



Chapter 5

Analog Transmission

5-1 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.

Topics discussed in this section:

- Aspects of Digital-to-Analog Conversion
- Amplitude Shift Keying
- Frequency Shift Keying
- Phase Shift Keying
- Quadrature Amplitude Modulation

Digital to Analog Conversion

- 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.

Figure 5.1 *Digital-to-analog conversion*

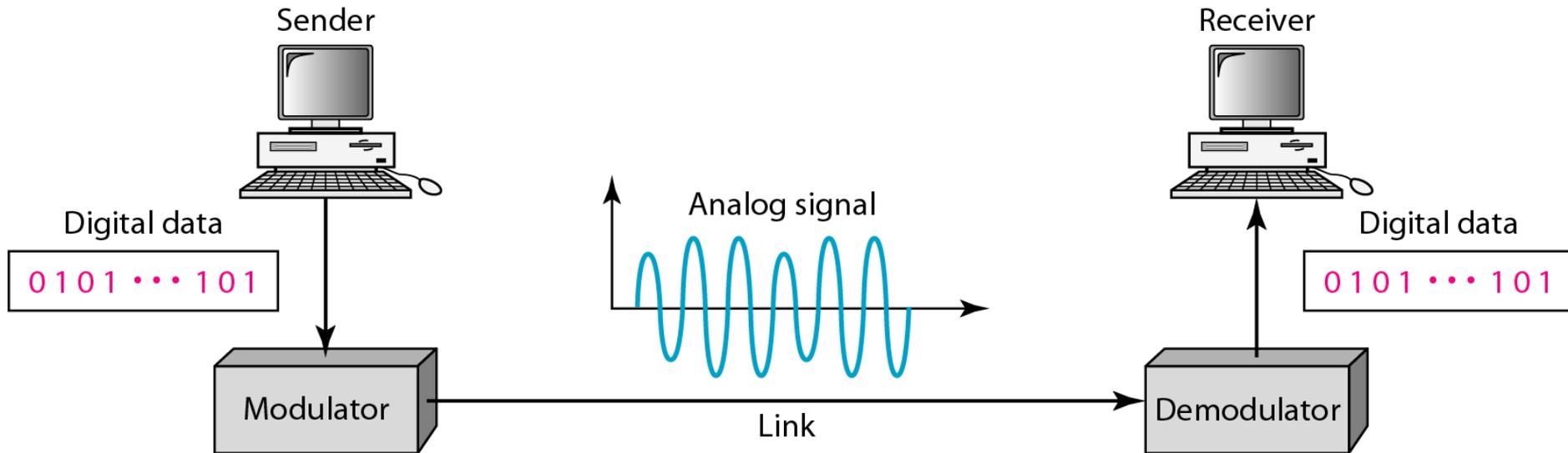
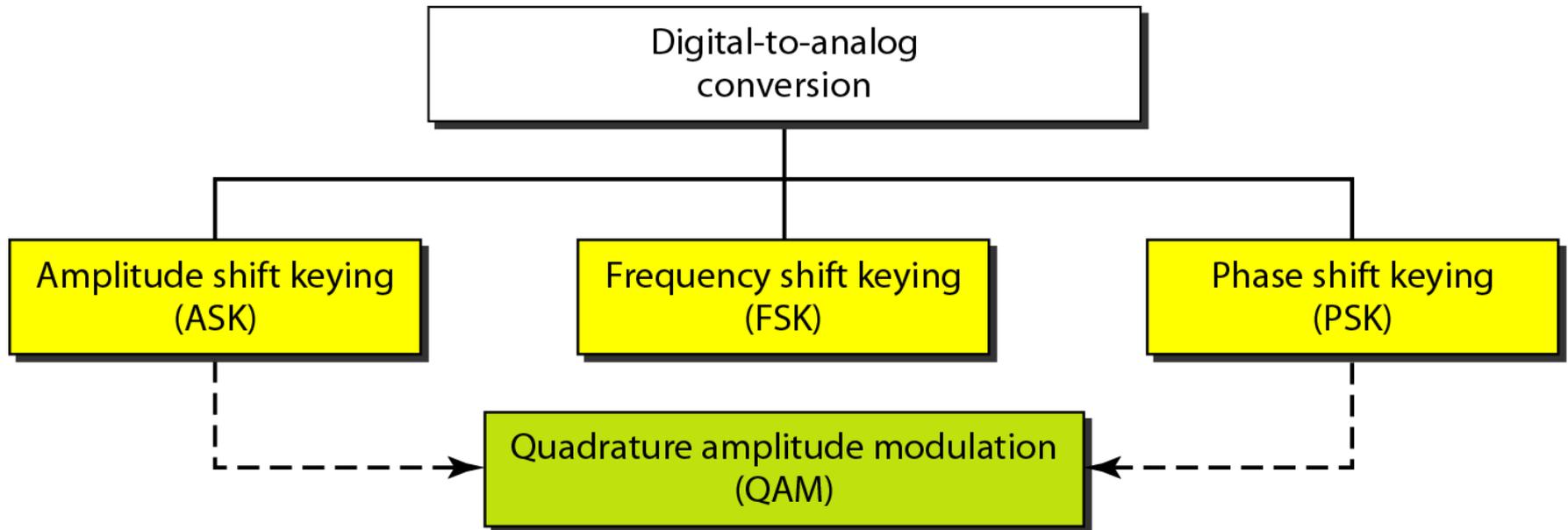
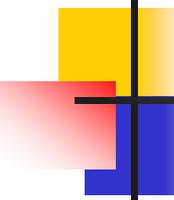


Figure 5.2 *Types of digital-to-analog conversion*





Note

Bit rate, N, is the number of bits per second (bps). Baud rate 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.

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

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

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 find first the value of r and then the value of L .

$$\begin{aligned} S = N \times \frac{1}{r} & \quad \rightarrow \quad r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud} \\ r = \log_2 L & \quad \rightarrow \quad L = 2^r = 2^8 = 256 \end{aligned}$$

Amplitude Shift Keying (ASK)

- ASK is implemented by changing the amplitude of a carrier signal to reflect amplitude levels in the digital signal.
- For 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.

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.

Figure 5.3 *Binary amplitude shift keying*

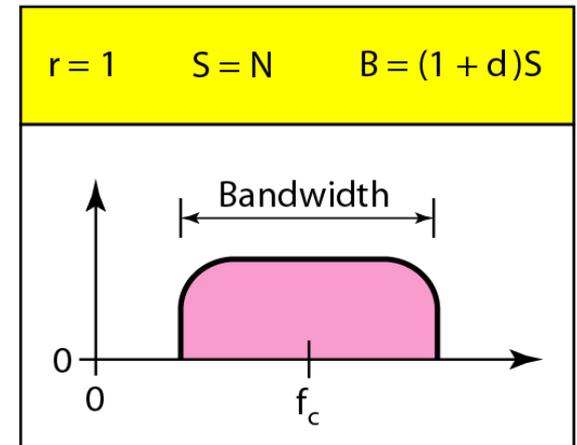
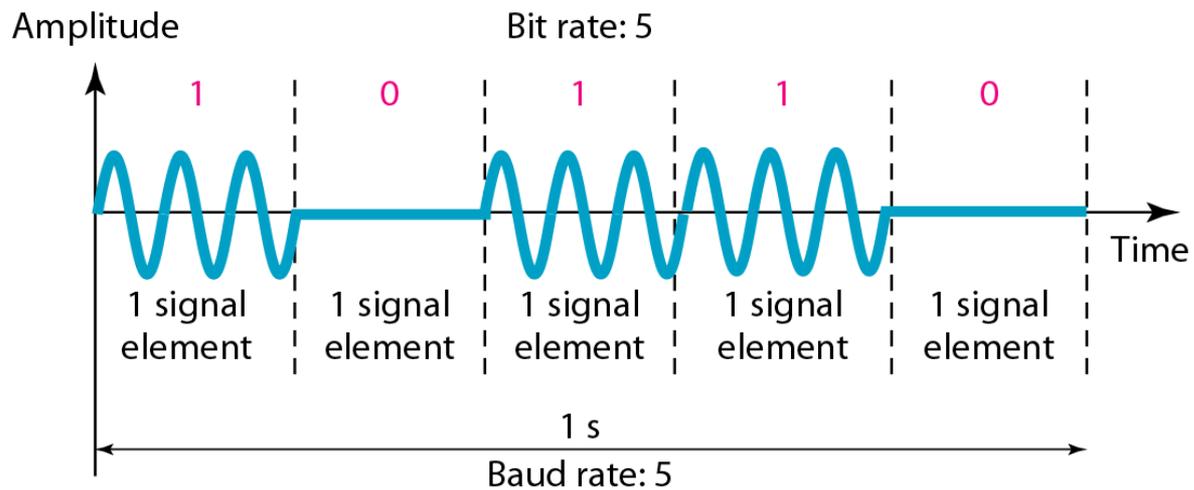
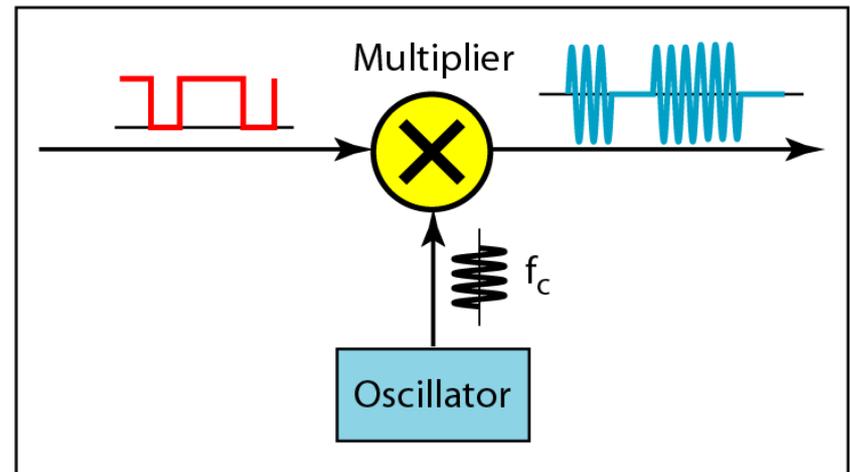
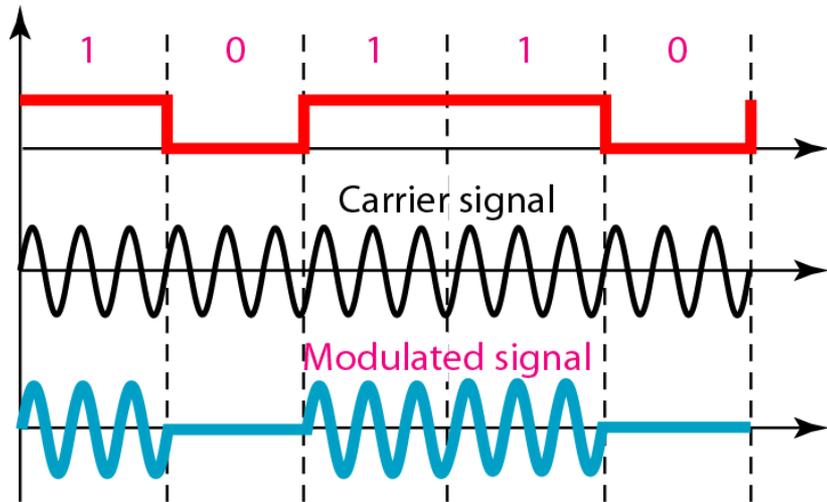


Figure 5.4 *Implementation of binary ASK*



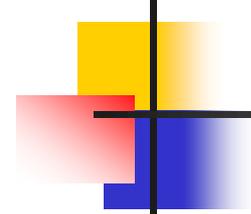
Example 5.3

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 $r = 1$).

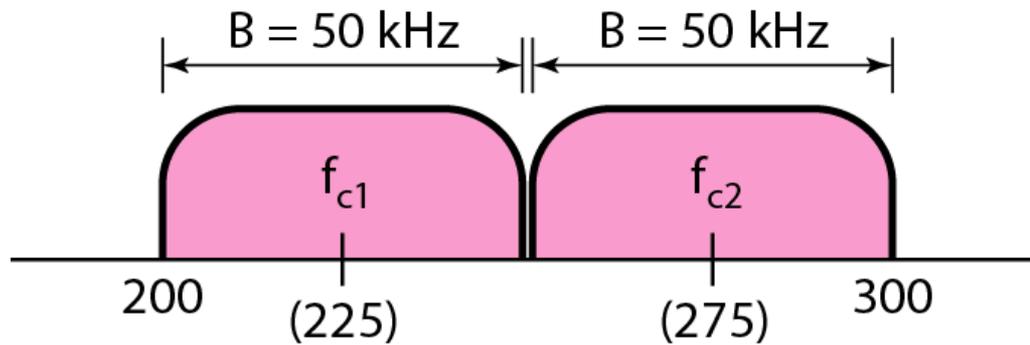
$$B = (1 + d) \times S = 2 \times N \times \frac{1}{r} = 2 \times N = 100 \text{ kHz} \quad \rightarrow \quad N = 50 \text{ kbps}$$



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.

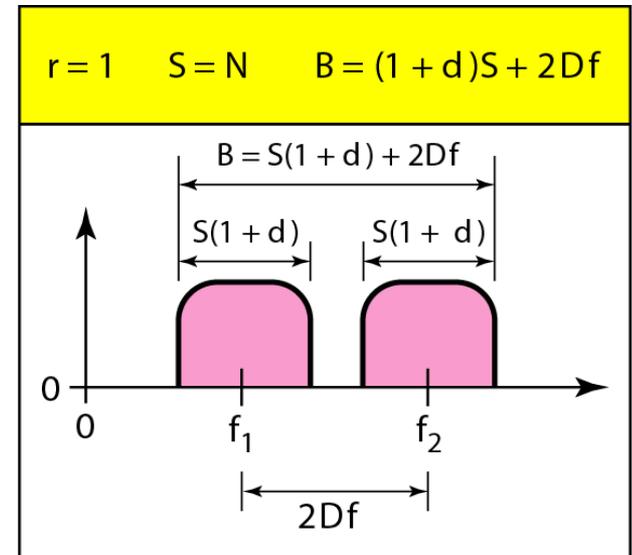
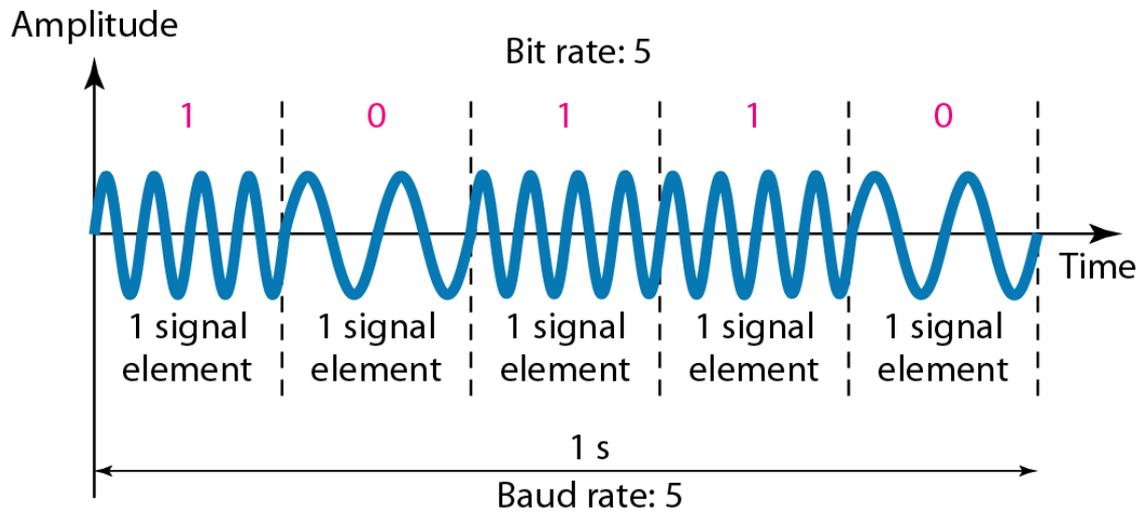
Figure 5.5 *Bandwidth of full-duplex ASK used in Example 5.4*



Frequency Shift Keying

- The digital data stream changes the frequency of the carrier signal, f_c .
- For example, a "1" could be represented by $f_1 = f_c + \Delta f$, and a "0" could be represented by $f_2 = f_c - \Delta f$.

Figure 5.6 *Binary frequency shift keying*



Bandwidth of FSK

- If the difference between the two frequencies (f_1 and f_2) is $2\Delta f$, then the required BW B will be:

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

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

$$B = (1 + d) \times S + 2\Delta f = 100 \quad \rightarrow \quad 2S = 50 \text{ kHz} \quad S = 25 \text{ kbaud} \quad N = 25 \text{ kbps}$$

Coherent and Non Coherent

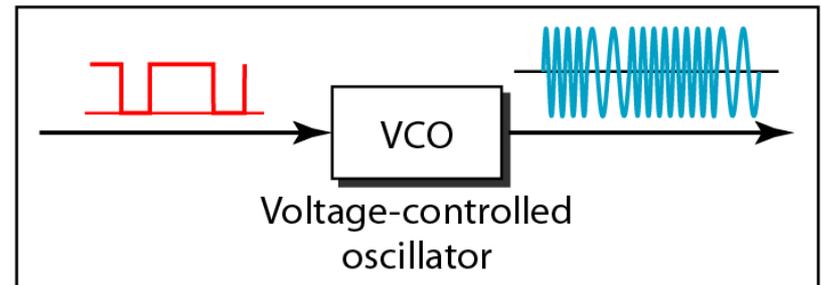
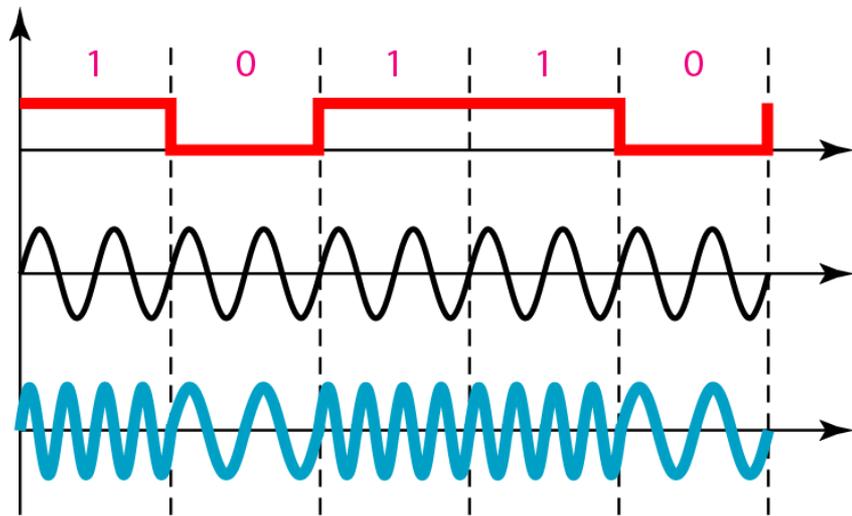
- In a non-coherent FSK scheme, when we change from one frequency to the other, we do not adhere to the current phase of the signal.
- In coherent FSK, the switch from one frequency signal to the other only occurs at the same phase in the signal.

Multi level FSK

- Similarly to ASK, 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.
- The bandwidth for FSK can be higher

$$B = (1+d) \times S + (L-1)/2 \Delta f = L \times S$$

Figure 5.7 *Bandwidth of MFSK used in Example 5.6*



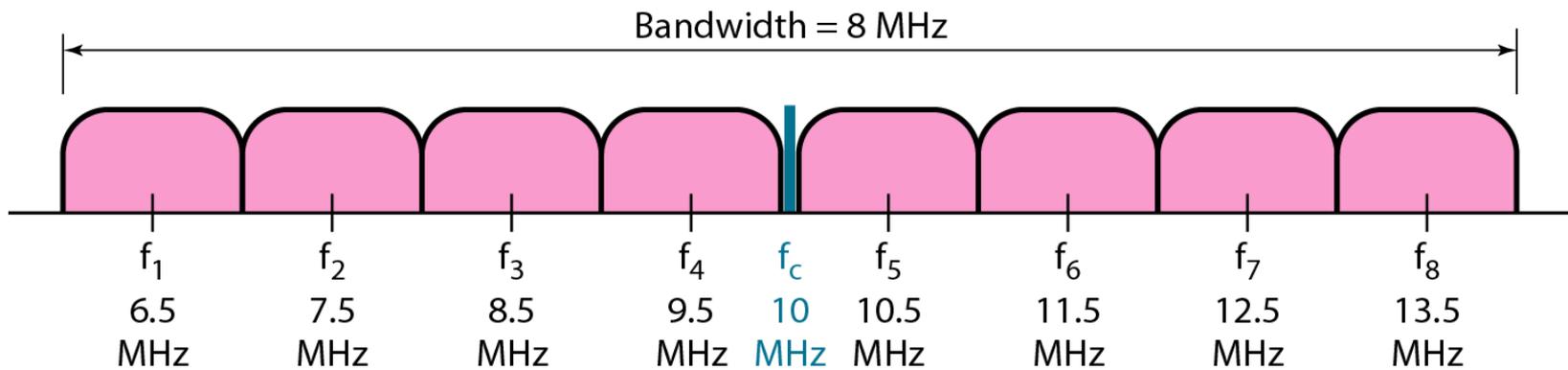
Example 5.6

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 $S = 3 \text{ Mbps}/3 = 1 \text{ Mbaud}$. This means that the carrier frequencies must be 1 MHz apart ($2\Delta f = 1 \text{ MHz}$). The bandwidth is $B = 8 \times 1\text{M} = 8\text{M}$. Figure 5.8 shows the allocation of frequencies and bandwidth.

Figure 5.8 *Bandwidth of MFSK used in Example 5.6*



Phase Shift Keying

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

Figure 5.9 *Binary phase shift keying*

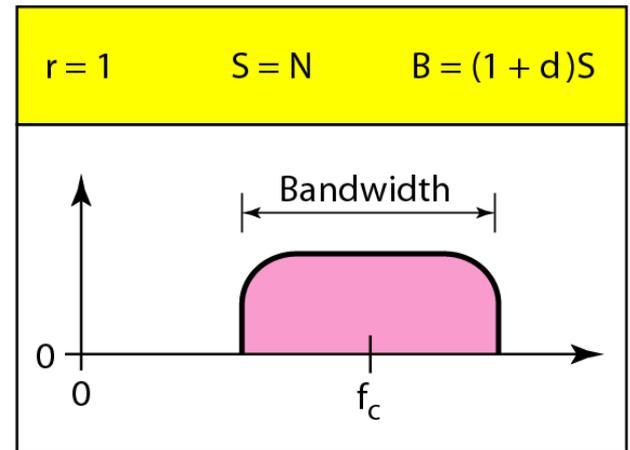
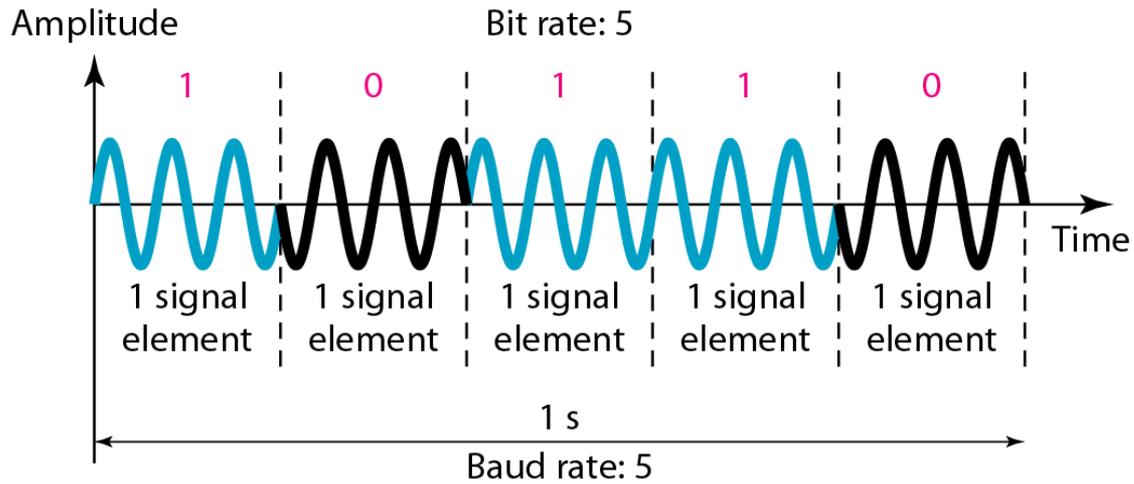
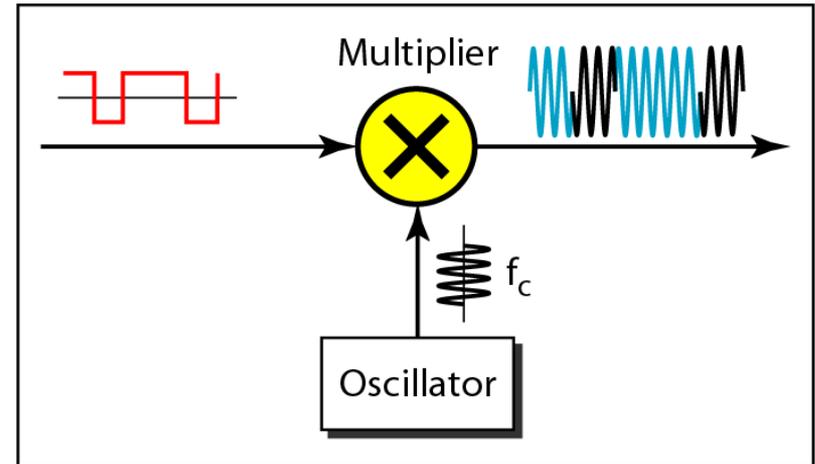
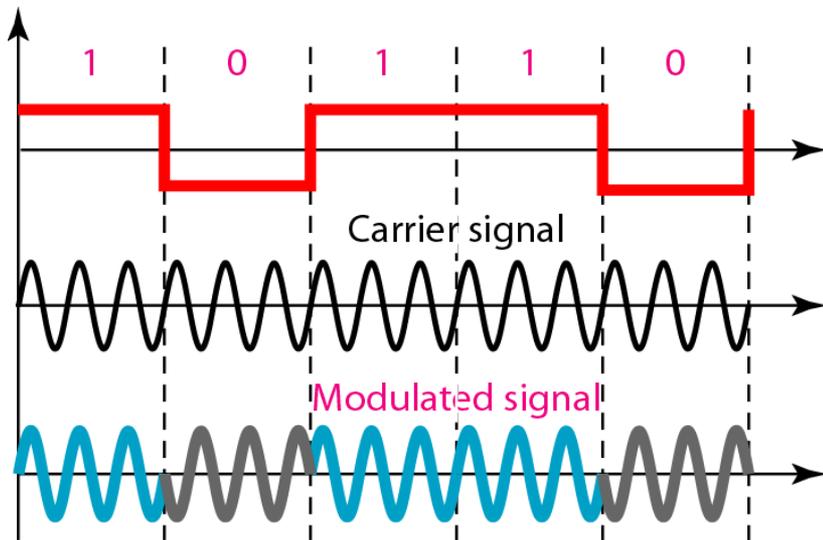


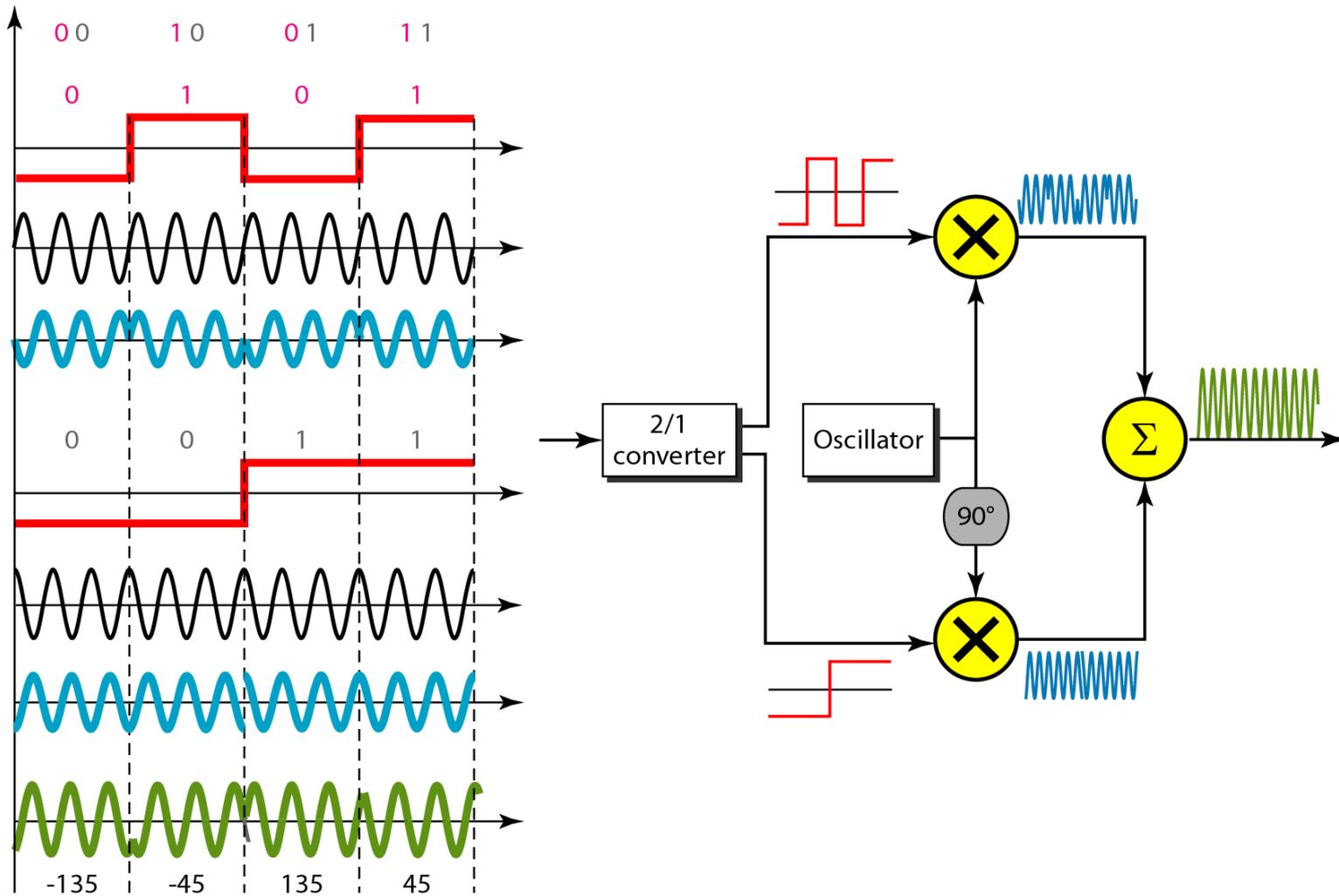
Figure 5.10 *Implementation of BASK*

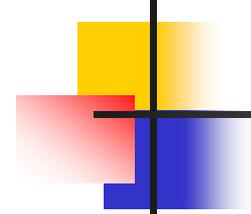


Quadrature PSK

- To increase the bit rate, we can code 2 or more bits onto one signal element.
- In QPSK, we parallelize the bit stream so that every two incoming bits are split up and PSK a carrier frequency. One carrier frequency is phase shifted 90° from the other - in quadrature.
- The two PSKed signals are then added to produce one of 4 signal elements. $L = 4$ here.

Figure 5.11 *QPSK and its implementation*





Example 5.7

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

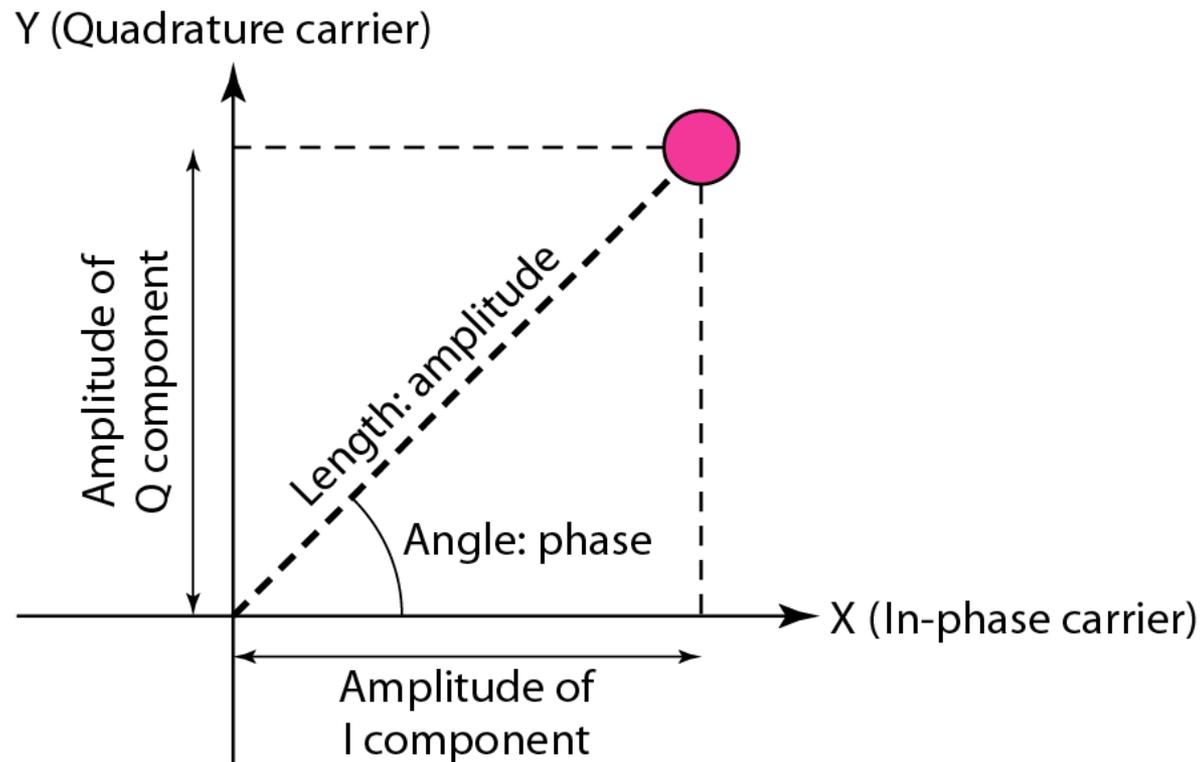
Solution

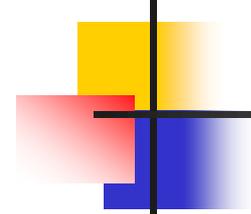
For QPSK, 2 bits is carried by one signal element. This means that $r = 2$. So the signal rate (baud rate) is $S = N \times (1/r) = 6$ Mbaud. With a value of $d = 0$, we have $B = S = 6$ MHz.

Constellation Diagrams

- A constellation diagram helps us to define the amplitude and phase of a signal when we are using two carriers, one in quadrature of the other.
- The X-axis represents the in-phase carrier and the Y-axis represents quadrature carrier.

Figure 5.12 *Concept of a constellation diagram*





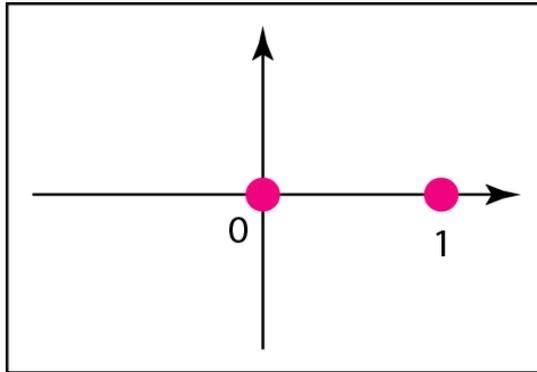
Example 5.8

Show the constellation diagrams for an ASK (OOK), BPSK, and QPSK signals.

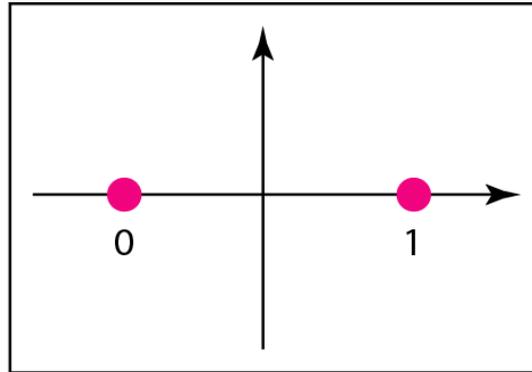
Solution

Figure 5.13 shows the three constellation diagrams.

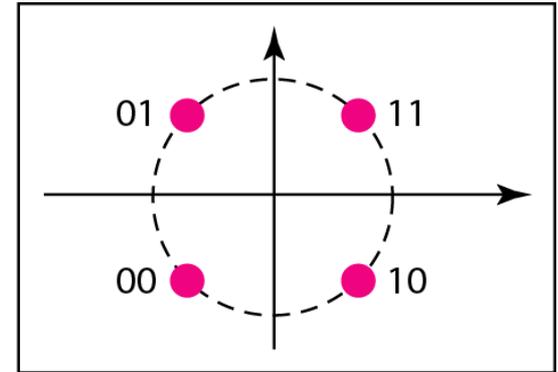
Figure 5.13 *Three constellation diagrams*



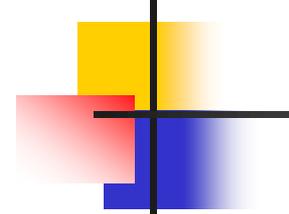
a. ASK (OOK)



b. BPSK



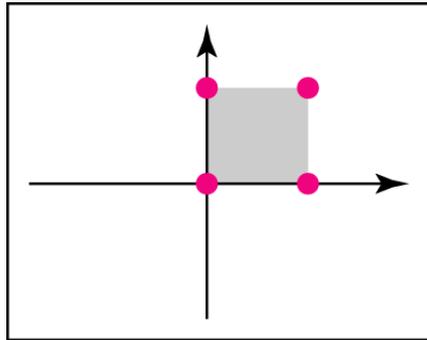
c. QPSK



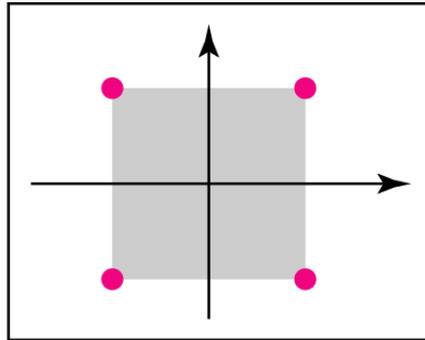
Note

Quadrature amplitude modulation is a combination of ASK and PSK.

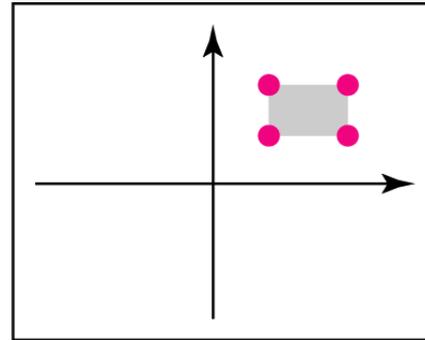
Figure 5.14 *Constellation diagrams for some QAMs*



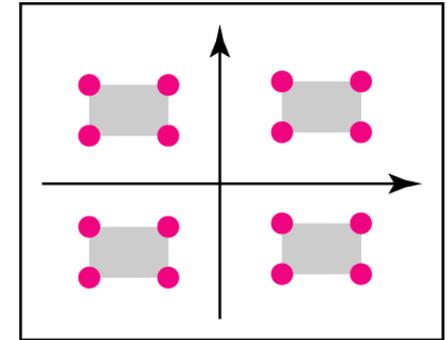
a. 4-QAM



b. 4-QAM



c. 4-QAM



d. 16-QAM



Chapter 5

Analog Transmission

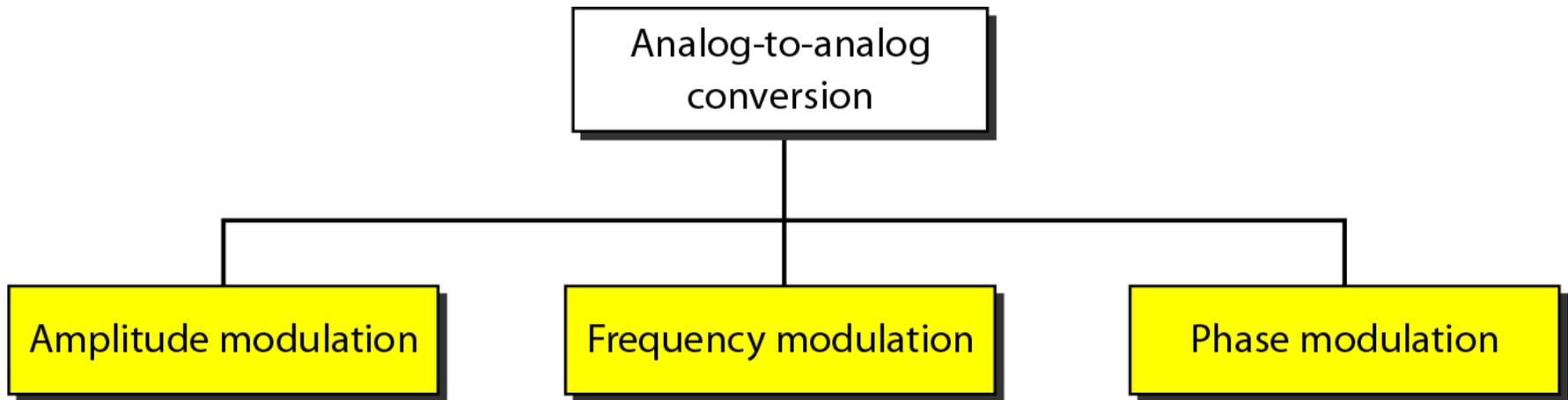
5-2 ANALOG AND DIGITAL

Analog-to-analog conversion is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us.

Topics discussed in this section:

- **Amplitude Modulation**
- **Frequency Modulation**
- **Phase Modulation**

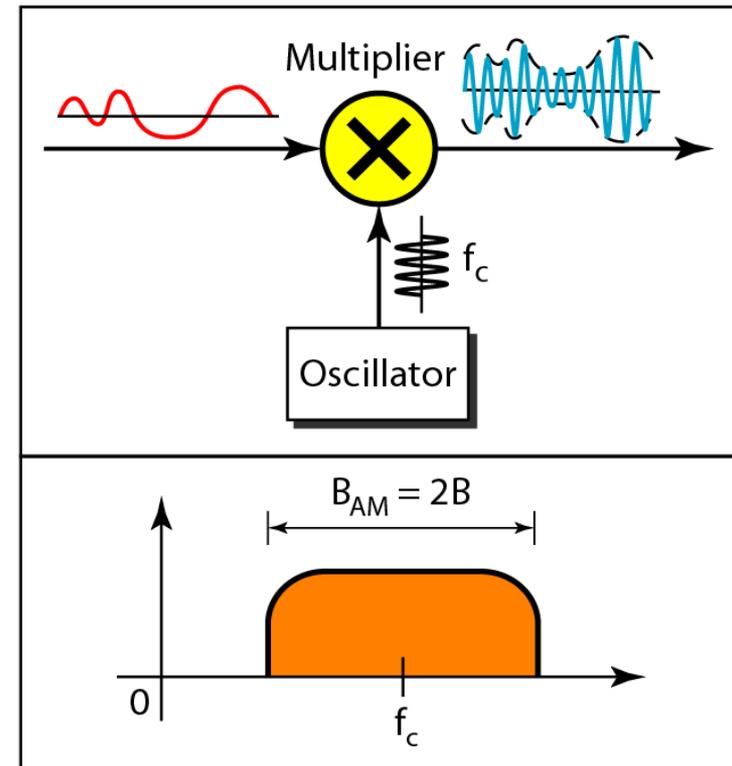
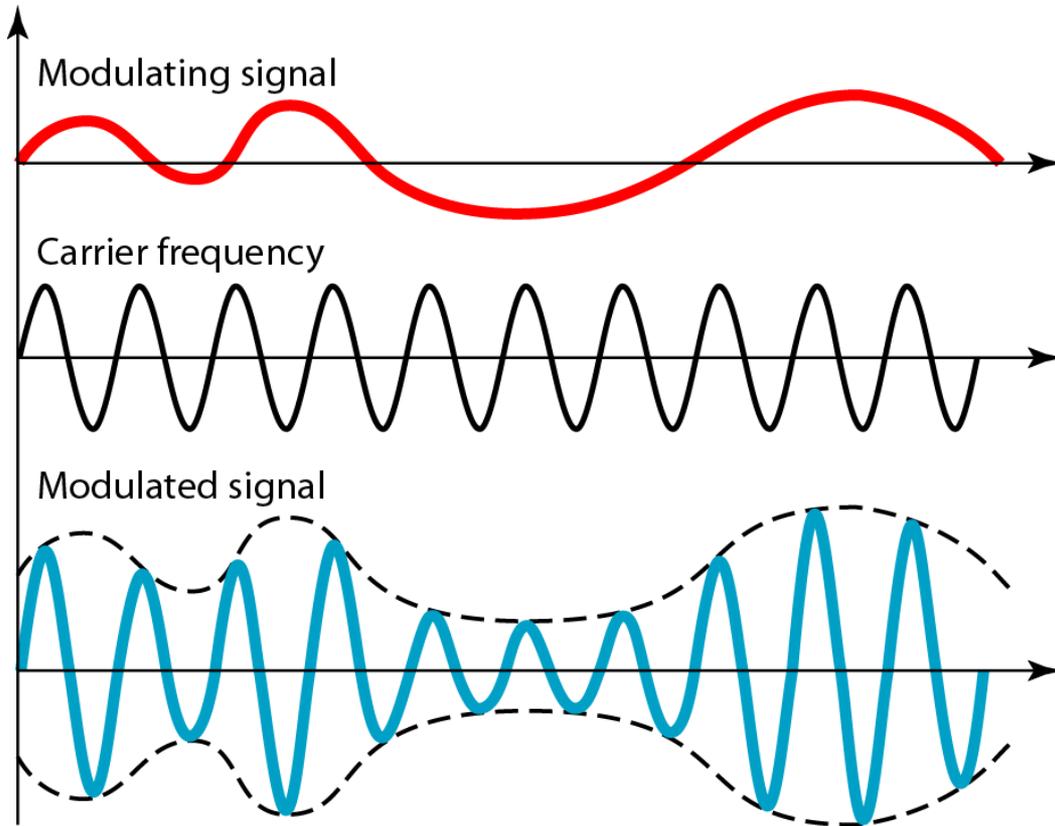
Figure 5.15 *Types of analog-to-analog modulation*

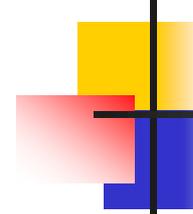


Amplitude Modulation

- A carrier signal is modulated only in amplitude value
- The modulating signal is the envelope of the carrier
- The required bandwidth is $2B$, where B is the bandwidth of the modulating signal
- Since on both sides of the carrier freq. f_c , the spectrum is identical, we can discard one half, thus requiring a smaller bandwidth for transmission.

Figure 5.16 *Amplitude modulation*

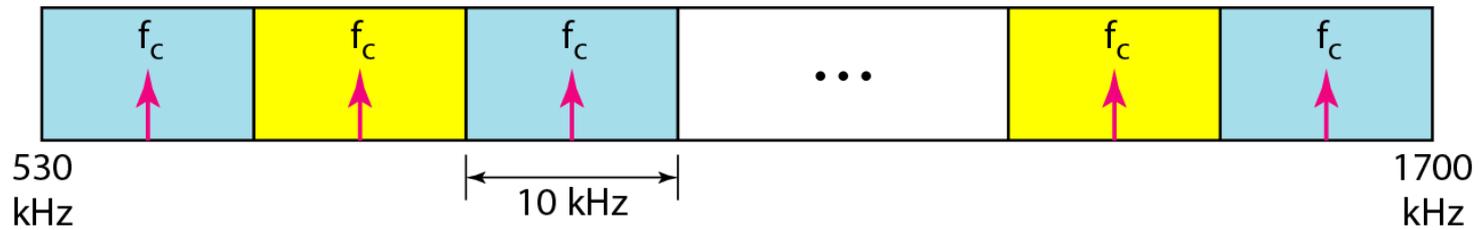




Note

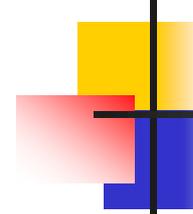
**The total bandwidth required for AM
can be determined
from the bandwidth of the audio
signal: $B_{AM} = 2B$.**

Figure 5.17 *AM band allocation*



Frequency Modulation

- The modulating signal changes the freq. f_c of the carrier signal
- The bandwidth for FM is high
- It is approx. 10x the signal frequency



Note

**The total bandwidth required for FM can be determined from the bandwidth of the audio signal: $B_{FM} = 2(1 + \beta)B$.
Where β is usually 4.**

Figure 5.18 *Frequency modulation*

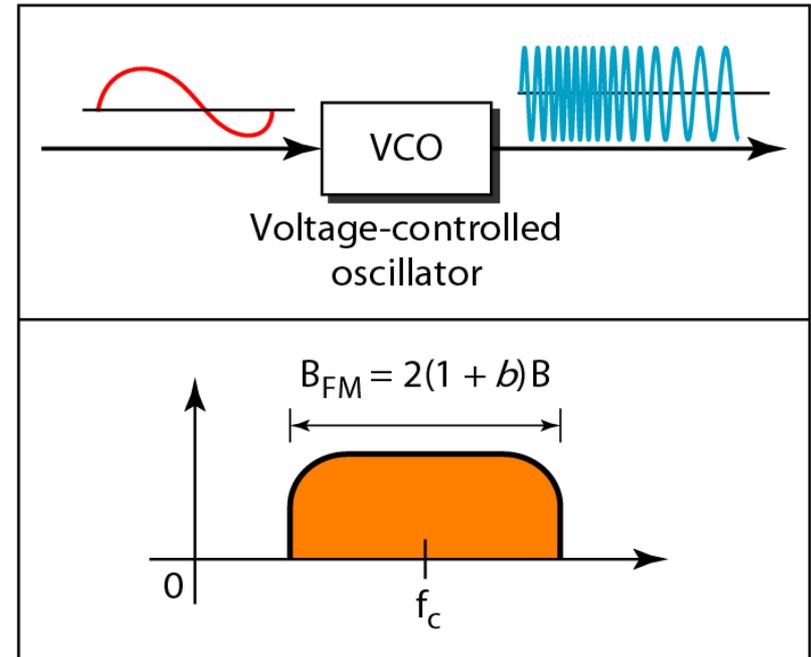
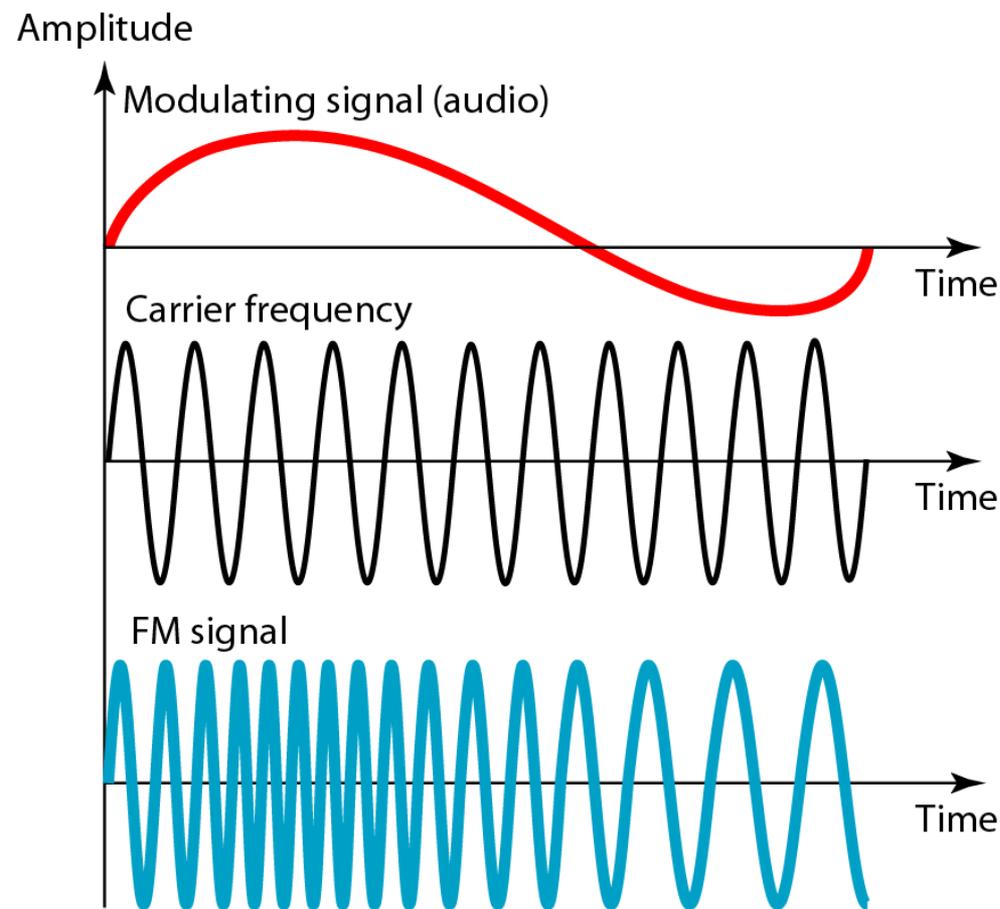
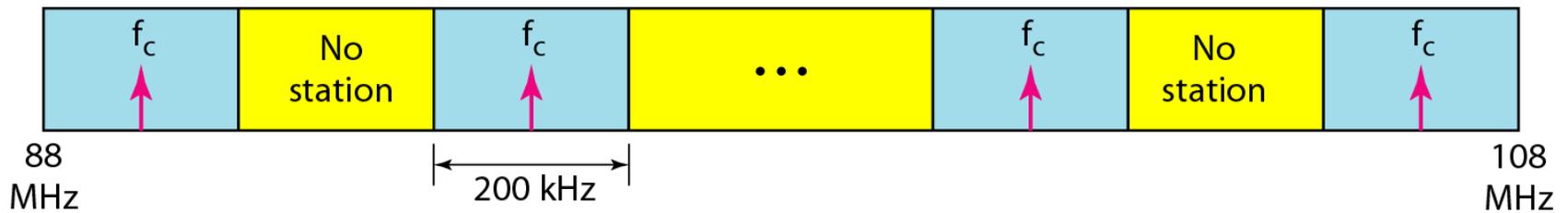


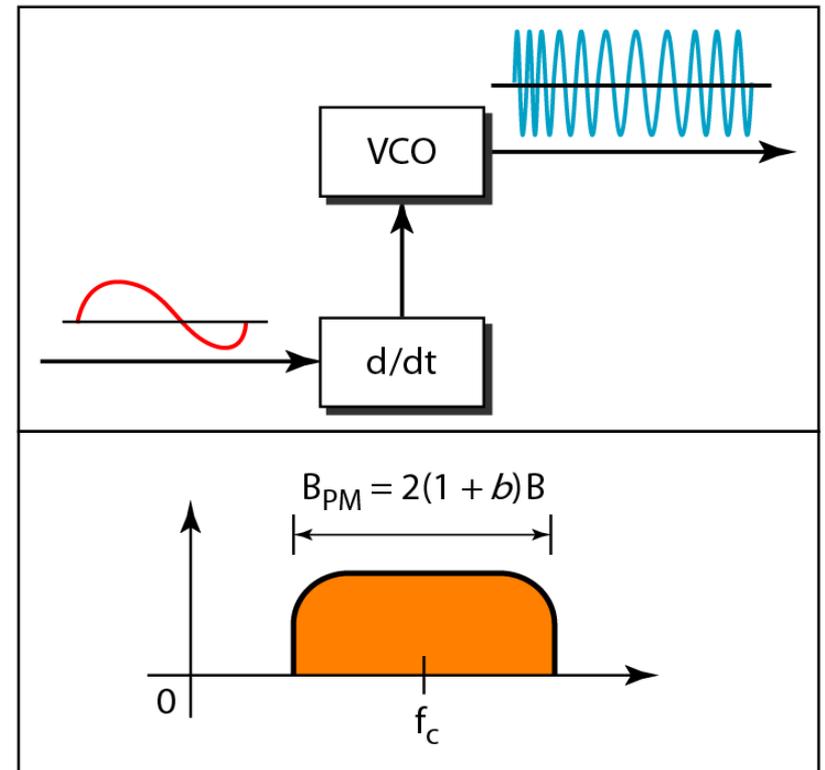
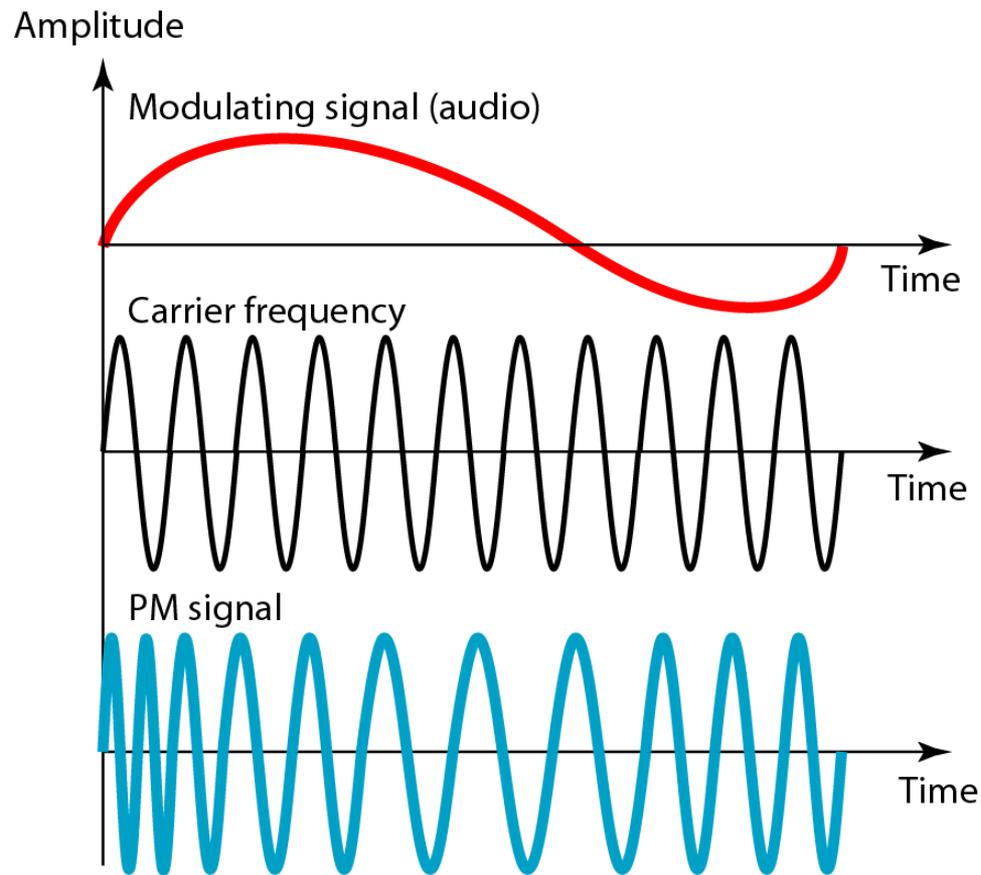
Figure 5.19 *FM band allocation*

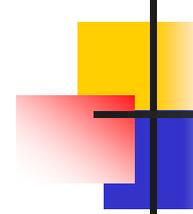


Phase Modulation (PM)

- The modulating signal only changes the phase of the carrier signal.
- The phase change manifests itself as a frequency change but the instantaneous frequency change is proportional to the derivative of the amplitude.
- The bandwidth is higher than for AM.

Figure 5.20 *Phase modulation*





Note

The total bandwidth required for PM can be determined from the bandwidth and maximum amplitude of the modulating signal:

$$B_{PM} = 2(1 + \beta)B.$$

Where $\beta = 2$ most often.