3.2 Principles of Offset QPSK

Quadrature-Phase Shift Keying

A Quadrature-Phase Shift Keying (QPSK)-modulated signal is a PAM where the signal carries 1bit per symbol interval on both the in-phase and quadrature-phase component. The original data stream is split into two streams,

$$\left.\begin{array}{lll} b1_i & = & b_{2i} \\ b2_i & = & b_{2i+1} \end{array}\right\}$$

b1i and b2i each of which has a data rate that is half that of the original data stream:

$$R_S = 1/T_S = R_B/2 = 1/(2T_B)$$

Let us first consider the situation where basis pulses are rectangular pulses, g(t)=gR(t, TS). Then we can give an interpretation of QPSK as either a phase modulation or as a PAM.

We first define two sequences of pulses

$$\left.\begin{array}{l} p1_D(t) = \sum_{i=-\infty}^{\infty} b1_i g(t - iT_S) = b1_i * g(t) \\ p2_D(t) = \sum_{i=-\infty}^{\infty} b2_i g(t - iT_S) = b2_i * g(t) \end{array}\right\}$$

When interpreting QPSK as a PAM, the bandpass signal (as in figure 3.2.2) reads

$$s_{BP}(t) = \sqrt{E_B/T_B}[p1_D(t)\cos(2\pi f_c t) - p2_D(t)\sin(2\pi f_c t)]$$

Normalization is done in such a way that the energy within one symbol interval is_

$\int_0^{T_S} s_{BP}(t)^2 dt =$ **$2E_B$**, E_B is the energy expended on transmission of a bit.

Data streams of in-phase and quadrature-phase components in quadrature-phase shift keying as shown in Fig 3.2.1.

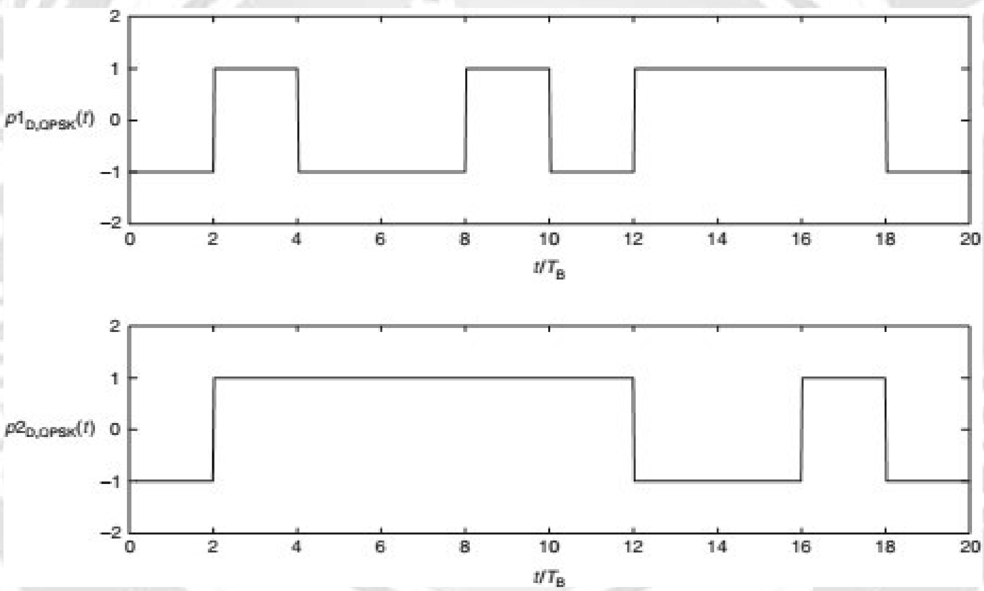

Fig 3.2.1: Data streams in –in phase and quadrature phase components .[Source : Wireless communications by Andreas F.Molisch]

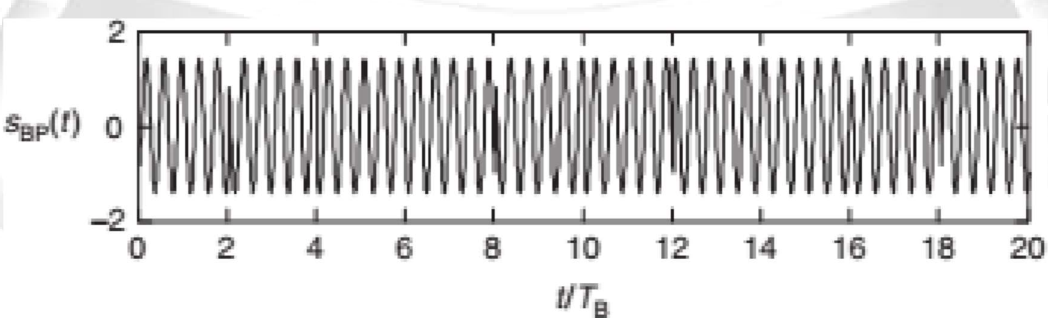

Fig 3.2.2: Quadrature-phase shift keying signal .[Source : Wireless communications by Andreas F.Molisch]

The baseband signal is

$$s_{LP}(t) = [p1_D(t) + jp2_D(t)]\sqrt{E_B/T_B}$$

When interpreting QPSK as a phase modulation, the low pass signal can be written as

$$\frac{\sqrt{2E_B}}{T_B} \exp\left(j\emptyset_s(t)\right) \; and$$

$$\Phi_S(t) = \pi \cdot \left[\frac{1}{2} \cdot p2_D(t) - \frac{1}{4} \cdot p1_D(t) \cdot p2_D(t)\right]$$

It is clear from this representation that the signal is constant envelope, except for the transitions at t = iTS.

Signal space diagram of quadrature-phase shift keying (Fig 3.2.3).

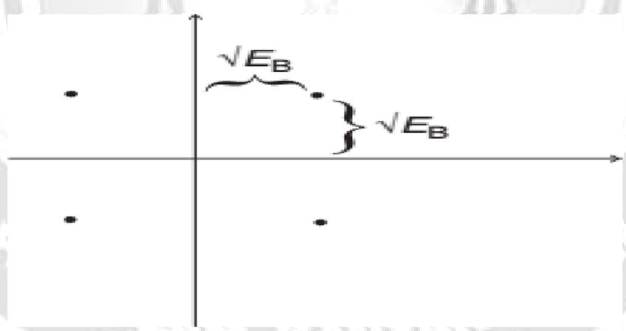

Fig 3.2.3: Signal space diagram of quadrature-phase shift keying .[Source : Wireless communications by Andreas F.Molisch]

The spectral efficiency of QPSK is twice the efficiency of BPSK, since both the in-phase and the quadrature-phase components are exploited for the transmission of information.

This means that when considering the 90% energy bandwidth, the efficiency is 1.1 bit/s/Hz, while for the 99% energy bandwidth, it is 0.1 bit/s/Hz.

Normalized power-spectral density of quadrature-phase shift keying.(Fig 3.2.4).

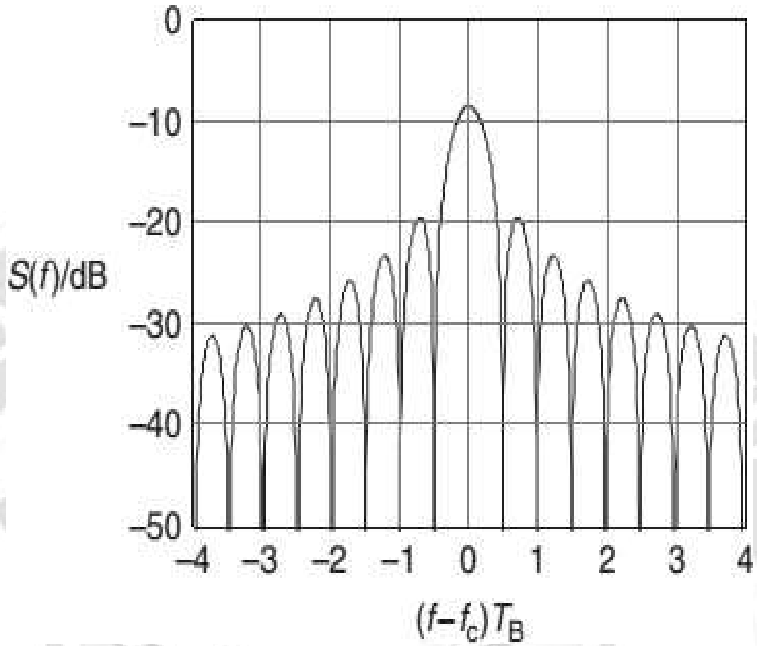

Fig 3.2.4 : Normalized PSD of quadrature-phase shift keying .[Source : Wireless communications by Andreas F.Molisch]

Offset Qpsk

Offset Quadrature-Phase Shift Keying

The method of improving the peak-to-average ratio in QPSK is to make sure that bit transitions for the in-phase and the quadrature-phase components occur at different time instants. This method is called OQPSK (offset QPSK).

The bit streams modulating the in-phase and quadrature-phase components are offset half a symbol duration with respect to each other (shown in Figure 3.2.5) , so that transitions for the in-phase component occur at integer multiples of the symbol duration (even integer multiples of the bit duration), while quadrature component transitions occur half a symbol duration (1-bit duration) later.

Thus, the transmit pulse streams are

$$\left.\begin{aligned} p1_D(t) &= \sum_{i=-\infty}^{\infty} b1_i g(t - iT_S) = b1_i * g(t) \\ p2_D(t) &= \sum_{i=-\infty}^{\infty} b2_i g\left(t - \left(i + \tfrac{1}{2}\right) T_S\right) = b2_i * g\left(t - \frac{T_S}{2}\right) \end{aligned}\right\}$$

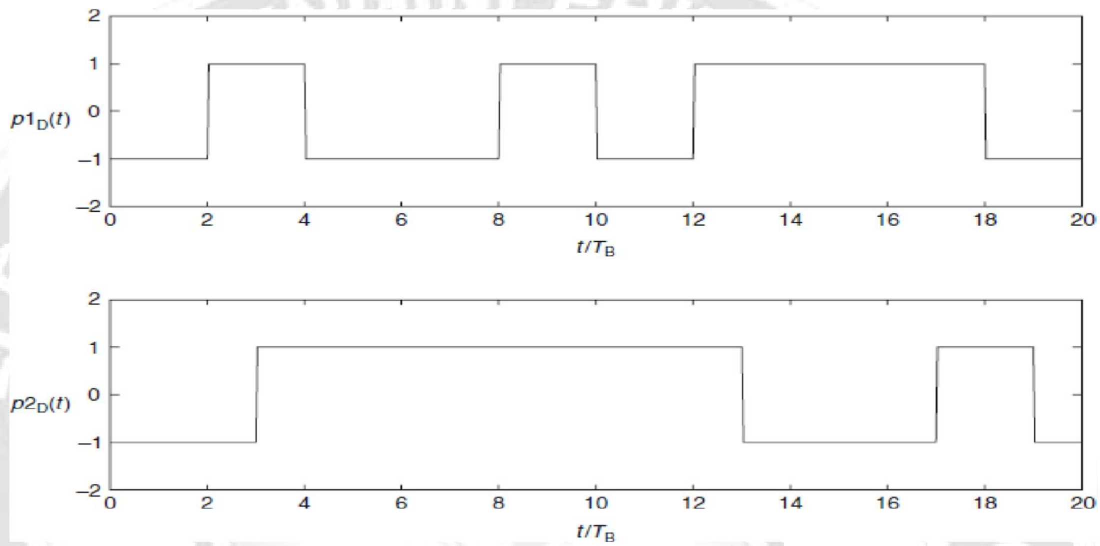

Fig 3.2.5: Sequence of basis pulses for offset QPSK .[Source : Wireless communications by Andreas F.Molisch]

These data streams can again be used for interpretation as PAM or as phase modulation.

The resulting band pass signal is shown in figure 3.2.6.

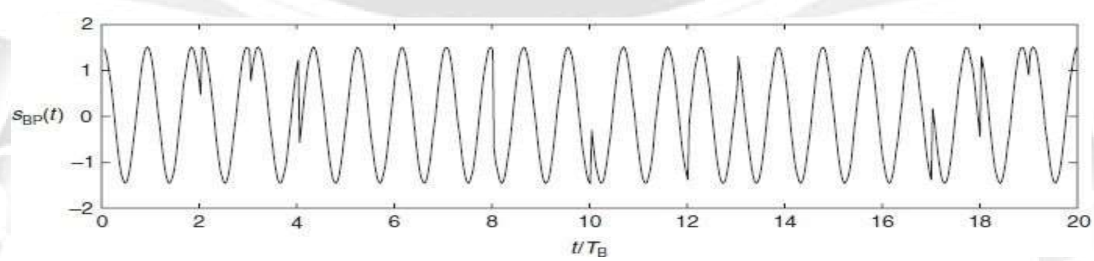

Fig3.2.6: Offset QPSK signal .[Source : Wireless communications by Andreas F.Molisch]

The representation in the **I–Q** diagram (Figure 3.2.7) makes clear that there are no transitions passing through the origin of the coordinate system; thus this modulation format takes care of envelope fluctuations .

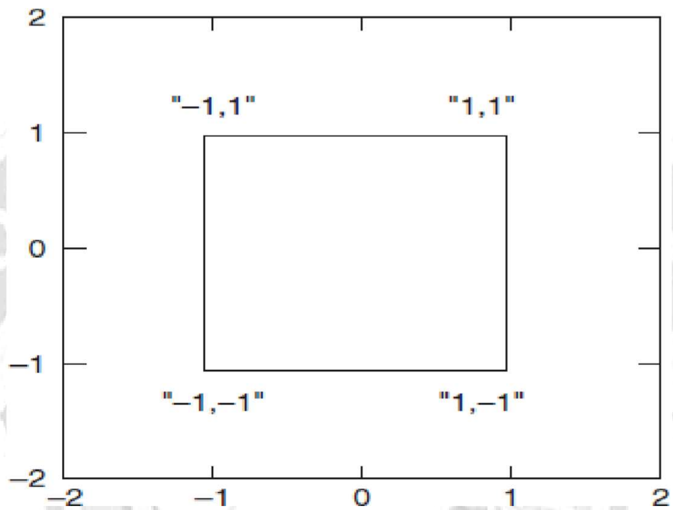

Fig 3.2.7 : I–Q diagram for offset QPSK signal .[Source : Wireless communications by Andreas F.Molisch]

I–Q diagram (above) for offset quadrature-phase shift keying with rectangular basis functions. Also shown are the four points of the normalized signal space diagram, (1, 1), (1,−1), (−1,−1), (−1, 1). Smoother basis pulses, like raised cosine pulses are used to improve spectral efficiency.

Figure 3.2.8 ,shows the I–Q diagram for offset quadrature amplitude modulation with raised cosine basis pulses.

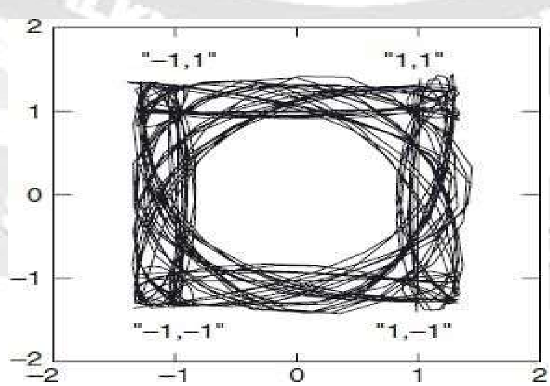

Fig3.2.8: I–Q diagram for offset QPSK signal with raised cosine basis pulses. .[Source : Wireless communications by Andreas F.Molisch] .

π/4-Differential Quadrature-Phase Shift Keying

QPSK has amplitude dips at bit transitions; The trajectories in the I–Q diagram pass through the origin for some of the bit transitions.

The duration of the dips is longer when non-rectangular basis pulses are used. Such variations of the signal envelope are undesirable, because they make the design of suitable amplifiers more difficult.

One possibility for reducing these problems lies in the use of $\pi/4$-DQPSK ($\pi/4$ differential quadrature-phase shift keying).

This modulation format had great importance for second-generation cellphones – it was used in several American standards (IS-54, IS-136, PWT), as well as the Japanese cellphone (JDC) and cordless (PHS) standards, and the European trunk radio standard (TETRA).

The principle of π/4-DQPSK can be understood from the signal space diagram of DQPSK (Figure3.2.9).

There exist two sets of signal constellations: (0, 90, 180, 270◦) and (45, 135, 225, 315 ◦).

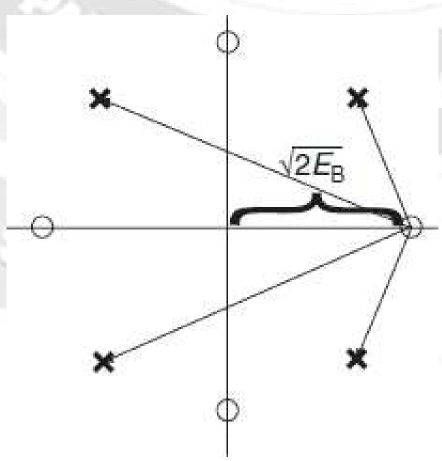

Fig 3.2.9: Allowed transitions in the signal space diagram.[Source : Wireless communications by Andreas F.Molisch]

All symbols with an even temporal index i are chosen from the first set, while all symbols with odd index are chosen from the second set. In other words: whenever t is an integer multiple of the symbol duration, the transmit phase is increased by **π/4,** in addition to the change of phase due to the transmit symbol.

Therefore, transitions between subsequent signal constellations can never pass through the origin (Figure ; in physical terms, this means smaller fluctuations of the envelope.

Figure 3.2.10 shows the Sequence of basis pulses for **π/4** differential quadrature-phase shift keying.

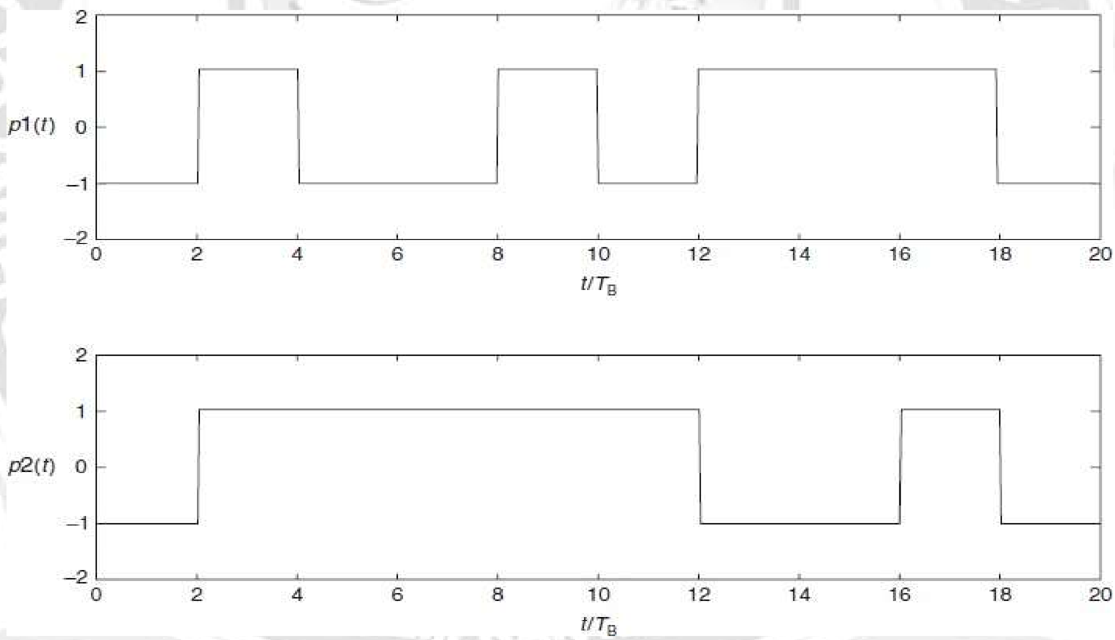

Fig 3.2.10. Basis pulses for π/4 differential .[Source : Wireless communications by Andreas F.Molisch]

The signal phase is given by

$$\Phi_S(t) = \pi \left[\frac{1}{2} p2_D(t) - \frac{1}{4} p1_D(t) p2_D(t) + \frac{1}{4} \left\lfloor \frac{t}{T_S} \right\rfloor \right]$$

where x denotes the largest integer smaller or equal to x. Comparing this with Eq. equation below,

we can see the change in phase at each integer multiple of TS.

$$\Phi_S(t) = \pi \cdot \left[\frac{1}{2} \cdot p2_D(t) - \frac{1}{4} \cdot p1_D(t) \cdot p2_D(t) \right]$$

Figure (below) shows the data sequences, and the resulting bandpass signals when using rectangular or raised cosine basis pulses.

π/4 differential quadrature-phase shift keying signals as function of time for rectangular basis functions (a) and raised cosine basis pulses (b) are shown in figure 3.2.11.

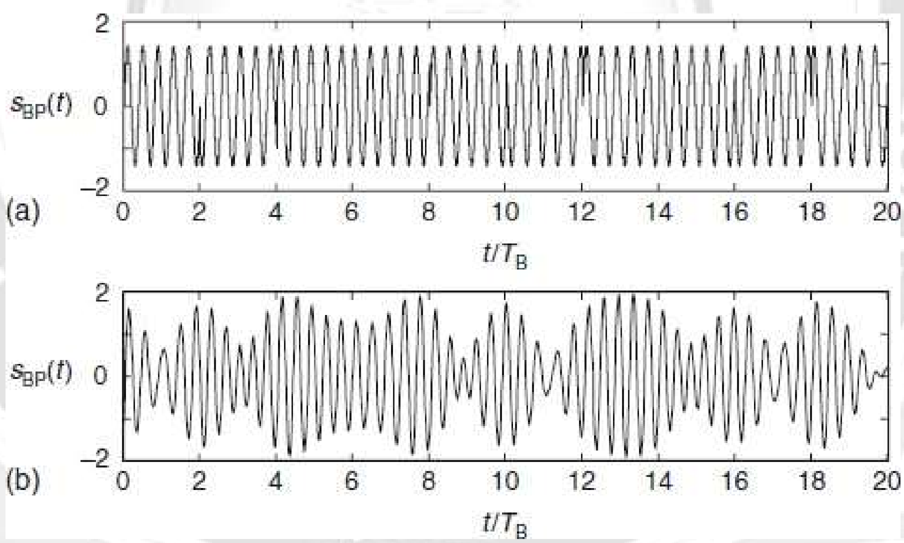

Fig 3.2.11. π/4 differential quadrature-phase shift keying signals as function of time for rectangular basis functions (a) and raised cosine basis pulses (b). .[Source : Wireless communications by Andreas F.Molisch]

I-Q diagram for **π/4** -differential quadrature-phase shift keying signal with rectangular basis functions is shown in figure 3.2.12.

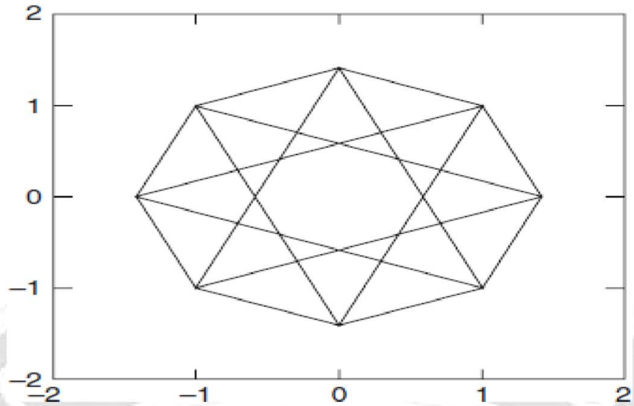

Fig 3.2.12: I-Q diagram of π/4 differential QPSK. .[Source : Wireless communications by Andreas F.Molisch]