



b. Oversampling: $f_s = 4\ f$

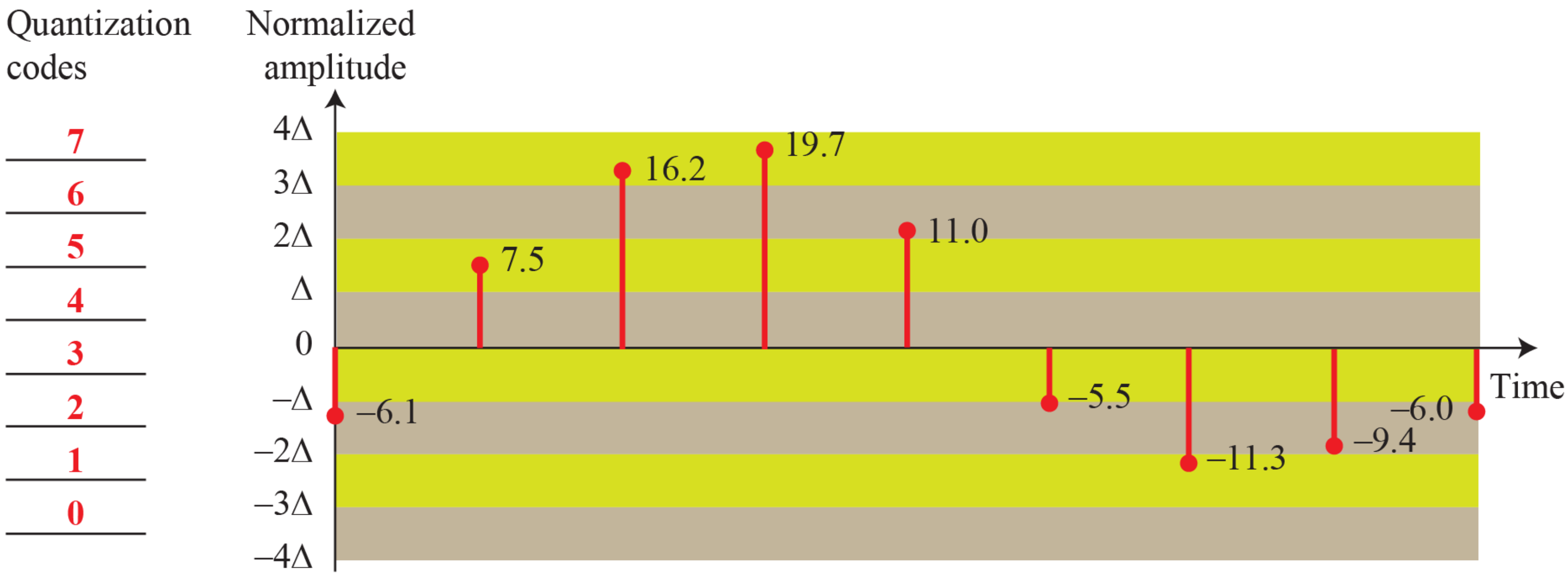


c. Undersampling: $f_s = f$

Example

Telephone companies digitize voice by assuming a maximum frequency of 4000 Hz. The sampling rate therefore is 8000 samples per second.

Quantization and encoding of a sampled signal



Normalized PAM values	–1.22	1.50	3.24	3.94	2.20	–1.10	–2.26	–1.88	–1.20
Normalized quantized values	–1.50	1.50	3.50	3.50	2.50	–1.50	–2.50	–1.50	–1.50
Normalized error	–0.28	0	+0.26	–0.44	+0.30	–0.40	–0.24	+0.38	–0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

Example

We want to digitize the human voice. What is the bit rate, assuming 8 bits per sample?

Solution

The human voice normally contains frequencies from 0 to 4000 Hz. So the sampling rate and bit rate are calculated as follows:

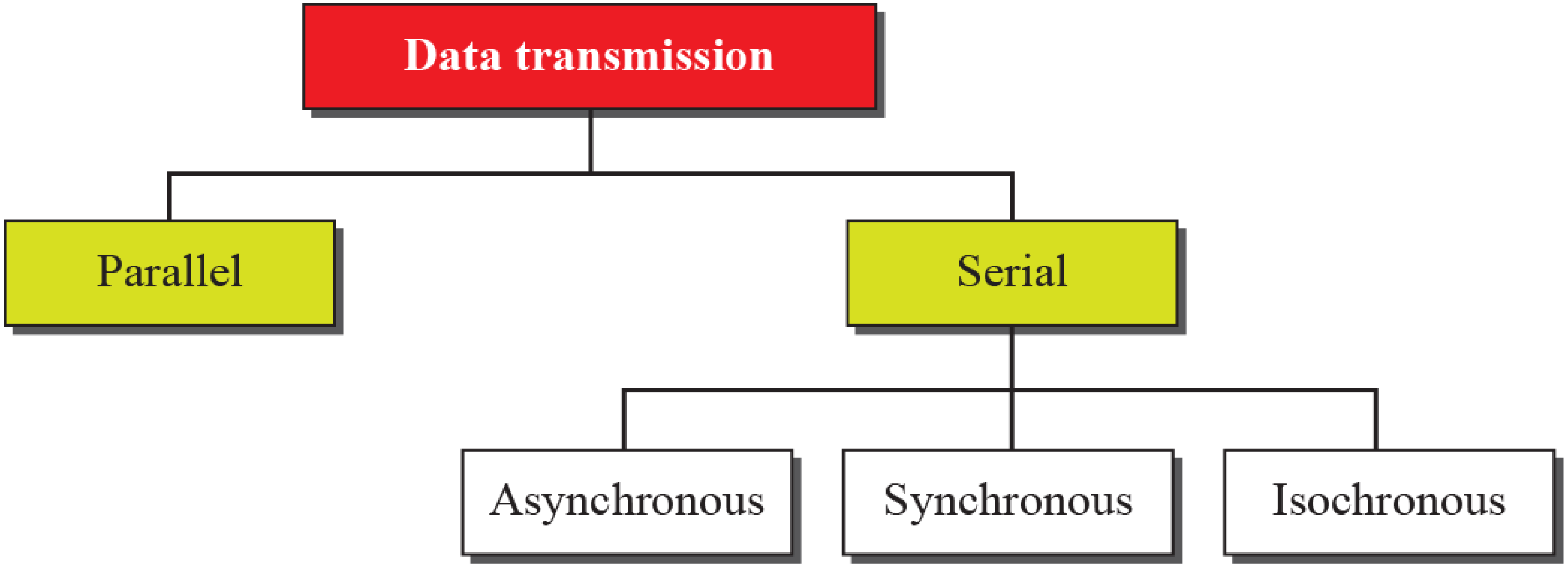
$$\text{Sampling rate} = 4000 \times 2 = 8000 \text{ samples/s}$$

$$\text{Bit rate} = 8000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$

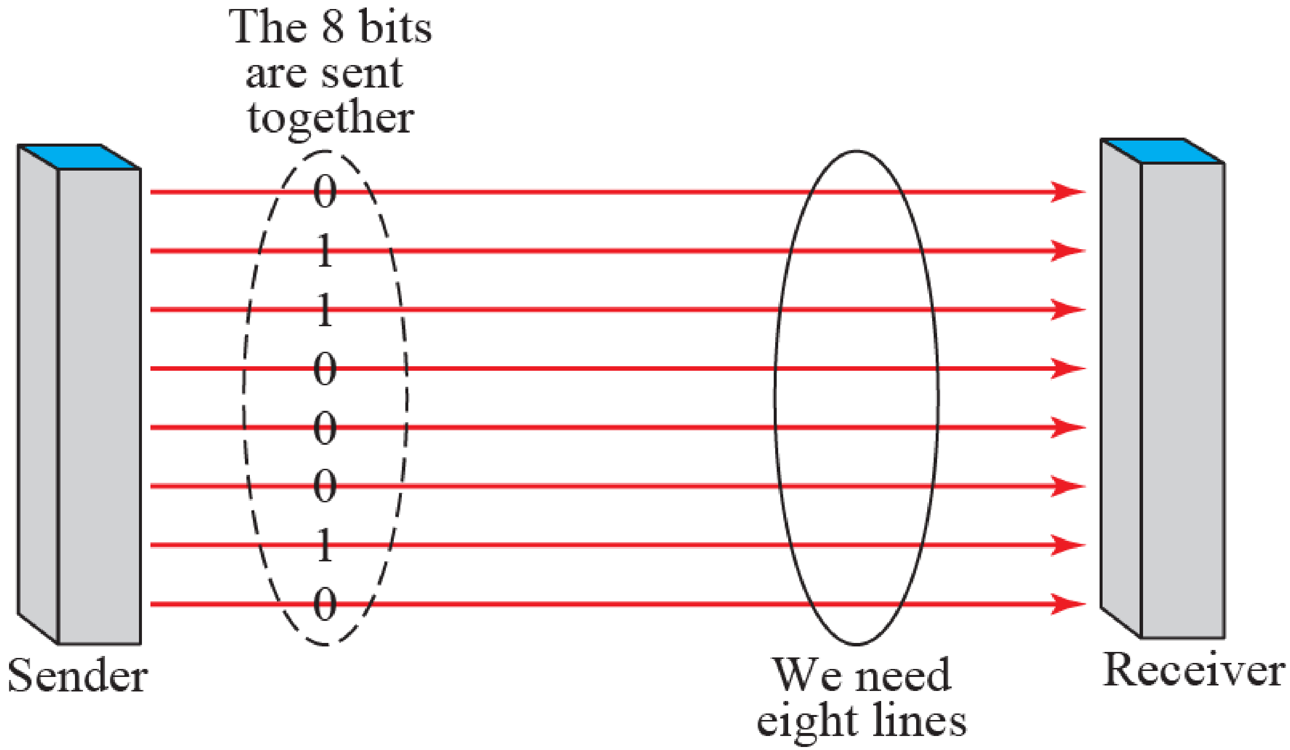
TRANSMISSION MODES

The transmission of binary data across a link can be accomplished in either parallel or serial mode.

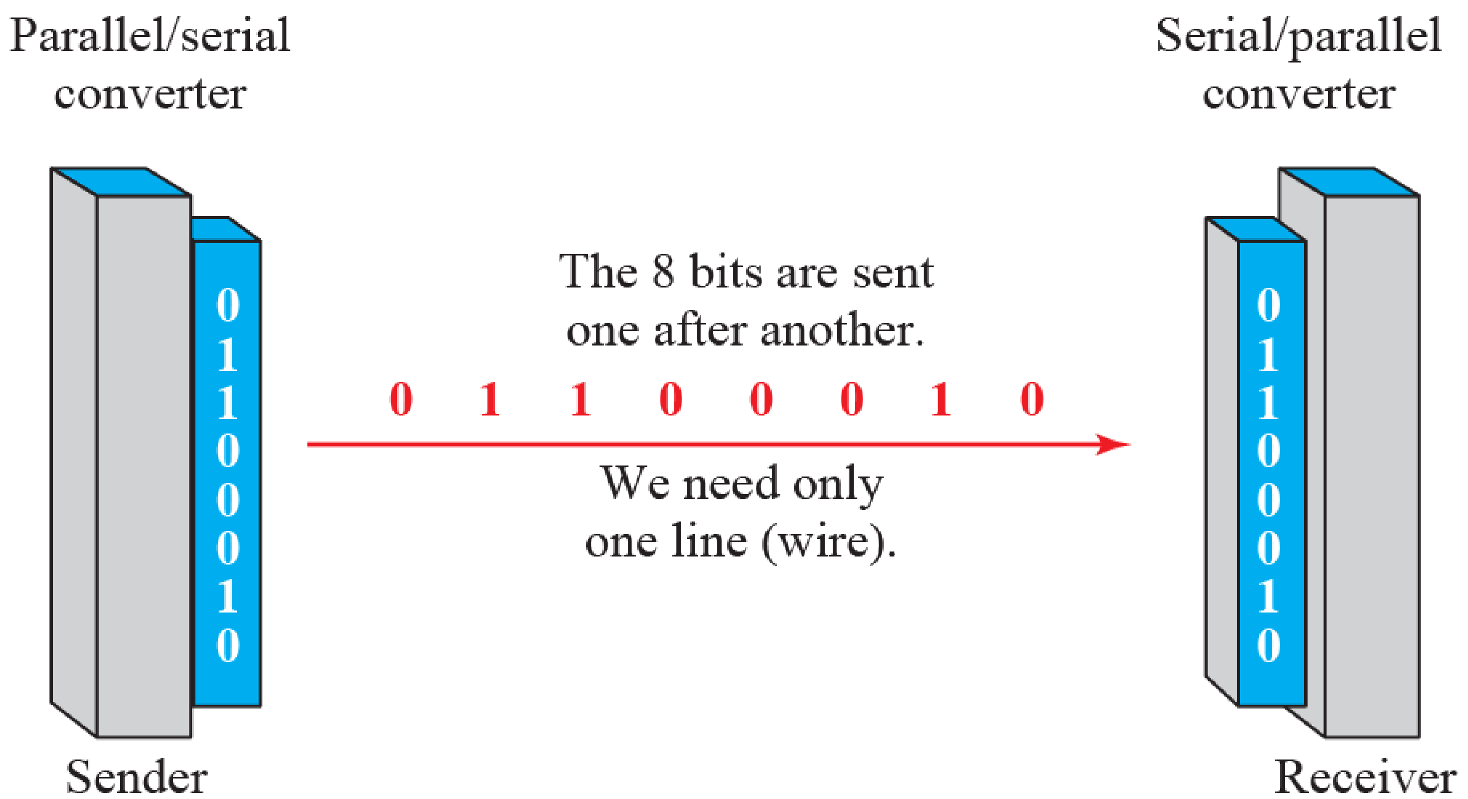
Data transmission modes



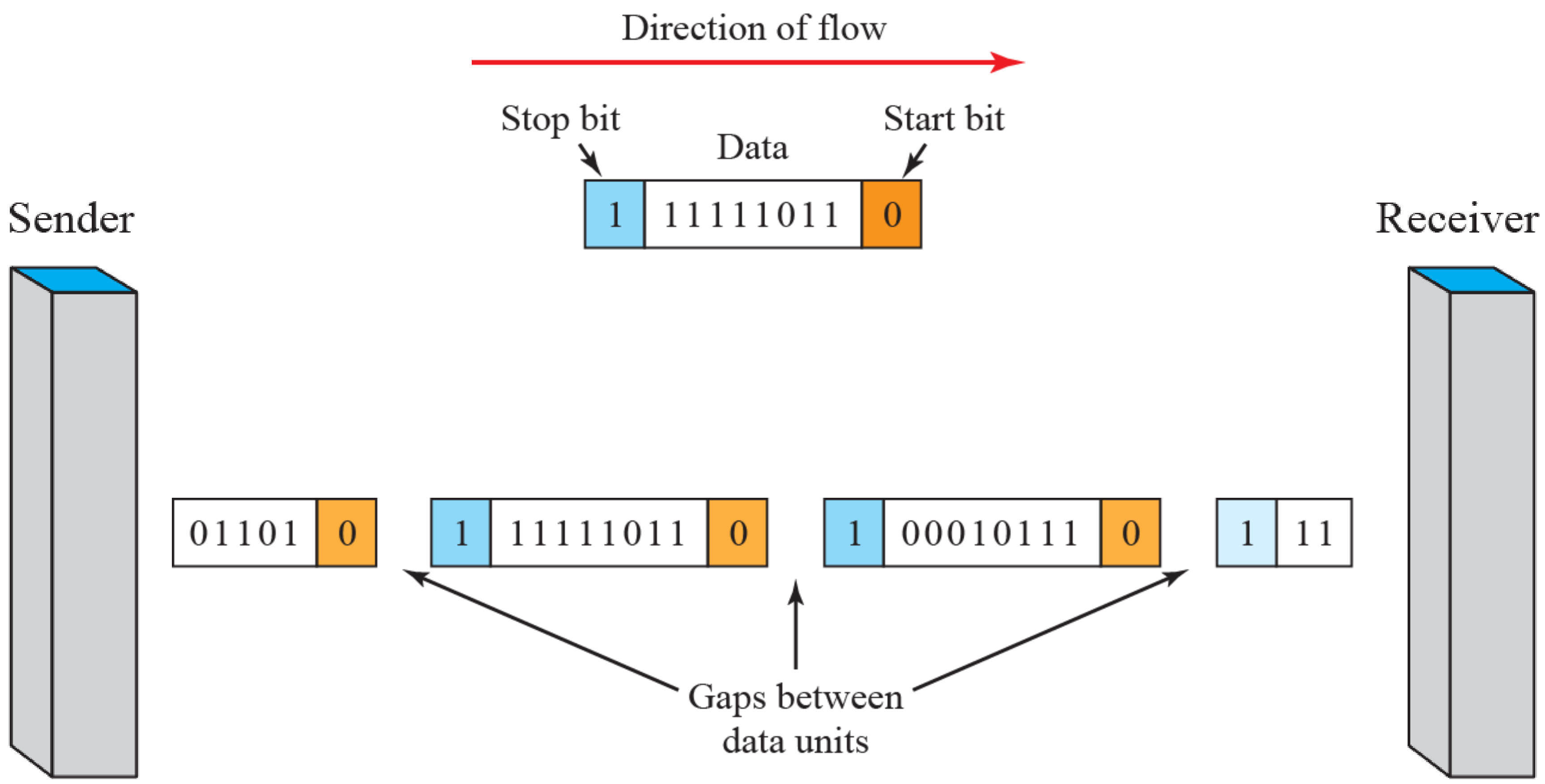
Parallel transmission



Serial transmission



Asynchronous transmission



Synchronous transmission