

# A Survey on Peak to Average Power Ratio Reduction Techniques in OFDM Systems

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**Abstract**— This review paper focuses on the various PAPR reduction schemes and also defines the parameters on the basis of which various techniques for PAPR reduction can be evaluated and compared. Orthogonal Frequency Division Multiplexing (OFDM) has become one of the most used techniques to be used in both wired and wireless communication where high data rates are required. One of the main challenges which this technique faces is high Peak To Average Power Ratio (PAPR) caused due to the Power being proportional to the square of the number of subcarriers in the worst case situation causing non-linear distortion. The paper compares various PAPR reduction techniques such as clipping, selective mapping, partially transmitting sequences etc, their complexities regarding computation and practical applicability. As the data rates and mobility supported by the OFDM system increase, the number of subcarriers also increases, which in turn leads to high PAPR. As future applications would demand higher data rates and higher mobility, PAPR reduction methods would be an ever increasing topic for research. The authors believe that this comparative study on different PAPR reduction techniques with their various tradeoffs would facilitate deeper insights into practicability of OFDM systems for both contemporary as well as future researchers.

**Index Terms**:-

OFDM, PAPR-ratio, High Power Amplifier, SLM.

## I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM) is one of the most powerful modulation techniques being used today where high data rates are needed both in wired and wireless systems. The major advantages of this technique are high spectral efficiency and efficient digital implementation. The drawback lies in the fact that the amplitude variations of OFDM signals is large, which requires large back-off in the transmitter amplifier and hence HPAs are not efficiently used. In order to reduce the distortion caused by a HPA without setting it to large back-offs, several techniques have been introduced that limit the peak of the envelope of the signal (**clipping**) [1],[5], a problem that is usually referred to as peak-to-average power ratio (PAPR) reduction. These techniques have varying PAPR-reduction capabilities, power, and bandwidth and complexity requirements. PAPR is a very well-known measure of the envelope fluctuations of a multicarrier (MC) signal and plays a decisive role in the adoption of any particular technique. The problem of reducing the envelope fluctuations with the aim to increase the system performance (reduce both BER and the out-of-band radiation) has boiled down to reducing PAPR. In this paper we introduce the basic concepts related to OFDM, the significance of PAPR

and various techniques devised to reduce PAPR in OFDM systems. [1],[5].

## II. OFDM Theory:

Orthogonal Frequency Division Multiplexing is a special form of multicarrier modulation which is particularly suited for transmission over a dispersive channel. Here the different carriers are orthogonal to each other, that is, they are totally independent of one another. This is achieved by placing the carrier exactly at the nulls in the modulation spectra of each other.

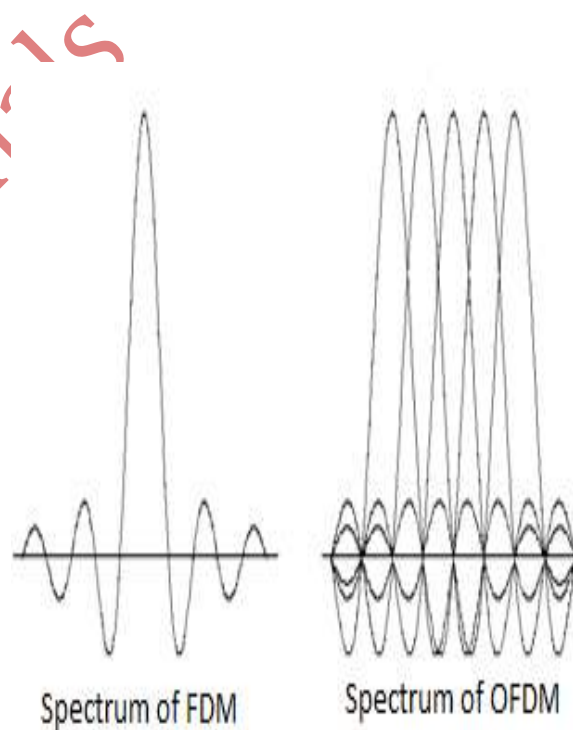


Fig-1:- Spectrum of frequency division multiplexing and Orthogonal frequency division multiplexing

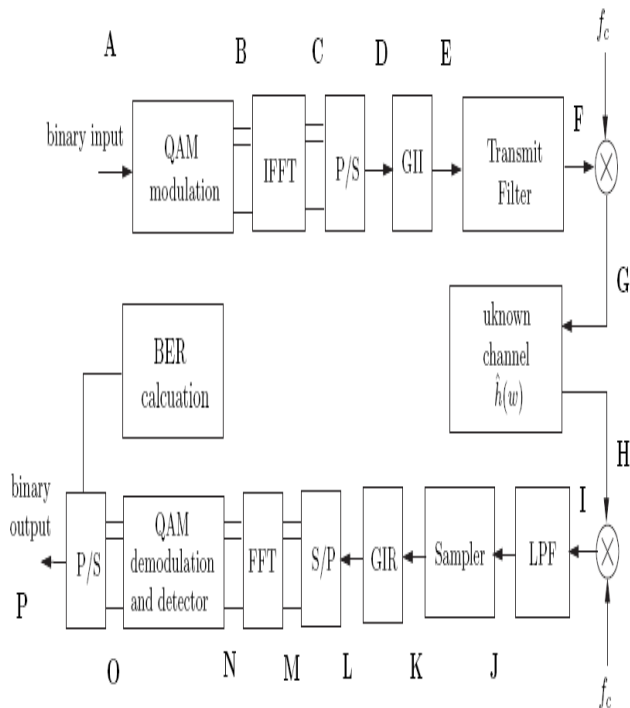


Fig-2:- OFDM Transceiver Structure

#### A. PEAK-TO-AVERAGE POWER RATIO (PAPR)

PAPR depends on the ratio between the maximum power of the complex pass-band signal and the mean power of it, we can calculate the PAPR. The value of PAPR can be calculated as following equation:

$$PAPR = \max \{ x^2(t) \} / \text{mean} \{ x^2(t) \}$$

Where  $x(t)$  is presented in the equation to denote the amplitude of the complex pass-band signal. To calculate the probability of having PAPR greater than the threshold value for the OFDM signal, we could use Complementary Cumulative Distribution Function (CCDF). By simulating the CCDF, we compare the theoretical values with the simulation results and the PAPR keeps increasing when the number of carriers increases. In the simulation part there is a figure showing the CCDFs of OFDM signals with different number of subcarriers.[9] The Input-Output characteristics of an HPA are shown below

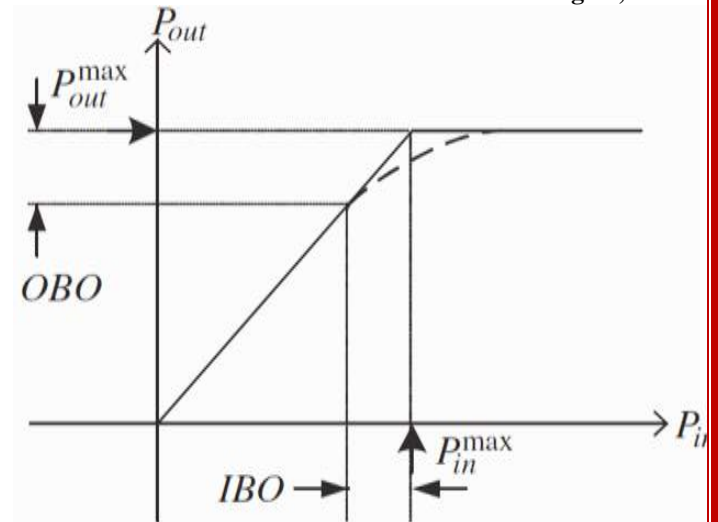


Fig-3:- Graph showing linearity between output and input power

In this diagram, the input power is denoted by  $P_{in}$  while the outputs power is represented by  $P_{out}$ . To keep the linearity, the maximum output power is limited by the value  $P_{outmax}$  and the maximum input power is pounded by  $(P_{inmax})$ . Both the input and output power are backed off to insure a linear operation and the area of the backing off is termed by Input Bach-Off (IBO) and Output Back-Off (OBO)[5],[9]

Due to the limit imposed on the maximum peak of the OFDM signal by the HPA, an increase is encountered in both the in-band and out-of-band distortions. The second causes undesirable increase in the power of the side lobes of the *power spectral density* (PSD) of the OFDM signal. This effect is referred to as spectral spreading or spectral re growth. As demonstrated in the figure, when the nonlinearity of the HPA is higher, IBO is smaller, and the spectral spreading is higher. Spectral spreading leads to higher interference between the sub bands of the OFDM signal, unless the frequency separation between adjacent subcarriers is also increased to maintain orthogonally. However, this solution has the disadvantage of lowering the spectral efficiency.

#### B. DIFFERENT TECHNIQUES FOR PAPR REDUCTION AND THEIR COMPARISON:

Different PAPR reduction techniques can be broadly categorized as:

**Signal Distortion Techniques:** These can be further divided into 4 categories:[1],[5],[7]

a) Clipping and Filtering: One of the simplest signal distortion methods is the method of clipping the high peaks of the OFDM signal prior to passing it through the PA. This method employs a clipper that limits the signal envelope to a predetermined *clipping level* (CL) if the signal exceeds that level; otherwise, the clipper passes the signal without change.

$$T(x[n]) = x[n] \text{ if } |x[n]| \leq CL$$

$$CL \text{ ej}\angle x[n] \text{ if } |x[n]| > CL,$$

b) Peak Windowing: Unlike peak clipping where the peaks that exceed a predetermined threshold are hard-limited, peak windowing limits such high peaks by multiplying them by a weighting function called a window function. Many window functions can be used in this process as long as they have good spectral properties good spectral properties window functions include Hamming, Hanning and Kaiser Windows. To reduce PAPR, a window function is aligned with the signal samples in such a way that its valley is multiplied by the signal peaks while its higher amplitudes are multiplied by lower amplitude signal samples around the are multiplied by lower amplitude signal samples around the way compared to hard clipping, resulting in reduced distortion.

c) Companding[2]: Companding transforms are number of bits per sample. Since OFDM and speech signals behave similarly in the sense that high peaks occur infrequently, same companding transforms can be used to reduce PAPR. Companding has lesser complexity and also doesn't depend on the number of sub-carriers, but does degrade the BER.

d) Peak Cancellation: In this technique, a peak cancellation waveform is generated, scaled, shifted and subtracted from those sections of the OFDM signal which exhibit spectral peaks.

**Multiple Signaling and Probabilistic Techniques:** They can be further classified into 6 categories.

- 1) Selective Mapping(SLM)[4],[9] : The basic idea is to generate a set of sufficient different OFDM symbols  $x(m)$ ,  $0 \leq m \leq M - 1$ , each of length N, all representing the same information as the original OFDM, and then transmitting the OFDM signal  $x$  having the smallest value of PAPR.

- 2) Partial Transmit Sequences (PTS)[3],[9]: In this method, an input data block of length  $N$  is partitioned into a number of disjoint sub-blocks. The IDFT for each of these sub-blocks is computed separately and then weighted by a phase factor. The phase factors are selected in such a way as to minimize the PAPR of the combined signal of all the sub-blocks.
- 3) Interleaved OFDM: Another method to generate multiple OFDM signals is to use interleavers, which is similar to the SLM technique but here interleavers are used in place of phase sequences.
- 4) Tone injection & tone reservation [8],[12]: In this technique, a subset of tones is reserved for reduction of PAPR. Due to their low SNR, they carry no information but reduce PAPR by statistical redistribution.
- 5) Active Constellation Extension [11],[14]: In this the modulation constellation over active subcarriers in the OFD data block is modified or pre-distorted so that the PAPR is reduced but at the cost of degrading the BER.
- 6) Constrained Constellation Shaping[11],[12],[13]: In this technique, the modulation points over the data sub carriers in OFDM symbol are modified within an allowed error to reduce the PAPR, again BER is the tradeoff.

Coding Techniques for reduction of PAPR[9]:

Due to the inherent error detection and correction capabilities of different coding techniques viz. Linear Block Codes, Golay Complementary Sequences, BCH codes etc, coded OFDM is a natural choice for reduction of PAPR. The coding pattern is modified in such a manner that the codes are not used to reduce BER but to reduce PAPR.

#### Comparison of various PAPR reduction techniques [7],[9]

Before selecting a particular PAPR reduction technique, one should bear in mind that the power required is proportional to  $N^2$ , where  $N$  is the number of sub-carriers of the OFDM system. In earlier OFDM systems, the main focus was on the simplicity of the PAPR reduction method in implementing it on hardware. Therefore, before comparing the various techniques, it becomes mandatory to analyze the computational complexity of the most common PAPR reduction techniques when it comes to hardware implementation. The table below depicts the computational complexities of the common PAPR reduction techniques.

Method	Complexity
Clipping and Filtering	$4NL + 2N$ multiplications, $4NL + 2N$ additions
SLM	$2MN(1 + \log_2 N) + M$ multiplications, $3MN(1 + \log_2 N) + M(N - 1) - 1$ additions
PTS	$2MN \log_2(N) + 2N + 1$ multiplications $3MN \log_2(N) + (M - 1)[2N(M + 1) - 1]$ additions

Apparently the least complex method as far as computational complexity is concerned, seems to be the Clipping and filtering technique. But a close look at the technique reveals its weakness. Let us consider the figure below which shows the time domain OFDM signal.

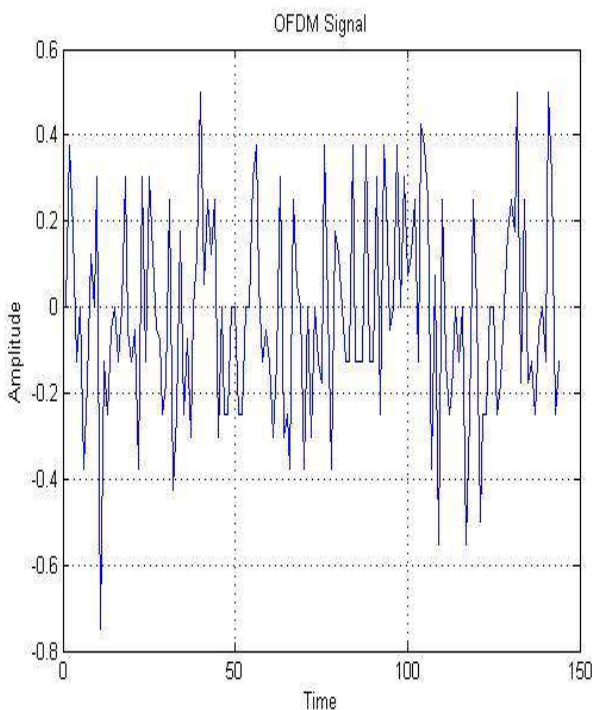


Fig 4:- Time domain OFDM signals

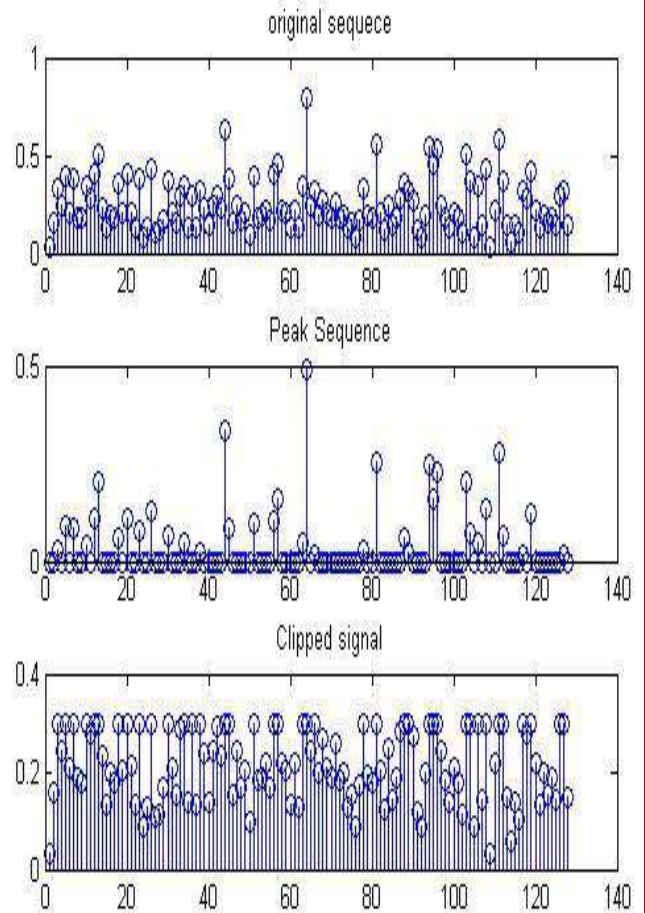


Fig 5:- Graphs showing output signal of original sequence, peak sequence, clipped signal.

If we look at the signal in time domain, it can be seen that the OFDM signal undergoes abrupt amplitude fluctuations, a characteristic which can be attributed to the fact that the message modulates the numerous subcarriers which add up in time domain. Now, if we wish to clip the signal in time domain maintaining a fixed threshold value, we would end up in clipping peaks which may contain crucial information. The consequence in the frequency domain would be an increase in BER.[5],[9] Presently wireless systems like Wi-Max, Mobile-Wi-Max, LTE, DVB-T standards support up to 512, 2048 and 8192 sub-carriers. Thus although clipping and filtering for one or more iterations may seem least demanding, but signal transmission and reception becomes substantially erroneous. With the advent of very high integrated circuits with ever increasing computational capabilities, the focus has now switched on SLM and PTS techniques. PTS technique requires sending transmitting sub-blocks of the original data. The main drawback is the overhead data needed to be sent which can be substantially large making PTS practically non-viable for large data blocks. The SLM requires generating replicas of the

same signal but with different values of PAPR attributed to different phase shifts. This creates a challenge in implementing practical systems on hardware which would be computationally efficient. Thus research has shifted to low weight and low complexity SLM techniques and blind SLM techniques which would be less demanding in terms of data overhead and computational costs.

**TABLE 2: COMPARATIVE RESULTS [1],[3],[5], [9]**

PAPR Reduction Technique	BER Increase	Implementation Complexity	Power Increase
Clipping and Filtering	yes	low	No
Companding	yes	low	No
SLM	no	high	No
PTS	no	high	No
Interleaving	no	high	No
Coding	no	high	Depends on the coding technique used

### III. CONCLUSION

The selection of a particular PAPR technique should be based on system requirements and design. Repetitive or iterative clipping and filtering method was the one to be used mostly in commercial and industrial applications due to its 'simplicity and low computational complexity'[1],[7],[9]. The price to pay is the high BER. The need for higher data rates and mobility asks for higher number of sub-carriers. The need would further increase in times to come. The low complexity SLM, blind SLM and Partially Transmitted Sequences (PTS) techniques have been proposed recently to circumvent the challenge of escalating complexity. Also, it has been proved that at higher number of sub-carriers ( $N > 256$ )[7],[13],[5]. With the advance in hardware design (High Speed Integrated Circuits), and alternative computational methods, there has been a paradigm shift in PAPR reduction techniques[1],[5],[9]. PTS needs additional side information at the receiving end which would require more power which would significantly affect power efficiency. On the other hand, SLM and Blind SLM don't have such requirements and hence can be adjudged among top contenders for PAPR reduction in times to come.

### REFERENCES

- [1]Performance Analysis of Deliberately Clipped OFDM Signals Hideki Ochiai, *Member, IEEE*, and Hideki Imai, *Fellow, IEEE* IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 50, NO. 1, JANUARY 2002
- [2]Exponential Companding Technique for PAPR Reduction in OFDM Systems Tao Jiang, Yang Yang, *Member, IEEE*, and Yong-Hua Song, *Senior Member, IEEE* IEEE TRANSACTIONS ON BROADCASTING, VOL. 51, NO. 2, JUNE 2005
- [3]PAPR Reduction of an OFDM Signal by Use of PTS With Low Computational Complexity L. Yang, R. S. Chen, Y. M. Siu, and K. K. Soo IEEE TRANSACTIONS ON BROADCASTING, VOL. 52, NO. 1, MARCH 2006
- [4]A Novel PAPR Reduction Scheme for OFDM Systems: Selective Mapping of Partial Tones (SMOPT) Seungsoo Yoo, *Student Member, IEEE*, Seokho Yoon, *Member, IEEE*, Sun Yong Kim, *Senior Member, IEEE*, and Ickho Song, *Senior Member, IEEE*, IEEE Transactions on Consumer Electronics, Vol. 52, No. 1, FEBRUARY 2006
- [5]Amplitude Clipping and Iterative Reconstruction of MIMO-OFDM Signals with Optimum Equalization Ui-Kun Kwon, Dongsik Kim, and Gi-Hong Im, *Senior Member, IEEE* IEEE TRANSACTIONS ON WIRELESS COMMUNICATIONS, VOL. 8, NO. 1, JANUARY 2009
- [6]Optimized Iterative Clipping and Filtering for PAPR Reduction of OFDM Signals Y.-C. Wang, *Member, IEEE*, and Z.-Q. Luo, *Fellow, IEEE* IEEE TRANSACTIONS ON COMMUNICATIONS, VOL. 59, NO. 1, JANUARY 2011
- [7]Performance Evaluation of Peak-to-Average Power Ratio Reduction and Digital Pre-Distortion for OFDM Based Systems Charles Nader, *Student Member, IEEE*, Per Niklas Landin, *Student Member, IEEE*, Wendy Van Moer, *Senior Member, IEEE*, Niclas Björnsell, *Member, IEEE*, and Peter Händel, *Senior Member, IEEE*, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 59, NO. 12, DECEMBER 2011
- [8]A Weighted OFDM Signal Scheme for Peak-to-Average Power Ratio Reduction of OFDM Signals Chang Eon Shin, Kyung Soo Rim, and Youngok Kim IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. 62, NO. 3, MARCH 2013
- [9]Peak To Average Power Ratio Reduction in OFDM Systems: A Survey And Taxonomy, Yasir Rahmatallah, Seshadri Mohan, IEEE Communications Surveys & Tutorials, Vol 15, No.4 Fourth Quarter 2013
- [10]Performance of 16 QAM-OFDM With New Null Subcarrier Shifting in an Intensity-Modulated Direct Detection System Hongxian Chen, Jing He, Jin Tang, Fan Li, Ming Chen, and Lin Chen VOL. 6, NO. 2/FEBRUARY 2014/J. OPT. COMMUN. NETW
- [11]A Crest Factor Reduction Scheme Based on Recursive optimum Frequency Domain Matrix Poolia Varahram, *Member, IEEE*, Borhanuddin Mohd Ali, *Senior Member, IEEE*, P. Varahram and B. M. Ali: A Crest Factor Reduction Scheme Based on Recursive Optimum Frequency Domain Matrix, 2014
- [12]Novel Metric-Based PAPR Reduction Schemes for MC-CDMA Systems Wan-Jen Huang, Wei-Wen Hu, Chih-Peng Li *Senior Member, IEEE*, and Jung-Chieh Chen, *Member, IEEE*, IEEE Transactions, 2014
- [13]Pilot-Assisted PAPR Reduction Technique for Optical OFDM Communication Systems Wasiu O. Popoola, Zabih Ghassemlooy, and Brian G. Stewart JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 32, NO. 7, APRIL 1, 2014
- [14]Joint PAPR Reduction and Sidelobe Suppression Using Signal Cancellation in NC-OFDM Based Cognitive Radio Systems Chunxing Ni, Tao Jiang, and Wei Peng IEEE TRANSACTIONS ON VEHICULAR TECHNOLOGY, VOL. X, NO. Y, MONTH 2014

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