

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:	
Lecturer:					

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

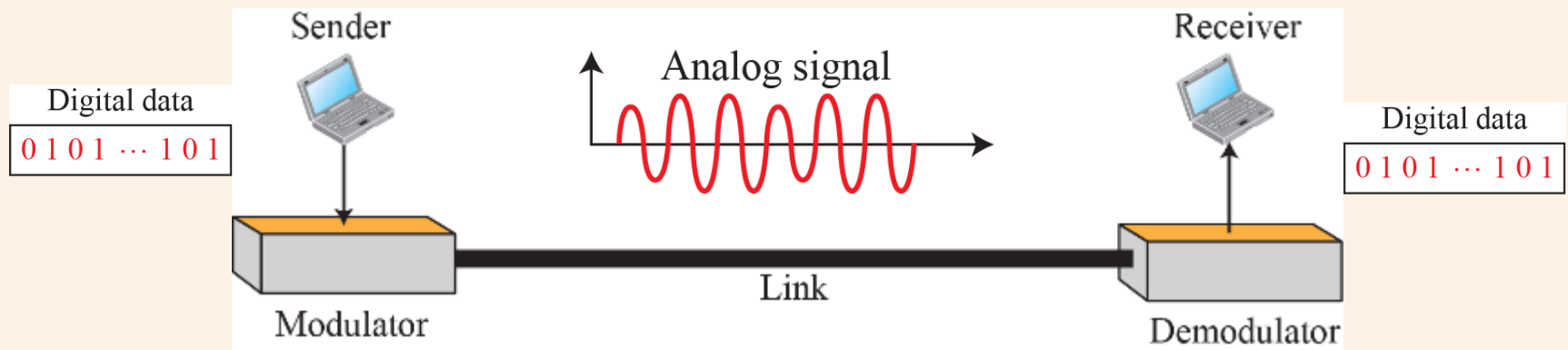
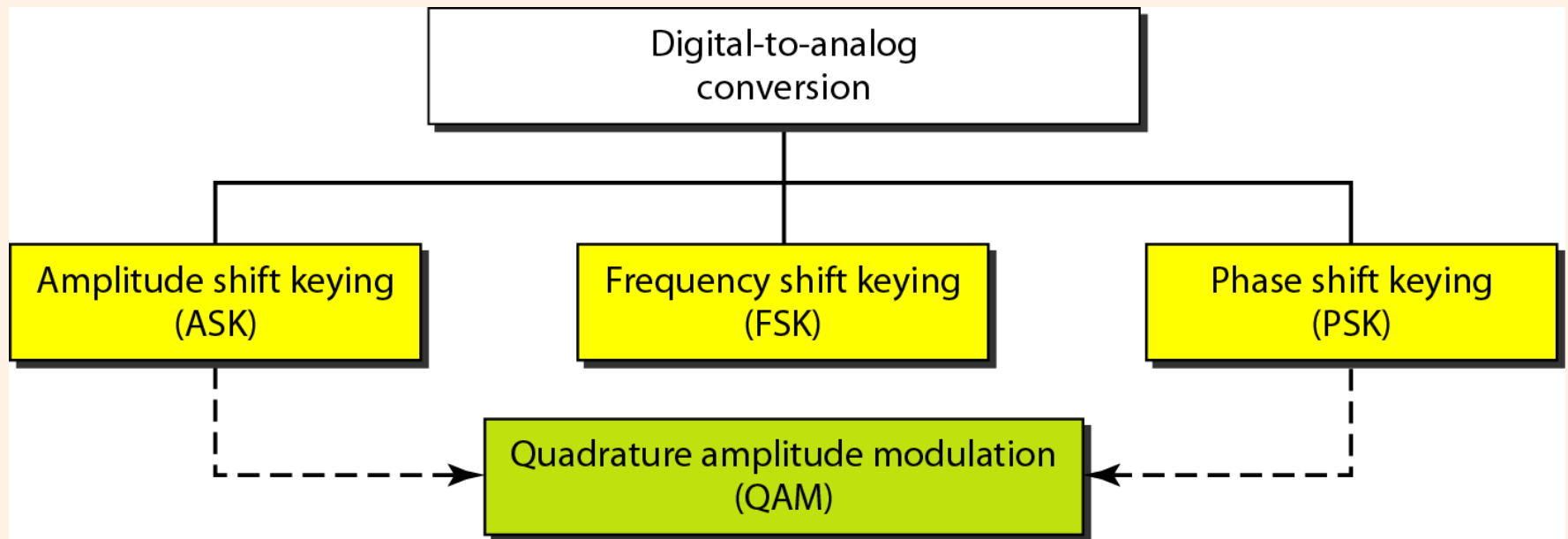


Figure 5.1: Digital-to-analog conversion

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.

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

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

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

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

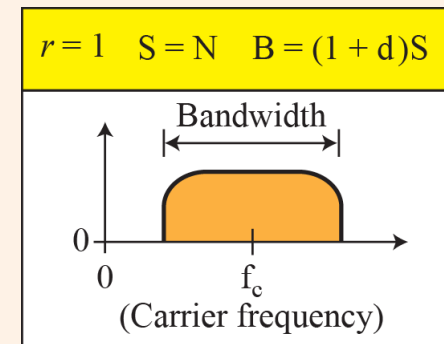
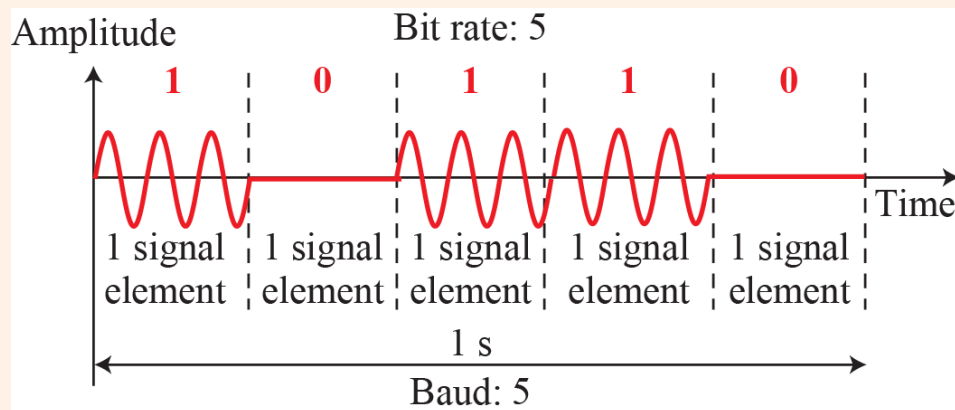
$$r = \log_2 L \longrightarrow L = 2^r = 2^8 = 256$$

Amplitude Shift Keying

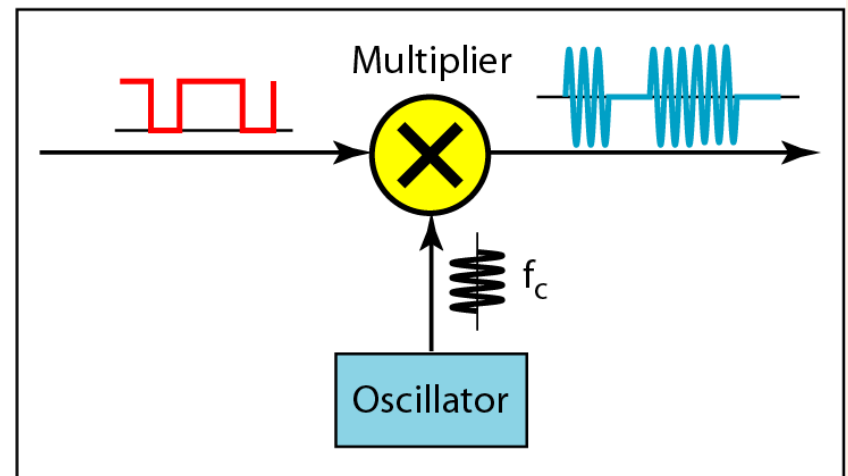
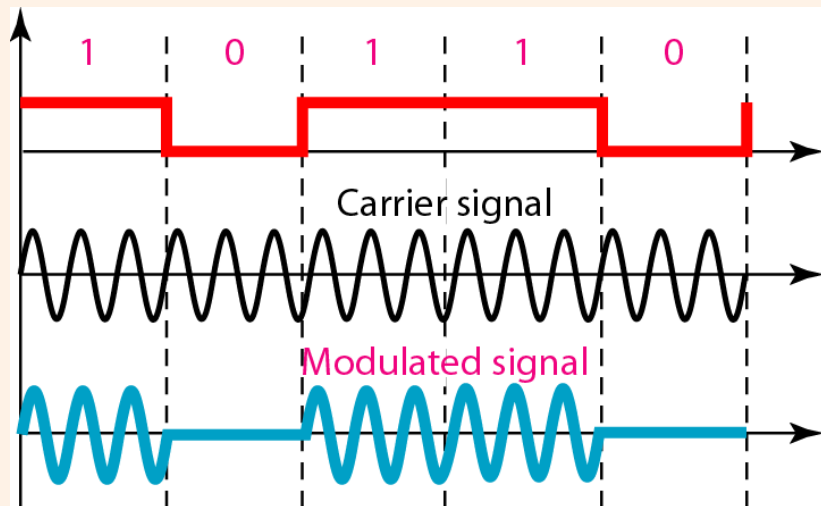


- In amplitude shift keying, the **amplitude of the carrier signal** is varied to create signal elements. Both **frequency** and **phase** remain constant while the amplitude changes.

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 $f_c = 250$ 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.

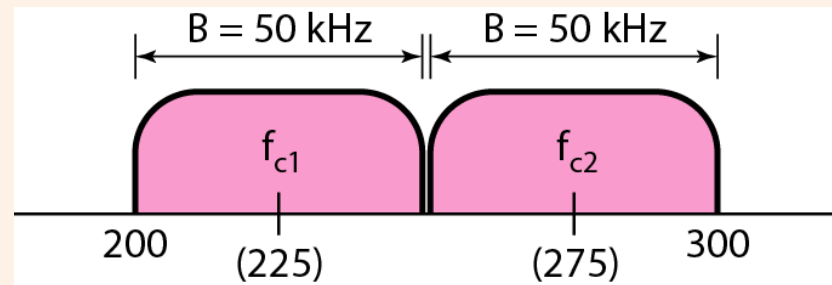


Figure 5.5: Bandwidth of a full-duplex ASK

Frequency Shift Keying



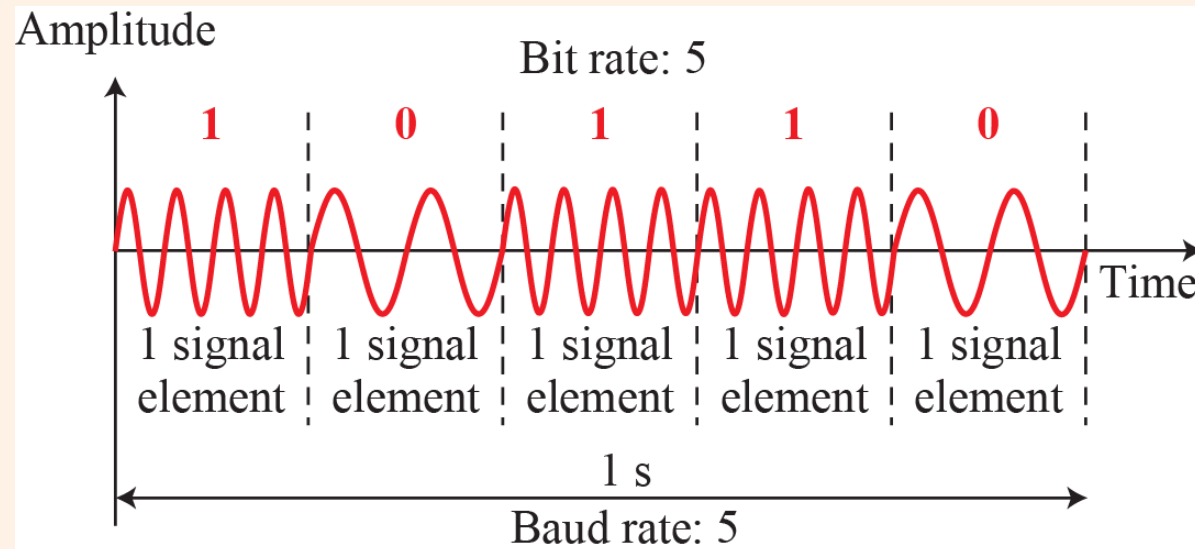
- In frequency shift keying, the **frequency** of the **carrier signal** is varied to represent data. The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes. Both peak amplitude and phase remain constant for all signal elements.

Frequency Shift Keying

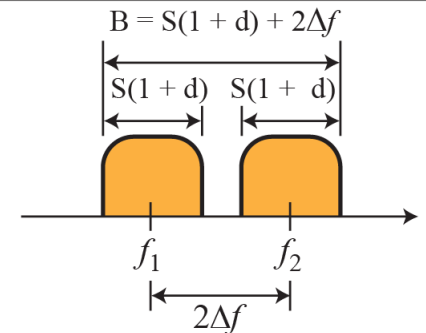


- In frequency shift keying, the **frequency of the carrier signal** is varied to represent data. The frequency of the modulated signal is **constant** for the duration **of one signal element**, but **changes** for the **next signal element** if the data element changes. Both peak amplitude and phase remain constant for all signal elements.

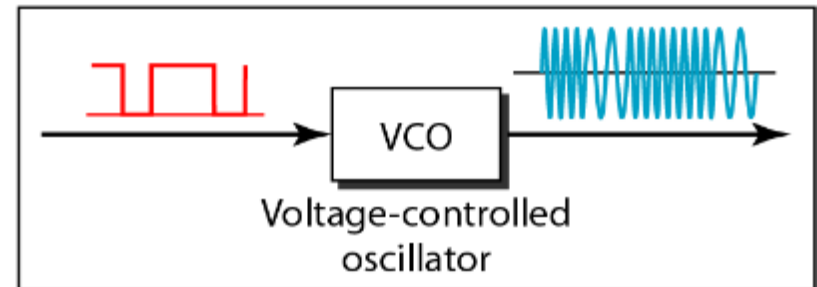
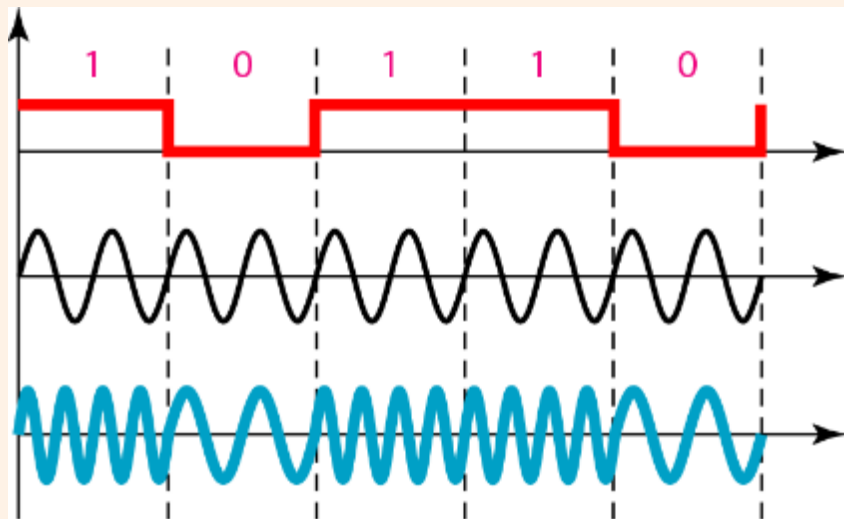
Binary Frequency Shift Keying



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



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 $2\Delta f$ to be 50 kHz; this means

Frequency Shift Keying

$$\text{Bandwidth} = (1+d) \times \text{Baud Rate } S + 2\Delta f$$

$$\text{Given: } 2\Delta f = 50\text{kHz}; \quad d=1; \quad \text{Bandwidth} = 100\text{kHz}$$

$$100\text{kHz} = (1+d) \times S + 50\text{kHz}$$

$$50\text{kHz} = 2S$$

$$S = 25\text{kbaud}$$

$$\text{Data rate } N = \text{Baud Rate } S \times r = 25\text{kbps}$$

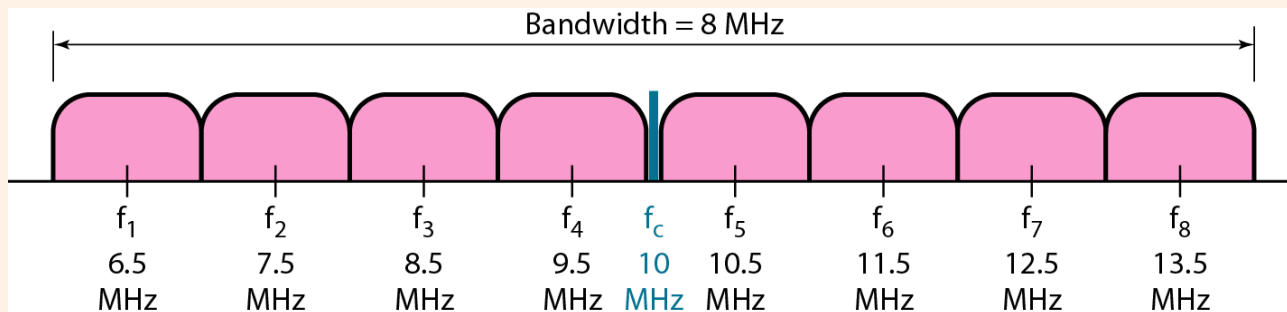
$$B = (1 + d) \times S + 2\Delta_f = 100 \longrightarrow 2S = 50 \text{ kHz} \longrightarrow S = 25 \text{ kbaud} \longrightarrow N = 25 \text{ kbps}$$

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 $S = 3 \text{ MHz}/3 = 1 \text{ Mbaud}$. This means that the carrier frequencies must be 1 MHz apart ($2\Delta f = 1 \text{ MHz}$). The bandwidth is $B = 8 \times 1 = 8 \text{ MHz}$.



Phase Shift Keying

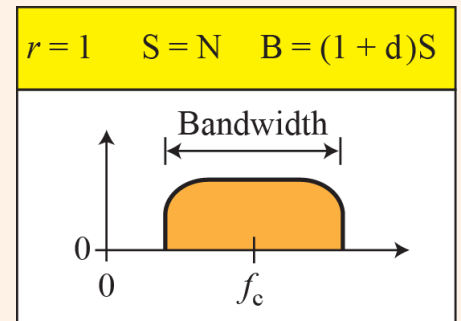
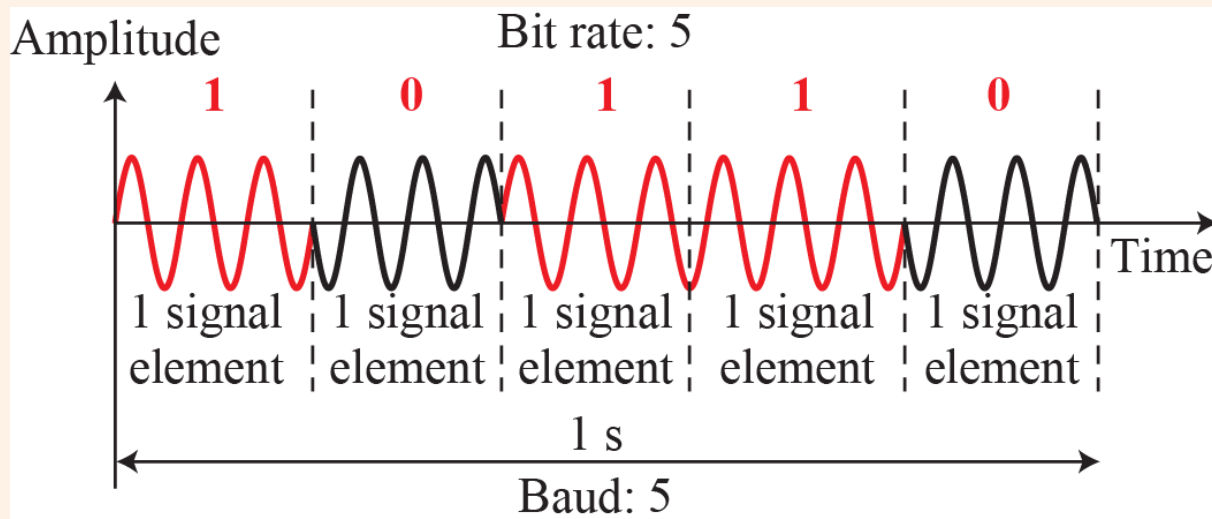


- In phase shift keying, the **phase of the carrier** is varied to represent **two or more different** signal elements. Both peak amplitude and frequency remain constant as the phase changes.
- Today, **PSK is more common** than ASK or FSK.
- However, we will see shortly that **QAM**, which combines ASK and PSK, is the **dominant method** of digital-to-analog modulation.

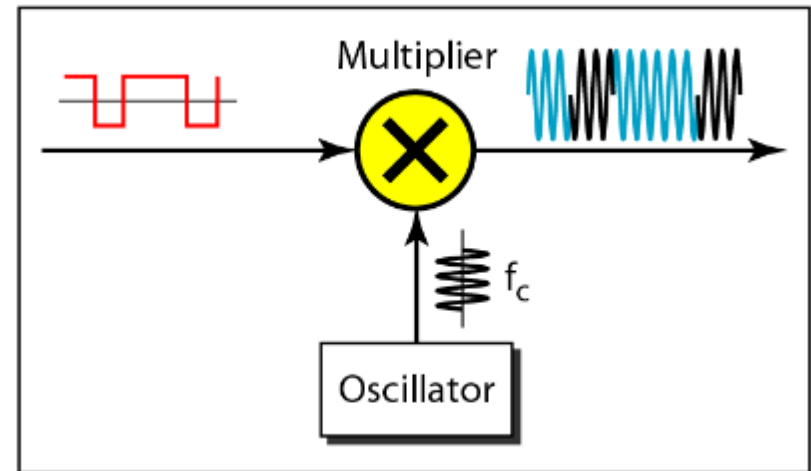
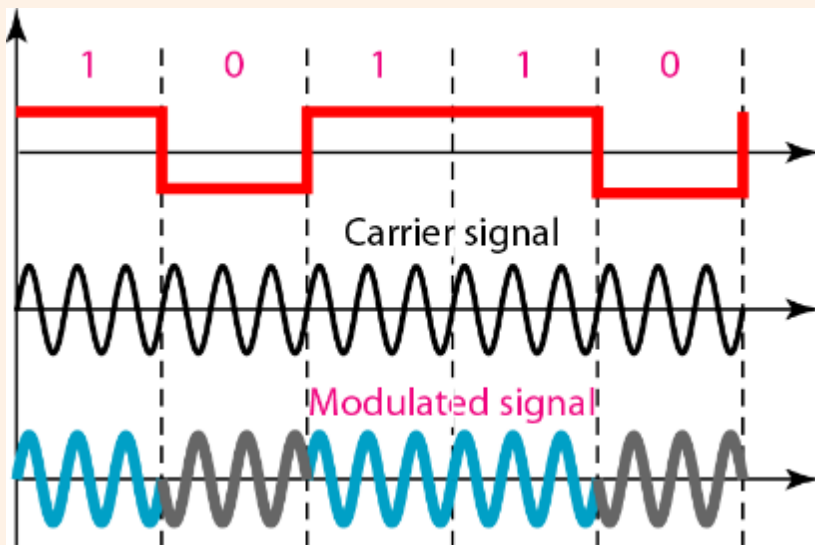


Binary Phase Shift Keying

- 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° .



Implementation of BPSK

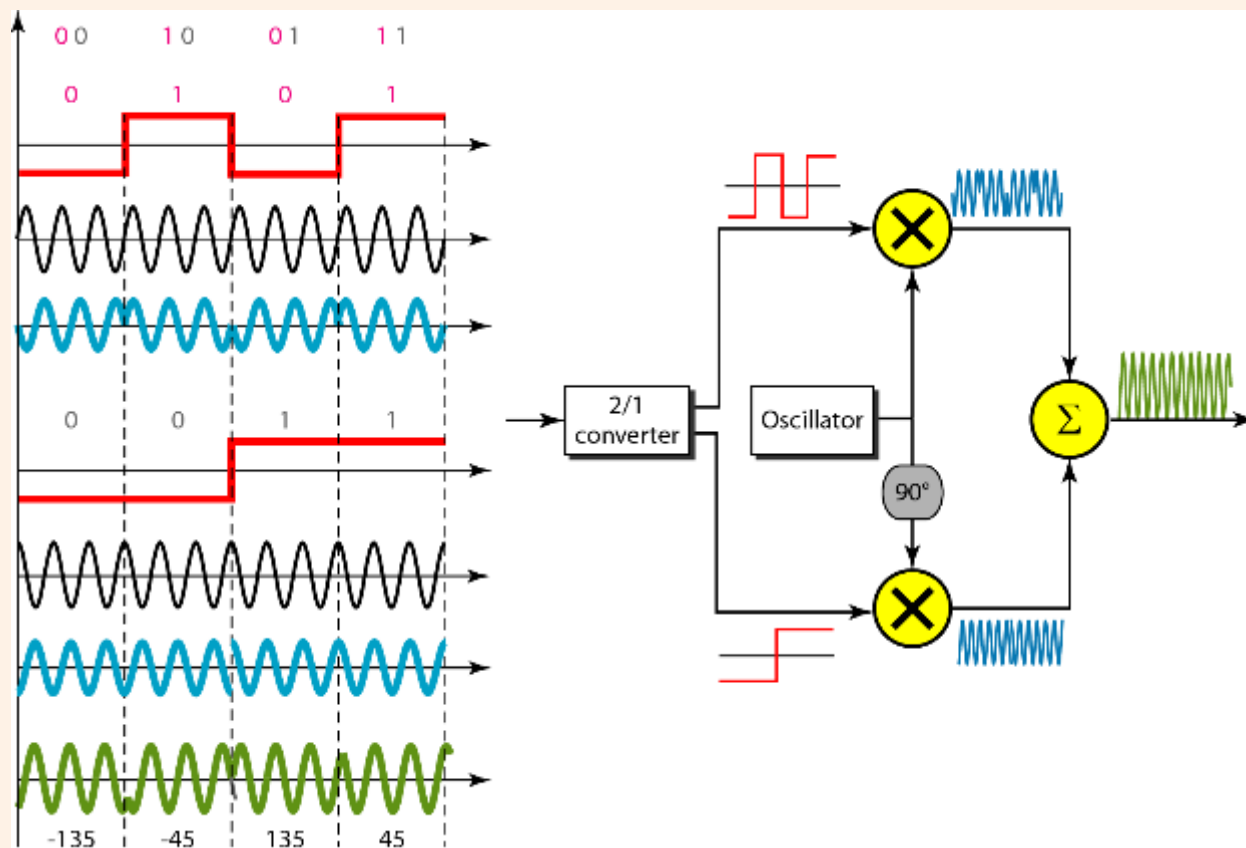


Quadrature PSK (QPSK)



- 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 **$2T$** .

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 $B = S(1+d) = 6$ MHz.

Constellation Diagram



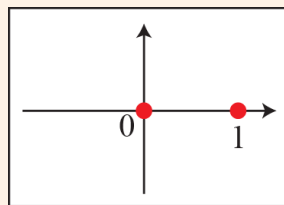
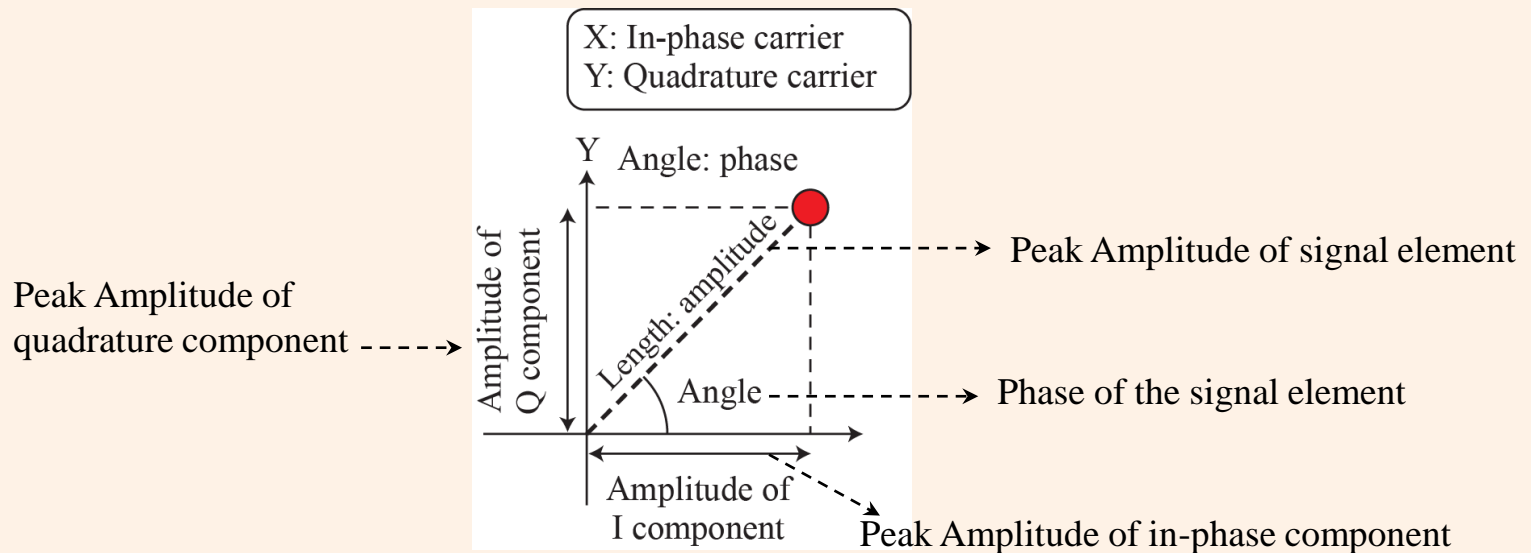
- A **constellation diagram** can help us define the **amplitude and phase of a signal element**, particularly when we are **using two carriers** (one in-phase and one quadrature).
- The diagram is useful when we are dealing with multilevel ASK, PSK, or QAM.
- In a constellation diagram, a **signal element**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

Constellation Diagram

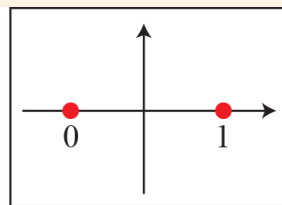


- The diagram has two axis. The horizontal **X axis** is related to the **in-phase carrier**; the vertical **Y axis** is related to the **quadrature carrier**.
- For each point on the diagram, four pieces of information can be deduced. The projection of the point on the **X axis** defines the **peak 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.

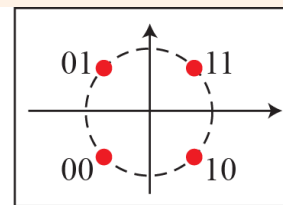
Constellation Diagram



a. BASK (OOK)



b. BPSK



c. QPSK

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. Let us analyze each case separately:

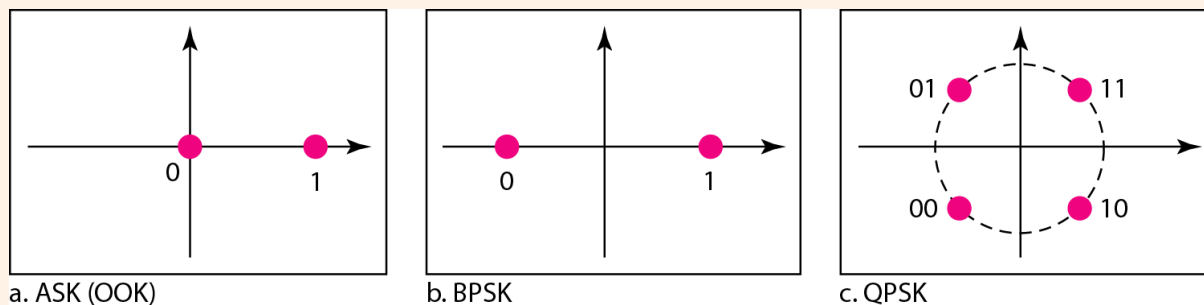


Figure 5.13: Three constellation diagrams

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.

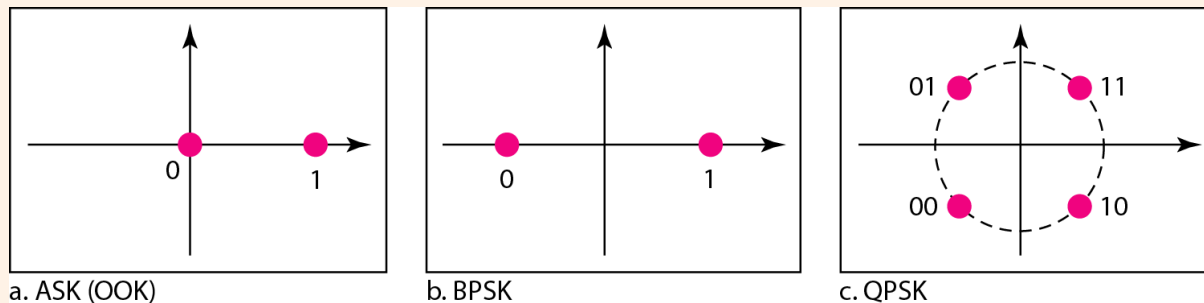


Figure 5.13: Three constellation diagrams

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 **0°** in phase and the other with amplitude **1 V** and **180°** out of phase.

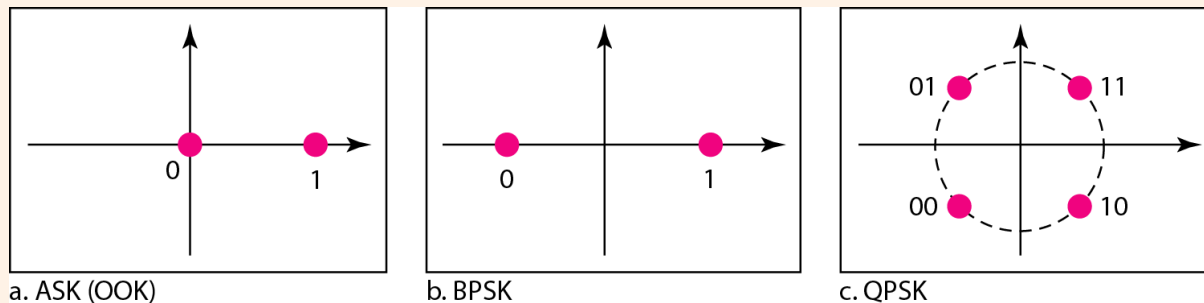


Figure 5.13: Three constellation diagrams

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°** .

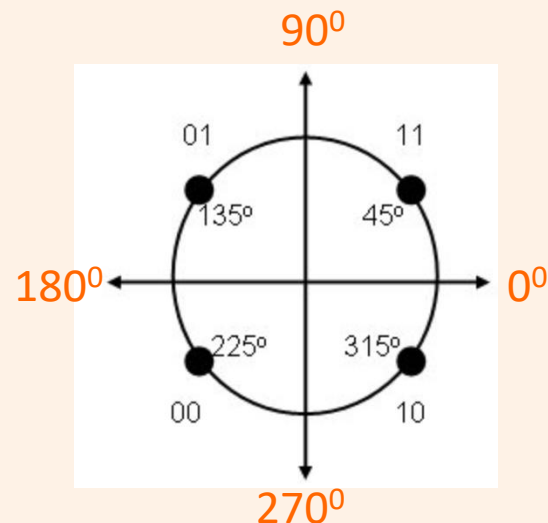
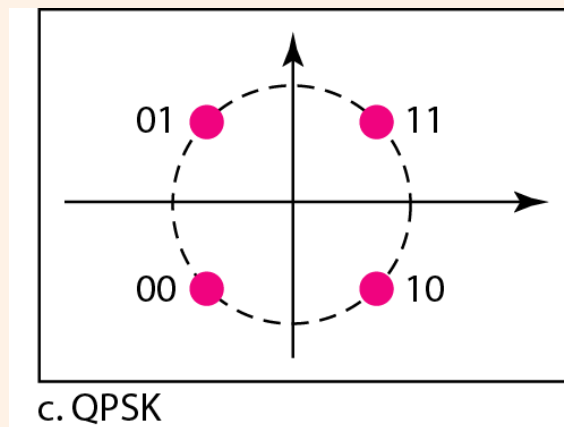
The argument is similar for the other three points.

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.



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).