PAPR Reduction using Pre-emphasis and Clipping in OFDM Communication System

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요 약

OFDM(orthogonal frequency division multiplexing) 시스템은 ISI와 주파수 선택적 채널에서 매우 강건한(robust) 특성을 갖기 때문에 차세대 고속 데이터 전송에 효과적인 기술이다. 그러나, OFDM 시스템에서는 많은 부반송파를 사용하므로 높은 PAPR(peak to average power ratio)이 발생된다. 높은 PAPR의 OFDM 신호가 송신단의 비선형 증폭기를 통과할 때 심각한 왜곡이 발생한다. 본 논문에서는 프리엠파시스 및 클리핑 기법을 이용하여 PAPR를 감소하였다. 이 방법은 IFFT 출력 신호를 프리엠파시스(pre-emphasis)시키고 SSPA(solid state power amplifiers)의 선형영역에 맞도록 클리핑을 하고, 수신단에서 디엠파시스(de-emphasis) 시키는 과정을 이용하여 효과적인 성능 개선을 갖는다. 부반송파의 수가 16개, QPSK 변조방식을 사용하고, 프리엠파시스 변화점이 IFFT 출력신호 최대진폭의 3/9이고, IFFT 출력진폭이 11인 지점에서 클립을 할 때, CCDF(complementary cumulative density function) 확률이 10^{-3} 에서 PAPR이 약 5.7 dB 정도이고, BER= 10^{-3} 에서 요구 SNR은 기존의 OFDM보다 약 2 dB 성능 개선을 보인다.

Abstract

OFDM is a good candidate for beyond-3G high-speed wireless communication application because of the robustness to the intersymbol interference and multipath fading. However, an OFDM signal has a serious problem of the high PAPR, which results in the significant nonlinear distortion when it passes through a nonlinear high power amplifier. We propose a new PAPR reduction method using pre-emphasis and clipping. Via the proposed method, the OFDM output signal can have a low PAPR and BER improvement. Then, de-emphasis process is requisite in OFDM receiver. PAPR is reduced to about 5.7 dB at the CCDF = 10^{-3} when the subcarrier number is 16, QPSK modulation is used, pre-emphasis change point is 3/9 of the peak amplitude of the IFFT output and clipping level is 11 in the IFFT output amplitude. The required SNR at BER=10^{-3} of the proposed system is improved by 2 dB than that of the original OFDM system.

Key words: OFDM, IFFT, PAPR, clipping, CCDF.

Ⅰ. Introduction

Since the OFDM(orthogonal frequency division multiplexing) system has the good spectral efficiency, the robustness to the intersymbol interference (ISI) and multipath fading, it is an attractive technique for beyond-3G wireless communication applications. In spite of many advantages, a major drawback of OFDM is the high PAPR(peak to average power ratio) problem. When the high PAPR

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signal passes through nonlinear device such as HPA(high power amplifier), the signal suffers significant distortion. To avoid the nonlinear distortion, a linear amplifier is required to get a wide linear dynamic range. However, this linear amplifier has poor power efficiency and may not be used in mobile terminal. So, the study on the PAPR reduction is important. To reduce the PAPR, typical some kinds of techniques have been proposed such as clipping[1],[2], block coding[3] and phase shift method[4],[5]. Clipping method is the simplest technique and an effective PAPR reduction method. However, it causes a serious in-band and out-of-band clipping noise. This makes BER performance degradation and adjacent channel interference (ACI). Block coding method seems attractive because it does not create any out-of-band radiation, but there is no proper coding solution that can maintain a reasonable coding rate for arbitrary large number of subcarriers. Phase shift method is another representative and flexible PAPR reduction method without signal distortion. However, it requires so many IFFT stages equivalent to subblocks and complex structure in OFDM transmitter. In addition, the spectral efficiency gets worse since the side information for the phase shift should be transmitted. For PAPR reduction, a companding method that decreases system complexity and has good spectral efficiency has been proposed[6], but PAPR reduction in this method is not great.

We propose a new PAPR reduction method using pre-emphasis and clipping. Unlike the conventional clipping method, IFFT output signal is pre-emphasized to enhance the average power before clipping. Next, it is clipped suitable to SSPA(solid state power amplifiers) linear region to cut away the peak power. De-emphasis process is operated in the OFDM receiver. This method can effectively makes BER performance improvement, simultaneously maintaining the PAPR at the wanted level. When the subcarrier number is 16, QPSK modulation is used, pre-emphasis change point is 3/9 of IFFT output peak amplitude and clipping level is 11 which is IFFT output amplitude, PAPR is about 5.7 dB at 10^{-3} CCDF(complementary cumulative density function). The required SNR at BER=10^{-3} is about 4.8 dB, which is improved than that of original OFDM system. The proposed method can be applied into the other cases.

Ⅱ. PAPR Reduction Method

2-1 SSPA Property

Unlikely TWTA(traveling waves tube amplifier), the SSPA(solid state power amplifier) has the different transfer characteristic that above the linear region is constant The SSPA output is written as[7]

$$g[A]=\frac{v_k A}{\left(1+\left(\frac{v_k A}{A_o}\right)^{2p_k}\right)^{1/2p_k}}, \qquad (1)$$

where is the input signal, is the small signal amplification, is the model parameter and is the output amplitude at the saturation point($A_0 \geq 0$). It is drawn in Fig. 1 for $v_k = 1$ and different values of $P_k := 1,\ 2,\ 4,$ and 10. The smoothness of the transition into the saturation region can be adjusted by the parameter P_k as indicated in Fig. 1.

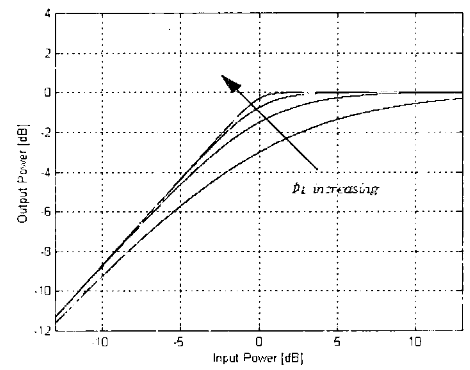


Fig. 1. Characteristic of typical SSPA.

2-2 Pre-emphasis/clipping Method

The pre-emphasis/clipping method is that IFFT output signal before being transmitted is pre-emphasized, and clipped suitable to SSPA(solid state power amplifiers) linear region. The peak power is cut away by clipping and the average power is increased by pre-emphasis, which makes PAPR of OFDM signal be reduced. Meanwhile, the noise signal that is added in transmission channel is decreased due to de-emphasis process in receiver. It improves the BER performance.

Fig. 2 shows the transfer characteristic of the pre-emphasis/clipping for applying OFDM system. In Fig. 2, Solid line is a transfer characteristic of the pre-emphasis and clipping in OFDM transmitter. Dashed line expresses the de-emphasis in receiver. (k_1, k_2) is the pre-emphasis change point.

Pre-emphasis is represented as

$$S_{pre}(t)=\frac{k_2}{k_1}S(t),\quad 0\le S(t)<k_1, \tag{2}$$

$$=\frac{L-k_2}{L-k_1}S(t)+L\left(1-\frac{L-k_2}{L-k_1}\right),\quad k_1\le S(t)\le L. \tag{3}$$

Then, the pre-emphasized signal is clipped at clipping level p.. Clipping level may be changed to

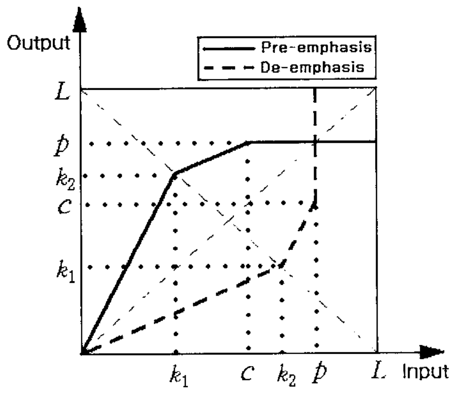


Fig. 2. Transfer characteristics of the pre-emphasis /clipping and de-emphasis.

the variation of the linear region of SSPA and also be set into any level in the signal design format.

$$S_{pre-clip}(t)=S_{pre}(t),\quad 0\le S_{pre}(t)<k_1, \tag{4}$$
$$=p,\quad c\le S_{pre}(t)\le L.$$

De-emphasis relationship is written as foll

$$S(t)=\frac{k_1}{k_2}S_{pre-clip}(t),\quad 0\le S_{pre-clip}(t)<k_2, \tag{5}$$

$$S(t)=\frac{c-k_1}{p-k_2}\left(S_{pre\ clip}(t)-p\right)+c,\quad k_2\le S_{pre\ clip}(t)<p, \tag{6}$$

$$S(t)=S_{pre\ clip}(t),\quad S_{pre-clip}(t)\ge p \tag{7}$$

When the input signal amplitude is $0\sim k_1$, it is pre-emphasized by eq. (2). When the input signal amplitude is k_1 L, it is pre-emphasized by eq. (3). Then, the pre-emphasized signal is clipped. This processes reduces PAPR. In receiver, the signal is de-emphasized by using eqs. (5)~(7). BER performance improvement can be obtained due to the noise suppression in the de-emphasis stage.

Ⅲ. Proposed OFDM System and Performance Analysis

Fig. 3 shows block diagram of the proposed OFDM system for the PAPR reduction. OFDM transmit signal is composed of N independent QPSK sub-signals with the same bandwidth. QPSK symbol is converted in serial-to-parallel block and is modu-

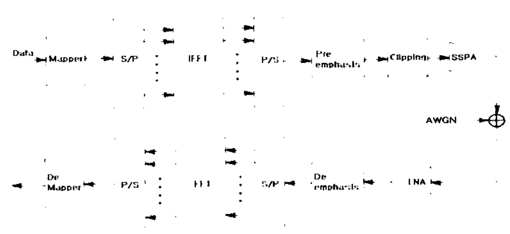


Fig. 3. Block diagram of the proposed OFDM system.

lated into the OFDM symbol in IFFT block. Let $X_k (0 \le k \le N-1)$ be a complex QPSK symbol.

The n-th OFDM signal can be written as

$$x_n = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X_k e^{j2\pi nk/N}, \quad 0 \le n \le N-1 \qquad (8)$$

where N denotes the number of subcarriers. The amplitude of the OFDM signal tends to have the Gaussian distribution when N is sufficiently large. The PAPR is defined as

$$PAPR = \frac{\max\{|x_n^2|\}}{E\{x_n^2\}} \qquad (9)$$

where $E\{\cdot\}$ is an expectation.

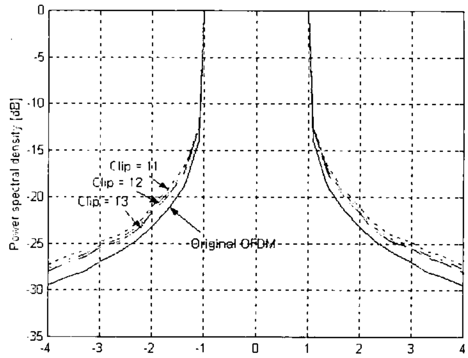
The OFDM signal is pre-emphasized, so that the average power becomes higher than that of the original OFDM. Then, the pre-emphasized signal is clipped at the wanted clipping level (p). The PAPR after pre-emphasis and clipping is expressed as

$$PAPR_{pre-clip} = \frac{\max\left\{\left|\tilde{x}_n^2\right|\right\}}{E\left\{\tilde{x}_n^2\right\}} \qquad (10)$$

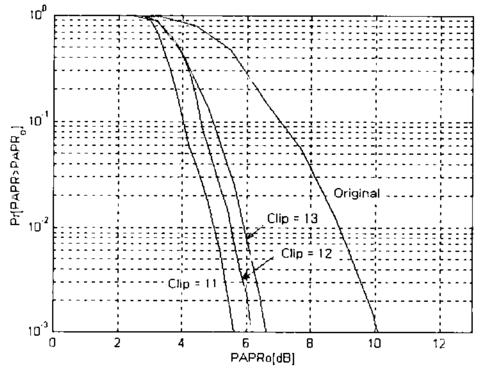
where $\tilde{x}_n$ is the pre-emphasized and clipped signal.

In this paper, it is considered that subcarriers number, N=16 and QPSK symbol is used. An OFDM signal is oversampled by a factor of 8. A pre-emphasis change point is $(k_1, k_2) = (3L/9, 6L/9)$. Clipping level (p) is $p = 11\left(=\frac{11}{16}L\right)$, $p = 12\left(=\frac{12}{16}L\right)$, $p = 13\left(=\frac{13}{16}L\right)$.

Fig. 4 shows the system performance. As shown in Fig. 4(a), the clip noise grows as clipping level becomes low. CCDF of PAPR is shown in Fig. 4(b). When clipping level P is 11, it shows the largest PAPR reduction. Then, PAPR is about 5.7 dB at 10^{-3} CCDF. Of course, the lower PAPR is taken when the clip level becomes lower. The QPSK (Theory) curve of solid line in Fig. 5 represents the BER of the original OFDM when pre-emphasis is not used.



(a) The spectrum comparison



(b) CCDF

Fig. 4. Spectra and CCDF.

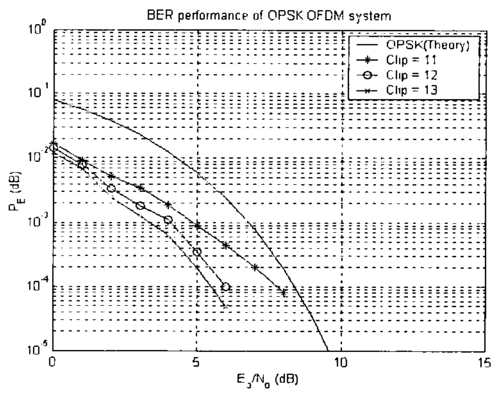


Fig. 5. BER performances.

Table 1. The PAPR and BER performance comparison.

	The original OFDM	The proposed OFDM system		
		Clip = 11	Clip = 12	Clip = 13
PAPR @ CCDF=10^{-3}	10.1 dB	5.7 dB	6.1 dB	6.8 dB
PAPR reduction	-	4.4 dB	4 dB	3.3 dB
Required SNR @ BER=10^{-3}	6.8 dB	4.8 dB	4 dB	3.3 dB
BER improvement	-	2 dB	2.8 dB	3.5 dB

As clipping level go down, the clip noise grows up. Therefore, the BER performance is the worst in Fig. 5 when clipping level is 11. Table 1 shows the PAPR and BER performance comparison of the original OFDM and the proposed OFDM system. If the clip level is set to lower value, the lower PAPR can be made.

Ⅳ. Conclusion

In this paper, a new PAPR reduction method using pre-emphasis and clipping has been proposed. Unlike the conventional clipping method, this method has effective performance improvement such as PAPR reduction and BER improvement. When the subcarriers number is 16, QPSK modulation uses, pre-emphasis change point is 3/9 of IFFT output peak amplitude and clipping level is 11 which is equivalent to 11/16 of the IFFT output peak amplitude, PAPR is reduced to about 5.7 dB at 10^{-3} CCDF(complementary cumulative distribution function). The lower PAPR can be made as the clip level becomes lower. Also, the BER performance is improved than that of the original OFDM because of the noise suppression effect. However, this proposed pre-emphasis method may makes the more power-consumption since the average power is increased.

References

[1] Xiaodong Li and L. J. Cimini Jr., "Effects of clipping on the performance of OFDM with transmitter diversity", in *Proc. IEEE Vehicular Technology Conf.*, vol. 3, pp. 1634-1638. May 1997.

[2] Xiaodong Li and L.J. Cimini Jr., "Effects of clipping and filtering on the performance of OFDM", *IEEE Communications Letters*, pp. 131 - 133, May 1998.

[3] A. E. Jones, T. A. Wilkinson and S. K. Barton, "Block coding scheme for reduction of peak to mean envelope power ratio of multicarrier trans mission schemes", *IEE Electronics Letters*, vol. 30, pp. 2098-2099, Dec. 1994.

[4] A. E. Jones and T. A. Wilkinson, "Combined coding for error control and increased robustness to system nonlinearities in OFDM", *Proc. IEEE 46th Vehicular Technology Conference*, pp. 904-908, 28 April-1 May 1996.

[5] V. Tarokh and H. Jafakhani, "On the computation and Reduction of the Peak-to-Average Power Ratio in Multicarrier Communications", *IEEE Trans. on Commun.* vol. 48, no. 1, pp. 37-44, Jan. 2000.

[6] Xiao Huang, Jianhua Lu, Junli Zheng, J. Chuang, and Jun Gu, "Reduction of peak-to-average power ratio of OFDM signals with companding transform", *IEE Electronics Letters*, vol. 37, no. 8, pp. 506-507, April 2001.

[7] E. Bogenfeld, R. Valentin, K. Metzer, and W. Sauer-Greff, "Influence of nonlinear HPA on trellis-Coded OFDM for terrestrial broadcasting of digital HDTV", *Global Telecommunications Conference, including a Communications Theory Mini-Conference, GLOBECOM '93., IEEE*, vol. 3, pp. 1433-1438, 1993.

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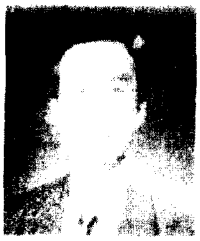

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