BACHELOR OF COMPUTER APPLICATIONS

SEMESTER 3

DCA2104

BASICS OF DATA COMMUNICATION

Unit 5

Analog Transmission

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1. INTRODUCTION

We have discussed digital transmission in unit 4. In this unit, we discuss analog transmission. Converting digital data to a bandpass analog signal is called digital to analog conversion. Converting a low pass analog signal to a bandpass analog signal is traditionally called analog to analog conversion.

In this unit, we discuss these two types of conversions. We will discuss digital to analog conversion methods such as amplitude shift keying, frequency shift keying, and phase shift keying and quadrature amplitude modulation. We will also see how an analog to analog conversion and different conversion methods such as amplitude modulation, frequency modulation and phase modulation take place.

1.1 Objectives

After studying this unit, you should be able to:

- *Describe amplitude shift keying*
- *Explain frequency shift keying*
- *Describe phase shift keying*
- *.Explain quadrature amplitude modulation*
- *Describe amplitude modulation*
- *Explain frequency modulation*
- *Describe phase modulation*

2. DIGITAL TO ANALOG CONVERSION

Digital to analog conversion can be defined as the process of changing one of the characteristics of analog signal based on the information in digital data. Figure 5.1 illustrates digital to analog conversion.

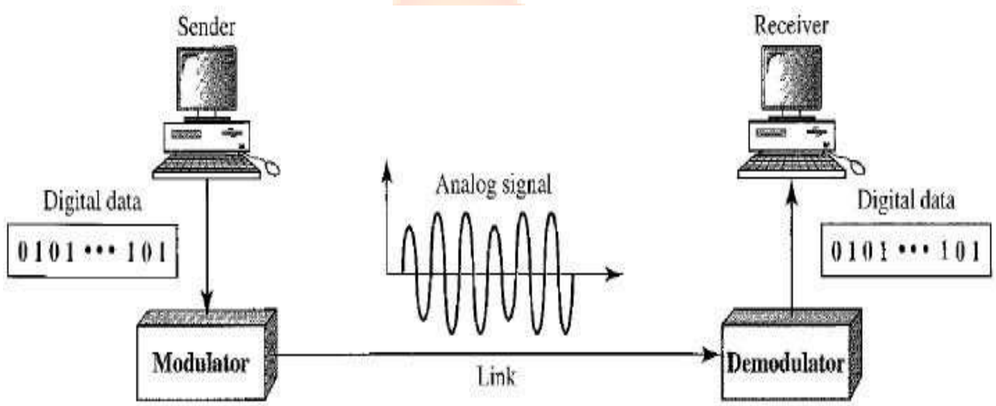

Figure 5.1: digital to analog conversion

As we discussed in unit 3, if we change amplitude, frequency or phase of a sine wave, we will get a different version of sine wave. So digital to analog conversion take place by changing any of the three characteristics of a simple electric signal so that it can be used to represent digital data. There are three mechanisms for modulating digital data into an analog signal. They are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK). There is another mechanism that combines changing both amplitude and phase, this is called Quadrature Amplitude Modulation (QAM). QAM is the most efficient mechanism and this is commonly used today. Figure 5.2 shows different types of digital to analog conversion.

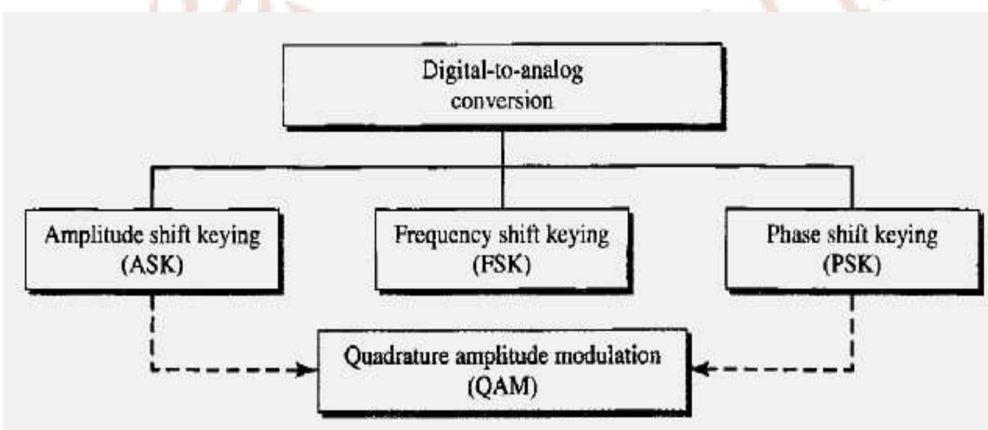

Figure 5.2: Types of digital to analog conversion

Aspects of digital to analog conversion

Data element versus signal element: Data element is the smallest piece of information to be exchanged (known as bit). Signal element is the smallest unit of a signal.

Data rate versus signal rate

As we discussed in unit 4, the data rate (bit rate) defines the number of data elements sent in one second and signal rate (baud rate) is the number of signal elements sent in one second. The relationship between them is:

$$S = N \times (1/r) \text{ baud}$$

Where N is the data rate (bps) and r is the number of data elements carried in one signal element. The value of r in analog transmission is $r = \log_2 L$, where L is the type of signal element.

Bandwidth: The required bandwidth for analog transmission of digital data is proportional to the signal rate except for Frequency Shift Keying (FSK), in which the difference between carrier signals need to be added.

Carrier signal: In analog transmission, sender produces a high frequency signal known as *carrier signal* or *carrier frequency*, which act as a base for the information signal. The receiving device is tuned to the frequency of the carrier signal that it expects from the sender. Digital data then changes the carrier signal by modifying one or more of its characteristics such as amplitude, frequency or phase. This kind of modification is called modulation.

2.1 Amplitude Shift Keying (ASK)

In this method, amplitude of the carrier signal is varied to create signal elements and both frequency and phase remain constant while amplitude changes.

Binary ASK (BASK)

Even though there are different levels of signal elements with different amplitudes, ASK is normally implemented using only two levels. This is referred to as binary amplitude shift keying or On-Off Keying (OOK). The peak amplitude of one signal level is 0 and the other is same as the amplitude of the carrier frequency. Figure 5.3 represents binary amplitude shift keying.

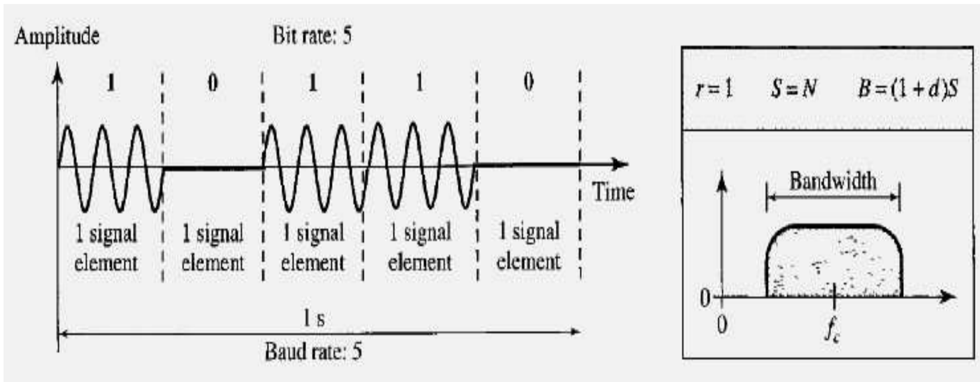

Figure 5.3: Binary amplitude shift keying

Figure 5.3 also shows the bandwidth for ASK. Although the carrier signal is one simple sine wave, modulation process produces a nonperiodic composite signal which has continuous set of frequencies. Bandwidth is proportional to signal rate and another factor d, which depends on the modulation and filtering process. The value of d is between 0 and 1. Bandwidth is expressed as:

$$B = (1+d) \times S$$

where S is the signal rate and B is the bandwidth. From the above formula, it is clear that the required bandwidth has a minimum value of S and maximum value of 2S. Carrier frequency f_c is located in the middle of the bandwidth. That is, if we have a bandpass channel available, we can choose our fc so that the modulated signal occupies that bandwidth. Important advantage of digital to analog conversion is that we can shift the resulting bandwidth to match the available bandwidth.

Now we discuss the simple ideas behind the implementation of binary ASK. Figure 5.4 shows the implementation of binary ASK.

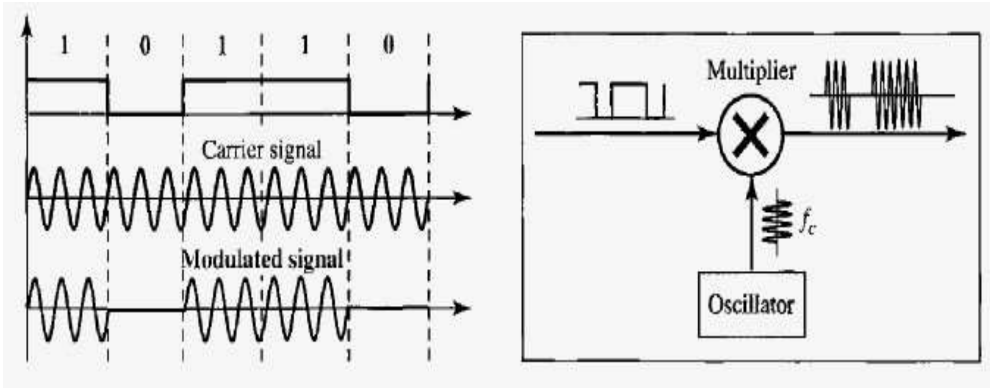

Figure 5.4: Implementation of binary ASK

If digital data are presented as a unipolar NRZ digital signal with a high voltage of 1V and a low voltage of 0V, the implementation can be achieved by multiplying the NRZ digital signal by the carrier signal coming from an oscillator. When the amplitude of the NRZ signal is 1, the amplitude of the carrier frequency is applied; when the amplitude of the NRZ signal is 0, the amplitude of the carrier frequency is zero.

Multilevel ASK

We can have multilevel ASK in which there are more than two levels. We can use 4, 8, 16 or more different amplitudes for the signal and modulate the data using 2, 3, 4 or more bits at a time. In these cases, r = 2, r =3, r = 4 and so on. Multilevel ASK is not implemented with pure ASK, but it is implemented with QAM, which we will discuss in 5.2.4.

2.2 Frequency Shift Keying

In Frequency Shift Keying, 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 FSK (BFSK)

In Binary FSK, there are two carrier frequencies f_1 and f_2. We use the first carrier if the data element is 0, and second if the data element is 1. But practically, the carrier frequencies are very high and difference between them is very small. Figure 5.5 shows binary frequency shift keying.

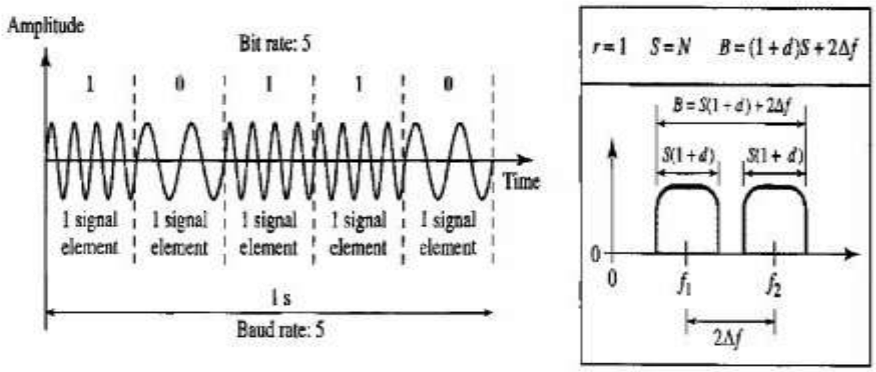

Figure 5.5: Binary frequency shift keying

We can see in figure, the middle of one bandwidth is f_1 and the middle of other is f_2. Both f_1 and f_2 are Δf apart from the midpoint between the two bands. The difference between two frequencies is $2\Delta f$. Figure 5.5 also shows the bandwidth of FSK. Carrier signals are simple sine waves, but modulation process creates a nonperiodic composite signal with continuous frequencies. FSK can be defined as two ASK signals, each with its own carrier frequency (f_1 or f_2). If the difference between two frequencies is $2\Delta f$, then the required bandwidth is

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

It can be shown that the minimum value should be at least S for the proper operation of modulation and demodulation.

Implementation

There are two implementations of BFSK. They are noncoherent and coherent. In noncoherent BFSK, there can be discontinuity in the phase when one signal element ends and the next begins. In coherent BFSK, the phase continues through the boundary of two signal elements. Noncoherent BFSK can be implemented by treating BFSK as two ASK modulations and using two carrier frequencies. Coherent BFSK can be implemented by using one Voltage-Controlled Oscillator (VCO) that changes its frequency based on input voltage. Simplified idea behind coherent BFSK is shown in figure 5.6. The input to the oscillator is unipolar NRZ signal. When the amplitude of NRZ is zero, the oscillator keeps its regular frequency. When the amplitude is positive, the frequency is increased.

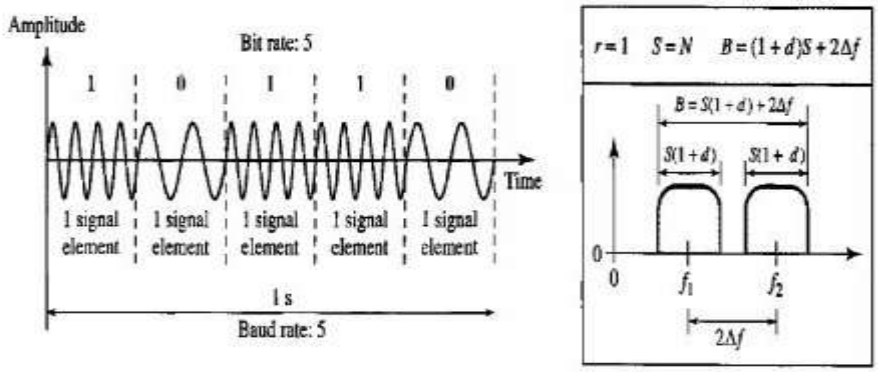

Figure 5.6: Implementation of BFSK

Multilevel FSK

In Multilevel FSK, we can use more than two frequencies. For instance, we can use four different frequencies f1, f2, f3 and f4 to send 2 bits at a time. To send 3 bits we can use eight frequencies and so on. But these frequencies need to be 2Δf apart. For perfect operation of modulator and demodulator, the minimum value of 2Δf needs to be S. The bandwidth with d=0 is

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

2.3 Phase Shift Keying (PSK)

In Phase Shift Keying (PSK), both peak amplitude and frequency remain constant and the phase of the carrier is changed to represent two or more different signal element. Compared to ASK and FSK, PSK is more common.

Binary PSK (BPSK)

The Simplest PSK is binary PSK. In that there are two signal elements, one with a phase of 0^{o} and other with a phase of 180^{o}. Figure 5.7 shows binary phase shift keying.

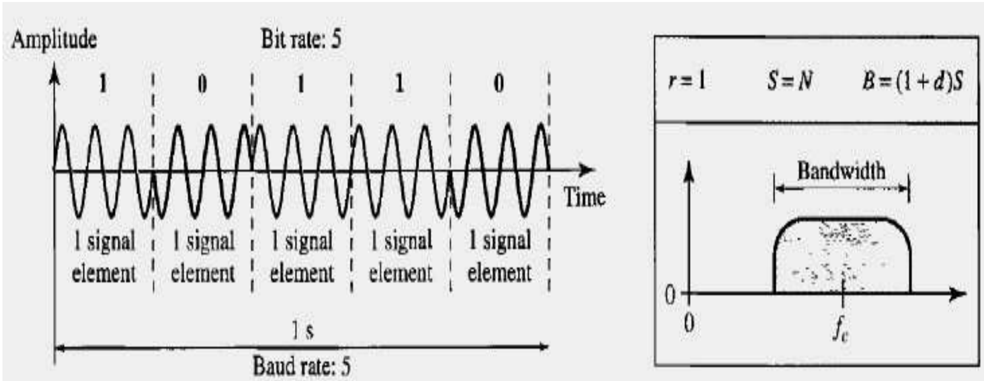

Figure 5.7: binary phase shift keying

Biggest advantage of BPSK is it is less susceptible to noise. In ASK, criterion for bit detection is amplitude of the signal but in PSK it is the phase. Noise can change amplitude easier than it can change the phase, so PSK is less open to noise than ASK. PSK is better compared to FSK also because we do not need two carrier signals. Bandwidth of BPSK is same as that of binary ASK but less than that of binary FSK. No bandwidth is wasted for separating two carrier signals.

Implementation

The implementation of BPSK is as simple as that of ASK, because the signal element with phase 180^{o} can be considered as the complement of signal element with phase 0^{o}. In BPSK, implementation idea is same as that of ASK but it uses a polar NRZ signal instead of a unipolar NRZ signal. Figure 5.8 shows the implementation of BPSK.

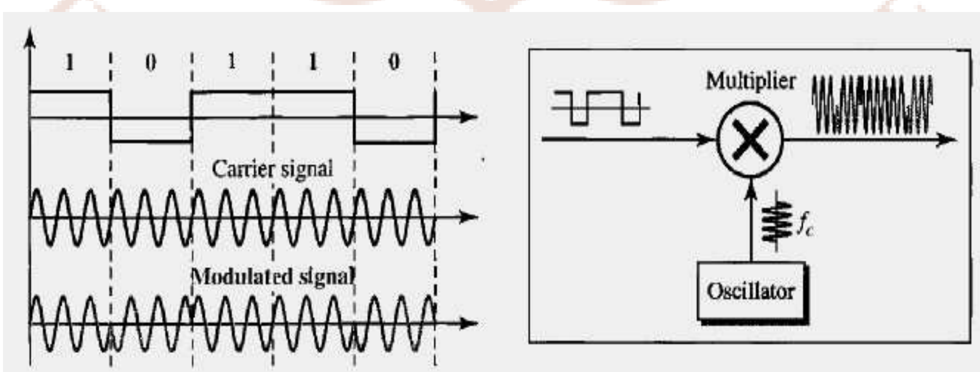

Figure 5.8: Implementation of BPSK

The polar NRZ signal is multiplied by the carrier frequency. The 1 bit (positive voltage) is represented by a phase starting at 0o. The 0 bit (negative voltage) is represented by a phase starting at 180o.

Quadrature PSK (QPSK)

In BPSK, we use 2 bits at a time, Quadrature PSK or QPSK uses two separate BPSK modulations; one is in-phase and 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 next bit to the other modulator. If the duration of each bit in the incoming signal is T, then the duration of each bit sent to corresponding BPSK signal is 2T. That means, the bit to each BPSK signals has one-half the frequency of original signal. Figure 5.9 shows QPSK and its implementation.

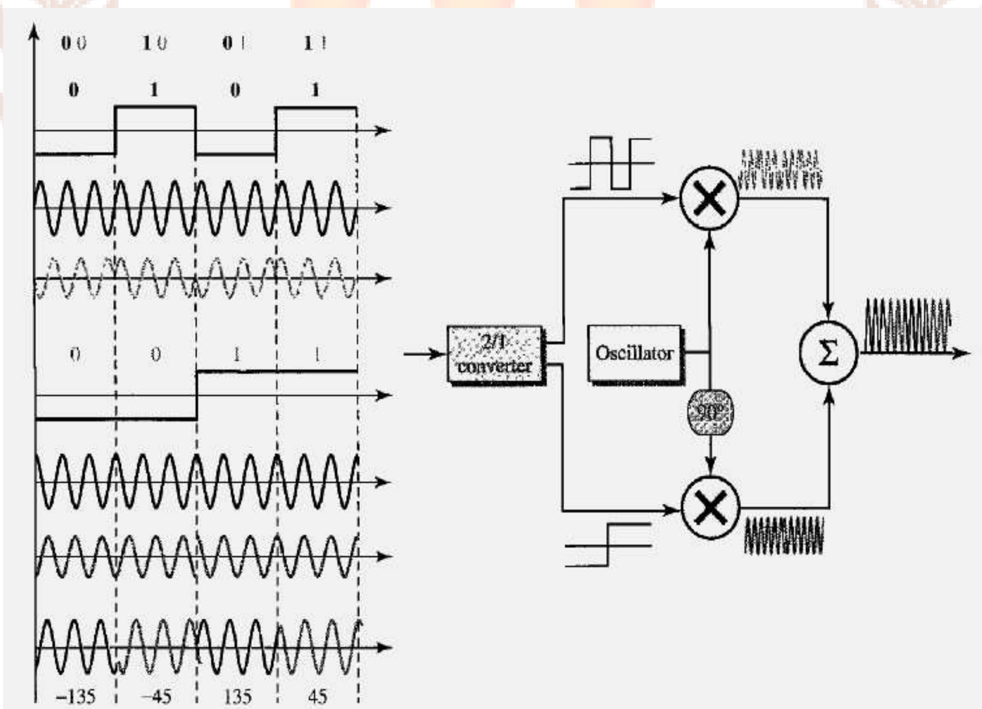

Figure 5.9: QPSK and its implementation

The two composite signals created by each multiplier are sine waves with the same frequency, but different phases. When they are added, the result is another sine wave with one of the four possible phases: 45o, -45o, 135o and -1350. There are four kinds of signal elements in the output signal (L =4) so we can send 2 bits per signal element (r = 2).

Constellation Diagram

A constellation diagram can help us define the amplitude and phase of a signal element especially when we use two carriers (one in phase and one quadrature). The diagram is useful when we are dealing with multilevel ASK, PSK or QAM. In 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.

The diagram has two axes. 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 derived. 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 that connects the point to the origin is the peak amplitude of the signal element (combination of X and Y components). The angle the line makes with the X axis is the phase of the signal element. Figure 5.10 shows a constellation diagram.

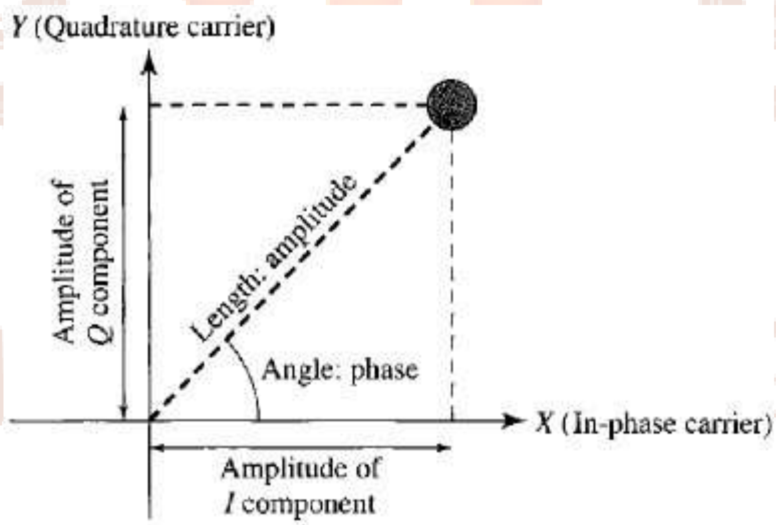

Figure 5.10: Concept of a constellation diagram

2.4 Quadrature Amplitude Modulation (QAM)

Drawback of PSK is that it can only distinguish small differences in phase and this limits its potential bit rate. The idea of using two carriers, one in- phase and the other quadrature with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM). Quadrature Amplitude Modulation is a combination of ASK and PSK. There are different variations of QAM. Figure 5.11 shows some of these schemes.

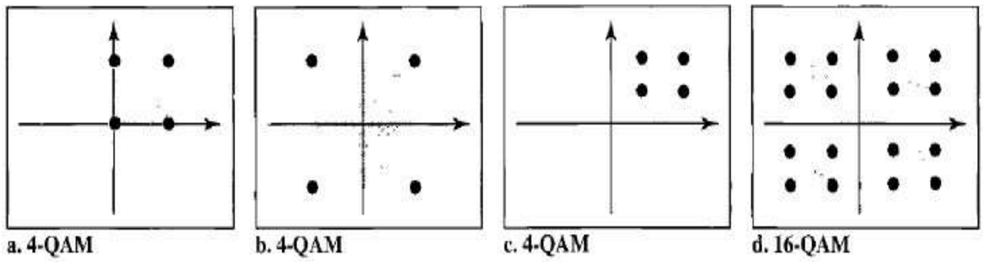

Figure 5.11: Constellation diagrams for some QAMs

Figure 5.11 (a) Shows the simplest 4-QAM scheme (four different signal element types) using a unipolar NRZ signal to modulate each carrier. This is the same mechanism we used for ASK. Figure 5.11 (b) Shows another 4- QAM using polar NRZ, but this is exactly same as QPSK. 5.11 (c) Shows another QAM-4 in which we used a signal with two positive levels to modulate each of the two carriers. Figure 5.11(d) Shows a 16-QAM constellation of signal with eight levels, four positive and four negative.

The minimum bandwidth required for QAM transmission is the same as that required for ASK and PSK transmission. QAM has the same advantages as PSK over ASK.

Self-Assessment Questions -1

1. Which of the following is a digital to analog conversion method?
    a) Amplitude modulation
    b) Amplitude shift keying
    c) Frequency modulation
    d) Phase modulation
2. In analog transmission, sender produces a high frequency signal known as_____________.
3. In_______________ , frequency of the carrier signal is varied to represent data.
4. In_____________ there are two signal elements, one with a phase of 0^{o} and other with a phase of 180^{o}.
5. ________________uses two separate BPSK modulations; one is in-phase and other quadrature.
6. ________________is a combination of ASK and PSK.
7. In_______________ , a signal element type is represented as a dot.

3. ANALOG TO ANALOG CONVERSION

Analog modulation or analog to analog conversion is the representation of analog information by analog signal. This analog modulation is required when the medium is bandpass in nature or if only a bandpass channel is available. For example, in case of radio broadcasting, the government assigns a narrow bandwidth to each radio station. The analog signal produced by each station is a low pass signal, all in the same range. To be able to listen to different stations, the low pass signals need to be shifted to a different range. Figure 5.12 illustrates different types of analog to analog modulation.

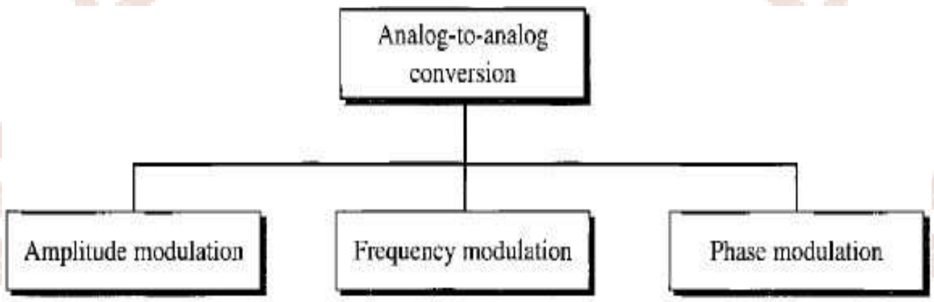

Figure 5.12: Types of analog to analog modulation

There are three categories of analog to analog conversion, they are Amplitude Modulation (AM), Frequency Modulation (FM) and Phase Modulation (PM).

3.1 Amplitude Modulation (AM)

In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal and frequency and phase remain the same. Only amplitude changes to follow variations in the information. Figure 5.13 shows amplitude modulation.

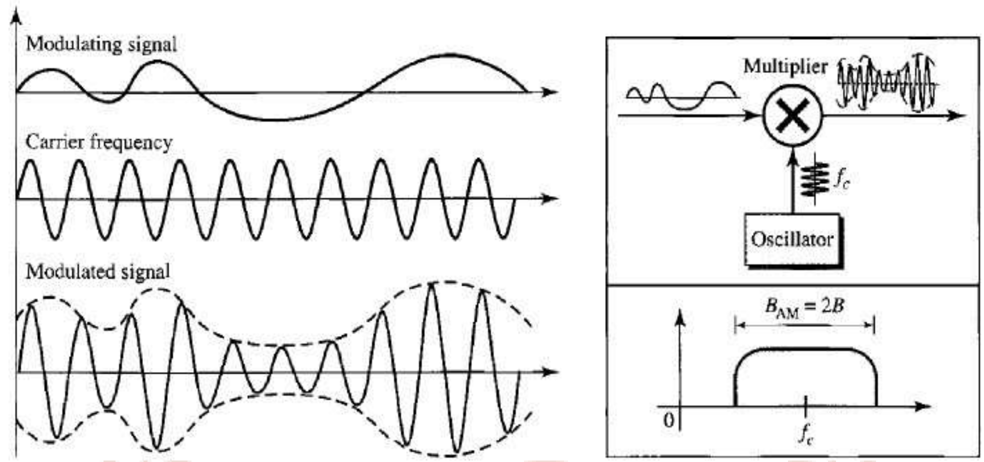

Figure 5.13: Amplitude modulation

As figure 5.13 shows, the modulating signal is the envelope of the carrier. AM is normally implemented by using a simple multiplier because the amplitude of the carrier signal needs to be changed according to the amplitude of the modulating signal.

Figure 5.13 also shows the bandwidth of an AM signal. The modulation creates a bandwidth which is twice the bandwidth of the modulating signal and covers a range centered on the carrier frequency. But the signal components above and below the carrier frequency carry exactly same information. Few implementations discard one half of the signals and cut the bandwidth in half. The total bandwidth required for AM can be determined from the bandwidth of the audio signal; B_{AM}= 2B.

3.2 Frequency Modulation (FM)

In frequency modulation, 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. Figure 5.14 shows the relationships of the modulating signal, the carrier signal and the resulting FM signal.

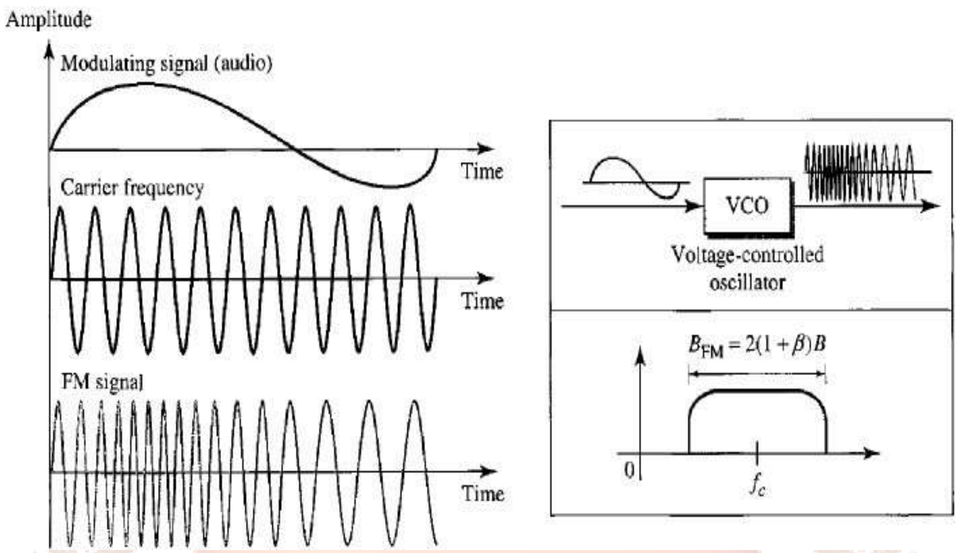

Figure 5.14: Frequency modulation

As shown in figure 5.14, FM is normally implemented by using a Voltage-Controlled Oscillator as with FSK. The frequency of the oscillator changes according to the input voltage which is the amplitude of the modulating signal. Figure 5.14 also shows the bandwidth of an FM signal. The actual bandwidth is difficult to determine exactly, but it can be shown that it is several times that of the analog signal or $2(1 + \beta)$ B where β is a factor depends on modulation technique with a common value of 4.

3.3 Phase Modulation (PM)

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. It can be proved that phase modulation is same as frequency modulation with one difference; in Frequency Modulation the instantaneous change in the carrier frequency is proportional to the amplitude of the modulating signal, in Phase Modulation the instantaneous change in the carrier frequency is proportional to the derivative of the amplitude of the modulating signal. Figure 5.15 shows the Phase Modulation.

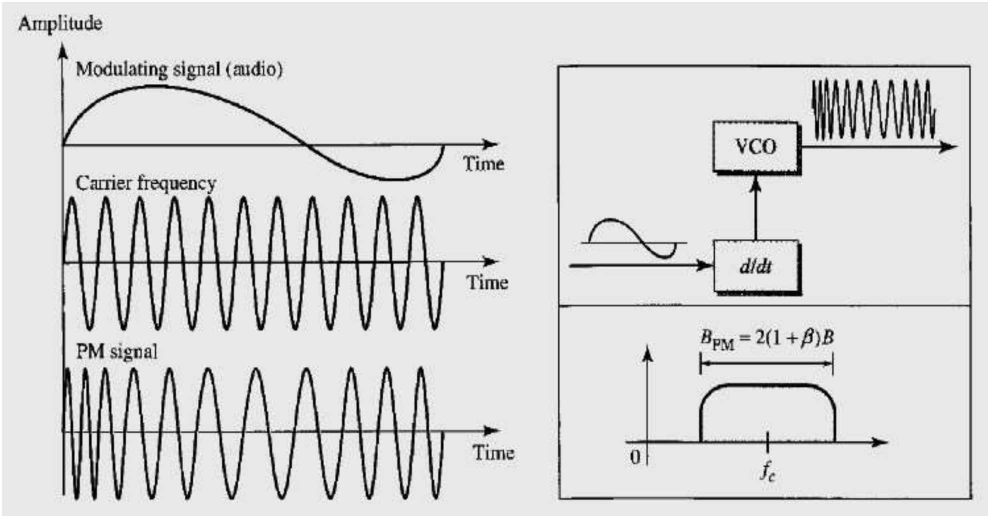

Figure 5.15: Phase modulation

Figure 5.15 shows the relationships of the modulating signal, the carrier signal and the resultant phase modulation signal. Phase modulation is normally implemented by using a Voltage Controlled Oscillator along with a derivative. The frequency of the oscillator changes according to the derivative of the input voltage which is the amplitude of the modulating signal. Figure 5.15 also shows the bandwidth of a PM signal. The actual bandwidth is difficult to determine exactly, but we can see that it is several times that of the analog signal. Even though, the formula shows the same bandwidth for FM and PM, the value of β is lower in the case of phase modulation.

Self-Assessment Questions -2

8. In______________ , frequency of the carrier signal is modulated to follow the changing voltage level of the modulating signal.
9. In_____________ , the phase of the carrier signal is modulated to follow the changing voltage level of the modulating signal.
10. Phase modulation is normally implemented by using _____________ a along with a derivative

4. SUMMARY

Let us recapitulate the important concepts discussed in this unit:

- Digital to analog conversion can be defined as the process of changing one of the characteristics of analog signal based on the information in digital data.
- There are three mechanisms for modulating digital data into an analog signal. They are Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), and Phase Shift Keying (PSK).
- Another mechanism which combines changing both amplitude and phase is called Quadrature Amplitude Modulation (QAM).
- In Amplitude Shift Keying, amplitude of the carrier signal is varied to create signal elements and both frequency and phase remain constant while amplitude changes.
- In Frequency Shift Keying, frequency of the carrier signal is varied to represent data.
- In Phase Shift Keying (PSK), both peak amplitude and frequency remain constant and the phase of the carrier is changed to represent two or more different signal element.
- The idea of using two carriers, one in-phase and the other quadrature with different amplitude levels for each carrier is the concept behind Quadrature Amplitude Modulation (QAM).
- In Amplitude Modulation, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal and frequency and phase remain the same.
- In Frequency Modulation, frequency of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.
- In Phase Modulation, the phase of the carrier signal is modulated to follow the changing voltage level (amplitude) of the modulating signal.

5. TERMINAL QUESTIONS

1. Differentiate between amplitude shift keying and frequency shift keying.
2. Explain phase shift keying
3. Describe quadrature amplitude modulation
4. Explain amplitude modulation
5. Differentiate between frequency modulation and phase modulation.

6. ANSWERS

Self-Assessment Questions

1. Amplitude shift keying
2. Carrier signal or carrier frequency
3. Frequency shift keying
4. Binary PSK
5. Quadrature PSK (QPSK)
6. Quadrature Amplitude Modulation (QAM)
7. Constellation diagram
8. Frequency modulation
9. Phase modulation
10. Voltage controlled oscillator

Terminal Questions

1. In amplitude shift keying, amplitude of the carrier signal is varied to create signal elements and both frequency and phase remain constant while amplitude changes. In frequency shift keying, frequency of the carrier signal is varied to represent data. (Refer section 2.1 and 2.2 for detail).
2. In phase shift keying (PSK), both peak amplitude and frequency remain constant and the phase of the carrier is changed to represent two or more different signal element. (Refer section 2.3 for detail).

3. The idea of using two carriers, one in-phase and the other quadrature with different amplitude levels for each carrier is the concept behind quadrature amplitude modulation (QAM). (Refer section 2.4 for detail).
4. In AM transmission, the carrier signal is modulated so that its amplitude varies with the changing amplitudes of the modulating signal and frequency and phase remain the same. Only amplitude changes to follow variations in the information. (Refer section 3.1 for detail).
5. In frequency modulation, frequency of the carrier signal is modulated to follow the changing voltage level of the modulating signal. In PM transmission, the phase of the carrier signal is modulated to follow the changing voltage level of the modulating signal. (Refer section 3.2 and for detail)

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