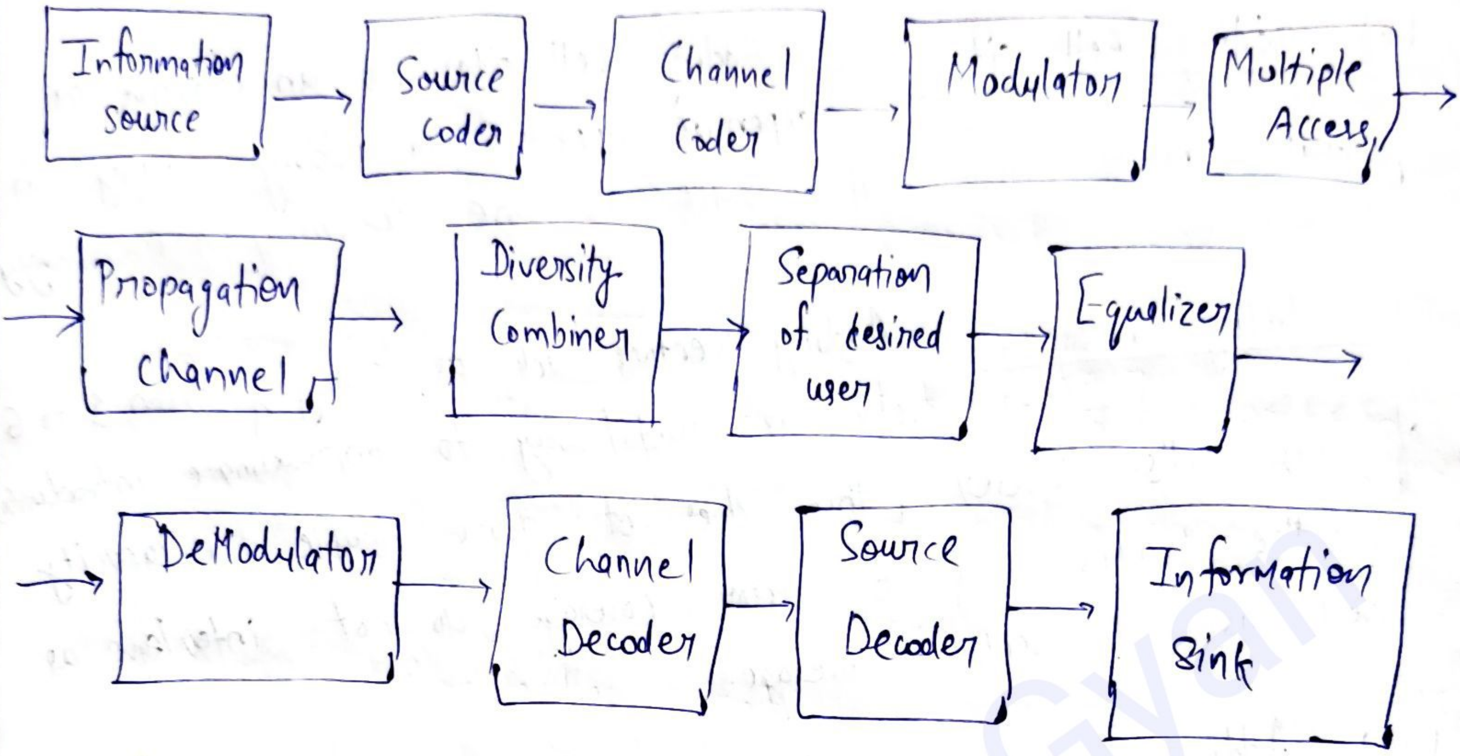
Structure of Wireless Communication link ⇒



Information Source :- It provides the source signal in digital or analog form.

Source coder :- Information bits are converted to symbols to improve the bit rate.

Channel coder :- To protect data against transmission errors ; additional bits are added.

Modulator :- It converts low frequency signals to high frequency signals.

Propagation Channel :- It attenuates signal & leads to delay & frequency dispersion.

Diversity Combiner :- A normal receiver will receive multiple signals from various antennas. All signals will be combined.

Equalizers :- Used to reduce ISI & dispersion

Demodulator :- Reverse process of modulation.

Channel Decoder:- Used to reconstruct original wave from encoded signal.

Source decoder:- They convert the symbols to message bits.

Data Sink:- These devices converts waveform to analog signals & they are fed to respective devices.

Quadrature Phase Shift Keying (QPSK) :-

Digital modulation is the mapping of data bits to signal waveforms that can be transmitted over an analog channel.

→ QPSK is a form of Phase Shift Keying in which two bits are modulated at once, selecting one of four possible carrier phase shifts (0, 90, 180 or 270 degrees).

→ QPSK-modulated signal is a PAM where signal carries 1 bit per symbol interval on both in-phase & quadrature-phase component. The original data stream is split into two streams, b_{1i} & b_{2i} : $b_{1i} = b_{2i}$, $b_{2i} = b_{2i+1}$ each of which has a data rate that is half that of 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, $g(t) = g_R(t, T_S)$.

Then we can give an interpretation of QPSK as either a phase modulation or as a PAM. We first define two sequences of pulses:

$$p_{1D}(t) = \sum_{i=-\infty}^{\infty} b_{1i}\, g(t - iT_S) = b_{1i} * g(t)$$

$$p_{2D}(t) = \sum_{i=-\infty}^{\infty} b_{2i}\, g(t - iT_S) = b_{2i} * g(t)$$

When interpreting QPSK as a PAM, the bandpass signal reads

$$S_{BP}(t) = \sqrt{E_B/T_B}\,[p_{1D}(t)\cos[2\pi f_c t] - p_{2D}(t)\sin(2\pi f_c t)]$$

Normalization is done in such a way that energy within one Symbol interval is $\int_0^{T_s} S_{BP}(t)^2\,dt = 2E_B$ → energy expended on transmission of a bit

The QPSK signal for this set of symbol states

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

$$i = 1, 2, 3, 4$$

where T_s is symbol duration & is equal to twice the bit period.

→ Using trigonometric identities, $0 \le t \le T_s$

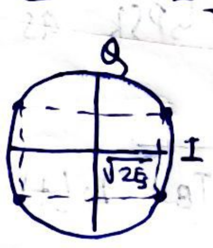
$$S_{QPSK}(t) = \sqrt{\frac{2E_s}{T_s}}\cos\left[(i-1)\frac{\pi}{2}\right]\cos(2\pi f_c t) - \sqrt{\frac{2E_s}{T_s}}\sin(i-1)\frac{\pi}{2}\sin 2\pi f_c t$$

Basic functions

$$\phi_1(t) = \sqrt{\frac{2}{T_s}}\cos(2\pi f_c t), \quad \phi_2(t) = \sqrt{\frac{2}{T_s}}\sin(2\pi f_c t)$$

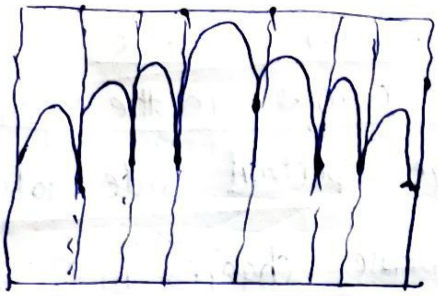
→ The 4 signals in set can be expressed in term of basis signals as

$$S_{QPSK}(t) = \sqrt{E_s}\cos\left[(i-1)\frac{\pi}{2}\right]\phi_1(t) - \sqrt{E_s}\sin\left[(i-1)\frac{\pi}{2}\right]\phi_2(t)$$



→ Since each symbol corresponds to two bits then $E_s = 2E_b$ so

$$P_{e,QPSK} = Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$



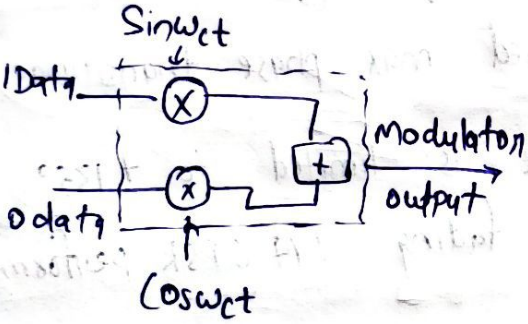
$$P_{QPSK}(f) = \frac{E_s}{2}\left[\left(\frac{\sin\pi(f-f_c)T_s}{\pi(f-f_c)T_s}\right)^2 + \left(\frac{\sin\pi(-f-f_c)T_s}{\pi(-f-f_c)T_s}\right)^2\right]$$

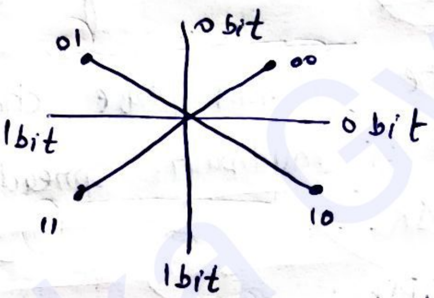
$$\frac{T_b}{2} = T_s$$

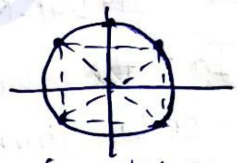
Baseband signal is

$$\hookrightarrow S_{QPSK}(t) = \sqrt{\frac{E_b}{T_b}}\left[P_{1D}(t) + j\,P_{2D}(t)\right]$$

$$\phi(t) = \pi\left[\frac{1}{2}P_{2D}(t) - \frac{1}{4}P_{1D}(t)\,P_{2D}(t)\right]$$ phase modulation

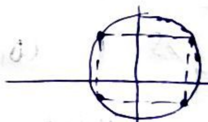






Conventional QPSK

OFFSET QPSK (OQPSK) ⇒



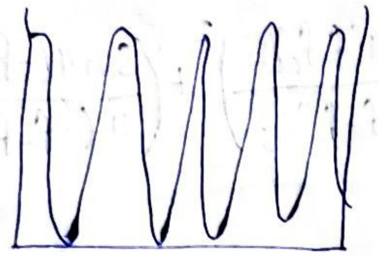
Offset QPSK

→ A modified form of QPSK, called offset QPSK is less susceptible to these deleterious effects.

→ The occasional phase shift of π radians can cause the signal evelope to pass through zero for just in instant.

→ OQPSK ensures there are fewer baseband signal transitions applied to RF amplifier, helps to eliminate spectrum regrowth after amplification.

Using Offset approach: First Symbol (00) at 0°, then an intermediate symbol at (10) at 90° then next full symbol (11) at 180°



The 180° phase transition in QPSK causes abrupt changes in the signal, resulting in large spectral side lobes. To prevent 180° phase changes in QPSK, **Offset-QPSK** is used.

$\frac{\pi}{4}$-DQPSK $\Rightarrow$ The $\pi/4$ shifted QPSK modulation is a quadrature phase shift keying technique offers a compromise b/w OQPSK & QPSK in terms of allowed max. phase transitions.

→ In $\pi/4$-DQPSK, the maximum phase change is limited to $\pm 135°$.

→ In the presence of multipath spread & fading, $\pi/4$ QPSK performs better than QPSK.

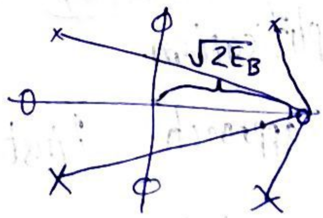
Why $\pi/4$ - DQPSK :-

QPSK is a constant evelope format, it has amplitude dips at bit transitions. The duration of dips is longer when non-rectangular basis pulses are used. Such variations of signal envelope are undesirable, because they make design of suitable amplifiers more difficult.

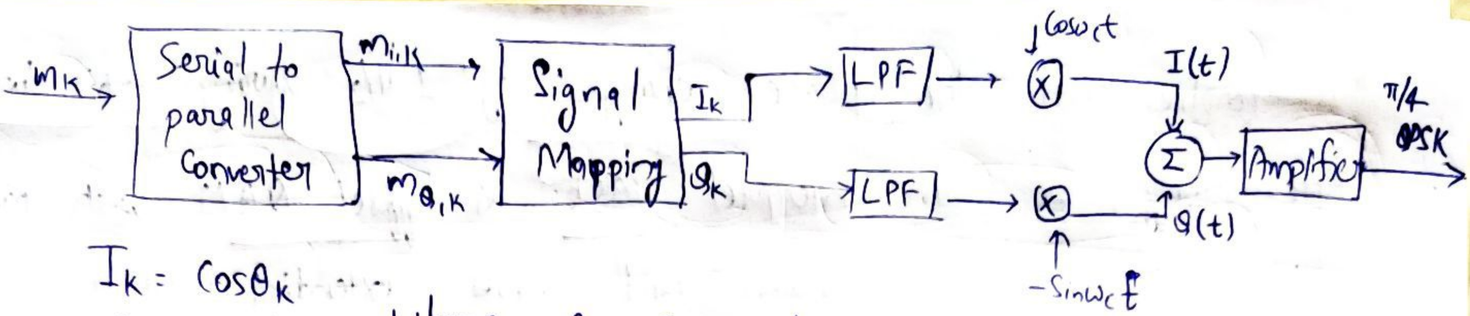
This can be reduced by using $\frac{\pi}{4}$-DQPSK.

$\pi/4$ - QPSK

Principle of $\pi/4$-DQPSK:-



Whenever t is an integer multiple of symbol duration, the transmit phase is increased by $\pi/4$, in addition to change of phase due to transmit symbol. Therefore, transitions b/w signal constellations can never pass through the origin.



$I_K = \cos\theta_K$

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

Information bits $m_{i,K}$, $m_{Q,K}$	Phase Shift ϕ_K
11	$\pi/4$
01	$3\pi/4$
00	$-3\pi/4$
10	$-\pi/4$

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

Where

$$I(t) = \sum_{K=0}^{N-1} I_K\, g\left(t - KT_s - \frac{T_s}{2}\right)$$

$$Q(t) = \sum_{K=0}^{N-1} Q_K\, g\left(t - KT_s - \frac{T_s}{2}\right)$$

QPSK	DQPSK	Pi/4-DQPSK
phase changes of +/- 90 & +/-180 degrees	phase changes of +/- 90 exist	Max. phase change of +/-45 and +/-135

Minimum Shift Keying (MSK) ⇒

MSK is one of the most important modulation formats for wireless commn. However, it can be interpreted in different ways.

1. Minimum Shift Keying (MSK) is a special type of continuous phase FSK where the peak frequency deviation, Δf is equal to 1/4 the bit rate, R_b.

$$\Delta f = \frac{1}{4} R_b = \frac{1}{4T_b}$$

- MSK is continuous phase FSK with a modulation index of 0.5.

$$h_{mod} = 0.5$$

This implies that the phase changes by $\pm \pi/2$ during 1-bit duration.

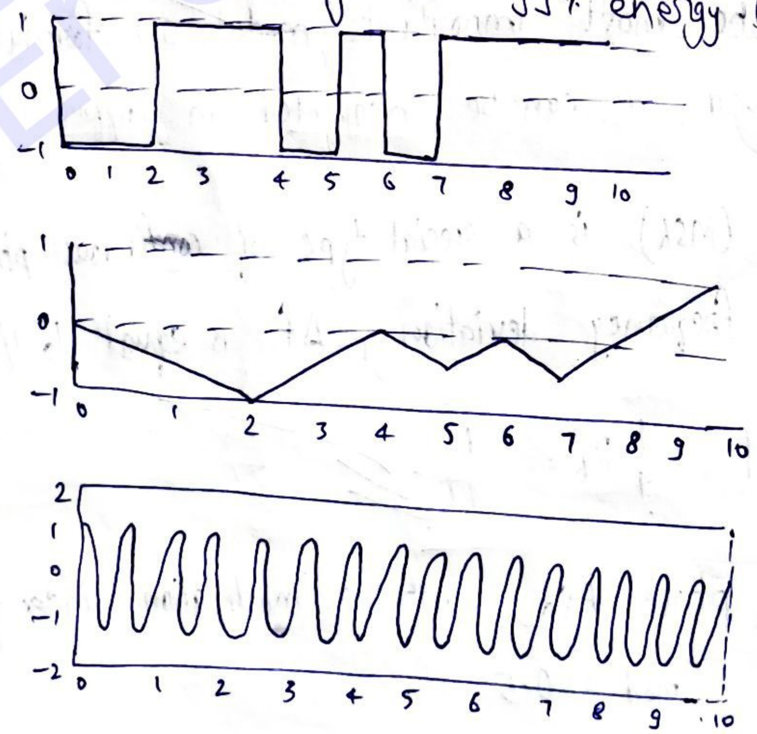
2. Alternatively, we can interpret MSK as offset QAM with basis pulses that are sinusoidal half waves extending over a duration of $2T_B$.

$$g(t) = \sin\left(2\pi f_{mod}(t+T_B)\right) g_R(t, 2T_B)$$

Due to use of smoother basis functions, the spectrum decreases faster than that of "regular" OQPSK:

$$S(f) = \frac{16T_B}{\pi^2}\left(\frac{\cos(2\pi f T_B)}{1-16f^2T_B^2}\right)^2$$

On other hand, MSK is only a binary modulation format, while OQPSK transmits 2 bits per symbol duration.
As a consequence, MSK has lower spectral efficiency when considering the 90% energy bandwidth (1.29 bit/s/Hz) but still performs reasonably well when considering the 99% energy bandwidth (0.85 bit/s/Hz).



$P_D(t)$ [phase pulse]

$\phi(t)$ [phase as function of time]

MSK [Modulated Signal]

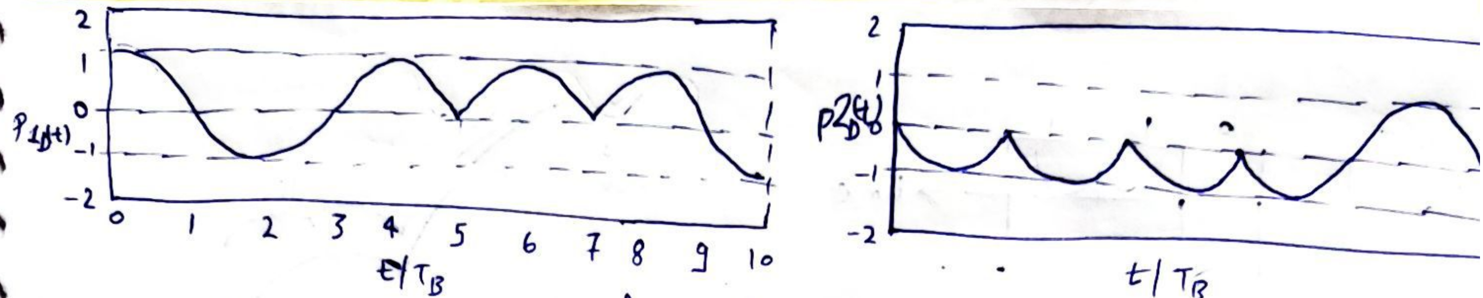


fig:- Composition of MSK from sinusoidal half waves.

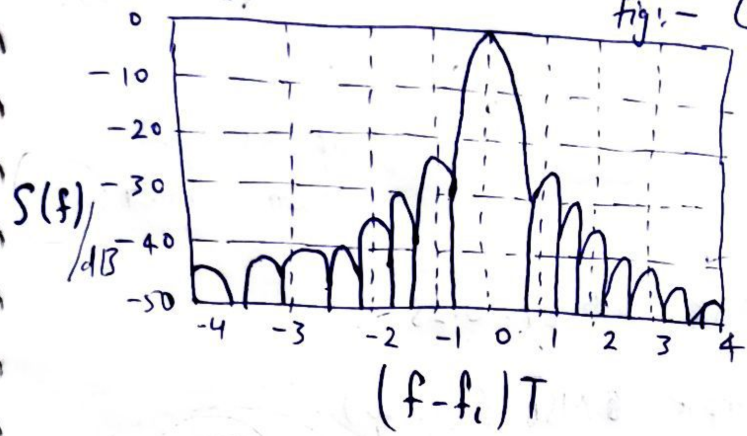


fig:- Power spectral density of MSK

Gaussian MSK :-

GMSK is CPFSK with modulation index $h_{mod} = 0.5$ & Gaussian phase basis pulses:-

$$\hat{g}(t) = g_G(t, T_B, B_G T)$$

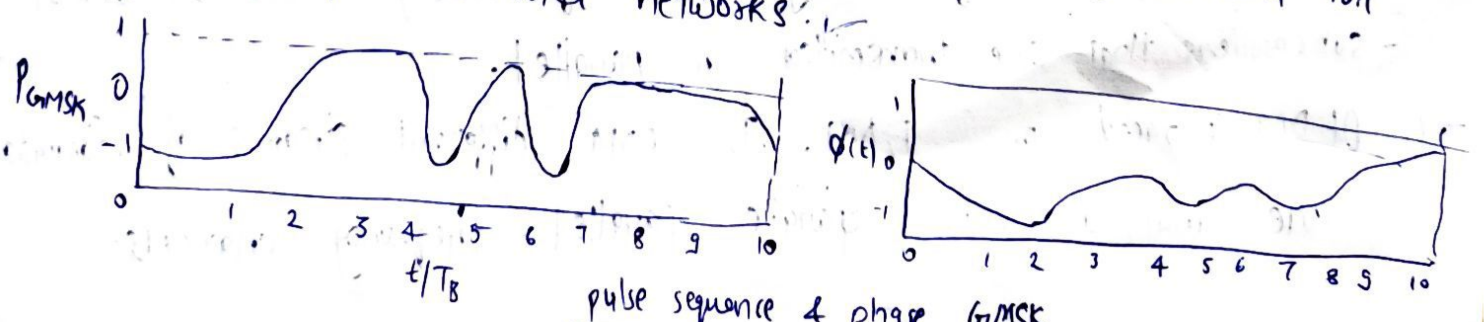
Thus the sequence of transmit phase pulses is

$$pD(t) = \sum_{i=-\infty}^{\infty} b_i \hat{g}(t - iT_B) = b_i * \hat{g}(t)$$

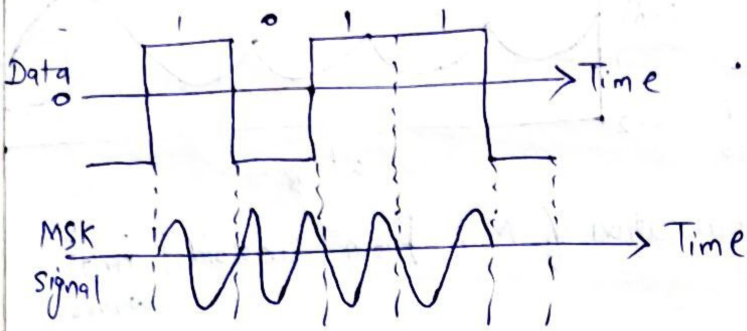
We see that GMSK achieves better spectral efficiency than MSK because it uses smoother Gaussian phase basis pulses as opposed to rectangular ones of MSK.

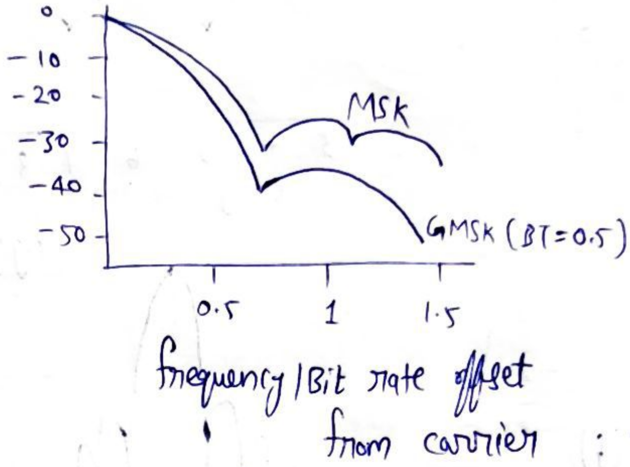
→ GMSK is applied in the cellular Global System for Mobile commn (GSM) standard (with $B_G T = 0.3$) & the cordless standard digital Enhanced Cordless Telecommunications (DECT) (with $B_G T = 0.5$).

→ It is also used in Bluetooth (IEEE 802.15.1) standard for wireless personal area networks.



pulse sequence & phase GMSK





$$\boxed{P_e = Q\left(\sqrt{\frac{2\gamma E_b}{N_0}}\right)}$$

Where $\gamma = \begin{cases} 0.68 & \text{for GMSK with } BT = 0.25 \\ 0.85 & \text{for simple MSK } (BT = \infty) \end{cases}$

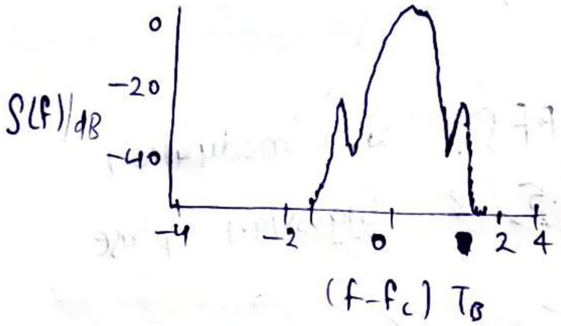


fig:- power spectral density GMSK

Orthogonal Frequency Division Multiplexing

OFDM is a modulation format that is being used for many of latest wireless & telecommunications standards.

→ OFDM has been adopted in Wi-Fi arena.

Principle of OFDM:-

→ OFDM splits a high rate data stream into N parallel streams, which are then transmitted by modulating N distinct carriers.

→ OFDM makes use of a large number of closely spaced Orthogonal subcarriers that are transmitted in parallel.

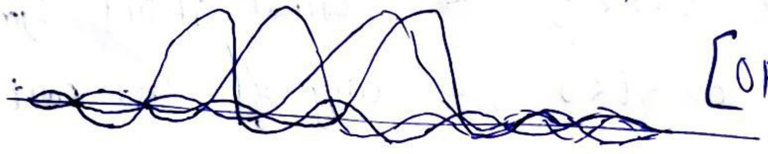
→ OFDM is based on FDM. In FDM, different streams of information are mapped onto separate parallel frequency channels.

The OFDM scheme differs from traditional FDM in following interrelated ways:-

(i) Multiple carriers carry the information stream.

(ii) The subcarriers are orthogonal to each other.

(iii) A guard interval is added to each symbol to minimize the channel delay spread & intersymbol interference.



[OFDM Splits high rate data stream into N parallel streams]

$$s(t) = \sum_{i=-\infty}^{\infty} s_i(t) = \sum_{i=-\infty}^{\infty} \sum_{n=0}^{N-1} c_{n,i}\, g_n(t - iT_s)$$

where $g_n(t) = \begin{cases} \frac{1}{\sqrt{T_s}} \exp\left(j2\pi n \frac{t}{T_s}\right), & \text{for } 0<t<T_s \\ 0, & \text{otherwise} \end{cases}$

signal only for $i=0$ & $t_K = \frac{kT_s}{N}$

$$s_K = s(t)_k = \frac{1}{\sqrt{T_s}} \sum_{n=0}^{N-1} c_{n,0} \exp\left(j2\pi n \frac{k}{N}\right)$$

FREQUENCY - SELECTIVE CHANNELS

Cyclic Prefix ⇒

Delay dispersion leads to

1. appreciable errors even when delay spread < symbol duration.
2. loss of orthogonality b/w carriers & thus leads to Inter Carrier Interference.

Both these negative effects can be eliminated by a special type of guard interval, called the Cyclic Prefix.

The Cyclic Prefix helps to eliminate residual delay dispersion.

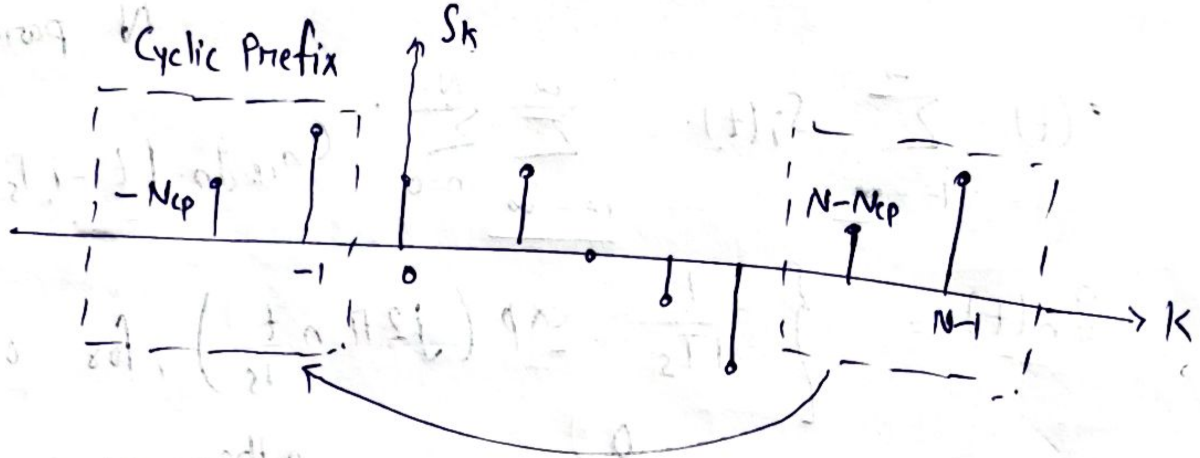
$$g_n(t) = \exp\left(j2\pi n \frac{W}{N} t\right) \quad \text{for } -T_{cp} < t < \hat{T}_s$$

where $\frac{W}{N}$ is the carrier spacing.

The symbol duration T_s is now $T_s = \hat{T}_s + T_{cp}$.

So for duration $0 < t < \hat{T}_s$ the normal OFDM symbol is transmitted.

During time $-T_{cp} < t < 0$, a copy of last part of symbol is transmitted.



The total signal $s(t)$ transmitted during time $-T_{cp} < t < 0$ is a copy of $s(t)$ during last part, $\hat{T}_s - T_{cp} < t < \hat{T}_s$.

This prepended part of signal is called <u>Cyclic Prefix</u>.

PAPR (Peak to Average Power Ratio)

PAPR is proportional to number of subcarriers used for OFDM systems. An OFDM system with large number of subcarriers will thus have a very large PAPR when the subcarriers add up coherently. Large PAPR of system makes implementation of digital to analog Converter (DAC) & analog to digital converter (ADC) extremely difficult. The design of RF amplifier also becomes increasingly difficult as the PAPR increases.

→ The clipping & Windowing techinque reduces PAPR by non-linear distortion of OFDM signal

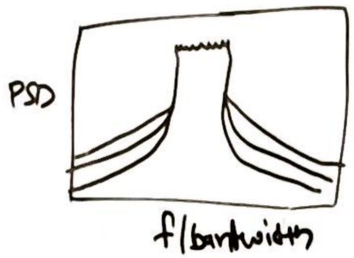
→ Another technique called linear - peak cancelation can also be used to reduce the PAPR.

PAR ⇒ power level of highest instantaneous power compared to the average power level

⇒ <u>Windowing</u> ✓

Windowing

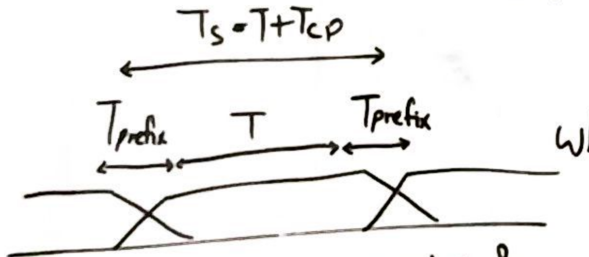
An OFDM signal consists of a number of unfiltered sub-carriers. Therefore the out of band spectrum decreases rather slowly, with speed depending on the number of sub-carriers, as shown in fig.



To make spectrum go down more rapidly, windowing can be applied to individual OFDM system.

$$w(t) = \begin{cases} 0.5 + 0.5\cos\left(\pi + t\pi/(\beta T_s)\right), & 0 \le t \le \beta T_s \\ 1.0, & \beta T_s \le t \le T_s \\ 0.5 + 0.5\cos\left((t - T_s)\pi/(\beta T_s)\right), & T_s \le t \le (1+\beta) T_s \end{cases}$$

where β is roll-off factor



OFDM cyclic extension & windowing