# PAPR Reduction in an OFDM System using Combined $N^{th}$ Root with Different Techniques

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## ABSTRACT

Orthogonal Frequency Division Multiplexing (OFDM) is an efficient modulation technique for high data rate communication systems such as Digital audio broadcasting, DSL internet access, 4G etc. Peak to Average Power Ratio (PAPR) is one of major problems in OFDM system. In this paper, a combined Nth root technique with other conventionally established methods such as Clipping, SLM and PTS is proposed. An elaborate analysis is carried out by plotting CCDF curve in MATLAB demonstrating a picturesque comparison between our proposed technique and other methods individually. The obtained results show that the proposed system is better than its competitors when considering the three performance criteria together. For depicting PAPR reduction CCDF curve will be plotted by MATLAB.

## Keywords

Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Ratio (PAPR), Clipping, Selected Mapping (SLM), Partial Transmit Sequence (PTS), Complementary Cumulative Distribution Function (CCDF).

## 1. INTRODUCTION

The Orthogonal Frequency Division Multiplexing (OFDM) technology being a multi-carrier digital modulation technique uses multiple sub-carriers and the frequency of overlapping technology [1]. The main application fields of OFDM are video and audio broadcasting, 4G mobile communications, power line networks, DSL Internet access and wireless networks [2].

The sum of a number of independent sub-carrier signal modulates the OFDM symbol. When the number of subcarriers reaches to a certain level, then the peak to average power becomes much larger than the single carrier system and the system power amplifier, A/D and D/A converter with a larger linear dynamic range are required. For this reason OFDM leads to interference between adjacent channels which destroys the orthogonality of the system. This is why PAPR reduction is needed [3]. With the increase of PAPR the efficiency of power consumption will be reduced in band distortion.

In OFDM transmission, multi-carrier is used by splitting it into several components. After that each of these components are sent over separate carrier signals [4]. In OFDM method, the data are divided into several channels or parallel data streams, then the subcarriers are transmitted simultaneously at different frequencies. Absence of Inter Symbol Interference (ISI) is the primary advantage of OFDM [5]. But high Peak to Average Power Ratio (PAPR) is a major drawback of OFDM system. As the number of subcarriers increases the maximum possible peak power becomes higher than the average power. In Band Interference (IBI) and Out of Band Interference (OBI) to signal are caused by inter modulation products among the subcarriers which results from high PAPR. Consequently, it is unenviable.

OFDM is suitable for LTE as well as 4G wireless communication because it offers high spectral efficiency, unaffected to the multipath delay, less inter-symbol interference (ISI), resistant to frequency selective fading and high power efficiency. Due to these advantages OFDM is opted as high data rate communication systems. However OFDM system has issues of severe problem of high PAPR. Superposition of multiple sub-carriers is the OFDM system output. This might result in high power output which can surpass the mean power of system. Transmission of signals with such high PAPR requires power amplifiers which are high-priced and have low efficiency. Transition in superposition of the signal spectrum causes performance degradation and rise of non-linear distortion. Practical applications of OFDM system could be greatly restrained if no measure is taken to reduce the high PAPR [6]. PAPR can be depicted by its complementary cumulative distribution function (CCDF). Researchers have proposed certain schemes in this probabilistic approach. These comprise clipping, signal scrambling techniques, coding, Tone Reservation (TR), Peak Windowing and so on.

Among these techniques, clipping and filtering is possibly the simplest PAPR-reduction scheme. This technique directly clips OFDM signals to a predefined threshold and then uses a filter to eliminate the out-of-band radiation. However, peak re-growth results from the filtering operation. Therefore in order to suppress the peak re-growth iterative clipping and filtering (ICF) is generally required [7].

Signal scrambling techniques includes (1) Partial transmit sequence (PTS) and (2) Selected Mapping (SLM). Despite the fact that some techniques of PAPR reduction have been summarized in [8], it is still needed to give an extensive review. Data rate loss, implementation complicacy, Bit Error Rate (BER) performance and best compromise between the capacity of PAPR reduction and transmission power etc. should be essential for an effective PAPR reduction technique.

PTS and SLM are such methods where phase is controlled to reduce PAPR. In the SLM scheme, an OFDM data sequence is multiplied by several phase sequences to generate some candidate OFDM symbols. The candidate data sequence is transmitted which has the lowest PAPR among them [9]. Similarly, in the PTS scheme, several sub-blocks are generated by dividing the input OFDM data sequence and phase rotation factors are multiplied to get the low PAPR signal [10]. In spite of these two methods being able to decrease PAPR efficiently with no signal distortion whatsoever, the transmission of side information to the receiver is obligatory. Moreover, complexity of the system considerably escalates due to many inverse fast Fourier transform (IFFT) stages and long phase optimization processes [11].

In this paper PAPR reduction techniques such as Clipping, SLM and PTS shall be briefly discussed. A comparison will be made between them. Eventually there will be a vivid illustration about the combined Clipping, SLM and PTS with proposed Nth Root technique. For depicting PAPR reduction CCDF curve will be plotted using MATLAB.

## 2. OFDM

Due to the difficulty in creating large banks of phase lock oscillators and receivers in the analog domain OFDM signals are mostly generated digitally. The digital data is converted by the transmitter section into a mapping of subcarrier amplitude and phase. Inverse Discrete Fourier Transform (IDFT) is used to transform this spectral representation of the data into the time domain. The functions of Inverse Fast Fourier Transform (IFFT) and Inverse Discrete Fourier Transform (IDFT) are similar, apart from the higher computational efficiency. So it is used in all practical systems. The calculated time domain signal is then mixed up to the required frequency, in order to transmit the OFDM signal.

Let, $X \in C^N$ be the frequency-domain OFDM symbol and $\{X(i), i = 1, \dots\dots, N\}$ be the symbol value carried by the i-th sub-carrier. Then, the time domain OFDM symbol, $x \in C^{\ell N}$, corresponding to with times over-sampling is expressed as

$$x(k) = \frac{1}{\sqrt{\ell N}} \sum_{i=1}^{N} X(i) e^{j\frac{2\pi}{\ell N}ki} \qquad (1)$$

where, $k = 1, \dots\dots, \ell N$ is time index. The frequency-domain OFDM symbol is computed using this equation.

The reverse operation of the transmitter is performed by the receiver, mixing the RF signal to base band for processing. A Fast Fourier Transform (FFT) is then used to analyze the signal in the frequency domain. The amplitude and phase of the subcarriers are then selected and converted back to digital data. The FFT and the IFFT are complementary function and the most appropriate term depends on whether the signal is being generated or received. The term IFFT and FFT is used alternately in cases where the signal is independent of this distinction.

$$X(i) = \frac{1}{\sqrt{\ell N}} \sum_{k=1}^{\ell N} x(k) e^{-j\frac{2\pi}{\ell N}ki} \qquad (2)$$

where, $i = 1, \dots\dots, N$. In practice, OFDM modulation and demodulation can be implemented via IFFT and FFT, respectively.

Data is transmitted generally in the form of a serial data stream. In OFDM, 40 - 4000 bits are typically transmitted by each symbol. This is why to convert the input serial bit stream to the data needs a serial to parallel conversion stage to be transmitted in each OFDM symbol. The modulation scheme used and the number of subcarriers determine the data allocation for each symbol. For example, for a subcarrier modulation of 16-QAM each subcarrier carries 4 bits of data. So for a transmission if 100 subcarriers are used then the number of bits per symbol might be 400.

For adaptive modulation technique, the modulation scheme used on each subcarrier can vary, for this the number of bits per subcarrier varies as well. As a result, filling the data payload is involved in the serial to parallel conversion stage for each subcarrier. At the receiver, the data from the subcarriers is converted back to the original serial data stream, which is the reverse process of the transmitter.

Frequency selective fading can result in groups of subcarriers being heavily attenuated when an OFDM transmission occurs in a multipath radio environment, which may generate bit errors. These nulls in the frequency response of the channel can cause the information sent in neighboring carriers to be destroyed, resulting in a clustering of the bit errors in each symbol. If the errors are evenly spread the majority of Forward Error Correction (FEC) schemes tend to work more efficiently, instead of large clusters. Therefore, data scrambling is used as a part of the serial to parallel conversion stage in order to improve the performance of most systems. The subcarrier allocation of each sequential data bit is randomized to implement this. The signal is decoded using the reverse scrambling at the receiver side. This original sequencing of the data bits is restored. However clusters of bit errors are spread. This leads to an approximate uniform distribution in time. The performance of the FEC and the system as a whole is improved significantly due to the stochastic ordering of the location of the bit errors.

Based on the data being sent and the modulation scheme each of the data subcarriers is set to an amplitude and phase following each subcarrier modulation stage; all subcarriers that are unused are set to zero. As a result the OFDM signal is set in the frequency domain. The signal is converted to time domain by using an IFFT to allow it to transmit each of the discrete samples of the IFFT corresponds to an individual subcarrier prior to applying the IFFT in the frequency domain. The majority of the subcarriers are modulated with data. The outer subcarriers are set to zero amplitude as they are un-modulated. A frequency guard band is provided by these zero subcarriers before the Nyquist frequency, acting efficiently as an interpolation of the signal therefore allowing for a realistic roll off in the analog anti-aliasing reconstruction filters.

A base band signal which is generated by the output of the OFDM modulator should be mixed up to the required transmission frequency. Analog techniques or a Digital Up can be used to implement this. The same operation is performed by both techniques, although, due to improved matching between the processing of the I and Q channels, and the phase accuracy of the digital IQ modulator, the performance of the digital modulation will tend to be more accurate.

## 3. PEAK TO AVERAGE POWER RATIO (PAPR)

The PAPR is defined at the ratio of maximum signal power to average power of signal for the discrete time OFDM signal x(n), [12], [13].

$$PAPR = 10\log\frac{\max|x(n)|^2}{\text{mean}|x(n)|^2}$$

When all the subcarriers are added-up constructively, the peak power of the OFDM signal is the sum of all the N subcarriers. The sum of all the values of the signal, divided by the total number of subcarriers, which is N in both cases, gives the mean power of the OFDM signal.

Therefore the maximum PAPR is,

$$\mathrm{PAPR_{max}} = \frac{N^2}{N} = N$$

The probability that the PAPR exceeds a certain threshold is indicated by the Complementary Cumulative Distributive Function (CCDF), which is a measure of the PAPR reduction capability. In order to determine the bounds for the minimum number of redundancy bits required to identify the PAPR sequences and evaluate the performance of any PAPR reduction schemes, the CCDF of PAPR can be applied.

The complex representation of OFDM signal x(n), become Gaussian distributed for large values of subcarriers (N>64). Hence, the envelope of the OFDM signal has a Rayleigh distribution with a cumulative distribution. It can be written by,

$$F(z) = 1 - e^{\mathrm{PAPR}_0}$$

The complementary cumulative distribution function (CCDF) of OFDM signals can be expressed as [14],

$$\mathrm{CCDF} = P_r(\mathrm{PAPR} > \mathrm{PAPR_0})$$

$$P_r(\mathrm{PAPR} > \mathrm{PAPR_0}) = 1 - \left(1 - e^{-\mathrm{PAPR}_0}\right)^N$$

Here, PAPR0 is the threshold level.

The power characteristics mentioned above can also be described in terms of their magnitudes by defining the crest factor (CF) as:

$$\mathrm{CF} = \sqrt{\mathrm{PAPR}} \qquad (4)$$

# 4. PAPR PEDUCTION TECHNIQUES

## 4.1 Clipping

To reduce PAPR, the simplest technique is amplitude clipping. The peak amplitude of the input signal is limited to a predetermined value for some desired signal level in this scheme. Clipping is used to reduce large peaks by nonlinearly distorting the signal [15], [16]. Additional information to the signal is not required and the probability of too large peaks is low. Therefore the signal is scarcely distorted. Maximum peak amplitude A is chosen, in this technique, so that the limits of this region are not exceeded by the OFDM signal. The symbols that exceed this maximum amplitude will be clipped. Square rooting and the Digital to Analog conversion is carried out after the clipping function is performed in digital time domain.

The clipping process is described by the following expression [17],

$$x_c(n) = \begin{Bmatrix} Ae^{j\emptyset(n), |x(n)| > A} \\ x(n), |x(n)| \le A \end{Bmatrix}$$

where, xc(n) is the clipped signal

A is the clipping threshold

## 4.2 Selective Mapping (SLM)

A set of candidate data blocks that are different enough is generated at the transmitter side, in the SLM technique. The same information as the original data block is represented and the most favorable for transmission is selected.

Each data block as a vector is defined as:

$$X = [X_0, X_1, \cdots\cdots\cdots, X_{N-1}]$$

The U different phase sequences each of length N are defined as:

$$B^{(u)} = [b_{u_r0}, b_{u_r1}, \cdots\cdots\cdots, b_{u_rN-1}]^T, \qquad u = 1, 2, \dots, U$$

Each data block is multiplied by U different phase sequences, which are of length N. This result in U modified data blocks. The length of the all-one vector is set as N, to include the unmodified data block in the set of modified data blocks. The modified data block for the u-th phase sequence is denoted as:

$$X^{(u)} = [X_0 b_{u_r0}, X_1 b_{u_r1}, \cdots\cdots\cdots, X_{N-1} b_{u_rN-1}]^T, \quad u = 1, 2, \dots, U$$

After applying SLM to X, the multicarrier signal becomes

$$x^{(u)}(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n b_{u_rn} . e^{j2\pi n \Delta f t}, \qquad 0 \le t \le NT, \quad u = 1, 2, \dots, U$$

Among the modified data blocks $X^{(u)}$, $u = 1, 2, \dots, U$ has the lowest PAPR which is chosen for transmission. Information about the selected phase sequence should be transmitted to the receiver as side information. The reverse operation is performed at the receiver, to recover the original data block. The SLM technique needs U IFFT operations, for implementation and the number of required side information bits is [log2U] for each data block. With all types of modulation and any number of subcarriers the approach is applicable. The data block to be transmitted is denoted X = [1, –1, 1, 1, 1, –1, 1, –1] T whose PAPR before applying SLM is 11.2 dB. The four phase factors are set as

B(1) = [1, 1, 1, 1, 1, 1, 1, 1]T,

B(2) = [–1, –1, 1, 1, 1, 1, 1, –1]T,

B(3) = [–1, 1, –1, 1, –1, 1, 1, 1]T, and

B(4) = [1, 1, –1, 1, 1, –1, 1, 1]T.

Among the four modified data blocks X(u), u = 1, 2, 3, 4, X(2), has the lowest PAPR of 7.1 dB. Therefore X(2) is selected and transmitted to the receiver. For this data block, the PAPR is reduced from 11.2 to 7.1 dB, which results in a reduction of 4.1 dB.

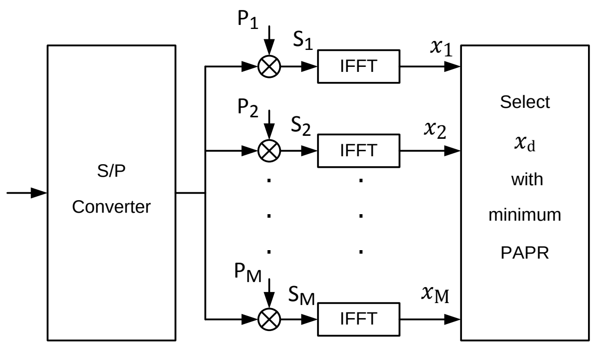


**Figure 4.1: Block diagram of SLM technique**

In this case the number of IFFT operations is 4 and the amount of side information is 2 bits. The amount of PAPR reduction may fluctuate from data block to data block. However, PAPR reduction is possible for all data blocks.

## 4.3 Partial Transmit Sequences (PTS)

In Partial Transmit Sequences (PTS), a signal is generated with a low PAPR through the summation of appropriately phase rotated signal parts. Figure 4.2 shows the block diagram of the partial transmit sequence (PTS) technique. The signal $X = [X_0, X_1, \cdots\cdots\cdots, X_{N_c-1}]^T$ to be transmitted is partitioned into disjoint sub-blocks $X^v$, of length $N_c/V$which is represented by the vector $X = [X^1, X^2, \cdots\cdots\cdots, X^V]^T$as [18], [19]:

$$X = \sum_{v=1}^{V} X^v \qquad (7)$$

where, $N_c$ is the number of subcarriers and V is the number of sub-blocks. Complex phase factors,

$b^v = e^{j\varphi_v}$, $\varphi_v \in [0, 2\pi)$ and

$v = 1, 2, \ldots, V$(8)

are introduced to combine the PTS's in the block diagram. All subcarriers positions which are occupied in another sub-block are set to zero. On each sub-block, an IFFT is performed, which are then all added together to create a possible transmit symbol as:

$$x = \mathrm{IFFT}\left\{\sum_{v=1}^{V} b^v X^v\right\}$$

$$= \sum_{v=1}^{V} b^v \mathrm{IFFT}[X^v] = \sum_{v=1}^{V} b^v x^v \qquad (9)$$

The phase vector is chosen so that the PAPR can be minimized, which is shown as [20]:

$$[\tilde{b}^1, \ldots, \tilde{b}^V] = \underset{\{b^1,\ldots,b^V\}}{\arg\min}\left[\max_{n=0,1,\ldots,N_c-1}\left|\sum_{v=1}^{V} b^v x^v(n)\right|\right] \qquad (10)$$

Then, the corresponding time-domain signal with the lowest PAPR vector can be expressed as:

$\tilde{x} = \sum_{v=1}^{V} \tilde{b}^v x_v$(11)

In order to recover the received data for PTS approach, the receiver must have information about the generation process of the transmitted OFDM. To decode the data the phase factors must then be transmitted as side- information. Reference [21] noted that to restrain the side information to a minimum, the number of angles should be kept low. The required number of bits for side information is$N_{SI} = \lfloor V\log_2 W \rfloor$bits per OFDM symbol, if each phase rotation is chosen from a set of admissible angles, $b = \{e^{j2\pi i/W}|_{i=0,1,\ldots,W-1}\}$. The number of phase rotation factors allowed, governs the computational complexity of PTS method. The selection of the phase factors$\{b^v\}_{v=1}^{V}$ is confined to $W^{V-1}$set of elements number todecline the search complicacies [22]. To find the optimum set of phase vectors the sets of phase factors should be searched. Moreover, the search complicacy rises exponentially with the number of sub-blocks. It also depends on the sub-block partitioning. As can be demonstrated in [23], better performance with low search complexity can be given by optimal combination of phase factors with a modified discrete PSO method and therefore OFDM signals with low PAPR can be obtained.

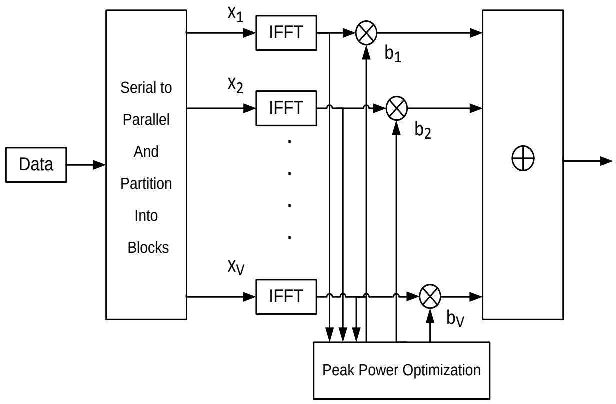


**Figure 4.2: Block diagram of PTS technique**

There are three different kinds of sub-block partitioning schemes: pseudo-random, interleaved and adjacent. For the pseudo-random partition, each subcarrier can be randomly assigned to any position of the sub-block with the length ; Interleaved partition also segments the sequence into sub-blocks but within each of them, subcarriers are allocated in a space of ; In the adjacent partition, the data sequence is divided into sub-blocks, for each one, it contains $N_c/V$ consecutive subcarriers. The common point of these three different partition schemes is that the length of each sub-sequence is same and also the subcarrier has only been assigned once.

# 5. PROPOSED NTH ROOT TECHNIQUE

The nth root – OFDM signals Xn is processed by,

$$X_{n^{th}\,root} = \sqrt[n]{|X_c(n)|}\exp(j\emptyset_n)\ n = 0, 1, \ldots.. N-1$$

where, $X_c(n)$ is the nth OFDM output signal.

$X_{n^{th}\,root}$ is the nth root of OFDM signal.

Φn is the phase of x(n).

During the entire signal processing in OFDM system, the phases of the OFDM output signals are kept unaltered while only the amplitudes of the OFDM signals Φn are considered and changed. Apart from changing the statistical distribution of OFDM signals, nth root technique, also changes the values of the mean, μ and variance, Ϭ2 of the OFDM signals.

For example, if the square root operation is applied to any signal the Rayleigh distribution of that signal will change into Gaussian distribution.

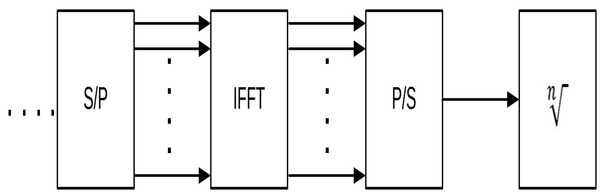


**Figure 5.1: Block diagram of $N^{th}$ root technique**

The chi-square distribution can also be transformed into Rayleigh distribution by applying nth rooting [24]. As a consequence the peak power value is lower than the average power value, which leads to reduction in the PAPR value.

# 6. COMBINED NTH ROOT TECHNIQUES

## 6.1 Combined Clipping with Nth root technique

We can use Nth root technique after Clipping of OFDM signal. Results are shown in Result section.

## 6.2 Combined SLM with Nth root technique

Combination of Nth root technique after selection of minimum PAPR in SLM technique. Results have been shown below.

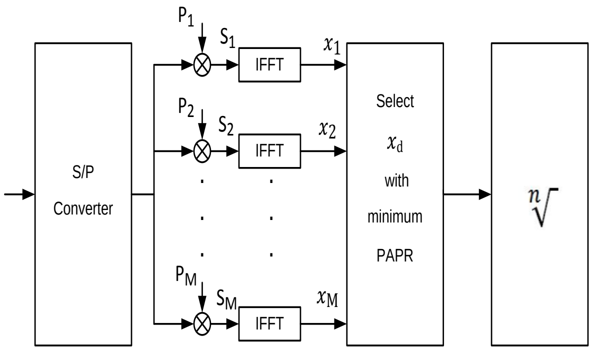


**Figure 6.1: Block diagram of combined SLM with N$^{th}$ root technique**

## 6.3 Combined PTS with Nth root technique

The combination of PTS with Nth root technique has been proposed here. After serial to parallel conversion, IFFT operation is performed separately. After that, PTS signal scrambling technique is performed. Parallel to serial conversion is performed next. Finally Nth root operation is used. On the other hand, the process is repeated inversely in the receiving side. However, the power of 'N' operation is used instead of Nth root operation.

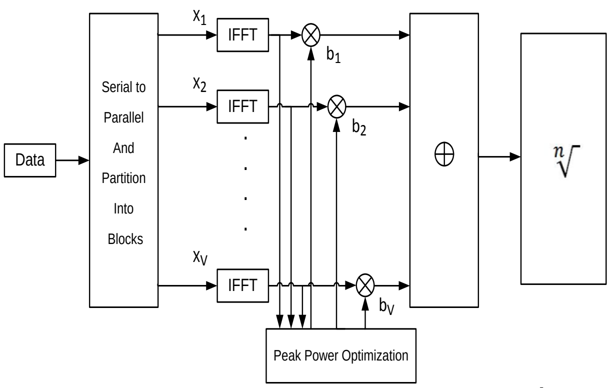


**Figure 6.2: Block diagram of combined PTS with N$^{th}$ root technique**

# 7. SIMULATION RESULTS

For simulation purpose MATLAB version 10.0 has been used. For checking the result, CCDF curve has been plotted. Some parameters of the performed experiment are as follows.

| Simulation parameters | Types/values |
|---|---|
| Number of OFDM symbols | 10000 |
| Number of sub-bands | 64 |
| Oversampling factor | 4 |
| Modulation Scheme | QPSK |
| Phase factor | 1, -1, j, -j |

## 7.1 PAPR reduction using Clipping method

X-axis of the graph represents PAPR in dB and Y-axis represents probability of PAPR which is greater than PAPR0.

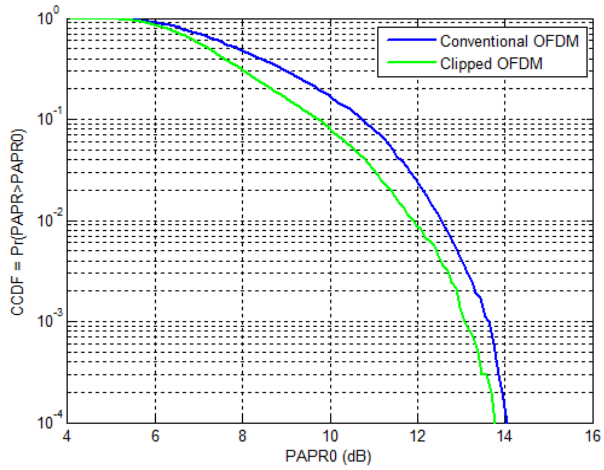


**Figure 7.1: PAPR reduction using Clipping method for OFDM data**

For conventional OFDM data PAPR is around 14 dB. After using Clipping operation PAPR is reduced to 13.6 dB. Reduction of PAPR is around 0.4 dB. So in spite of very moderate improvement, Clipping is not the most efficient of reduction techniques.

## 7.2 PAPR reduction using SLM method:

In this case PAPR of conventional OFDM data is 11.2 dB.

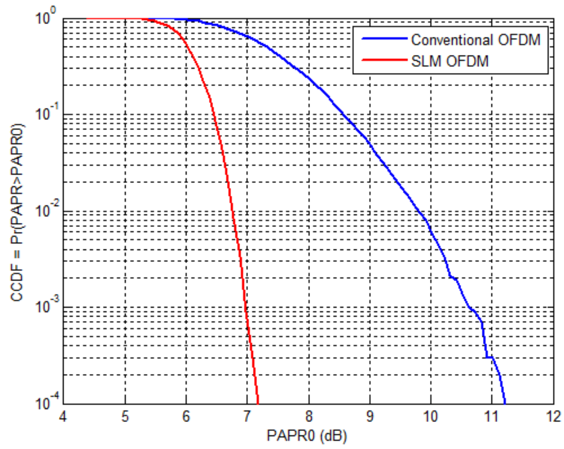


**Figure 7.2: PAPR reduction using SLM method for OFDM data**

After using SLM operation PAPR is reduced to around 7.2 dB. Reduction of PAPR is around 4 dB. Therefore a very significant improvement can be observed indicating a superior performance of SLM technique.

## 7.3 PAPR reduction using PTS method

X-axis of the graph represents PAPR in dB and Y-axis represents probability of PAPR which is greater than PAPR0. For conventional OFDM data PAPR is more than 11 dB. After using PTS operation PAPR reduced to less than 6 dB. Reduction of PAPR is around 5 dB. So PTS is very efficient for PAPR reduction.

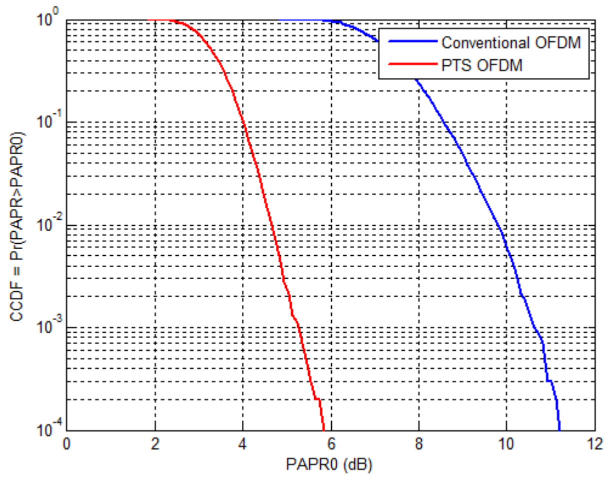


**Figure 7.3: PAPR reduction using PTS method for OFDM data**

## 7.4 PAPR reduction using Nth root operation

In this simulation it can be observed that, improvement of PAPR is increasing with order of root number. In this case, several number of root operation such as 2, 3, 4, 5, 6, 7 root are used. Blue line represents the PAPR of conventional OFDM data. For root operation 2, 3, 4, 5, 6, 7 PAPR is 6 dB, 4.2 dB, 3.1 dB, 2.6 dB, 2.3 dB and less than 2.2 dB respectively. From the obtained data it can be inferred that PAPR reduction is proportional to number of root operation.

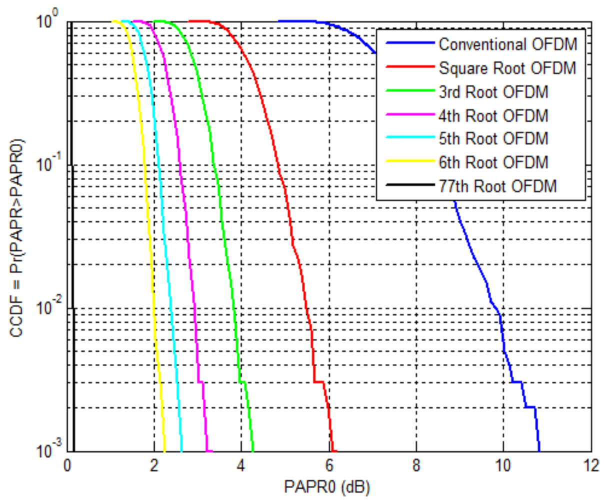


**Figure 7.4: PAPR reduction performance of N$^{th}$ root operation**

## 7.5 PAPR reduction using Clipping and 5th root operation

A comparison of Clipping and 5th root technique is demonstrated. After using Clipping operation PAPR is reduced by approximately 0.2 dB. 5th root technique reduces the PAPR by approximately 10.2 dB. Simulation results show that 5th root technique gives a highly significant improvement compared to Clipping only.

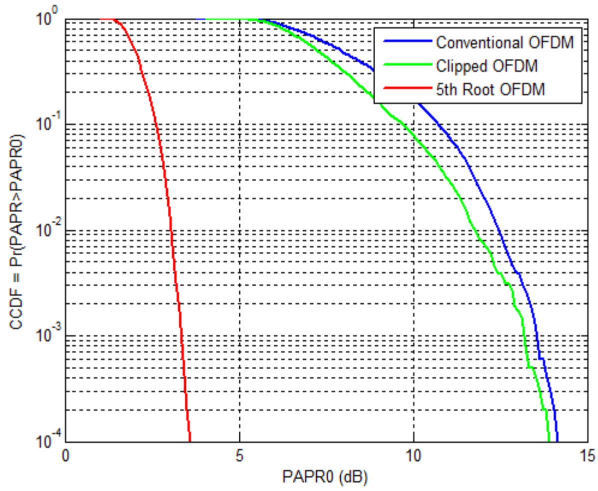


**Figure 7.5: PAPR reduction using Clipping method and 5$^{th}$ root operation for OFDM data**

## 7.6 PAPR reduction using combined Clipping with 5th root operation

Here, the proposed technique is combined Clipping with 5th root operation. Simulation results show a massive improvement compared to using Clipping only. Green line represents PAPR after Clipping only, which is around 13.5 dB. Red line shows PAPR after combined Clipping with 5rh root which is around 3 dB.

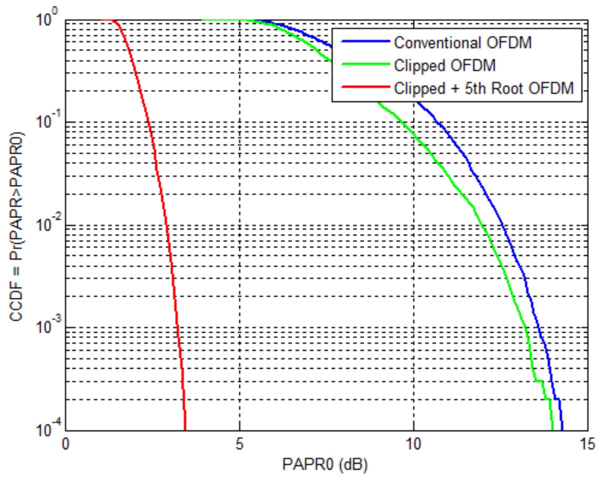


**Figure 7.6: PAPR reduction using combined Clipping with 5$^{th}$ root operation for OFDM data**

## 7.7 PAPR reduction using SLM and 4th root operation

A comparison of 4th root technique and SLM technique is observed. After using SLM operation PAPR is reduced from 10.8 dB to 7.1 dB approximately. 4th root technique reduces the PAPR from 10.8 dB to 3.2 dB. Although SLM technique provides with a very good reduction, SLM gives an even better performance.

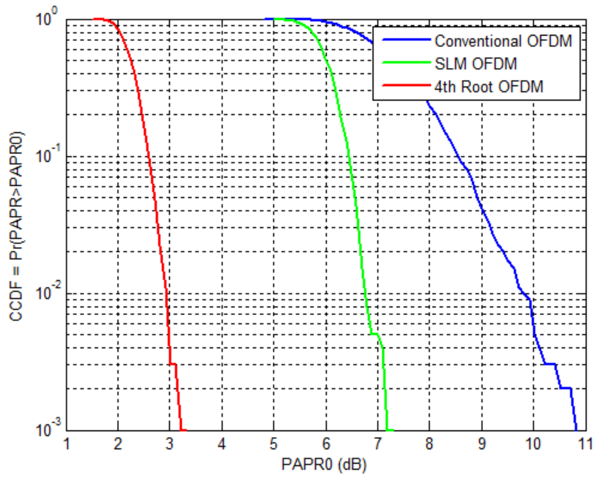


**Figure 7.7: PAPR reduction using SLM method and 4th root operation for OFDM data**

## 7.8 PAPR reduction using combined SLM with 4th root operation

In this case, the proposed technique is combined SLM with 4th root operation. A very significant improvement is observed compared to using SLM only. Green line represents PAPR after SLM only, which is around 7 dB. Red line shows PAPR after combined SLM with 4th root which is around 2 dB.

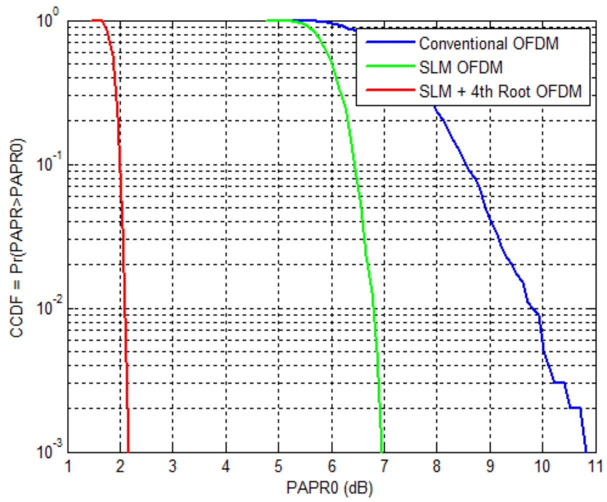


**Figure 7.8: PAPR reduction using combined SLM with 4th root operation for OFDM data**

## 7.9 PAPR reduction using PTS and 3rd root operation

A comparison is made between 3rd root technique and PTS technique. After using PTS operation, PAPR is reduced by approximately 5.8 dB. 3rd root technique reduces the PAPR by 6.6 dB approximately. Therefore root technique gives a better performance despite very good results from PTS alone.

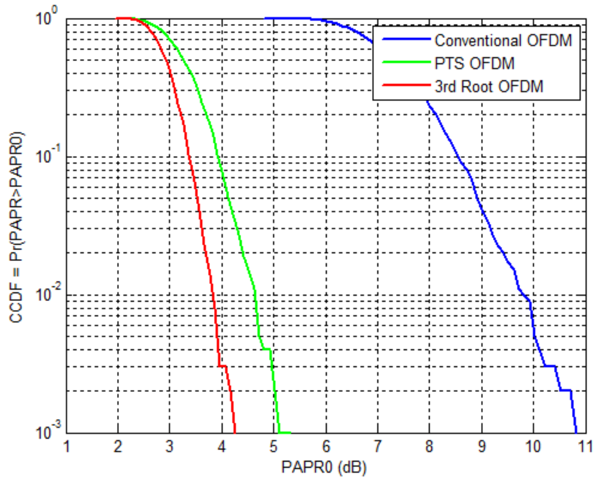


**Figure 7.9: PAPR reduction using PTS method and 3rd root operation for OFDM data**

## 7.10 PAPR reduction using combined PTS with 3rd root operation

Here, the proposed technique is combined PTS with 3rd root operation, which is far better than PTS only. Green line represents PAPR after PTS only. which is around 6 dB. Red line shows PAPR after combined PTS with 3rd root technique which is approximately 2 dB.

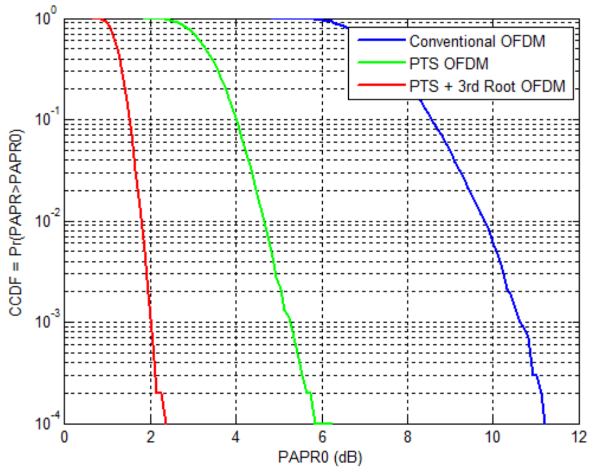


**Figure 7.10: PAPR reduction using combined PTS with 3rd root operation for OFDM data**

## 8. CONCLUSION

In this paper, the problem of PAPR in OFDM signals is addressed. An efficient PAPR reduction method for the OFDM system by combining both PTS and Nth rooting has been suggested and investigated. Simulation results of QPSK OFDM systems show that PAPR was reduced effectively by using PTS and 3rd rooting operation of the OFDM signals. The results of computer simulation show that about 9 dB PAPR reduction at 10-4 CCDF was achieved with a penalty of only 6.5 dB difference in SNR. Actually, these concepts are parts of another technique to reduce PAPR. So combination of different techniques can be done experimentally to realize better PAPR performance. One of the drawbacks of the proposed technique is that, with the increase of order of root bit error probability increases proportionally. Hence, as future work the threshold level can be set for the order of root for which PAPR reduction will be satisfactory and bit error rate will be lower as well.

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