DATA COMMUNICATION (CC-2103)

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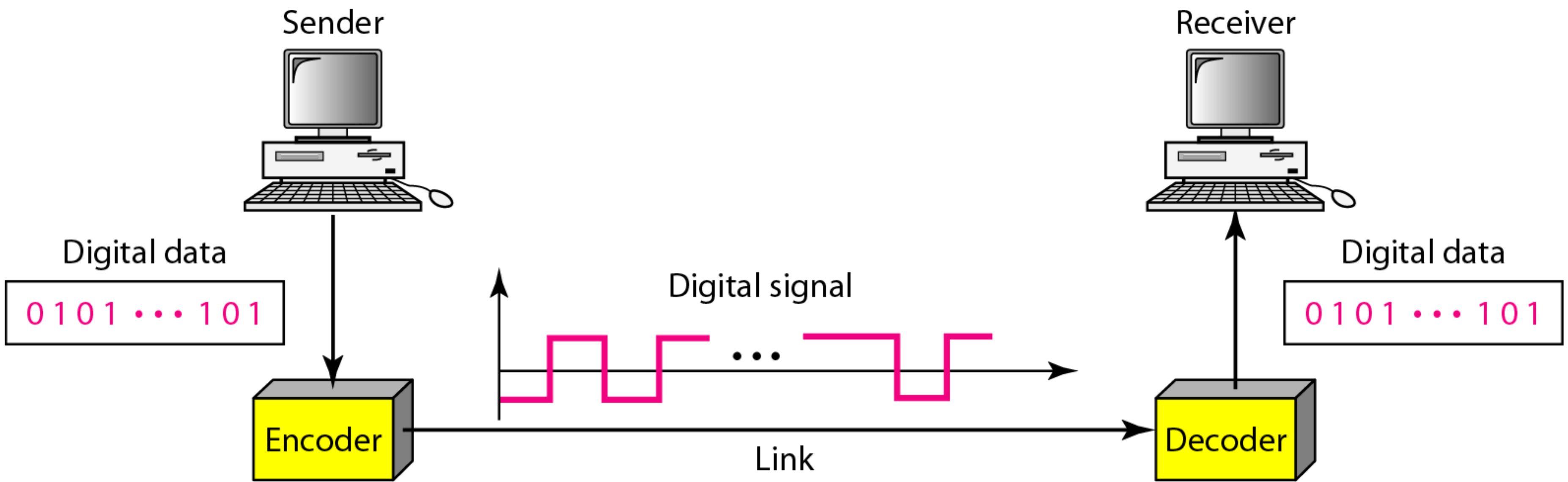
Signal Encoding Techniques

- **Digital Transmission**
- **DIGITAL-TO-DIGITAL CONVERSION**
- ***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.***

Signal Encoding Techniques

- **Line coding**
- Converting a string of 1's and 0's (digital data) into a sequence of signals that denote the 1's and 0's.
- For example a high voltage level (+V) could represent a "1" and a low voltage level (0 or -V) could represent a "0".



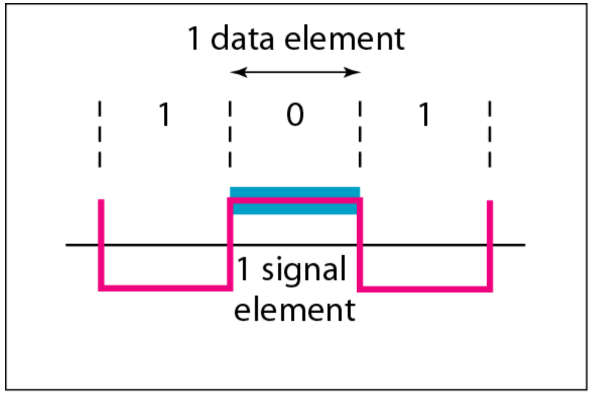
Signal Encoding Techniques

- **Data Rate Versus Signal Rate**
- The data rate defines the number of data elements (bits) sent in 1 sec. The unit is bits per second (bps).
- The signal rate is the number of signal elements sent in 1 sec. The unit is the baud.
- The data rate is sometimes called the bit rate; the signal rate is sometimes called **the pulse rate**, the **modulation rate**, or the **baud rate**.

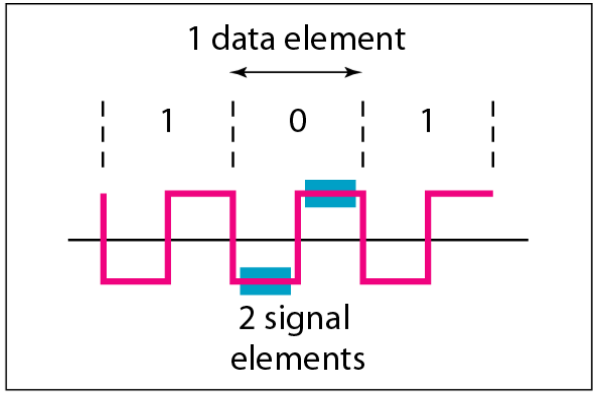
Signal Encoding Techniques

- **Mapping Data symbols onto Signal levels**
- A data symbol (or element) can consist of a number of data bits:
  - 1 , 0 or
  - 11, 10, 01, ……
- A data symbol can be coded into a single signal element or multiple signal elements
  - 1 -> +V, 0 -> -V
  - 1 -> +V and -V, 0 -> -V and +V
- The ratio ‘r’ is the number of data elements carried by a signal element.

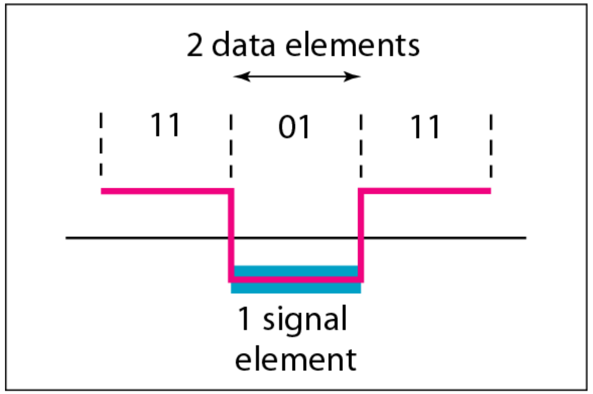
Signal Encoding Techniques



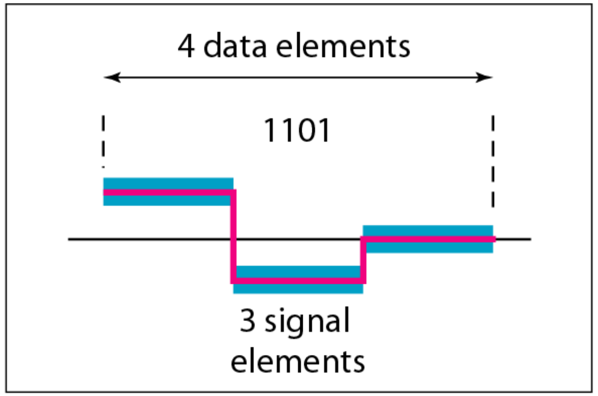
a. One data element per one signal element (r = 1)



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

Signal Encoding Techniques

- **Data Rate Versus Signal Rate**
- We can formulate the relationship between data rate and signal rate as:

  S =c x N x 1/r 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
  - r is the ratio of data elements carried by each signal element

Signal Encoding Techniques

- **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

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

Signal Encoding Techniques

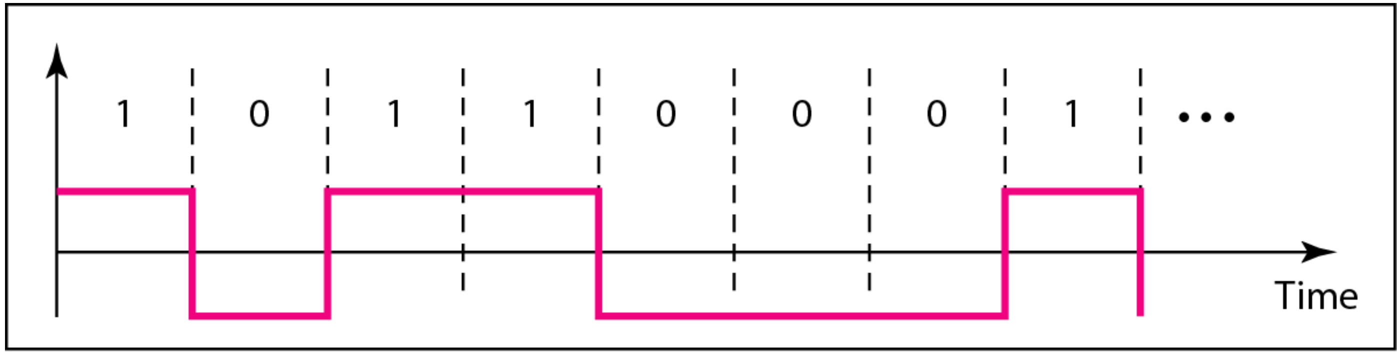
- Baseline wandering - a receiver will evaluate the average power of the received signal (called the baseline) and use that to determine the value of the incoming data elements.
- A long string of 0s or 1s can cause a drift in the baseline (baseline wandering) and make it difficult for the receiver to decode correctly.
- A good line coding scheme needs to prevent baseline wandering
- If the incoming signal does not vary over a long period of time, the baseline will drift and thus cause errors in the detection of incoming data elements.

Signal Encoding Techniques

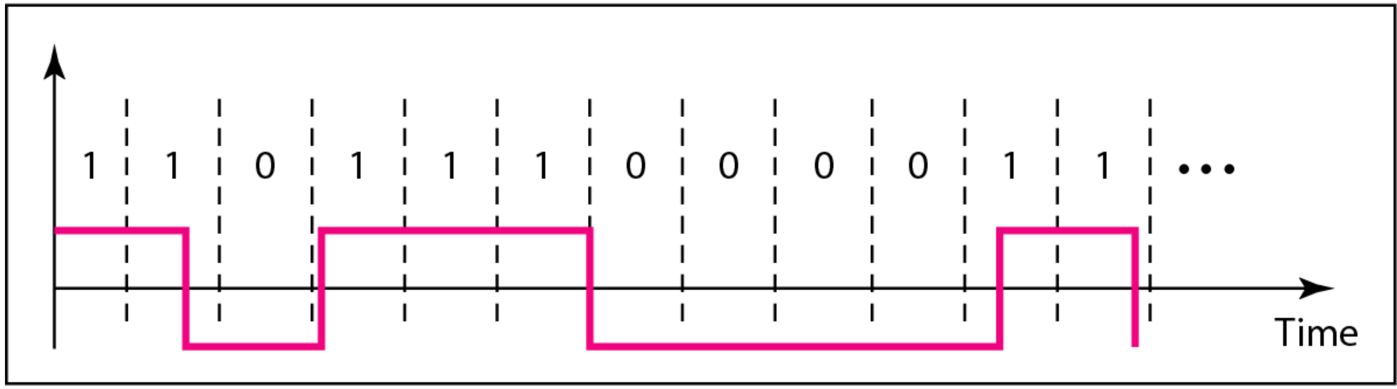
- DC components - when the voltage level remains constant for long periods of time, there is an increase in the low frequencies of the signal. Most channels are bandpass and may not support the low frequencies.
- This will require the removal of the dc component of a transmitted signal.

Signal Encoding Techniques

- Self-synchronization: The sender and receiver clocks must have the same bit interval.
- If the receiver clock is faster or slower it will misinterpret the incoming bit stream.



a. Sent



b. Received

Signal Encoding Techniques

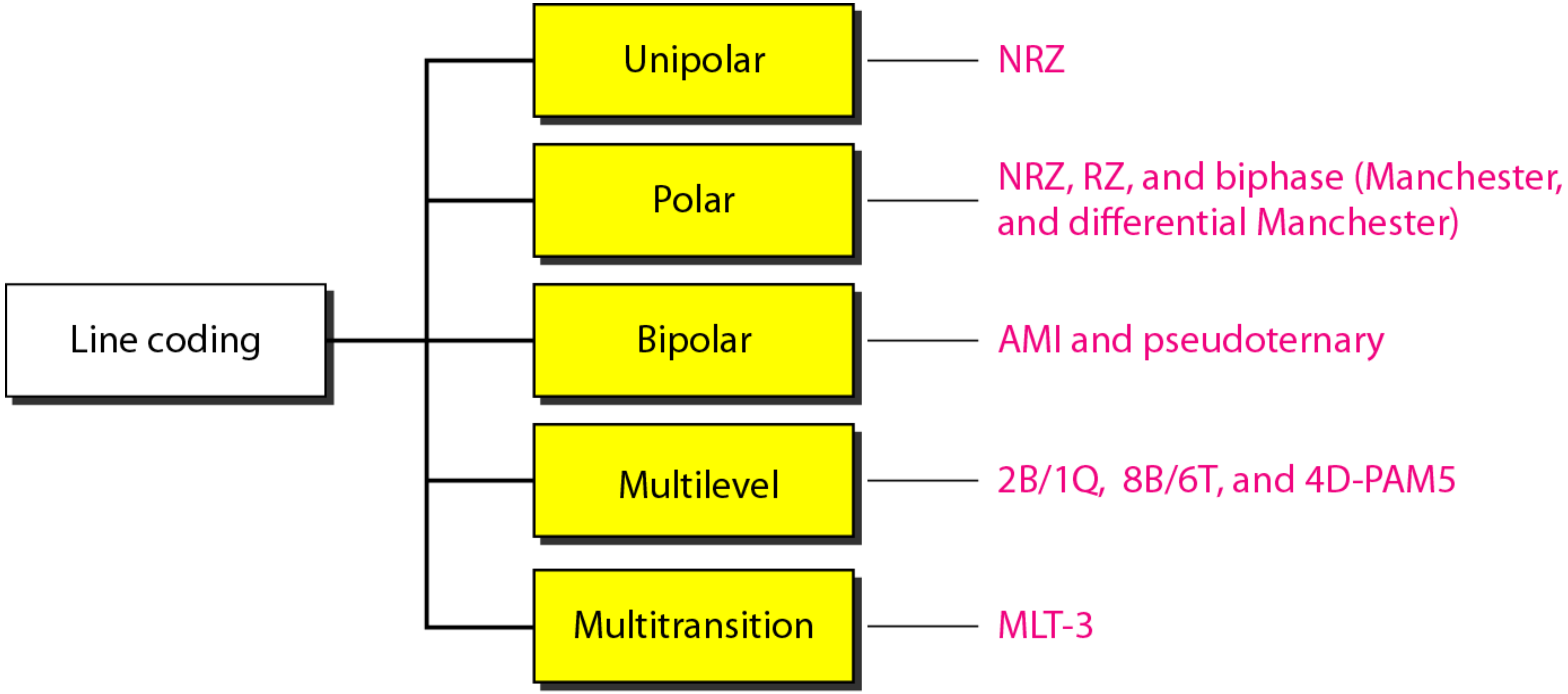
- Line encoding
- Error detection: Errors occur during transmission due to line impairments.
- Some codes are constructed such that when an error occurs it can be detected.
- For example, a particular signal transition is not part of the code. When it occurs, the receiver will know that a symbol error has occurred.
- Noise and interference: There are line encoding techniques that make the transmitted signal “immune” to noise and interference.
- This means that the signal cannot be corrupted, it is stronger than error detection.

Signal Encoding Techniques

- Line encoding
- Complexity: The more robust and resilient the code, the more complex it is to implement and the price is often paid in baud rate or required bandwidth.

Signal Encoding Techniques

- Line coding schemes

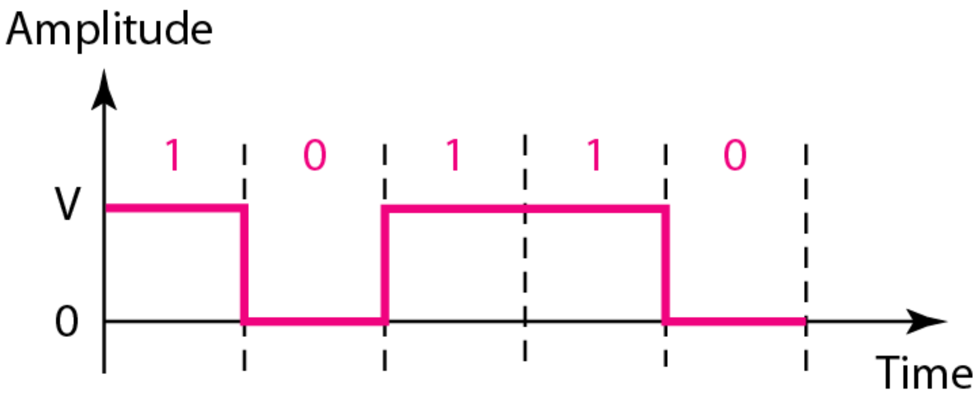


Signal Encoding Techniques

- **Unipolar Scheme**
- In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.
- NRZ (Non-Return-to-Zero) Traditionally, a unipolar scheme was designed as a non-return-to-zero (NRZ) scheme in which the positive voltage defines bit l and the zero voltage defines bit O.
- It is called NRZ because the signal does not return to zero at the middle of the bit

Signal Encoding Techniques

- **Unipolar Scheme**
- The normalized power (power needed to send 1 bit per unit line resistance) is double that for NRZ. For this reason, this scheme is normally not used in data communications today.



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

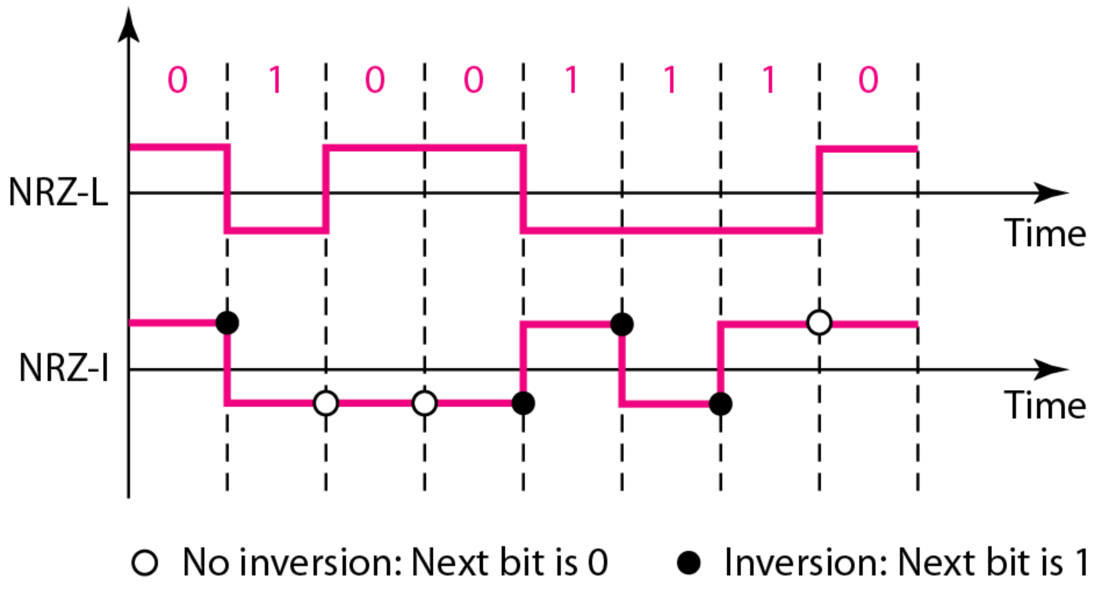
Normalized power

Signal Encoding Techniques

- **Polar - NRZ**
- The voltages are on both sides of the time axis.
- Polar NRZ scheme can be implemented with two voltages. E.g. +V for 1 and -V for 0.
- There are two versions:
  - NZR - Level (NRZ-L) - positive voltage for one symbol and negative for the other
  - NRZ - Inversion (NRZ-I) - the change or lack of change in polarity determines the value of a symbol. E.g. a “1” symbol inverts the polarity a “0” does not.

Signal Encoding Techniques

- **Polar - NRZ**
- The voltages are on both sides of the time axis.



Signal Encoding Techniques

- Polar - NRZ
- NRZ-L and NRZ-I both have a DC component problem and baseline wandering, it is worse for NRZ-L.
- Both have no self synchronization &no error detection.
- Both are relatively simple to implement.

Signal Encoding Techniques

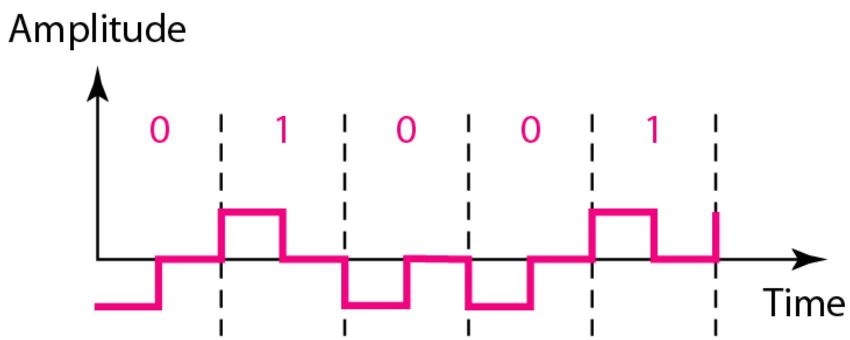
- Polar – RZ
- Return to Zero (RZ) The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized.
- The receiver does not know when one bit has ended and the next bit is starting
- The Return to Zero (RZ) scheme uses three voltage values. +, 0, -.
- Each symbol has a transition in the middle. Either from high to zero or from low to zero.

Signal Encoding Techniques

- Polar – RZ
- This scheme has more signal transitions (two per symbol) and therefore requires a wider bandwidth.
- No DC components or baseline wandering.
- Self synchronization - transition indicates symbol value.
- More complex as it uses three voltage level. It has no error detection capability.

Signal Encoding Techniques

- Polar – RZ
  - 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

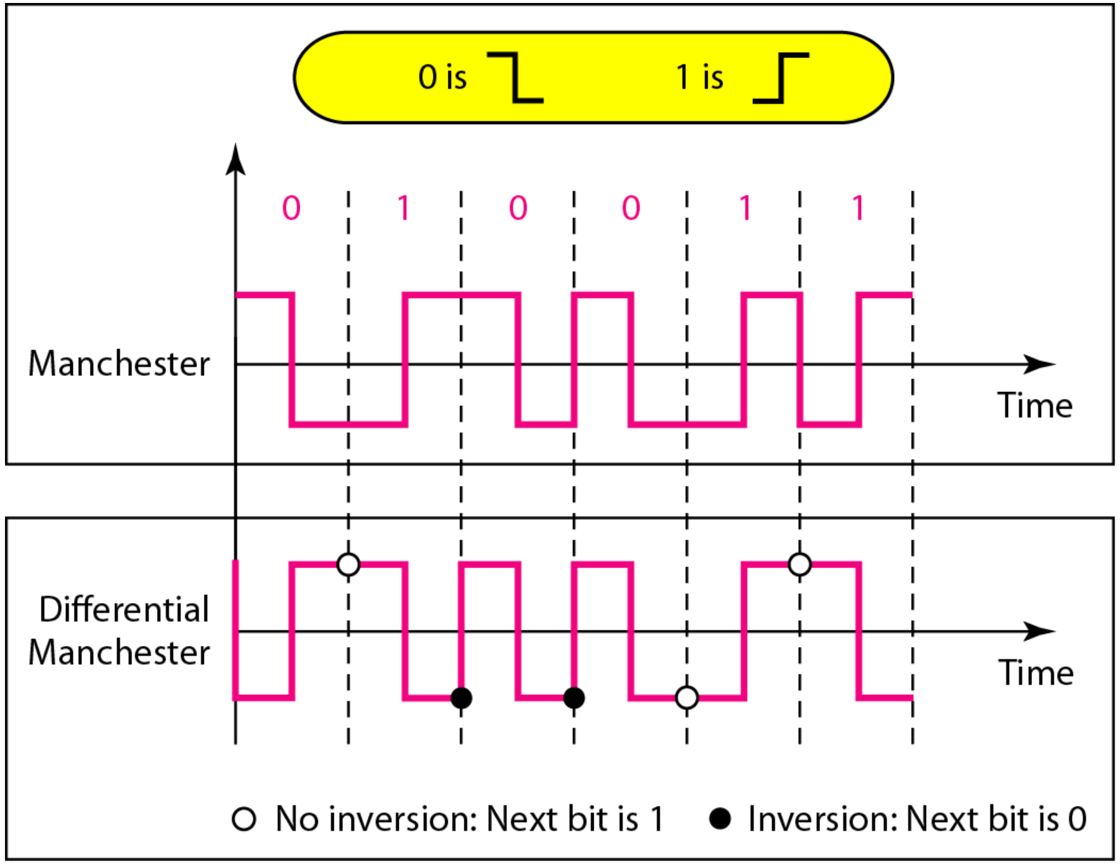


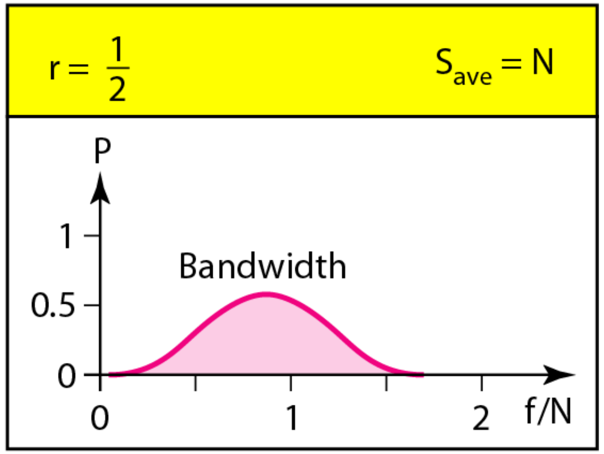
Signal Encoding Techniques

- **Polar - Biphase: Manchester and Differential Manchester**
- Manchester coding consists of combining the NRZ-L and RZ schemes.
  - Every symbol has a level transition in the middle: from high to low or low to high. Uses only two voltage levels.
- Differential Manchester coding consists of combining the NRZ-I and RZ schemes.
  - Every symbol has a level transition in the middle. But the level at the beginning of the symbol is determined by the symbol value. One symbol causes a level change the other does not.

Signal Encoding Techniques

- Polar - Biphase: Manchester and Differential Manchester





Signal Encoding Techniques

- **Bipolar Encoding:**
- In bipolar encoding (sometimes called multilevel binary), there are three voltage levels:positive, negative, and zero.
- The voltage level for one data element is at zero, while the voltage level for the other element alternates between positive and negative.
- Bipolar Alternate Mark Inversion (AMI) - the “0” symbol is represented by zero voltage and the “1” symbol alternates between +V and -V.
- Pseudoternary is the reverse of AMI.

Signal Encoding Techniques

- Bipolar Encoding:
- Bipolar Alternate Mark Inversion (AMI) - the “0” symbol is represented by zero voltage and the “1” symbol alternates between +V and -V.
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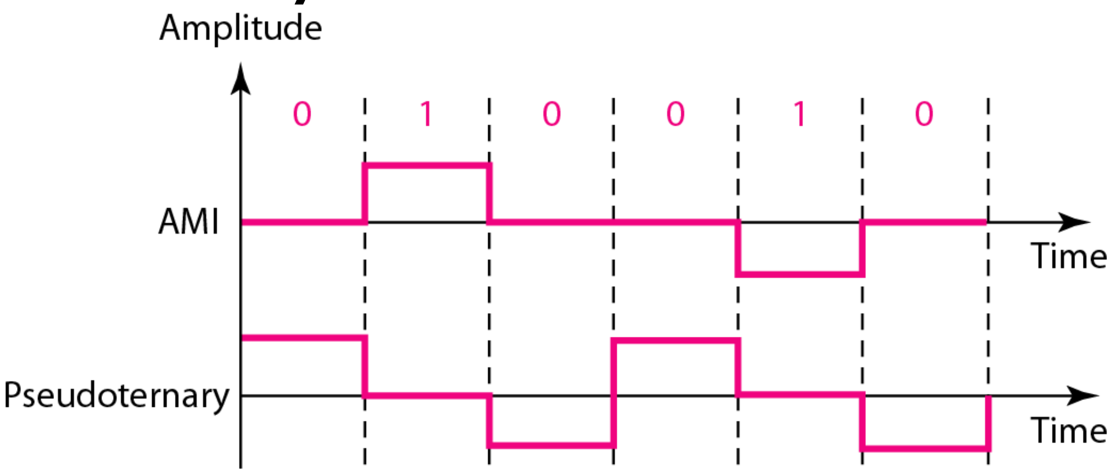
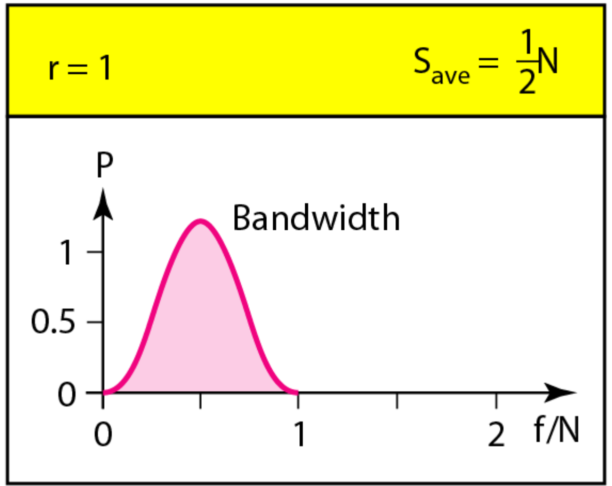


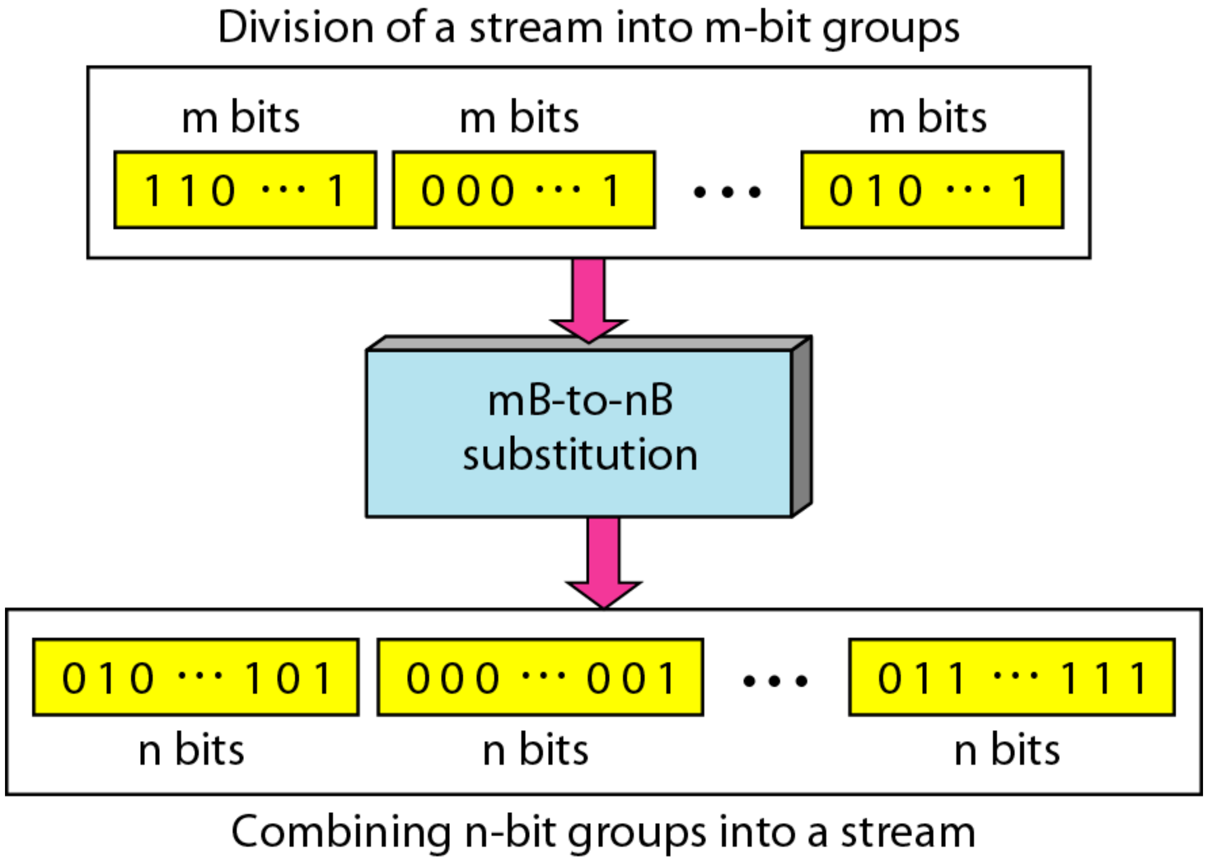


Signal Encoding Techniques

- **Block Coding:**
- For a code to be capable of error detection, we need to add redundancy, i.e., extra bits to the data bits.
- Synchronization also requires redundancy - transitions are important in the signal flow and must occur frequently.
- Block coding is done in three steps: division, substitution and combination.
- It is distinguished from multilevel coding by use of the slash - xB/yB.
- The resulting bit stream prevents certain bit combinations that when used with line encoding would result in DC components or poor sync. quality

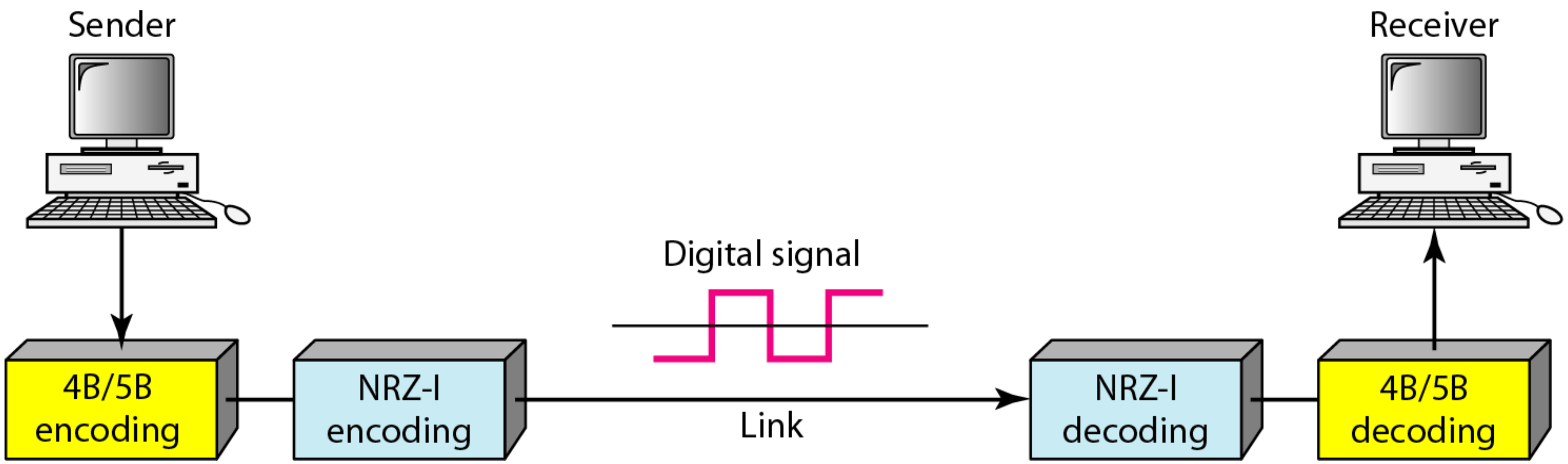
Signal Encoding Techniques

- Block Coding:



Signal Encoding Techniques

- Block Coding:



Si

- Block Coding:

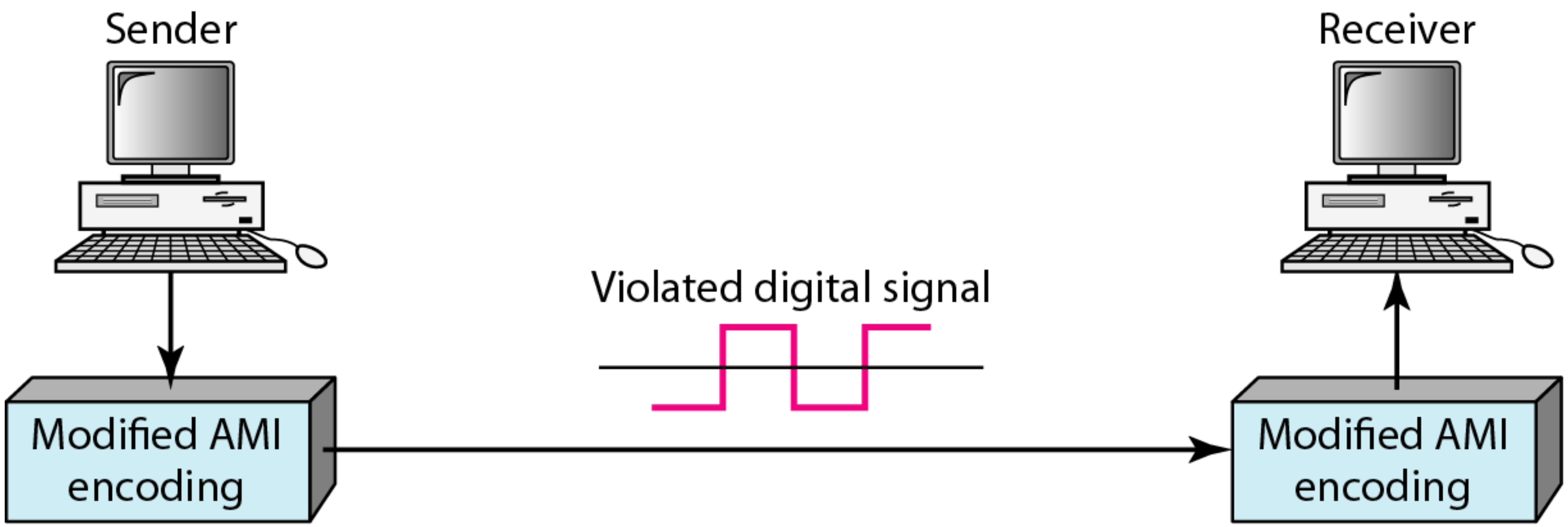
Data Sequence	*Encoded Sequence*	*Control Sequence*	*Encoded Sequence*
0000	11110	Q (Quiet)	00000
0001	01001	I (Idle)	11111
0010	10100	H (Halt)	00100
0011	10101	J (Start delimiter)	11000
0100	01010	K (Start delimiter)	10001
0101	01011	T (End delimiter)	01101
0110	01110	S (Set)	11001
0111	01111	R (Reset)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

Signal Encoding Techniques

- Scrambling:
- The best code is one that does not increase the bandwidth for synchronization and has no DC components.
- Scrambling is a technique used to create a sequence of bits that has the required c/c's for transmission - self clocking, no low frequencies, no wide bandwidth.
- It is implemented at the same time as encoding, the bit stream is created on the fly.
- It replaces 'unfriendly' runs of bits with a violation code that is easy to recognize and removes the unfriendly c/c.

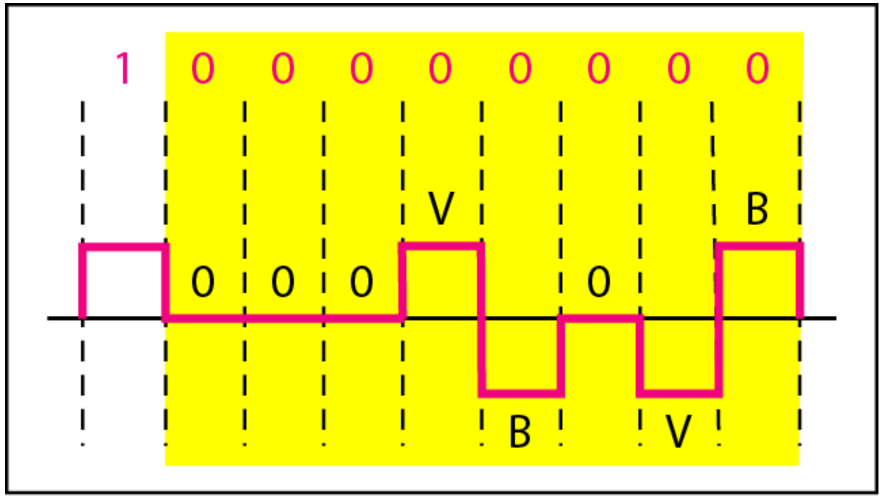
Signal Encoding Techniques

- Scrambling:

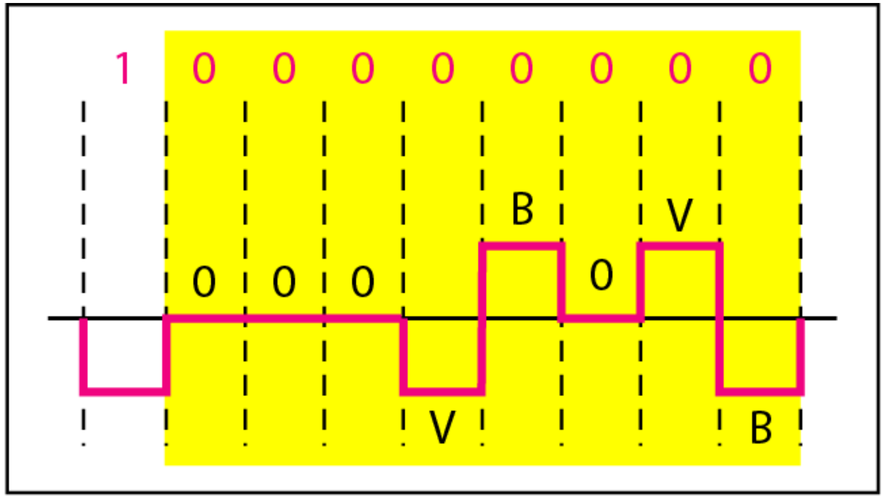


Signal Encoding Techniques

- Scrambling:
- B8ZS substitutes eight consecutive zeros with 000VB0VB.
- The V stands for violation, it violates the line encoding rule
- B stands for bipolar, it implements the bipolar line encoding rule



a. Previous level is positive.

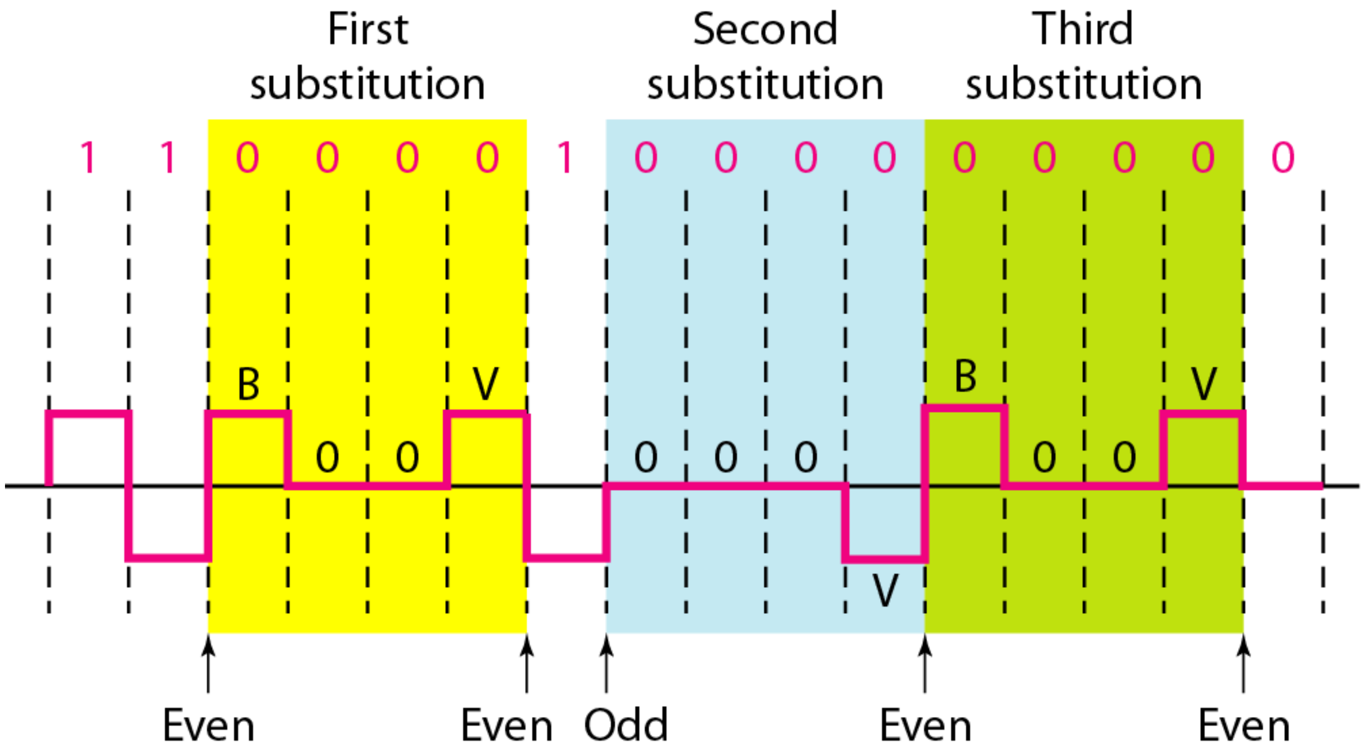


b. Previous level is negative.

Signal Encoding Techniques

Scrambling:

- HDB3 substitutes four consecutive zeros with 000V or B00V depending
- on the number of nonzero pulses after the last substitution.
- If # of non zero pulses is even the substitution is B00V to make total # of non zero pulse even.
- If # of non zero pulses is odd the substitution is 000V to make total # of non zero pulses even.



Signal Encoding Techniques

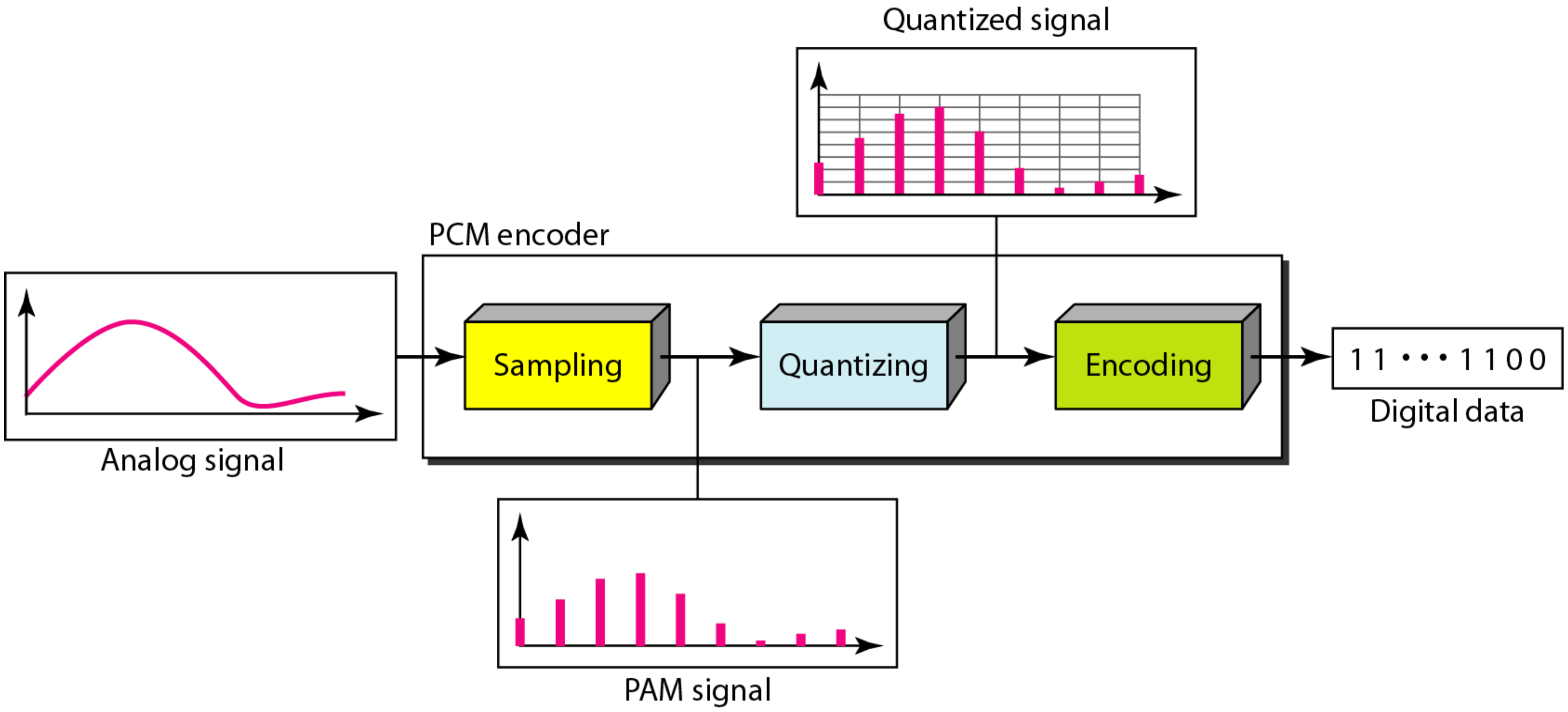
- A digital signal is superior to an analog signal because it is more robust to noise and can easily be recovered, corrected and amplified.
- For this reason, the tendency today is to change an analog signal to digital data.

Signal Encoding Techniques

- Pulse Code Modulation (PCM)
- The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM).
- PCM consists of three steps to digitize an analog signal:
  - Sampling
  - Quantization
  - Binary encoding
- Before we sample, we have to filter the signal to limit the maximum frequency of the signal as it affects the sampling rate.
- Filtering should ensure that we do not distort the signal, i.e. remove high-frequency components that affect the signal shape.

Signal Encoding Techniques

- Components of Pulse Code Modulation (PCM):

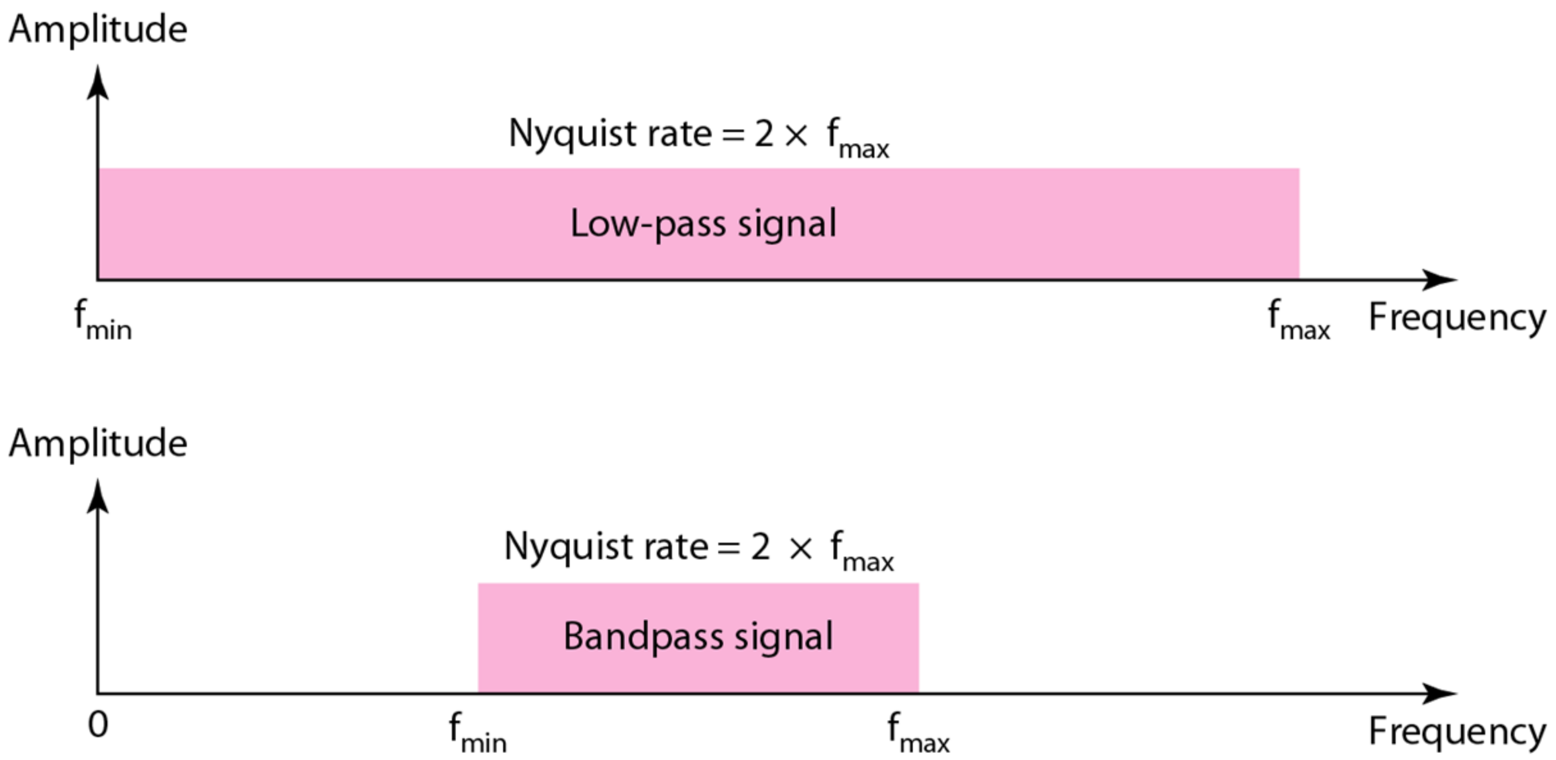


Signal Encoding Techniques

- **Sampling:**
- Analog signal is sampled every T_S secs.
- T_s is referred to as the sampling interval.
- $f_s = 1/T_s$ is called the sampling rate or sampling frequency.
- There are 3 sampling methods:
  - Ideal - an impulse at each sampling instant
  - Natural - a pulse of short width with varying amplitude
  - Flattop - sample and hold, like natural but with single amplitude value
- The process is referred to as pulse amplitude modulation PAM and the outcome is a signal with analog (non integer) values

Signal Encoding Techniques

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



Signal Encoding Techniques

- **Quantization:**
- Sampling results in a series of pulses of varying amplitude values ranging between two limits: a min and a max.
- The amplitude values are infinite between the two limits.
- We need to map the *infinite* amplitude values onto a finite set of known values.
- This is achieved by dividing the distance between min and max into L zones, each of height Δ.

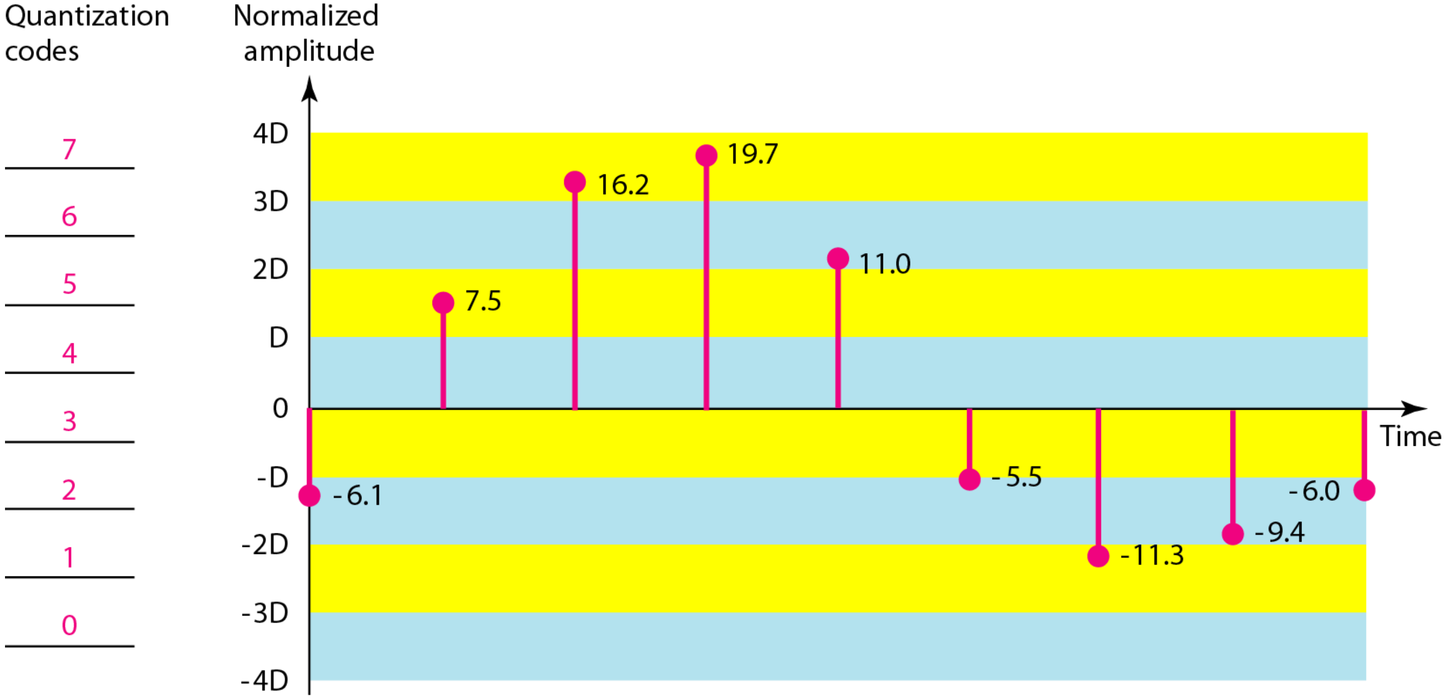
$$\Delta = (\text{max} - \text{min})/L$$

Signal Encoding Techniques

- **Quantization:**
- Assume we have a voltage signal with amplitutes V_{min}=-20V and V_{max}=+20V.
- We want to use L=8 quantization levels.
- Zone width $\Delta = (20 - -20)/8 = 5$
- The 8 zones are: -20 to -15, -15 to -10, -10 to -5, -5 to 0, 0 to +5, +5 to +10, +10 to +15, +15 to +20
- The midpoints are: -17.5, -12.5, -7.5, -2.5, 2.5, 7.5, 12.5, 17.5

Signal Encoding Techniques

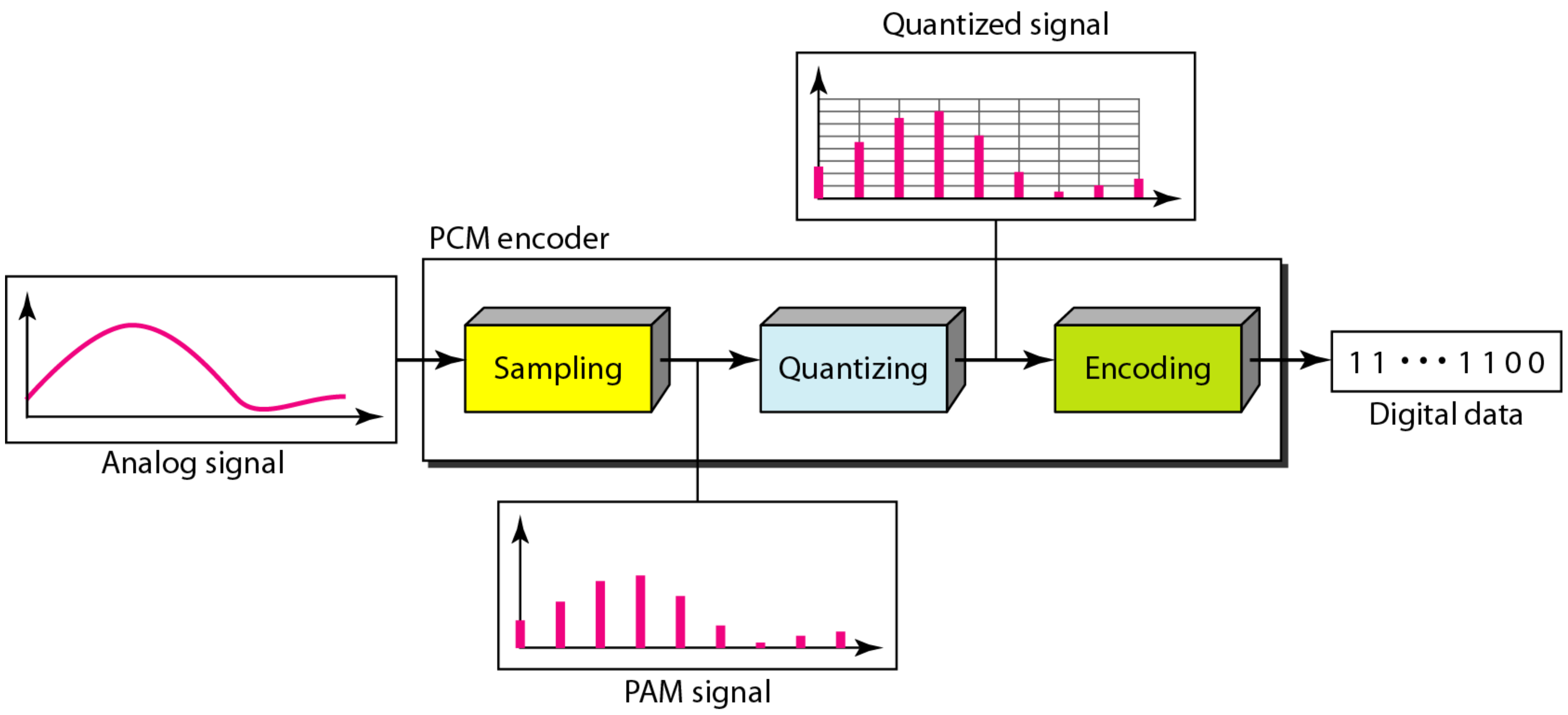
- **Quantization:**



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

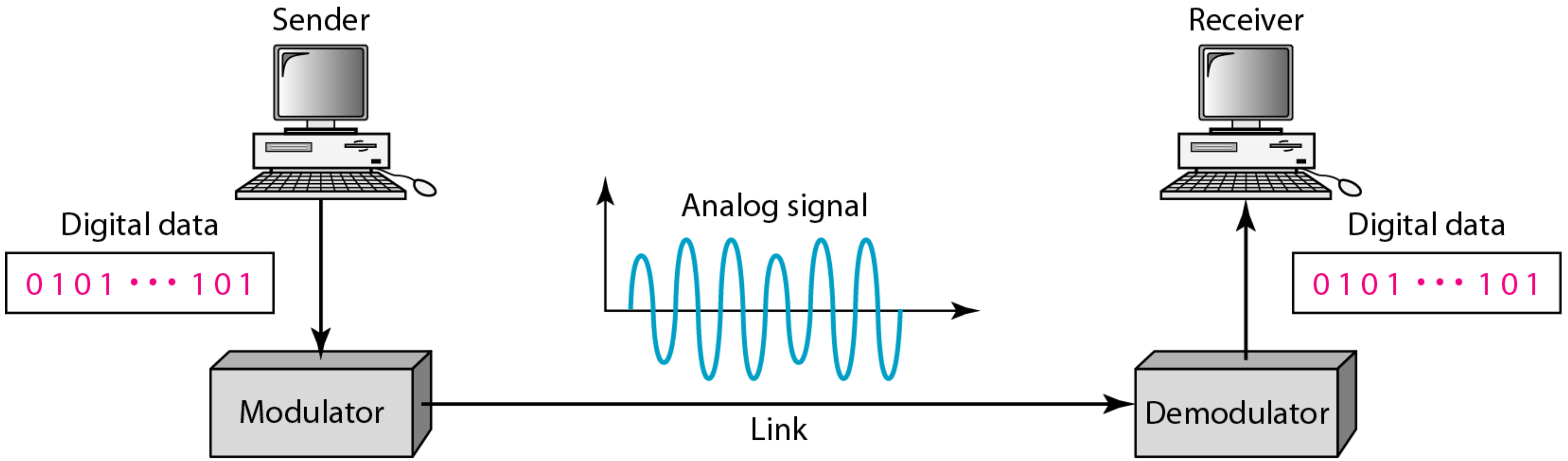
Signal Encoding Techniques

- **PCM:**



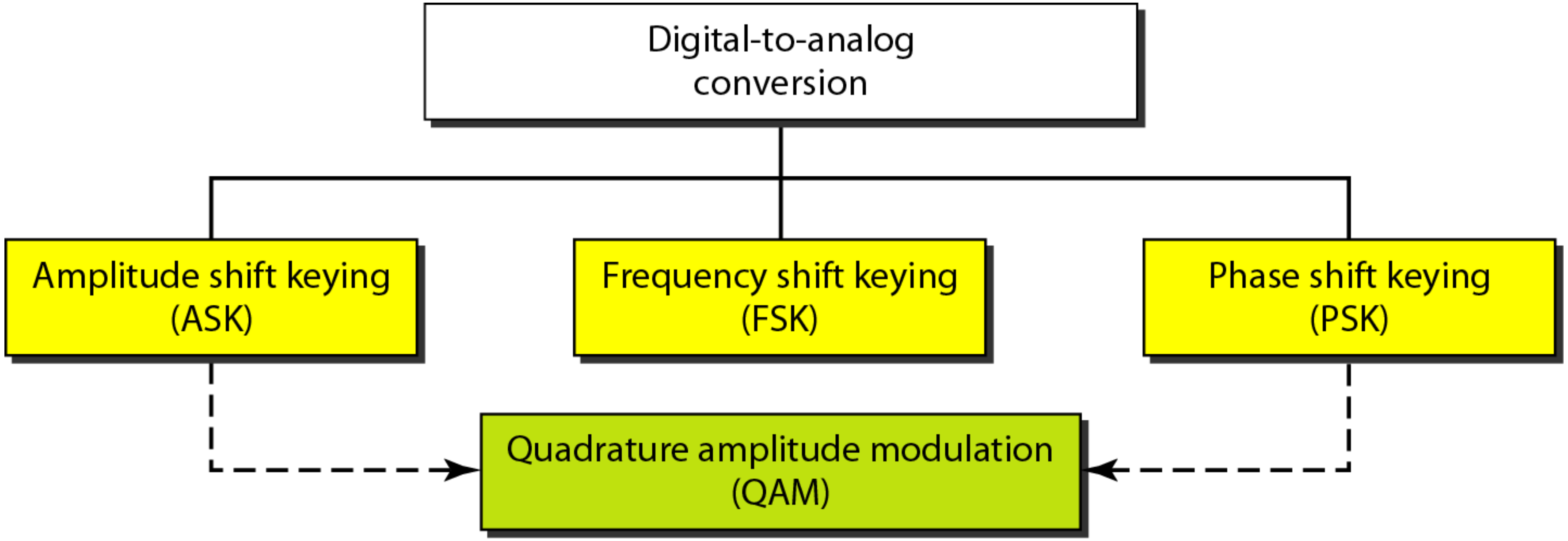
Signal Encoding Techniques

- Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.



Signal Encoding Techniques

- Digital data needs to be carried on an analog signal.
- A carrier signal (frequency f_c) performs the function of transporting the digital data in an analog waveform.
- The analog carrier signal is manipulated to uniquely identify the digital data being carried.



Signal Encoding Techniques

- Bit rate, N, is the number of bits per second (bps).
- Baud rate S is the number of signal elements per second (bauds).
- In the analog transmission of digital data, the signal or baud rate is less than or equal to the bit rate.

$$S = N \times 1/r \text{ bauds}$$

Where r is the number of data bits per signal element.

Signal Encoding Techniques

- **Example:** An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate.
- **Solution**
- **In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from**

$$S = N \times \frac{1}{r} \quad \text{or} \quad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

Signal Encoding Techniques

- **Amplitude Shift Keying (ASK):**
- ASK is implemented by changing the amplitude of a carrier signal to reflect amplitude levels in the digital signal.
- Example: A digital "1" could not affect the signal, whereas a digital "0" would, by making it zero.
- The line encoding will determine the values of the analog waveform to reflect the digital data being carried.

Signal Encoding Techniques

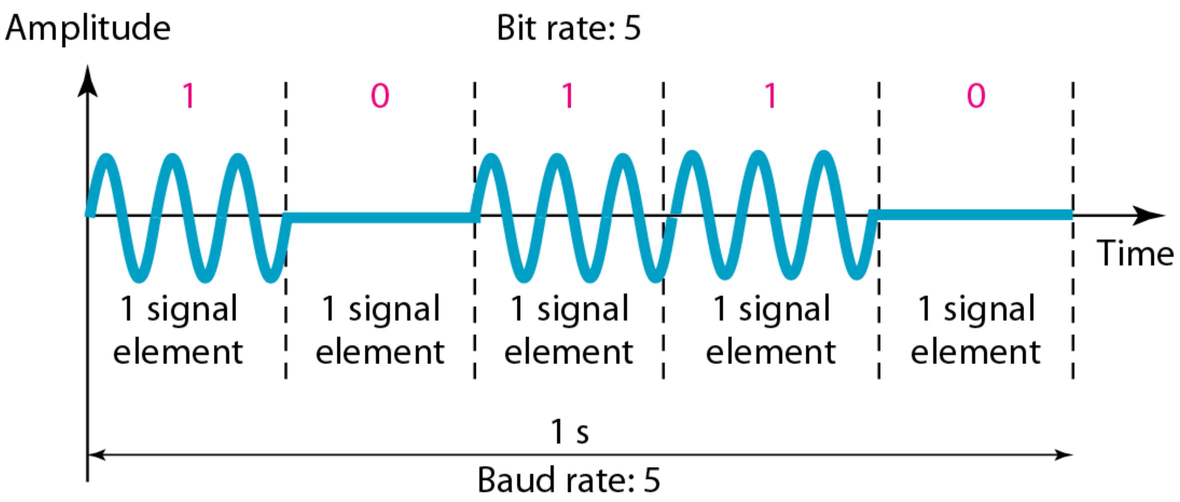
- Bandwidth of ASK:
- The bandwidth B of ASK is proportional to the signal rate S.

$$B = (1+d)S$$

- "d" is due to modulation and filtering, lies between 0 and 1.

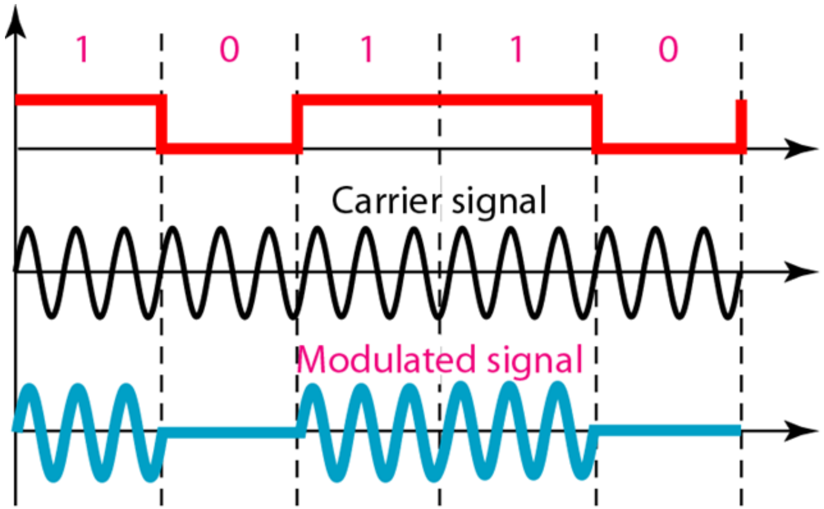
Signal Encoding Techniques

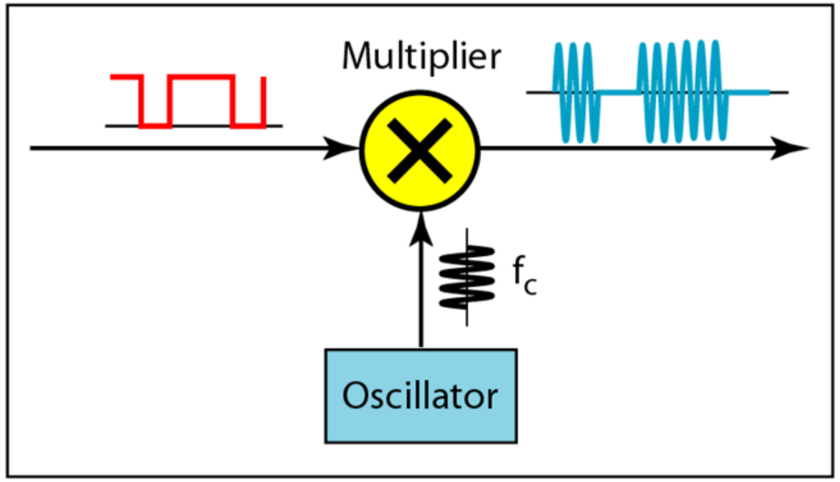
- **Binary amplitude shift keying:**
- Although we can have several levels (kinds) of signal elements, each with a different amplitude, ASK is normally implemented using only two levels.
- This is referred to as binary amplitude shift keying or on-off keying (OOK).
- The peak amplitude of one signal level is 0; the other is the same as the amplitude of the carrier frequency



Signal Encoding Techniques

- **Implementation of BASK**





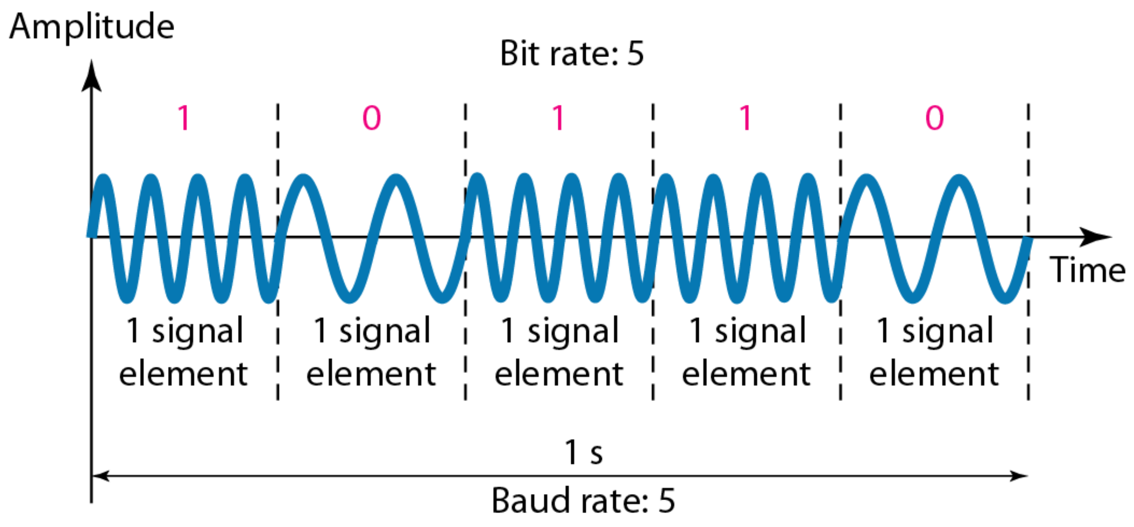
Signal Encoding Techniques

- **Frequency Shift Keying**
- The frequency of the carrier signal is varied to represent data.
- The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes.
- Both peak amplitude and phase remain constant for all signal elements.
- The digital data stream changes the frequency of the carrier signal, f_c.
- Example: A "1" could be represented by $f_1=f_c+\Delta f$, and a "0" could be represented by $f_2=f_c-\Delta f$.

Signal Encoding Techniques

Binary FSK (BFSK)

- One way to think about binary FSK (or BFSK) is to consider two carrier frequencies.
- In Figure, we have selected two carrier frequencies f1 and f2. We use the first carrier if the data element is 0; we use the second if the data element is 1.



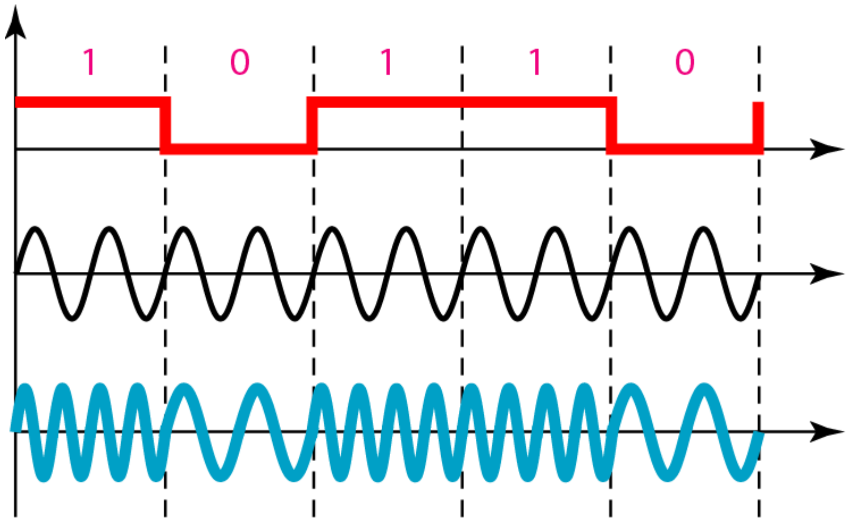
Signal Encoding Techniques

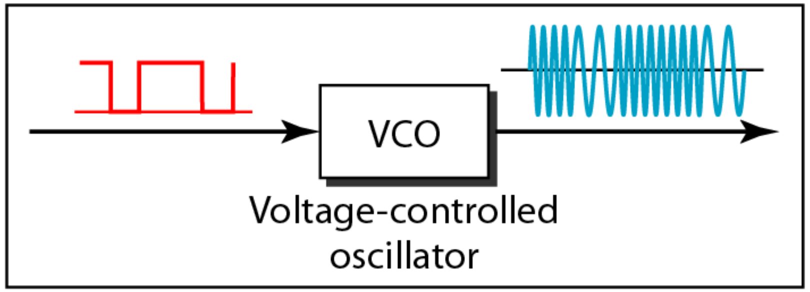
- **Multi level FSK (MFSK):**
- FSK can use multiple bits per signal element.
- That means we need to provision for multiple frequencies, each one to represent a group of data bits.
- We can use more than two frequencies.
- **Example:** We can use four different frequencies f1, f2, f3, and f4 to send 2 bits at a time. To send 3 bits at a time, we can use eight frequencies.

Signal Encoding Techniques

- **Multi level FSK (MFSK):**
- The bandwidth for FSK can be higher

$$B = (1+d)xS + (L-1)/2\Delta f = LxS$$



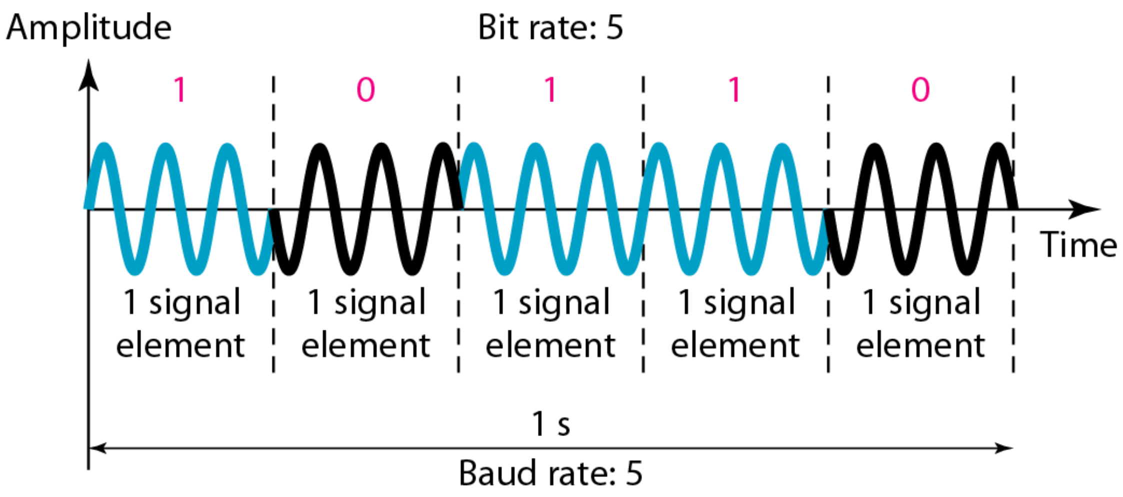


Signal Encoding Techniques

- **Phase Shift Keying:**
- We vary the phase of the carrier signal to represent digital data.
- The bandwidth requirement, B is: B = (1+d)xS
- PSK is much more robust than ASK as it is not that vulnerable to noise, which changes the amplitude of the signal.

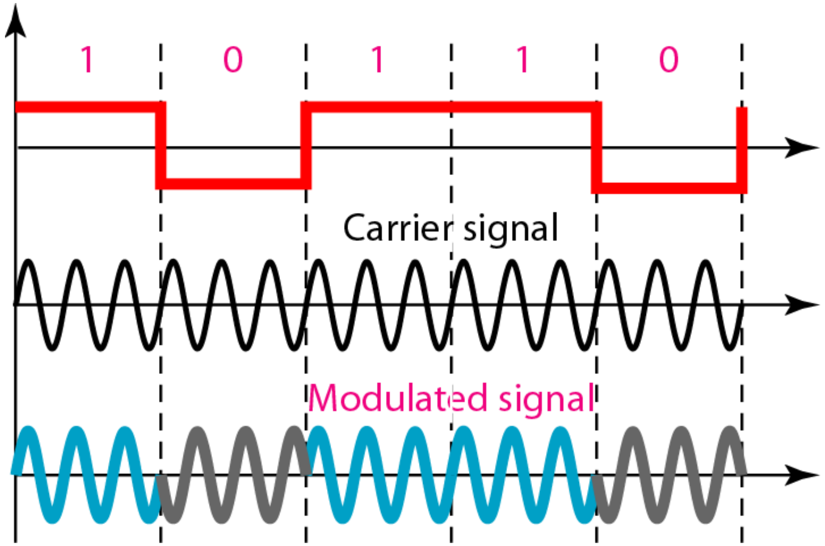
Signal Encoding Techniques

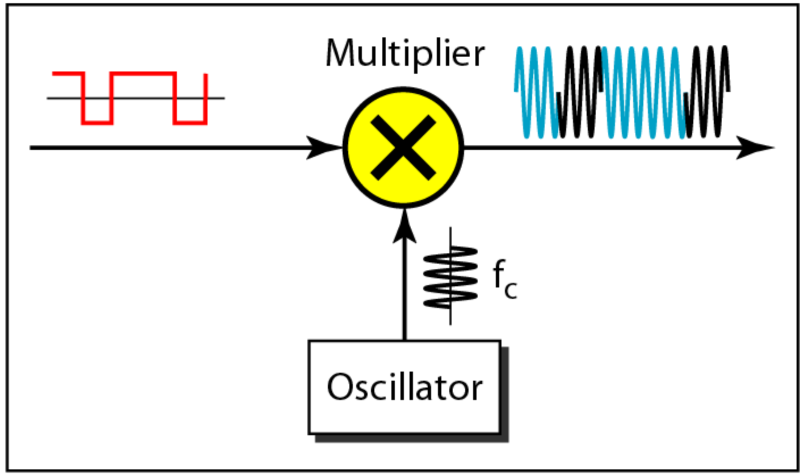
- **Binary PSK (BPSK):**
- The simplest PSK is binary PSK, in which we have only two signal elements, one with a phase of 0°, and the other with a phase of 180°.



Signal Encoding Techniques

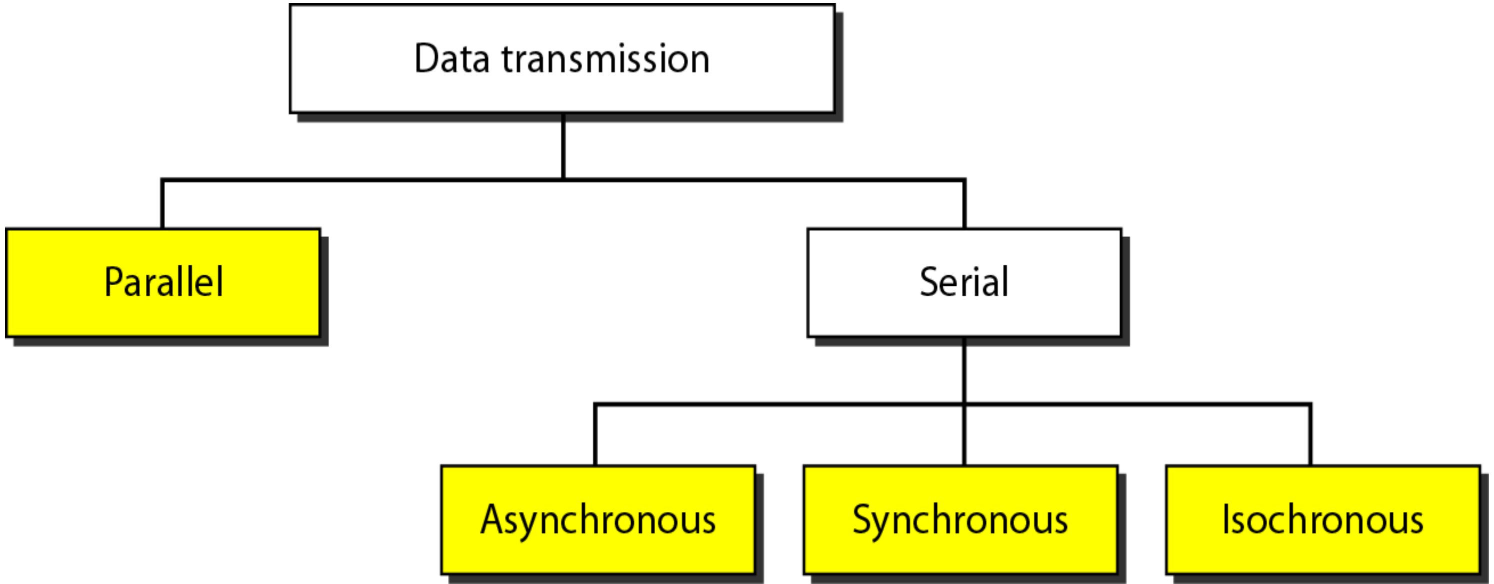
- ## Binary PSK (BPSK):





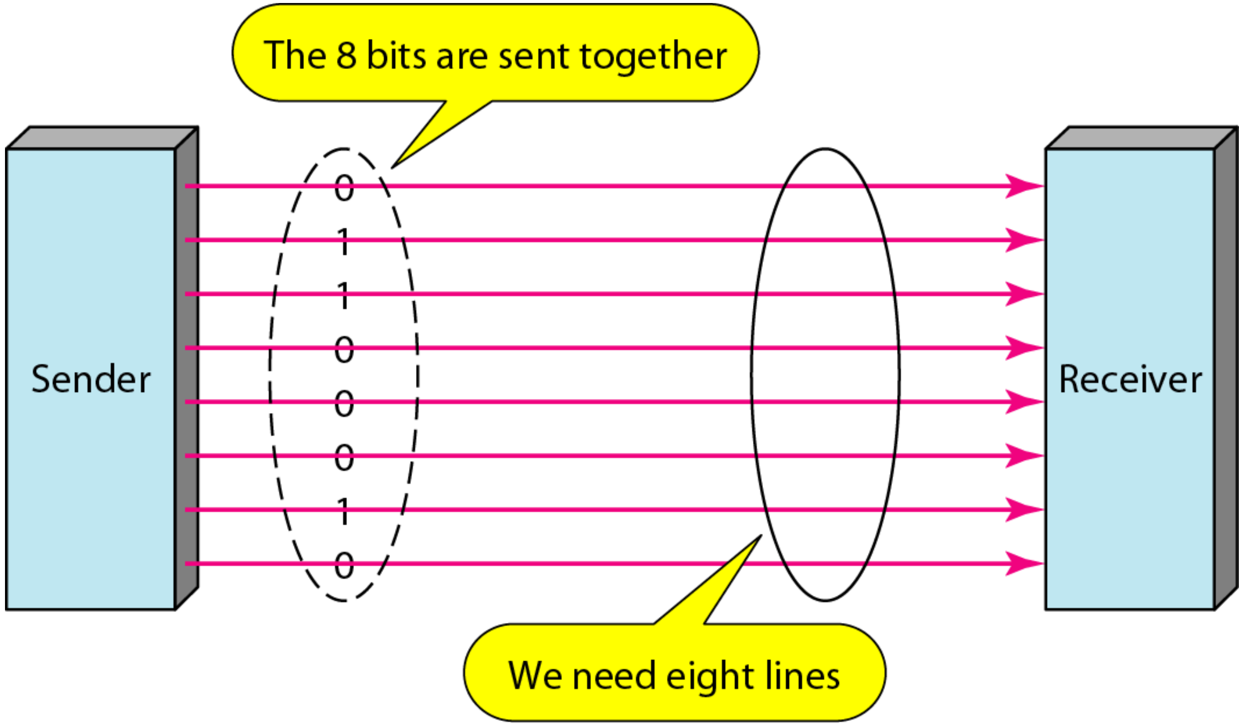
Signal Encoding Techniques

- **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.



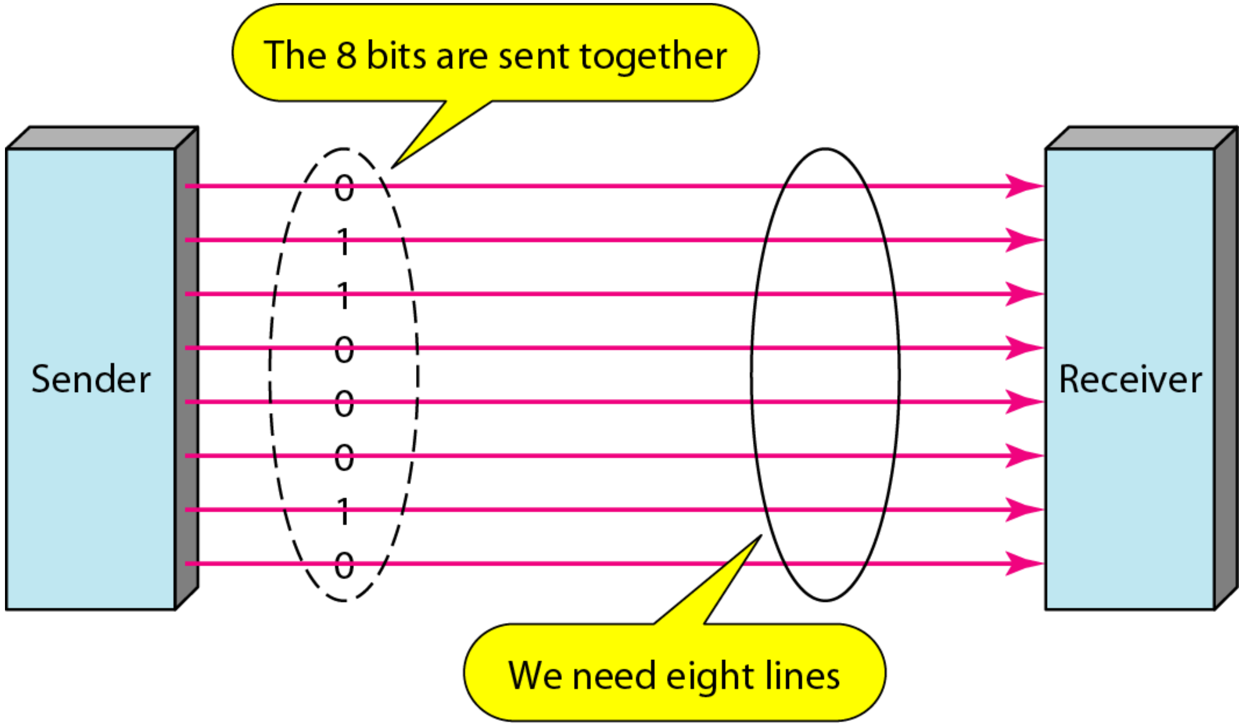
Signal Encoding Techniques

- **Parallel transmission:**
- Binary data, consisting of 1s and 0s, may be organized into groups of n bits each.
- Computers produce and consume data in groups of bits
- By grouping, we can send data n bits at a time instead of 1. This is called parallel transmission



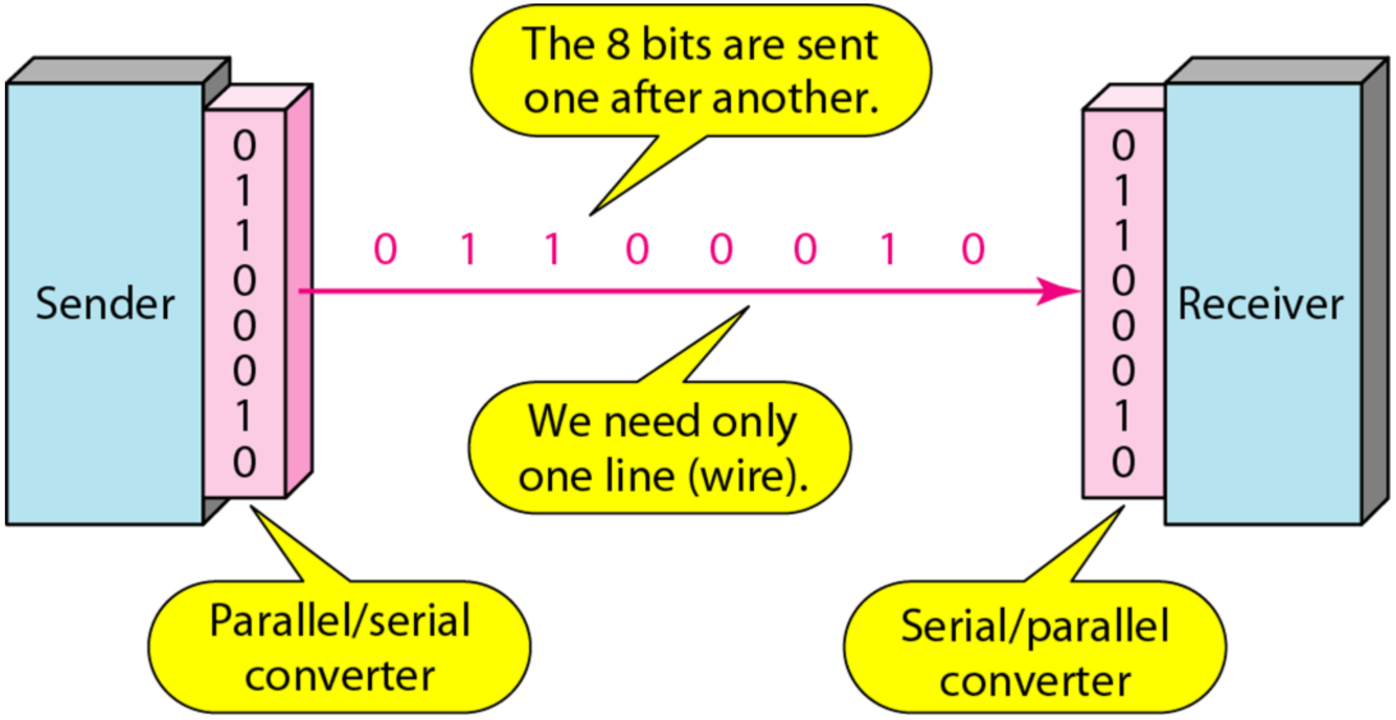
Signal Encoding Techniques

- **Parallel transmission:**
- The mechanism for parallel transmission is a conceptually simple one: Use n wires to send n bits at one time.
- That way each bit has its own wire, and all n bits of one group can be transmitted with each clock tick from one device to another



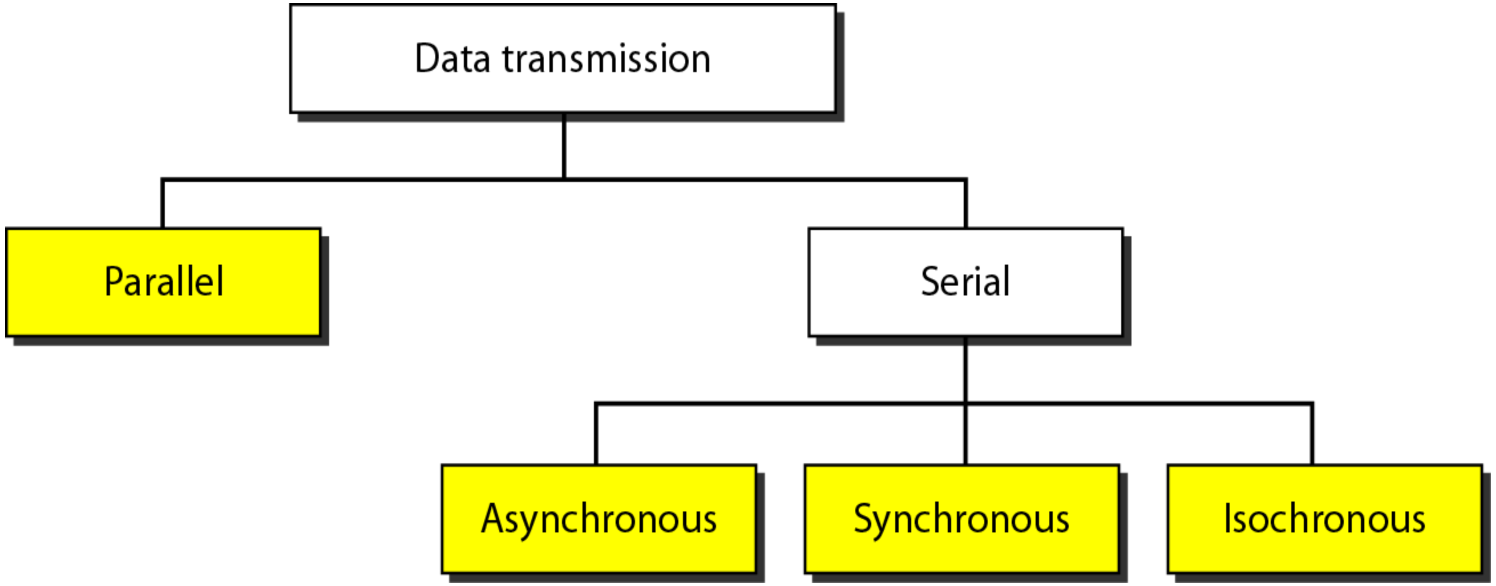
Signal Encoding Techniques

- **Serial Transmission:**
- In serial transmission one bit follows another



Signal Encoding Techniques

- **Serial Transmission:**
- The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission over parallel by roughly a factor of n.



Signal Encoding Techniques

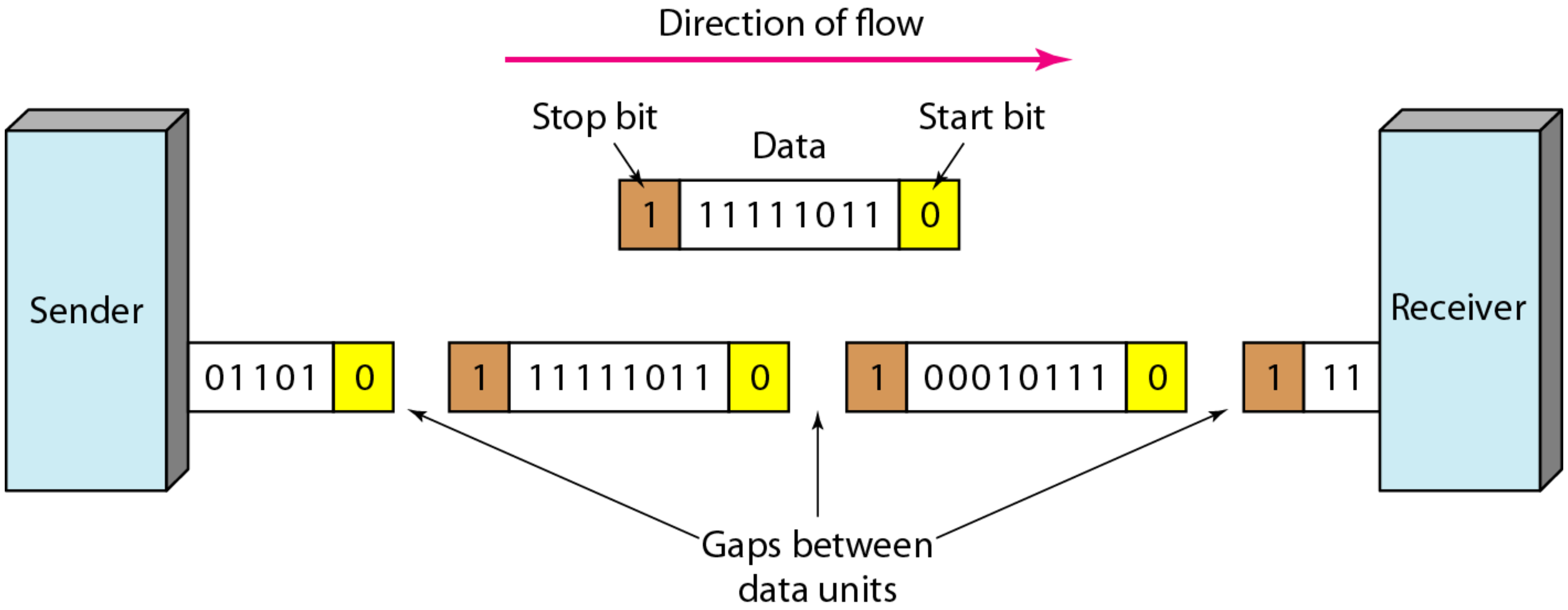
- **Asynchronous Transmission:**
- Asynchronous transmission is so named because the timing of a signal is unimportant.
- Instead, information is received and translated by agreed upon patterns.
- Patterns are based on grouping the bit stream into bytes. Each group, usually 8 bits, is sent along the link as a unit.
- The sending system handles each group independently, relaying it to the link whenever ready, without regard to a timer.

Signal Encoding Techniques

- **Asynchronous Transmission:**
- Without synchronization, the receiver cannot use timing to predict when the next group will arrive.
- To alert the receiver to the arrival of a new group, therefore, an extra bit is added to the beginning of each byte. This bit, usually a 0, is called the start bit.
- To let the receiver know that the byte is finished, 1 or more additional bits are appended to the end of the byte. These bits, usually 1s, are called stop bits.
- By this method, each byte is increased in size to at least 10 bits, of which 8 bits is information and 2 bits or more are signals to the receiver.
- In addition, the transmission of each byte may then be followed by a gap of varying duration. This gap can be represented either by an idle channel or by a stream of additional stop bits.

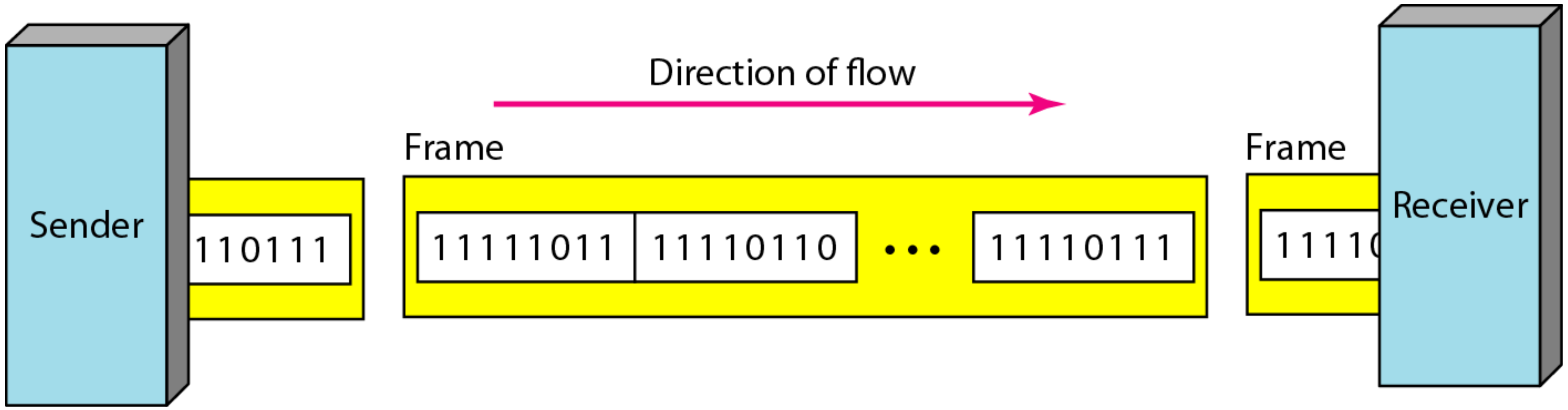
Signal Encoding Techniques

- **Asynchronous Transmission:**



Synchronous Transmission:

- In synchronous transmission, bits are usually sent as bytes and many bytes are grouped in a frame. A frame is identified with a start and an end byte
- 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.



Signal Encoding Techniques

- **Isochronous:**
- In real-time audio and video, in which uneven delays between frames are not acceptable, synchronous transmission fails.
- For example, TV images are broadcast at the rate of 30 images per second; they must be viewed at the same rate.
- If each image is sent by using one or more frames, there should be no delays between frames.
- In isochronous transmission we cannot have uneven gaps between frames.
- Transmission of bits is fixed with equal gaps.

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