doi:10.3788/gzxb20144307.0706017

降低 OFDM 系统峰均比的可恢复限幅技术

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摘 要:针对正交频分复用系统中峰值平均功率比过高的问题,提出了一种基于限幅技术的改进算法.该算法对限幅后的信号进行标记,并将标记序列发送到接收端,从而使得接收端能够正确的解调出输入信号.此外,本文还将该改进算法应用于光载无线通信系统中.仿真结果表明,与传统限幅算法相比,改进算法能够明显降低系统的误码率,同时保证良好的抑制峰均比的性能.

关键词:正交频分复用;正交幅度调制;信号处理;光载无线通信;误码率
中图分类号:TN929.11; TN911.72 **文献标识码**:A **文章编号**:1004-4213(2014)07-0706017-7

A Restorable Clipping Scheme for PAPR Reduction of OFDM -ROF System

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Abstract: In order to reduce the Peak-to-Average Power Ratio (PAPR) of Orthogonal Frequency Division Multiplexing (OFDM), a restorable Clipping scheme is proposed and used in the OFDM and Radio Over Fiber (OFDM-ROF) system. The algorithm is to set a peak detection threshold on the input signals and the signals can be recorded in an array, at the receiving end, the original siginal can be restored in the array effectively. Simulation results show that the new scheme is not only simple, but also significantly improve the BER and the out-of-band radiation performance while guaranteeing the PAPR performance of the QAM-OFDM system.

Key words: Orthogonal frequency division multiplexing; Quadrature amplitude modulation; Signal processing; Radio Over Fiber(ROF); Bit error rate
OCIS Codes: 060.2630; 060.4230; 150.1135; 130.4310

0 Introduction

The ROF system has been proved to be a promising technology for Next Generation Network (NGN) access applications for its low transmission loss and ultra-wide bandwidth. Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier modulation technique. The essential of this technique is to convert a high-rate data stream into several low-rate streams which are modulated to the mutually orthogonal sub-carriers afterwards[1]. Thus, the symbol period can be extended effectively and frequency selective fading effect due to multi-path can be reduced. The OFDM technology utilizes the time-frequency orthogonality of the input signal; allow partially overlapping of the sub-carriers, making the spectrum utilization nearly doubled. Based on these advantages, OFDM technology is widely applied in Digital Audio Broadcasting (DAB), Digital Video Broadcasting (DVB), Wireless LAN (WLAN) and high-rate data

Foundation item: The National Natural Science Foundation of China (No. 61272507), Fundamental Research Funds for the Central Universities(No. FRF-TP-09-015A)
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Received: Nov. 4, 2013; **Accepted**: May. 14, 2014

transmission system. OFDM technology now also considered being the core technology of 4G.

Unlike the conventional single carrier systems, the OFDM signals are summed by a series of modulated signal from N sub-carriers, the synthesized signal is likely to produce a relatively large peak power, which requires some of the components within the system, such as power amplifiers, A /D, D/A, etc. to have a large linear range. If the PAPR exceeds the nonlinearity limits of high-power amplifier, channel in-band interference and out-of-band radiation may occur[2]. Thus, researches in the recent years have been focused on reducing the PAPR.

Several schemes have been proposed for reducing the PAPR of multicarrier system, which can be classified into two classes[3]: distortion algorithm and non-distortion algorithm. The signal distortion technology limits the OFDM signal below a given threshold by nonlinear distortion[4] such as: clipping[5], peak window[6], or companding transformation[7]. The advantage of nonlinear distortion is that it is simple, no redundant information and free from the limitation of the number of subcarriers and modulation. However, the in-band distortion and out-of-band radiation still exist because of the nonlinear operation, resulting in degradation of system performance in terms of bit error rate and spectrum efficiency. The non-distortion algorithm optimizes the carrier phase of each sub-channel to find the phases combination with the lowest PAPR. This algorithm will not cause distortion on the input signals and it includes Selective Mapping (SLM)[8], Partial Transmit Sequence (PTS)[9], Tone Reservation (TR)[10]. The non-distortion algorithm does not make the signal distortion, and the application is not limited by modulation type and the number of subcarriers. But they also have some disadvantages, such as the need to transmit sideband information, high computational complexity, more difficult to be realized on hardware.

Those methods mentioned above provide effective solutions to reduce the PAPR of the OFDM signals at different costs. Among them, signal clipping is the most simple and direct algorithm, with decrease in BER performance and spectrum distortion. Clipping will process nonlinear distortion on OFDM time-domain signal, which will lead to serious in-band distortion and out-of-band radiation. Out-of-band radiation will not only cause Inter-Carrier Interference (ICI) but also reduce the efficiency of spectrum utilization; In-band distortion will destroy the orthogonality between the subcarriers, resulting in deterioration of the BER performance of the OFDM system.

A lot of research has been done to reduce the out-of-band radiation, and the Clipping and Filtering (CF)[11] proposed by Jean Armstrong is the most classic one. By using the CF technology, the input frequency domain signal is over-sampled and clipped. The clipping is followed by frequency domain filtering to reduce out-of-band power. Since the filter operates on a symbol-by-symbol basis, it causes no inter-symbol interference, but the filtering does cause some peak regrowth. So Jean Armstrong propose an improved algorithm: Repeat Clipping and Filtering Algorithm (RCF)[12].

Based on these two classic schemes, much more methods have been proposed. In 2005, Luqing wang proposed a simplified Clipping and Filtering technique[13], which scales the clipping noise generated in the first iteration to get a new clipping and filtering technique. In Ref. [14], the SFBC encoding is used in the relay which enables the source to transmit clipped SISO-OFDM signals without an increase in PAPR and computational complexity. An adaptive clipping control algorithm is proposed in Ref. [15], which uses a new suboptimal PRT set selection scheme based on the Genetic Algorithm (GA) to solve the NP-hard problem. An Optimized Iterative Clipping and Filtering scheme is proposed in Ref. [16], which determines an optimal frequency response filter for each ICF iteration using convex optimization techniques. In Ref. [17], a companding transform for reduction in PAPR is proposed, by compressing large signals while enhancing small signals along with taking into account their statistical characteristics, this method can achieve significant reduction in PAPR with low implementation complexity. All these methods provide effective solutions to reduce the PAPR of the OFDM signals at different costs.

In this paper, we present a new clipping scheme to reduce the PAPR of the OFDM-ROF system called restorable clipping. The main idea of the algorithm is to set a peak detection threshold on the input signal, the signals with the amplitude less than the threshold would go through without interference; otherwise, the signal will be multiplied by a coefficient m ($m<1$), thereby the input signal with large amplitude can be suppressed. At the same time, we create an array to record the signals that have been clipped. At the receiving end, we can use the records in the array to restore the original signal effectively and then greatly improve the BER performance. It can be seen from the simulation results that the modified scheme can achieve same PAPR performance with the traditional clipping scheme while greatly improve the out-of-band radiation and the BER performance.

1 OFDM system and the traditional clipping scheme

In an OFDM system with N sub-carriers, the input symbol in frequency domain can be written as $\boldsymbol{X}=[X_0, X_l, \cdots, X_{N-1}]$, where X_k, $k=0,1,\cdots,N-1$ represents the complex data of the kth subcarrier and they are independent with each other. Then the complex OFDM symbol in time domain can be shown as

$$x(t)=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}X_n e^{j2\pi(n/NT)t},\ 0\leqslant t<NT \tag{1}$$

where $x(t)$ is the modulated time domain signal and $j=\sqrt{-1}$. T represents a period of input symbol; NT is the length of the valid data block.

The PAPR of OFDM signal sequence X is defined as the ratio of maximum to the average power of the signal[18], which can be expressed as

$$\mathrm{PAPR}=\frac{\max\limits_{0\leqslant t\leqslant N-1}|x(t)|^2}{E[|x(t)|^2]} \tag{2}$$

For the data block with the length of N, N points sample values obtained by the N-point IFFT are not able to accurately reflect the PAPR characteristics of the continuous time domain signal. To approximate PAPR in discrete time domain, an oversampled version can be used. The oversampled time-domain signal X_n can be obtained by using a LN-point IFFT operation, with extending X to a vector with the length of LN by inserting $(L-1)N$ zeros in the middle, i. e. $\boldsymbol{X}_n=[x_0,\cdots,x_{N/2},0,\cdots,0,\cdots,X_{N/2+1},\cdots,X_{N-1}]$, $n=0, 1, \cdots, NL-1$. Where L is the oversampling factor, and usually $L\geqslant 4$is used to capture the peaks of the continuous time-domain signal.

In a multi-carrier system, a large PAPR occurs rarely, so use the maximum PAPR to measure the performance of the OFDM system performance does not mean much. It is more useful to consider PAPR as a random variable and use a statistical description given by the Complementary Cumulative Density Function (CCDF), defined as the probability that PAPR exceeds a given threshold.

1.1 Conventional clipping scheme

The fundamental principle of clipping algorithm: Detect its peak before the time domain OFDM signal is supplied to the power amplifier. If any part of the signal exceeds the threshold, a non-linear processing should be applied for peak signal, to limit the amplitude of the signal within the pre-set threshold; Otherwise let the signal through without interference[5]. The schematic diagram of clipping scheme is shown in Fig. 1.

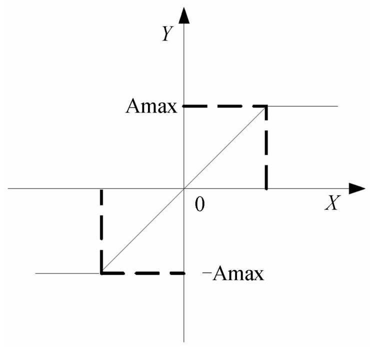

Fig. 1 The schematic diagram of traditional Clipping scheme

The clipped time domain signal can be written as

$$\hat{x}(t)=\begin{cases}x(t), & |x(t)|\leqslant A\\ Ae^{j\varphi(t)}, & |x(t)|>A\end{cases} \tag{3}$$

where A is the clipping threshold, and $\varphi(t)$ represents the phase of $x(t)$.

1.2 The Clipping-Filtering (CF) and the Repeat Clipping-Filtering (RCF)

The clipping operation will process nonlinear distortion on OFDM time domain signal, which will result in serious in-band noise and out-of-band power radiation. In order to reduce the out-of-band radiation, Jean Armstrong proposed the Clipping and Filtering algorithm. The CF scheme can effectively solve band interference problem while ensure the PAPR performance[11]. The schematic diagram of CF is shown in Fig. 2.

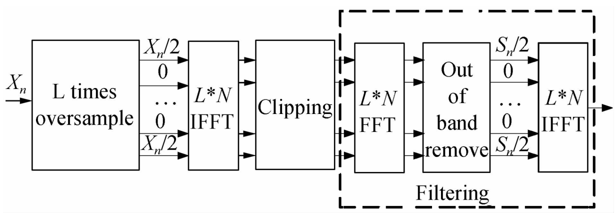

Fig. 2 The schematic diagram of Clipping and Filtering

The input frequency domain signal is L times oversampled (insert $(L-1)*N$ 0 in the middle of the N input data), and then the convert the signal from frequency to the time domain using an oversize IFFT. The interpolated signal is then clipped. The clipping is followed by frequency domain filtering to reduce out-of-band power radiation. The filter consists of two FFT operations. The forward FFT transforms the clipped signal back into the discrete frequency domain. The in-band discrete frequency components of the clipped signal are passed unchanged to the inputs of the second IFFT while the out-of-band components are nulled.

The signal after filtering process can effectively suppress the out-of-band radiation caused by clipping, but the filtering operation will also cause peak regrowth and worsen the PAPR performance of the system . So

Jean Armstrong proposes an improved algorithm: Repeat clipping and filtering algorithm (RCF). The principle of the algorithm is: By repeatedly clipping and filtering operation, so that the peak regrowth caused by filtering can be reduced and achieve a better PAPR performance[12].

2 The restorable clipping scheme

In order to solve the high BER problem in the traditional clipping scheme, we proposed a modified clipping scheme in this paper which uses a marker sequence to recovery the clipped signal. The algorithm draws on the use of phase tag sequence in the traditional SLM[8, 19] and PTS scheme[9, 20]: by transmitting a set of side information, we can correctly recover the clipped signal at the receiving end. The new scheme can greatly improves the system bit error rate performance.

The algorithm implementation process: Same with the traditional clipping scheme, we first constellation mapping the input signal, generally use QAM modulation. Then modulate the complex modulated signal to each subcarrier through IFFT transform. The modulated signal is set to $x(t)$, and its expression as Eq. (1).

If the OFDM signal is sampled at Nyquist sampling rate, then $x(t)$ can be expressed as

$$x_k=\frac{1}{\sqrt{N}}\sum_{n=0}^{N-1}A_n \mathrm{e}^{\mathrm{j}2\pi(n/NT)k},\ k=0,1,\cdots,N-1 \tag{4}$$

x_k can be expressed in the form of a vector $x=[x_1,x_2,\cdots x_k,\cdots,x_{N-1}]$.

Set the threshold value A, the clipping compression ratio $m(m<1)$, a marker sequence $C_k=[C_1, C_2,\cdots, C_k, C_{N-1}]$. Operate the modified clipping scheme on the input signal and then the clipped signal can be expressed as

$$\hat{x}_k=\begin{cases}x_k, |x_k|\leqslant A\\ m\cdot x_k, |x_k|>A\end{cases} \tag{5}$$

where x_k is the input signal, $\hat{x}_k$ is the signal after clipping. It can be seen from Eq. (5), in the modified scheme, the signal with a amplitude less than the threshold can pass without interference, and the signal above the threshold is no longer compressed to the uniform threshold value, but are multiplied by a scale factor m which is less than 1, thereby we can compressing the amplitude without changing the signals' phase information. At the same time, we tag the sequence C_k, the tagging process can be expressed as

$$C_k=\begin{cases}0, |x_k|\leqslant A\\ 1, |x_k|>A\end{cases} \tag{6}$$

From the expression we can see that the sequence C is a sequence consists of 0, 1, where k is an index for subcarrier. If $C_k=0$, it indicates that the amplitude of the signal x_k on the k-th subcarrier is less than the threshold value, that is, the signal has not been compressed. Conversely, if $C_k=1$, then it means the amplitude of x_k is greater than the threshold value and has been compressed m times after the clipping operation.

Send the clipped signal $\hat{x}_k$ and the marker sequence C_k to the receiving end through the wireless channel. The length of the marker sequence is N and we suppose that each sideband carriers M bits marker symbol, then the number of sidebands we need is M/N. As the phase sequence transmits in the conventional SLM[8, 19] and PTS[9, 20] scheme, the marker sequence in our scheme wouldn't take much bandwidth. Furthermore, compared to the traditional TR[10] scheme which uses several subcarriers to transmit peak canceling signal, the bandwidth utilization ratio of our scheme is much higher.

We assume that the receiving end can correctly receive the marker sequence. At the receiving end, we can using the received marker sequence C to recover the OFDM signals. Set the received OFDM signal as $y=[y_1,y_2,\cdots y_k,\cdots,y_{N-1}]$, then the signal recovered by the modified clipping scheme can be expressed as

$$\hat{y}_k=\begin{cases}y_k, C_k=0\\ y_k/m, C_k=1\end{cases} \tag{7}$$

As can be seen from the formula, when detecting the marker signal $C_k=0$, it means that the corresponding received signal y_k on the k-th subcarrier has not been compressed and can be demodulated directly; When $C_k=1$, it indicates that the corresponding signal has been distorted, divide it by the scale factor m to expand its amplitude of m times, so as to effectively recover the original signal and greatly reduce the bit error rate of the OFDM system.

While the modified clipping algorithm can greatly improve the BER performance, but the distortion of the input signal will cause a very serious out-of-band interference. Therefore, we consider adding the filtering operation after clipping so that the Inter-Carrier Interference (ICI) caused by out-of-band dispersion can be eliminated. The filtering process is the same with the conventional clipping and filtering scheme. The schematic diagram as follows.

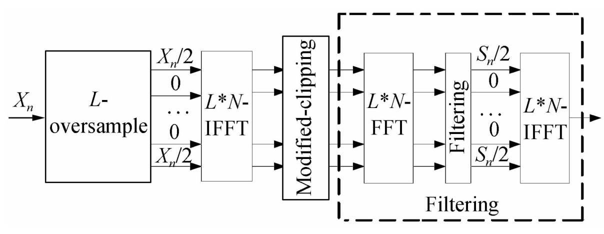

Fig. 3 The schematic diagram of the modified Clipping and Filtering

3 Simulation results

We compare the PAPR reduction performance of the conventional Clipping scheme and the modified Clipping scheme. The numerical analysis has been performed for the OFDM system specified in the IEEE 802.16 standard for the mobile Wireless Metropolitan Area Network (WMAN), which uses 256 and 2 048 sub-carriers respectively, and 16-QAM modulations. The OFDM system use the 200 subcarriers for data transmission and the remaining 56 subcarriers are set to zero to shape the power spectral density of the transmitted signal. The OFDMA system uses 1 702 subcarriers for the data transmission and 346 subcarriers as guard carriers. In the numerical analysis performed in this paper, the guard subcarriers have been ignored and the number of subcarriers for the input symbol sequence is 256 or 2 048.

The OFDM-ROF system simulation model is shown in Fig. 4. First of all, the data stream uses Golay coding, and then employs MPSK or MQAM modulation. Then transform the sequence from serial to parallel and use IFFT to modulate the signal to the subcarriers. We introduce restorable clipping method to process the modulated sequence, and then add cyclic prefix to elimination the interference between each OFDM sub-carriers. After D/A conversion, the signal is sent into the wireless channel. The electrical signal arrived at the base station; the first step is electrical-optical conversion. Then the optical signal injects into the optical channel and transmits to center control station.

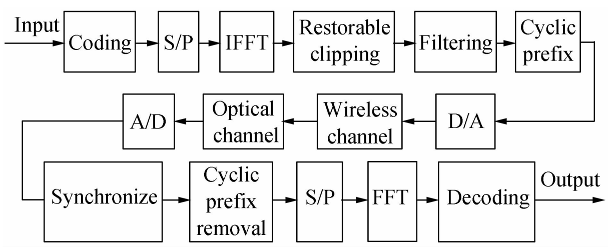

Fig. 4 The OFDM-ROF system simulation model

The Complementary Cumulative Distribution Functions (CCDFs) of PAPR are numerically obtained for the conventional Clipping scheme with $CR=1.0$ and the modified Clipping scheme with $CR=1.0$ and $m=0.5$ respectively. Fig. 5 (a) and (b) compares the PAPR reduction performance of the two Clipping schemes for 16-QAM with $N=256$ and $N=2\ 048$. The performance of the modified scheme is not as good as that of the conventional Clipping scheme, but is similar with that of the conventional RCF scheme with 1 iterations.

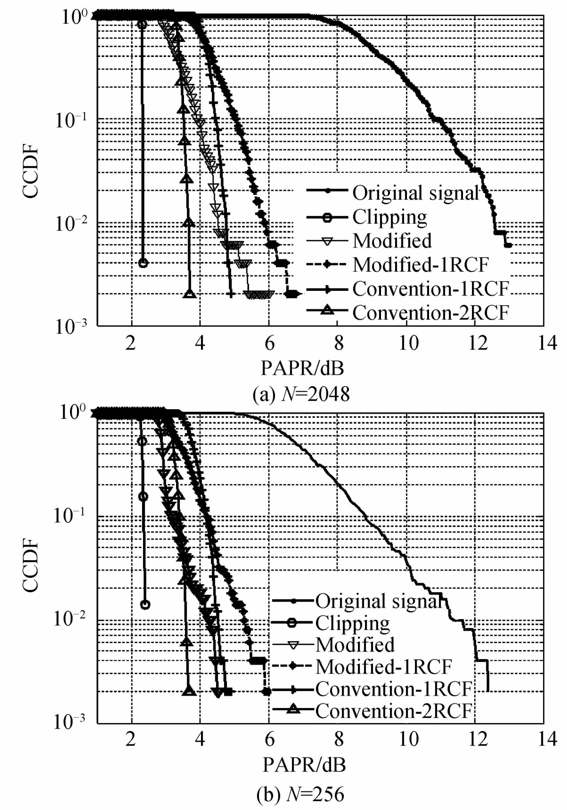

Fig. 5 The PAPR performance of the Conventional Clipping and modified scheme

Fig. 6 compares the PSD reduction performance of

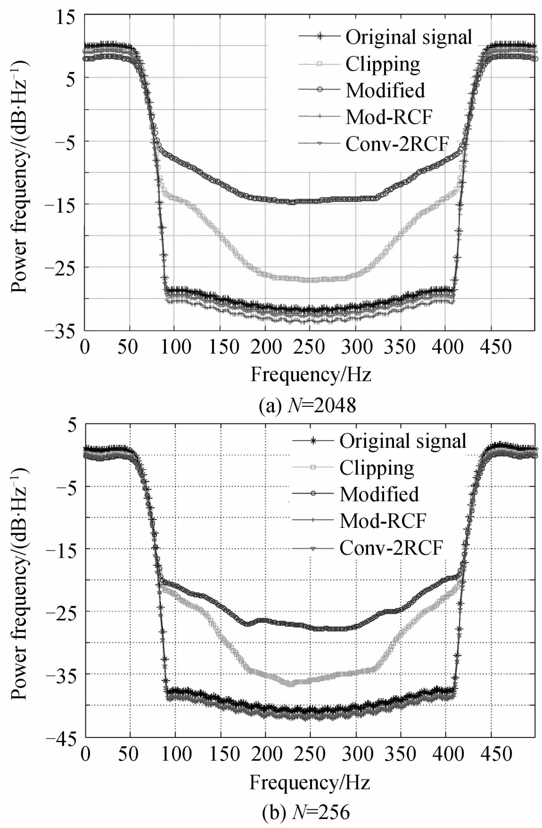

Fig. 6 The PSD performance of the Conventional Clipping and modified scheme

the two Clipping schemes for 16-QAM with $N=256$ and $N=2\ 048$. We can see that the conventional Clipping method leads to about 4 dB lower out-of-band radiation than that of without using any PAPR reduction technique, and our proposed technique leads to about 12 dB lower out-of-band radiation than the conventional Clipping scheme. The severe out-of-band radiation will cause Inter-Carrier Interference (ICI) so that the signal cannot be transmitted correctly. Therefore, we propose an improved limiter clipping filtering algorithm which adds a filtering operation after the modified clipping. It can be seen from the simulation results that, the out of band performance of the modified scheme after filtering operation is the same with that of the traditional CF scheme. The out-of-band interference is effectively suppressed by the filtering operation.

The Bit Error Rate (BER) as a function of Signal to Noise Ratio (SNR) is shown in Fig. 7. As expected, the restorable clipping scheme results in far more better noise immunity than the conventional Clipping scheme. The BER performance of the modified RCF scheme is almost the same with the original OFDM signal without any PAPR reduction operation.

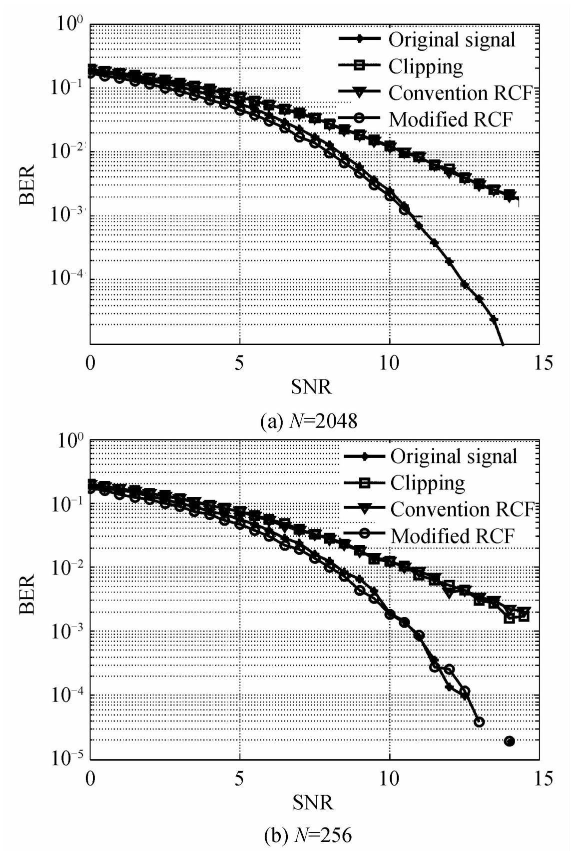

Fig. 7 The BER performance of the Conventional Clipping and modified scheme

4 Conclusion

In this paper, we have proposed a novel scheme called Restorable Clipping, in which the side information is used to recovery the original OFDM signal. From the simulation results, it can be concluded that the newly proposed scheme with filtering operation is not only simple, but also can greatly reduce the BER and out-of-band radiation of the system while ensuring the PAPR performance.

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