6

DIGITAL MODULATION TECHNIQUES

The amplitude and angle modulation techniques help in translating the analog message from low frequency or baseband range to high frequency or passband range. The pulse modulation techniques deal with representing the message at discrete instants of time. The message as a result of pulse digital modulation is termed as digital message. The digital message is still in the basedband range. Direct transmission of such message over long distance via the high frequency channels is not possible. As in the case of analog message, the digital message needs to be translated to the high frequency range. The techniques for achieving the same are termed as digital modulation techniques which is the focus of this chapter.

The digital modulation techniques are based on the analog modulation techniques. The main difference between analog and digital modulation process is, the former involves message having infinite levels where as the latter involves message having finite levels. The basic digital modulation techniques include amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK). The variants of basic modulation techniques termed as M-ary include M-ary PSK, M-ary FSK and M-ary QAM. This chapter describes all these techniques in detail.

Objectives *Upon completing the material in Chapter 6, the student will be able to*

- **Define** ASK, FSK and PSK
- **Describe** generation and demodulation of ASK, FSK and PSK
- **Define** M-ary ASK, M-ary FSK, M-ary PSK and M-ary QAM
- **Differentiate** binary and M-ary digital modulation techniques
- **Describe** generation and demodulation of M-ary PSK, M-ary FSK and M-ary QAM

6.1 INTRODUCTION

The basic motivation for analog modulation is to develop techniques for shifting the analog message signal from low to high frequency range so that it can be conveniently transmitted over high frequency communication channels. This resulted in AM, FM and PM techniques. The pulse modulation represents the message signal at discrete instants of time. However, the resulting message will still be in the low-frequency region. Thus pulse modulation is essentially used for the digitization of analog message (like PCM) and represent if possible in compact manner (like DPCM). The digitized message is nothing but sequence of 0's and 1's termed more commonly as *digital or binary message*. Thus using a suitable pulse modulation technique, we can convert analog message into digital from. Alternatively, the message may be directly generated in digital form like in the case of computer.

The requirement in the digital communication field is to transfer the digital message from one place to the other. There are broadly two approaches, namely, *basedband transmission and passband transmission.* Baseband digital transmission involves transmission of digital message in the low frequency (baseband) range itself. Passband transmission involves transmission of digital message in the high frequency (passband) range. Since, original digital message is in basedband range, it is first modulated to the high frequency range and then transmitted. The set of modulation techniques for shifting the digital message from the baseband to passband are termed as *digital moduation techniques*. The detailed study of these techniques is the aim of this chapter.

The digital modulation techniques are based on the conventional analog modulation techniques. Since the digital message will have only two levels, 0 and 1, the modulation process needs to store this information in the high frequency range. This can be done using AM, FM and PM techniques. Accordingly we have *amplitude shift keying (ASK), frequency shift keying (FSK) and phase shift keying (PSK)* as basic digital modulation techniques. ASK deals with shifting the amplitude of the carrier signal between two distinct values. FSK deals with shifting the frequency of the carrier signal between two distinct values. Similarly, PSK deals with shifting the phase of the carrier signal between two distinct values.

Apart from these basic digital modulation techniques, their variants are also available termed as M-ary digital modulation techniques. These include M-ary ASK, M-ary FSK and M-ary PSK. The hybrid schemes involving more than one parameter variation like amplitude-phase shift keying (APK) are also present under M-ary digital modulation techniques. The main merit of M-ary techniques is the increased transmission rate for the given channel bandwidth. From the perspective of M-ary, the basic digital modulation techniques are also termed as binary digital modulation techniques. Accordingly, we have binary ASK (BASK), binary FSK (BFSK) and binary PSK (BPSK).

Depending on the nature of demodulation scheme, the digital modulation techniques are classified as coherent and non-coherent detection techniques. In case of coherent detection, the carrier in the receiver is in synchronism with that of the transmitter and no such constraint in non-coherent detection. The digital modulation techniques may be further grouped as binary or M-ary signalling schemes. In binary signalling scheme, the parameters of the carrier are varied between only two levels whereas they are varied between M levels in case of M-ary signalling.

Thus, there are a number of digital modulation techniques for passband digital message transmision. The choice of a particular technique is based on the two important resources of communicatoin, namely, transmitted power and channel bandwidth. The ideal requirement is the one which uses minimum transmitted power and channel bandwidth. But this will be conflicting requirements, i.e., to conserve bandwidth we need to spend more power and hence trade off needs to be achieved.

6.2 BASIC DIGITAL MODULATION SCHEMES

6.2.1 Amplitude Shift Keying (ASK)

ASK is a digital modulation technique defined as the process of shifting the amplitude of the carrier signal between two levels, depending on whether 1 or 0 is to be transmitted.

Let the message be binary sequence of 1's and 0's. It can be represented as a function of time as follows:

$$v_m = V_m \quad \text{when symbol is 1}$$
$$= 0 \quad \text{when symbol is 0} \qquad (6.1)$$

Let the carrier be defined as

$$v_c = V_c \cos\omega_c t \tag{6.2}$$

The corresponding ASK signal is given by the product of v_m and v_c as

$$v_{ASK} = V_m V_c \cos\omega_c t \qquad \text{when symbol is 1}$$
$$= 0 \qquad \text{when symbol is 0}$$

Figure 6.1 shows the time domain representation of the generation of ASK signal. The digital message i.e., binary sequence can be represented as a message signal as shown in Fig. 6.1*a*. The carrier signal of frequency $f_c = \omega_c/2\pi$ is generated continuously from an oscillator circuit as shown in Fig. 6.1*b*. When the oscillator ouput is multiplied by the message signal, it results in a signal as shown in Fig. 6.1*c* termed as ASK signal. When the binary symbol is 1, the ASK signal will have information equal to the carrier multiplied by message amplitude and when the binary symbol is 0, it will be zero. Thus the output shifts between two amplitude levels, namely, $V_m V_c$ and 0. Hence the name amplitude shift keying. Based on this discussion a block diagram for the generation of ASK signal can be written as given in Fig. 6.2. ASK modulator is essentially an analog multiplier that takes baseband message v_m and passband carrier v_c, and multiplies the two resulting in the product signal termed a ASK.

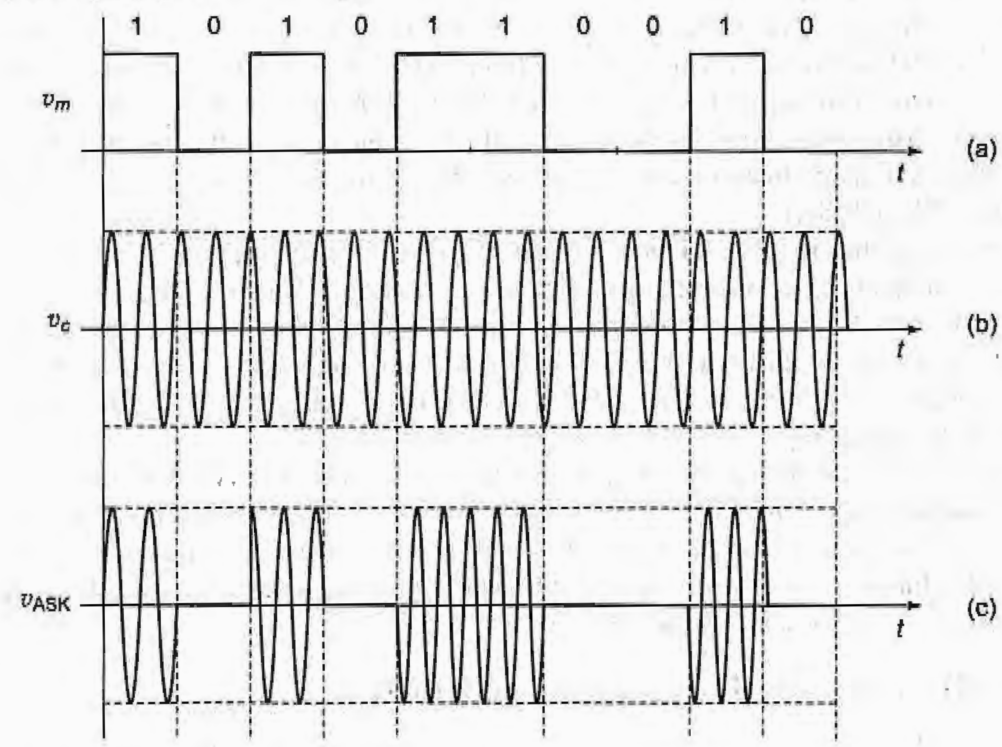

Fig. 6.1 *Time domain representation of generation of ASK signal: (a) mesage, (b) carrier, and (c) ASK signal*

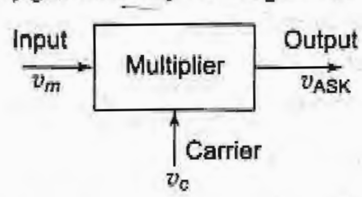

Fig. 6.2 *Block diagram of generation of ASK signal.*

The next question is whether such a process results in the shift of spectrum of baseband message to the passband? The answer is from the amplitude modulation process discussed in the earlier chapter. This can be illustrated pictorially as follows: Without worrying about the mathematical intricacies, let the spectrum of v_m be as shown in Fig. 6.3*a*. It will be essentially a *sinc* function in the frequency domain and has information concentrated mainly in the low frequency range. The sinusoidal carrier v_c will have impulses at f_c and $-f_c$ as shown in Fig. 6.3*b*. The product of the two in the time domain results convolution in the frequency domain giving rise to the spectrum of ASK signal as shown in Fig. 6.3*c*. Thus the ASK signal will have the message shifted to the passband range.

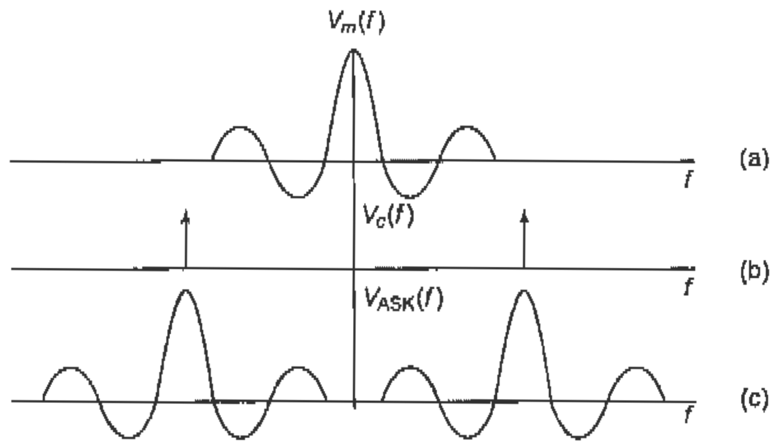

Fig. 6.3 *Spectra during generation of ASK signal. Spectrum of (a) message, (b) carrier, and (c) ASK signal.*

Demodulation of ASK Signal The demodulation is also termed as detection. There are two ways in which the message can be demodulated, namely, coherent and non-coherent detection. Due to the requirement of carrier in the receiver which is in sychronism with that of the transmitter, the coherent detection circuit is more complex compared to non-coherent detector. However, the coherent detector provides better performance under noisy condition.

In coherent detection, a copy of carrier used for modulation is assumed to be available at the receiver. The incoming ASK signal is multiplied with the carrier signal. The output of the multiplier will be a low frequency component representing amplitude scaled version of baseband message and ASK signal at twice the carrier frequency. The baseband message is retreived by passing this signal through a low pass filter. Figure 6.4 shows the block diagram of a coherent ASK detector.

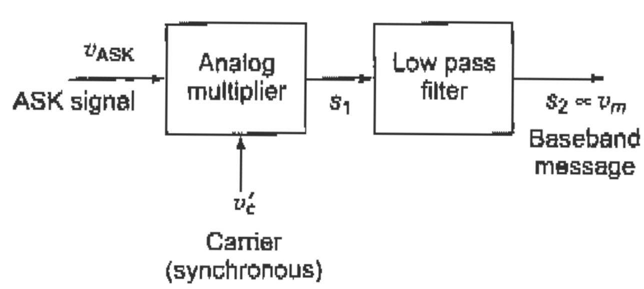

Fig. 6.4 *Block diagram of coherent ASK detector.*

Let the synchronous carrier at the receiver be given by

$$v_c' = V_c' \cos\omega_c t. \tag{6.3}$$

The output of the multiplier is given by

$$\begin{aligned} s_1 = v_{ASK} v_c' &= \frac{V_m V_c V_c'}{2}(1 + \cos 2\omega_c t) && \text{when symbol is 1} \\ &= 0 && \text{when sumbol is 0} \end{aligned} \tag{6.4}$$

The output of the low pass filter is given by

$$\begin{aligned} s_2 &= V_m(V_c V_c') && \text{when symbol is 1} \\ &= 0 && \text{when symbol is 0} \end{aligned} \tag{6.5}$$

Thus the filter output is

$$s_2 \propto v_m \tag{6.6}$$

Hence, the recovery of baseband message is carried out.

In non-coherent detection, there is no reference carrier made available at the receiver. Hence we have to follow other approach. In case of ASK, simple envelope detector will suffice. The incoming ASK signal is passed through an envelope detector which tracks the envelope of the ASK signal which is nothing but the baseband message. Figure 6.5 shows the block diagram of non-coherent ASK detector. The output of the diode will be an unipolar signal containing the envelope information. The high frequency variations are further removed by passing it through a low pass filter. The output of the low pass filter may be further refined by passing it through a comparator which compares the output of the envelope detector to a preset threshold and sets all values greater than or equal to the threshold to high level and rest to the low level. The waveforms at various stages of the non-coherent ASK detector are shown in Fig. 6.6.

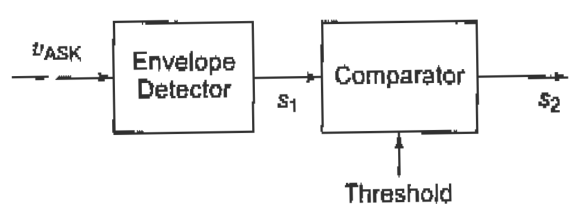

Fig. 6.5 *Block diagram of non-coherent ASK detector.*

6.2.2 Frequency Shift Keying (FSK)

FSK is a digital modulation technique defined as the process of shifting the frequency of the carrier signal between two levels, depending on whether 1 or 0 is to be transmitted.

Let the two carriers be defined as

$$v_{c1} = V_c \cos\omega_{c1} t \tag{6.7}$$

$$v_{c2} = V_c \cos\omega_{c2} t \tag{6.8}$$

The corresponding FSK signal is defined as

$$\begin{aligned} v_{ASK} &= V_m V_c \cos\omega_{c1} t && \text{when symbol is 1} \\ &= V_m V_c \cos\omega_{c2} t && \text{when symbol is 0} \end{aligned}$$

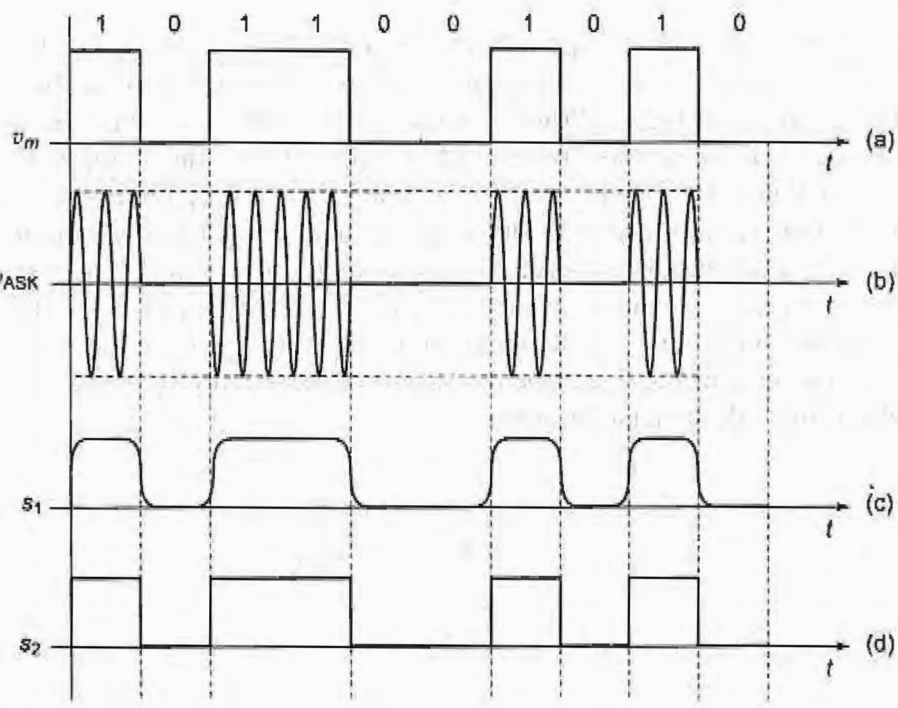

Fig. 6.6 *Time domain representation of signals at various stages of non-coherent ASK detector. (a) message, (b) ASK signal, (c) output of envelope detector and (d) output of comparator.*

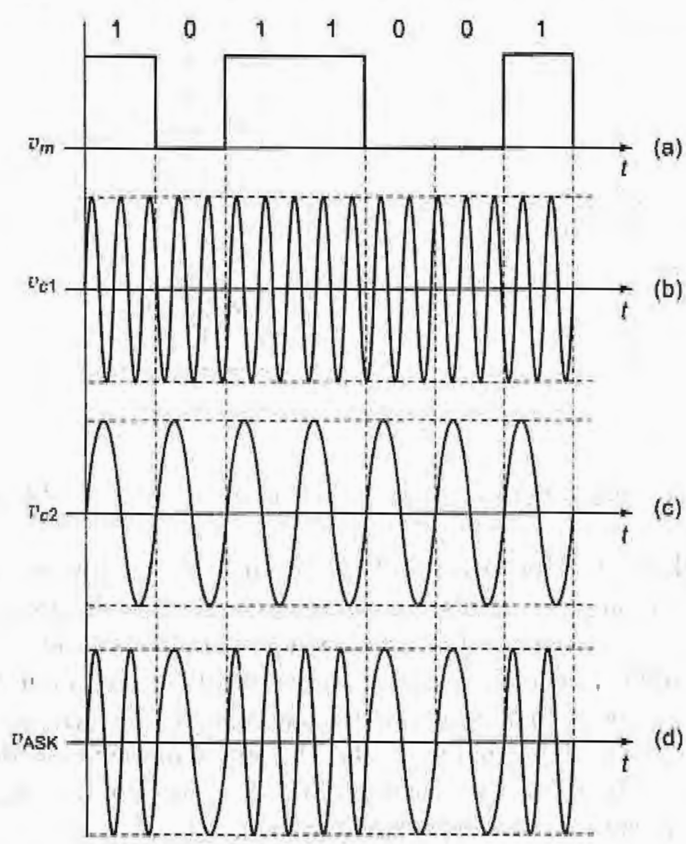

Fig. 6.7 *Time domain representation of signals at various stages of FSK generation. (a) message, (b) first carrier, (c) second carrier and (d) FSK signal.*

Figure 6.7 shows the time domain representation of the generation of FSK signal. The digital message, i.e., binary sequence can be represented as a message signal as shown in Fig. 6.7*a*. Two carrier signals of frequencies ω_{c1} and ω_{c2} as shown in Figs. 6.7*b* and *c*. When binary symbol is 1, the FSK signal will have the carrier signal with frequency ω_{c1}. Alternatively, the FSK signal will have the carrier signal with frequency ω_{c2} when the binary symbol is 0. This can be achieved by using a suitable combinational logic circuit which selects one of the two carrier signals based on the input signal value applied at its control input. For instance, a 2 × 1 multiplexer can be used for this purpose. Thus the output of the multiplexer shifts between the two distinct frequency values, namely, ω_{c1} and ω_{c2}. Hence, the name frequency shift keying. Based on this discussion a block diagram for the generation of FSK signal can be written as given in Fig. 6.8. FSK modulator is essentially a 2 × 1 multiplexer that takes baseband message v_m at the control input and two carriers v_{c1} and v_{c2} at its input, and produces the FSK signal at its output.

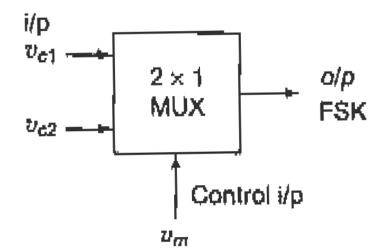

Fig. 6.8 *Block diagram of FSK generator.*

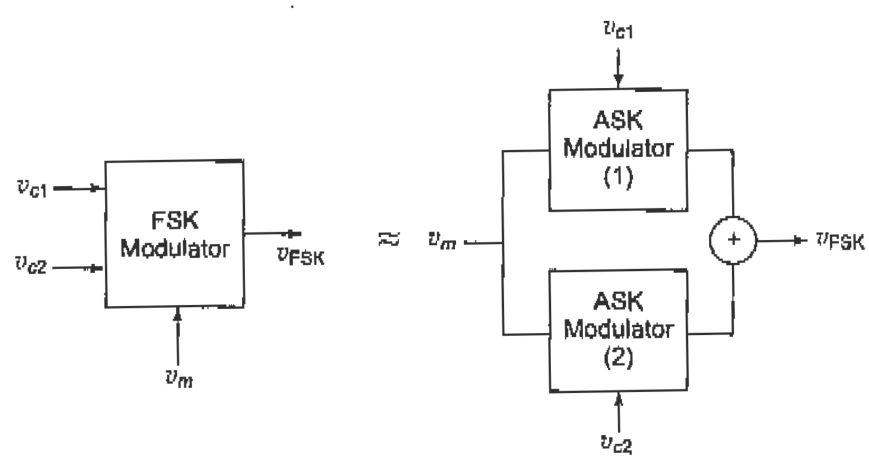

Fig. 6.9 *Equivalent representation of FSK modulator in terms of two ASK modulators.*

The next question is whether such a process results in the shift of spectrum of baseband message to the passband? The answer is yes. To appreciate this, we can treat the FSK modulation process conceptually as two ASK processes, one using carrier signal with frequency ω_{c1} and other using ω_{c2}. This is shown in Fig. 6.9. Thus the first ASK modulator shifts the baseband message to passband centered around ω_{c1} and the second ASK modulator shifts the baseband message to passband centered around ω_{c2}. This can be illustrated pictorially as follows: Let the spectrum of v_m be as shown in Fig. 6.10*a*. The output of the first ASK modulator is shown in Fig. 6.10*b* and that of second in Fig. 6.10*c*. The spectrum of FSK modulator may be viewed as given in Fig. 6.10*d*. Thus the FSK signal will have the message shifted to the passband range.

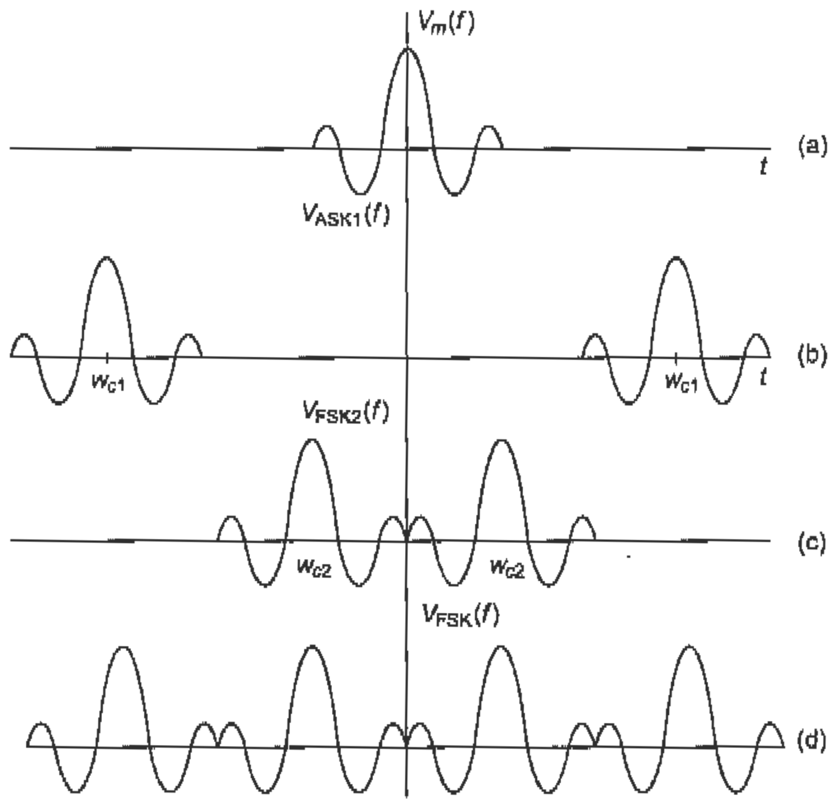

Fig. 6.10 *Spectra of various signals involved FSK generation. Spectrum (a) message, (b) first ASK modulator, (c) second ASK modulator and (d) FSK modulator.*

Demodulation of FSK Signal In this case also, the message can be demodulated either by coherent or non-coherent detection. Both demodulation processes can be understood easily by considering the ASK view of FSK as illustrated in Fig. 6.9.

The block diagram for the coherent detection of FSK is drawn as given in Fig. 6.11. The incoming FSK signal is multiplied by the carrier signal with frequency ω_{c1} in the upper channel and carrier signal with frequency ω_{c2} in the lower channel. The output of the multiplier in the upper channel will be low frequency message and ASK signal at twice ω_{c1} during the intervals when the FSK is due to the carrier of frequency ω_{c1} and will be ASK signals at $(\omega_{c1} \pm \omega_{c2})$ during intervals when the FSK is due to the carrier of frequency ω_{c2}. Thus the output of the low pass filter in the upper channel will contain baseband message during intervals belonging to the carrier frequency ω_{c1} and zero during the intervals belonging to ω_{c2}. Exactly opposite happens in the lower channel. The outputs of the two channels are further passed onto a comparator. The ouput of the comparator will be high when upper channel output is greater than the lower channel and low when lower channel output is greater than the upper channel. In this way the baseband message is retreived from the FSK signal
Let the synchronous carriers at the receiver be given by

$$v'_{c1} = V'_c \cos\omega_{c1} t \tag{6.9}$$

$$v'_{c2} = V'_c \cos\omega_{c2} t \tag{6.10}$$

The output of the multiplier in the upper channel during the interval having frequency ω_{c1} is given by

$$s_{1u} = v_{FSK}\, v'_{c1} = \frac{V_m V_c V'_c}{2}(1 + \cos 2\omega_{c1} t) \tag{6.11}$$

The output of the multiplier in the upper channel during the interval having frequency ω_{c2} is given by

$$s_{1u} = \frac{V_m V_c V'_c}{2}(\cos(\omega_{c1} - \omega_{c2})t + \cos(\omega_{c1} + \omega_{c2})t) \quad (6.12)$$

The output of the low pass filter in the upper channel during the interval having frequency ω_{c1} is given by

$$s_{2u} = \frac{V_m V_c V'_c}{2} \quad (6.13)$$

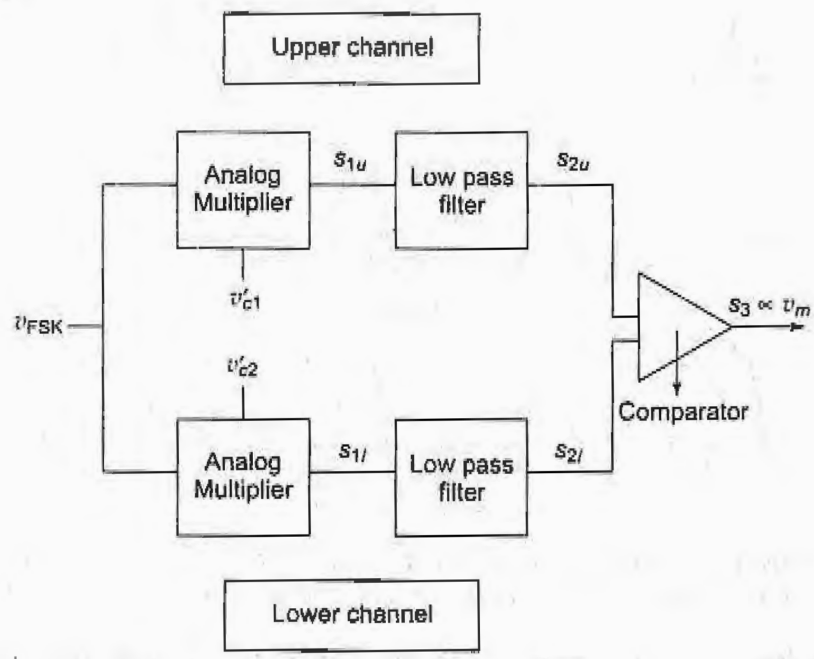

Fig. 6.11 *Block diagram of coherent detector of FSK.*

The output of the low pass filter in the upper channel during the interval having frequency ω_{c2} is given by

$$s_{2u} = 0 \quad (6.14)$$

Thus the filter output in the upper channel is

$$s_{2u} \propto v_m \quad (6.15)$$

during the interval having frequency ω_{c1} and

$$s_{2u} \propto 0 \quad (6.16)$$

during the interval having frequency ω_{c2}.

The output of the multiplier in the lower channel during the interval having frequency ω_{c1} is given by

$$s_{1l} = \frac{V_m V_c V'_c}{2}(\cos(\omega_{c1} - \omega_{c2})t + \cos(\omega_{c1} + \omega_{c2})t) \quad (6.17)$$

The output of the multiplier in the lower channel during the interval having frequency ω_{c2} is given by

$$s_{1l} = v_{FSK}\, v'_{c1} = \frac{V_m V_c V'_c}{2}(1 + \cos 2\omega_{c1}t) \quad (6.18)$$

The output of the low pass filter in the lower channel during the interval having frequency ω_{c1} is given by

$$s_{2l} = 0 \tag{6.19}$$

The output of the low pass filter in the lower channel during the interval having frequency ω_{c2} is given by

$$s_{2l} = \frac{V_m V_c V'_c}{2} \tag{6.20}$$

Thus the filter output in the lower channel is

$$s_{2l} \propto 0 \tag{6.21}$$

during the interval having frequency ω_{c1} and

$$s_{2l} \propto V_m \tag{6.22}$$

during the interval having frequency ω_{c2}.
Therefore the output of the compartor is given by

$$s_3 \propto V_m \tag{6.23}$$

Hence, the recovery of baseband message is carried out.

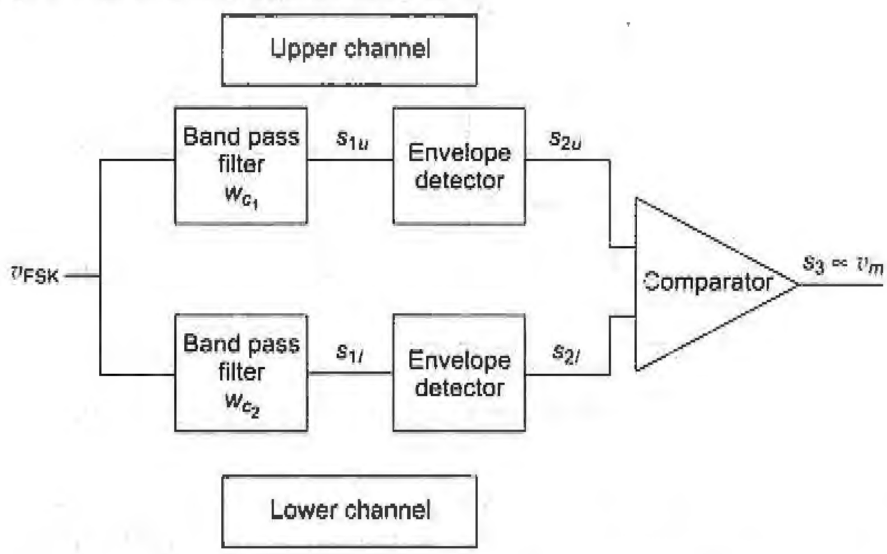

Fig. 6.12 *Block diagram of non-coherent detector of FSK.*

In case of non-coherent detection, envelope detectors can be used as shown in the arrangement given in Fig. 6.12. The incoming FSK signal is passed through a filter tuned to ω_{c1} and then an envelope detector in the upper channel. Similarly, the same FSK signal is passed throug a filter tuned to ω_{c2} and then an envelope detector in the lower channel. Thus the distinction between the upper and lower channels is due to the two filters. During the interval represented by the carrier signal with frequency ω_{c1}, the output the upper channel will be high whereas that of the lower channel is low. Exactly opposite happens during the inerval represented by the carrier signal with frequency ω_{c2}. The outputs of the upper and lower channels envelope detectors are applied to a comparator which produces the output proportional to the message. The waveforms at various stages of the non-coherent FSK detector are shown in Fig. 6.13.