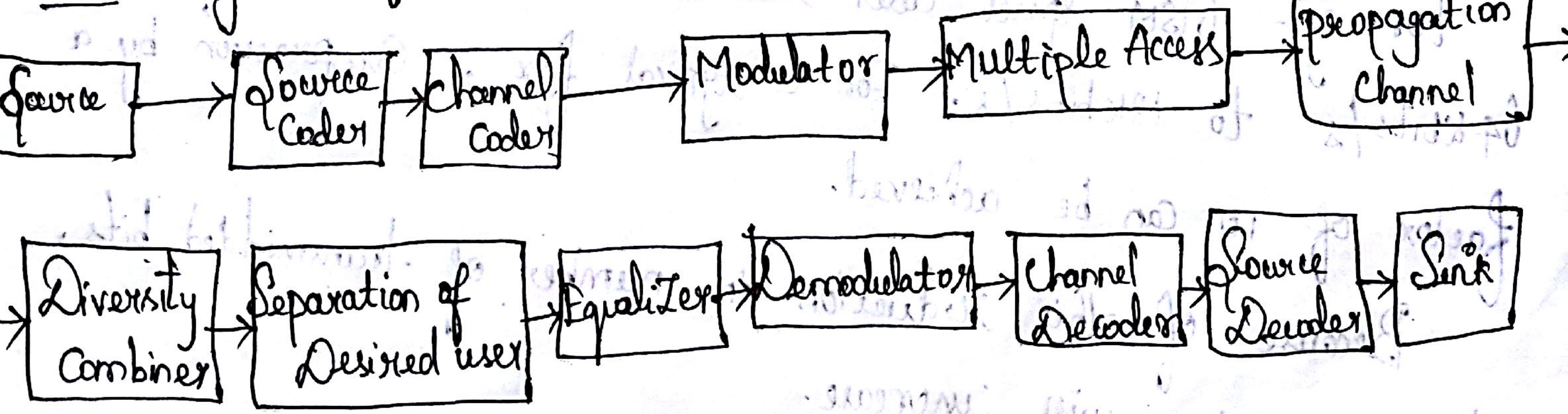
UNIT III : WIRELESS TRANSCEIVERS

Structure of a Wireless Communication link, Modulation and Demodulation. Quadrature phase shift Keying, π/4 - Differential Quadrature phase Shift Keying, Offset - Quadrature phase Shift Keying, Binary frequency Shift Keying, Minimum Shift Keying, Gaussian Minimum Shift Keying, power Spectrum and Error performance in fading Channels.

3.1 Structure of a Wireless link :-

The goal of a Wireless Communication link is to transmit the data from an analog information Source [Microphone, VideoCamera] via an analog wireless channel to an analog information Sink [Loudspeaker, TV Screen]. In most of the Cases, information is digitized in order to increase the reliability of the link.

Block diagram of Transmitter and Receiver :



Transmitter :- It Consists of the following Components :-

Information Source :

It provides an analog Source Signal and feeds it into the Source ADC [Analog to Digital Converter]. This ADC first band-limits the Signal from the analog information Source & then Converts the Signal into a stream of digital data at a certain Sampling rate and resolution.

For example, Speech signal would be Sampled at 8 KSamples/s with 8-bit resolution, resulting in a datastream at 64Kbits/sec.

Source Coder:

It uses a Priori information on the properties of the Source data in Order to reduce redundancy in the Source. This reduces the amount of Source data to be transmitted and thus the required transmission time and/or bandwidth.

For eg:- GSM Speech Coder reduces the Source data from 64 Kbits/s to 13K bits/s. For a typical fax, Compression by a factor of 10 Can be achieved.

Because of this reduction in number of transmitted bits, bit error rate will increase.

Scanned by CamScanner

Channel Coder :-

It adds redundancy in order to protect data against transmission errors. This increases the data rate that has to be transmitted.

Eg:- GSM Channel Coding increases the data rate from 13K bits/s to 22.8 kbits/s.

Channel coder often use information about the statistics of the error sources in the channel [eg:- Noise power, Interference statistics]

Signaling :-

It adds Control information for the establishing and ending of connections, for associating information with the correct users, synchronization, etc... Signaling information is protected by error correction codes.

Multiplexer :-

It combines user data and signaling information and combines data from multiple users.

In GSM, multiaccess multiplexing increases the data rate from 22.8 to 182.4 kbits/s for the standard case of eight participants.

Baseband Modulator :-

It assigns the gross data bits to complex transmit symbols in the baseband. The output from the baseband modulator provides the transmit symbols in oversampled form, discrete in time and amplitude.

Digital to Analog Converter [DAC] :-

It generates a pair of analog, discrete amplitude voltages Corresponding to the real and imaginary part of the transmit symbol respectively.

Analog low pass filter [LPF] :-

It eliminates the Spectral Components outside the desired transmission bandwidth. These Components are Created by

* Imperfections of D/A Converter,
* Imperfections of baseband modulator. ~~and~~

Tx Local Oscillator [LO] :-

It provides an unmodulated Sinusoidal signal, Corresponding to one of the admissible centre frequencies of the Considered system.

Upconverter :-

It Converts analog, filtered baseband signal to a passband signal by mixing it with the local oscillator signal.

It is done in one or in Several steps. Finally, amplification in the RF domain is required.

RF Tx filter :-

It eliminates out-of-band emissions in the RF domain. Even if LPF eliminates all out-of-band emissions, upconversion produces some additional out-of-band Components.

Scanned by CamScanner

Communication Channel :-

The (analog) propagation channel attenuates the signal and leads to delay and frequency dispersion. In addition to this, the environment adds AWGN [Additive White Gaussian Noise] and Co-channel Interference.

Receiver :- It consists of the following components :

Rx filter :-

It performs a rough selection of the received band. The bandwidth of the filter corresponds to the total bandwidth assigned to a specific service, and can thus cover multiple communications channels belonging to the same service.

Low Noise Amplifier [LNA] :-

It amplifies the signal, so that noise added by later components of Rx chain has less effect on the Signal-to-Noise Ratio [SNR].

Rx Local oscillator [LO] :-

It provides sinusoidal signals corresponding to possible signals at the Tx LO. The oscillations produced by both Tx and Rx are in same frequency and phase. This is maintained by carrier recovery algorithm.

Rx downconverter :-

It converts the received signal into baseband in one or several steps.

Rx Low pass filter :-

It provides a selection of desired frequency bands fore one

Specific user. It also eliminates adjacent channel interference and noise.

Rx Analog-to-Digital Converter [ADC]:-

It Converts the analog signal into values that are discrete in time and amplitude. The required resolution of the ADC is determined by the dynamics of the subsequent signal processing.

Carrier Recovery:-

It determines the frequency and phase of the carrier of the received signal and uses it to adjust the Rx LO.

Baseband Demodulator:-

It obtains soft-decision data from digitized baseband data and ~~to~~ hands them over to the decoder. It can be an optimum, Coherent demodulator, or a simpler differential or incoherent demodulator.

If there are multiple antennas, then the Rx either selects the signal from one of them for further processing, or the signals from all of the antennas have to be processed. [filtering, amplification, downconversion].

In the latter case, those baseband signals are then either Combined before being fed into a Conventional baseband demodulator, or they are fed directly into a joint demodulator that can make use of information from the different antenna elements.

Symbol-timing Recovery :-

It uses demodulated data to determine an estimate of the duration of symbols, and uses it to fine-tune sampling intervals.

Decoder :-

It uses soft estimates from the demodulator to find the original data source. In uncoded systems, the decoder is just a hard-decision (threshold) device.

For Convolutional codes, Maximum Likelihood Sequence Estimators (such as Viterbi Decoder) are used.

Signaling recovery :-

It identifies the parts of the data that represent signaling information and controls the subsequent demultiplexer.

Demultiplexer :-

It separates the user data and signaling information.

Source Decoder :-

It reconstructs the source signal. If the source data are digital, the o/p signal is transferred to the data sink.

Otherwise, the data are transferred to the DAC which converts the transmitted information into an analog signal and hands it over to the information sink.

3.2 Modulation and Demodulation :-

Information Signals are transmitted via a medium. These Signals must be transformed from Original form into a form that is more Suitable for transmission.

This process of impressing low frequency information Signals onto a high-frequency carrier Signal is called modulation.

Definition :-

Modulation is defined as the process by which Some characteristics of a Carrier [Amplitude, Frequency, phase] is varied in accordance with the modulating wave (Signal).

Demodulation is the reverse process where the received Signals are transformed back to their Original form.

Need for modulation :-

* To Reduces the need for having large length antennas. Since the distance between tx and Rx is larger, higher frequency is used. High frequency systems require larger height antennas
* Modulated Signal Can reach larger distance.
* To reduce the noise & distortions
* To reduce Equipment Complexity
* To multiplex the more number of Signals.

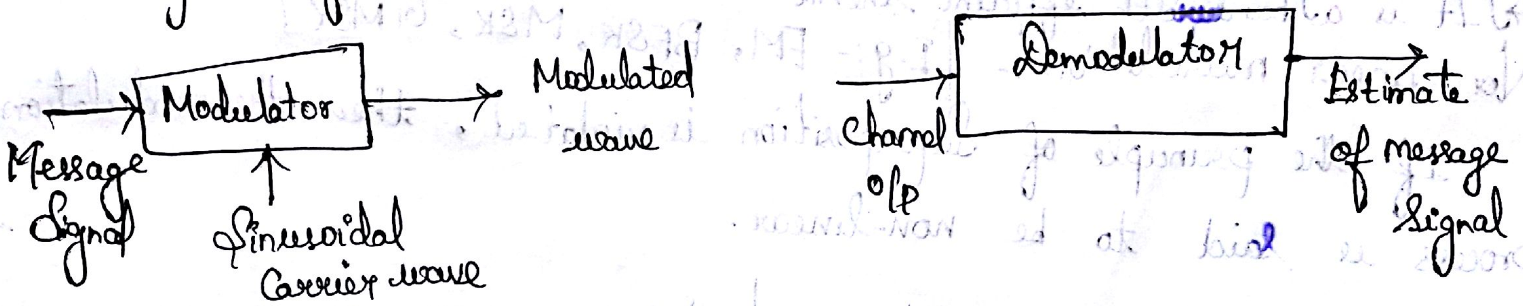
Benefits of modulation :-

* Modulation is used to shift the spectral content of a message signal so that it lies inside the operating frequency band of the wireless channel.

* Modulation provides a mechanism for putting the information content of a message signal into a form that may be less vulnerable to noise or interference.

* Modulation permits the use of multiple-access techniques.

Block diagram of Modulator and demodulator :-



Types of Modulation process :-

Modulation process is classified on the following (two) basis :-

* Based on Input-output relationship :-
  1) Linear Modulation
  2) Non-Linear Modulation

* Based on nature of information signal :-
  1) Analog Modulation
  2) Digital Modulation

Linear Modulation :- [E.g:- Amplitude modulation, BPSK, QPSK]

The modulation process is said to be linear if the input-output relationship satisfies the principle of superposition.

According to this principle, the modulation process satisfies the following conditions :-

1) The output of the modulator produced by a number of inputs applied simultaneously is equal to the sum of the outputs that result when the inputs are applied one at a time.

2) If the input is scaled by a certain factor, the output is scaled by exactly the same factor.

→ It is a bandwidth efficient scheme.

Non-Linear modulation :- [E.g:- FM, BFSK, MSK, GMSK]

If the principle of superposition is violated, then the modulation process is said to be non-linear.

Analog and Digital Modulation techniques :-

In analog modulation, both the message signal m(t), and the modulated signal s(t) are a continuous functions of time. It is commonly called as <u>Continuous Wave (CW) modulation</u>.

Eg:- In digital modulation, the modulated signal s(t) may exhibit discontinuities at the instants of time at which the message signal m(t) switches from symbol 1 to symbol 0 or viceversa.

Types of Analog Modulation :-

Analog Modulation

- Amplitude modulation [AM]
- Angle modulation
  - Frequency modulation [FM]
  - Phase modulation [PM]

Amplitude modulation :-

It is ~~the~~ a process in which the amplitude of the high frequency carrier is varied linearly in proportion with the instantaneous value of the message signal.

Angle modulation :-

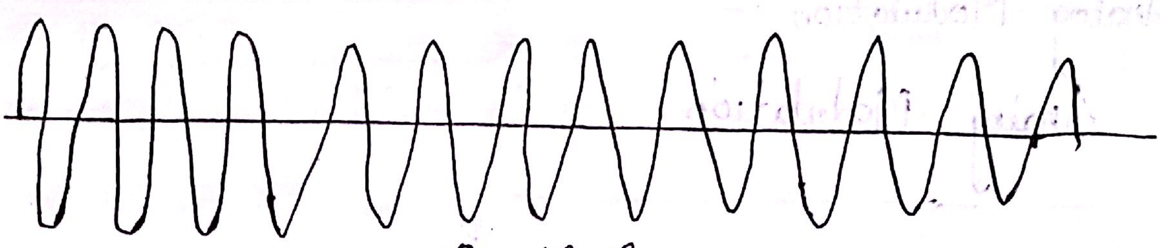
It is a process in which the angle of the carrier namely $\psi(t) = 2\pi f_c t + \theta$ is varied linearly with the message signal $m(t)$.

(i) Frequency modulation :-

It is a process in which the frequency of the carrier f_c is varied linearly with the message signal $m(t)$.

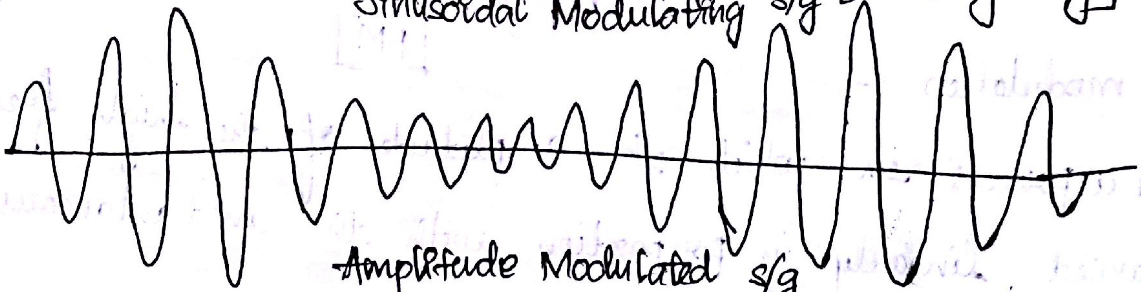
(ii) Phase modulation :-

It is a process in which the phase of the carrier θ is varied with the message signal $m(t)$.



Carrier Wave

Sinusoidal Modulating s/g [Message s/g]

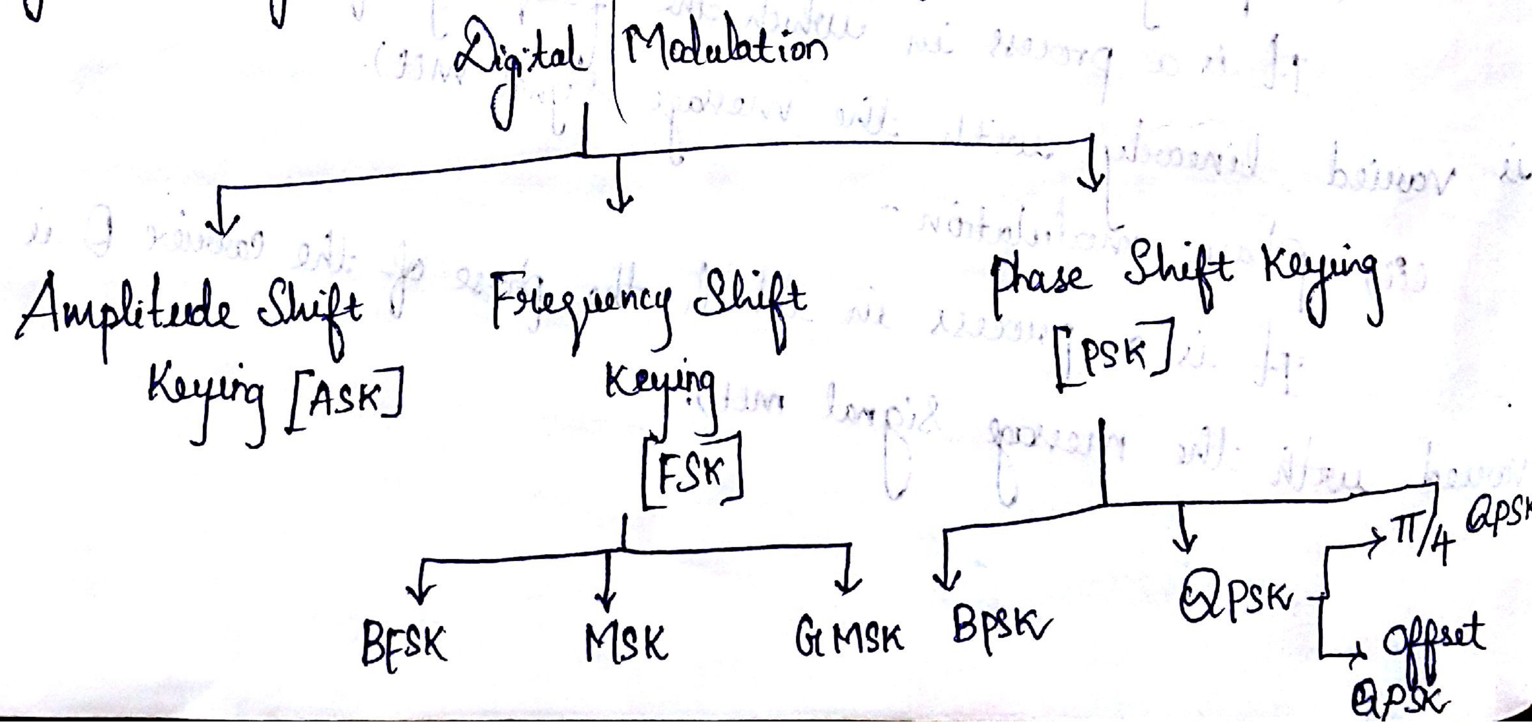


Amplitude Modulated s/g

Frequency Modulated s/g

Types of Digital modulation :-

Digital modulation is the transmission of digitally modulated analog signals (carriers) between two or more points in a Communication System. Digital modulation is called Digital radio.



Amplitude - Shift Keying :- (ASK)

It is the Simplest digital modulation technique where a binary information signal directly modulates the amplitude of an analog Carrier. ASK is Similar to standard amplitude modulation except there are only two output amplitudes possible.

ASK is Sometimes Called as digital amplitude modulation (DAM).

Mathematically, ASK wave is

$$V(t) = [1 + v_m(t)] \left[\frac{A}{2} \cos(\omega_c t)\right] \longrightarrow (1)$$

where $V(t) \rightarrow$ ASK wave

$v_m(t) \rightarrow$ Modulating signal (volts)

$A/2 \rightarrow$ Unmodulated Carrier amplitude (volts)

$\omega_c \rightarrow$ Analog Carrier frequency (radians per second)

For a logic 1 input, equ (1) reduces to $[\because v_m(t) = +1V$

$$V(t) = 2\left[\frac{A}{2} \cos(\omega_c t)\right]$$

$$\boxed{V(t) = A \cos(\omega_c t)}$$

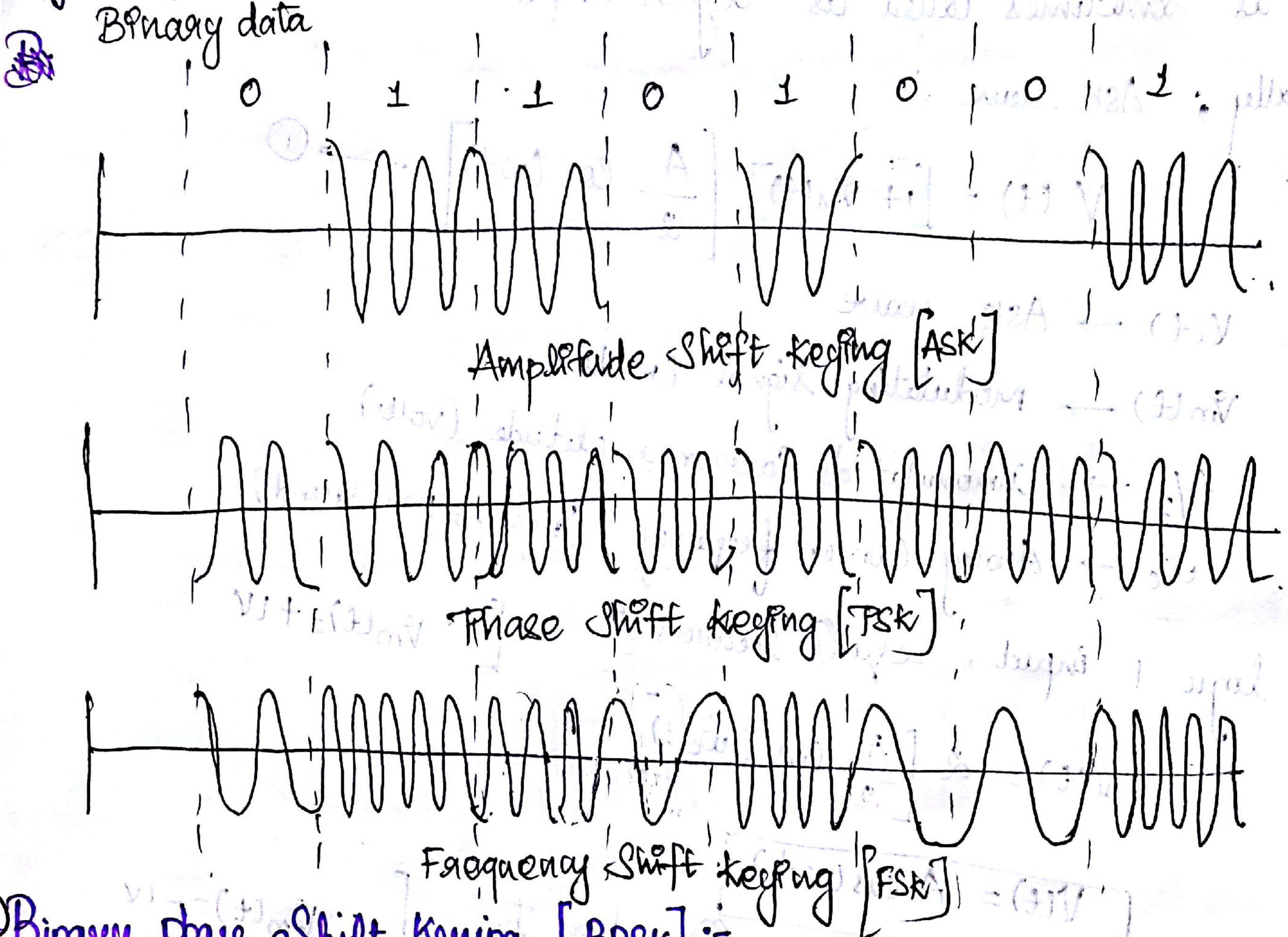
and for a logic 0 input, equ (1) reduces to $[\because v_m(t) = -1V$

$$\boxed{V(t) = 0}$$

Thus, the modulated wave $V(t)$ is either $A \cos(\omega_c t)$ or 0. Hence the Carrier is either "on" or "off". So ASK is Sometimes referred as On-off Keying (OOK).

Phase Shift Keying [PSK] :-

PSK is another form of angle-modulated, Constant-amplitude digital modulation. PSK is an M-ary digital modulation Scheme Similar to Conventional phase modulation except with PSK the input is a binary digital Signal and there are a limited number of output phases possible.



① Binary phase Shift Keying [BPSK] :-

In binary phase Shift Keying (BPSK), the phase of a Constant amplitude Carrier Signal is Switched between two values according to the two possible Signals m_1 and m_2 Corresponding to binary 1 and 0 respectively. It is one of the linear modulation Scheme.

The two phases are separated by 180°.

The transmitted BPSK signal is either

$$S_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \theta_c) \quad , \quad 0 \le t \le T_b \quad (\text{Binary } 1)$$

(or) $$S_{BPSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \pi + \theta_c)$$

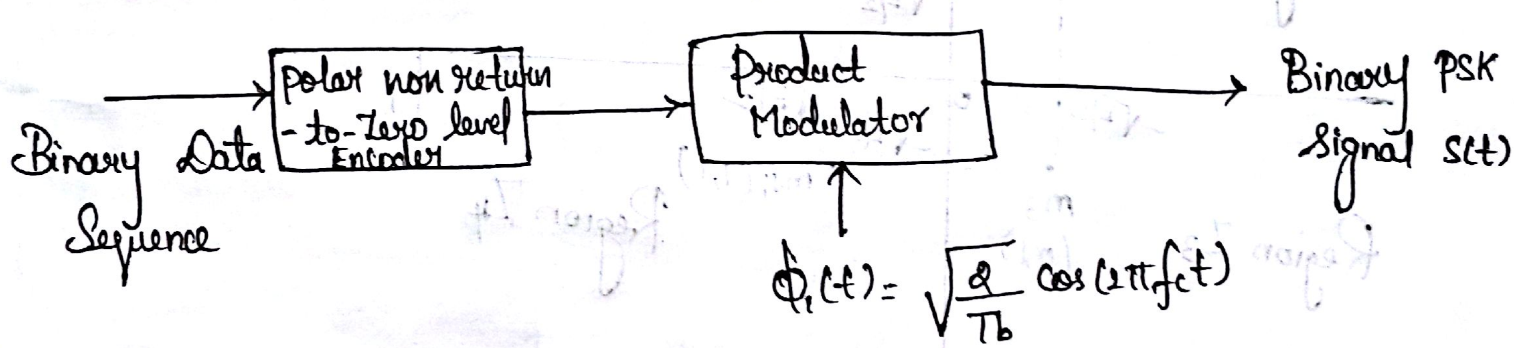
$$= -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \theta_c) \quad , \quad 0 \le t \le T_b \quad (\text{Binary } 0)$$

where E_b is the transmitted signal energy per bit.

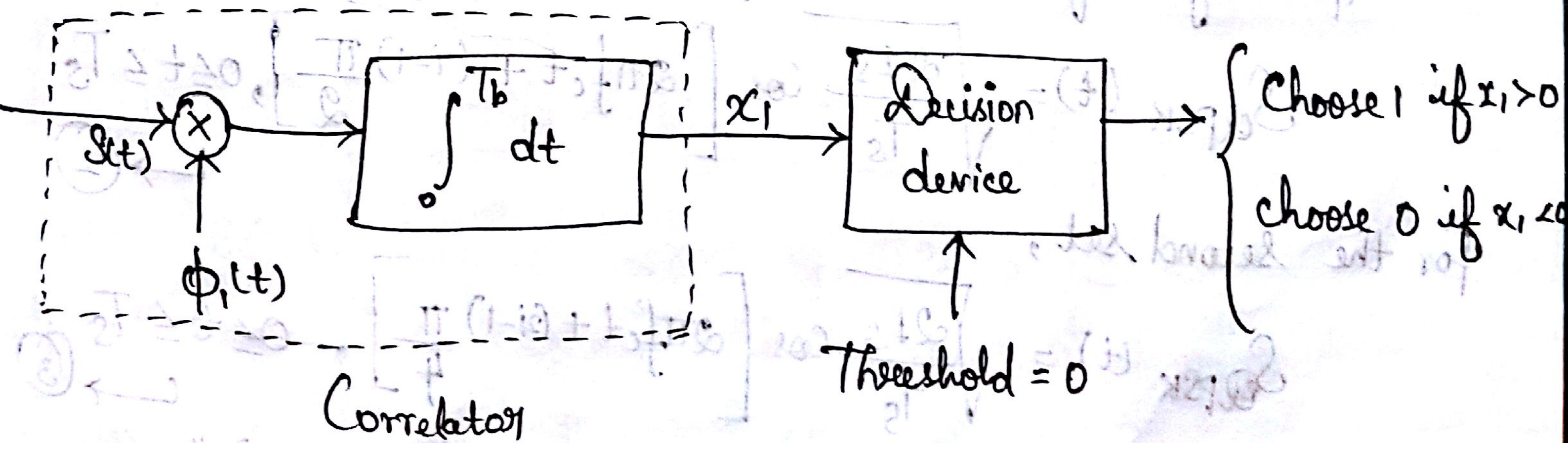
T_b is the bit duration

Generation and Detection of Coherent Binary PSK :-

BPSK Transmitter :-



BPSK Receiver :-



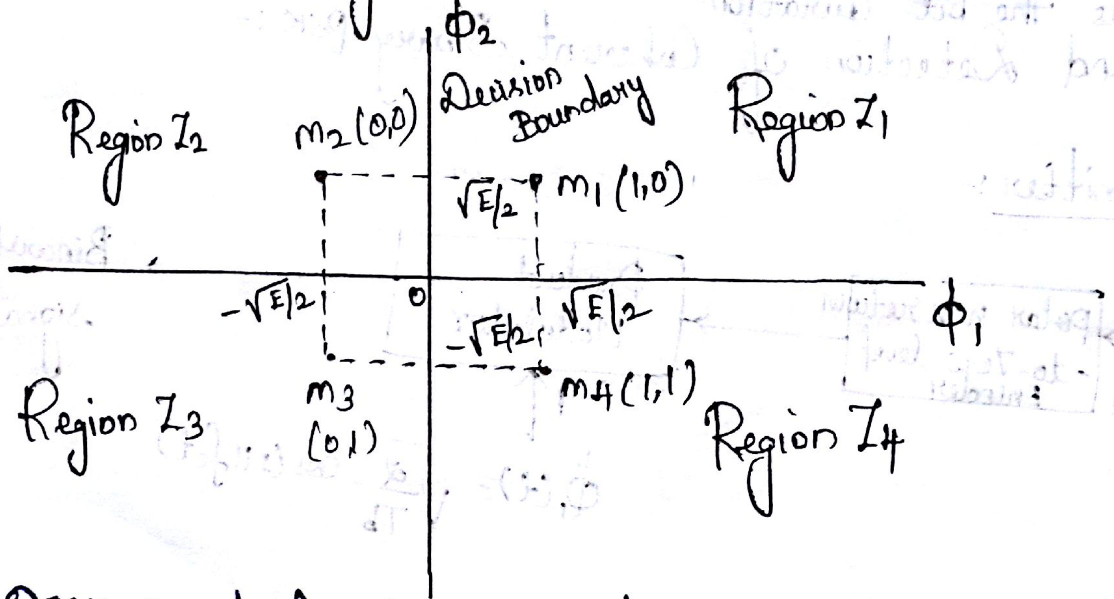
Scanned by CamScanner

In QPSK, two bits are transmitted in a single modulation symbol.

Here it has twice the bandwidth efficiency of BPSK. It is also known as bandwidth conserving modulation scheme.

The phase of the carrier takes on one of four equally spaced values such as $0, \pi/2, \pi$ and $3\pi/2$ or $[\pi/4, 3\pi/4, 5\pi/4, 7\pi/4]$

QPSK Constellation diagram :-



The QPSK signal for the above first set of symbol states is

$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[2\pi f_c t + (i-1)\frac{\pi}{2}\right], 0 \le t \le T_s \quad (2)$$

For the second set,

$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[2\pi f_c t + (2i-1)\frac{\pi}{4}\right], \; 0 \le t \le T_s \quad (3)$$

where $T_s \rightarrow$ Symbol duration $= 2T_b$ and $i = 1, 2, 3, 4$

Using trigonometric identities, (2) can be written as [for second set]

$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}} \cos\left[(2i-1)\pi/4\right] \cos(2\pi f_c t)$$
$$- \sqrt{\frac{2E_s}{T_s}} \sin\left[(2i-1)\pi/4\right] \sin(2\pi f_c t) \quad \rightarrow (4).$$

$\{\because \cos(A+B) = \cos A \cos B - \sin A \sin B$

Here $A = (2i-1)\pi/4$, $B = 2\pi f_c t$

Based on the above representation, QPSK signal can be depicted using a two-dimensional constellation diagram with four points as shown in figure.

Signal space characteristics :- [For the second set]

Gray Encoded Input Dibit	Phase of QPSK signal (radians)	Coordinates of Message points	
		S_{i1}	S_{i2}
10	$\pi/4$	$+\sqrt{E/2}$	$-\sqrt{E/2}$
00	$3\pi/4$	$-\sqrt{E/2}$	$-\sqrt{E/2}$
01	$5\pi/4$	$-\sqrt{E/2}$	$+\sqrt{E/2}$
11	$-\pi/4$	$+\sqrt{E/2}$	$+\sqrt{E/2}$

From the Constellation diagram of QPSK; the distance between adjacent points in the constellation is $\sqrt{2E_s}$. Since each symbol corresponds to two bits, then $E_s = 2E_b$.

Thus the distance between two neighbouring points is equal to $2\sqrt{E_b}$

The four message points and the associated signal vectors are

$$S_i = \begin{bmatrix} \sqrt{E}\cos\left[(2i-1)\frac{\pi}{4}\right] \\ -\sqrt{E}\sin\left[(2i-1)\frac{\pi}{4}\right] \end{bmatrix}, \quad i=1,2,3,4$$

[for the second set]

Note :-

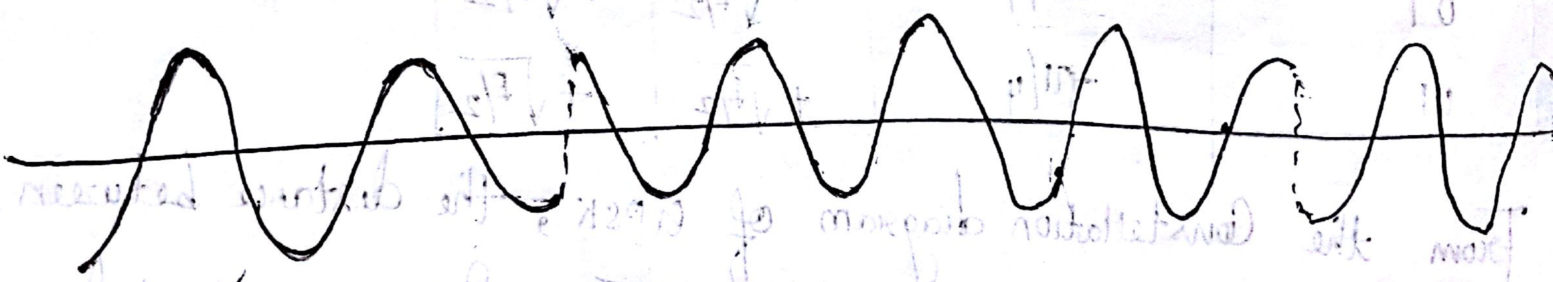
* A QPSK signal has a two dimensional signal Constellation (i.e) N=2 and four message points (M=4) whose phase angles increase in a Counterclockwise direction.

* QPSK signal has minimum average energy

Input binary Sequence :-

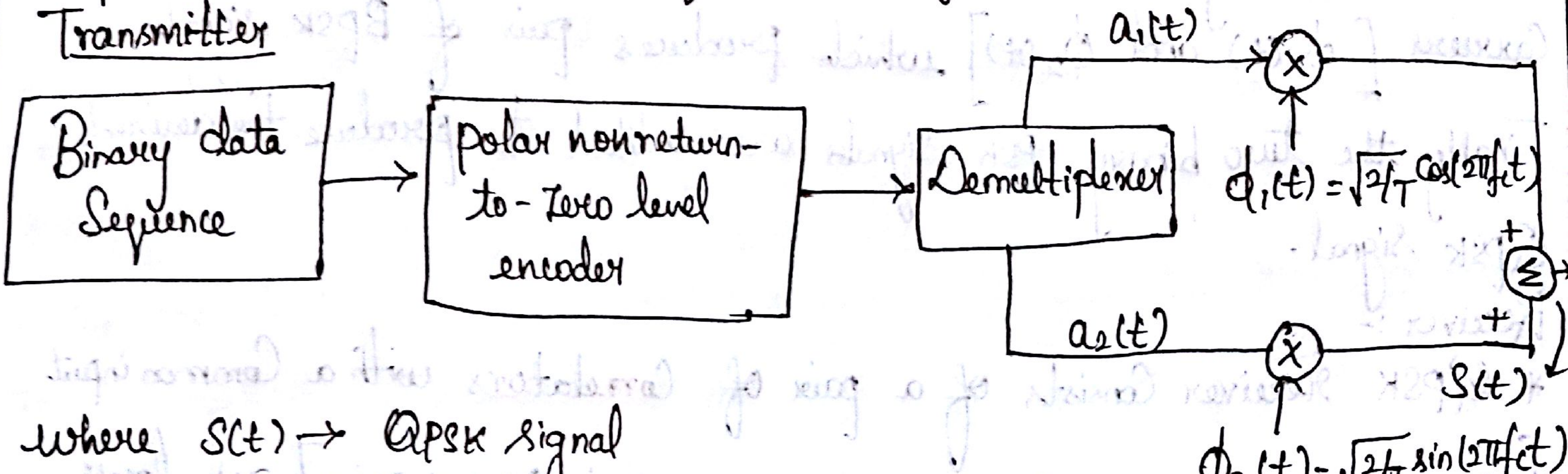
$$\underbrace{0 \quad 1}_{\text{Dibit } 01} \quad \underbrace{1 \quad 0}_{\text{Dibit } 10} \quad \underbrace{1 \quad 0}_{\text{Dibit } 10} \quad \underbrace{0 \quad 0}_{\text{Dibit } 00}$$

QPSK Waveform :-



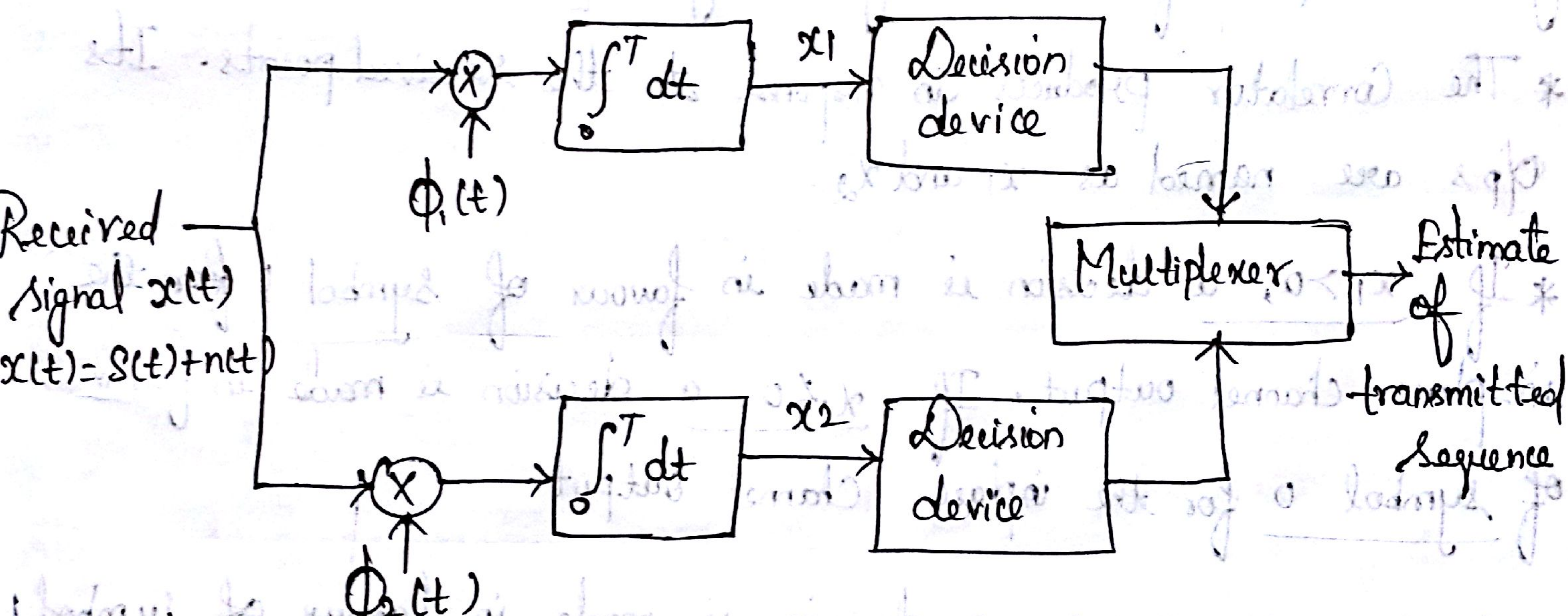
Generation and Detection of QPSK signals :-

Transmitter



where $S(t) \rightarrow$ QPSK signal

Receiver



Transmitter :-

The incoming binary sequence [1,0] is first transformed into polar form by polar non return to zero level encoder. [i.e. $1 \rightarrow +\sqrt{E_b}$, $0 \rightarrow -\sqrt{E_b}$].

This binary wave is divided by demultiplexer into two separate binary forms consisting of odd ($a_1(t)$) and even numbered input bits [$a_2(t)$].

The two binary waves are used to modulate a pair of quadrature Carriers [$\phi_1(t)$ and $\phi_2(t)$] which produces pair of BPSK signals.

Finally the two binary PSK signals are added to produce the desired QPSK signal.

Receiver :-

* QPSK receiver Consists of a pair of Correlators with a Common input [received signal $x(t) = S(t) + n(t)$, where $n(t)$ is AWGN noise] and locally generated pair of Coherent reference signals [$\phi_1(t)$ and $\phi_2(t)$].

* The Correlator produces in response to the received points. Its O/ps are named as x_1 and x_2.

* If $x_1 > 0$, a decision is made in favour of symbol 1 for the in-phase channel output. If $x_1 < 0$, a decision is made in favor of symbol 0 for the inphase Channel output.

* Similarly if $x_2 > 0$, a decision is made in favour of symbol 1 for the quadrature Channel output. If $x_2 < 0$, a decision is made in favour of symbol 0 for the quadrature channel output.

* Finally these binary sequences at the in-phase and quadrature Channel outputs are Combined in a multiplexer to produce original binary Sequence at transmitter input with minimum error.

3.4 Offset QPSK :-

* The amplitude of a QPSK Signal is ideally Constant. However, when QPSK Signals are pulse shaped, they lose the Constant envelope property.

* The occasional phase shift of π radians can cause the Signal envelope to pass through Zero for just an instant. Any kind of hardlimiting or non linear amplification of the zero-crossings brings back the filtered sidelobes since the fidelity of the Signal at small voltage levels is lost in transmission.

* To prevent the regeneration of sidelobes and Spectral widening, QPSK Signals that use pulse shaping will be amplified only using linear amplifiers which are less efficient.

* A modified form of QPSK called offset QPSK (OQPSK) or Staggered QPSK is less Susceptible to errors and Supports more efficient amplification.

* It is a another way of improving the peak-to-average ratio in QPSK.

* The bit Streams modulating the inphase and Quadrature-phase Components are offset half a Symbol duration with respect to each Other.

$\pi/4$ - Differential Quadrature Phase Shift Keying :-

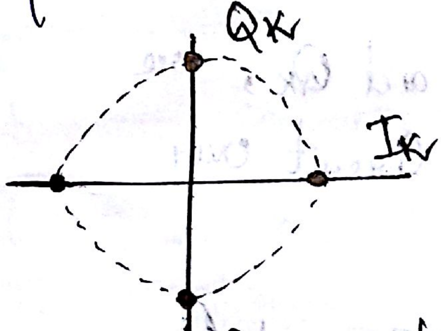
* The $\pi/4$ Shifted QPSK modulation offers a Compromise between OQPSK and QPSK in terms of the maximum phase transitions. It may be demodulated in a Coherent or noncoherent fashion.

* In $\pi/4$ QPSK, the maximum phase change is limited to $\pm 135^\circ$, as compared to 180° for QPSK and 90° for OQPSK.

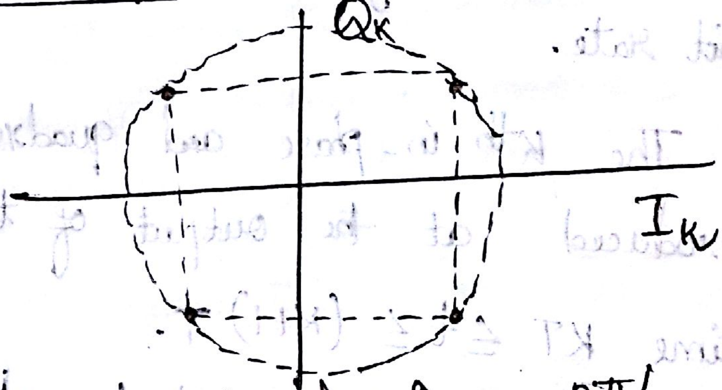
* Hence, the bandlimited $\pi/4$ QPSK signal preserves the Constan[t] envelope property better than bandlimited QPSK.

* It is more susceptible to envelope variations than OQPSK.
When differentially encoded, $\pi/4$ QPSK is called $\pi/4$ DQPSK.
* $\pi/4$ DQPSK provides easier implementation of differential detection or coherent demodulation with phase ambiguity in the recovered carrier.
* In a $\pi/4$ QPSK modulator, signaling points of the modulated signal are selected from two QPSK constellations which are shifted by $\pi/4$ with respect to each other.
* The following constellation diagram shows the combined constellation where the links between two signal points indicate the possible phase transitions.

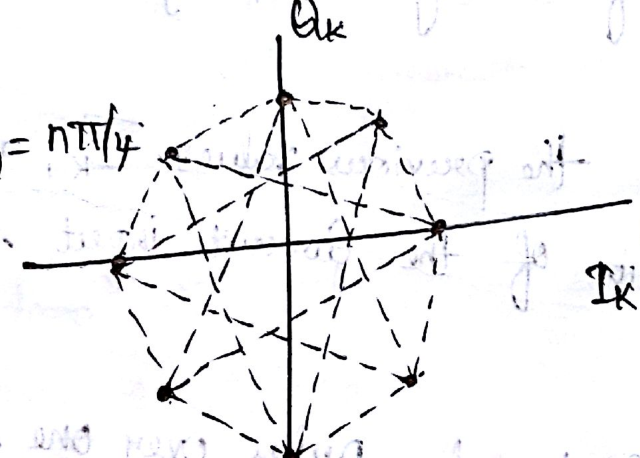
Constellation diagram of a $\pi/4$ QPSK signal



a) when $\theta_{K-1} = n\pi/4$



b) when $\theta_{K-1} = n\pi/2$



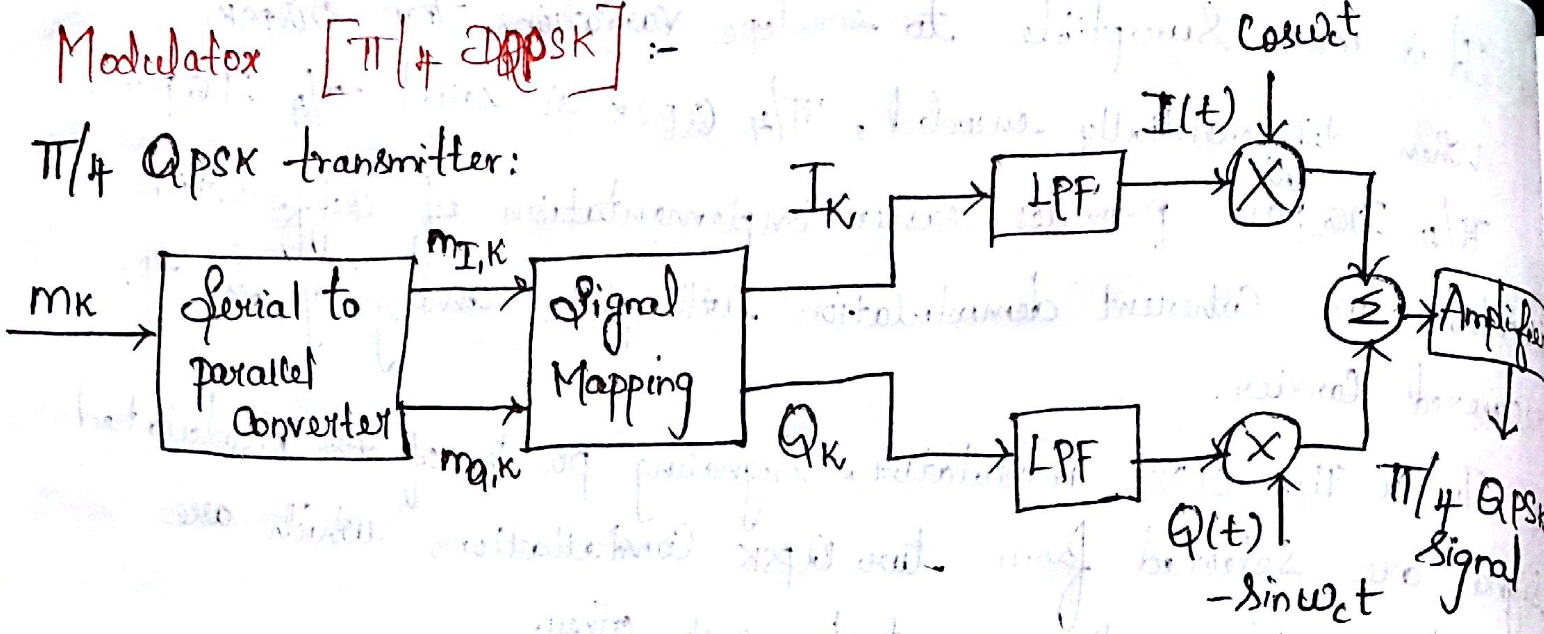
c) all possible states

Carrier phase corresponding to various input bit pairs

Information bits m_{IK}, m_{QK}	Phase shift ϕ_K
11	$\pi/4$
01	$3\pi/4$
00	$-3\pi/4$
10	$-\pi/4$

Modulator [π/4 DQPSK] :-

π/4 QPSK transmitter:



The input bit stream is partitioned by a serial-to-parallel converter into two parallel data streams $m_{I,K}$ and $m_{Q,K}$, each with a symbol rate equal to half that of the incoming bit rate.

The K^{th} in-phase and quadrature pulses, I_K and Q_K, are produced at the output of the signal mapping circuit over time $KT \le t \le (K+1)T$.

They are determined by the previous values I_{K-1} and Q_{K-1} and θ_K which is a function of the current input symbols m_{IK} and m_{QK}.

I_K and Q_K represent rectangular pulses over one symbol duration having amplitudes given by,

$$I_K = \cos\theta_K = I_{K-1}\cos\phi_K - Q_{K-1}\sin\phi_K$$

$$Q_K = \sin\theta_K = I_{K-1}\sin\phi_K + Q_{K-1}\cos\phi_K.$$

where $\theta_K = \theta_{K-1} + \phi_K$

θ_K and θ_{K-1} are phases of the K^{th} and $(K-1)^{st}$ symbols.

The in-phase and quadrature bit streams I_K and Q_K are then separately modulated by two carriers which are in quadrature with one another, to produce the $\pi/4$ QPSK waveform given by,

$$S_{\pi/4\,QPSK}(t) = I(t)\cos\omega_c t - Q(t)\sin\omega_c t$$

where

$$I(t) = \sum_{K=0}^{N-1} I_K\, p(t-KT_s-T_s/2) = \sum_{K=0}^{N-1} \cos\theta_K\, p(t-KT_s-T_s/2)$$

$$Q(t) = \sum_{K=0}^{N-1} Q_K\, p(t-KT_s-T_s/2) = \sum_{K=0}^{N-1} \sin\theta_K\, p(t-KT_s-T_s/2)$$

Both I_K and Q_K are usually passed through raised cosine rolloff pulse shaping filters before modulation, in order to reduce the bandwidth occupancy. Pulse shaping reduces the spectral restoration problem.

$\pi/4$ DPSK detection techniques :-

Due to ease of hardware implementation, differential detection is employed to demodulate $\pi/4$ QPSK signals.

In an AWGN channel, the BER performance of a differentially detected $\pi/4$ QPSK is about 3dB inferior to QPSK, while coherently detected $\pi/4$ QPSK has the same error performance as QPSK.

In low BER, fast Rayleigh fading channels, differential detection offers a lower error floor since it does not rely on phase synchronisa

Frequency Shift Keying :- (FSK)

It is a non-linear modulation scheme. In this method, amplitude of the carrier is constant regardless of the variation in the modulating signal. FSK is a frequency modulation scheme in which digital information is transmitted through discrete frequency change of a carrier wave.

3.6 Binary Frequency Shift Keying [BFSK] :-

In BFSK, the frequency of a constant amplitude carrier signal is switched between two values according to two possible message states, corresponding to a binary 1 or 0.

Depending on how the frequency variations are imparted into the transmitted waveforms, FSK signal will have either a discontinuous phase or continuous phase between bits.

Generally an FSK signal is represented as,

$$S_{FSK}(t) = V_H(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c + 2\pi \Delta f)t, \quad 0 \le t \le T_b$$

[Binary 1]

$$S_{FSK}(t) = V_L(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c - 2\pi \Delta f)t, \quad 0 \le t \le T_b$$

(Binary 0)

where $2\pi\Delta f$ is a constant offset from the nominal carrier frequency.

Scanned by CamScanner

Signal-Space diagram for BFSK :-

A Coherent BFSK system is characterized by having a signal space that is two dimensional $(N=2)$ with two message points $(M=2)$.

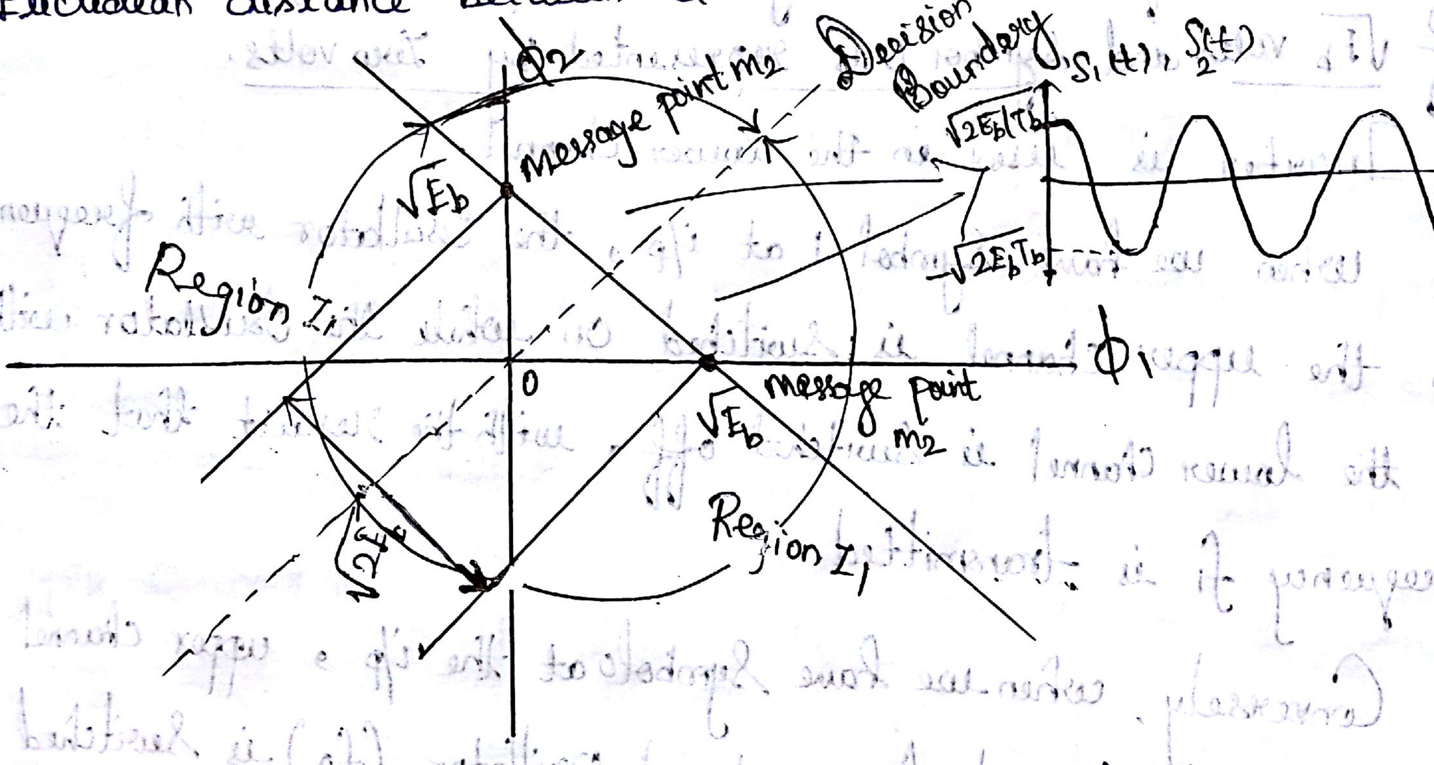
Orthonormal basis function is

$$\phi_i(t) = \begin{cases} \sqrt{\frac{2}{T_b}} \cos(2\pi f_c t + 2\pi \Delta f)t, & 0 \le t \le T_b \\ 0, & \text{Otherwise.} \end{cases}$$

The two message points are

$$S_1 = \begin{bmatrix} \sqrt{E_b} \\ 0 \end{bmatrix} \quad \text{and} \quad S_2 = \begin{bmatrix} 0 \\ \sqrt{E_b} \end{bmatrix}$$

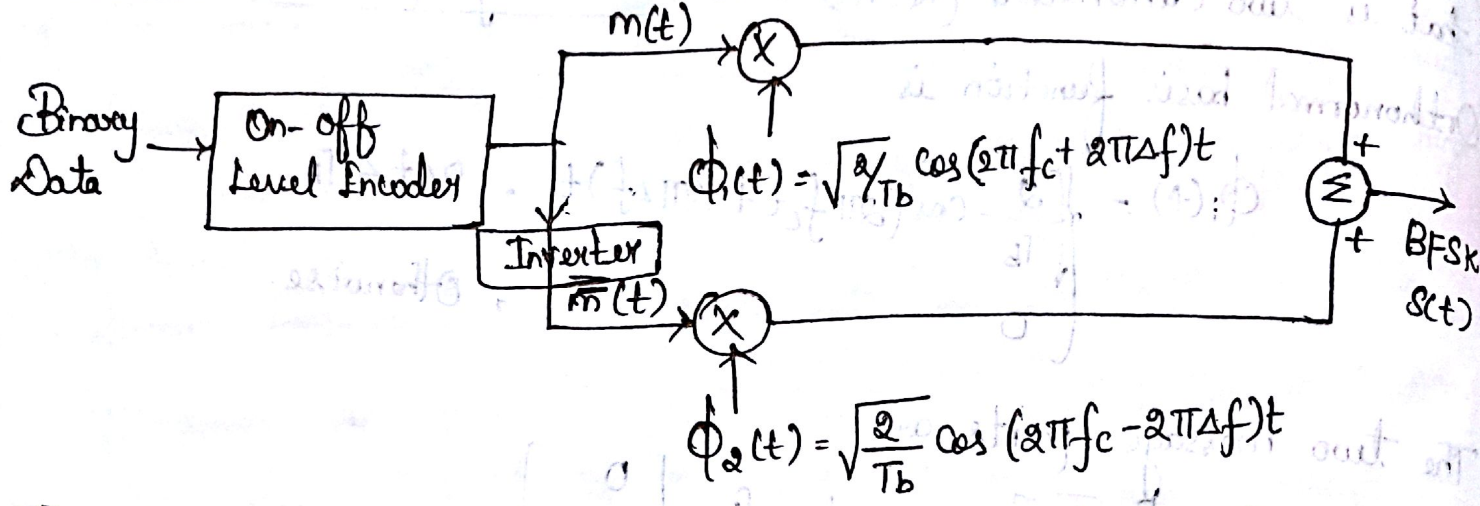
The Euclidean distance between S_1 & S_2 is $\sqrt{2E_b}$.



* This modulation is a kind of Continuous-phase frequency shift Keying [CPFSK]. (i.e). Here phase Continuity is always maintained

Generation and Detection of BFSK:-

Transmitter:-



* The incoming binary data is first applied to an on-off level encoder.
* At the o/p of this encoder, Symbol 1 is represented by a constant amplitude of $\sqrt{E_b}$ volts and Symbol 0 is represented by Zero volts.
* Inverter is used in the lower Channel.
* When we have Symbol 1 at i/p, the Oscillator with frequency f_1 in the upper channel is switched on while the Oscillator with f_2 in the lower Channel is Switched off, with the result that the frequency f_1 is transmitted.
* Conversely, when we have Symbol 0 at the i/p, upper channel Oscillator is switched off and lower channel Oscillator (f_2) is switched on, with the result that frequency f_2 is transmitted.
* Thus Switching between f_1 & f_2 takes place based on binary Symbol at i/p.

Scanned by CamScanner

* Because of this switching, discontinuities arise and this type of generated FSK signal is called as discontinuous FSK.

* These phase discontinuities create some problems such as spectral spreading and spurious transmissions.

* So this type is generally not used in highly regulated wireless system.

* Another common way of generating an FSK signal is to frequency modulate a message waveform using a single keyed (voltage-controlled) oscillator.

* This kind of FSK generated signal can be written as

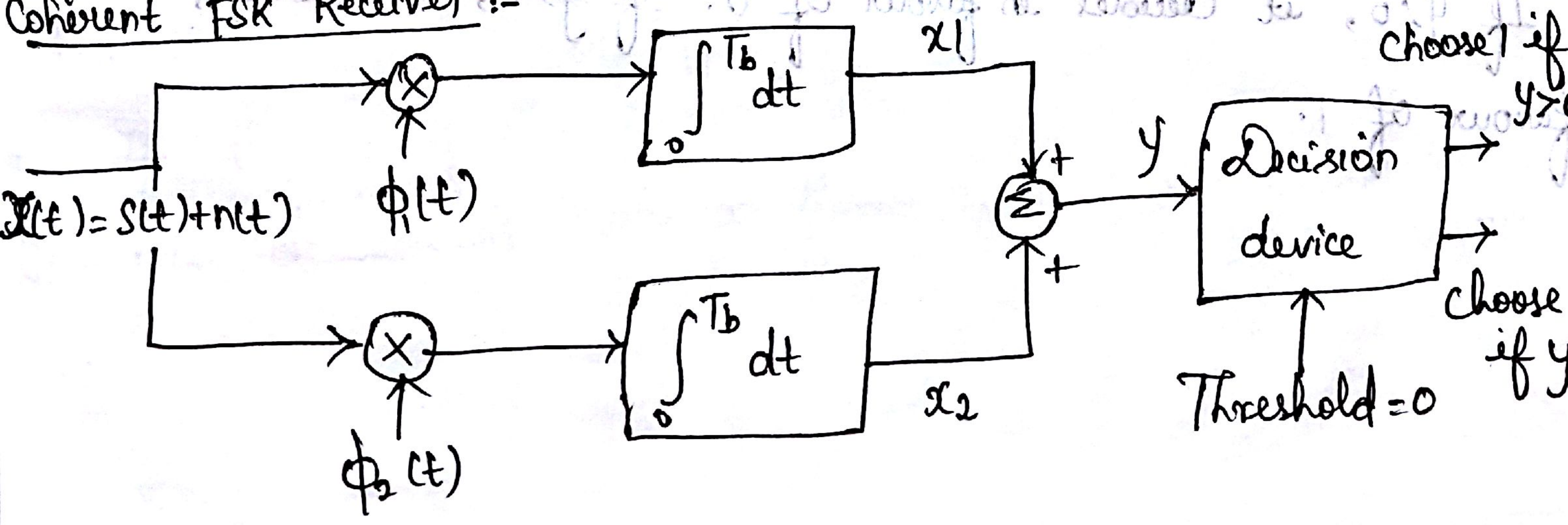
$$S_{FSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left[2\pi f_c t + \theta(t)\right]$$

$$S_{FSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left[2\pi f_c t + 2\pi K_f \int_{-\infty}^{\infty} m(\eta)\, d\eta\right]$$

* This type is similar to analog FM, except that m(t) is a gen binary waveform.

Receiver :-

Coherent FSK Receiver :-



Scanned by CamScanner

There are two ways of detecting FSK signal.

* Coherent and
* Non-coherent.

Coherent Detection :-

* This type of detector contains phase recovery circuit.
* phase recovery circuit ensures that the oscillator supplying the locally generated carrier wave in the receiver is synchronized (in both frequency and phase) to the oscillator supplying the carrier wave used to originally modulate the data at transmitter.

* Non-coherent Detection :-

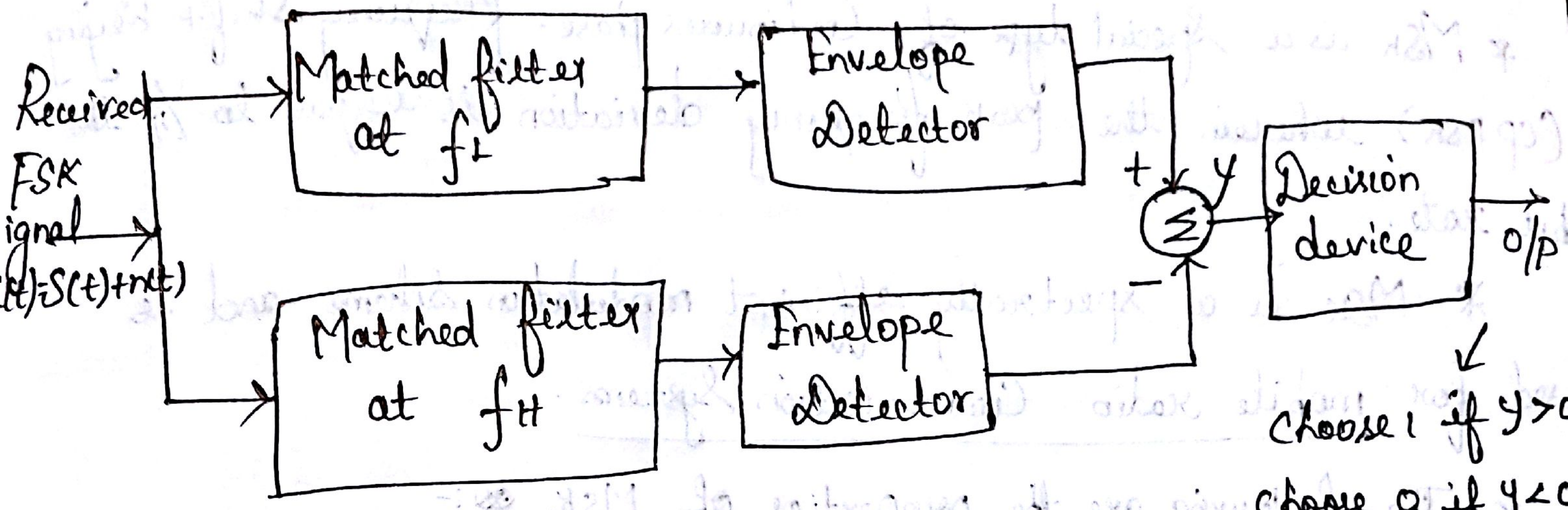
* This type of detector doesnot contains phase recovery circuit.

* * In coherent FSK detector, there are two correlators with a
* common input, which are supplied with a locally generated coherent reference signals $\phi_1(t)$, and $\phi_2(t)$.

* The correlator outputs are then subtracted which produces y

If $y<0$, it decides in favour of 0. If $y>0$, it decides in favour of 1.

Non-Coherent FSK Receiver:-



* The non-Coherent FSK receiver Consists of a pair of matched filters followed by envelope detector.
* The filter in the upper path is matched to ~~a~~ the FSK signal of frequency f_H and the filter in the lower path is matched to the signal of frequency f_L.
* These matched filters function as a bandpass filters centered on f_H and f_L.
* The output of the envelope detectors are sampled at every $t = KT_b$, where K is an integer and their values are compared.
* If the o/p of the envelope detector $y>0$, choose symbol 1. Otherwise decision is made in favour of 0. [when $y<0$]

3.7 Minimum Shift Keying [MSK] :-

* MSK is a special type of Continuous phase - frequency shift keying (CPFSK) wherein the peak frequency deviation is equal to 1/4 the bit rate.

* MSK is a spectrally efficient modulation scheme, and is used for mobile radio Communication Systems.

* The following are the properties of MSK :-

1) Constant Envelope,
2) Good BER performance,
3) Self - synchronizing Capability.
4) Relatively narrow bandwidth

* MSK is sometimes referred to as fast FSK, as the frequency spacing used is half of the Conventional non coherent FSK.

The MSK signal is defined as

$$S_{MSK}(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_1 t + \theta(0)) & \text{for symbol } 1 \\ \sqrt{\frac{2E_b}{T_b}} \cos[2\pi f_2 t + \theta(0)] & \text{for symbol } 0 \end{cases}$$

where E_b is the transmitted signal energy per bit and T_b is the bit duration.

$\theta(0) \longrightarrow$ value of the phase at time $t=0$.

Scanned by CamScanner

The frequencies f_1 and f_2 are sent in response to binary symbols and 0 appearing at the modulator input respectively.

MSK Signal can also be represented as

$$S(t) = \sqrt{\frac{2E_b}{T_b}} \cos\left[2\pi f_c t + \theta(t)\right] \longrightarrow (5)$$

where $\theta(t)$ is the phase of $S(t)$.

$$\theta(t) = \theta(0) \pm \frac{\pi h}{T_b} t \quad , \quad 0 \le t \le T_b \longrightarrow (6)$$

where the plus sign corresponds to sending symbol 1.
Minus sign corresponds to sending symbol 0.

Phase Trellis :-

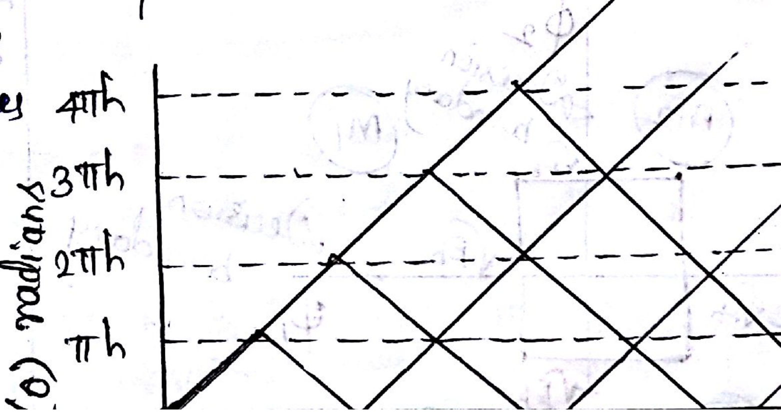
From (6), $\theta(t) - \theta(0) = \pm \frac{\pi h}{T_b} t$

when $t = T_b$, $\theta(T_b) - \theta(0) = \begin{cases} \pi h, & \text{for Symbol 1} \\ -\pi h, & \text{for Symbol 0} \end{cases}$

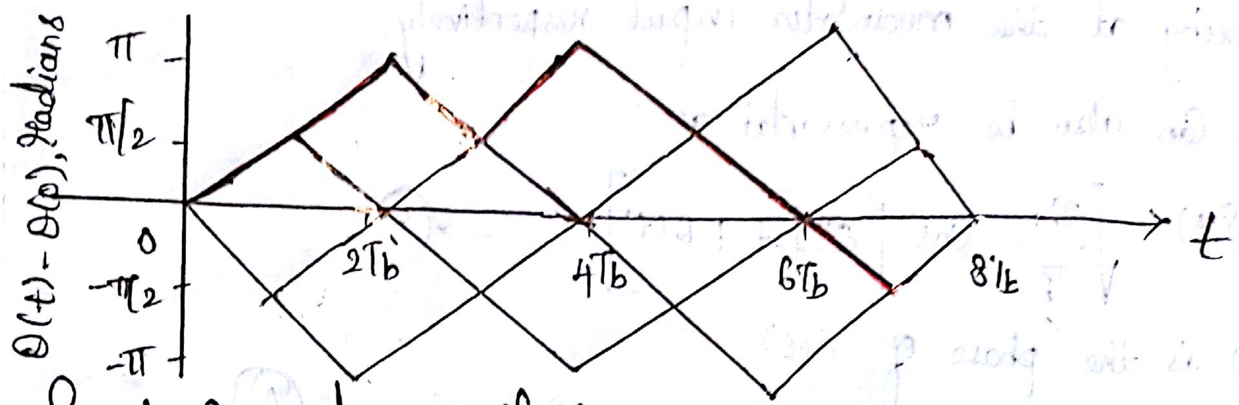
Sending of symbol 1 increases the phase of a MSK signal $S(t)$ by πh, whereas sending of symbol 0 reduces it by an equal amount.

The phase tree makes clear the ... of phase across interval

Phase tree



Phase Trellis :- 1101000



Signal Space diagram of MSK :-

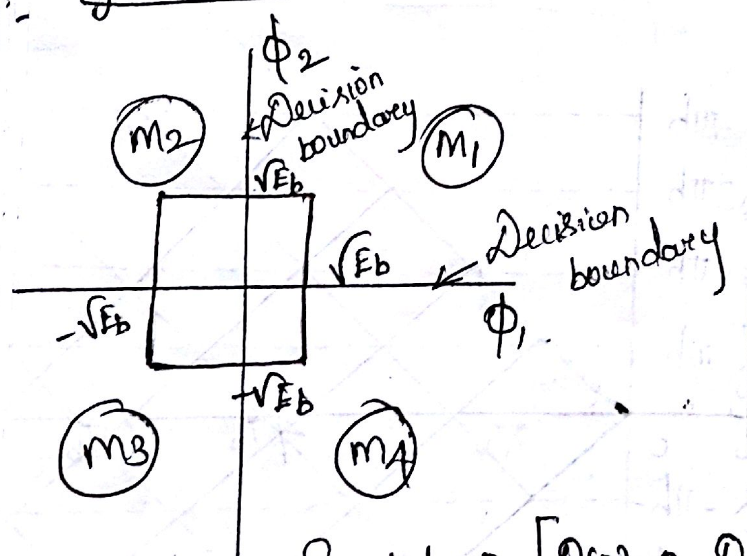
Using a trigonometric identity in (5), MSK signal $S(t)$ can also be represented as :

$$S_{MSK}(t) = \sqrt{\frac{2E_b}{T_b}} \cos[\theta(t)] \cos(2\pi f_c t) - \sqrt{\frac{2E_b}{T_b}} \sin[\theta(t)] \sin(2\pi f_c t)$$

With the deviation ratio $h = 1/2$ in (6),

$$\theta(t) = \theta(0) \pm \frac{\pi}{2T_b} t, \quad 0 \le t \le T_b$$

Signal Constellation :-



Transmitted Binary Symbol	Phase States (radians)		Coordinates of message Points	
	$\theta(0)$	$\theta(T_b)$	S_1	S_2
0	0	$-\pi/2$	$+\sqrt{E_b}$	$+\sqrt{E_b}$
1	π	$-\pi/2$	$-\sqrt{E_b}$	$+\sqrt{E_b}$
0	π	$+\pi/2$	$-\sqrt{E_b}$	$-\sqrt{E_b}$
1	0	$+\pi/2$	$+\sqrt{E_b}$	$-\sqrt{E_b}$

$m_1 \longrightarrow$ Symbol 0 $[\theta(0)=0, \theta(T_b)=-\pi/2]$

$m_2 \longrightarrow$ Symbol 1 $[\theta(0)=\pi, \theta(T_b)=-\pi/2]$

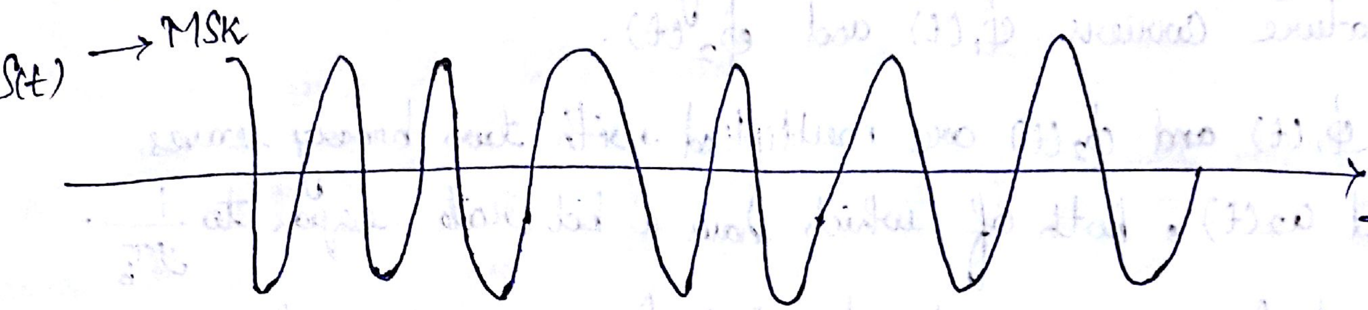
$m_3 \longrightarrow$ Symbol 0 $[\theta(0)=\pi, \theta(T_b)=\pi/2]$

$m_4 \longrightarrow$ Symbol 1 $[\theta(0)=0, \theta(T_b)=\pi/2]$

Input Binary Sequence

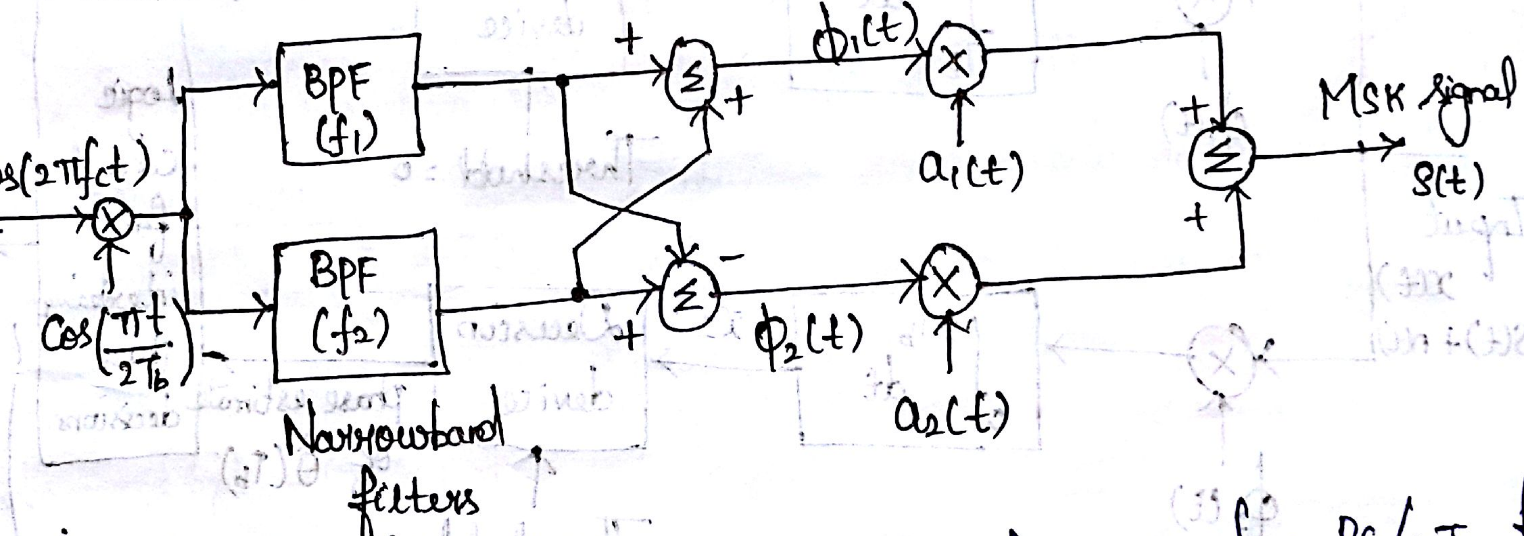
1 1 0 1 0 0 0

$S(t) \rightarrow$ MSK



MSK Transmitter and Receiver:-

Transmitter:-



Two input sinusoidal waves are of frequency $f_c = n_c/4T_b$ for some fixed integer n_c, and the other of frequency $1/4T_b$ are first applied to a product modulator.

This produces two phase-coherent sinusoidal waves. These two sinusoidal waves are separated from each other by two narrowband filte[rs], one centered at f_1 and the other at f_2.

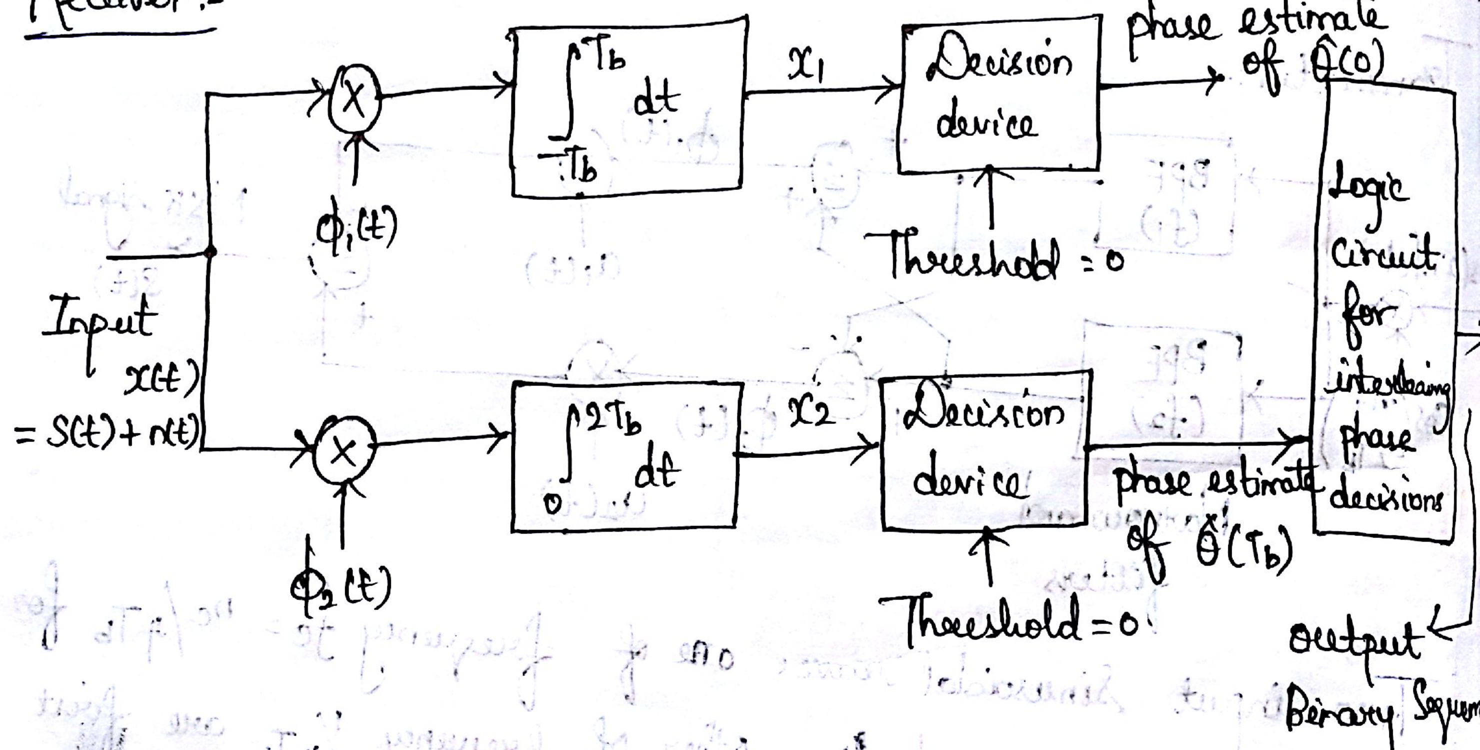
~~These two Sinusoidal waves are Separated from~~

The resulting filter outputs are linearly Combined to produce the pair of quadrature Carriers $\phi_1(t)$ and $\phi_2(t)$.

Finally $\phi_1(t)$ and $\phi_2(t)$ are multiplied with two binary waves $a_1(t)$ and $a_2(t)$, both of which have a bit rate equal to $\frac{1}{2T_b}$.

Multiplied Signals are combined which forms MSK Signal.

<u>Receiver :-</u>



The received signal $x(t)$ is Correlated with locally generated replicas of the Coherent Reference Signals $\phi_1(t)$ and $\phi_2(t)$.

The resulting in-phase and quadrature channel Correlator outputs, x_1 and x_2, are each Compared with a threshold of zero, and phase estimates $\theta(0)$ and $\theta(T_b)$ are determined.

Scanned by CamScanner

Finally these phase decisions are interleaved so as to reconstruct the Original input binary sequence with the minimum error.

3.8 Gaussian Minimum Shift Keying [GMSK] :-

* GMSK is a simple binary modulation scheme which may be viewed as a derivative of MSK.

* In GMSK, the sidelobe levels of the spectrum are further reduced by passing the modulating NRZ data waveform through a premodulation Gaussian pulse-shaping filter.

* Baseband Gaussian pulse shaping smooths the phase trajectory of the MSK signal and hence stablizes the instantaneous frequency variations over time.

* This has the effect of reducing the sidelobe levels in the transmitted spectrum.

Advantages of GMSK over MSK :-

* The out-of-band spectral characteristics of MSK do not satisfy the requirements of multiuser communication. This may create more amount of adjacent channel interference in mobile communication.

* This limitation of MSK is modified by changing its power spectrum into a compact form by maintaining the constant envelope property of the MSK signal. This technique is called GMSK

The modification of the power spectrum can be achieved through the use of a premodulation low-pass filter [baseband pulse-shaping filter].

The pulse-shaping filter should satisfy the following properties:-

(1) * Frequency response with narrow bandwidth and sharp cutoff characteristics.

(2) * Impulse response with relatively low overshoot.

(3) * The carrier phase of the modulated signal in phase trellis possess ~~assumes~~ the two values $\pm \pi/2$ at odd multiples of T_b and the two values 0 and π at even multiples of T_b [As in MSK].

Condition (1) is needed to suppress the high-frequency components of the transmitted signal.

Condition (2) avoids excessive deviations in the instantaneous frequency of the FM signal.

Condition (3) ensures that the modified FM signal can be coherently detected in the same way as the MSK signal, or it can be noncoherently detected as a simple BFSK signal.

The GMSK premodulation filter has an impulse response given by

$$h_G(t) = \frac{\sqrt{\pi}}{\alpha} \exp\left[-\frac{\pi^2}{\alpha^2} t^2\right] \longrightarrow (7)$$

and the transfer function given by

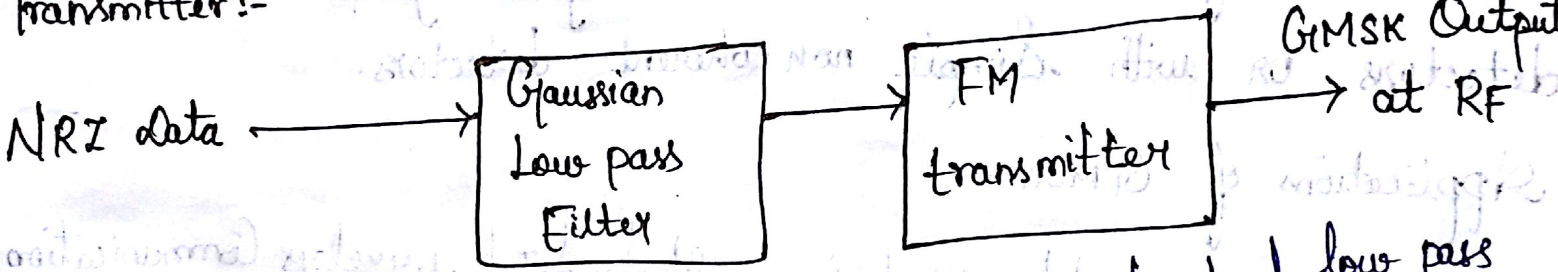
$$H_G(f) = \exp(-\alpha^2 f^2) \longrightarrow (8)$$

The parameter α is related to, B, the 3dB baseband bandwidth of $H_G(f)$, by

$$\alpha = \frac{\sqrt{\ln 2}}{\sqrt{2}\,B} = \frac{0.5887}{B}$$

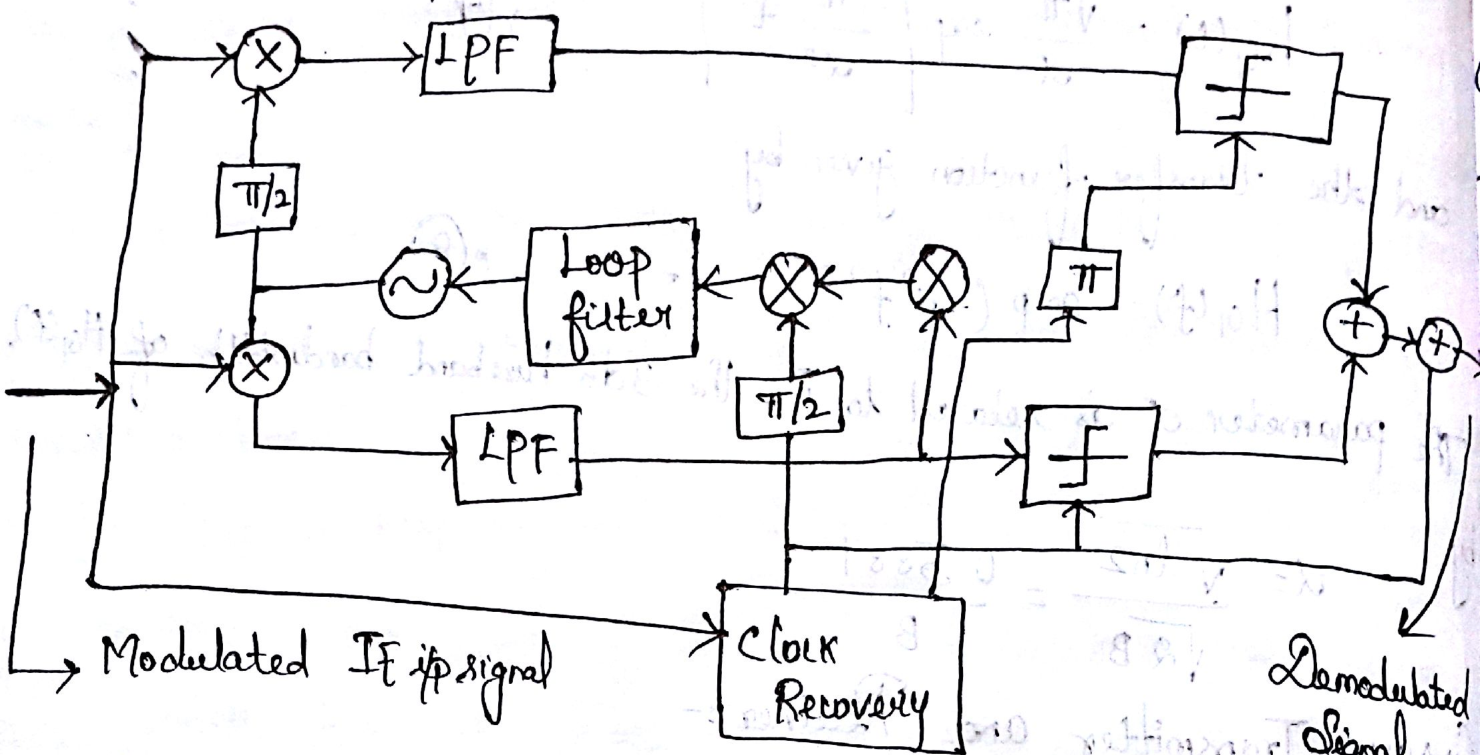
GMSK Transmitter and Receiver:-

Transmitter:-



* NRZ message bits are passed through a Gaussian baseband low pass filter having an impulse response given by (7), followed by an FM Modulator.
* It is the simplest way to generate a GMSK signal.
* This modulation technique is currently used in a variety of analog and digital implementations for the US Cellular Digital packet Data [CDPD] system and GSM [Global system for Mobile system].

Receiver :-



GMSK signals can be detected using orthogonal coherent detectors or with simple non coherent detectors.

Applications of GMSK :-

* GMSK is widely used in a standardized wireless communication system known as GSM [Global System for Mobile communications Systems].

* For GSM, the time bandwidth product WT_b of GMSK is standardized at 0.3, which provides the best compromise between increased bandwidth occupancy and resistance to co-channel interference.

* It is also used in the Bluetooth standard [IEEE 802.15.1]

* Ninety-nine percent of the radio frequency (RF) power of GMSK signals so specified is confined to a bandwidth of 250 KHZ, which means that, for all practical purposes, the sidelobes are virtually zero outside this frequency band.

.9 Power Spectrum and Error Performance in Fading Channels :-

.1 Power Spectrum of Different Modulation Schemes :-

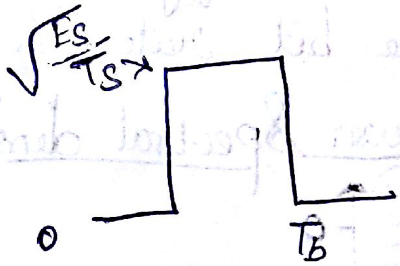
① **QPSK :-**

The complex envelope of a QPSK wave consists of an in-phase component and quadrature component. The in-phase component and the quadrature component equal $+g(t)$ or $-g(t)$ depending on the symbol 1 or symbol 0 at the modulator input ~~deper~~ during the signaling interval.

The symbol shaping function is given by,

$$g(t) = \begin{cases} \sqrt{\dfrac{E_s}{T_s}}, & 0 \le t \le T_s \\ 0, & \text{otherwise} \end{cases}$$

The Fourier transform of this pulse is given by,



$$= A\, T_s\, \text{sinc}(f T_s)$$

$$\left\{ A \rightarrow \text{Amplitude} = \sqrt{\frac{E_s}{T_s}} \right.$$

$$= \sqrt{\frac{E_S}{T_S}}\, T_S\, \text{Sinc}(f T_S)$$

$$= \sqrt{E_S T_S}\, \text{Sinc}(f T_S)$$

The power Spectrum is given by

$$P_{QPSK}(f) = \left| A\, T_s \operatorname{sinc}(f T_s) \right|^2$$

$$= \left| \sqrt{\frac{E_s}{T_s}}\, T_s \operatorname{sinc}(f T_s) \right|^2$$

$$= \left| \sqrt{E_s T_s} \operatorname{sinc}(f T_s) \right|^2$$

$$= E_s T_s \operatorname{sinc}^2 (f T_s)$$

$$= (2E_b)(2T_b) \operatorname{sinc}^2 (2f T_b) \qquad \left\{ \because \begin{array}{l} E_s = 2E_b \\ T_s = 2T_b \end{array} \right.$$

$$= 4 E_b T_b \operatorname{sinc}^2 (2f T_b)$$

Power Spectrum $P_{QPSK}(f) = \frac{\text{Energy}}{\text{Time}}$

$$\boxed{P_{QPSK}(f) = 4E_b \operatorname{sinc}^2 (2f T_b)}$$

The PSD of a QPSK signal for rectangular pulses is shown in ~~plotted~~ figure. The null-to-null RF bandwidth is equal to the bit rate R_b, which is half that of a BPSK signal.

Power Spectral density of a QPSK Signal:-

(2) BFSK :-

In-phase Component :-

This is Completely independent of the input binary wave.

Inphase Component of BFSK = $\sqrt{\frac{2E_b}{T_b}} \cos\left(\frac{\pi t}{T_b}\right)$ → (11)

The PSD of this Component Consists of two delta functions weighted by the factor $\frac{E_b}{2T_b}$ and occurring at $f = \pm \frac{1}{2T_b}$.

Quadrature Component :-

This is directly related to input binary wave. During the signaling interval $0 \le t \le T_b$, it equals $-g(t)$ and $+g(t)$ for symbol 1 and 0 respectively. The symbol shaping function $g(t)$ is given by,

$$g(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} \sin\left(\frac{\pi t}{T_b}\right), & 0 \le t \le T_b \\ 0, & \text{otherwise} \end{cases} \rightarrow (10)$$

The energy spectral density of $g(t)$ is

$$\psi_g(f) = \frac{8E_b T_b \cos^2(\pi T_b f)}{\pi^2 (4T_b^2 f^2 - 1)^2}$$

$$\text{PSD of } g(t) = \frac{\psi_g(f)}{T_b} = \frac{8E_b \cos^2(\pi T_b f)}{\pi^2 [4T_b^2 f^2 - 1]^2}$$

∴ PSD of BFSK = PSD [Inphase Component] + PSD [Quadrate Component] → (12)

$$P_{BFSK}(f) = \frac{E_b}{2T_b}\left[\delta\left(f-\frac{1}{2T_b}\right)+\delta\left(f+\frac{1}{2T_b}\right)\right]+\frac{8E_b\cos^2(\pi T_b f)}{\pi^2(4T_b^2f^2-1)^2}$$

Thus the PSD of a continuous phase FSK falls off as the inverse fourth power of the frequency offset from f_c.

③ MSK :-

Inphase Component :-

Depending on the value of phase state $\theta(0)$, the in-phase Component equals $+g(t)$ or $-g(t)$. The $g(t)$ is given by,

$$g(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}}\cos\left(\frac{\pi t}{2T_b}\right), & -T_b \leq t \leq T_b \\ 0, & \text{otherwise} \end{cases}$$

The energy spectral density of this $g(t)$ is

$$\psi_g(f) = \frac{32E_bT_b}{\pi^2}\left[\frac{\cos(2\pi T_b f)}{16T_b^2f^2-1}\right]^2 \longrightarrow (13)$$

The power spectral of in-phase Component $= \frac{\psi_g(f)}{2T_b}$

$$PSD = \frac{16E_b}{\pi^2}\left[\frac{\cos(2\pi T_b f)}{16T_b^2f^2-1}\right] \longrightarrow (14)$$