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Digital Modulation Schemes

Most communication system falls into one of three categories : bandwidth efficient, power efficient or cost efficient.

Bandwidth Efficiency: Ability of a modulation scheme to accomodate data within a limited BW

Power Efficiency: describes the ability of the system to reliably send information at lowest practical power level.

The parameter to be optimized depends on the demands of the particular system.

For example, for designers of terrestrial microwave radios. their highest priority is good bandwidth efficiency with low bit-error-rate.

Designers of hand-held cellular phones put high priority on power efficiency, because these phones need to run on a battery.

cost is also a high priority because cellular phones must be low-cost to encourage more users.

Why Digital Modulation:

To move to digital modulation provides more information capacity. compatibility with digital data services, higher data security, better quality communications, and quicker system availability. Developers of communication systems face three constraints:

- available bandwidth
- permissible power
- inherent noise level of the system

The RF spectrum must be shared, yet everyday there are more users for that spectrum as demand. Digital modulation schemes have greater capacity to convey large amounts of information than analog modulation schemes.

<u>Transmitting Information:</u> To transmit a signal over the air, there are three main steps:

1. A pure carrier is generated at the transmitter.
2. The carrier is modulated with the information to be transmitted. Any reliably detectable change in signal characteristics can carry information.
3. At the R receiver signal modifications or changes are detected and demodulated

Advantages of Digital Modulation Techniques over Analog Modulation Techniques :-

- Greater noise immunity & robustness to channel impairments.
- Perform better in fading environments.
- Easier multiplexing with various forms of information (like, voice, data & video) etc

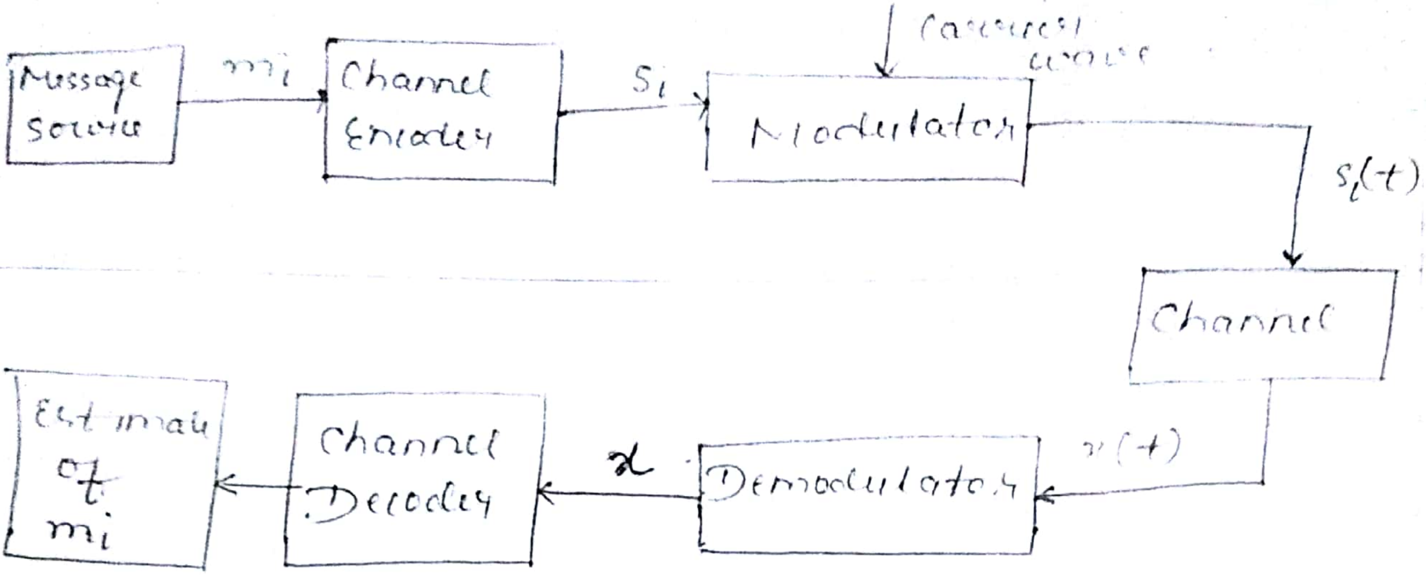
Three basic signalling schemes

- Amplitude - shift keying (ASK)
- Frequency - shift keying (FSK)
- Phase - shift keying (PSK)

Emphasis on the following issues:

- Optimum design of the reciver
- calculate the average probability of symbol error of the RX.
- Spectral properties of the modulated signals.

Model of a digital passband system.



mi → digitized voice, image, video, fax

Channel encoder puts redundancies in a known manner so as to overcome the effects of noise and other channel impairments.

Modulator uses carrier and sends out waveform in the time domain.

The above waveform passes through the channel wherein various channel impairments and noise come into play and signal $x(t)$ is received which is very different from ~~that~~ the $s(t)$.

$x(t)$ passes through a demodulator. Demodulator provides estimate of the message and also creates some kind of a limitation on the effects of noise. We get back x and channel decoder decodes x which reduces the effect of noise, then finally get an estimate of m_i.

The communication channel used for passband data transmission may be microwave radio link, a satellite channel, or the like.

Possible applications of passband data transmission — design of passband line codes for use on digital subscriber loops.

Orthogonal frequency ~~divid~~ - division multiplexing for broadcast.

Digital Modulation process involves switching (keying) the amplitude, frequency, or phase of a sinusoidal carrier in some fashion in accordance with the incoming data.

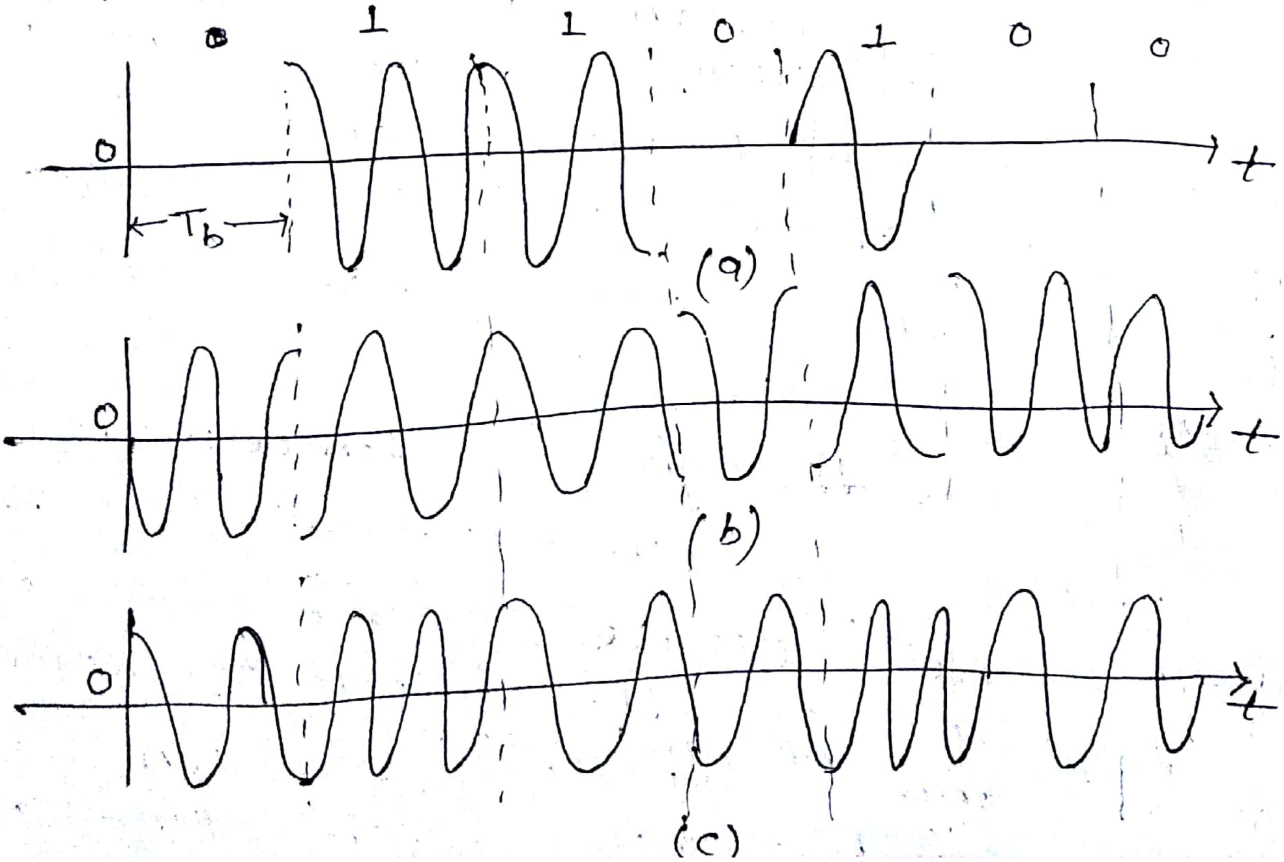


Fig : waveforms for (a) Amplitude shift keying. b) Phase- shift keying (c) frequency - shift keying with continuous phase.

Unlike ASK signals, both PSK and FSK signals have a constant envelope. Thus PSK and FSK signals get unaffected by amplitude nonlinearities, commonly encountered in microwave radio and satellite channels. So PSK and FSK signals are preffered to ASK signals for passband data transmission over non-linear channels.

Message source transmits one symbol every T ~~seconds~~ seconds. ~~That~~ M symbols which belongs to an alphabet are denoted by $m_1, m_2, \ldots, m_M$. The a priori probabilities $P(m_1), P(m_2), \ldots, P(m_M)$ specify the message source o/p. When M symbols of the alphabet are equally likely, we write

$$p_i = P(m_i)$$
$$= \frac{1}{M} \text{ for all } i \quad \cdots\cdots (1)$$

The M-ary o/p of the msg source is presented to a signal transmission encoder, producing a corresponding vector s_i. With the vector s_i as input, the modulator constructs the distinct signal $s_i(t)$ of duration T seconds as the representa.

tion of the symbol m_i generated by the message source.

energy of the signal $s_i(t)$ is,

$$E_i = \int_0^T |s_i^2(t)|^2 dt, \quad i = 1, 2, \ldots, M \quad (2)$$

Assumptions for band pass communication channel —

i) The channel is linear, with a BW that is wide enough to accomodate the transmitted of the modulated signal $s_i(t)$ with negligible or no distortion.

ii) The channel noise $w(t)$ is the sample function of a white Gaussian noise process of zero mean & power spectral density $N_0/2$.

The receiver, which consists of detector followed by a signal transmission decoder, performs two functions:

1. It reverses the operations performed in the transmitter.

2. It minimizes the effect of channel noise on the estimate $\hat{m}$ computed for the transmitted symbol m_i.

Binary Phase-shift Keying

In coherent binary PSK

$s_1(t) \rightarrow 1$

$s_2(t) \rightarrow 0$.

$$s_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \quad \ldots (3)$$

$$s_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \pi)$$

$$= -\sqrt{\frac{2E_b}{T_b}} \cos 2\pi f_c t \quad \ldots\ldots (4)$$

where, $0 \le t \le T_b$

$E_b \rightarrow$ transmitted signal energy per bit

To ensure that each transmitted signal contains an integral no. of cycles of the carrier wave, the carrier frequency f_c is chosen equal to n_c/T_b for some fixed integer n_c.

$s_1(t)$ & $s_2(t)$ differ only in a relative phase-shift of 180 degrees, referred to as 'antipodal signals'.

The eqns 3 & 4 it is clear that, in case of binary PSK, there is only one basis function of unit energy, namely,

$$\phi_1(t) = \sqrt{\frac{2}{T_b}} \cos 2\pi f_c t, \quad 0 \le t < T_b$$

(5)

So, $s_1(t)$ and $s_2(t)$ may be expressed in terms of $\phi_1(t)$ as follows:

$$s_1(t) = \sqrt{E_b}\ \phi_1(t), \quad 0 \le t < T_b \qquad (6)$$

$$s_2(t) = -\sqrt{E_b}\ \phi_1(t), \quad 0 \le t < T_b \qquad (7)$$

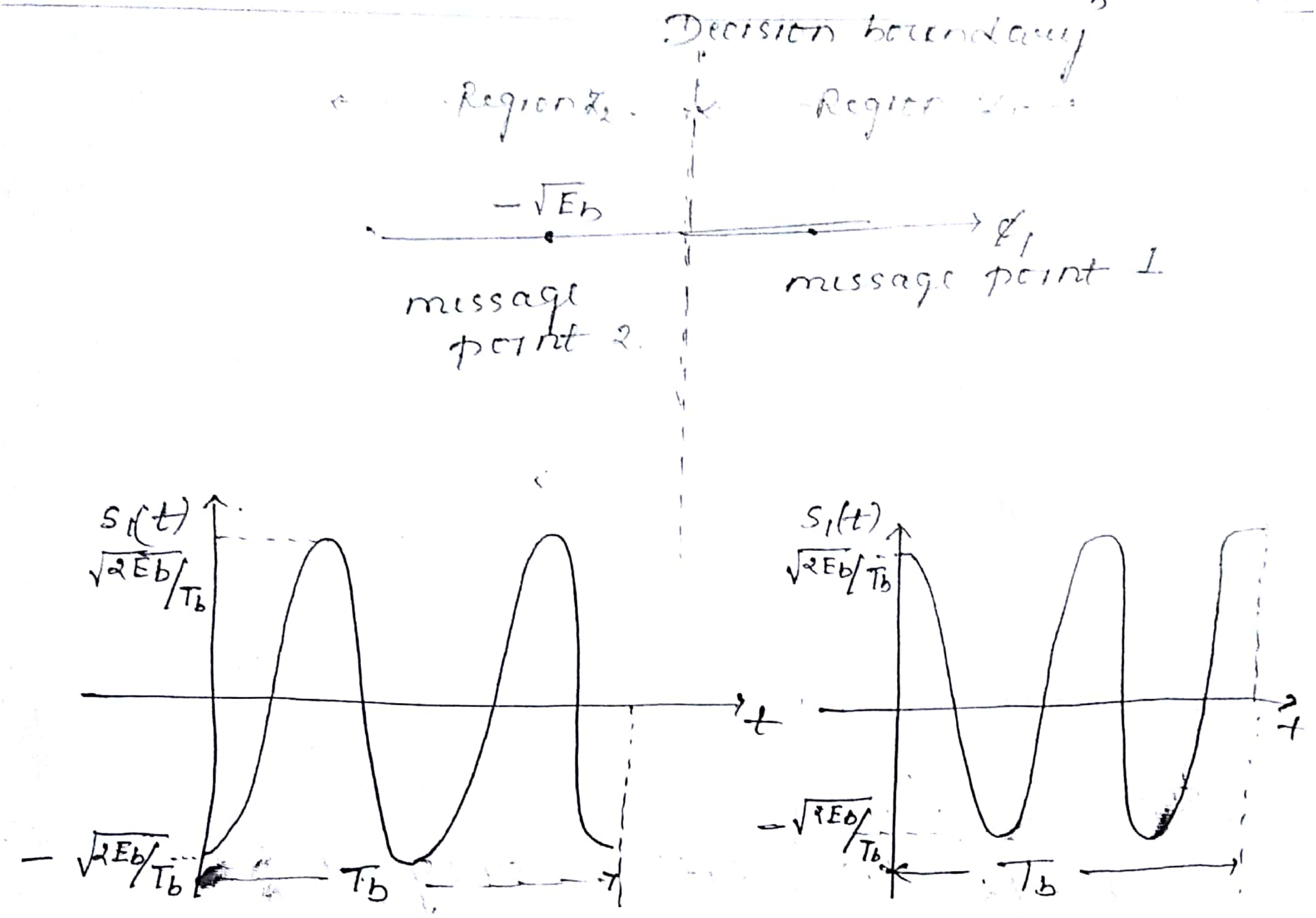


Fig: signal-space diagram for coherent binary PSK. $(n_c = 2)$

So, for coherent binary PSK system, signal space have 1-dimension (i.e. $N=1$) with a signal constellation consists of two message points (i.e. $M=2$). The coordinates of message points are

$\cancel{+\sqrt{E_b}}$ $+\sqrt{E_b}$ & $-\sqrt{E_b}$

constellation of binary PSK has minimum average energy.

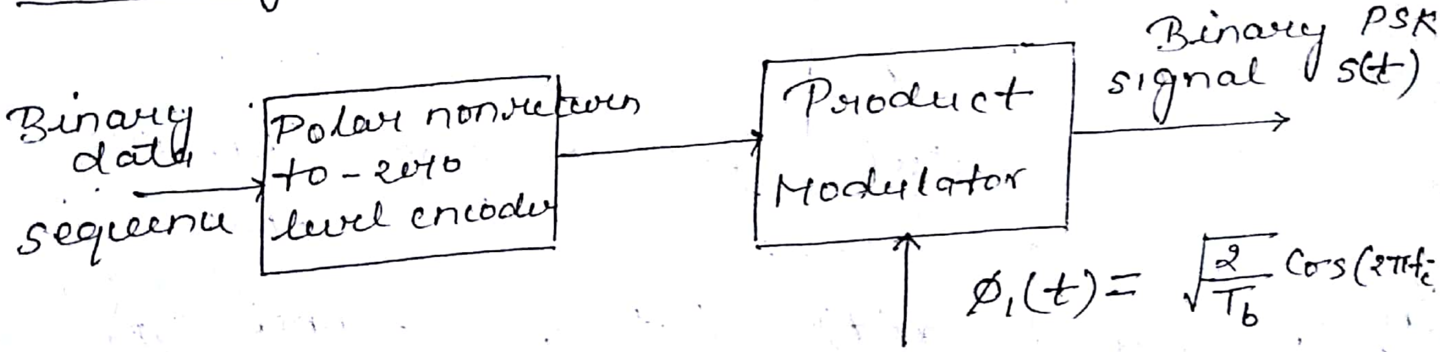
~~Er~~

Error Probability of Binary PSK:

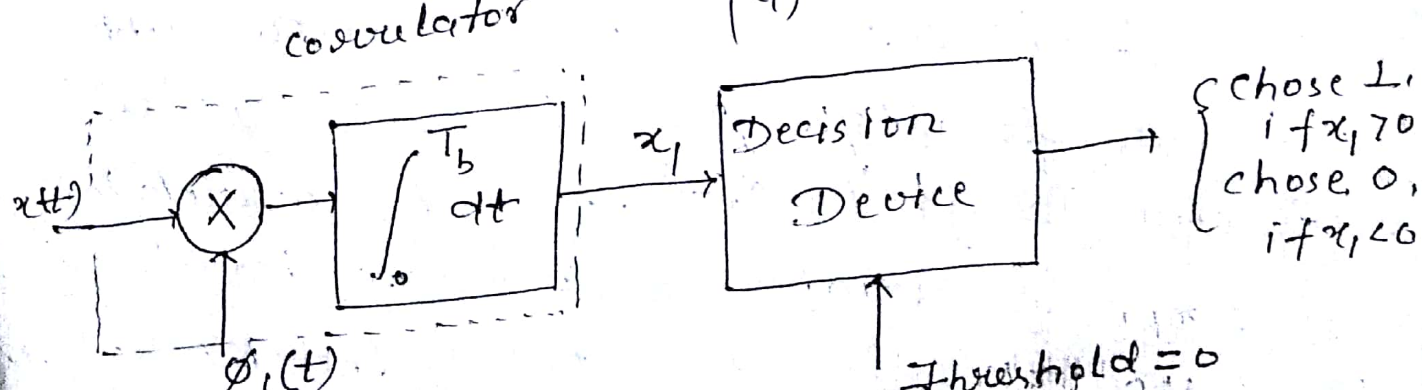
$$P_e = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_0}}\right) \quad (8)$$

As we increase the transmitted signal energy per bit, E_b, for a specified noise spectral density N_0, the message points corresponding to symbol 1 and 0 move further apart, and the average probability of error is reduced, in accordance with equation 8.

Generation and Detection of Coherent Binary PSK signals.



(a)



(a)

Fig: a) Block diagram for binary PSK transmitter b) Block diagram for coherent binary PSK Rx

To generate a binary PSK signal, we have to represent the input binary sequence in polar form with symbols 1 & 0 represented by constant amplitude levels of $+\sqrt{E_b}$ & $-\sqrt{E_b}$ respectively. This signal encoding transmission encoding is performed by a polar nonreturn-to-zero (NRZ) level encoder. The resulting binary wave & and a sinusoidal carrier $\phi_1(t)$, whose frequency $f_c = (n_c/T_b)$ for some fixed integer n_c, are applied to a product modulator. The carrier and the timing pulses used to generate the binary wave are extracted from a common master clock. The desired PSK is obtained at the modulator o/p.

To detect the original binary sequence of 1s & 0s, we apply the noisy PSK singnal $x(t)$ (at the channel o/p) to a correlator, which is also supplied with a locally generated coherent reference signal $\phi_1(t)$. The correlator o/p, x_1, is compared with a threshold of zero volts. If $x_1 > 0$, the Rx decides in favour of symbol 1. On the other hand, if $x_1 < 0$, it decides in favour the RX makes random guess in-favour of 0 or 1.

<u>Quadriphase-Shift keying</u>: In quadriphase-shift keying (QPSK), as with binary PSK, information ~~catarried~~ by carried by transmitted signal is contained in the phase. In particular, the phase of the carrier takes on one of four equally spaced values, such as $\pi/4$, $3\pi/4$, $5\pi/4$, and $7\pi/4$. For this set of value, we may defined the transmitted signal as:

$$s_i(t) = \begin{cases} \sqrt{\frac{2E}{T}} \cos\left[2\pi f_c t + (2i-1)\frac{\pi}{4}\right] & , 0 \le t \le T \\ 0 & , \text{elsewhere} \end{cases} \quad (9)$$

where $i = 1, 2, 3, 4$. $E \rightarrow$ transmitted signal energy per symbol

$T \rightarrow$ symbol duration

Each possible values of phase correspond to a unique dibit.

<u>Signal-space Diagram of QPSK</u>:

$$s_i(t) = \sqrt{\frac{2E}{T}} \left[\cos\left[(2i-1)\pi/4\right]\right] \cos 2\pi f_c t - \left[\sqrt{\frac{2E}{T}} \sin\left[(2i-1)\pi/4\right]\right] \sin(2\pi f_c t) \quad (10)$$

where $i = 1, 2, 3, 4$ ~~By the above~~