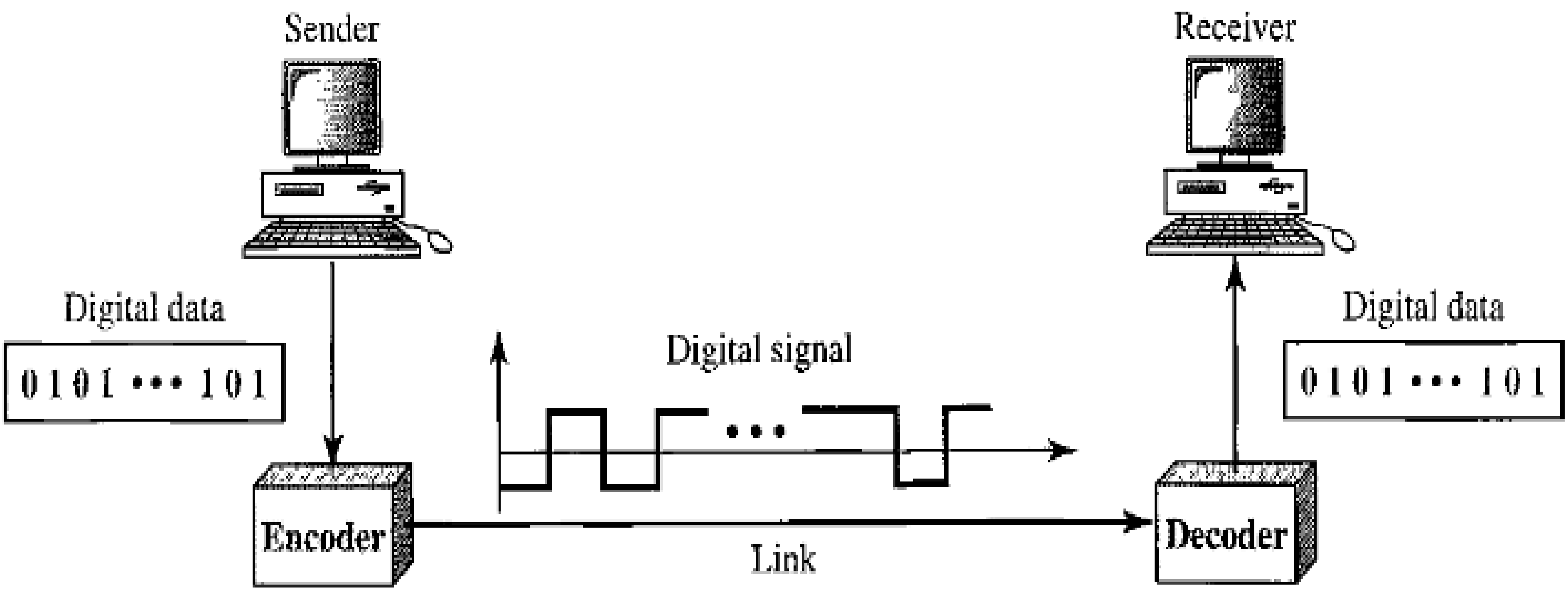
Chapter 4

Digital-to-Digital Conversion Techniques

- Line Coding
- Block Coding
- Scrambling

Line Coding

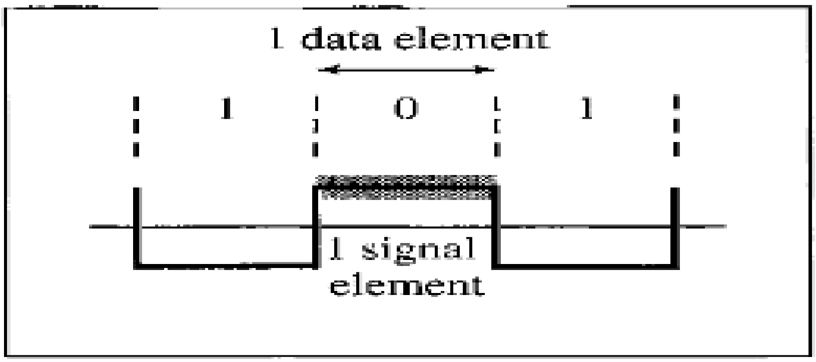
- Digital data is assumed to be stored in computer memory as sequences of bits



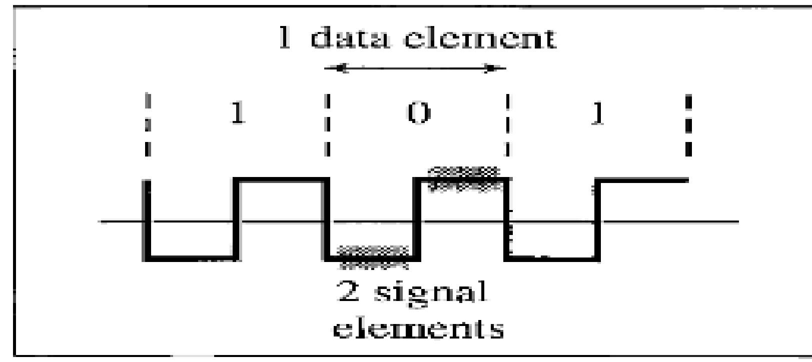
Definitions

- Data Element
  - Smallest entity that can represent a piece of information (bit)
- Signal Element
  - Shortest unit (timewise) of a digital signal
- Let r = number of data elements carried by each signal element

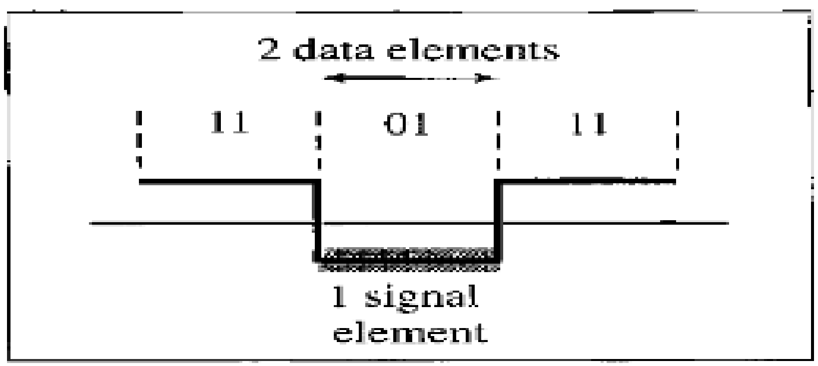
Different r values



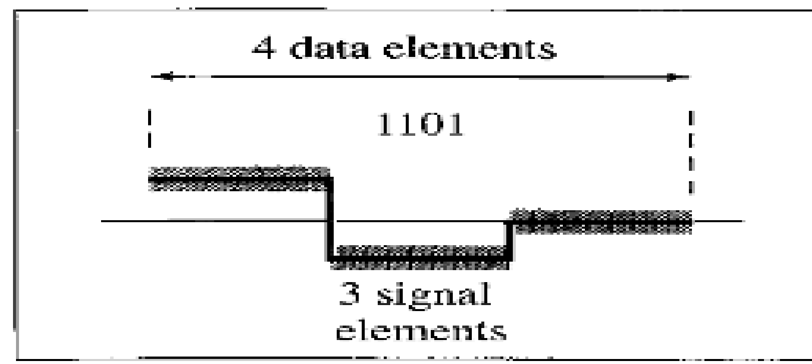
a. One data element per one signal element ($r = 1$)



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

Definitions

- Data Rate(aka Bit Rate)
  - Number of bits sent in 1 second (bps)
- Signal Rate (aka Pulse Rate, Modulation Rate, Baud Rate)
  - Number of signal elements sent in 1 second (baud)
- Goal: Increase data rate(increase speed) while decreasing signal rate (decrease bandwidth requirement)

$$S = c \times N \times \left(\frac{1}{r}\right)$$

N-data rate
c-case factor
S-number of signal elements
r-ratio of data element per signal element

Definitions

- Effective Bandwidth
  - Finite compared to Absolute Bandwidth
  - Baud Rate determines the required bandwidth
  - For now: Bandwidth is proportional to Baud Rate

$$B_{min} = c \times N \times \left(\frac{1}{r}\right)$$

$$N_{max} = \left(\frac{1}{c}\right) \times B \times r$$

Definitions

- Baseline Wandering
  - Receiver calculates a running average of the received singal power – baseline
  - Incoming signal is evaluated against baseline (to determine 1 or 0)
  - Long sequence of 0's or 1's can cause a drift in the baseline
  - Line coding scheme must prevent this

Definitions

- Direct Current (DC) Components
  - Spectrum creates very low(near zero) frequencies when digital signal is constant for a while
  - Some systems cannot pass low frequencies
  - Some systems use electrical coupling
  - No DC component is desired
- Self-synchronization
  - Timing information is in the signal itself

Definitions

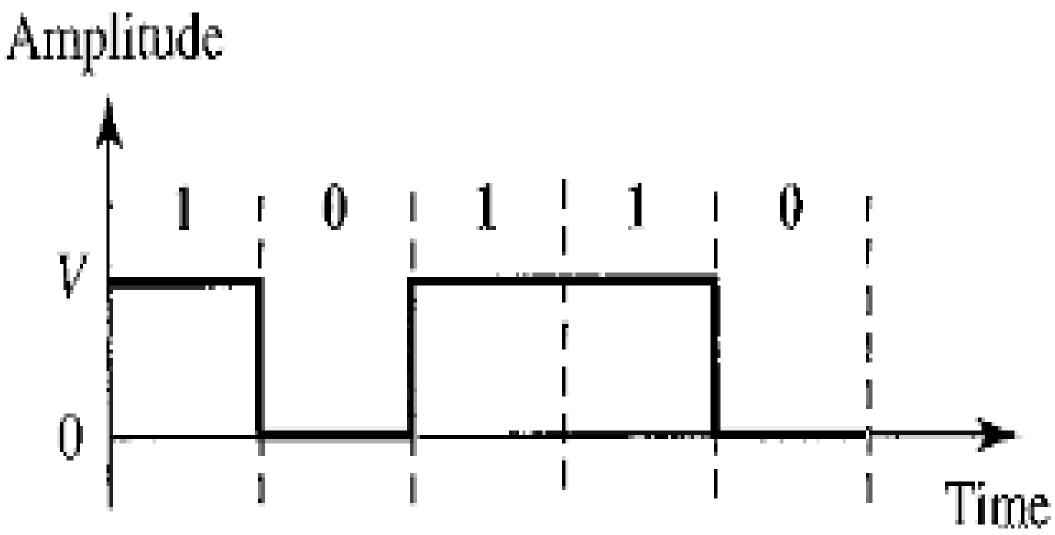
- Built-in Error Detection
  - Signal has built-in error detection
- Immunity to Noise and Interference
  - Signal generated is immune to noise
- Complexity
  - Scheme should be simple

Line Coding Schemes

- Unipolar – all signal levels are above or below time axis
  - NRZ
- Polar – signal levels are on both sides of the time axis
  - NRZ, RZ, biphase (Manchester and Differential Manchester)
- Bipolar – three levels: positive, negative, zero; one signal level alternates between positive and negative
  - AMI and pseudoternary
- Multilevel – increase number of bits per baud
  - 2B/1Q, 8B/6T, and 4D-PAM5
- Multitransition
  - MLT-3

Unipolar NRZ

- Non-Return-to-Zero
- 1 – positive voltage, 0 – zero voltage

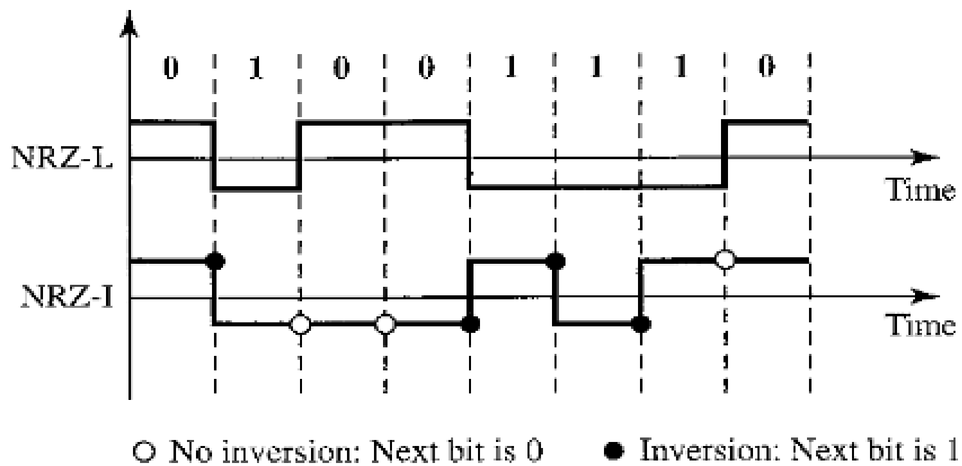


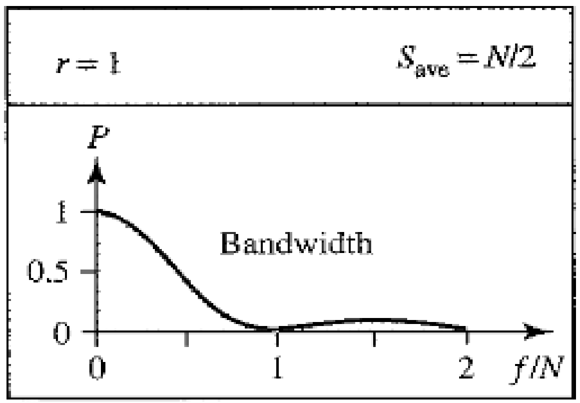
$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

Normalized power

Polar NRZ

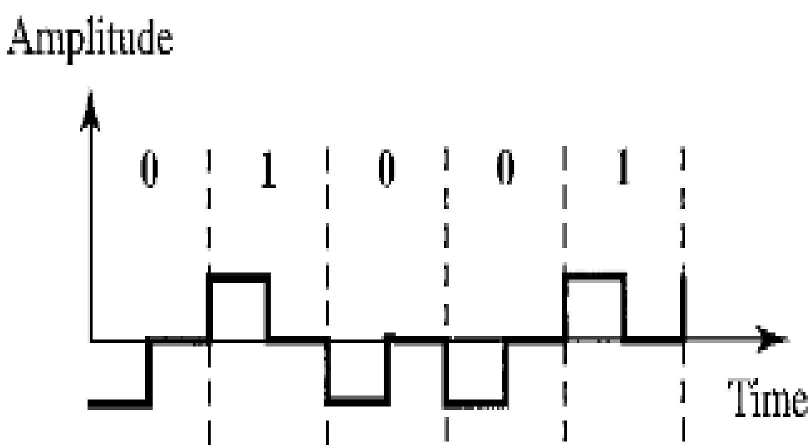
- NRZ-L (Level)
  - Level of voltage determines value of bit
- NRZ-I (Invert)
  - Change or lack of change in the level of the voltage determines the value of the bit (0 – no change)

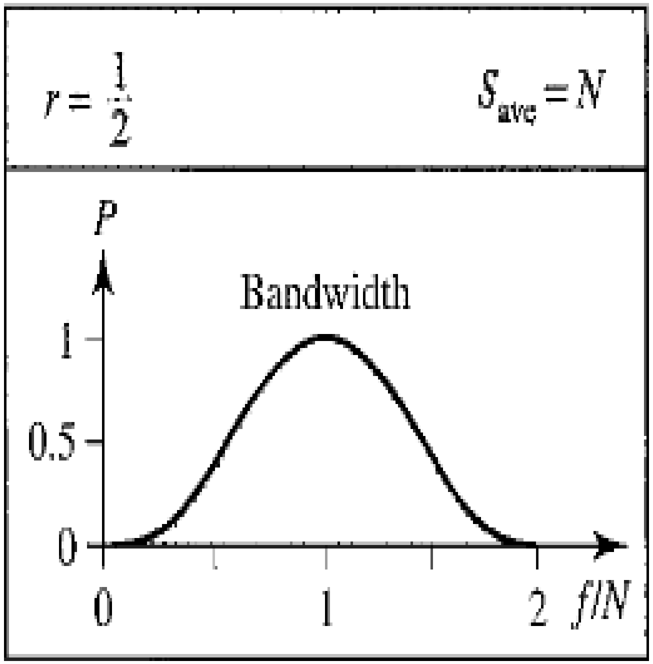




Polar RZ

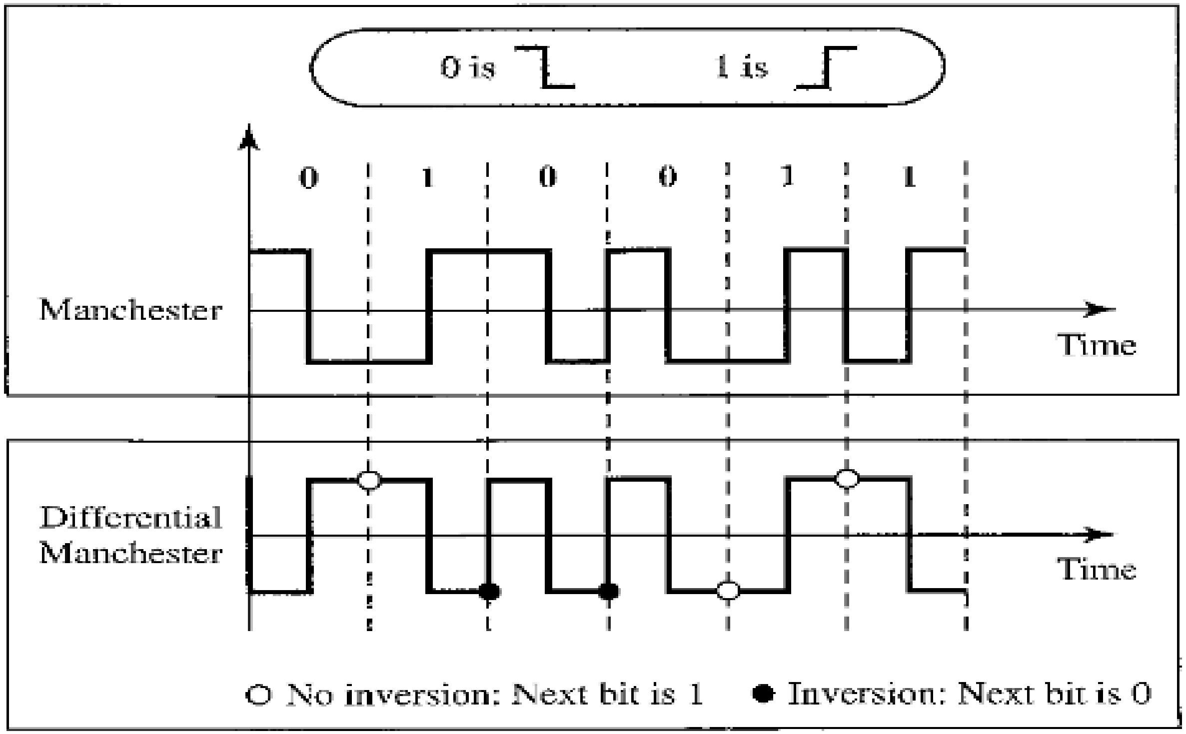
- Midbit transition, solves sync problem of NRZ
- More complex, more bandwidth, no DC component

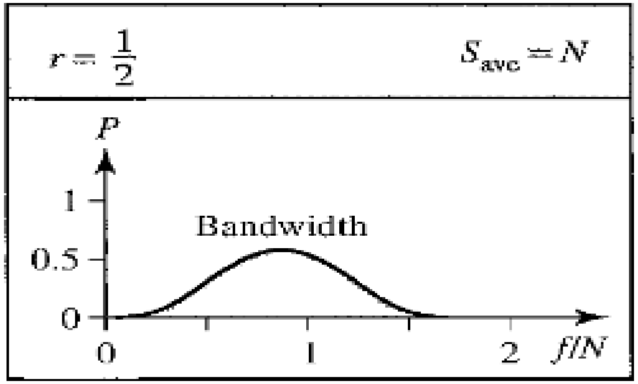




Manchester/Differential Manchester

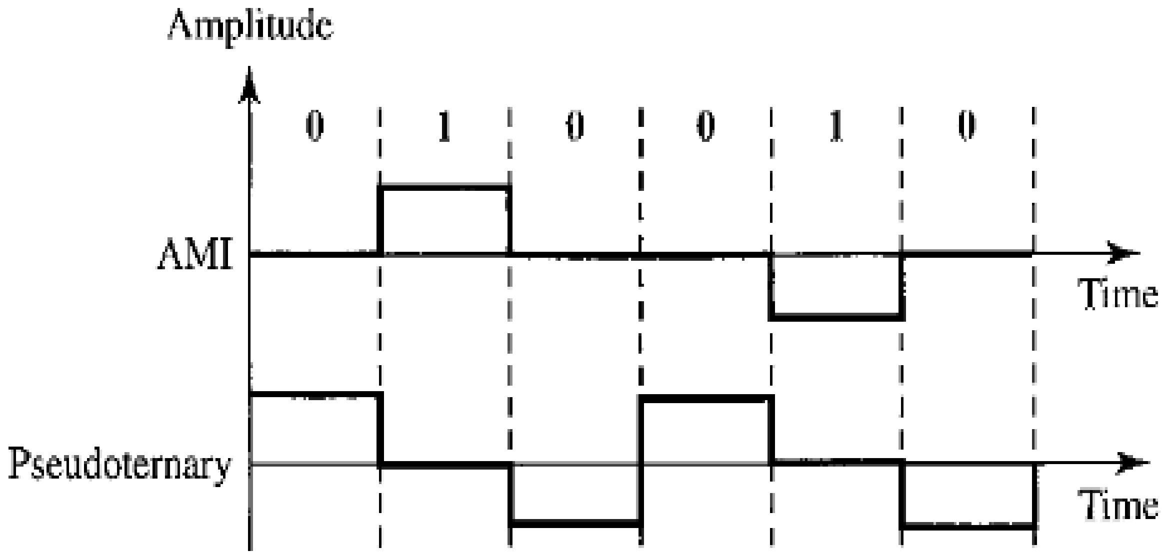
- Midbit transtition for sync, twice the bandwidth of NRZ

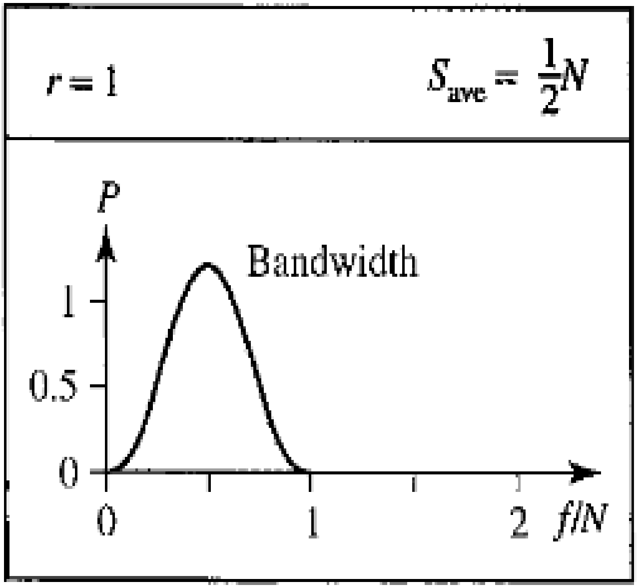




AMI/Pseudoternary

- Alternate Mark Inversion
  - Neutral zero voltage – 0, alternating (+) and (-) - 1
- Pseudoternary – reverse of AMI





Multilevel Schemes

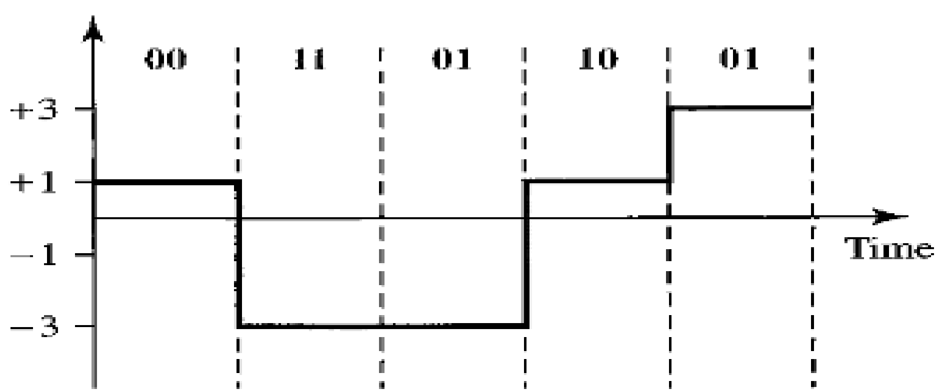
- Encode a pattern of **m** data elements into a pattern of **n** signal elements
- 2^m data patters, L^n signal patterns
- If $2^m = L^n$, each data pattern is encoded in one signal pattern
- If $2^m < L^n$, data elements occupy a subset of the signal patterns
- **mBnL**, pattern of m data elements is encoded in a pattern of n signal elements in which $2^m <= L^n$

2B1Q

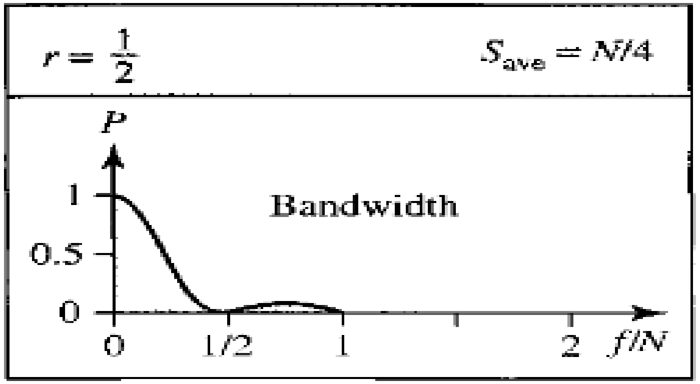
- Two binary, one quaternary
- Used in DSL (Digital Subscriber Line)

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

Transition table

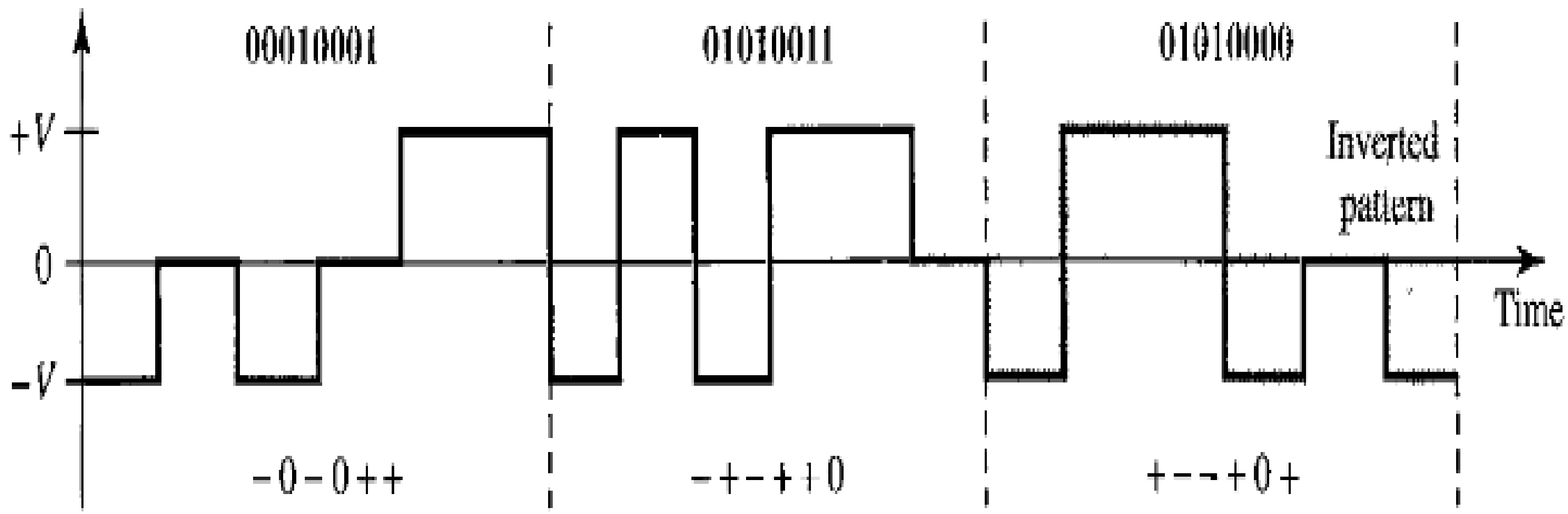


Assuming positive original level



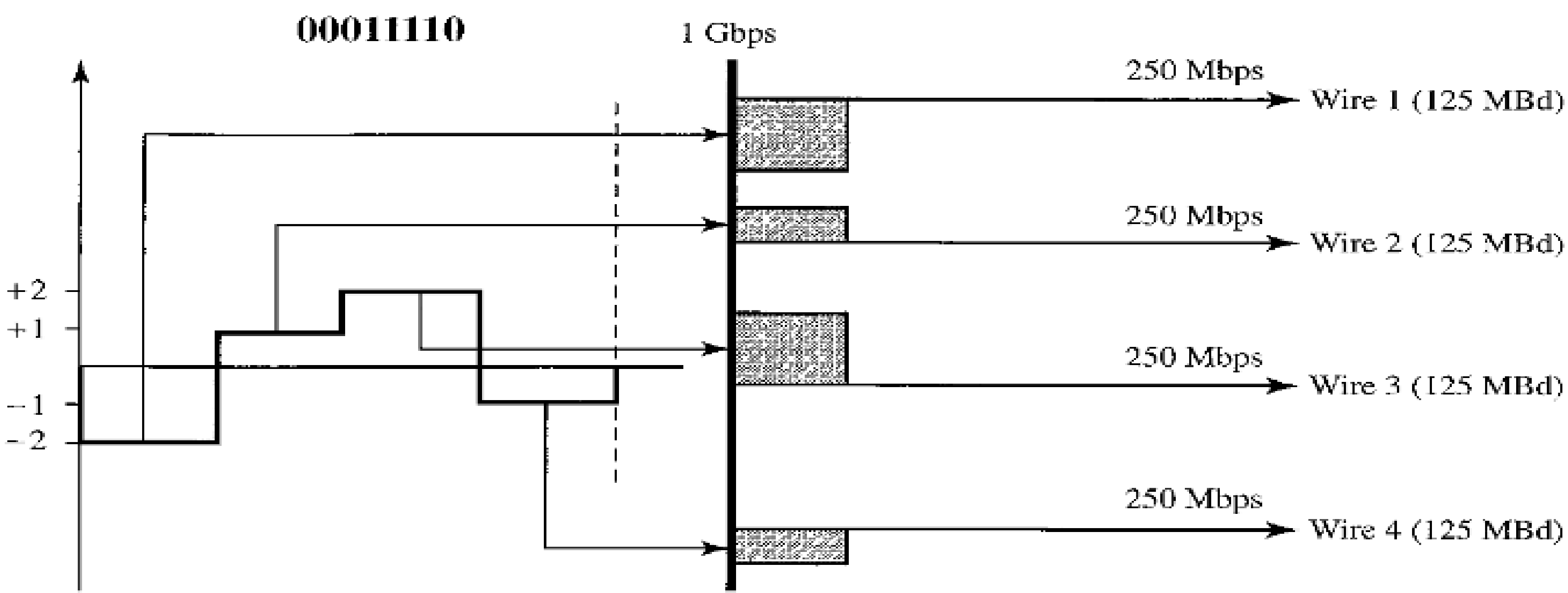
8B6T

- Eight binary, six ternary
- Used in 100Base-4T, bandwidth 6N/8

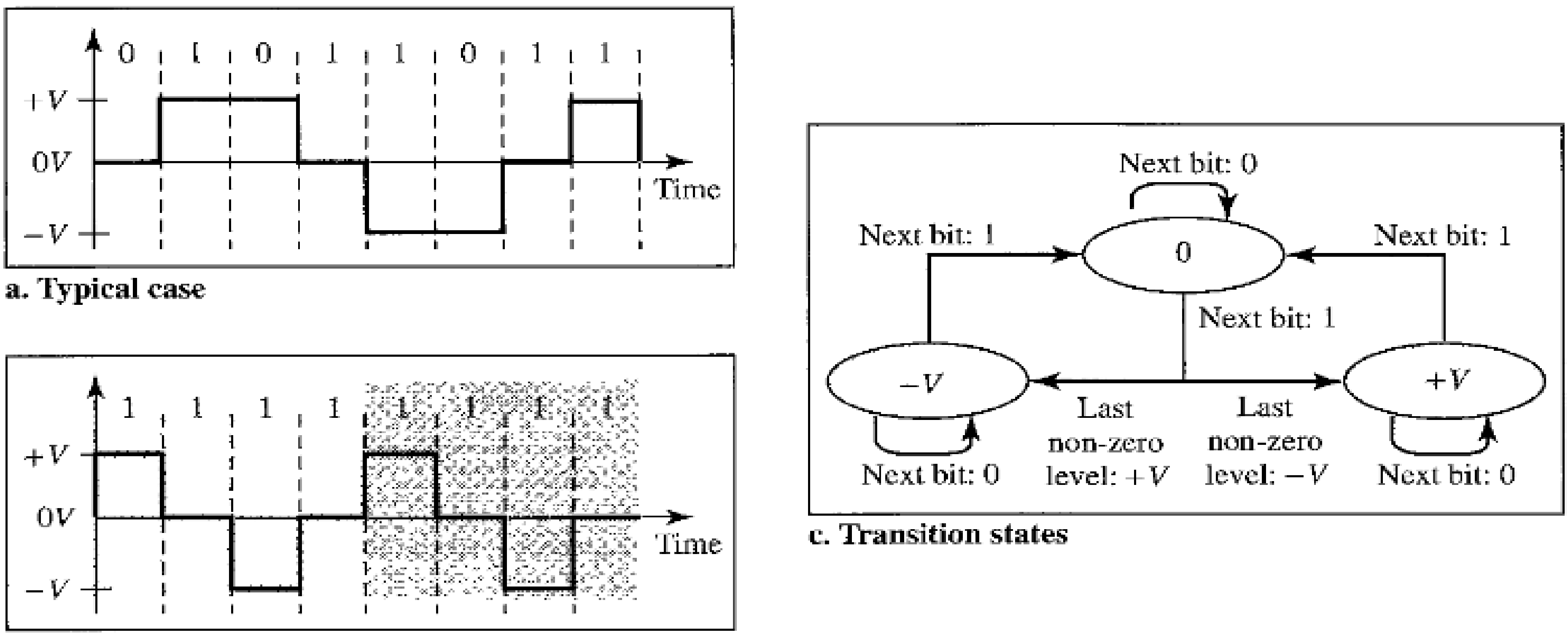


4D-PAM5

- Four dimensional five-level pulse amplitude modulation
- Used in Gigabit LANs, uses 4 wires



Multiline Transmission: MLT-3



a. Typical case

b. Worse case

c. Transition states

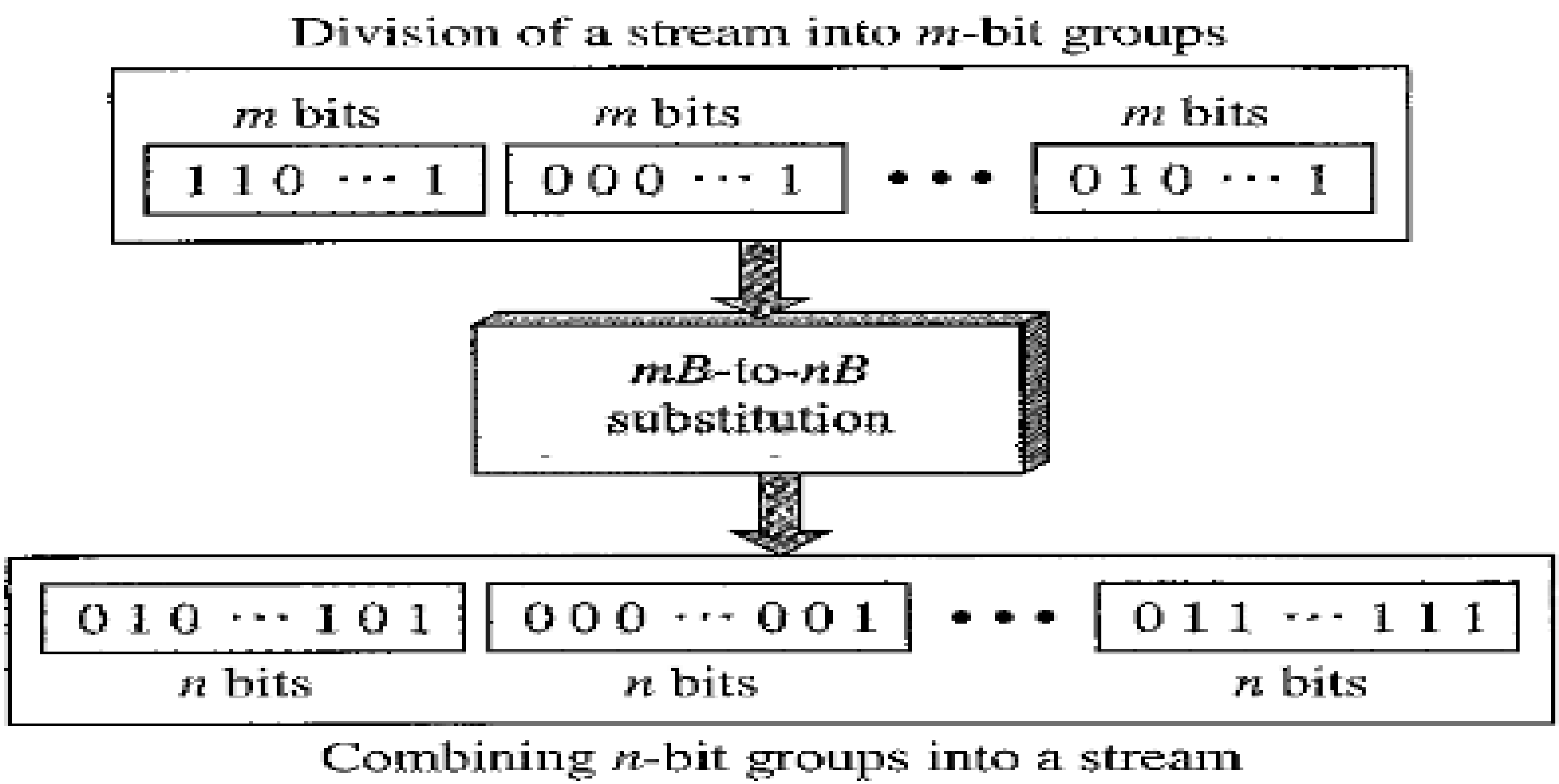
Summary

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

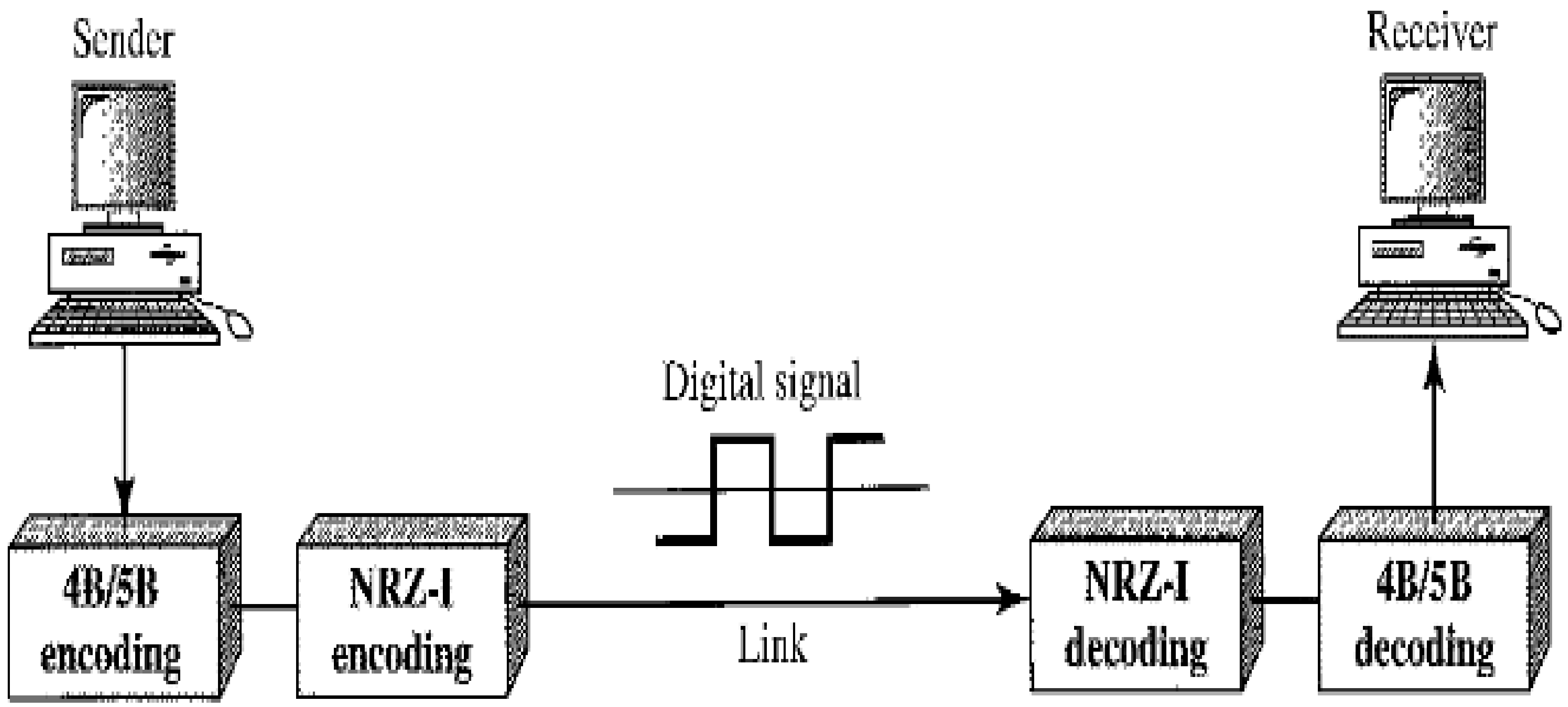
Block Coding

- Redundancy to ensure synchronization and error detection
- Changes a block of **m** bits into a block of **n** bits, where **n > m**
- aka **mB/nB** encoding
- Involves division, substitution, and combination steps
- ex. 4B/5B (often combined with NRZ-I), 8B/10B

Block Coding



4B/5B and NRZ-I



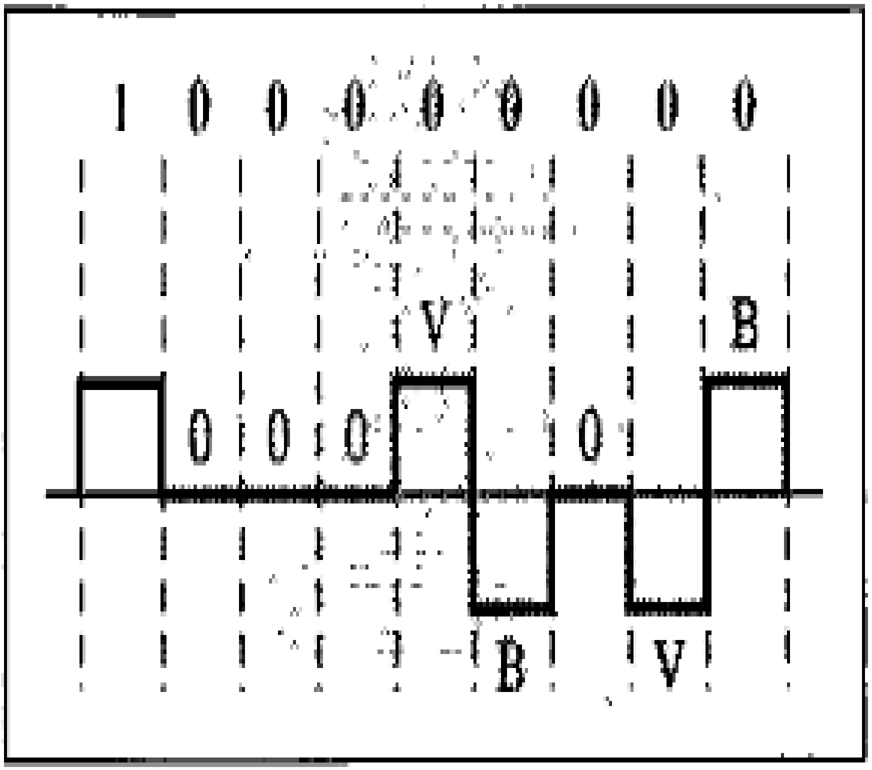
Scrambling

- Bipolar AMI is most suitable for long-distance transmission (has narrow bandwidth and no DC component)
- However, long sequence of 0's disrupts synchronization
- Solution: substitute long sequences of 0's with a combination of other levels
- Scrambling is done at the same time as encoding
- ex. B8ZS and HDB3

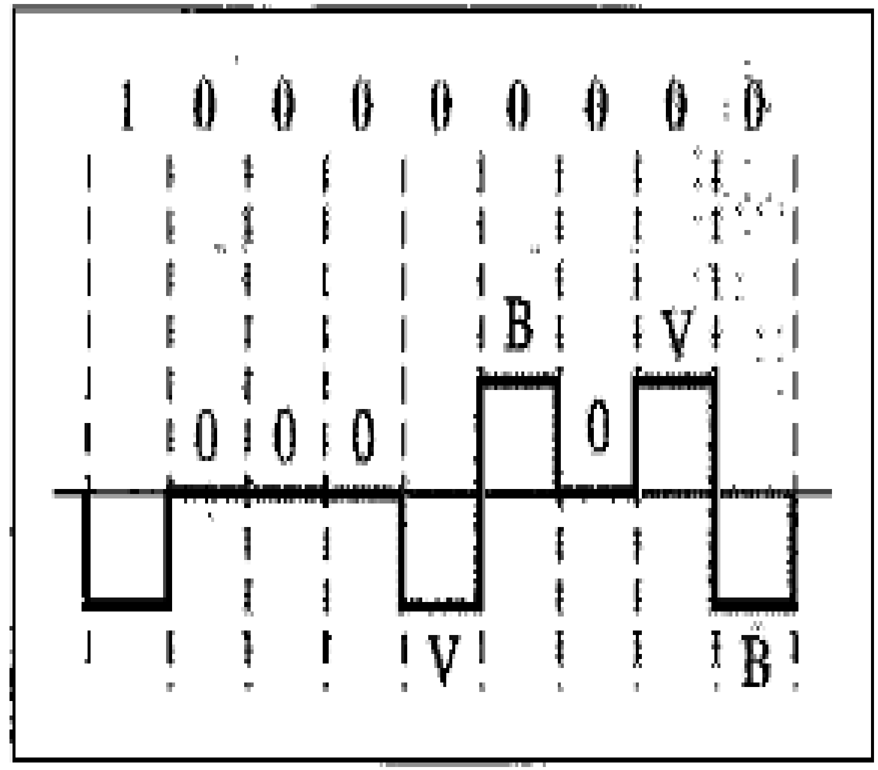
B8ZS

- Bipolar with 8-zero substitution
- Eight consecutive zero-level voltages are replaced by a sequence **000VB0VB**
- V – non-zero voltage violating the AMI rule
- B – bipolar non-zero voltage
- Does not change the bit rate, balances (+) and (-) voltages, substitution may change the polarity of a 1

B8ZS



a. Previous level is positive.

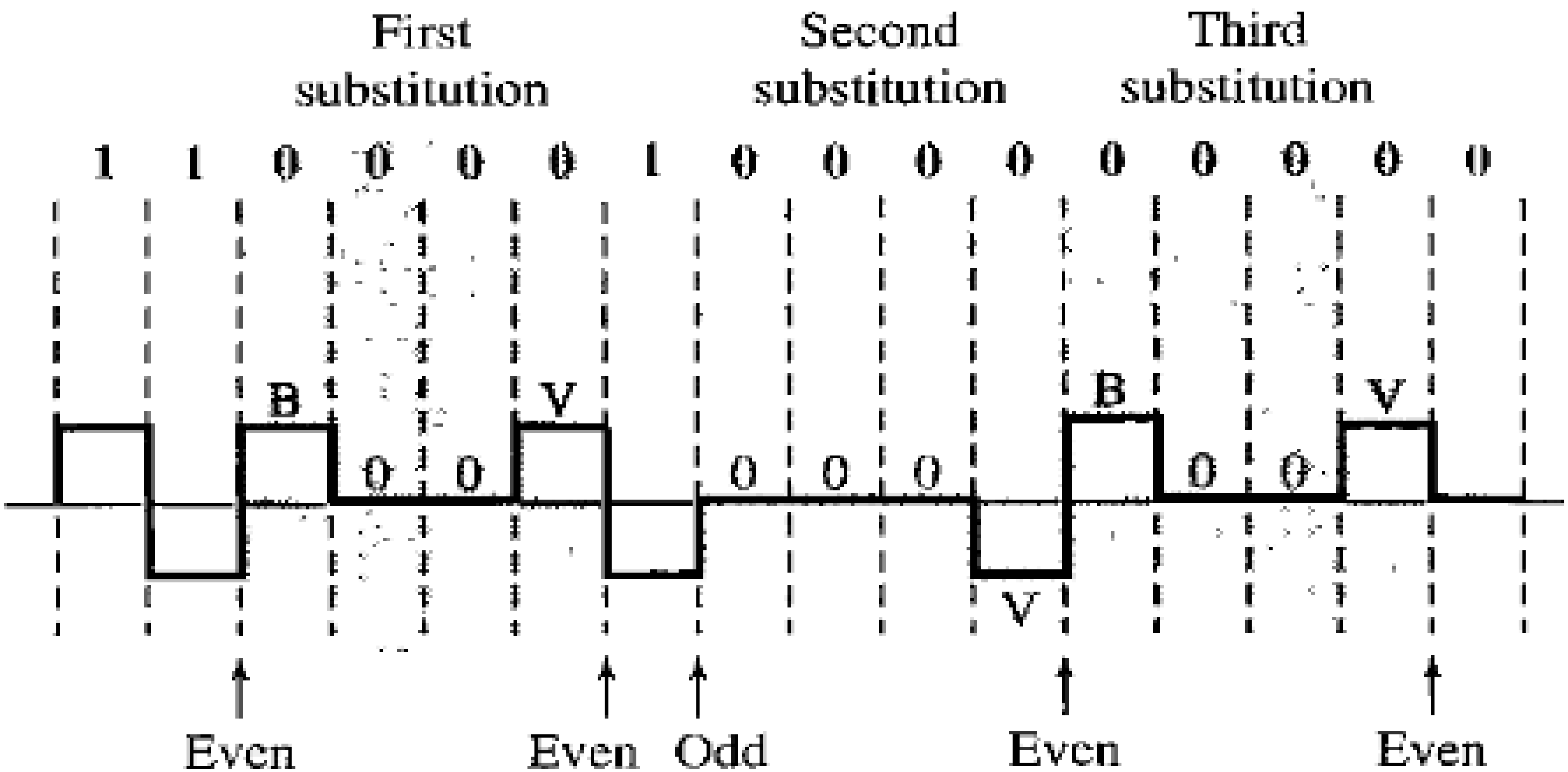


b. Previous level is negative.

HDB3

- High-density bipolar 3-zero (HDB3)
- Four consecutive zero-level voltages are replaced with a sequence of **000V** or **B00V**
- Why two sequences? - to maintain the even number of non-zero pulses after each substitution
  - If the number of nonzero pulses after the last substition is odd, 000V
  - If the number of nonzero pulses after the last substition is even, B00V

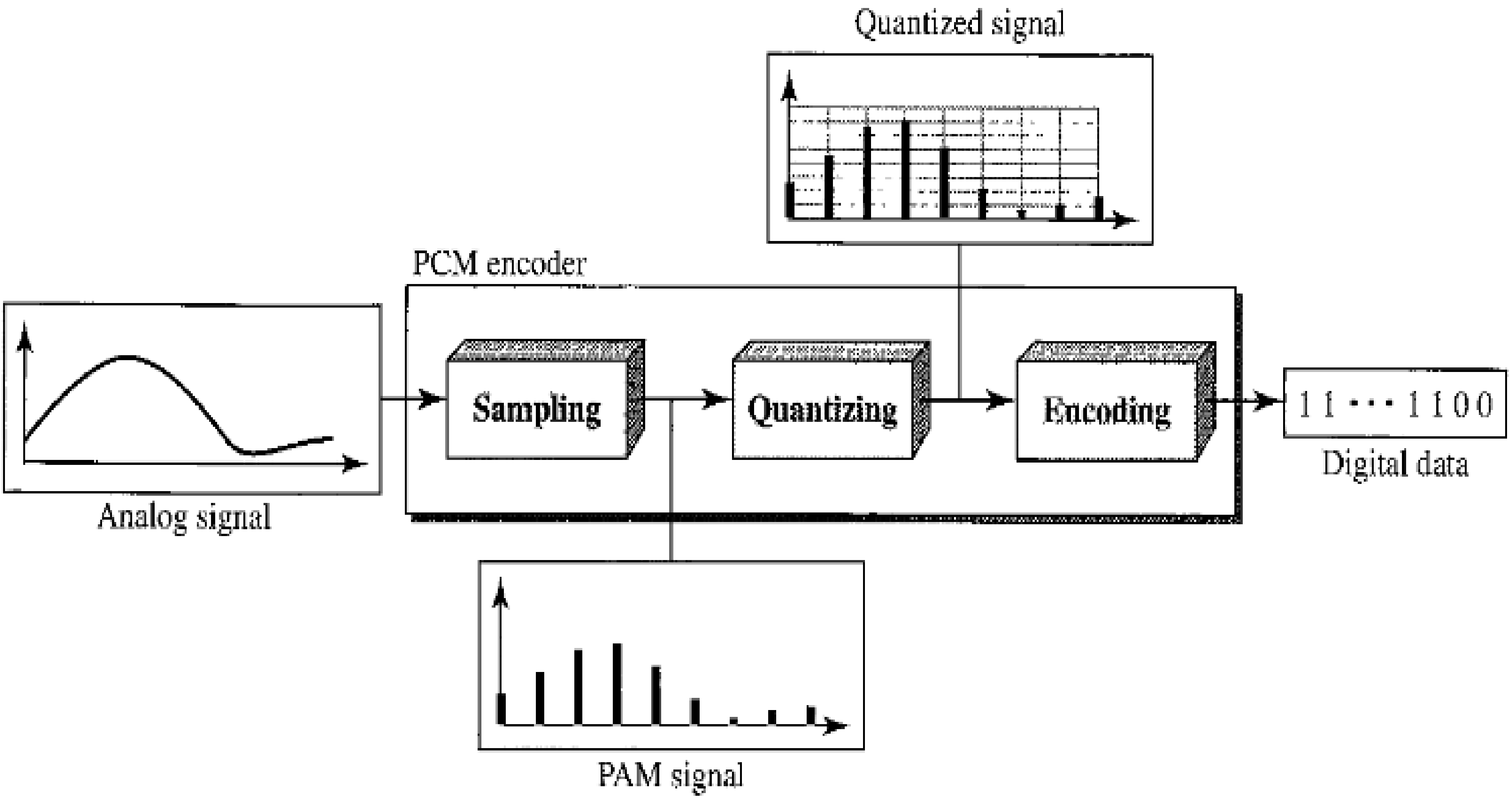
HDB3


First substitution
Second substitution
Third substitution
1 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0
B
V
0 0
0 0 0
V
B
0 0
V
Even
Even
Odd
Even
Even

Analog-to-Digital Conversion

- Signals from camera or microphone are analog
- Digitization – converts analog data to digital data
- Pulse Code Modulation (PCM)
- Delta Modulation

Pulse Code Modulation

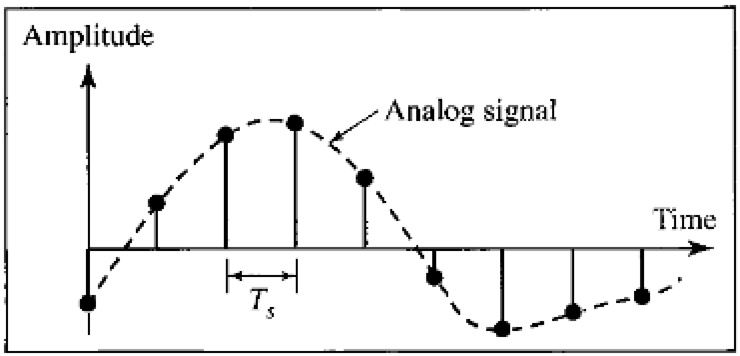


Pulse Code Modulation

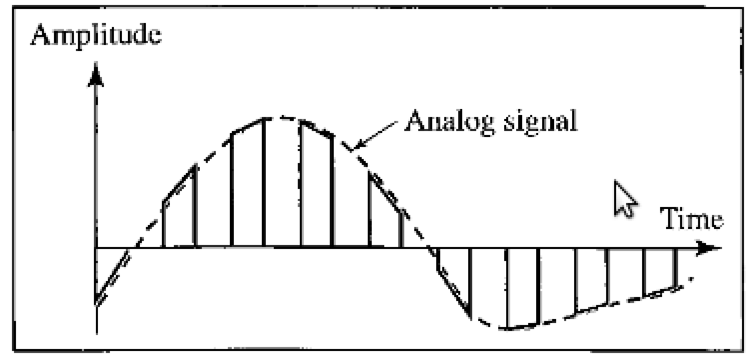
- Sampling (aka Pulse Amplitude Modulation)
  - Analog signal is sampled within a certain time period (Sampling period)
  - ideal, natural, flat-top
  - Result is still an analog signal with nonitgral values
  - Sampling rate must be at least twice the highest frequency in the original signal

Pulse Code Modulation

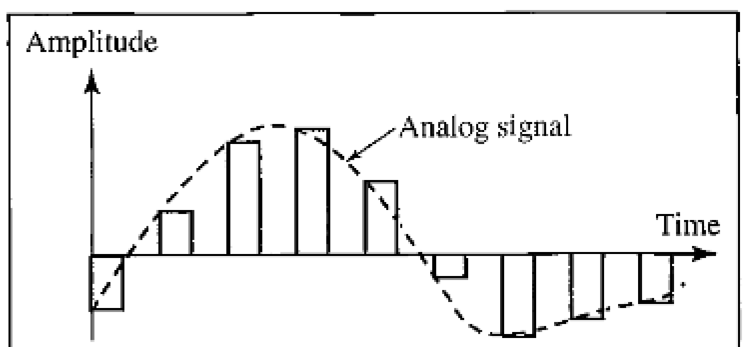
- Sampling



a. Ideal sampling



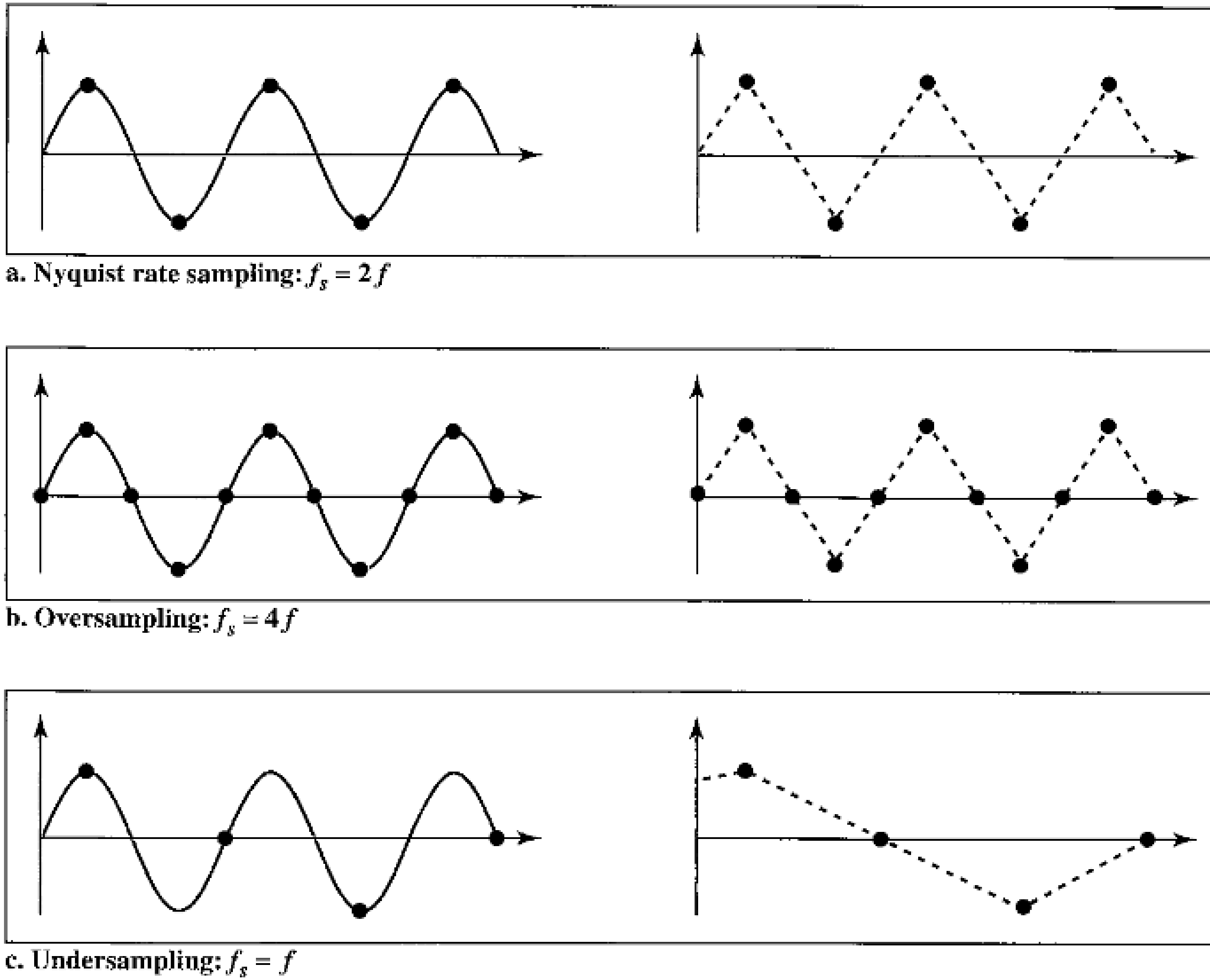
b. Natural sampling



c. Flat-top sampling

Pulse Code Modulation

- Sampling Rates

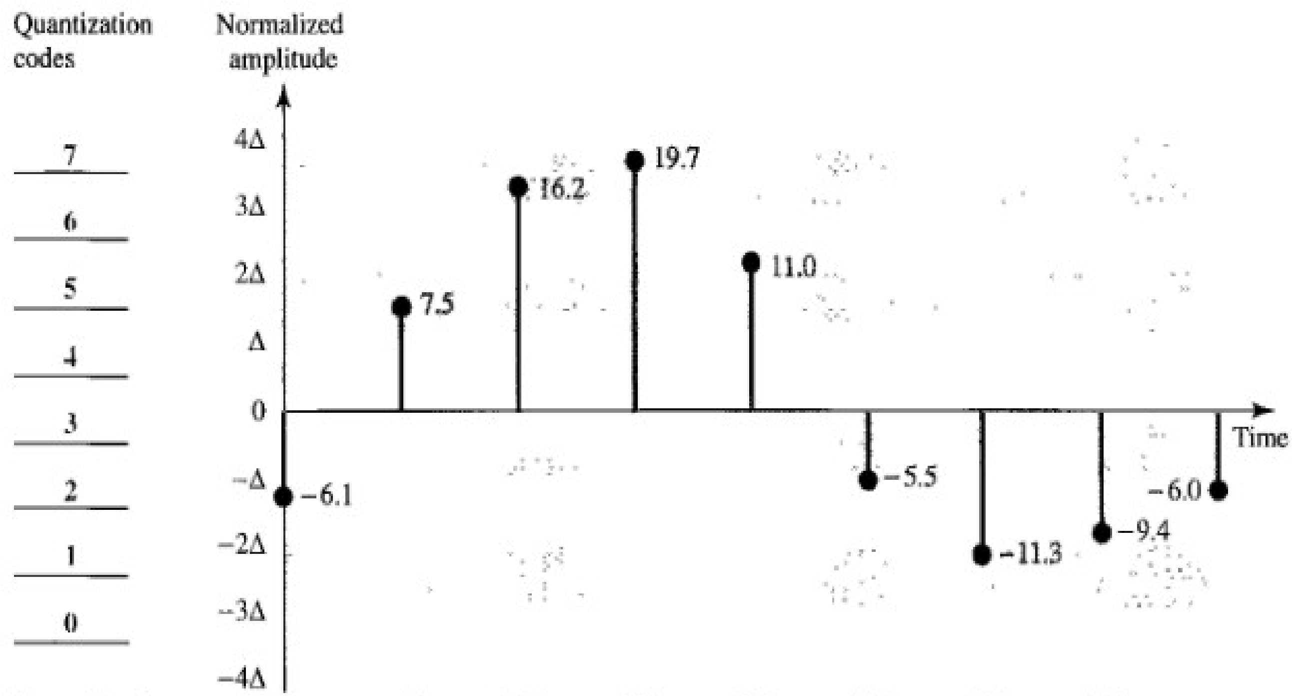


Pulse Code Modulation

- Quantization
  - Assume orig signal has instantaneous amplitudes between v_{min} and v_{max}
  - Divide the range into L zones, each of height delta
    - delta = $(v_{max} – v_{min}) / L$
  - Assign quantized values of 0 to L-1 to the midpoint of each zone
  - Approximate the value of the sample amplitude to the quantized values

Pulse Code Modulation

- Quantization



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

Pulse Code Modulation

- Encoding
  - Each sample can be changed to an n_b-bit code word
  - Number of bits for each sample is determined from the number of quantization levels
    - If the number of quantization levels is L, the number of bits is $n_b = \log_2 L$
- What is the bit rate needed to digitize human voice assuming 8 bits per sample?

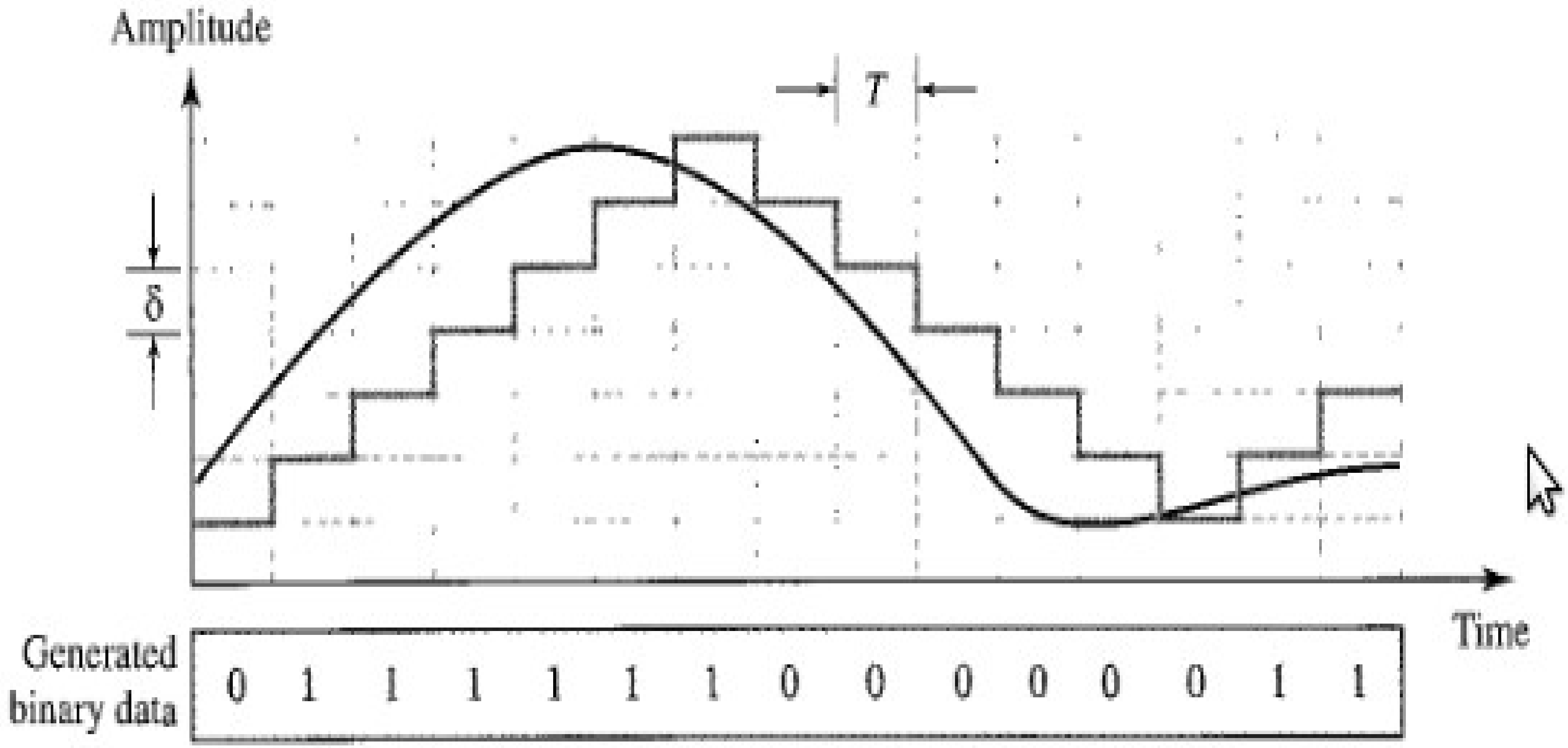
  Sampling rate = 4000 x 2 = 8000 samples/s

  Bit rate = 8000 x 8 = 64,000 bps = 64 kbps
- Bandwidth required is n_b times the analog

Delta Modulation

- PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample

Delta Modulation

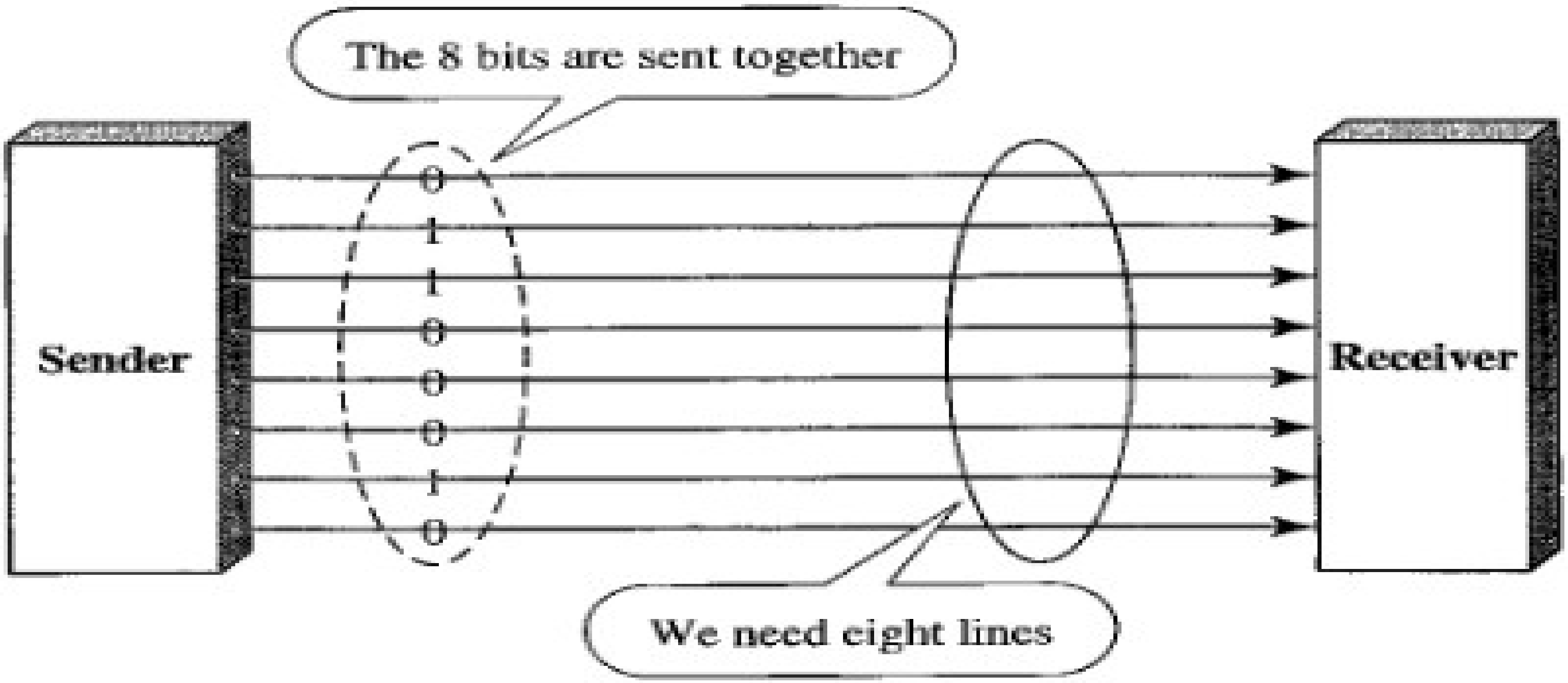


TRANSMISSION MODES

- How to send the bits?
- Parallel
- Serial
  - Asynchronous
  - Synchronous
  - Isochronous

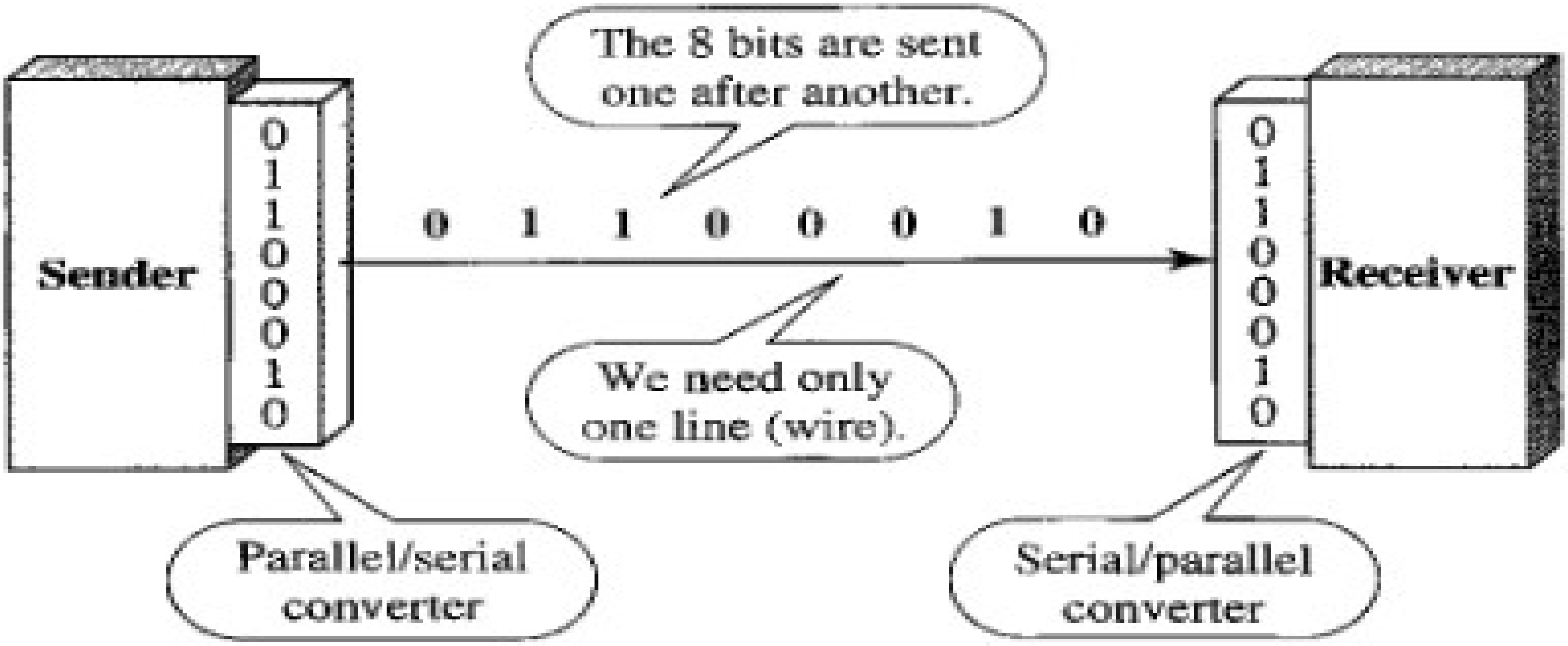
Parallel Transmission

- Use n wires to send n bits of data



Serial Transmission

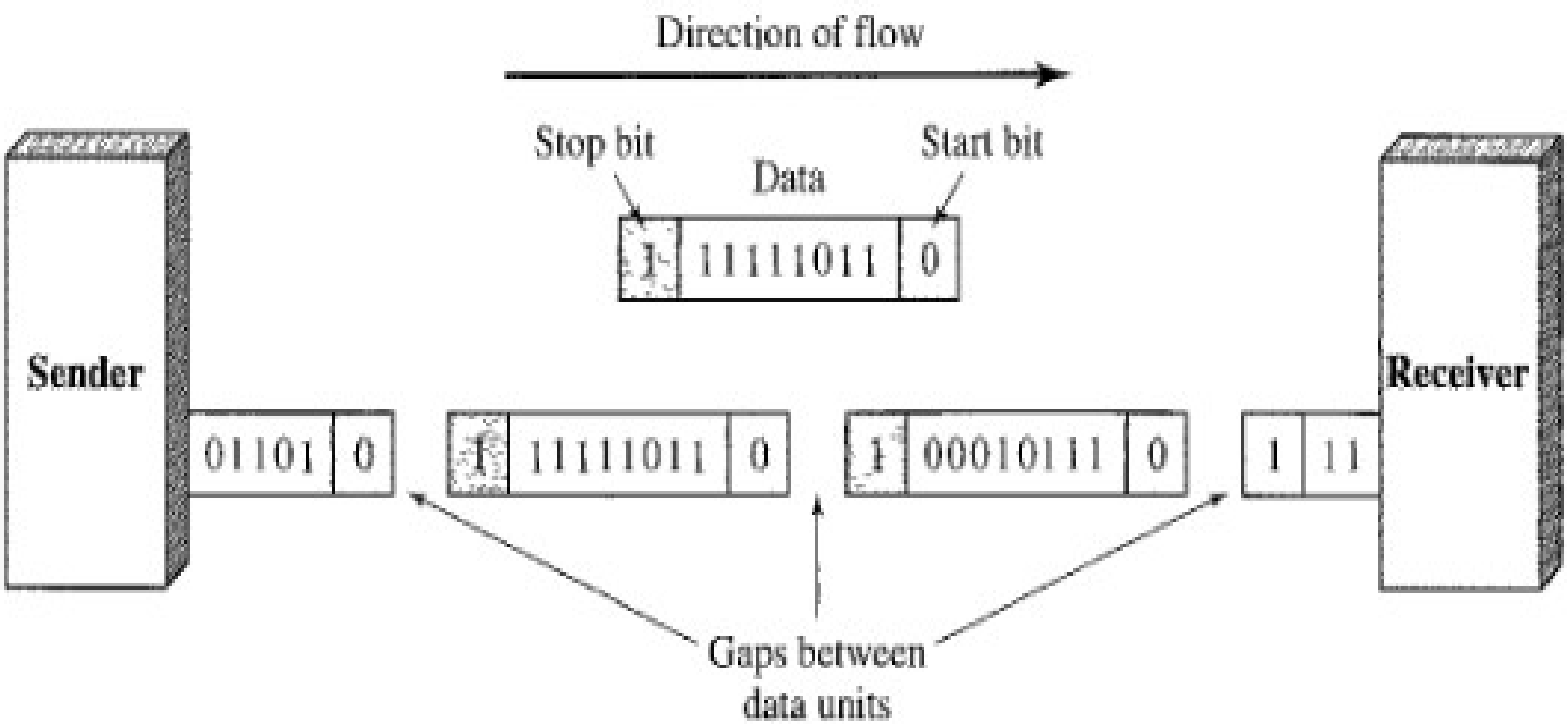
- 1 bit at a time



Asynchronous Transmission

- Timing of a signal is unimportant
- Uses "patterns" - grouping of bit streams into bytes
- Start bit (0), Stop bit (1)
- No synch at byte level, but present in bit level

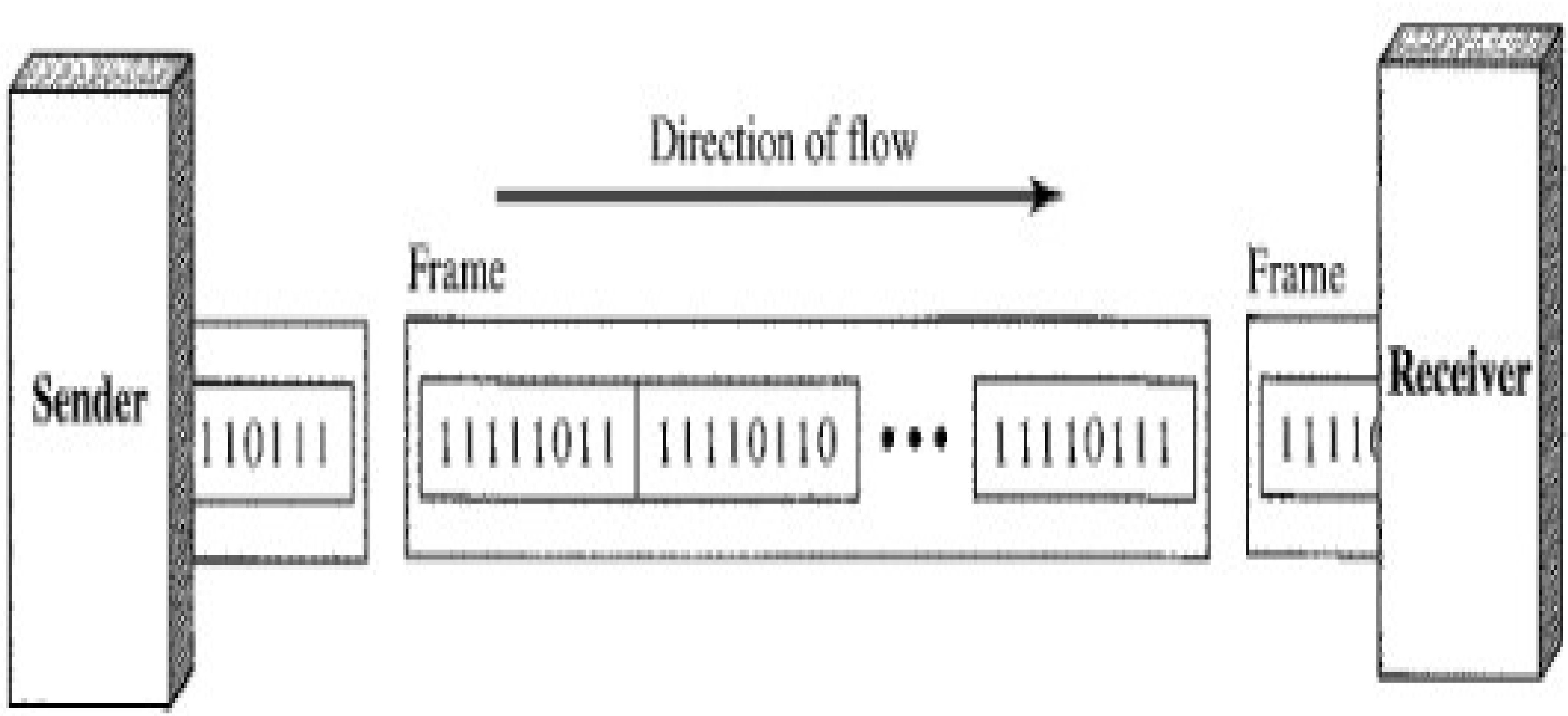
Asynchronous Transmission



Synchronous Transmission

- Bit stream combined into frames which may contain multiple bytes
- The receiver is responsible for decoding

Synchronous Transmission



Isochronous

- Multimedia data
- Guarantees that the data arrive at a fixed rate

Enjoy! :)