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Original Article

A new PAPR reduction in OFDM systems using PTS combined with APPR for TWTA nonlinear HPA

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Abstract

In this paper, we propose a new Peak-to-Average Power Ratio (PAPR) reduction technique using a partial transmit sequence (PTS) combined with adaptive peak power reduction (APPR) methods. This technique is used in a system based on Orthogonal Frequency Division Multiplexing (OFDM). In order to reduce PAPR, the sequence of input data is rearranged by the PTS for the reduction of PAPR and then fed to the APPR process in the proposed system. The APPR method controls the peak level of the modulation signal by an adaptive algorithm. The proposed method shows the improvement on PAPR, on the power spectrum density (PSD) and on the high performance on bit error rate (BER) of an OFDM system.

Keywords: OFDM, PAPR, adaptive peak power reduction (APPR), PTS, nonlinear HPA

1. Introduction

Orthogonal Frequency Division Multiplexing (OFDM) has many well known advantages such as robustness against frequency selective fading or narrowband interference, high bandwidth efficiency, and efficient implementation. Recently, OFDM is mainly used in digital audio broadcasting (DAB), digital video broadcasting-terrestrial (DVB-T), and mobile multimedia access communication (MMAC), IEEE802.11a, IEEE802.16 and IEEE 802.20. (Nee *et al.*, 2000; Han *et al.*, 2005)

One major drawback of the OFDM is the large Peak-to-Average Power Ratio (PAPR). It is causes nonlinear distortions after amplified by a power amplifier. Several techniques to reduce PAPR have been proposed. These techniques have been known as amplitude clipping, clipping and filtering, coding, tone reservation (TR), tone injection (TI), active constellation extension (ACE), selected mapping (SLM), partial transmit sequence (PTS). (Nee *et al.*, 2000; Tellado, 2005) binary tree based PTS (Wu *et al.*, 2006), clipping and PTS (Wen *et al.*, 2006)

In the TR approach, the transmitter does not send data on a small subset of tones in order to optimize the PAPR reduction. In the TI approach, the substitution of the points in the basic constellations by new points in the larger constellation is equivalent to the injection of appropriate tone and phase in the OFDM signal. In the ACE approach, some of the outer signal constellation points in the data block are dynamically extended towards the outside of the original constellation for the PAPR reduction. In the SLM approach, an input sequence is weighted by each phase rotations in order to generate some alternative input sequences. These alternative input sequences are transformed by IFFT and then the optimum sequence with the low PAPR is selected for transmission. In the PTS approach, the input data block is partitioned into disjoint sub-blocks and then it is transformed by IFFT. The sub-carriers in each sub-block are weighted by

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phase rotations. The phase rotations are selected such that the PAPR of the combined signal is minimized. The binary tree based PTS approach supplies good selections on the tradeoffs of implementation complexity and PAPR reduction performance. In the clipping and PTS approach, the PAPR of the input OFDM signal are compared with a preset threshold, in order to judge whether the operation of PTS is needed. If the PAPR exceeds the preset threshold, PTS is performed. Then, clipping with is performed to the ultimate signal.

In this paper, we propose a new PAPR reduction technique. This technique using a PTS combined with APPR methods. In the proposed method, for the first PAPR reduction, an input data block is partitioned into disjoint sub-blocks. The sub-carriers in each sub-block are weighted by a phase rotations. The modified input data are fed to the APPR process for the second PAPR reduction. The APPR method adaptively controls the gain based on a minimum least-mean-square (LMS) error. It reduces modulation signals over a predefined range. Using these two methods at the same time, a high efficiency of PAPR reduction with lower out-of-band radiation can be obtained, and simultaneously a high BER property can be realized.

2. OFDM Signal and PAPR Reduction

Let us define N frequency domain signals in OFDM as$\{X_n,\ n = 0, 1,2 \ldots, N\text{-}1\}$. These N signals construct 1 OFDM block. A set of N sub-carriers, i.e., $\{f_n,\ n = 0, 1,2 \ldots, N\text{-}1\}$, is used for these symbols in the OFDM. The sub-carriers are chosen to be orthogonal, which is, $f_n = n\Delta f$ in the frequency domain, where $\Delta f = 1/NT$ and T and is the OFDM symbol duration. The OFDM signal is expressed as

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t} \quad , \quad 0 \le t \le T \tag{1}$$

The PAPR is defined as (Tellado, 2000; Choe *et al.*, 2004)

$$PAPR = \frac{\max |x(t)|^2}{E\left[|x(t)|^2\right]} \tag{2}$$

where $E\ \{.\}$ denotes an expectation. In some blocks of the OFDM signals, large PAPR happens, since the structure of the given symbols may cause this peak.

High PAPR is a serious issue in RF analog circuits, in particular, at high power amplifiers (HPA). The nonlinearity of HPA causes inter-carrier interferences (ICI) and thus out-of-band radiation. Accordingly, the BER performance is degraded.

3. Model of Nonlinear High Power Amplifiers (HPA)

A nonlinear HPA can be modeled a memory-less device. The complex input signal to the HPA is represented as (Santella *et al.*, 1998; Tellado, 2000; Zheng *et al.*, 2004)

$$x = \rho . e^{j\varphi} \tag{3}$$

The complex output signal is thus expressed by

$$g(x) = F[\rho] . e^{j(\varphi + \Phi[\rho])} \tag{4}$$

where $F[\rho]$ and $\Phi[\rho]$ represent the AM/AM and AM/PM conversion characteristics of the nonlinear amplifier, respectively. In this paper, a Traveling Wave Tube Amplifiers (TWTA) model is used for our simulation. The input-output relationship of the TWTA can be model as

$$F(\rho) = \frac{\rho}{\left[1 + \left(\frac{\rho}{2A}\right)^2\right]} \tag{5}$$

$$\Phi[\rho] = \frac{\pi}{3} \cdot \frac{\rho^2}{\rho^2 + 4A^2} \tag{6}$$

Figure 1 shows the characteristic of the TWTA nonlinear HPA. The value of A^2 is defined as the input saturation power to the HPA model. The input back off (IBO) at a nonlinear device is defined in terms of A^2 as

$$IBO = 10\log_{10}\left\{\frac{A^2}{E\{|x|^2\}}\right\}[dB] \tag{7}$$

where $E\{|x|^2\}$ is the average of the input power to the HPA model.

4. Partial Transmit Sequence

In Partial Transmit Sequence (PTS) approach, the input data block is partitioned into disjoint sub-blocks. The sub-carriers in each sub-block are weighted by phase rotations. The phase rotations are selected such that the PAPR is

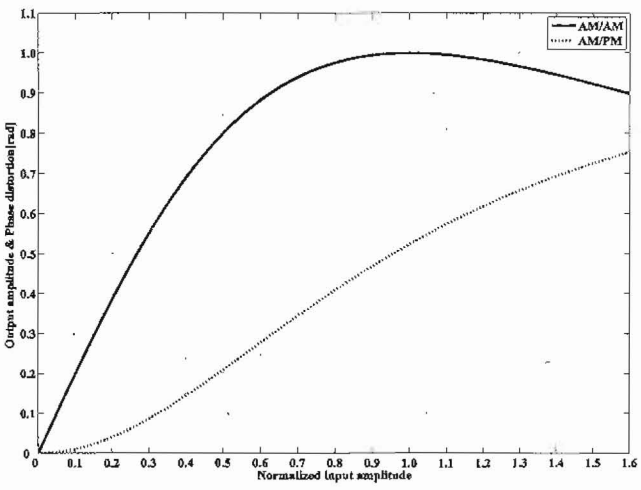

Figure 1. Characteristic of TWTA nonlinear HPA

minimized. At the receiver, the original data are recovered by applying inverse phase rotations. A block diagram of the PTS technique is shown in Figure 2 (Muller *et al.*, 1997 ; Cimini *et al.*, 2000; Han *et al.*, 2003)

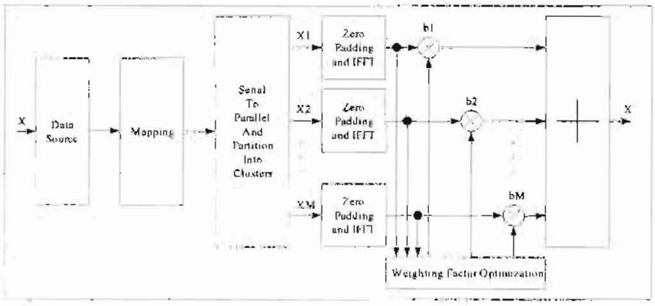

Figure 2. Block diagram of the conventional PTS technique.

Define the data block as a vector

$$X = \left[X_0 \quad X_1 \cdots X_{N-1}\right]^T \tag{8}$$

The vector X is partitioned into M disjoint sets. It is represented by vectors $\{X_m, m = 1,2,3 \ldots, M\}$:

$$X = \sum_{m=1}^{M} X_m \tag{9}$$

An IFFT is employed as

$$x = IFFT\{X\} \tag{10}$$

Applying phase rotations to sub-blocks allows the optimization of combining the weighted partial transmit sequence. The combined sequence as

$$x' = \sum_{m=1}^{M} b_m x_m \tag{11}$$

where $\{b_m, m = 1,2,3 \ldots, M\}$ is the weighting phase rotations for each sub-block. Choosing $b_m \in \{\pm 1, \pm i\} (W = 4)$ is very interesting for an efficient implementation. In addition, we can set $b_1 = 1$ without any loss of performance. The PAPR can be minimized by the exhaustive search for an appropriate combination of each sub-block and its corresponding phase rotation.

5. Adaptive Peak Power Reduction (APPR)

The Adaptive Peak Power Reduction (APPR) method controls the peak level of the modulation signal. An adaptive algorithm reduces the amplitude of modulation signals over a predefined range. A block diagram of APPR scheme is shown in Figure 3. (Sano *et al.*, 2006)

The value of $x(i)$ is an OFDM signal and it is considered as an input of the APPR. The $|x(i)|$ is fed into the clipping module where the amplitude component $|d(i)|$ is generated by

$$d(i) = \begin{cases} d_{th}.\exp\{j.\arg(x(i))\} & |x(i)| \rangle\, d_{th} \\ x(i) & |x(i)| \le d_{th} \end{cases} \tag{12}$$

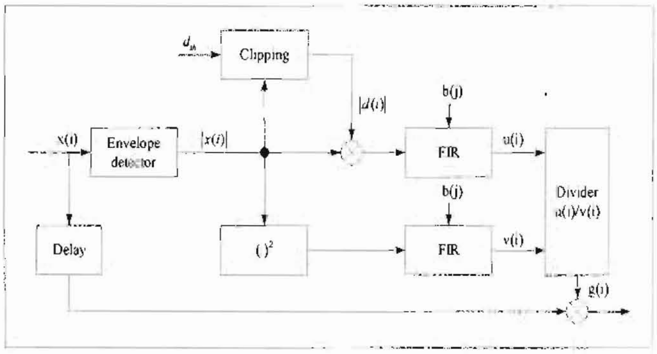

Figure 3. Block diagram of conventional APPR

If $|x(i)|$ is smaller than the target value d_{th}, then $|d(i)|$ takes the same value as $|x(i)|$. On the other hand, if $|x(i)|$ is larger than d_{th}, then $|d(i)|$ is chosen as d_{th}. Next, $|d(i)|$ and $|x(i)|$ are multiplied together and the result is fed to a finite impulse response (FIR) filter. The cross-correlation between complex target signals and complex modulation signals weighted by $b(j)$ is calculated by

$$u(i) = \frac{1}{P+1} \sum_{p=-P/2}^{P/2} b(p + P/2).\, x(i-p).d^*(i-p) \tag{13}$$

where the weighting coefficient $b(j)$ is given from the Blackman-Harris window function:

$$b(j) = 0.35875 - 0.48829\cos(2\pi j/P) + 0.14128\cos(4\pi j/P) - 0.01168\cos(6\pi j/P) \tag{14}$$

At the same time, $|x(i)|$ goes to the module of "$(.)^2$" and $(P+1)$ then is fed to an stage FIR filter. The autocorrelation function of $x(i)$ weighted by $b(j)$ is calculated by

$$v(i) = \frac{1}{P+1} \sum_{p=-P/2}^{P/2} b(p + P/2) x(i-p).x^*(i-p) \tag{15}$$

Finally, the gain $g(i)$ is calculated by Equation (16) and multiplied by the complex modulation signal for reduction of the signal's peak level

$$g(i) = \begin{cases} \dfrac{u(i)}{v(i)} & v(i) \rangle\, 0 \\ 1 & v(i) = 0 \end{cases} \tag{16}$$

If d_{th} is determined small, low PAPR is obtained. In other words, the high efficiency of the PAPR reduction can be realized when d_{th} is small. However, in this case, the OFDM signal is considerably distorted. It yields a large out-of-band radiation.

6. The Proposed Method

A new technique using PTS combined with APPR method is proposed in this paper. Figure 4 shows the block diagram of the proposed method. Using this method, both the high PAPR reduction and the suppression of the out-of-

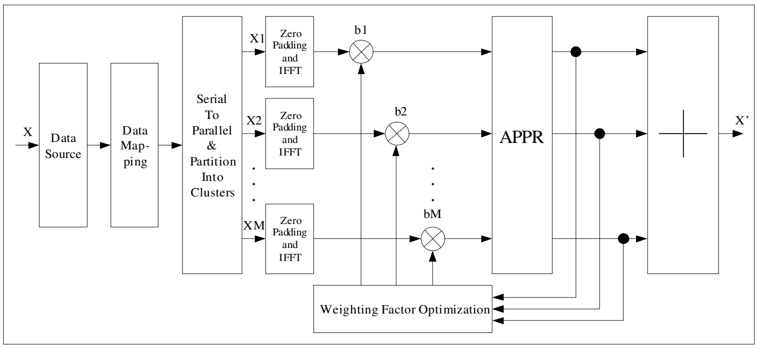

Figure 4. Block diagram of the proposed method

band radiation can be realized. Its performance is higher than of conventional methods.

First, a sequence of the input data is rearranged using a PTS method. An input data block is partitioned into disjoint sub-blocks. The sub-carriers in each sub-block are weighted by phase rotations. Since we can select many phase rotations for its weighting, many sets of weighted input data are obtained. Among them, the input data with a minimum PAPR are selected after the APPR is applied to the OFDM signals.

Using this method, even if large d_{th} is used in the APPR, the PAPR becomes low. In addition, an out-of-band radiation can be suppressed because of a large d_{th}.

7. Simulation Results and Discussions

To evaluate and compare the performance of the conventional APPR methods and the proposed methods here, simulation results are presented. The simulation parameters are listed in Table 1. (Engles, 2002) The modulation signal $|x(i)|$ is used in the APPR is normalized to maximum equal "1", the definition of d_{th} as the target value is normalized varying to 0.80 and 0.90 respectively. The total system is described in Figure 5.

7.1 PAPR Performance

Figure 6 and 7 illustrate the PAPR performance, where CCDF is complementary cumulative distribution function (Han *et al.*, 2005). In Figure 6, the proposed method can be reduce the PAPR more than the conventional APPR with a maximum of 3.40 dB. In Figure 7 the proposed method can reduce the PAPR more than the conventional APPR by 3.52 dB. In case of P=32(P = filter order), the improvement is maximal compared with the APPR. When the number of filter orders (P) becomes large, the proposed method suppresses the out-of-band radiation efficiently.

Table 1. The parameter simulation

Modulation	64 - QAM
Number of data subcarriers	48
Number of FFT points	64
Number of sub-blocks(M)	4
Phase rotations (ϕ)	$0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}$
Target value (d_{th})	0.80 , 0.90
Number of filter coefficients (P)	16 , 32
Window function	Blackman-Harris
HPA Model	TWTA
Channel Model	AWGN
Coding rate	3/4
Decoding	Soft – Decision Viterbi

7.2 Bit Error Rate

Figure 8 and 9 show the BER of the proposed tech-

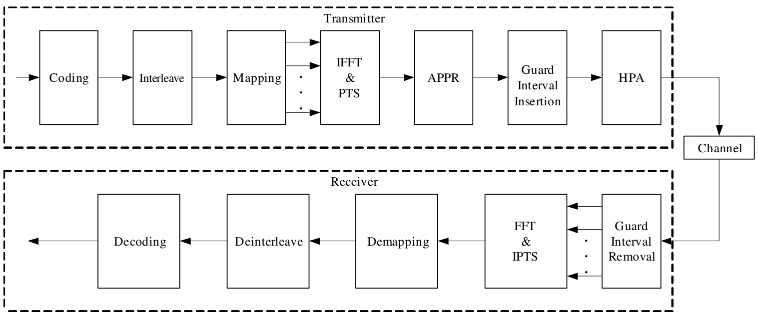

Figure 5. Block diagram of the total system used for the simulation

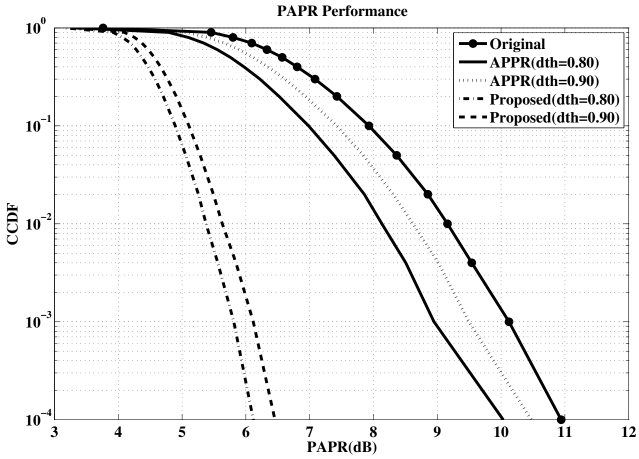

Figure 6. PAPR performance of the OFDM signal (filter order = 16)

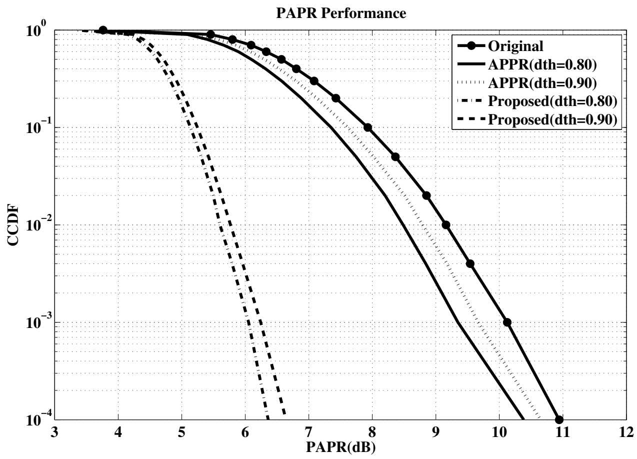

Figure 7. PAPR performance of the OFDM signal (filter order = 32)

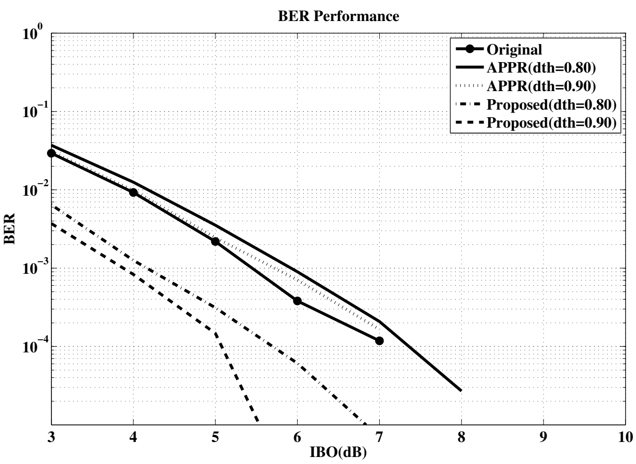

Figure 8. BER performance of the OFDM signal (filter order = 16)

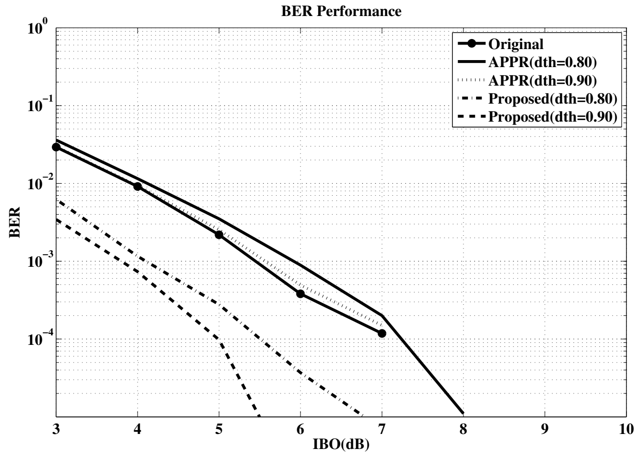

Figure 9. BER performance of the OFDM signal (filter order = 32)

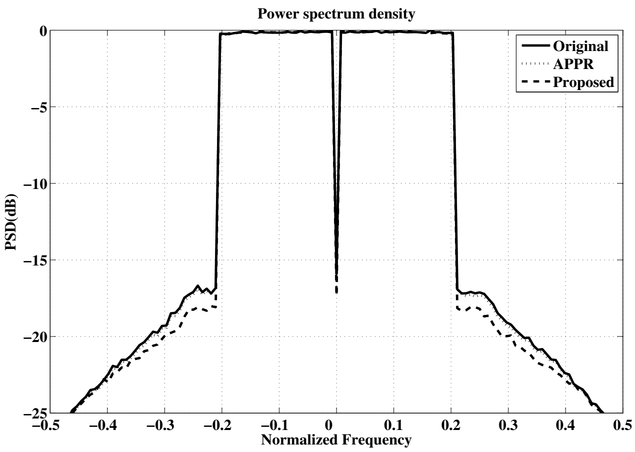

Figure 10. PSD of the OFDM signal (IBO = 3dB)

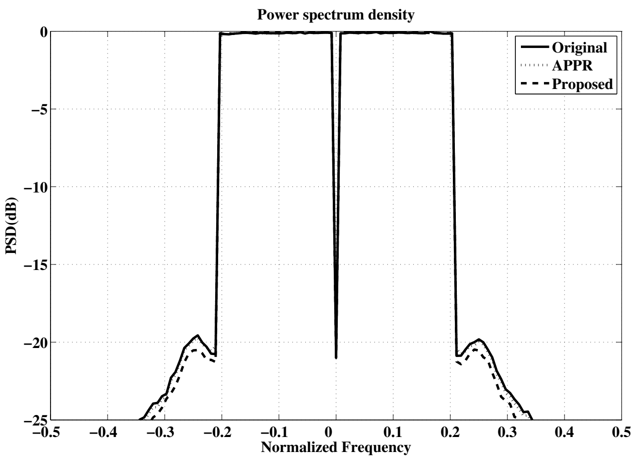

Figure 11. PSD of the OFDM signal (IBO = 7dB)

niques. The definition of IBO is shown in Equation (7). It is also compared with the APPR. The conventional APPR presents more wrong property than the OFDM system without the APPR method. The proposed method shows better

BER than others since the proposed method reduces the PAPR by using PTS and thus the influence of a TWTA nonlinear model becomes small. Additionally, when the number of filter order becomes large, the degradation of BER performance in the same d_{th} becomes smaller.

7.3 Power Spectrum Density

Figure 10 and 11 shows the PSD characteristics when the TWTA model is used and the IBO is varied at 3 and 7 dB, respectively. When the IBO is 7 dB, the out of band radiation versus the power spectrum in the bandwidth can be reduced by 4-5 dB compared with the IBO at 3 dB.

8. Conclusions

This paper has proposed a new PAPR reduction technique using a PTS combined with APPR methods. First, the input data are fed into in order to reduce the PAPR process by using the PTS method. The PAPR is computed for each resulting sequence and then the signal sequence with the minimum PAPR is fed to the APPR process. The minimum PAPR in the PTS is calculated and its corresponding phases are selected after the APPR is applied. Accordingly, the proposed method can usually realize the optimum PAPR reduction with the suppression of out-of-band radiation. The simulation results shows that the proposed method has a better PAPR performance and PSD than a conventional APPR. Additionally, the BER improvement of the proposed method is higher than of conventional APPR methods.

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