- Throughput

- The throughput is a measure of how fast we can actually send data through a network. Although, at first glance, bandwidth in bits per second and throughput seem the same, they are different.

- Latency

- The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

Latency = propagation time +transmission time +queuing time + processing delay

- *Propagation Time*
- Propagation time measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.
- $$\text{Propagation time} = \frac{\text{Distance}}{\text{Propagation speed}}$$

- Transmission Time
- In data communications we don't send just 1 bit, we send a message. Time taken to put a packet onto link. In other words, it is simply time required to put data bits on the wire/communication medium. It depends on length of packet and bandwidth of network.
- Transmission time = $\dfrac{\text{Message size}}{\text{Bandwidth}}$

- *Queuing Time*

- The third component in latency is the queuing time, the time needed for each intermediate or end device to hold the message before it can be processed.

Digital Transmission

4-1 DIGITAL-TO-DIGITAL CONVERSION

In this section, we see how we can represent digital data by using digital signals. The conversion involves three techniques: line coding, block coding, and scrambling. Line coding is always needed; block coding and scrambling may or may not be needed.

Topics discussed in this section:

Line Coding
Line Coding Schemes

Figure 4.1 *Line coding and decoding*

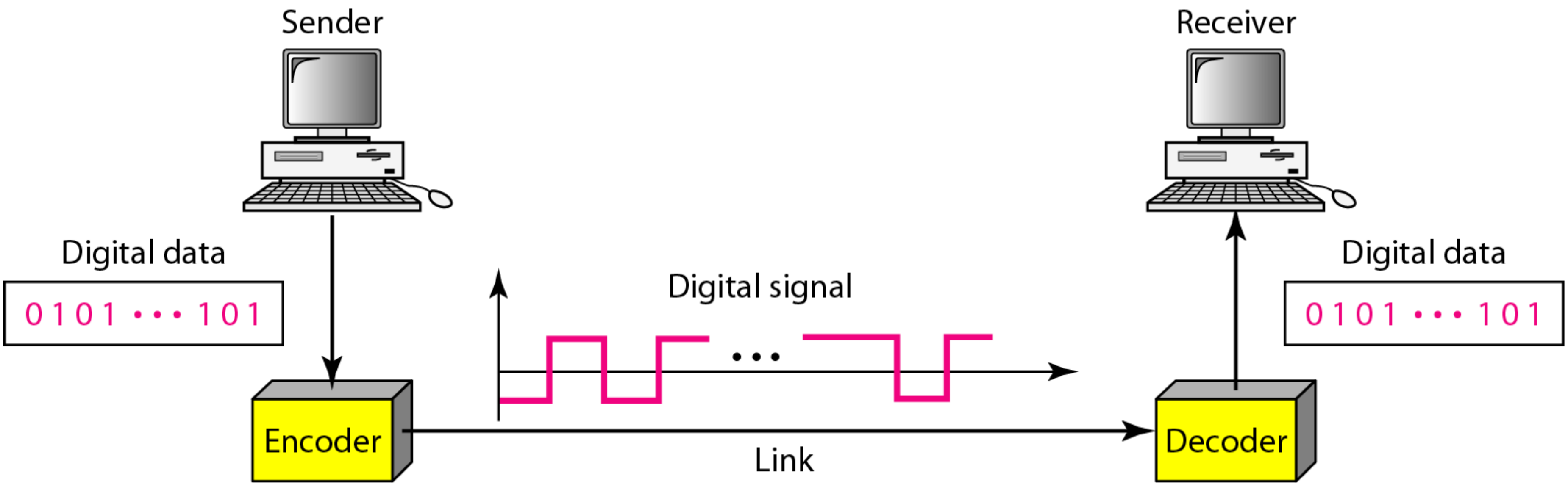
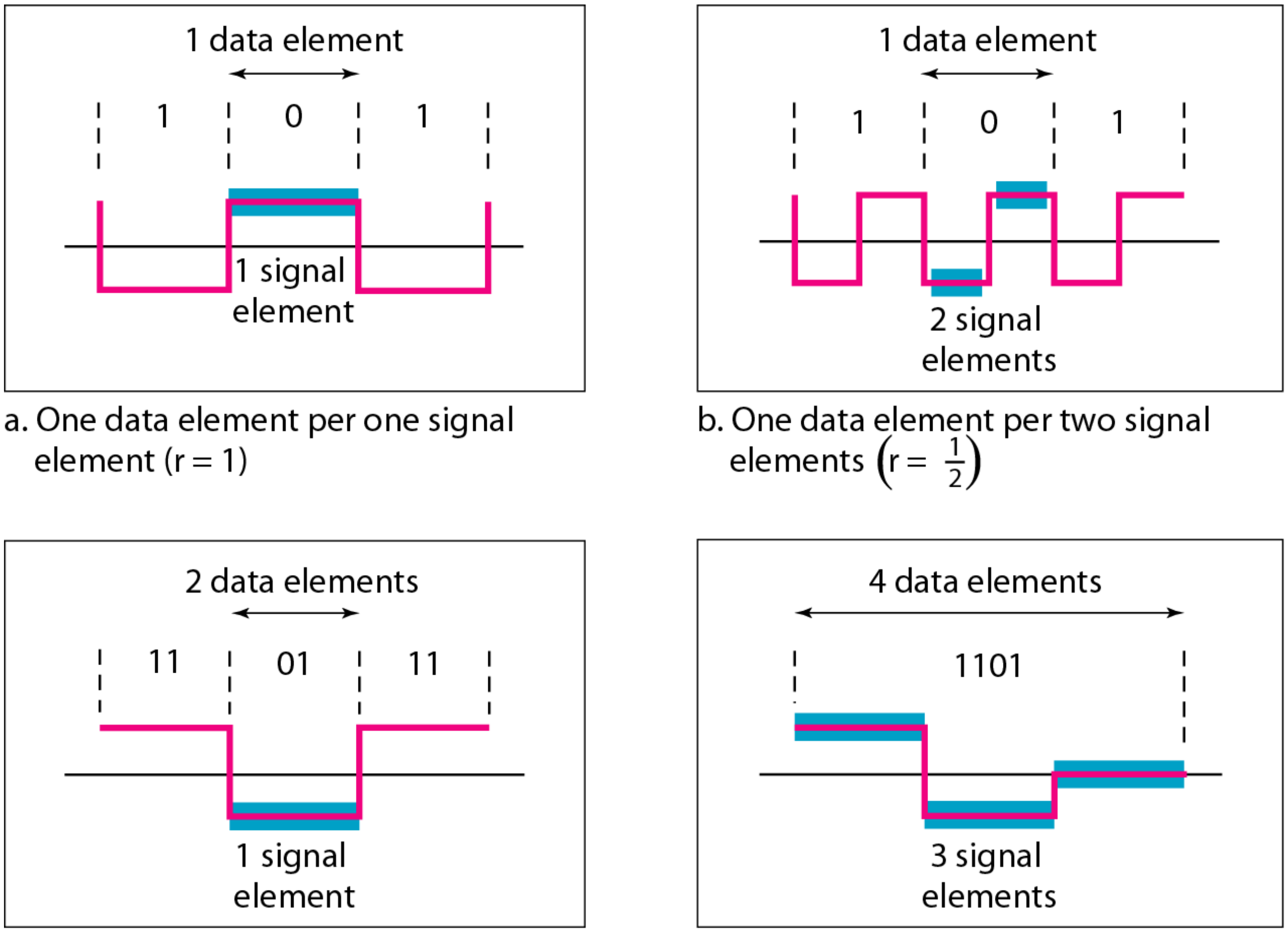


Figure 4.2 *Signal element versus data element*



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 $\left(r = \frac{4}{3}\right)$

Data Rate Versus Signal Rate

The data rate defines the number of data elements (bits) sent in Is. The unit is bits per second (bps).

The signal rate is the number of signal elements sent in Is. The unit is the baud.

One goal in data communications is to increase the data rate while decreasing the signal rate.

We can formulate
the relationship between data rate and signal rate as

$$S = c \times N \times \frac{1}{r} \quad \textit{baud}$$

where *N is the data rate (bps); c is the case factor, which varies for each case; S is the* number of signal elements; and *r is* number of data elements carried by each signal element

Example 4.1

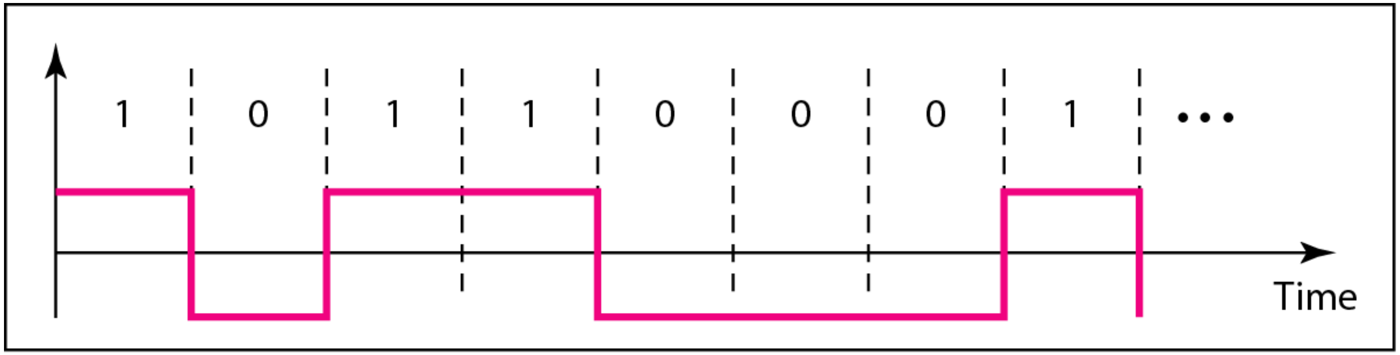
A signal is carrying data in which one data element is encoded as one signal element (r = 1). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

Solution

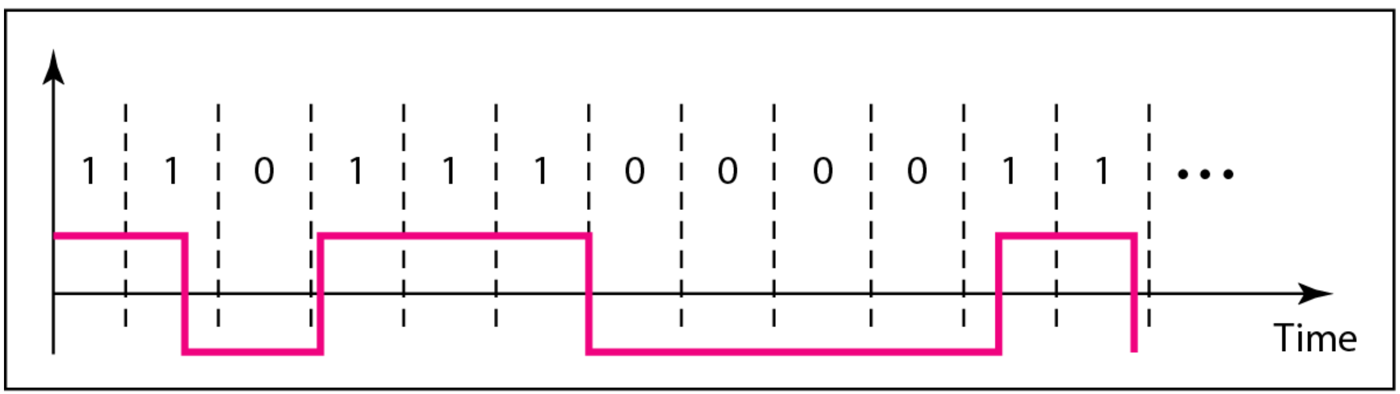
We assume that the average value of c is 1/2 . The baud rate is then

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

Figure 4.3 *Effect of lack of synchronization*



a. Sent



b. Received

Figure 4.4 *Line coding schemes*

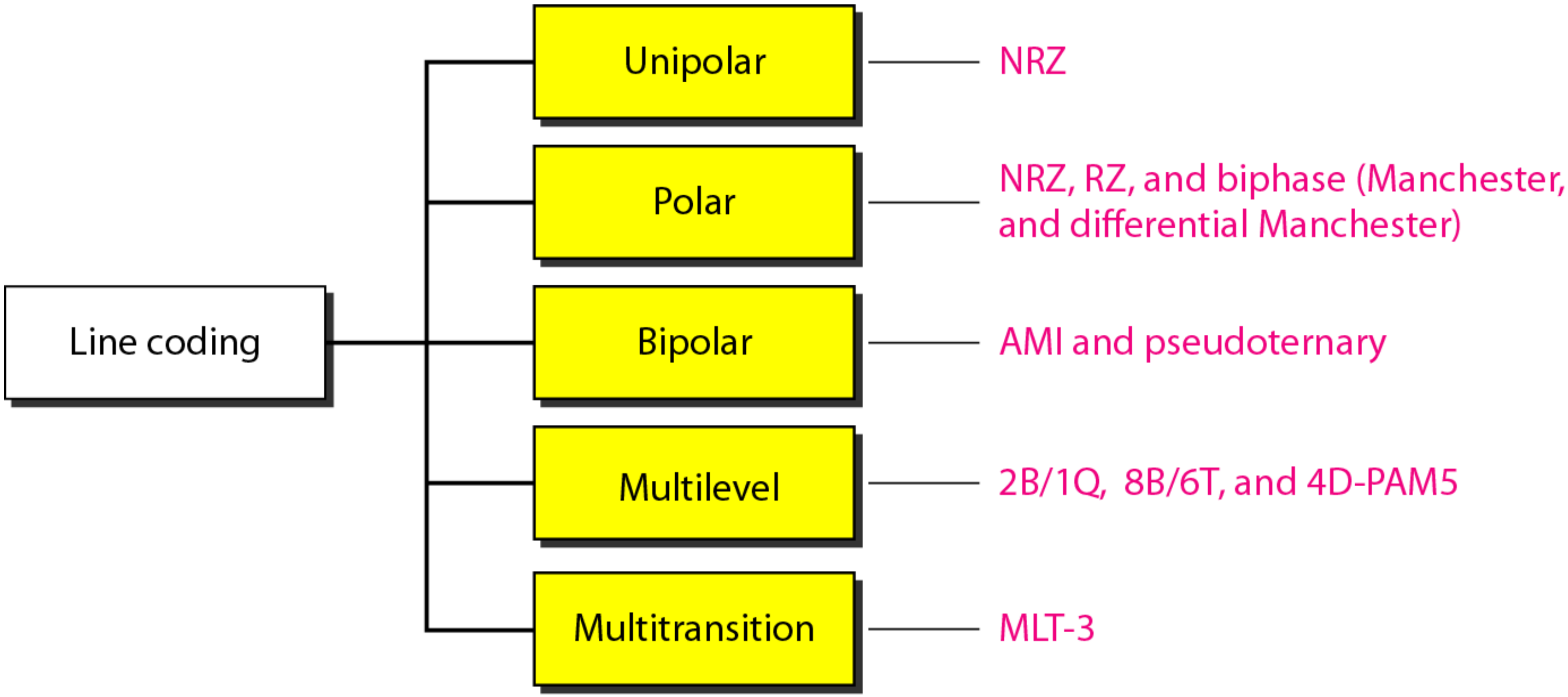
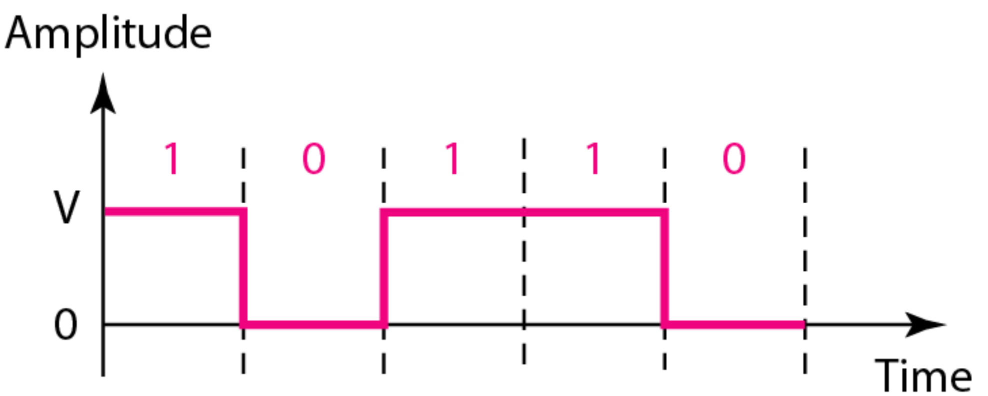


Figure 4.5 *Unipolar NRZ scheme*

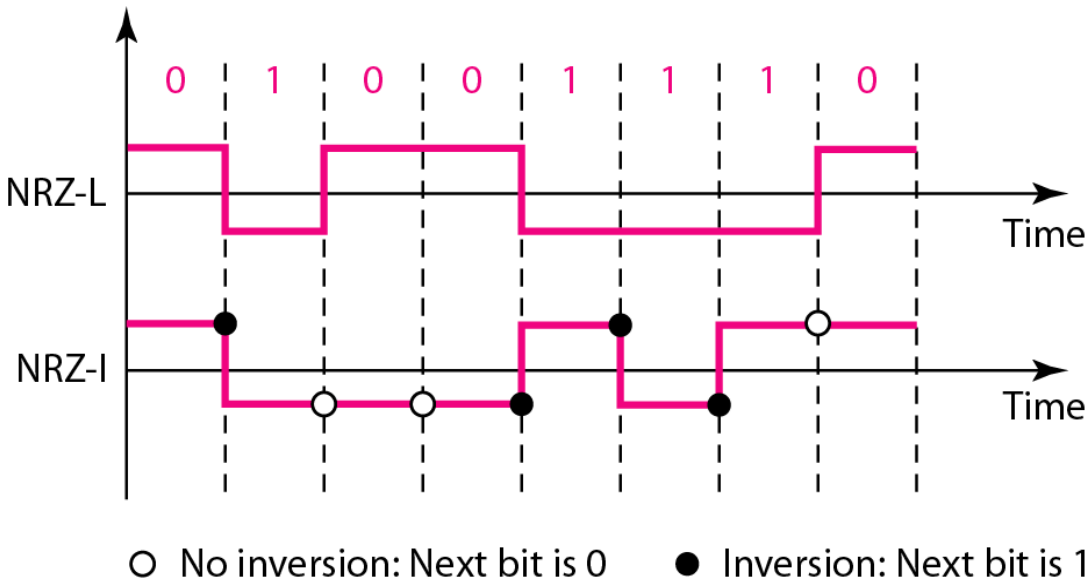


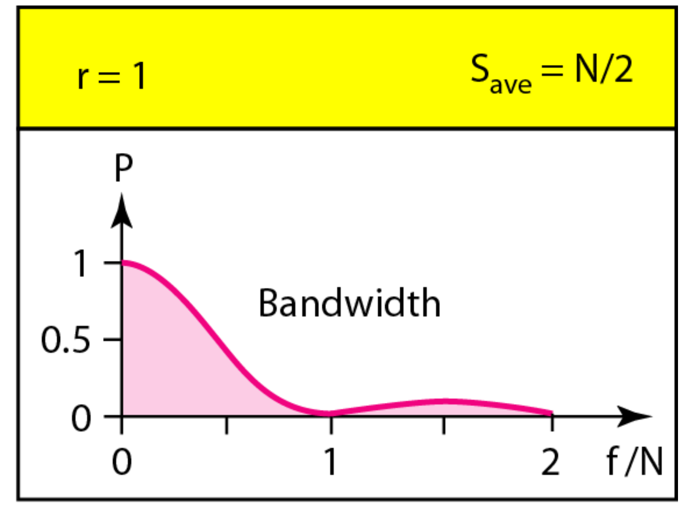
$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

Compared with its polar counterpart (see the next section), this scheme is very costly. As we will see shortly, the normalized power (power needed to send 1 bit per unit line resistance) is double that for polar NRZ. For this reason, this scheme is normally not used in data communications today.

Figure 4.6 *Polar NRZ-L and NRZ-I schemes*





Note

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.

Note

NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.

Note

NRZ-L and NRZ-I both have a DC component problem.

DC Components When the voltage level in a digital signal is constant for a while, the spectrum creates very low frequencies (results of Fourier analysis). These frequencies around zero, called DC (direct-current) *components*, *present problems for a* system that cannot pass low frequencies or a system that uses electrical coupling (via a transformer). For example, a telephone line cannot pass frequencies below 200 Hz. Also a long-distance link may use one or more transformers to isolate different parts of the line electrically. For these systems, we need a scheme with no DC component.

Example 4.4

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.

Figure 4.7 *Polar RZ scheme*

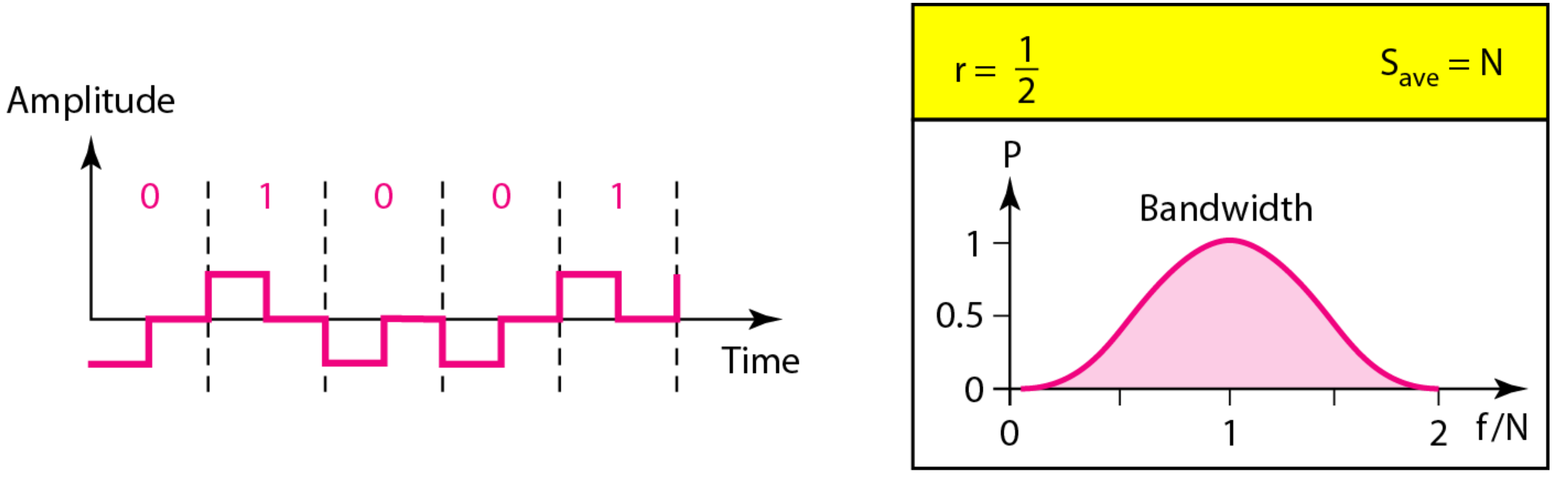
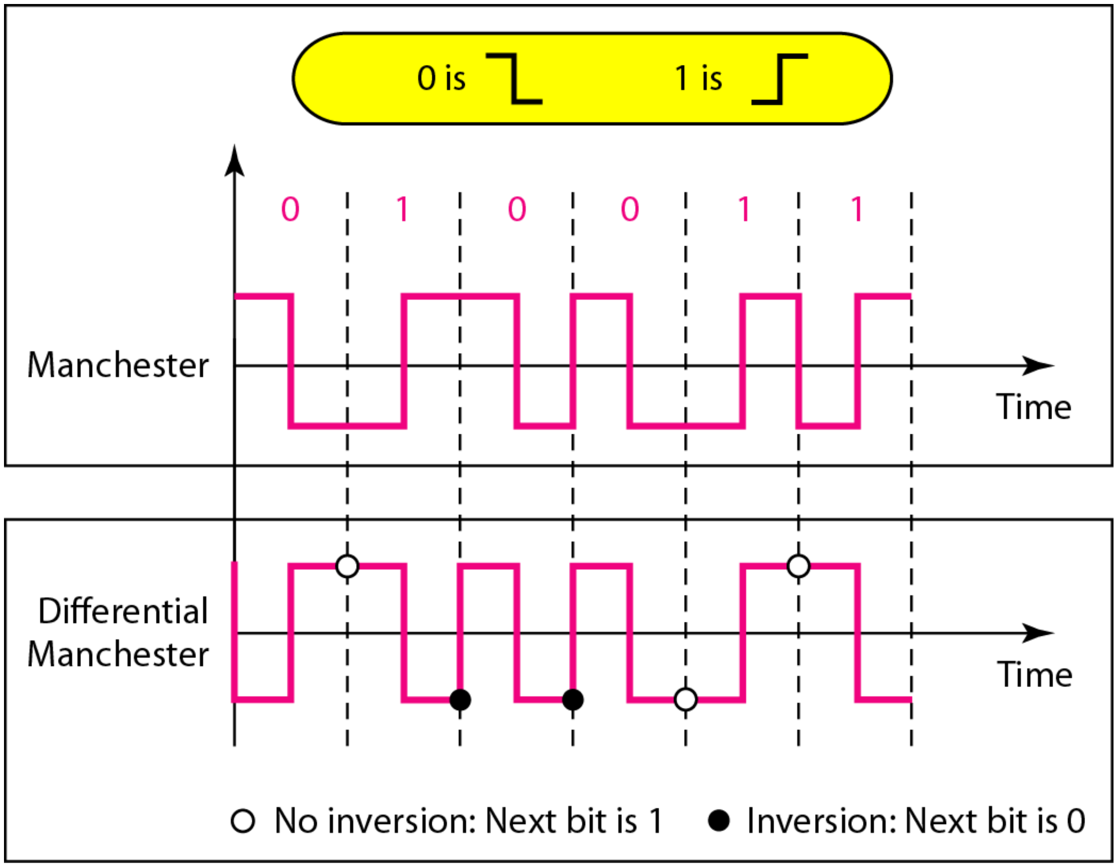
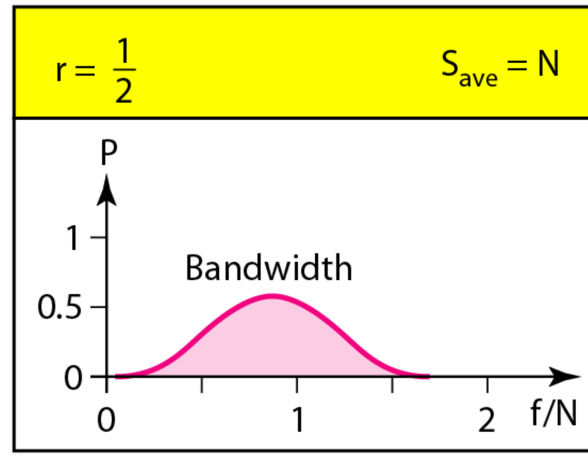


Figure 4.8 *Polar biphase: Manchester and differential Manchester schemes*





Note

In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.

Note

The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.

Note

In bipolar encoding, we use three levels: positive, zero, and negative.

Figure 4.9 *Bipolar schemes: AMI and pseudoternary*