Comparison of SLM technique of PAPR reduction in OFDM with Non-linear companding technique

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ABSTRACT

One of the challenging issues for Orthogonal Frequency Division Multiplexing (OFDM) system is its high Peak-to-Average Power Ratio (PAPR). That is the time domain OFDM signal which is a sum of several sinusoids leads to high peak to average power ratio (PAPR). Numbers of techniques have been proposed in the literature for reducing the PAPR in OFDM systems. In this paper comparison of SLM technique of PAPR reduction with Non linear companding technique in terms of various parameter such as coding gain, bit error rate and SNR.

***Keywords* -** Complementary cumulative distribution function (CCDF), high power amplifier (HPA), Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR).

I. INTRODUCTION

Wireless communications has many advantages, such as speed, simplicity, mobility and flexibility, but in the same time it suffers from, inter-symbol interference (ISI) and multipath propagation (frequency selective fading). Supporting high data rates channel of the conventional single carrier system required various modulation techniques.

These days the OFDM technique is considered as a strong candidate for the fourth generation (4G) of mobile communication systems. OFDM has many advantages: such as, flexibility to the channel conditions without the need of channel equalization, robustness to the fading, and resistanceto multipath [1]. On the other hand, OFDM suffers a high Peak to Average Power Ratio (PAPR). A high PAPR makes the signal peaks move into the non-linear region of the RF power amplifier which causes signal distortion. A large PAPR increases the complexity of the analog-to-digital and digital-to-analog converters and reduces the efficiency of the RF power amplifier. Recently, researchers have discovered many techniques on PAPR reduction, for instances, clipping(7), coding(8), selected mapping (SLM) and companding technique. Non-linear companding technique prove to be most important in for reduction of PAPR by increasing the average power.

II. Peak to Average Power Ratio (PAPR)

In the orthogonal frequency division multiplexing (OFDM) the peak power might be much larger than the average power, due to adding up subcarriers coherently which resulting in large peak-to-average power ratio (PAPR). PAPR is a very important situation in the communication system because it has big effects on the transmitted signal. Low PAPR makes the transmit power amplifier works efficiently, on the other hand, the high PAPR makes the signal peaks move into the non-linear region of the RF power amplifier which reduces the efficiency of the RF power amplifier. In addition, high PAPR requires a high-resolution digital- to-analog converter (DAC) at the transmitter, high-resolution analog -to -digital converter (ADC) at the receiver and a linear signal. Any non-linearity in the signal will cause distortion such as inter-carrier interference (ICI) and inter symbol interference (ISI). The PAPR effect is shown in figure. 1.1. And it can be seen that the peak power is about 17 times the average power [4]. sequentially using 1, 2, 3, etc. The complementary cumulative distribution function (CCDF) is one of the most frequently used performance measures for PAPR reduction techniques, which denotes the probability that the PAPR of a data block exceeds a given threshold z. The CCDF of the PAPR of a data block of N symbols with Nyquist rate sampling is derived as

$$P(PAPR>z)=1-P(PAPR\leq z)=1-(1-e^{-z})^N \quad \text{eq-1}$$

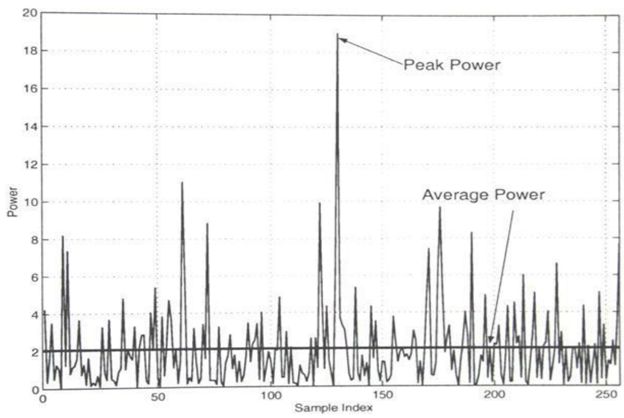

Figure 1.1 peak and average power

III. SELECTED MAPPING(SLM)

1.1 Introduction to Selected Mapping (SLM)

Selected Mapping (SLM) technique is the most promising reduction technique to reduce Peak to Average Power Ratio (PAPR) of Orthogonal Frequency Division Multiplexing (OFDM) system. The first SLM scheme was introduced by Bauml, Fischer and Huber in 1996 [8].The basic idea of this technique is based on the phase rotation. The lowest PAPR signal will be selected for transmission from a number of different data blocks (independent phase sequences) that have the same information at the transmitter. Figure 2.1 shows a block diagram of SLM scheme .

In SLM technique each data block will create U times phase sequences, if each mapping considered statistically independent, then CCDF of the Peak to Average Power Ratio (PAPR) in Selected Mapping (SLM) will be,

$$P(PAPR > z) = (1- (1 - e^{-z})^{N})^{U}$$

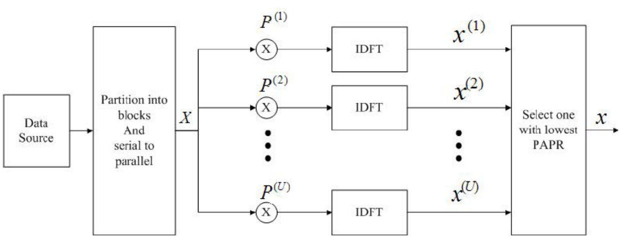

Figure 2.1 Block diagram of SLM

2.2 Power Savings through Selected Mapping

The average input power in the OFDM system need to be adjusted to decrease the affect of the distortion in the peak of the signals, to do so, an input backoff (IBO) needs to be applied. IBO is the measurement of how much reduction of the input power is needed, so that the desired output power can be achieved.

The amount of IBO applied is related to peak to average power PAPR and the efficiency , high PAPR result in increasing IBO and decreasing . IBO is equivalent to PAPR in certain probability. The efficiency of the power amplifier that is used in OFDM system can be given as

$$\eta = \frac{P_{out,avg}}{P_{DC}} \qquad \text{eq-2}$$

Class A amplifiers, for instance, are inefficient amplifiers, the efficiency range is between 10-25%, and they can increase their efficiency to 50% which is the maximum. Thus, an ideal linear power amplifier should be used to maintain the saturation point. This ideal power amplifier has the following condition,

$$\eta = \frac{0.5}{PAR} \qquad \text{eq-3}$$

Power saving can be defined as the the related power consumption P_{DC} to the efficiency η,

$P_{DC}= P_{out,avg} / \eta$ eq-4

Now by substituting eq-1 into eq-2,it can point out this result,

$P_{DC}= P_{out,avg} /1/(2PAR)$ eq-5

$P_{DC}= 2P_{out,avg}\, PAR$ eq-6

Therefore , power saving from efficiency to another can be written as follows

$P_{saving}=2P_{out,avg}(PAR_1-PAR_2)$ eq-7

To calculate saving gain G_s,let us indicate that the saving gain G_s as the ratio of savings power to the output power,

$G_s= P_{,saving} / P_{out,avg}$ eq-8

From eq-5 into eq-6,it can infer to the result that,

$G_s= 2 P_{out,avg}(PAR_1-PAR_2) / P_{out,avg}$ eq-9

Thus the saving gain G_s as the result of PAPR can be expressed as,

$G_s= 2 (PAR_1- PAR_2)$ eq-10

Figure 3 shows the performance of peak to average power ratio (PAPR) reduction of OFDM symbol by using selected mapping (SLM) schemes. That was achieved by using equation 1 where number of subcarriers N is set to 256 , with different values of phase sequences U (1, 2, 4, 8, and16). It is clear from the figure that by increasing the number of phase sequences U (SLM scheme) large PAPR reduction can be obtained. The main focus on here is the saving power through selected mapping, as it mentioned in the previous section the saving gain is the difference in peak to average power ratio. Table 1 gives an overview of several PAPR reduction performances corresponding to probability of clipping where N equal to 256. All values in the table are corresponding to the curves. It is clear from the table that, by increasing the phase sequences (SLM phase sequences) savings in gain is increased as well. Equation 8 infers that by increasing in saving gain, the power saving will increase. Thus, power saving can be achieved through selected mapping.

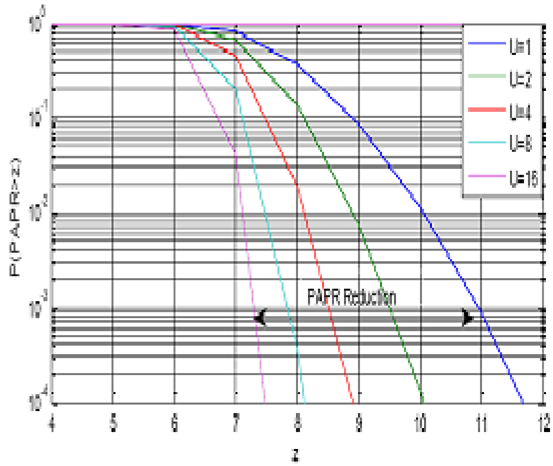

Figure3.PAPR Reduction for SLM where N=256 and U=1,2,4,8,16

Table 1. PAPR Reduction and savings gain using SLM

U (Phase Sequences)	PAPR (Peak to Average Ratio)	G_s (Savings Gain)
1 (No SLM)	10.9	0
2	9.6	2.6
4	8.6	4.6
8	7.9	6
16	7.4	7

II. Companding Technique(Non-linear)

The idea of companding comes, from the use of companding in Speech Processing. Since, the Orthogonal Frequency Division Multiplexing (OFDM) signal is similar to that of the speech signal, in the sense that large signals occur very infrequently, the same companding technique can be used to improve the OFDM transmission performance .The key idea of the Non-linear Companding Transform is to effectively reduce the Peak-to-Average Power Ratio (PAPR) of the transmitted or the companded Orthogonal Frequency Division Multiplexing (OFDM) signals by transforming the statistics of the amplitudes of these signals into uniform distribution. The uniform distribution of the signals can be obtained by compressing the peak signals and expanding the small signals. The process of companding enlarges the amplitudes of the small signals, while the peaks remain unchanged. Therefore, the average power is increased and thus the Peak-to-Average Power Ratio (PAPR) can be reduced.

3.1 PAPR FORMULATION FOR µ- *Law* AND MODIFIED *µ* -*Law* COMPANDING

In the companding technique, the compression of OFDM signals at the transmitter and expansion at the receiver, compression given by

$$y = V\frac{\log(1+\mu\frac{|x|}{V})}{\log(1+\mu)}sign(x)$$

Where *V* is the peak amplitude of the input and output signals specified for the µ- *Law* compander, and *x* is the instantaneous amplitude of the input signal. Decompression is simply the inverse of *y* .The companding algorithm as described by (3) amplifies the signals of lower amplitude with the peaks remaining unchanged.The modified companding profile called the peak ratio (PR),expressed as the ratio of peak amplitude V of the signal specified for the *µ* - *Law* compander to the peak amplitude of the actual signal to be companded i.e. given by

$$PR = \frac{\text{peak amplitude of the compressor}}{\text{peak of the actual signal}}$$

The transfer characteristics of the µ - *Law* compander involving the new parameter PR can be obtained through implementing above equations i.e.,

$$y = PR \times X_{peak} \times \frac{\log(1+\mu\frac{|x|}{PR\times X_{peak}})}{\log(1+\mu)}sign(x)$$

The following Fig.4 shows a standard companding profiles for different values of *µ* , and Fig.5 shows the modified companding profiles for different values of PR for a value of µ=255.

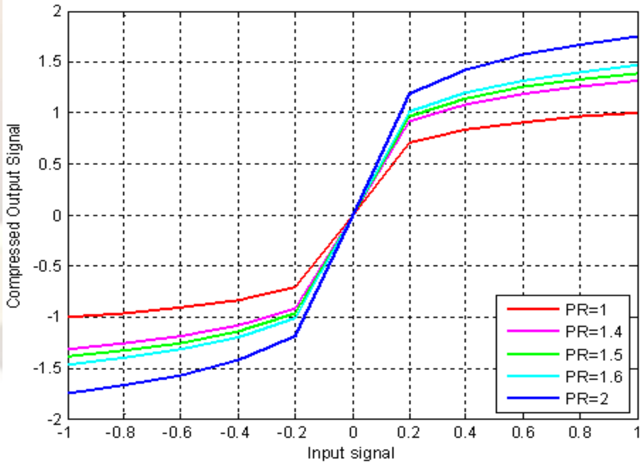

Figure 4. Companding profiles for different value of µ

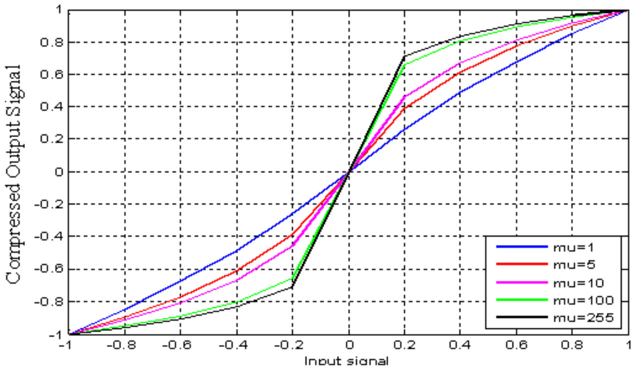

Figure 5.The modified companding profiles for different values of PR

Fig.4 and Fig.5 helps in understanding the difference between the profiles arising from variations in PR and variations in µ. The main difference between the two profiles is that varying µ will compress the higher amplitude signals and expand the lower amplitude signals, where as, varying PR will expand both the higher amplitude signals with lower gain and the lower amplitude signals with higher gain. Having a value of *PR* = 1 means no alteration to the companding and the companding curves would remain the same as those with *µ=255* shown in Fig.5.

Table2 shows PAPR reduction using Non-linear or exponential companding.Table3.shows simulation parameter using µ-law companding.

Different Techniques	PAPR (in dB)	CCDF
Original OFDM Signal	11.8	10^{-2} or 0.01
Exponential Companding Transform	4.5	10^{-2} or 0.01

Table2

Table3. Simulation parameter

SL. No.	Descriptions	Specification
01	Modulation scheme	QPSK / M=4
02	Number of sub-carriers	256/512
03	μ value	255
04	Channel	AWGN
05	Signal to Noise ratio	18 dB
06	Number of bits per symbol	1
07	Input signal power referenced to 1ohm	1 watts

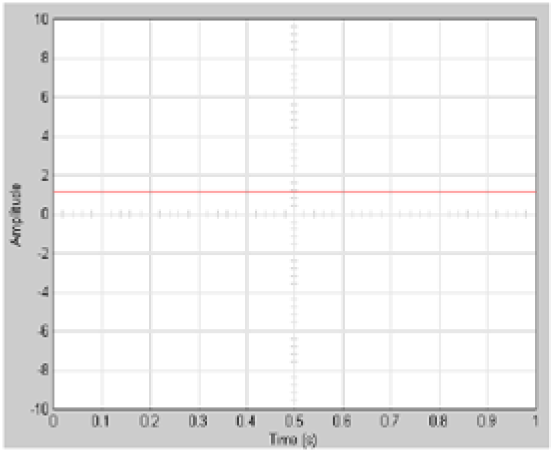

Figure 6 simulation result of µ law compressor output

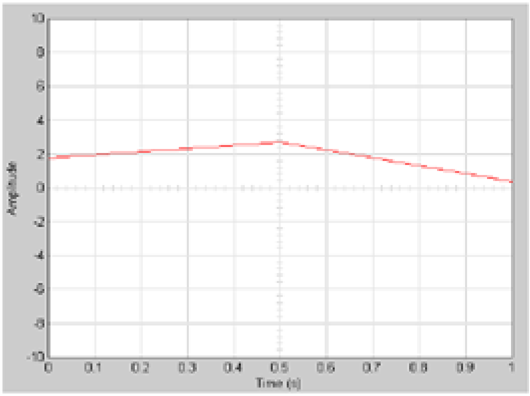

Figure 7 simulation result of µ law expander output

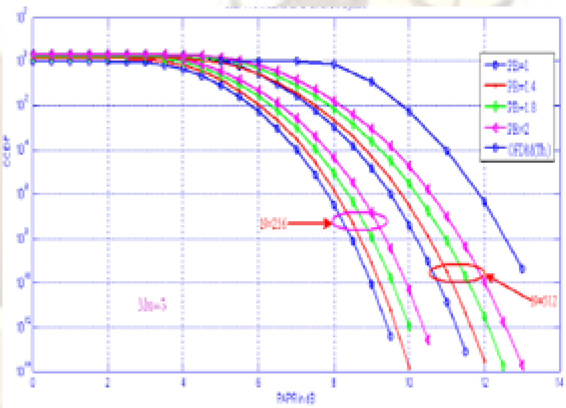

Figure 8 CCDF as function of µ and PR

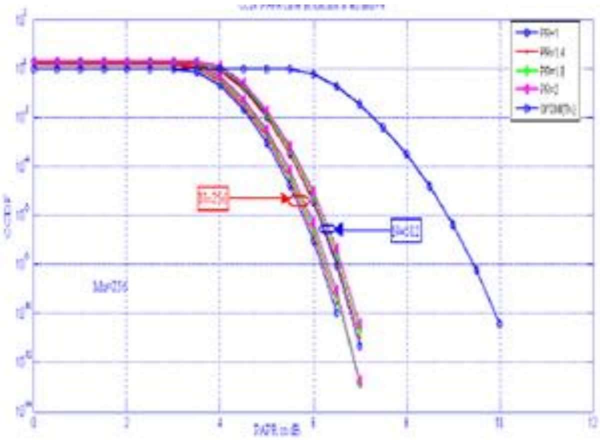

Figure 9. CCDF as function of µ and PR

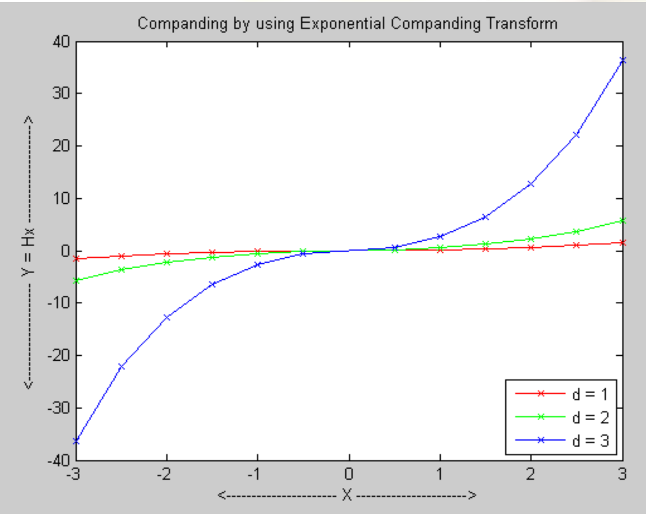

FIGURE10. COMPANDING OF OFDM SIGNAL BY USING EXPONENTIAL COMPANDING TRANSFORM

The original Orthogonal Frequency Division Multiplexing (OFDM) signal is converted into the companded signal by using the Exponential Companding Transform. The companded signal obtained by using the Exponential or Nonlinear Companding Transform is given by the equation

$$H(x) = sgn\,(x)\sqrt[d]{\alpha\left[1 - exp\left(-\frac{x^2}{\sigma^2}\right)\right]}$$

Where, h(x) – Companded Signal obtained by Exponential Companding Transform, sgn(x) -sign Function, α-Average Power of Output Signals, x-original OFDM signal.The average power of the output signals, denoted by α, is required in order to maintain the average amplitude of both the input and output signals at the same level.

The Non-linear or exponential Companding Technique improves the Bit Error Rate (BER) and minimizes the Out-of-Band Interference (OBI) in the process of reducing the Peak-to-Average Power Ratio (PAPR) effectively by compressing the peak signals and expanding the small signals. The improved BER transmits the data via a transmission channel with fewer errors, while the minimized OBI (5) reduces the effects caused by clipping. Hence, by reducing the Peak-to-Average Power Ratio (PAPR), the complexity of the Analog-to-Digital Converter (ADC) and Digital-to-Analog Converter (DAC) can be reduced. The reduced PAPR also increases the efficiency of the Power Amplifiers.

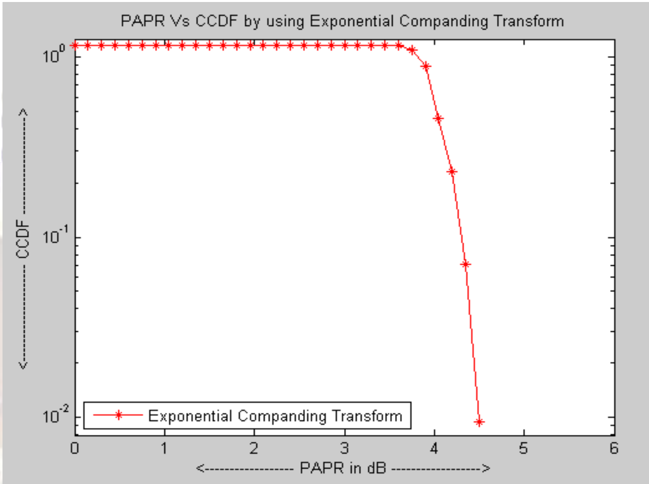

FIGURE10. PAPR VS CCDF BY USING EXPONENTIAL COMPANDING TRANSFORM

CONCLUSION

In this paper we have considered the problem of the PAPR reduction in OFDM system. The proposed PAPR reduction method is based on the companding method.The performance of OFDM system is simulated for modified µ-*Law* Companding, which is called as PR (Peak ratio), as this factor increases the PAPR goes on increases and it is also observed that as µ increases, there is a significant reduction in the PAPR value. And it is clear that by selecting the proper value of *µ* and PR, we can get the desired PAPR value. But in case of SLM technique power saving can be achieved. The simulation results indicated that large PAPR reduction is possible with selected mapping scheme, and showed how by increasing the number of phase sequences
µ large PAPR reduction can be obtained effectively.One of the major advantage of Non-linear companding of original OFDM signal amplitude is that it reduces spectrum side lobes without increasing system complexity and bandwidth.

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