

# **PAPR Reduction Approach by Iterative Companding and Filtering Signal in OFDM System**

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**ABSTRACT:** In the OFDM system the main disadvantage factor is Peak Average to Power Ratio (PAPR) which bounds the performance of the overall system. To unbound this factor so many techniques, depends on the system like clipping, partial transmission sequence, Selective mapping method, Companding transform etc. are there. Out of these technique companding technique is a simple methodology to compress or compand the input signal based on the inflection points to reduce the PAPR in the system. Whereas decompander is the technique in the receiver which works exactly opposite to expand the companded signal from the transmitter section in the OFDM. By means of a specially designed iterative procedure, ICTF is able to obtain both an improved Bit Error Rate (BER) and minimized Out-of-Band Interference (OBI) while reducing the PAPR significantly. A comprehensive theoretical analysis is presented, and some important results such as the achievable PAPR gain, impact of companding distortion, and selection criteria for companding parameters and maximum iteration number are derived. In particular, it is shown that the ICTF without decompanding at the receiver can offer a good BER performance. Simulations show that compared to the classic Iterative Clipping and Filtering (ICF) technique, ICTF can dramatically decrease the number of required iterations to reach the desired PAPR with low complexity. In addition, the companded OFDM symbols by the proposed ICTF technique have less in-band distortion, and lower out-of-band spectral regrowth than traditional companding schemes.

**KEYWORDS:** OFDM, PAPR, Companding Transform and Filtering (CTF), Out of Band Interference (OBI), Signal Attenuation Factor (SAF).

## **I. INTRODUCTION**

Orthogonal Frequency Division Multiplexing (OFDM) is most awaited technology in the field of mobile communication. The purpose of efficient use of spectrum and for the high transmission efficiency to support high speed internet, high quality multimedia and high definition streaming videos with its multicarrier transmission technique. OFDM is widely adopted in many wireless mobile communication techniques and also for the wireless communication standards. It is a modification in the Frequency Division Multiplexing (FDM) only difference is all about orthogonality. The orthogonality is maintained by maintaining the phase difference between the signals at right angle. Along with the great advantages, it has disadvantages as Bit Error Rate (BER), Peak Power to Average Power (PAPR) ratio, carrier frequency offset and time jitters.

The ratio of Peak Power to Average Power is referred as Peak to Average Power (PAPR) ratio. Practically the power amplifier has limited linear region and after multiplexing the extra peaks are generated and these peaks force the power amplifier to operate in saturation region. The extra peak having extra power goes out of linear region of the amplifier. Thus, such an efficient technique needs to be investigated to operate the power amplifier in a linear region by reducing the PAPR ratio in the OFDM technique. A number of approaches have been studied within a few years of span such as selective mapping (SLM) [3], partial transmit sequence (PTS) [4], tone reservation (TR) [5], tone injection (TI) [5], active constellation extension (ACE) [6], clipping [7] and companding [8]–[15]. Iterative companding transform and filtering scheme has the effects of companding distortion on BER. It is seen that BER performance can be effectively improved by reducing companding distortion. Based on the analysis results, a new iterative companding transform and filtering (ICTF). In the proposed companding transform, the signals with amplitudes over a given companded peak amplitude are clipped for peak power reduction, and the signals with amplitudes close to the given companded peak

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amplitude are linearly scaled for power compensation. With the careful design of the companded peak amplitude and the linear transform scale, the proposed transform can effectively reduce companding distortion. With the careful design of the companded peak amplitude and the linear transform scale the studied transform scheme achieve enhanced BER and power spectral density performance, while reducing PAPR effectively.

## II. OFDM SIGNAL AND PAPR

The discrete-time transmitted OFDM signal is given by

Let  $X = [X_0, X_1, \dots, X_{N-1}]$  represents the data sequence to be transmitted independently in an OFDM symbol with  $N$  subcarriers. The time-domain OFDM symbol with  $J$  times oversampling  $x_n = [x_0, x_1, \dots, x_{JN-1}]$  can be generated as

$$x_n = \frac{1}{\sqrt{JN}} \sum_{k=0}^{N-1} x_k e^{j2\pi \frac{kn}{JN}} \quad 0 \leq n < JN - 1 \quad (1)$$

Where,  $n$  is time index and  $j = \sqrt{-1}$ . Assume that the sequences  $k, X$  are statistically independent and identically distributed. Based on the central limit theorem, when  $N$  is large, the real and imaginary parts of  $x_n$  become Gaussian distributed, each with zero mean and a common variance  $\sigma^2$ . As a result, the signal amplitude  $|x_n|$  follows a Rayleigh distribution with the Probability Distribution Function (PDF) as follows,

$$p(x) = \frac{2x}{\sigma_x^2} e^{-\frac{x^2}{\sigma_x^2}} \text{ for } x \geq 0 \quad (2)$$

Where,  $\sigma_x^2$  is the variance of  $x_n$ .  $\sigma_x^2 = E[|x_k|^2]$ , where  $|\cdot|$  denotes modulus and  $E[\cdot]$  is the mathematical expectation. The PAPR of the transmitted signal can be expressed as

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

The Companding transform is an extra operation after the. The reverse process is done at the receiver.

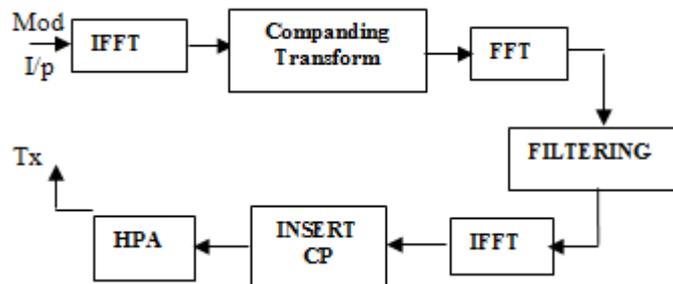


Fig.1 Block diagram of Basic OFDM system.

## III. PROPOSED ICTF TECHNIQUE

### A. Iterative Companding Transform and Filtering Signal Scheme.

**Step1:** Initialization of desired PAPR, Signal Attenuation Factor (SAF) and the maximum iteration number  $M$ . Select companding parameters.

**Step2:** Convert the frequency-domain symbol  $X$  to oversampled time-domain OFDM symbol  $x$  using  $NJ$  -points IFFT. For 1<sup>st</sup> iteration  $m=1$ , a new symbol enters the Iterative loop. Then, both  $K1$  and  $K2$  are set to 2.

**Step3:** If  $m=1$ , let  $x_0^m = x$ ; otherwise, let  $x_0^m = x^{m-1}$

**Step4:**  $x_0^m$  is companded by CT function to generate  $Y_m$ .

**Step5:** Convert  $Y_m$  to frequency domain to generate  $C_m$  using  $NJ$  -points FFT.

**Step6:** Perform the frequency-domain filtering on  $C_m$

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using rectangular window function  $H$  to null the out-of-band spectral components.

**Step7:** Convert  $C_m$  to time-domain symbol  $x_m$  using  $NJ$

-points IFFT. Calculate the PAPR of  $x_m$  denoted by  $PAPR_m$ .

Step8. If  $des PAPR_m \leq PAPR_{desired}$  or  $m > M$ , transmit  $x_m$ , and reset  $m = 1$ , return to Step 2 to process the next original symbol. Otherwise, let  $m = m + 1$ , return to Step3 to repeat the iteration for the current symbol. In Step 6, to eliminate the out-of-band components, CT is followed by the filtering, which is defined by a rectangular window with the frequency response  $H \times C = JN$  as follows.

The initial signal  $x_n$  is companded with a given peak amplitude  $A_c$ , the proposed companding scheme shown in Fig.5 clips the signals with amplitudes over  $A_c$  for peak power reduction, and linearly transforms the signals with amplitudes close to  $A_c$  for power compensation. Then, the companding function of the proposed companding scheme is

$$H(k) = \begin{cases} 1 & 1 \leq k \leq N - 1 \\ 0 & N \leq k \leq JN - 1 \end{cases} \quad (4)$$

## B. Companding Function.

The selection criterion for companding parameters in Step 1 is derived in this subsection. Two typical linear companding profiles are adopted in ICTF procedure to evaluate its overall performance. Note that, other well-known linear and nonlinear CT functions can also be adopted to replace them.

### CT 1. Linear Symmetrical Transform

Linear Symmetrical Transform (LST) is the simplest CT profile, whose companding function is defined as

$$F(x) = (k|x| + b) \times \text{sgn}(x)$$

Where  $\text{sgn}(x)$  is a sign function, and two parameters  $0 < k < 1$

And  $b > 0$  are used to specify the companding profile. In order

to maintain an unchanged average power after CT, it yields  $k^2 + \sqrt{\pi} \times \frac{kb}{\sigma} + \frac{b^2}{\sigma^2} = 1$ . Thus, once  $k$  was selected,  $b$  can also be determined, and vice versa. The corresponding decompanding function is given by

$$f^{-1}(x) = \frac{|x-b|}{k} \times \text{sgn}(x)$$

The SAF of LST function can be calculated as

$$SAF = 1/\sigma^2 \int_0^\infty x f(x) p(x) dx = k + \frac{\sqrt{\pi}}{2\sigma} \times b$$

$$PAPR(LST) = 10 \log_{10} \frac{\max(y_n^2)}{E(y_n^2)}$$

The theoretical SAF values of LST are observed, SAF (LST) decreases quickly along with  $k$  decreasing. Hence, LST cannot offer a satisfactory PAPR and BER performance due to the same-scale treatment on all original symbol and serious signal distortion. However, the signal attenuation in TPWC may become less apparent while it is noteworthy that, though the PAPR reduction and BER performance affect each other oppositely, an effective trade-off with moderate dynamic range between them is offered. Once the desired PAPR and SAF are assigned, by selecting the optimal parameters based on the closed-form expressions in (9), (10), (14) and (15), it is preferable to make the undesired signal distortion as small as possible before entering the ICTF procedure.

## C. Computation Complexity

The companding function can be numerically pre-computed

and performed. Thus, the computation complexity of ICTF procedure is nearly the same as that of ICF [2], i.e.  $O(2MJN \times \log JN)$ , where  $M$  is the maximum number of iterations. Obviously, the increased number of iterations means increased computation complexity, especially when the number of subcarriers is very large. When compared to ICF

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method, as this paper shows later, ICTF can dramatically decrease the number of required iterations to reach a desired PAPR. Its computation complexity, therefore, can be significantly reduced. In addition, the optimized ICF [4] based on the convex optimization has a high computation complexity, which is  $O(M N^3 + (M+1)JN \times \log JN)$ .

## IV. COMPANDING DISTORTION ANALYSIS

In this section, the impacts of the companding distortion on The BER performance in ICTF procedure is investigated.

### A. Companding Noise.

Based on Bussgang theorem for real and complex Gaussian Signal [6], the companded signal can be approximately decomposed into two parts: the attenuated signal component

And companding noise  $\rho_n$ , i.e.  $y_n = SAF \times x_n + \rho_n$ . Thus, the transmitted symbol with m iterations using ICTF can be Approximately decomposed as  $x_n^m = SAF^m \times x_n + \rho_n$ .

## V. SIMULATION RESULTS

To verify the performance of the proposed piecewise linear companding scheme with respect to the PAPR reduction, BER and PSD performance, numerical simulation results are presented for OFDM systems and the proposed algorithm can also be applied in Wi-MAX base stations with a larger number of OFDM subcarriers. The overall performances of the proposed ICTF technique are evaluated and compared with classic CT and ICF schemes. Simulations are performed for an un-coded OFDM system based on Digital Video Broadcasting-second generation Terrestrial (DVB-T2). Assume that the number of sub-carriers is  $N=1024$ , using Quaternary Phase Shift Keying (QPSK) or 16- Quadrature Amplitude Modulation (16-QAM). In the results which follow, 106 random OFDM frames are generated to obtain the CCDFs, which have been computed with an oversampling ratio  $J=4$  to offer an accurate estimation for PAPR. In order to investigate BER performance, both the AWGN and multipath fading channels are applied. A cyclic prefix with the length of  $\frac{1}{4}$  symbol is inserted to mitigate the inter-symbol interference. It is also assumed that the symbol timing is precise, the frequency offset is absent, and perfect channel estimation and single-tap frequency domain equalizer are performed at the receiver. For comparisons, five PAPR-reduction schemes including LST [9] ( $k=0.6$ ),

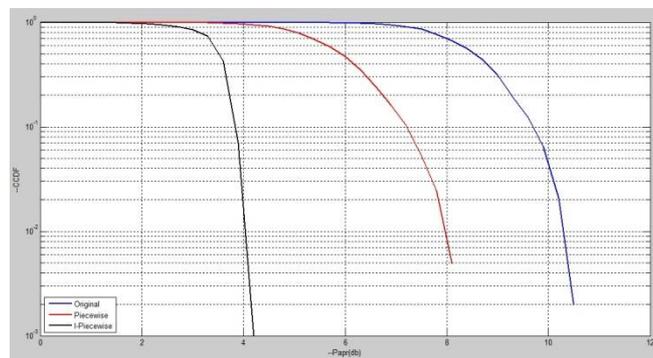


Fig.2 CCDF of original OFDM signal and companded signals

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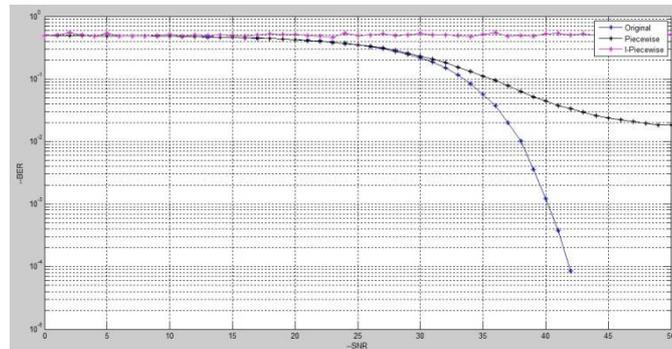


Fig.3BER of Iterative companding transform and filtering scheme.

## VI. CONCLUSION

An iterative companding transform and filtering scheme with respect to the PAPR reduction, BER performance and numerical simulation results are studied for OFDM systems. The presented algorithm can also be applied in WiMAX base stations with a larger number of OFDM subcarriers. In the simulations, perfect synchronization and channel estimation at the receiver is obtained. The presented ICTF technique not only obtains significant PAPR reduction with improved BER and OBI performance, but also dramatically decreases the iterations number.

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