Analog Transmission: ASK, FSK, PSK & QPSK

Course Code: COE 3201

Course Title: Data Communication

Dept. of Computer Engineering
Faculty of Engineering

Lecture No:	**7**	**Week No:**	**8**	**Semester:**	**Fall 23-24**
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Lecture Outline

1. Digital to Analog Conversion
2. Aspects of Conversion
3. Amplitude Shift Keying
4. Frequency Shift Keying
5. Phase Shift Keying
6. Constellation Diagram

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 5.1 shows the relationship between the digital information, the digital-to-analog modulating process, and the resultant analog signal

Digital to Analog Conversion

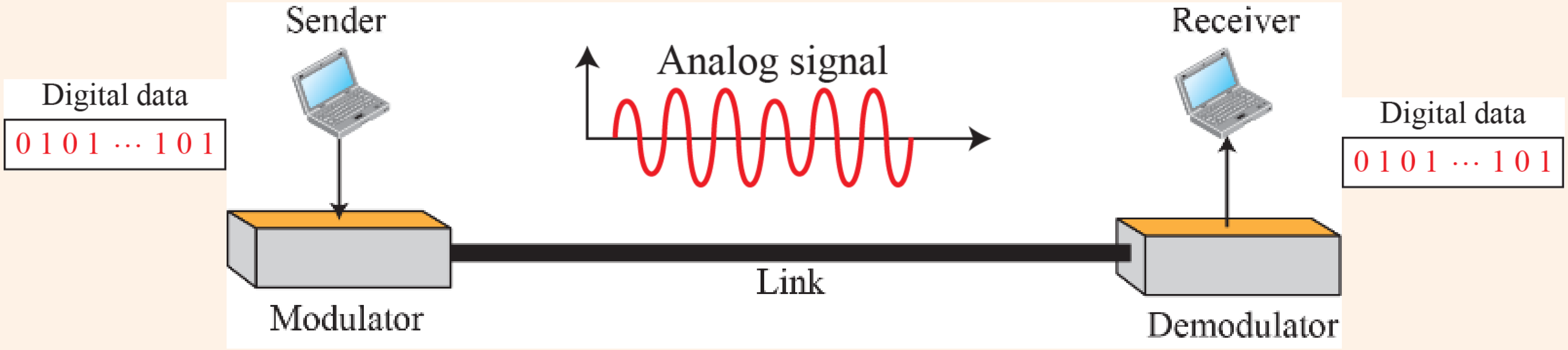
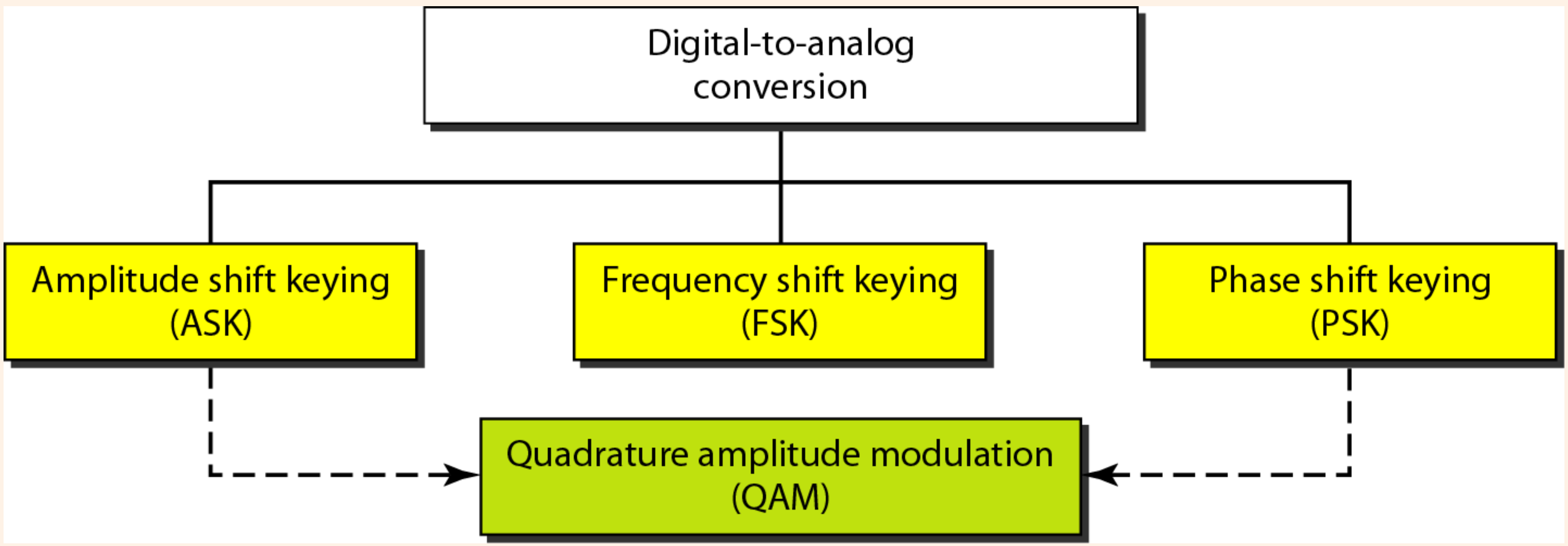


Figure 5.1: Digital-to-analog conversion

Digital to Analog Conversion

Types of digital to analog conversion



Aspects of Conversion

- Before we discuss specific methods of digital-to-analog modulation, two basic issues must be reviewed: bit and baud rates and the carrier signal.
- **Bit rate**: is the number of bits sent in 1s, expressed in bits per second (bps).
- **Baud rate**: is the number of signal elements sent in 1s.
- **Carrier signal**: In analog transmission, sender produces a high-frequency signal that acts as a base for the information signal. This base signal is called carrier signal.

Analog transmission

Data Rate Versus Signal Rate

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

$$r = \log_2 L$$

Aspects of Conversion

Example 5.1: 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

$$S = N \times (1/r) \qquad \text{or} \qquad N = S \times r = 1000 \times 4 = 4000 \text{ bps}$$

Aspects of Conversion

Example 5.2: An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

Solution: In this example, S = 1000, N = 8000, and r and L are unknown. We first find the value of r and then the value of L

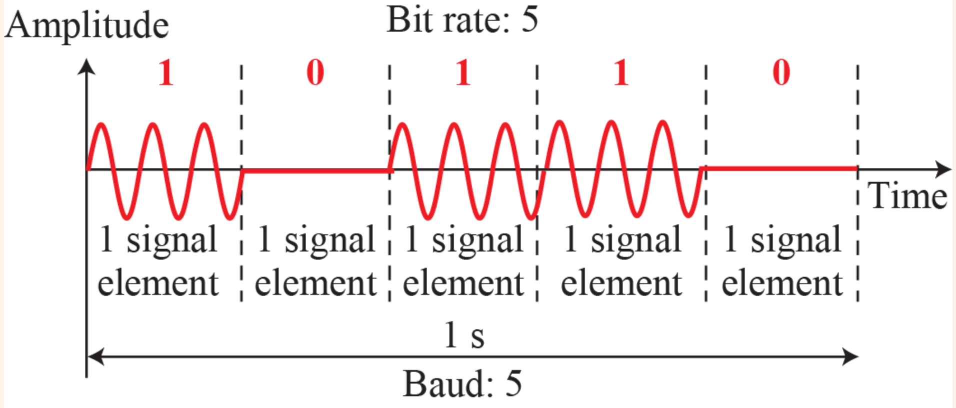
$$S = N \times 1/\mathrm{r} \longrightarrow r = \mathrm{N} / \mathrm{S} = 8000 / 10{,}000 = 8 \text{ bits/baud}$$

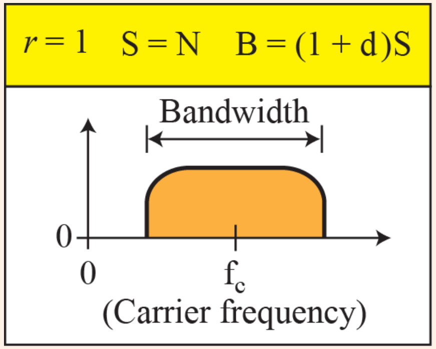
$$r = \log_2 L \longrightarrow L = 2^r = 2^8 = 256$$

Amplitude Shift Keying

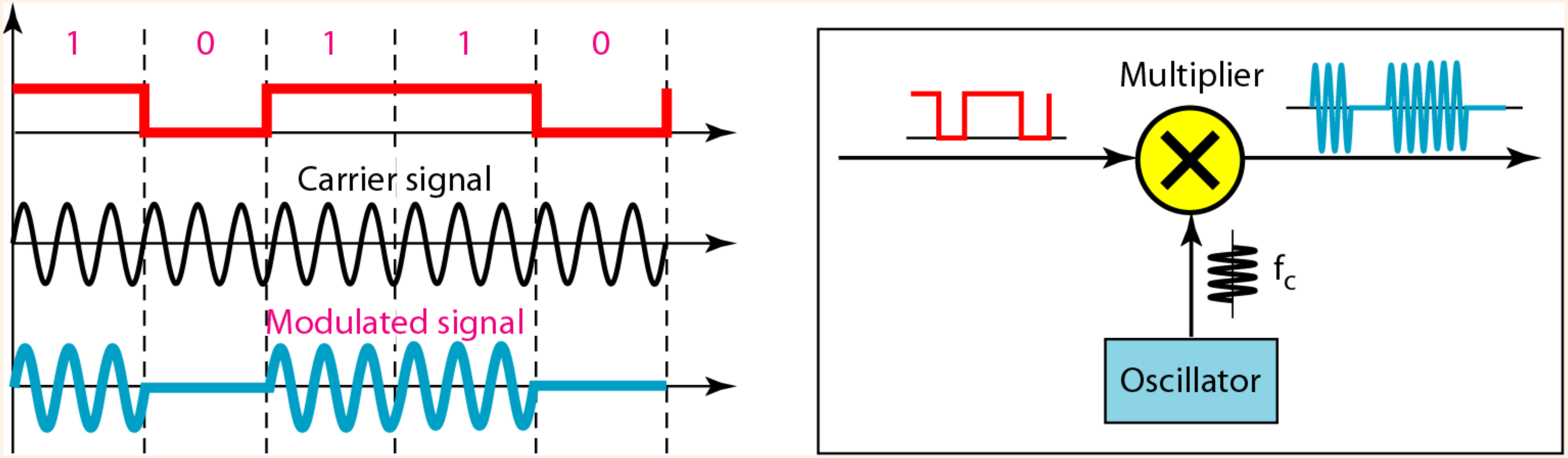
In amplitude shift keying, the amplitude of the carrier signal is varied to create signal elements. Both frequency and phase remain constant while the amplitude changes.
This is referred to as binary amplitude shift keying or on-off keying (OOK).

Binary Amplitude Shift Keying





Implementation of binary ASK



Amplitude Shift Keying

Example 5.3: 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. This means that our carrier frequency can be at fc = 250 kHz. We can use the formula for bandwidth to find the bit rate (with d = 1 and r = 1).

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

Amplitude Shift Keying

Example 5.4: In data communications, we normally use full-duplex links with communication in both directions. We need to divide the bandwidth into two with two carrier frequencies, as shown in Figure 5.5. The figure shows the positions of two carrier frequencies and the bandwidths. The available bandwidth for each direction is now 50 kHz, which leaves us with a data rate of 25 kbps in each direction.

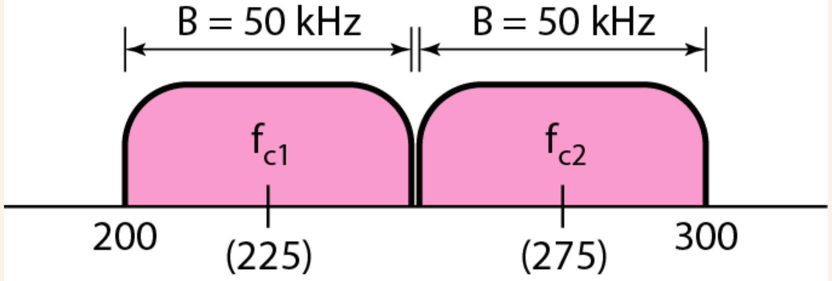


Figure 5.5: Bandwidth of a full-duplex ASK

Frequency Shift Keying

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.

Frequency Shift Keying

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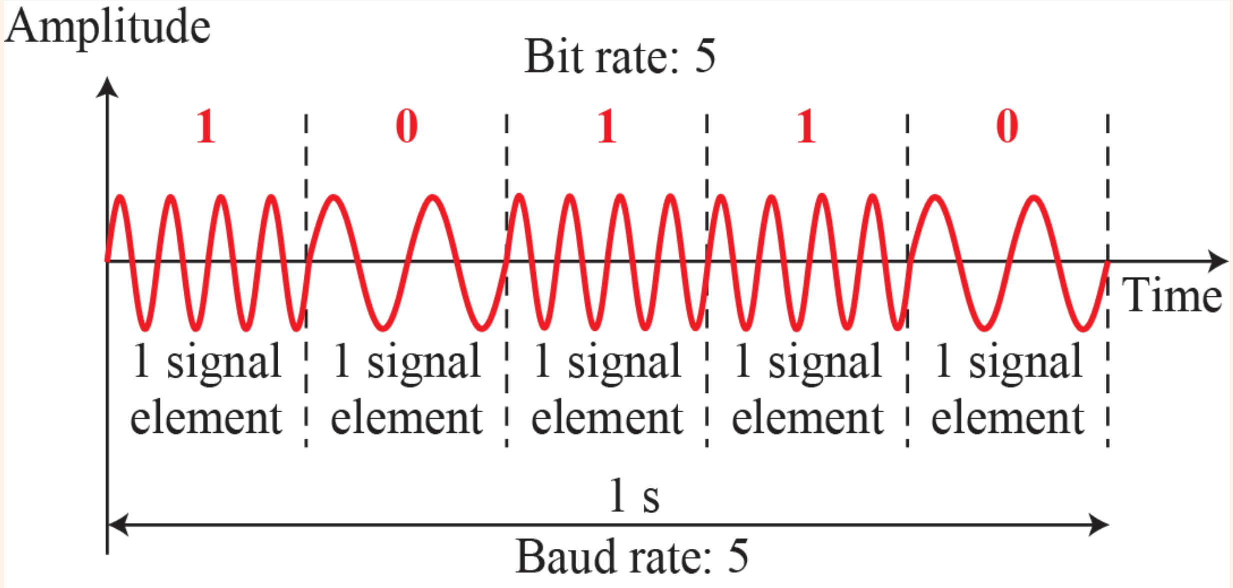
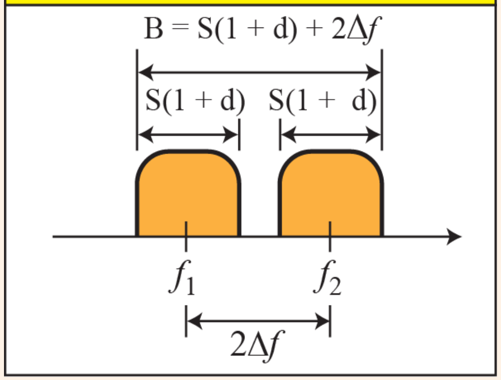
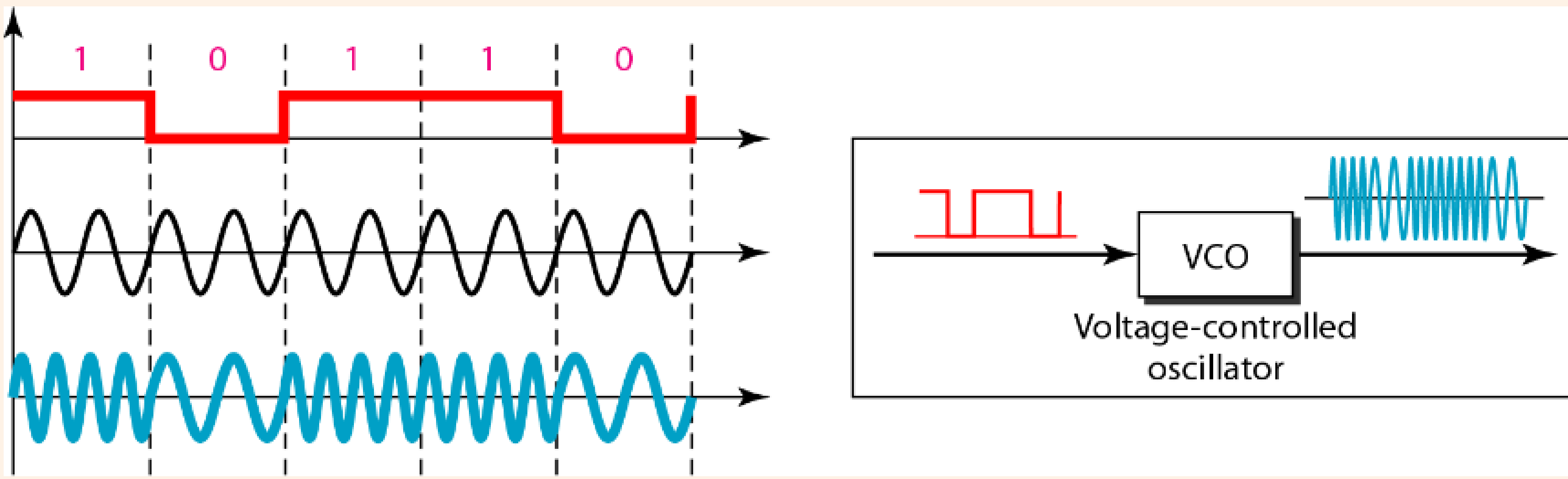
Binary Frequency Shift Keying



$r = 1 \quad S = N \quad B = (1 + d)S + 2\Delta f$



Implementation of BFSK



Frequency Shift Keying

Example 5.5: 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?

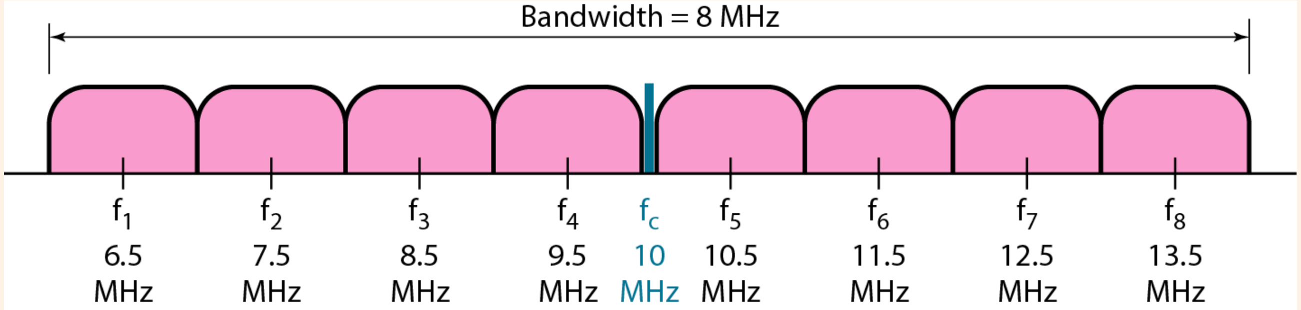
Solution: This problem is similar to Example 5.3, but we are modulating by using FSK. The midpoint of the band is at 250 kHz. We choose 2Δf to be 50 kHz; this means

$$B = (1 + d) \times S + 2\Delta_f = 100 \longrightarrow 2S = 50 \text{ kHz} \longrightarrow S = 25 \text{ kbaud} \longrightarrow N = 25 \text{ kbps}$$

Frequency Shift Keying

Example 5.6: 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.

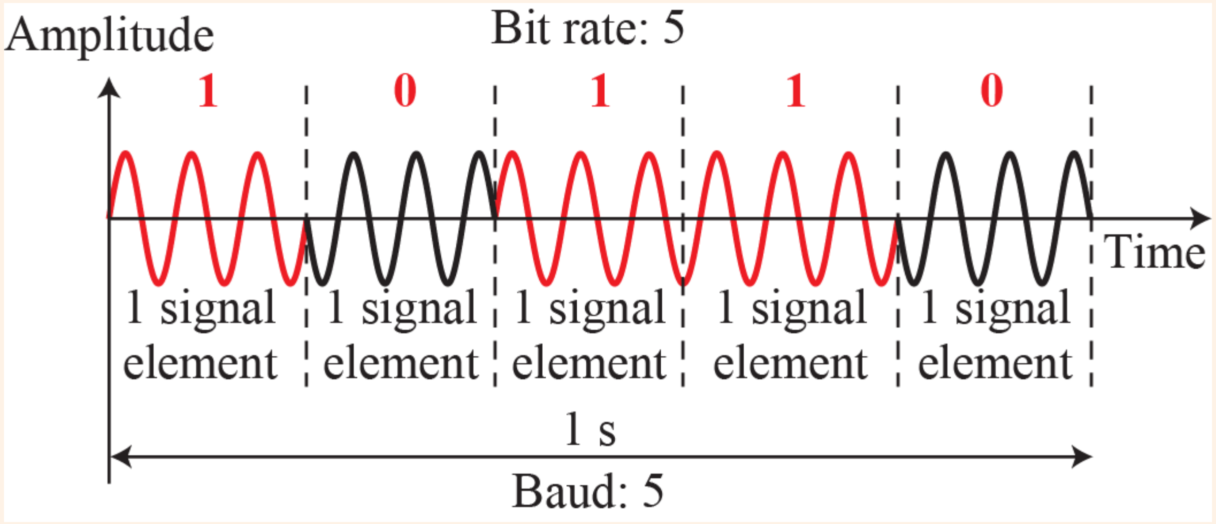


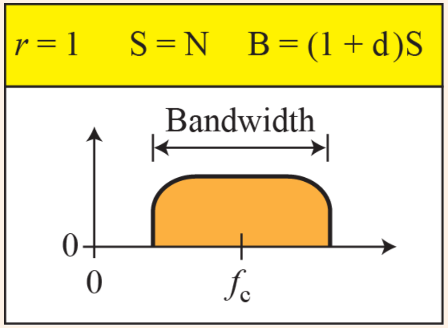
Phase Shift Keying

- 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.
- Today, PSK is more common than ASK or FSK.
- However, we will see shortly that QAM, which combines ASK and PSK, is the dominant method of digital-to-analog modulation.

Binary Phase Shift Keying

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°.

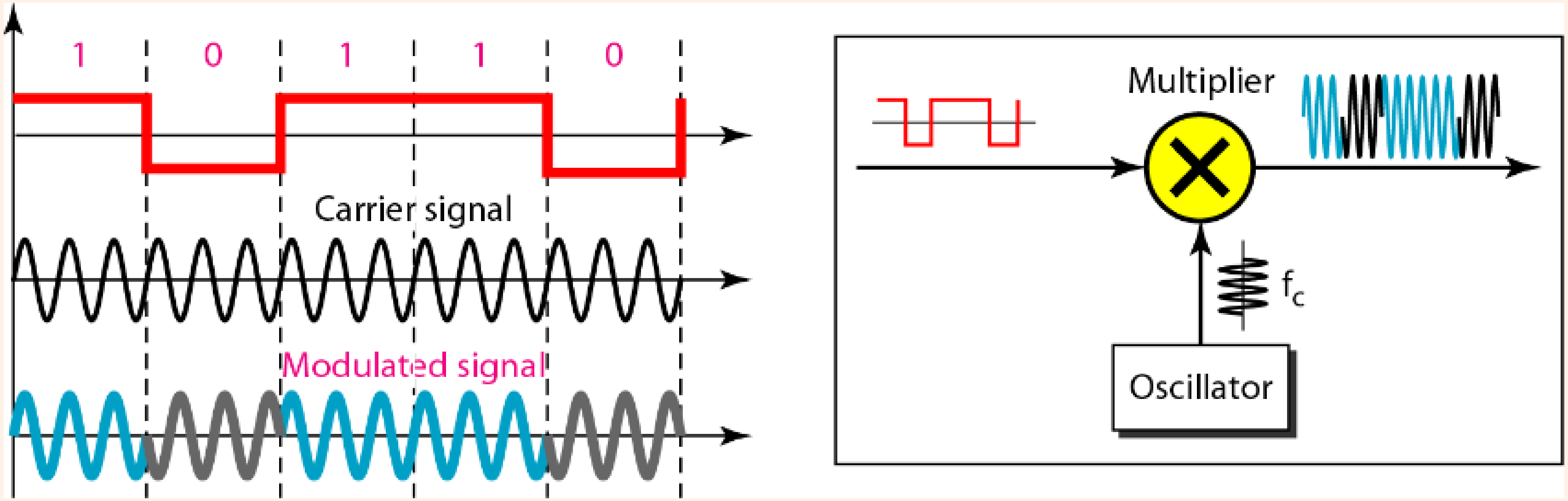




Advantages of BPSK

- Binary PSK is as simple as binary ASK with one big advantage—it is **less susceptible to noise**. In ASK, the criterion for bit detection is the amplitude of the signal; in PSK, it is the phase. Noise can change the amplitude easier than it can change the phase.
- PSK is superior to FSK because we do not need two **carrier signals**. However, PSK needs **more sophisticated hardware** to be able to distinguish between phases

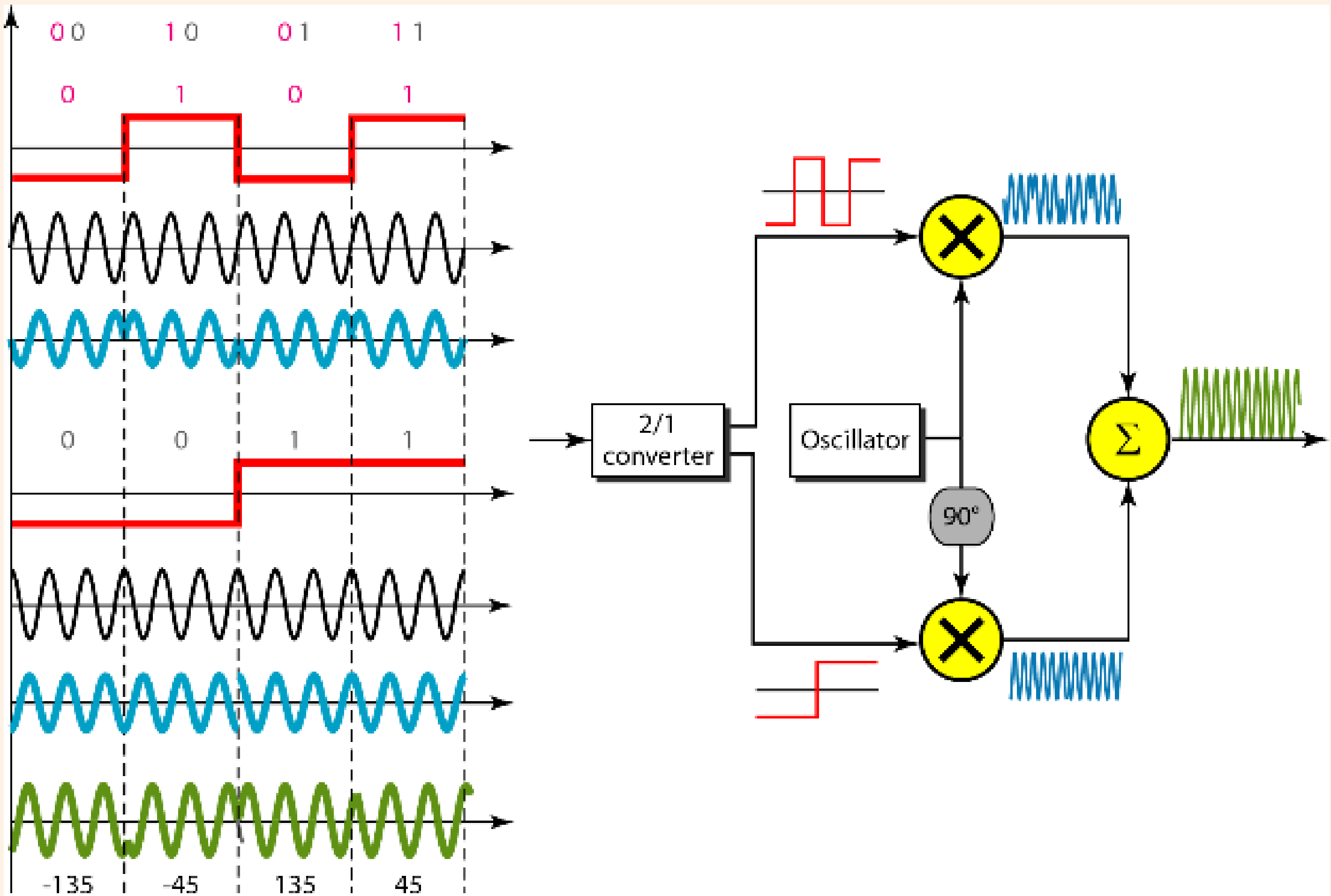
Implementation of BPSK



Quadrature PSK (QPSK)

- The simplicity of BPSK enticed designers to use 2 bits at a time in each signal element, thereby decreasing the baud rate and eventually the required bandwidth.
- The scheme is called quadrature PSK or QPSK because it uses two separate BPSK modulations; one is in-phase, the other quadrature (out-of-phase).
- The incoming bits are first passed through a serial-to-parallel conversion that sends one bit to one modulator and the next bit to the other modulator.
- If the duration of each bit in the incoming signal is T, the duration of each bit sent to the corresponding BPSK signal is 2T. This means that the bit to each BPSK signal has one-half the frequency of the original signal.

Implementation of QPSK



Quadrature PSK (QPSK)

Example 5.7: Find the bandwidth for a signal transmitting at 12 Mbps for QPSK. The value of $d = 0$.

Solution: For QPSK, 2 bits are carried by one signal element. This means that $r = 2$. So the signal rate (baud rate) is $S = N \times (1/r) = 6$ Mbaud. With a value of $d = 0$, we have $B = S = 6$ MHz.

Constellation Diagram

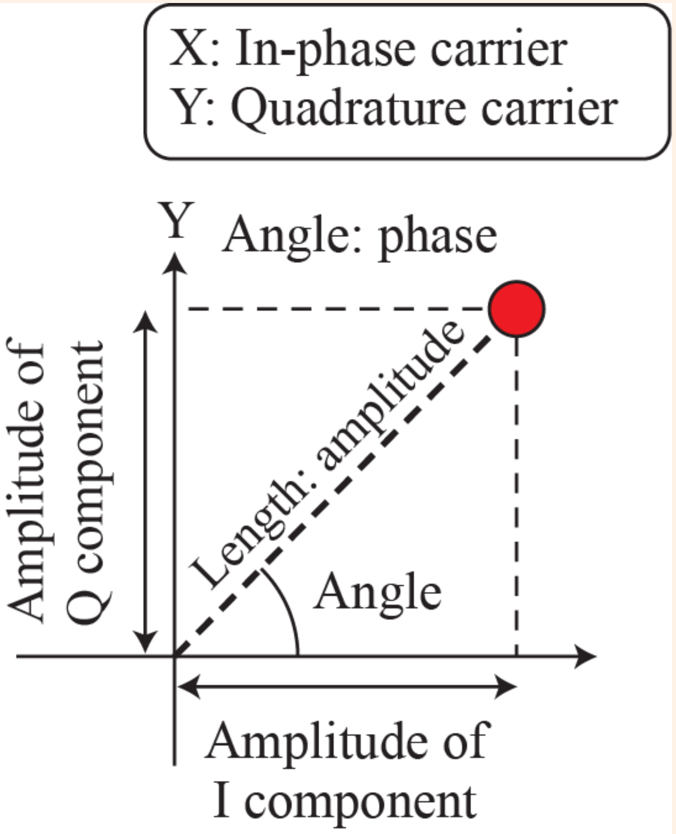
- A constellation diagram can help us define the amplitude and phase of a signal element, particularly when we are using two carriers (one in-phase and one quadrature).
- The diagram is useful when we are dealing with multilevel ASK, PSK, or QAM.
- In a constellation diagram, a signal element type is represented as a dot.
- The bit or combination of bits it can carry is often written next to it.

Constellation Diagram

- The diagram has two axes. The horizontal X axis is related to the in-phase carrier; the vertical Y axis is related to the quadrature carrier.
- For each point on the diagram, four pieces of information can be deduced. The projection of the point on the X axis defines the peak amplitude of the in-phase component; the projection of the point on the Y axis defines the peak amplitude of the quadrature component. The length of the line (vector) that connects the point to the origin is the peak amplitude of the signal element (combination of the X and Y components); the angle the line makes with the X axis is the phase of the signal element.

Constellation Diagram

- The diagram has two axes. The horizontal *X* axis is related to the in-phase carrier; the vertical *Y* axis is related to the quadrature carrier.
- For each point on the diagram, four pieces of information can be deduced.
- The projection of the point on the ***X* axis** defines **the peak amplitude of the in-phase component**; the projection of the point on the ***Y* axis** defines the **peak amplitude of the quadrature component**.
- The **length of the line (vector)** that connects the point to the origin is the **peak amplitude of the signal element** (combination of the *X* and *Y* components); the **angle** the line makes with the *X* axis is the **phase of the signal element**.



Constellation Diagram

Example 5.8: Show the constellation diagrams for ASK (OOK), BPSK, and QPSK signals.

Solution: Figure 5.13 shows the three constellation diagrams.

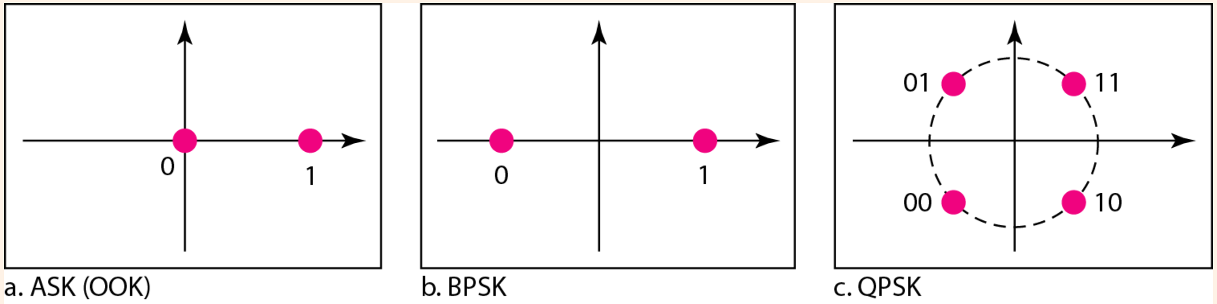
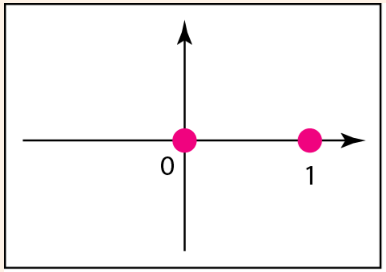


Figure 5.13: Three constellation diagrams

Constellation Diagram ASK

For ASK, we are using only an in-phase carrier. Therefore, the two points should be on the X axis. Binary 0 has an amplitude of 0 V; binary 1 has an amplitude of 1 V (for example). The points are located at the origin and at 1 unit.

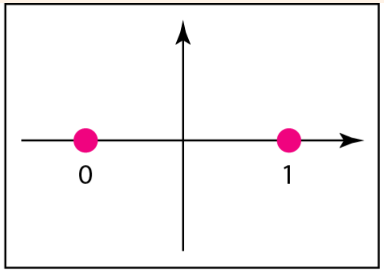


a. ASK (OOK)

Figure 5.13: Constellation diagram for ASK

Constellation Diagram BPSK

BPSK also uses only an in-phase carrier. However, we use a polar NRZ signal for modulation. It creates two types of signal elements, one with amplitude 1 and the other with amplitude −1. This can be stated in other words: BPSK creates two different signal elements, one with amplitude 1 V and in phase and the other with amplitude 1 V and 180° out of phase.



b. BPSK

Figure 5.13: Constellation diagram for BPSK

Constellation Diagram QPSK

QPSK uses two carriers, one in-phase and the other quadrature. The point representing 11 is made of two combined signal elements, both with an amplitude of 1 V.

One element is represented by an in-phase carrier, the other element by a quadrature carrier.

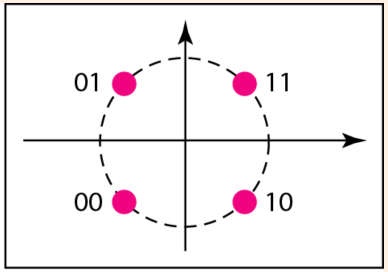
The amplitude of the final signal element sent for this 2-bit data element is $2^{1/2}$, and the phase is 45°.

The argument is similar for the other three points.

Constellation Diagram QPSK

All signal elements have an amplitude of $2^{1/2}$, but their phases are different (45°, 135°, −135°, and −45°).

Of course, we could have chosen the amplitude of the carrier to be $1/(2^{1/2})$ to make the final amplitudes 1 V.



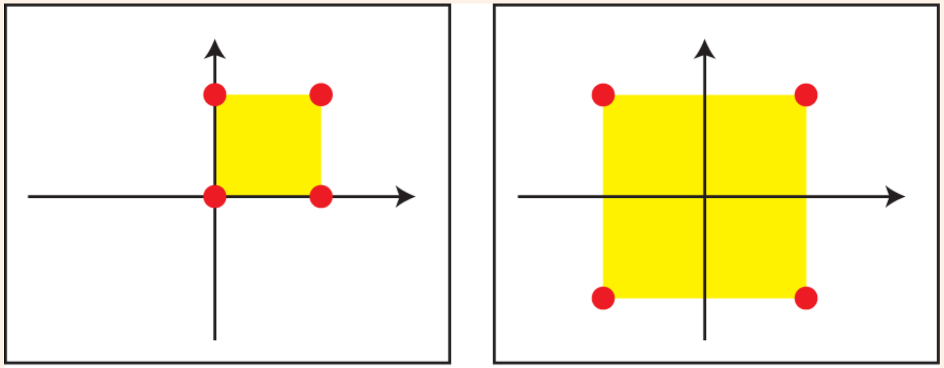
c. QPSK

Figure 5.13: Constellation diagram for QPSK

QAM

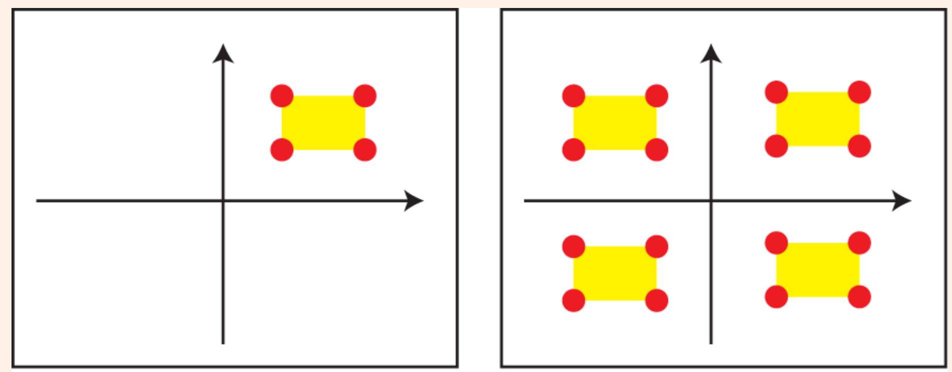
- PSK is limited by the ability of the equipment to distinguish small differences in phase.
- This factor limits its potential bit rate.
- So far, we have been altering only one of the three characteristics of a sine wave at a time; but what if we alter two? Why not combine ASK and PSK?
- The idea of using two carriers, one in-phase and the other quadrature, with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM).

Constellation diagrams for some QAMs



a. 4-QAM b. 4-QAM

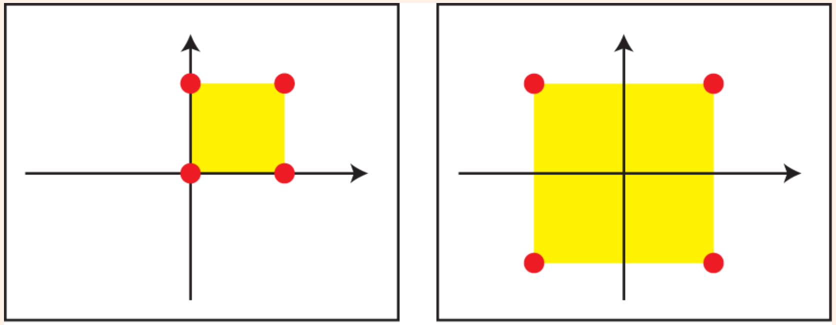
Figure 5.14: Constellation diagrams for some QAMs



c. 4-QAM d. 16-QAM

Constellation diagrams for some QAMs

- Figure 5.14 shows some of these schemes. Figure 5.14a shows the simplest 4-QAM scheme 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 the same as QPSK.

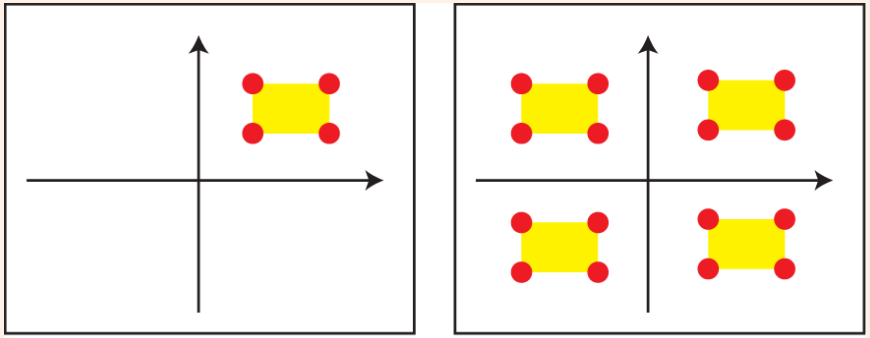


a. 4-QAM

b. 4-QAM

Constellation diagrams for some QAMs

- Part c shows another QAM-4 in which we used a signal with two positive levels to modulate each of the two carriers.
- Finally, Figure 5.14d shows a 16-QAM constellation of a signal with eight levels, four positive and four negative.



c. 4-QAM d. 16-QAM

Books

[1] Forouzan AB. Data communications & networking. 5th ed., Tata McGraw-Hill Education.

References

1. Prakash C. Gupta, “Data communications”, Prentice Hall India Pvt.
2. William Stallings, "Data and Computer Communications”, Pearson
3. Forouzan, B. A. "Data Communication and Networking. Tata McGraw." (2005).