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IPTS BASED PAPR REDUCTION OF OFDM SYSTEM WITH A LINEARIZATION TECHNIQUE

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ABSTRACT

Orthogonal frequency division multiplexing (OFDM) is very attractive for high data rate transmission in a radio environment, but high peak to average power ratio (PAPR) is very serious problem due to many subcarriers, which seriously limits the power efficiency of the high power amplifier (HPA). One of the most promising approaches for the mitigation of this nonlinear distortion is to use a predistorter, applied to the OFDM signal prior to its entry in to HPA. Predistortion is a linearization technique used for the compensation of nonlinear distortion in HPA. However this linearization is not enough to control the problem of PAPR and large back off is required to improve the power efficiency, therefore, the PAPR reduction of the OFDM signal before the linearization would be more reasonable to improve power efficiency. In this paper iterative partial transmit sequence (IPTS) based PAPR reduction with a linearization technique is proposed. Simulation result shows that BER performance is significantly improved and power efficiency of HPA can be enhanced due to low PAPR of OFDM signal.

KEYWORDS: OFDM, PAPR, HPA

INTRODUCTION

Multicarrier transmission has recently seen rising popularity in wireless applications [1]. As an attractive technology for wireless communication, orthogonal frequency division multiplexing (OFDM), which is one of the multicarrier modulation techniques, offers considerable high spectral efficiency, multipath delay spread tolerance, immunity to frequency selective fading and improved power efficiency [2]. As a result OFDM has been chosen for high data rate communications and has been widely deployed in many wireless communication standards such as digital video broadcasting (DVB), digital audio broadcasting (DAB), WiMA5X, IEEE 802.11, 1EEE.16 , IEEE 802.20, European Telecommunication Standard Institutes (ETSI) and Broadcast Radio Access Network (BRAN) committees.

One of major problems in OFDM is high peak to average power ratio (PAPR), which makes system performance very sensitive to distortion introduced by nonlinear devices such as power amplifiers (PAs). The basic solution to this problem is to use a linear amplifier or to back-off the operating point into the linear region of the nonlinear HPA. However, power efficiency of HPA becomes very low so that this large back off is not desirable. Another method to avoid the nonlinear distortion is a linearization technique [3], which is good for the single carrier signal with just 3 dB PAPR. However, this linearization is not enough for the OFDM signal of multi-carrier system as large back-off is still required. There have been many studies on the PAPR reduction methods such as block coding method, clipping method, phase control method, partial transmit sequence (PTS) method and selective mapping (SLM) method. In PTS, the lowest PAPR signal is produced by optimally phase combining of the signal sub-blocks. In SLM, OFDM signal of the lowest PAPR is selected from a set of several phase rotated signals containing the same information data .These are very flexible and effective for the PAPR reduction without any signal degradation. However, both techniques need much computational burden because of the many IFFT stages and complex optimization procedure [4].

The combination of both PAPR reduction scheme and linearization technique will be more powerful as it reduces the nonlinear distortion more effectively. The linearized constant peak-power (LCP) OFDM was proposed which lowers high peak power and suppresses the out-of-band radiation. This method reduces the peak power by the signal suppression to the saturation point of HPA. Next, it pre-distorts the signal for linearization [5]. This method may increase some power efficiency of HPA because of the signal suppression process, but BER performance becomes degraded because of the signal suppression process.

In this paper, the combination of iterative PTS (IPTS) for PAPR reduction and linearization technique is proposed. Initially, PAPR of OFDM signal is reduced by iterative PTS method because it can be easily implemented with low combining complexity and then linearization in the predistorter is performed on the PAPR reduced OFDM signal. Simulation result shows that BER performance is significantly improved and power efficiency of HPA can be enhanced due to low PAPR of OFDM signal.

PROPOSED METHOD

In this section the system model of the proposed method and high power amplifier model used in the proposed method is described.

System Model

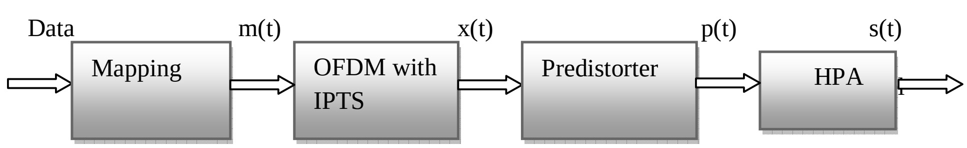


Fig.1 Block Diagram of the Proposed Method

Figure 1 shows the system block diagram of the proposed method. First, information bits are mapped into M-QAM symbols and then the inverse fast Fourier transform is taken.

The baseband complex OFDM symbol is expressed as

$$x(t) = x_I(t) + jx_Q(t)$$

$$= \sum_{n=0}^{N-1} X_n e^{j2\pi f_n t} \quad , 0 \le t \le T_s \qquad (1)$$

where T_s is the OFDM symbol duration and N is the number of subcarriers, f_n is the subcarrier frequency.

$$f_n = n\Delta f \quad = n/ T_s \qquad , \; n=0, 1,\ldots\ldots N-1$$

then signal mapping is done by using QAM modulation technique, after that, iterative PTS (IPTS) scheme is applied to the mapped OFDM signal for PAPR reduction. Then the OFDM- IPTS signal is applied to a predistorter which is actually a linearizer and finally the linearized signal becomes input to HPA.

High Power Amplifier Model

OFDM symbol x(t) changes into p(t) after linearization and s(t) is the HPA output. s(t) is transmitted to the receiver and the reverse processing for the data detection is carried out. The input complex envelope of HPA is written as

$$p(t) = r(t)\exp[\,j\phi(t)] \tag{2}$$

Where r(t) and φ(t) are the amplitude and phase of HPA input signal. The output signal of HPA is as follows

$$s(t) = u[r(t)]\exp\{\,j[\psi(r(t)) + \phi(t)\;]\} \tag{3}$$

Here, u[r(t)] and ψ[r(t)] are AM/AM and AM/PM conversion of the nonlinear amplifier, respectively. If OFDM signal is amplified in the nonlinear HPA, the interference is produced, that is, crosstalk and ACI (adjacent channel interference) happen due to inter-modulation distortion (IMD).

There are two kinds of the nonlinear HPA: traveling wave tube amplifier (TWTA) with strong nonlinear AM/PM characteristic and solid state power amplifier (SSPA) without AM/PM characteristic. In this paper, the SSPA model is considered since it is generally used in mobile phones.AM/AM and AM/PM conversions of SSPA is modeled as

$$u[r(t)] = \frac{r(t)}{\left[1 + \left(\dfrac{r(t)}{A_0}\right)^{2p}\right]^{\frac{1}{2p}}} \tag{4}$$

$$\psi[r(t)] = 0 \tag{5}$$

where A_0 is the maximum output amplitude at the saturation point [7].

The parameter p controls the transition smoothness from the linear region to the saturation region and the characteristic of nonlinear HPA becomes linear as the parameter is large.

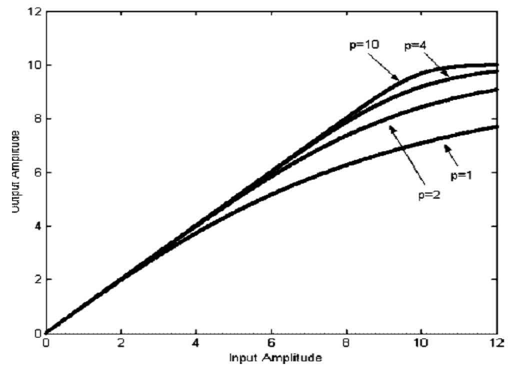


Figure 2: Transfer Characteristics of SSPA

Fig.2 shows the input-output transfer characteristic of SSPA according to the variation of p when the gain of HPA is normalized.

Two kinds of back-off are defined as

$$\text{Input back-off (IBO)} = 10\log10_{10}\frac{p_{in,sat}}{pin} \tag{6}$$

$$\text{Output back-off (OBO)} = 10\log10_{10}\frac{p_{out,sat}}{p_{out}} \tag{7}$$

where p_{in} and p_{out} are the average input and output power

and $p_{in,sat}$ and $p_{out,,sat}$ are the input and output saturation power of HPA.

PAPR AND IPTS SCHEME

Section 3 describes the mathematical representation of PAPR in OFDM system and also gives idea about the conventional PTS and iterative PTS scheme for PAPR reduction.

Peak to Average Power Ratio (PAPR)

The PAPR of OFDM signal x(t) is defined as the ratio between maximum instantaneous power and its average power [6]

$$PAPR[x(t)] = \frac{\max_{0\le t\le NT}\left[\left|x(t)\right|^2\right]}{P_{av}} \tag{8}$$

where P_{av} is the average power of x(t)

For a large number of N subcarriers, an OFDM signal can be modeled as a zero-mean asymptotically complex Gaussian distributed random variable, because it is a superposition of a large number of modulated signals.

The probability that the PAPR of the Nyquist rate sampled OFDM signals exceeds a given threshold χ_0 can be calculated as

$$p_r(\chi > \chi_0) = 1 - \left(1 - \exp(-\chi_0)\right)^N \tag{9}$$

In this expression it is assumed that the N time domain signal samples are mutually independent and uncorrelated, however, this is not true, when oversampling is applied.

Iterative Partial Transmit Sequence (IPTS)

Figure3 shows the conventional partial transmit sequence method for PAPR reduction. In the PTS technique, an input data block of N symbols is partitioned into M disjoints sub blocks. The subcarriers in each sub block are weighted by a phase factor for that sub block. The phase factors are selected such that the PAPR of the combined signal is minimized.

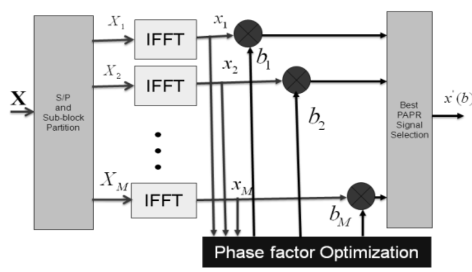


Fig. 3 Block diagram of PTS Technique

Input data block **X** is partitioned into M disjoint sub blocks

$$X = \sum_{m=0}^{M-1} X^{(m)} \tag{10}$$

where $X^{(m)} = \left[X_0^{(m)}, X_1^{(m)}, X_2^{(m)} .... X_{N-1}^{(m)}\right]$

After taking IFFT of each block the sub blocks $X^{(m)}$ are transformed into M time-domain partial transmit sequences such as

$$x^{(m)} = \left[x_0^{(m)}, x_1^{(m)} x_2^{(m)} ... x_{LN-1}^{(m)}\right] = IFFT_{LN\times N}\left[X^{(m)}\right] \tag{11}$$

These partial sequences are independently rotated by phase factors

$$b = \left\{b_m = e^{j\theta_m}, m = 0,1,2,....,M-1\right\}$$

The objective is to optimally combine the sub blocks to obtain the time domain OFDM signals with the lowest PAPR

$$x'(b) = \sum_{m=0}^{M-1} b_m x^{(m)} \tag{12}$$

Cimini and Sollenberger's iterative PTS (IPTS) algorithm is developed as a sub-optimum technique for PTS. IPTS flips between two phase rotation values 1and -1 for making it less complex.

The IPTS flipping algorithm can be written as follows [12]:

Step 1: Assume that $b_m = 1$ for all m and compute the PAPR of the combined signal.

Step 2: Invert the first phase factor ($b_1 = -1$) and recomputed the resulting PAPR.

Step 3: If the new PAPR is lower than in the previous step, retain b_1 as part of the final phase sequence; otherwise, reverts to its previous value.

Step 4: The algorithm continues in this fashion until all M phase factors have been explored and finally, the sequence with the smallest PAPR is transmitted.

HPA LINEARIZATION USING A PREDISTORTER

One of the most promising approaches for mitigation of the nonlinear distortion of HPA is to use a predistorter, which is a linearization device applied to the OFDM signal prior to its entry into the HPA. The predistorter (PD) is a nonlinear zero memory device that precomputes and cancels the nonlinear distortion present in the zero memory HPA which follows the PD.In this section,the PD for SSPA model of HPA is discussed. Fig.4 shows the block diagram of predistorter for time varying HPA. Let q and u denote the nonlinear zero memory input-output maps of the PD and HPA $x_l(n)$,the input of the PD, $y_l(n)$,the output of the PD which is also the input to the HPA, and z(t) the output of the HPA as in Figure 4.

Then for any given HPA, an ideal PD is one for which the input-output maps satisfy

$$u[q(x_l(n))] = k.x_l(n) \tag{13}$$

where k is a desired prespecified linear amplification constant. In this paper, k = 1 is assumed

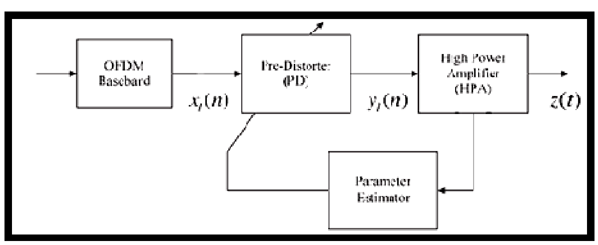


Fig.4.Block Diagram of PD for Time Varying HPA

Predistorter for SSPA

The general baseband (equivalent low pass signal) expressions for the input $x_l(n)$ and output $y_l(n)$of the PD for the SSPA are

$$x_l(n) = r(n)e^{j\phi(n)} \tag{14}$$

$$y_l(n) = q[r(n)]e^{j\phi(n)} \qquad (15)$$

where the functions q and ϕ are to be determined by requiring (13) to be satisfied. As it is assumed that phase distortion is neglected, so there is no need to consider phase predistortion. According to (4) and (5), the input and output of the SSPA are

$$y(t) = q[r(t)]\cos(\omega_c(t) + \phi(t)) \qquad (16)$$

$$z(t) = u[q[r(t)]]\cos(\omega_c(t) + \phi(t)) \qquad (17)$$

where

$$u[q(r)] = \frac{q(r)}{\left(1 + \left(\frac{q(r)}{A_0}\right)^{2p}\right)^{\frac{1}{2p}}} \qquad (18)$$

According to (18), (13) implies

$$r = \frac{q(r)}{\left(1 + \left(\frac{q(r)}{A_0}\right)^{2p}\right)^{\frac{1}{2p}}} \qquad (19)$$

Then, after algebraic manipulation, the exact expression for the PD characteristic q(r) will be as follows:

$$q(r) = \frac{r}{\left(1 - \left(\frac{r}{A_0}\right)^{2p}\right)^{\frac{1}{2p}}}, \qquad r < A_0 \qquad (20$$

Here HPA is considered as a time-varying system, so the parameters A_0 and p in the SSPA model will change with time. To track two parameters A_0 and p, training symbols are used. Using training symbols, we get input of the PD, q(n) , and the output of the PD, u(n) . During the training stage, we assume that the PD is turned off, that is, the input and output of the PD would be the same $r\,(n) = q\,(n)$

To estimate parameters A_0 and p, we first change (18) as

$$A_0 = \frac{q.u}{\left(q^{2p} - u^{2p}\right)^{\frac{1}{2p}}} \qquad (21)$$

If we know p, we can easily obtain A_0 from (21). However, it is assumed that both A_0 and p change with time. In this case, the following algorithm is proposed. First, send two training symbols and then by knowing two different training symbols, we get two different estimations of A_0, namely A_{01} and A_{02}:

$$A_{01} = \frac{q_1.u_1}{\left(q_1^{\,2p} - u_1^{\,2p}\right)^{\frac{1}{2p}}} \tag{22}$$

$$A_{02} = \frac{q_2.u_2}{\left(q_2^{\,2p} - u_2^{\,2p}\right)^{\frac{1}{2p}}} \tag{23}$$

where q_1, u_1 are the output amplitudes of the PD and HPA for the first training symbol

and q_2,u_2 are the output amplitudes of the PD and HPA for the second training symbol.

Training symbols are not affected by the function of the PD, as it is stated previously. During the training period, we can replace q_1 and q_2 as r_1 and r_2 , which are the original amplitudes of the training symbols.

SIMULATION RESULTS AND DISCUSSIONS

For the simulation the parameters are given below:

Modulation format: QAM

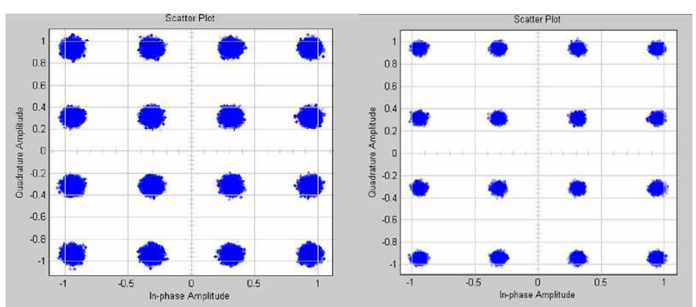
Channel: AWGN

Number of data subcarriers: 256

HPA model: SSPA with Rapp's coefficient, p=1

Input backoff (IBO): 5dB

Figure 5(a) and 5(b) shows the scatter plots of conventional PTS scheme and the proposed method respectively



(a) **(b)**

Fig.5. The Constellation Points of (A) Conventional PTS Scheme and (B) Proposed Method

PAPR reduction performance curves of conventional PTS scheme and IPTS with and without predistorter with M=8 are depicted in figure 6. Although IPTS without predistorter has a little performance degradation than conventional PTS scheme, the performance can further be improved by using a predistorter after IPTS. It is clear from the simulation results that the proposed method gives the better performance of PAPR reduction.

BER performance of conventional PTS, IPTS with or without predistorter is shown in fig.7. Predistorter makes a small improvement in the BER performance. To meet BER $=10^{-4}$ at IBO =5dB, the IPTS with predistorter can achieve 6 dB SNR gain than conventional PTS.

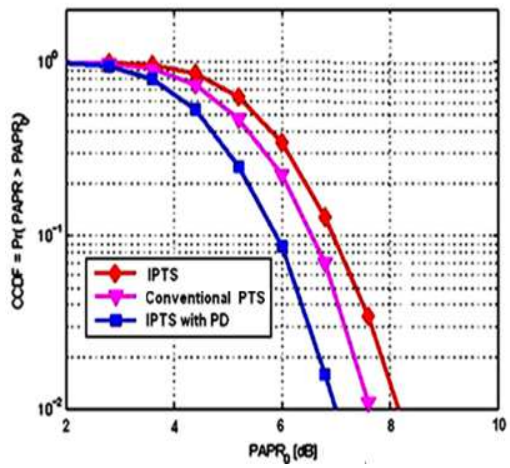


Fig.6 PAPR Performance of Convenentional PTS, IPTS and IPTS with Predistorter (PD)

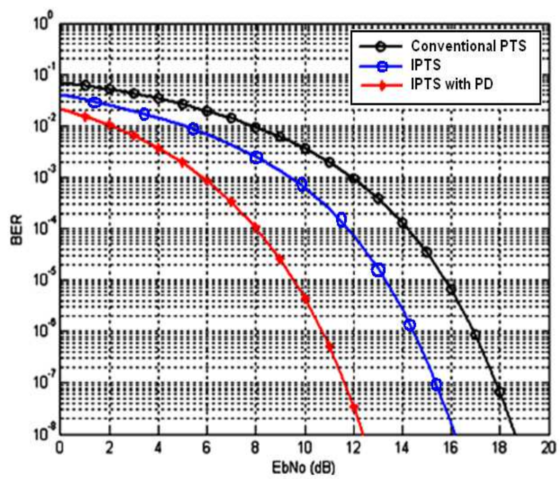


Fig.7 BER Performance of Conventional PTS, IPTS and IPTS with Predistortion

CONCLUSIONS

In this paper, a combined method of an iterative PTS with predistorter as a linearization technique is proposed to compensate the nonlinear distortion of HPA. The proposed method reduces spectral regrowth because peak power of the OFDM signal is reduced by IPTS without signal distortion. This paper compares the PAPR reduction and BER performance of conventional PTS and IPTS with and without predistoter. Simulation results show that the proposed method is an effective method for PAPR reduction of OFDM system with lesser computational complexity than conventional PTS scheme.

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