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Comparison of SLM and clipping & Filtering for PAPR Reduction in OFDM systems

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Abstract: *OFDM uses multicarrier subcarriers as it is used in many applications like BRAN, DAB, HF radio, DVB-T etc. which suffers from PAPR that reduces the peak value of data transmission. Analysis of PSD of OFDM is done in this paper by taking different Oversampling rate. To reduce the PAPR, a design is proposed that combines the SLM technique and Clipping & Filtering method. This paper includes the comparison between OFDM signals with and without these techniques applied.*

Keyword: *BER, Clipping & Filtering, OFDM, PAPR, SLM, SNR*

1. INTRODUCTION

OFDM is known for high data transmission systems which is adopted by ASTC, 3GPP LTE, IEEE 802.11 n/ax standards [1,2] also WiMAX. The concept of OFDM involves the transmission of multiple sub-carriers of frequency spectrum which are independently orthogonal to each other to avoid interference. In each subcarrier, there is a conversion of data from serial-to-parallel in different channel. Orthogonal sub-carriers are producing by IFFT and input data samples are generated by either QAM or PSK modulation, these samples and sub-carriers are joint by correlation. Cyclic prefix is a time domain signal which is converted into frequency domain via FFT. There is a problem of ISI which occurs when symbol time is less than delay time. This problem is resolved by either adding cyclic prefix or by adding guard band interval between the consecutive signals.

Major disadvantage of this system is high PAPR value that limits signal transmission power efficiency. This is due to power consumption is more because of power amplifier which reduces the amplitude of signal. This problem is resolved by placement of DPD at before power amplifier which helps to increase the dynamic range of power amplifier [3&4]. Since DPD is an expensive device, instead of using this device PAPR reduction techniques are used widely. There are two types of PAPR reduction techniques one is distortion PAPR reduction technique which involves distortion of signal, clipping is famous distortion PAPR reduction technique and another is distortionless PAPR technique like SLM. Some uses combination of both distortion and distortionless PAPR techniques to increase the efficiency.

Standard coding is applied to OFDM earlier via many researchers that include redundant bits in the data streams which can be used for error correction at receivers. This was helpful in low PAPR but there is a disadvantage that is complexity. There are two types of error detection and correction codes, block codes and convolutional codes. From [10], 'k' are the information bits that are used for encoding process that is encoded in 'n' code 'd' bits, therefore (n-k) redundant non information bits are added to the 'k' information bits. Block code is given as: (n,k) code and rate of the code as $R_c = k/n$.

In this paper, distortionless and distortion PAPER reduction technique are combined together systematically. Clipping technique is widely used PAPR technique so it is choosing for distortion and SLM is choose for distortionless PAPR reduction technique because it doesn't require minimum or may be not additional resources. This combination is important as it compensate the faults of each other and increases the advantages of each other.

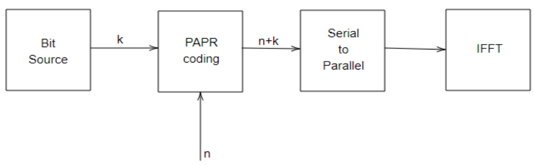

Figure 1Block diagram of OFDM transmitter showing PAPR coding

Such a proposal is needed to show combined technique is systematically structured for proper operation. Based on analysis combined technique provide better efficiency and applied to most of OFDM transmission signal system.

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In section 2, system description is represented which shows various parameters and terms are described about OFDM and PAPR. In section 3, simulation results based on Combined technique is shown which validates this technique. Lastly conclusion is mention which shows the essence of this paper.

Abbreviation:

ASTC	Advanced Television Systems Committee
BER	Bit Error Rate
BRAN	Broadband Radio Access Networks
BW	Band Width
CCDF	Complementary Cumulative Distribution Function
CF	Crest Factor
CR	Clipping Ratio
DAB	Digital Audio Broadcasting
DPD	Digital Predistorter
DVB	Digital Video Broadcasting
HPA	High Power Amplifier
IFFT	Inverse Fast Fourier Transform
i.i.d.	Independent identically distributed
IoT	Internet of Things
ISI	Inter Symbol Interference
mPSK	Minimum Phase Shift Keying
OFDM	Orthogonal Frequency Division Multiplexing
OOB	Out-of-Band distortion
PAPR	Peak-to-Average Power Ratio
PTS	Partial Transmit Sequence
SLM	Selective Mapping
TI	Tone Injection
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
WiMAX	Worldwide Interoperability for Microwave Access
3GPP LTE	Third Generation Partnership Project Long Term Evaluation

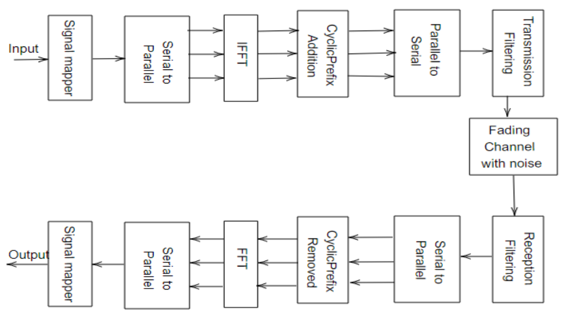


Figure 1Block Diagram of OFDM system

2. SYSTEM DESCRIPTION

This section describes basic terms and parameters about OFDM and PAPR.

2.1Mathematical representation of OFDM signal

Suppose $'N'$ be length of data block in OFDM system which is represented by input vector:

$$X = [X_0\, X_1 \ldots\ldots\ldots\ldots X_{N-1}]^T \qquad (1)$$

and duration of any symbol in input vector X is T. In Fig. (2), orthogonal transmission of OFDM signal is represented where are subcarriers is $'N'$, from spectrum it is concluded that:

$$f_n = n\Delta f = {}^{1}/_{NT} \qquad (2)$$

and NT is the duration OFDM data block of X.
OFDM of signal is equated as:

$$X(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n\, e^{j2\pi n\Delta f t} \qquad 0 \le \mathrm{t} \le \mathrm{NT} \qquad (3)$$

To create window function in OFDM system, An OFDM symbol in baseband is represented as:

$$X(t) = \frac{1}{\sqrt{N}} \sum_{N=\frac{n}{2}}^{\frac{n}{2}-1} \left(b_n + \frac{n}{2}\right) e^{\left(\frac{j2\pi nt}{T}\right)} w(t) \qquad (4)$$

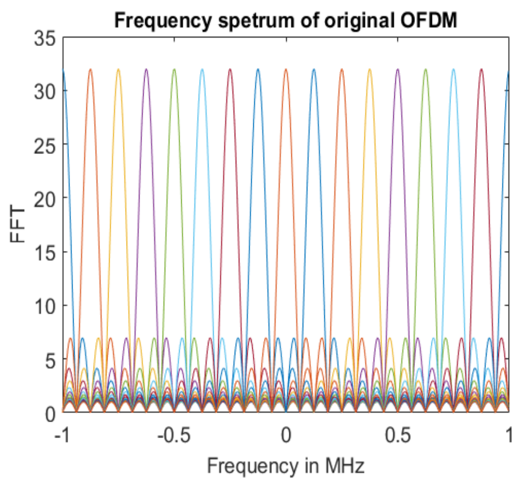
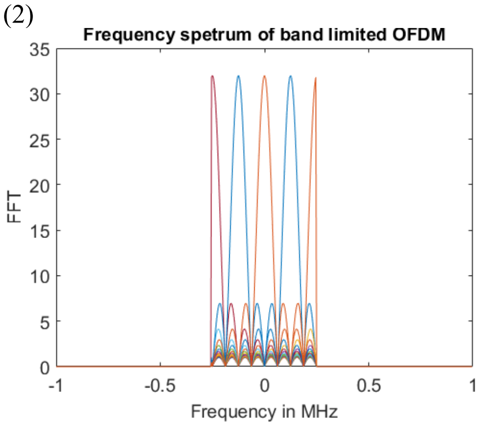


Figure 2Frequency spectrum of OFDM system {BW=2MHz, cut-off frequency=0.5MHzand number of carriers=16]

where $b_n + \frac{n}{2}$ in above equation is complex modulating symbol the n^{th} carrier, $w(t)$ is the window function operated in between the duration of [0, T] and n is the number of subcarriers.

Spacing of Subcarriers are $\Delta f = {}^{1}/_{T}$ which is shown below for above frequency spectrum of OFDM in Figure (2)



2.2 PAPR of OFDM signal

In continuous time domain, PAPR of any is defined as the ratio of peak value of instantaneous output power of signal to its average power. PAPR for signal $X(t)$ is given as:

$$PAPR = \frac{p_{peak}}{p_{av}} = \frac{max|x(t)|^2}{E|x(t)|^2} \quad (5)$$

where p_{peak} represents maximum output power and p_{av} average output power of sample in OFDM symbol. For discrete signal x(n), PAPR is given as:

$$PAPRx[n] = \frac{p_{peak}}{p_{av}} = \frac{max|x[n]|^2}{E|x[n]|^2} \quad (6)$$

where E[.] is the expectation operator

In discrete time domain OFDM signal is written k^{th}symbol for length L as:

$$X[n] = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \, e^{j2\pi nk/N} \quad 0 \le n \le N \quad (7)$$

Oversampled OFDM is represented for as:

$$X[n] = \frac{1}{\sqrt{LN}} \sum_{k=0}^{LN-1} X_n e^{j2\pi nk/LN}, 0 \le n \le LN \quad (8)$$

CCDF is the measuring parameter used to evaluate the performance of PAPR. CCDF for Nyquist sampling rate is approximated as:

$$P_r(PAPR > PAPR_0) \approx 1 - (1 - e^{-PAPR_0})^N \quad (9)$$

where $P_r(.)$ is probability, $PAPR_0$ is the reference of PAPR and N is the number of subcarriers. This is the approach followed by chi-square distribution which is not for practical purpose because it is unable to determine actual PAPR value. So, above equation modified using heuristic approach:

$$P_r(PAPR > PAPR_0) \approx 1 - (1 - e^{-PAPR_0})^{\propto N} \quad (10)$$

α is the arbitrary adjustable parameter.
Author in [11,12] more approximated the above as:

$$P_r(PAPR > PAPR_0) \approx$$
$$1\text{- exp}\left(\text{-}\sqrt{\frac{\pi PAPR_0}{3}} Ne^{\text{-}PAPR_0}\right) \quad (11)$$

$$P_r(PAPR > PAPR_0) \approx$$
$$1 - \exp\left(-\sqrt{\frac{\pi lnN}{3}} Ne^{-PAPR_0}\right) \quad (12)$$

Threshold and efficiency are calculated as:

$$Threshold = \left(\frac{PAPR_{max} - PAPR_{min}}{PAPR_{max} PAPR_{min}}\right) \quad (13)$$

$$\& \, Efficiency = \left[\frac{1 - PAPR_{dB}}{PAPR_{dB}}\right] \times 100 \quad (14)$$

3. PAPR Reduction Techniques

As above mentioned, distortion and without distortion are the categories to reduce the PAPR. Clipping and companding comes in distortion reduction technique and SLM, PTS, TI comes in distortionless reduction technique.

3.1 Clipping

It is the most widely used PAPR reduction technique for the OFDM system because it is simple and effective. But it causes In-band and out-of-band distortion [5]. Through clipping peak level is reduces up to the predetermined value. From[y], Amplitude clipping is shown below in the form of equation as:

$$Y(t) = \begin{cases} -L, \; if \; x(t) < -L \\ x(t), \; -L \le x(t) \le L \\ L, \; if \; x(t) > L \end{cases} \quad (15)$$

where Y(t) is clipped passband signal, L is pre-specified clipping level and $x(t)$ is passband signal.

TABLE1: PARAMETERS OF CLIPPING AND FILTERING TECHNIQUE ON OFDM SYSTEM

Parameters	Value
Modulation	QAM
Channel Model	AWGN
FFT Size	180
Sub Carriers	160
Phase sequence	16

Clipping is done at transmitter and receiver estimates the signal depends on clipping level. In-band distortion and out of band distortion is caused by

clipping. This may affect BER and SNR of the system. Through filtering out of band radiation reduces up to a level.
Above equation stated is in linear form but the if the system is complex then above equation (15) is modified as

$$Y(n) = \begin{cases} x(n), & |x(n)| \leq A_m \\ A_m e^{j\theta_n}, & |x(n)| > A_m \end{cases} \tag{16}$$

$x(n)$ is the OFDM signal before clipping the signal, A_m is the maximum allowable amplitude and θ_n is the phase of the OFDM signal. The clipping level can be measured by using CR, which is expressed as:

$$\vartheta = \frac{A_m}{\sqrt{P_{avg}}}$$

where P_{avg} is the average input power of OFDM signal. From [6], since distortion is unavoidable so Bussgang Theorem states that clipping PAPR reduction technique is a non-linear function which works to reduce the PAPR of the signal based on signal distortion

$$let\ \widehat{x(n)} = y(n) = \alpha x(n) + d(n) \tag{17}$$

where $d(n)$ is the distortion noise term due to clipping which is not related to $x(n)$ and α is the attenuation term due to clipping which can be represented as:

$$\alpha = \frac{E[x(n)\widehat{x(n)}]}{E[|x(n)|^2]} \tag{18}$$

where $E[.]$ is the expectation operation, $*$ is the complex conjugate operation, ν is the clipping ratio. For (7), assume that there is no correlation between distortion noise term and signal $E[x(n)^* c(n)] = 0$
The frequency representation of the clipping noise term $c(n)$ can be written as:

$$C[k] = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} c(n) e^{-j2\pi nk/N} \tag{19}$$

When the number of subcarriers increases then, $C[k]$ approaches a complex Gaussian random variable with a zero mean due to the central limit theorem. According to Parseval's theorem, the expectation of $|C[k]\,|^2, E\,(|C[k]\,|)^2$ also can be calculated in the time domain. From (x9), amplitude of distortion noise

$$|d(n)| = |x(n)| - A_m\,, \quad |x(n)| > A_m \tag{20}$$

Since it is well-known that the amplitude of the OFDM signal, $|x(n)|$ has a Rayleigh distribution, the average distortion power, $|c(n)|$

$$E(|d(n)|^2) = \int_{A_m}^{\infty} (r - A_m)^2\, P_{|x(n)|} r dr \tag{21}$$

where $p_{|x(n)|}r$ is the Rayleigh probability density function (pdf).

$$E(|d(n)|^2) = e^{-\nu^2} - \sqrt{\pi}\nu.erfc(\nu) \tag{22}$$

Whatever the CR is set, in practical system actual CR is more due to peak- regrowth

3.2 SLM

This is a distortionless PAPR technique and with the help of rotating the phase of OFDM symbols PAPR reduced. SLM makes many sets of phases from original OFDM symbols. PTS also a phase representation of PAPR reduction technique but SLM is easy to implement [8]

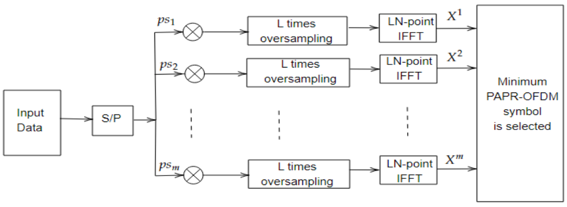


Figure 4 Block Diagram of SLM technique

Above shows the input data streams 'X' which is multiplied with many phase sets which is written as $ps_j, j = 1,2 \ldots\ldots\ldots\ldots m,$ in frequency domain that is used to generate m different symbols in time domain symbols, $x^j, j = 1,2 \ldots\ldots\ldots\ldots m.$ Lowest PAPR symbol is chosen from the different sets and transferred to receiver via channel.

TABLE2: PARAMETERS OF SLM TECHNIQUE ON OFDM SYSTEM

Parameters	Value
Modulation	QAM
Channel Model	AWGN
FFT Size	180
Sub Carriers	160
Phase sequence	16

From [9], it is said that Side information (SI) is used for receiver to identify the set.
In [8], it is clearly mention in the literature that CCDF of SLM-OFDM signal is represented as:

$$\Pr(PAPR > PAPR_0) \approx (1 - (1 - e^{-PAPR_0})^{\propto N})^m$$

Where m is the different phase sets, to generate random phase sets we can multiply with '1'or '-1' There is trade-off between complexity and phase sets.

There is a drawback of SLM that is complexity as more IFFT blocks are used. Since SI is transmitted to recover the original signal at receiver side which reduces the data rate.

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4. Simulation Results and Discussion:

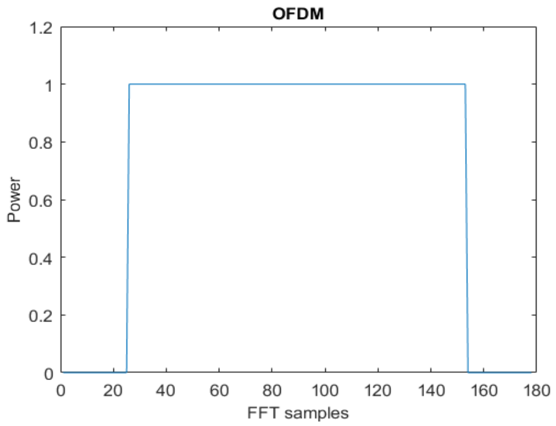

Figure 4: Frequency spectrum of OFDM {no. of transmitted symbols (power of 2) =128, no. of zeros padded in the middle=50}

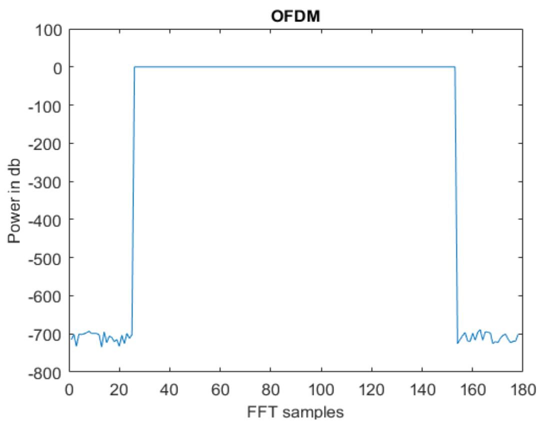

Figure 5: Frequency spectrum of OFDM in dB {no. of transmitted symbols (power of 2) =128, no. of zeros padded in the middle=50}

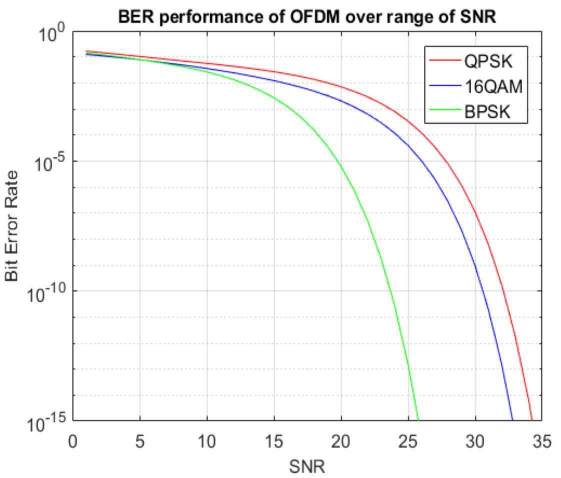

Figure 6: Above shows the BER for different modulation schemes for various SNR. The SNR is calculated for BPSK, 16 QAM and QPSK are 26dB, 32.5 dB and 34dB. QPSK shows highest SNR among all.

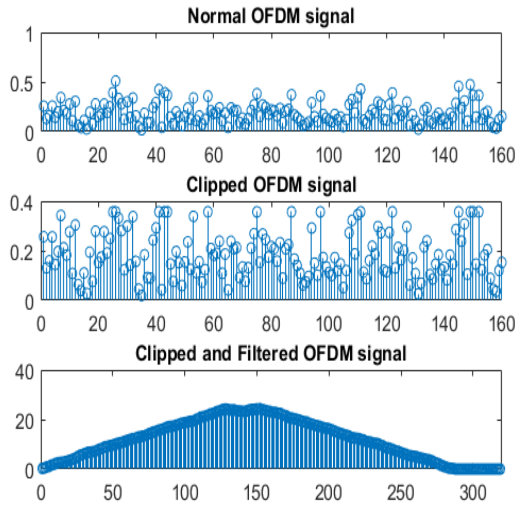

Figure 7 above figure is divided into 3 sub-figures. Fig. (7a) shows the normal OFDM signal without applying any technique, the normal OFDM signal is confined within amplitude of 0.5 with PAPR of 5.7064. Figure (7b) shows the clipped version of OFDM signal after clipping technique is applied whose amplitude is slightly reducing within the range of 0.4, after clipping PAPR reduces to 2.7694. Fig(7c) shows the clipped and filtered version of OFDM signal

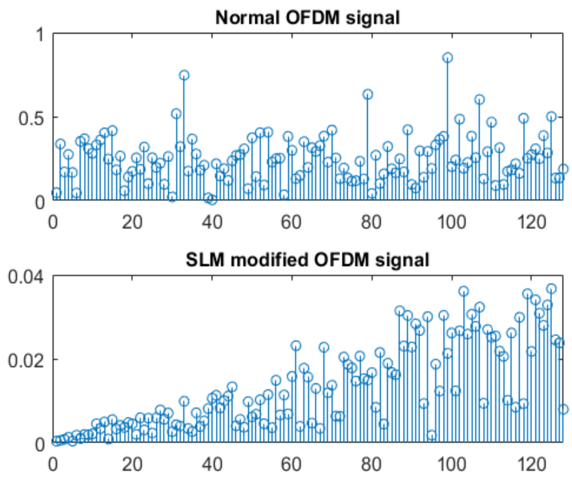

Figure 8 above figure is divided into 2 sub-figures. Fig. (8a) shows the normal OFDM signal without applying SLM technique, the normal OFDM signal is confined within amplitude of 1 with PAPR of 21.7202. Figure (8b) shows the modified version of OFDM signal after SLM modified technique is applied whose amplitude is reducing within the range of 0.04, after application of SLM PAPR reduces to 15.7818. Here size of L is taken as 1.25 and no. of transmitted symbols =128(power of 2) &alphabet size is16.

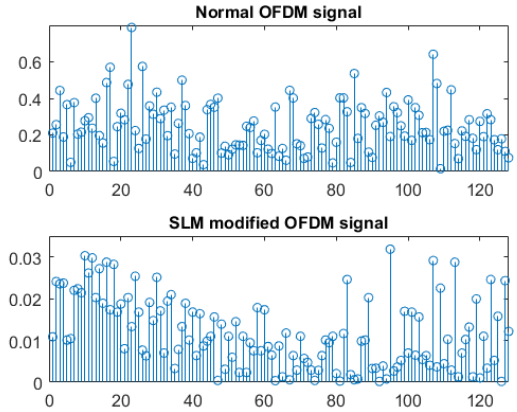

Figure 9.

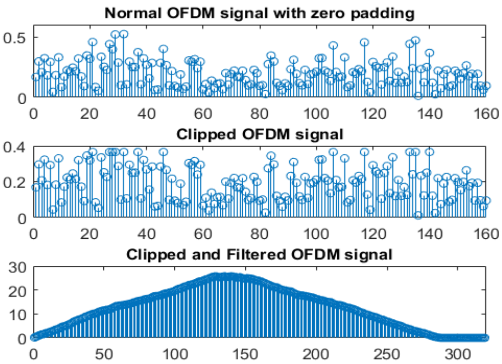

Figure 10

Comparative analysis is shown in Figure 9 and 10 for the same parameters. It is found that:

PAPR of normal OFDM =20.3594

PAPR of SLM modified OFDM=15.8435

PAPR of clipped + filtered OFDM=10.6746

Efficiency of SLM technique in %=22.1812

Efficiency of clipping + filtering technique in %=47.5691

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