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# Improved Performance of Companded OFDM System using Non Symmetric Approach

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***Abstract* – Companding transforms signals useful under assumption of infinite bandwidth. Under band limited conditions Out of band radiation (OBR) parameter filters out. So bandwidth is a factor that decides the filtering out OBR on the performance of companded OFDM systems. As a result filtering becomes essential under band limited conditions in turn this does deteriorate the system performance significantly.**

**In this paper method proposed to overcome the performance degradation of various aspects on linear/nonlinear companders using for digital modulation techniques, method called non linear symmetric scheme based on the use of curve fitting method to find out a suitable polynomial to be used for decompanding at the receiver in sufficient bandwidth conditions. This method indeed improves the performance in comparison in various aspects like PAPR, BER, OBR, functions of FFT, IFFT etc. to existing symmetric methods when filtering is necessary for band limited conditions.**

***Keywords* – Companding, OFDMA, CDMA, TDMA, FDMA, Digital Techniques and their performance.**

## I. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a digital modulation technique who consists of transmitting a data stream using a large number of parallel narrowband sub carriers instead of a single wide-band carrier i.e. in OFDM multiplexing is applied to independent signals but these independent signals are a subset of one main signal. Therefore OFDM is a combination of modulation and multiplexing with better immunity to impulse noise and intersymbol interference (ISI), low complexity and high spectral efficiency. Implementation of OFDM modulation is illustrated by the OFDM system as shown in figure 1.1. OFDM system has been used for the high-speed digital communications such as DAB (digital audio broadcasting),DVB (digita1video broadcasting),digital high definition television (HDTV) and asymmetric digital subscriber line (ADSDL) due to robustness to the narrowband interference and severe multi-path fading .One major difficulty, however, is its large peak-to-average power ratio (PAPR) which reduces the resolution of the digital-to-analog (D/A) and analog-to digital(A/D) converters in the transmitter and receiver[9].

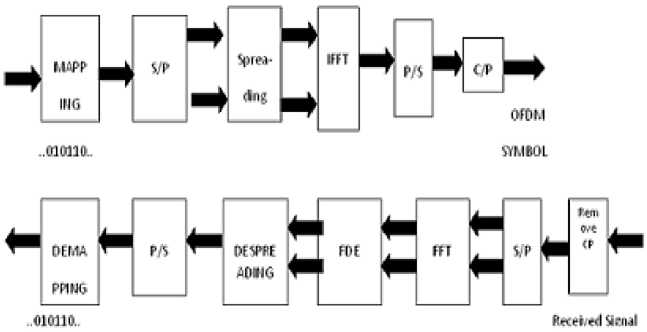

Fig.1.1. OFDMA System

## II. System Functioning

*OFDM Transmitter :*

- Data coming from the input are arranged into vectors with number of components equal to the N number of carriers. Each component is composed by a number of bits depending on the alphabet of the modulation scheme used on the next stage.
- Each component (group of bits) is mapped into a complex symbol depending on the alphabet of the modulation scheme used[3].
- The Inverse Fast Fourier Transform algorithm (IFFT) is applied to the vector giving a real samples vector.
- The guard interval is added at the beginning of the vector by repeating the components of the end. Vectors are concatenated to form a time signal (parallel/serial conversion)
- Windowing the signal is necessary to limit the bandwidth. Most used window is the raised cosine.

*Channel :*

- The signal is then passed through the channel. Channel is modeled by a linear system with frequency response c(t) together with a source of additive Gaussian noise[4].

*OFDM Reciever :*

- At the reception, signal is rearranged again into vectors (serial/parallel conversion) and guard interval is dropped.
- Fast Fourier Transform (FFT) is computed in order to get back the complex vector of symbols.

## III. Companded OFDM System

OFDM system has been used for the high-speed digital communications such as DAB (digital audio broadcasting),DVB (digita1video broadcasting),digital high definition television (HDTV) and asymmetric digital subscriber

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line (ADSDL) due to robustness to the narrowband interference and severe multi-path fading .One major difficulty, however, is its large peak-to-average power ratio (PAPR) which reduces the resolution of the digital-to-analog (D/A) and analog-to digital(A/D) converters in the transmitter and receiver[2]. A simple but effective companding technique to reduce the peak-to-average power ratio of OFDM signal. The idea is to make use of companding in speech processing. Since OFDM signal is similar to speech signal in the sense that large signals only occur very infrequently, the same companding technique can be used to improve OFDM transmission performance. The block diagram of OFDM system with commanding technique is shown in fig 3.2 as follows.

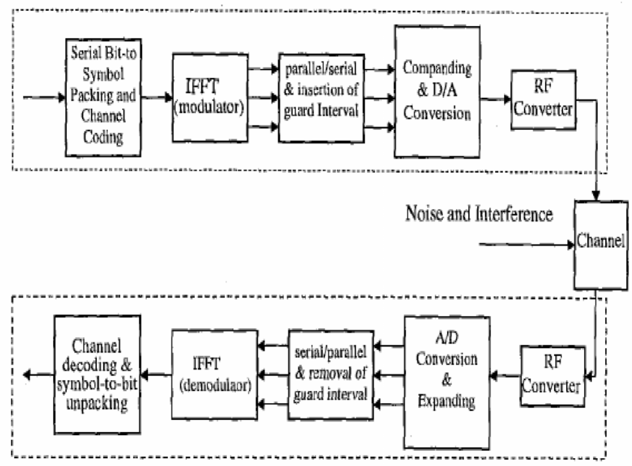


Fig 3.2. Companded OFDM System

## IV. Limitations in Companded OFDM System

In companded OFDM system the PAPR of OFDM signals is reduced by increasing the average power of signals while keeping the peak unchanged, but this reduction in PAPR may be very limited under certain BER performance constraint. i.e. Out of band radiation (OBR), filtering in system and even the bandwidth plays a key role on the performance of companded OFDM systems [1].

*Problem Statement*

- Companding transforms mitigate the effects of OFDM only under sufficient bandwidth.
- Band limited case; the OBR value is not satisfied. Thus we filter the OBR parameter.
- To avoid PAPR regrowth companding parameters are tighten to compress large amplitude and enhance small amplitude. In spite of these remedies, the overall system performance degrades with BER performance degradation.

## V. Paper Work and Objective

- Analysis & study of the effects of filtering on the performance of various companding transforms.
- To overcome this and improve system performance, a simple effective method of Non symmetric companding and decompanding is used.
- To improve the performance degradation, Non symmetric companding and decompanding method is used based on the use of curve fitting method to find out a suitable polynomial, used for decompanding at the receiver.

The main objective of this paper is to develop a method based on companding transform that provides a simple but effective tradeoff between reduction in PAPR and bit error rate (BER) performance which is required in modern wireless transmission systems.

## VI. Algorithm for Solution Approach

*Calculation of OBR to IBR Ratio*

Unwanted emissions [15] are composed by out of band and spurious emission.

- Spurious emission according to ITU_R recommendation defines that any unwanted emission which falls at frequencies separated from the centre frequency of the emission by 250% or more of the relevant channel separation, where the system is intended to be used, will generally be considered spurious emission.
- Out of band emissions, defined based on their source, occur in the out of band domain and, to a lesser extent in the spurious domain.
- Spurious emissions likewise may occur in the out of band domain as well as in the spurious domain.

We analyze theoretically the average value of OBR to IBR ratio for clipping and different companding schemes that achieve a reasonable level of PAPR. The parameter constraints considered are target PAPR of 6.5 dB, CCDF of atleast 10−5 at this value of PAPR. The modulation scheme used is QPSK and the number of sub carriers chosen is N=256, oversampling factor of 4.

*Clipping:*

The clipping operation is done on the over sampled OFDM signal after the base band OFDM is digitally modulated into band pass signal [7]. The over sampled OFDM signal after IFFT is

$$X_k' = \begin{cases} X_{k+N/2}, & 0 \le k \le N/2-1 \\ 0, & N/2 \le k \le mN - N/2 - 1 \\ X_{k-(mN-N/2)}, & mN - N/2 \le k \le mN - 1 \end{cases} \tag{6.1}$$

To generate the bandpass signal digitally, let the bandpass carrier frequency $f_c$ be 1/4 of the sampling frequency $f_s$. Then, the real bandpass samples can be written as

$$\begin{aligned} y_n &= x_n \cos(2\pi \frac{f_c}{f_s} n) - x_n \sin(2\pi \frac{f_c}{f_s} n) \\ &= x_n \cos(\frac{n\pi}{2}) - x_n \sin(\frac{n\pi}{2}). \end{aligned} \tag{6.2}$$

The output power of the clipped OFDM signals after the BPF is given by

$$\hat{P}_{\text{av}} \triangleq \frac{1}{N} \sum_{k=0}^{N-1} E\left[\left|\tilde{A}_k\right|^2\right] \tag{6.3}$$

Where $A_k$ is the distorted version of the original data $A_k$.

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So the out band power to in band power is equivalent to average output power after clipping to the output power before clipping is less than or equal to 1 as shown by equation below and over sampling factor (J=1)

$$\frac{\hat{P}_{av}}{P_{out}} = \frac{\sum_{k=0}^{N-1} E\left[\left|\widetilde{A}_k\right|^2\right]}{\sum_{k=0}^{JN-1} E\left[\left|\widetilde{A}_k\right|^2\right]} \leq 1 \qquad (6.4)$$

So the constant value of OBR/IBR is -15 under band limited case.

*Exponential Companding:*

The outputs of the N-point Inverse Fast Fourier transform (IFFT) of $S_k$ are the OFDM signal samples over one symbol interval [13], or mathematically

$$s_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_k \exp\left(\frac{j \cdot 2\pi kn}{N}\right) \qquad (6.5)$$

The amplitude, or modulus, of OFDM signal $s_n$ is given by

$$|s_n = \sqrt{Re^2\{s_n\} + Im^2\{s_n\}}$$

(6.6)

Considering the phase of input signals, the companding function h(x) is given by

$$\begin{aligned} h(x) &= \operatorname{sgn}(x) F_{t_n|}^{-1}\left(F_{|s_n}(x)\right) \\ &= \operatorname{sgn}(x) \sqrt[d]{\alpha\left[1-\exp\left(-\frac{x^2}{\sigma^2}\right)\right]} \end{aligned} \qquad (6.7)$$

The positive constant $\alpha$ determines the average power of output signals given by

$$\alpha = \left(\frac{E\left[|s_n|^2\right]}{E\left[\sqrt[d]{\left[1-\exp\left(-\frac{|s_n|^2}{\sigma^2}\right)\right]^2}\right]}\right)^{\frac{d}{2}}. \qquad (6.8)$$

Where $\sigma^2 = E[|S_k|^2]/2$ is the common variance

So this constant determines the power OBR/IBR whose constant value is -12 under the case of limited bandwidth.

*A-Law Companding:*

The OFDM signal samples in real form after inverse fast Fourier transform (IFFT) [10] can be formulated as

$$s(n) = \frac{2}{\sqrt{N}} \sum_{k=1}^{\left(\frac{N}{2}\right)-1} \left\{a_k \cos\left(\frac{2\pi kn}{N}\right) + b_k \sin\left(\frac{2\pi kn}{N}\right)\right\} \qquad (6.9)$$

$a_k - j b_k$ is the transmitted data for the $k^{th}$ sub carrier and N is the IFFT size.

From the central limit theorem, the variance of the Gaussian distributed MCM signal can be easily determined as

$$\sigma_s^2 = \frac{2(N-2)}{N} P_s \qquad (6.10)$$

Where $P_s = E\{1/2(a_k^2 + b_k^2)\}$ is the signal power for each sub carrier.

The maximum peak value of OFDM signal is found as

$$A = (N-2)\sqrt{\frac{2P_s}{N}}. \qquad (6.11)$$

The A-law compressed OFDM signal in our proposed PAPR reduction technique is described by

$$s_c(n) = \begin{cases} \frac{\mu s(n)}{1+\ln \mu} & 0 \leq s(n) \leq \frac{A}{\mu} \\ \frac{A + A\ln\left(\frac{\mu s(n)}{A}\right)}{1+\ln \mu} & \frac{A}{\mu} \leq s(n) \leq A \end{cases} \qquad (6.12)$$

Where μ is the companding coefficient. So the maximum peak value determines the OBR/IBR ratio under band limited case whose value is -10.

*Linear Symmetric Transform (LST)*

With linear symmetrical transform [10], the transmitted signals may be expressed by

$$S'_{k,m} = u \cdot S_{k,m} + Sgn(S_{k,m}) \cdot v \qquad (6.13)$$

Where 0<u<=1 and 0<=v<=A are the transform parameters.

Further, the received signal is

$$R'_{k,m} = S'_{k,m} + n_{k,m} + q_{k,m} \qquad (6.14)$$

Where $n_{k,m}$ denotes the AWGN term with zero mean and variance $\sigma_0^2 = N_0/2$

Therefore the OBR to IBR ratio determined at the receiver using above equation and the constant value is -9 under band limited case.

*Non Linear Symmetric Transform (NLST)*

With NLST [10], the transmitted signals can be expressed by,

$$S'_{k,m} = \begin{cases} Sgn(S_{k,m}) \frac{M}{\ln(1+u)} \ln\left[1 + \frac{u}{M}|S_{k,m}|\right], & |S_{k,m}| \leq M \\ Sgn(S_{k,m}) \frac{v}{u}\left\{\exp\left[\frac{\ln(1+u)}{v} S_{k,m} - Sgn(S_{k,m})M\right] - 1\right\} + Sgn(S_{k,m})M, & |S_{k,m}| > M \end{cases} \qquad (6.15)$$

Where u>0 and 0<v<=A-M

By the inverse transform of the above equation, we get the received signal through which OBR to IBR ratio constant value is -14 under the band limited case.

*Non Linear Non Symmetric Transform (NLNST):*

With the assumption of any type of companding for NLNST. The transformed signals is expressed as

$$S'_{k,m} = Sgn(S_{k,m}) \frac{v}{\ln(1+u)} \ln\left(1 + \frac{u}{v}|S_{k,m}\right) \qquad (6.16)$$

Where u>0 and 0<v<=A

For the case of large signal-to-noise ratio (SNR), the received signals through the inverse transform can be approximated as

$$\begin{aligned} R_{k,m} &= Sgn(R'_{k,m}) \frac{v}{u}\left\{\exp\left[\left|R'_{k,m}\right| \frac{\ln(1+u)}{v}\right] - 1\right\} \\ &\approx S_{k,m} + \ln(1+u)\left[\frac{1}{u} + \frac{|S_{k,m}|}{v}\right](n_{k,m} + q_{k,m}). \end{aligned} \qquad (6.17)$$

The relevant OBR to IBR ratio under band limited case with receive and transmitted average power known the constant value is -13. By the above analysis we found that all the schemes not able to meet the stringent requirement

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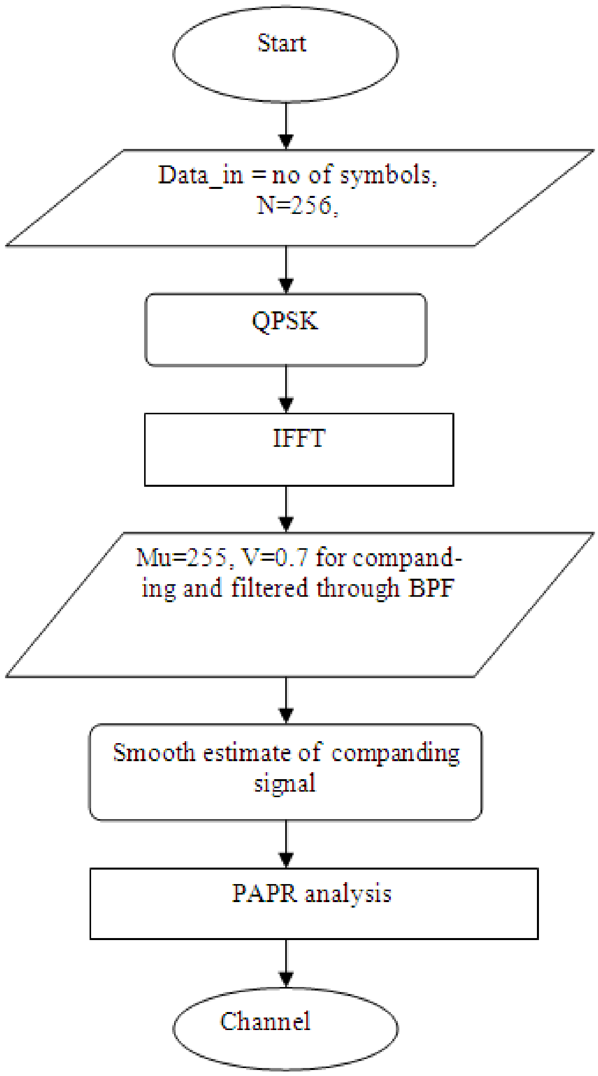
of OBR in order to prevent interference with adjacent channels and generally less than 1.

## HELPFUL HINTS

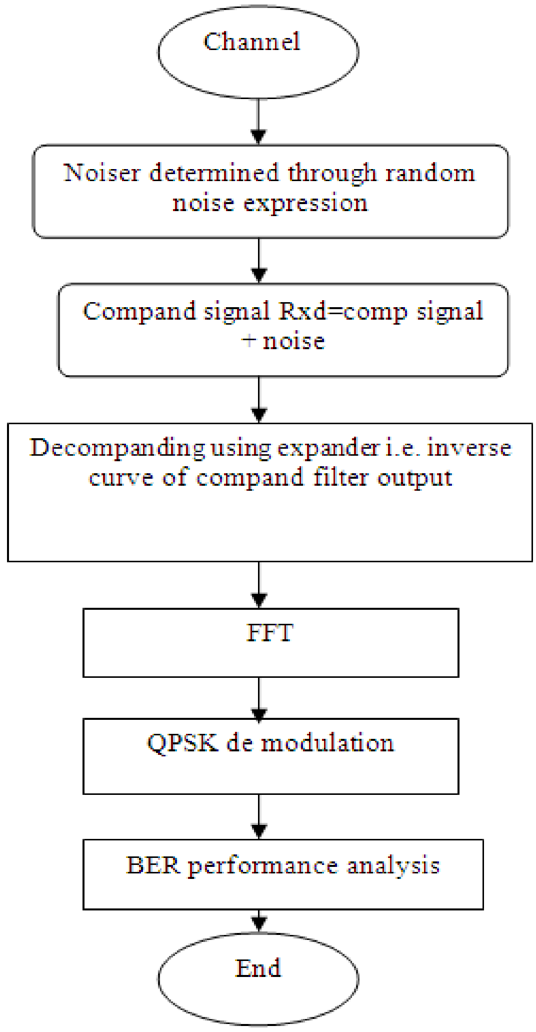
*Flow Chart of Process:*

*1) Implementation at Transmitter*




➢ The relevant OBR to IBR ratio under band limited case with receive and transmitted average power known the constant value is -13. By the above analysis we found that all the schemes not able to meet the stringent requirement of OBR in order to prevent interference with adjacent channels and generally less than 1[7]. So clearly we require filtering .we can use any kind of band pass filtering to filter out the OBR in the band limited conditions [7]. Typically the equip ripple band pass FIR filter with sufficient number of coefficients used. In case of companding, the BER performance depends on the in-band signal to noise ratio after decompanding at the receiver.

*2) Implementation at Receiver*




*Simulation Results*

Simulation was performed to measure the BER Vs SNR for various companding schemes with filtering and without filtering using symmetric method and verified PAPR calculation. The results were analyzed by taking following constraints N=256(no. of subcarriers), target PAPR=6.5DB, modulation scheme used QPSK. BER Vs SNR analysis also done for the proposed technique non symmetric method for modulation schemes QPSK and 8-PSK.comparison done between symmetric and non symmetric methods and PAPR calculated for allschemes.

*a) PAPR analysis*

PAPR calculations in fig. 6.1 for the signals undergone clipping and companding schemes (without filtering):

PAPR Symbol = (Peak Value)/(mean square value)

where Mean Square Value = (compsig* compsig')/(length (compsig)) and Peak Value = max (compsig*conj(compsig)

where

comp_sig'=compsig_real'+j*compsig_img'=smooth (comp_sig)

1. PAPR (Clipping) =2.2130db
2. PAPR symbol(A-Law) =7.1352db
3. PAPR symbol(Exponential) =6.6543db

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4. PAPR symbol(LST) =1.0007db
5. PAPR symbol(NLST) =1.857db
6. PAPR symbol(NLNST) =6.8069db

*Inference*

The BER performance analysis in clipping and companding schemes of non filtered case is not achieving the required constraints i.e. not able to meet the target PAPR=6.5db

PAPR calculations for the signals undergone various companding schemes (with filtering):

1. PAPR (Clipping) = 2.3673db
2. PAPR (A-Law) = 7.5785db
3. PAPR(Exponential)= 7.3613db
4. PAPR (LST) =1.0009db
5. PAPR (NLST) = 1.8923db
6. PAPR (NLNST) = 7.3877db

*Inference*

The BER performance analysis in clipping is same for filtered and non filtered case but in companding schemes there is a BER degradation when compared to clipping and not able to meet the require PAPR.

*b) PAPR Analysis*

PAPR calculations for the signals undergone various symmetric companding schemes QPSK (with filtering):

1. PAPR (Clipping) = 2.3673db
2. PAPR (A-Law) = 7.5785db
3. PAPR (Exponential)=7.3613db
4. PAPR(LST) =1.0009db
5. PAPR(NLST) = 1.8923db
6. PAPR(NLNST) = 7.3877db

*Inference*

The BER performance analysis in clipping is same for filtered and non filtered case but in companding schemes there is a BER degradation so from fig. 6.2 we infer that v cannot meet the require PAPR and this is same as for 8-PSK as shown in fig. 6.3.

PAPR calculations for the signals undergone various non symmetric companding schemes QPSK (with filtering):

1. PAPR (Clipping) = 2.3673db
2. PAPR (A-Law) = 6.5785db
3. PAPR (Exponential)=6.3613db
4. PAPR(LST) =2.0009db
5. PAPR (LNST)=2.8923db
6. PAPR(NLNST) = 6.3877db

*Inference*

The BER performance analysis in clipping is same for filtered and non filtered case and could not able to mitigate the BER degradation, but in non symmetric approach of companding schemes there is a BER performance improvement when compared to clipping and able to meet the target PAPR as shown in fig 6.2 and fig 6.3 using QPSK and 8-PSK respectively.

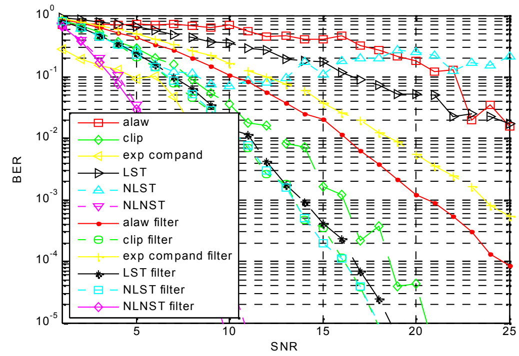


Fig.6.1. Performance Analysis of the Filtered and Non Filtered case

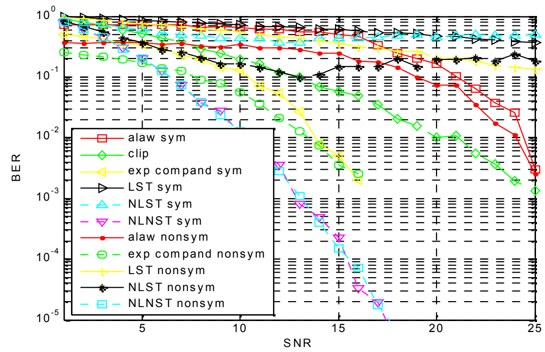


Fig.6.2. Performance Analysis of Symmetric and Non-symmetric Method with QPSK

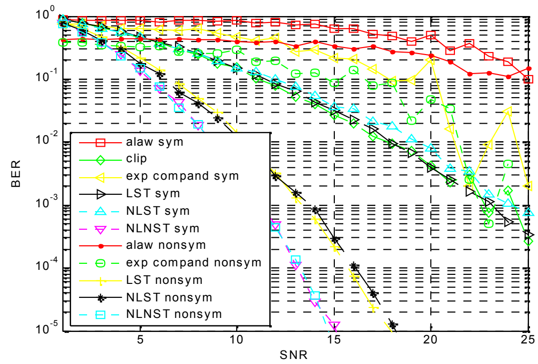


Fig.6.3. Performance Analysis of Symmetric and Non-symmetric Method with 8-PSK

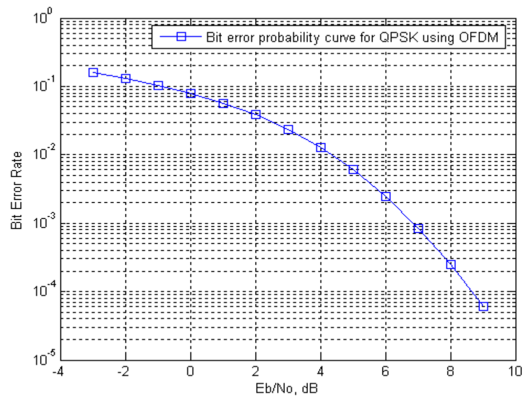


Fig.6.4. Performance Analysis of the Filtered and Non Filtered case- BER Performance curve for QPSK using OFDM

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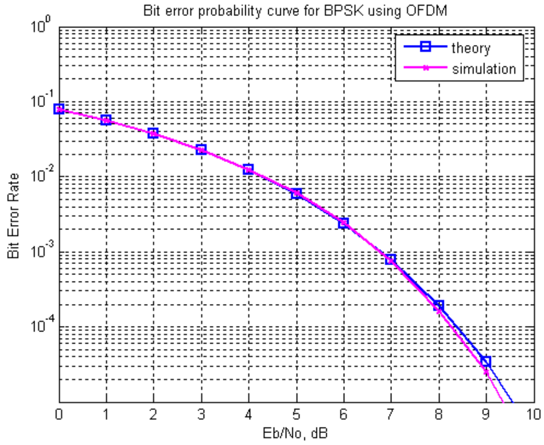


Fig.6.5. Performance Analysis of the Filtered and Non Filtered case- BER Performance comparison curve for BPSK using OFDM

## VII. Conclusion

The poor performance of companding schemes under band limited conditions is portraited. The impact of filtering and without filtering on various companding schemes and respective PAPR analysis infers that the required objective is met. A nonsymmetric companding method is used to improve the performance of this BER degradation in symmetric methods. Extensive simulation results and qualitative discussions have shown that the method used does perform better than previous symmetric method[16]. Main aspects of this research paper is to implement design a algorithm for following features like with comparisons of clipping and companding techniques, all the above simulation results show one common feature, with previous symmetric methods, achieved a better performance closely to clipping under band limited conditions, with proposed scheme.

The future scope of the project is likely to be that we can put forth the proposed technique using some other advanced mathematical method or method from any respective domain like networking, optical to have further more reduction in target PAPR

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