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# STUDY OF PAPR REDUCTION IN OFDM USING REDUCED COMPLEXITY PTS WITH COMPANDING

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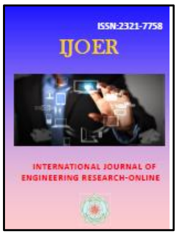


**ABSTRACT**

The efficiency of High Power Amplifiers (HPA) is improved by many Peaks-to-Average Power Ratio (PAPR) reduction Techniques. The probabilistic methods scramble the signal by computing with phase factors. Partial Transmit Sequence (PTS) is one of the techniques which reduces PAPR. The computational complexity of PTS can be reduced by using cost function $Q_s$ for each OFDM symbol. The symbols with $Q_n \geq$ threshold are considered as the signal with lowest PAPR. To promote the lowest PAPR a µ- law and A- law companding is used without amplifying the complexity.

**Keywords:** Companding, OFDM, PAPR, PTS

## 1.0 Introduction

Orthogonal Frequency Division Multiplexing (OFDM) is a navigating technology for 3G and 4G Wireless and Mobile communication. OFDM is multiplexer and multicarrier technology disburses the data over large number of carriers spaced at definite frequencies. The interval provides orthogonally. OFDM is operated in [1] wired coaxial line i.e., x DSL cables and wireless communication like DVB, DAB, IEEE802.11, IEEE802.20, Wi Fi, Wi Max. OFDM is a multicarrier which suppresses multipath distortion and improves spectral efficiency. Due to orthogonal carriers, OFDM signal has high PAPR which lowers efficiency of HPA. The high PAPR is mitigated by many techniques [2] like clipping, peak windowing, peak cancellation, companding, tone reservation, tone injection or by distorting the signal or by scrambling and spreading the signal like selected mapping (SLM), partial transmit sequence (PTS) [3][4], interleaving, precoding by using liable sequences. The hardware complexity is less in PTS technique but computational complexity increases as the number of IFFT's increases. The computational complexity is reduced by many reduced PTS techniques [5] - [8]. One technique is by applying Cost Function $Q_n$ to OFDM symbols [8]. To reduced complexity PTS summation, the A-law or µ- law compander is fixed to further improve HPA efficiency without hardware complexity.

## 1.2 Background to orthogonal frequency division multiplexing

### 1.2.1 OFDM History

OFDM history dates in mid-1960's [9]. Frequency division multiplexing (FDM) is designed based on parallel data transmission and FDM concept is first officially published in 1960's. Historical evidences are traced of early developments on parallel data transmission in early 1950's but the first patent is registered in United States of America in 1970 [10]. The parallel data



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scheme has changed the total look of modern wireless communications, started with FDM without Orthogonally (non-overlapping) and ends with Orthogonality based OFDM. Initially the parallel data transmission is used in military, multi carrier modulation, discrete multi-tone (DMT) and multi-channel modulation. OFDM supports orthogonally where the sub-carriers are orthogonal to each other but orthogonally condition is cannot maintained by MCM in every case, hence OFDM is regarded as ideal version of multicarrier transmission schemes

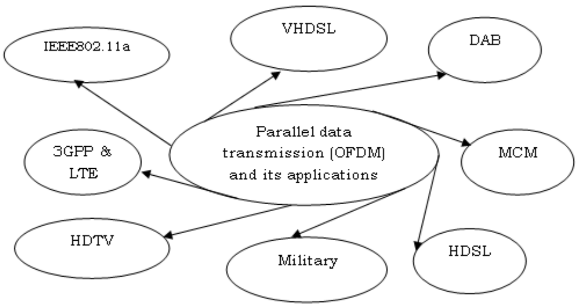


Fig.1.1: Applications of parallel data transmission

**1.2.3 PAPR Reduction Techniques**

**1.2.3.1 Partial Transmit Sequence**

The data symbols are separated by V disjoint sub blocks. These sub blocks continuous time OFDM signal is computed with weighting factor

$b_v = e^{j\theta i}$ for i = 0, … , V-1.

The symbols with optimum PAPR are selected.

**1.2.3.2 Reduced Complexity Partial Transmit Sequence [8]**

The PAPR for discrete – time version x[n] is:

$$PAPR(x[n]) = \max_{0 \le n \le N-1} \frac{|x[n]|^2}{E[|x[n]|^2]}$$

$$PAPR\{x(t)\} = \frac{P_{peak}}{P_{avg}}$$

The OFDM PTS signal is:

$$x_{pts} = \sum_{v=1}^{v} b_v x_{vs} \ for\ b_v = e^{j\theta i}\ with\ 's'\ samples$$

The power of above equation:

$$|x_{pts}|^2 = \left|\sum_{v=1}^{v} b_v x_{vs}\right|^2 = \left(\sum_{v=1}^{v} b_v x_{vs}\right)\left(\sum_{v=1}^{v} b_v x_{vs}\right)^*$$

$$= \frac{|\sum_{v=1}^{v} b_v x_{vs}|^2}{Q_s}$$

$$\sum_{v=1}^{v} \sum_{\substack{v_1=1 \\ v_2 \ne v_1}}^{v} (b_{v_2} x_{vs})\ (b_{v_2} x_{v_2 s})^*$$

$Q_s$ Is the sum of power of samples at time s in V sub blocks? Samples with $Q_s \ge \frac{\emptyset_s}{V}$are processed in each symbol for calculating PAPR ($\emptyset_s$minimum power).

**1.2.4 Companding Techniques** [9– 12]

**1.2.4.1 A-Law companding:**

A-law has non-zero value and it has mid riser at the origin point. Hence it contains non-zero value. The practically used value of "A" is 87.6 As shown in Fig. 1.4 low level inputs the characteristics is linearly segmented and for high level inputs the characteristics is logarithmic segmented.

$$y(x) = \begin{cases} y_{max} \dfrac{A \frac{|x|}{x_{max}}}{(1+A)} sgn(x) & 0 < \dfrac{|x|}{x_{max}} \le \dfrac{1}{A} \\ y_{max} \dfrac{\left[1 + log_e \left[A \frac{|x|}{x_{max}}\right]\right]}{(1 + log_e A)} sgn(x) & \dfrac{1}{A} < \dfrac{|x|}{x_{max}} \le 1 \end{cases}$$

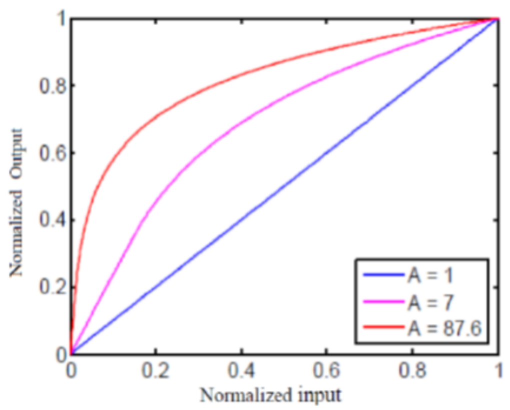


**Fig. 1.4 A - law compressor characteristics**

The value of A=87.6 (defined by CCITT (Consultative Committee for International Telephony and Telegraphy)). The A - Law companding is used in PCM for telephone communications.

**1.2.4.2 µ - law companding:**

In µ - law companding, as shown in Fig. 1.5 the characteristics is linear when µ=0 (no compression) which is uniform quantization. µ - Law has non-zero

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value and it has mid tread at the origin point. The practically used value of μ is 255.

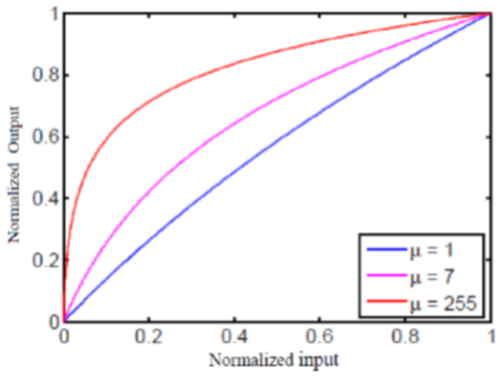


**Fig. 1.5 μ-law compressor characteristics**

The μ-law compressor characteristic is defined as:

$$y(x) = V\frac{\log(1+\mu\frac{|x|}{V})}{\log(1+\mu)}sgn(x)$$

Where V: peak amplitude of signal

x: instantaneous amplitude if input signal

## 2.0 OFDM SYSTEM AND ITS PROBLEM

### 2.1 OFDM System Model

In OFDM system, parallel transmission method provides high-rate serial data stream splits into a set of low-rate sub streams then each data is modulated on separate sub carrier. With this bandwidth of the subcarriers becomes small compared with the coherence bandwidth of the channel the individual subcarriers experience flat fading it allows for simple equalization. Due to this the symbols period of sub streams is made long compared the delay spread of the time dispersive radio channels. Selecting a special set of carrier frequencies, high spectral efficiency is obtained, because the spectra of the sub-carriers overlap, while mutual influence among the sub-carriers can be avoided. The derivation of the system model shows that, by introducing a cyclic prefix orthogonality can be maintained over a dispersive channel.

The OFDM signal is expressed as a sum of the prototype pulses shifted in the time- and frequency directions and multiplied by the data symbols. The most appealing feature of OFDM is the simplicity of the receiver design due to the efficiency with which OFDM can handle with the effects of frequency-selective multipath channels. Multicarrier systems such as OFDM are, however, more sensitive to carrier frequency offset than are single-carrier systems. Here, we have studied the details of OFDM communications systems model and then address the issues related to synchronization, and finally analyzed the frequency offset mathematically. The discrete time baseband OFDM system model with N sub-carriers consisting of transmitter, channel, and receiver blocks are described below this section starts with a brief introduction to the OFDM transmission technique, based on the description of the system's block diagram.

We then discuss some hardware-related design consideration that become relevant if an OFDM system is implemented in hardware. For instance the DC-subcarrier and sub-carriers near the Nyquist-frequency must be avoided. Next, we derive the system model for a perfectly synchronized system, and we investigate the impact of the most relevant synchronization errors. For a more elaborate introduction to OFDM, the reader may refer to the respective chapters. An excellent overview over the effects of many non-ideal transmission conditions is given, wherein numerous further references are found.

We introduced the OFDM transmission technique based on the above block diagram

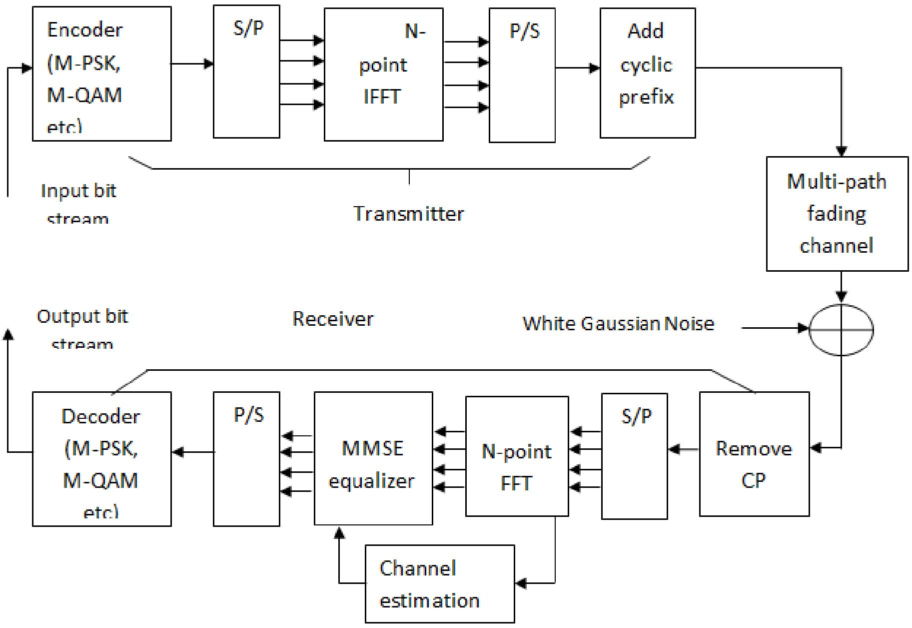


Fig. 2.1: Baseband OFDM System

**2.1.4 Advantages of OFDM**

Orthogonal frequency division multiplexing is commonly implemented in many emerging communications protocols because it provides several advantages over the traditional FDM approach to communications channels. More specifically, OFDM systems allow for greater spectral efficiency reduced inter symbol interference (ISI), and resilience to multi-path distortion.

**(a) Immunity to Delay Spread**

The presence of multipath channel is the major problem in most wireless systems. The transmitted signal reflects off of several objects in a multipath environment. As a result, delayed versions of the transmitted signal arrive at the receiver. At the receiver side, it gets distorted due to multiple version of signal. The occurrences of the maximum time delay so called delay spread of the signal in that environment. In OFDM, there occur two problems due to multipath channel .

The first problem is inter-symbol interference (ISI) which occurs when the received OFDM symbol is distorted by the previously transmitted OFDM symbol. In single-carrier system, the effect of ISI is same, but the interference is typically due to several other symbols instead of previous symbol. In single-carrier system, the symbol period is much shorter than the time span of the channel, whereas the typical OFDM, the symbol period is much longer than the time span of the channel. The next trouble is called Intra-symbol interference, which is the outcome of interference among a given OFDM symbol's own sub-carriers

The use of discrete- time property is the solution to the problem of intra-symbol interference. It is not practical to have an infinite length OFDM symbol; however, it is possible to make the OFDM symbol as periodic.

**(b) Simple Equalization**

In OFDM, the time-domain signal is still convolved with the channel response. However, in the receiver side by the help of FFT, the date will be transformed back into frequency domain. This time-domain convolution will result in the multiplication of the spectrum of the OFDM signal with the frequency response of the channel because of the periodic nature of cyclically-extended OFDM symbols. The result is each subcarrier's symbol will be multiplied by complex number which equal to channel frequency response at that subcarrier's frequency. Due to the channel, each received sub-carrier experiences amplitude and phase distortion. To reverse these effects, a frequency-domain equalizer consists of a simple complex multiplication for each subcarrier is employed which is much simpler than a time-domain equalizer.

**(c) Spectral Efficiency**

In a traditional FDM system, each channel is spaced by about 25% of the channel width. This is done to ensure that adjacent channels do not interfere. This is illustrated in the diagram below, which shows the guard bands between individual channels.

**(d) Favorable Properties:**

OFDM receiver does not need to constantly adapt an equalizer as a single carrier system would. OFDM system shows much favorable properties such as high spectral efficiency, robustness to channel fading, immunity to impulse interference, capability of handling very strong echoes (multipath fading).

**(e) Efficient Bandwidth Usage**

In OFDM, the main concept is orthogonality of sub-carriers. We know area under one period of a sine or a cosine wave is zero, as the carriers are all sine and cosine wave. Each sub-carrier has a different frequency and it is chosen in such a way that the integral numbers of cycles in a symbol period signal are mathematically orthogonal.

**(f) Resistance to Frequency Selective Fading**

In the case of single carrier modulation techniques, the complex equalization is required if the channel undergoes frequency selective fading but in the case of OFDM the available bandwidth is split among many orthogonal narrowly spaced sub-carriers. We can say that if the channel gain/phase associated with the sub-carriers varies, then the sub-carrier experiences flat fading. Even if some sub-carrier are lost completely due to fading, then we can recover user data by applying proper coding and inter-leaver at the transmitter.

**(g) Implementation Complexity**

OFDM implementation complexity is significantly lower than that of a single-carrier system with an equalizer.

**(h) Enhanced Capacity**

In relatively slow time-varying channels, it is possible to enhance capacity significantly by adapting the data rate per SC according to the signal-to-noise ratio (SNR) of that particular SC.

**(i) Robust against Interference:**

OFDM is robust against narrowband interference because such interference affects only a small percentage of the SCs.

**(j) Broadcasting Applications:**

OFDM makes single-frequency networks possible, which is especially attractive for broadcasting applications.

**(k) Reduced Inter Symbol Interference (ISI)**

In mono-carrier systems, inter symbol interference is often caused through the multi-path characteristics of a wireless communications channel. Note that when transmitting an electromagnetic wave over a long distance, the signal passes through a variety of physical mediums. As a result, the actual received signal contains the direct path signal overlaid with signal reflections of smaller amplitudes. The diagram below illustrates how, at high symbol rates reflected signals can interfere with subsequent symbols.

In wireless systems, this creates difficulty because the received signal can be slightly distorted. In this scenario, the direct path signal arrives as expected, but slightly attenuated reflections arrive later in time. These reflections create a challenge because they interfere with subsequent symbols transmitted along the direct path. These signal reflections are typically mitigated through a pulse-shaping filter, which attenuates both the starting and ending sections of the symbol period. However, as the figure above illustrates, this problem becomes much more significant at high symbol rates. Because the reflections make up a significant percentage of the symbol period, ISI will also be substantial.

**2.4 Basics of PAPR**

The Peak-to-Average Power Ratio (PAPR) is the peak amplitude squared (giving the peak power)

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divided by the RMS value squared. Orthogonal Frequency Division Multiplexing (OFDM) is considered to be a promising technique against the multipath fading channel for wireless communications. However, OFDM faces the PAPR problem that is a major drawback of multicarrier transmission system which leads to power inefficiency in RF section of the transmitter.

OFDM is one of the most efficient multicarrier modulation techniques. Which provides high spectral efficiency, low implementation complexity, less vulnerability to echoes and non –linear distortion? Due to these advantages of the OFDM system, it is vastly used in various communication systems. The major problem faced by implementing this system is the high peak to average power ratio. A large PAPR increases the complexity of the analog to digital and digital to analog converter and reduces the efficiency of the radio – frequency (RF) power amplifier. Some applications are implemented to reduce the peak powers transmitted which in turn reduces the range of multicarrier transmission. This leads to the prevention of spectral growth and the transmitter power amplifier is no longer confined to linear region in which it should operate. This produces a harmful effect on the battery lifetime.

$$\text{PAPR}=\frac{\text{Peak power}}{\text{Average Power}} = \frac{max|x(t)|^2}{E[|x(t)|^2]}$$

This above given PAPR is actually represented in db (decibel).which is the ratio of maximum power required by any peak to the mean power required by the total signals.

We also simulate the selected mapping technique (SLM) for different route number which is most efficient technique for PAPR reduction when the number of subcarrier is large. Simulation shows that the PAPR problem reduced as the route number increases.

Orthogonal frequency division multiplexing (OFDM) technology is one of the most attractive candidates for Fourth Generation (4G) wireless communication. It effectively combats the multipath fading channel and improves the bandwidth efficiency. At the same time, it also increases system capacity so as to provide a reliable transmission. OFDM uses the principles of Frequency Division Multiplexing (FDM) but in much more controlled manner, allowing an improved spectral efficiency. The basic principle of OFDM is to split a high-rate data stream into a number of lower rate streams that are transmitted simultaneously over a number of subcarriers. These subcarriers are overlapped with each other. Because the symbol duration increases for lower rate parallel subcarriers, the relative amount of dispersion in time caused by multipath delay spread is decreased. Inter- symbol interference (ISI) is eliminated almost completely by introducing a guard time in every OFDM symbol. OFDM faces several challenges. The key challenges are ISI due to multipath-use guard interval, large peak to average ratio due to non linearity's of amplifier; phase noise problems of oscillator, need frequency offset correction in the receiver.

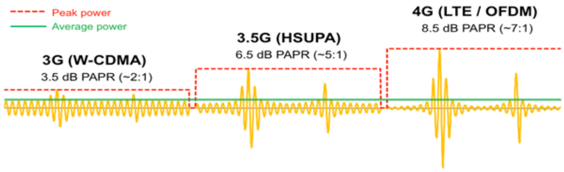


**Fig. 2.2: It shows how the peak power is increased with advance techniques (more in OFDM)**

Large peak-to-average power ratio (PAPR) results in distorted signal if the transmitter contains nonlinear components such as power amplifiers (PAs). The nonlinear effects on the transmitted OFDM symbols are spectral spreading, inter modulation and changing the signal constellation. In other words, the nonlinear distortion causes both in-band and out-of-band interference to signals. Therefore the PAs requires a back off which is approximately equal to the PAPR for distortion-less transmission. This decreases the efficiency for amplifiers. Therefore, reducing the PAPR is of practical interest.

Many PAPR reduction methods have been proposed. Some methods are designed based on employing redundancy, such as coding selective mapping with explicit or implicit side information or tone reservation.

An apparent effect of using redundancy for PAPR reduction is the reduced transmission rate.

PAPR reduction may also be achieved by using extended signal constellation, such as tone injection or multi-amplitude CPM. The associated drawback is the increased power and implementation complexity. A simple PAPR reduction method can be achieved by clipping the time-domain OFDM signal. In this work, we survey the PAPR reduction techniques for OFDM. We also present PAPR reduction technique based on selective mapping (SLM) under different route number M. The remainder of this paper is organized as follows. In section II, some basics about PAPR problem in OFDM is given.

**2.4.3 Partial Transmit sequence (PTS)**

Partial transmit sequence (PTS) is one of the most important techniques for reducing the peak to average power ratio (PAPR) in OFDM systems.

**2.4.3.1 Principle of PTS**

PTS is technique for improving the statistic of a multi –carrier signal. The basic idea of partial transmit sequences algorithm is divide the original OFDM sequence into several sub-sequences , and for each sub-sequence , multiplied by different weights until an optimum value is chosen .

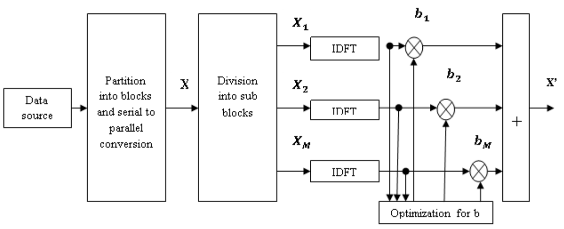


Fig.2.3: Block diagram of PTS algorithm

The above figure is the PTS algorithm. From the left side of diagram, we see that the data information in frequency domain X is separated into V non-overlapping sub-blocks and each sub-block vectors has the same size N hence we know that for every sub-block, it contains N/V nonzero elements and set the rest part to zero. Assume that these sub-blocks have the same size and no gap between each other, the sub-block vector is given by:

$$X = \sum_{v=1}^{V} b_v X_v \quad (2.9)$$

Where $b_{v=e^{j\varphi_v}}(\varphi_{v\in[0,2\pi]})\{v = 1,2, \ldots\ldots, V\}$is weighting factor been used for phase rotation. The signal in time domain is obtained by applying IFFT operation on Xv, that is

$$\hat{X} = \mathrm{IFFT}(b_v.X_V) \quad (2.10)$$

Select one suitable factor combination b= [$b_1$, $b_{2,\ldots,}$bv] which makes the result achieve optimum. The combination can be given by

$$b = [b_1, b_2, .., b_v] = \operatorname{argmin}_{(b1,b2,..bv)} \left(\max_{1\le n\le N} \left| \sum_{v=1}^{V} b_v x_v \right|^2\right) \quad (2.11)$$

Where argmin (·) is the judgment condition that output the minimum value of function. In this way we can find the best **b** so as to optimize the PAPR performance. The additional cost we have to pay is the extra V-1 times IFFTs operation.

In conventional PTS approach, it requires the PAPR value to be calculated at each step of the optimization algorithm, which will introduce tremendous trials to achieve the optimum value. Furthermore, in order to enable the receiver to identify different phases, phase factor b is required to send to the receiver as sideband information (usually the first sub-block $b_1$, is set to 1). So the redundancy bits account for (V − 1) $\log_{2(W)}$, in which V represents the number of sub-block, W indicates possible variations of the phase. This causes a huge burden for OFDM system, so studying on how to reduce the computational complexity of PTS has drawn more attentions; nowadays.

The optimization is achieved by searching thoroughly for the best phase factor.

Theoretically= [$b_1$,b $_2$, … ,bv ] is a set of discrete values, and numerous computation will be required for the system when this phase collection is very large. For example, if v contains W possible values, theoretically, b will have W^v different combinations, therefore, a total of V· (W^v) IFFTs will be introduced.

**3 Proposed Method**

In this method the reduced complexity is combined with linear companding techniques as follows:

• As shown in Fig. 3 the data signal is divided into V disjoint sub blocks

- Find $x_v = IFFT\{X_V\}$
- Compute $Q = \{Q_0, Q_1, \dots \dots \dots, Q_{N-1}\}^T$
  $Q_s = \sum_{v=1}^{V=1} |x_{v,s}|^2$ for 0≤s≤N-1
- Tabulate $Q_s \geq \frac{\emptyset_s}{V}$ $as\ a\ set\ (T)$

• Signals of the samples $S_\in$ and T are used to compute optimum signal for PAPR

• The computed optimum signal of samples $S_\in$ T is again computed by A-law or µ-law companders

• The companded OFDM signal PAPR is calculated.

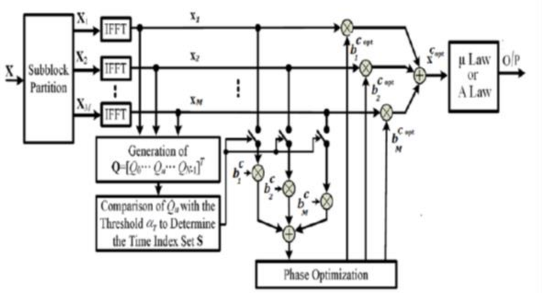


**Fig. 3 Reduced Complexity PTS with Companding OFDM System**

## 4 RESULTS

To show the performance of PAPR reduction, the OFDM is combined with Reduced complexity PTS and companding methods which are imitative of the existing methods with number of symbols 500, subcarriers 6,16-QAM and V=2 which are simulated by randomly generated data. A CCDF=Prob {PAPR>PAPRo}, was used to present the range of PAPR in term of a probability of occurrence.

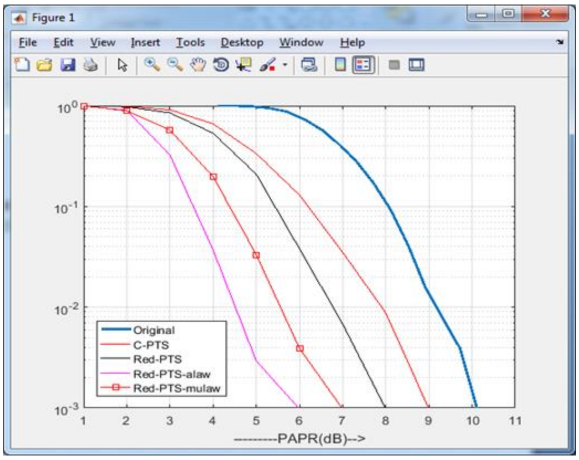


Fig. 4.1 Comparison of PAPR for Reduced Complexity PTS with Companding OFDM System

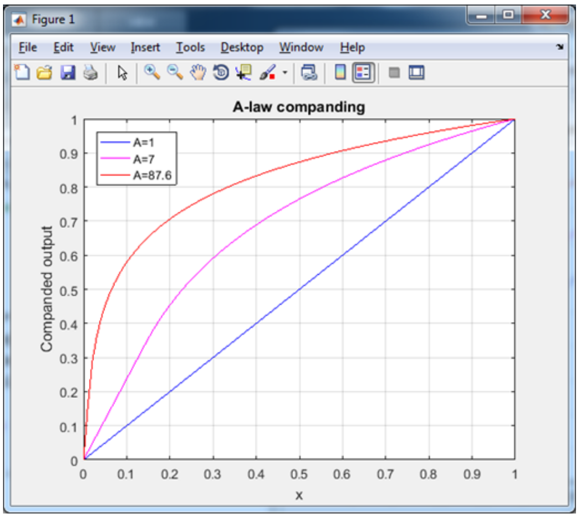


FIG.4.2 A law companding

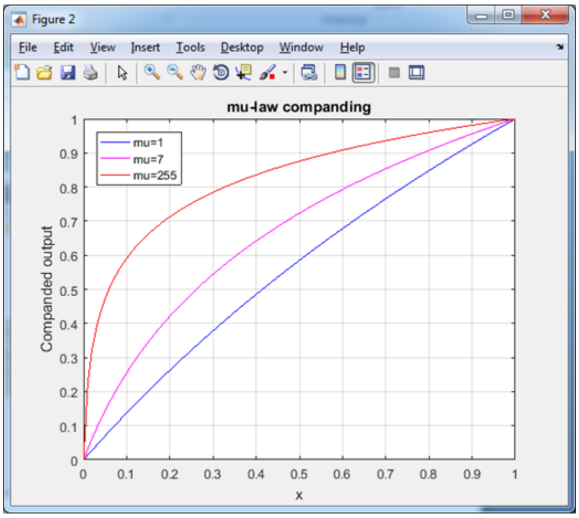


FIG. 4.3 mu-law companding

## 5 Conclusion

In reduced complexity PTS OFDM system [8], the PAPR is reduced compared with conventional PTS. Using this method, the computational complexity is reduced based on the cost function by summing the samples of the time symbols 's'in V disjoint subblocks. As the γ decreases, the PAPR decreases. The reduced complexity PTS with compading OFDM system further increases the efficiency of high power amplifiers by reducing the PAPR to lower values. For better efficiency, γ=1.000 is considered.

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