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A Novel Approach on Effect of PAPR Reduction on Spectrum and Energy Efficiencies in OFDM System

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***Abstract*—Orthogonal Frequency Division Multiplexing (OFDM) is a promising innovation for wireless Communications, which is one of Multi-Carrier Modulation (MCM) strategies. It is one of the vital contender for high information rate interchanges However, a noteworthy disadvantage of OFDM framework is that the transmitted signals on distinctive Antennas might exhibit high Peak-to-Average Power Ratio (PAPR). Here in this paper an endeavor to demonstrate the impact of PAPR decrease by utilizing Clipping and Filtering and Partial Transmit Sequence strategy on Spectrum Efficiency (SE), and Energy Efficiency (EE) of High power Amplifier, Simulation results shows that clipping and filtering provides a better PAPR reduction than the others methods in reception part of signal.**

***Index Terms*— Energy Efficiency (EE), Orthogonal Frequency Division Multiplexing (OFDM), Peak-to-Average power ratio (PAPR), Spectrum Efficiency (SE).**

I. INTRODUCTION

The rapid data traffic growth suggests a demand for communication systems that support higher data rate. Meanwhile, the expanding uses of portable computing devices and smart phones surely require low power utilization for extended battery life. As such, efficient energy usage becomes a crucial concern for wireless communication system designs. Moreover, the shortage of the spectrum resource has drawn attentions as well. Therefore, the next generation wireless communication systems are expected to provide both high data rate and more efficient power and spectrum usages [1].

As a promising innovation for wireless communications, orthogonal frequency division multiplexing (OFDM) offers an extensive high spectral efficiency, multipath delay spread tolerance, frequency selective fading immunity and power efficiency [2]. The OFDM based physical layer has been chosen for several wireless standards such as Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB-T), The IEEE 802.11a. Local Area Network (LAN) standard and the IEEE 802.16a. Metropolitan Area Network (MAN) standard [3]. One of significant issues in OFDM is large amplitude fluctuations. Because of the loss of orthogonality between subcarriers, resulting in cross talk and exhibit very large peak to average ratio (PAPR).

As of late, the SE execution of OFDM has been all around explored in the writing [4], [5], [6], and the EE execution has additionally been talked about in the writing [7], [8]. However, examinations on the effect of the PAPR reduction to the SE and EE performances are missing, which will be the focus of this paper. In this paper, fundamentally discuss the effect of the PAPR reduction on the EE and SE performances. In addition, reducing the PAPR of OFDM signals can lead to the decrease of the nonlinear distortion noise and the required linear range of the HPA. Hence, improve the data rate and reduce the power consumption by reducing the PAPR of OFDM signals. In this paper, clipping and filtering technique and partial transmit sequence (PTS) scheme with V=4 and V=8 are used as an example for the analysis, since it can significantly reduce the PAPR of OFDM signals without any signal distortion [9], [10].

Furthermore, the clipping and filtering technique transfer the large amount of subcarriers. Therefore, the rate is improved and the power consumption is reduced. When the clipping and filtering technique is employed in OFDM systems, compared with PTS scheme. Therefore, reducing the PAPR can improve the SE and EE performances for OFDM systems and the quantitative relations between PAPR reduction, SE, and EE are also derived in this paper.

The rest of this paper is organized as follows. In Section II, A typical OFDM system is reviewed, and the PAPR, SE, and EE are defined, respectively. Then, the nonlinear distortion Noise caused by HPA, and the characteristics of HPA are discussed in detailed in Section III. In Section IV, the relations between the PAPR reduction, SE, and EE are derived, followed by Conclusions in Section V.

II. OFDM PAPR DESCRIPTIONS

A discrete-time OFDM model with N subcarriers is considered. With the linear property of the N narrowband subcarriers, the discrete-time OFDM signals can be written as

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j\frac{2\pi kn}{N}} \quad (1)$$

Where $n = 0,1..., N-1$ For simplicity, consider $X = IIFT\{X\}$ Where $\mathbf{X} = [X(0), \ldots, X(N-1)]^T$ and $\mathbf{X} = [x(0), \ldots, x(N-1)]^T$. Because of the statistical independency of the transmitted subcarriers, the time domain OFDM samples $x(n)$ are approximate Gaussian distribution. The definition of PAPR can be written as

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

Where $E\{\cdot\}$ denotes expectation operator.

In the literature, the complementary cumulative distribution function (CCDF) of the PAPR is one of the most frequently used performance measures for PAPR reduction techniques. The CCDF of PAPR denotes the probability that the PAPR of an OFDM symbol exceeds a given threshold PAPR*o*, that is, the CCDF of PAPR can be written as

$$\text{CCDF}(\text{PAPR}_0) = P_r(\text{PAPR} > \text{PAPR}_0) \quad (3)$$

In general, for OFDM systems with Gaussian time domain samples, the CCDF of PAPR can be written as

$$P_r(PAPR > PAPR_0) = 1 - (1 - e^{-PAPR_0})^N \quad (4)$$

III. HPA Model

The circuit diagram of class A HPA as an example shown in Fig. 1, and the corresponding operating characteristics and Amplitude/Amplitude (AM/AM) characteristics are shown in Fig. 2 and Fig. 3, respectively, where the amplifier gain is denoted as *Gh*. The operating point of the HPA is set as the IBO (input back off), which is defined as

$$IBO = 10\log_{10}\frac{P_{max}}{P_{avg}} \quad (5)$$

Where *Pmax* denotes the saturation input power of the HPA, and *Pavg* is the average power of the input signals.

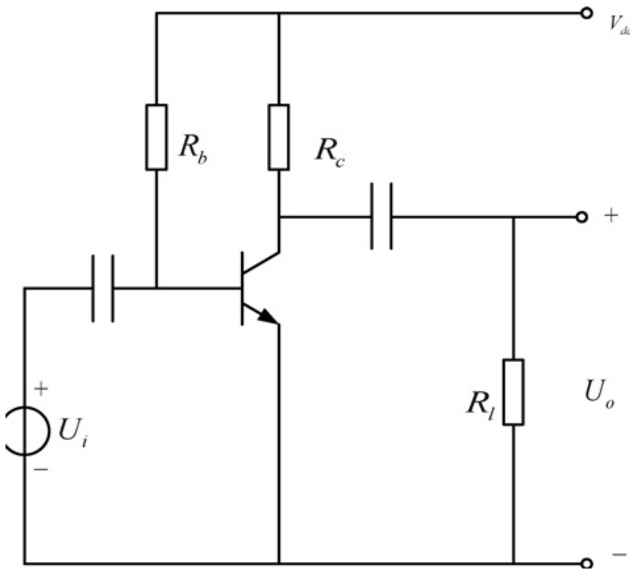

Fig 1. Simplified circuit diagram of class-*A* HPA.

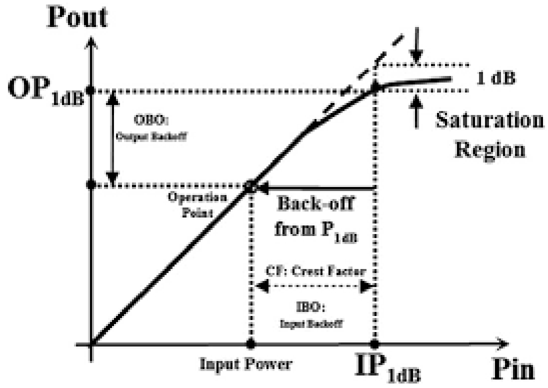

Fig 2. A typical power amplifier response for IBO and OBO.

IV. Effect of PAPR Reduction on SE /EE

The spectrum efficiency with the transmitted and average power is

$$\eta_{SE} = \log_2\left(1 + \frac{P_t}{P_{nc} + P_{sav} + P_t}\right) \quad (6)$$

This equation show that the combination of the increment of $F_{xi}\sqrt{IBO..P_{oav}}$ and the decrement of the (PAPR>IBO). If the IBO is little then the SE is obtained better than the previous result while the PTS (*V*=8) method is applied for the PAPR reduction. EE performance of OFDM system is able to be improving by decreasing the IBO and reducing the PAPR. The data rate R can be improved by reducing the PAPR at this time the spectrum bandwidth is constant.

V. Performances Analysis

In this section, both theoretical analysis and numerical simulations are conducted to evaluate the effect of the PAPR reduction on the EE and SE performances in OFDM systems.

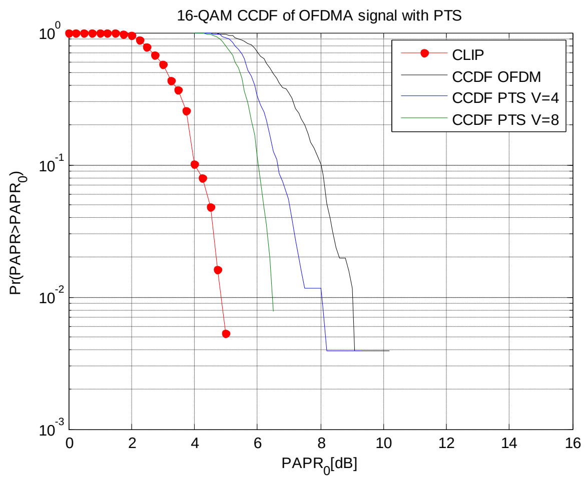

Fig 3. PAPR reductions of the Clipping and Filtering and PTS scheme with *V* = 4 and *V* = 8, respectively.

Here assume that the duration of one OFDM signal is normalized as *T* = 1, and the bandwidth is *B* = *N*. For all simulations, quadrature amplitude modulation (QAM-16) is employed, the number of subcarriers is *N* = 64, and the signal-to-noise ratio (SNR) is 15dB. To illustrate that the OFDM systems with different PAPR have different SE and

EE performances, the clipping and filtering and PTS scheme is employed as an example for the PAPR reduction, where the Phase rotation factor is chosen from {+1,−1}, and the number of subblocks is $V = 4$ and $V = 8$, respectively. Seen from Fig. 3, the PAPR of the original OFDM signal is 9dB at $CCDF = 10^{-3}$, and the PAPR reduction is 4dB, 0.90dB and 2.70dB when the clipping and PTS method is employed with $V = 4$ and $V = 8$, respectively.

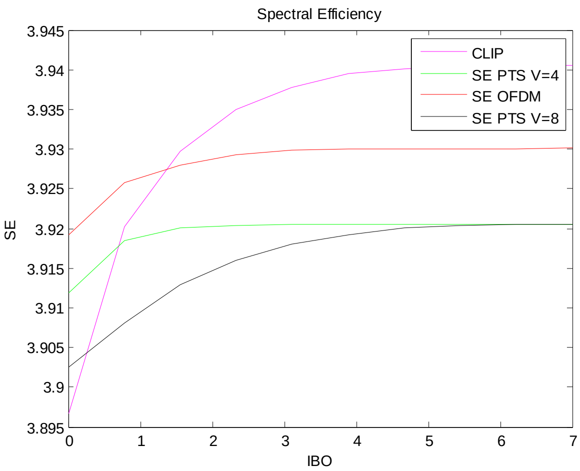

Fig 4. SE performance with different PAPR reduction at different IBO in OFDM system.

Fig. 4 shows the SE performance of the OFDM systems with different PAPR. Seen from Fig. 4, if the IBO is small, the best SE performance is achieved when the clipping and filtering method is employed for PAPR reduction. For example, the original OFDM systems provide η_{SE} = 3.918 bits/s/Hz at IBO = 0dB, however, the PTS schemes with $V = 4$ and $V = 8$ can provide η_{SE} = 3.9125bits/s/Hz and η_{SE} = 3.9025bits/s/Hz at IBO = 0dB, clipping can provide η_{SE} = 3.8975 bits/s/Hz respectively.

In summary, when the IBO of the HPA is small, the SE performance can be significantly improved by reducing the PAPR of OFDM signals. When the IBO is significantly large, the improvement will be marginal. However, the IBO is usually small in real OFDM systems, which indicates the practical significance of RAPR reduction.

Fig. 5 shows the EE performance of the OFDM systems with different PAPR. It can be observed that the EE performance decreases when the IBO increases, because the increment of the data rate is smaller than that of the power consumption. Moreover, when $IBO \leq$ 5.0dB, the EE performance of OFDM systems employing the clipping and filtering is better than PTS scheme. The PTS scheme with V = 8 is better than that of the PTS scheme with V = 4.

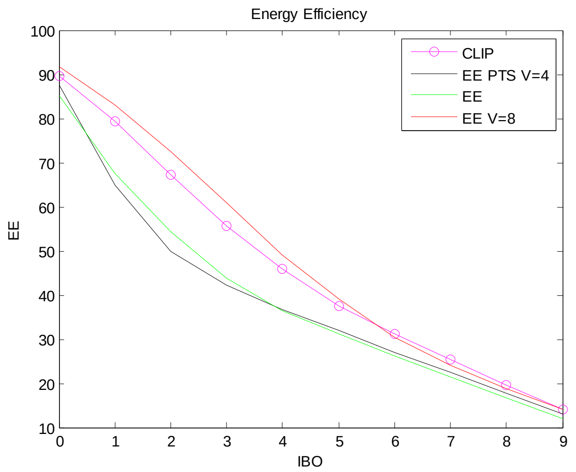

Fig 5. EE performance with different PAPR reduction at different IBO in OFDM system.

When $IBO \leq$ 6dB, the original OFDM systems without PAPR reduction exhibit worse EE performance than the OFDM systems employing the clipping and PTS scheme. When $IBO >$ 6.0dB, the signals with different PAPR have the same EE. Therefore, when $IBO \leq$ 5.0dB, reducing the PAPR can lead to the improvement of the EE performance.

In summary, the EE performance of the OFDM systems can be improved by decreasing the IBO and reducing PAPR.

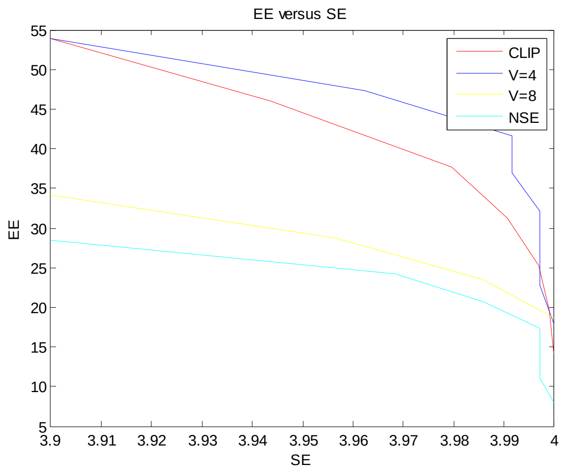

Fig 6. Relation between SE and EE with constant *Poav* when the PAPR reduction is different.

Fig. 6 depicts the relation between the SE and EE when *Poav* is constant with different IBO. Seen from Fig. 6, the OFDM system with the smallest PAPR offers the best SE EE performance. For example, when η_{SE} = 4bits/s/Hz, the clipping and filtering technique offers an EE performance of η_{EE} = 54.00bits/Joule. PTS scheme with V = 8 offers an EE performance of η_{EE} = 34.00bits/Joule. However, the EE performance is η_{EE} = 54.00bits/Joule when the PTS scheme with V = 4 is employed, and the EE performance is η_{EE} = 28.00bits/Joule in the original OFDM system. Therefore, reducing the PAPR of OFDM signals can improve the SE-EE performance.

In summary, when the IBO is small, reducing the PAPR of

OFDM signals can improve both the SE and EE performances. In practice, the IBO of the HPA cannot be too large, especially for energy limited OFDM systems. Therefore, the PAPR reduction can help practical OFDM systems to achieve better SE and EE performances, compared with OFDM systems without PAPR reduction.

VI. CONCLUSION

In this paper, examined the effect of the PAPR reduction on the SE and EE in OFDM systems with class-*A* HPA. With the PAPR reduction, the power efficiency of the HPA is improved, and the nonlinear distortion noise caused by the HPA is reduced. Thus, compared with the original OFDM systems without PAPR reduction, the OFDM systems with PAPR reduction can achieve higher data rate with lower power consumption. Therefore, both the SE and EE performances can be improved by reducing the PAPR of the OFDM signals.

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