An Efficient PAPR Reduction Scheme for OFDM System using Peak Windowing and Clipping

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***Abstract*—OFDM (Orthogonal frequency division multiplexing) has become the most attractive modulation technique for the majority of new generation of wireless communication systems which require high speed data transmission. High PAPR (Peak to average power ratio) is a major problem of this modulation technique. High PAPR reduces the power efficiency of the transmitter RF power amplifier. This paper presents an overview on the popular PAPR reduction techniques in OFDM system; by firstly investigating the peak windowing method, the clipping method by highlighting the major parameters with high effect on PAPR and BER performance, and finally a combination of these two techniques with an emphasis on the PAPR reduction. The results of simulation using MATLAB shows a PAPR reduction of 4dB at the probability of $10^{-3}$and improvement of signal to noise ratio SNR of about 2dB at the probability of 10^{-3}.**

Keywords*— Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Ratio (PAPR), Complementary Cumulative Distribution Function (CCDF), Bit error rate, SNR.

I. INTRODUCTION

OFDM is very appropriate for high speed wireless transmission systems due to its robustness against multipath propagation and efficient use of bandwidth [1]. OFDM has been also used for a number of standards like DAB (Digital Audio Broadcast) and DVB (Digital Video Broadcast) standards [2]. One dominant problem of OFDM based systems is its high PAPR (peak to average power ratio) which bounds its applications to a certain degree. OFDM signal consist of a number of subcarriers independent to each other [3], resulting in high peak to average power ratio [4]. PAPR demands high dynamic range in ensuring amplification, especially for transmitter power amplifier. If not properly biased, high PAPR drives the power amplifier (PA) into saturation by producing non-linear amplification of large amplitude signals. To accommodate such larger PAPR signals the PA must operate to a point that is not efficient in terms of power and BER (Bit Error Rate) [5-6].

The nonlinear distortion generated on the communication channel when the high PAPR signals amplified by PA with finite amplitude ranges and nonlinear response, creates out-of-band radiation which invoke to co-channel interference among users and self- interference caused by in-band distortion. A reasonable question to ask about using nonlinear PAs instead of linear PAs, is that linear power amplifier are costly and power inefficient. Thus PAPR must be kept at minimum level to ensure efficient use of power and cost of practical system implementation [7-8].

Numerous methods have been proposed to reduce PAPR. Such as peak windowing, clipping [4], partial ~~transmit~~ sequence (PTS) [7], [9], Reed-Muller codes [5], tone injection, tone reservation [7], interleaving [10], etc. The computation complexity, BER and data rate are some of trade-offs of these techniques.

Clipping is the simplest one; this method clips the signal amplitudes exceeding a certain fixed level, without introducing any change in the signal parameters. However clipping suffers from out-of-band radiation due to peak regrowth when not filtered out. Peak windowing, on the other hand, results into a reduction of the signal out-of-band radiation and does not cause any peak regrowth. By considering these drawbacks; a new scheme that combines the peak windowing with clipping is proposed in this paper and shows a dramatic good performance over conventional peak windowing and clipping.

II. MATHEMATICAL EXPRESSION OF PAPR IN OFDM SYSTEM

OFDM signal in its complex form can be expressed as:

$$S(t) = \sum_{n=0}^{N-1} g_n e^{j2\pi nt/T} \quad 0 \le t \le \mathrm{T} \qquad (1)$$

where N, T, and g_n are number of subcarriers, symbol time, and transmitted information in the n^{th} sub-channel/subcarrier.

The PAPR of the OFDM signal is defined as

$$PAPR = \frac{\max\{|s(t)|^2\}}{E\{|s(t)|^2\}} \quad 0 \le t \le T \qquad (2)$$

where $\max\{|s(t)|^2\}$ is maximum power of the signal and $E\{|s(t)|^2\}$ is average power of the signal.

A. PAPR REDUCTION APROACHES

High PAPR pushes the system power amplifier into saturation, creating interference between subcarriers and disturbing the signal spectrum. To prevent the power amplifier from operating into non-linear region [6], it vital to reduce system peak to average power ratio of the signal to be transmitted. While reducing the PAPR attention must be taken as some of PAPR reduction techniques may also result into in-band distortion and out-of-band radiation as well as to system BER degradation [6].

Many PAPR reduction approaches have been proposed such as peak windowing, clipping and filtering, selected mapping (SLM), partial transmit, etc. In this paper, we have been interested on two signal distortion techniques [11], peak windowing and clipping, which simply reduce or clip the high peak amplitude of the signal by slightly introducing distortion to the spectrum of the signal.

1) CLIPPING

Clipping is the simplest technique which bounds the signal peak to a certain fixed threshold level prior to sending the signal to power amplifier [10]. Clipping is independent of number of subcarriers and provides easy implementation. In other words, clipping technique clips the peak of the input OFDM signal to a fixed threshold when the amplitude of the signal exceeds this fixed threshold value and passes the input signal without any change on its phase when the signal amplitude is equal or less than the clipping threshold value [1], [4], [11].

The clipped signal can be mathematically expressed as:

$$B(x) = \begin{cases} X & \leq C_L \\ C_L & else \end{cases} \tag{3}$$

where B(x), C_L, and X are clipped signal, clipping level, and input signal respectively.

The modified PAPR resulting from clipping can be expressed as

$$PAPR = C_L^2 / E\{|B(x)|^2\} \tag{4}$$

Thus clipping signal level (C_L) plays an important role in reduction of PAPR, as it is evident from (4).

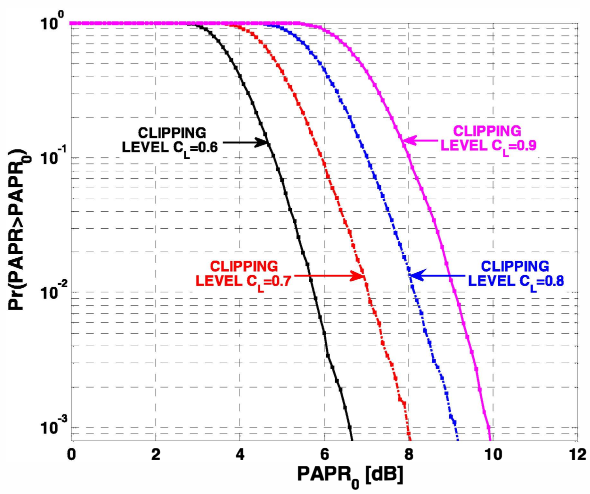

Fig. 1. Comparison of CCDF with different clipping threshold values.

Fig. 1 shows the effect of clipping threshold level on PAPR, after many simulations it has been found that the larger the value of C_L, the smaller reduction of the PAPR or in other words it can be said that the smaller the value of C_L, the larger the reduction of PAPR (Table I). But as it can be observed from Table II and Fig. 2; the larger the clipping threshold value, the less peak amplitudes are clipped and therefore leads to a better BER performance, but on other hand, the smaller C_L results in BER performance degradation, Hence the clipping threshold value must be wisely chosen for optimum performance of PAPR and BER.

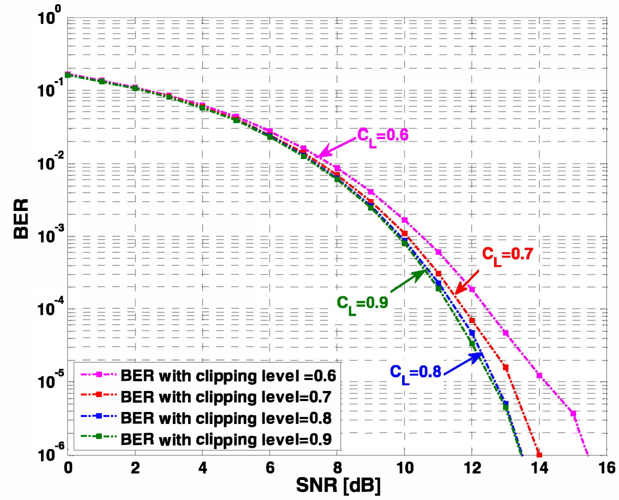

Fig. 2. BER Vs SNR using different clipping Threshold levels.

TABLE I. COMPARISON OF PAPR AND CCDF AT DIFFERENT CLIPPING THRESHOLD VALUES (CL)

Clipping threshold(C_L)	CCDF at $PAPR_0$= 5dB	CCDF at $PAPR_0$= 8dB
C_L=0.6	0.0680	0.0000
C_L=0.7	0.4326	0.0009
C_L=0.8	0.9061	0.0150
C_L=0.9	0.9988	0.1028

TABLE II. BER VS SNR VALUES USING DIFFERENT CLIPPING THRESHOLD VALUES (CL)

Clipping threshold (C_L)	BER at SNR= 5dB	BER at SNR= 10dB
C_L=0.6	0.0420	0.0017
C_L=0.7	0.0392	0.0011
C_L=0.8	0.0382	0.0009
C_L=0.9	0.0379	0.0008

2) PEAK WINDOWING

In peak windowing, a window function is applied to the signal where there exist large signal amplitude and multiplying the signal with the window function in such a way that the signal with high amplitude peak fall in the valley of the window function while signal samples with lower amplitude align themselves with large amplitude segment of the window function [12]. Hann, Hamming, and Kaiser are commonly used window functions [5], [8], [13]. Clipping and peak windowing techniques are characterized by very attractive characteristics as their implementations minimize the system complexity; also these techniques are independent of number of subcarriers [11].

By assuming that the envelope of the signal to be transmitted as $S_E(t)$, peak windowing method multiply these envelope with a weighting function f(t). Thus, the peak windowed signal $S'_E(t)$ can be expressed as:

$$S'_E(t) = S_E(t) * f(t) \tag{5}$$

where weighting function, f(t), is given by

$$f(t) = 1 - \sum_{t=t'}^{L} \alpha * W(t - t') \tag{6}$$

where W(t), t', L, and α are window function, the position or location of maximum (large peak) of the envelope $S_E(t)$, window length, and weighting coefficient, respectively. The weighting function is chosen as

$$\alpha = \frac{(S_E(t) - Cl)}{S_E(t)} \tag{7}$$

Hanning window was used during this study due to its better performance observed after extensive simulations and mathematical analysis. Hanning window is given by

$$W_{hn}(t) = 0.5(1 - \cos(\frac{2\pi t}{T-1}))0 \leq t \leq T \tag{8}$$

In proposed technique, OFDM signal after being peak windowed, a hard limiter is applied to eliminate the possible remained high peak amplitudes.

To preserve the spectrum of transmitted OFDM signal and enhance the PAPR and BER performance attention must be taken while choosing of window function as well as window length. Theoretically, the window should be as narrow as possible for preserving the signal spectrum. On the other hand, a very short window leads to many multiplications and more searches of high peak amplitude signals resulting in computation complexity and take more simulation time. On the other hand, a longer window function would affect more signal samples which results in BER performance degradation. Hence, window function and window length must be wisely chosen by considering the system PAPR and BER performance. The results drawn after extensive simulation experiments, it has been found that window function of L=8 to be the appropriate choice for optimum PAPR and BER performance.

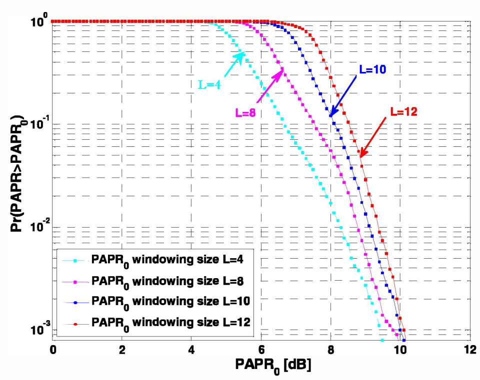

Fig. 3. Comparison of CCDF with different window sizes.

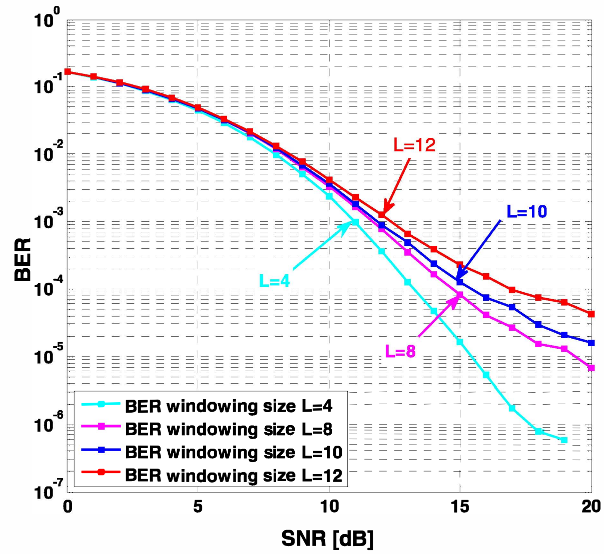

Fig. 4. BER versus SNR using different window sizes.

Table III gives comparison of the results drawn from the curve showing the effect of different window sizes on CCDF performance for PAPR reduction using peak windowing method (Fig. 3).

TABLE III. COMPARISON OF PAPR AND CCDF VALUES FOR DIFFERENT WINDOW SIZES (L)

WINDOW SIZE (L)	CCDF at $PAPR_0$= 5dB	CCDF at $PAPR_0$= 8dB
L=4	0.7702	0.0170
L=8	0.9971	0.0549
L=10	0.9998	0.1196
L=12	1.0000	0.2833

Table IV gives comparison of the results drawn from the curve showing the effect of different window sizes on BER performance (Fig. 4).

TABLE IV. COMPARISON OF BER VALUES USING DIFFERENT WINDOW SIZES (L)

WINDOW SIZE (L)	BER at SNR= 5dB	BER at SNR= 10dB
L=4	0.0442	0.0023
L=8	0.0472	0.0033
L=10	0.0476	0.0036
L=12	0.0493	0.0041

III. PROPOSED SCHEME

In this study a combination of peak windowing and clipping methods is proposed (Fig. 5). The randomly generated binary sequence data is firstly mapped into QPSK symbols, oversampled and IFFT module is used to obtain the interpolated OFDM signal. The peak windowing along with clipping is employed to eliminate high peak values of the power of the signal for PAPR reduction.

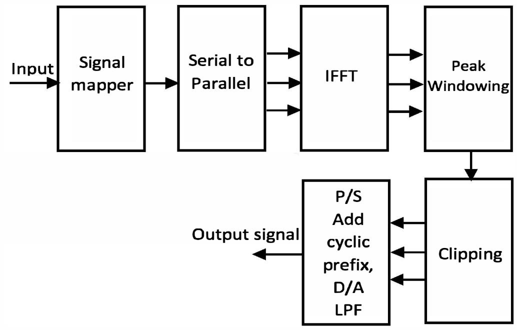

Fig. 5. Proposed scheme for PAPR reduction in OFDM system.

A. PEAK WINDOWING ALONG WITH CLIPPING SCHEME

Firstly, the peak windowing approach is used in which a window function is applied to the signal where the signal envelope exceeds the threshold level. Windowing results in smoothed version of OFDM signal and the possible remained high peak amplitude signals are hard limited by clipping approach [12]. The intention of combining peak windowing method with clipping method is to obtain lower PAPR and to improve BER performance of OFDM system compared to conventional peak windowing and clipping methods.

B. SYSTEM PARAMETERS USED FOR SIMULATIONS

In the present work, an OFDM system with 256 subcarriers, 2 bits/symbol was considered and modulated using QPSK. The output of modulator is oversampled, and then passed through IFFT module which perform the OFDM modulation implementation. The peak window along with clipping was used to eliminate the peak values of the power.

To efficiently acquire signal peaks and accurate computation of the peak to average power ratio (PAPR) of the OFDM system, an oversampling factor of 4 has been taken, and this factor was found to be sufficient to detect signal high peak amplitudes accurately. Selection of proper window size is of utmost importance. After many simulations by assuming that the total energy of the system is equally distributed among subcarriers it has been found that a Hanning window with length of 8 to be an appropriate choice for better system performance for PAPR reduction.

TABLE V. SIMULATION PARAMETERS

PARAMETER DESCRIPTION	
Number of subcarriers	256
Bits per symbol	2
Oversampling rate	4
FFT size	1024
Number of OFDM block	10000
Clipping level	0.8
Window function	Hanning window
Window length	8
Modulation	QPSK
Channel	AWGN

C. SIMULATION RESULTS

A comparison of combination of peak windowing with clipping approach was carried out in terms of PAPR and BER performance, with different possibilities of choices for clipping levels, window function types and modulation techniques, all these toward the better performance of PAPR reduction of the system. The simulation results given in this section was obtained by using the system and channel parameters as given in Table V.

Fig. 6 shows the CCDF performance of PAPR of all schemes used during this study. Here, the probability of OFDM symbol to exceed a given PAPR is shown by CCDF (complementary cumulative distribution function).

By simple observation from the results shown in Fig 6, it is evident that the proposed method provides a better CCDF performance for PAPR reduction over peak windowing alone and clipping alone. The proposed scheme which combines peak windowing with clipping provides a PAPR reduction of about 4dB at the probability of 10^{-3} over original or conventional OFDM signal.

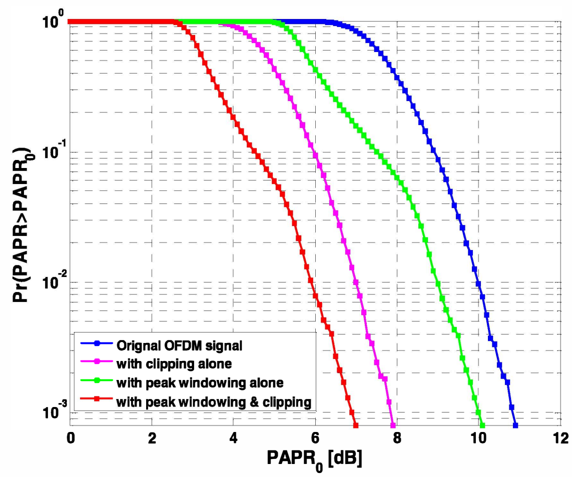

Fig. 6. CCDF performance of PAPR.

As it has been mentioned; the window size and clipping level are the most important parameters that affect PAPR reduction and SNR performance of the OFDM signal. Hence, the appropriate choice of these two parameters is vital for the better performance of the OFDM system.

As it is shown in Table VII, the proposed scheme gives a much better performance of about 1dB and 3dB of PAPR reduction over clipping alone and peak windowing alone methods, respectively.

Fig. 7 shows the BER versus SNR plots for the proposed scheme. The performance of proposed method compared with that of peak windowing alone, clipping alone and original OFDM signals over Additive White Gaussian Noise (AWGN) channel is shown in Table VIII. The results show BER improvement of about 4.5 dB at 10^{-4} of the proposed method over original OFDM signal.

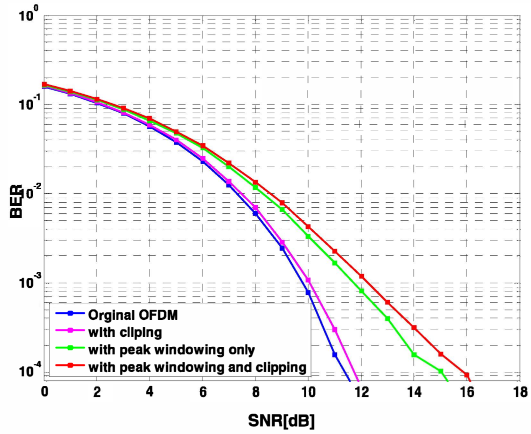

Fig. 7. BER performance.

Observation of the simulation results also indicate that the proposed scheme leads to improvement of SNR reduction of about 2dB at 10^{-3} BER probability and about 4dB SNR improvement at 10^{-3} BER probability. The comparison of the performance of the proposed method with clipping and peak windowing methods shows that the proposed method gives SNR improvement of about 2dB at 10^{-3} BER probability over clipping technique. And as it is shown in Fig. 7, the proposed method gives a better SNR performance over peak windowing method with little sacrifice in BER.

D. SUMMARY OF SIMULATION RESULTS

Table VI and Table VII summarize the CCDF and BER performance for various techniques of PAPR reduction in OFDM system.

TABLE VI. CCDF PERFORMANCE FOR DIFFERENT PAPR REDUCTION METHODS

METHOD	**CCDF at PAPR$_0$ (5dB)**	**CCDF at PAPR$_0$ (10dB)**
Original OFDM signal	1.0000	0.3709
Peak windowing	0.9828	0.0627
Clipping	0.4288	0.0006
Proposed	0.0596	0.0000

TABLE VII. BER FOR DIFFERENT PAPR REDUCTION TECHNIQUES

METHOD	**BER at SNR (5dB)**	**BER at SNR (10dB)**
Original OFDM	0.03774	0.00084
Peak windowing	0.03926	0.00319
Clipping	0.04730	0.00110
Proposed	0.04971	0.00395

IV. CONCLUSION

In this paper, proposed scheme for PAPR reduction of OFDM signals has been presented. A detailed simulation has been carried out for proper choice of system parameters, towards the better performance of the proposed scheme for PAPR reduction, the proposed method which combines peak windowing with clipping method has shown a significant PAPR reduction and signal to noise ratio improvement over peak windowing and clipping methods.

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