Thesis Title: ‘’ Reduction of Peak average Power Ratio in Orthogonal Frequency Division Multiplexing using Peak Windowing and Clipping Techniques’’.

Submitted by

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Thesis Title: ‘’ Reduction of Peak average Power Ratio in Orthogonal Frequency Division Multiplexing using Peak Windowing and Clipping Techniques’’.

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A dissertation submitted in partial fulfilment of the requirements for the degree of

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Supervisor: Dr. MUSABE Richard

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Declaration

I declare that this Dissertation contains my own work except where specifically acknowledged

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Signed………………………………………..

Date…………………………………………..

Certificate

This is to certify that the project work entitled ‘’ Reduction of Peak average Power ratio in Orthogonal frequency division using peak windowing and clipping techniques ‘’ is a record of original work done by BOBO MAFREBO Lionel with the registration number 216350433 in partial fulfilment of the requirement for the award masters of science in Information Communication and Technology of College of Science and Technology, University of Rwanda during the academic year 2016-2017.

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Abstract

The frequency division multiplexing (OFDM) has been used in wireless local area network, digital audio broadcasting and in 4G mobile communication. The techniques present a high data transmission, efficient use of bandwidth and also reduce inter symbol interference. Besides the bandwidth efficiency and high data transmission of the OFDM, a high peak to average power ratio (PAPR) is a major impairment to the scheme; large peaks due to sinus waves in inverse fast fourrier transformer (IFFT), limited word length which lead to saturation, frequency errors, carrier phase noise and timing error among others reduces the power efficiency at the transmitter side and lead to an inefficiency of the OFDM scheme. In order to respond to the problem of high PAPR two techniques are proposed; the peak windowing and the clipping techniques. Peak windowing consist of multiplying the envelop of OFDM signal with a window function; when the amplitude of the envelop of the OFDM signal exceeds a threshold, a window function is applied to the envelop of the OFDM signal to eliminate the peak amplitude; three window techniques were considered in the reduction of PAPR; the Hamming, Hanning and Kaiser . Another technique we considered in this research work is the clipping techniques where we limit the maximum of transmit signal to a specified level and evaluate the performance of the BER.

As results, when comparing the effect of clipping technique in OFDM, the result indicated that clipped signal has less peak average power ratio compare to the unclipped signal. The effect of clipping ratio in the ODFM system was also been investigated and found that when less value of threshold clipping level improve the PAPR but affect the BER. The complementary cumulative distribution function and bit error rate were used to measure the reduction of PAPR in OFDM using the two proposed techniques; Peak windowing and clipping.

Keywords: PAPR, Peak windowing, Clipping, CCDF and BER

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List of acronyms

4G LTE: 4th Generation Long term evolution

AWGN: Additive white Gaussian Noise

BER: Bit error rate

BPSK: Binary Phase shift keying

OFDM: Orthogonal frequency division multiplexing

CCDF: Complementary cumulative distribution function

FFT: Fast fourier transformer

IFFT: Inverse fast fourier transformer

MIMO: Multiple input multiple ouput

SLM: Selected Mapping

QPSK: Quadrature phase shift keying

PSK: Phase shift keying

HPA: High power amplifier

IDFT: Inverse discrete fourier transformer

SNR: Signal to noise ratio

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Chapter 1 Introduction

The higher demand for data transmission in mobile communication has increased consistently. OFDM system provided high bandwidth efficiency and high data rate in both wireless and wired communication, digital audio broadcasting and in digital video broadcasting. OFDM has gained interest in 4th generation wireless communication. The systems uses multiple transmit and receive antennas to improve link reliability and data rates. Link reliability is obtained through transmit and receive diversity and leads to improve coverage [1]. The high data rate multiplexing is obtained through spatial multiplexing where independent data streams are transmitted in parallel over different transmit antennas. The basic principle of OFDM is to split a high data rate streams into a number of lower data streams in parallel using several orthogonal sub carriers. When the subcarriers have appropriate spacing and satisfy the orthogonality, then their spectra will overlap [2].

When signal in OFDM is transformed to time domain by the inverse fast fourier transformer, the output is the summation of the subcarriers which are add up and as a results in higher peak N times higher than the average power of the subcarrier. The higher peak average power ratio degrade the performance of the OFDM system with implication in the radio frequency and force the system to operate in the nonlinear region and reducing the efficiency of the high power amplifier.

OFDM offers many advantages over carriers' modulation; however, the major difficulty with the scheme is the high peak average power ratio (PAPR) that distorts the signal if the transmitter contains nonlinear components such as power amplifier. Researchers described several PAPR reduction techniques such as block coding techniques, selected mapping (SLM), Peak Windowing, clipping, etc.

1.1 Overview of OFDM

The orthogonal frequency division multiplexing is a technique which is based on multicarrier modulation (MCM) and frequency division multiplexing (FDM). It is considered as a modulation or multiplexing method. The idea behind this scheme is to divide the signal bandwidth into parallel subcarrier. Unlike traditional MCM system, where subcarriers are non-overlapping; OFDM uses subcarriers which are orthogonal. The information is easily sent parallel overlapping subcarriers from which information can be extracted individually. This characteristics help to reduce interference caused by neighboring carriers and make OFDM efficient [3]

An orthogonal frequency division multiplexing represents the sum of subcarriers that modulated by the phase shift keying (PSK) or by the quadrature amplitude modulation (QAM) signals.

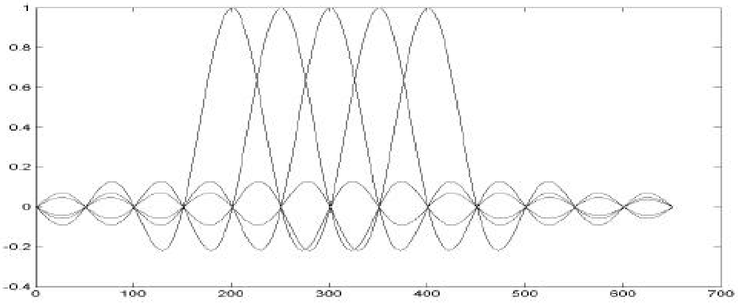


Figure 1.1: Frequency spectrum of OFDM subcarrier signals [3]

The baseband formulation of the OFDM signal is expressed as [3]

$$S\ (t) = \sum_{i=-\frac{N}{2}}^{\frac{N}{2}-1} \mathrm{di} + \frac{\mathrm{N}}{2} e^{(j2\pi} \mathrm{i}/\pi(t - ts)) \qquad (1.1)$$

where $ts \leq t \leq ts + T$

$S\ (t) = 0,\ t < ts$ or $t > ts + T$

d= transmitted symbol

N= Number of subcarriers

T= symbol duration

ts = starting time of the OFDM symbol.

The pass band OFDM signal S (t) contains the in phase and quadrature components that correspond to the term multiplied by the cosine and sine of the desired carriers.

From figure 2, the parallel streams are generated the inverse discret fourier transformer operator substitutes the local subcarrier oscillators.

The IDFT operation is described as [4]

$$F(n) \xrightarrow{IDFT} \mathrm{f}(\mathrm{k}) \qquad (1.2)$$

This expression is described as

$$f(k) = 1/\sqrt{N} \sum_{n=0}^{N-1} F(n) e^{j2pkn/N} \qquad (1.3)$$

The guard interval (called cyclic prefix) is the common guard interval and eliminate the inter block interference. The delay visions of the transmitted waveform are found at the receiver, without the GI the waveforms would interfere with each other.

1.2 MIMO - OFDM and symbol creation

The multiple input multiple output (MIMO) is used to describe a range of systems with multiple transmit and/ or received antennas. Depending on the relationship between the signals transmitted from different antennas schemes is used to either increase the overall capacity of the system or to reduce the probability of outage. Because wireless channels usually introduce significant multipath dispersion, MIMO is often combined with OFDM. The technique has also been shown to give significant benefit across a range of optical systems. Indoor optical wireless can be used to increase the probability of line of sight between transmitter and receiver [4]

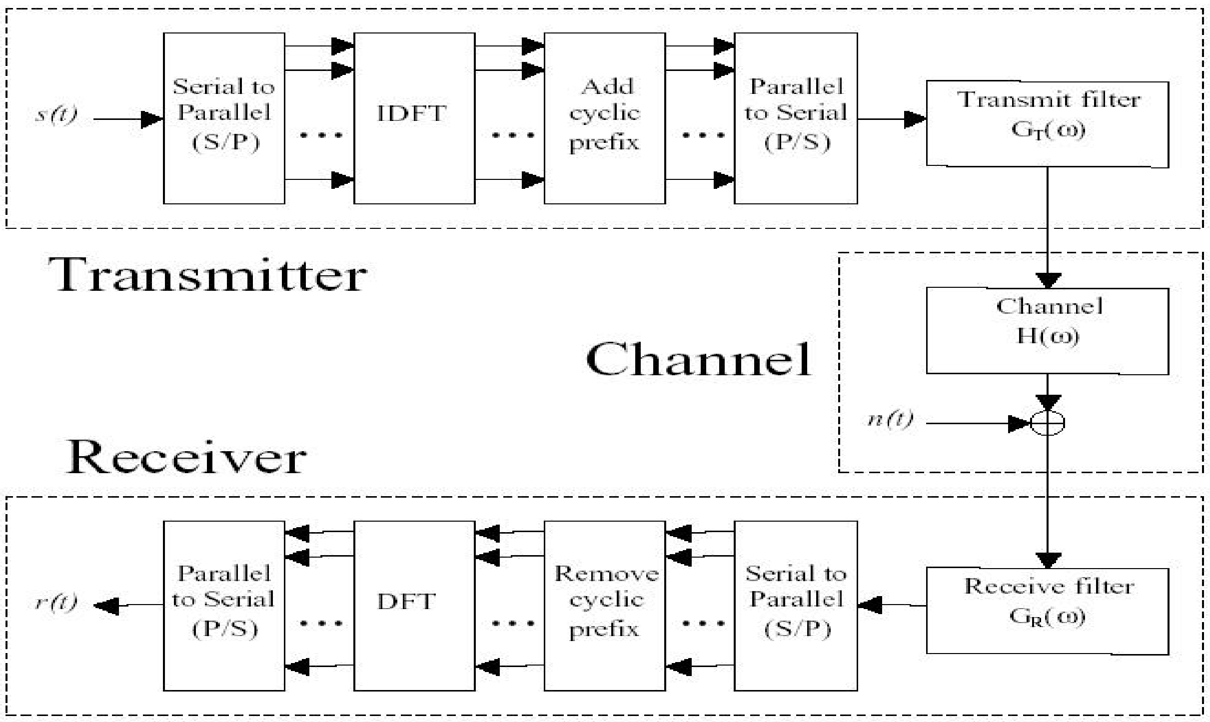


Figure 1.2: OFDM System Model [4]

The OFDM symbol is generated in the digital domain before the transmission. Serial data is first mapped using the common methods (BPSK, 16-QAM). The data is converted into N parallel streams which are to be converted into OFDM symbol.

The OFDM symbol is expressed by

$$x_k = \sum_{n=0}^{N-1} a_n \, e^{j2\pi kn/N} \qquad (1.4)$$

Where a_n is the data sysmbol on the n^{th} carrier and equation (1.4) is the equivalent of the N- point inverse discrete Fourier transform (IDFT).

1.3 Orthogonality

The use of orthogonal subcarriers allowed the subcarrier's spectra to overlap, thus increase the spectra efficiency. As long as orthogonality is maintained, it is possible to recover the individual subcarriers' signals despite their overlapping spectrums. If the product of two deterministic signals is equal to zero, these signals are said to be orthogonal to each other.

To be orthogonal, the time averaged integral product of two signals should be zero.

$$1/\mathrm{T}\int_{t1}^{t1+T} f_k\ (\mathrm{t})\ \mathrm{x}\ f_l\ (\mathrm{t})\ \mathrm{dt} = 0 \text{ if } \mathrm{k} \neq l \qquad (1.5)$$

Where f_k (t) and $f_l\ (t)$ are any two signals overtime interval [t_1, t_1 + T]

T is a signal time period.

The mathematical representation of Orthonormality of two signals is expressed as [5]

$$1/\mathrm{T}\int_{t1}^{t1+T} f_k\ (\mathrm{t})\ \mathrm{x}\ f_l\ (\mathrm{t})\ \mathrm{dt} = 1 \text{ if } \mathrm{k} = l \qquad (1.6)$$

For the orthonormal, the time averaged product of two signals is one.

If consider equation (1) and (2), the orthogonality for the OFDM system is expressed as

$$\frac{1}{T}\int_{0}^{T} e^{j\,2\pi f k(t)} * e^{-j2\pi f l(t)}\, dt$$

$$=\frac{1}{T}\int_{0}^{T} e^{j\,2\pi k(t)/T} * e^{-j2\pi l(t)/T}\, dt$$

$$=\frac{1}{T}\int_{0}^{T} e^{j\,2\pi(k-l)t/T}\ \mathrm{dt} \qquad (1.7)$$

Solving the equation (1.6) ;

$$=\frac{1}{T}\int_{0}^{T} e^{2\pi f k t} * e^{-j2\pi f l t}\, dt = \ 0\ ¥\ \mathrm{k} \neq l \text{ and } 1\ ¥\ \mathrm{k} = l$$

1.4 Application of OFDM and limitation

The application of OFDM for wire line communications was pioneered by Coffi and others at standford who demonstrated its potential as a modulation technique for digital subscribers loop (DSL) application [6]. OFDM is the basis of many practical telecommunications standard including wireless local area network, fixed wireless, television and radio broadcasting in different part of the world.

The orthogonal frequency division multiplexing is a multicarrier modulation which has several advantages in it use like efficiency, being robust in wireless communication and less impact of inter symbol interference; despite such advantages, some problems are identified when using OFDM system but not limited to [32]:

- The high peak to average power ratio in OFDM system reduces power efficiency and performance of the system.
- When high peak PAPR is transmitted and allocated in a non linear device it affect signal and result in the attenuation of the received signal.
- The inter carrier interference due to frequency offset errors is also observed in the system.
- Limited word length which leads to saturation, frequency errors, carrier phase noise and timing error.
- computation complexity or data rate loss
- Highly vulnerable to synchronization errors
- High power transmitter amplifiers require high linearization.
- Vulnerable to phase noise issues in local oscillators.

1.5 Peak to average power ratio

The high PAPR of OFDM means that if the signal is not to be distorted, many of components in the transmitter and receiver must have a wide dynamic range. The output amplifier of the transmitter must be very linear over a wide range of signal levels. In wireless systems the expense and power consumption of these amplifiers is often an important design constraint [6]

1.6 Sensitivity to frequency offset, Phase noise

Differences in the frequency and phase of the receiver local oscillator and the carrier of the received signal can degrade the system performance. These impairments are usually classified in terms of their source frequency offset between transmitter and receiver local oscillator, Doppler spread in the channel and variety of phase noise models with characteristics that depend on the mechanisms of carrier recovery in the receiver.

1.7 Background of the study

In recent many years the frequency division multiplexing has been used in digital transmission such as in wireless local area network, digital audio broadcasting and in 4th generation mobile communication. The technique facilitate high data transmission, efficient use of bandwidth and also reduce inter symbol interference.

A part of presenting advantages in the use of OFDM, disadvantages are observed in the system such as large peaks due to sinus waves in IFFT, limited word length which lead to saturation, frequency errors, carrier phase noise and timing error among others.

In order to respond to the problem mentioned, different methods and techniques were proposed by researchers such as coding techniques, tone injection, filtering, oversampling and multiple signal representation. The main purpose of this study is to propose techniques for the reduction of peak average power ratio in OFDM system. Two techniques are proposed to solve the problem observed when using OFDM system; the Peak Windowing and the clipping techniques. The behavior of the peak average power ratio and bit error rate will be evaluated for the OFDM system when not using any reduction technique and also when using a reduction technique; the analysis of the results is examined and come up with constructive recommendations. The tool to be used to perform simulations is the MATLAB; version 2015 and 2011 will be used. This thesis is composed of six chapters, chapter one gives an over view of the study, objectives, scope, techniques to be used and the organization of the study. Chapter two analyzes principles of OFDM with main focus on the PAPR problem in OFDM, the proposed solution and major contribution to the existing literatures. Chapter three gives research flow and sequences of the entire part of methodology to be used, simulations and parameters to be considered in this work. Chapter four will be the design of the techniques mentioned, chapter five is the implementation of the results and finally chapter six is the conclusion and recommendations for future work.

1.8 Statement of the problem

The presence of a large number of subcarriers with varying amplitude results in high peak to average power ratio of the system (OFDM) and has implication in the efficiency of the radio frequency amplifier. This degrades the bit error rate and increases the cost of the system. This research is to come up with techniques which will improve the OFDM system.

1.9 Objectives of the project

1.9.1 General Objective

The main purpose of this work is to study and analyze the PAPR reduction technique of the OFDM system and thereafter propose new scheme (peak windowing and clipping) with low computational complexity and better performance of BER.

1.9.2 Specific objectives

The following activities will be performed in this study:

a) By considering the clipping technique, simulate and analyze the reduction on PAPR compare to the conventional OFDM
b) Considering the clipping technique, analyze the performance of the system by allocating different clipping level in the system
c) Analyze the bit error rate and signal to noise ratio for Clipped and conventional OFDM
d) Design and analyze the reduction on PAPR using Peak windowing technique

1.10 Scope and limitation of the project

The work will be focused on OFDM with two proposed reduction techniques; the peak windowing and clipping technique. MATLAB tool version 11 and 15 were used to simulate the results.

1.11 Organization of the Project

This project is organized into six chapters:

The first chapter is general introduction which contains the background, statement of the problem, project objectives, scope, interests of the project, and organization of the work.

- The second chapter provides the literature review.
- The third chapter describes the research methodology.
- The fourth chapter describes the design.
- The firth chapters will be presentation of the results
- The six chapter will the conclusion and recommendations

1.12 Justification of the study

In most case radio system operates in high power amplifier in the transmitter and required sufficient transmission power. The high power amplifier operate near the saturation region, this characteristics has a negative impact in signal amplitude variation. This variation in OFDM is wide when using high PAPR. The high power amplifier in one way or another introduce interferences in OFDM signals due to the high PAPR and imply the increase of BER.

With the high demand of data communication, spectral efficiency, frequency selective channels; power consumption is very important factor to take into consideration in wireless communication. The prevention of occurrence of interference in reducing the PAPR of the transmitter using OFDM is considered and two techniques are taken into consideration to attain the objectives; peak windowing and clipping.

1.13 Conclusion

This chapter introduces the research problem about OFDM PAPR techniques; highlight its background, describe the problem, objectives, scope, limitation and organization of the study.

Chapter 2 Literature review

2.1 Introduction

Researcher has been challenged to send high data rate over a wireless channel due to physical factors such as fading, additive noise among others. One of the proposed solutions to solve the problem is the use of orthogonal frequency division multiplexing. The experimental results show multipath delay tolerance and immunity to frequency selective channel fading; this characteristic make the OFDM scheme a model for high data rate wireless communication.

In this chapter, the researcher reviewed the published and unpublished documents to acquire knowledge in OFDM system and other proposed reduction techniques. A deep understanding on OFDM system is provided, the PAPR is defined and parameters that influencing PAPR performances. Different techniques used in the reduction of PAPR are also discussed. The chapter also highlights issues that exist in the system and contribution to the existing literature.

2.2 PAPR Definition in OFDM

In OFDM system the analysis of the PAPR performance is similar to the OFDM system with single antenna. The PAPR of the entire system is defined as the maximum of the PAPRs among all the transmit antenna [7].

The peak average power ratio [8] of OFDM signals$s(n)$is defined as the ratio between the maximum instantaneous power and its average power.

The mathematical representation is provided as [8]

$$s(n) = {}^{1}/_{\sqrt{N}} \sum_{K=0}^{N-1} e^{j2\pi kn/N} \quad (2.1)$$

Where :

X(k) represents the transmitted information in the kth subcarriers.

N the number of subcarriers

The peak average power ratio is defined as:

$$PAPR = \max|s(n)|^2 / \mathrm{E}|s(n)|^2 \qquad (2.2)$$

Where $\max|s(n)|^2$ is the maximum power ratio of the OFDM and

$\mathrm{E}|s(n)|^2$ is the average power ratio of the OFDM signal

Normally the instantaneous output of an OFDM system has a large fluctuation compare to single carrier systems.

The power amplifier and converter analogue to digital and digital to analogue shall have large linear dynamic ranges. If the requirement is not fulfilled a series of undesirable interference is observed when the peak signal gas into non linear region of the transmitter; in this case the distortion is observed.

The high PAPR of OFDM [9] is generated in a situation where some instantaneous power outputs can be increased and become greater than the mean power of the system and create condition where phases of the carrier are the same. This condition creates high PAPR. If is the case it could be out of the scope of the linear region of system devices such as power amplifiers, analog to digital converters and digital to analog converters. This has an implication to non linear region distortion ad affect the position of the signal spectrum and degrades in the performance.

2.3 Parameters influencing PAPR performances

Parameters that are considering to reduce the PAPR are as follow:

a. Modulation schemes
b. Number of subcarriers
c. Sampling rate factor

These parameters have direct influence in PAPR performance.

a. Modulation schemes

One type of modulation scheme is used before the conversion of the frequency domain to time domain through using the inverse fourier transformer to generate OFDM samples. For modulating the transmitted signal, several types of modulation schemes are proposed: Binary phase shift keying (BPSK), quadrature phase shift keying (QPSK), 16- quadrature amplitude modulation (16-QAM) and 64- quadrature amplitude modulation (64-QAM). These schemes are used to evaluate the PAPR performance.

b. Number of subcarrier (N)

The working principle of OFDM depends on dividing the frequency into sub-carriers and each one sub-carrier occupies one channel. The increment of sub-carriers leads to increase the transmitted information and imply on the number of users which also increase and the different numbers of sub-carriers result in PAPR performance.

c. Oversampling rate factor (L)

The oversampling is utilized by L*N to the inverse fourier transformer of the original data with (L-1)*N zero padding to ensure to catch the peaks of the signal and PAPR performance to be accurate. The OFDM signal x(n) as [10]

$$x\left(\frac{n}{L}\right) = \frac{1}{\sqrt{\mathrm{LN}}}\sum_{K=0}^{N-1} \mathrm{X\,K} * \mathrm{e}^{\mathrm{j}2\pi \mathrm{nk/NL}} \quad 0 \leq n \leq N\,(L-1) \qquad (2.3)$$

Where L represents an oversampling factor and influences the PAPR performance.

2.4 Cyclic Prefix

The inter-symbol interference has an effect on multipath channel on some subcarriers of the OFDM symbol. The length of the guard interval is set longer than or equal to the maximum delay of multipath channel, the inter-symbol interference effect of an OFDM symbol on the next symbol is confined within the guard interval so that it may not affect the FFT on the next OFDM symbol.This implies that the guard interval longer than the maximum delay of the multipath channel allows for maintaining the orthogonality among the subcarriers [11]

$$\text{Tsym} = Tsub + TG \qquad (2.4)$$

Let TG be the length of cyclic prefix (CP) in terms of sample

$$1/Tsub \int_0^{Tsub} e^{J2\pi fk(t-t0)} e^{-j2\pi fi(t-t0)} dt = 0; \quad k \neq i \qquad (2.5)$$

2.5 Criteria for selection of PAPR reduction techniques

There are several factors that are considered when selecting the PAPR [12];

- PAPR reduction capability
- Power increase in transmit signal
- BER increase at the receiver
- Loss in data rate
- Computational complexity increase

Other factors that can also taken into account are transmit filter, digital to analog converter and the transmit power amplifier.

2.6 Proposed PAPR Reduction Techniques in OFDM Systems

To generate broadband multimedia mobile communication systems [13], it is obviously to use high data-rate transmission of megabits per second. It is known that the mobile channel is characterized by multipath reception that creates the inter-symbol interference which definitely affect or degrade the network performance. To compensate the interference at the receiver side the equalization is used to compensate the inter-symbol interference. From the results it difficult to operate the equalization at higher rate of megabits per second. To avoid that complexity of equalization parallel data are transmitted by using the OFDM scheme. The trust in using that scheme is due to the fact it has high spectral efficiency; it is robustness and easy to be implemented.

Various techniques have been proposed to reduce the PAPR. The PAPR is classified in three categories [14]:

a) Signal distortion techniques

This includes clipping, peak windowing. It reduces or clip the peak amplitudes of a signal at the expense of introducing a slight distortion of the spectrum of the signal.

b) Coding technique

Special coding sequences are used in the purpose of generating OFDM symbols.

c) symbol scrambling

This includes Peak windowing and selected mapping. The main purpose of the technique is to scramble the input OFDM symbols by using number scrambled sequences. The output scrambled signal is equivalent to the smallest PAPR transmitted.

2.6.1 Signal distortion techniques

a) Clipping and filtering

The clipping approach is the simplest PAPR reduction scheme which limits the maximum of transmit signal to a specified level; however it has the following drawbacks:

It causes in- band signal distortion resulting in BER performance degradation which imposes out-of band interference signals to adjacent channels.

The clipping and filtering technique algorithm allows to limit the distortion of the frequency domain . The following is the sequences for clipping and filtering [29]:

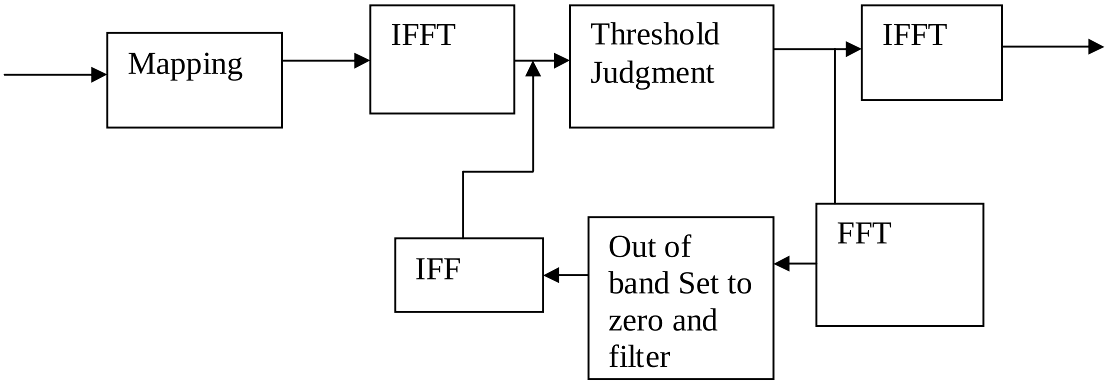


Figure 2.1: Clipping and filtering process for OFDM

The comparison study of two clipping based filtering methods for PAPR reduction in OFDM signals [14]; the long term evolution adopted the orthogonal frequency division multiplexing due to the fact that it met the requirements for the spectrum flexibility and cost efficient solutions for wide carriers. It has also been used in mobility mode of IEEE 802.16 Wimax and currently a working specifications in 3GPP long term evolution downlink.

b) Peak windowing

Reducing the PAPR by multiplying a large signal peak by a Gaussian shaped window [15]. The result spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window (cosine, Kaiser and hamming functions). It has been observed that peak windowing provide considerable result independently from the number of subcarriers.

The basic idea of peak windowing is to multiply the envelop of OFDM signal with a window function [15];

$$x'_{e\ (t)}=x_e(t).f(t) \qquad [2.6]$$

Where x_e (t) = | x (t)| [2.7]

$$f(t) = 1- \sum \propto . w(t-t') \quad [2.8]$$

w(t): is the window function

t' : denotes the position of a local maximum of the envelop x_e (t)

$\propto$: attenuation constant

When the amplitude of the envelop amplitude signal exceed a threshold, a window function is applied to the envelop of the orthogonal frequency multiplexing signal to eliminate the peak amplitude [15].

The expression of the peak windowing is as follow:

$$w(t) = 0.5 - 0.5\cos\left(\frac{2\pi t}{T}\right) \qquad 0 \le t \ge T \qquad (2.9)$$

2.6.2 Coding technique

In block coding [16], all probable message symbols with message symbols with low peak power will be selected by coding as valid code words for transmission.

2.6.3 symbol scrambling

2.6.3.1 Selected Mapping

A set of statistical independent alternative transmit sequences $F^{(u)}$ with u= 1,2,…U is generated and carrying the same data information and select the lowest PAPR, this depends on the number of vector (u). The increase of number of vectors will directly increase the peak power reduction and also the number required IFFT and imply in the system implementation [16].

It is assumed that U statistically independent alternative transmit sequences $a_u^{(u)}$ which represent the same information.

To calculate $a_u^{\sim}$ = IDFT $\left\{A_u^{\sim(v)}\right\}$ (2.10)

The linearity of IDFT is exploited as

$$a_u^{\sim} = \sum_{v=1}^{V} b_u^{(v)} \cdot \text{IDFT}\left\{A_u^{\sim(v)}\right\} \qquad (2.11)$$

$$= \sum_{v=1}^{V} b_u^{(v)} \cdot a_u^{(v)} \qquad (2.12)$$

$b_u^{(v)}$ is the continuous valued phase angle.

The selected mapping techniques are very flexible as they do not impose any restriction on modulation applied.

2.7 Distribution of PAPR

The complementary cumulative distribution function (CCDF) is used to estimate the bound for the minimum number of redundancy bits to identify the PAPR sequences and evaluate the performance of any PAPR reduction schemes.

An approximation of PAPR is expressed as [17]

$$prob(PAPR > \gamma) = 1 - e^{-2\, e - \gamma \sqrt{\pi\gamma \sum_{k=-K}^{k} \mathrm{K}^2}} \tag{2.13}$$

2.8 Proposed solution for problems identified in OFDM system

As mentioned, the OFDM presents different impairment in its system and among other is the higher peak to average power ratio. Different methods are presented in this work to reduce the high peak to average power ratio; the method we are proposing in this study are not yet exploited, that why in this study emphasis will be put on the Peak windowing and clipping and filtering techniques. A proper description will be provided when using OFDM system without any reduction technique, where evaluation of the bit error rate will be described. OFDM system will be analyzed when using the partial transmits sequences with clear analysis of the BER and the PAPR value observed. A second analysis is the use of the clipping technique in the OFDM system with clear analyses of the PAPR and the bit error rate from the transmitter to the receiver. A combination study will be also conducted, using Peak windowing and clipping and compare the output of the two techniques so that a proposed technique will be presented to the user. The behavior of the high power amplifier will also be considered during this study.

2.9 Major contribution to the existing literature

To come out with a good reduction in PAPR researcher proposed the recursive Golay complementary sequence and results show that the PAPR of the sequence is bounded up to 3.6 dB and the information rate is bounded up to 3.6 dB and the information rate is twice as the rate for Golay QPSK codes. From the comparison results of the amplitude clipping and filtering based on PAPR reduction techniques on quadrature phase shift keying and quadrature amplitude modulation from the same number of subcarrier (N=128) and CR=0.8) no difference has been observed between QPSK and QAM. However, when increasing the value of CR changes was observed; the QAM provide less value of PAPR compare to QPSK; this means that the QAM is more appropriate than QPSK in case of proposed filter. If considering changes in bit error rate with gradual increasing of

CR values, BER for QPSK decreasing and for the high values of CR=1.2,1.4,1.6 the BER increase slightly in proposed method [10].

A comparison of different PAPR reduction techniques in OFDM using various modulations[5] such as QPSK, 4-QAM,PAM were used in order to evaluate the behavior of the said modulation scheme in different PAPR reduction techniques especially the classical clipping, selective mapping, tone reservation and Peak windowing. The results shows that the increase in the number of subcarriers results into more PAPR shows the effect of clipping and filtering over the CCDF of PAPR of QAM,PAM and QPSK signals; the decrease in PAPR is 7.89dB over QAM, 9.73dB over PAM and 7.89dB over QAM, 9.73dB over PAM and 7.68dB over QPSK; the results show also that classical clipping is better than tone reservation, selective mapping and Peak windowing.

A systematic comparison of different PAPR reduction methods in OFDM systems was conducted [18]. The research proposed a simple technique for the reduction of high peak to average power ratio (PAPR) based on clipping and differential scaling, in orthogonal frequency division multiplexing (OFDM). The proposed up and down scaling technique was to achieve PAPR reduction of the order of 8.5dB from 12dB PAPR initially. A reduction of 3.5dB was achieved for PAPR when maintaining the BER within a margin of 3 times the BER values at the performance bound at SNR of 10 dB.

OFDM-PAPR reduction using statistical clipping and window based noise filtering [9]; researchers present an alternative approach for iterative clipping and filtering (ICF) method used for the peak to average power ratio in OFDM. The performance of SC-W method and ICF presents same results with a difference of 0.32dB in 6dB whereas in 3dB case SC-W is slightly inferior with a difference of 1.3dB at 10^{-3} BER level. Complexity of conventional PTS increases as the number of sub-blocks increases.

The performance comparison of two clipping based filtering methods for PAPR reduction in OFDM signal [10] was proposed to solve the major generic problem of OFDM techniques which is high peak to average power ratio of the peak power to the average power of the OFDM signal. A tradeoff is necessary for reducing PAPR with the increasing bit error rate (BER), computational complexity or data loss. The simulation results using QPSK and QAM for N=128 and CR values 0.8,1.0,1.4,1.6 indicated that there is no differences between using QAM and QPSK; however, with the increasing value of CR, QAM provides less PAPR than QPSK. QAM is more suitable than QPSK.

The author [19] investigate the effects of clipping and filtering on the performance of OFDM based on power spectral density, the crest factor and bit error rate to solve the issue of PAPR which result in the distortion when passed through nonlinear device such as transmitter power amplifier. From the result, with clipping ratio around 1.4 and filtering the CR of a band-pass OFDM signal with 128 tones at the 99.999% point is reduced from 13 to about 9dB, which is comparable to the absolute CF of a raised cosine pulse-shaped band-pass QPSK signal.

The author [20] investigate the reduction of PAPR in orthogonal frequency division multiplexing signals, an optimized iterative clipping and filtering techniques were used. From the results obtained both Amstrong and optimization methods reduced significantly PAPR while at the same time achieving a comparable sharp drop in the their CCDF's. For ICF method, the PAPR is reduced by 5.4dB at a probability of 10^{-3} after iteration and about 5.7dB after two iterations. Amstrong's method requires only 8 and 16 iterations to achieve these levels of PAPR reduction. The number of iterations required to reach a given PAPR reduction. The number of iterations required to reach a given PAPR level is greatly decreased, the proposed OFDM symbols have less distortion and better out of band radiation.

The PAPR reduction through amplitude clipping and filtering for 3GPP LTE MIMO communications [21] was evaluate using the complementary cumulative distribution. The result shows that PAPR is decreases as the number of clip and filtering is increased. Clipping and filtering exceed the clipping level at the same point. The iterative clipping and filtering operation reduce the overall peak re-growth in a desired level.

The author [22] proposed an efficient technique (peak windowing and interleaving) for reducing PAPR of orthogonal frequency division system in the presence of nonlinear high power amplifier. QPSK, 16 QAM and 64 QAM modulations schemes and number of subcarriers (256,512,1024) were considered in the study. The results shows that 16-QAM required SNR for BER=10^{-2} is almost the same and when considering BER=10^{-3} is improved by 3dB, 3.5dB and 5dB for N=256,512, and 1024 respectively.

The author [23] proposes that a large peak average power ratios occur only infrequently; it is possible to remove these peaks at the cost of slight amount of self interference. Peak windowing can achieve PAPR around 4dB for an arbitrary subcarriers at the cost of slight increase in BER and out of band interference.

In windowing technique [15] a large signal peak is multiplied with a certain window, such as Gaussian shaped window, cosine, Kaiser and hamming window.

In this paper [24] the author presents a PAPR reduction technique which exploit the phase of the signal in the frequency domain. The author tested the technique in the IEEE 802.11a and IEEE 802.16e Wimax systems. In the IEEE 802.11a and IEEE802.16e wimax systems. In the IEEE 802.11a system there are 48 data carriers and 4 pilot tones and 12 unused tones while in the Wimax system there are 192 data carriers ad 8 pilot tones and 56 unused tones; the oversample by a factor of 4 is employed in both cases to ensure peak detection and prevention of peak regrowth. The result shows that, PAPR is reduced by 3-4 dB; the proposed technique causes a lower BER than clipping and windowing techniques since much of the clipping effects have already been absorbed by the unused tones and the phase of pilot tones. The output power spectrum of an IEEE 802.11a employing 16 QAM where 5 tones were used for PAPR reduction and power spectrum for a Wimax system where 4 tones were used for PAPR reduction. In both cases out-of band distortion is significantly lower than that of windowing and clipping.

The author proposed in [25] a technique to reduce the PAPR using Huffman coding combined with clipping and filtering. Parameters considered are as follows: the number of sub-carriers is 52, the modulation is the quadrature phase shift keying, IFFFT length 128; clipping ratio 1.4; the result shows that the proposed method reduces the PAPR significantly about 7dB at probability < 10^{-3}. When clipping is used the PAPR reduction is only about 6dB and when use Huffman coding the PAPR reduction is about 3dB. When considering the compression ratio =1, Huffman coding assigns same bits to all symbols, no PAPR reduction is performed by Huffman coding.

A proposed scheme for PAPR reduction of OFDM system combining Hadamard transform and Hann peak windowing, the author [26] in this study analyze the performance of PAPR reduction technique by determining the bit error rate. Parameters considered are 64 subcarriers and BPSK modulation technique was considered. The results demonstrated that about 5dB PAPR reduction at 10^{-24} within decrease of Eb/No at 10^{-4} BER ;

The author [27] studied the performance improvement of PAPR reduction for OFDM signal in LTE system. The author proposed an improved scheme of amplitude clipping and filtering method. In the method the result demonstrate that for different CR values, the proposed method reduces PAPR significantly. For both QAM and QPSK modulation with N=128, the QAM provides less PAPR rather than QAM. When considering the value of CR=1.6 no differences between QAM and QPSK was observed. To solve the main problem in OFDM for the high peak average power ratio using windowing technique to improve the BER, the technique proposed is Kaiser and Hamming through the cumulative distribution function. The result simulated shows that Hamming and Kaiser have lot of differences on the same spectrum characteristics; hamming window technique at normalized frequency -1 and 0.999MHz the spectral density is -81.5 and -46.05 respectively. For Kaiser window technique at normalized frequency -2 and 1.998 the spectral density is -81.5 and -46.05. the power spectral frequency is same for different normalized frequency but they are equal for maximum values. In addition, the simulation of window length to a certain values degrades the BER performance and provides good out-of band rejection.

In the review paper of author [28] peak windowing remove larger peaks at the rate of little amount of interference where large peaks arise infrequently. It reduces PAPR at cost of increases BER and out of band radiation. The window size should be narrow otherwise it affects the number of signal sample which increase bit error rate. The PAPR level decrease to 4dB with peak windowing method.

The author[29] conducted a survey on peak windowing as a technique to improve the bit error rate of OFDM compared to other techniques such as partial transmit sequence, tone reservation, tone injection, selective mapping among others. From the results, peak windowing (Hanning window) gives better results than clipping technique.

The author [30] study the impact of modulation adaptation and power control on the reduction of peak average power ratio. The technique proposed was the clipping in different modulations such as BPSK, 4-QAM, 16-QAM,64 QAM and 64 QAM. The results obtained indicated that about 2.7dB was reduced when using 4-QAM. It shows that the bit rate increasing as the value of SNR is increasing.

2.10 Conclusion

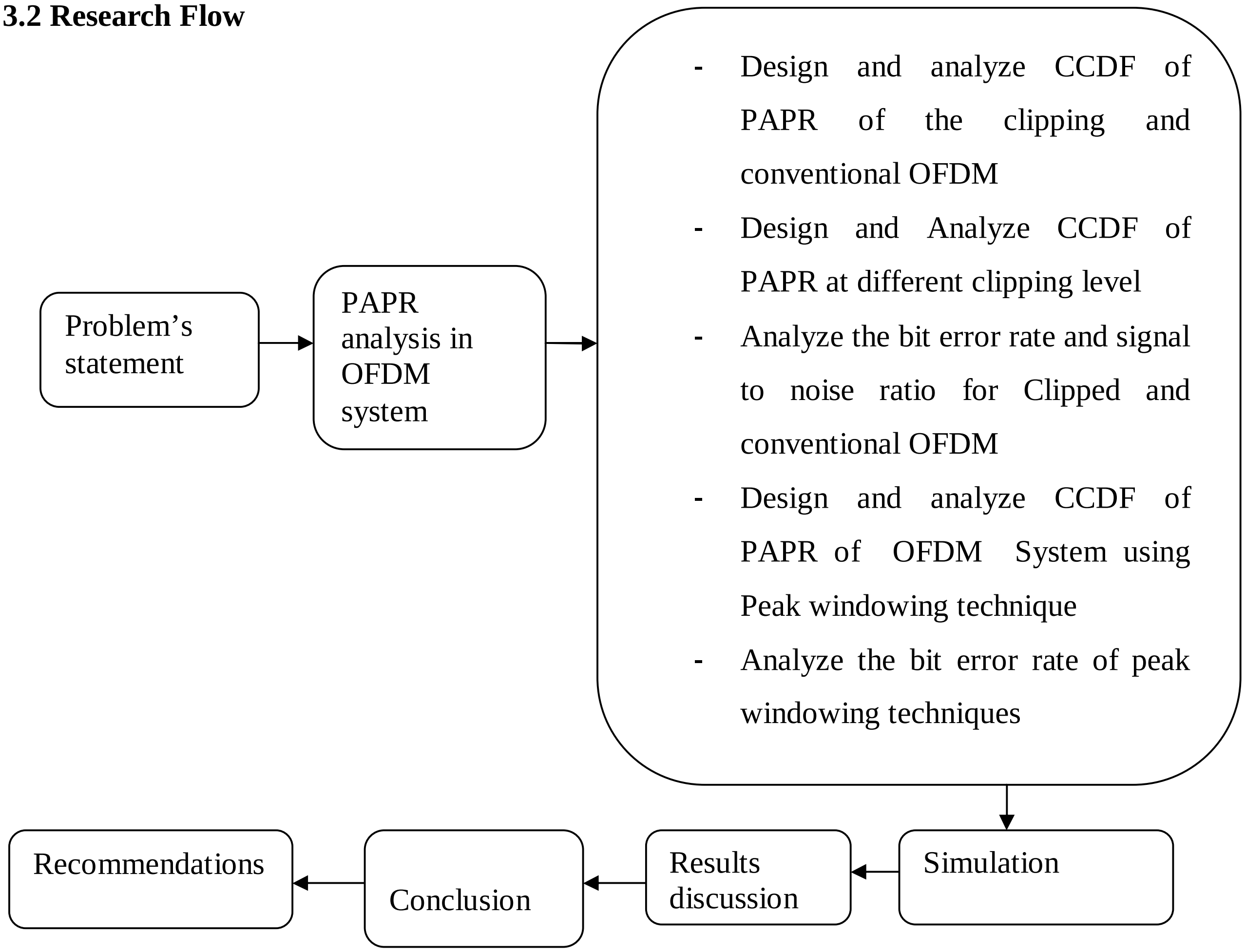
This chapter introduced the concept of OFDM system, principle of orthogonality, criteria for selection of PAPR reduction techniques and also provides contributions from different researchers on reduction techniques using Peak windowing and clipping as a solution to reduce PAPR.

Chapter 3 Research methodology

3.1 Introduction

This chapter provides processes on how the research will be conducted with the main purpose of attaining objectives outlined. This study is based on PAPR reduction in OFDM using two techniques; the Peak windowing and clipping. The aim of this study is to provide a suitable technique that will be considered for the reduction of peak average to power ratio in OFDM scheme. In this study scientific method will be highly considered; the logic aids in formulating proposition explicitly and accurately so that the possible alternatives become clear. Two approaches will be considered in this research; the experimental research approach and simulation approach. A brief description of the two approaches will be provided, design process, data collection and conclusion.

3.2 Research Flow



- Design and analyze CCDF of PAPR of the clipping and conventional OFDM
- Design and Analyze CCDF of PAPR at different clipping level
- Analyze the bit error rate and signal to noise ratio for Clipped and conventional OFDM
- Design and analyze CCDF of PAPR of OFDM System using Peak windowing technique
- Analyze the bit error rate of peak windowing techniques

Figure 3.1: Research flow Process

During this research suitable techniques will be proposed to reduce the peak average power to ratio in OFDM system. The approach to be considered into will be the simulation model and mathematical representation.

3.2.1 Scientific research method and experimental approach

In this research work we have identified a need to improve the OFDM techniques using PEAK WINDOWING and clipping techniques. In order to come up with fruitful contribution, consideration will be given to past work in the related field. Different techniques were proposed by researchers for the reduction of peak average power ratio. For each techniques proposed by researcher presented advantages and disadvantages; this work will consider the differences observed with the main purpose of improving the scheme as mentioned in this work focus will be put into two techniques; the Peak windowing and clipping. To come up with a consistent literature review; journals, reports, published papers, unpublished thesis were used in order to enrich the chapter.

3.3 Analysis and Design

For a better performance of OFDM scheme, a clear analysis of different techniques with determined parameters will be considered. A clear plan and sequences for the achievement of this study will be clearly determined and strategies for the achievement of the said study. To be systematic in the analysis each steps will be critically and systematically analyzed. First of all the peak average to power ratio of the existing OFDM will be analyzed without using any reduction techniques where the behavior and analysis of the BER will be conducted; this analysis will be feasible through simulations and results will be interpreted. The second step to follow is the analysis of the PAPR in - OFDM using Peak windowing alone, here the behavior of the system will be considered and analyze the value obtained for the bit error rate. Another step to consider is the analysis of the PAPR in OFDM using clipping technique. Another consideration to be considered in this work is the analysis of combined techniques; the Peak windowing and clipping; the results obtained will give clear guidance on the proper techniques to be used for better efficiency of the OFDM system. The results obtained after analysis and discussion will guide us for a proper design of the OFDM scheme using Peak windowing and clipping and filtering techniques.

3.4 Conclusion

This chapter provides processes and approaches required for the successful accomplishment of this study. Information on scientific research and experimental approach was provided. This chapter also indicates how the analysis and design will be carried out.

Chapter 4 System analysis and design

4.1 Introduction

Orthogonal frequency division multiplexing and multiple input multiple output are the multicarrier techniques. The both systems provide various advantages; however, one of the major drawbacks of the OFDM signal based on multicarrier transmission is the high peak to average power ratio of the transmission signal. This large peak average power ratio of the signal causes clipping when the signal is passed through the non-linear amplifier which will have implication in the performance degradation of the system.

The Peak windowing scheme partition the frequency domain symbol sequence or data blocks into number of sub-sequences. The obtained signals are converted into times domain signal (IFFT of data). The PAPR is measured from the result and the signal containing lowest PAPR is transmitted.

4.2 System Model

The flow of the work is represented in figure 3; the modulation starts with transmitted signal and this is done by performing the quadrature phase shift keying modulation for the input data. The obtain data is convert into time domain by performing the inverse fast fourrier transformer. Peak windowing is applied to reduce the PAPR but not the BER. With the main purpose of reducing the PAPR; clipping techniques is utilized to reduce the PAPR at higher level including the bit error rate. Signal is transmitted through communication channel Rayleigh channel and an addition AWGN noise is added. The de-modulation starts with FFT of the received signal and the QPSK de-modulation is performed and the bit error rate is calculated as provided in the diagram below

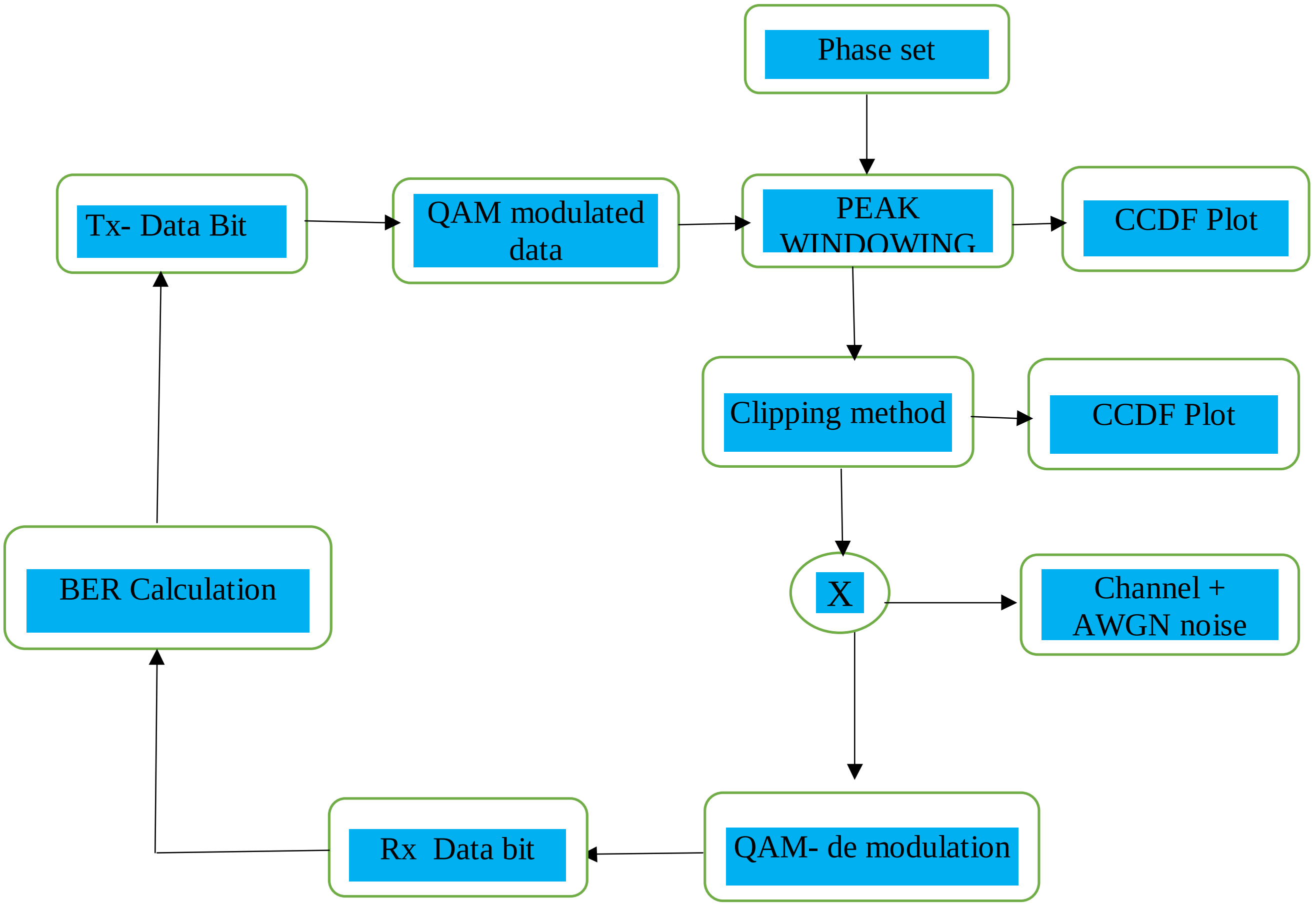


Figure 4.1: Block diagram of system mode

4.3 Mathematical Model

4.3.1 Windowing

Windowing [15] consists of multiplying the signal by finite length window with amplitude that varies smoothly and gradually toward zero at the edges. There are different types of window functions that are applied depending on the signal. In this study we considered three window functions: Hamming window, Hanning window and Kaiser window. Below is the mathematical representation of the three window functions:

a) Hamming Window

Hamming window is represented as [15]:

Whamm $= 0.54 + 0.46\cos\left(\frac{2\pi n}{N} - 1\right) for\ 0 \leq n \geq N - 1$ [4.1]

=0 otherwise

N represent the width in samples of a discrete-time of window function.

b) Hanning Window

Hanning window is represented as in [15]

Hann=$= 0.5 + 0.5\cos\left(\frac{2\pi n}{N} - 1\right) for\ 0 \leq n \geq N - 1$ (4.2)

N represents the width in samples of a discrete-time of window function.

c) Kaiser Window

Wkaiser= $I_0(\sqrt[\pi\alpha]{1 - (\frac{2n}{N-1} - 1)2})/I_0\,(\pi\alpha)$; $0 \leq n \geq N-1$ (4.3)

0 otherwise,

where :

N is the length of the sequence

I_0 is the zeroth-order modified Bessel function

α is the arbitrary non- negative real number that determines the shape of the window.

4.3.2 Peak windowing presentation based on PAPR for OFDM system

Considering that the envelop of the OFDM signal to be Se(t) and the window function W_f, the function is expressed as [15]:

$$S_p(t) = Se(t)*W_f \qquad (4.4)$$

The PAPR after peak windowing is expressed as :

$$PAPR = \max|Sp(t)|^2/E|Sp(t)|^2 \qquad (4.5)$$

4.3.3 Clipping method

For the recall, the clipping techniques is a distortional technique which is used to reduce PAPR by clipping the high peak of the OFDM signals by limiting the peak amplitude value to the threshold value. Amplitude above the threshold value is clipped and information is lost. Due to the non-linear operation, clipping causes the in-band distortion and out-band radiation. Due to the in-band distortion BER performance is reduced.

Mathematically, the clipping technique is defined as [31] :

$$\boldsymbol{B(x)} = \begin{cases} \boldsymbol{X \le C_L} \\ \boldsymbol{C_L else} \end{cases} \qquad (4.6)$$

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

$$\boldsymbol{PAPR = C_L^2/E\{|B(x)|^2\}} \qquad (4.7)$$

4.4 Conclusion

This chapter highlighted the system model used for the reduction of Peak average power ratio in OFDM system using two main techniques; peak windowing and clipping. The system model was presented in a way that is understandable. Apart of presenting the system model; mathematical representation of the peak windowing and clipping techniques was presented in clear manner including the block diagram of the clipping model and PAPR and Bit error rate Analysis in OFDM system.

Chapter 5 Presentation of the results

5.1 PAPR reduction using Clipping

A higher signal at the input of high power amplifier causes non linear distortion at its output leading to an efficient operation of HPA. The distortion cause inter-modulation products resulting to an unwanted out-of band power [32]. The non-linear characteristics of HPA shows that when large input out of linear range arrives received signal will be attenuated, rotated as well as offset in phase is observed . In order to reduce the PAPR of OFDM signals, many solutions have been proposed and analyzed and among other is the clipping.

Clipping technique is performed by clip the time domain signal to predefined level or threshold. As the OFDM signal contains high peaks; it is transferred as provided in the block diagram 6. When the amplitude crosses the threshold or cutoff level, the amplitude is clipped off and safeguards the phase. The mathematical representation of the clipping technique is described in 4.3.2; the clipping level plays an important role in reducing the PAPR. The smaller the value of clipping lever the larger the reduction of the PAPR but the small value of clipping level means a degradation of the BER performance.

The algorithm for the clipping technique is described as follow:

1) The incoming data is converted from serial to parallel
2) Modulate the data using the quadrature amplitude modulation
3) The data modulated are transformed into OFDM signal by passing through the inverse fast fourier transformer
4) Clipped the signal based on the threshold level
5) Determination of PAPR

The following is the block diagram describing the process of clipping technique:

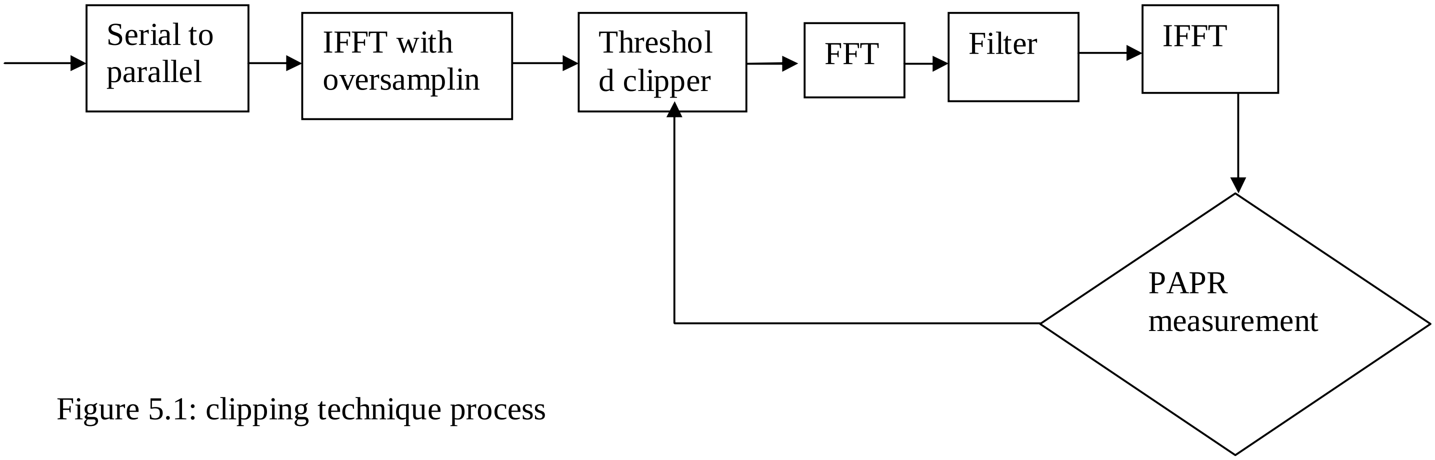


Figure 5.1: clipping technique process

5.1.1 Parameters Used for simulations

In order to come out with comprehensive results in OFDM system, 256 subcarriers operating in 2 bits/ second using the quadrature amplitude modulation was considered and the output was oversampled when pass through the inverse fast fourier transformer . The clipping method was used in order to eliminate the peak values of the power and consider the BER performance.

Table 5.1 : Simulation parameters for the clipping technique

Parameters	Values used
Number of sub-carrier	256,512
oversampling rate	4
Bit per symbol	2
FFT size	1024
Number of OFDM block	10000
Clipping levels	0.7
Modulation	QAM
Channel	AWGN

5.1.2 Presentation of the Results

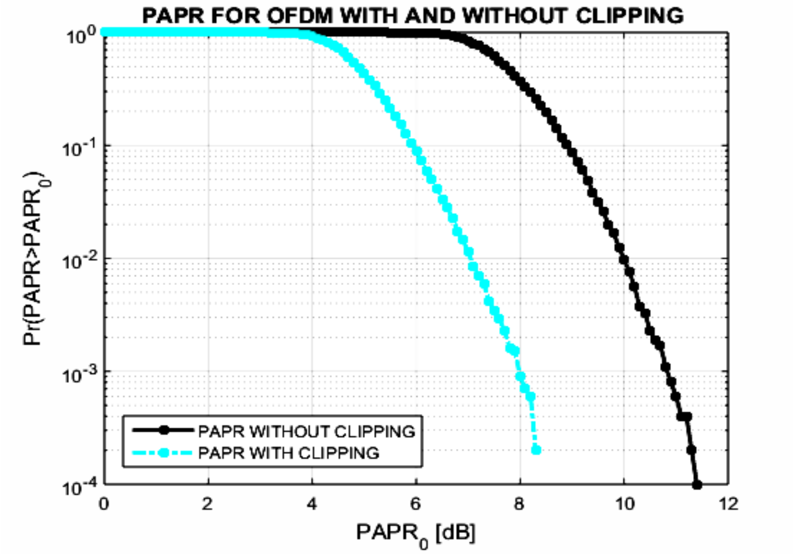
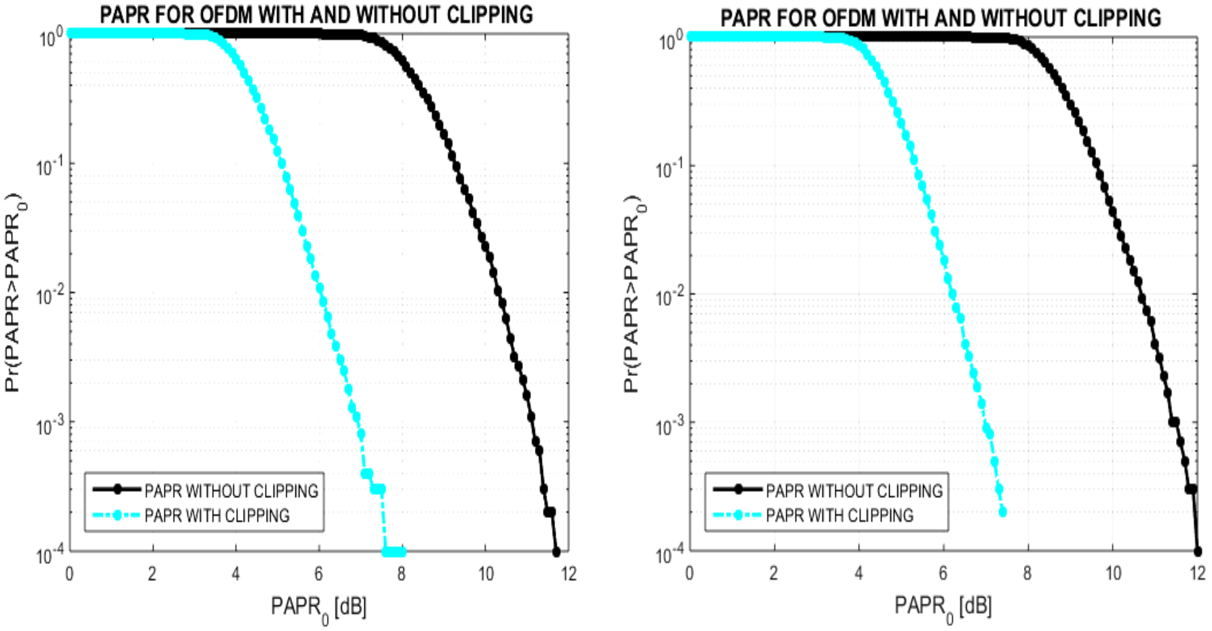


Figure 5.2: Presentation of CCDF of PAPR of clipping and conventional OFDM

The results highlighted in figure 6 present the performance of the OFDM system when considering the clipping technique and also when the reduction technique is not considered. The tool used for the evaluation of the PAPR is the complementary cumulative distribution function (CCDF) to estimate the bound for the minimum number of redundancy bits. From the result above one can observe the contribution of the clipping technique when comparing with the conventional OFDM one. Quantitatively there is reduction of more than 2dB of PAPR when considering probability of 10^{-4}. Another important observation we made is the effect of clipping level in the reduction of PAPR and on the BER. Figure 5.5 gives more explanatory on the effect of threshold level on PAPR and effect on BER is provided in figure 5.6, 5.7 and 5.8.



Figures 5.3 and 5.4: Presentation of CCDF of PAPR of clipping and conventional OFDM for number of sub-carriers= 512 and 1024

As mentioned previously one of the parameter that can influence the PAPR is the number of sub-carriers, from figure 5.3 when considering the number of sub-carriers equal to 512 at the probability of 10^{-4} the value of PAPR is reduced compared to the value obtained in figure 5.4. Same comparison when considering the number of sub-carriers equal to 1024, we observed an improvement on PAPR by using the clipping technique. We can also observed that when increasing the number of sub-carries the OFDM signal degraded then distortion and noises are observed.

Table 5.2 Simulation parameters on the effect of threshold clipping level

Parameters	Values used
Number of sub-carrier	256
oversampling rate	4
Bit per symbol	2
FFT size	1024
Number of OFDM block	10000
Clipping levels	0.6:0.7:0.8:0.9
Modulation	QAM
Channel	AWGN

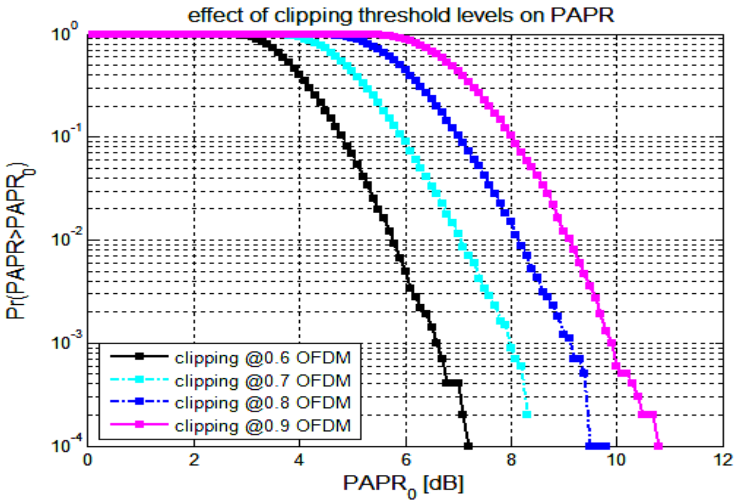


Figure 5.5: CCDF of PAPR at different clipping level

From the results when considering the threshold clipping level at 0.6, 0.7; 0.8 and 0.9 this imply good performance in the reduction of PAPR as it is indicated in figure 6, the threshold clipping level at 0.6 compare to the threshold clipping level at 0.9 there is an impressive reduction of PAPR of about 3.5dB, however, this does not mean that the system has a good performance in BER. In figure below we compare SNR vs BER of a clipped signal and conventional OFDM.

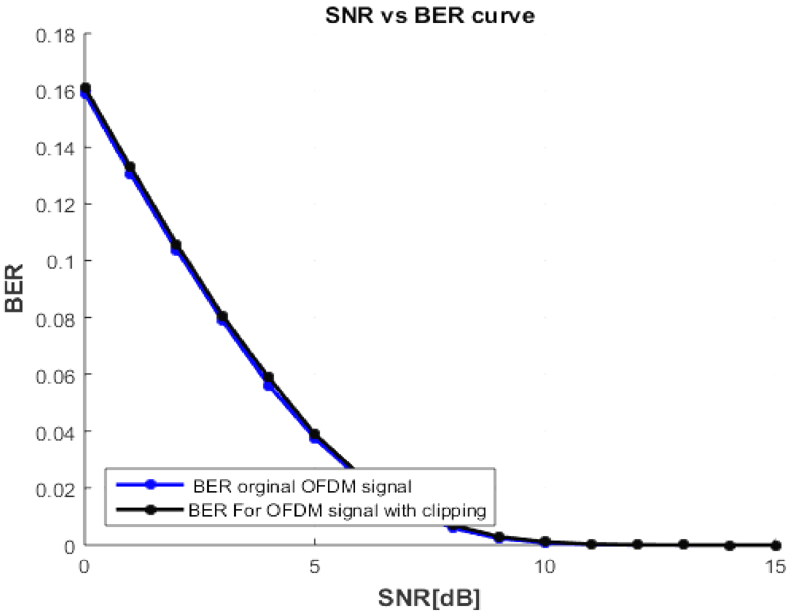


Figure 5.6: SNR vs BER for Clipped and conventional OFDM signals, clipping level 0.7

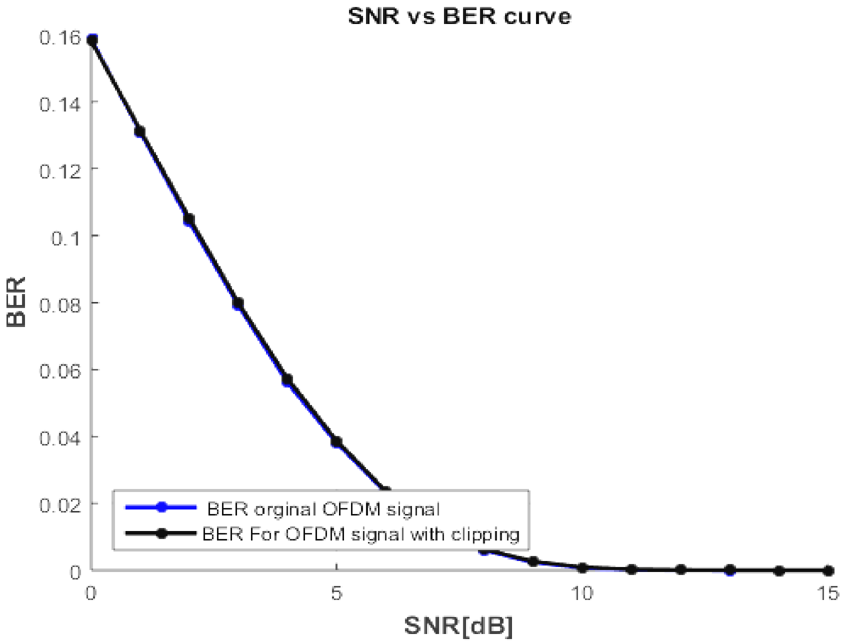


Figure 5.7: SNR vs BER for Clipped and conventional OFDM signals; Clipping level 0.8

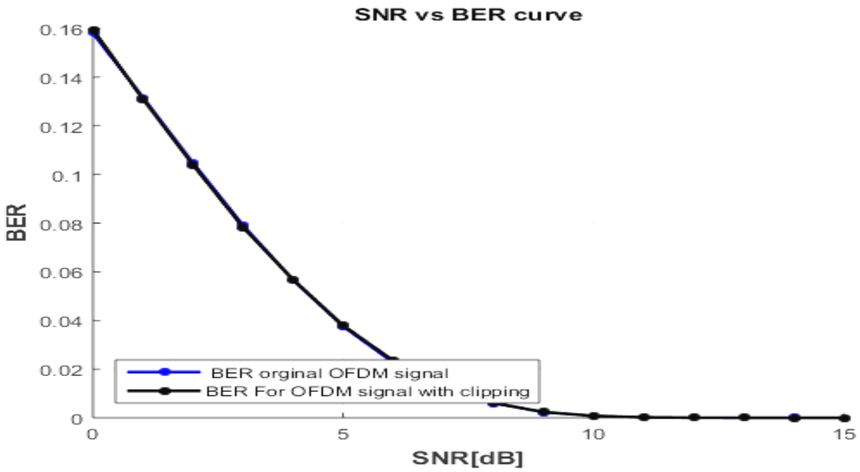


Figure 5.8: SNR vs BER for Clipped and conventional OFDM signals; Clipping level 0.9

When comparing results obtained in figure 5.5 when allocating different values of clipping threshold levels and comparing results obtained in figure 5.6,5.7 and 5.8; we come up with the following conclusion: In clipping technique; allocating a small value of clipping level reduced considerably the

PAPR ; let consider clipping threshold level of 0.7, from figure 5.5 we observed a reduction of PAPR of a value more than 8dB and when comparing the performance of the BER we can observe a slightly change introduced by clipping. Let compare when allocating clipping threshold values of 0.8 and 0.9; the BER is improved as per the figure 5.7 and 5.8. Having an improved BER this reduces the complexity of OFDM system, facilitate the implementation cost and improve the power consumption.

5.2 PAPR reduction using Peak windowing

The orthogonal frequency division multiplexing is based on dividing high data stream into smaller data then modulated the data and transmit it with orthogonal subcarriers. The orthogonality principle allows the best use of bandwidth; however this does not prevent the system to suffer from high peak average power ratio. The large peak to average power ratio in OFDM is degrading due to low power efficiency in nonlinear power amplification. To minimize this drawback; clipping and peak windowing techniques are proposed to improve the performance of the OFDM system. Peak windowing consist of removing larger peaks at the rate of a little amount of interference where large peaks arise infrequently. It reduces PAPR at cost of increases BER and out of band radiation. It provides better PAPR migration with better spectral properties. Large signal is multiply with a specific window. The window size should be narrow otherwise it affects the number of signal sample which increase bit error rate.

In windowing technique a large signal peak is multiplied with a certain window such as Gaussian shaped window, cosine, Kaiser and Hamming window. Since the OFDM signal is multiplied with several of these windows, the resulting spectrum is a convolution of the original OFDM spectrum with the spectrum of the applied window.

The algorithm of the peak windowing is described as follow:

- Identify the peak which are greater than pre-defined threshold
- The signal get multiplied with Hanning window function
- The lower amplitude sample align with high amplitude of the window
- PAPR is reduced by applying peak windowing
- Clipping is applied for escaped peak windowing

The following is the block diagram describing the peak windowing technique:

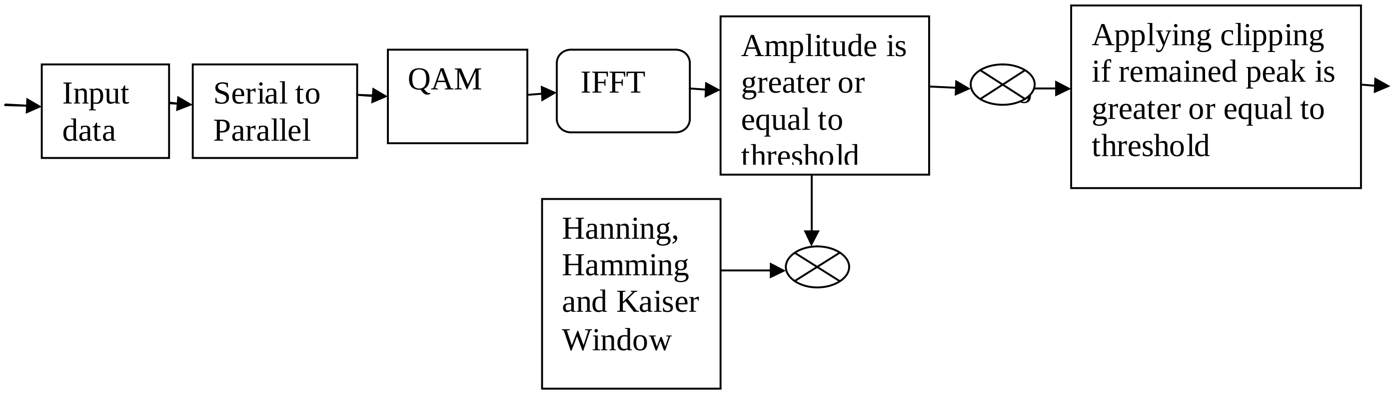


Figure 5.9: Peak windowing flow diagram

The expression of the peak windowing is provided as**:**

Considering that the envelop of the OFDM signal to be $S_e(\ t)$ and the window function W_f, the function is expressed as :

$$S_p(t) = Se(t)*W_f$$

$$W_{hann} == 0.5 + 0.5\cos\left(\frac{2\pi n}{N} - 1\right) for\ 0 \leq n \geq N - 1$$

N represents the width in samples of a discrete-time of window function

Table 5.3: Parameters considered for Peak windowing techniques

Parameters	Values used
Number of sub-carrier	256
Bit per symbol	2
FFT size	1024
Number of OFDM block	10000
Clipping levels	0.8
Modulation	QAM
Window size	4
Window function	Hanning, Hamming and kaiser
Channel	AWGN

5.2.2 Results

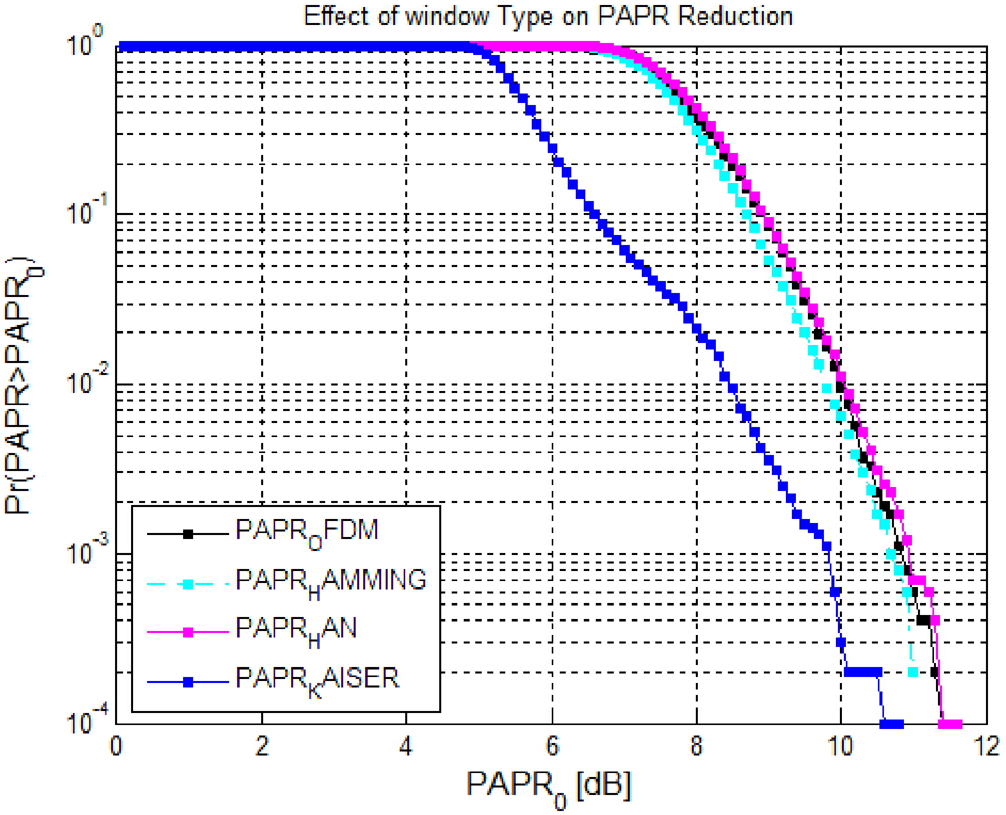


Figure 5.10: CCDF performance for PAPR reduction for Hamming, Hanning and Kaiser window techniques.

To evaluate the performance of types of peak windowing on the reduction of PAPR, Hamming, Hanning and Kaiser windowing were considered; the complementary cumulative distribution functions indicated that when considering the probability of value 10^{-4}, the reduction of PAPR for the peak windowing when considering Kaiser window is about 11dB and more improved compared to other techniques. If comparing the tree techniques, Kaiser window is proposed to reduce the PAPR.

Table 5.4: Parameters considered for BER for Peak windowing

Parameters	Values used
Number of sub-carrier	512
Bit per symbol	6
FFT size	1024
Number of OFDM block	1000
Clipping levels	0.8
Modulation	QAM
Window size	4
Window function	Hanning, Hanning and Kaiser
Channel	AWGN

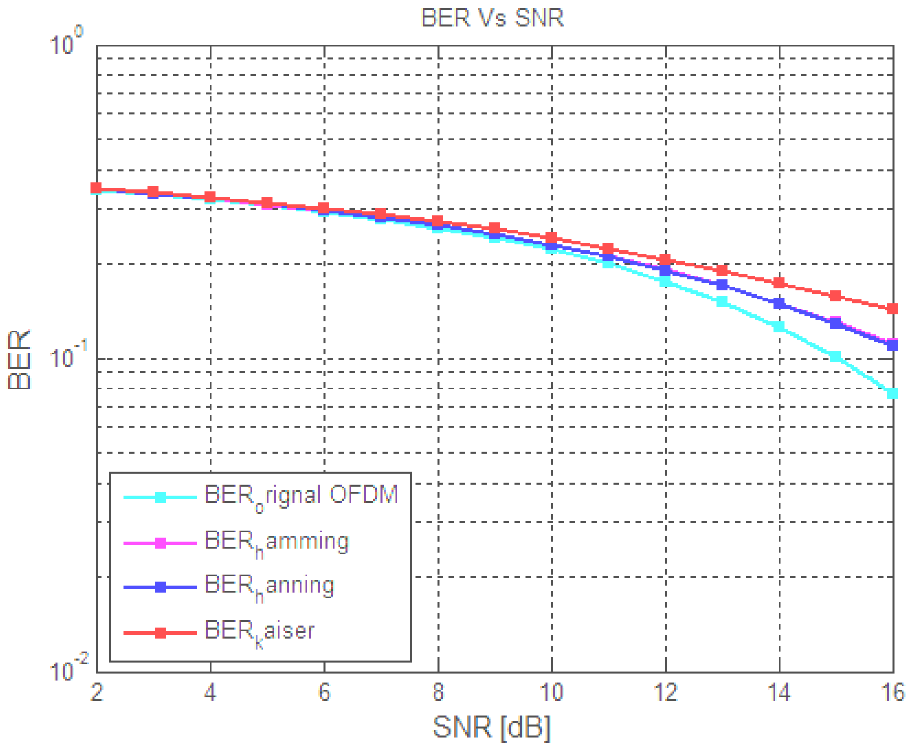


Figure 5.11: BER performance for different windowing

From the result presented in figure 14 shows that the performance in BER for the Hamming and Hanning provide the same BER, however as per the result Hanning window gives better PAPR performance.

5.3: Conclusion

This chapter present simulation results for the reduction of PAPR in OFDM system. To reduce the PAPR in OFDM two techniques were considered, the peak windowing and clipping techniques. From the peak windowing which has different types of windowing techniques; three techniques were considered in this work, the Hamming, Hanning and Kaiser Windows. The complementary cumulative distribution function and the bit error rate were considered as tools to measure the performance of OFDM. When comparing the results obtained, Kaiser window provides reduction on PAPR comparing to other two remaining techniques; however when considering the BER vs SNR, the results shows that Hanning window as better BER comparing to Kaiser wind

Chapter 6 Conclusion and recommendations

6.1 Conclusion

In this research work, reduction of peak average power ratio in orthogonal frequency division multiplexing using peak windowing and clipping techniques, it was related to the drawback identified in the orthogonal frequency division multiplexing system whereby high peaks are identified in the receiver side and affect the performance of the signal by causing impairments such as inter-symbol interference, distortion of the signal and higher error rate. To minimize these impairments; two techniques were proposed; the peak windowing and clipping techniques. As we have different types of windows in peak windowing; in this research work we considered the Hamming, Hanning and Kaiser windows. To quantify the peak average power ratio, the complementary cumulative distribution function were used and the bit error rate vis a vis to the signal to noise ratio were considered. Additional to that, the mathematical model expressing the peak windowing and clipping techniques were considered to provide simulations. Through different results obtained and after analysis we concluded that the two proposed techniques contributed in the reduction of PAPR; when considering and comparing the three windows techniques, the Kaiser window contributed more in the reduction of PAPR and when considering the contribution in bit error rate, Hanning were proposed better performance for PAPR.

When considering the clipping technique comparing with the original OFDM, the clipping signal provide better reduction in PAPR comparing to the original OFDM signal, to come up with a clear understanding of the technique, different threshold clipping levels were assigned and found that threshold clipping levels has an influence on the technique, the lower the threshold clipping level the higher the improvement in PAPR but affect the bit error rate. This allow us to come up with a conclusion; peak windowing and clipping techniques contribute in the reduction of PAPR but emphasis shall be put in the choice of the technique by considering the number of sub-carriers, the modulation and bit error rate. Having an improved BER reduces the complexity of OFDM system, facilitate the implementation cost and improve the power consumption.

6.2 Recommendations

Following the higher demand for data transmission in mobile communication, provision of high bandwidth efficiency, high data rate in both wireless and wired communication, digital audio broadcasting and in digital video broadcasting; we recommend that the two techniques proposed be considered in the area mentioned above and other techniques be developed with the main purpose of improving the OFDM system. For further studies, we recommend to study the peak windowing and clipping techniques using different modulation schemes; also to extend the techniques using MIMO in OFDM system.

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Appendices

A. Clipping techniques

PAPR WITH AND WITHOUT CLIPPING TECHNIQUES

```
% cleraing commands
clc; %cears command window
clear all;%clears all variables in workspace
close all;%closes all the opened figures etc..
%% system parameters
No_of_subcarriers= 256;%Number of of subcarriers per OFDM symbol
Upsampling_Factor=4;%Upsampling factor
Bit_Per_Symbol=2;% Bits per symbol 1->BPSK,2->QPSK,4->16-QAM
PAPR_Range_in_dB=[0:0.1:12];%PAPR Range
No_of_OFDM_Blocks_Per_Iteration = 10000;%Number of OFDM blocks per simulations
rand_seed = 0; % Random number seed state initiliazation
%Thresold_for_clipping =0.4:0.001:1;%percentage of maximum value
rand('state',rand_seed);%Initializing the random number generator seed
IFFT_Size=No_of_subcarriers*Upsampling_Factor; % IFFT size
M=2^Bit_Per_Symbol;%Modulation order
Es=1;%symbol energy
A=sqrt(3/2/(M-1)*Es); % Normalization factor for M-QAM
mod_object=modem.qammod('M',M,'SymbolOrder','gray');%Modulation object with gray coding
%OFDM PAPR
for ii=1:No_of_OFDM_Blocks_Per_Iteration
   QAM_Symbols = A*modulate(mod_object,randint(1,No_of_subcarriers,M));%Getting the modulated symbols
   QAM_Symbols_Upsampled = upsample(QAM_Symbols,Upsampling_Factor);%upsampling
   OFDM_timedomain=ifft(QAM_Symbols_Upsampled,IFFT_Size);%IFFT output x(t)
   Instantaneous_power=abs(OFDM_timedomain).^2;%p(t)=real(x(t))^2+imag(x(t))^2
   Mean_Power(ii)=mean(Instantaneous_power); %Mean power = E[p(t)]
   Peak_Power(ii)=max(Instantaneous_power); % Peak power = max(p(t))
end
PAPR=Peak_Power./Mean_Power; %PAPR in Linear scale
%CCDF = CCDF_Calc(PAPR,PAPR_Range_in_dB,No_of_OFDM_Blocks);%CCDF calculation

PAPRdB=10*log10(PAPR); % Measure PAPR in dB
PAPR_dB_Midpoints = PAPR_Range_in_dB + (PAPR_Range_in_dB(2)-PAPR_Range_in_dB(1))/2;%For plotting histogram
count = 0;
%% Finding the CCDF
N_bins = hist(PAPRdB,PAPR_dB_Midpoints);
for i=length(PAPR_Range_in_dB):-1:1
   count = count+N_bins(i);
   CCDF(i) = count/No_of_OFDM_Blocks_Per_Iteration;
```

```
end

%PAPR CLIPPING

for iter=1:No_of_OFDM_Blocks_Per_Iteration
     Thresold_for_clipping=0.6;
    QAM_out_Symbols = A*modulate(mod_object,randint(1,No_of_subcarriers,M));%generating QAM
symbols
    QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
    ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
    Instantaneous_Power = abs(ifft_sym);%p(t) = real(x(t))^2+imag(x(t))^2
    [ max_level max_index] = max(Instantaneous_Power);%Finding the maximum amplitude level
    indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%Finding the indices
corresponding which have amplitude more than threshold
    Instantaneous_Power(indices)=Thresold_for_clipping*max_level;%clipping the signal with threshold level
    sym_pow = Instantaneous_Power.^2; % Symbol power
    PAPRs(iter) = max(sym_pow)/mean(sym_pow);%PAPR calculation
end
PAPRdB=10*log10(PAPRs); % Measure PAPR in dB
PAPR_dB_Midpoints = PAPR_Range_in_dB + (PAPR_Range_in_dB(2)-PAPR_Range_in_dB(1))/2;%For
plotting histogram
count = 0;
%% Finding the CCDF
N_bins = hist(PAPRdB,PAPR_dB_Midpoints);
for i=length(PAPR_Range_in_dB):-1:1
    count = count+N_bins(i);
    CCDF1(i) = count/No_of_OFDM_Blocks_Per_Iteration;
end
%% plotting the results
figure(1)
h1=semilogy(PAPR_Range_in_dB,CCDF,'-ks','LineWidth',2,...
'MarkerEdgeColor','k',...
'MarkerFaceColor','k',...
'MarkerSize',4);
hold on
h2=semilogy(PAPR_Range_in_dB,CCDF1,'-.cs','LineWidth',2,...
'MarkerEdgeColor','c',...
'MarkerFaceColor','c',...
'MarkerSize',4);
xlabel('PAPR_0 [dB]','fontsize',12);
ylabel('Pr(PAPR>PAPR_0)','fontsize',12);
title('PAPR FOR OFDM WITH AND WITHOUT CLIPPING ','fontsize',12);
axis([PAPR_Range_in_dB([1 end]) 1e-4 1]);
legend('PAPR WITHOUT CLIPPING','PAPR WITH CLIPPING','location','southwest');
grid on;
zoom on;
```

ESTIMATION OF BER WITH CLIPPING TECHNIQUE

```
%% clearing commands
clc% clear command window
clear all;%clears all variables in workspace
close all;%closes all the opened figures etc..
%% system parameters
No_of_subcarriers= 256;%Number of of subcarriers per OFDM symbol
Upsampling_Factor=4;%Upsampling factor
Bits_Per_Symbol=2;% Bits per symbol 1->BPSK,2->QPSK,4->16-QAM
SNR = 0:1:20;
No_of_OFDM_Blocks = 1000;%Number of OFDM blocks per simulations
rand_seed = 0; % Random number seed state initiliazation
rand('state',rand_seed);
IFFT_Size=No_of_subcarriers*Upsampling_Factor; % IFFT size
M=2^Bits_Per_Symbol;%Modulation order
for i = 1:length(SNR)
    Number_of_bit_errors(i)=0;
for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);% Generating random data
        QAM_out_Symbols = qammod(Tx_bit,M);%Modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
        ifft_sym= awgn(ifft_sym,SNR(i)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);%FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err, ber_temp]=biterr(recovered.',Tx_bit);%Bit error calculation
        Number_of_bit_errors(i)= Number_of_bit_errors(i)+ber_temp;%Accumulating the total bit errors for
each SNR
end
    BER(i) = Number_of_bit_errors(i)/No_of_OFDM_Blocks;%Bit error rate for each SNR
end
for i = 1:length(SNR)
    Number_of_bit_errors(i)=0;
for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);%Random data generation
        QAM_out_Symbols = qammod(Tx_bit,M);% QAM modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
%% clipping
        Thresold_for_clipping = 0.7;0.8;0.9
        Instantaneous_Power = abs(ifft_sym);% calculation of instantaneous power
        [ max_level, max_index] = max(Instantaneous_Power);% finding maximum value
        indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%find the samples which has
amplitude more than threshold
```

```
        ifft_sym(indices) =
Thresold_for_clipping*max_level*ifft_sym(indices)./abs(ifft_sym(indices));%clipping the samples which has
amplitude more than threshold
         ifft_sym= awgn(ifft_sym,SNR(i)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);%FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err, ber_temp]=biterr(recovered.',Tx_bit);
        Number_of_bit_errors(i)= Number_of_bit_errors(i)+ber_temp;
end
    BER1(i) = Number_of_bit_errors(i)/No_of_OFDM_Blocks;
end
%% plotting the results
figure(1)
hold on
semilogy(SNR,BER,'-bs','LineWidth',2,...
'MarkerEdgeColor','b',...
'MarkerFaceColor','b',...
'MarkerSize',4);
semilogy(SNR,BER1,'-ks','LineWidth',2,...
'MarkerEdgeColor','k',...
'MarkerFaceColor','k',...
'MarkerSize',4);
xlabel('SNR[dB]','fontsize',12,'fontweight','b');
ylabel('BER','fontsize',12,'fontweight','b');
title('SNR vs BER curve');
legend(' BER orginal OFDM signal','BER For OFDM signal with clipping','Location','Southwest')
grid on;
zoom on;
```

BER ESTIMATION OF PAPR USING DIFFERENT CLIPPING LEVEL

```
%% cleraing commands
clc % cears command window
clear all; %clears all variables in workspace
close all; %closes all the opened figures etc..
%% system parameters
No_of_subcarriers= 256;%Number of of subcarriers per OFDM symbol
Upsampling_Factor=4;%Upsampling factor
Bit_Per_Symbol=2;% Bits per symbol 1->BPSK,2->QPSK,4->16-QAM
SNR = 0:1:20;
No_of_OFDM_Blocks = 10000;%Number of OFDM blocks per simulations
%Thresold_for_clipping = 0.7;%percentage of maximum value
rand_seed = 0; % Random number seed state initiliazation
rand('state',rand_seed);
IFFT_Size=No_of_subcarriers*Upsampling_Factor; % IFFT size
M=2^Bit_Per_Symbol;%Modulation order
for i = 1:length(SNR)
    Number_of_bit_errors(i)=0;
for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);%Random data generation
        QAM_out_Symbols = qammod(Tx_bit,M);% QAM modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
%% clipping
        Thresold_for_clipping = 0.6;
        Instantaneous_Power = abs(ifft_sym);% calculation of instantaneous power
        [ max_level, max_index] = max(Instantaneous_Power);% finding maximum value
        indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%find the samples which has
amplitude more than threshold
        ifft_sym(indices) =
Thresold_for_clipping*max_level*ifft_sym(indices)./abs(ifft_sym(indices));%clipping the samples which has
amplitude more than threshold
         ifft_sym= awgn(ifft_sym,SNR(i)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);%FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err, ber_temp]=biterr(recovered.',Tx_bit);
        Number_of_bit_errors(i)= Number_of_bit_errors(i)+ber_temp;
end
    BER(i) = Number_of_bit_errors(i)/No_of_OFDM_Blocks;
end
for j = 1:length(SNR)
    Number_of_bit_errors(j)=0;
for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);%Random data generation
        QAM_out_Symbols = qammod(Tx_bit,M);% QAM modulation
```

```
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
        %% clipping
        Thresold_for_clipping = 0.7;
        Instantaneous_Power = abs(ifft_sym);% calculation of instantaneous power
        [ max_level, max_index] = max(Instantaneous_Power);% finding maximum value
        indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%find the samples which has amplitude more than threshold
        ifft_sym(indices) = Thresold_for_clipping*max_level*ifft_sym(indices)./abs(ifft_sym(indices));%clipping the samples which has amplitude more than threshold
         ifft_sym= awgn(ifft_sym,SNR(j)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);%FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err, ber_temp]=biterr(recovered.',Tx_bit);
        Number_of_bit_errors(j)= Number_of_bit_errors(j)+ber_temp;
end
    BER1(j) = Number_of_bit_errors(j)/No_of_OFDM_Blocks;
end
for k = 1:length(SNR)
    Number_of_bit_errors(k)=0;
for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);%Random data generation
        QAM_out_Symbols = qammod(Tx_bit,M);% QAM modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
        %% clipping
        Thresold_for_clipping = 0.8;
        Instantaneous_Power = abs(ifft_sym);% calculation of instantaneous power
        [ max_level, max_index] = max(Instantaneous_Power);% finding maximum value
        indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%find the samples which has amplitude more than threshold
        ifft_sym(indices) = Thresold_for_clipping*max_level*ifft_sym(indices)./abs(ifft_sym(indices));%clipping the samples which has amplitude more than threshold
         ifft_sym= awgn(ifft_sym,SNR(k)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);%FFT
        y = downsample(y,Upsampling_Factor);%downsampling

        recovered = qamdemod(y,M);%demodulation
        [err, ber_temp]=biterr(recovered.',Tx_bit);
        Number_of_bit_errors(k)= Number_of_bit_errors(k)+ber_temp;
end
    BER2(k) = Number_of_bit_errors(k)/No_of_OFDM_Blocks;
end
for ii = 1:length(SNR)
```

```
    Number_of_bit_errors(ii)=0;
for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);%Random data generation
        QAM_out_Symbols = qammod(Tx_bit,M);% QAM modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
        %% clipping
        Thresold_for_clipping = 0.9;
        Instantaneous_Power = abs(ifft_sym);% calculation of instantaneous power
        [ max_level, max_index] = max(Instantaneous_Power);% finding maximum value
        indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%find the samples which has
amplitude more than threshold
        ifft_sym(indices) =
Thresold_for_clipping*max_level*ifft_sym(indices)./abs(ifft_sym(indices));%clipping the samples which has
amplitude more than threshold
         ifft_sym= awgn(ifft_sym,SNR(ii)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);%FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err, ber_temp]=biterr(recovered.',Tx_bit);
        Number_of_bit_errors(ii)= Number_of_bit_errors(ii)+ber_temp;
end
    BER3(ii) = Number_of_bit_errors(ii)/No_of_OFDM_Blocks;
end
%% plotting the results
figure(1)
hold on
semilogy(SNR,BER,'-.ms','LineWidth',2,...
'MarkerEdgeColor','m',...
'MarkerFaceColor','m',...
'MarkerSize',4);
hold on
semilogy(SNR,BER1,'-.rs','LineWidth',2,...
'MarkerEdgeColor','r',...
'MarkerFaceColor','r',...
'MarkerSize',4);
hold on
semilogy(SNR,BER2,'-.bs','LineWidth',2,...
'MarkerEdgeColor','b',...
'MarkerFaceColor','b',...
'MarkerSize',4);
hold on
semilogy(SNR,BER3,'-.ys','LineWidth',2,...
'MarkerEdgeColor','y',...
'MarkerFaceColor','y',...
'MarkerSize',4);
xlabel('SNR[dB]','fontsize',12,'fontweight','m')
```

```
ylabel('BER','fontsize',12,'fontweight','m')
title('SNR vs BER curve AT DIFFRENT CLIIPING THRESHOLD LEVELS',12,'fontweight','m')
legend('BER with clipping@0.6','BER with clipping@0.7','BER with clipping@0.8','BER with
clipping@0.9','Location','Southwest')
zoom on;
grid on;
```

B. Peak windowing techniques

```
%% cleraing commands
clc; % cears command window
clear all;%clears all variables in workspace
close all;%closes all the opened figures etc..
%% system parameters
No_of_subcarriers= 256;%Number of of subcarriers per OFDM symbol
Upsampling_Factor=4;%Upsampling factor
Bit_Per_Symbol=2;% Bits per symbol 1->BPSK,2->QPSK,4->16-QAM
PAPR_Range_in_dB=[0:0.1:12];%PAPR Range
No_of_OFDM_Blocks_Per_Iteration = 10000;%Number of OFDM blocks per simulations
rand_seed = 0; % Random number seed state initiliazation
Thresold_for_clipping =0.7;%percentage of maximum value
 %1->hamming 2->hann 3->kaiser
 L =3;%window length
% W_start= 2;%Window starting point
% W_end= L-W_start-1;%Window ending point
alpha = 0.4;%attenuation factor in peak windowing method
rand('state',rand_seed);
IFFT_Size=No_of_subcarriers*Upsampling_Factor; % IFFT size
M=2^Bit_Per_Symbol;%Modulation order
Es=1;%symbol energy
A=sqrt(3/2/(M-1)*Es); % Normalization factor for M-QAM
mod_object=modem.qammod('M',M,'SymbolOrder','gray');%Modulation object with gray coding
for ii=1:No_of_OFDM_Blocks_Per_Iteration
    QAM_Symbols = A*modulate(mod_object,randint(1,No_of_subcarriers,M));%Getting the modulated
symbols
    QAM_Symbols_Upsampled = upsample(QAM_Symbols,Upsampling_Factor);%upsampling
    OFDM_timedomain=ifft(QAM_Symbols_Upsampled,IFFT_Size);%IFFT output x(t)
Instantaneous_power=abs(OFDM_timedomain).^2;%p(t)=real(x(t))^2+imag(x(t))^2
    Mean_Power(ii)=mean(Instantaneous_power); %Mean power = E[p(t)]
    Peak_Power(ii)=max(Instantaneous_power); % Peak power = max(p(t))
end
PAPR=Peak_Power./Mean_Power; %PAPR in Linear scale
%CCDF = CCDF_Calc(PAPR,PAPR_Range_in_dB,No_of_OFDM_Blocks);%CCDF calculation
PAPRdB=10*log10(PAPR); % Measure PAPR in dB
PAPR_dB_Midpoints = PAPR_Range_in_dB + (PAPR_Range_in_dB(2)-PAPR_Range_in_dB(1))/2;%For
plotting histogram
count = 0;
%% Finding the CCDF
N_bins = hist(PAPRdB,PAPR_dB_Midpoints);
for i=length(PAPR_Range_in_dB):-1:1
    count = count+N_bins(i);
    CCDF(i) = count/No_of_OFDM_Blocks_Per_Iteration;
end
```

```
for iter=1:No_of_OFDM_Blocks_Per_Iteration
    QAM_out_Symbols = A*modulate(mod_object,randint(1,No_of_subcarriers,M));%generating QAM
symbols
    QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
    ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
    Instantaneous_Power = abs(ifft_sym);%p(t) = real(x(t))^2+imag(x(t))^2
    [ max_level max_index] = max(Instantaneous_Power);%Finding the maximum amplitude level
    indices = find(Instantaneous_Power>(Thresold_for_clipping.*max_level));%Finding the indices
corresponding which have amplitude more than threshold
     %% Selecting the window
   type=1; %hamming window
   if(type==1)
        h_window = hamming(L);%hamming window
    elseif(type==2)
        h_window = hann(L);%hann window
    elseif(type==3)
        h_window = kaiser(L);%kaiser window
   end

    %%HAMMING peak windowing -> multiplying with the window function wherever peak
    %% is detected
    for g= 1:length(indices)

W_start= 2;%Window starting point
W_end= L-W_start-1;%Window ending point
        if(indices(g)-W_start >0 && indices(g)+W_end<IFFT_Size)
            ifft_sym(indices(g)-W_start:indices(g)+W_end)= (1-alpha*h_window).*ifft_sym(indices(g)-
W_start:indices(g)+W_end);
        end
    end

    %% PAPR calculation
    Instantaneous_Power = abs(ifft_sym);%p(t) = real(x(t))^2+imag(x(t))^2
    sym_pow = Instantaneous_Power.^2; % Symbol power
    PAPRs(iter) = max(sym_pow)/mean(sym_pow);%PAPR calculation
end
PAPRdB=10*log10(PAPRs); % Measure PAPR in dB
PAPR_dB_Midpoints = PAPR_Range_in_dB + (PAPR_Range_in_dB(2)-PAPR_Range_in_dB(1))/2;%For
plotting histogram
count = 0;
%% Finding the CCDF
N_bins = hist(PAPRdB,PAPR_dB_Midpoints);
for i=length(PAPR_Range_in_dB):-1:1
    count = count+N_bins(i);
    CCDFHAM(i) = count/No_of_OFDM_Blocks_Per_Iteration;
end
for iter=1:No_of_OFDM_Blocks_Per_Iteration
```

```
    QAM_out_Symbols = A*modulate(mod_object,randint(1,No_of_subcarriers,M));%generating QAM
symbols
    QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
    ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
    Instantaneous_Power = abs(ifft_sym);%p(t) = real(x(t))^2+imag(x(t))^2
    [ max_level max_index] = max(Instantaneous_Power);%Finding the maximum amplitude level
    indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%Finding the indices
corresponding which have amplitude more than threshold
     %% Selecting the window
   type=2; %hann window
     if(type==1)
        h_window = hamming(L);%hamming window
    elseif(type==2)
        h_window = hann(L);%hann window
    elseif(type==3)
        h_window = kaiser(L);%kaiser window
   end

    %%HANN peak windowing -> multiplying with the window function wherever peak
    %% is detected
    for k= 1:length(indices)

W_start= 2;%Window starting point
W_end= L-W_start-1;%Window ending point
        if(indices(k)-W_start >0 && indices(k)+W_end<IFFT_Size)
            ifft_sym(indices(k)-W_start:indices(k)+W_end)= (1-alpha*h_window).*ifft_sym(indices(k)-
W_start:indices(k)+W_end);
        end
    end
    %% PAPR calculation
    Instantaneous_Power = abs(ifft_sym);%p(t) = real(x(t))^2+imag(x(t))^2
    sym_pow = Instantaneous_Power.^2; % Symbol power
    PAPRs(iter) = max(sym_pow)/mean(sym_pow);%PAPR calculation
end
PAPRdB=10*log10(PAPRs); % Measure PAPR in dB
PAPR_dB_Midpoints = PAPR_Range_in_dB + (PAPR_Range_in_dB(2)-PAPR_Range_in_dB(1))/2;%For
plotting histogram
count = 0;
%% Finding the CCDF
N_bins = hist(PAPRdB,PAPR_dB_Midpoints);
for ii=length(PAPR_Range_in_dB):-1:1
    count = count+N_bins(ii);
    CCDFHAN(ii) = count/No_of_OFDM_Blocks_Per_Iteration;
end
for iter=1:No_of_OFDM_Blocks_Per_Iteration
    QAM_out_Symbols = A*modulate(mod_object,randint(1,No_of_subcarriers,M));%generating QAM
symbols
```

```
    QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
    ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
    Instantaneous_Power = abs(ifft_sym);%p(t) = real(x(t))^2+imag(x(t))^2
    [ max_level max_index] = max(Instantaneous_Power);%Finding the maximum amplitude level
    indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%Finding the indices
corresponding which have amplitude more than threshold

     %% Selecting the window
    type=3; %KAISER window
     if(type==1)
        h_window = hamming(L);%hamming window
    elseif(type==2)
        h_window = hann(L);%hann window
    elseif(type==3)
        h_window = kaiser(L);%kaiser window
   end

    %% peak windowing -> multiplying with the window function wherever peak
    %% is detected
    for h= 1:length(indices)

W_start= 2;%Window starting point
W_end= L-W_start-1;%Window ending point
        if(indices(h)-W_start >0 && indices(h)+W_end<IFFT_Size)
            ifft_sym(indices(h)-W_start:indices(h)+W_end)= (1-alpha*h_window).*ifft_sym(indices(h)-
W_start:indices(h)+W_end);
        end
    end

    %% PAPR calculation
    Instantaneous_Power = abs(ifft_sym);%p(t) = real(x(t))^2+imag(x(t))^2
    sym_pow = Instantaneous_Power.^2; % Symbol power
    PAPRs(iter) = max(sym_pow)/mean(sym_pow);%PAPR calculation
end
PAPRdB=10*log10(PAPRs); % Measure PAPR in dB
PAPR_dB_Midpoints = PAPR_Range_in_dB + (PAPR_Range_in_dB(2)-PAPR_Range_in_dB(1))/2;%For
plotting histogram
count = 0;
%% Finding the CCDF
N_bins = hist(PAPRdB,PAPR_dB_Midpoints);
for ij=length(PAPR_Range_in_dB):-1:1
    count = count+N_bins(ij);
    CCDFKAS(ij) = count/No_of_OFDM_Blocks_Per_Iteration;
end

figure(1)
```

```
semilogy(PAPR_Range_in_dB,CCDF,'-ks','LineWidth',1,...
    'MarkerEdgeColor','k',...
    'MarkerFaceColor','k',...
    'MarkerSize',4);
hold on
semilogy(PAPR_Range_in_dB,CCDFHAM,'-.cs','LineWidth',1,...
    'MarkerEdgeColor','c',...
    'MarkerFaceColor','c',...
    'MarkerSize',4);
hold on
semilogy(PAPR_Range_in_dB,CCDFHAN,'-ms','LineWidth',1,...
    'MarkerEdgeColor','m',...
    'MarkerFaceColor','m',...
    'MarkerSize',4);
hold on
semilogy(PAPR_Range_in_dB,CCDFKAS,'-bs','LineWidth',1,...
    'MarkerEdgeColor','b',...
    'MarkerFaceColor','b',...
    'MarkerSize',4);

xlabel('PAPR_0 [dB]','fontsize',12);
ylabel('Pr(PAPR>PAPR_0)','fontsize',12);
title('Effect of window Type on PAPR Reduction');
axis([PAPR_Range_in_dB([1 end]) 1e-4 1]);
legend('PAPR_OFDM','PAPR_HAMMING','PAPR_HAN','PAPR_KAISER','location','southwest');
grid on;
zoom on;
```

BER ESTIMATION USING PEAK WINDOWING FOR THE REDUCTION OF PAPR

```
%% system parameters
clc
clear all
close all
No_of_subcarriers= 512;%Number of of subcarriers per OFDM symbol
Upsampling_Factor=4;%Upsampling factor
Bit_Per_Symbol=6;% Bits per symbol 1->BPSK,2->QPSK,4->16-QAM
SNR = 2:1:16;
No_of_OFDM_Blocks = 1000;%Number of OFDM blocks per simulations
Thresold_for_clipping = 0.8;%percentage of maximum value
rand_seed = 0; % Random number seed state initiliazation
L = 4;%window length
% type =2;%1->hamming 2->hann 3->kaiser
W_start= 2;%Window starting point
W_end= L-W_start-1;%Window ending point
alpha = 0.4;%attenuation factor in peak windowing method
rand('state',rand_seed);% Random number initilization
IFFT_Size=No_of_subcarriers*Upsampling_Factor; % IFFT size
M=2^Bit_Per_Symbol;%Modulation order
for i = 1:length(SNR)
    Number_of_bit_errors(i)=0;
    for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);% Generating random data
        QAM_out_Symbols = qammod(Tx_bit,M);%Modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
        ifft_sym= awgn(ifft_sym,SNR(i)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);%FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err ber_temp]=biterr(recovered.',Tx_bit);%Bit error calculation
        Number_of_bit_errors(i)= Number_of_bit_errors(i)+ber_temp;%Accumulating the total bit errors for each SNR
    end
    BER(i) = Number_of_bit_errors(i)/No_of_OFDM_Blocks;%Bit error rate for each SNR
end

for i = 1:length(SNR)
    Number_of_bit_errors(i)=0;
    for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);%Generating random data
        QAM_out_Symbols = qammod(Tx_bit,M);% modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT
         Instantaneous_Power = abs(ifft_sym);% calculating power
```

```
    [ max_level max_index] = max(Instantaneous_Power);%max power
    indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%indices with amplitude
more than threshold

   %% peak windowing
      h_window = hamming(L);%hamming window

    %% peak windowing -> multiplying with the window function wherever peak
    %% is detected
    for g= 1:length(indices)
      if(indices(g)-W_start >0 && indices(g)+W_end<IFFT_Size)
        ifft_sym(indices(g)-W_start:indices(g)+W_end)= (1-alpha*h_window).*ifft_sym(indices(g)-
W_start:indices(g)+W_end);
      end
    end
     ifft_sym= awgn(ifft_sym,SNR(i)-10*log10(Upsampling_Factor),'measured');% AWGN noise
    y = fft(ifft_sym);% FFT
    y = downsample(y,Upsampling_Factor);%downsampling
    recovered = qamdemod(y,M);%demodulation
    [err ber_temp]=biterr(recovered.',Tx_bit);%Calculating number of bit errors
    Number_of_bit_errors(i)= Number_of_bit_errors(i)+ber_temp;%Accumulating the bit errors for each
symbol
  end
  BER1(i) = Number_of_bit_errors(i)/No_of_OFDM_Blocks;%BER calculation

end

for i = 1:length(SNR)
  Number_of_bit_errors(i)=0;
  for iter=1:No_of_OFDM_Blocks
    Tx_bit = randint(1,No_of_subcarriers,M);%Generating random data
    QAM_out_Symbols = qammod(Tx_bit,M);% modulation
    QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
    ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT

     Instantaneous_Power = abs(ifft_sym);% calculating power
    [ max_level max_index] = max(Instantaneous_Power);%max power
    indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%indices with amplitude
more than threshold

   %% peak windowing

      h_window = hann(L);%hann window
%

    %% peak windowing -> multiplying with the window function wherever peak
    %% is detected
```

```
        for gg= 1:length(indices)
            if(indices(gg)-W_start >0 && indices(gg)+W_end<IFFT_Size)
                ifft_sym(indices(gg)-W_start:indices(gg)+W_end)= (1-alpha*h_window).*ifft_sym(indices(gg)-
W_start:indices(gg)+W_end);
            end
        end
         ifft_sym= awgn(ifft_sym,SNR(i)-10*log10(Upsampling_Factor),'measured');% AWGN noise
        y = fft(ifft_sym);% FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err ber_temp]=biterr(recovered.',Tx_bit);%Calculating number of bit errors
        Number_of_bit_errors(i)= Number_of_bit_errors(i)+ber_temp;%Accumulating the bit errors for each
symbol
    end
    BER2(i) = Number_of_bit_errors(i)/No_of_OFDM_Blocks;%BER calculation

end

for i = 1:length(SNR)
    Number_of_bit_errors(i)=0;
    for iter=1:No_of_OFDM_Blocks
        Tx_bit = randint(1,No_of_subcarriers,M);%Generating random data
        QAM_out_Symbols = qammod(Tx_bit,M);% modulation
        QAM_out_Symbols_upsampled = upsample(QAM_out_Symbols,Upsampling_Factor);%upsampling
        ifft_sym=ifft(QAM_out_Symbols_upsampled,IFFT_Size).';  % IFFT

         Instantaneous_Power = abs(ifft_sym);% calculating power
        [ max_level max_index] = max(Instantaneous_Power);%max power
        indices = find(Instantaneous_Power>(Thresold_for_clipping*max_level));%indices with amplitude
more than threshold

     %% peak windowing

           h_window = kaiser(L);%kaiser window
%

        %% peak windowing -> multiplying with the window function wherever peak
        %% is detected
        for gj= 1:length(indices)
            if(indices(gj)-W_start >0 && indices(gj)+W_end<IFFT_Size)
                ifft_sym(indices(gj)-W_start:indices(gj)+W_end)= (1-alpha*h_window).*ifft_sym(indices(gj)-
W_start:indices(gj)+W_end);
            end
        end


         ifft_sym= awgn(ifft_sym,SNR(i)-10*log10(Upsampling_Factor),'measured');% AWGN noise
```

```
        y = fft(ifft_sym);% FFT
        y = downsample(y,Upsampling_Factor);%downsampling
        recovered = qamdemod(y,M);%demodulation
        [err ber_temp]=biterr(recovered.',Tx_bit);%Calculating number of bit errors
        Number_of_bit_errors(i)= Number_of_bit_errors(i)+ber_temp;%Accumulating the bit errors for each
symbol
    end
    BER3(i) = Number_of_bit_errors(i)/No_of_OFDM_Blocks;%BER calculation

end

%% Printing the results
fprintf('SNR(dB))\twindowing@L=6\t\twindowing@L=7\t windowing@L=8\twindowing@L=9\n');
for i=1:length(SNR)
    fprintf('%.2f\t    %.4f\t\t%.4f\t    %.4f\t\t\t%.4f\n',SNR(i),BER(i),BER1(i),BER2(i),BER3(i));
end

%% plotting the results
figure(1)
semilogy(SNR,BER,'-cs','LineWidth',2,...
    'MarkerEdgeColor','c',...
    'MarkerFaceColor','c',...
    'MarkerSize',4);
hold on
semilogy(SNR,BER1,'-ms','LineWidth',2,...
    'MarkerEdgeColor','m',...
    'MarkerFaceColor','m',...
    'MarkerSize',4);
hold on
semilogy(SNR,BER2,'-bs','LineWidth',2,...
    'MarkerEdgeColor','b',...
    'MarkerFaceColor','b',...
    'MarkerSize',4);
hold on
semilogy(SNR,BER3,'-rs','LineWidth',2,...
    'MarkerEdgeColor','r',...
    'MarkerFaceColor','r',...
    'MarkerSize',4);
xlabel('SNR [dB]','fontsize',12);
ylabel('BER','fontsize',12);
title('BER Vs SNR');
% axis([SNR([1 end]) 1e-4 1]);
legend('BER_orignal OFDM','BER_hamming','BER_hanning','BER_kaiser','location','southwest');
grid on;
zoom on;
```