

FIFTH EDITION

Data Communications AND Networking



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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

Figure 5.1 *Digital-to-analog conversion*

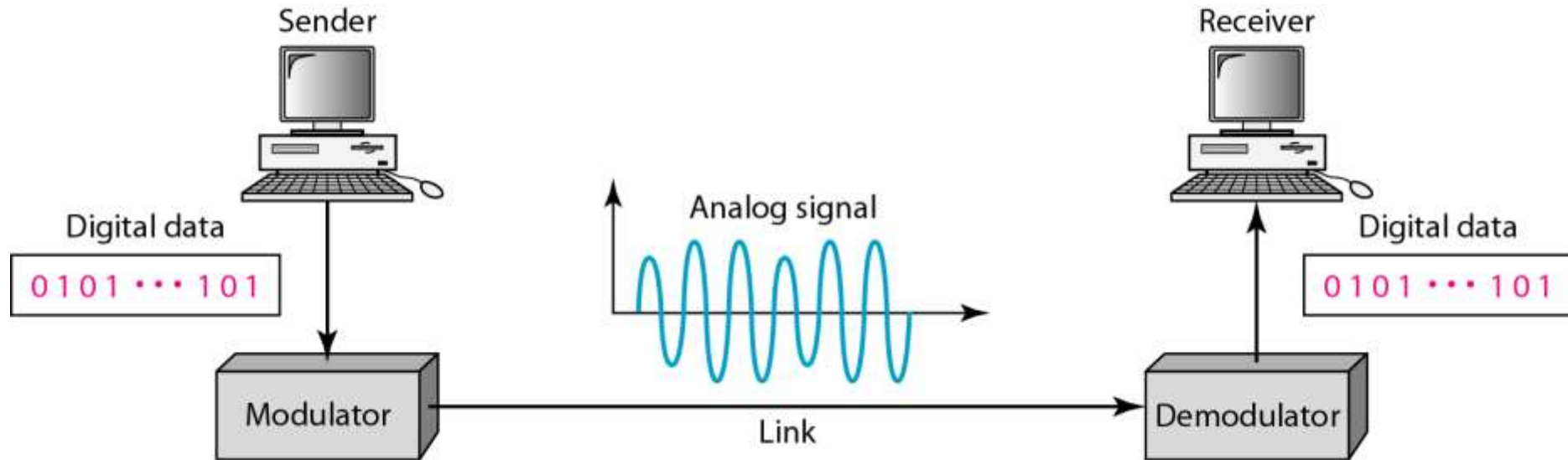
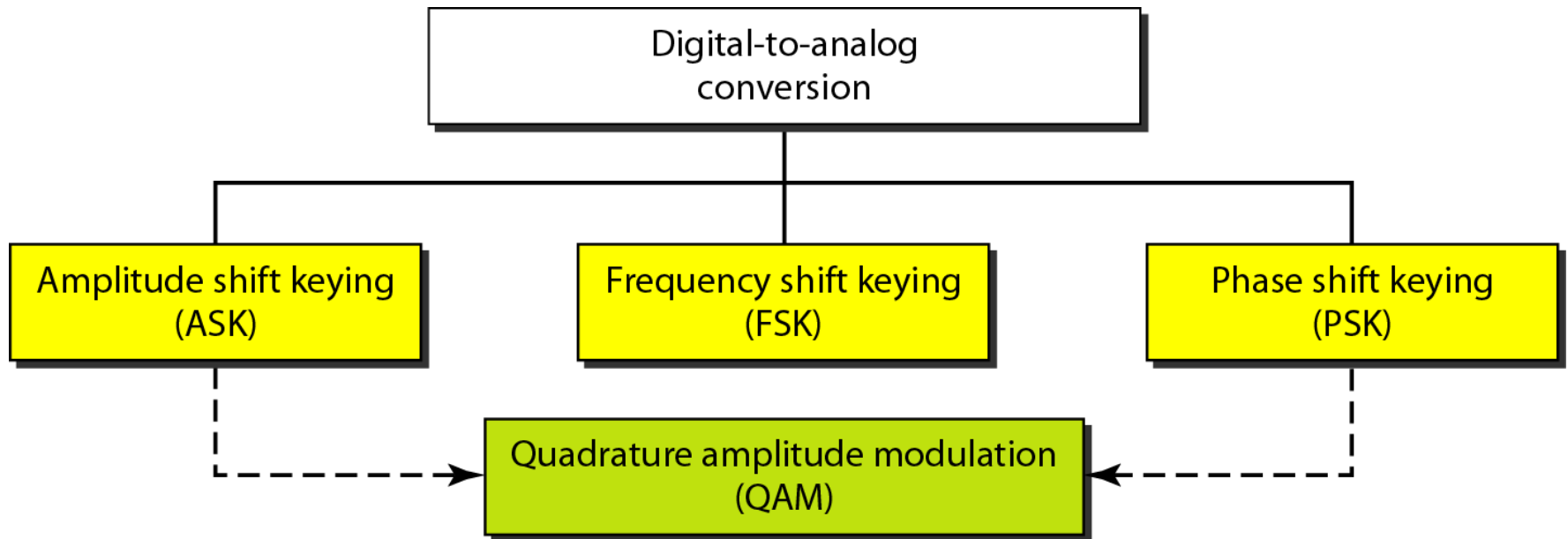


Figure 5.2 *Types of digital-to-analog conversion*



Note

**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.**

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 .

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

Carrier Signal

- The required bandwidth for analog transmission of digital data is proportional to the signal rate except for FSK, in which the difference between the carrier signals needs to be added.
- Carrier signal
 - In analog transmission, the sending device produce a high-frequency signal that acts as a base for the information signal. This base signal is called the **carrier signal** or *carrier frequency*.
- Digital information changes the carrier signal by modifying one or more of its characteristics (**amplitude**, **frequency**, or **phase**).

Figure 5.3 *Binary amplitude shift keying*

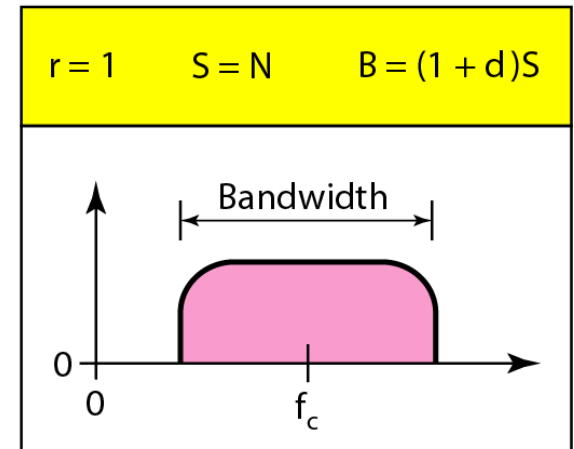
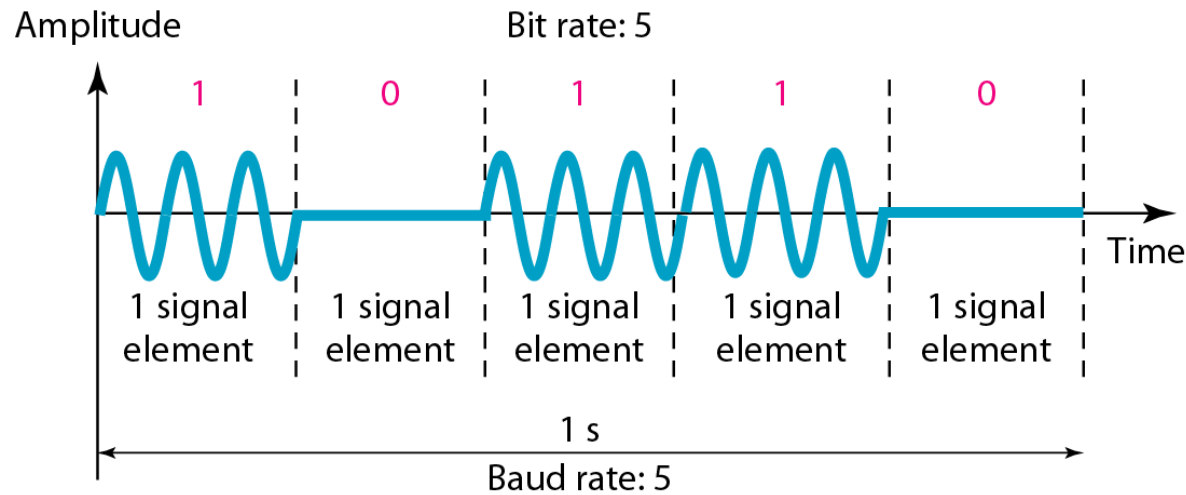
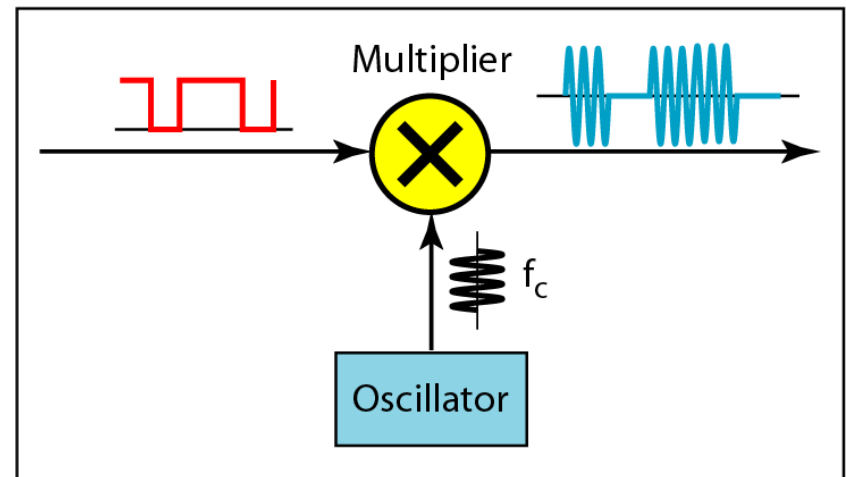
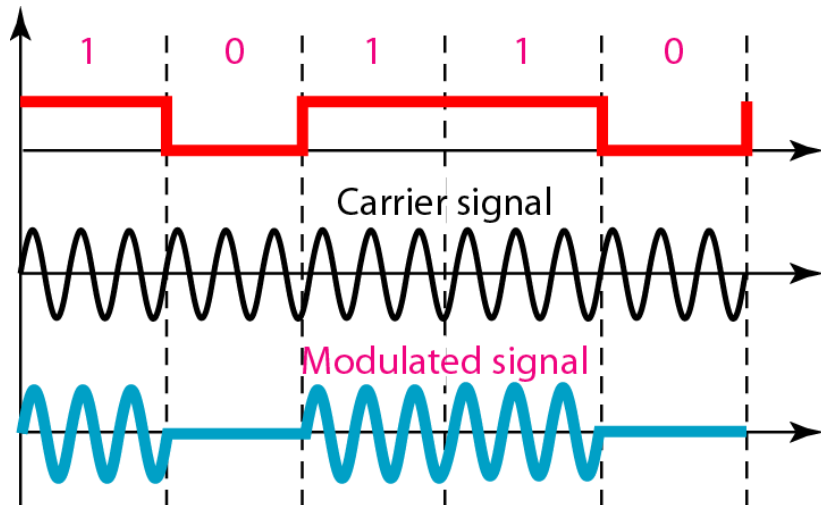


Figure 5.4 *Implementation of binary ASK*



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*

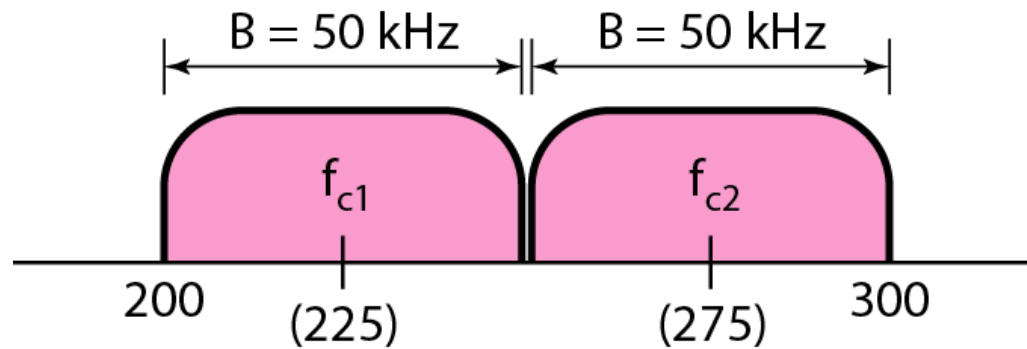
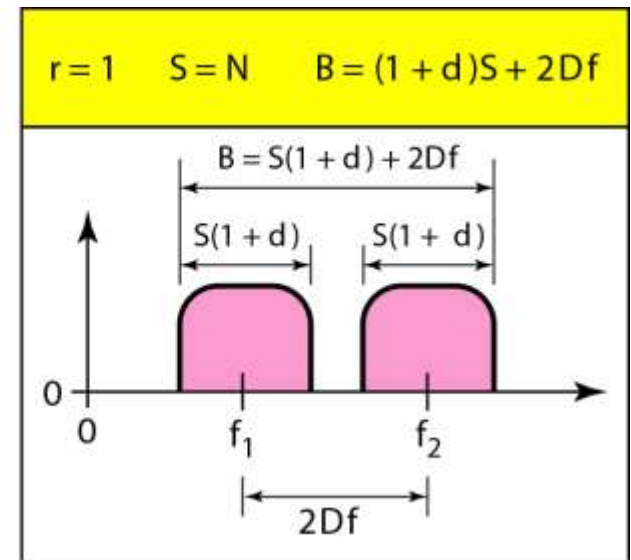
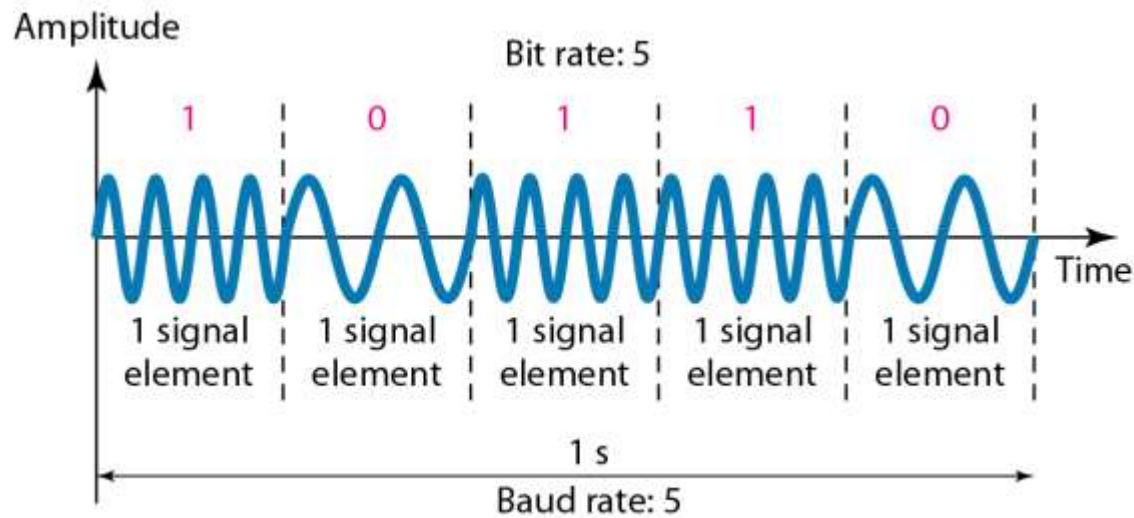


Figure 5.6 *Binary frequency shift keying*



Example 5.5

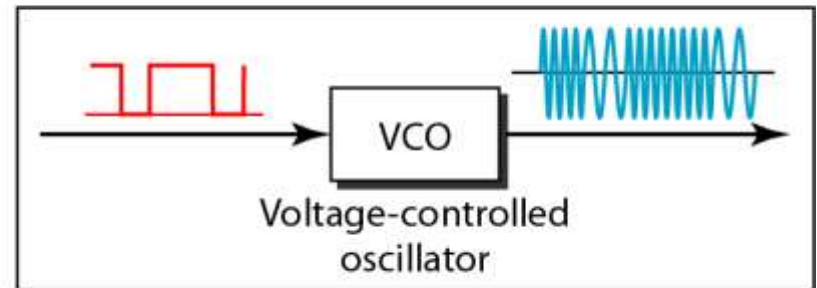
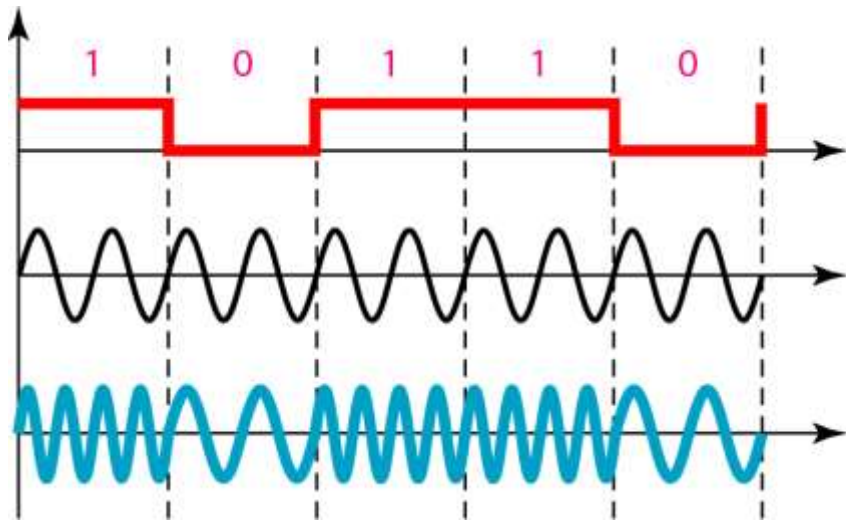
We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with $d = 1$?

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

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

Figure 5.7 *Implementation of BFSK*



Multilevel FSK

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

The minimum value of $2\Delta f$ should be at least S for the proper operation of modulation and demodulation.

$$B = L \times S$$

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 $L = 2^3 = 8$. (Thus 8 frequency band) The baud rate is $S = N \times 1/r = 3 \text{ MHz}/3 = 1 \text{ Mbaud}$.

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

Figure 5.8 *Bandwidth of MFSK used in Example 5.6*

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

$$B = L \times S$$

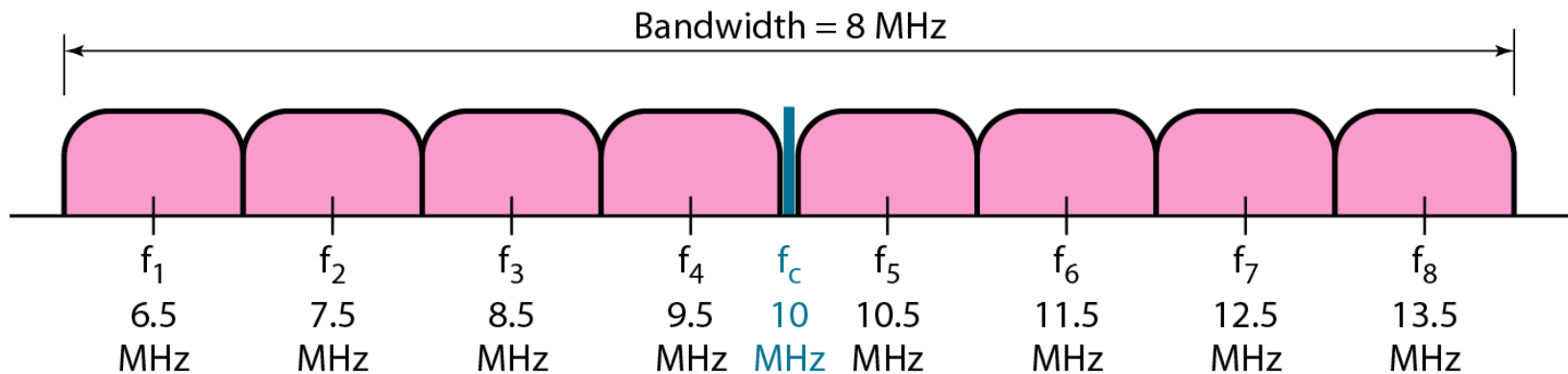


Figure 5.9 *Binary phase shift keying*

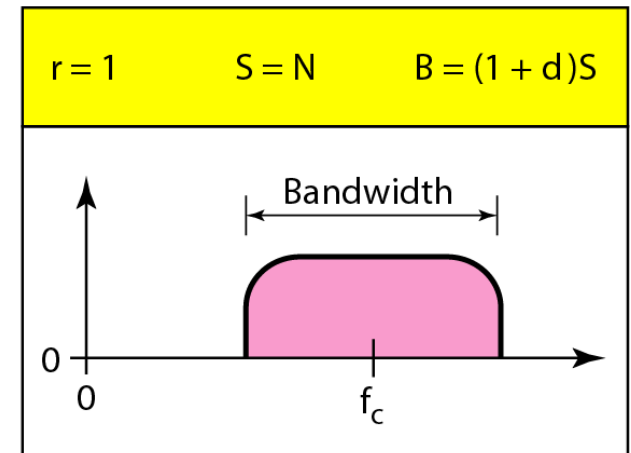
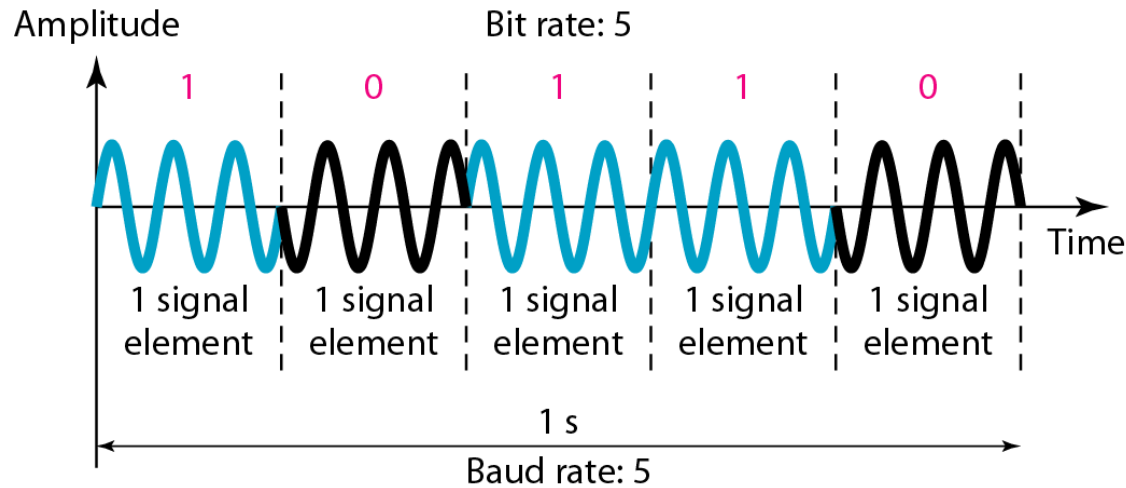


Figure 5.10 *Implementation of BPSK*

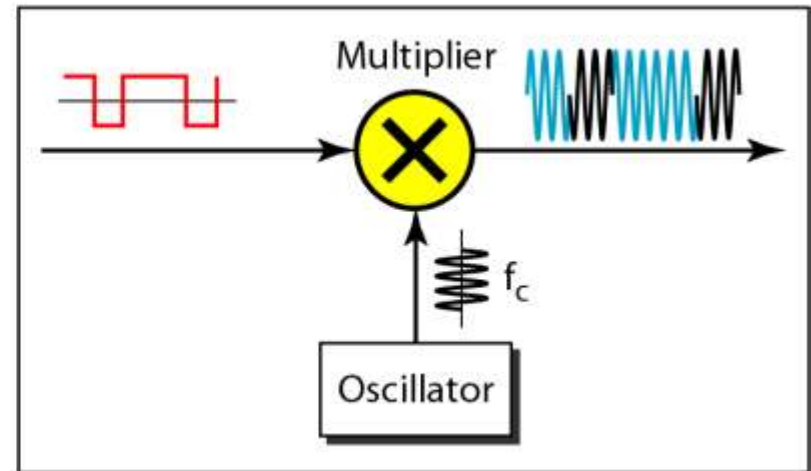
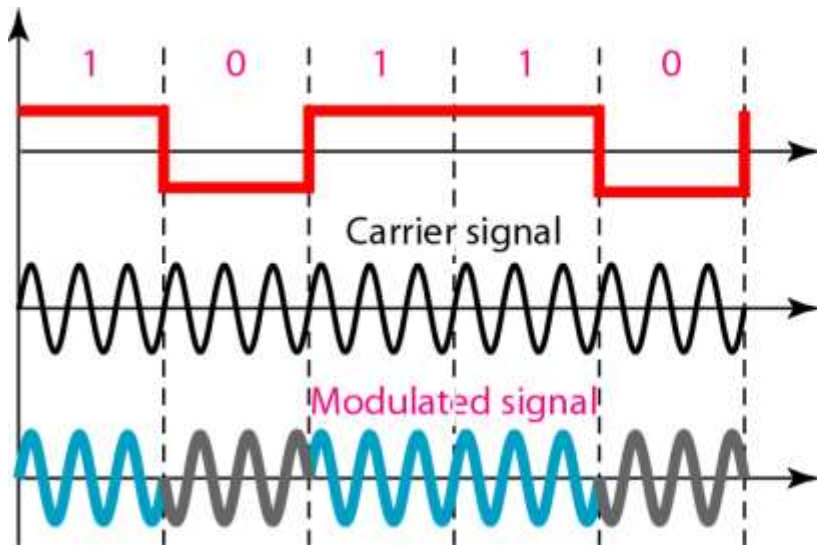
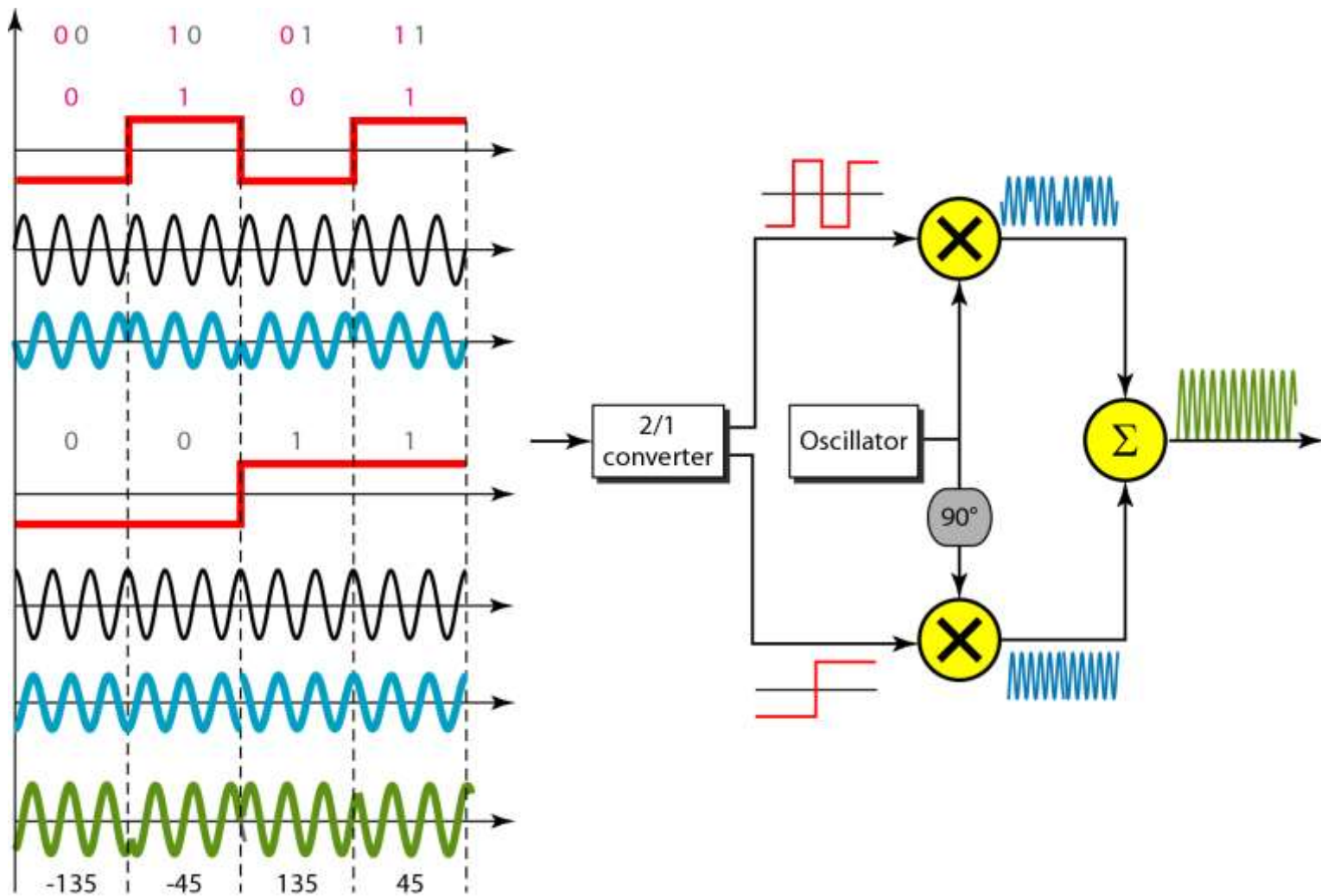


Figure 5.11 *QPSK and its implementation*



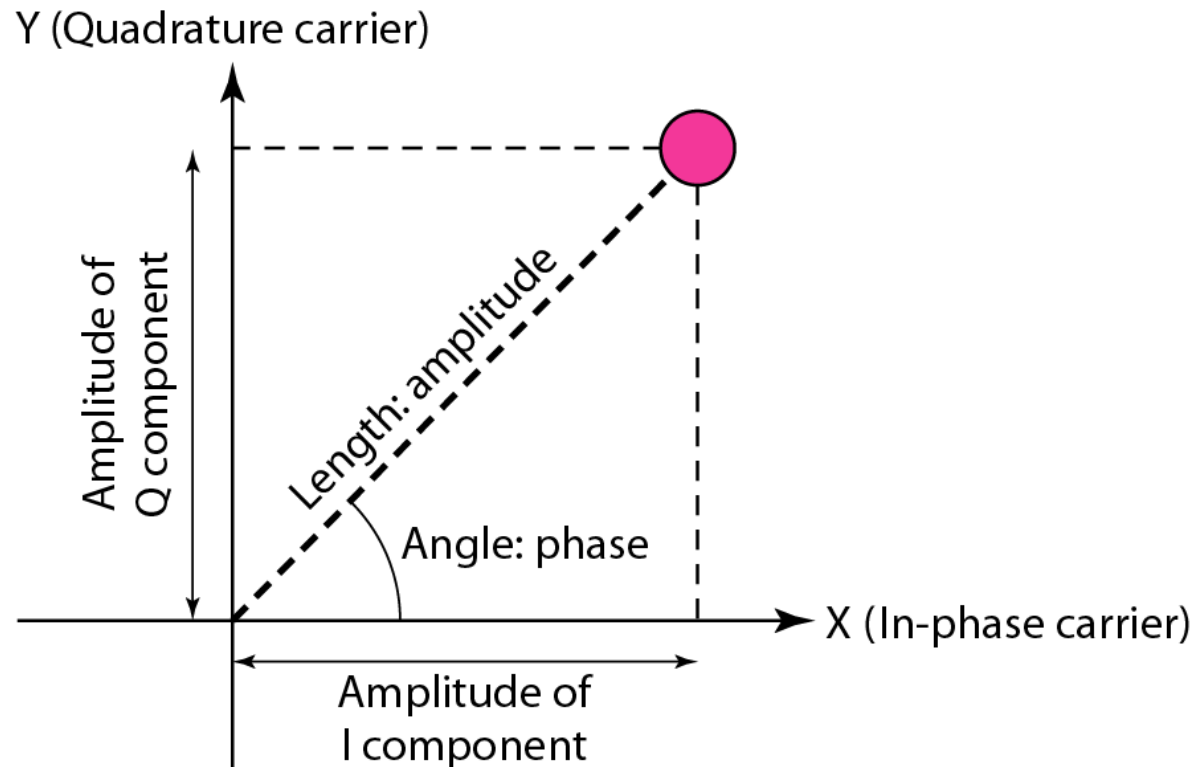
Example 5.7

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 $S = N \times (1/r) = 6 \text{ Mbaud}$. With a value of $d = 0$, we have $B = S = 6 \text{ MHz}$.

Figure 5.12 *Concept of a constellation diagram*



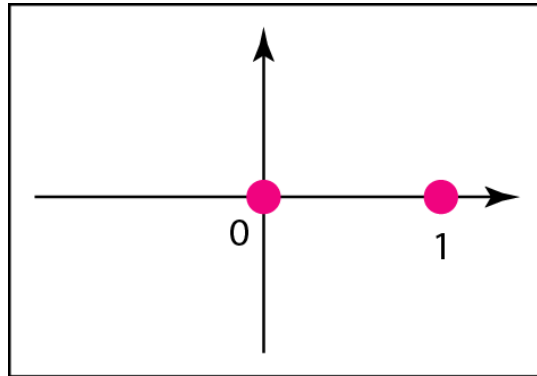
Example 5.8

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

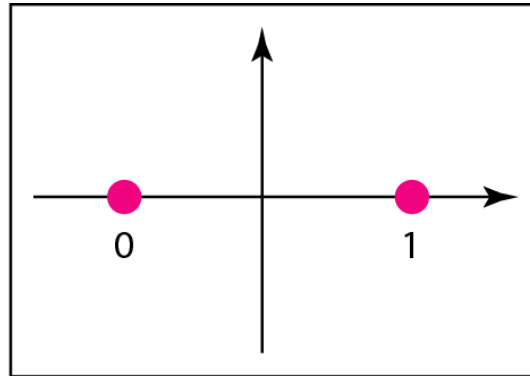
Solution

Figure 5.13 shows the three constellation diagrams.

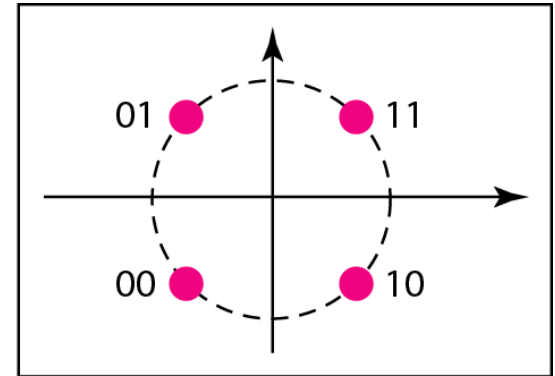
Figure 5.13 *Three constellation diagrams*



a. ASK (OOK)



b. BPSK

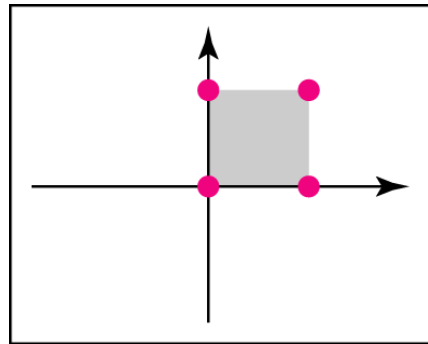


c. QPSK

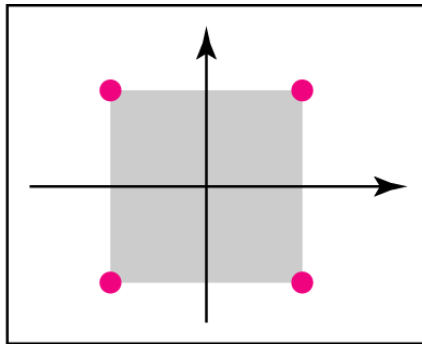
Note

Quadrature amplitude modulation is a combination of ASK and PSK.

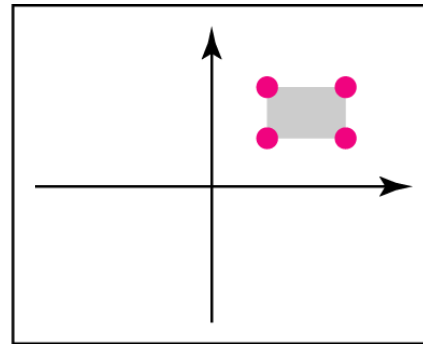
Figure 5.14 *Constellation diagrams for some QAMs*



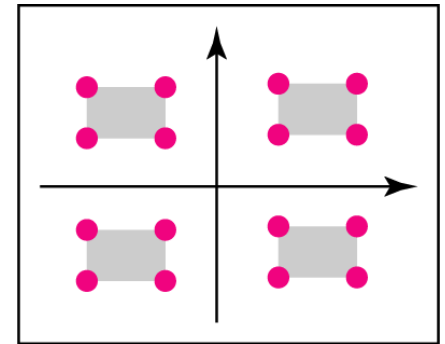
a. 4-QAM



b. 4-QAM



c. 4-QAM



d. 16-QAM

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*

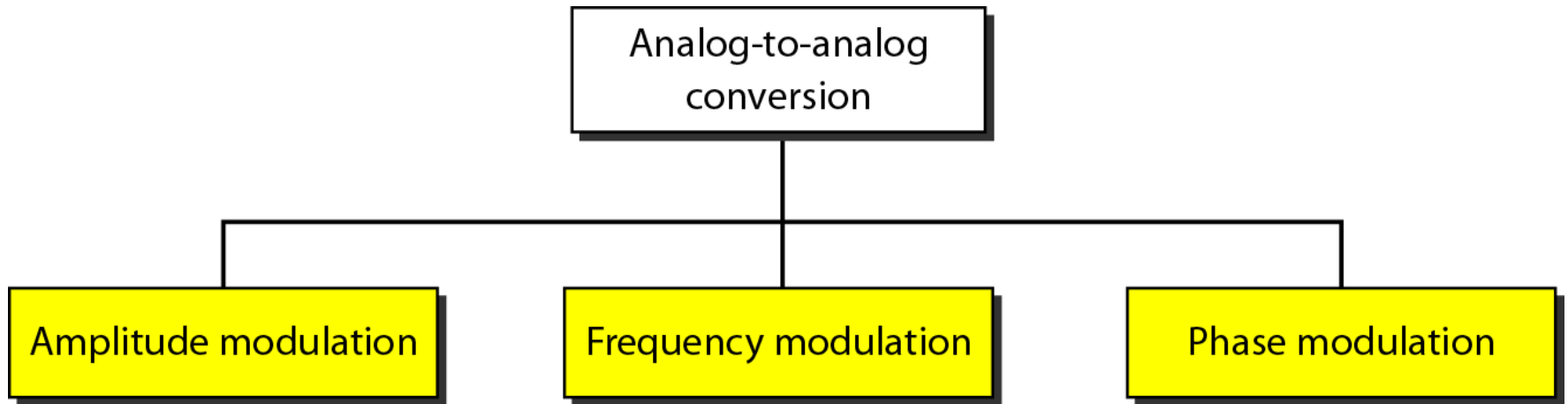
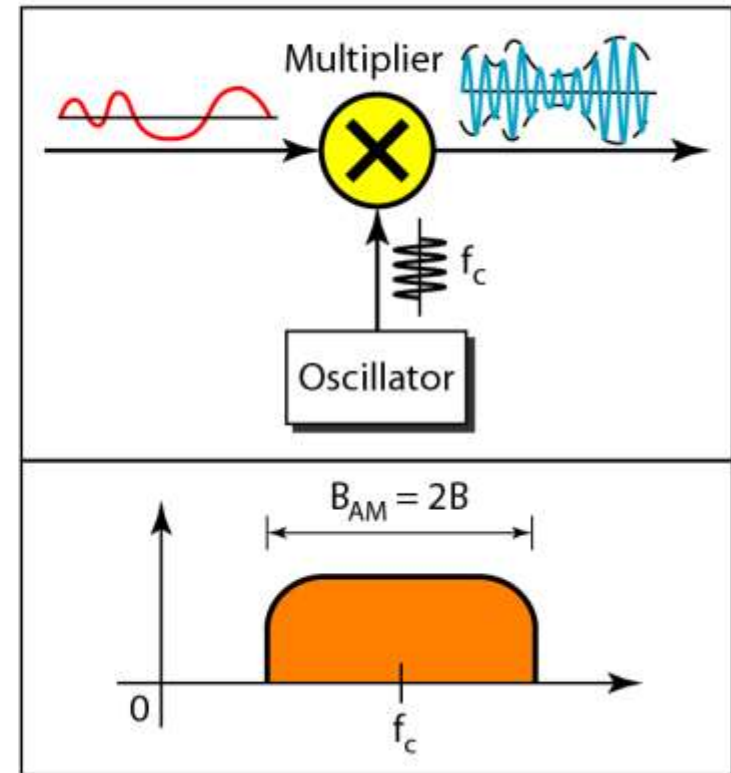
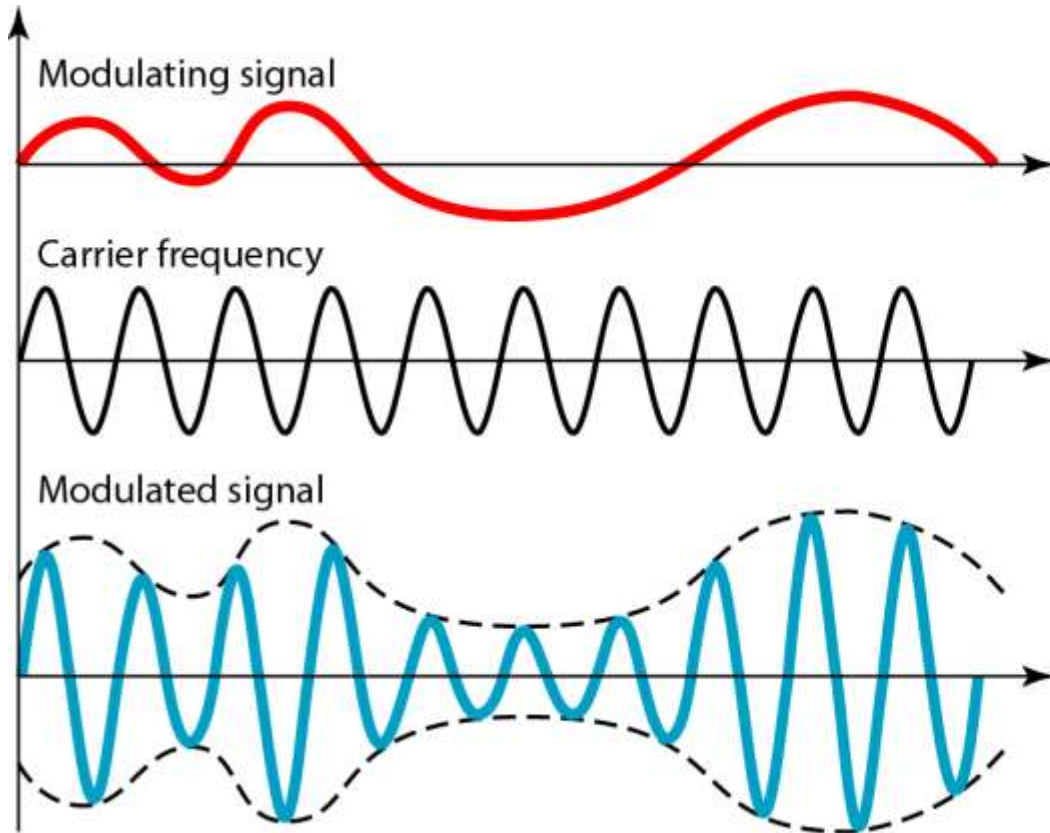


Figure 5.16 *Amplitude modulation*



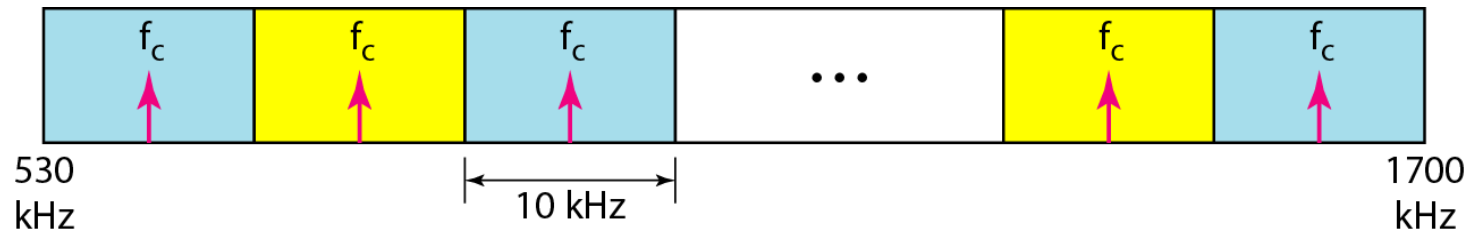
Note

**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*

The bandwidth of an audio signal is usually 5 kHz.

Therefore, an AM radio station needs a bandwidth of $2 \times 5 \text{ kHz} = 10 \text{ kHz}$.



Note

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

β is a factor depends on modulation technique with a common value of 4.

Figure 5.18 *Frequency modulation*

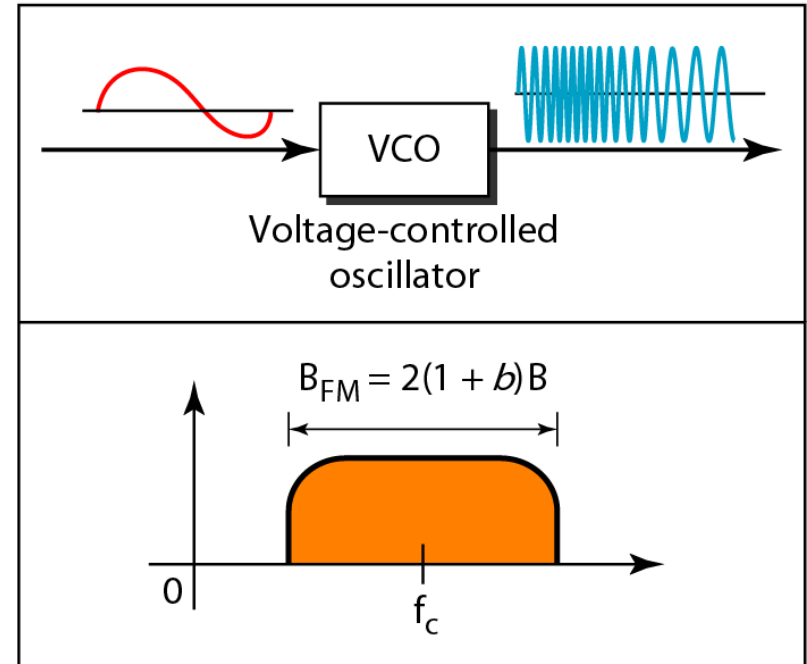
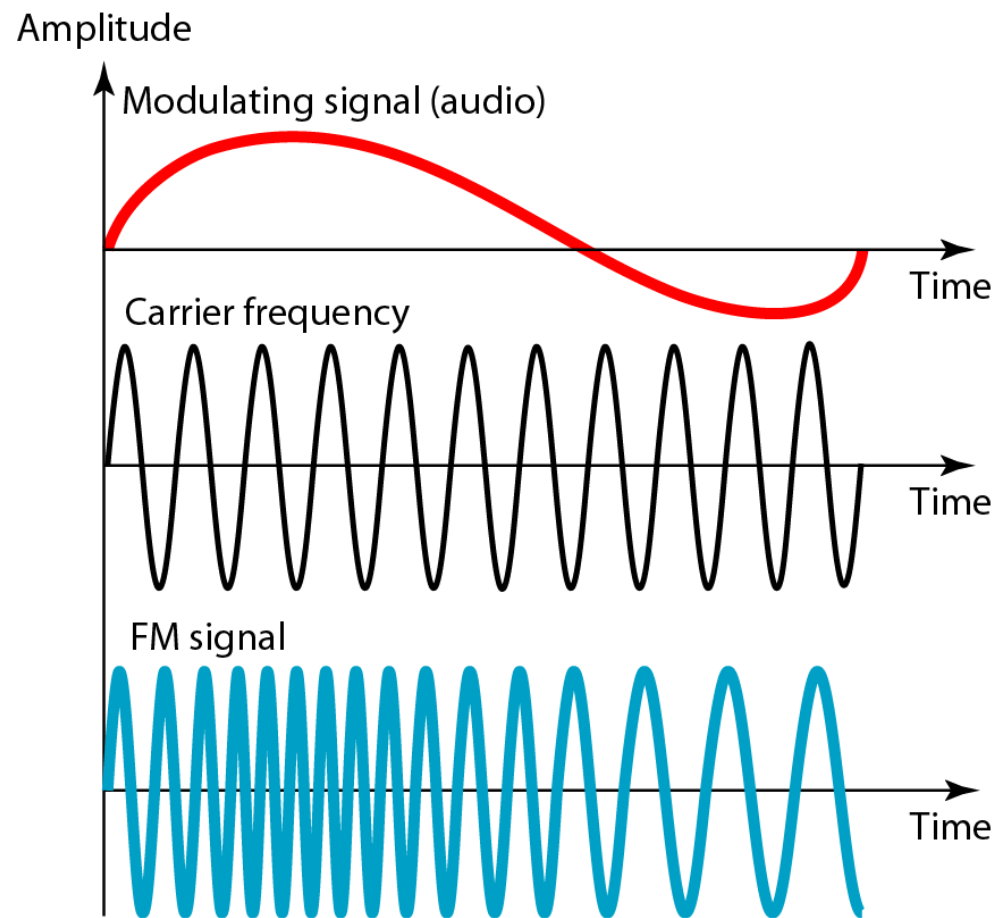


Figure 5.19 *FM band allocation*

The bandwidth of an audio signal (speech and music) broadcast in stereo is almost 15 kHz. FCC allows 200 kHz (0.2 MHz) for each station. This means $\beta=4$ with some extra guard band.

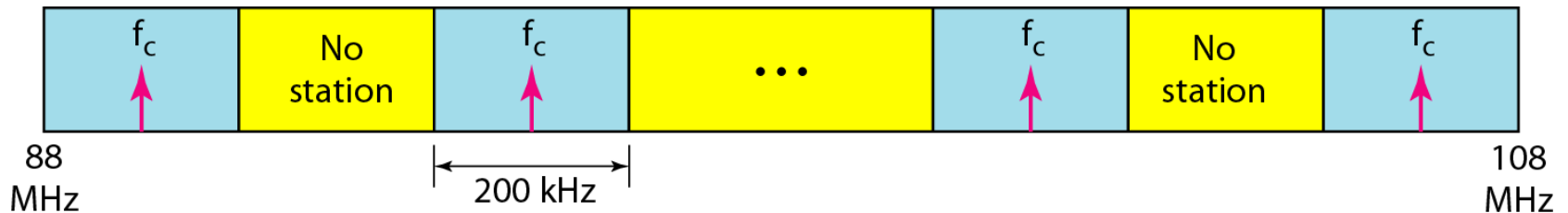
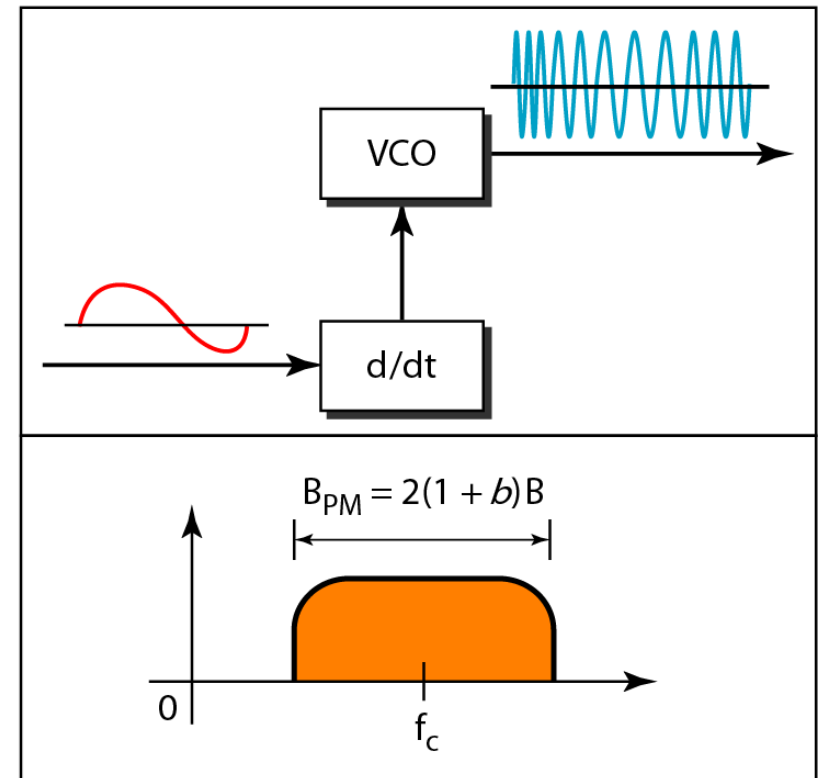
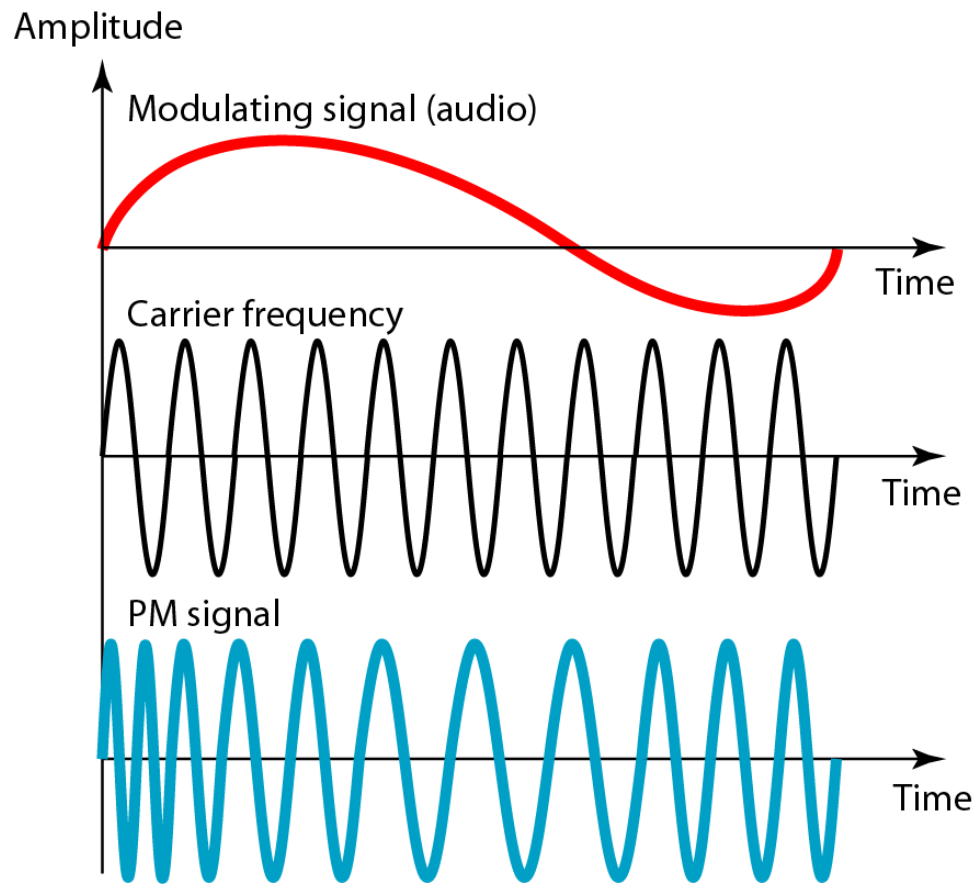


Figure 5.20 *Phase modulation*



Note

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

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