SEOULTECH

Lecture 04
Digital Transmission

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Course Schedule (Tentative)

- FL: Flipped learning
- **Rec: Recorded video for makeup class**

No	Topics	Date-M		Date-Th	
1	Introduction to course and data communications (Ch1)	09/05	FL (**Zoom**)	09/08	FL
2	Intro. to data communications (Ch1) & Network models (Ch2)	09/12	**Rec**	09/15	FL
3	Intro. to physical layer (Ch3)	09/19	FL	09/22	FL
4	Digital transmission (Ch4)	09/26	FL	09/29	FL
5	Analog transmission (Ch5) & Bandwidth utilization: multiplexing (Ch6.1)	10/03	**Rec**	10/06	**Rec**
6	Bandwidth utilization: spread spectrum (Ch6.2) Transmission Media (Ch7)	10/10	**Rec**	10/13	FL
7	Switching (Ch8) Introduction to Data-Link Layer (Ch9)	10/17	FL	10/20	FL
8	**Midterm exam**	**10/24**	**Evening**	**10/24**	**Evening**
9	Error detection and correction (Ch10)	10/31	FL	11/03	FL
10	Data link control (Ch11)	11/07	FL	11/10	FL
11	Media Access Control (Ch12)	11/14	FL	11/17	**Rec**
12	Wired LAN (Ethernet) (Ch13) & Other wired network (Ch14)	11/21	**Rec**	11/24	FL
13	Wireless LAN (Ch15)	11/28	FL	12/01	FL
14	Other wireless networks (Ch16) Connecting devices and virtual LANs (Ch17)	12/05	FL	12/08	FL
15	**Final exam**	**12/12**	**Evening**	**12/12**	**Evening**

OUTLINES

- Chapter 4
  - Digital-to-digital conversion
  - Analog-to-digital conversion
  - Transmission modes

- Summary & Next class

Ch 4. Digital Transmission

: Digital-to-digital conversion, Analog-to-digital conversion, Transmission modes

Ch 4 Objective

- The first section discusses digital-to-digital conversion.
  - Line coding is used to convert digital data to a digital signal.
    - Several common schemes are discussed.
  - The section also describes block coding, which is used to create redundancy in the digital data before they are encoded as a digital signal.
    - Redundancy is used as an inherent error detecting tool.
  - The last topic in this section discusses scrambling, a technique used for digital-to-digital conversion in long-distance transmission.

- The second section discusses analog-to-digital conversion.
  - Pulse code modulation (PCM) is described as the main method used to sample an analog signal.
  - Delta modulation is used to improve the efficiency of the pulse code modulation.

Ch 4 Objective

- The third section discusses transmission modes.
  - When we want to transmit data digitally, we need to think about parallel or serial transmission.
  - In parallel transmission, we send multiple bits at a time; in serial transmission, we send one bit at a time.

4-1 DIGITAL-TO-DIGITAL CONVERSION

- In Ch 3, we discussed that
  - Data can be either digital or analog.
  - Signals that represent data can also be digital or analog.

- In this section, we see how we can represent digital data by using digital signals.

- The conversion involves three techniques
  - Line coding
  - Block coding
  - Scrambling.

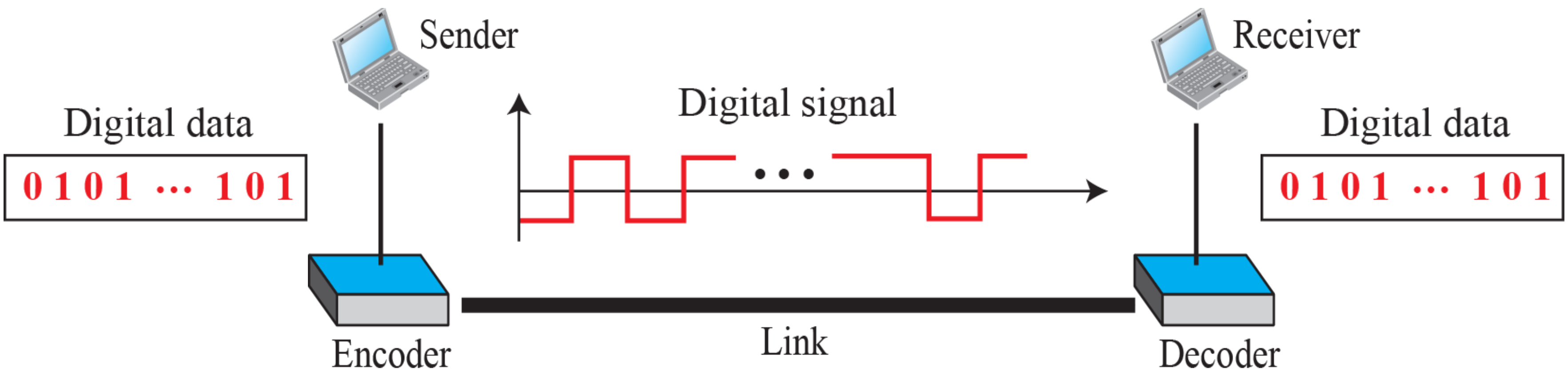
- Line coding is always needed; block coding and scrambling may or may not be needed.

4.1.1 Line Coding

- Line coding
  - The process of converting digital data to digital signals.
  - Line coding converts a sequence of bits to a digital signal.
    - Data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits (see Chapter 1)
    - At the sender, digital data are encoded into a digital signal; at the receiver, the digital data are recreated by decoding the digital signal.
  - Figure 4.1 shows the process.

4.1.1 Line Coding

- Figure 4.1: Line coding and decoding

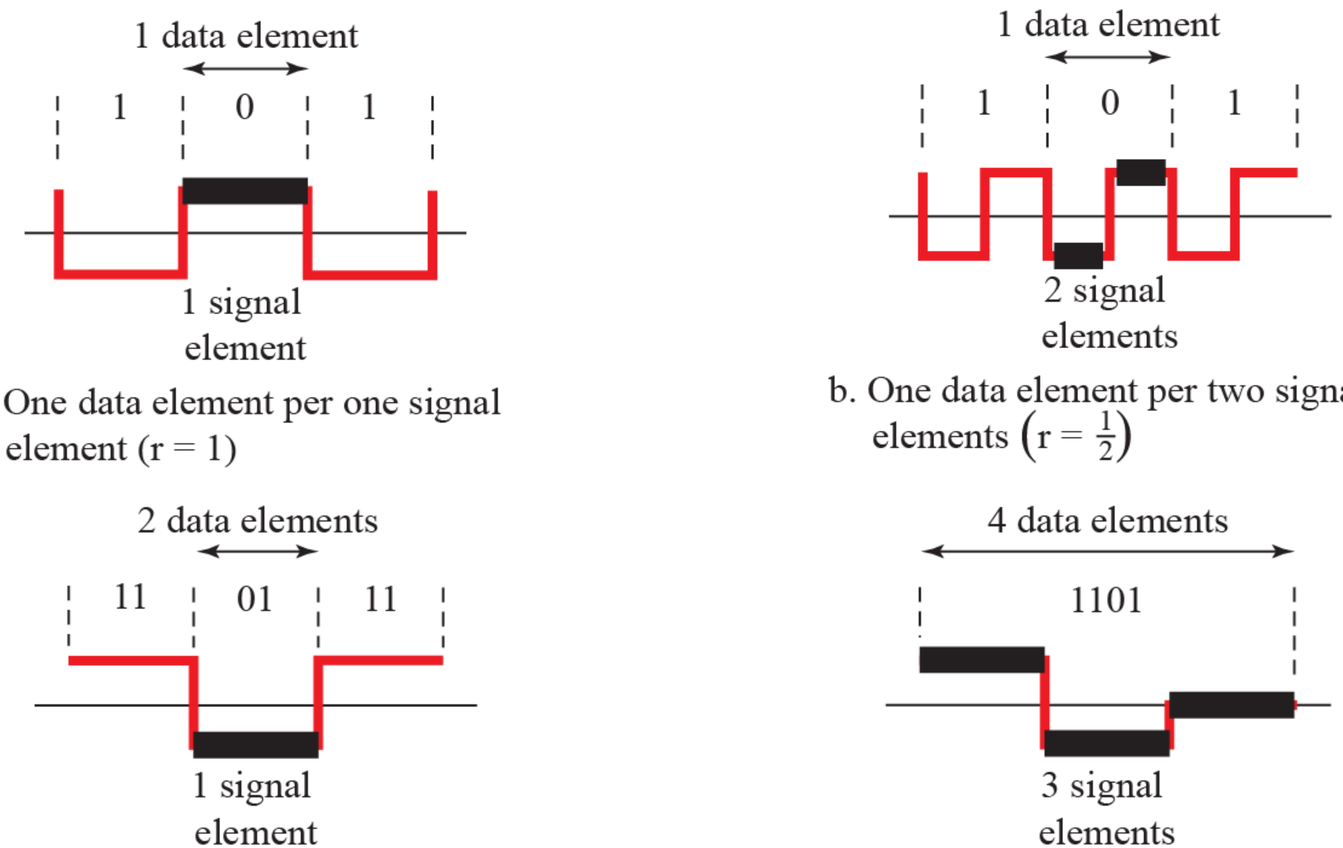


4.1.1 Line Coding

- Signal Element Versus Data Element
  - A signal element carries data elements
  - Data element: the smallest entity that can represent a piece of information; this is the bit
  - Signal element: the shortest unit (timewise) of a digital signal
  - Define a ratio r which is the number of data elements carried by each signal element
    - The extra signal element is needed to guarantee synchronization.

4.1.1 Line Coding

- Figure 4.2: 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 $\left(r = \frac{4}{3}\right)$

4.1.1 Line Coding

Data Rate Versus Signal Rate

- Data rate
  - The number of data elements (bits) sent in 1s.
  - The unit is bits per second (bps)
- Signal rate (or baud rate)
  - The number of signal elements sent in 1s.
  - The unit is the baud.
- Relationship between data rate (N) and signal rate (S)

$$S = N/r$$

4.1.1 Line Coding

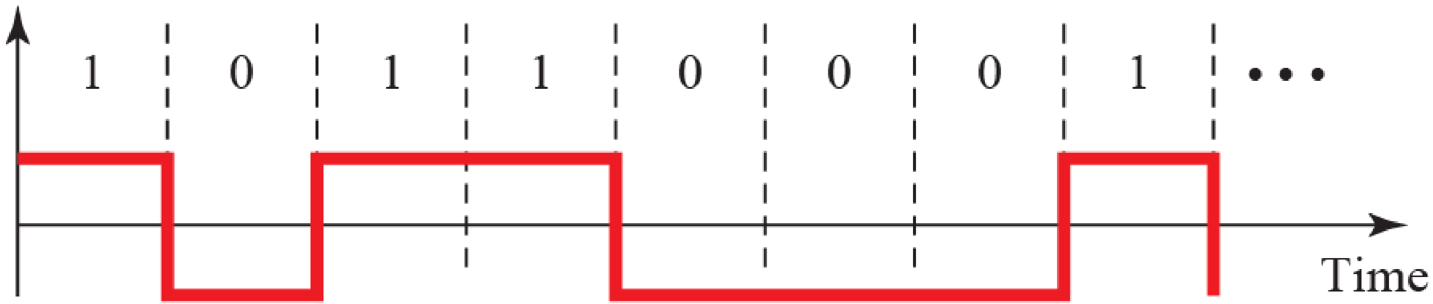
- Bandwidth
  - Bandwidth of a nonperiodic signal is continuous with an infinite range
  - Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite
  - The baud rate, not the bit rate, determines the required bandwidth for a digital signal

4.1.1 Line Coding

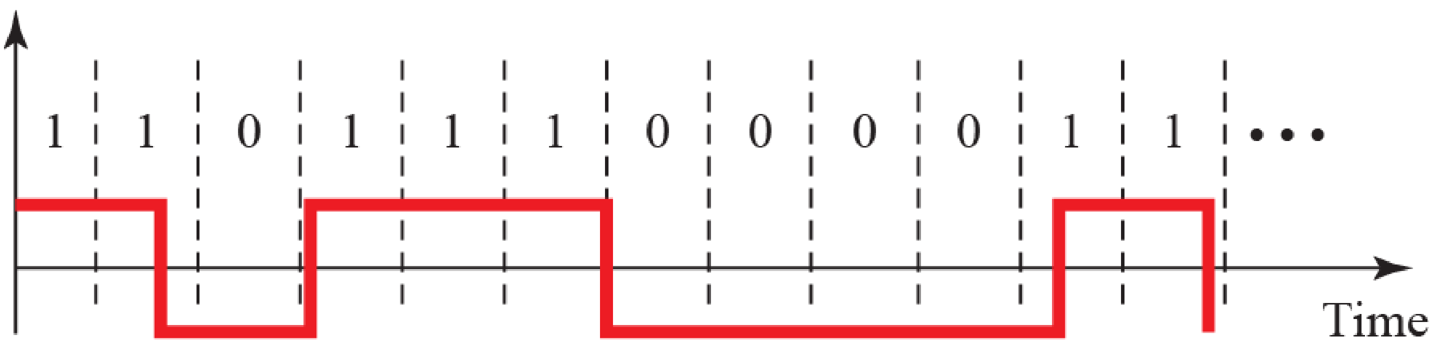
- Baseline Wandering
  - Baseline: a running average of the received signal power
  - A long string of 0s or 1s can cause a drift in the baseline (baseline wandering) and make it difficult for the receiver to decode correctly.
- DC Components
  - Frequencies around zero, called DC (direct-current) components, present problems for a system that cannot pass low frequencies
    - E.g., a telephone line cannot pass frequencies below 200 Hz
- Self-synchronization
  - To correctly interpret the signals received from the sender, the receiver's bit intervals must correspond exactly to the sender's bit intervals
  - A self-synchronizing digital signal includes timing information in the data being transmitted

4.1.1 Line Coding

- Figure 4.3: Effect of lack of synchronization



a. Sent



b. Received

4.1.1 Line Coding

- Example 4.3
  - 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.

$$1000 \text{ bits sent} \quad \longrightarrow \quad 1001 \text{ bits received} \quad \longrightarrow \quad 1 \text{ extra bps}$$

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

$$1{,}000{,}000 \text{ bits sent} \quad \longrightarrow \quad 1{,}001{,}000 \text{ bits received} \quad \longrightarrow \quad 1000 \text{ extra bps}$$

4.1.1 Line Coding

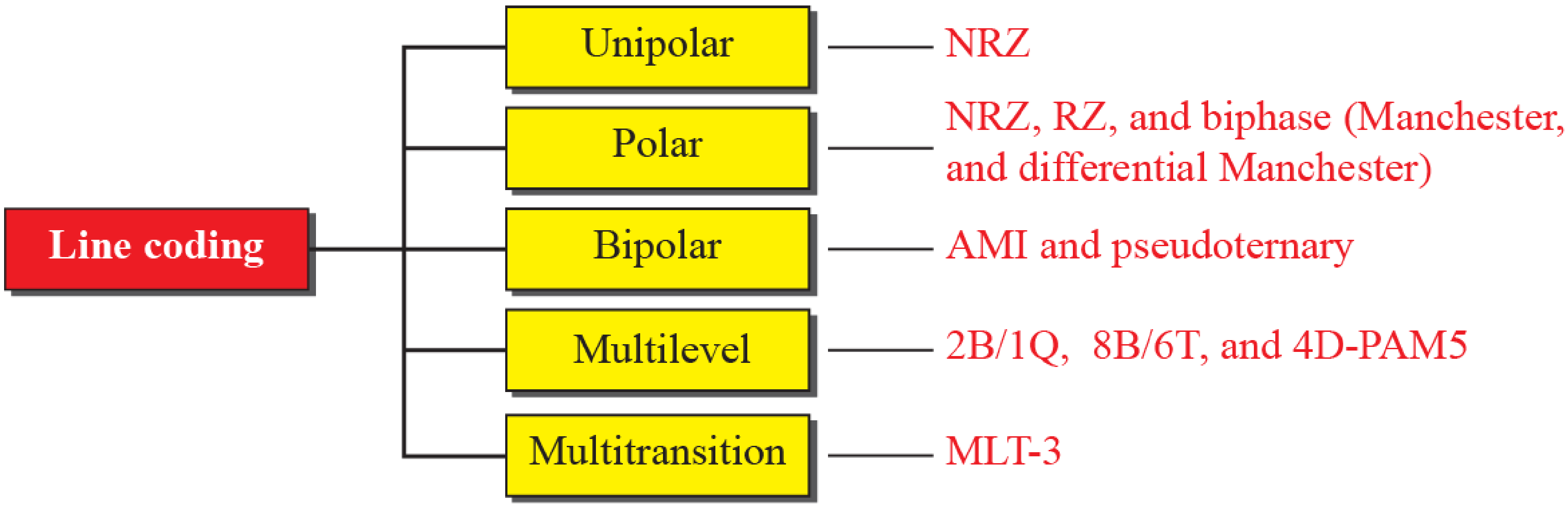
- Built-in Error Detection
  - Built-in error-detecting capability in the generated code to detect some or all of the errors that occurred during transmission.
- Immunity to Noise and Interference
  - Immune to noise and other interferences.
- Complexity
  - A complex scheme is more costly to implement than a simple one

4.1.2 Line Coding Schemes

- Roughly divide line coding schemes into five broad categories, as shown in Figure 4.4.
- There are several schemes in each category.
- We need to be familiar with all schemes discussed in this section to understand the rest of the book.
- This section can be used as a reference for schemes encountered later.

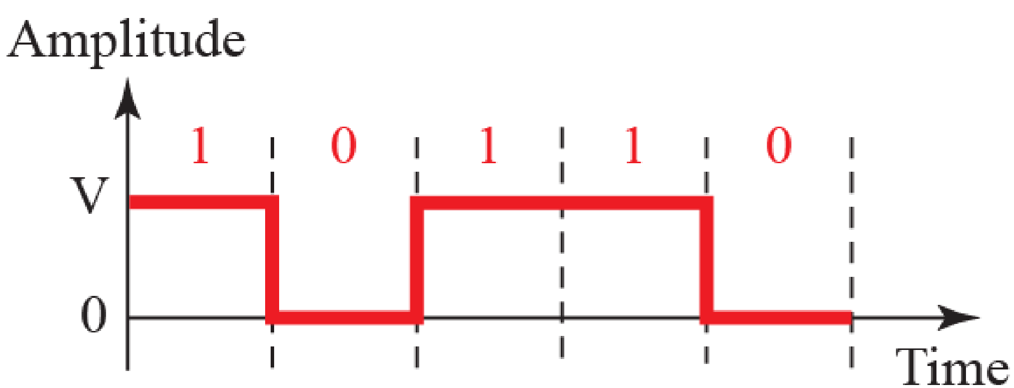
4.1.2 Line Coding Schemes

- Figure 4.4: Line coding scheme



4.1.2 Line Coding Schemes

- Unipolar Scheme
  - All the signal levels are on one side of the time axis, either above or below
- Unipolar Scheme: NRZ (Non-Return-to-Zero)
  - Signal does not return to zero at the middle of the bit.
- Figure 4.5: Unipolar NRZ scheme
- Double normalized power



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

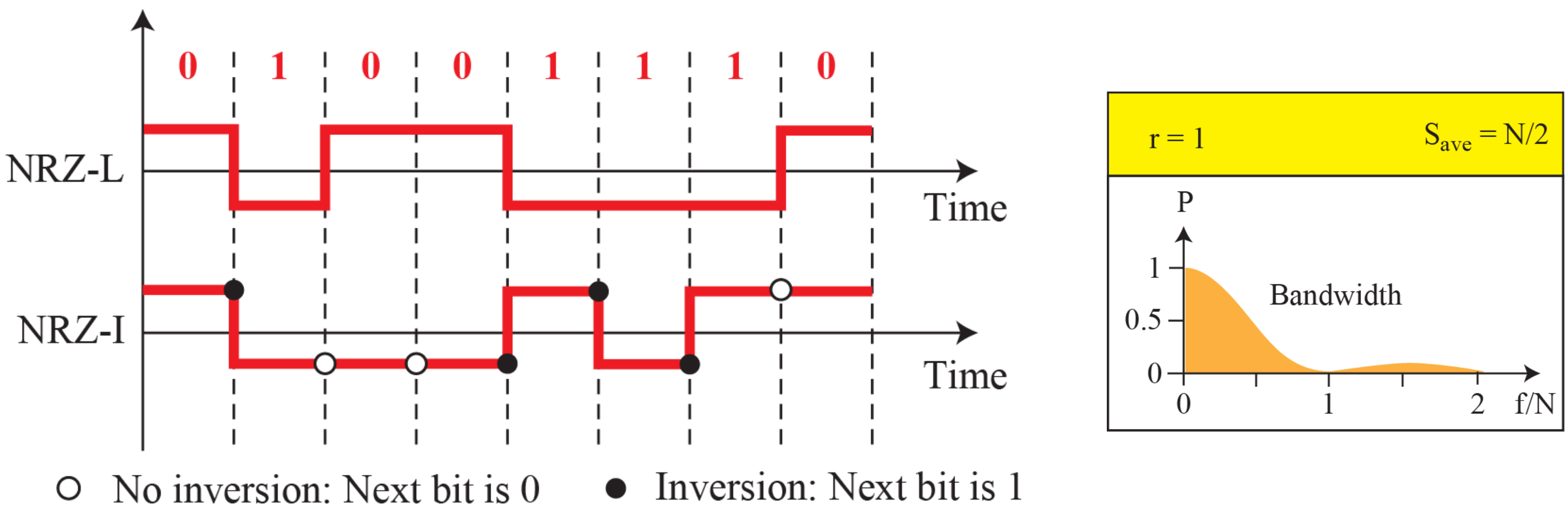
Normalized power

4.1.2 Line Coding Schemes

- Polar Schemes
  - Voltages are on both sides of the time axis.
- Polar Schemes: Non-Return-to-Zero (NRZ)
  - NRZ-L (NRZ-Level) and NRZ-I (NRZ-Invert)
  - 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.
  - NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.
  - NRZ-L and NRZ-I both have a DC component problem.

4.1.2 Line Coding Schemes

- Figure 4.6: Polar schemes (NRZ-L and NRZ-I)



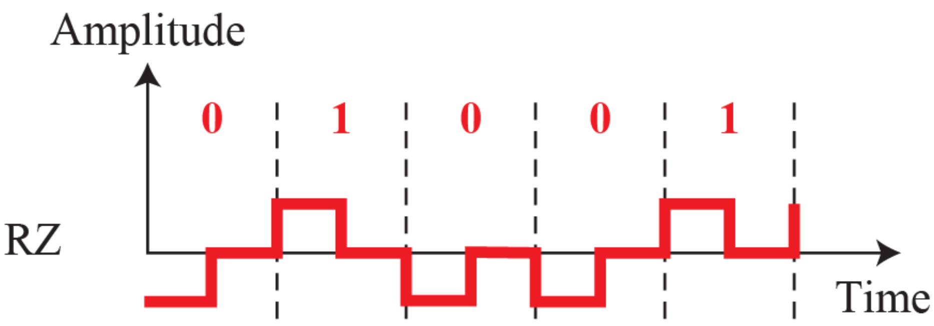
4.1.2 Line Coding Schemes

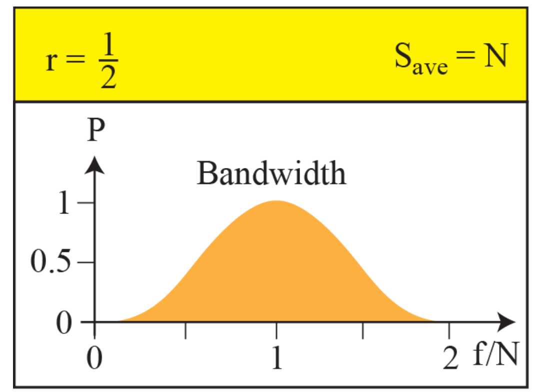
Return-to-Zero (RZ)

- The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized.
  - The receiver does not know when one bit has ended and the next bit is starting
- One solution is the return-to-zero (RZ) scheme, which uses three values: positive, negative, and zero.
- In RZ, the signal changes not between bits but during the bit.
- No DC component problem
- Disadvantages
  - A sudden change of polarity resulting in all 0s interpreted as 1s and all 1s interpreted as 0s
  - RZ uses three levels of voltage, which is more complex to create and discern.
- Not used today

4.1.2 Line Coding Schemes

- Figure 4.7: Polar schemes (RZ)





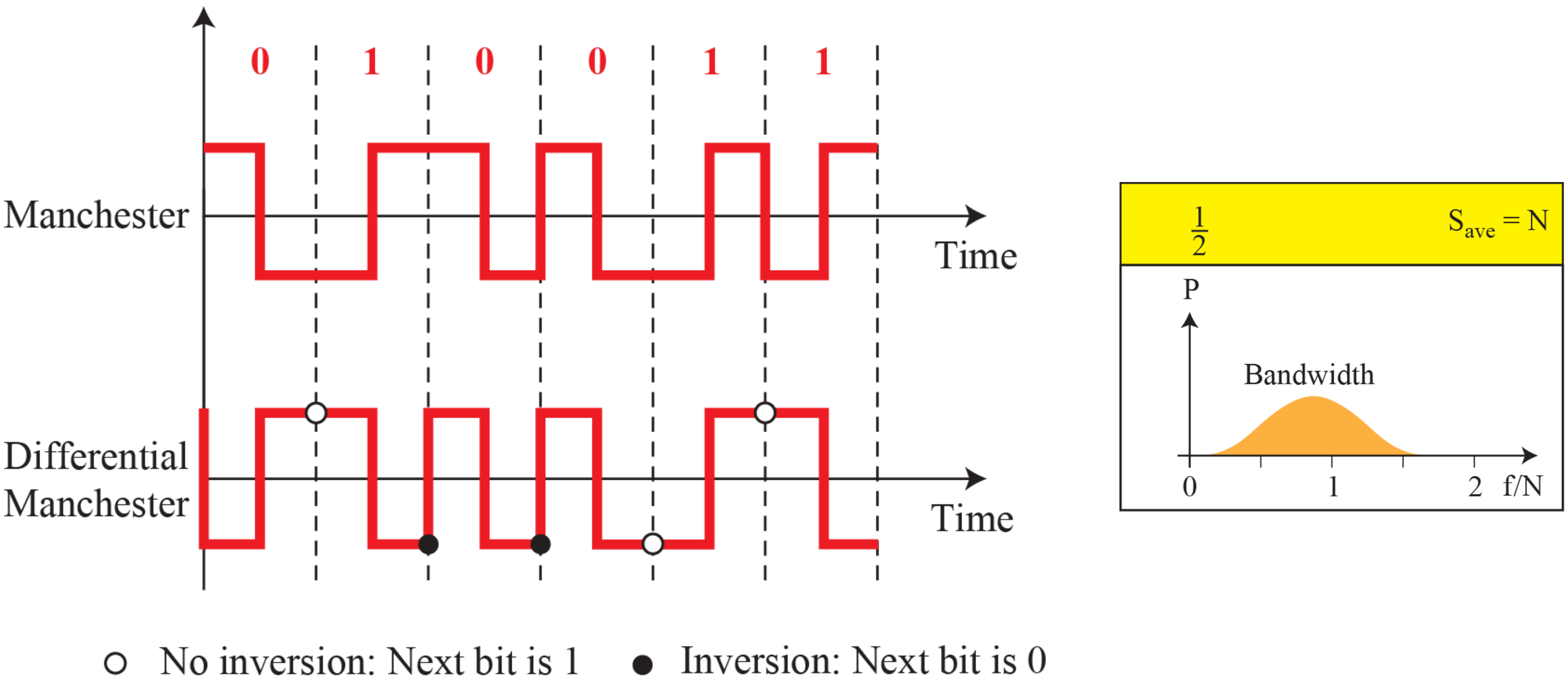
4.1.2 Line Coding Schemes

- Biphase: Manchester and Differential Manchester
  - The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme
  - Manchester
    - The voltage remains at one level during the first half and moves to the other level in the second half.
    - The transition at the middle of the bit provides synchronization.
  - Differential Manchester
    - Always a transition at the middle of the bit, but the bit values are determined at the beginning of the bit.
      - If the next bit is 0, there is a transition;
      - If the next bit is 1, there is none

4.1.2 Line Coding Schemes

- Biphase: Manchester and Differential Manchester (continued)
  - No baseline wandering, no DC component
  - Drawback: signal rate
  - The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.
  - In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization

- Figure 4.8: Polar biphase

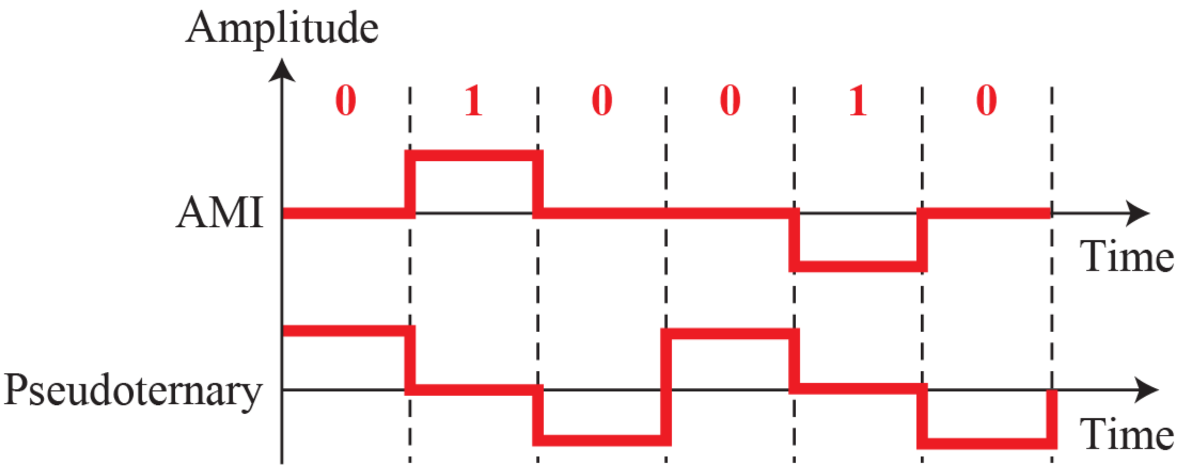


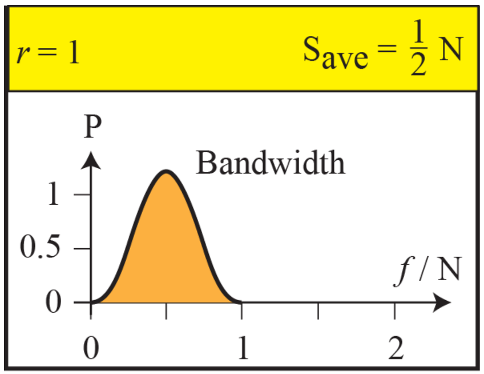
4.1.2 Line Coding Schemes

- Bipolar Schemes
  - In bipolar encoding (sometimes called multilevel binary), we use three levels: positive, zero, and negative.
- Bipolar Schemes: AMI and Pseudoternary
  - Alternate mark inversion (AMI)
    - Alternate 1 inversion.
    - A neutral zero voltage represents binary 0.
    - Binary 1s are represented by alternating positive and negative voltages
  - Pseudoternary
    - A variation of AMI encoding
    - The 1 bit is encoded as a zero voltage
    - The 0 bit is encoded as alternating positive and negative voltages.

Cha4.1.2 Line Coding Schemes

- Figure 4.9: Bipolar schemes: AMI and pseudoternary





4.1.2 Line Coding Schemes

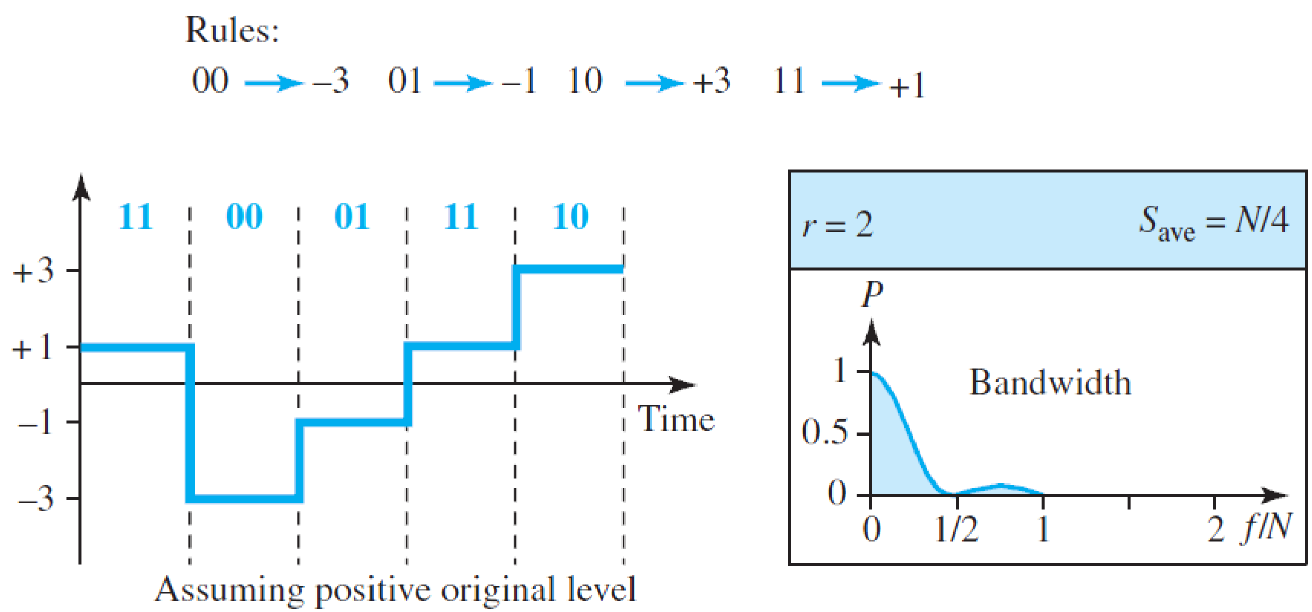
- Bipolar Schemes: AMI and Pseudoternary (continued)
  - No DC component
    - A sequence of 1's: alternating → no DC
    - A sequence of 0's: zero voltage → no DC
  - The concentration of the energy in bipolar encoding is around frequency N/2.
  - AMI is commonly used for long-distance communication, but it has a synchronization problem when a long sequence of 0s is present in the data
    - A scrambling technique can solve this problem

4.1.2 Line Coding Schemes

- Multilevel Schemes
  - The goal is to increase the number of bits per baud by encoding a pattern of m data elements into a pattern of n signal elements.
  - Group of m data elements can produce a combination of 2^m data patterns.
  - If $2^m = L^n$, then
    - Each data pattern is encoded into one signal pattern.
  - If $2^m < L^n$,
    - The subset can be carefully designed to prevent baseline wandering, to provide synchronization, and to detect errors that occurred during data transmission.
  - $2^m > L^n$ not possible
  - In mBnL schemes
    - A pattern of m data elements is encoded as a pattern of n signal elements in which $2^m \le L^n$
    - m: length of binary pattern, B: binary data
    - n: length of signal pattern, L: number of levels in signaling
    - In place of L: B (binary) for L = 2, T (ternary) for L = 3, and Q (quaternary) for L = 4

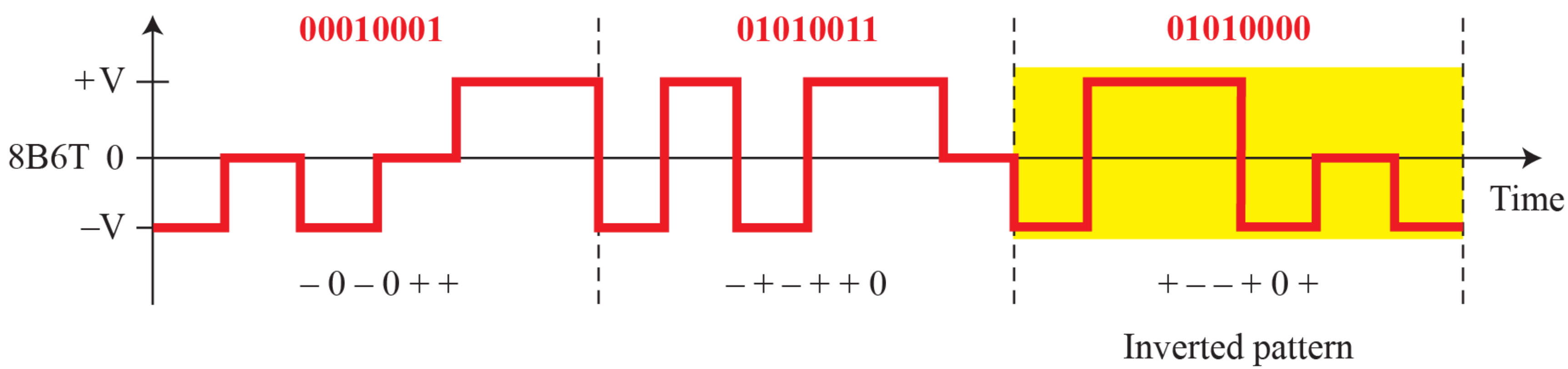
4.1.2 Line Coding Schemes

- Multilevel Schemes: 2B1Q
  - Two binary, one quaternary (2B1Q), uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal.
  - The 2B1Q scheme is used in DSL (Digital Subscriber Line) technology to provide a high-speed connection to the Internet by using subscriber telephone lines (see Chapter 14).
- Figure 4.10: Multilevel: 2B1Q



4.1.2 Line Coding Schemes

- Multilevel Schemes: 8B6T
  - Eight binary, six ternary (8B6T).
  - Used with 100BASE-4T cable
  - $3^6 - 2^8$ = 473 redundant signal elements that provide synchronization, error detection, and DC balance
    - Each signal pattern has a weight of 0 or +1 DC values.
- Figure 4.11: Multilevel: 8B6T

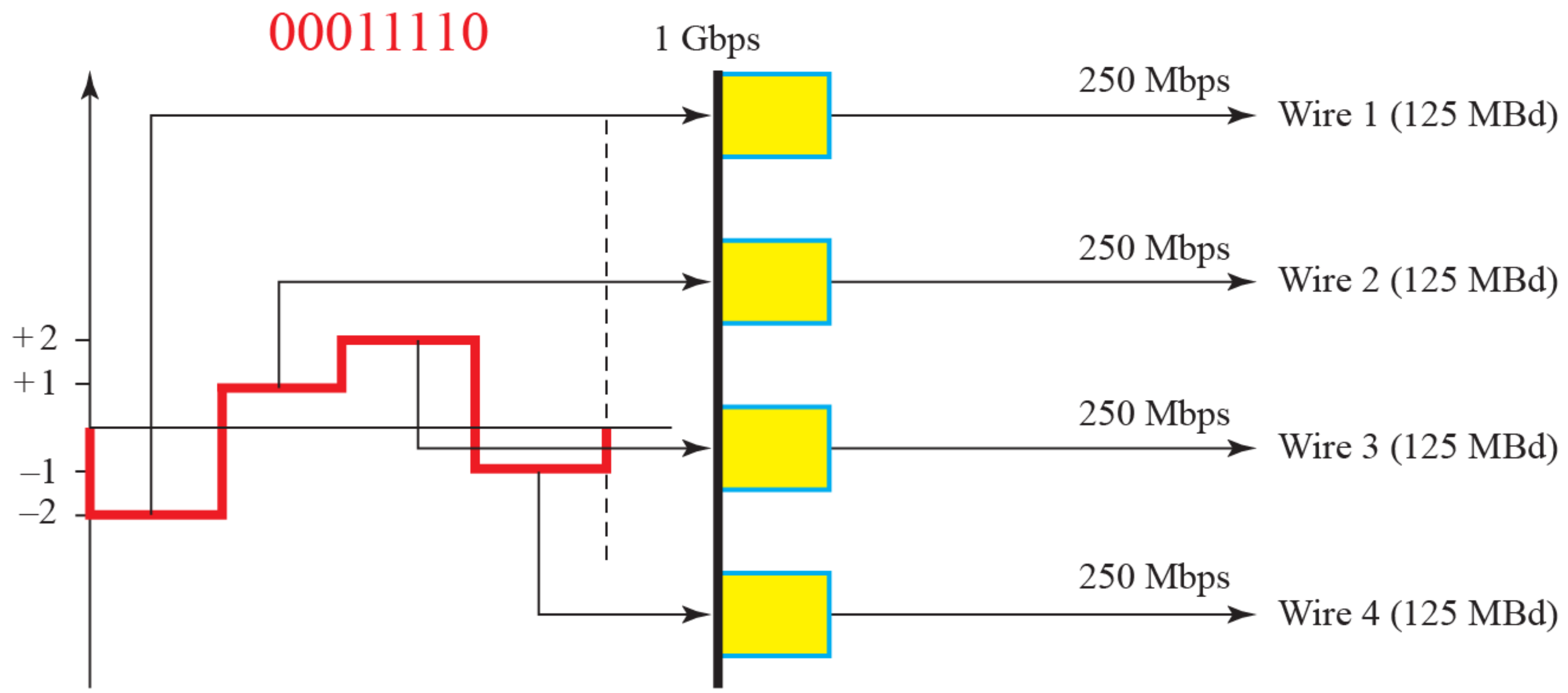


4.1.2 Line Coding Schemes

- Multilevel Schemes: 4D-PAM5
  - Four-dimensional five level pulse amplitude modulation (4D-PAM5)
    - The 4D means that data is sent over four wires at the same time.
    - It uses five voltage levels, such as −2, −1, 0, 1, and 2.
      - 0 for FEC
  - Similar to 8B4Q.
    - An 8-bit word is translated to a signal element of four different levels.
  - Gigabit LANs (see Chapter 13) use this technique to send 1-Gbps data over four copper cables that can handle 125 Mbaud

4.1.2 Line Coding Schemes

- Figure 4.12: Multilevel: 4D-PAM5 scheme



4.1.2 Line Coding Schemes

- Table 4.1: Summary of line coding schemes

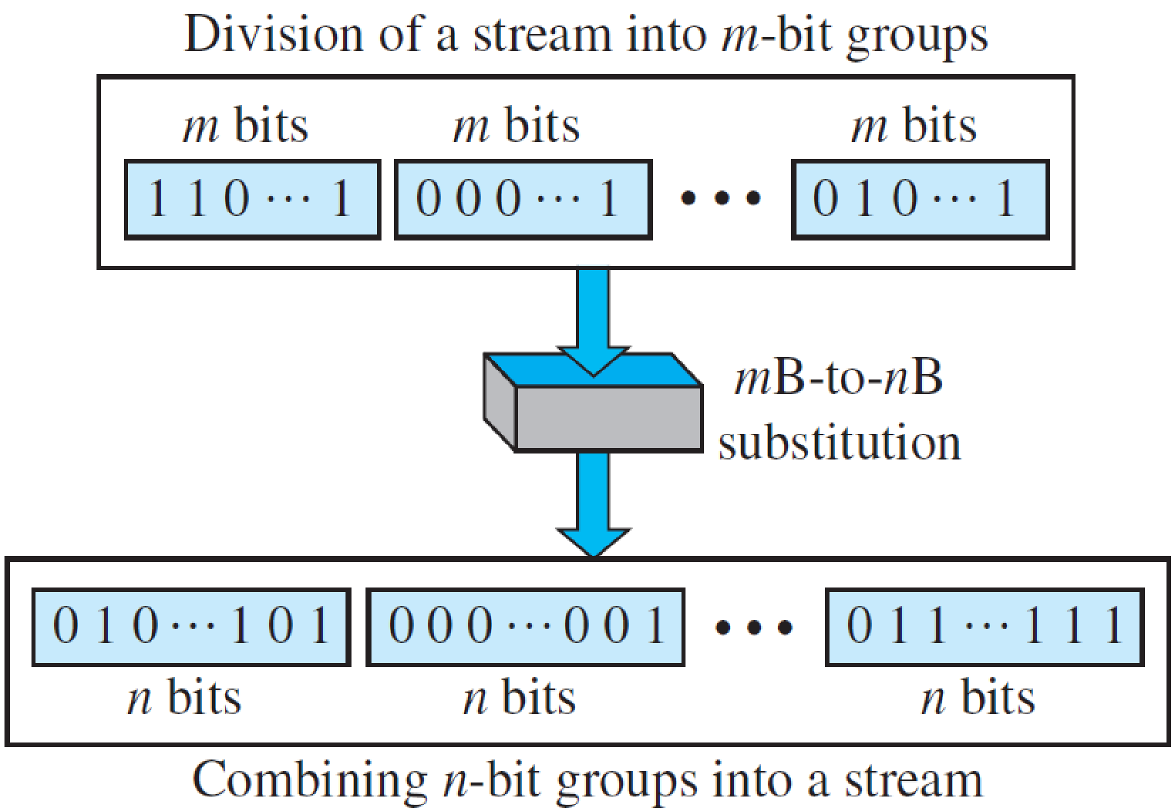
Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Polar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, 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
Multitransition	MLT-3	$B = N/3$	No self-synchronization for long 0s

4.1.3 Block Coding

- We need redundancy to ensure synchronization and to provide some kind of inherent error detecting.
- Block coding can give us this redundancy and improve the performance of line coding.
- In general, block coding changes a block of m bits into a block of n bits, where n is larger than m.
- Block coding is normally referred to as mB/nB coding
  - It replaces each m-bit group with an n-bit group.

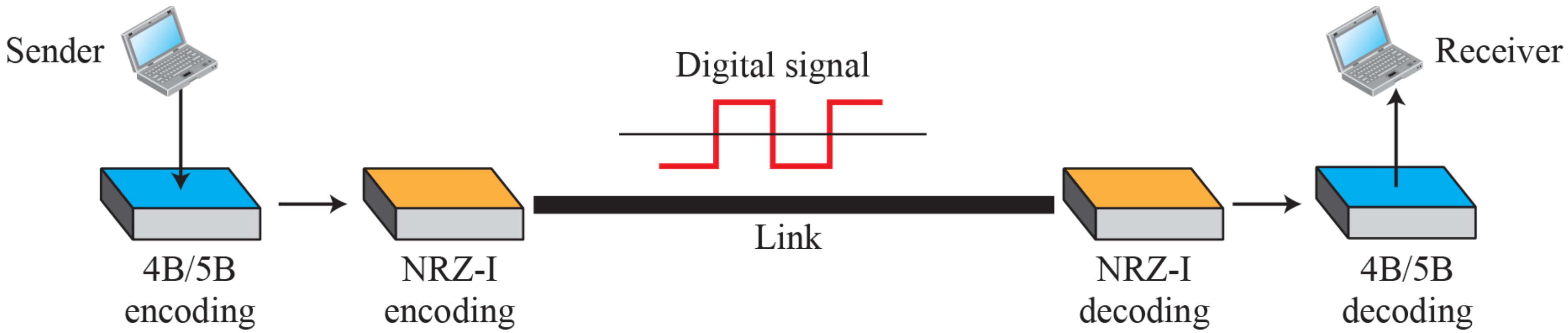
4.1.3 Block Coding

- Figure 4.14: Block coding concept



4.1.3 Block Coding

- 4B/5B
  - The four binary/five binary (4B/5B) coding scheme was designed to be used in combination with NRZ-I.
  - A long sequence of 0s can make the receiver clock lose synchronization.
    - One solution is to change the bit stream, prior to encoding with NRZ-I, so that it does not have a long stream of 0s.
    - The block-coded stream does not have more than three consecutive 0s
- Figure 4.15: Using block coding 4B/5B with NRZ-I line coding scheme



4.1.3 Block Coding

- 4B/5B (continued)
  - In 4B/5B, the 5-bit output that replaces the 4-bit input has no more than one leading zero (left bit) and no more than two trailing zeros (right bits)
    - Never more than three consecutive 0s
  - Some of unused groups are used for control purposes; the others are not used at all

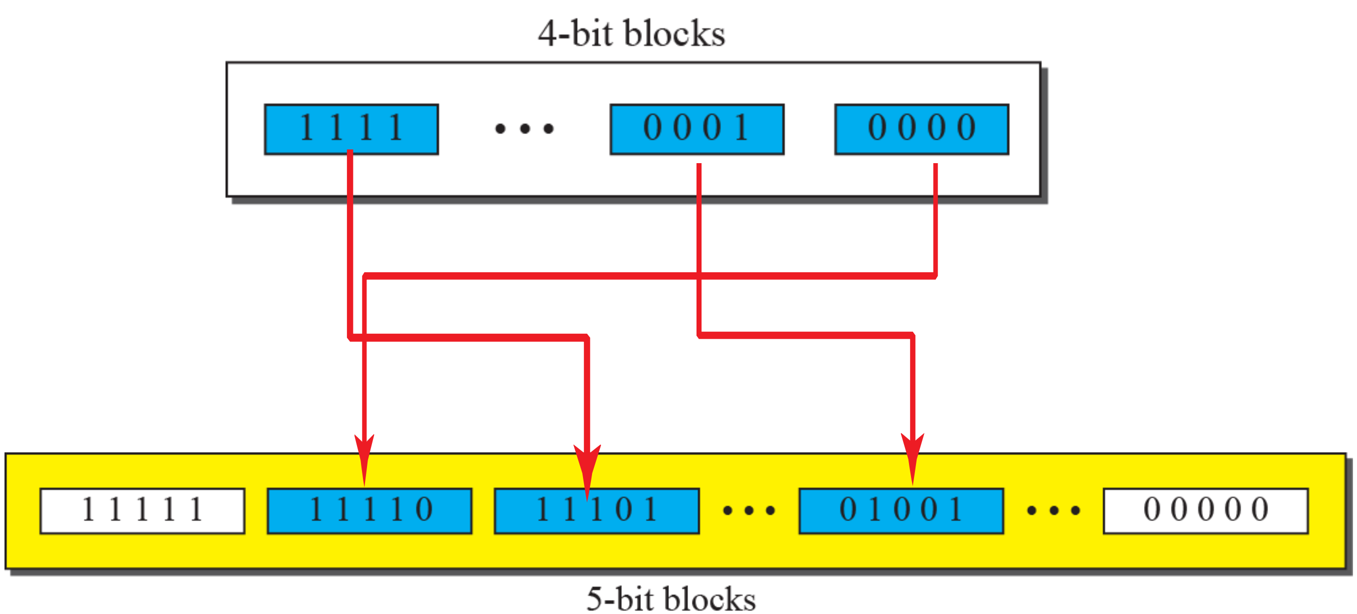
4.1.3 Block Coding

- Table 4.2: 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		

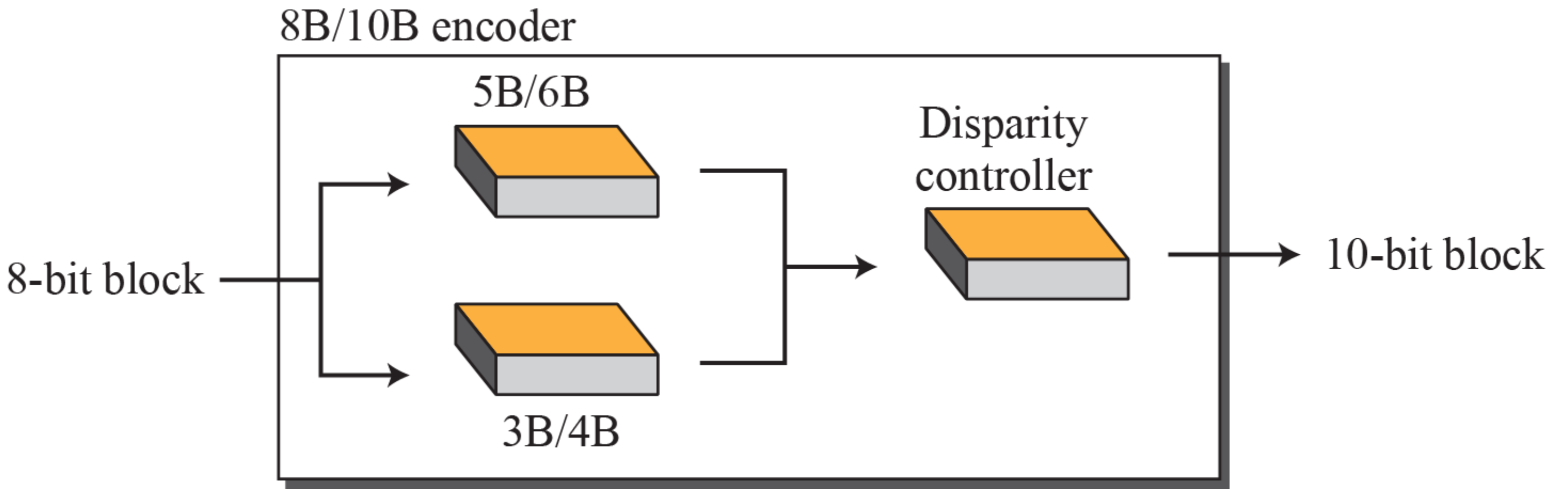
4.1.3 Block Coding

- Figure 4.16: Substitution in 4B/5B block coding
  - The redundant bits add 20 percent more baud.
    - Still, the result is less than the biphase scheme which has a signal rate of 2 times that of NRZ-I.
  - Not solve the DC component problem of NRZ-I. If a DC component is unacceptable, we need to use biphase or bipolar encoding.



4.1.3 Block Coding

- 8B/10B
  - Eight binary/ten binary (8B/10B) encoding
  - Greater error detection capability than 4B/5B.
  - The 8B/10B block coding is actually a combination of 5B/6B and 3B/4B encoding
    - The split is done to simplify the mapping table.

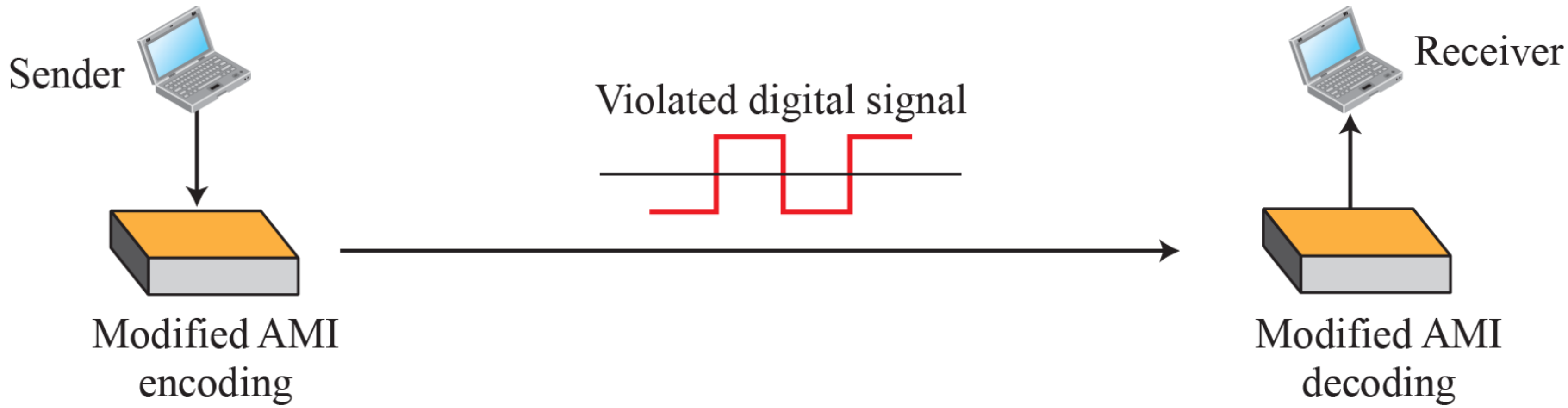


4.1.4 Scrambling

- We modify line and block coding to include scrambling, as shown in Figure 4.18.
- Note that scrambling, as opposed to block coding, is done at the same time as encoding.
- The system needs to insert the required pulses based on the defined scrambling rules.
- Two common scrambling techniques are B8ZS and HDB3.

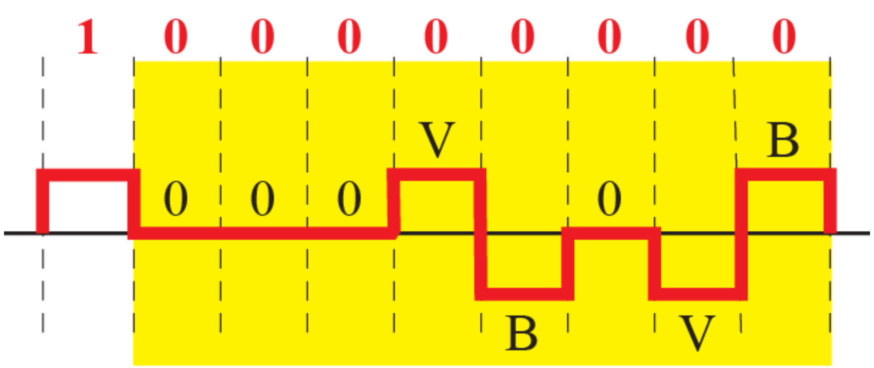
4.1.4 Scrambling

- Figure 4.18: AMI used with scrambling

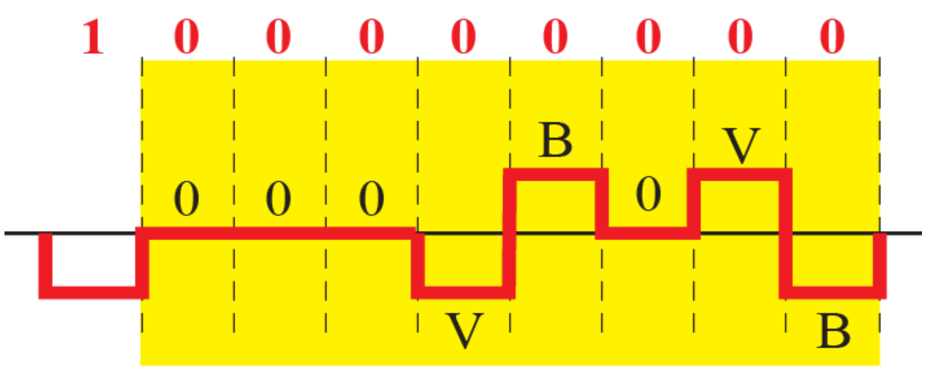


4.1.4 Scrambling

- B8ZS
  - Bipolar with 8-zero substitution (B8ZS)
  - Eight consecutive zero-level voltages are replaced by the sequence 000VB0VB
    - V: violation, B: bipolar
- Figure 4.19: Two cases of B8ZS scrambling technique



a. Previous level is positive.



b. Previous level is negative.

4-2 ANALOG-TO-DIGITAL CONVERSION

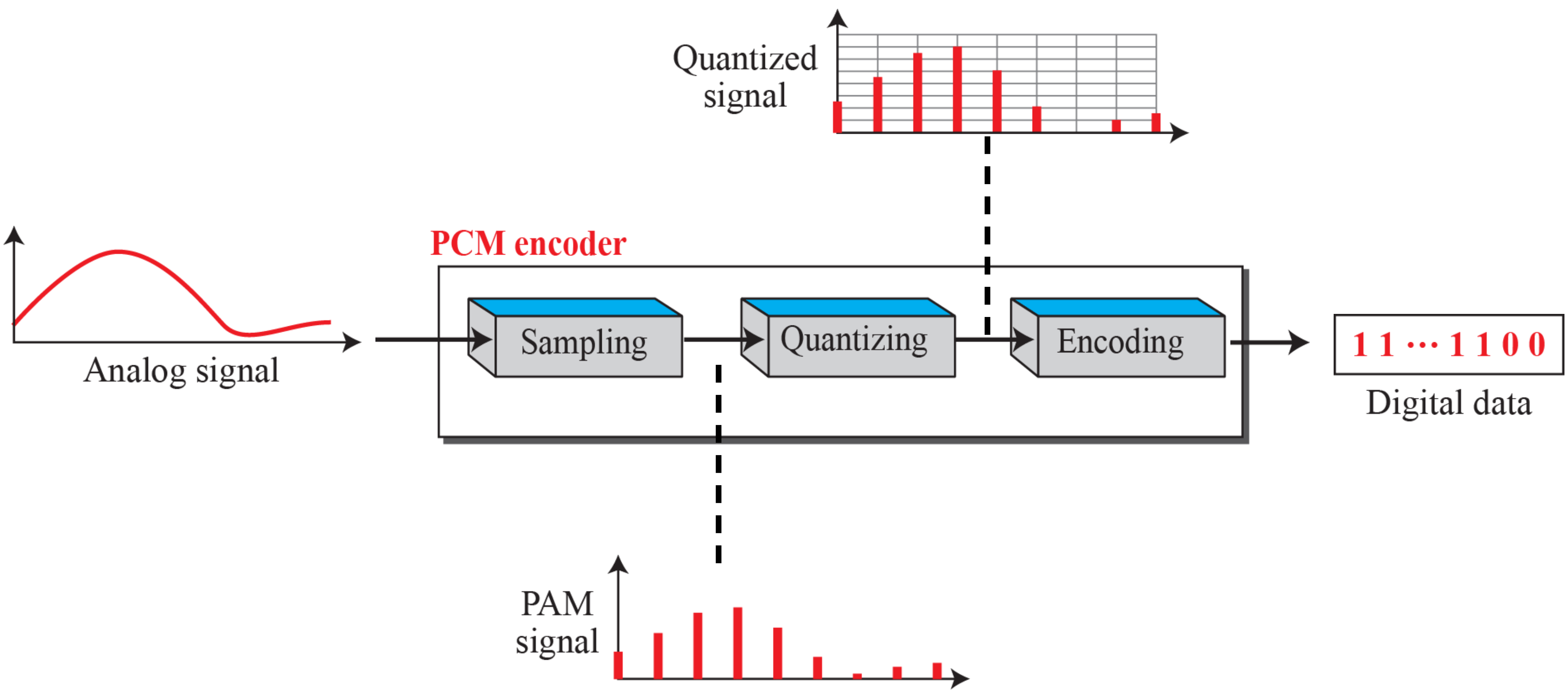
- The techniques described in Section 4.1 convert digital data to digital signals.
- Sometimes, however, we have an analog signal such as one created by a microphone or camera.
- We have seen in Chapter 3 that a digital signal is superior to an analog signal.
- The tendency today is to change an analog signal to digital data.
- In this section we describe two techniques, pulse code modulation and delta modulation.

4.2.1 Pulse Code Modulation (PCM)

- The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM).
- A PCM encoder has three processes, as shown in Figure 4.21.
  1. The analog signal is sampled.
  2. The sampled signal is quantized.
  3. The quantized values are encoded as streams of bits.

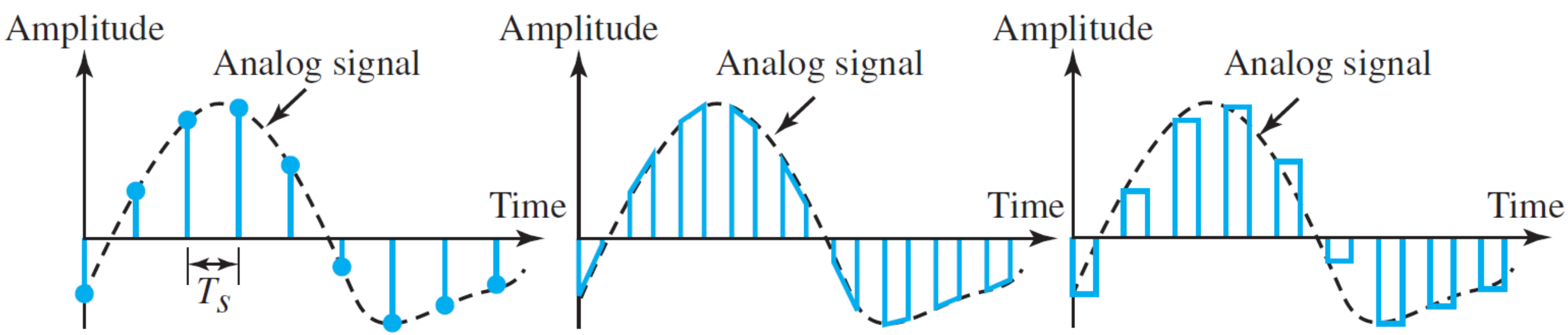
4.2.1 Pulse Code Modulation (PCM)

- Figure 4.21: Components of PCM encoder



4.2.1 Pulse Code Modulation (PCM)

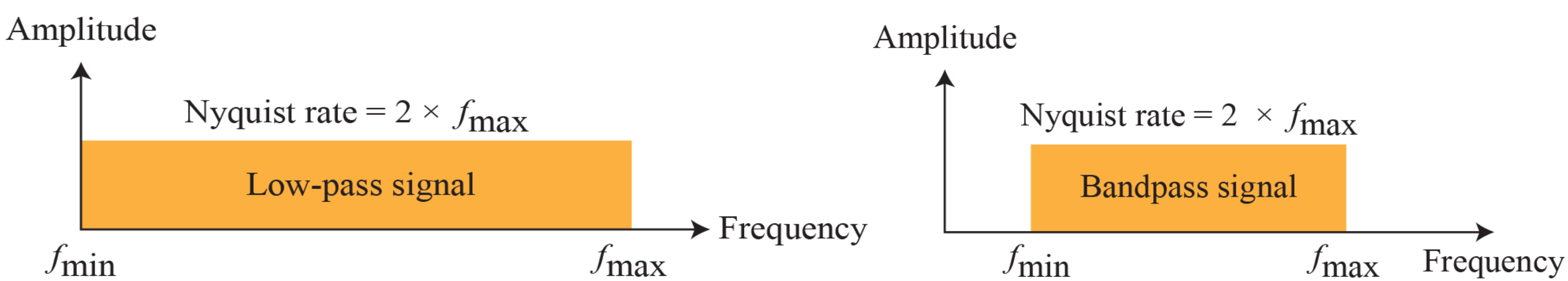
- Sampling
  - The first step in PCM is sampling
  - T_s is the sample interval or period.
  - Sampling rate or sampling frequency, denoted by f_s, where $f_s = 1/T_s$.
  - The most common sampling method: sample and hold
  - Sometimes referred to as pulse amplitude modulation (PAM).
- Figure 4.22: Three different sampling methods for PCM



a. Ideal sampling b. Natural sampling c. Flat-top sampling

4.2.1 Pulse Code Modulation (PCM)

- Sampling theorem
  - According to the Nyquist theorem, the sampling rate must be at least 2 times the highest frequency contained in the signal.
- Figure 4.23: Nyquist sampling rate for low-pass and bandpass signals

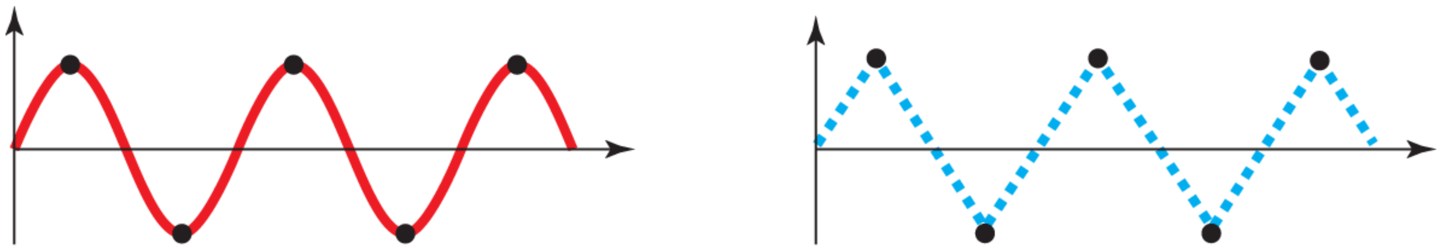


4.2.1 Pulse Code Modulation (PCM)

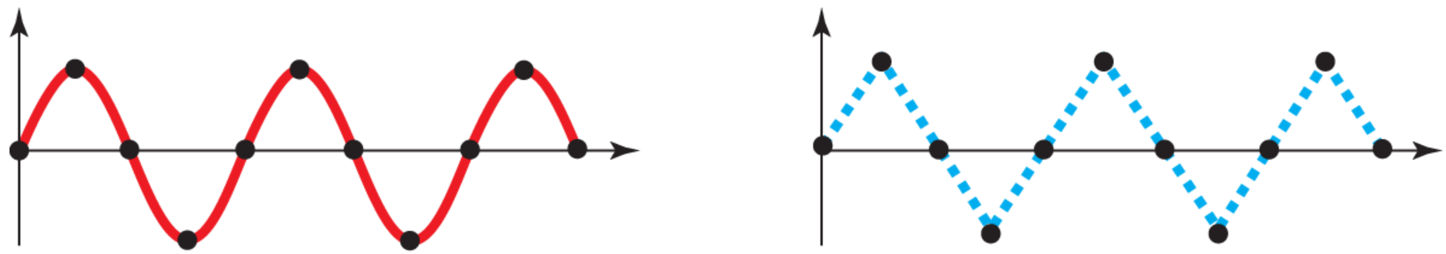
- Example 4.6
  - For an intuitive example of the Nyquist theorem, let us sample a simple sine wave at three sampling rates: $f_s = 4f$ (2 times the Nyquist rate), $f_s = 2f$ (Nyquist rate), and $f_s = f$ (one-half the Nyquist rate). Figure 4.24 shows the sampling and the subsequent recovery of the signal. It can be seen that sampling at the Nyquist rate can create a good approximation of the original sine wave (part a). Oversampling in part b can also create the same approximation, but it is redundant and unnecessary. Sampling below the Nyquist rate (part c) does not produce a signal that looks like the original sine wave.

4.2.1 Pulse Code Modulation (PCM)

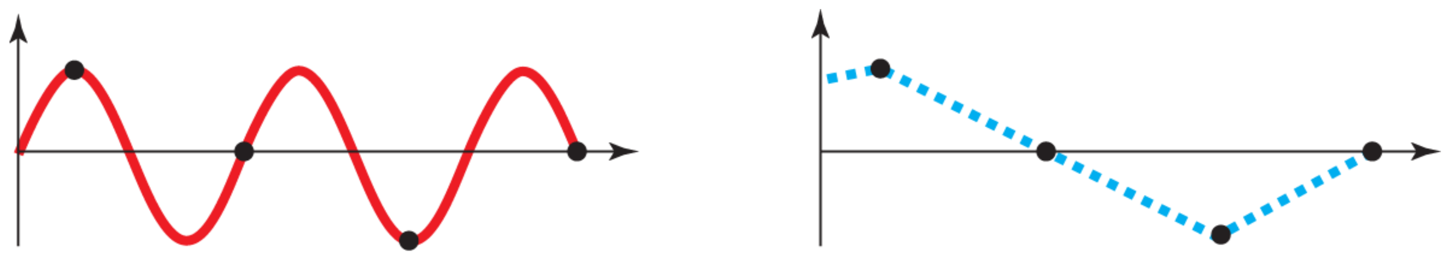
- Figure 4.24: Recovery of a sine wave with different sampling rates.



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



b. Oversampling: $f_s = 4\ f$



c. Undersampling: $f_s = f$

4.2.1 Pulse Code Modulation (PCM)

- Example 4.9
  - Telephone companies digitize voice by assuming a maximum frequency of 4000 Hz. The sampling rate therefore is 8000 samples per second.

- Example 4.10
  - 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.

4.2.1 Pulse Code Modulation (PCM)

- Example 4.11
  - A complex bandpass signal has a bandwidth of 200 kHz. What is the minimum sampling rate for this signal?
  - Solution
    - We cannot find the minimum sampling rate in this case because we do not know where the bandwidth starts or ends. We do not know the maximum frequency in the signal.

4.2.1 Pulse Code Modulation (PCM)

- Quantization
  - The set of amplitudes can be infinite with nonintegral values between the two limits → finite amplitudes
  - Quantization steps
    1. We assume that the original analog signal has instantaneous amplitudes between V_{min} and V_{max}.
    2. We divide the range into L zones, each of height Δ (delta).
    3. We assign quantized values of 0 to $L - 1$ to the midpoint of each zone.
    4. We approximate the value of the sample amplitude to the quantized values.
  - The quantization process selects the quantization value from the middle of each zone.

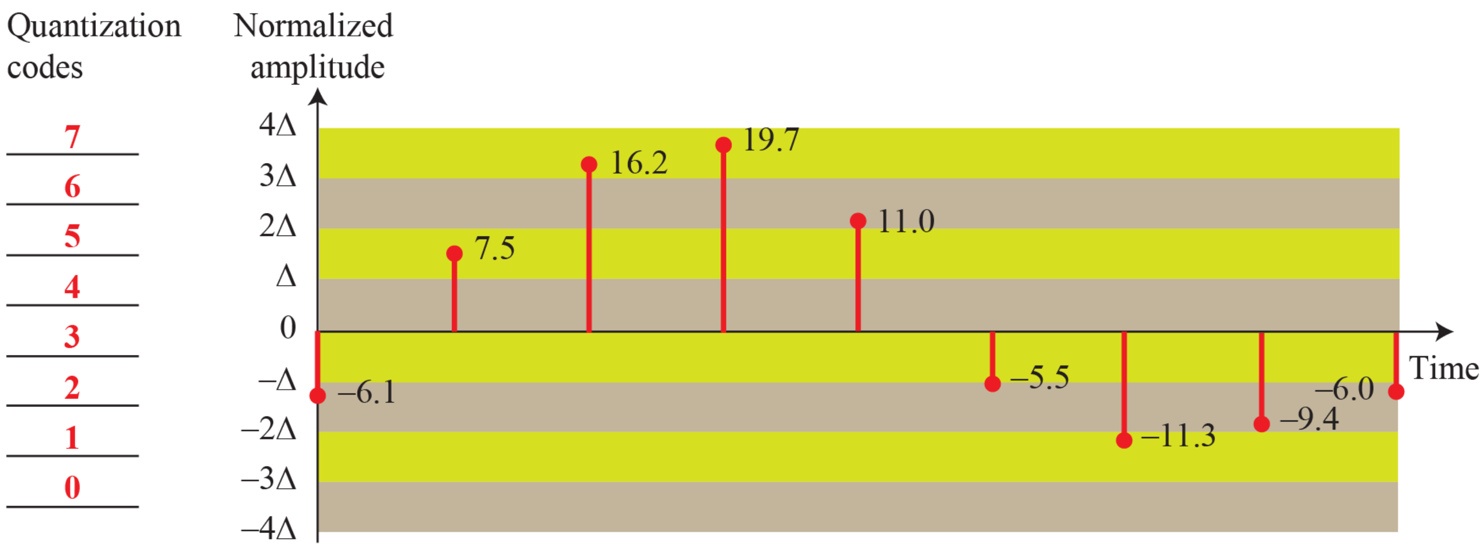
4.2.1 Pulse Code Modulation (PCM)

- Quantization (continued)
  - Quantization Levels
    - The choice of L, the number of levels, depends on the range of the amplitudes of the analog signal and how accurately we need to recover the signal.
    - In audio digitizing, L is normally chosen to be 256; in video it is normally thousands
  - Quantization Error
    - The error created in the quantization process
    - Quantization is an approximation process
    - The value of the error for any sample is less than $\Delta/2$. In other words, we have $-\Delta/2 \le \text{error} \le \Delta/2$.
    - the quantization error to the SNR_{dB} of the signal
      - n_b: the bits per sample

$$\text{SNR}_{\text{dB}} = 6.02 n_b + 1.76 \quad \text{dB}$$

4.2.1 Pulse Code Modulation (PCM)

- Figure 4.26: 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

4.2.1 Pulse Code Modulation (PCM)

- Uniform Versus Nonuniform Quantization
  - Changes in amplitude often occur more frequently in the lower amplitudes than in the higher ones.
  - Better to use nonuniform zones.

4.2.1 Pulse Code Modulation (PCM)

- **Encoding**
  - The last step in PCM is encoding
  - Each sample can be changed to an n_b-bit code word
  - If the number of quantization levels is L, the number of bits is $n_b = \log_2 L$.
  - Bit rate formula

$$\textbf{Bit rate} = \textbf{sampling rate} \times \textbf{number of bits per sample} = f_s \times n_b$$

4.2.1 Pulse Code Modulation (PCM)

- Example 4.14
  - 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:

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

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

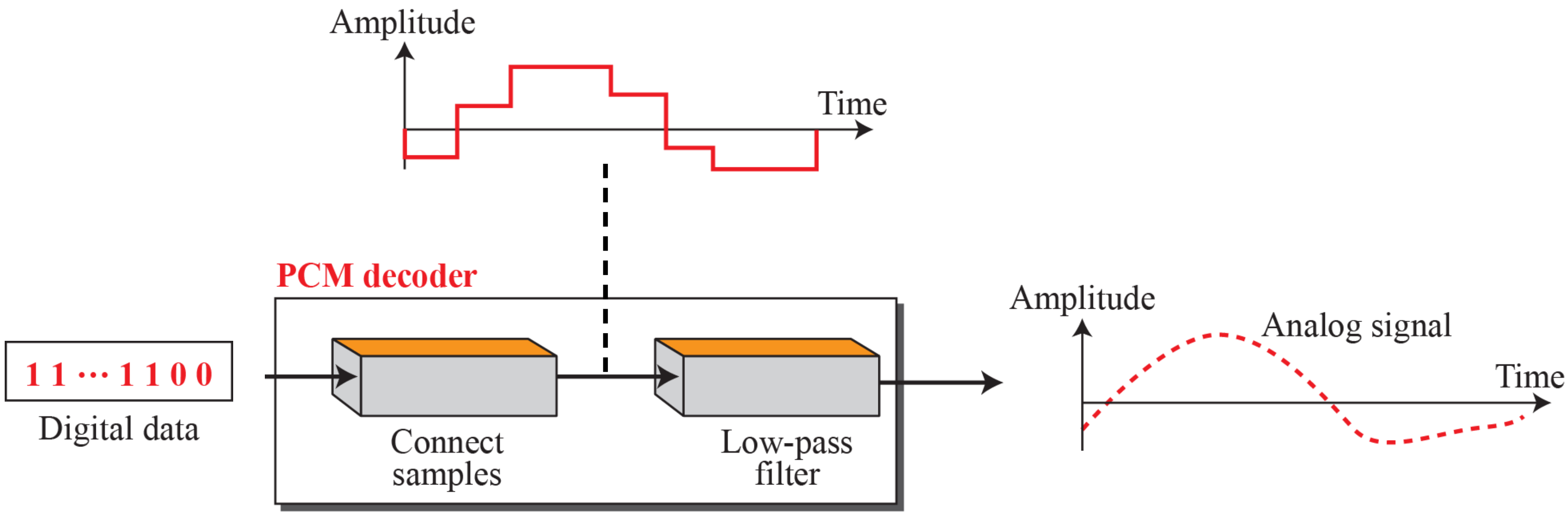
4.2.1 Pulse Code Modulation (PCM)

Original Signal Recovery

- The recovery of the original signal requires the PCM decoder
- After the staircase signal is completed, it is passed through a low-pass filter to smooth the staircase signal into an analog signal
  - The filter has the same cutoff frequency as the original signal at the sender.
  - If the signal has been sampled at (or greater than) the Nyquist sampling rate and if there are enough quantization levels, the original signal will be recreated.

4.2.1 Pulse Code Modulation (PCM)

❑ Figure 4.27: Components of a PCM decoder

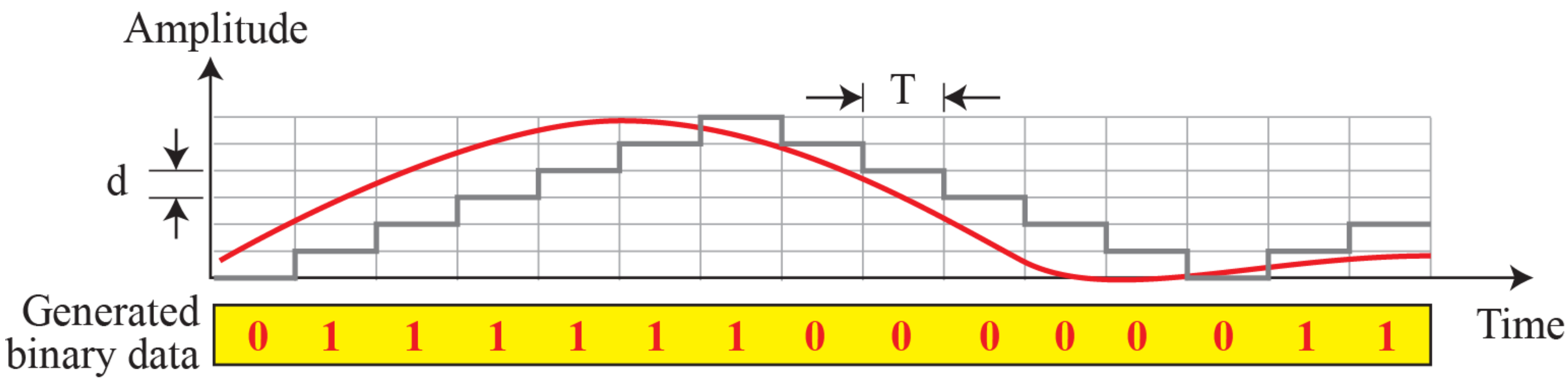


4.2.2 Delta Modulation (DM)

- PCM is a very complex technique.
- Other techniques have been developed to reduce the complexity of PCM.
- The simplest is delta modulation (DM).
  - PCM finds the value of the signal amplitude for each sample;
  - DM finds the change from the previous sample.
- Figure 4.28 shows the process.
  - Note that there are no code words here; bits are sent one after another.

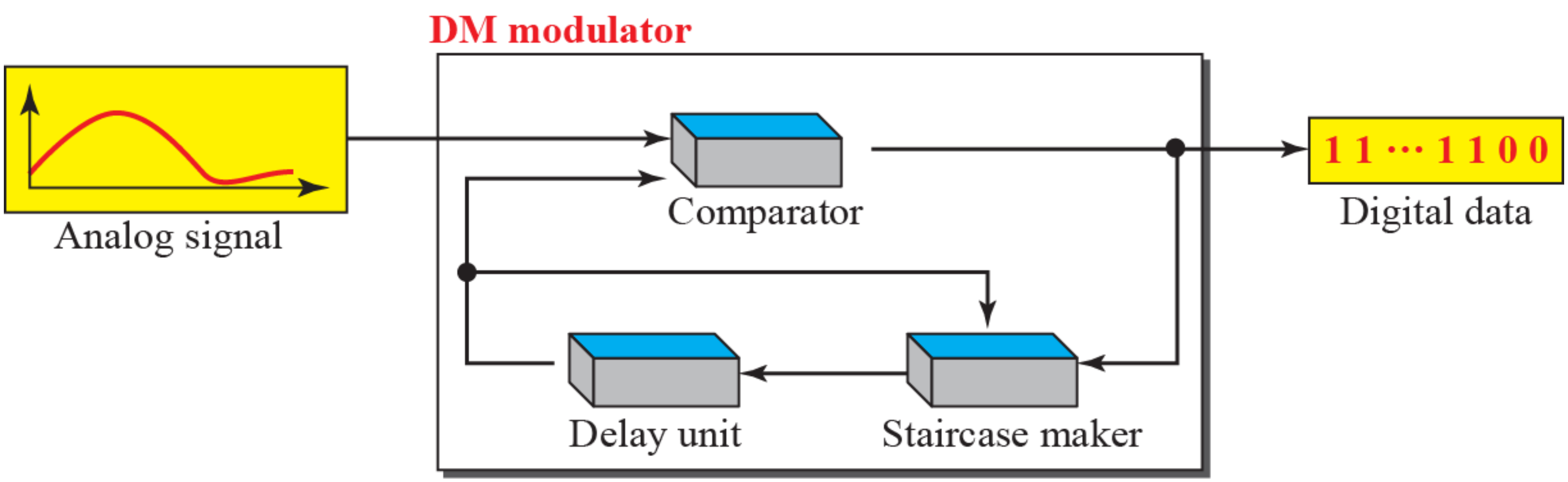
4.2.2 Delta Modulation (DM)

- Figure 4.28: The process of delta modulation



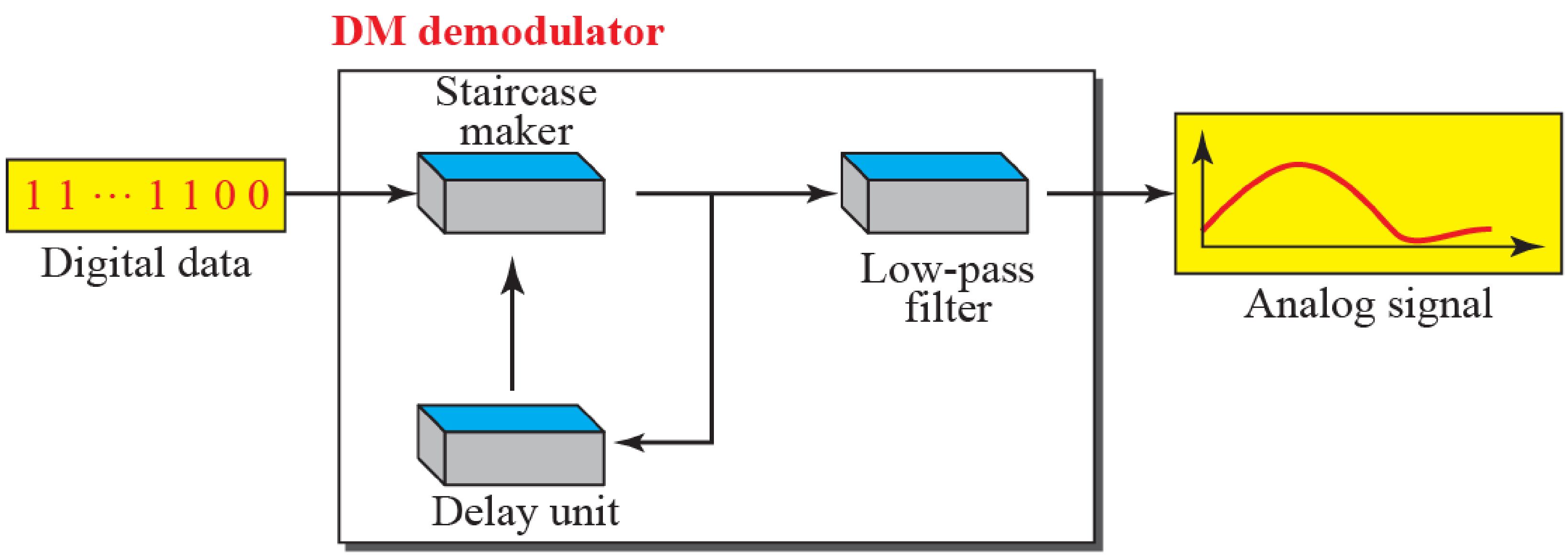
4.2.2 Delta Modulation (DM)

- Figure 4.29: Delta modulation components
  - The process records the small positive or negative changes, called delta δ.
    - If the delta is positive, the process records a 1;
    - If it is negative, the process records a 0.



4.2.2 Delta Modulation (DM)

- Demodulator
  - The created analog signal, however, needs to pass through a low-pass filter for smoothing
- Figure 4.30: Delta demodulation components

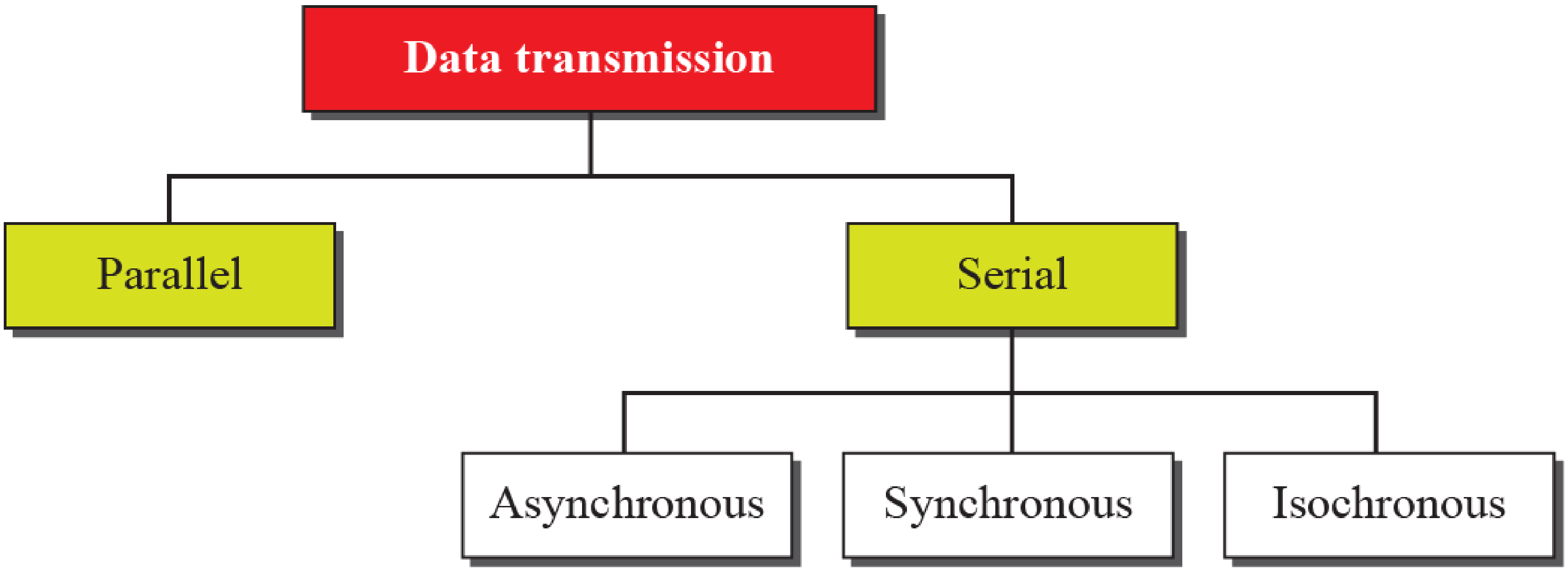


4-3 TRANSMISSION MODES

- Of primary concern when we are considering the transmission of data from one device to another is the wiring, and of primary concern when we are considering the wiring is the data stream.
- Do we send 1 bit at a time; or do we group bits into larger groups and, if so, how?
  - The transmission of binary data across a link can be accomplished in either parallel or serial mode. and isochronous (see Figure 4.31).

4-3 TRANSMISSION MODES

- Figure 4.31: Data transmission modes

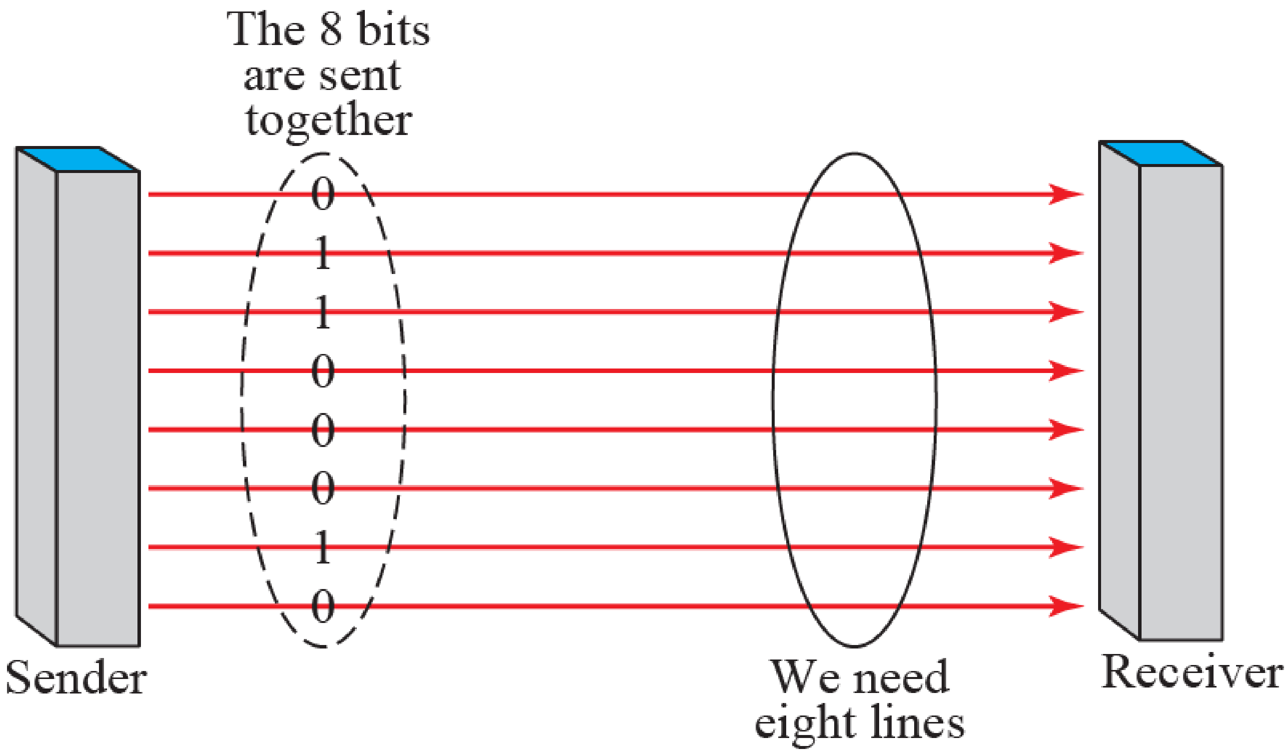


4.3.1 Parallel Transmission

- Line coding is the process of converting digital data to digital signals.
- We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits (see Chapter 1).
- Line coding converts a sequence of bits to a digital signal.
  - At the sender, digital data are encoded into a digital signal
  - At the receiver, the digital data are recreated by decoding the digital signal.
  - Figure 4.1 shows the process.

4.3.1 Parallel Transmission

- Figure 4.32: Parallel transmission

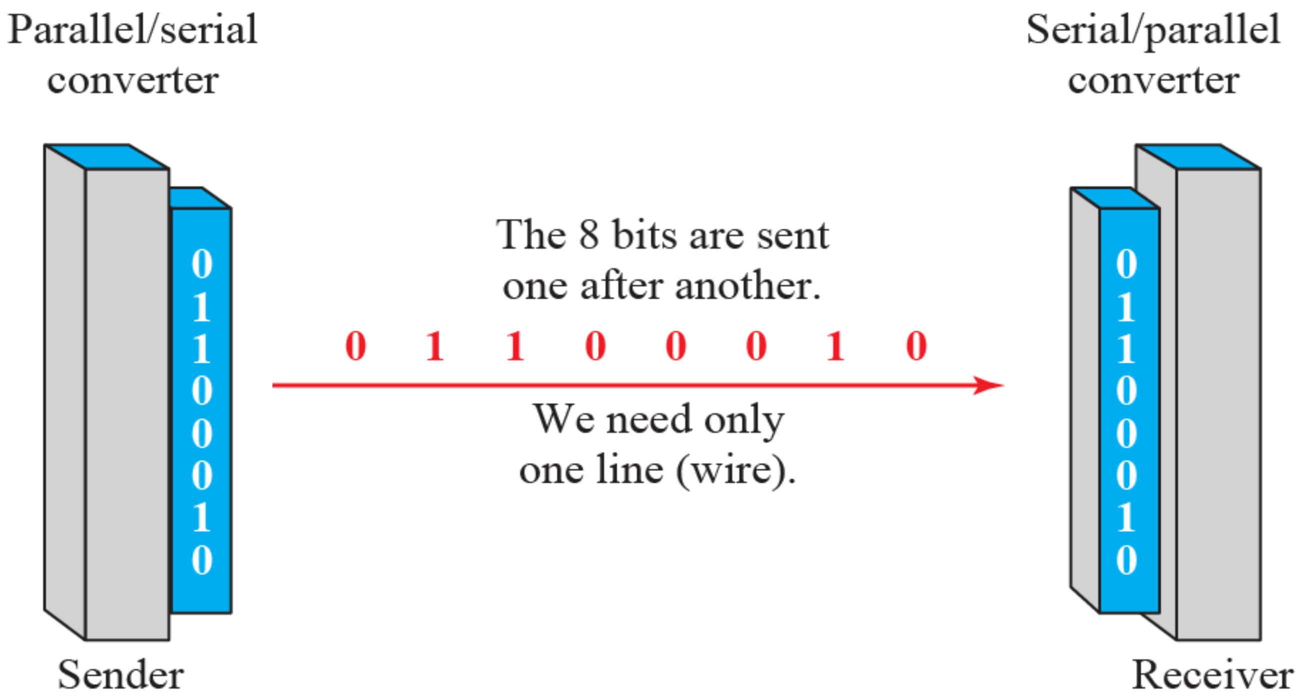


4.3.1 Parallel Transmission

- The advantage of parallel transmission is speed.
- But, expensive
  - Parallel transmission requires n communication lines (wires in the example) just to transmit the data stream

4.3.2 Serial Transmission

- In serial transmission one bit follows another, so we need only one communication channel rather than n to transmit data between two communicating devices (see Figure 4.33)..
- Figure 4.33: Serial transmission

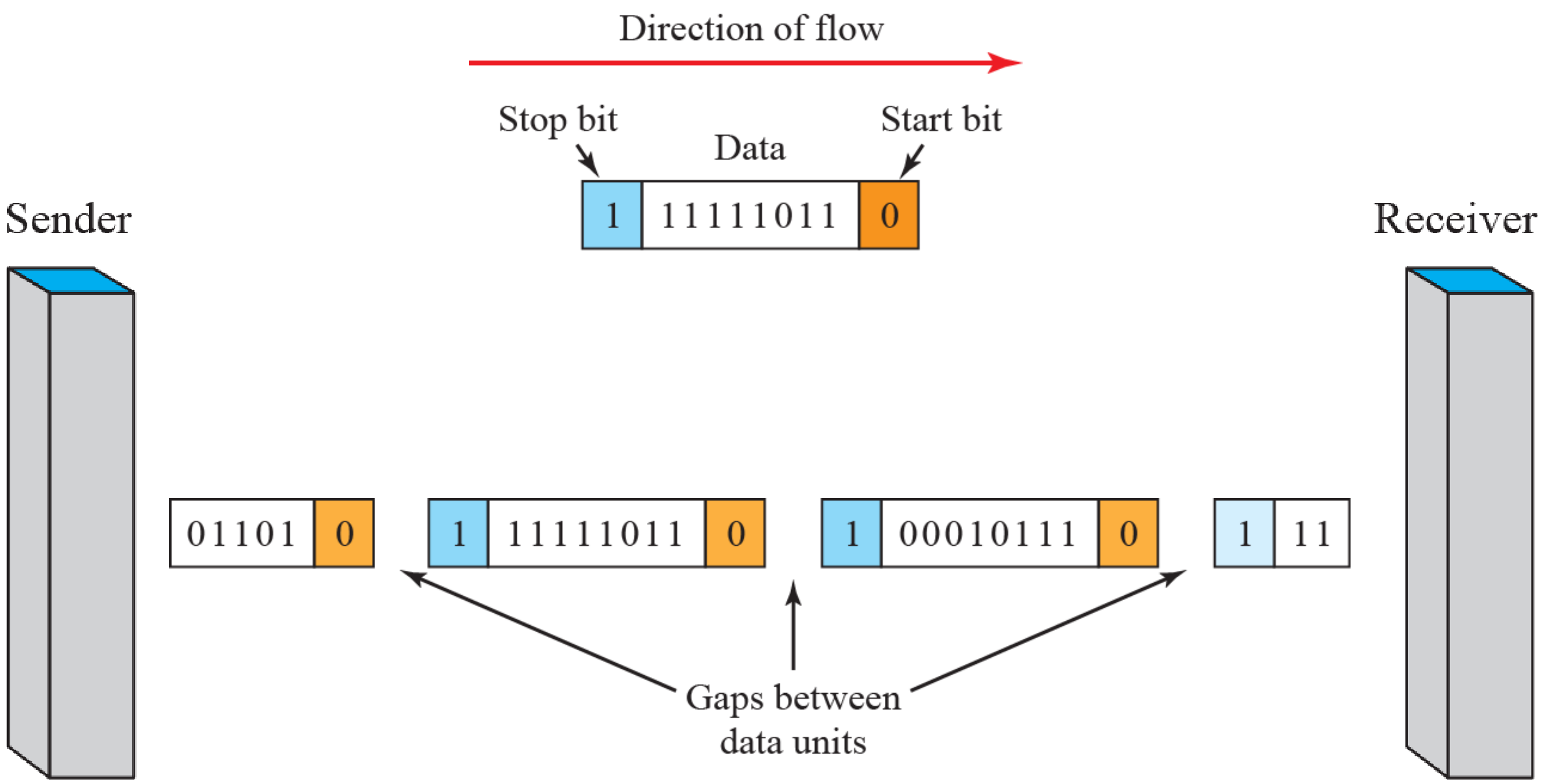


4.3.2 Serial Transmission

- Asynchronous Transmission
  - The timing of a signal is unimportant.
    - Instead, information is received and translated by agreed upon patterns.
  - In 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 bytes.
  - Asynchronous here means "asynchronous at the byte level," but the bits are still synchronized; their durations are the same.
  - Cheap and effective
  - Slower than forms of transmission that can operate without the addition of control information
  - E.g., the connection of a keyboard to a computer is a natural application for asynchronous transmission.

4.3.2 Serial Transmission

- Figure 4.34: Asynchronous transmission

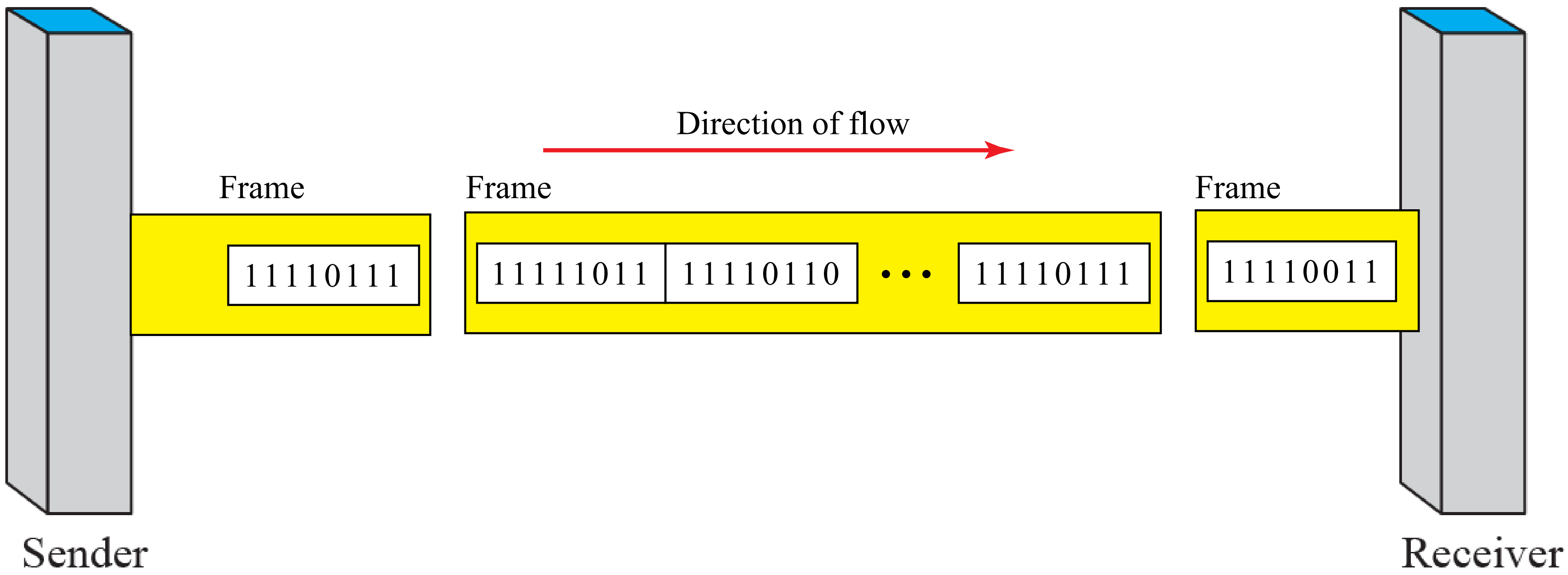


4.3.2 Serial Transmission

- Synchronous Transmission
  - The bit stream is combined into longer “frames,” which may contain multiple bytes.
  - In 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.
  - The advantage of synchronous transmission is speed
    - More useful for high-speed applications such as the transmission of data from one computer to another
  - There may be uneven gaps between frames.

4.3.2 Serial Transmission

- Figure 4.35: Synchronous transmission



4.3.2 Serial Transmission

- Isochronous
  - The entire stream of bits must be synchronized.
  - The isochronous transmission guarantees that the data arrive at a fixed rate.
  - In real-time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails.

Summary & Next Class

- ❑ Ch 4. Digital transmission
- ❑ Summary & Next Class

Summary: Ch 4

- Digital-to-digital conversion
  - Line coding, block coding, and scrambling.
- The technique to change an analog signal to digital data (digitization)
  - Pulse code modulation (PCM)
    - Sampling: sampling rate
    - Nyquist theorem
      - To reproduce the original analog signal, one necessary condition is that the sampling rate be at least twice the highest frequency in the original signal
  - Delta modulation
- Transmission mode
  - Parallel transmission
  - Serial transmission: asynchronous, synchronous, and isochronous

Assignment

- **Solve Assignment # posted on eClass website exercise**
  - eClass → Data Communication → Assignment
  - Textbook problems
  - **Upload your answer sheet** on eClass **until the dealine**
  - **Firm deadline!!**: **late** submission is **not accepted**
  - Only **docx, hwp, pdf** format allowed (**NOT any figure format including jpg, bmp, png** etc.)
  - eClass → Data Communciaton → Assignment
  - Don't forget to write your **name**, **student ID number**.
  - It is not important whether or not your answers are correct. That is, if you **just try to write an answer**, you can **get the perfect scores**.
  - Exams will rigorously check your efforts on solving the assignment and practice problems by yourself.
- In order to inquire about the assignment (problem or scoring), please contact to the teaching assistant

Course Schedule (Tentative)

- FL: Flipped learning
- **Rec: Recorded video for makeup class**

No	Topics	Date-M		Date-Th	
1	Introduction to course and data communications (Ch1)	09/05	FL (**Zoom**)	09/08	FL
2	Intro. to data communications (Ch1) & Network models (Ch2)	09/12	**Rec**	09/15	FL
3	Intro. to physical layer (Ch3)	09/19	FL	09/22	FL
4	Digital transmission (Ch4)	09/26	FL	09/29	FL
5	Analog transmission (Ch5) & Bandwidth utilization: multiplexing (Ch6.1)	10/03	**Rec**	10/06	**Rec**
6	Bandwidth utilization: spread spectrum (Ch6.2) Transmission Media (Ch7)	10/10	**Rec**	10/13	FL
7	Switching (Ch8) Introduction to Data-Link Layer (Ch9)	10/17	FL	10/20	FL
8	**Midterm exam**	**10/24**	**Evening**	**10/24**	**Evening**
9	Error detection and correction (Ch10)	10/31	FL	11/03	FL
10	Data link control (Ch11)	11/07	FL	11/10	FL
11	Media Access Control (Ch12)	11/14	FL	11/17	**Rec**
12	Wired LAN (Ethernet) (Ch13) & Other wired network (Ch14)	11/21	**Rec**	11/24	FL
13	Wireless LAN (Ch15)	11/28	FL	12/01	FL
14	Other wireless networks (Ch16) Connecting devices and virtual LANs (Ch17)	12/05	FL	12/08	FL
15	**Final exam**	**12/12**	**Evening**	**12/12**	**Evening**