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Performance Enhancement of Wireless Link using Optimized Two Piecewise Companding by PAPR Reduction

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Abstract: Orthogonal Frequency Division Multiplexing (OFDM) can provide very high data rates with comparative ease of equalization. It has high bandwidth efficiency as the concept of orthogonality is used while going for digital signal processing. OFDM has many draw backs like high Peak to Average Power Ratio (PAPR) and imperfect synchronization between transmitter and receiver. If we reduce PAPR, then the Bit Error Rate (BER) degrades i.e. more noise is being introduced in the OFDM system. So focus should be on the desirable BER while reducing PAPR. In Two Piecewise Companding (TPWC) method, compression of large signal amplitudes and expansion of small amplitudes take place with two different functions respectively. Simulation results in MATLAB clearly show the further reduction in PAPR by choosing the appropriate parameters in case of optimized TPWC compared to earlier paper of TPWC [1] in which approximation in TPWC transform was considered and that method was not optimized. For optimization, BER of 10^{-5} is considered at Eb/No of 19.5 dB while keeping eye on PAPR value. As power peaks reduces, the cell edge boundary increases. Usually the lower of PAPR value leads to increase in back up time of battery of the link.

***Keywords*: Orthogonal Frequency Division Multiplexing (OFDM), Peak to Average Power Reduction (PAPR), Bit Error Rate (BER), Matrix Laboratory (MATLAB), Two Piecewise Companding (TPWC).**

I. INTRODUCTION

Now a days mobile communication has become very active and super wide area for research for scientist and engineers. The initial purpose of the technology was to use it for voice telephony, but later on its implementation is used for services like video, data, text and images while moving even at high speed like hundreds of kmph with air as a channel. OFDM also has some draw backs like high PAPR, frequency offset between transmitter & receiver and synchronization between transmitter and receiver etc. It suffers from huge envelope fluctuation, which produces high peak-to-average power ratio (PAPR) in Power Amplifier (PA) at the side of digital-to-analog (D/A) converter in transmitter and it can also be problematic at analog-to-digital (A/D) conversion side at the receiver end. The worst-case signal peaks, which are comparatively very high compare to normal peaks. The high value of PAPR needs a very wide linear range of the PA to combat a nonlinear distortion which can occur when signal goes up to the non linear region of in the input and output relationship of PA. The cost of HPA is based on the linear range of PA. The larger linear range gives more costly PA. In order to solve such problem of high PAPR in OFDM system many PAPR reduction methods are being used over several years as a separate method or in hybrid combination of methods, such as PTS Technique[2],SLM Technique[3],clipping [4], block coding [5], tone reservation [6], companding transform[1],[7-11], Hadamard transform[12]. The simplest technique out of above is clipping but it causes not only out-of-band radiation (OBR) but also in-band distortion (IBD). Companding transform is also a very simple method, which processes the OFDM signals directly. This makes the process very fast and relatively easy.

II. OFDM SYSTEM WITH COMPANDING TRANSFORM

The patent was applied for the basic concept of OFDM in the mid of 1960 whose importance was not realized at that time but today it is a base of latest technology for research [13]. The realisation of FFT and IFFT techniques made this possible due to digital signal processing methods supported by VLSI technology in the current era. In OFDM the information from single stream after mapping is subdivided into N parallel streams by serial to parallel converter on which IFFT operation is being performed, then again parallel to serial is being done [14]. Cyclic prefix is added after companding and then Digital to Analog (D/A) conversion is being done and at last transmitted. The receiver concept is just opposite to the transmitter concept. Here Analog to Digital (A/D) conversion is being done after receiving the signal and then cyclic prefix is completely removed. The serial to parallel is being done after decompanding followed by doing FFT operation on signal which is just inverse of IFFT operation at transmitter end. In the end parallel to serial conversion is being done. At last the parallel to serial conversion is being done which is followed by demapping. OFDM is very popular now a day and currently Wireless Local Area Networks (IEEE 802.11a, IEEE802.11g) uses the technology.

III. PROPOSED SCHEME AND ITS THEORY

If the input symbols of information are identically distributed and statistically independent, then input x can be approximately considered as a complex Gaussian process as per the concept of central limit Theorem.[15] When the number of sub-carriers N is more than or equal to 64, assuming that it has zero mean and variance σ, so its magnitude |x| has a Rayleigh distribution with the Probability Distribution Function (PDF) given by[12].

$$qn = f(x) = \frac{2x}{\sigma^2} e^{-x^2/\sigma^2} \quad \text{... (1)}$$

Larger peaks for OFDM system is now a day usually expressed as Peak to Average Power Ratio (PAPR).
PAPR is usually defined as

$$\text{PAPR}=\frac{Peak\ Power}{Average\ Power} \quad \text{...(2)}$$

$$\text{PAPR}=10\log_{10}\frac{max[|x_n|^2]}{E[|x_n|^2]} \quad \text{...(3)}$$

Here,
$max[|x_n|^2]$=maximum value of signalx_n and $E[|x_n|^2]$ =expected value of signalx_n.
And $x_n$is an OFDM signal which is obtain after taking IFFT operation on input symbols X_k.
Mathematically x_n can be given as (for *N* sub carriers)

$$x_n = \frac{1}{(N)^{1/2}}\sum_{k=0}^{N-1} X_k W_N^{nk} \quad (4)$$

The point is to be noted here that the PAPR is a variable, whose performance can be measured by evaluating its complement cumulative distribution function (CCDF).

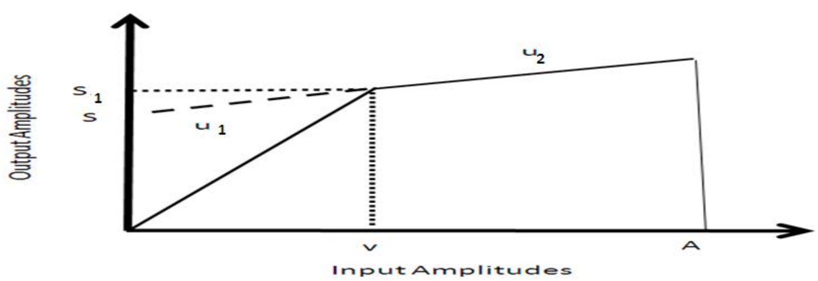

Fig. 1 Transfer characteristics of TPWC

Here, yn is the output of companding transform at the transmitter end.

$$yn = \begin{cases} (u1|xn|) * sgn(xn), & |xn| \le v \\ (u2|xn| + d1) * sgn(xn), & |xn| > v \end{cases} \quad \text{... (5)}$$

If zn is the output of decompanding transform at receiver end and rn is a received signal after passing through channel at the decompanding end.

Then

$$n = \begin{cases} \left(\left[\frac{1}{u1}\right]|rn|\right) * sgn(rn), & |rn| \le (u1 * v) \\ \left(\left[\frac{1}{u2}\right]\{|rn| - S\}\right) * sgn(rn) & ,|rn| > (u1 * v) \end{cases} \quad (6)$$

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The main highlight of the method is that the average value of signals at the transmitter end before and after the companding remains same. Here two numbers of different TPWC cases are taken one is from already published paper in which approximation is taken as explained in the short mathematical derivation followed by another method in which exact values are taken.

For equal average power in TPWC,

$$[\int_0^v (u1\ \ x)^2\ f(x)\ dx + \int_v^\infty (u2\ \ x\ \ +S\ )^2 f(x)\ dx\ ] = \int x^2 f(x)\, dx \qquad ...(7)$$

Where, $f(x) = \frac{2x}{\sigma^2} e^{-x^2/}\sigma^2$

Here, $\int_0^\infty x^2 \frac{2x}{\sigma^2} e^{-x^2/}\sigma^2 dx \ = \ \sigma^2 = I.$

That is,

$$I = \int_0^v (u1\ \ x)^2 f(x)dx + \int_v^\infty (u2\ \ x\ \ +S\ )^2 f(x)dx \qquad (8)$$

In Approximate two piecewise companding case in the paper [1] it was assumed that complimentary function $\emptyset_m$ is defined as

$$\emptyset(m) = \ \frac{\sqrt{\pi}}{2}[\int_0^m e^{-x^2} dx] \qquad (9)$$

$I = \sigma^2$ is the condition of equal power after companding.

This can be simplified as as below:

$$0 = \left[(u1)^2 - (u1)^2 e^{-m^2} + \ (u2\ )^2\ \ e^{-m^2} + u2(u1 - u2)m\left(\left(1 - \mathrm{erf}\ (m)\right)\sqrt{\pi}\right) - 1\right]$$

If $A = 1 - e^{-m^2}$ $and\ B = m\ \ ((1 - \mathrm{erf}(m))\sqrt{\pi}$ then final exact equation for TPWC can be given as below.

$$\left((u1^2 - u2^2)\right)A + (u2)^2 + u1u2B - (u2)^2 B = 1 \qquad (12)$$

The point to be noted that u2 and m are assumed and u1 is found keeping eye on BER of10^{-5}at Eb/No of 19.5 dB as a limit for the optimization.

From values of u2 and the value of m we can find the value of u1. The optimization is done by coding in MATLAB by taking PAPR values in matrix by keeping different values of m on Y axis and different values of u2 on X axis .The one eye should be on Eb/No so that it should not get worst.

In the paper [1] for $m \geq 1.2$, the complimentary function$\emptyset(m) \approx 1$which gives approximate final equation as below[1]

$$\left[\left(1 - e^{-m^2}\right)(u1)^2 + e^{-m^2}(u2)^2\right] = 1 \qquad (10)$$

Value of u1 is derived assuming the values of u2for given m (where $v = m\sigma$).

Table I Approximate TPWC parameters

Case no. of Parameters	m	$u2$	$u1$
1	1.2	0.13	1.143
2	2	0.14	1.009

Table I is regarding the parameters for approximate two piecewise companding already given in paper [1].

Let

$$\begin{aligned} I = {} & (u1)^2 \int_0^v (x)^2 f(x)dx + (u1)^2 \int_v^\infty (x)^2 f(x)dx \\ & + (u1^2 + u2^2 - 2\, u1\, u2) m^2 \sigma^2 \int_v^\infty f(x)dx \\ & + 2\, u2\ \ S(\int_v^\infty x f(x)dx) \end{aligned} \qquad ...(11)$$

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IV. RESULTS

Results are taken with the help of MATLAB software considering parameters shown in Table 2 and assumptions given subsequently below the table. Both of these considerations are applicable for both cases of approximate TPWC and exact TPWC.

Table II Simulation parameters used in MATLAB

S.N.	Parameter	Parameter kind/ Value
1	Modulation Scheme	QPSK
2	No. of Carriers	1024
3	Cyclic Prefix used	256
4	Oversampling Factor	4
5	Channel used	AWGN
6	Optimization Parameters considered	BER of 10^{-5}at Eb/No of 19.5 dB

A. *Assumptions Used Here are as Below*

1) Frequency offset is zero between transmitter and receiver.
2) Perfect synchronization between transmitter and receiver.

Now considering approximate TPWC technique using parameters given in table number one, MATLAB plots are as given in figure 4 and figure5 for PAPR and BER respectively.

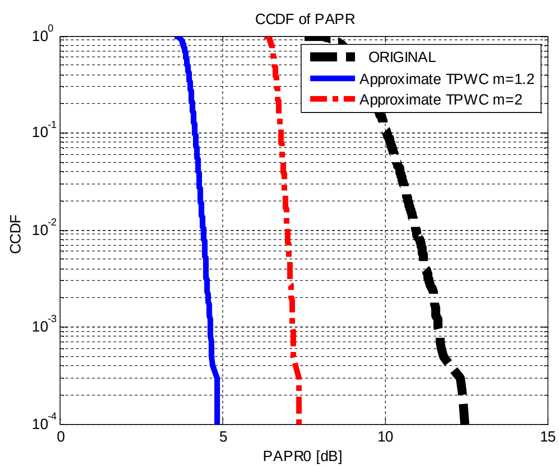

Fig. 2 PAPR of Approximate Two Piecewise Companding

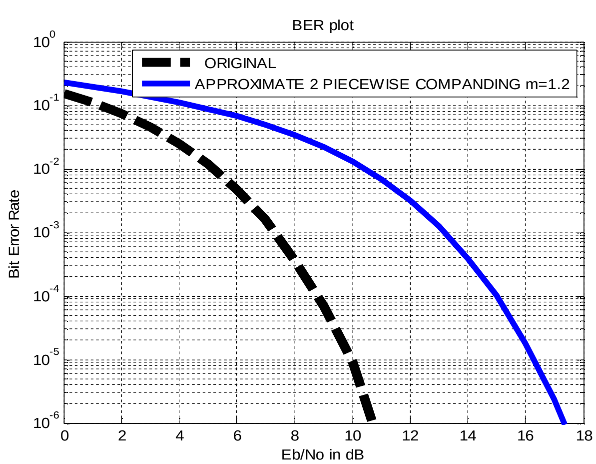

Fig. 3 BER plot of Approximate Two Piecewise Companding

As shown in figure 4, the original PAPR at CCDF of 10^{-4} is 12.5 dB. The approximate TPWC gives PAPR of 7.5 dB and 4.85 dB respectively for the values of *m*=2 and *m*=1.2 at the same CCDF. It is also shown in BER plot in figure 5 that there is change in BER due to companding-decompanding for *m*=1.2. The change is that BER gets worsen due to application of approximate TPWC. The value for *m*=1.2 is only selected because out of two cases mentioned above *m*=1.2 gives lower PAPR.
The optimized TPWC parameters are given below:

Table III Optimized TPWC parameters

m	u1	u2
0.90344	1.30521	0.11421

As indicated in the figure 6 that in the exact two piecewise case with the parameters shown in below table are used which are obtained in optimization process of the exact TPWC gives much lower PAPR of 3.85 dB compare to earlier TPWC case which gives PAPR of 4.85 dB. Of-course, both readings are taken at CCDF of 10^{-4}as a same reference.

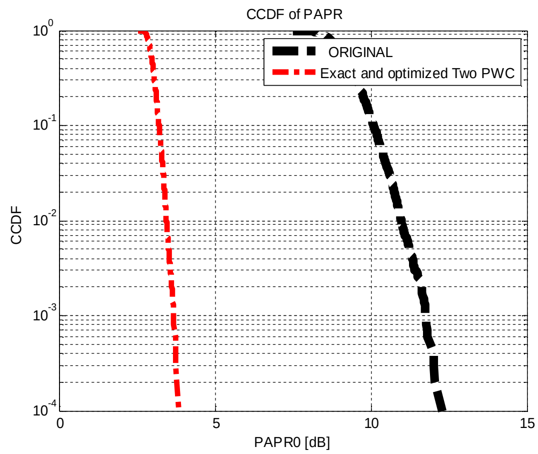

Fig. 4 PAPR of Optimized Two Piecewise Companding

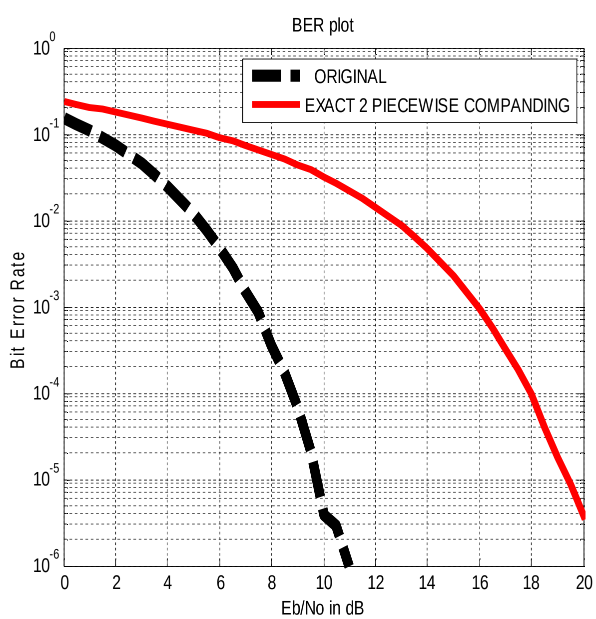

Fig. 5 BER plot of Optimized Two Piecewise Companding

Table IV Complete comparison can be tabled in the table 4 which is self-explanatory

S.N.	Method used	PAPR at CCDF of 10^{-4}	% Reduction compare to early method
1	Original with no companding	12.5 dB	Not Applicable
2	Approximate TPWC	4.85 dB	61.2%
3	Exact TPWC with optimization	3.85dB	20.61%

The PAPR can be further reduced in exact TPWC but the BER gets worsen. The other coding techniques like convolution encoding can be used to improve BER. The MIMO technology can also be employed which is very effective to improve the BER in view to reduce PAPR further.

V. CONCLUSION

Exact optimized TPWC is better way to reduce PAPR for given hardware /software system compare to approximate TPWC. The optimization has to be done for given desired conditions keeping in mind BER & Eb/No. If we can employ technique like MIMO with OFDM system then PAPR can be reduced to a large extent. The MIMO system embedded with OFDM can be helpful. In the given optimizing condition as mentioned earlier the Exact TPWC gives value of m=0.9034 for which the condition of $\emptyset(m) = \frac{\sqrt{\pi}}{2}\left[\int_0^m e^{-x^2} dx\right]$ approximately equals to 1 does not holds true here, it may be true for some specific conditions. So the generic method of Exact TPWC should be considered. Reducing peaks of signal leads to save the battery power. Hence back up time of battery increases. HPA is one of the costly elements of the equipment whose cost will be reduced. It is also concluded that lowering the peaks leads to increase in the cell edge boundary hence the performance of wireless link improves.

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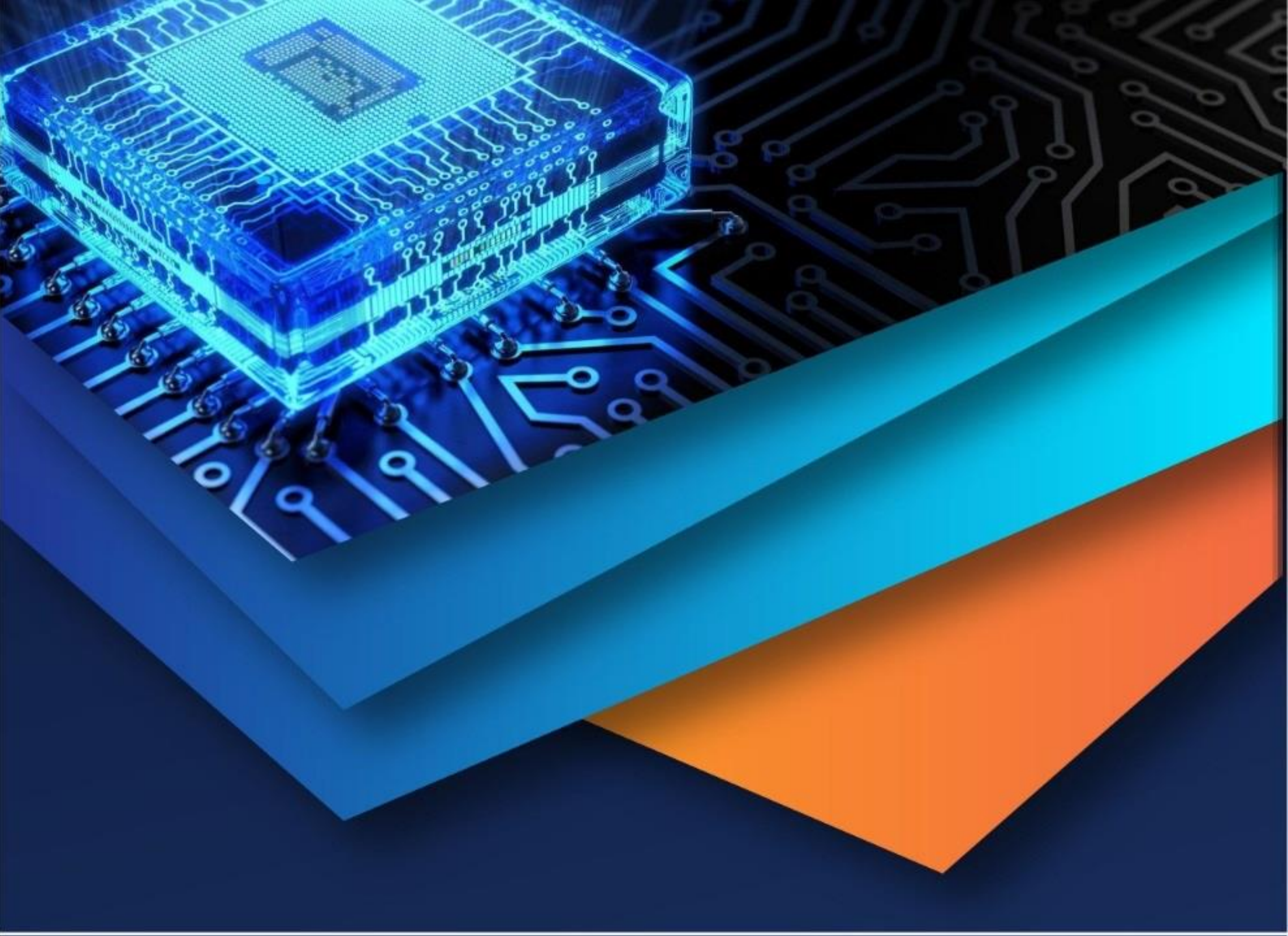

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