Data Communications and Networking Fourth Edition

Chapter 5

Analog Transmission

5.1 DIGITAL-TO-ANALOG CONVERSION

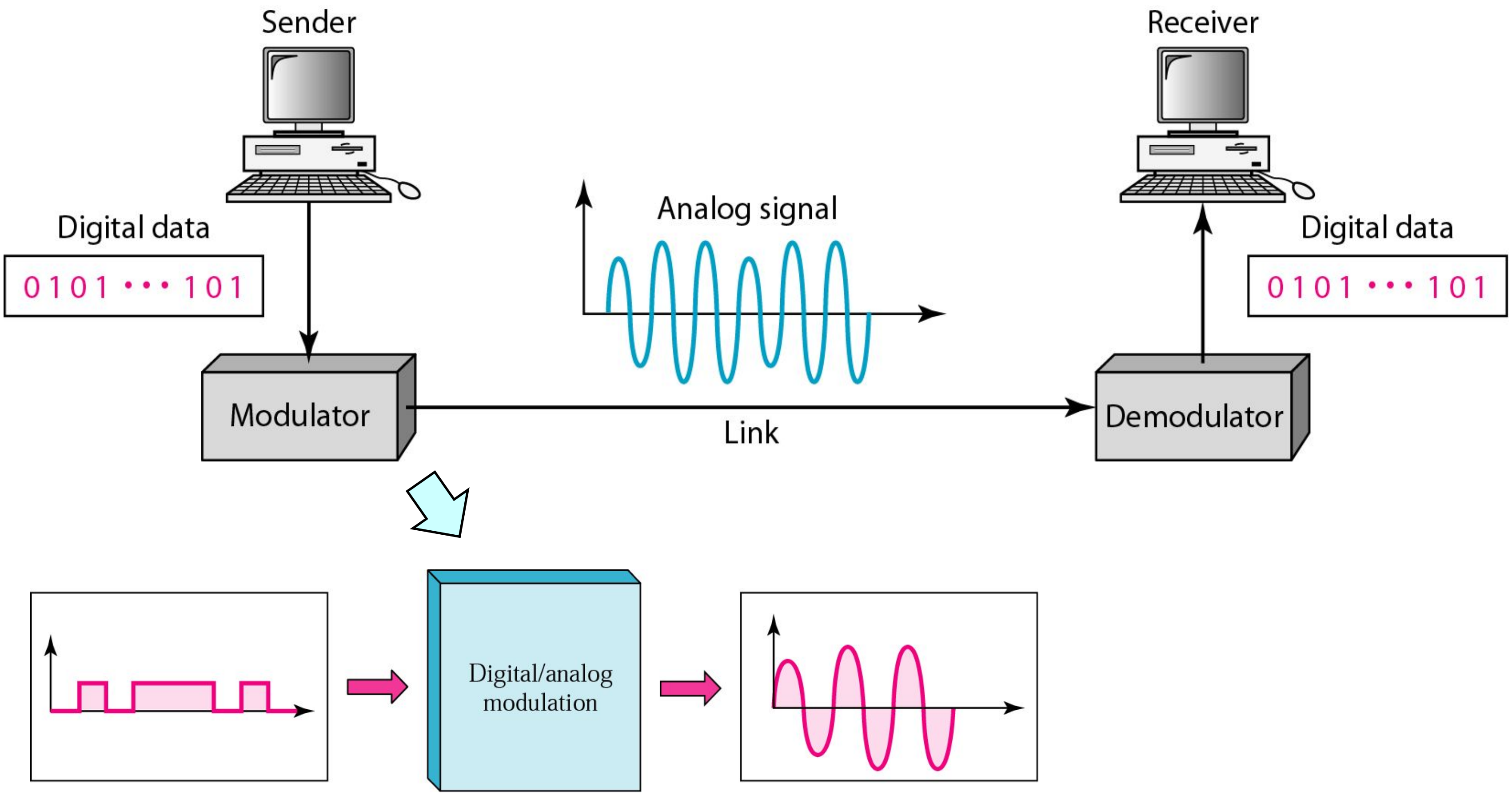
Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.

Topics discussed in this section:

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

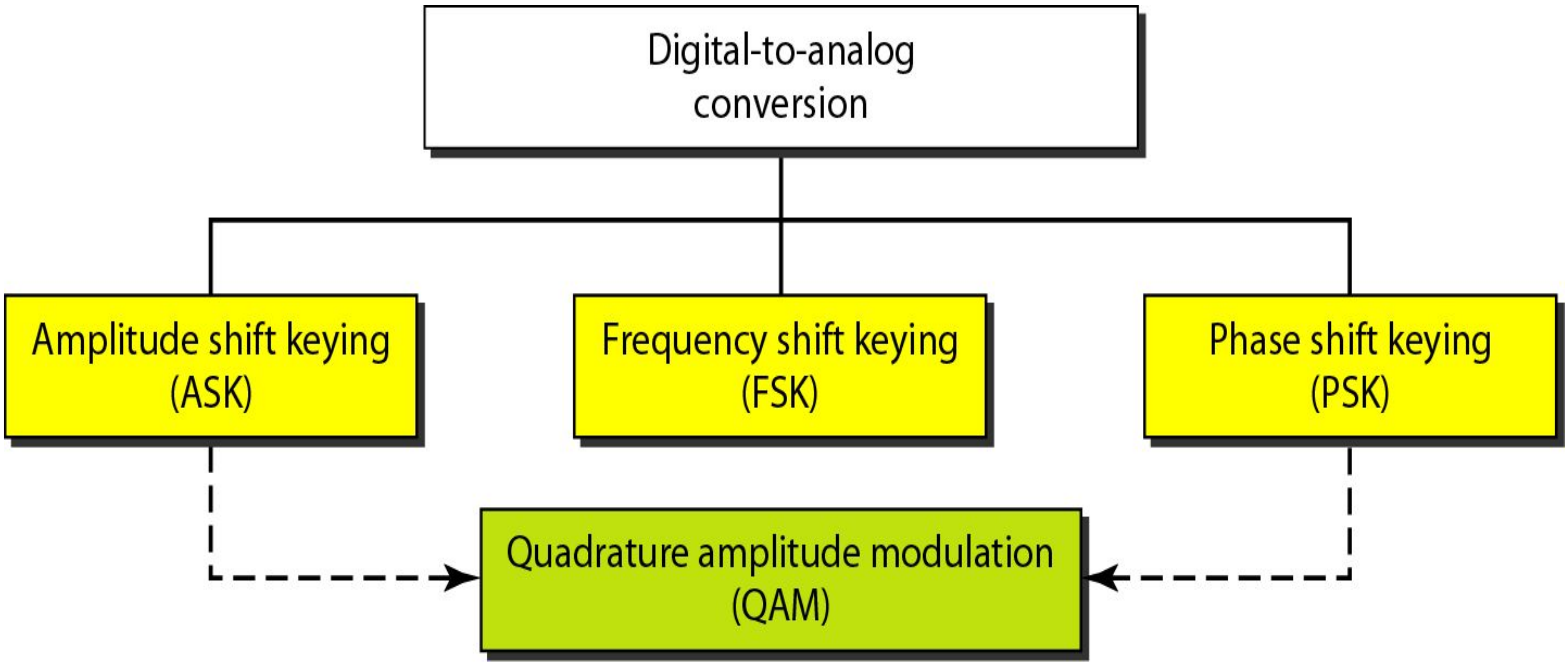
5.1 Digital-to-Analog Conversion

Figure 5.1 *Digital-to-analog conversion*



Digital-to-Analog Conversion (cont'd)

- Type of Digital-to-Analog encoding



Digital-to-Analog Conversion

Data Rate Vs Signal rate

- Data (bit) rate : the number of bits per second.
- Signal (baud) rate : the number of signal elements per second.
- $S = N \times 1/r$
  - where N= data rate (bit per second)
  - $r = \log_2 L$ (No. of data elements carried in one signal element)
- Bit rate = baud rate x No. of bits represented by each signal element
- In the analog transmission of digital data, the Baud rate is less than or equal to the bit rate

Carrier Signal or Carrier Frequency

- base signal for the information signal

Example 5.1

An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the baud rate and bit rate.

Solution

In this case, r = 4, S = 1000, and N is unknown. We can find the value of N from

- *Baud rate = Number of signal elements = 1000 bauds per second*

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

Digital-to-Analog Conversion (cont'd)

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.

$$S = N \times \frac{1}{r} \quad \longrightarrow \quad r = \frac{N}{S} = \frac{8000}{1000} = 8 \text{ bits/baud}$$

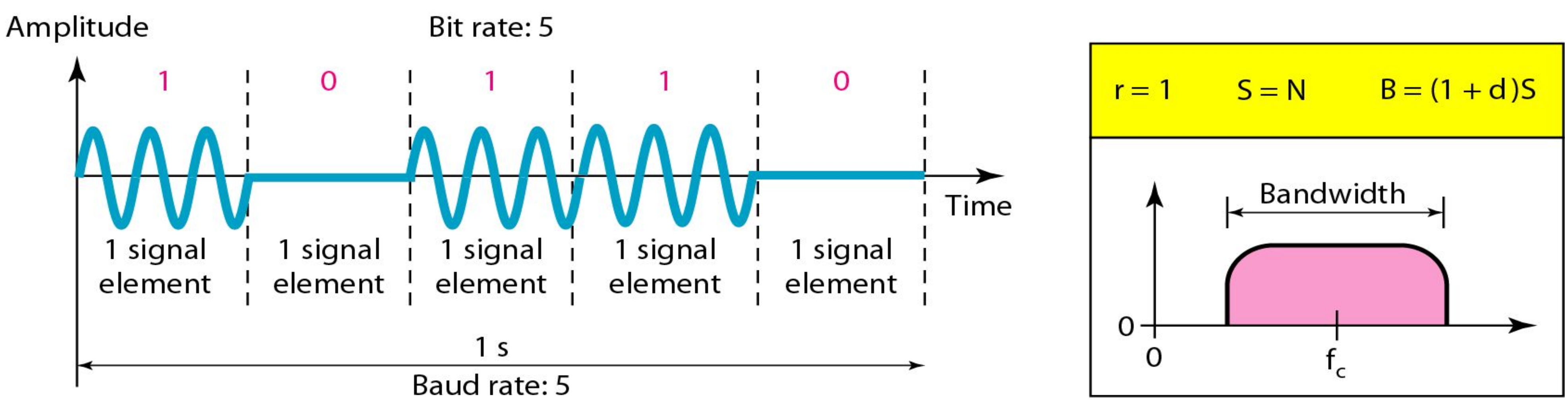
$$r = \log_2 L \quad \longrightarrow \quad L = 2^r = 2^8 = 256$$

Digital-to-Analog Conversion - ASK

ASK(Amplitude Shift Keying)

- **The amplitude of the carrier signal is varied to create signal element. Both frequency and phase remain constant while the amplitude changes.**
- **Highly susceptible to noise interference**

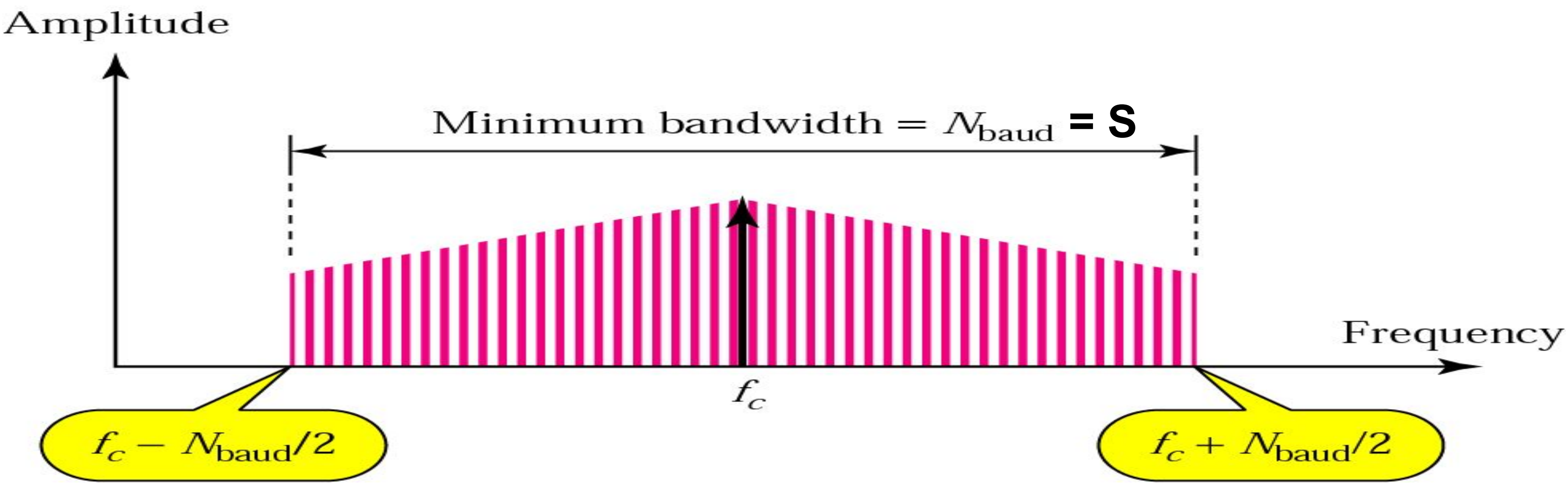
Figure 5.3 *Binary amplitude shift keying*



Digital-to-Analog Conversion - ASK

Bandwidth for ASK

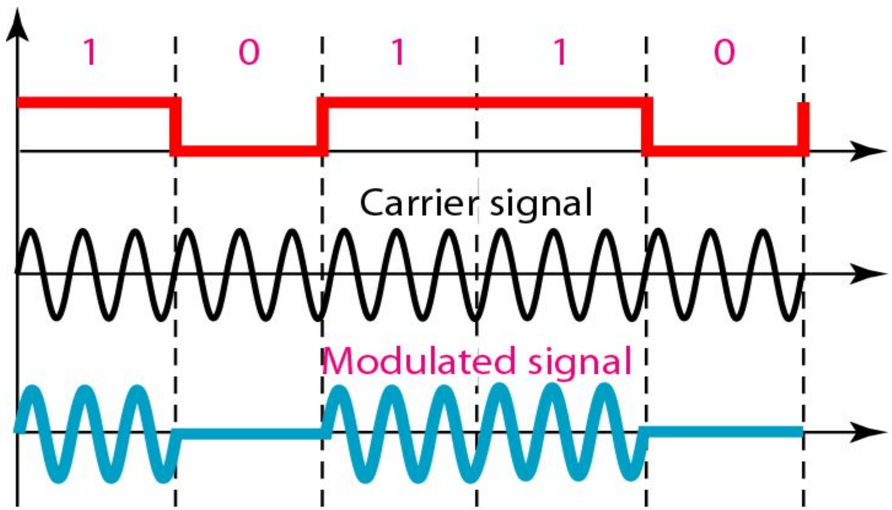
- Although the carrier signal is only one simple sine wave, the process of modulation produces a nonperiodic composite signal.
- Relationship between Signal rate and Bandwidth in ASK
  - B (Bandwidth) = (1 + d) x S
    - S : Signal rate (baud)
    - d : factor related to the modulation and filtering process (value of d is between 1 & 0)

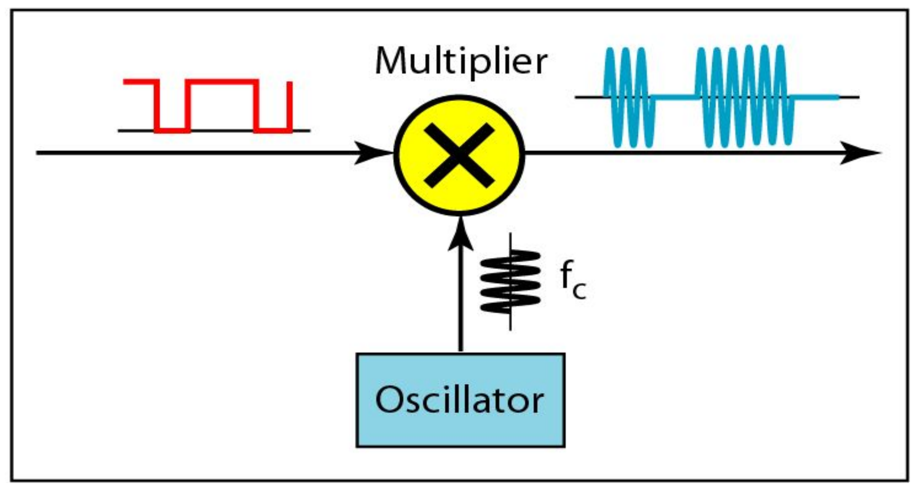


Maximum Bandwidth = 2S

Digital-to-Analog Conversion - ASK

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

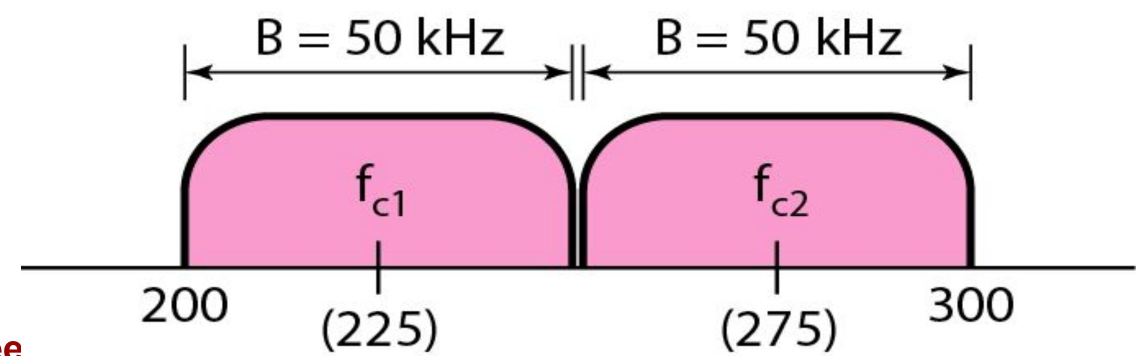
The middle of the bandwidth is located at 250 kHz. This means that our carrier frequency can be at f_c = 250 kHz. We can use the formula for bandwidth to find the bit rate (with d = 1 and r = 1).

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

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***

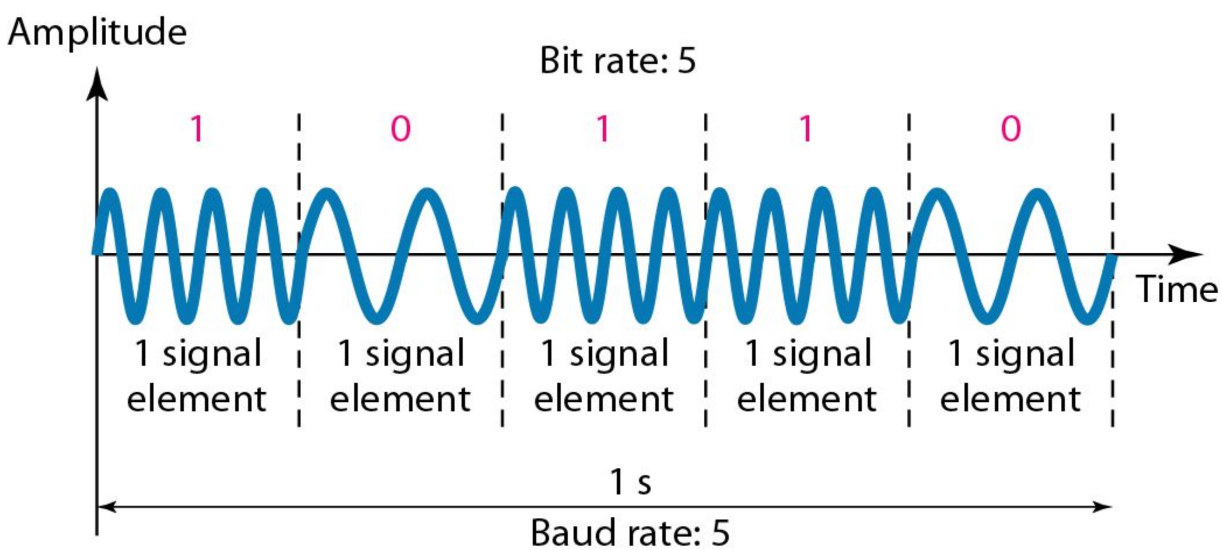


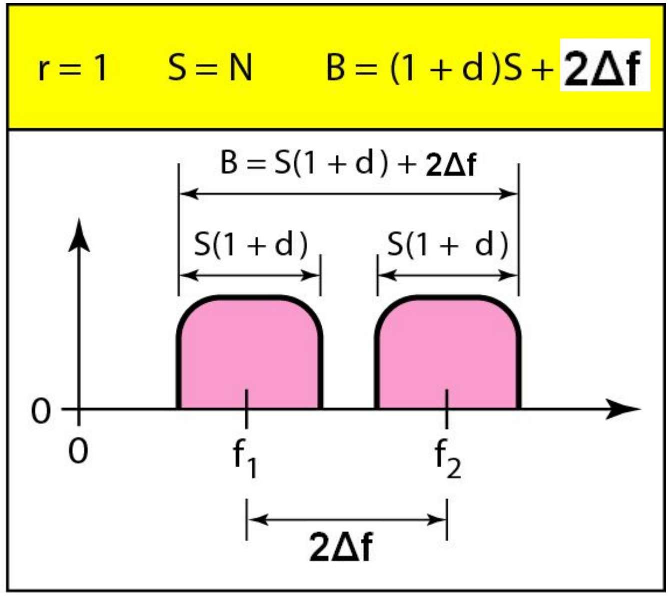
Digital-to-Analog Conversion - FSK

❑ FSK(Frequency Shift Keying)

- the frequency of the carrier signal is varied to represent binary 1 or 0. (Peak amplitude and phase remain constant)

Figure 5.6 *Binary frequency shift keying*

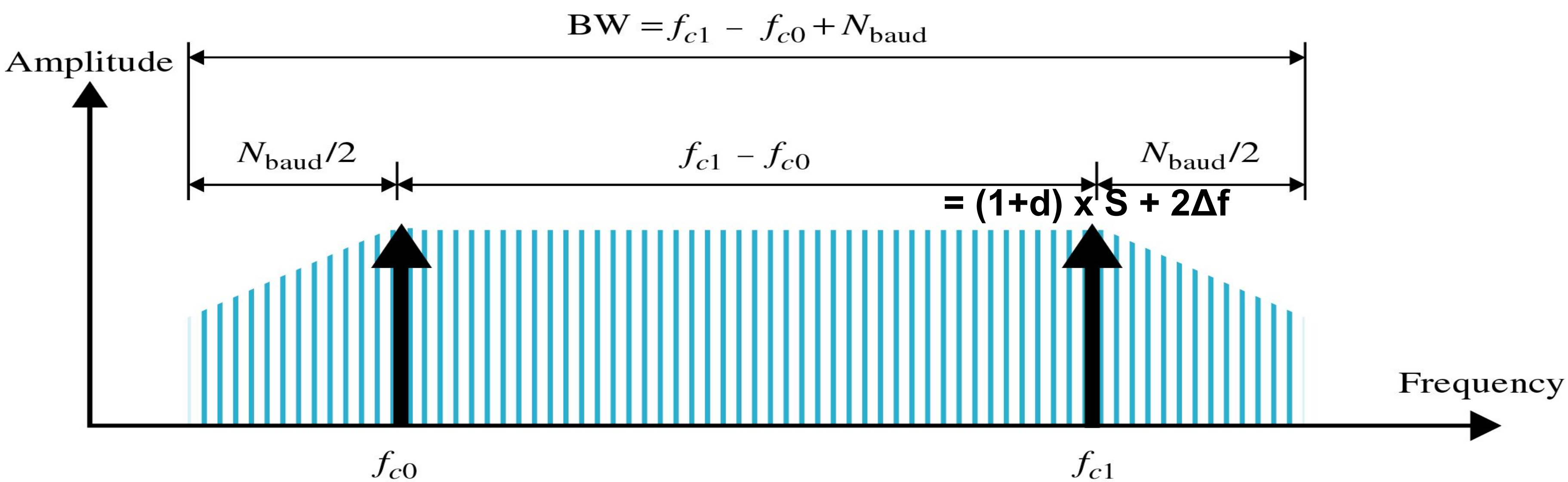




- Both f_1 & f_2 are Δf apart from the midpoint between the two bands.
- The difference between the two frequency is $2\Delta f$

Digital-to-Analog Conversion - FSK

- **Bandwidth for FSK**
  - **The carrier signals are only simple sine waves, but the modulation creates a nonperiodic composite signal with continuous frequencies.**
  - **FSK as two ASK signals, each with its own carrier frequency (f_1 or f_2)**
- **B_{FSK} (Bandwidth) = (1+d) x S + 2Δf**



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?

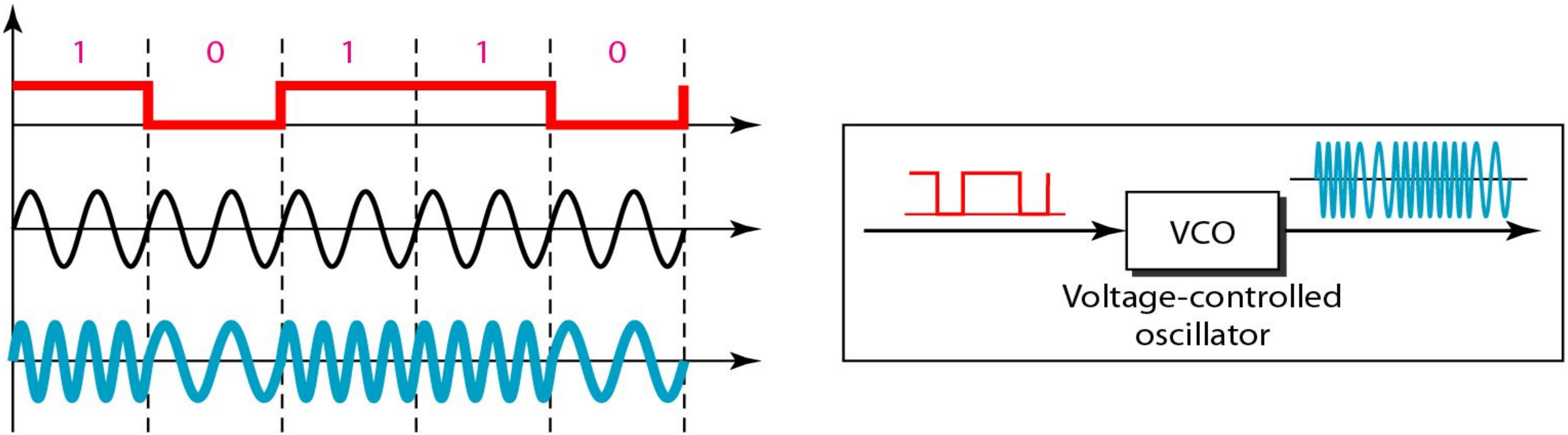
Solution

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

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

Digital-to-Analog Conversion - FSK

Figure 5.7 *Implementation of binary FSK*



Digital-to-Analog Conversion - FSK

- **MFSK : Multilevel FSK**

  - We can send data 2-bits at a time by using 4 frequencies.
  - B_{MFSK} (Bandwidth) = $(1+d) \times S + (L-1)2\Delta f$ => $L \times S$
    - The minimum value of $2\Delta f$ should be at least S for the proper operation of modulation and demodulation.

Digital-to-Analog Conversion - FSK

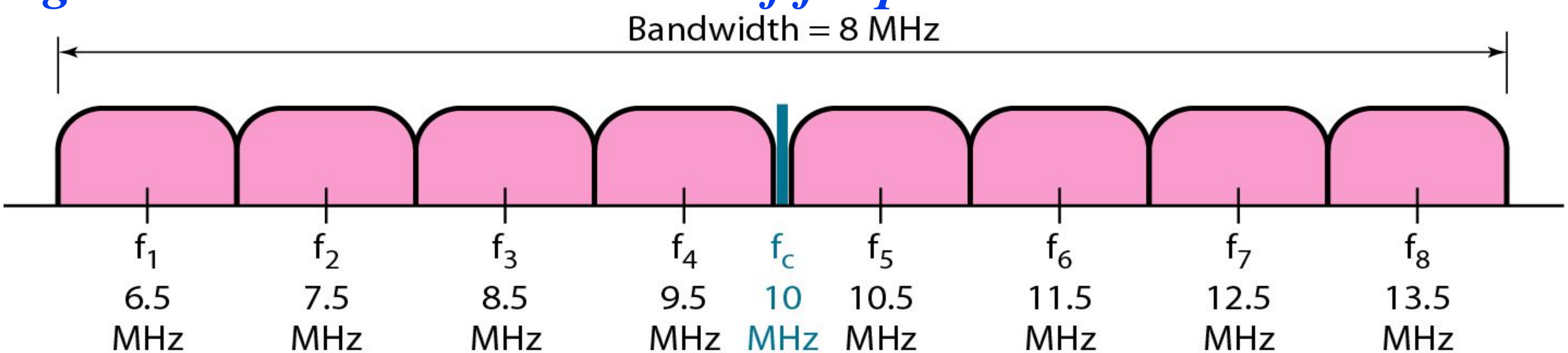
Example 5.6

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 (2Δf = 1 MHz). The bandwidth is B = 8 × 1000 = 8000KHz.

Figure 5.8 shows the allocation of frequencies and bandwidth.

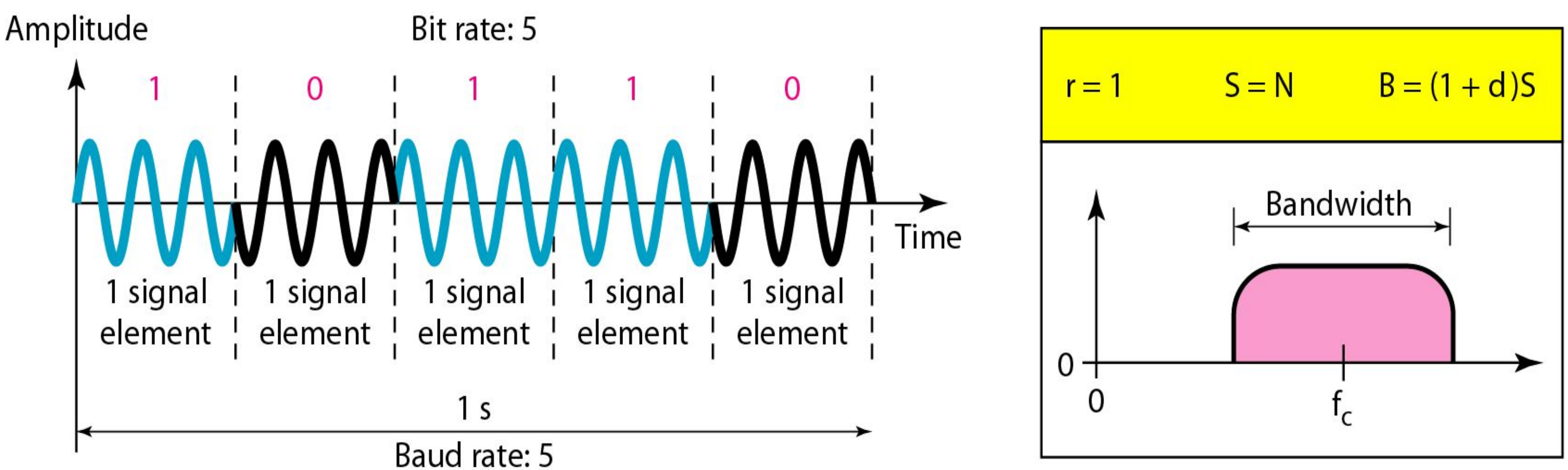


Digital-to-Analog Conversion - PSK

PSK

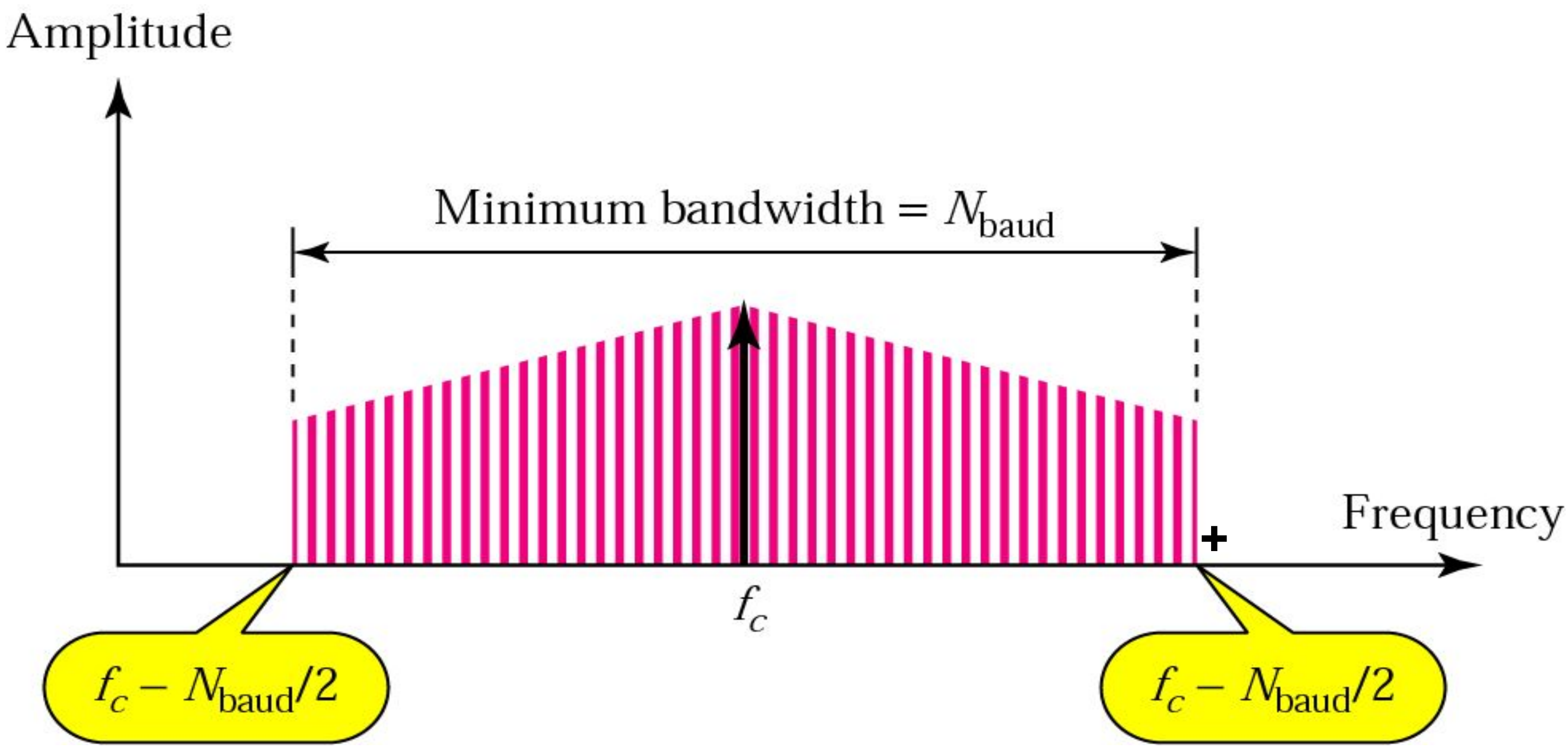
- The phase of the carrier is varied to represent two or more different signal elements.
- Both peak amplitude and frequency remain constant as the phase changes.

Figure 5.9 *Binary phase shift keying*



Relationship between baud rate and bandwidth in PSK

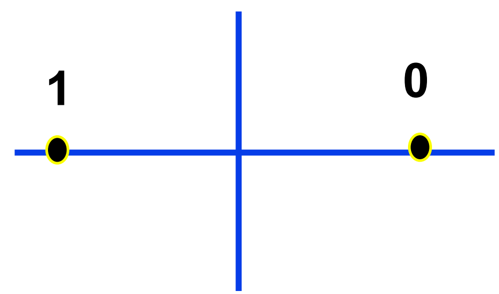
- The bandwidth is the same as that for binary ASK, but less than that for BFSK.



Digital-to-Analog Conversion - PSK

- **BPSK (Phase Shift Keying)**
  - **the phase is varied to represent binary 1 or 0.**

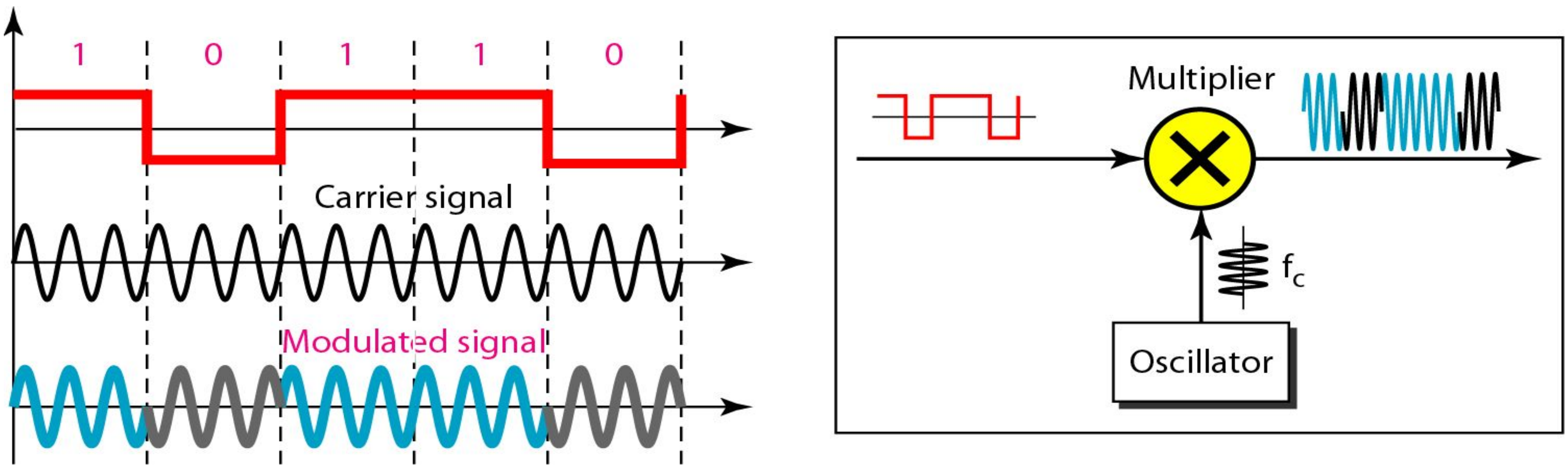
bit	phase
0 1	0º 180º



Constellation diagram

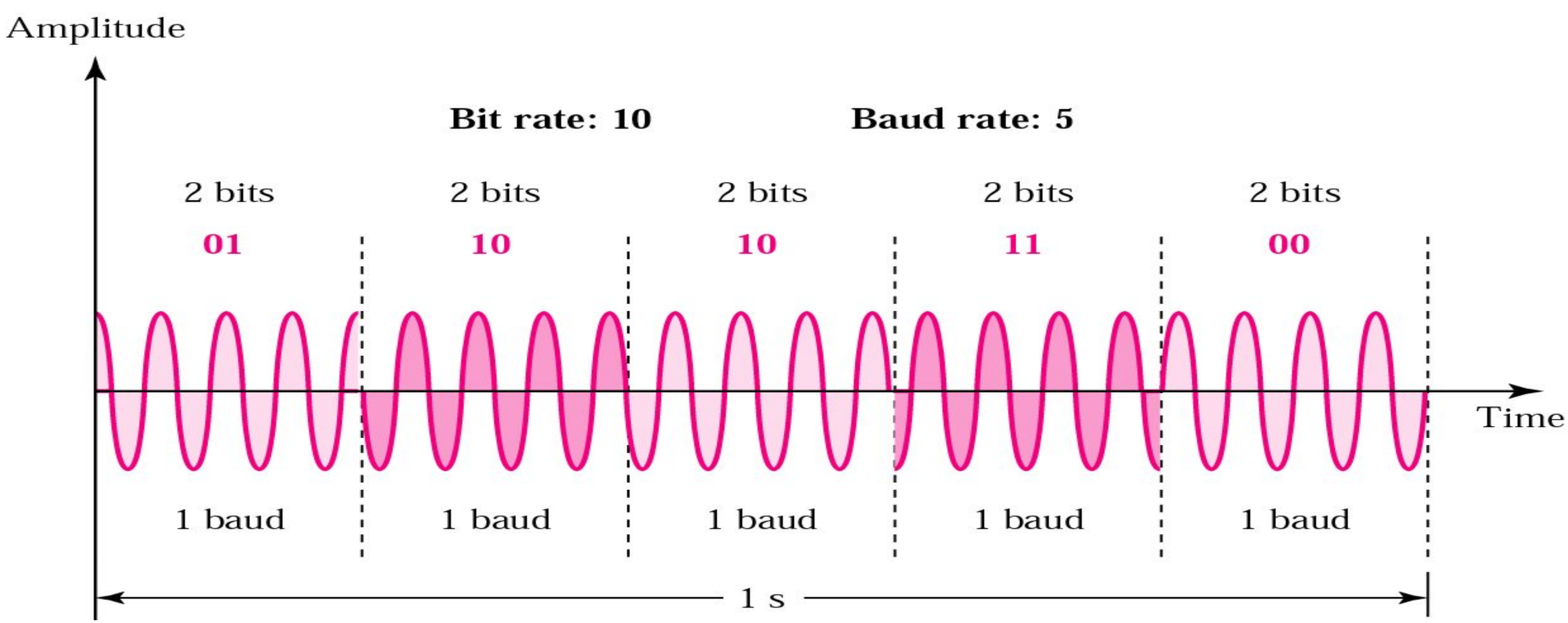
Digital-to-Analog Conversion - PSK

Figure 5.10 *Implementation of BPSK*



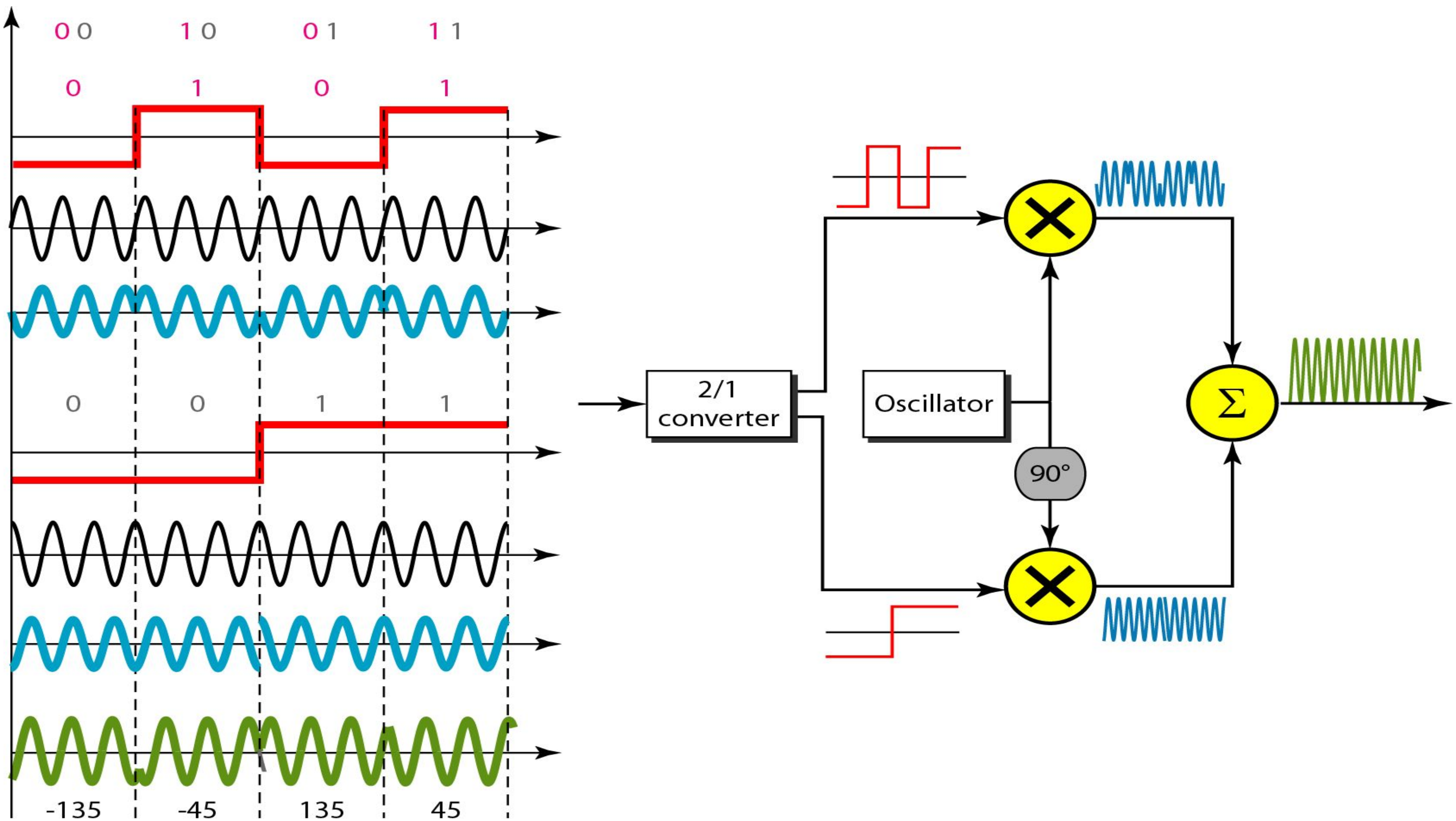
QPSK(4-PSK) method

- Instead of utilizing only two variations of a signal, We can use 4 variations and let each phase shift represent 2 bits.
- This technique is called 4-PSK or Q-PSK.



QPSK(4-PSK) method

Figure 5.11 ***QPSK and its implementation***



Example 5.7

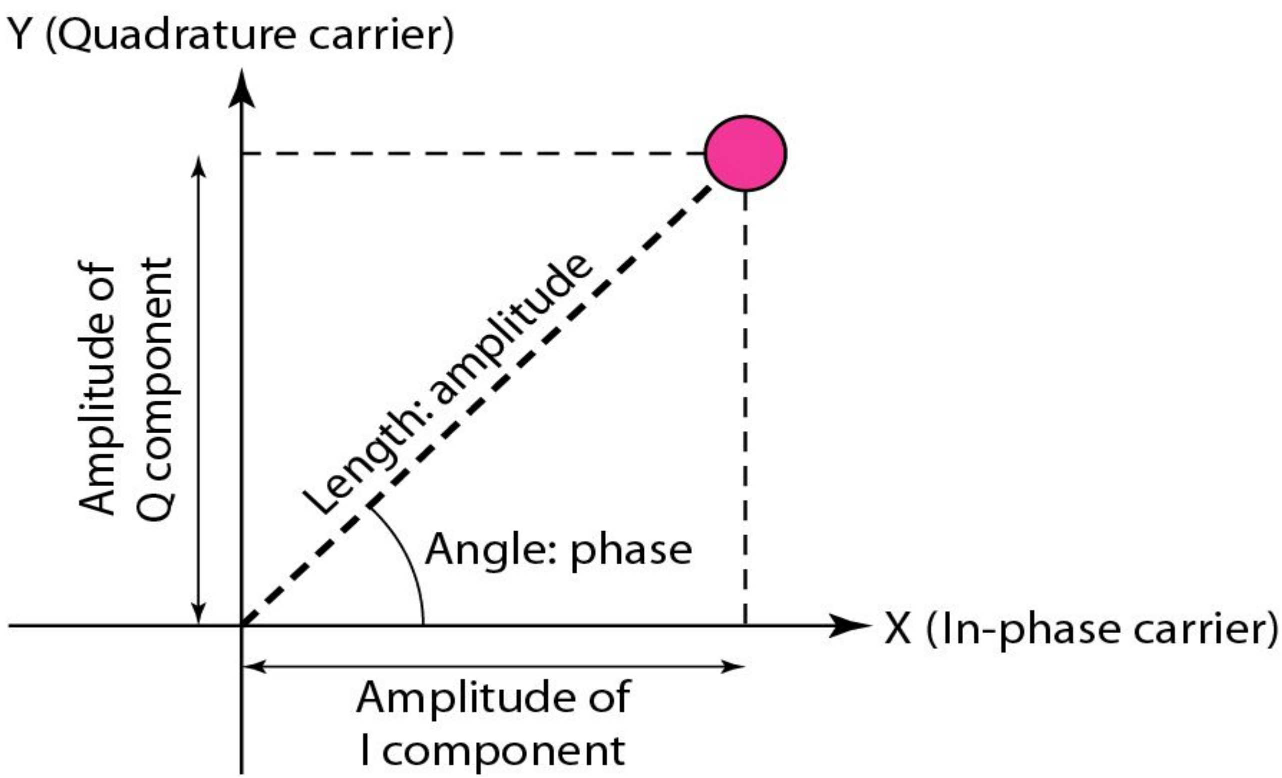
Find the bandwidth for a signal transmitting at 12 Mbps for QPSK. The value of d = 0.

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 × (1/r) = 6 Mbaud. With a value of d = 0, we have B = S = 6 MHz.

Constellation Diagram

Figure 5.12 ***Concept of a constellation diagram***



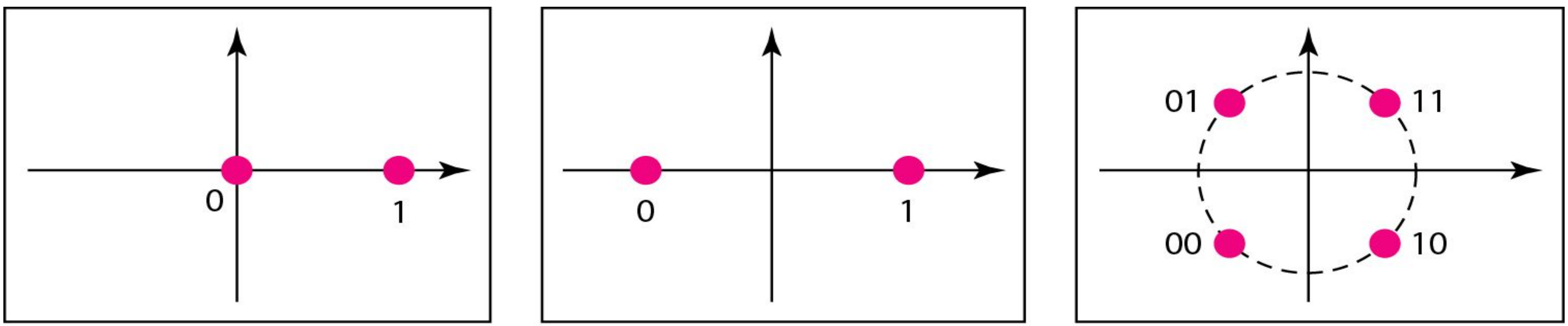
Constellation Diagram

Example 5.8

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

Solution

Figure 5.13 shows the three constellation diagrams.

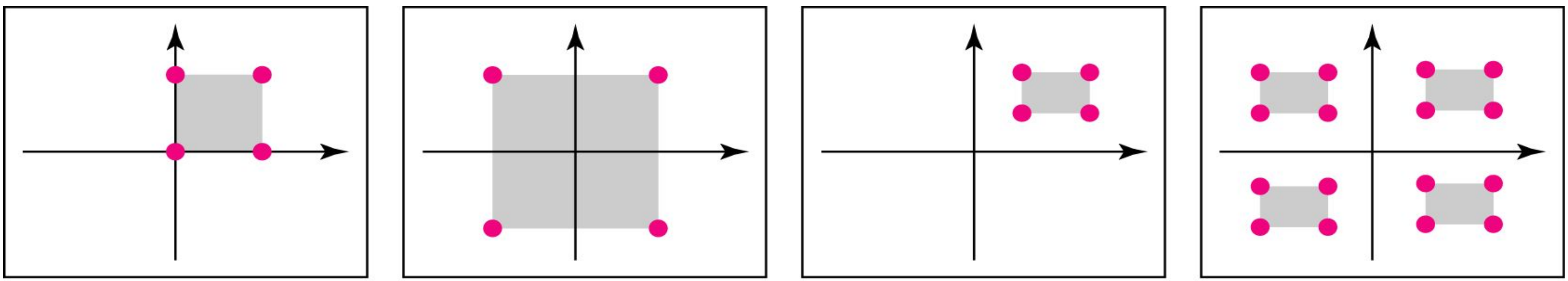


a. ASK (OOK) b. BPSK c. QPSK

Digital-to-Analog Conversion - QAM

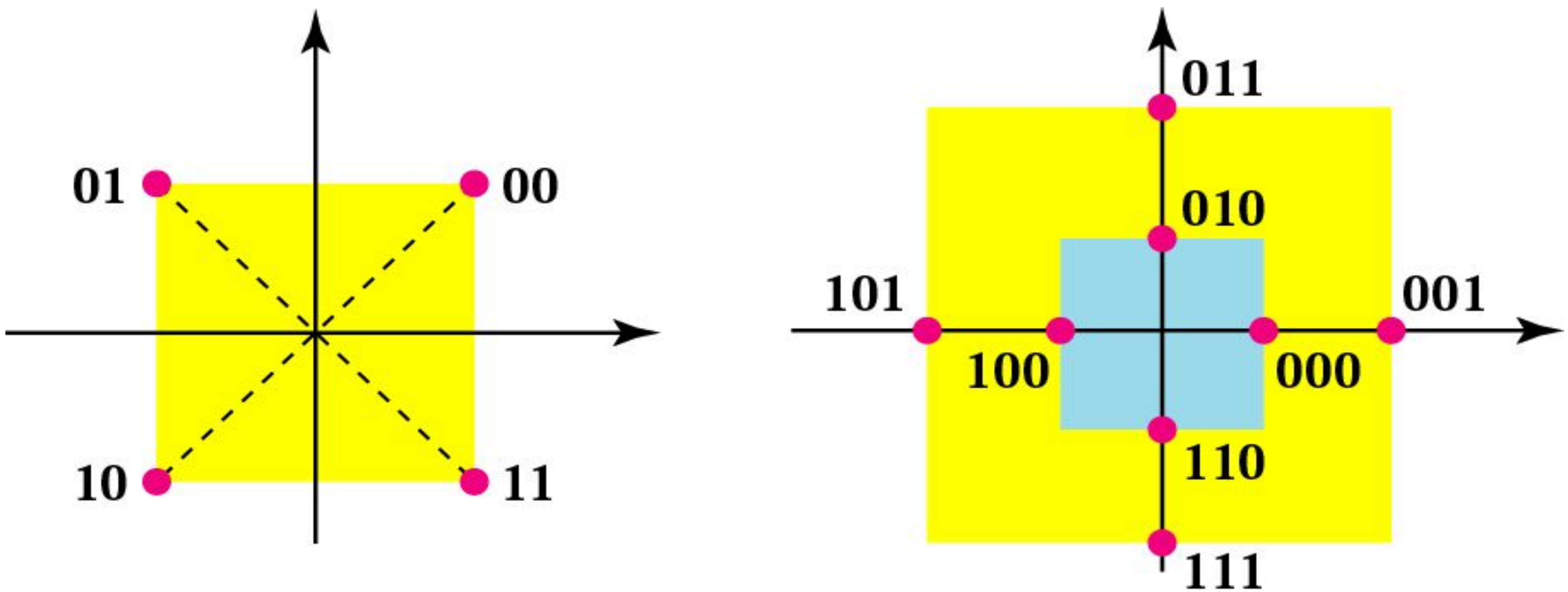
- **QAM(Quadrature Amplitude Modulation)**
  - **Quadrature amplitude modulation is a combination of ASK and PSK so that a maximum contrast between each signal unit (bit, dibit, tribit, and so on) is achieved**

Figure 5.14 Constellation diagrams for some QAMs



a. 4-QAM b. 4-QAM c. 4-QAM d. 16-QAM

Digital-to-Analog Conversion - QAM



4-QAM
1 amplitude, 4 phases

8-QAM
2 amplitudes, 4 phases

5.2 ANALOG-TO-ANALOG CONVERSION

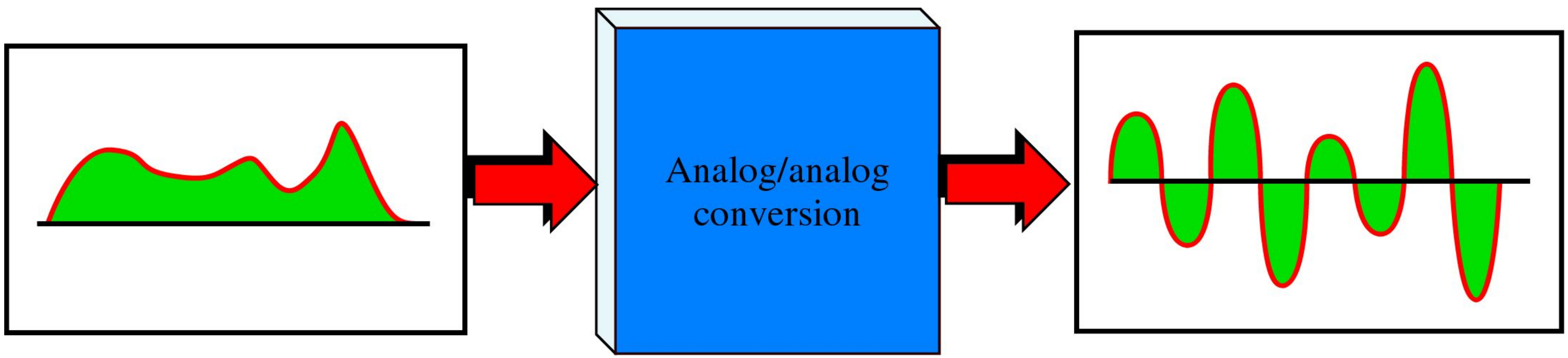
Analog-to-analog conversion is the representation of analog information by an analog signal. One may ask why we need to modulate an analog signal; it is already analog. Modulation is needed if the medium is bandpass in nature or if only a bandpass channel is available to us.

Topics discussed in this section:

Amplitude Modulation
Frequency Modulation
Phase Modulation

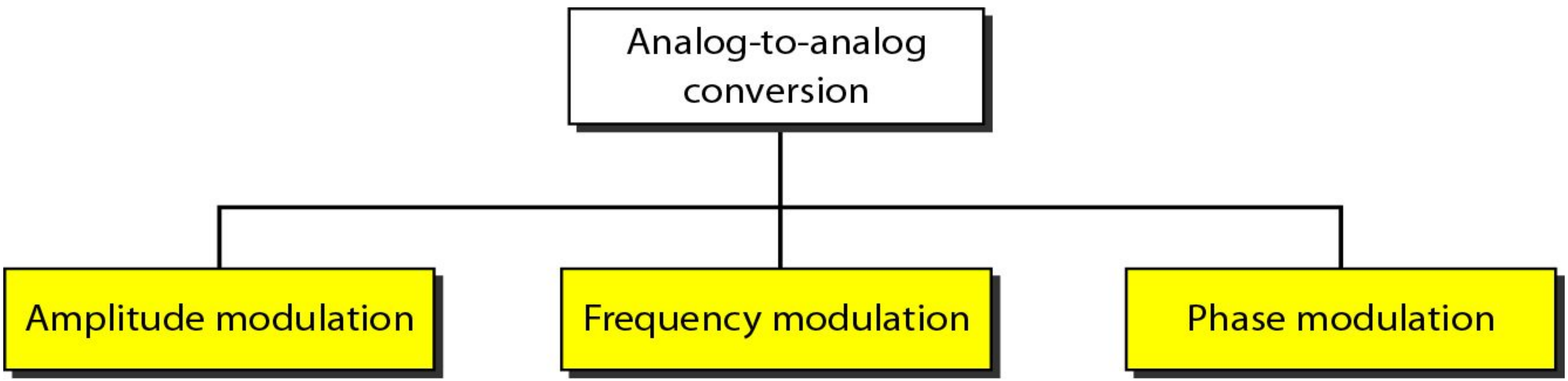
Analog-to-analog Conversion

- Analog-to-Analog encoding is the representation of analog information by an analog signal.
- Analog-to-Analog encoding



Analog-to-Analog Conversion

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

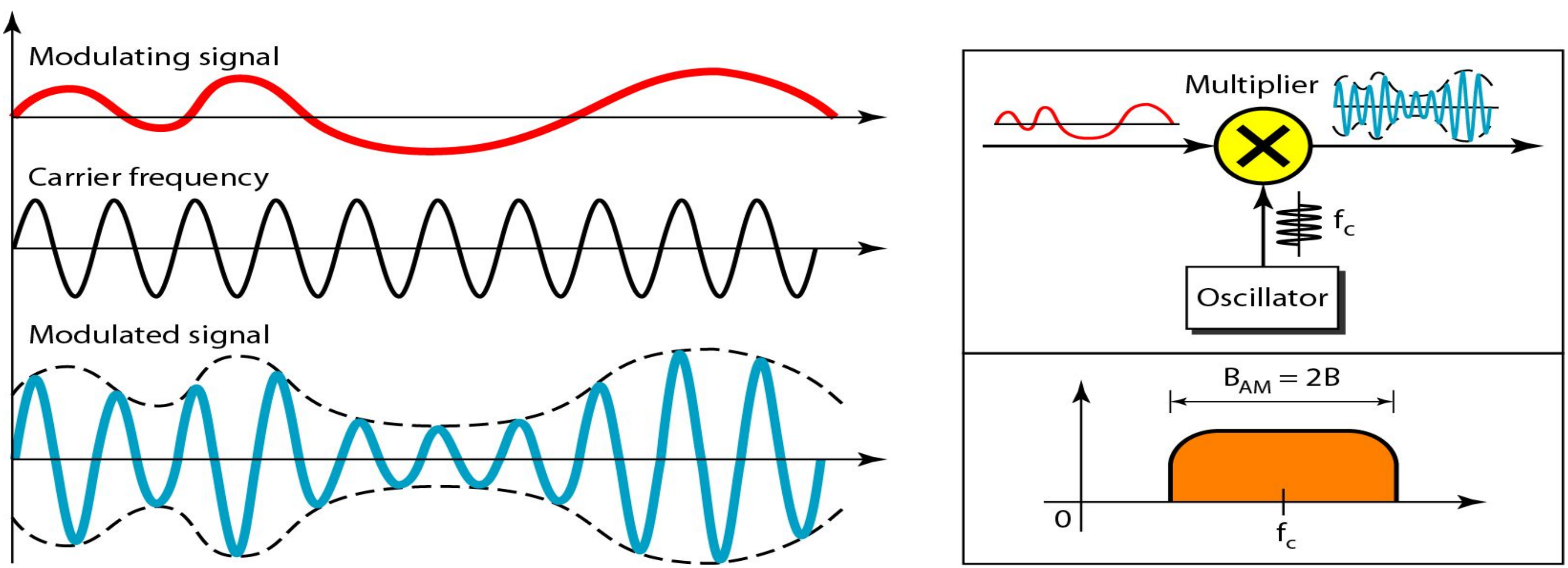


Analog-to-Analog Conversion - AM

AM(Amplitude Modulation)

~ The frequency and phase of the carrier remain the same; only the amplitude changes to follow variations in the information.

Figure 5.16 *Amplitude modulation*



Analog-to-Analog Conversion - AM

AM bandwidth

- The total bandwidth required for AM can be determined from the bandwidth of the audio signal.

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

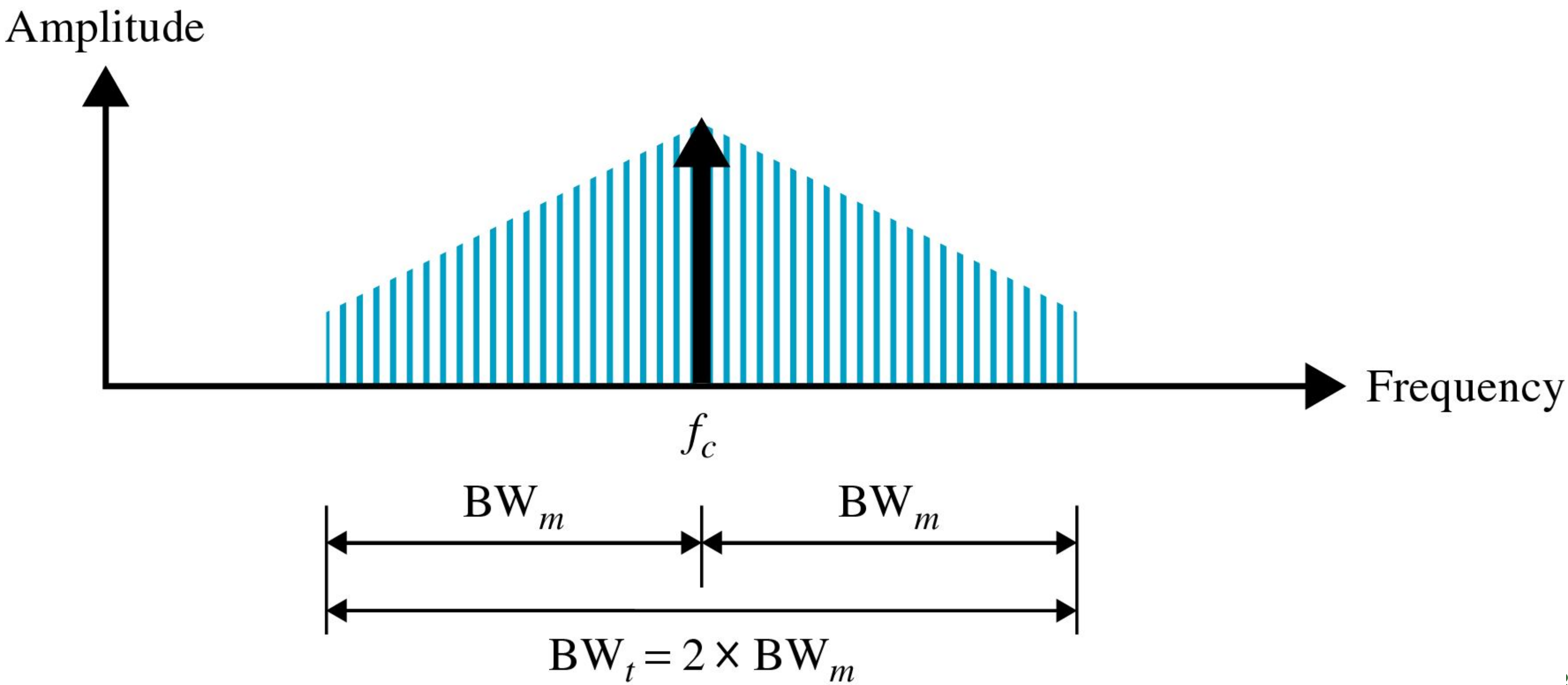
Analog-to-Analog Conversion - AM

- **AM bandwidth**

BW_m = Bandwidth of the modulating signal (audio)

BW_t = Total bandwidth (radio)

f_c = Frequency of the carrier

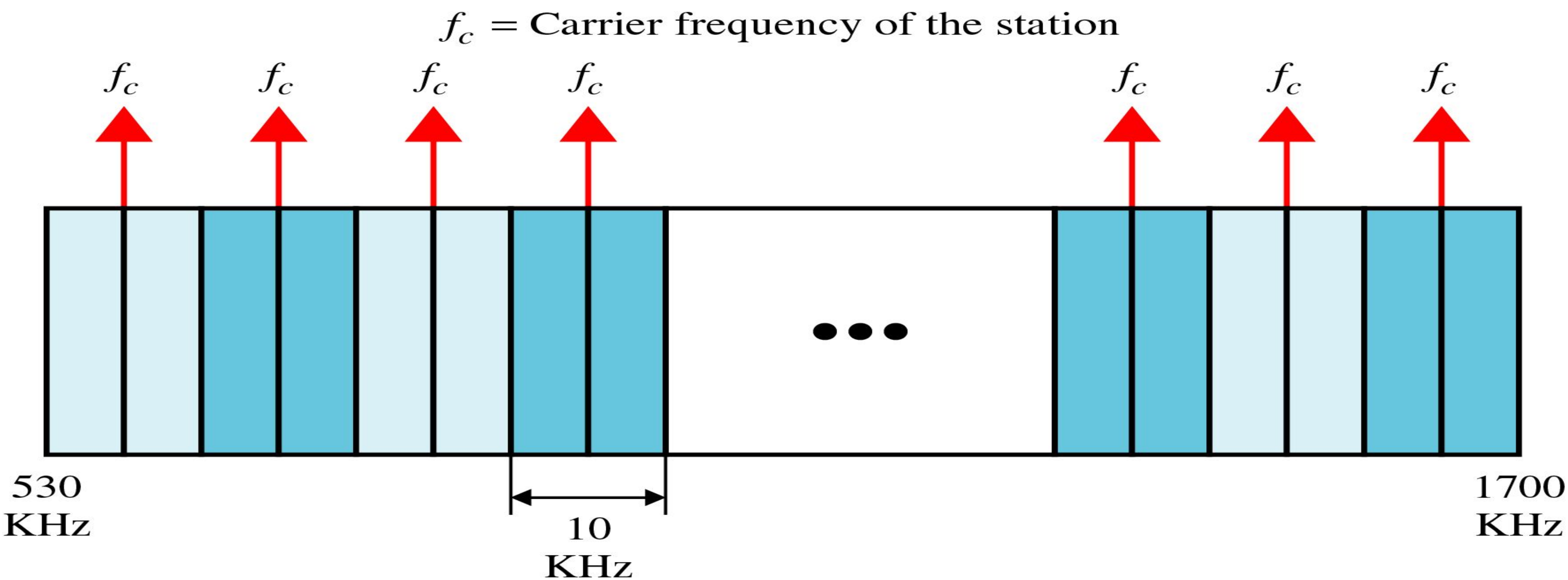


Analog-to-Analog Conversion - AM

- Audio signal bandwidth : 5 KHz
- Minimum bandwidth : 10 KHz (bandwidth for AM radio station)
- AM stations are allowed carrier frequencies anywhere between 530 and 1700 KHz(1.17 MHz)
- each frequency must be separated by 10 KHz

Analog-to-Analog Conversion - AM

- AM band allocation

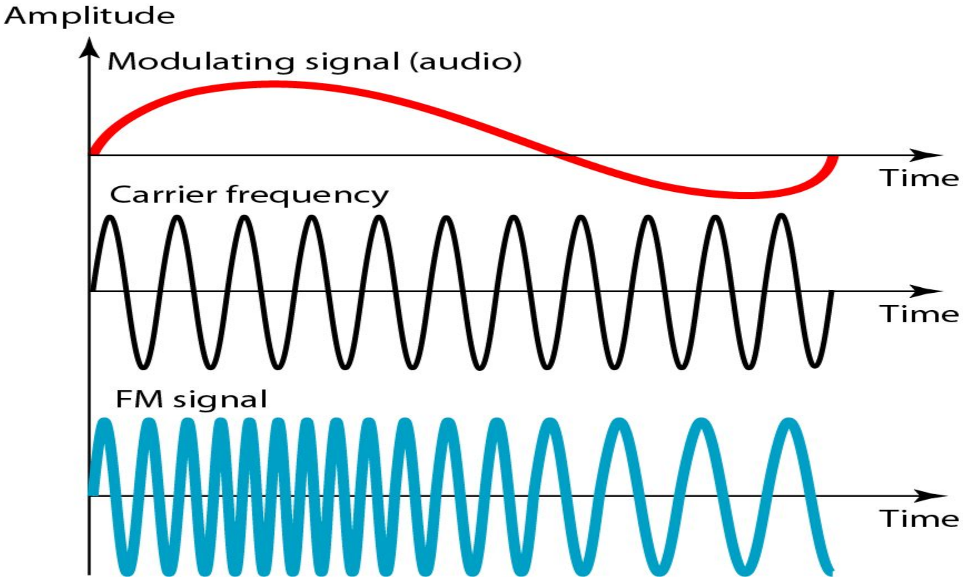


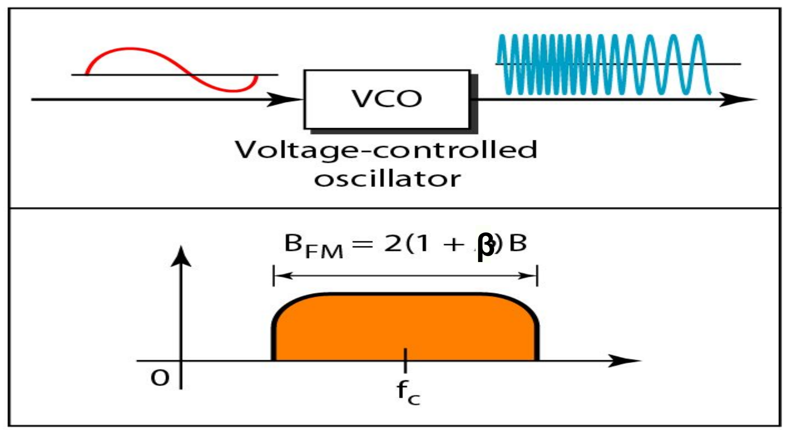
Analog-to-Analog Conversion - FM

FM(Frequency Modulation)

- **as the amplitude of the information signal changes, the frequency of the carrier changes proportionately.**

Figure 5.18 *Frequency modulation*





Analog-to-Analog Conversion - FM

FM Bandwidth

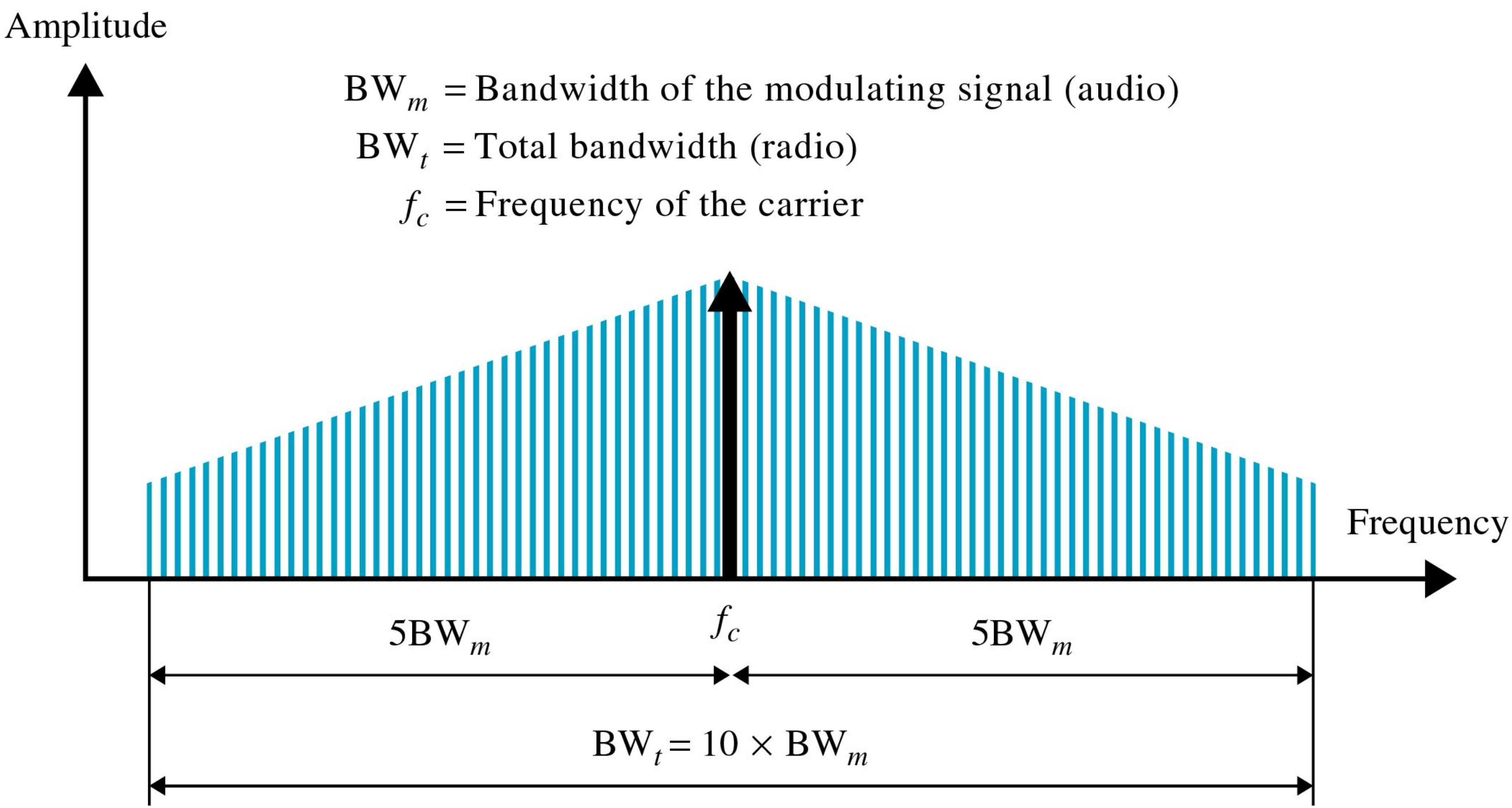
- The bandwidth of an FM signal is equal to 10 times the bandwidth of the modulating signal.

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

β depends on modulation technique with a common value of 4

Analog-to-Analog Conversion - FM

- FM bandwidth

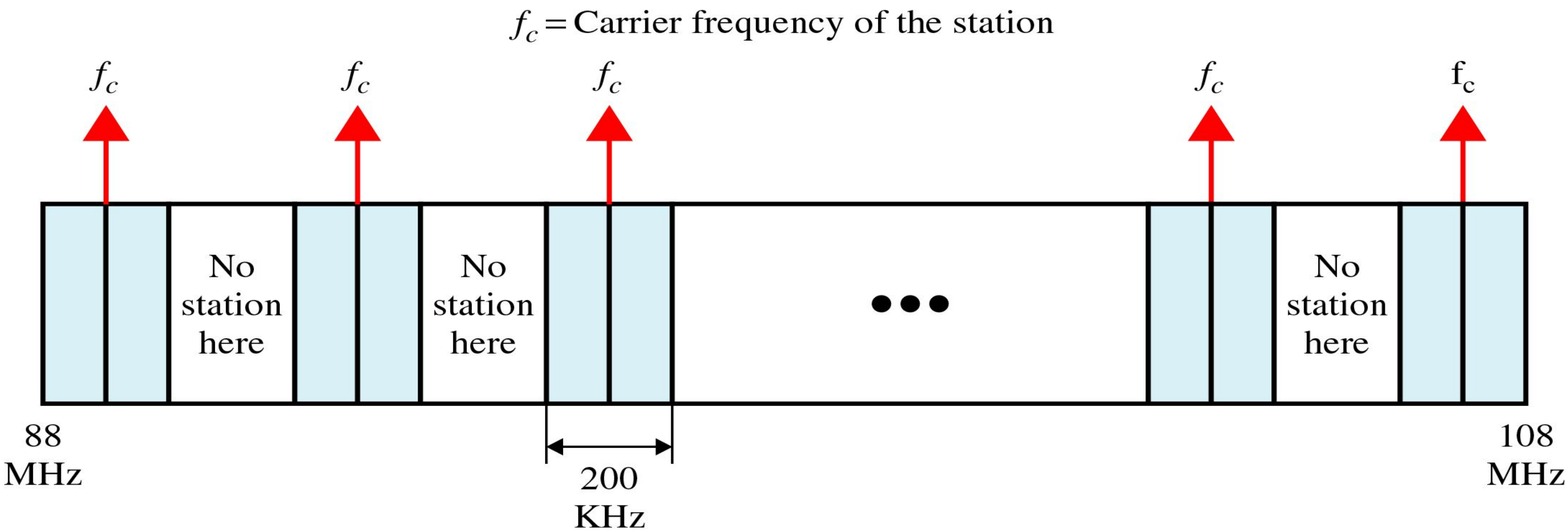


Analog-to-Analog Conversion - FM

- Bandwidth of an audio signal broadcast in stereo : 15 KHz
- minimum bandwidth : 150 KHz
- allows generally 200 KHz(0.2 MHz) for each station
- FM station are allowed carrier frequencies anywhere 88 and 108 MHz (each 200 KHz)

Analog-to-Analog Conversion - FM

- FM band allocation

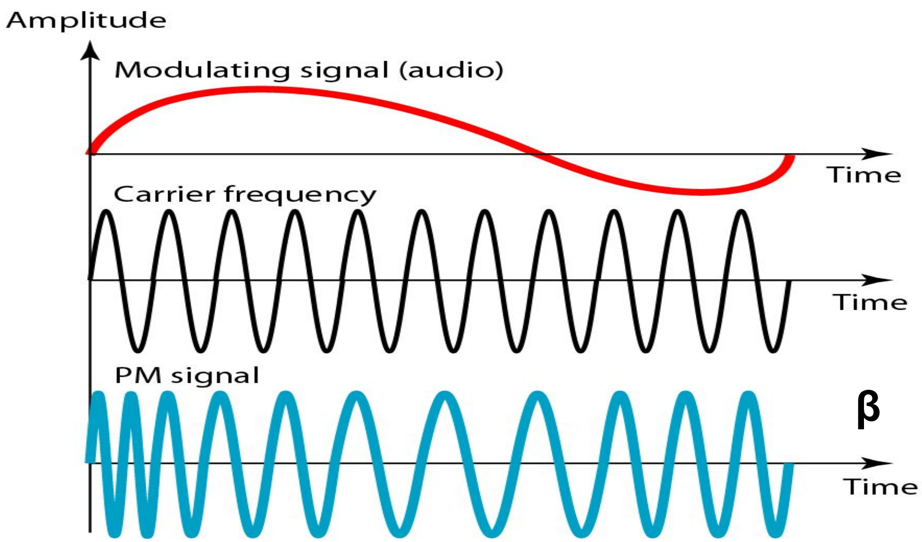


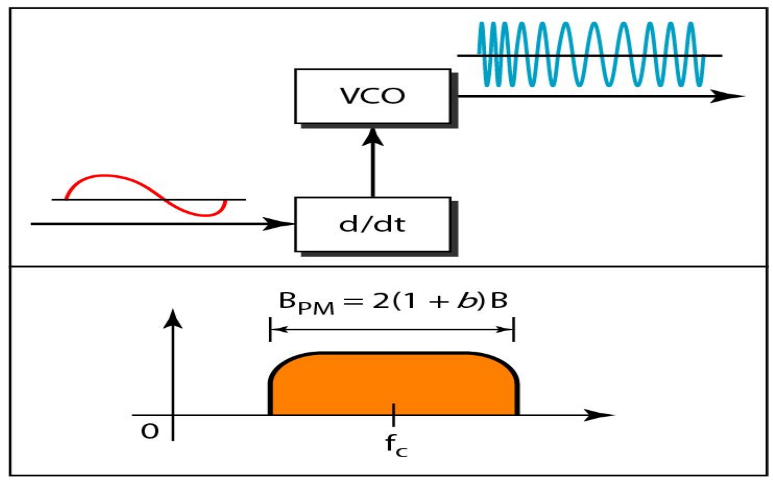
Alternate bandwidth allocation

PM(Phase Modulation)

- The phase of the carrier signal is modulated to follow the changing voltage (amplitude) of the modulating signal
- ~ is used in some systems as an alternative to frequency modulation.

Figure 5.20 *Phase modulation*





Analog-to-Analog Conversion - PM

Note

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

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

β : a factor depending on modulation technique with around 1 for narrowband and 3 for wideband

Summary (1)

- Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in the digital data.
- Digital-to-analog conversion can be accomplished in several ways: amplitude shift keying(ASK), frequency shift keying (FSK), and phase shift keying(PSK). Quadrature amplitude modulation(QAM) combines ASK and PSK.
- 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.
- 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.

Summary (2)

- 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.
- A constellation diagram shows us the amplitude and phase of a signal element, particularly diagram when we are using two carriers(one in-phase and one quadrature).
- Quadrature amplitude modulation(QAM) is a combination of ASK and PSK. QAM uses two carriers, one in-phase and the other quadrature, with different amplitude levels for each carrier.
- Analog-to-analog conversion is the representation of analog information by an analog signal. Conversion is needed if the medium is bandpass in nature or if only a bandpass bandwidth is available to us.
- Analog-to-analog conversion can be accomplished in three ways: amplitude modulation(AM), frequency modulation(FM), and phase modulation(PM).

Summary (3)

- In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal. The frequency and phases of the carrier remain the same; only the amplitude changes to follow variations in the information.
- In FM transmission, the frequency of the carrier signal is modulated to follow the changing voltage level(amplitude) of the modulating signal. 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.
- In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level(amplitude) of the modulating signal. 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.

Q & A