Chapter 5: Analog Transmission

Outline

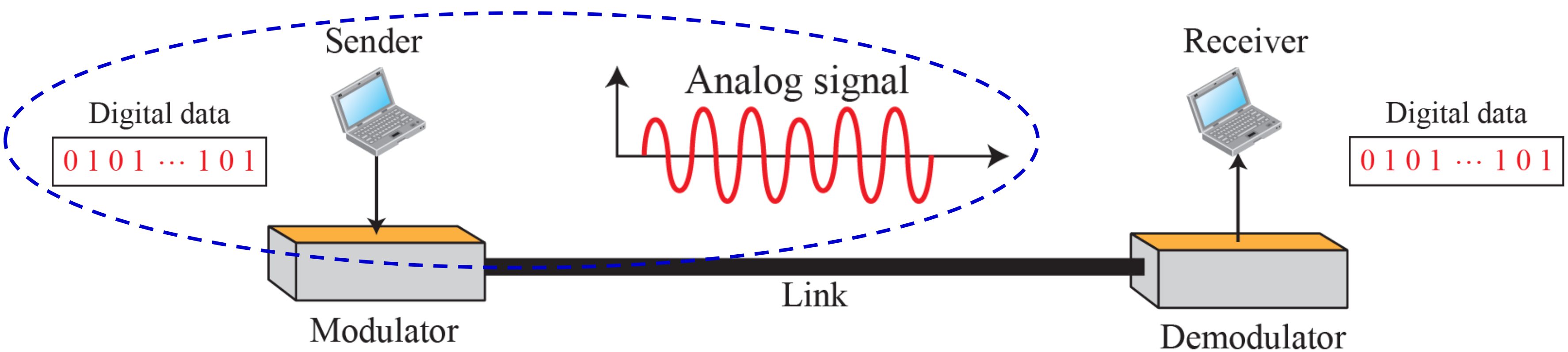
5.1 DIGITAL-TO-ANALOG CONVERSION

5.2 ANALOG-TO-ANALOG CONVERSION

5-1 DIGITAL-TO-ANALOG CONVERSION

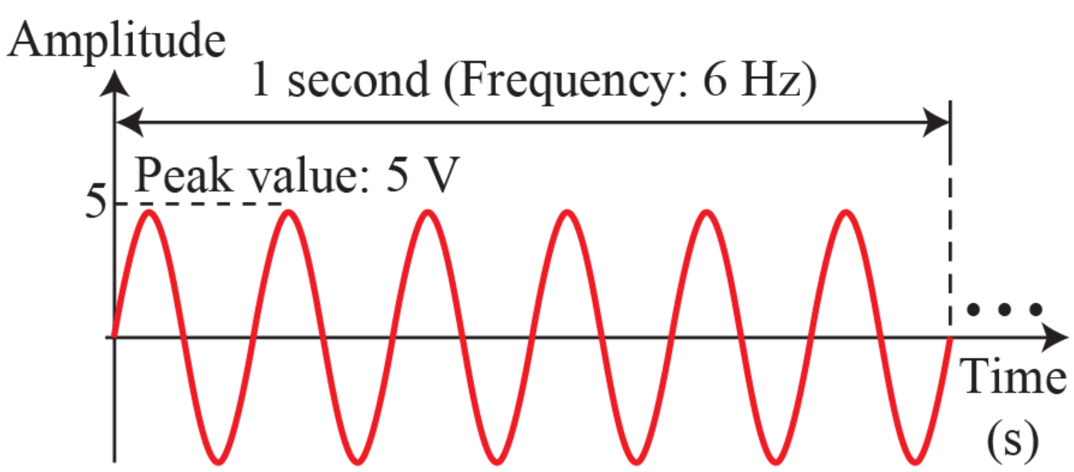
Digital-to-analog ***conversion is the process of*** ***changing*** ***one of the*** ***characteristics*** ***of an*** ***analog signal*** ***based on*** ***the information in*** ***digital data.***

The relationship between the ***digital data***, ***the*** ***digital-to-analog*** ***modulating process and the resultant*** ***analog signal*** ***is shown below:***



3.2.1 Sine Wave

Recall that the <u>sine wave</u> is the <u>most fundamental form of a periodic analog signal</u>. It is <u>comprehensively defined</u> by its <u>peak amplitude</u>, <u>frequency</u>, and <u>phase</u>. The <u>time-domain plot</u> shows changes in signal amplitude with respect to time.



a. A sine wave in the time domain

Figure 3.4: ***Two signals with <u>different amplitudes</u>***

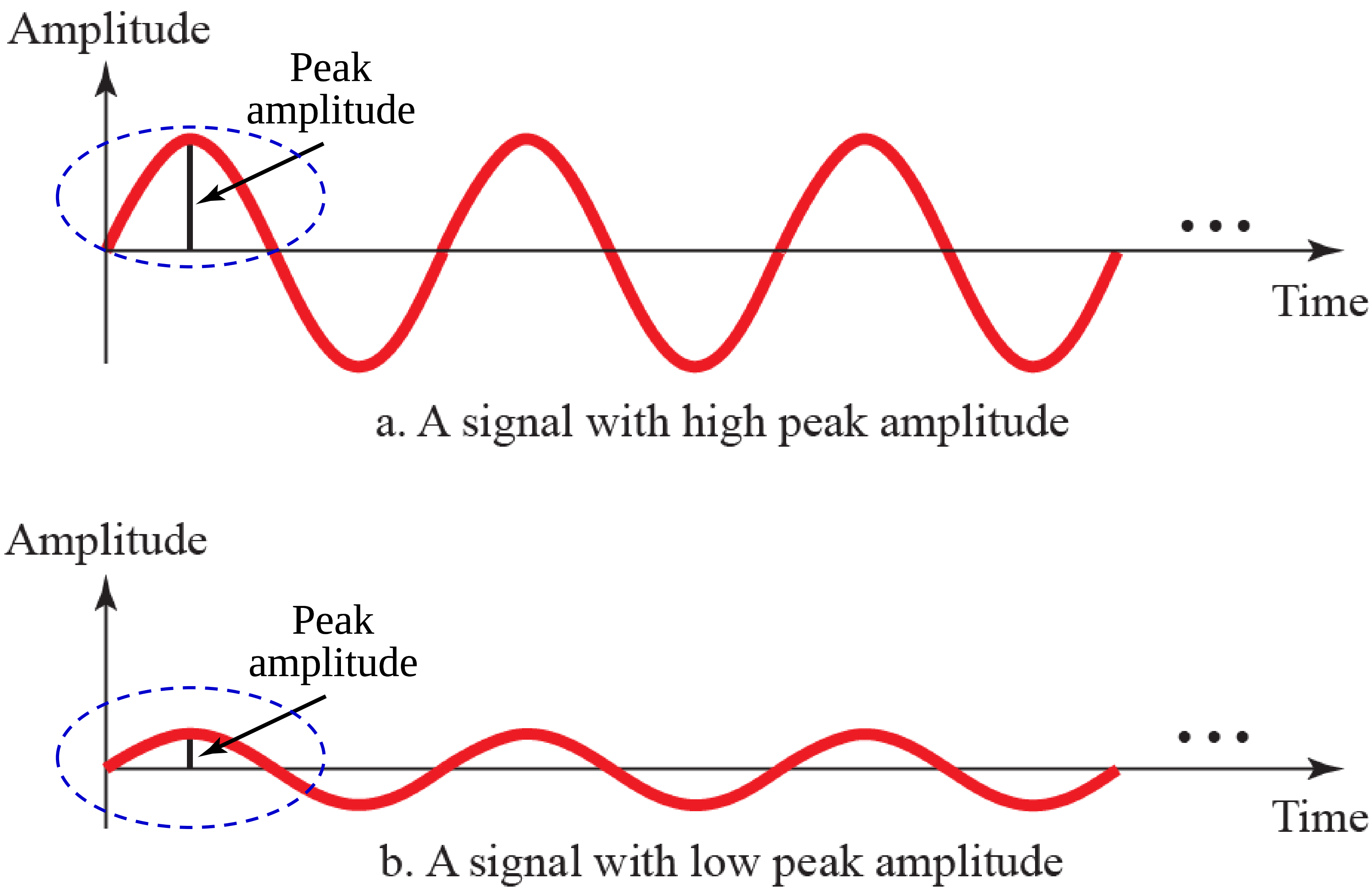
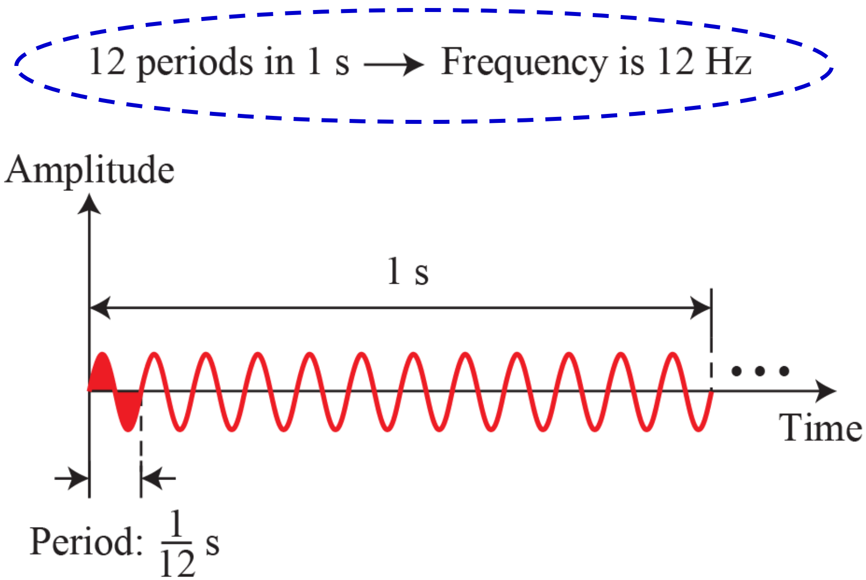
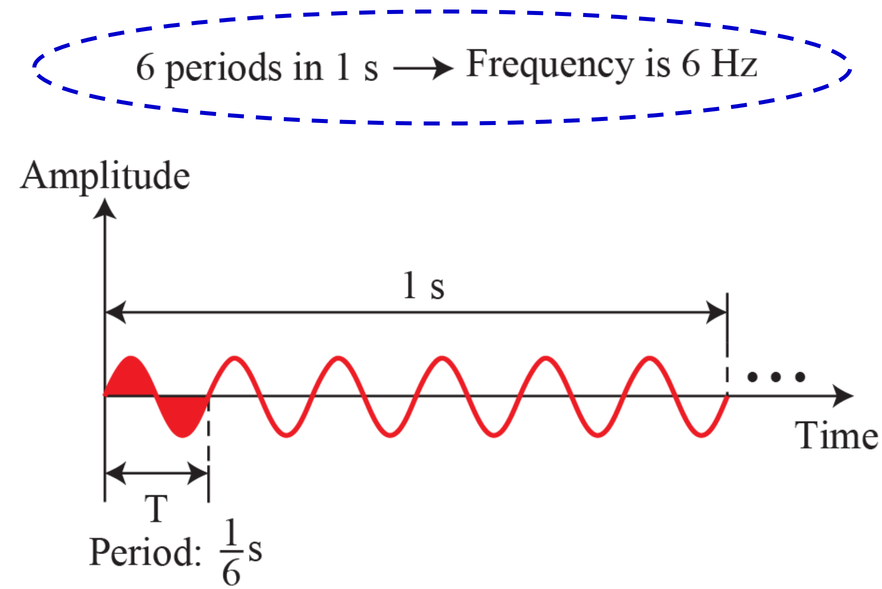


Figure 3.5: ***Two signals with <u>different frequencies</u>***

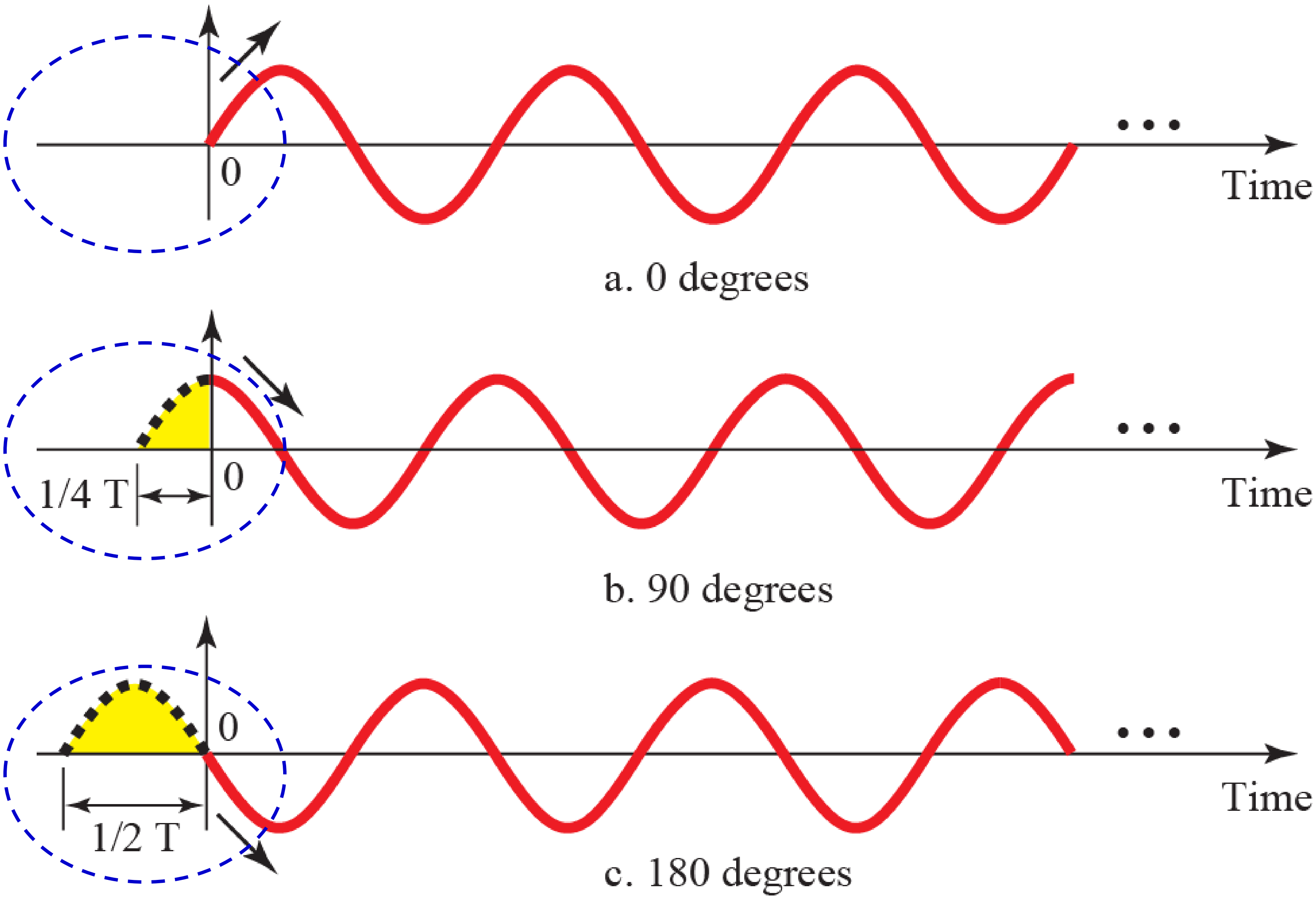


a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Figure 3.6: Three signals with different phases



5.1.1 Bit and Baud Rates, Carrier Frequency

The relationship between the <u>data rate</u> (bit rate), N, and the <u>signal rate</u> (baud rate), S, is defined as

$$\boxed{S = N \times \frac{1}{r}}$$

where $r = \log_2 L$, is the number of data elements carried in one signal element and L is the number of different signal elements.

The <u>carrier frequency</u> (carrier signal) is a high-frequency signal that acts as a base for the information signal. <u>Digital information</u> then changes the carrier signal by modifying (shift keying) one or more of its <u>characteristics</u> (amplitude, frequency or phase).

Problem

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

Solution

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

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

Problem

An analog signal has a data rate of 8000 bps and a signal rate of 1000 baud. Determine the number of data elements that are carried by each signal element. How many different signal elements are needed?

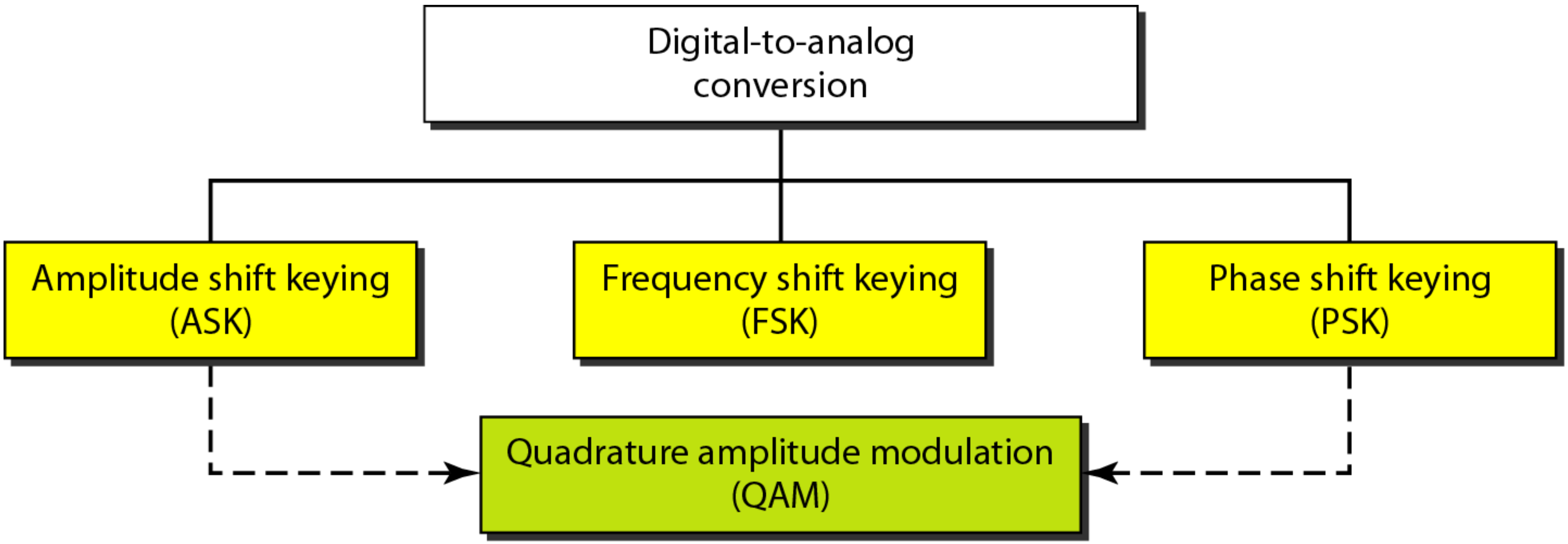
Solution

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

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

$$r = \log_2 L \longrightarrow L = 2^r = 2^8 = 256 \text{ signal elements}$$

Figure 5.2: *Types of digital to analog conversion*



5.1.2 Amplitude Shift Keying (ASK)

In amplitude shift keying (ASK), the <u>amplitude</u> of the carrier signal is <u>varied</u> to create signal elements. Both the frequency and phase remain constant while the amplitude changes.

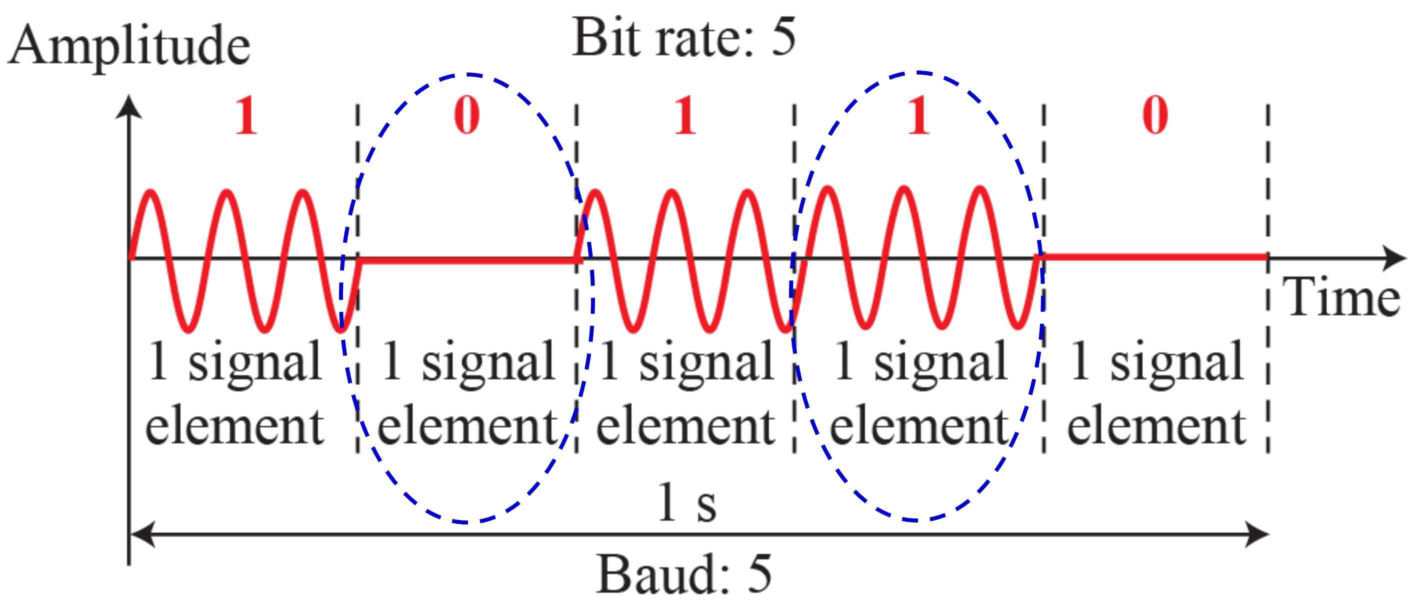
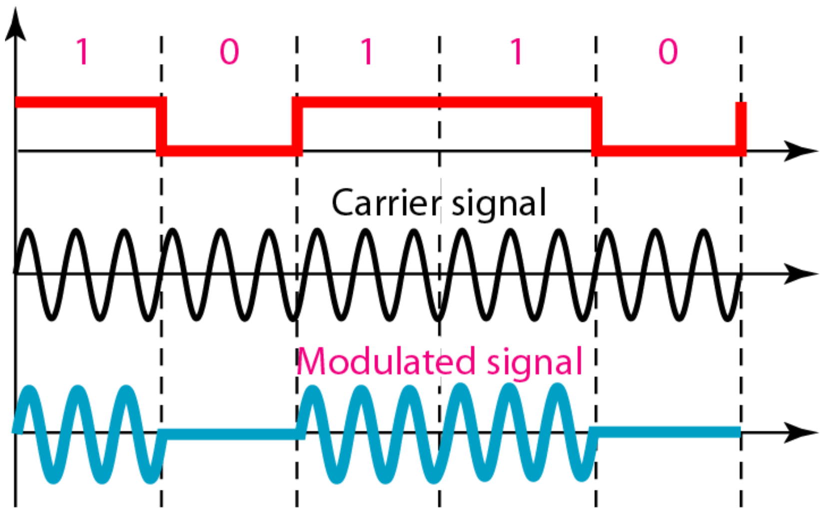
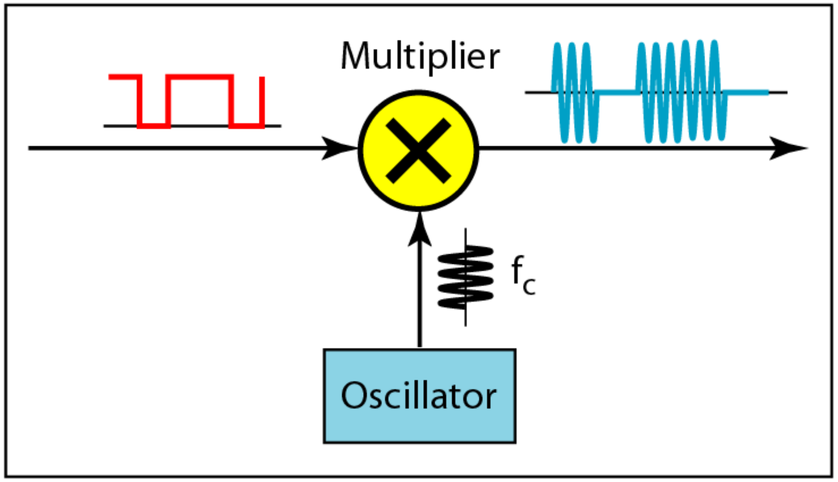


Figure 5.4: Implementation of binary ASK





The implementation of BASK can be achieved by <u>multiplying the digital signal</u> with the <u>carrier signal</u> coming from an oscillator: when the <u>digital signal is 1</u>, the <u>amplitude</u> of the carrier frequency <u>is held</u>; when the <u>digital signal is 0</u>, the <u>amplitude</u> of the carrier frequency <u>is zero</u>.

5.1.3 Frequency Shift Keying (FSK)

In frequency shift keying (FSK), the <u>frequency</u> of the carrier signal is <u>varied</u> to represent data. Both the peak amplitude and phase remain constant for all signal elements.

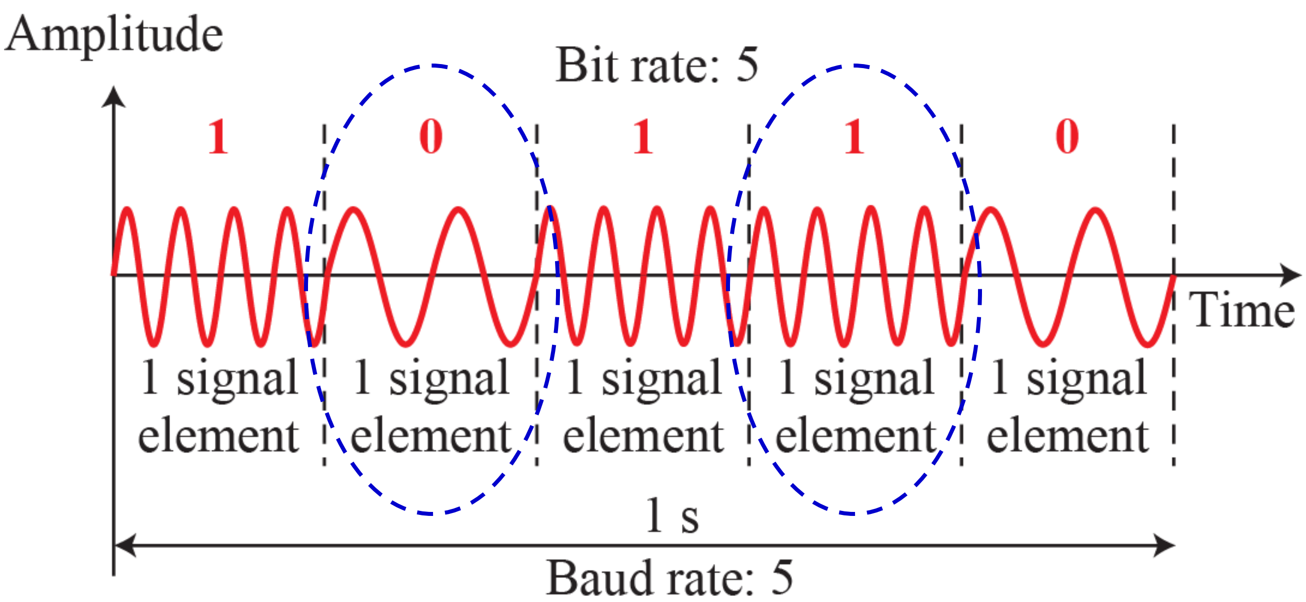
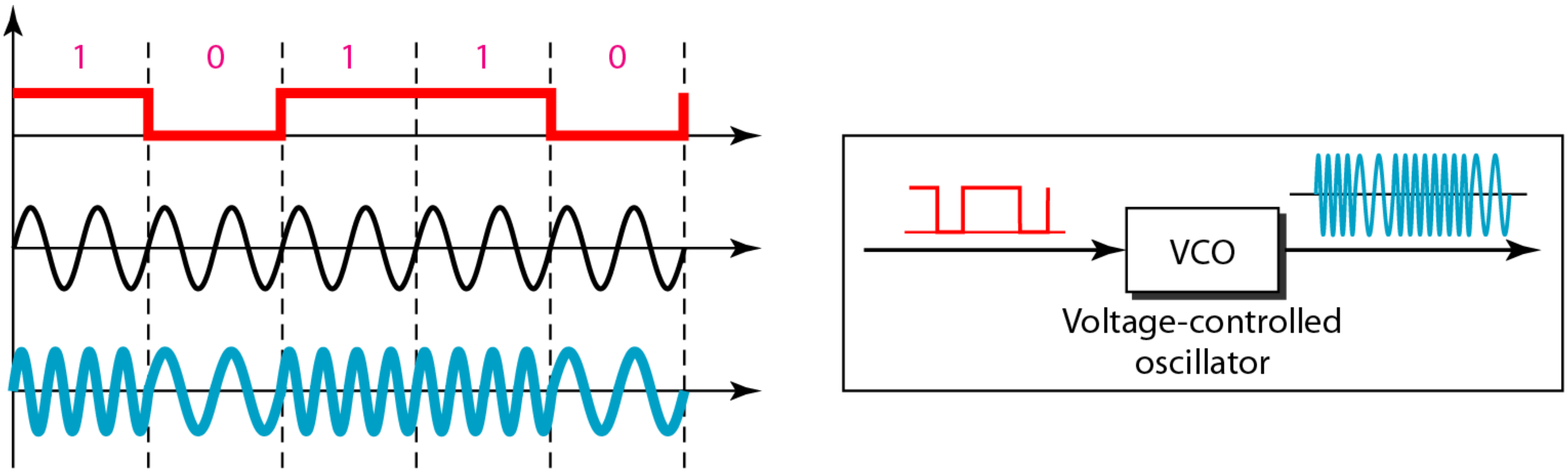


Figure 5.7: *Implementation of BFSK*

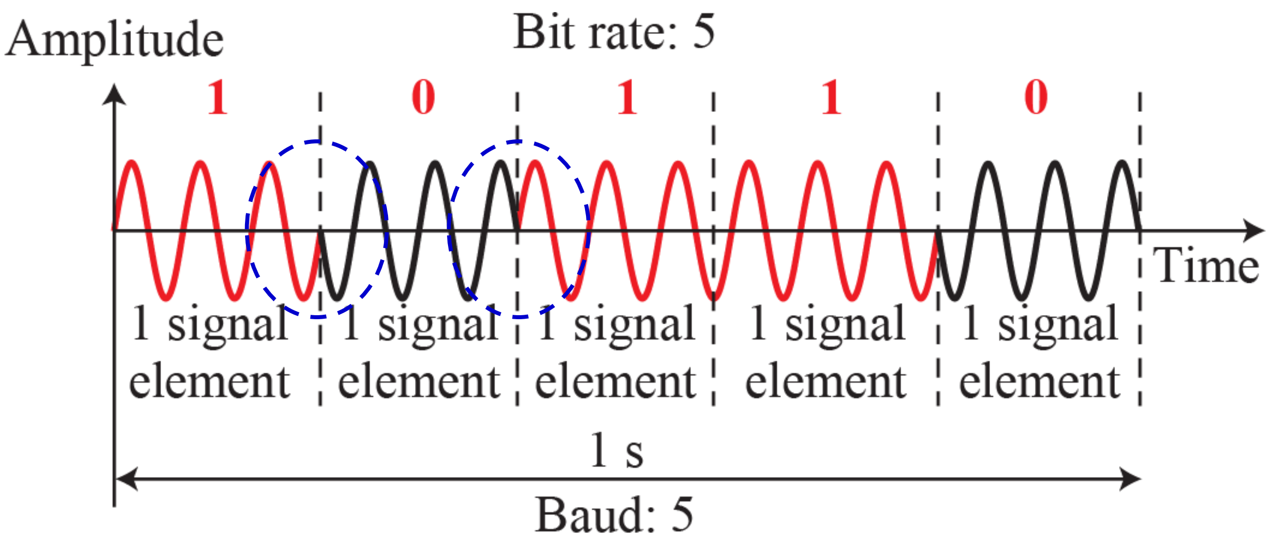


***Coherent* BFSK (phase continues through the boundary of two signal elements) can be implemented by using a voltage-controlled oscillator that changes its frequency according to the input voltage: when the digital signal is 0, the oscillator keeps its regular frequency; when the digital signal is 1, the frequency is increased.**

(Noncoherent BFSK can be implemented by treating BFSK as two ASK modulations and using two carrier frequencies.)

5.1.4 Phase Shift Keying (PSK)

In phase shift keying (PSK), the <u>phase</u> of the carrier is <u>varied</u> to represent two or more different signal elements. Both the peak amplitude and frequency remain constant as the phase changes.



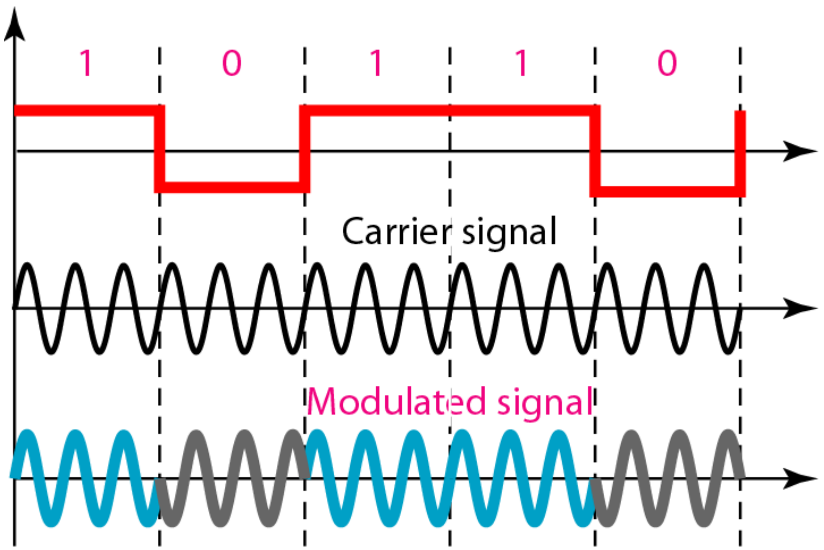
Advantages:

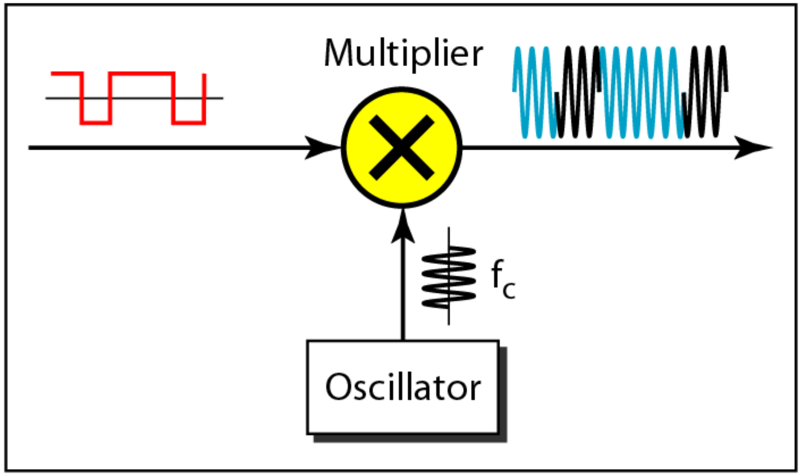
1) **PSK is <u>less susceptible to noise</u> than ASK (noise changes amplitude easier than it can change the phase)**
2) **PSK <u>does not require multiple carrier signals</u> as compared to FSK.**

Disadvantage:

1) **PSK requires more <u>sophisticated hardware</u> to be able to distinguish between phases.**

Figure 5.10: Implementation of BPSK





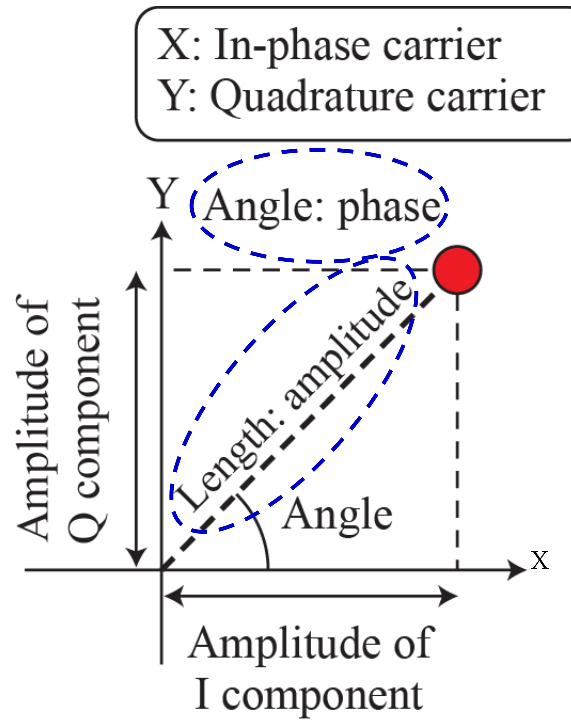
The implementation of BPSK can be achieved by <u>multiplying the digital signal</u> with the <u>carrier signal</u> coming from an oscillator: when the <u>digital signal is 1</u>, the phase starts at <u>0°</u>; when the <u>digital signal is 0</u>, the phase starts at <u>180°</u>.

5.1.5 Quadrature Amplitude Modulation (QAM)

So far, we have been altering only one of the three characteristics of a sine wave at a time; but what if we <u>alter two</u> and combine ASK (<u>amplitude</u>) and PSK (<u>phase</u>)?

The idea of using <u>two carriers</u> (same frequency, 90° out-of-phase with each other), one <u>in-phase</u> and the other <u>quadrature</u>, with <u>different amplitude levels</u> for each carrier is the concept behind <u>quadrature amplitude modulation</u> (QAM).

Constellation Diagram



Constellation Diagrams

Constellation diagrams define the <u>amplitude</u> and <u>phase</u> of a signal element, particularly when two carriers (in-phase and quadrature) are used. The diagrams are useful when dealing with <u>multi-level</u> ASK, PSK and QAM.

The diagram has <u>two axes</u>:

1. **<u>X-axis</u> relates to the <u>in-phase carrier</u>**
2. **<u>Y-axis</u> relates to the <u>quadrature carrier</u>**

For <u>each point</u> (symbol) on the diagram, <u>four pieces of information</u> can be deduced:

- ***i. Peak amplitude of in-phase (I) component***
- ***ii. Peak amplitude of quadrature (Q) component***
- ***iii. <u>Peak signal amplitude of the signal element</u>***
- ***iv. <u>Phase of the signal element</u>***

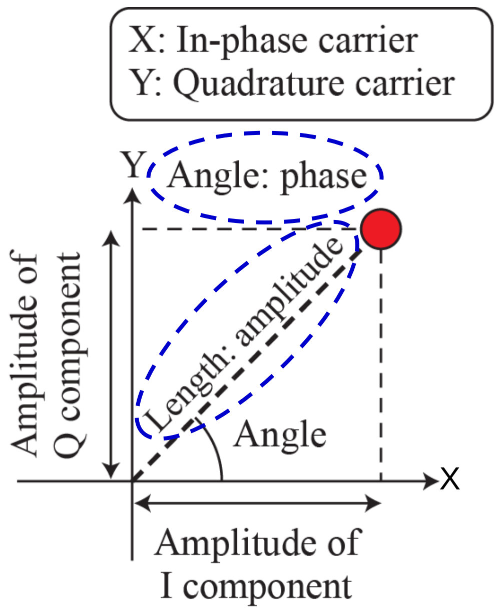
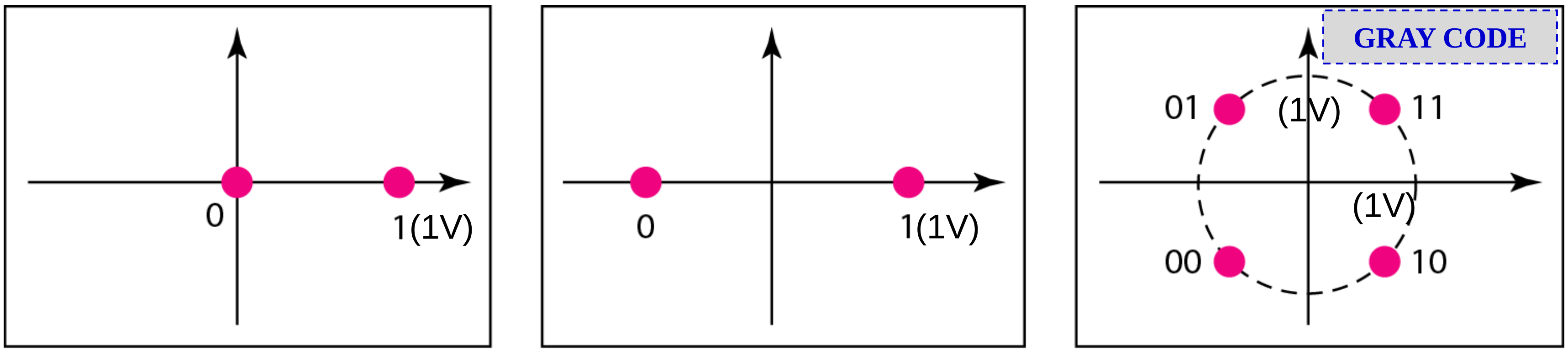


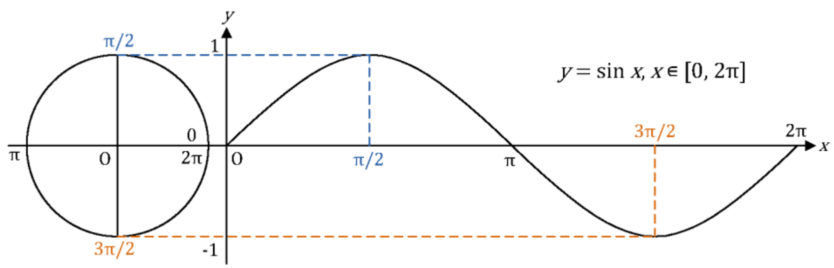
Figure 5.13: *Constellation diagrams for BASK, BPSK and QPSK*



a. BASK b. BPSK c. QPSK

Legend: **B**: Binary (2 points – 1 bit) **Q**: Quadrature (4 points – 2 bits)

Unit Circle – Sine Wave Relationship



BASK: uses only an **in-phase** carrier ➔ two points are on the X-axis.

Binary 0 has an amplitude of 0 V;
Binary 1 has an amplitude of 1 V.

BPSK: uses only an **in-phase** carrier ➔ two points are on the X-axis.

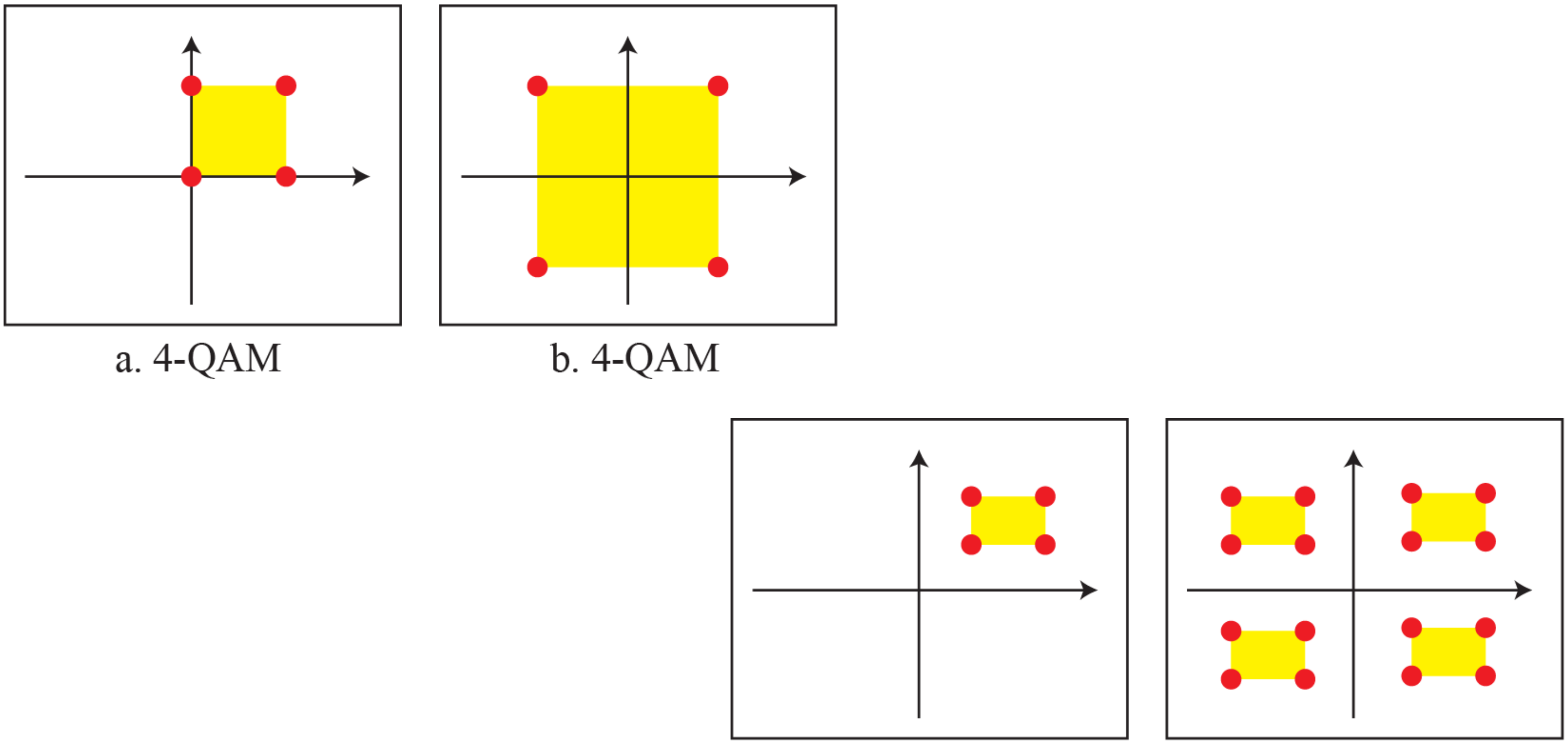
Binary 0 has an amplitude 1 V (180° out of phase);
Binary 1 has an amplitude of 1 V (0°).

QPSK: **uses both in-phase and quadrature carriers ➔ the point representing '11' is made of 2 combined signal elements (in-phase and quadrature), each with an amplitude of 1 V.**

The amplitude of '11' is $\sqrt{2}$ V (Pythagoras' Theorem) at 45°. The other signal elements also have amplitudes of $\sqrt{2}$ V but at 135°, -135° and -45°.

Figure 5.14: Constellation diagrams for QAM

There are numerous possible variations of QAM:



c. 4-QAM

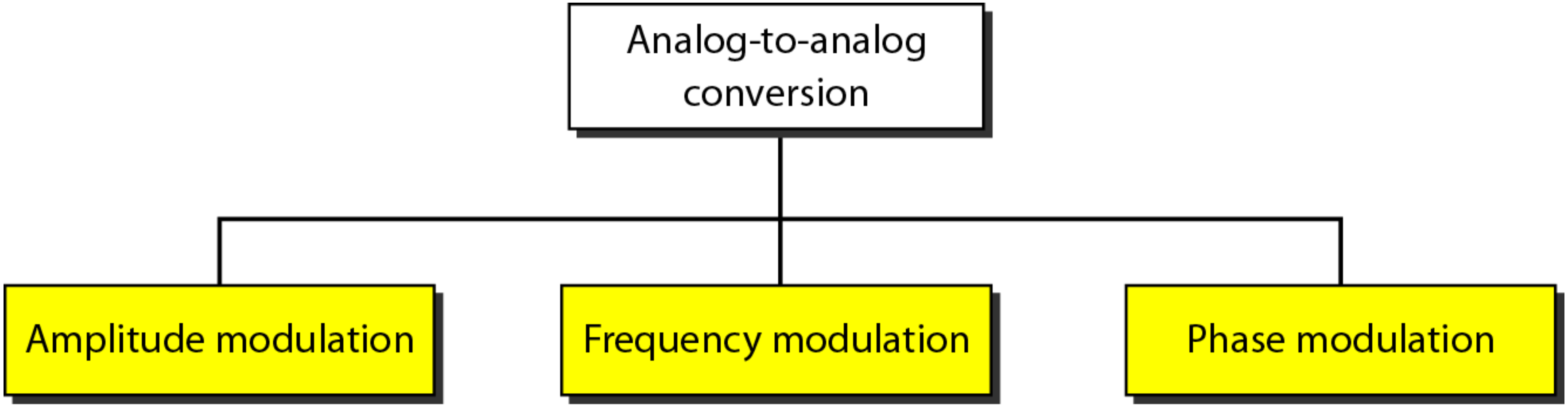
d. 16-QAM

Note: 4-QAM shown in (b) is the same as QPSK.

5-2 ANALOG-TO-ANALOG CONVERSION

<u>Analog-to-analog</u> conversion, or analog modulation, is the <u>representation</u> of <u>analog data</u> by an <u>analog signal</u>.

Modulation is needed if the medium is <u>bandpass</u> in nature or if only a bandpass channel is available.

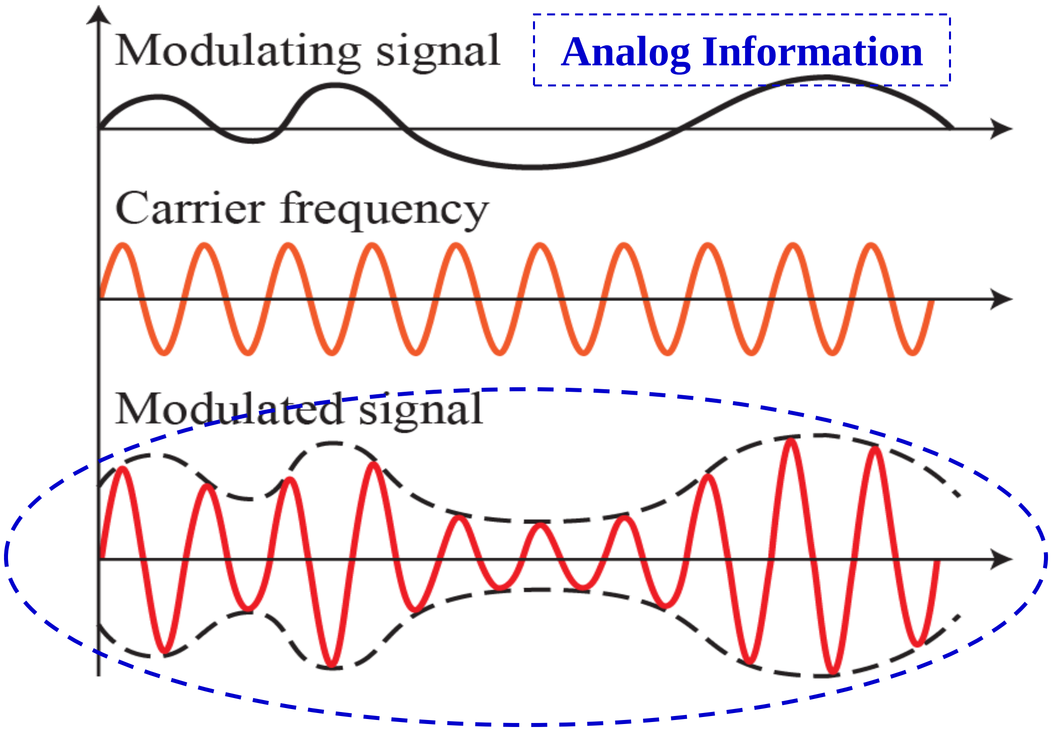


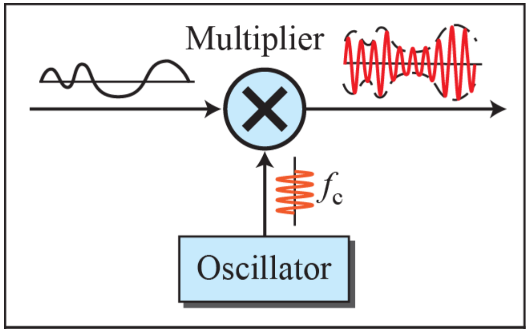
5.2.1 Amplitude Modulation (AM)

In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal.

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





The <u>amplitude of the carrier signal</u> needs to be <u>changed</u> according to the <u>amplitude of the modulating signal</u>. The <u>modulating signal</u> is the <u>envelope</u> of the <u>carrier</u>.

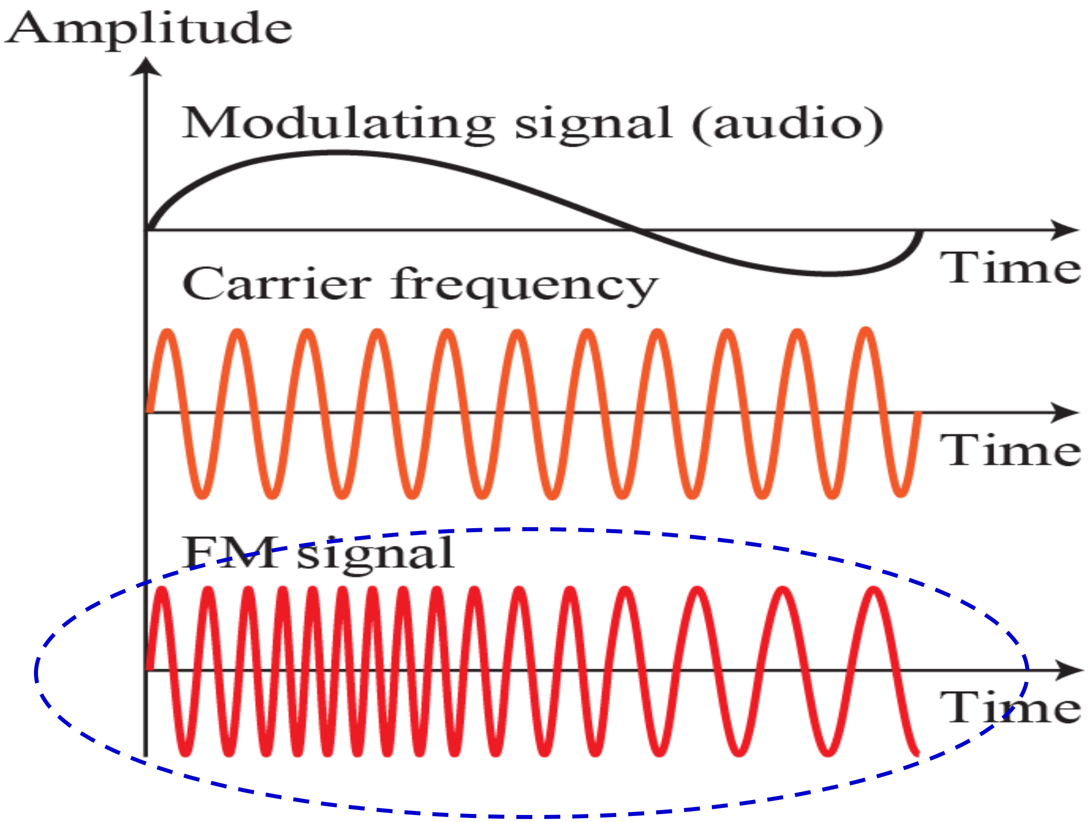
AM is normally implemented using a simple multiplier.

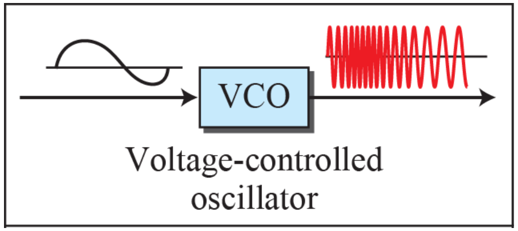
5.2.2 Frequency Modulation (FM)

In FM transmission, the frequency of the carrier signal is modulated to follow the changing amplitude of the modulating signal.

The peak amplitude and phase of the carrier signal remain constant.

Figure 5.18: Frequency modulation





As the <u>amplitude</u> of the information signal changes, the <u>frequency</u> of the carrier changes correspondingly.

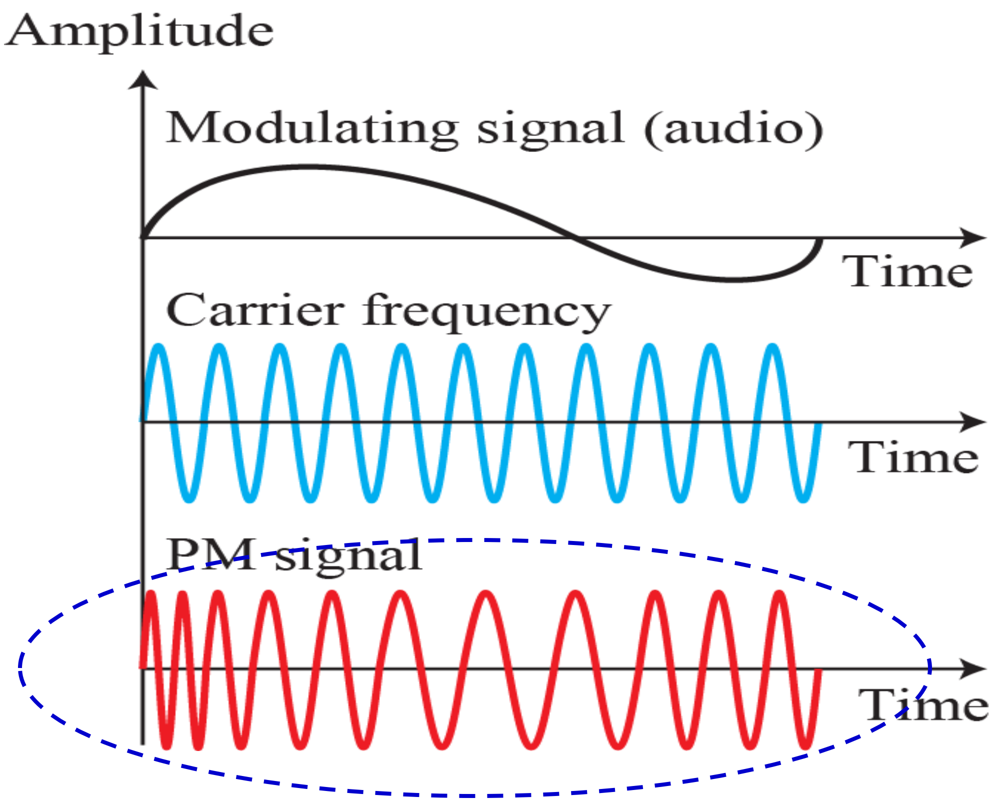
FM is normally implemented by using a voltage-controlled oscillator as with FSK.

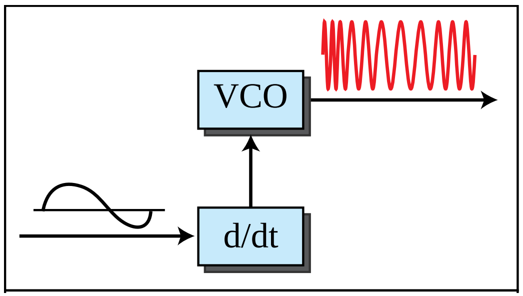
5.2.3 Phase Modulation (PM)

In <u>PM transmission</u>, the <u>phase</u> of the <u>carrier signal</u> is modulated to follow the <u>changing amplitude</u> of the <u>modulating signal</u>. The peak amplitude and frequency of the carrier signal remain constant.

PM can be mathematically shown (Appendix E) to be the same as FM with a difference: in PM, the instantaneous change in the carrier frequency is proportional to the <u>derivative</u> of the amplitude of the modulating signal (as opposed to the amplitude of the modulating signal in FM).

Figure 5.20: Phase modulation





As the <u>amplitude</u> of the information signal changes, the <u>phase</u> of the carrier changes correspondingly.

PM is normally implemented by using a voltage-controlled oscillator along with a derivative.