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Iterative Clipping and Filtering Method for PAPR Reduction in OFDM

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Abstract— *Orthogonal frequency division multiplexing (OFDM) is an attractive technique for wireless communication applications. One of the challenging issues for OFDM is its high peak-to-average-power ratio (PAPR), which can lead to low power efficiency and nonlinear distortion at the transmitter power amplifier. Clipping is a simplest technique for PAPR reduction. We investigate, through extensive computer simulations, the effects of clipping and filtering on the performance of OFDM, including the PAPR reduction capability, the peak regrowth effect and power spectral density. In this paper the technique of Iterative clipping and filtering is simulated for OFDM and it is found that using this technique with 4 iteration, PAPR is reduced to approximately 4 dB and effect of peak regrowth can be reduced considerably.*

Keywords— *Orthogonal frequency division multiplexing (OFDM), Peak-to-Average Power Ratio (PAPR), Clipping Ratio (CR), Iterative Clipping & Filtering (ICF), Bit error rate (BER).*

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing has many advantages including resistance to multipath fading and high data rates. However a major drawback of OFDM is the manner in which the phases can align in the frequency domain causing high peaks to result in the time domain [1]. High peak values cause saturation of the power amplifier and both in-band and out-of-band distortion when limiting effects occurs. To prevent such phenomena amplifiers are normally “backed off” by approximately the PAPR. This however severely impacts power amplifier efficiency, making it preferable to reduce the PAPR of the signal before it enters the power amplifier [1].

Several alternative solutions have been proposed to reduce the PAPR of the signal input to the amplifier [2]. One of these approaches, and the simplest, is to deliberately clip the OFDM signal before amplification. In particular, since the large peaks occur with very low probability, clipping could be an effective technique for PAPR reduction. However, clipping is a nonlinear process and may cause significant in-band distortion, which degrades the bit-error-rate (BER) performance, and out-of-band noise, which reduces the spectral efficiency. Filtering after clipping can reduce the spectral splatter but may also cause some peak regrowth. Due to iterative clipping and filtering, considerably PAPR reduction can be achieved and peak regrowth can be minimised.

II. PAPR IN OFDM

OFDM signals have a higher Peak-to-Average Power Ratio (PAPR) than single carrier signals. The reason for this is that in the time domain, a multicarrier signal is the sum of many narrowband signals. At some time instances, this sum is large, at other times it is small, which mean that the peak value of the signal is substantially larger than the average value. This high PAPR is one of the most important implementation challenges that face OFDM because it reduces the efficiency and hence increases the cost of the RF power amplifier.

Let a block of N symbols $X = \{X_k, k = 0,1,\ldots,N-1\}$ is formed with each symbol modulating one of a set of subcarriers $\{f_k, k = 0,1,\ldots,N-1\}$, where N is the number of subcarriers. The N subcarriers are chosen to be orthogonal, that is, $f_k = k\Delta f$, where $\Delta f = 1/NT$ and T is the original symbol period. Therefore, the complex envelope of the transmitted OFDM signals can be written as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t}, \quad 0 \le t \le NT$$

$$= \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi kt/NT}, \quad 0 \le t \le NT \tag{1}$$

In general, the PAPR of OFDM signals $x(t)$ is defined as the ratio between the maximum instantaneous power and its average power

$$PAPR\{x(t)\} = \frac{\max_{0\le t\le NT}\left[|x(t)|^2\right]}{1/_{NT}\cdot\int_0^{NT}|x(t)|^2\,dt} \qquad (2)$$

To better approximate the peak to average power ratio of continuous-time OFDM signals, the OFDM signals samples are obtained by L times over sampling. L-times over sampled time-domain samples are LN–point IFFT of the data block with (L-1)N zero-padding. Therefore, the over sampled IFFT output can be expressed as,

$$x[n] = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1} X_k e^{j2\pi nk/LN} \text{ , } 0 \le n \le LN-1 \qquad (3)$$

The PAPR computed from the L-times oversampled time domain OFDM signal samples can be defined as

$$PAPR\{x[n]\} = \frac{\max_{0\le n\le NL-1}\left[|x[n]|^2\right]}{E\left[|x[n]|^2\right]} \qquad (4)$$

Where, $E[\cdot]$ denotes the expectation operator [2].

Statistically it is possible to characterize the PAPR distribution (probability that PAPR exceeds given threshold χ_0) using its cumulative distribution function (CDF) or complementary cumulative distribution function (CCDF). For the case of OFDM, the following expression for the CCDF holds,

$$P_r\{PAPR > \chi_0\} = 1 - \left(1 - \exp(-\chi_0)\right)^N$$

$$CCDF_{PAPR} = 1 - CDF_{PAPR} \qquad (5)$$

III. CLIPPING & FILTERING METHOD

The clipping technique is used to limit the amplitude of the peaks to a particular clipping level and fix the phase when the peaks are higher than the clipping level.

$$g(x) = \begin{cases} x & |x| \le A \\ Ae^{j\phi(x)} \text{ , } & |x| > A \end{cases} \qquad (6)$$

where A is the maximum permissible amplitude level, and $\phi(x)$ is the phase of x.

In clipping algorithm, clipping ratio (CR) is an important parameter which determines the value of A. It is defined as

$$CR = 20\log_{10}\frac{A}{\sigma} \quad \text{(dB)} \qquad (7)$$

where σ is the root mean squared value of the signal x_n [3].The higher the clipping ratio, few OFDM samples will be clipped. So it is important to choose the CR carefully to get a good reduction in the PAPR without degrade the performance of BER.

Clipping is a simple and effective technique for PAPR reduction, but it will cause both in-band and out-of-band noise. If clipping is performed on a Nyquist sampled signal, all the clipping noise will fall in-band which cannot be filtered and results in degradation in the BER performance. So it is suggested that the clipping operation could be performed on an oversampled signal, then the in-band noise is reduced but out-of -band noise will be introduced which reduces the spectral efficiency.

To remove the out-of-band components, the clipped signal could be filtered through the use of a forward FFT followed by an IFFT [6]. However, it may also cause some peak regrowth. Therefore, the predetermined threshold could be approached by ICF (Iterative Clipping & Filtering) operations. Figure 1 illustrates the block diagram of the ICF algorithm.

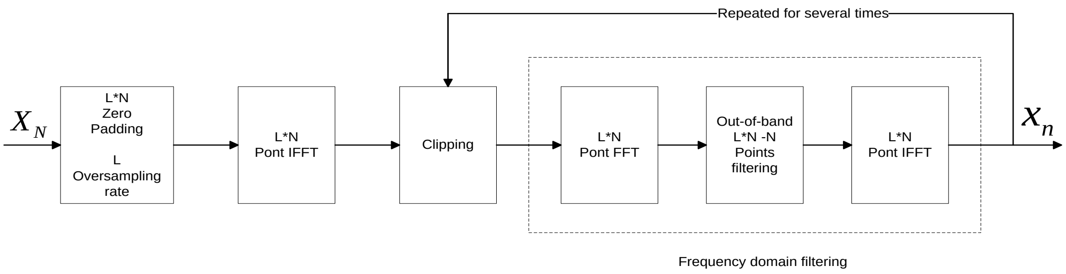

Figure 1. Block diagram of ICF algorithm

Complex base band data $X_0, X_1, \ldots, X_{N-1}$ are used as input and are converted to time domain data $x_0, \ldots, x_{N-1}, x_N, \ldots, x_{LN-1}$ by *LN*-point IFFT, which are then clipped by the soft limiter model. The output of the soft limiter model is represented by Eq.6. Then $g(x_0), g(x_1), \ldots, g(x_{LN-1})$ are converted to $\hat{X}_0, \hat{X}_1, \ldots, \hat{X}_{N-1}, \ldots, \hat{X}_{LN-1}$ by using the LN– point FFT, i.e.,

$$\hat{X}_k = \frac{\sqrt{\mathrm{N}}}{LN} \sum_{n=0}^{LN-1} g(x_n)\, e^{-j2\pi nk/LN}, \quad 0 \le k \le LN-1 \tag{8}$$

The filtering operation removes out-of-band components and gets $\hat{X}_0, \ldots, \hat{X}_{N-1}, 0, \ldots, 0$. After the filtering operation, the time domain signal becomes

$$\hat{x}(n) = \frac{1}{\sqrt{\mathrm{N}}} \sum_{k=0}^{N-1} \hat{X}_k e^{j2\pi nk/LN}, \quad 0 \le n \le LN-1 \tag{9}$$

which exhibits the problem of peak power regrowth. That means the peak power $\max_{0 \le n \le NL-1} |\hat{x}(n)|^2$ will be greater than A^2 again. The average in-band power becomes lower than the original due to clipping and filtering operation. Since a single round of the clipping and filtering operation encounters the problem of peak power regrowth, so approx. 3 or 5 times repeated clipping and filtering operation is necessary to suppress the final peak power. These repetitions result in huge signal processing - for each frequency domain filtering the pair of FFT and IFFT operation is necessary [4][5].

IV. DESIGN AND SIMULATION RESULT

The OFDM system is implemented using MATLAB to allow various parameters of the system to be varied and tested. The following OFDM system parameters are considered.

Mapping: 16- QAM
Number of data sub-carriers: 52
Number of FFT points: 64
Channel Mode: AWGN
Data rate: 54 Mbps
Over sampling factor: 2
Total no. of symbols to TX. : 10000

The 64 point IFFT mapping is shown in Figure 2. For generation of real output, IFFT mapping is done by taking its conjugate.

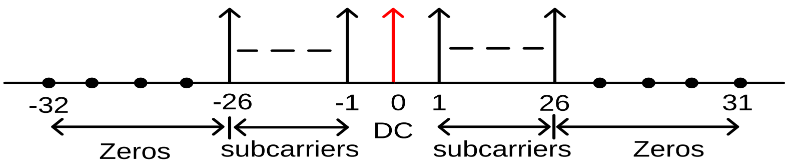

Figure 2. IFFT mapping for complex time output OFDM signal

According to definition of clipping ratio given by Eq. 7, CR of 0.8 means the clipping level is about 3 dB lower than the rms level and a CR of 2 dB means the clipping level is about 3 dB higher than the rms level. Figure 3 shows that CR=0.8 reduces PAPR much more compare to CR=2 or 4.

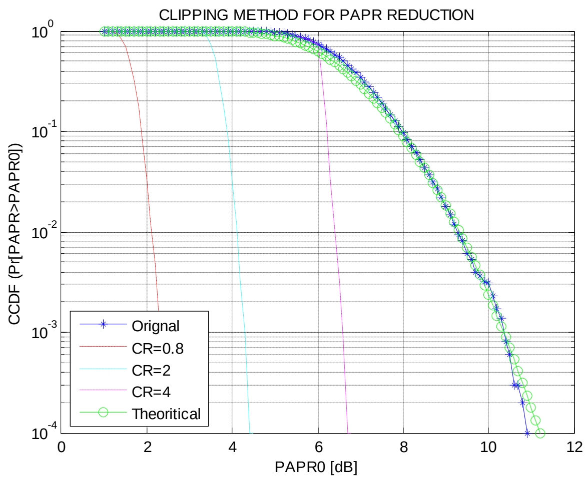

Figure 3. CCDF plot for clipping method with different CR

Figure 4 shows that BER is dependent on the clipping ratio (CR). Very less and very high values of clipping ratio is of no use, hence middle values are used. With increase in clipping the bit errors increases which degrades the BER performance. Signal can be purposely clipped by 3-4 dB so that the peak to average ratio can be reduced and BER performance closely matches with original OFDM transmission.

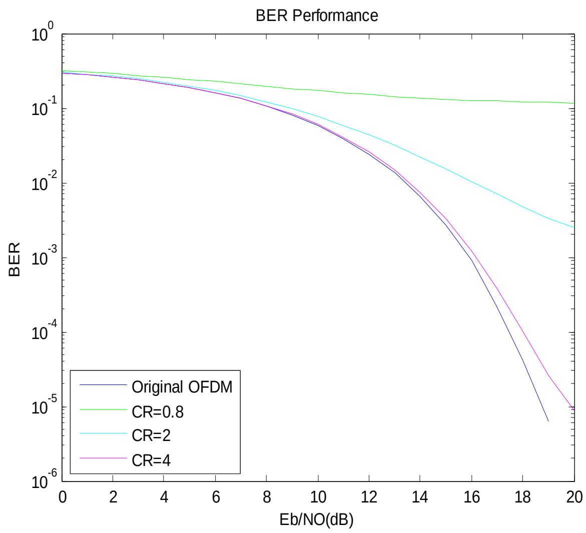

Figure 4. BER plot for clipping method with different ratio

Iterative clipping and filtering works in recursive fashion until target PAPR is obtained. Figure 5 shows peak regrowth occur after first iteration of clipping and filtering. But due to repeated operation of clipping and filtering, peak value can be reduced below threshold level. For clipping and filtering operation CR = 4 is set

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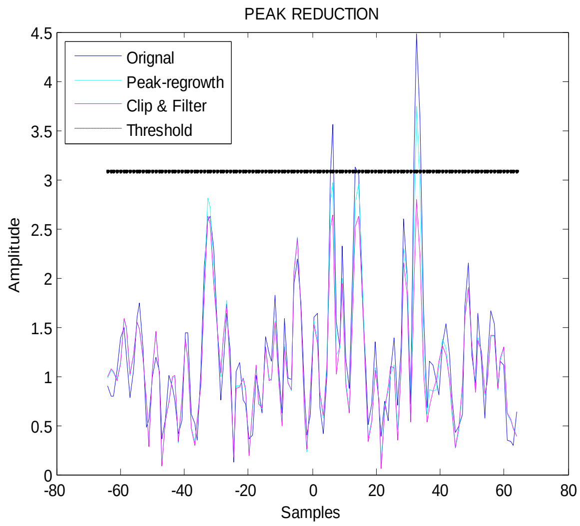

Figure 5. Peak-regrowth in clipping and filtering method

Figure 6 shows that, 4 dB PAPR reductions can be achieved with 4^{th} iteration clipping and filtering. The PSD shown in Figure 7 was computed by means of periodogram – Welch method. The PSD is the distribution of power per unit frequency. The out-of-band radiation introduced by the nonlinearity is considerably reduced when applying iterative clipping and filtering operation.

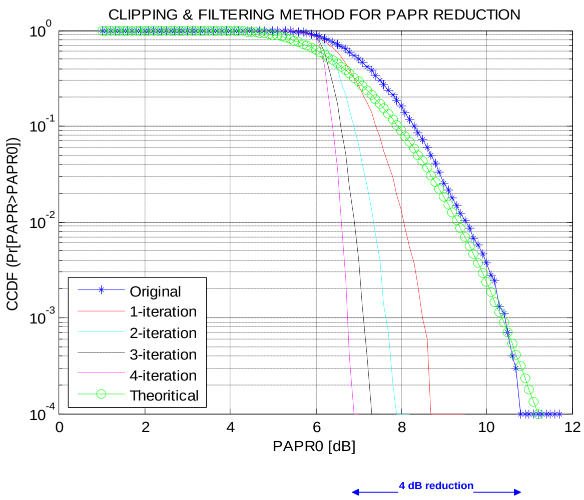

Figure 6. CCDF plot for iterative clipping and filtering method

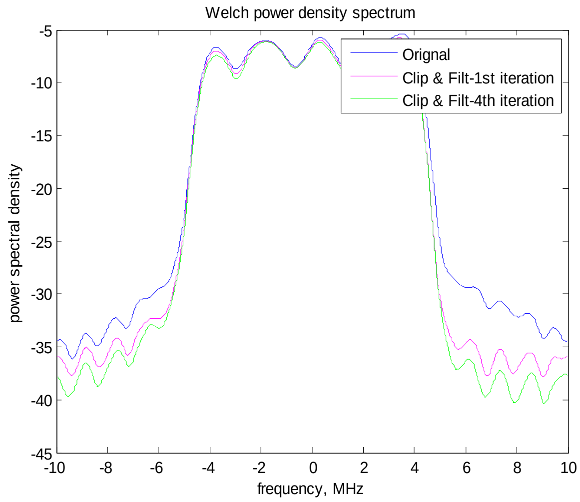

Figure 7. PSD plot for iterative clipping and filtering method

V. CONCLUSION

The clipping is a simple, distortion method with minimal computational complexity. Signal can be purposely clipped with CR = 4 dB so that the peak to average ratio can be reduced by 4.2 dB and BER performance closely matches with original OFDM transmission. The higher order constellation modes of the OFDM system are more sensitive to large Clipping than the lower order constellation modes. Approximately same PAPR reduction can be achieved with iterative clipping and filtering method after 4^{th} iteration.

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