Data Communications and Networking

Lecture 3

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Outlines

- Digital Transmission
  - Digital-to-Digital Conversion
  - Analog-to-Digital Conversion
  - Transmission Modes
- Analog Transmission
  - Digital-to-Analog Conversion
  - Analog-to-Analog Conversion

Lecture Objectives

- To introduce
  - Digital-to-Digital Conversion
  - Analog-to-Digital Conversion
  - Transmission Modes
  - Digital-to-Analog Conversion
  - Analog-to-Analog Conversion
- To convert digital data to a digital signal using line coding scheme
- To discuss analog to digital conversion
- To understand parallel and serial transmission
- To understand how to convert digital data to a bandpass analog signal
- To understand how to convert a low-pass analog signal to a bandpass analog signal

Topic 1: Digital Transmission

Digital-To-Digital Conversion

- The conversion involves three techniques: line coding, block coding, and scrambling.

Line Coding

- Line coding is the process of converting digital data to digital signals.
- 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 as depicted in figure 1.

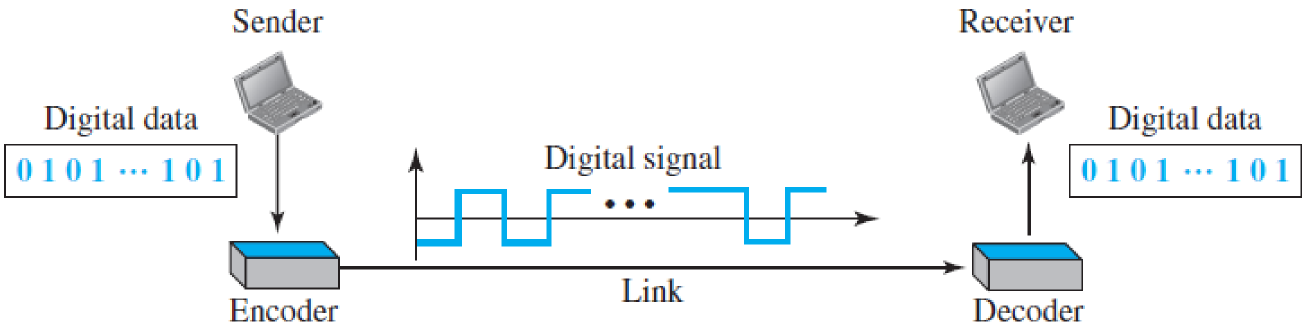


Figure 1. Line coding and decoding

Digital-To-Digital Conversion (Continue)

Signal Element Versus Data Element

- A data element is the smallest entity that can represent a piece of information: this is the bit.

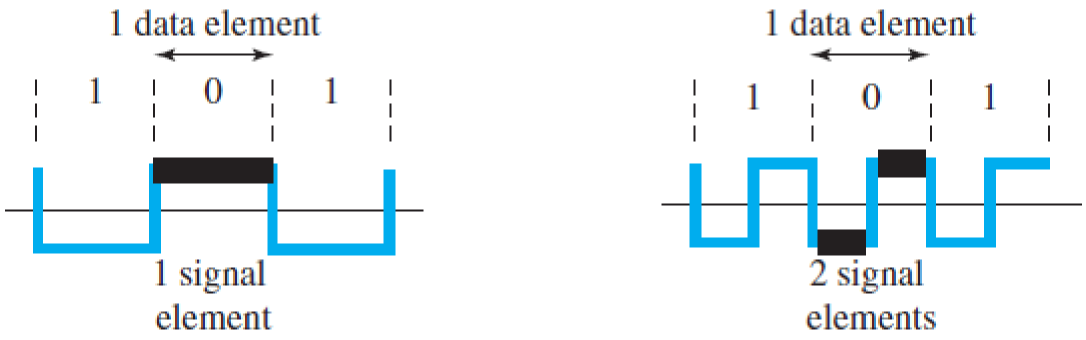
- In digital data communications, a signal element carries data elements.

- In other words, data elements are being carried; signal elements are the carriers.

- A ratio r which is the number of data elements carried by each signal element.

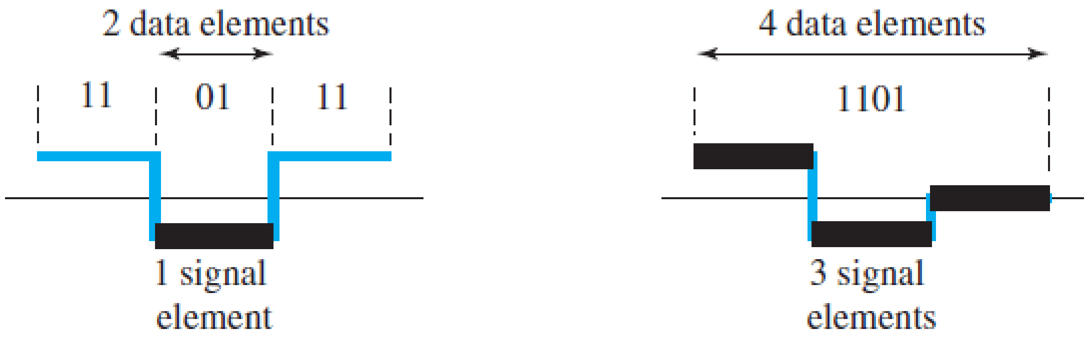
- Figure 2 shows several situation with different values of r.

Digital-To-Digital Conversion (Continue)



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

Figure 2. Signal element versus data element

Digital-To-Digital Conversion (Continue)

Data Rate Versus Signal Rate

- The data rate, bit rate (bps) defines the number of data elements (bits) sent in 1s.
- The signal rate, pulse rate (baud) is the number of signal elements sent in 1s .
- The formula between data rate and signal rate is

$$S = N/r$$

$$S_{ave} = c \times N \times (1/r) \qquad \text{baud}$$

- Where, N is data rate and S is the number of signal elements per second; and c is the case factor which varies for each case.

Digital-To-Digital Conversion (Continue)

Example 1

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

Solution: $S_{ave} = c \times N \times (1/r)$

$= \frac{1}{2} \times 100{,}000 \times (1/1)$

$= 50{,}000 = 50$ kbaud

Baseline Wandering

- 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.

Digital-To-Digital Conversion (Continue)

DC Components

- These frequencies around zero, called DC (direct-current) components, present problems for a system that cannot pass low frequencies or a system that uses electrical coupling (via a transformer).

Built-in Error Detection

- It is desirable to have a 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

- Another desirable code characteristic is a code that is immune to noise and other interferences.

Complexity

- A complex scheme is more costly to implement than a simple one.

Digital-To-Digital Conversion (Continue)

Self-synchronization

- A self-synchronizing digital signal includes timing information in the data being transmitted.
- This can be achieved if there are transitions in the signal that alert the receiver to the beginning, middle, or end of the pulse.
- If the receiver’s clock is out of synchronization, these points can reset the clock.

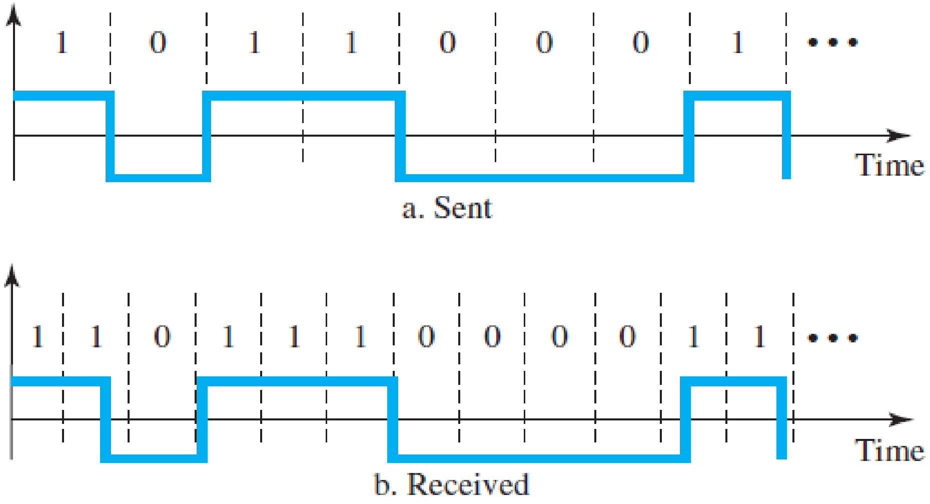


Figure 3. Effect of lack of synchronization

Digital-To-Digital Conversion (Continue)

Line Coding Schemes

- Line coding schemes can be divided into five broad categories as shown in figure 4.

Unipolor Scheme

- In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.

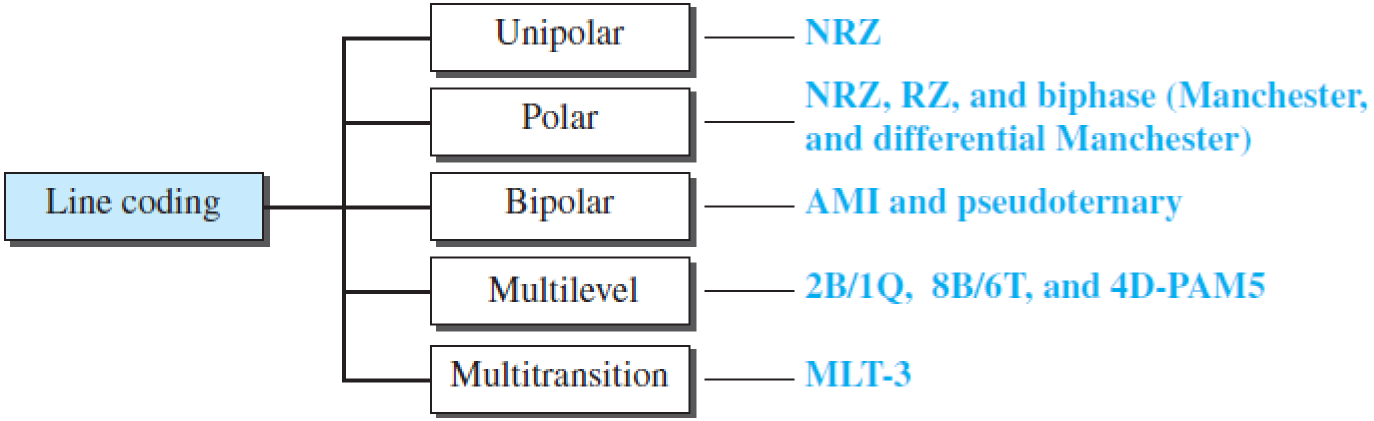
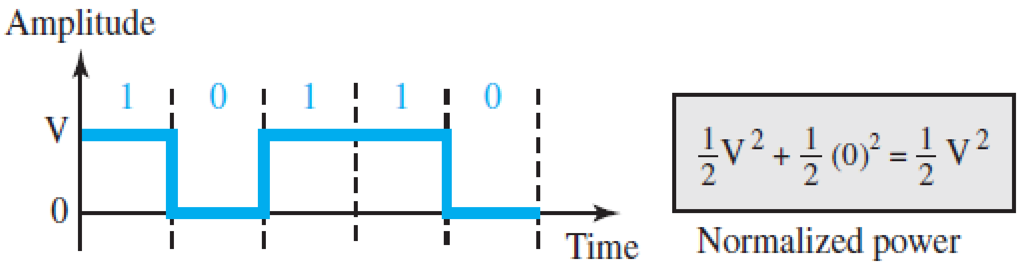


Figure 4. Line coding schemes

Digital-To-Digital Conversion (Continue)

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 1 and the zero voltage defines bit 0.
- It is called NRZ because the signal does not return to zero at the middle of the bit.
- Figure 5 shows a unipolar NRZ scheme.



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

Figure 5. Unipolor NRZ scheme

Digital-To-Digital Conversion (Continue)

Polar Scheme

- In polar schemes, the voltages are on both sides of the time axis.

- 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 as shown in figure 6.

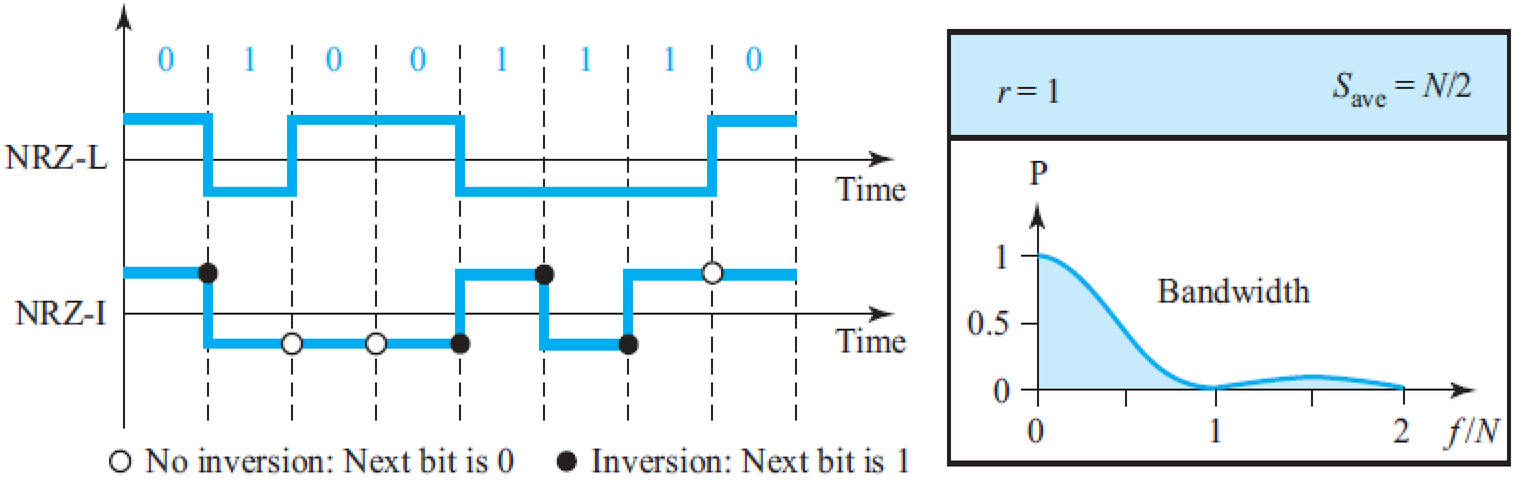


Figure 6. Polar NRZ-L and NRZ-I schemes

Digital-To-Digital Conversion (Continue)

Return-to-Zero (RZ)

- In RZ, the signal changes not between bits but during the bits as depicted in figure 7.

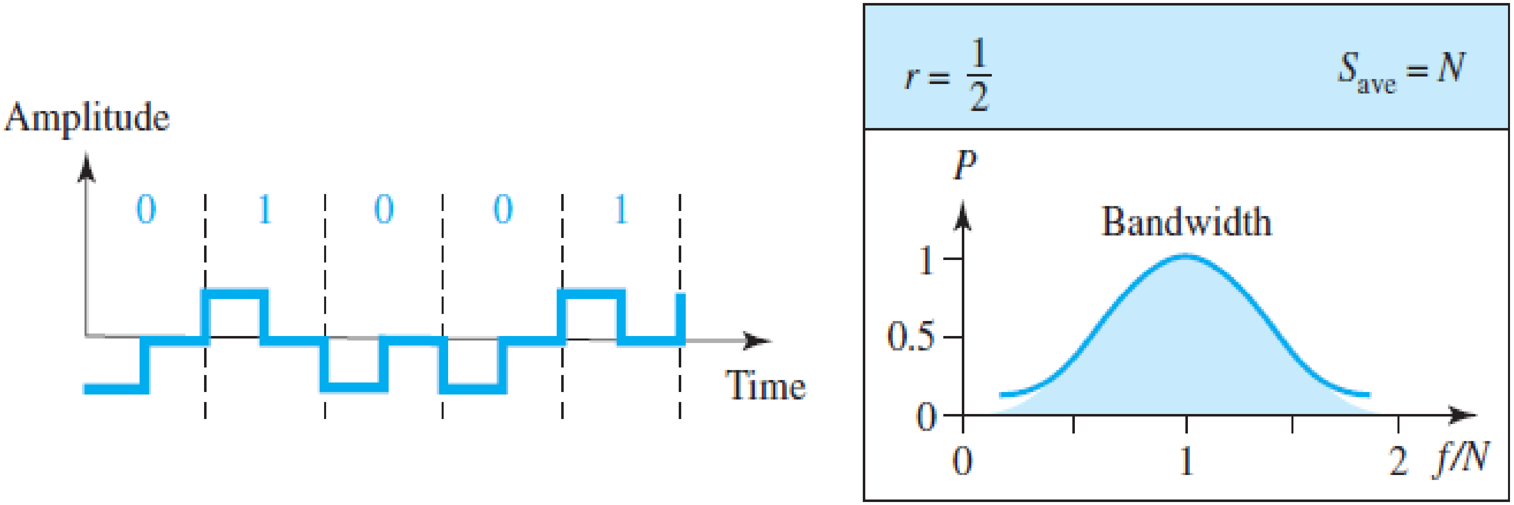


Figure 7. Polar RZ scheme

Digital-To-Digital Conversion (Continue)

Biphase: Manchester and Differential Manchester

- In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization as shown in figure 8.

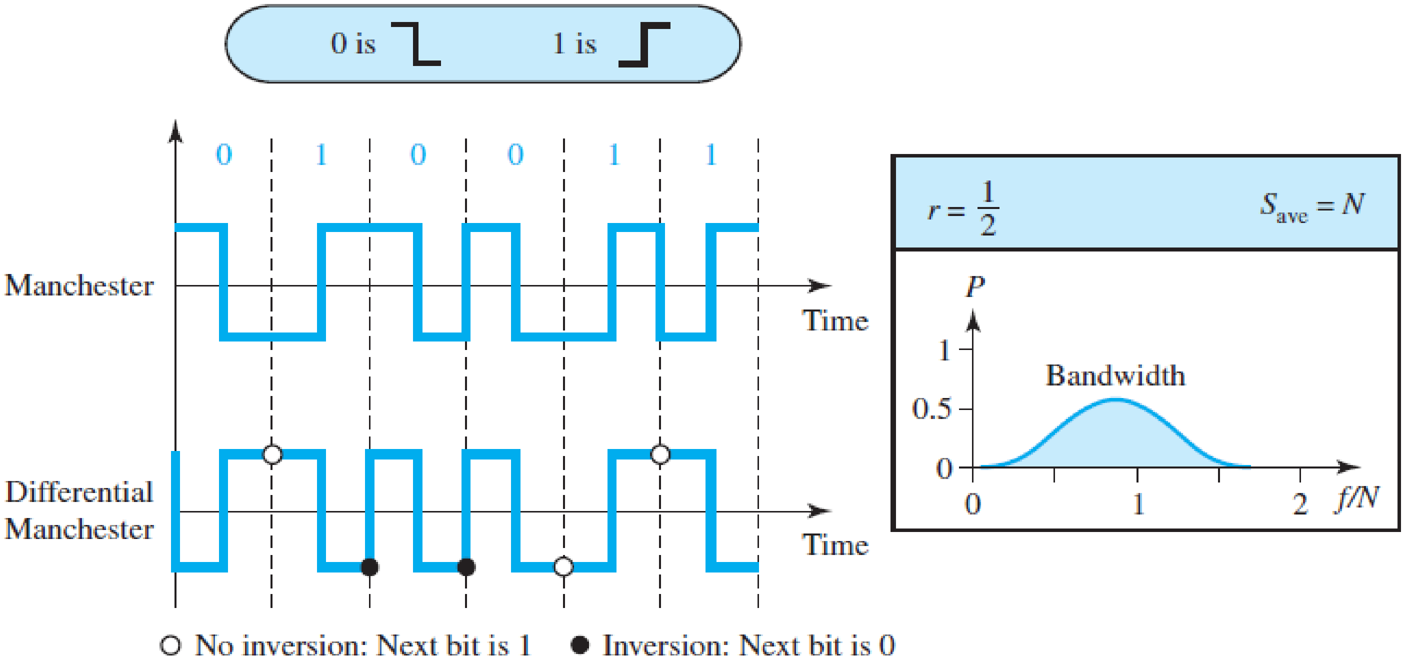


Figure 8. Polar biphase: Manchester and differential Manchester schemes

Digital-To-Digital Conversion (Continue)

Bipolar Schemes

- 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.
- Figure 9 shows two variations of bipolar encoding: alternate mark inversion (AMI) and pseudoternary.

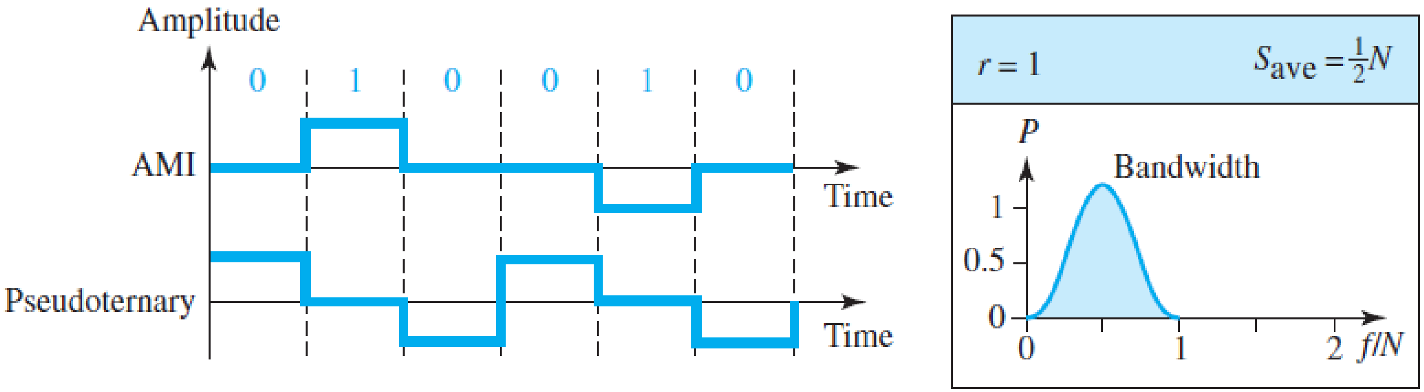


Figure 9. Bipolar schemes: AMI and pseudoternary

Digital-To-Digital Conversion (Continue)

Multilevel Schemes

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

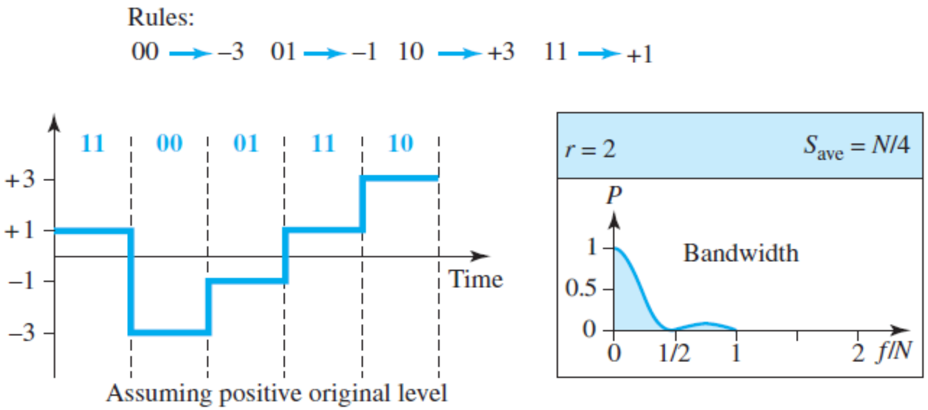


Figure 10. Multilevel: 2B1Q scheme

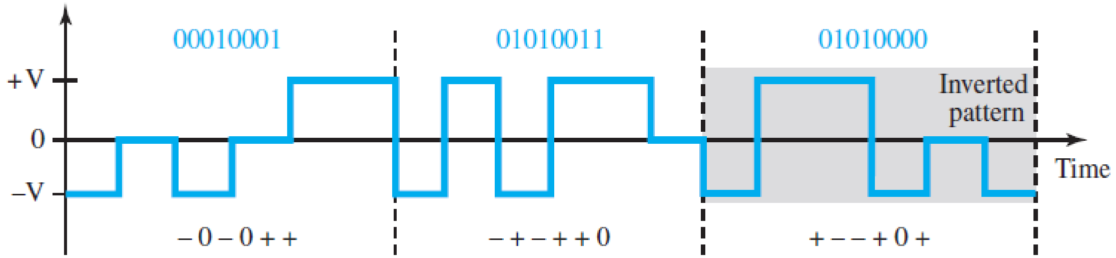


Figure 11. Multilevel: 8B6T scheme

Digital-To-Digital Conversion (Continue)

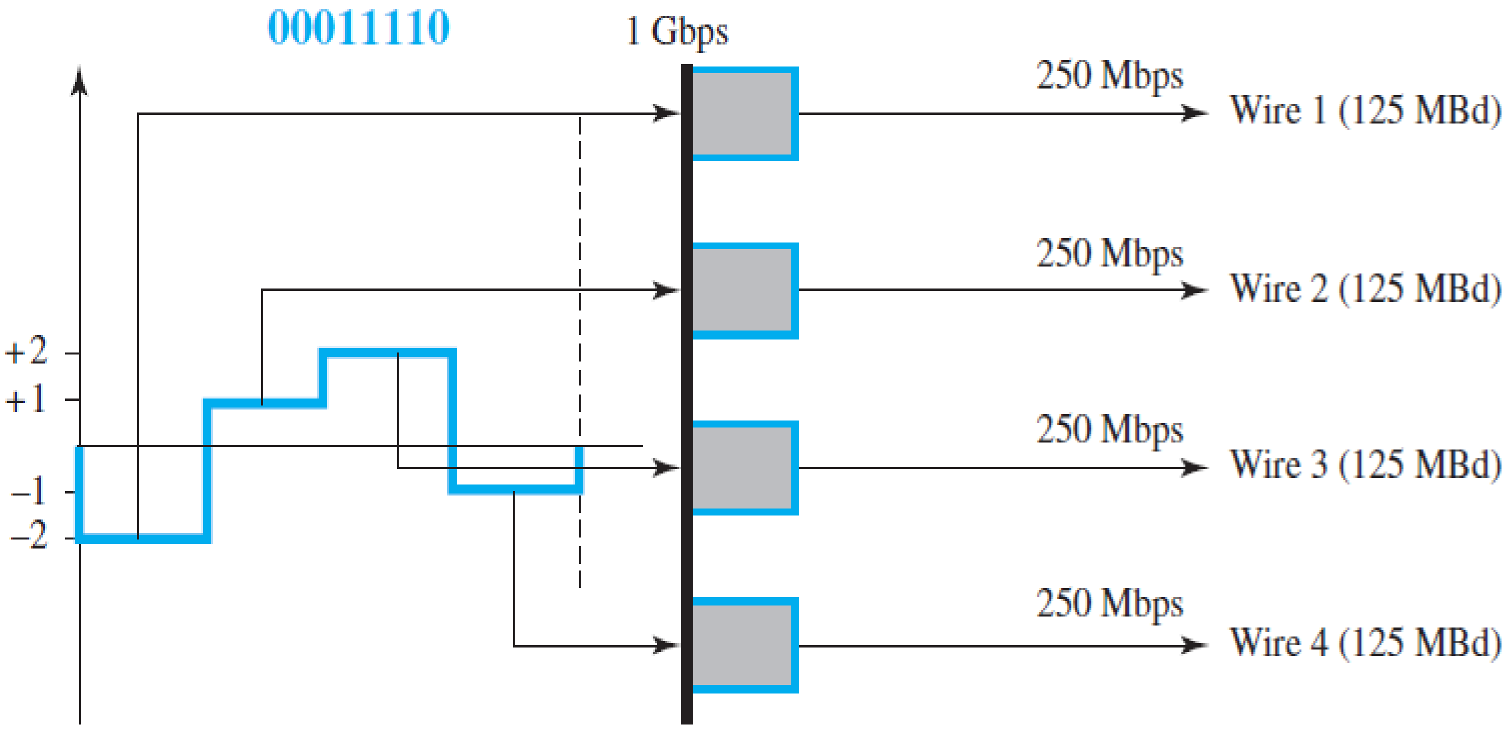


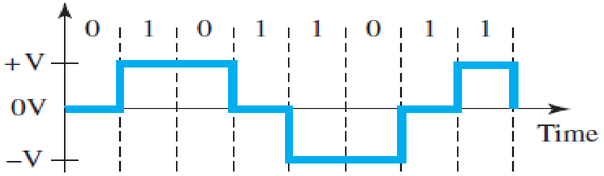
Figure 12. Multilevel: Four-dimensional five-level pulse amplitude modulation (4D-PAM5) scheme

Digital-To-Digital Conversion (Continue)

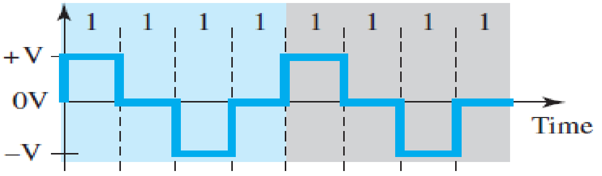
Multitransition: MLT-3

- The multiline transmission, three-level (MLT-3) scheme uses three levels (+V, 0, and −V) and three transition rules to move between the levels.

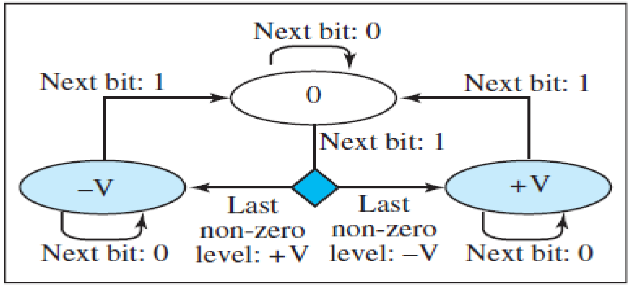
1. If the next bit is 0, there is no transition.
2. If the next bit is 1 and the current level is not 0, the next level is 0.
3. If the next bit is 1 and the current level is 0, the next level is the opposite of the last nonzero level.



a. Typical case



b. Worst case

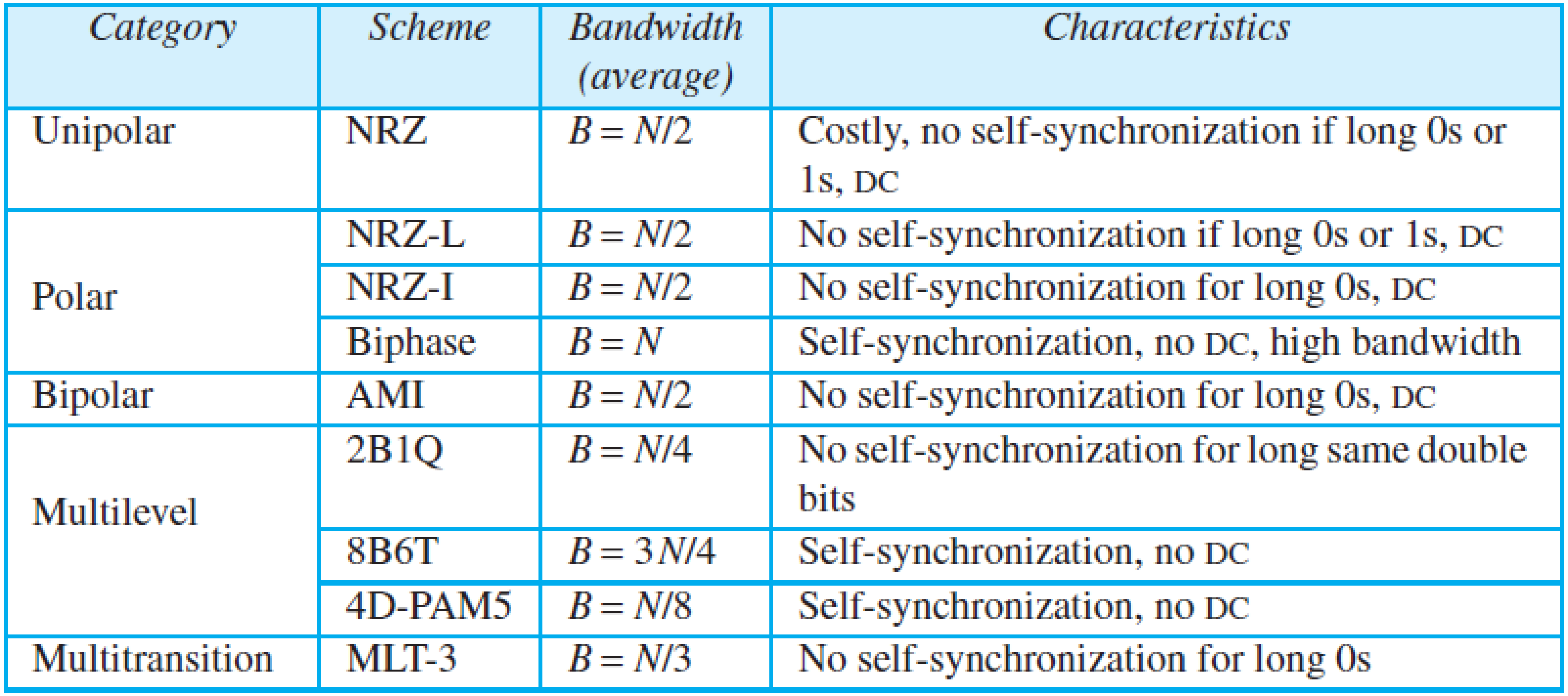


c. Transition states

Figure 13. Multitransition: MLT-3 scheme

Digital-To-Digital Conversion (Continue)

Table 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

Digital-To-Digital Conversion (Continue)

Block Coding

- 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.
- The slash in block encoding (for example, 4B/5B) distinguishes block encoding from multilevel encoding (for example, 8B6T), which is written without a slash.
- Block coding normally involves three steps: division, substitution, and combination.
- In the division step, a sequence of bits is divided into groups of m bits.

Digital-To-Digital Conversion (Continue)

- For example, in 4B/5B encoding, the original bit sequence is divided into 4-bit groups.
- In substitution step, it substitutes an m-bit group with an n-bit group.
- For example, in 4B/5B encoding we substitute a 4-bit group with a 5-bit group.
- Finally, the n-bit groups are combined to form a stream.
- The new stream has more bits than the original bits.
- Figure 14 shows the procedure.

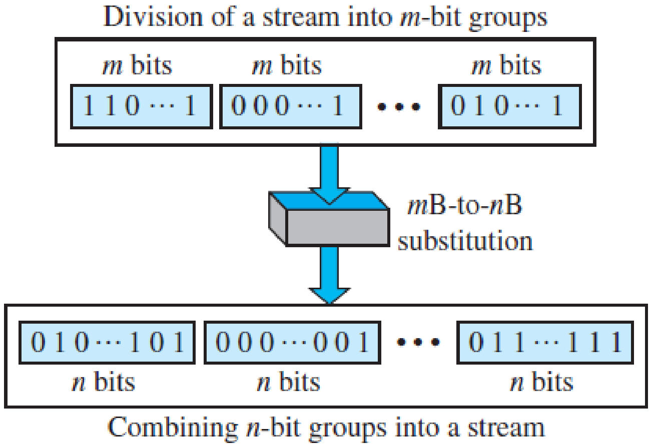


Figure 14. Block coding concept

Digital-To-Digital Conversion (Continue)

4B/5B

- The four binary/five binary (4B/5B) coding scheme was designed to be used in combination with NRZ-I.

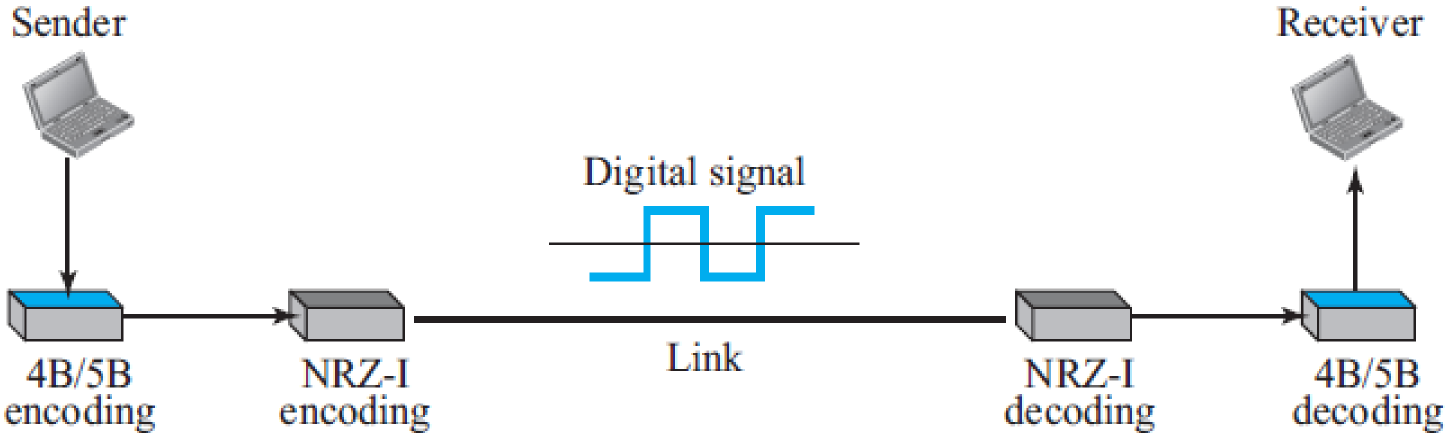


Figure 15. Using block coding 4B/5B with NRZ-I line coding scheme

Digital-To-Digital Conversion (Continue)

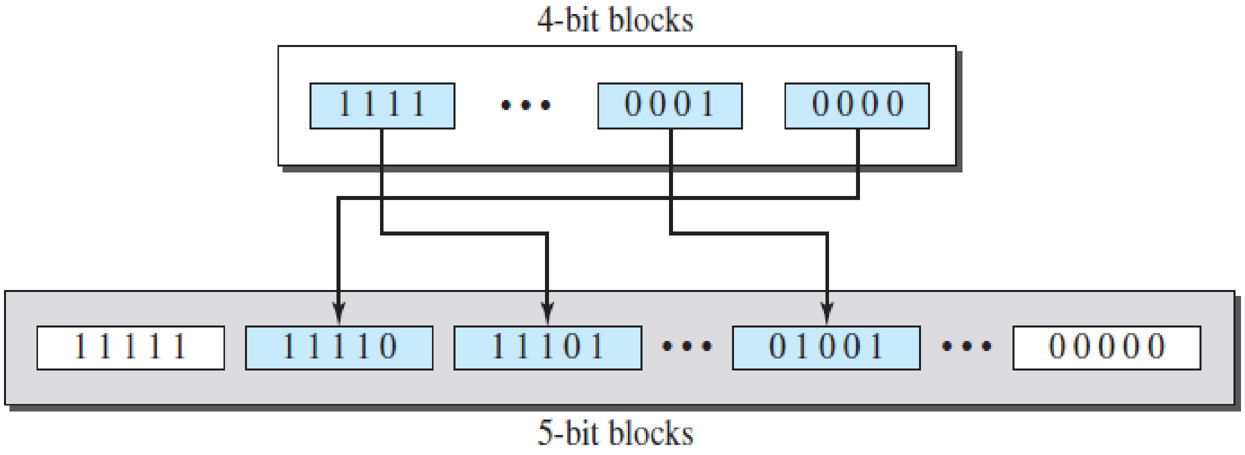


Figure 16. Substitution in 4B/5B block coding

8B/10B

- The eight binary/ten binary (8B/10B) encoding is similar to 4B/5B encoding except that a group of 8 bits of data is now substituted by a 10-bit code.
- It provides greater error detection capability than 4B/5B.

Digital-To-Digital Conversion (Continue)

- The 8B/10B block coding is actually a combination of 5B/6B and 3B/4B encoding, as shown in figure 17.

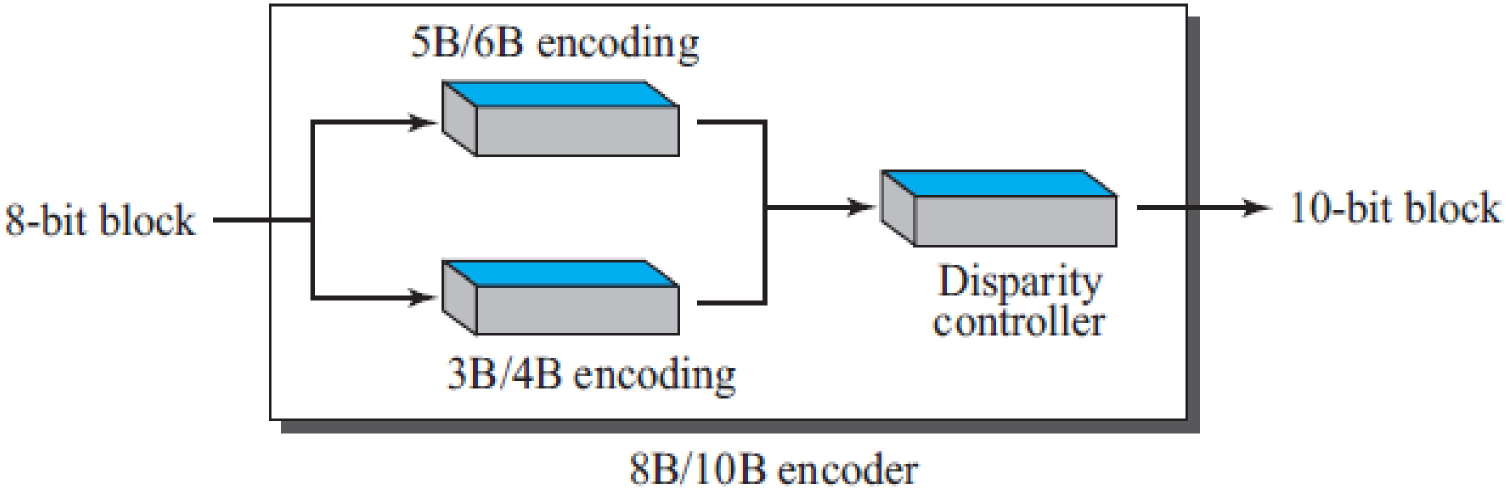


Figure 17. 8B/10B block encoding

Digital-To-Digital Conversion (Continue)

Scrambling

- 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 bipolar with 8-zero substitution (B8ZS) and high-density bipolar 3-zero (HDB3).

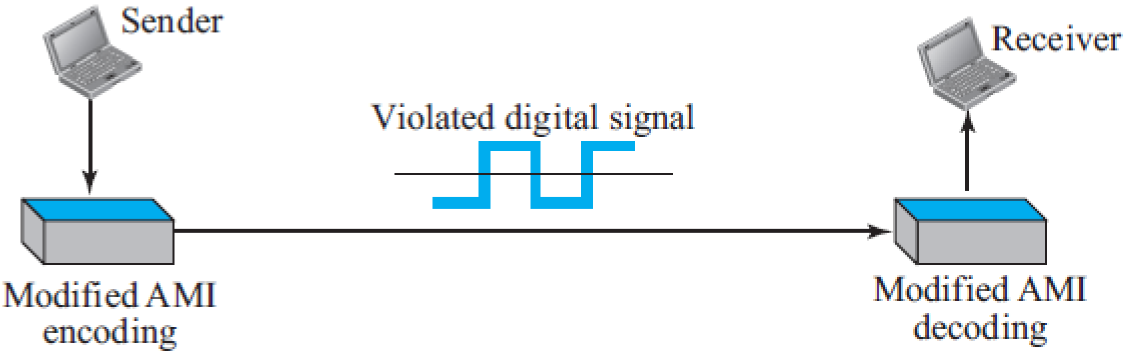
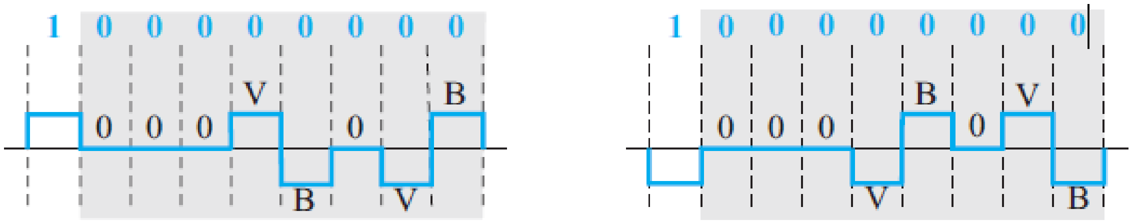


Figure 18. AMI used with scrambling

Digital-To-Digital Conversion (Continue)

B8ZS

- In bipolar with 8-zero substitution (B8ZS), eight consecutive zero level voltages are replaced by the sequence 000VB0VB.
- The V in the sequence denotes violation; this is a nonzero voltage that breaks an AMI rule of encoding (opposite polarity from the previous).
- The B in the sequence denotes bipolar, which means a nonzero level voltage in accordance with the AMI rule.
- There are two cases, as shown in Figure 19.



a. Previous level is positive.

b. Previous level is negative.

Figure 19. Two cases of B8ZS scrambling technique

Digital-To-Digital Conversion (Continue)

HDB3

- In high-density bipolar 3-zero (HDB3), which is more conservative than B8ZS, four consecutive zero-level voltages are replaced with a sequence of 000V or B00V.
- The reason for two different substitutions is to maintain the even number of nonzero pulses after each substitution.
- The two rules can be stated as follows:
  1. If the number of nonzero pulses after the last substitution is odd, the substitution pattern will be 000V, which makes the total number of nonzero pulses even.

Digital-To-Digital Conversion (Continue)

2. If the number of nonzero pulses after the last substitution is even, the substitution pattern will be B00V, which makes the total number of nonzero pulses even as shown in figure 20.

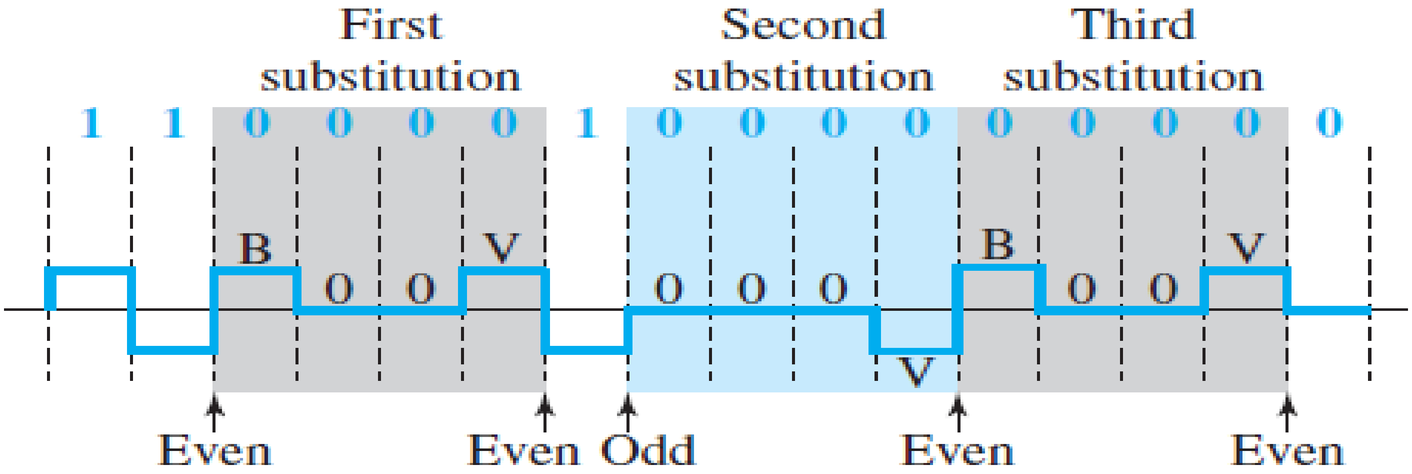


Figure 20. Different situations in HDB3 scrambling technique

Analog-To-Digital Conversion

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 21.

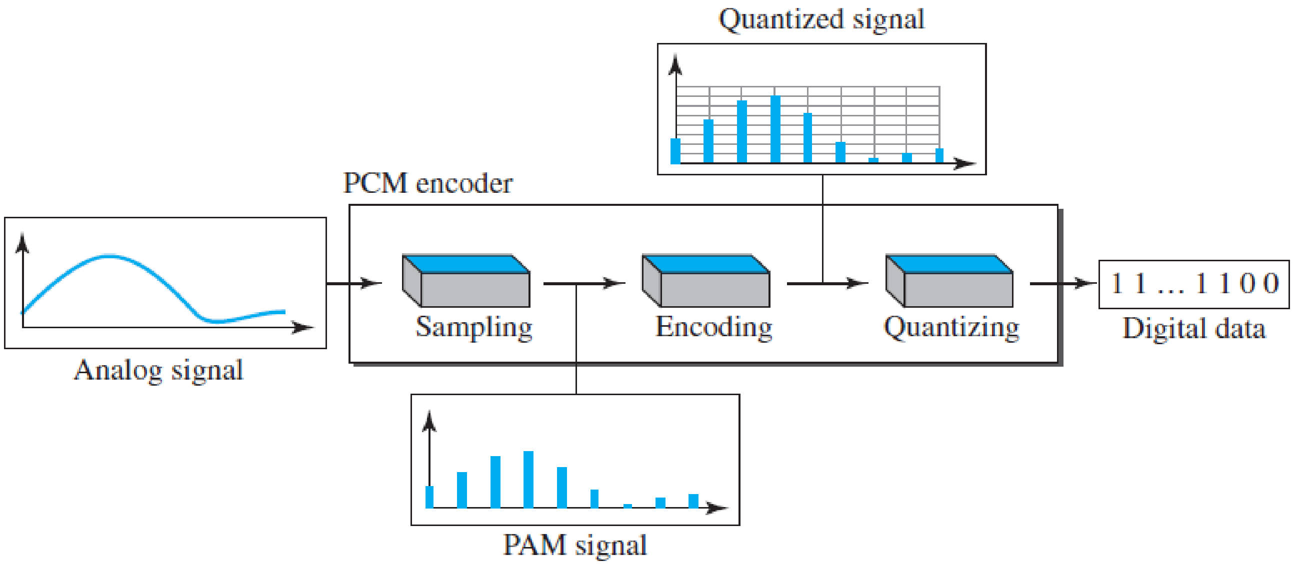


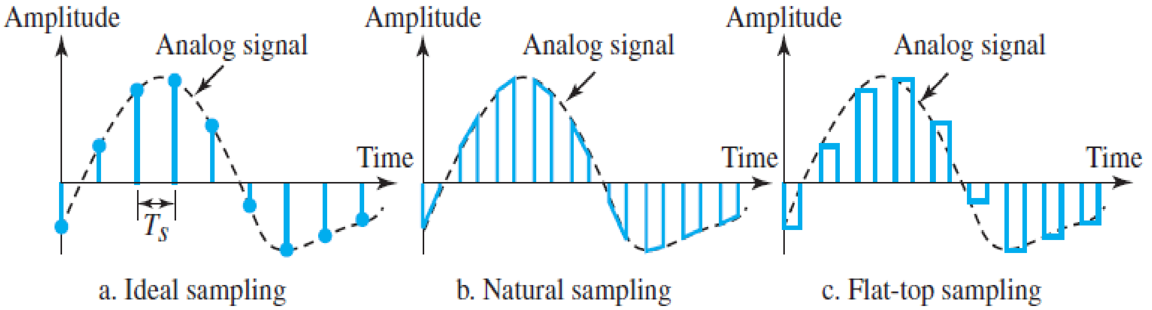
Figure 21. Components of PCM encoder

Analog-To-Digital Conversion (Continue)

1. The analog signal is sampled.
2. The sampled signal is quantized
3. The quantized values are encoded as streams of bits.

Sampling

- The first step in PCM is sampling. The analog signal is sampled every T_s s, where T_s is the sample interval or period.
- The inverse of the sampling interval is called the sampling rate or sampling frequency and denoted by f_s, where $f_s = 1/ T_s$.
- There are three sampling methods: ideal, natural, and flat-top as shown in figure 22.



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

Figure 22. Three different sampling methods for PCM

Analog-To-Digital Conversion (Continue)

Quantization

- The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal.
- The set of amplitudes can be infinite with nonintegral values between the two limits.
- These values cannot be used in the encoding process.
- The following are the steps in quantization:

1. It is assumed that the original analog signal has instantaneous amplitudes between V_{min} and V_{max} .
2. The range is divided into L zones, each of height Δ (delta).

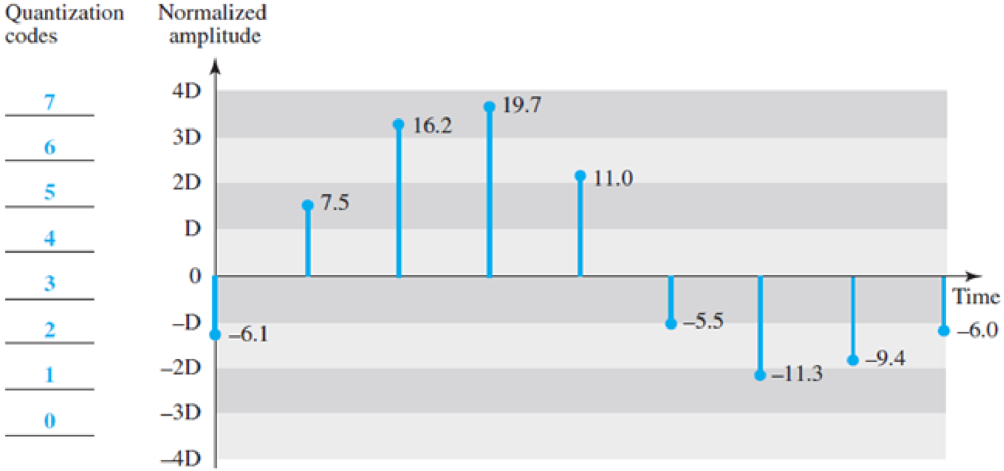
$$\Delta = \frac{V_{max} - V_{min}}{L}$$

3. It is assigned quantized values of 0 to L-1 to the midpoint of each zone.
4. It is approximated the values of the sample amplitude to the quantized values.

Analog-To-Digital Conversion (Continue)

Example 2

It is assumed that we have a sampled signal and the sample amplitudes are between −20 and +20 V. We decide to have eight levels (L = 8). This means that Δ = 5 V.



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

Figure 23. Quantization and encoding of a sampled signal

Analog-To-Digital Conversion (Continue)

Encoding

- The last step in PCM is encoding.

- After each sample is quantized and the number of bits per sample is decided, each sample can be changed to an n_b -bit code word.

- In Figure 23, the encoded words are shown in the last row.

- A quantization code of 2 is encoded as 010; 5 is encoded as 101; and so on.

- The bit rate can be found from the following formula:

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

Analog-To-Digital Conversion (Continue)

Delta Modulation (DM)

- The simplest is delta modulation.

- PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample as shown in figure 24.

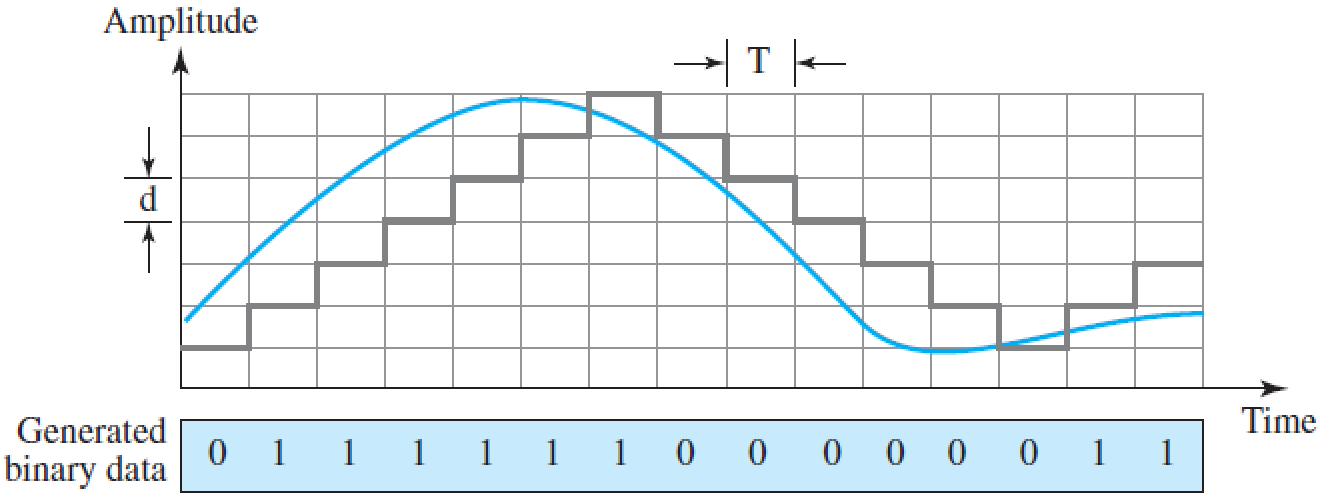


Figure 24. The process of delta modulation

Analog-To-Digital Conversion (Continue)

Modulator

- The modulator is used at the sender site to create a stream of bits from an analog signal.
- 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.
- The modulator builds a second signal that resembles a staircase.
- Finding the change is then reduced to comparing the input signal with the gradually made staircase signal.
- Figure 25 shows a diagram of the process.

Analog-To-Digital Conversion (Continue)

- The modulator, at each sampling interval, compares the value of the analog signal with the last value of the staircase signal.
- If the amplitude of the analog signal is larger, the next bit in the digital data is 1; otherwise, it is 0.
- The output of the comparator, however, also makes the staircase itself.
- If the next bit is 1, the staircase maker moves the last point of the staircase signal δ up; if the next bit is 0, it moves it δ down.

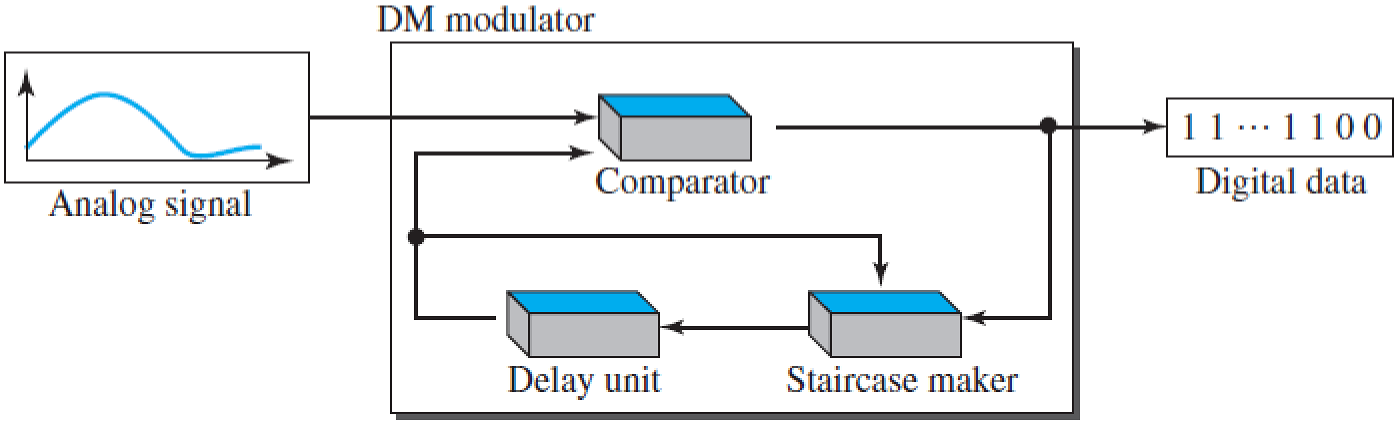


Figure 25. Delta modulation components

Analog-To-Digital Conversion (Continue)

Demodulator

- The demodulator takes the digital data and, using the staircase maker and the delay unit, creates the analog signal.
- The created analog signal, however, needs to pass through a low-pass filter for smoothing.
- Figure 26 shows the schematic diagram.

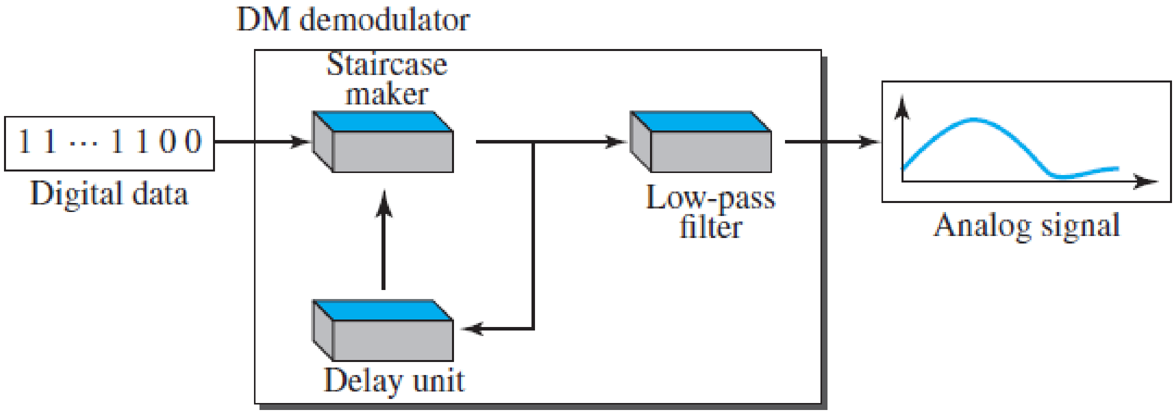


Figure 26. Delta demodulation components

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 as depicted in figure 27.

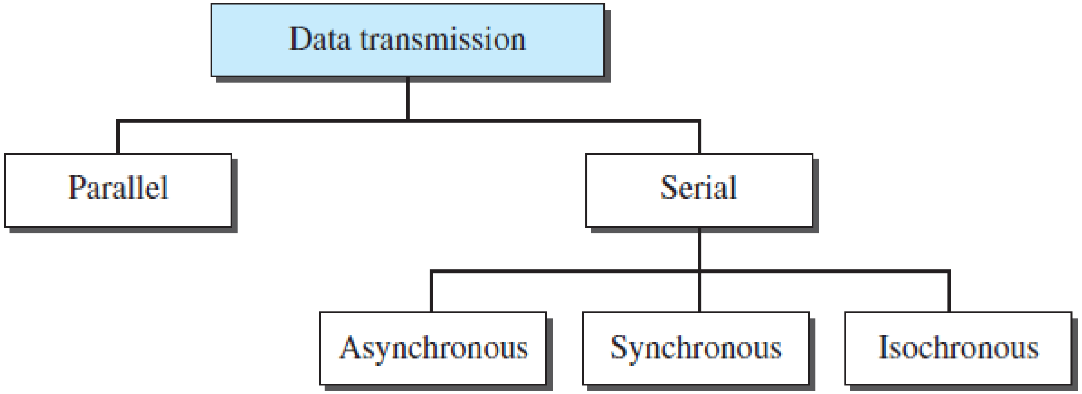


Figure 27. Data transmission and modes

Transmission Modes (Continue)

Parallel Transmission

- Binary data, consisting of 1s and 0s, may be organized into groups of n bits each.
- By grouping, data n bits can be sent at a time instead of 1.
- This is called 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.
- Figure 28 shows how parallel transmission works for n = 8.
- The advantage of parallel transmission is speed.
- But there is a significant disadvantage: cost.

Transmission Modes (Continue)

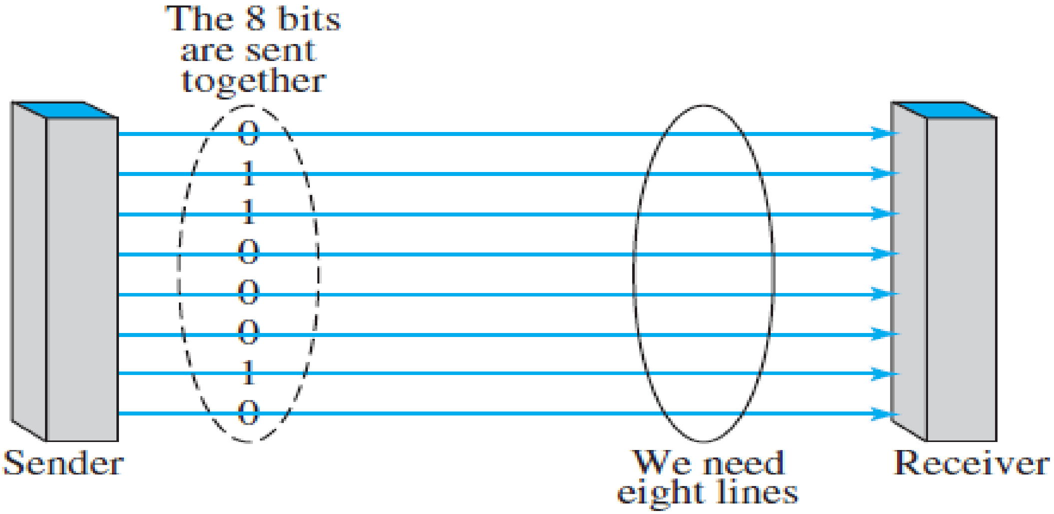


Figure 28. Parallel transmission

Serial Transmission

- In serial transmission one bit follows another, so it is needed only one communication channel rather than n to transmit data between two communicating devices as shown in figure 29.

Transmission Modes (Continue)

- The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission.
- Since communication within devices is parallel, conversion devices are required at the interface between the sender and the line (parallel-to serial) and between the line and the receiver (serial-to-parallel).
- Serial transmission occurs in one of three ways: asynchronous, synchronous, and isochronous.

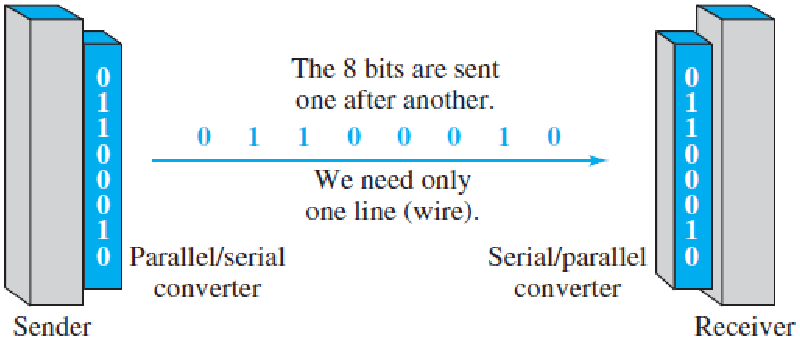


Figure 29. Serial transmission

Transmission Modes (Continue)

- In asynchronous transmission, 1 start bit (0) is sent at the beginning and 1 or more stop bits (1s) at the end of each byte.
- There may be a gap between bytes.

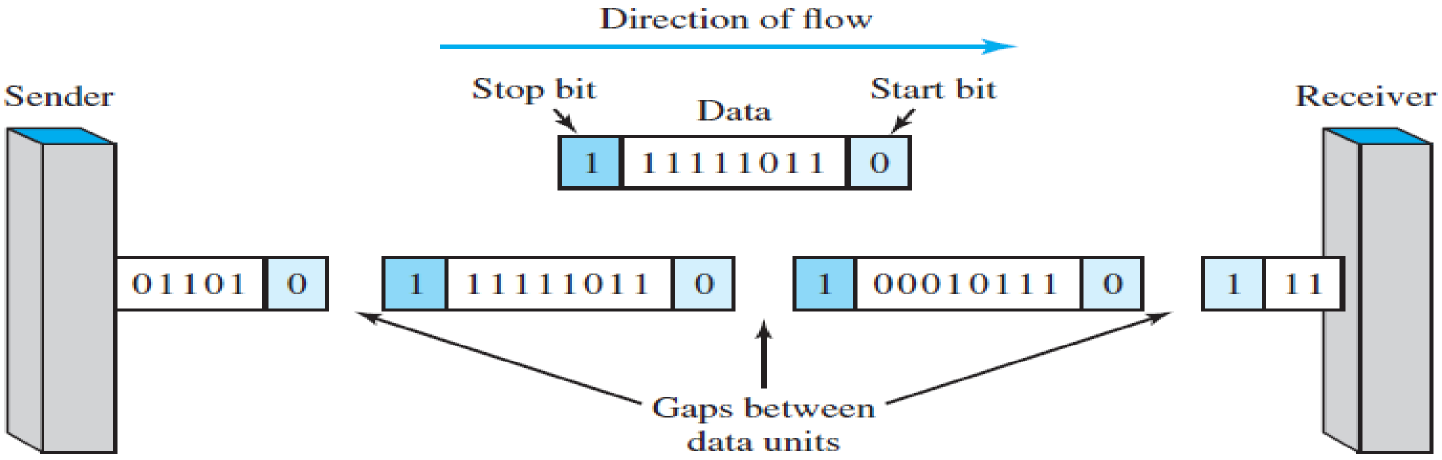


Figure 30. Asynchronous transmission

Transmission Modes (Continue)

- In synchronous transmission, bits are sent one after another without start or stop bits or gaps.
- It is the responsibility of the receiver to group the bits.

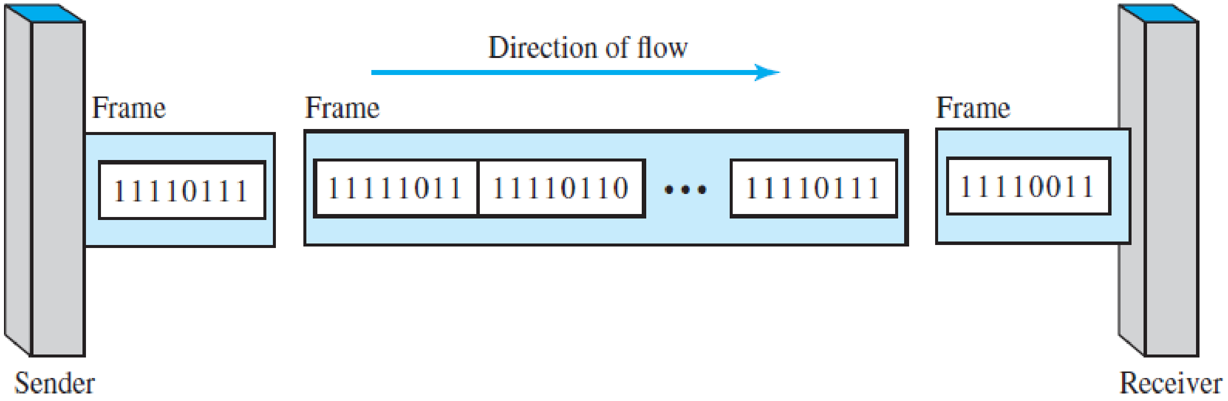


Figure 31. Synchronous transmission

- The isochronous transmission guarantees that the data arrive at a fixed rate.

Questions for Topic 1

1. Answer the followings.
   a. List three techniques of digital-to-digital conversion.
   b. Distinguish between a signal element and a data element.
   c. Distinguish between data rate and signal rate.
   d. List five line coding schemes discussed in this book.
   e. Define block coding and give its purpose.
   f. Define scrambling and give its purpose.
   g. Compare and contrast PCM and DM.
   h. What are the differences between parallel and serial transmission?
   i. List three different techniques in serial transmission and explain the differences.

Topic 2: Analog Transmission

Digital-To-Analog Conversion

- Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.
- Figure 32 shows the relationship between the digital information, the digital-to-analog modulating process, and the resultant analog signal.
- There are three mechanisms for modulating digital data into an analog signal: amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK).

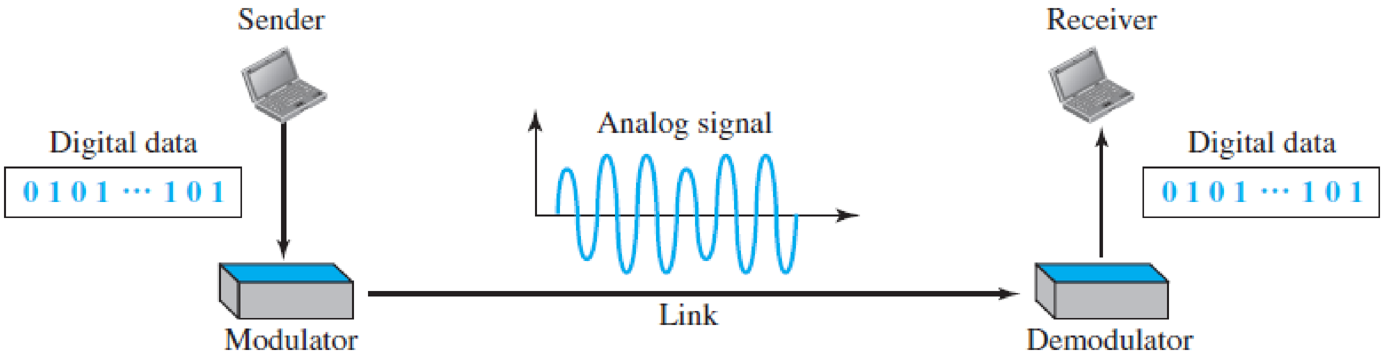


Figure 32. Digital-to-analog conversion

Digital-To-Analog Conversion (Continue)

- In addition, there is a fourth (and better) mechanism that combines changing both the amplitude and phase, called quadrature amplitude modulation (QAM).
- QAM is the most efficient of these options and is the mechanism commonly used today as depicted in figure 33.

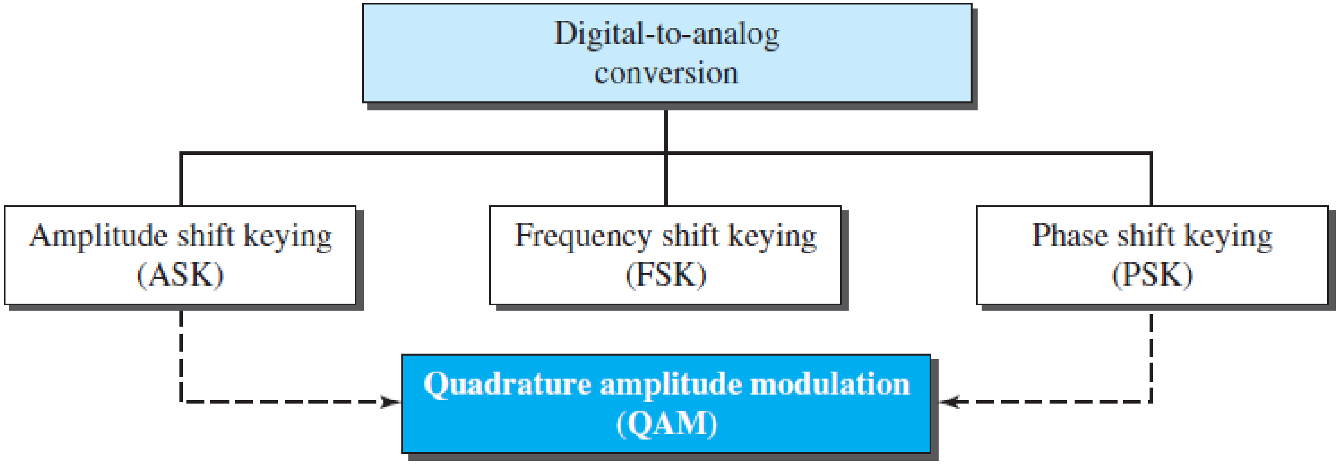


Figure 33. Types of digital-to-analog conversion

Digital-To-Analog Conversion (Continue)

Data Rate Versus Signal Rate

- Bit rate is the number of bits per second.

- Baud rate is the number of signal elements per second.

- In the analog transmission of digital data, the baud rate is less than or equal to the bit rate.

- The relationship between them is

$$S = N \times \frac{1}{r} \text{ baud}$$

- where, N is the data rate (bps) and r is the number of data elements carried in one signal element.

- The value of r in analog transmission is $r = \mathrm{Log}_2 L$, where L is the number of different signal elements.

Digital-To-Analog Conversion (Continue)

Amplitude Shift Keying

- 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.
- Figure 34 gives a conceptual view of binary ASK.

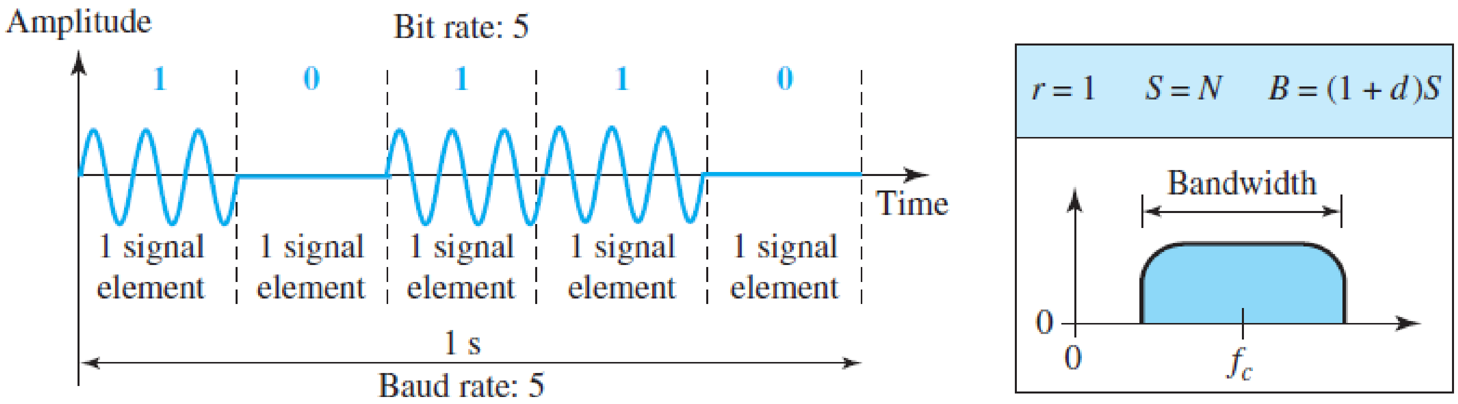


Figure 34. Binary amplitude shift keying

Digital-To-Analog Conversion (Continue)

- There is normally another factor involved, called d, which depends on the modulation and filtering process.
- The value of d is between 0 and 1.
- This means that the bandwidth can be expressed as shown, where S is the signal rate and the B is the bandwidth.

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

Example 3

We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What are the carrier frequency and the bit rate if we modulated our data by using ASK with $d = 1$?

Solution: The middle of the bandwidth is located at 250 kHz. Therefore, the carrier frequency is 250 kHz

$$B = (1 + d) \times S = 2 \times N \times (1/r) = 2 \times N = 100 \text{ kHz} \longrightarrow N = 50 \text{ kbps}$$

Digital-To-Analog Conversion (Continue)

Frequency Shift Keying (FSK)

- In 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.
- One way to think about binary FSK (or BFSK) is to consider two carrier frequencies.
- In Figure 35, it has selected two carrier frequencies, $f1$ and $f2$.
- It uses the first carrier if the data element is 0; it uses the second if the data element is 1.

Digital-To-Analog Conversion (Continue)

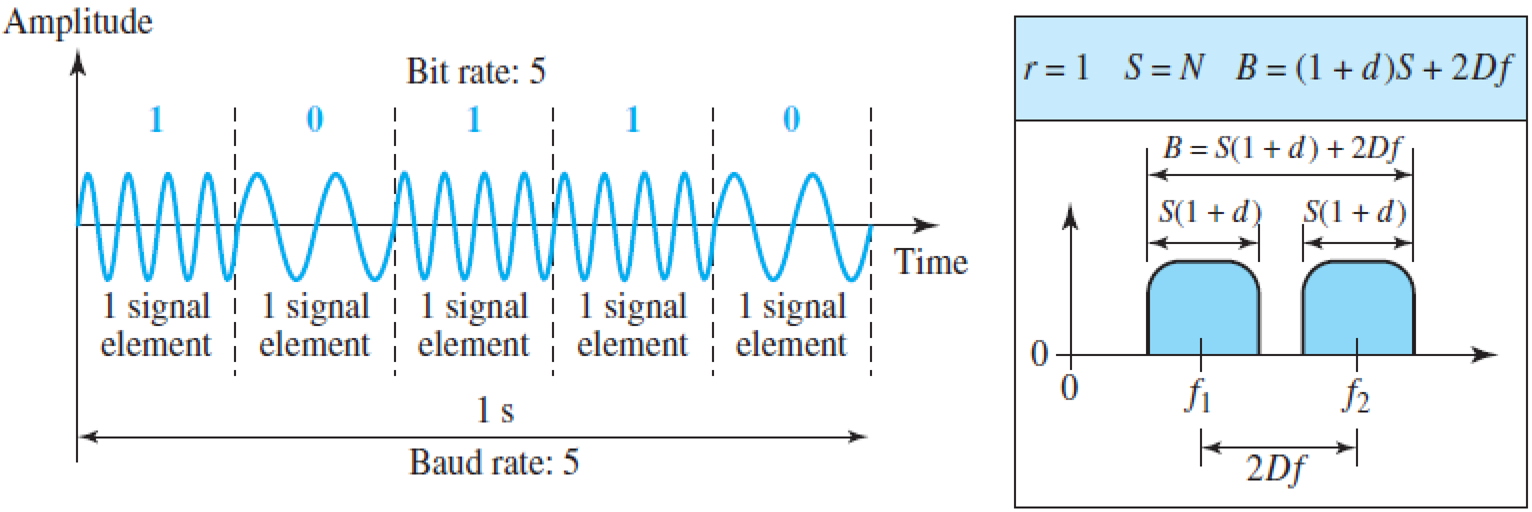


Figure 35. Binary frequency shift keying (BFSK)

Bandwidth for BFSK

- If the difference between the two frequencies is $2\Delta_f$, then the required bandwidth is

$$B = (1 + d) \times S + 2\Delta\emptyset$$

Digital-To-Analog Conversion (Continue)

Example 4

We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with d = 1?

Solution: $B = (1 + d) \times S + 2\Delta_f$

$2S = 100$

$2S = 50 \text{ kHz}$

$S = 25 \text{ kbaud}$

$N = 25 \text{ kbps}$

Implementation

- There are two implementations of BFSK: noncoherent and coherent.
- In noncoherent BFSK, there may be discontinuity in the phase when one signal element ends and the next begins.

Digital-To-Analog Conversion (Continue)

- In coherent BFSK, the phase continues through the boundary of two signal elements.

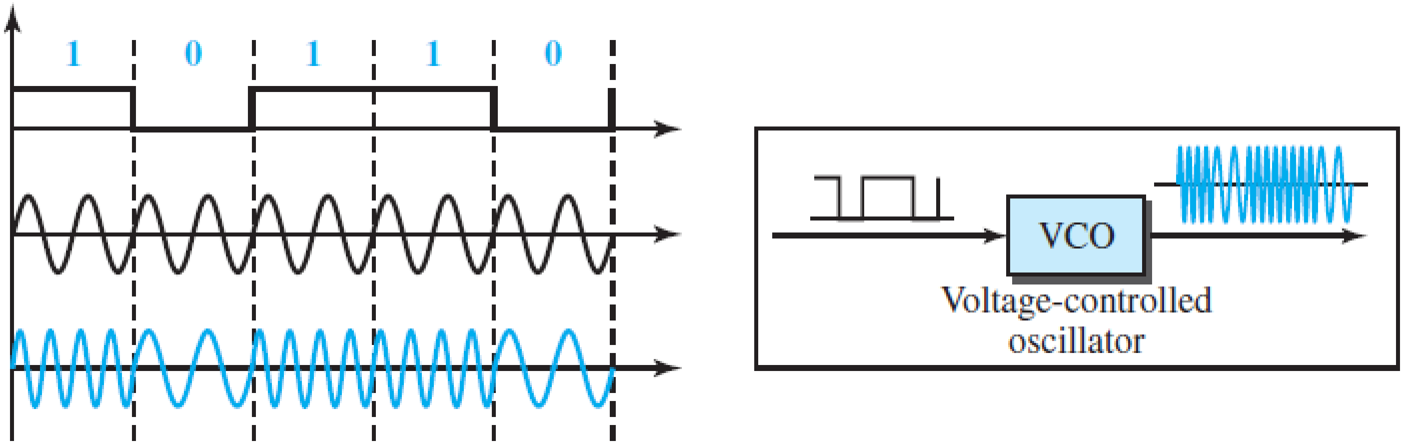


Figure 36. Implementation of BFSK

Multilevel FSK

- Multilevel modulation (MFSK) is not uncommon with the FSK method.
- It can use more than two frequencies.

Digital-To-Analog Conversion (Continue)

- The bandwidth for multilevel FSK is as follow:

$B = (1 + d) \times S + (L - 1)\, 2\Delta_f \longrightarrow B = L \times S$

Example 5

We need to send data 3 bits at a time at a bit rate of 3 Mbps. The carrier frequency is 10 MHz. Calculate the number of levels (different frequencies), the baud rate, and the bandwidth.

Solution: We can have $L = 2^3 = 8$. The baud rate is $S = 3$ MHz/3 = 1 Mbaud. This means that the carrier frequencies must be 1 MHz apart ($2\Delta_f = 1$ MHz). The bandwidth is $B = 8 \times 1 = 8$ MHz. Figure 37 shows the allocation of frequencies and bandwidth.

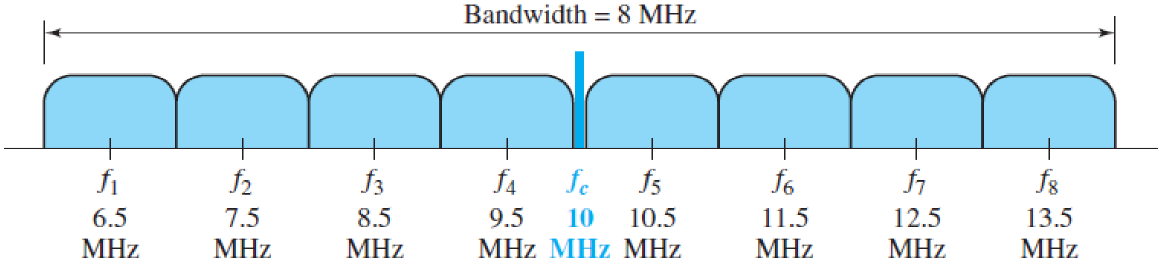


Figure 37. Bandwidth of MFSK

Digital-To-Analog Conversion (Continue)

Phase Shift Keying

- In phase shift keying, the phase of the carrier is varied to represent two or more different signal elements.
- Both peak amplitude and frequency remain constant as the phase changes.
- 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° as shown in figure 38.

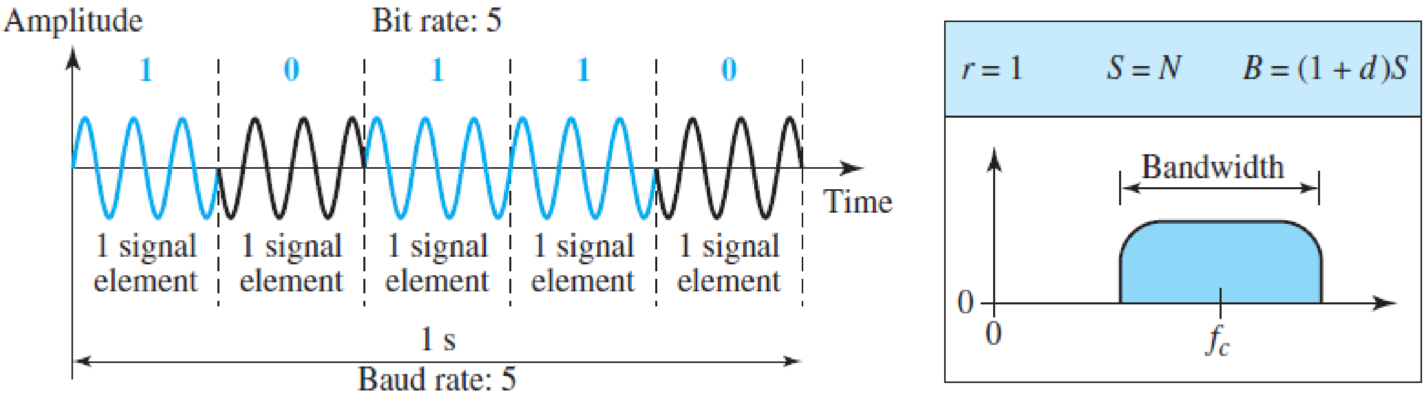


Figure 38. Binary phase shift keying

Digital-To-Analog Conversion (Continue)

- The bandwidth is the same as that for binary ASK, but less than that for BFSK.
- The implementation of BPSK is as simple as that for ASK.

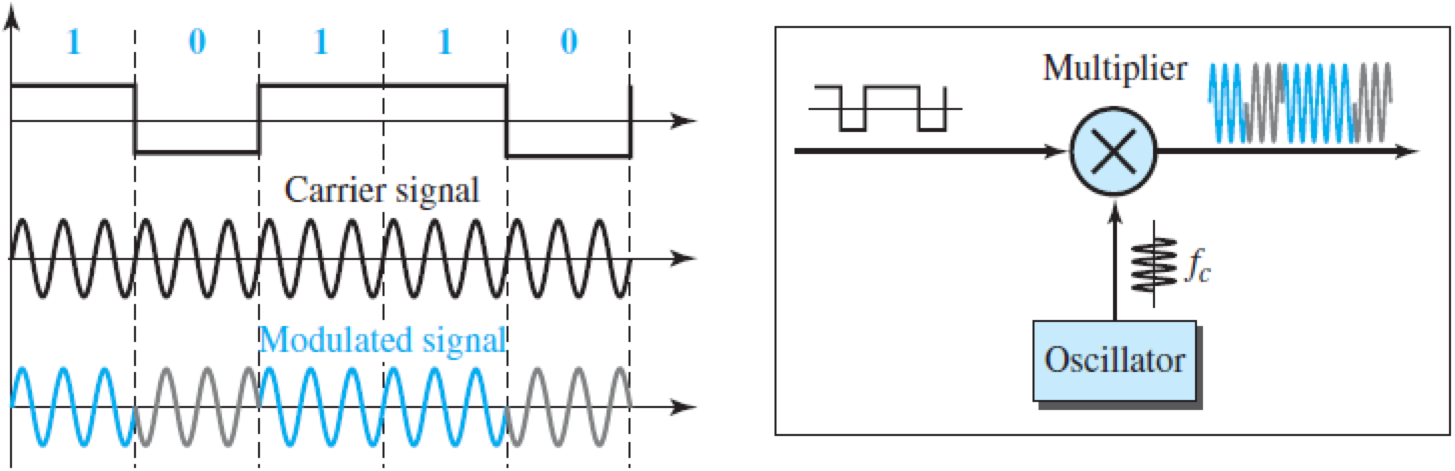


Figure 39. Implementation of BASK

Digital-To-Analog Conversion (Continue)

Quadrature Amplitude Modulation

- Quadrature amplitude modulation is a combination of ASK and PSK.
- The possible variations of QAM are numerous.
- Figure 40 shows some of these schemes.
- Figure 40 a shows the simplest 4-QAM scheme (four different signal element types) using a unipolar NRZ signal to modulate each carrier.
- This is the same mechanism we used for ASK (OOK).
- Part b shows another 4-QAM using polar NRZ, but this is exactly the same as QPSK.
- Part c shows another QAM-4 in which it is used a signal with two positive levels to modulate each of the two carriers.

Digital-To-Analog Conversion (Continue)

- Finally, Figure 39 d shows a 16-QAM constellation of a signal with eight levels, four positive and four negative.

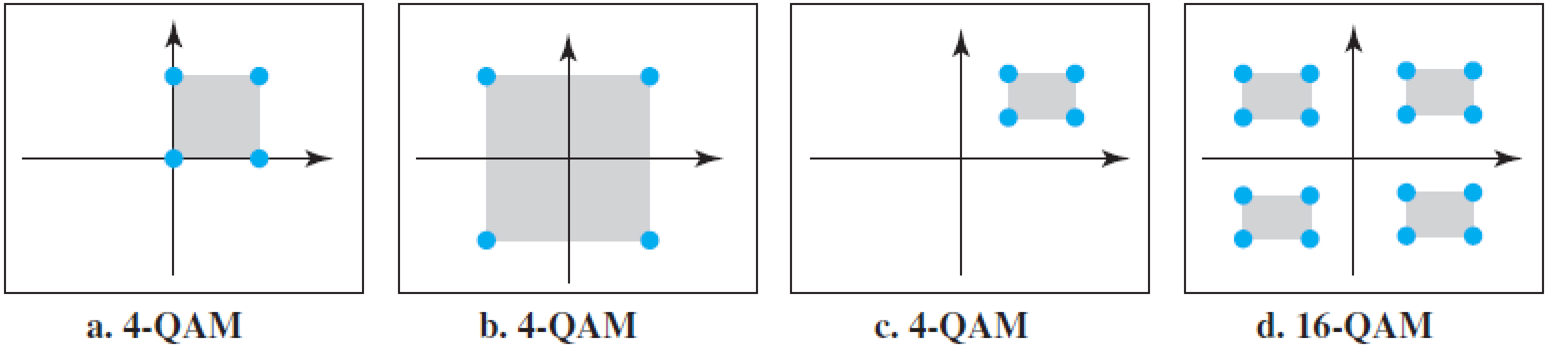


Figure 40. Constellation Diagrams for Some QAMs

Analog-to-Analog Conversion

- Analog-to-analog conversion, or analog modulation, is the representation of analog information by an analog signal.
- Analog-to-analog conversion can be accomplished in three ways: amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM) as shown in figure 41.

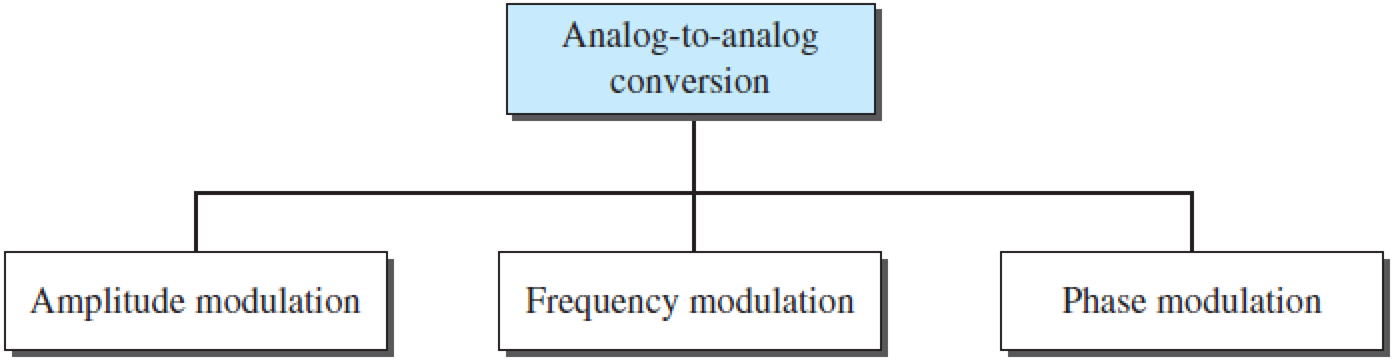


Figure 41. Types of analog-to-analog modulation

Analog-to-Analog Conversion (Continue)

Amplitude Modulation (AM)

- In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal.
- The frequency and phase of the carrier remain the same; only the amplitude changes to follow variations in the information.
- Figure 42 shows how this concept works.
- In this figure, AM is normally implemented by using a simple multiplier because the amplitude of the carrier signal needs to be changed according to the amplitude of the modulating signal.
- The total bandwidth required for AM can be determined from the bandwidth of the audio signal: $B_{AM} = 2B$.

Analog-to-Analog Conversion (Continue)

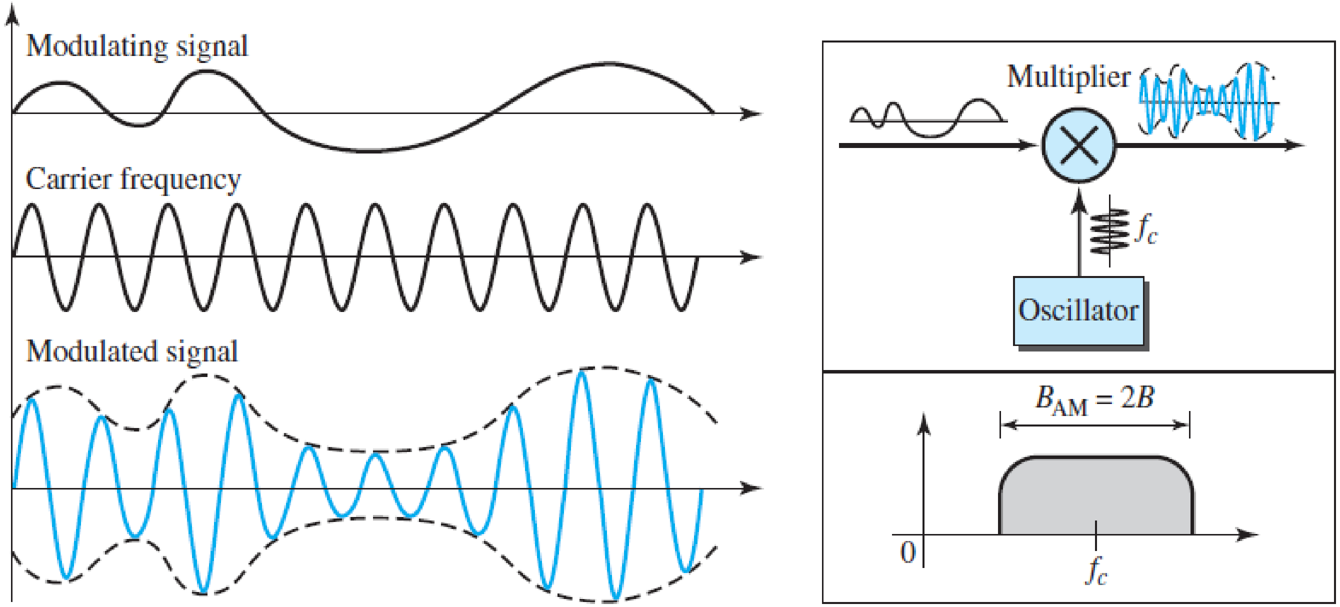


Figure 42. Amplitude modulation

Frequency Modulation (FM)

- In FM transmission, the frequency of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.

Analog-to-Analog Conversion (Continue)

- The peak amplitude and phase of the carrier signal remain constant, but as the amplitude of the information signal changes, the frequency of the carrier changes correspondingly.

- Figure 43 shows the relationships of the modulating signal, the carrier signal, and the resultant FM signal.

- In this figure, FM is normally implemented by using a voltage-controlled oscillator as with FSK.

- The frequency of the oscillator changes according to the input voltage which is the amplitude of the modulating signal.

- The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 \times ß)B$.

Analog-to-Analog Conversion (Continue)

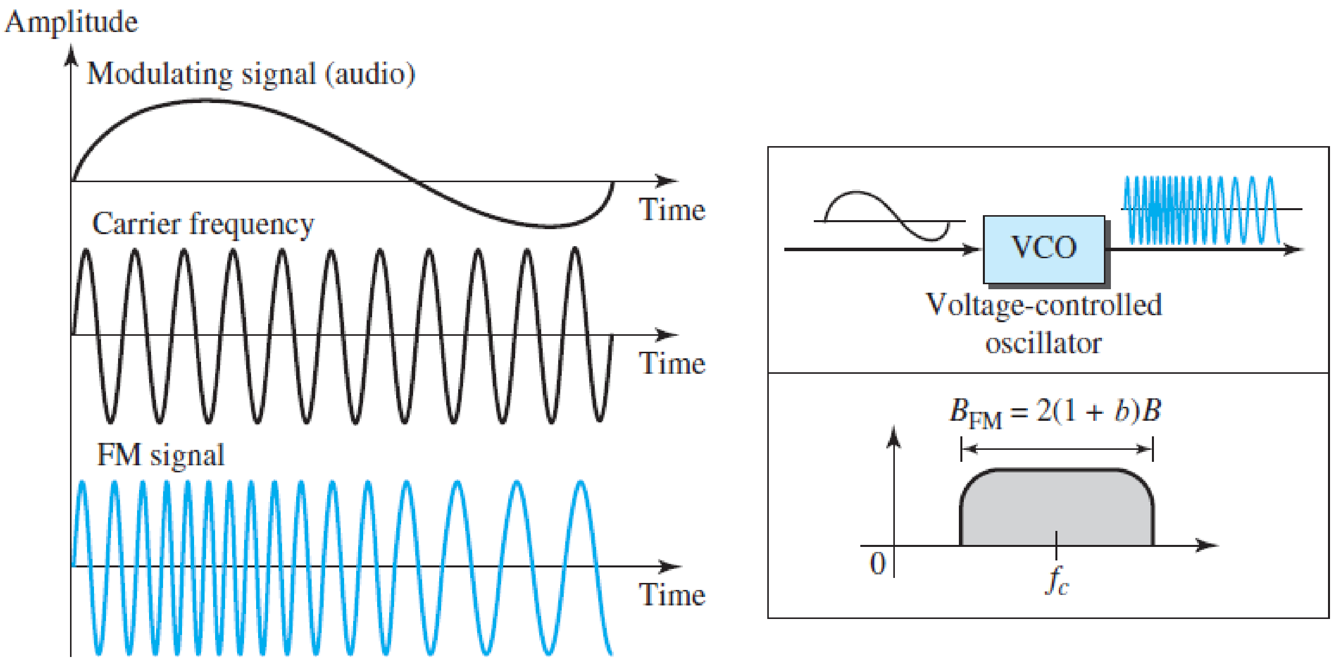


Figure 43. Frequency modulation

Phase Modulation (PM)

- In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.

Analog-to-Analog Conversion (Continue)

- The peak amplitude and frequency of the carrier signal remain constant, but as the amplitude of the information signal changes, the phase of the carrier changes correspondingly.
- Figure 44 shows the relationships of the modulating signal, the carrier signal, and the resultant PM signal.
- In this figure, PM is normally implemented by using a voltage-controlled scillator along with a derivative.
- The frequency of the oscillator changes according to the derivative of the input voltage, which is the amplitude of the modulating signal.

Analog-to-Analog Conversion (Continue)

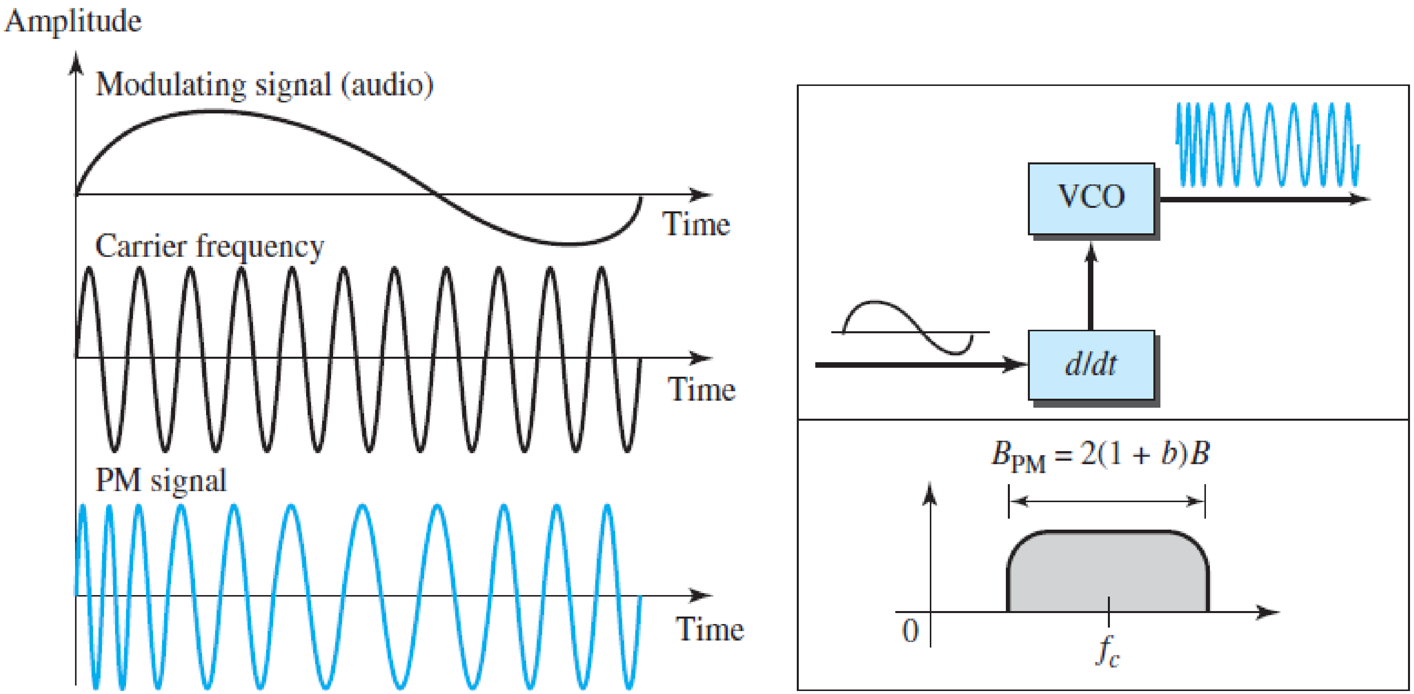


Figure 44. Phase modulation

- The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal: B_{PM} = 2(1 + ß)B.

Next Week Lecture

- Bandwidth Utilization: Multiplexing and Spectrum Spreading
  - Multiplexing
  - Spread Spectrum
- Transmission Media
  - Guided Media
  - Unguided Media: Wireless
- Switching
  - Introduction
  - Circuit-Switched Networks
  - Packet Switching

Thank You