CHAPTER-4

Digital Modulation Techniques :

4.1 INTRODUCTION

As discussed earlier, Modulation is defined as the process by which some characteristics of a carrier is varied in accordance with a modulating signal. In digital communications, the modulating signal consists of binary data or an M-ary encoded version of it. This data is used to modulate a carrier wave (usually sinusoidal) with fixed frequency. In fact, the input data may rep- resent the digital computer outputs or PCM waves generated by digitizing voice or video signals. The channel may be a telephone channel, microwave radio link, satellite channel or an optical fiber. In digital communication, the modulation process involves switching or keying the amplitude, frequency or phase of the carrier in accordance with the input data*.

Thus, there are three basic modulation techniques for the transmission of digital data. They are known as amplitude -shift keying (ASK), frequency shift keying (FSK) and phase-shift keying (PSK) which can be viewed as special cases of amplitude modulation, frequency modulation and phase modulation noise performance, spectral properties, their merits and limitations, applications and other The present chapter is devoted to detailed discussion of digital modulation techniques: their related aspects.

4.2DIGITAL MODULATION FORMATS

When we have to transmit a digital signal over a long distance, we need continuous-wave (CW) modulation. For this purpose, the transmission medium can be in form of radio, cable or other type of channel. Also, a carrier signal having some frequency f_c is used for modulation. Then the modulating digital signal modulates some parameter like frequency, phase or amplitude of the carrier. Due to this process, there is some deviation in carrier frequency f_c. This deviation is known as the bandwidth of the channel. This means that the channel has to transmit some range or band of frequencies. Such type of transmission is known as bandpass transmission and the communication channel is known as bandpass channel.

Here, the word bandpass is used since the range of frequencies does not start from zero Hz to f_m Hz. In fact, the range of frequencies from zero Hz to f_m Hz is known as low-pass signal and such channel is known as low-pass channel.

Now, when it is required to transmit digital signals on a bandpass channel, the amplitude, frequency or phase of the sinusoidal carrier is varied in accordance with the incoming digital data. Since the digital data is in discrete steps, the modulation of the bandpass sinusoidal carrier is also done in discrete steps. Due to this reason, this type of modulation (i.e., Digital modulation) is also known as switching or signaling. Now, if an amplitude of the carrier is switched depending on the input digital signal, then it is called Amplitude shift keying (ASK).

This process is quite similar to analog amplitude modulation. If the frequency of the sinusoidal carrier is switched depending upon the input digital signal, then it is known as the frequency shift keying (FSK). This is very much similar to the analog frequency modulation. If the phase of the carrier is switched depending upon the input digital signal, then it is called phase shift keying (PSK). This is similar to phase modulation. Since the phase and frequency modulation has constant amplitude envelope, therefore FSK and PSK also has a constant amplitude envelope. Because of constant amplitude of FSK and PSK, the effect of nonlinearities, noise interference is minimum on signal detection. However, these effects are more pronounced on ASK. Therefore, FSK and PSK are preferred over ASK.

Figure 4.1 shows the waveforms for amplitude-shift keying, phase-shift keying and frequency shift keying. In these waveforms, a single feature of the carrier (i.e., amplitude, phase or frequency)

undergoes modulation.

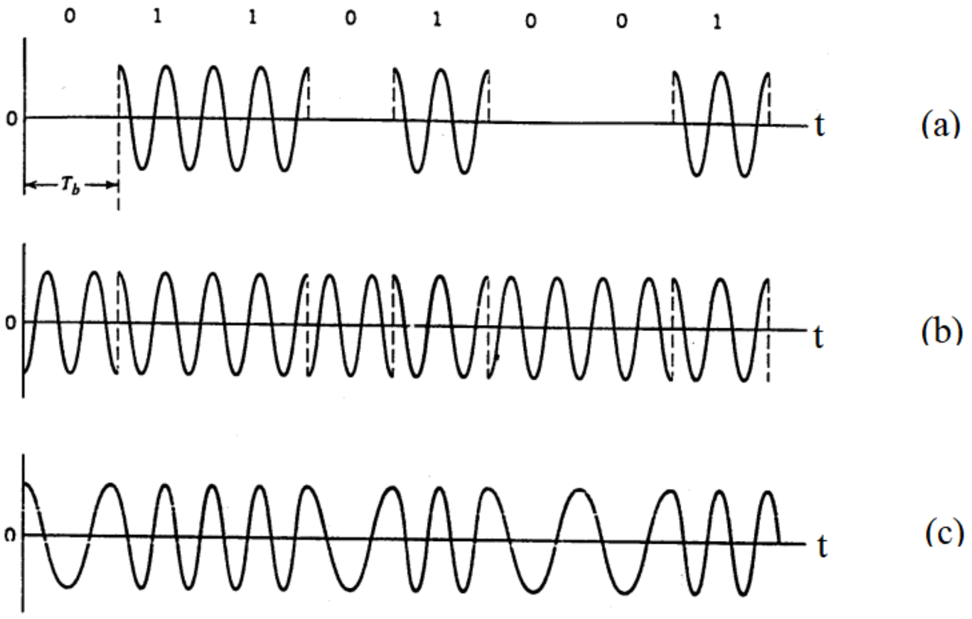

Fig.4.1 The three basic forms of signaling binary information, (a) Amplitude-shift keying, (b) Phase-shift keying. (c) Frequency shift keying with continuous phase

In digital modulations, instead of transmitting one bit at a time, we transmit two or more bits simultaneously. This is known as M-ary transmission. This type of transmission results in reduced channel bandwidth. However, sometimes, we use two quadrature carriers for modulation. This process is known as Quadrature modulation.

Thus, we see that there are a number of modulation schemes available to the designer of a digital communication system required for data transmission over a bandpass channel.

Every scheme offers system trade-offs of its own. However, the final choice made by the designer is determined by the way in which the available primary communication resources such as transmitted and channel bandwidth are best exploited. In particular, the choice is made in favour of a scheme power which possesses as many of the following design characteristics as possible characteristics as possible :

i. Maximum data rate.
ii. Minimum probability of symbol error.

iii. Minimum transmitted power.
iv. Maximum channel bandwidth.
v. Maximum resistance to interfering signals.
vi. Minimum circuit complexity.

4.3 TYPES OF DIGITAL MODULATION TECHNIQUES

Basically, digital modulation techniques may be classified into coherent or non-coherent techniques, depending on whether the receiver is equipped with a phase-recovery circuit or not. The phase- recovery circuit ensures that the oscillator supplying the locally generated carrier wave receiver is synchronized* to the oscillator supplying the carrier wave used to originally modulate the incoming data stream in the transmitter.

i. Coherent Digital Modulation Techniques

Coherent digital modulation techniques are those techniques which employ coherent detection. In coherent detection, the local carrier generated at the receiver is phase locked with the carrier at the transmitter. Thus, the detection is done by correlating received noisy signal and locally generated carrier. The coherent detection is a synchronous detection.

ii. Non-coherent Digital Modulation Techniques

Non-coherent digital modulation techniques are those techniques in which the detection process does not need receiver carrier to be phase locked with transmitter carrier. The advantage of such type of system is that the system becomes simple. But the drawback of such a system is that the error probability increases. In fact, the different digital modulation techniques are used for various specific application areas.

4.4COHERENT BINARY MODULATION TECHNIQUES

As mentioned earlier, the binary (i.e., digital) modulation has three basic forms amplitude-shift keying (ASK), phase-shift keying (PSK) and frequency-shift keying (FSK). In this section, let us discuss different coherent binary modulation techniques.

4.5 COHERENT BINARY AMPLITUDE SHIFT KEYING OR ON-OFF KEYING

i. Definition

Amplitude shift keying (ASK) or ON-OFF keying (OOK) is the simplest digital modulation technique. In this method, there is only one unit energy carrier and it is switched depending upon the input binary sequence.

Expression and Waveforms

The ASK waveform may be represented as,

$$S(t) = \sqrt{2P_8}\ \cos(2\pi f_c t)\ \ (To\ Transmit\ '1') \qquad (1)$$

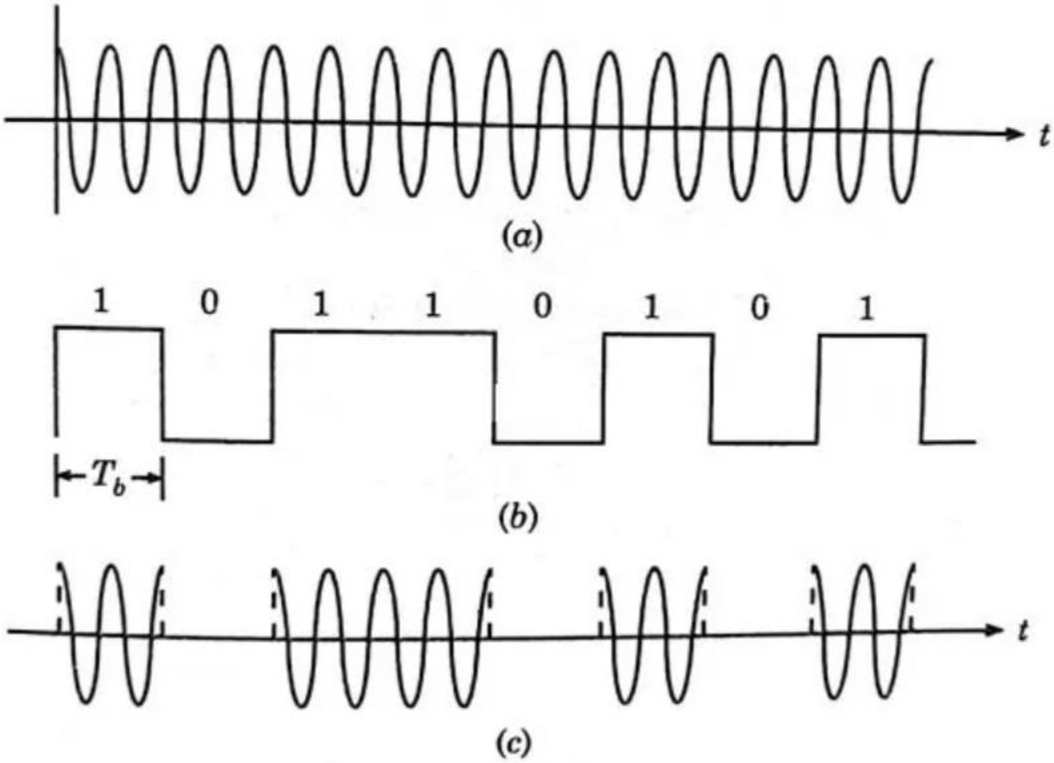

Fig. 4.2 Amplitude-shift keying waveforms, (a) Unmodulated carrier, (b) NRZ Unipolar bit sequence, (c) ASK waveform.

To transmit symbol '0', the signal s(t) = 0 i.e., no signal is transmitted. Signal s(t) contains some complete cycles of carrier frequency 'f_c'

Hence, the ASK waveform looks like an ON-OFF of the signal. Therefore, it is also known as the ON-OFF keying (OOK). Figure.2 shows the ASK waveform.

4.5.1 .Signal Space Diagram of ASK

The ASK waveform of equation (1) for symbol '1' can be represented as,

$$S(t) = \sqrt{P_8 T_b} . \sqrt{2/T_b}\cos(2\pi f_c t) = \sqrt{P_8\ T_b}\,\phi_1(t) \qquad (2)$$

This means that there is only one carrier function $\phi_1(t)$. The signal space diagram will have two points on $\phi_1(t)$. One will be at zero and other will be at $\sqrt{P_8 T_b}$ Figure 3 shows this aspect.

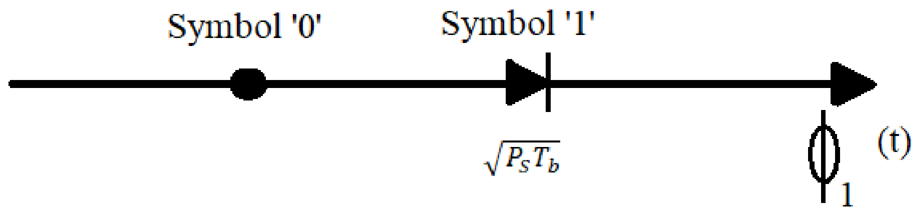

Fig. 4.3 Signal space diagram of ASK.

Thus, the distance between the two signal points is,

$$d = \sqrt{P_8 T_b} = \sqrt{E_b} \qquad (3)$$

4.5.2 Generation of ASK Signal

i. Description and Working Operation

ASK signal may be generated by simply applying the incoming binary data (represented in unipolar form) and the sinusoidal carrier to the two inputs of a product modulator (i.e., balanced modulator). The resulting output will be the ASK waveform. This is shown in figure 4. Modulation causes a shift of the baseband signal spectrum.

ii. Power Spectral Density (psd)

The ASK signal, which is basically the product of the binary sequence and the carrier signal, has a power spectral density (PSD) same as that of the baseband on-off signal but shifted in the frequency domain by $\pm f_c$. This is shown in figure 5. It may be noted that two impulses occur at $\pm f_c$.

iii. Bandwidth of BASK

The spectrum of the ASK signal shows that it has an infinite bandwidth. However for practical purpose, the bandwidth is often defined as the bandwidth of an ideal bandpass filter centered at f_c whose output contains about 95% of the total average power content of the ASK signal. It may be proved that according to this criterion the bandwidth of the ASK signal is approximately $3/T_b$ Hz. The bandwidth of the ASK signal can however, be reduced by using smoothed versions of the pulse waveform instead of rectangular pulse waveforms.

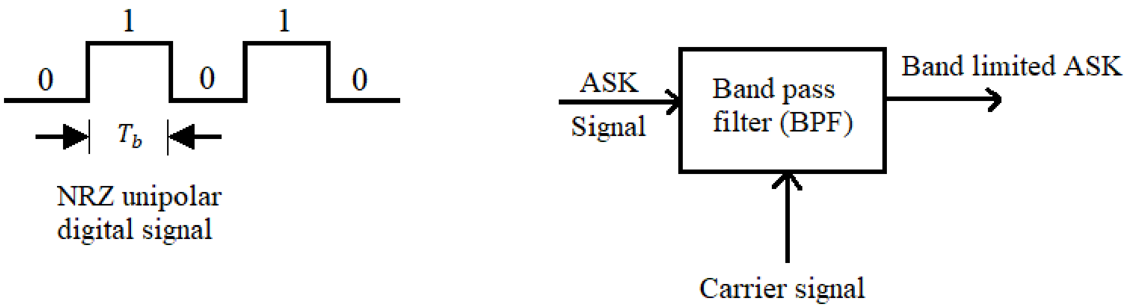

Fig. .4.4 Generation of binary ASK waveform (1)

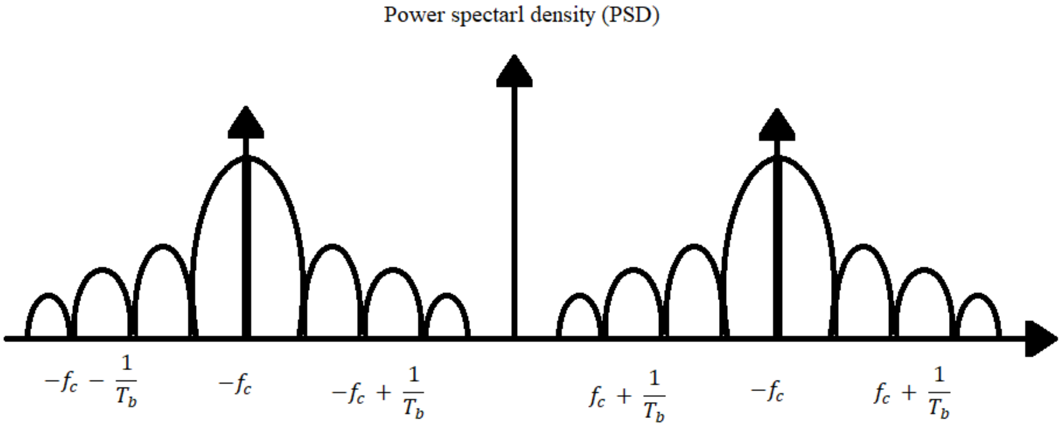

Fig. 4.5 Power spectral density of ASK signal.

4.5.3 BASK Reception: Coherent Detection or Demodulation of Binary ASK Signal

i. Working Operation

The demodulation of binary ASK waveform can be achieved with the help of coherent detector As shown in figure 6 . It consists of a product modulator which is followed by an integrator and decision-making device. The incoming ASK signal is applied to one input of the product modulator. The other input of the product modulator is supplied with a sinusoidal carrier which is generated with the help of a local oscillator. The output of the product modulator goes to input of the integrator. The integrator operates on the output of the multiplier for successive bit intervals and essentially performs a low-pass filtering action. The output of the integrator goes to the input of a decision-making device.

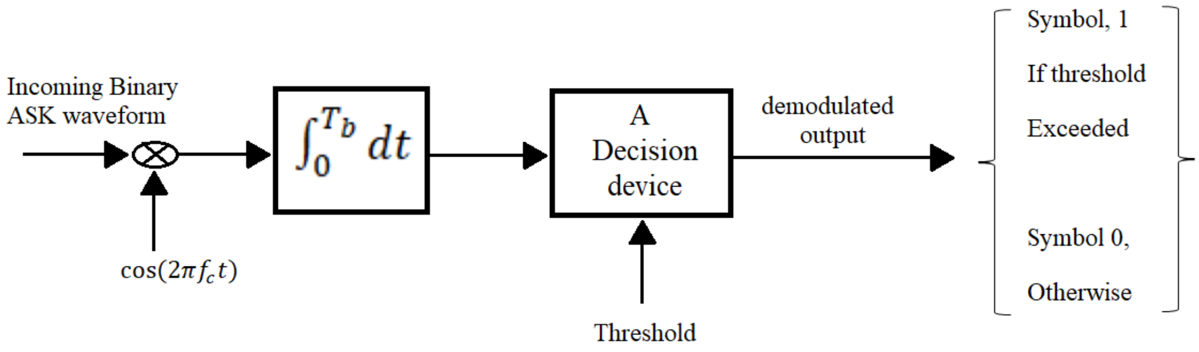

Fig.4. 6 Coherent detection of binary ASK signals.

Now, the decision-making device compares the output of the integrator with a preset threshold. It makes a decision in favour of symbol 1 when the threshold is exceeded and in favour of symbol 0 otherwise. The coherent detection makes the use of linear operation. In this method we have assumed that the local carrier is in perfect synchronisation with the carriers used in the transmitter. This means that the frequency and phase of the locally generated carrier is same as those of the carriers used in the transmitter.

ii. Synchronization Requirement

The following two forms of synchronisation are required for the operation of coherent (or synchronous detector):

1. Phase synchronisation which ensures that carrier wave generated locally in the receiver is locked in phase with respect to one that is employed in the transmitter.

2. Timing synchronisation which enable proper timing of the decision making operation in the receiver with respect to switching instants (switching between 1 and 0) in the original binary data.

4.5.4 Salient Feature of BASK

The advantage of using BASK is its simplicity. It is easy to generate and detect.

4.5.5 Drawback

But the drawback of BASK is that it is very sensitive to noise, therefore, it finds limited application in data transmission. It is used at very low bit rates, upto 100 bits per sec.

4.5.6 Bit Error Rate (BER) or Probability of Error

As a matter of fact, bit error rate (BER) or probability of error is a very important parameter. This parameter is used to judge the performance of a digital communication system. It is represented by P_e. P_e must be as small as possible.

4.6 BINARY PHASE SHIFT KEYING (BPSK)

i. Definition

Binary phase shift keying (BPSK) is the most efficient of the three digital modulation, i.e., ASK, FSK and PSK. Hence, binary phase shift keying (BPSK) is used for high bit rates. In BPSK, phase of the sinusoidal carrier is changed according to the data bit to be transmitted. Also, a bipolar NRZ signal is used to represent the digital data coming from the digital source.

ii. Expression for BPSK

In a binary phase shift keying (BPSK), the binary symbols '1' and '0' modulate the phase of the carrier. Let us assume that the carrier is given as,

$$S(t) = A\cos(2\pi f_c t) \qquad (4)$$

Here 'A' represents peak value of sinusoidal carrier. For the standard 1 Ω load resistor, the power dissipated would be,

$$P = \frac{1}{2}A^2$$

Or

$$A = \sqrt{2P} \qquad (5)$$

Now, when the symbol is changed, then the phase of the carrier will also be changed by an amount of 180 degrees (i.e., л radians). Let us consider, for example,

For symbol '1', we have

$$S_1(t) = \sqrt{sP}\cos(2\pi f_c t) \qquad (6)$$

If next symbol is '0', then we have

For symbol '0', we have

$$S_2\,(t) = \sqrt{2P}\cos(2\pi f_c t + \pi) \qquad (7)$$

Now, because cos (0+π) = cos 0, therefore, the last equation can be written as,

$$S_2(t) = -\sqrt{sP}\cos(2\pi f_c t) \qquad (8)$$

With the above equation, we can define BPSK signal combinely as,

$$S_1(t) = b(t)\sqrt{sP}\cos(2\pi f_c t) \qquad (9)$$

Where b(t) = +1 when binary ‘1’ is to be transmitted

b(t) = -1 when binary ‘0’ is to be transmitted

iii. Binary Sequence and its Equivalent Signal b(t)

Figure 7 illustrates binary sequence and its equivalent signal b(t).

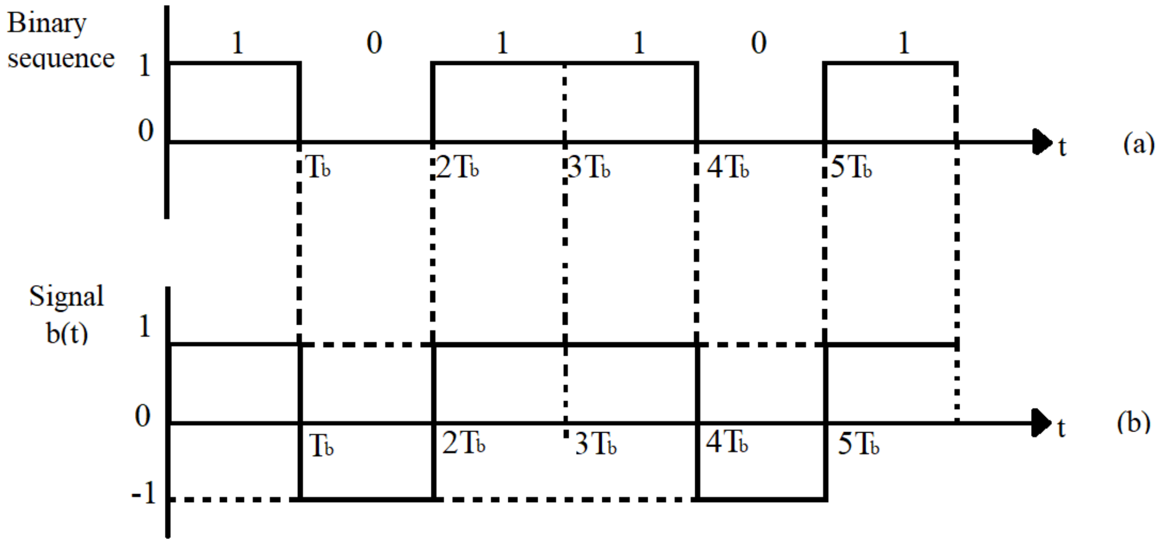

Fig.4. 7 (a) Binary sequence, (b) The corresponding bipolar signal b(t).

4.6.1 Generation of BPSK Signal

BPSK signal may be generated by applying carrier signal to a balanced modulator. The binary data signal (Os and 1s) is converted into a NRZ bipolar signal by an NRZ encoder. Here, the bipolar signal b(t) is applied as a modulating signal to the balanced modulator.

Figure 4.8 shows the block diagram of a BPSK signal generator.

A NRZ level encoder converts the binary data sequence into bipolar NR7 signal.

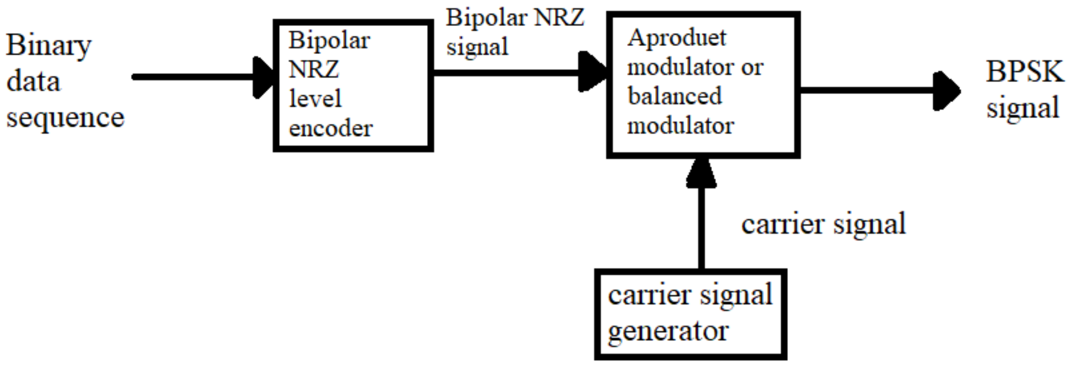

Fig. 4.8 Generation of BPSK,

Table 7.1. shows input digital and corresponding bipolar NRZ signal.

S. No.	Input digital signal	Bipolar NRZ signal b(t)	BPSK output signal
1.	Binary 0	b(t) = -1	$-\sqrt{2P}\, cos\ \omega_c t$
2.	Binary 1	b(t) = +1	$+\sqrt{2P}\, cos\ \omega_c t$

In above table,

i. $P = \frac{E_b}{T_b}$where, E_b is the signal energy and T_b is the bit duration.

ii. Also, $\omega_c = 2\pi f_c$.

4.6.2 Reception of BPSK Signal: Coherent Detections

Figure 4.9 shows the block diagram of the scheme to recover baseband signal from BPSK signal. The transmitted BPSK signal is given as

$$S(t) = b(t)\sqrt{2P}\cos(2\pi f_c t)$$

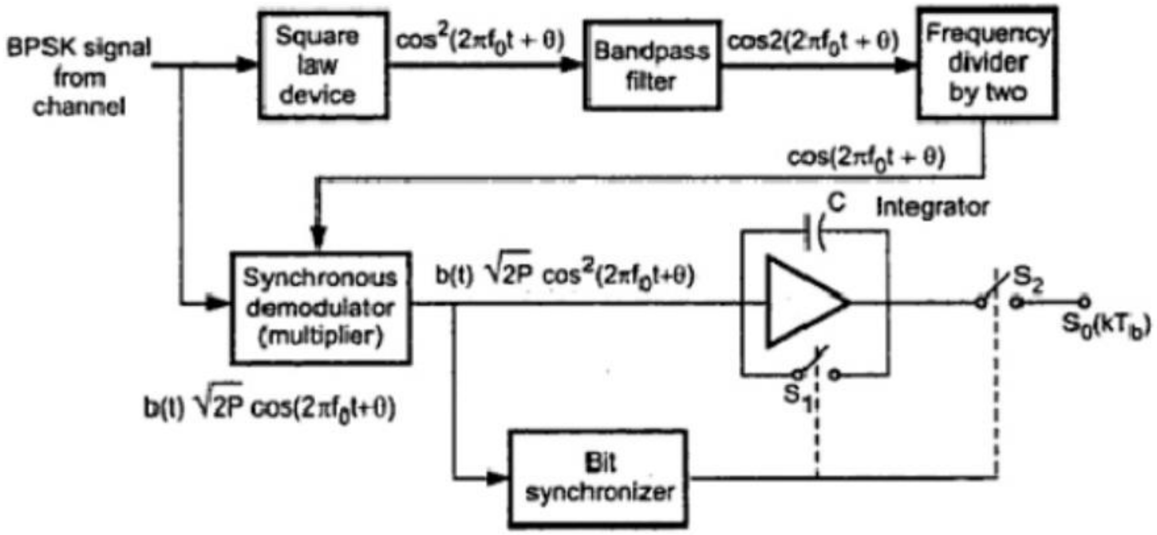

Fig. 4.9 Reception of baseband signal in BPSK signal.

This signal undergoes the phase change depending upon the time delay from transmitter end to receiver end. This phase change is, usually, a fixed phase shift in the transmitted signal. Let us consider that this phase shift is 0. Because of this, the signal at the input of the receiver can be written as

$$S(t) = b(t)\sqrt{2P}\cos(2\pi f_c t + 0) \qquad (10)$$

Now, from this received signal, a carrier is separated because this is coherent detection. As shown in the figure 9, the received signal is allowed to pass through a square law device. At the output of the square law device, we get a signal which is given as

$$\cos^2(2\pi f_c t + 0)$$

Here, it may be noted that we have neglected the amplitude, since we are only interested in the carrier of the signal.

Again, we know that

$$\cos^2\theta = \frac{1+\cos 2\theta}{2}$$

Therefore, we have

$$cos^2(2\pi f_c t+\theta)=\frac{1+cos2(2\pi f_c t+\theta)}{2}=\frac{1}{2}+\frac{1}{2}\cos 2\,(2\pi f_c t+\theta)$$

Here $\frac{1}{2}$represents a DC level. This signal is then allowed to pass through a bandpass filter (BPF) whose passband is centred around $2f_c$ Bandpass filter removes the DC level of $\frac{1}{2}$ and at the output, we obtain,

$$\cos 2\,(2\pi f_c t+\theta)$$

This signal is having frequency equal to 2 f_c. Hence, it is passed through a frequency divider by two. Thus, at the output of frequency divider, we get a carrier signal whose frequency is f_c *i.e.*, cos $(2\pi f_c t+\theta)$.

The synchronous (i.e., coherent) demodulator multiplies the input signal and the recovered carrier. Hence, at the output of multiplier, we get

$$b(t)\sqrt{2P}\cos(2\pi f_c t+\theta)\times\cos(2\pi f_c t+\theta)=b(t)\sqrt{2P}cos^2(2\pi f_c t+\theta)$$

$$=b(t)\sqrt{2P}\times\frac{1}{2}[\,1+cos2(2\pi f_c t+\theta)]$$

$$=b(t)\sqrt{\frac{P}{2}}[1+cos2(2\pi f_c t+\theta)] \qquad (11)$$

his signal is then applied to the bit synchronizer and integrator. The integrator integrates the signal over one bit period. The bit synchronized takes care of starting and ending times of a bit. At the end of bit duration T_b, the bit synchronizer closes switch S_2, temporarily. This connects the output of an integrator to the decision device. In fact, it is equivalent to sampling the output of integrator. The synchronizer then opens switch S_2, and switch S_1, is closed temporarily. T.; resets the integrator voltage to zero. The integrator then integrates next bit. Let us assume that one bit period 'T_b' contains integral number of cycles of the carrier. This means that the phase change occurs in the carrier only at zero crossing. This has been shown in figure 10. This BPSK waveform has full cycles of sinusoidal carrier.

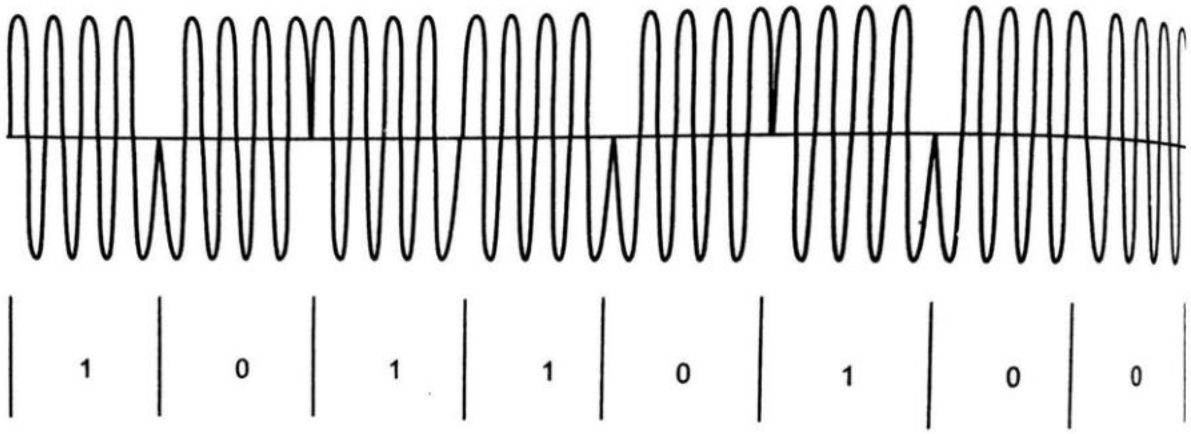

Fig. 4.10 The BPSK waveform

Also, in the kth bit interval, we can write output signal as under:

$$S_0(kT_b) = b(kT_b)\sqrt{\frac{P}{2}}\int_{(k-1)T_b}^{kT_b}[1+\cos(2\pi f_c t+\theta)]dt$$

This equation gives the output of an interval for k^{th}bit. Hence, integration is performed from (k-1)T_b, to kT_b. Here, T_b, is the one bit period. We can write the above equation as under:

$$S_0(kT_b) = b(kT_b)\sqrt{\frac{P}{2}}\left[\int_{(k-1)T_b}^{kT_b} 1dt + \int_{(k-1)T_b}^{kT_b} \cos(2\pi f_c t+\theta)\,dt\right]$$

Where

$$\int_{(k-1)T_b}^{kT_b} cos2(2\pi f_c t+\theta)dt = 0$$

since average value of sinusoidal waveform is zero if integration is done over full cycles. Hence, we can write above equation as,

$$S_0(kT_b) = b(kT_b)\sqrt{\frac{P}{2}}\int_{(k-1)T_b}^{kT_b} 1dt = b(kT_b)\sqrt{\frac{P}{2}}[t]_{(k-1)T_b}^{kT_b}$$

Or

$$S_0(kT_b) = b(kT_b)\sqrt{\frac{P}{2}}\{kT_b - (k-1)T_b\} = b(kT_b)\sqrt{\frac{P}{2}}T_b \qquad (12)$$

The last equation shows that the output of the receiver depends on input.

Thus,$S_0(kT_b) \propto b(kT_b)$

Depending upon the value of $b(kT_b)$, the output $S_0(kT_b)$ is generated in receiver. This signal is then applied to a decision device which decides whether transmitted symbol was zero or one.

4.6.3 The Spectrum of BPSK Signals

We know that the waveform b(t) is a NRZ binary waveform. In this waveform, there are rectangular pulses of amplitude ±V_b. If we assume that each pulse is ± $\frac{T_b}{2}$ around its centre, then it becomes easy to find Fourier transform of such pulse. The Fourier transform of this type of pulse is given as,

$$X(f) = V_b T_b \frac{\sin(\pi f T_b)}{(\pi f T_b)} \qquad (13)$$

For a large number of such positive and negative pulses, the power spectral density S(f) is expressed as

$$S(f) = \frac{\left|\overline{X(f)}\right|^2}{T_s} \qquad (14)$$

Here, $\overline{X(f)}$ denotes average value of X(f) due to all the pulses in b(t). And T_s, is symbol duration. Substituting value of X(f) from equation (13) in equation (14), we get

$$S(f) = \frac{V_b^2 T_b^2}{T_s}\left[\frac{\sin(\pi f T_b)}{\pi f T_b}\right]^2$$

For BPSK, because only one bit is transmitted at a time, therefore, symbol and bit durations are same i.e., T = T. Then the last equation becomes,

$$S(f) = V_b^2 T_b \left[\frac{\sin(\pi f T_b)}{\pi f T_b}\right]^2 \qquad (15)$$

This equation gives the power spectral density (psd) of baseband signal b(t). The BPSK signal is generated by modulating a carrier by the baseband signal b(t). Due to modulation of the carrier of frequency f_c, the spectral components are translated from f to f_c + f and f_c -f. The magnitude of these components is divided by half.

Therefore, from equation (15) we can write the power spectral density of BPSK signal as under:

$$S_{BPSK}(f) = V_b^2 T_b \left\{ \frac{1}{2}\left[\frac{\sin \pi(f_c - f)T_b}{\pi(f_c - f)T_b}\right] + \frac{1}{2}\left[\frac{\sin \pi(f_c + f)T_b}{\pi(f_c + f)T_b}\right]^2 \right\}$$

It may be noted that this equation consists of two half magnitude spectral components of same frequency 'f' above and below f_c. Let us assume that the value of $\pm V_b = \pm\sqrt{P}$. This that the NRZ signal is having amplitudes of $+\sqrt{P}$ and $-\sqrt{P}$. Then the last equation becomes,

$$S_{BPSK}(f) \frac{PT_b}{2} \left\{ \left[\frac{\sin \pi(f_c - f)T_b}{\pi(f_c - f)T_b}\right]^2 + \frac{1}{2}\left[\frac{\sin \pi(f_c + f)T_b}{\pi(f_c + f)T_b}\right]^2 \right\} \qquad (16)$$

This equation gives power spectral density (psd) of BPSK signal for modulating signal b(t) having amplitudes equal to $\pm\sqrt{P}$.

Further, we know that the modulated signal is given as

$$S(t) \pm \sqrt{2P}\cos(\pi f_c t)$$

$$[\because A = \sqrt{2P}]$$

If b(t)=$\pm\sqrt{P}$, then the carrier becomes,

$$\phi(t) = \sqrt{2}\cos(2\pi f_c t) \qquad (17)$$

Equation (15) describes power spectral density (psd) of the NRZ waveform. For one rectangular pulse, the shape of S(f) will be a sine pulse as shown in figure 11.

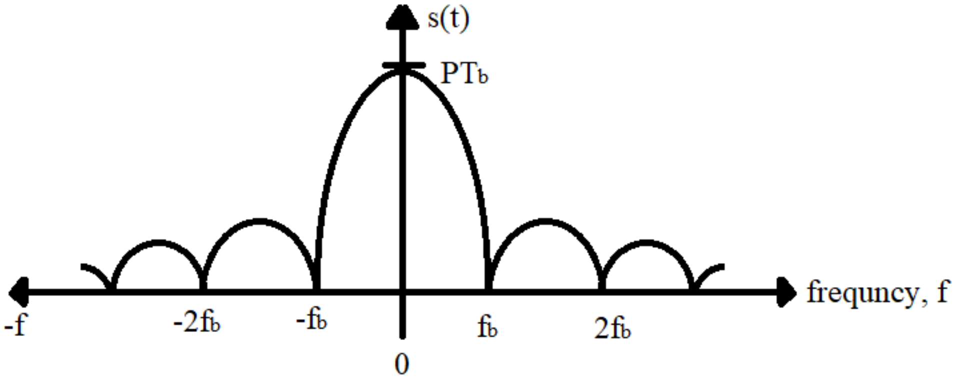

Fig. 4.11 Plot of power spectral density (psd) of NRZ baseband signal.

may be observed from this figure that the main lobe ranges from $-f_b$ to $+ f_b$. Because we have taken $\pm V_b = \pm\sqrt{P}$ in equation (15), therefore, the peak value of the main lobe is PT_b. Now let us consider the power spectral density (psd) of BPSK signal expressed by equation (16).

Figure 12 shows the plot of this equation. This figure, thus, clearly shows that there are two lobes, one at f_c, and other at $-f_c$. The same spectrum of figure 7.11 has been placed at $+ f_c$ and $-f_c$. However, the amplitudes of main lobes are $\frac{PT_b}{2}$ in figure 12.

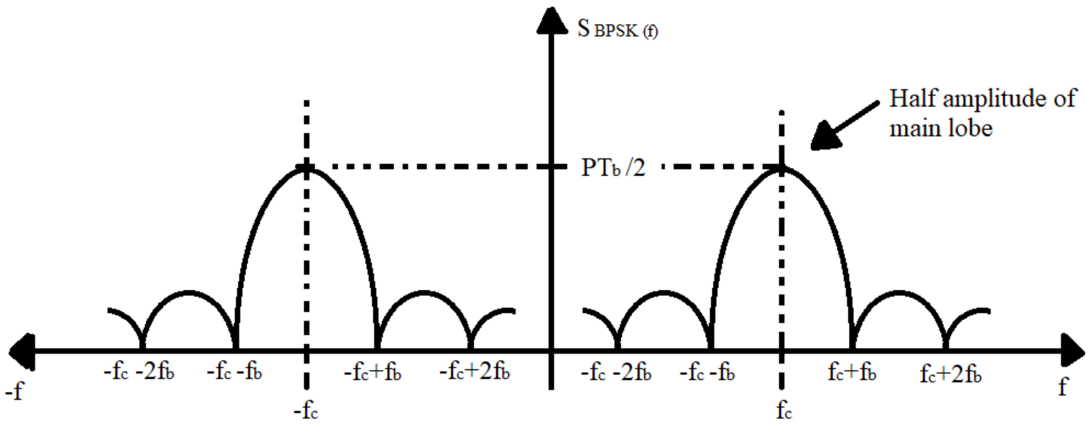

Fig. 4.12 Plot of power spectral density of BPSK signal.

Hence, they are reduced to half. The spectrum of S(f) as well as $S_{BPSK}(f)$ extends overall the frequencies.

4.6.4 A Geometrical Representation for BPSK Signals

We know that BPSK signal carries the information about two symbols. These symbols are symbol '1' and symbol '0'. We can represent BPSK signal geometrically to show these two symbols. From equation (9), we know that BPSK signal is expressed as,

$$S(t) = b(t)\sqrt{2P}\cos(2\pi f_c t) \qquad (18)$$

Let us rearrange the last equation as,

$$S(t) = b(t)\sqrt{PT_b}.\sqrt{\frac{2}{T_b}}\cos(2\pi f_c t) \qquad (19)$$

Now, let $\phi_1(t) = \sqrt{\frac{2}{T_b}} cos\ (2\pi f_c t)$represents an orthonormal carrier signal. Equation (17).

also gives equation for carrier. It is slightly different than , $\phi_1(t)$ defined here. Then, we may write equation (19) as,

$$S(t) = b(t)\sqrt{PT_b}\phi_1(t) \qquad (20)$$

The bit energy E_b, is defined in terms of power 'P' and bit duration T_b, as,

$$E_b = PT_b \qquad (21)$$

Therefore, equation (20) becomes, the

$$S(t) = \pm\sqrt{E_b}\phi_1(t) \qquad (22)$$

Here, b(t) is simply ± 1. Thus, on the single axis of $\phi_1(t)$, there will be two points. One point will be located at $+\sqrt{PT_b}$or $+\sqrt{E_b}$ and other point will be located at $-\sqrt{PT_b}$or $-\sqrt{E_b}$This has been shown in figure 13.

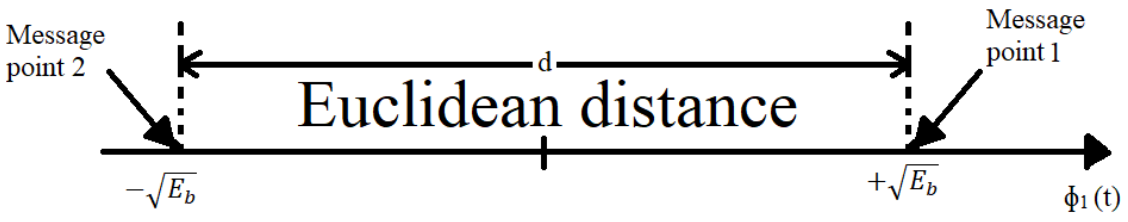

Fig. 4.13 Geometrical representation of BPSK signal.

At the receiver end, the point at $+\sqrt{E_b}$ on $\phi_1(t)$ represents symbol '1' and point at$-\sqrt{E_b}$ represents symbol '0'. The separation between these two points represents the isolation in symbols '1' and '0' in BPSK signal. This separation is generally called distance 'd. From figure 13, it is obvious that the distance between the two points is,

$$d = +\sqrt{E_b} - \left(-\sqrt{E_b}\right) = 2\sqrt{E_b} \qquad (23)$$

As this distance 'd' increases, the isolation between the symbols in BPSK signal is more. Thus, probability of error reduces.

4.6.5 Bandwidth for BPSK Signal

As discussed earlier, the spectrum of the BPSK signal is centred around the carrier frequency f_c.

If $f_b = \frac{1}{T_b}$ then for BPSK, the maximum frequency in the baseband signal will be f_b shown in figure 12. In this figure, the main lobe is centred around carrier frequency f_c, and extends from $f_c – f_b$ to $f_c + f_b$

Therefore Bandwidth of BPSK signal will be,

BW = Highest frequency - Lowest frequency in the main lobe

$$BW = f_c + f_b - (f_c - f_b)$$

$$\text{or } BW = 2f_b \qquad (24)$$

Hence, the minimum bandwidth of BPSK signal is equal to twice of the highest frequency contained in baseband signal.

4.6.6 Salient Features of BPSK

i. BPSK has a bandwidth which is lower than that of a BFSK signal.

ii. BPSK has the best performance of all the three digital modulation techniques in presence of noise. It yields the minimum value of probability of error.

iii. Binary phase shift keying (BPSK) has a very good noise immunity.

4.6.7 Drawbacks of BPSK

Figure 9 shows the block diagram of BPSK receiver. To regenerate the carrier in the receiver, we start by squaring $b(t)\sqrt{2P}\cos(2\pi f_c t + \theta)$ .If the received signal is $- b(t)\sqrt{2P}\cos(2\pi f_c t + \theta)$), then the squared signal remains same as before. Hence, the recovered carrier is unchanged even if the input signal has changed its sign. Therefore, it is not possible to determine whether the received signal is equal to b(t) or- b(t). Infact, this results in ambiguity in the output signal.

Remedy

This problem can be removed if we use differential phase shift keying (DPSK). However, differential phase shift keying (DPSK) also has some other problems. DPSK will be discussed in detail later on in this chapter. Other problems of BPSK are ISI and Interchannel interference. However, these problems can be reduced to some extent by making use of filters.

4.6.8 Bit Error Rate (BER) or Probability of Error

The expression for probability of error, P_e, of a BPSK system is given by

$$P_e = \frac{1}{2}\, erfc\left[\sqrt{\frac{E}{N_0}}\right]$$

The above expression shows that the probability of error depends only on the energy contents of the signal i.e., E. Also, as the energy increases, the value of complementary error function erfc decreases and the value of P_e reduces.

4.7 COHERENT BINARY FREQUENCY SHIFT KEYING (BFSK)

In binary frequency shift keying (BFSK), the frequency of a sinusoidal carrier is shifted according to the binary symbol. In other words, the frequency of a sinusoidal carrier is shifted between two discrete values. However, the phase of the carrier is unaffected. This means that we have two different frequency signals according to binary symbols. Let there be a frequency shift by Ω. Then we can write following equations.

$$If\ b(t) =' 1', than\ S_H(t) = \sqrt{2P_s}\cos(s\pi f_c + \Omega)T \qquad (25)$$

$$If\ b(t) =' 0', than\ S_L(t) = \sqrt{2P_s}\cos(s\pi f_c - \Omega)T \qquad (26)$$

Hence, there is increase or decrease in frequency by Ω. Let us use the following conversion table to combine above two FSK equations:

Table 7.2. Conversion table for BPSK representation

b(t) input	d(t)	$P_H(t)$	$P_L(t)$
1	+1V	+1V	0V
0	-1V	0V	+1N

The equations (7.25) and (7.26) combinely may be written as

$$S(t) = \sqrt{2P_s}\cos[(2\pi f_c + d(t)\Omega)t] \qquad (27)$$

Hence, if symbol '1' is to be transmitted, the carrier frequency will be $f_c + \left(\frac{\Omega}{2\pi}\right)$ and is represented

By f_H If symbol '0' is to be transmitted, then the carrier frequency will be $f_c - \left(\frac{\Omega}{2\pi}\right)$ and is represented by f_L.

Therefore, we have

Thus,

$$f_H = f_c + \frac{\Omega}{2\pi} \quad for\ symbol'1' \qquad (28)$$

$$f_L = f_c - \frac{\Omega}{2\pi} \quad for\ symbol'0' \qquad (29)$$

4.7.1 Generation of BFSK

be observed from Table 1 that $P_H(t)$ is same as b(t) and also $P_L(t)$ is inverted version of b(f). The block diagram for BFSK generation is shown in figure 14.

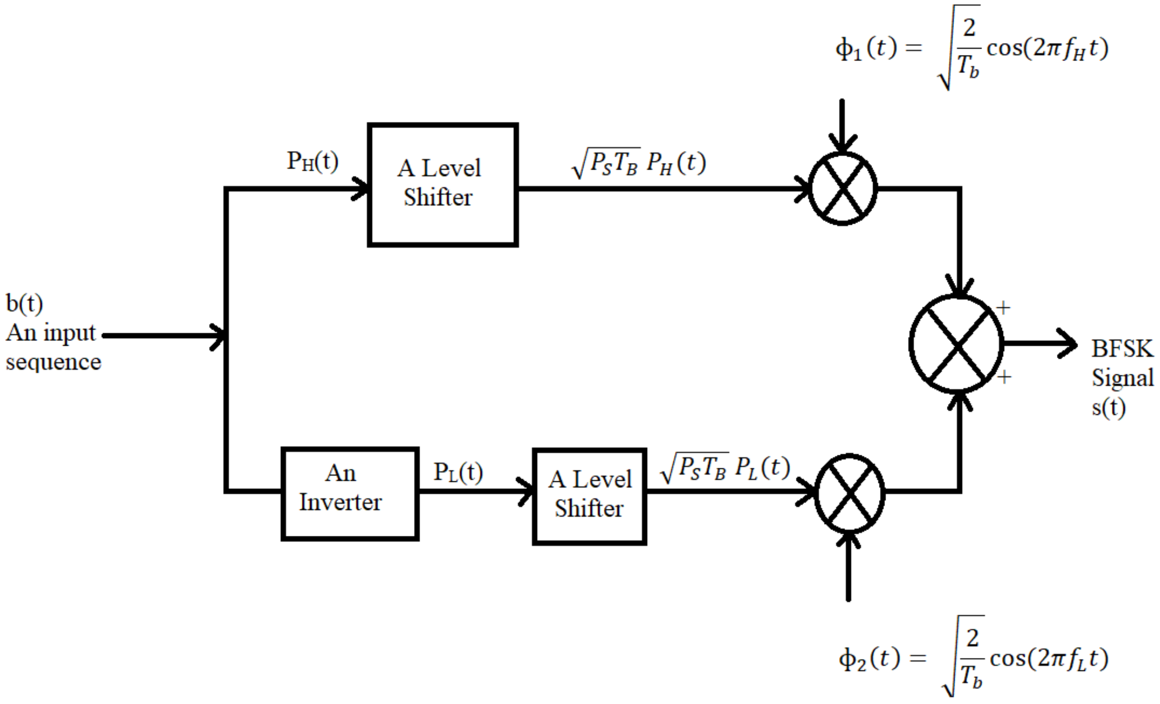

Fig. 7.14 Block diagram for BFSK generation.