Lecture seven

Objective of Lecture:

- Baseband modulation (Digital Modulation)
- Amplitude Shift Keying (ASK) [Modulation and demodulation]
- Frequency Shift Keying (FSK) [Modulation and demodulation]
- Phase Shift Keying (PSK) [Modulation, Coherent and Noncoherent Detection]
- Differential PSK.

Band pass waveform

Introduction:

When a digital is to be transmitted over a long distance, it needs Continue Wave (CW) modulation. A high frequency carrier of f_0 is modulated, then $f_0$has some deviation called ***bandpass*** transmission which is not start from 0 Hz.

When it is required to transmit digital signals on banpass channel, the amplitude, frequency or phase of sinusoidal carrier is varied in accordance with the incoming digital data, then it is called Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) respectively. Instead of transmitting one bit, it can be transmit two or more bits simultaneously. This called *M-ary transmission*, which result in reduce channel bandwidth.

Any digital modulation scheme should satisfy the following requirements:

- Maximum data rate.
- Maximum resistance to interfering signals.
- Minimum probability of symbol error.
- Minimum channel bandwidth.
- Minimum transmitted power.
- Minimum circuit complexity.

1- Binary Phase Shift Keying(BPSK):

In BPSK, binary "1" and "0" modulate the phase of the carrier. Let the carrier be,

$$s(t) = Acos(2\pi f_0 t)$$

If the load resistance is standard 1Ω, the power dissipated will be

$$P = \frac{1}{2}A^2 \quad \rightarrow \quad A = \sqrt{2P}$$

If the symbol is 1

$$s_1(t) = \sqrt{2P}cos(2\pi f_0 t)$$

If next symbol is 0

$$s_2(t) = \sqrt{2P}cos(2\pi f_0 t + \pi) = -\sqrt{2P}cos(2\pi f_0 t)$$

Thus we can define BPSK as:

$$s(t) = b(t)\sqrt{2P}cos(2\pi f_0 t)$$

$where\ b(t) = +1\ for\ binary\ 1\ and -1\ for\ binary\ 0\ as\ shown\ in\ Fig. 1$

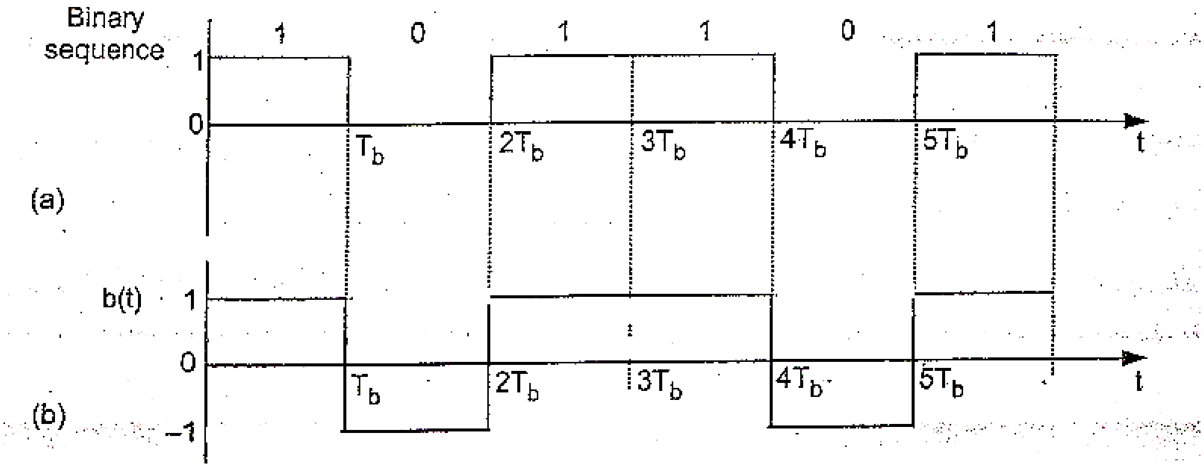


Figure 1

1-1 BPSK generation:

The BPSK signal can be generated by applying carrier signal to the balanced modulator. The baseband signal $b(t)$ is applied as modulating signal to the balanced modulator as shown in Fig. 2.

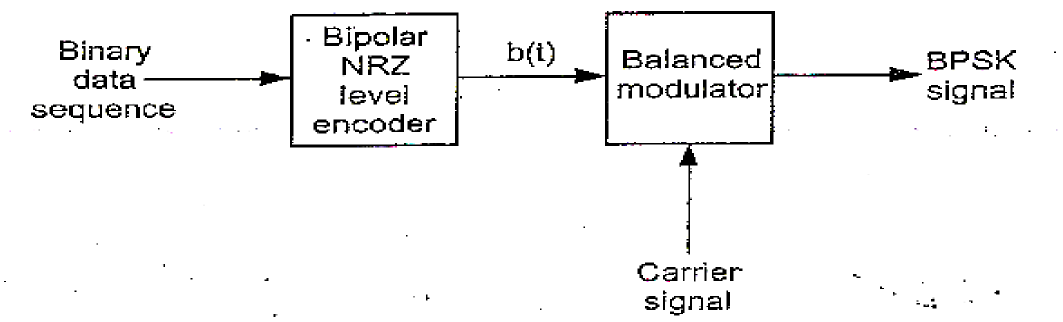
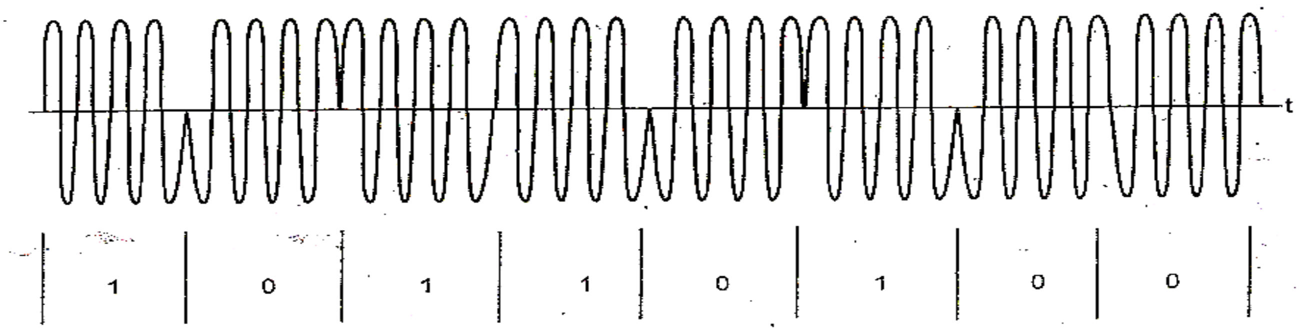


Figure 2

Fig. 3 shows the waveform of BPSK



1-2 The spectrum and bandwidth of BPSK:

The Fourier transform of modulating signal which is consider here as NRZ bipolar, its amplitude is $\pm V_b$ and each pulse is $\pm \frac{T_b}{2}$:

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

The power spectral density $S(f)$is:

$$S(f) = \overline{|X(f)|^2}/T_s$$

So that

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

For BPSK $T_b = T_s$ and;

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

The shape of psd for NRZ is shown in Fig. 4

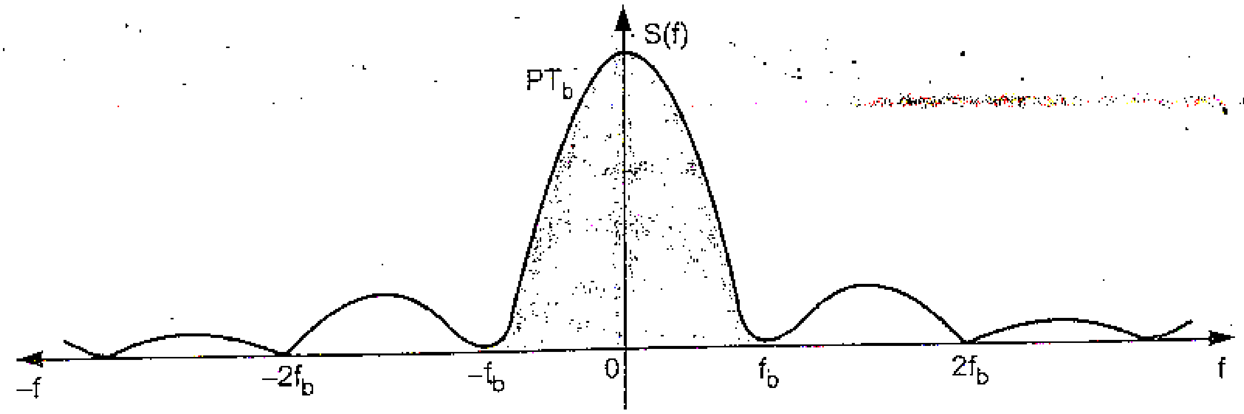


Figure 4

After modulation the spectrum of BPSK is centered around the carrier frequency f_0. If $f_b = 1/T_b$ then the maximum frequency in the baseband signal will be f_b, from Fig. 5 the bandwidth of BPSK can be calculated as:

$$BW = f_0 + f_b - (f_0 - f_b) = 2f_b$$

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

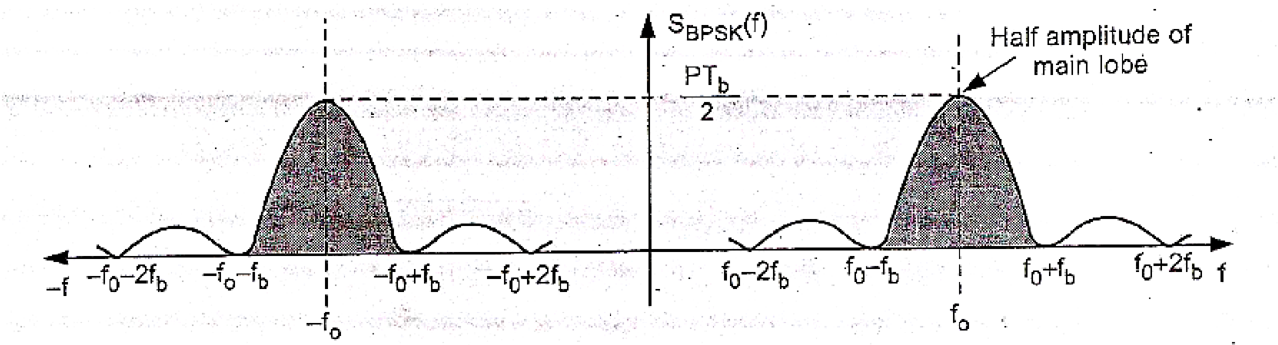


Figure 5

1-3 Detection of BPSK (Coherent Detection):

Fig. 6 shows the bock diagram of the scheme to recover baseband signal from BPSK signal. The transmitted signal is:

$$s(t) = b(t)\sqrt{2P}cos(2\pi f_0 t)$$

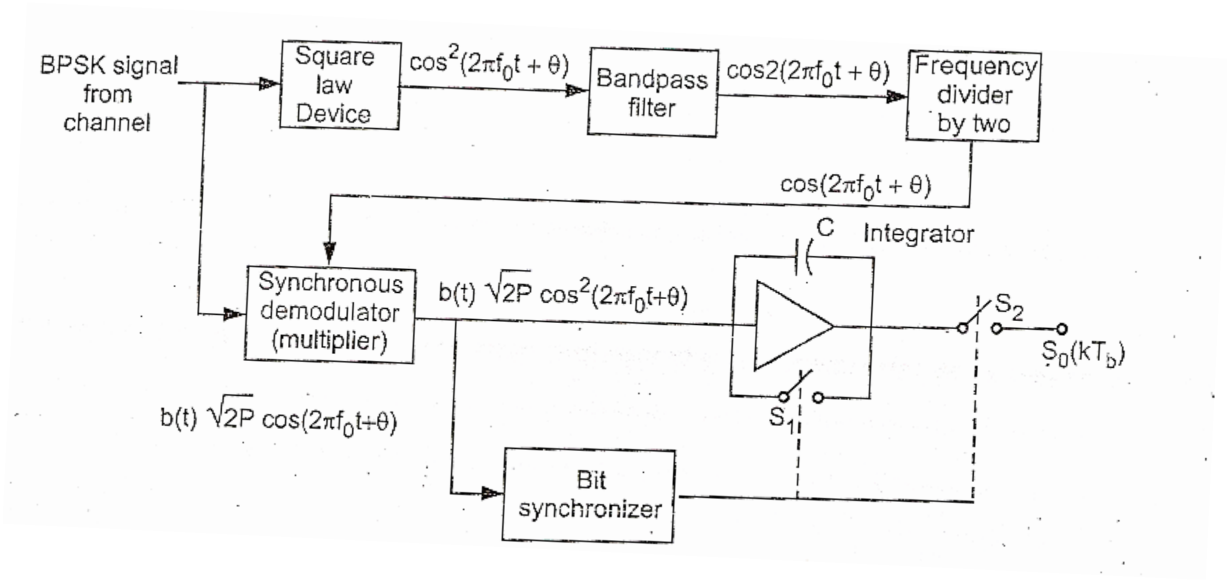


Figure 6

The received signal is:

$$s(t) = b(t)\sqrt{2P}cos(2\pi f_0 t + \theta)$$

Since it is coherent detection the signal is separated and then multiplied with its self in the synchronous demodulator. The part of received signal that pass through square low device is:

$$cos^2(2\pi f_0 t + \theta) = \frac{1}{2} + \frac{1}{2}cos2(2\pi f_0 t + \theta)$$

The band pass filter will remove the DC component $(1/2)$, so we get $cos2(2\pi f_0 t + \theta)$, and pass through frequency divider to get $cos(2\pi f_0 t + \theta)$ as second input to the multiplier. At the output of multiplier we get:

$$b(t)\sqrt{2P}cos(2\pi f_0 t + \theta) \times cos(2\pi f_0 t + \theta) = b(t)\sqrt{2P}cos^2(2\pi f_0 t + \theta)$$
$$= b(t)\sqrt{2P} \times \frac{1}{2} \times [1 + cos2(2\pi f_0 t + \theta)]$$
$$= b(t)\sqrt{P/2} \times [1 + cos2(2\pi f_0 t + \theta)]$$

The integrator integrate the signal over one bit period. The bit synchronizer take care of starting and ending times of a bit. At the end of bit duration T_b, the synchronizer closes switch S_2 temporarily which is same to sampling to output of integrator. The synchronizer then opens switch S_2 and switch S_1 is closed temporarily. This reset integrator voltage to zero to integrate next bit and so on. In the k^{th} bit interval we can write output signal as,

$$S_0(kT_b) = b(kT_b)\sqrt{\frac{P}{2}} \int_{(k-1)T_b}^{kT_b} [1 + cos2(2\pi f_0 t + \theta)]dt$$

$$= b(kT_b)\sqrt{\frac{P}{2}}\left[\int_{(k-1)T_b}^{kT_b} 1dt + \int_{(k-1)T_b}^{kT_b} [cos2(2\pi f_0 t + \theta)]dt\right]$$

Here $\int_{(k-1)T_b}^{kT_b}[cos2(2\pi f_0 t + \theta)]dt = 0$, because the average value of sinusoidal waveform is zero if integration performed over full cycles, so that above equation becomes:

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

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

$$S_0(kT_b) = b(kT_b)\sqrt{\frac{P}{2}}T_b$$

This equation shows that the output of the receiver depending upon the value of $b(kT_b)$ to generate the output of $S_0(kT_b)$

2- Binary Frequency Shift Keying (BFSK):

In BFSK the frequency of the carrier is shifted according to the binary symbol. Let there be a frequency shift by Ω. Then we can write following equations:

$$if\ b(t) = 1; \quad s_H(t) = \sqrt{2P_s}\cos(2\pi f_0 + \Omega)\,t$$

$$if\ b(t) = 0; \quad s_L(t) = \sqrt{2P_s}\cos(2\pi f_0 - \Omega)\,t$$

We can combine above equations as:

$$s(t) = \sqrt{2P_s}\cos(2\pi f_0 + d(t)\Omega)\,t$$

Thus when symbol "1" is to be transmitted, the carrier frequency will be $f_0 + (\Omega/2\pi)$, and $f_0 - (\Omega/2\pi)$ for symbol "0".

2-1 BFSK generation:

Fig. 7 shows the block diagram of BFSK generator, the input sequence $b(t)$ is the same as $P_H(t)$, but an inverter is added to get $P_L(t)$.

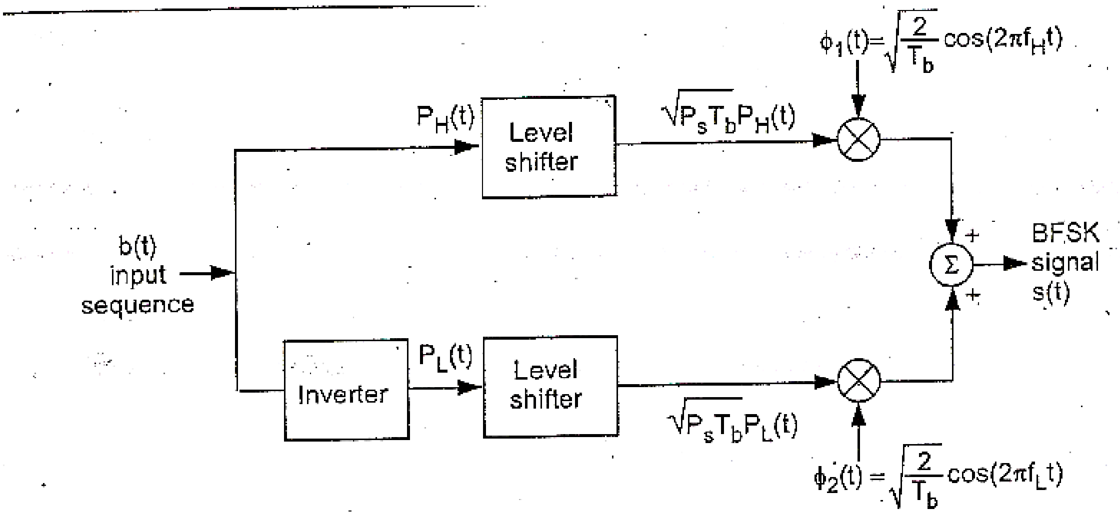


Figure 7

Each of $P_H(t)$ and $P_L(t)$ are unipolar signals. If the input to level shifter is "1" then its output is $\sqrt{P_s T_b}$, and zero if the input is "0".

After level shifter there are product modulators with two carriers $\emptyset_1(t)$ and $\emptyset_2(t)$ orthogonal with each other. In one bit period of input signal T_b, $\emptyset_1(t)$ or $\emptyset_2(t)$ have integral number of cycles. Not that the output of both multiplier is not possible because $\emptyset_1(t)$ and $\emptyset_2(t)$ are complementary to each other as shown in Fog. 8.

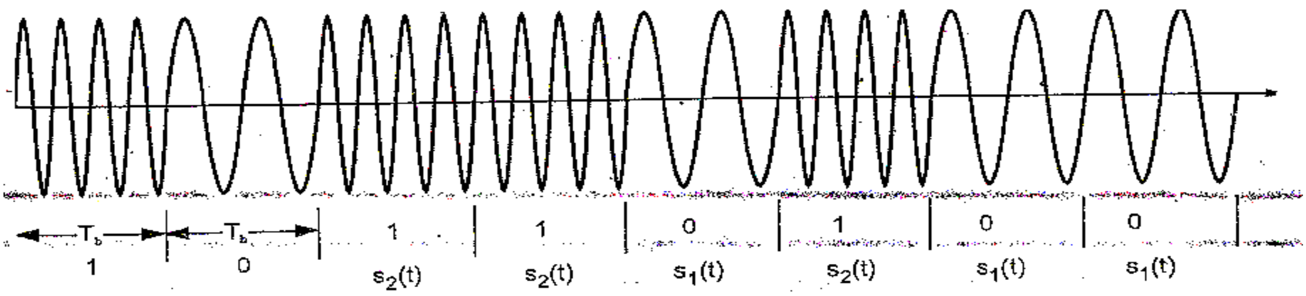


Figure 8

2-2 The spectrum and bandwidth of BFSK:

The output of BFSK generator can be write as:

$$s(t) = \sqrt{2P_s}P_H(t)\cos(2\pi f_H t) + \sqrt{2P_s}P_L(t)\cos(2\pi f_L t)$$

The above equation is the BFSK signal equation:

$$s_{BPSK}(t) = \sqrt{2P}b(t)\cos(2\pi f_0 t)$$

The equation of BPSK is similar to BFSK but $b(t)$ is a bipolar signal while the coefficient $P_H(t)$ and $P_L(t)$ are unipolar. Therefore let convert those coefficients in bipolar form as follows:

$$P_H(t) = \frac{1}{2} + \frac{1}{2}P'_H(t)$$

And

$$P_L(t) = \frac{1}{2} + \frac{1}{2}P'_L(t)$$

Here $P'_H(t)$ and $P'_L(t)$ will be bipolar (i.e. $+1\ or -1$). Substitute those value in BFSK equation, we get:

$$s(t) = \sqrt{2P_s}\left[\frac{1}{2} + \frac{1}{2}P'_H(t)\right]\cos(2\pi f_H t) + \sqrt{2P_s}\left[\frac{1}{2} + \frac{1}{2}P'_L(t)\right]\cos(2\pi f_L t)$$

$$= \sqrt{\frac{P_s}{2}}\cos(2\pi f_H t) + \sqrt{\frac{P_s}{2}}\cos(2\pi f_L t) + \sqrt{\frac{P_s}{2}}P'_H(t)\cos(2\pi f_H t) + \sqrt{\frac{P_s}{2}}P'_L(t)\cos(2\pi f_L t)$$

In the above equation the first two terms represent two frequencies f_H and f_L with constant amplitude while the last two terms are similar to BPSK.

$$S(f) = \sqrt{\frac{P_s}{2}}\{\delta(f - f_H) + \delta(f - f_L)\} + \frac{P_s T_b}{2}\left[\frac{\sin(\pi f_H T_b)}{(\pi f_H T_b)}\right]^2 + \frac{P_s T_b}{2}\left[\frac{\sin(\pi f_L T_b)}{(\pi f_L T_b)}\right]^2$$

Fig.9 shows the power spectral density of BFSK signal given by above equation:

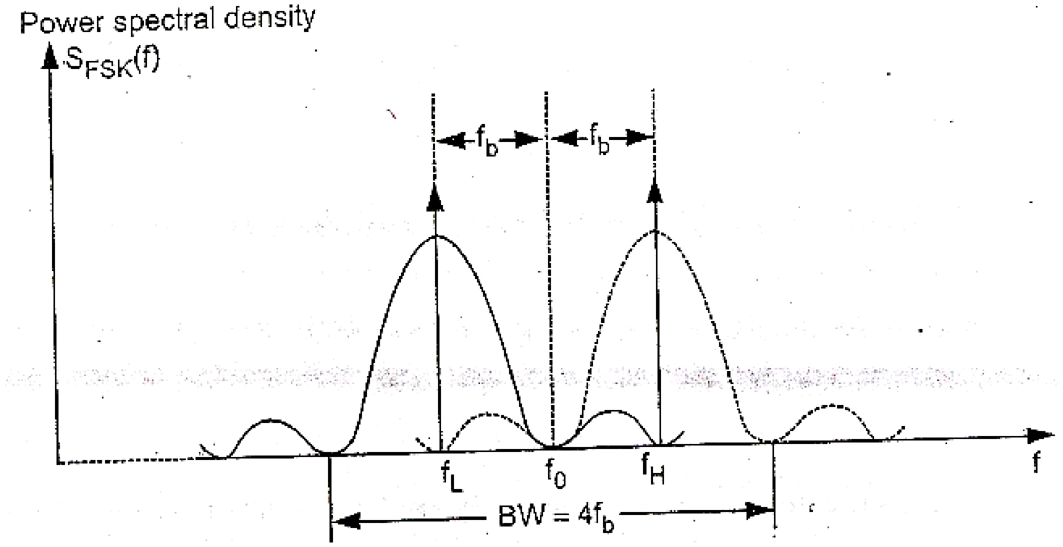


Figure 9

It is clear that the width of one lobe is $2f_b$ so that the total bandwidth:

$$BW = 2f_b + 2f_b$$

or $$BW = 4f_b$$

so that $$BW(BFSK) = 2 \times BW(BPSK)$$

2-3 BFSK detection:

The block diagram of BFSK receiver is consist of two bandpass filters one with center frequency f_H and other with f_L, since $f_H - f_L = 2f_b$, the output do not overlap. The output of filters are applied to envelop detectors. The outputs of detectors are compared by the comparator, which introduced bit sequence $b(t)$.

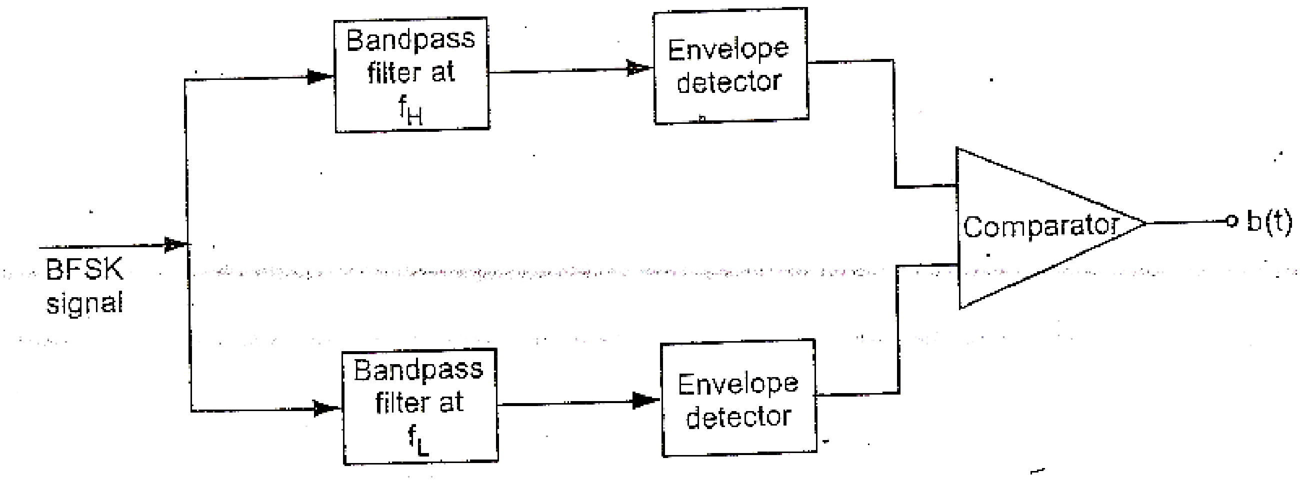


Figure 9

2-4 Advantages and disadvantages of BFSK:

Even though the generation of BFSK is easier, it has many disadvantages compared with BPSK:

a- The bandwidth is almost double bandwidth of BPSK.
b- If we expand the equation of BFSK:

$$s(t) = \sqrt{2P_s}\cos(2\pi f_0 + d(t)\Omega)\,t$$

$$s(t) = \sqrt{2P_s} cos\{d(t)\Omega\}\cos(2\pi f_0 t) - \sqrt{2P_s} sin\{d(t)\Omega\}\sin(2\pi f_0 t)$$

Since $d(t) = \pm 1$ $\quad\therefore\quad$ $cos\{\pm\Omega t\} = \cos(\Omega t)$

And $\quad sin\{\pm\Omega t\} = \pm sin(\Omega t) = d(t)\sin(\Omega t)$

$$s(t) = \sqrt{2P_s}\cos(\Omega t)\cos(2\pi f_0 t) - \sqrt{2P_s}d(t)\sin(\Omega t)\sin(2\pi f_0 t)$$

Form above equation it is clear that only second term carry information, thus half the transmitted energy carries information signal.

3- **Binary Amplitude Shift Keying (BASK) or ON- OFF keying (OOK):**

ASK or OOK is the simplest digital modulation technique. The ASK waveform can be represented as:

$s(t) = \sqrt{2P_s}\cos(2\pi f_0 t)$ to transmit symbol "1", and pulse is transmitted. To transmit symbol "0" $s(t) = 0$, that is no signal transmitted for such symbol.

Thus ASK waveform looks like an ON-OFF of the signal as shown in figure 10.

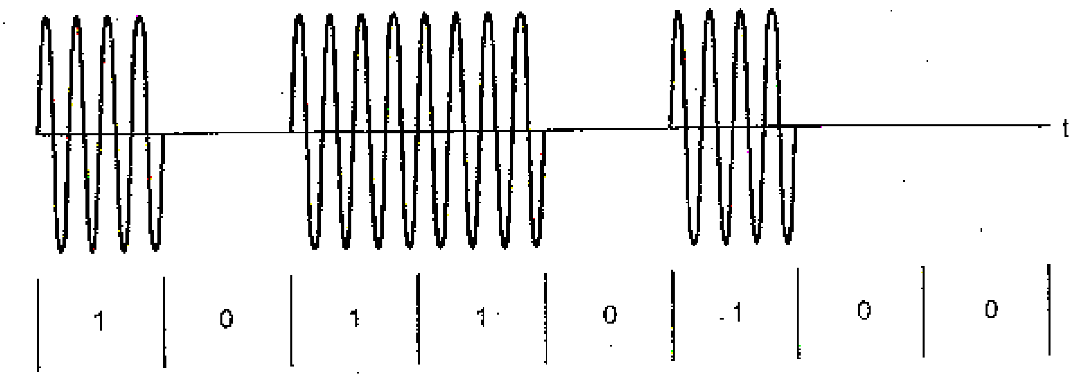


Figure 10

The ASK wave form for symbol "1" can be represented as:

$$s(t) = \sqrt{P_s T_b} . \sqrt{2/T_b} \cos(2\pi f_0 t)$$

$$= \sqrt{P_s T_b} \emptyset_1(t)$$

Thus there is only one carrier function $\emptyset_1(t)$. If we take $\emptyset_1(t) = \sqrt{2/T_b} \cos(2\pi f_0 t)$ as the orthonormal basis function. The signal space diagram will have two points on $\emptyset_1(t)$. One will be at zero and other will be at $\sqrt{P_s T_b}$. As shown in Fig.11:

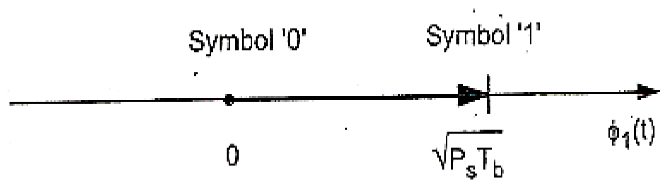


Figure 11

Therefore the distance between the two signal points will be,

$$d = \sqrt{P_s T_b} = \sqrt{E_b}$$

3-1 Generation of BASK:

Fig. 12 shows BASK generator. The input binary sequence is applied to the product modulator. The modulator passes the carrier when the input bits is "1", and block the carrier (zero output) when input bit is "0".

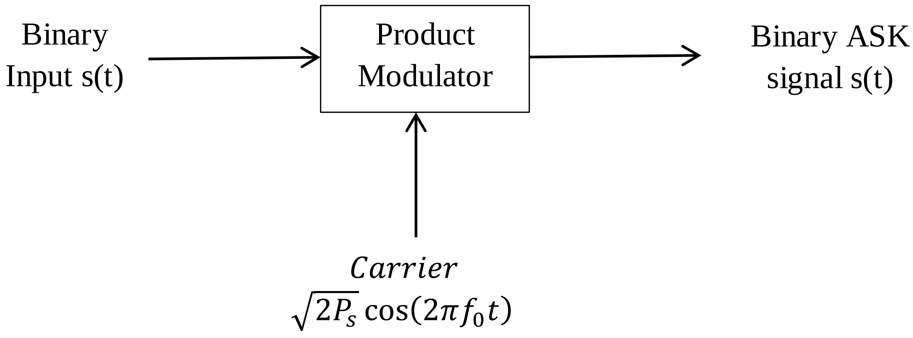


Figure 12

The bandwidth of ASK is

$$BW = R(1 + r)$$

Where R is the bit rate and $0 < r < 1$ is related to how signal is filtered.

3-2 ASK Detector:

The ASK signal is applied to the correlator consisting of multiplier and integrator. The locally generated coherent carrier and applied to multiplier as shown in Fig. 13.

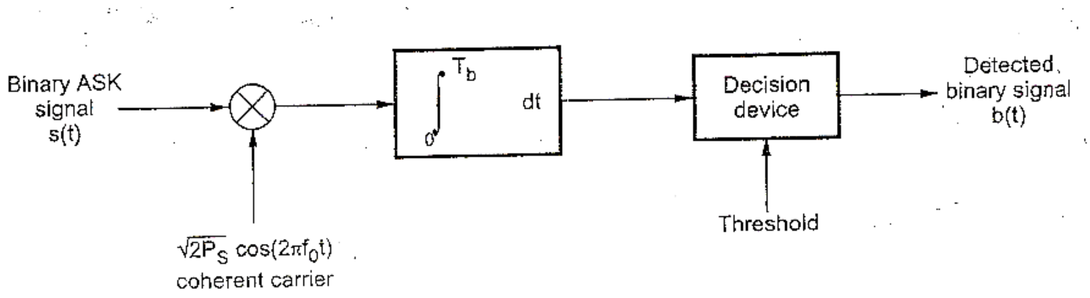


Figure 13

The output of multiplier is integrated over the bit period. The decision device takes the decision at the end of every bit period. It compare the output of integrator with the threshold.

4- **Differential Phase Shift Keying (DPSK):**

DPSK is differentially coherent modulation method. It does not need synchronous (coherent) carrier at the demodulator. The input sequence of binary bits is modified such that the next bit depends upon the previous bit.

Therefore in the receiver the previous received bits are used to detect the present bit.

4-1 Generator of DPSK:

The input sequence d(t), the output sequence is b(t) and $b(t - T_b)$ is the previous output delayed by one bit period. Depending upon values of d(t) and $b(t - T_b)$, exclusive OR gate generates the output sequence b(t) as shown in Fig. 14.

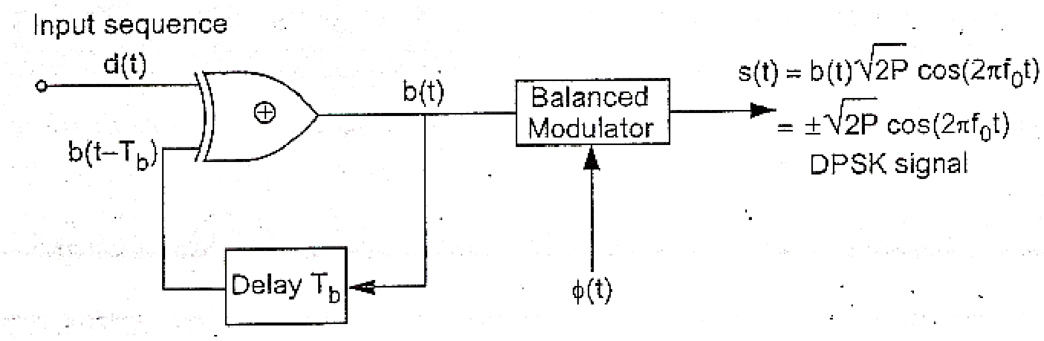


Figure 14: DPSK generator

The truth table of exclusive OR gate is used to derive the level of waveforms shown in Fig. 15, which satisfied in any interval b(t) is given as,

$$b(t) = d(t) \circ b(t - T_b)$$

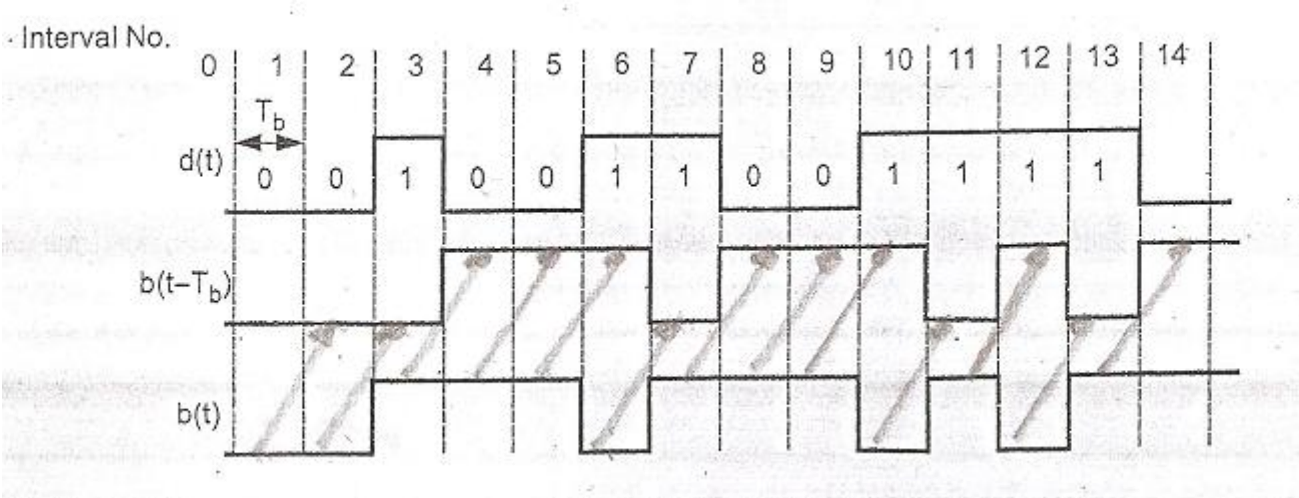


Figure 15: DPSK waveform

Note that the output sequence b(t) changes level at the beginning of each interval in which d(t)=1 and does not change level when d(t)=0, so that symbol duration (T)= duration of two bits $2T_b$. The sequence b(t) is applied to the balanced modulator as shown in Fig. 14 with carrier $\sqrt{2P}\cos(2\pi f_0 t)$, the modulator output is:

$$s(t) = b(t)\sqrt{2P}\cos(2\pi f_0 t)$$
$$= \pm\sqrt{2P}\cos(2\pi f_0 t)$$

As shown in in Fig.15 the phase changes only when d(t)=1.

4-2 DPSK Receiver:

During the transmission, the DPSK signal undergoes some phase shift θ. Therefore the signal received at the input of receiver is

Received signal $y(t) = b(t)\sqrt{2P}\cos(2\pi f_0 t + \theta)$

The signal is multiplied with delayed version by one bit:

Multiplier output= $b(t)b(t - T_b)(2p)\cos(2\pi f_0 t + \theta)\cos(2\pi f_0(t - T_b) + \theta)$

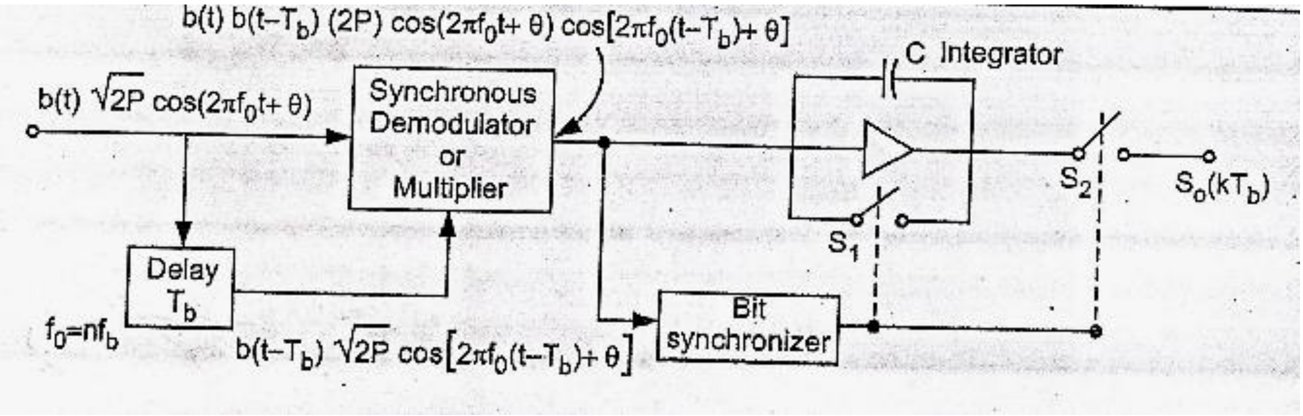
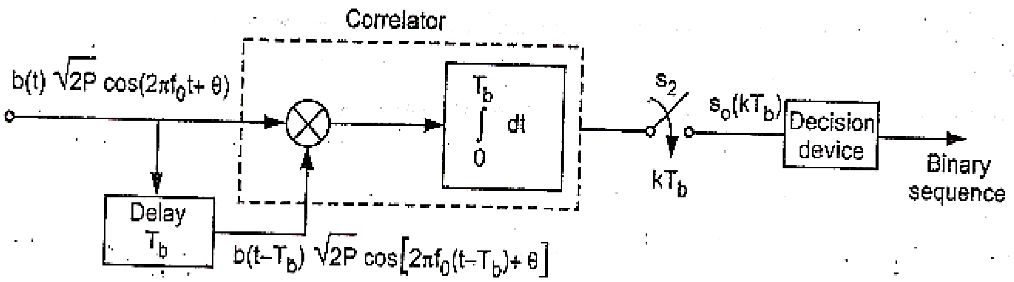


Figure 16a: DPSK receiver

This signal is fed to integrator and to the decision device. The integrator and decision is controlled by bit synchronizer to get the output binary sequence. The block diagram of such system is shown in Fig.16a, and the equivalent of this system is shown in Fig.16b.



4-3 Bandwidth of DPSK:

We know that one previous bit is used to decide the phase shift of next bit. Change in b(t) occurs only if input bitt is at level '1'. No change occurs if input bit is at level '0'. Since one previous bit is always used to define the phase in next bit, the symbol can be said to have two bits. Therefore one symbol duration (T) is equivalent to two bits duration $(2T_b)$, so that

Symbol duration $T = 2T_b$

Bandwidth is given as, $BW = \frac{2}{T} = \frac{1}{T_b}$

Or $BW = f_b$

4-4 Advantages and disadvantages of DPSK:

Advantages:

1- DPSK does not need carrier at its receiver. Hence it is simple than BPSK.
2- The bandwidth required of DPSK is reduced compared to that of BPSK.

Disadvantages:

1- The probability of bit error rate of DPSK is higher than BPSK.
2- Error in the first bit creates error in the second bit. Hence error propagation in DPSK is more, while in PSK each bit is independent.
3- Noise interference in DPSK is more.