Synchronization in TCS

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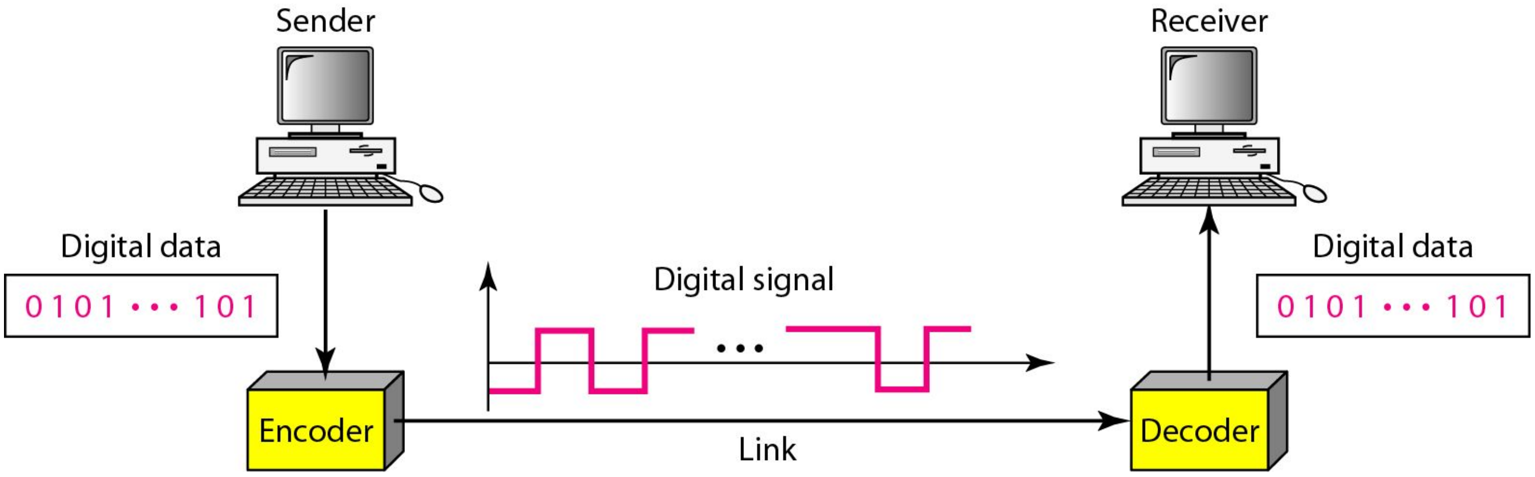
Lecture 8

TIMING RECOVERY IN BASEBAND TRANSMISSION

DIGITAL-TO-DIGITAL CONVERSION

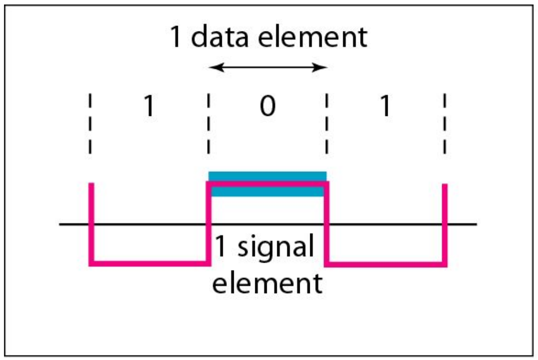
- We can represent digital data by using digital signals.
- The conversion involves three techniques: line coding, block coding, and scrambling.
  - Line coding is always needed.
  - Block coding and scrambling may or may not be needed.



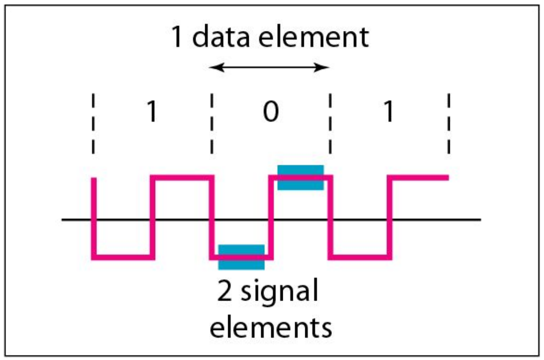
Line coding and decoding

Signal element versus data element

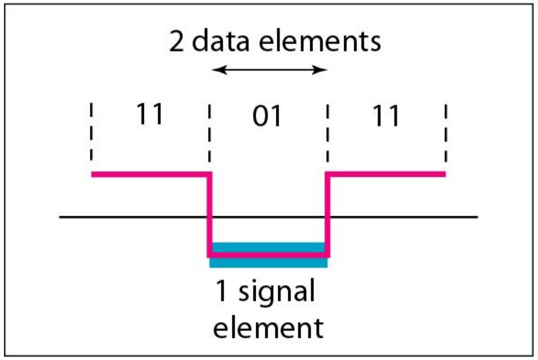
Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite.



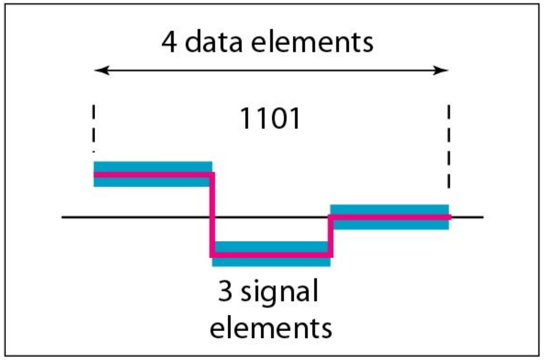
a. One data element per one signal element (r = 1)



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

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

Example

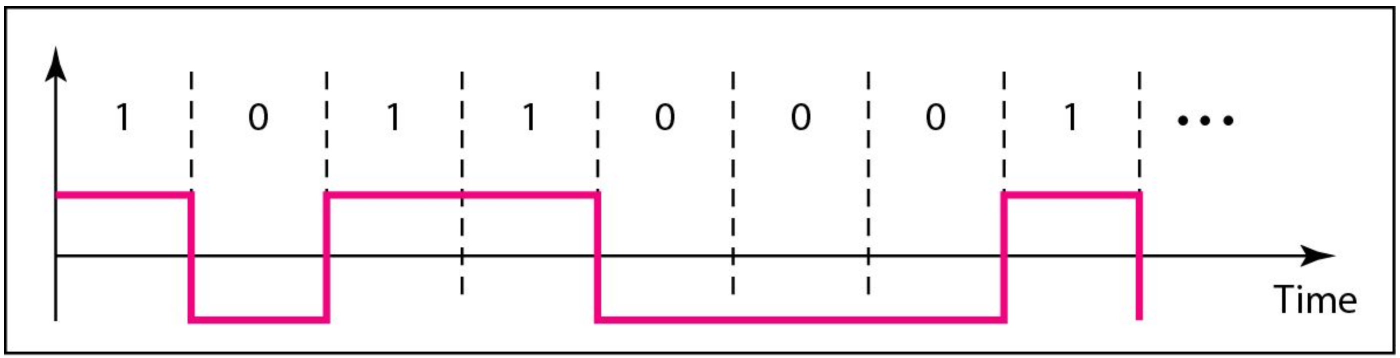
The maximum data rate of a channel is
$N_{max} = 2 \times B \times \log_2 L$ (defined by the Nyquist formula).
Does this agree with the previous formula for N_{max}?

Solution

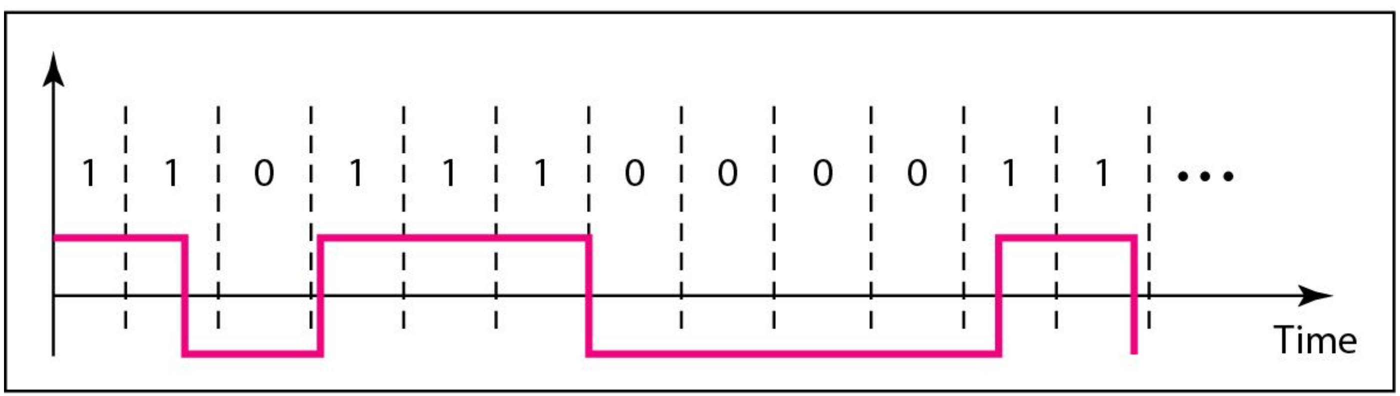
A signal with L levels actually can carry $\log_2 L$ bits per level.
If each level corresponds to one signal element and we assume the average case ($c = 1/2$), then we have

$$N_{max} = \frac{1}{c} \times B \times r = 2 \times B \times \log_2 L$$

Effect of lack of synchronization



a. Sent



b. Received

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

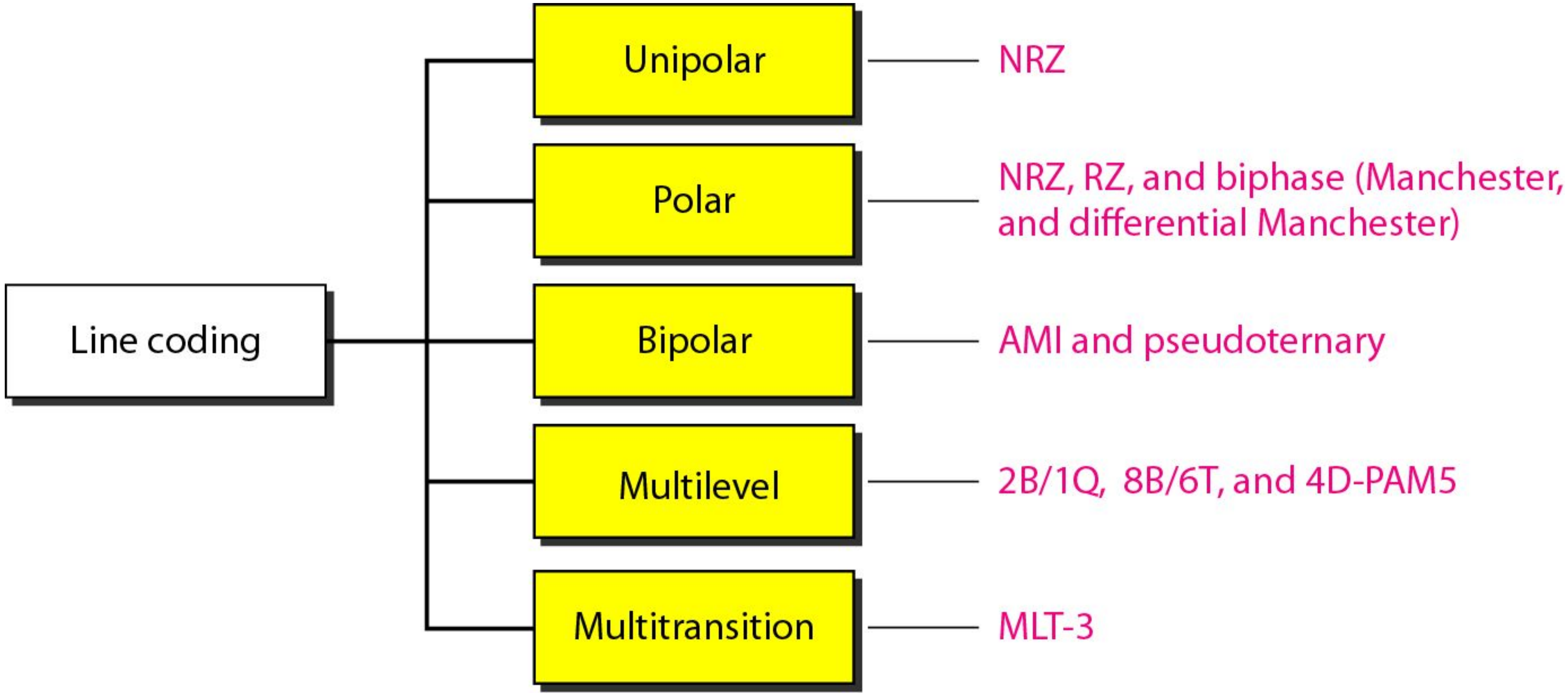
At 1 kbps, the receiver receives 1001 bps instead of 1000 bps.

1000 bits sent	1001 bits received	1 extra bps

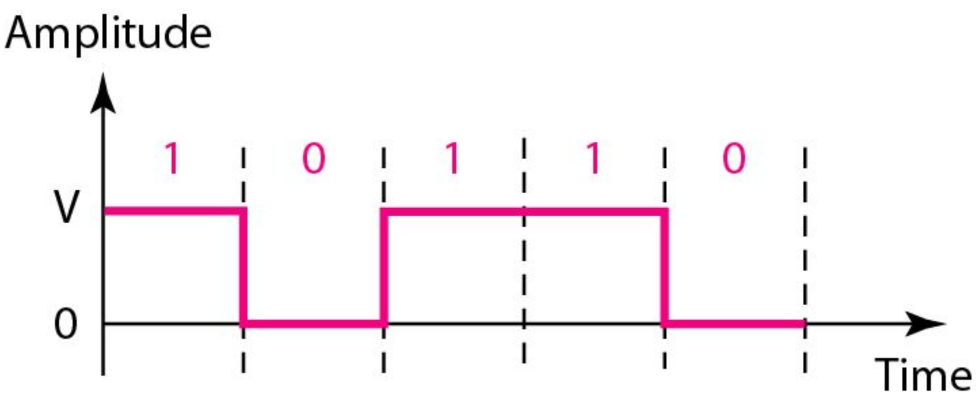
At 1 Mbps, the receiver receives 1,001,000 bps instead of 1,000,000 bps.

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

Line coding schemes



Unipolar NRZ scheme

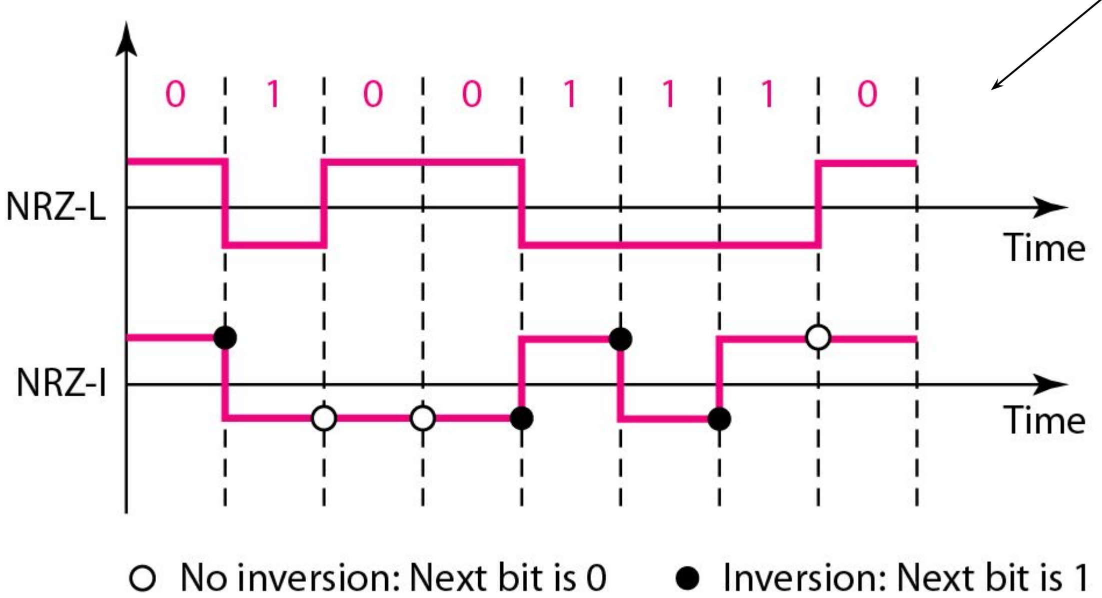


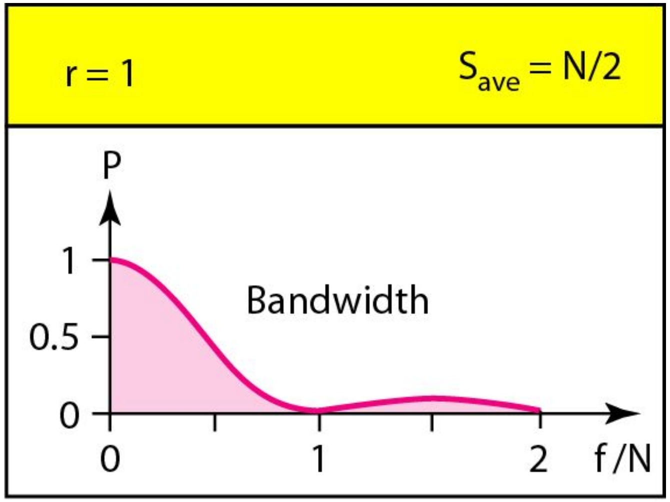
$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

Polar NRZ-L and NRZ-I schemes

level of voltage determines value of the bit





inversion or lack of inversion determines value of the bit

- Both have an average signal rate of N/2 Bd.
- Both have a DC component problem.

Example

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

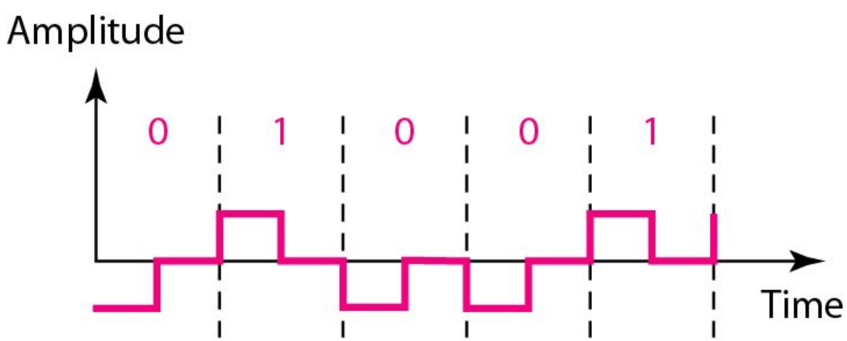
Solution

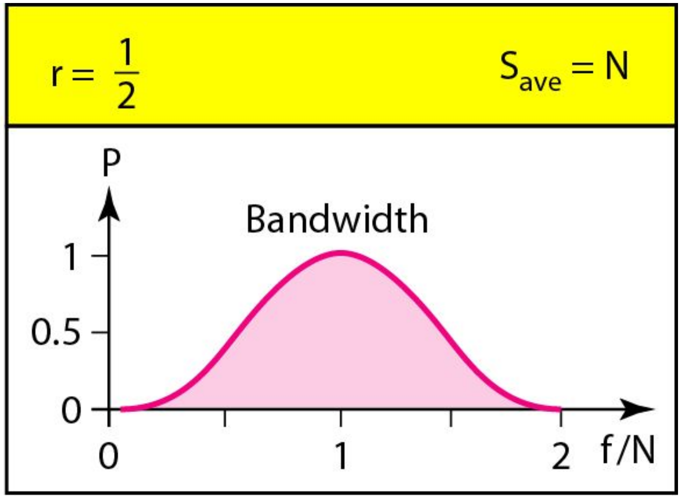
The average signal rate is S = N/2 = 500 kbaud.

The minimum bandwidth for this average baud rate is

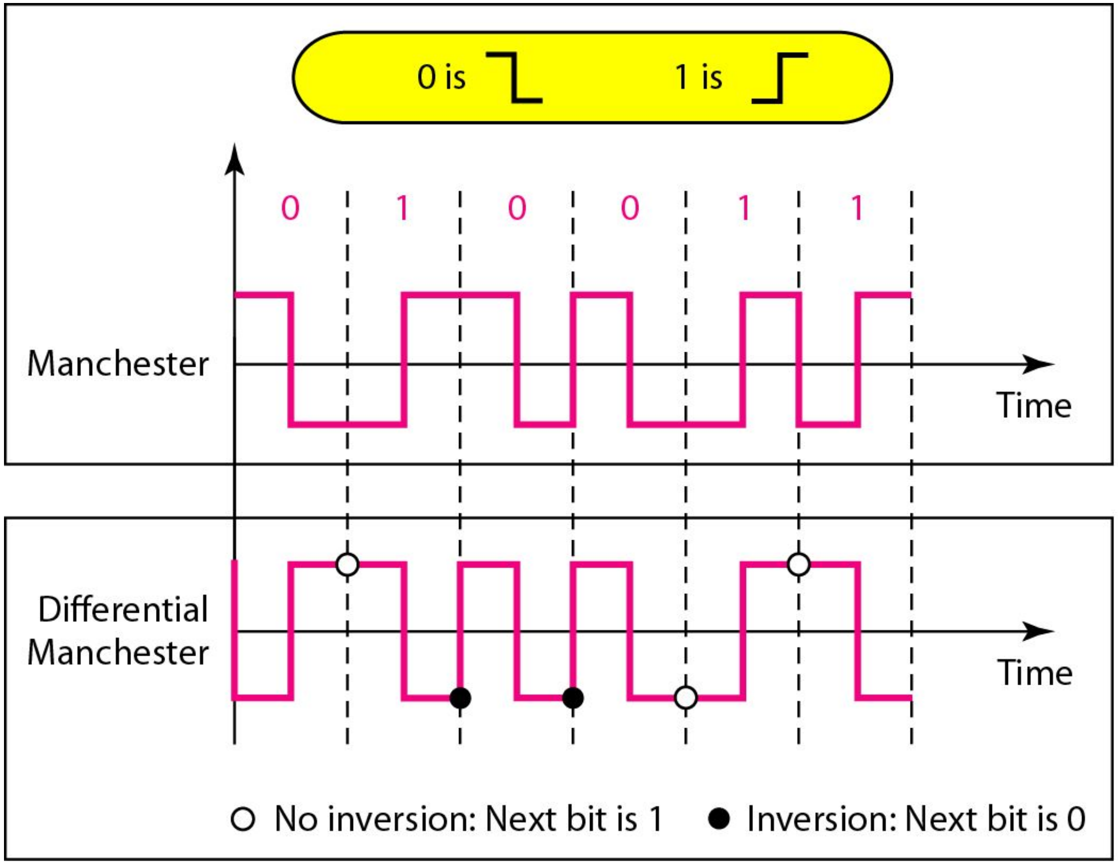
$$B_{min} = S = 500 \text{ kHz}.$$

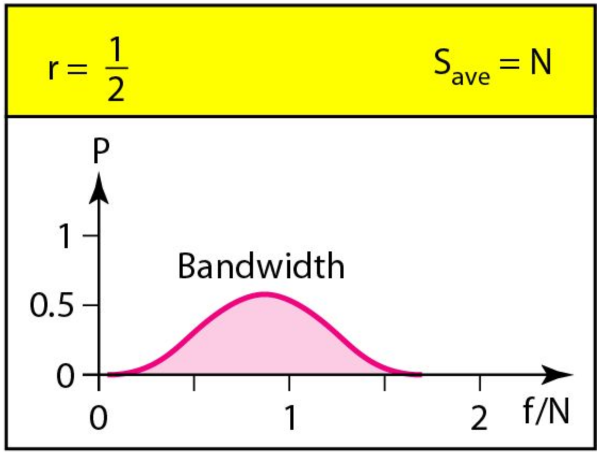
Polar RZ scheme





Polar biphase: Manchester and differential Manchester schemes

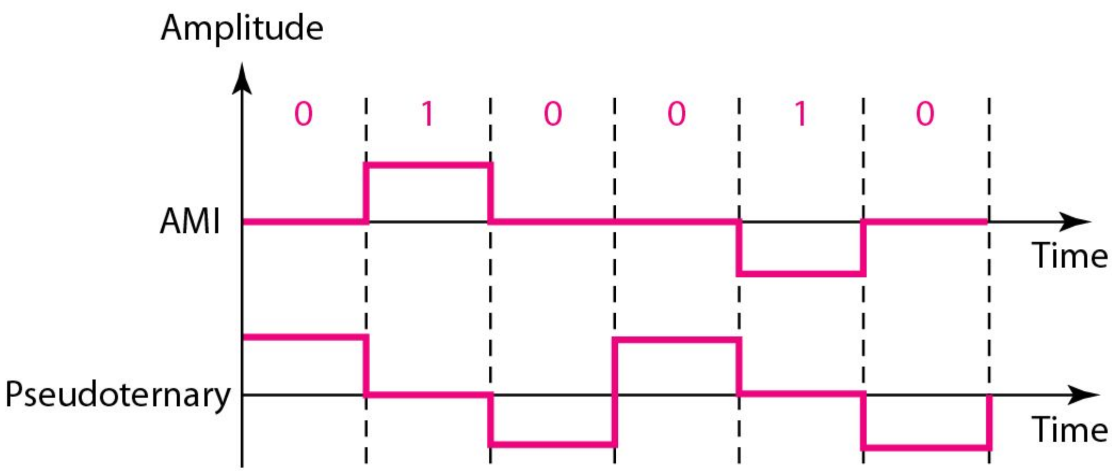


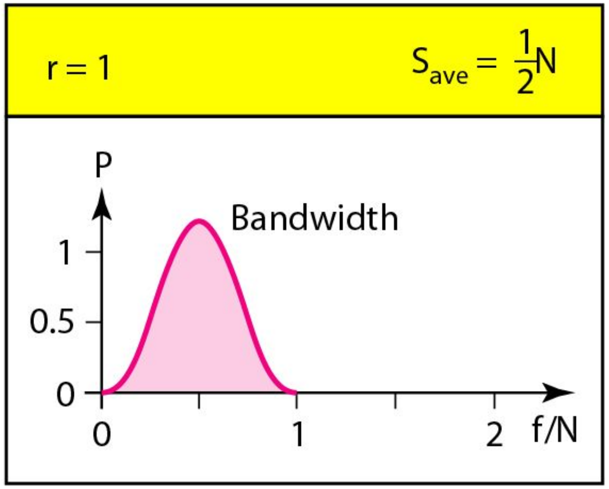


- ❑ Transition at the middle is used for synchronization
- ❑ The minimum bandwidth is 2 times that of NRZ

Bipolar schemes: AMI and pseudoternary

We use three levels: positive, zero, and negative.



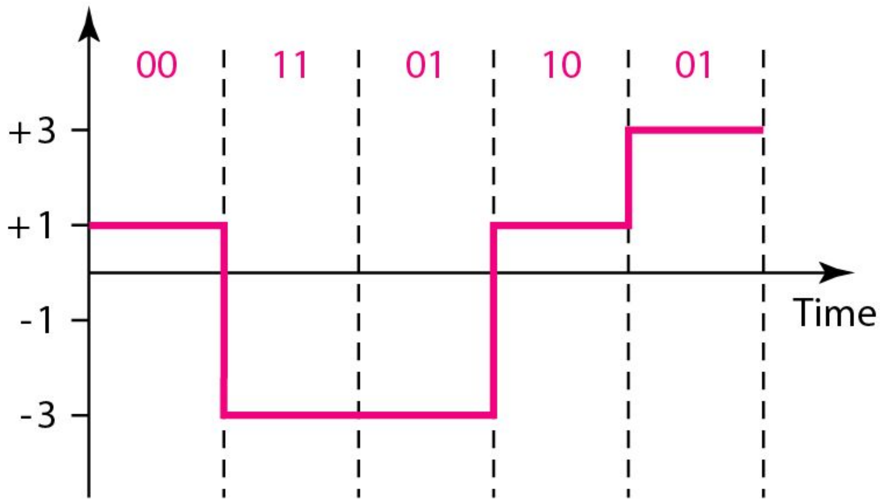


- ❑ In mBnL schemes, a pattern of m data elements is encoded as a pattern of n signal elements in which $2^m \leq L^n$

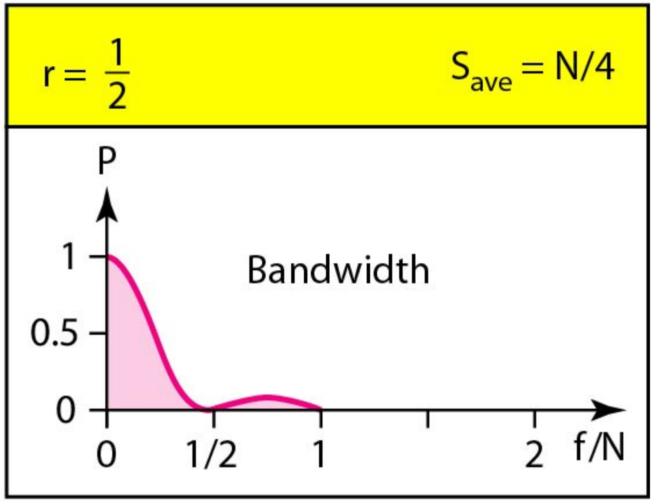
Multilevel: 2B1Q scheme

Next bits	Previous level: positive Next level	Previous level: negative Next level
00	+1	-1
01	+3	-3
10	-1	+1
11	-3	+3

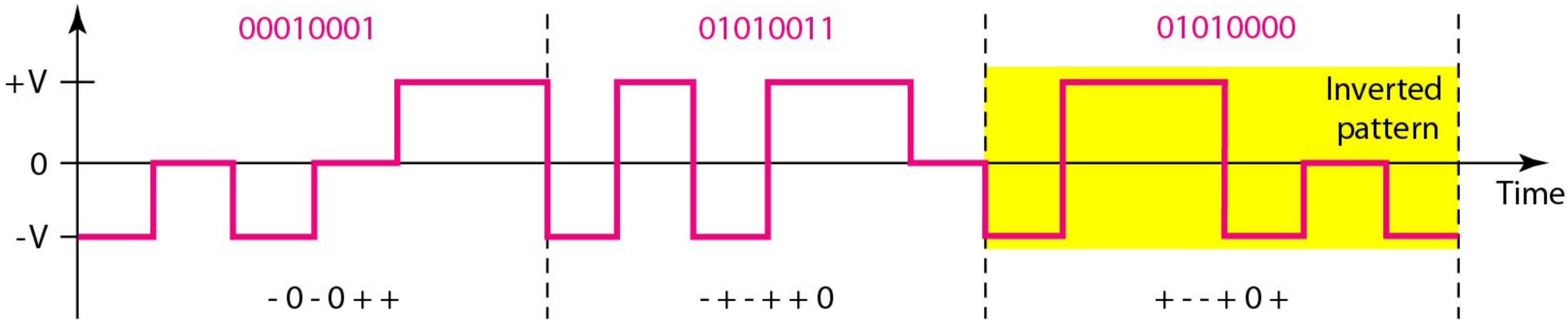
Transition table



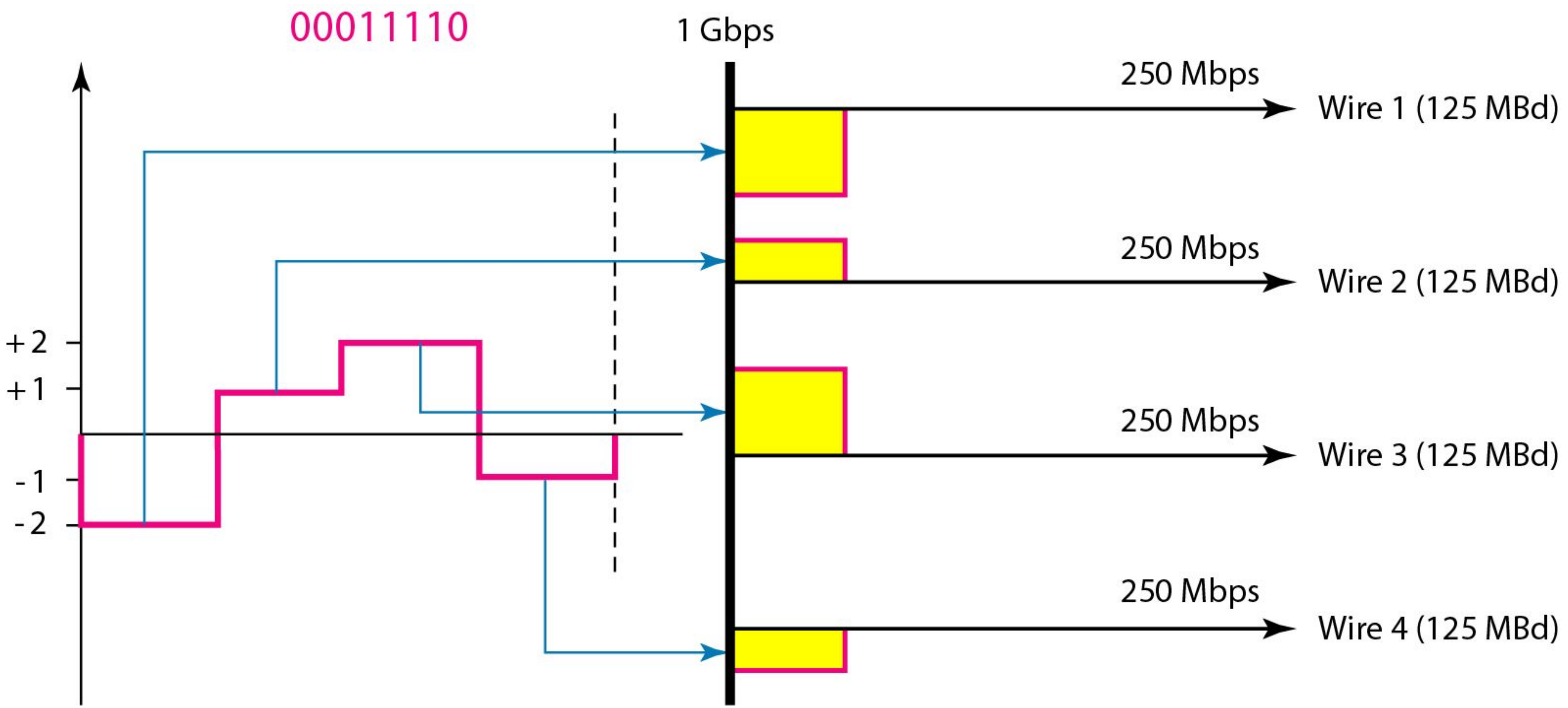
Assuming positive original level



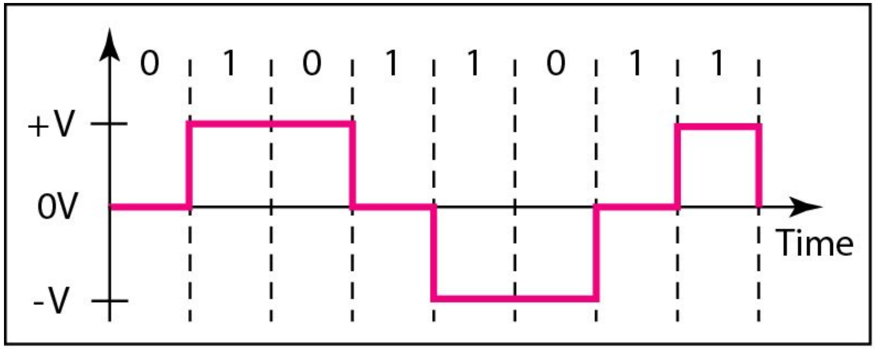
Multilevel: 8B6T scheme



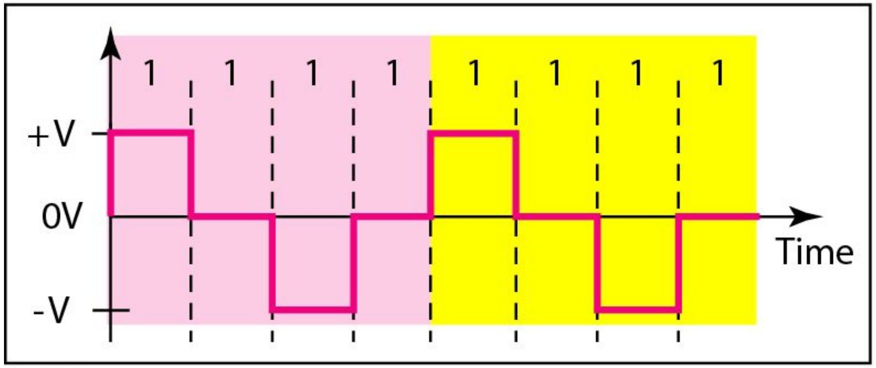
Multilevel: 4D-PAM5 scheme



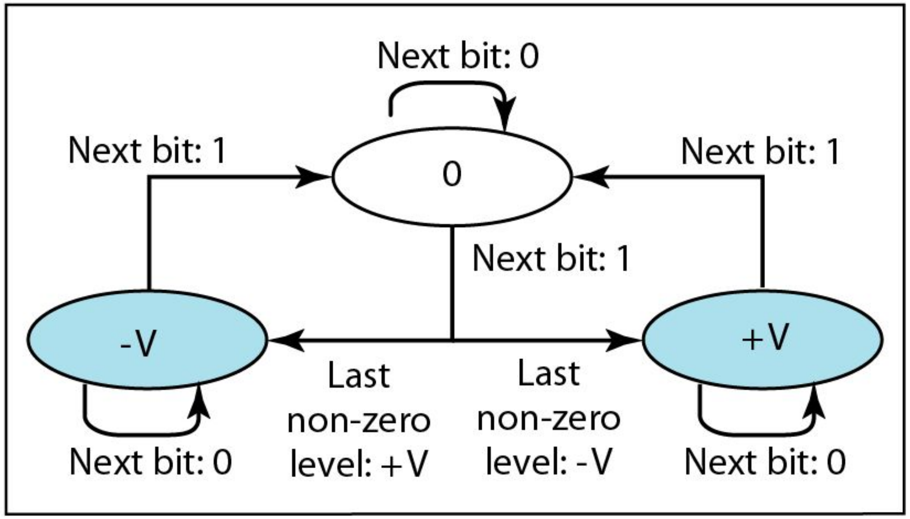
Multitransition: MLT-3 scheme



a. Typical case



b. Worse case



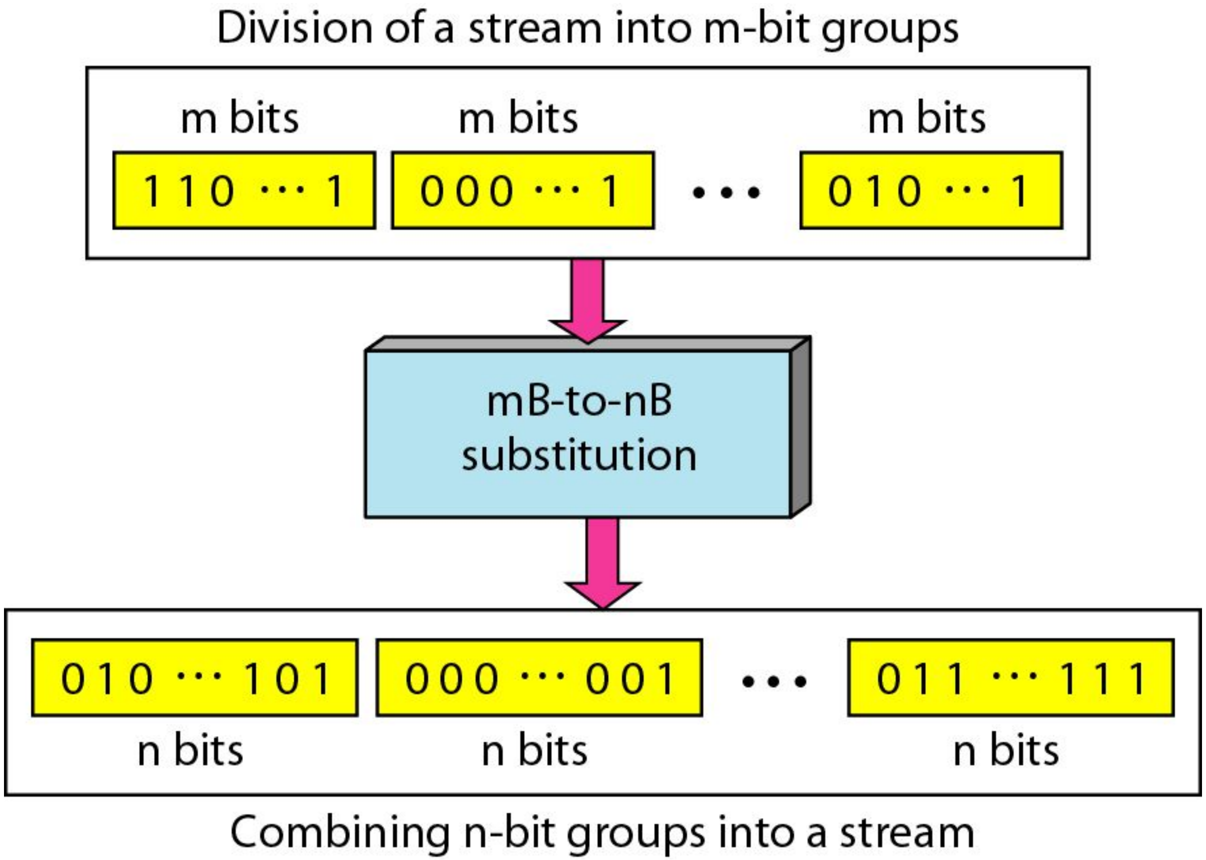
c. Transition states

Summary of line coding schemes

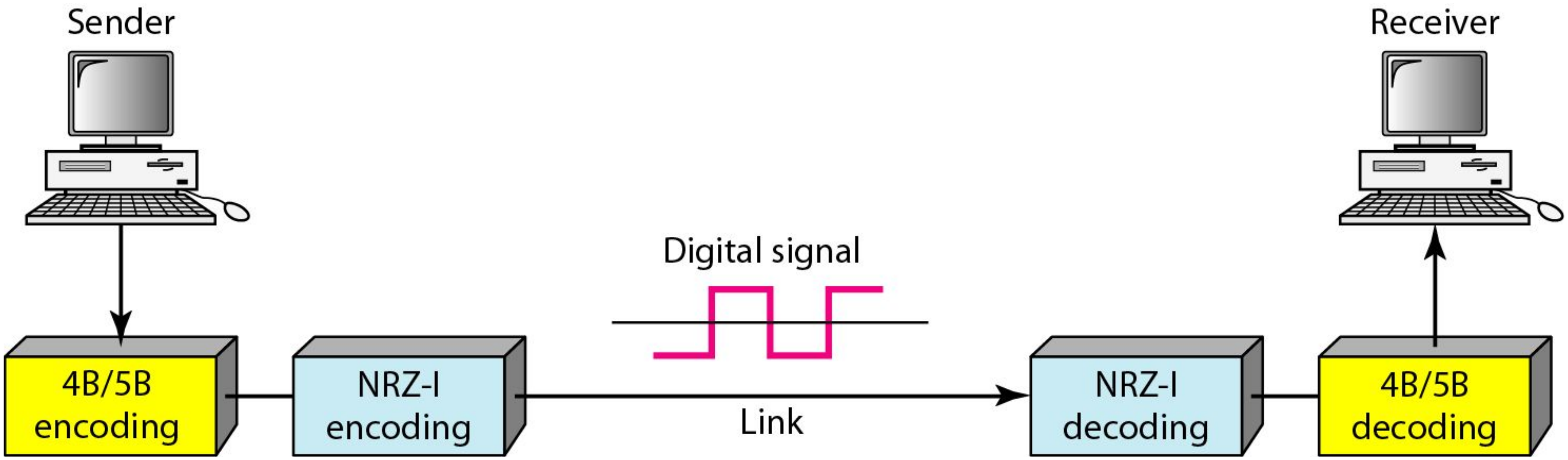
Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Unipolar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multiline	MLT-3	$B = N/3$	No self-synchronization for long 0s

Block coding concept

Block coding is normally referred to as mB/nB coding; it replaces each m-bit group with an n-bit group.



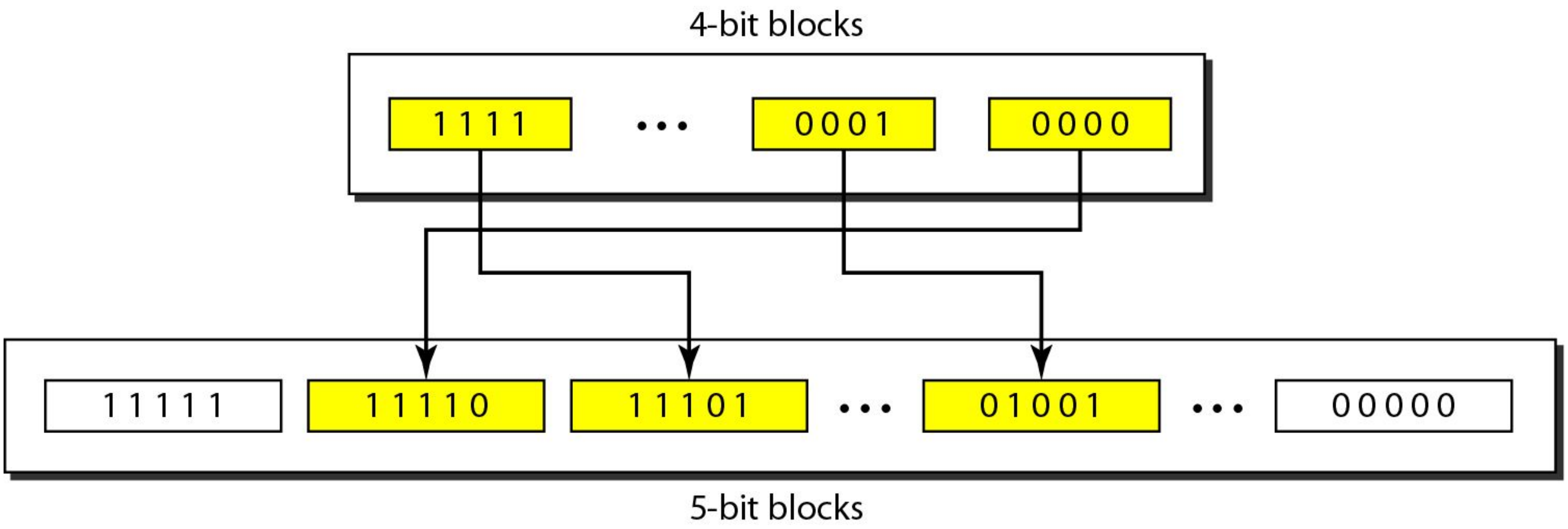
Using block coding 4B/5B with NRZ-I line coding scheme



4B/5B mapping codes

Data Sequence	*Encoded Sequence*	*Control Sequence*	*Encoded Sequence*
0000	11110	Q (Quiet)	00000
0001	01001	I (Idle)	11111
0010	10100	H (Halt)	00100
0011	10101	J (Start delimiter)	11000
0100	01010	K (Start delimiter)	10001
0101	01011	T (End delimiter)	01101
0110	01110	S (Set)	11001
0111	01111	R (Reset)	00111
1000	10010		
1001	10011		
1010	10110		
1011	10111		
1100	11010		
1101	11011		
1110	11100		
1111	11101		

Substitution in 4B/5B block coding



Example

We need to send data at a 1-Mbps rate.
What is the minimum required bandwidth, using a combination of 4B/5B and NRZ-I or Manchester coding?

Solution

First 4B/5B block coding increases the bit rate to 1.25 Mbps.

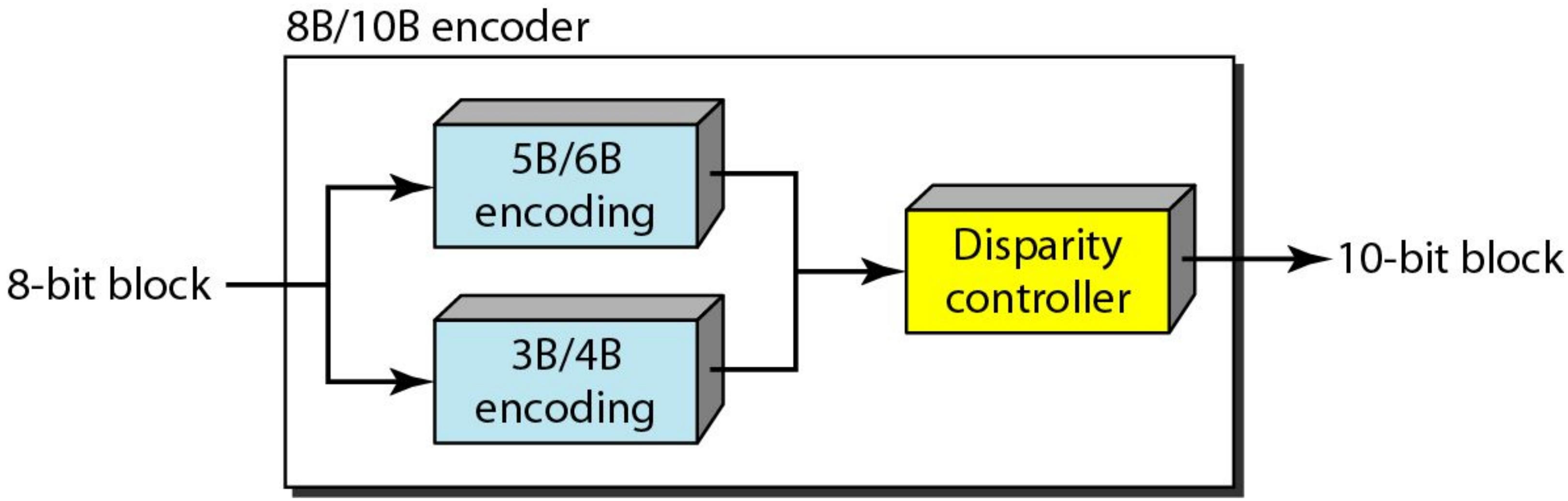
The minimum bandwidth using NRZ-I is N/2 or 625 kHz.

The Manchester scheme needs a minimum bandwidth of 1 MHz.

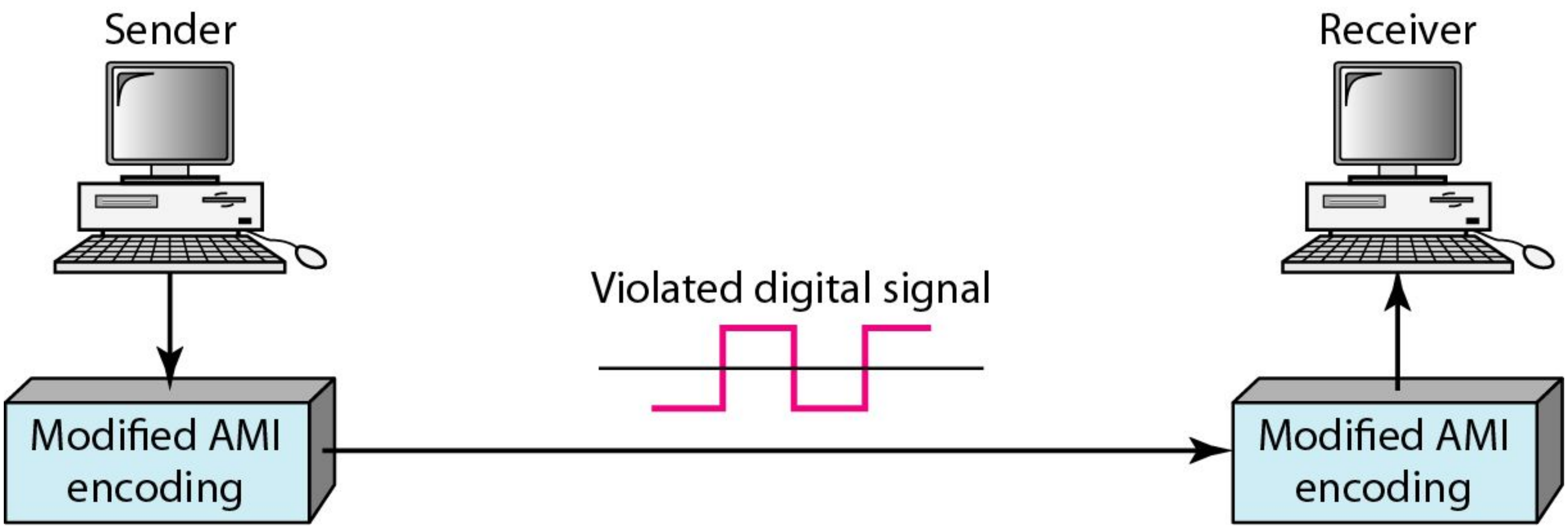
The first choice needs a lower bandwidth, but has a DC component problem;

The second choice needs a higher bandwidth, but does not have a DC component problem.

8B/10B block encoding

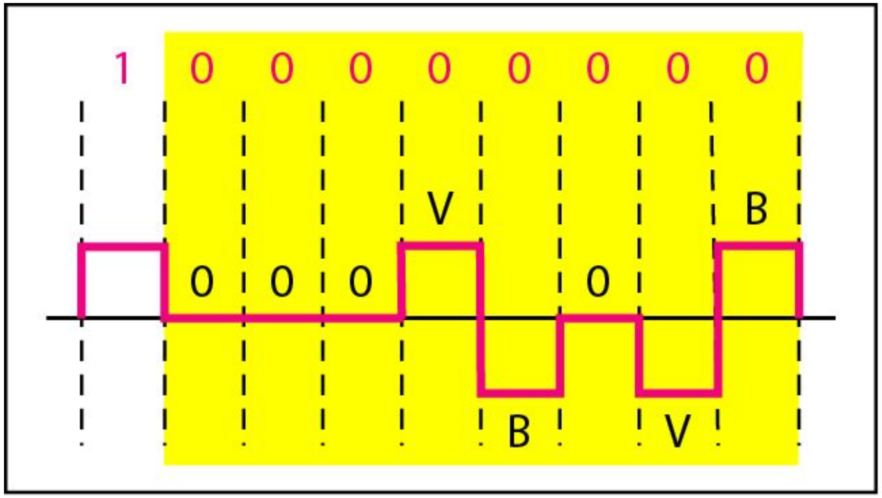


AMI used with scrambling

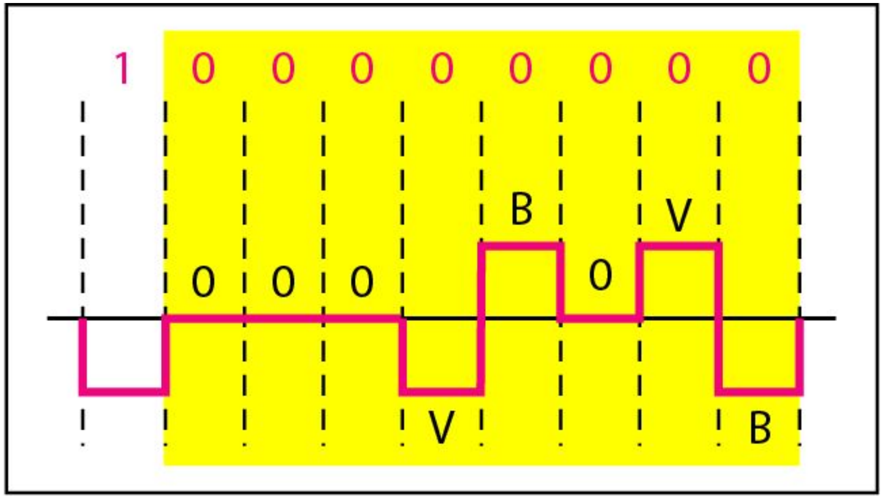


Two cases of B8ZS scrambling technique

B8ZS substitutes eight consecutive zeros with 000VB0VB.



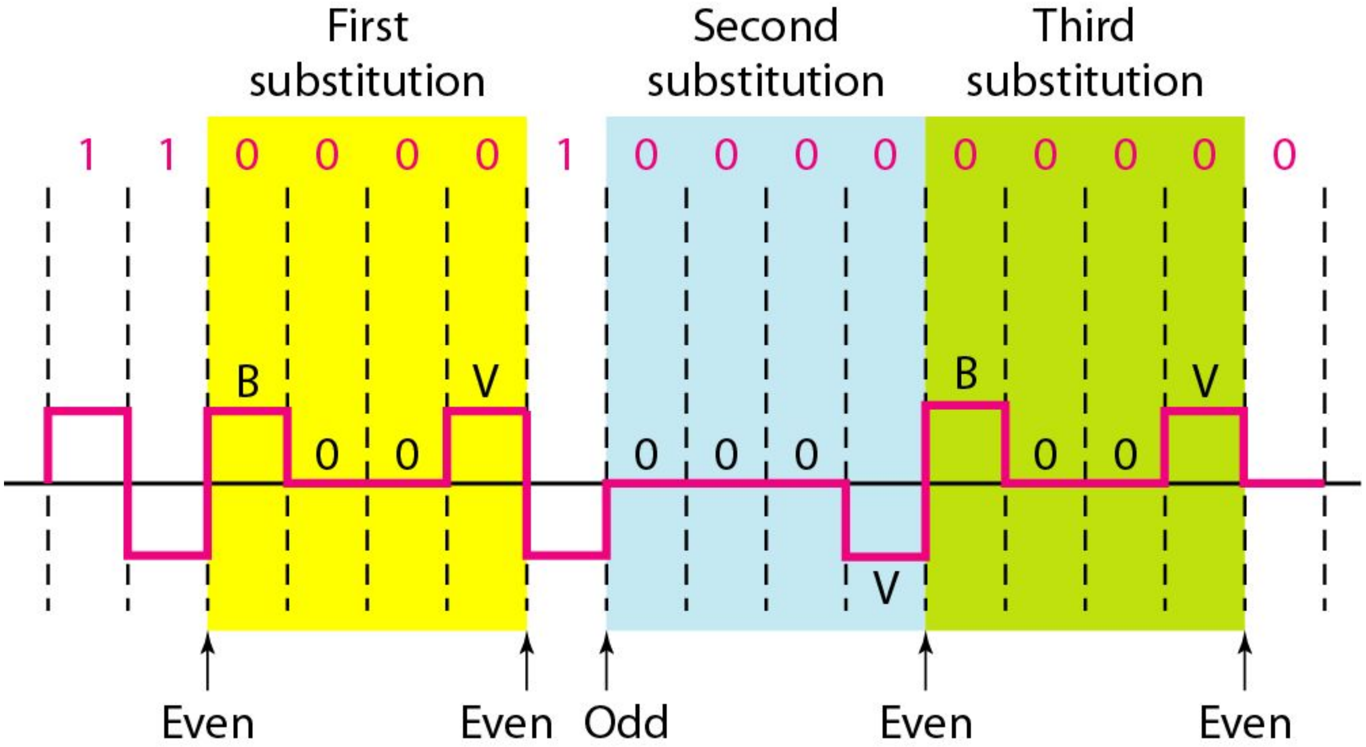
a. Previous level is positive.



b. Previous level is negative.

Different situations in HDB3 scrambling technique

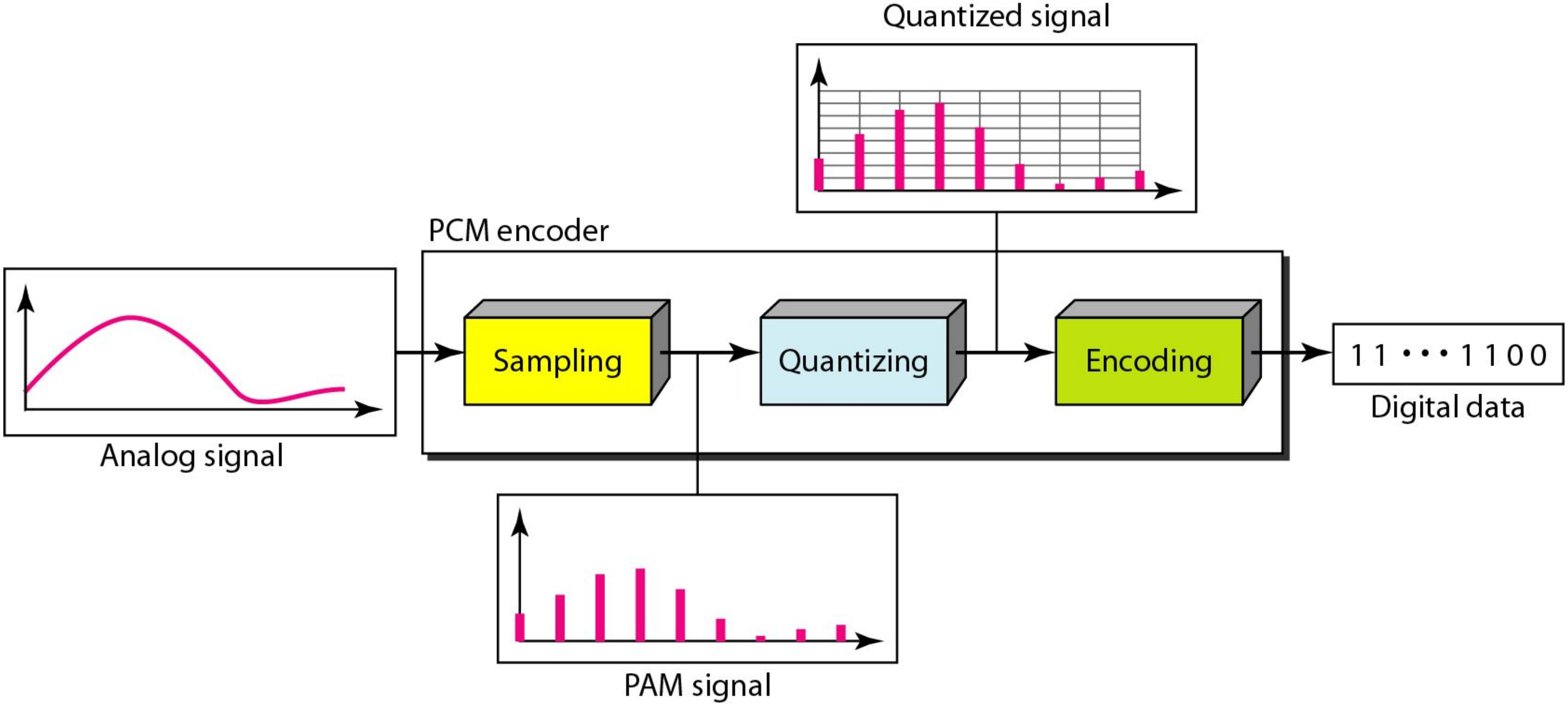
HDB3 substitutes four consecutive zeros with 000V or B00V depending on the number of nonzero pulses after the last substitution.



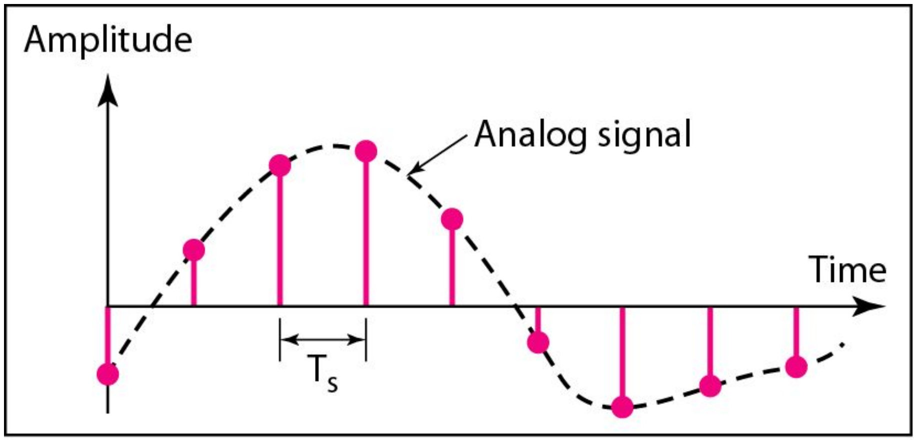
ANALOG-TO-DIGITAL CONVERSION

- A digital signal is superior to an analog signal.
- The tendency today is to change an analog signal to digital data.
- In this section we describe two techniques, pulse code modulation and delta modulation.

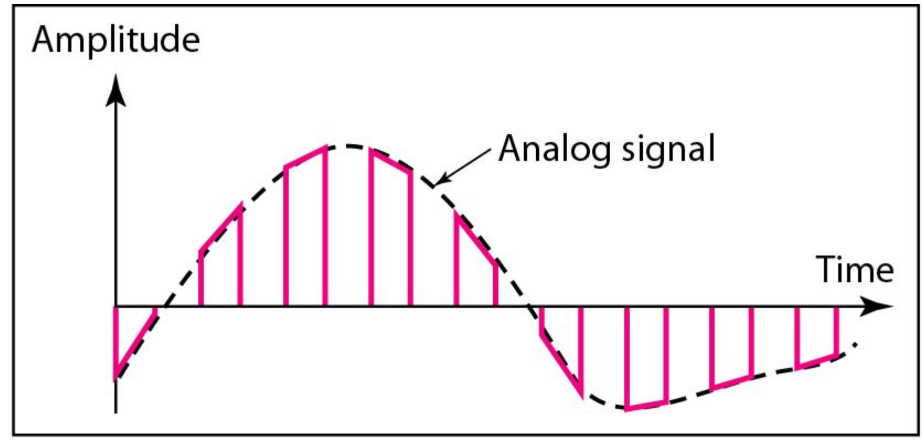
Components of PCM encoder



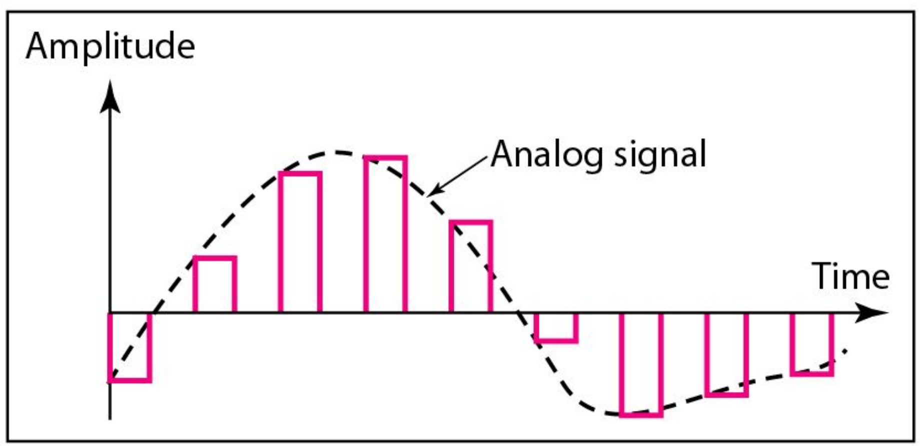
Three different sampling methods for PCM



a. Ideal sampling



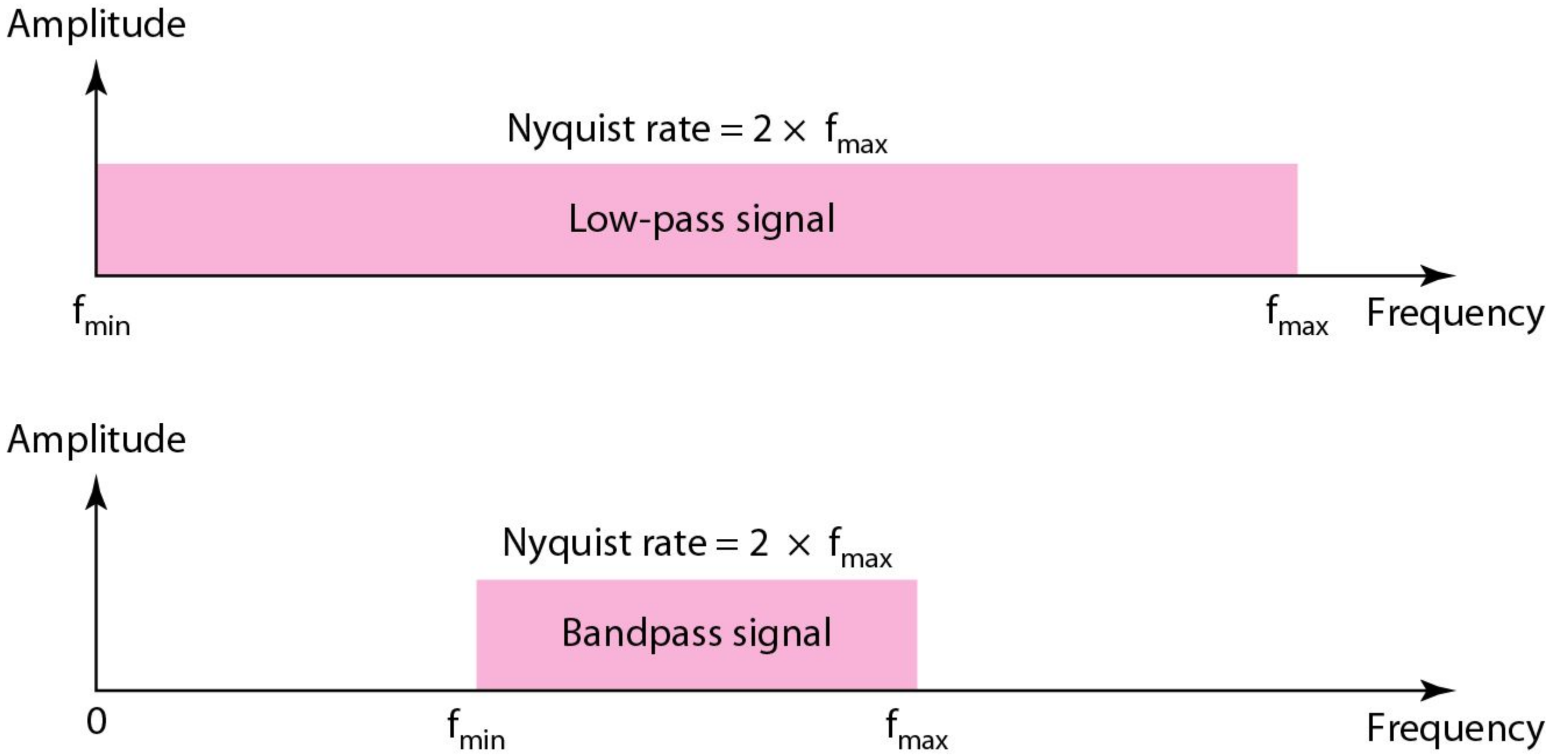
b. Natural sampling



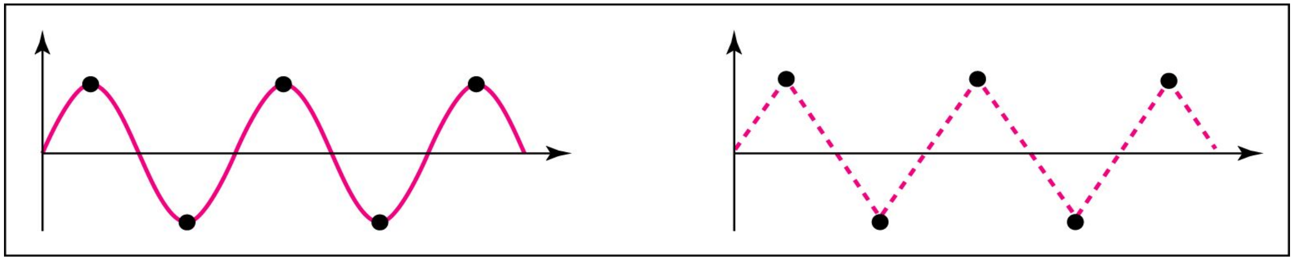
c. Flat-top sampling

Nyquist sampling rate for low-pass and bandpass signals

According to the Nyquist theorem,
the sampling rate must be at least 2 times the highest frequency contained in the signal.

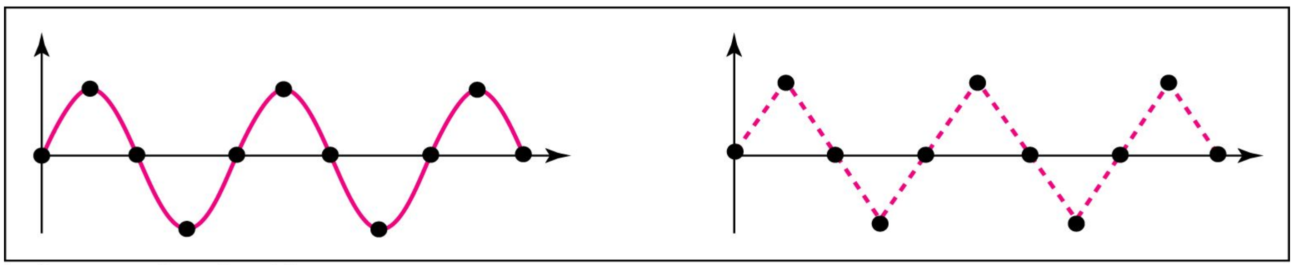


Recovery of a sampled sine wave for different sampling rates



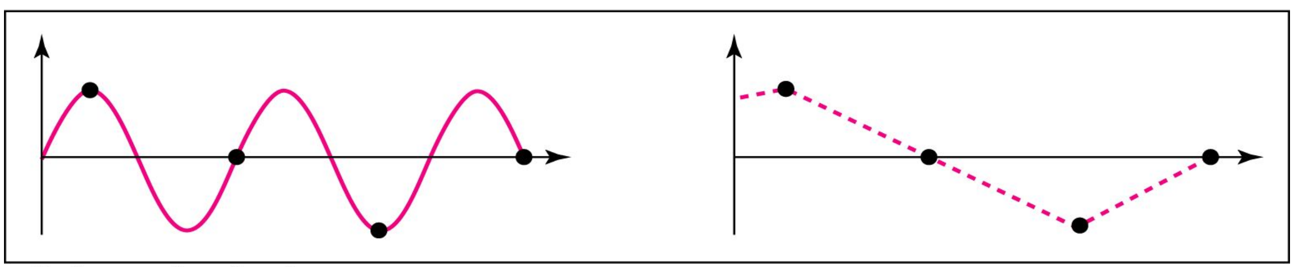
a. Nyquist rate sampling: $f_s = 2\,f$

Sampling at the Nyquist rate can create a good approximation of the original sine wave.



b. Oversampling: $f_s = 4\,f$

Oversampling can also create the same approximation, but is redundant and unnecessary.

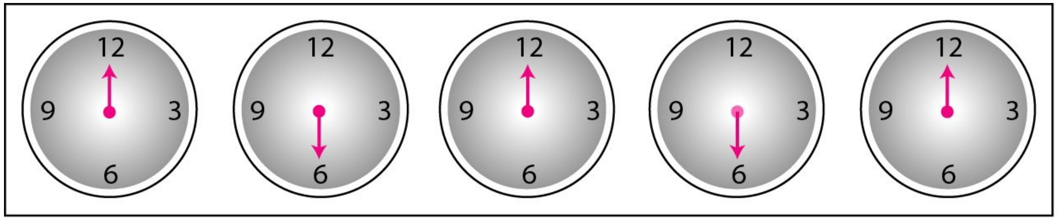


c. Undersampling: $f_s = f$

Sampling below the Nyquist rate does not produce a signal that looks like the original sine wave.

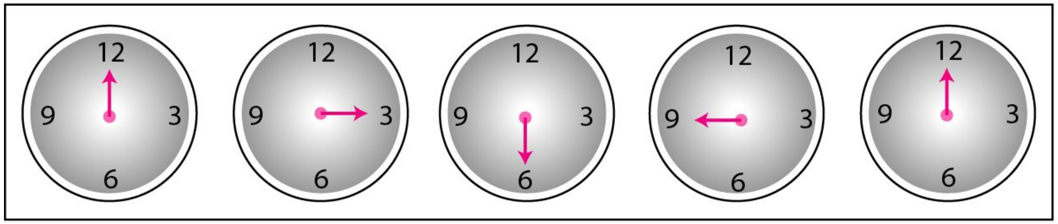
Sampling of a clock with only one hand

The second hand of a clock has a period of 60 s.
According to the Nyquist theorem, we need to sample hand every 30 s



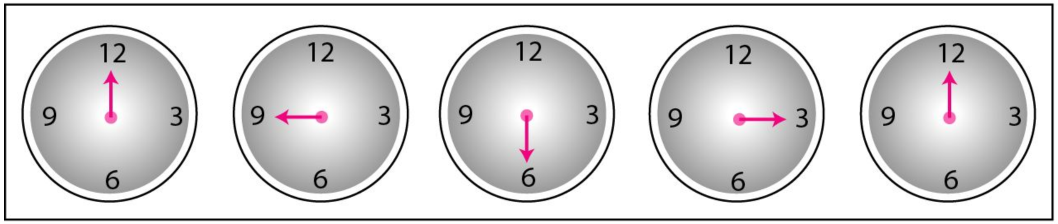
Samples can mean that the clock is moving either forward or backward. (12-6-12-6-12)

a. Sampling at Nyquist rate: $T_s = T\frac{1}{2}$



Samples show clock is moving forward. (12-3-6-9-12)

b. Oversampling (above Nyquist rate): $T_s = T\frac{1}{4}$



Samples show clock is moving backward. (12-9-6-3-12)

c. Undersampling (below Nyquist rate): $T_s = T\frac{3}{4}$

Examples

An example of under-sampling is the seemingly backward rotation of the wheels of a forward-moving car in a movie.

A movie is filmed at 24 frames per second.

If a wheel is rotating more than 12 times per second, the under-sampling creates the impression of a backward rotation.

Telephone companies digitize voice by assuming a maximum frequency of 4000 Hz.

The sampling rate therefore is 8000 samples per second.

Example

A complex low-pass signal has a bandwidth of 200 kHz.

What is the minimum sampling rate for this signal?

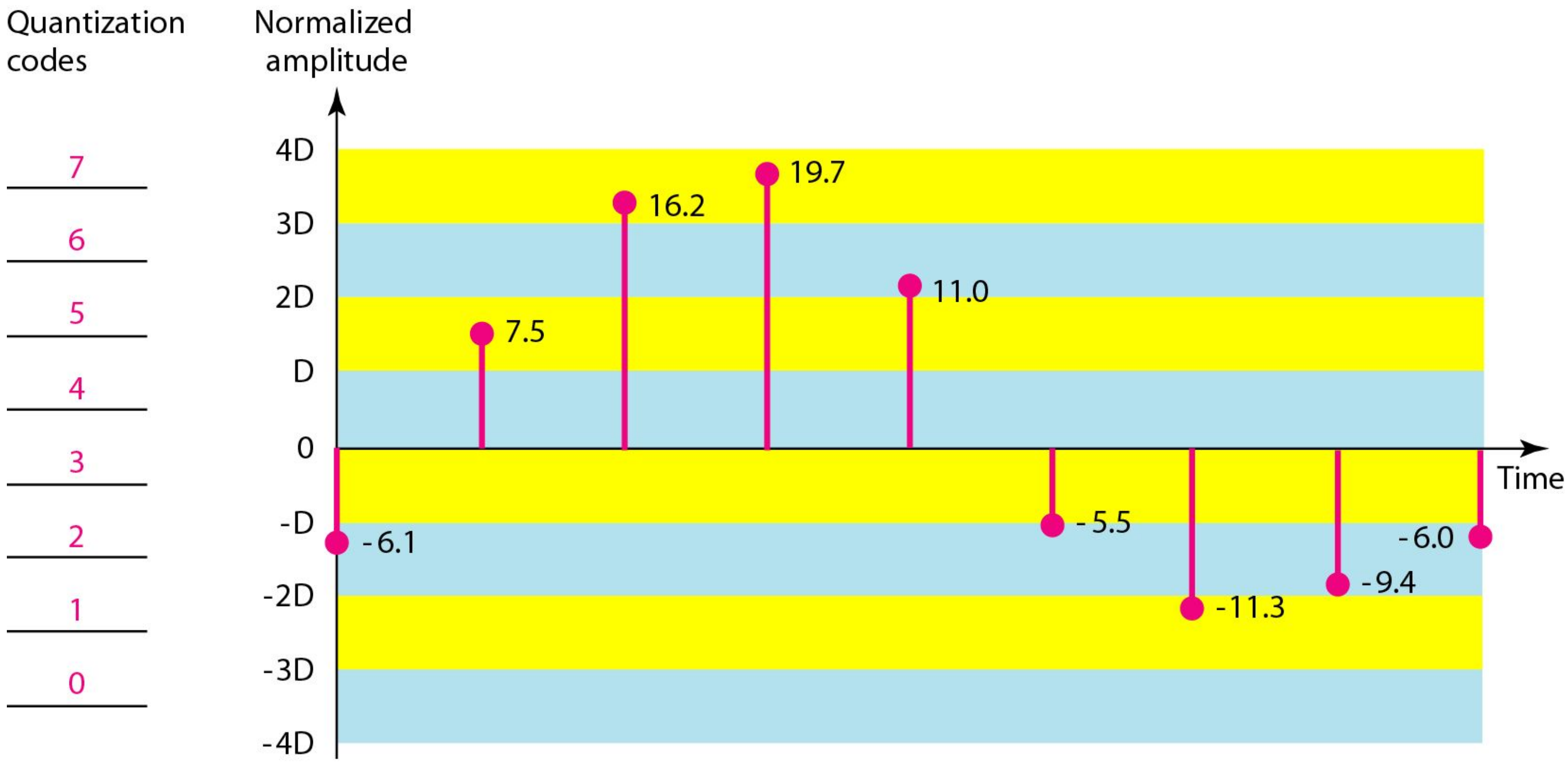
Solution

The bandwidth of a low-pass signal is between 0 and f, where f is the maximum frequency in the signal.

Therefore, we can sample this signal at 2 times the highest frequency (200 kHz).

The sampling rate is therefore 400,000 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	-0.38	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

A telephone subscriber line must have an SNRdB above 40. What is the minimum number of bits per sample?

Solution

We can calculate the number of bits as

$$\text{SNR}_{\text{dB}} = 6.02n_b + 1.76 = 40 \quad \rightarrow \quad n = 6.35$$

Telephone companies usually assign 7 or 8 bits per sample.

Example

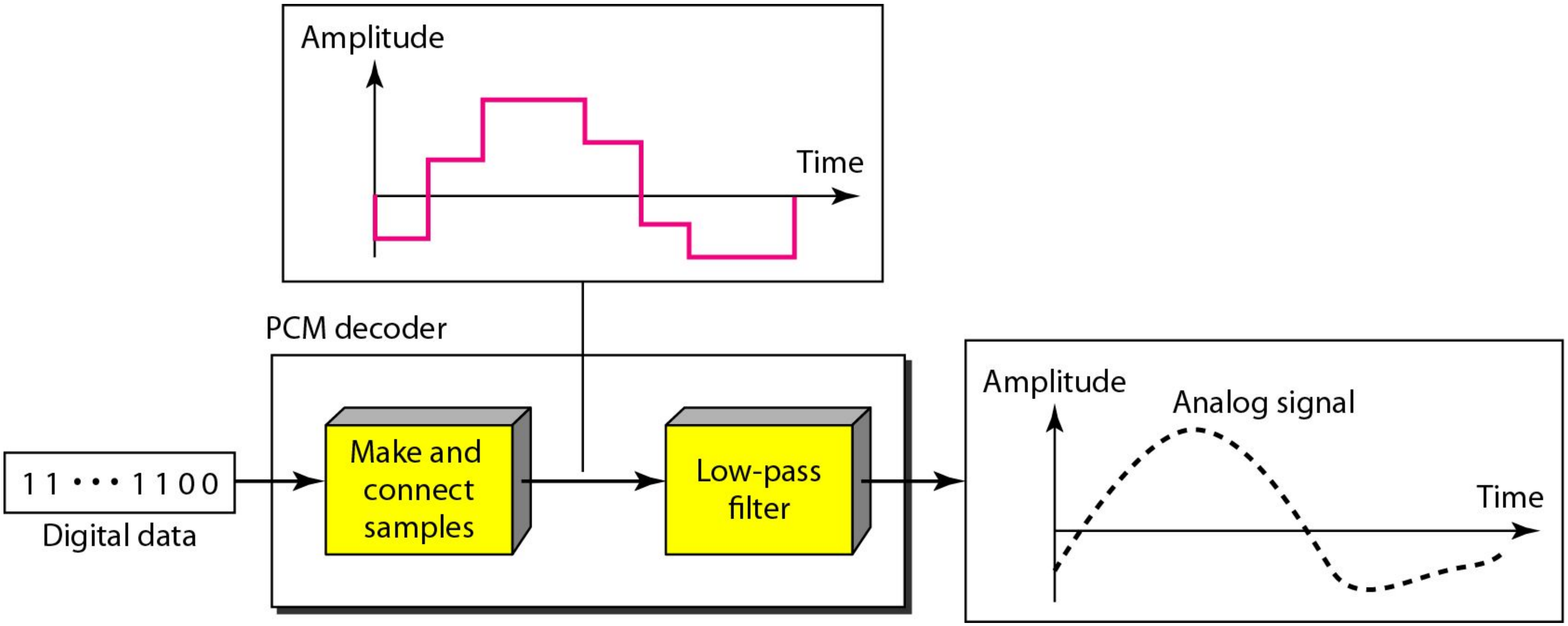
We want to digitize the human voice. What is the bit rate, assuming 8 bits per sample?

Solution

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

$$\text{Sampling rate} = 4000 \times 2 = 8000 \text{ samples/s}$$
$$\text{Bit rate} = 8000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$

Components of a PCM decoder



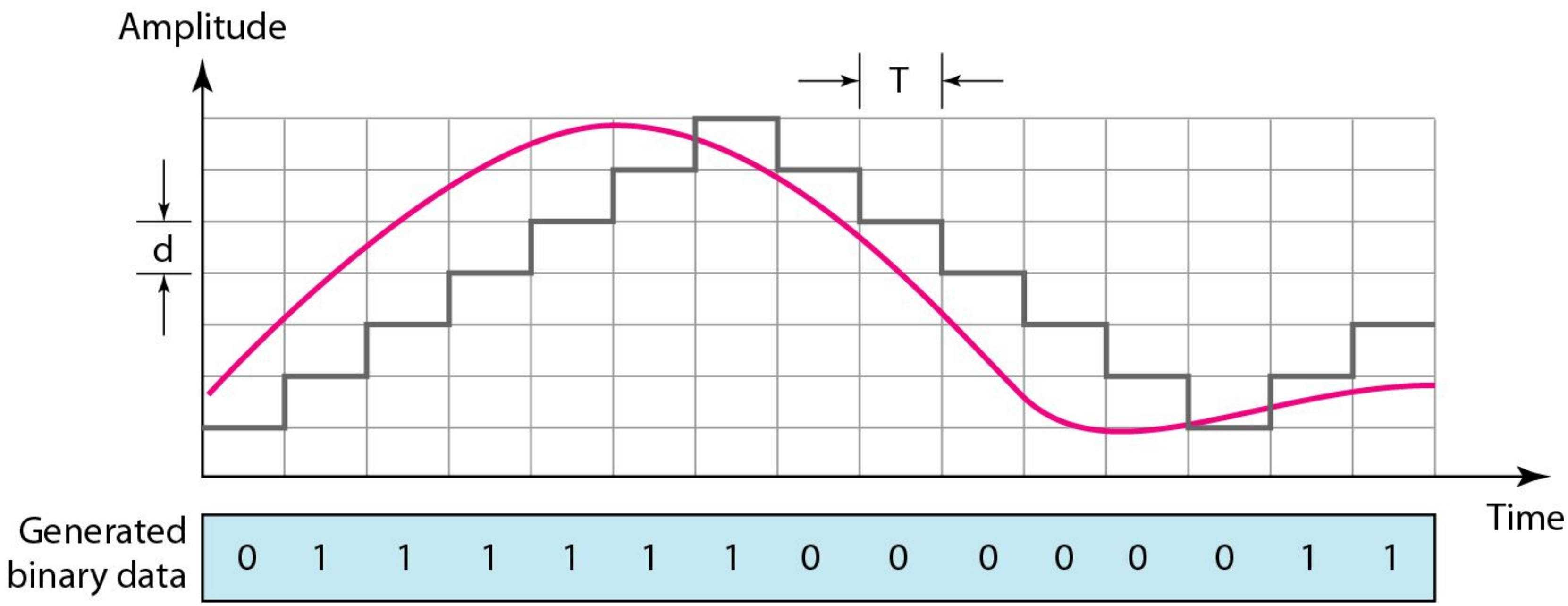
Example

We have a low-pass analog signal of 4 kHz.

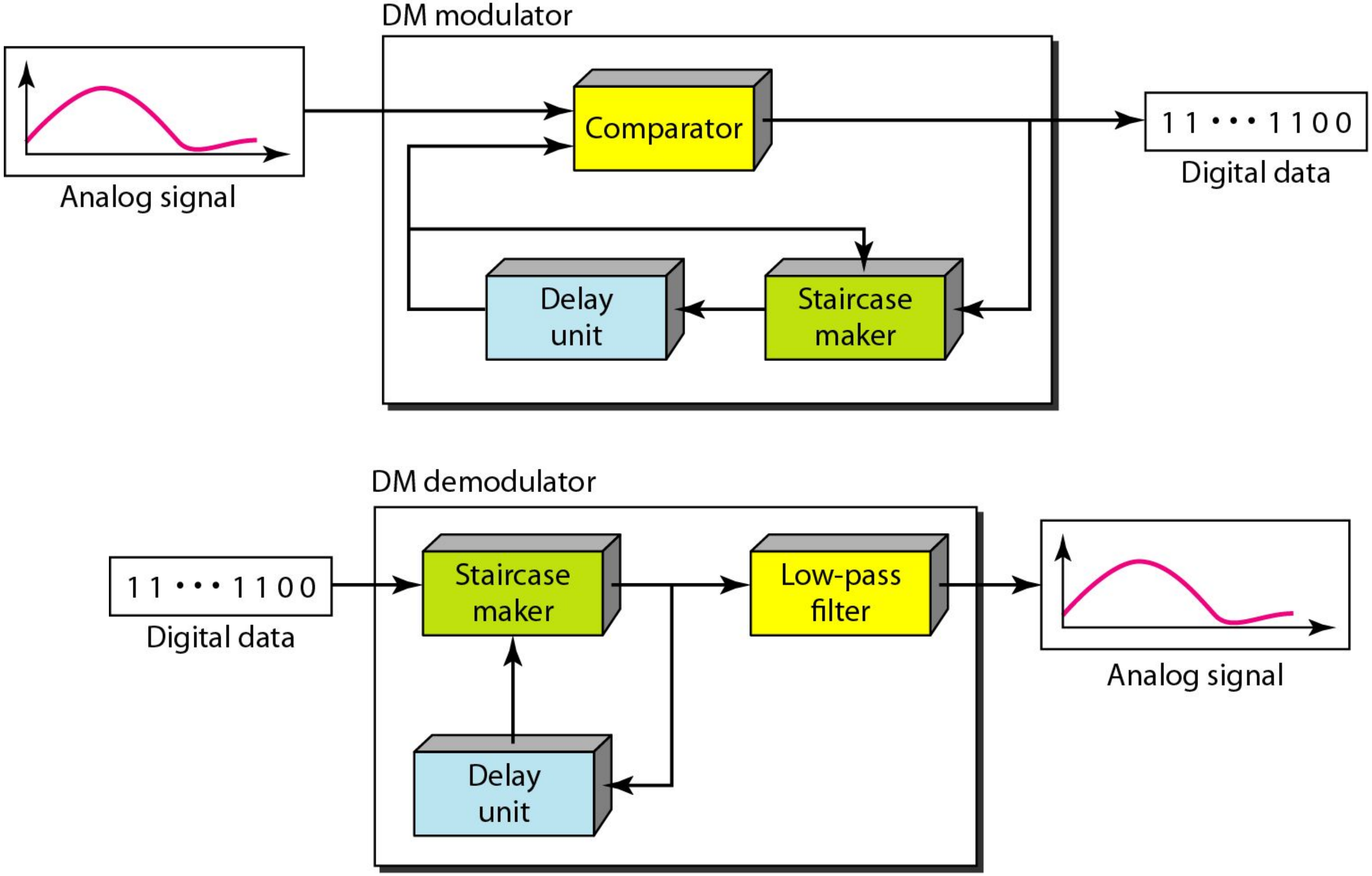
If we send the analog signal, we need a channel with a minimum bandwidth of 4 kHz.

If we digitize the signal and send 8 bits per sample, we need a channel with a minimum bandwidth of 8 × 4 kHz = 32 kHz.

The process of delta modulation



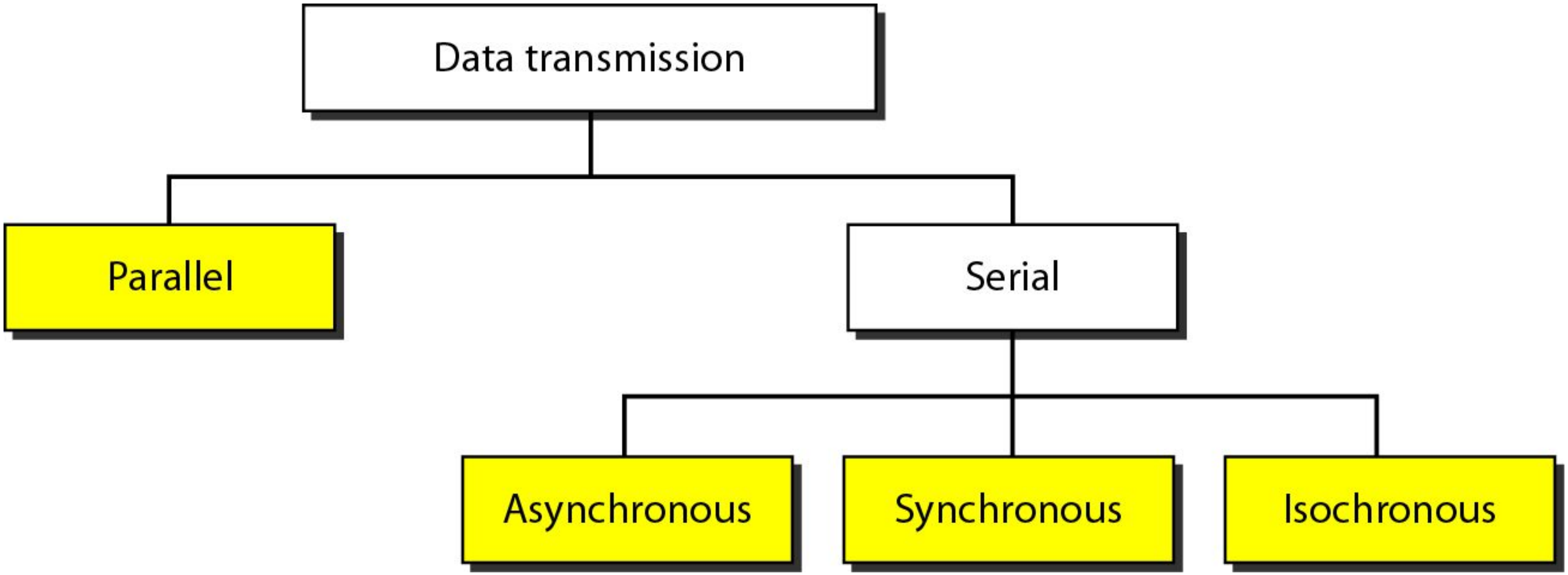
Delta modulation components



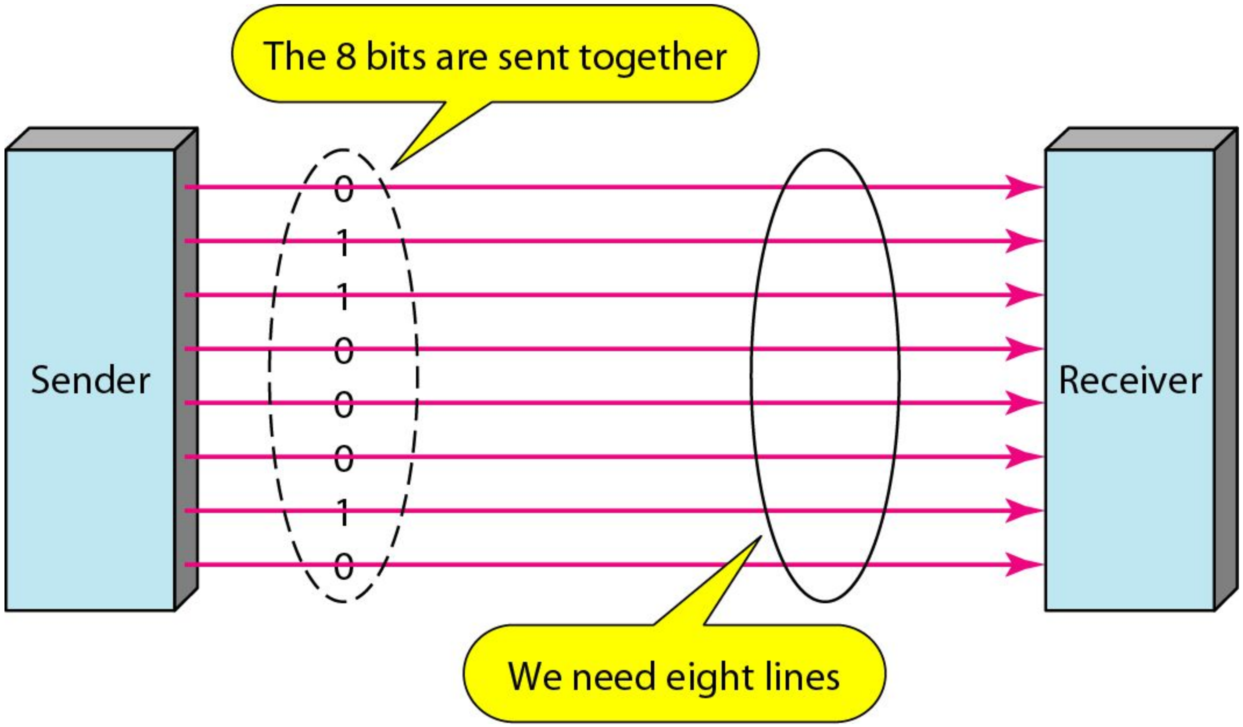
TRANSMISSION MODES

- The transmission of binary data across a link can be accomplished in either parallel or serial mode.
- In parallel mode, multiple bits are sent with each clock tick.
- In serial mode, 1 bit is sent with each clock tick.
- While there is only one way to send parallel data, there are three subclasses of serial transmission: asynchronous, synchronous, and isochronous.

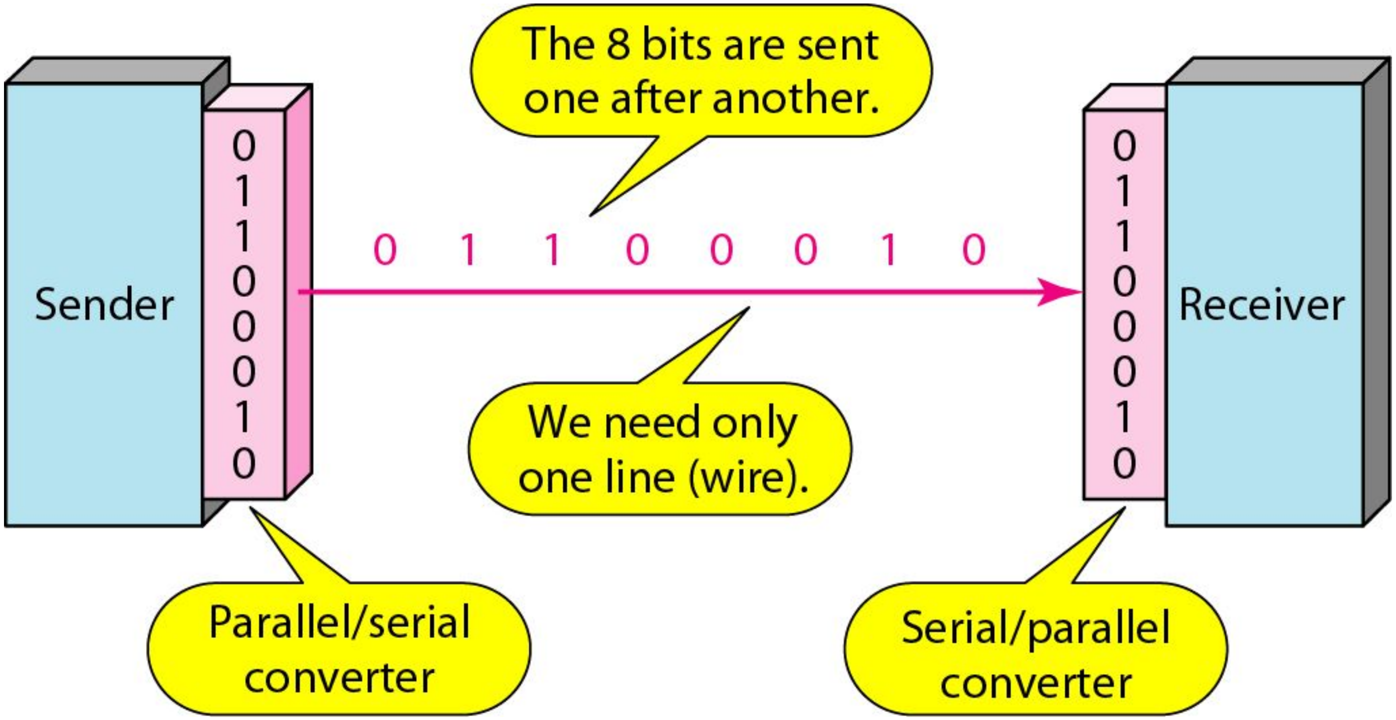
Data transmission and modes



Parallel transmission

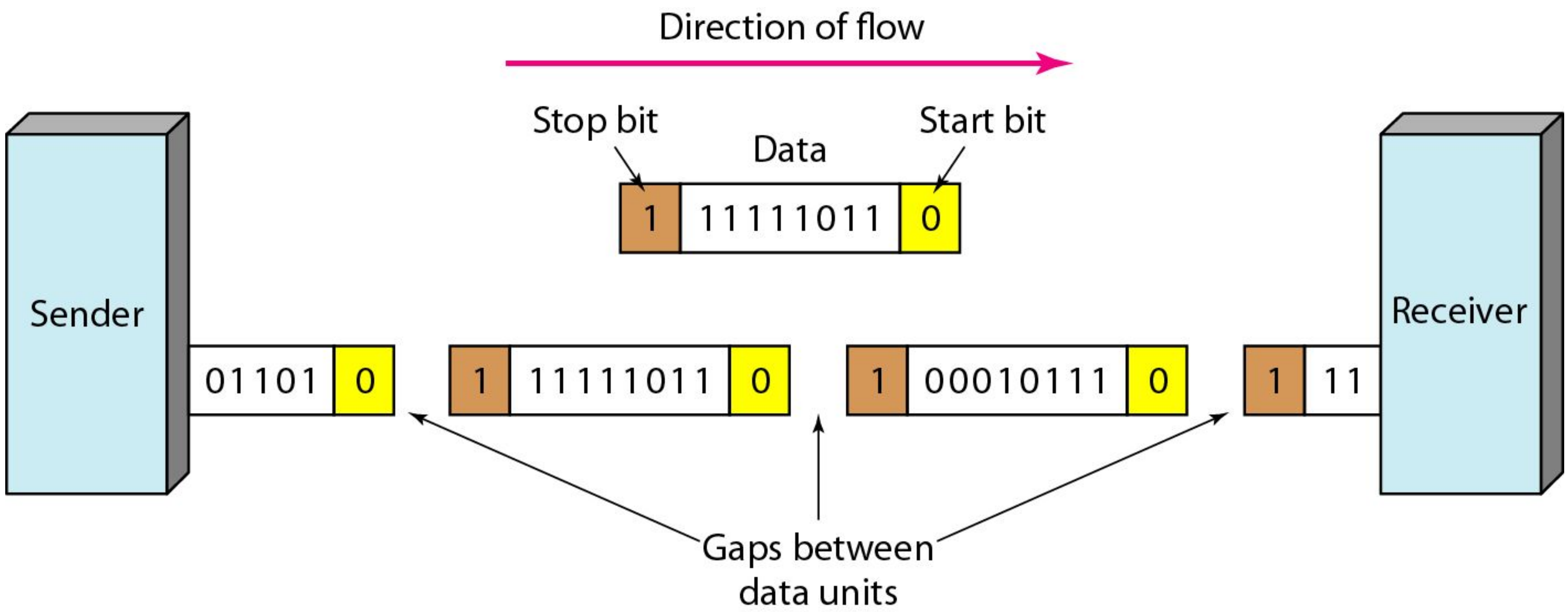


Serial transmission



Asynchronous transmission

We send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte.
There may be a gap between each byte.



It is "asynchronous at the byte level," bits are still synchronized; their durations are the same.

Synchronous transmission

We send bits one after another without start or stop bits or gaps.
It is the responsibility of the receiver to group the bits.