An SLM based PAPR Reduction Method using New Volterra Predistorter Model in the OFDM System

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Abstract: - Orthogonal frequency division multiplexing (OFDM) is a strong candidate for future wireless communication because it is marked by its higher frequency multiplicity and greater immunity to multipath fading. However, the main drawback of OFDM is high peak-to-average power ratio (PAPR), which leads to power inefficiency and requires expensive high power amplifier (HPA) with very good linearity. In this paper, we have propose SLM with volterra series models (VSM) technique to linearize the high power amplifier (HPA).

Key-Words: - OFDM, PAPR, SLM, VSM, Nonlinear HPA.

1 Introduction

OFDM is a multicarrier modulation technique for future mobile communication systems due to many advantages such as robustness in frequency-selective fading channel, immunity to inter-symbol interference and high spectral efficiency. This technique has been adopted for a number of applications such as the standard for audio broadcasting (DAB), digital video broadcasting (DVB), HIPERLAN/2, wireless LAN (IEEE802.11x) and WiMAX , etc [1].

However, one of the major drawbacks of OFDM system is that the OFDM signal have high peak to average power ratio (PAPR) of the transmitted signal. The high PAPR signal can cause inter-modulation noise and out-of-band radiation due to power amplifier nonlinearity. In addition, the effects of amplitude modulation (AM)/AM and AM/Phase modulation (PM) can also cause power loss and the signal distortion that can degrade the bit error rate (BER) performance. The transmit power amplifier must be operated in its linear region.

At present, several methods have been proposed for reducing PAPR, such as clipping method, coding method, SLM (Selected Mapping) and PTS (Partial Transmit Sequence), etc. Clipping method clips the peak above a certain prescribed level. The merit of the clipping method is that PAPR can be easily reduced. But the BER performance becomes worse due to many defected signals [4, 5]. Block coding is another important method for PAPR reduction. SLM and PTS may be classified in to the phase control scheme to escape the high peak. In SLM, one signal of the lowest PAPR is selected a set of several signals containing the same information data. In PTS, the lowest PAPR signal is made by optimally phase combining the signal sub-blocks. Both techniques are very flexible scheme and have an effective performance of the PAPR reduction without any signal distortion. However, they require much system complexity and computational burden by using of many IFFT blocks.

In this paper, we have used SLM technique with volterra series models (VSM). VSM is applied at the transmitter side,which consist of two identical volterra models such as predistorter and training. [8]-[12]. The main idea of VSM is to shape the transmitted data symbols (data pre-distortion) or the input signals of the HPA amplifier (signal pre-distortion) so that the output signal of the HPA is less distorted. VSM does not reduce the information rate. But it is also improves the power density spectrum of the transmitted signal and bit error performance.

This paper is organized as follows: In Section II, system model and PAPR are described. In Section III, explain the SLM and VSM technique. Simulation results are provided in Section IV, and Section V contains the conclusion.

2 System Model

2.1 PAPR of an OFDM System

In OFDM system, the input data symbols are first passed through serial to parallel converter, forming a complex vector of size N. We Call the vector as $X=[X_0, X_1, ..., X_{N-1}]^T$. After IFFT Transform the signal can be written as equation (1).

$$x(t) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n e^{j2\pi n \Delta f t}, 0 \le t \le NT \qquad (1)$$

Where $j = \sqrt{-1}$, Δf is sub-carrier spacing and NT is OFDM symbol period.

The PAPR of an OFDM signal, is to be

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

Where $\max|x(t)|^2$ is the peak of signal power, and $E[|x(t)|^2]$ is the average signal power.

According to Central Limit Theorem, x is approximately independently and identically distributed (i.i.d) .Hence, when N is large. The complex Gaussian random variables with zero mean and variance $\sigma^2 = E[|X_n|^2]/2$ [8].

2.2 CCDF of PAPR

The cumulative distribution function of the peak power per OFDM symbol can be found based on the assumption of the uncorrelated samples.The cumulative distributed function (CDF) of the signal is

$$F(PAPR_0) = 1\text{-}e^{(-PAPR0)}$$

If there are N subcarriers in an OFDM system and all the sampling values are complete independence, the CDF of the system is

$$Pr(PAPR \le PAPR_0) = [F(PAPR_0)]^N$$

$$= [1\text{-}e^{(-PAPR_0)}]^N \qquad (3)$$

As equation (3) does not hold for the over sampling case. Therefore, adding a certain number of extra independent samples approximates the effect of oversampling. The distribution of the PAPR is expressed as

$$Pr(PAPR \le PAPR_0) = [1\text{-}e^{(-PAPR_0)}]^{\alpha N} \qquad (4)$$

The complementary cumulative distributed function (CCDF) of PAPR denotes the probability of a data block exceeds a given threshold ($PAPR_0$), it can be calculated as [4].

$$Pr(PAPR > PAPR_0) = 1\text{-}(1\text{-}e^{(-PAPR_0)})^{\alpha N} \qquad (5)$$

where α is 2.4

2.3 Model of Nonlinear High Power Amplifier (HPA)

In this section, we have described the memory less model for the nonlinear HPA. The AM/AM and AM/PM conversion of a solid-state power amplifier (SSPA) can be approximated as [2]

$$f[A(t)] = \frac{vA(t)}{\left(1+\left[\frac{vA(t)}{A_0}\right]^{2p}\right)^{\frac{1}{2p}}} \tag{6}$$

$\Phi[A(t)] \approx 0,$

Where $v \geq 0$ is the small signal gain, $A_0 \geq 0$ is the output saturating amplitude and $p \geq 0$ is a parameter to control the smoothness of the transition from the linear region to the saturation level.

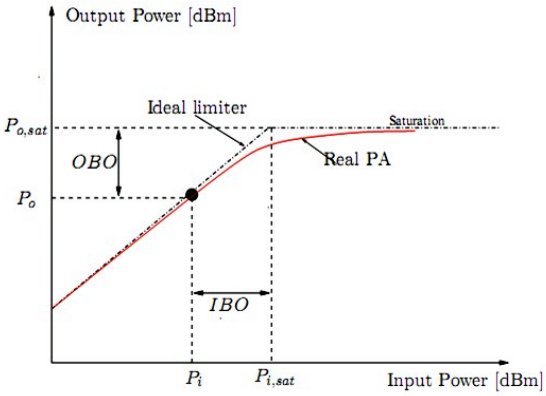

Fig. 1 Power amplifier response for IBO and OBO

2.4 Non-linear Effect on OFDM Signal

The nonlinear amplifier distortion of a SSPA depends on the back-off. Fig.1 shows a typical AM/AM response for an HPA, with the associated input and output back-off regions (IBO and OBO, respectively) [5].

It is characterized by the input back-off and output-back-off and it is defined as [4]

$$\mathrm{IBO} = 10\log_{10}\frac{P_{i,sat}}{\overline{P_i}} \tag{7}$$

and

$$\mathrm{OBO} = 10\log_{10}\frac{P_{o,sat}}{\overline{P_o}} \tag{8}$$

Where $P_{i,sat}$ and $P_{o,sat}$ are the input and output saturation powers, $\overline{P_i}$ and $\overline{P_o}$ are the average power of the input and output signals.

3 Proposed Technique: SLM Method With VSM

3.1 SLM Method

SLM (selective mapping) method is a kind of phase rotation methods. Phase-rotated data of the lowest PAPR will be selected to transmit.

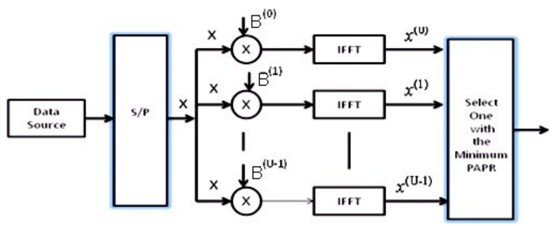

Fig. 2 OFDM system using selective mapping method (SLM)

Fig.2 is block diagram of SLM method. Let's define data stream after S/P conversion as $X = [X_0, X_1, \ldots, X_{N-1}]^T$. Then phase-rotated data due to the phase rotation factor $B^{(u)}$ can be written as

$$x^{(u)} = \mathrm{IFFT}(X \otimes B^{(u)}) \tag{9}$$

where

$$B^{(u)} = [B_0^{(u)}, B_1^{(u)}, \ldots\ldots\ldots B_{N-1}^{(u)}]^T (u = 0,1,\ldots\ldots\ldots\ldots U-1)$$

is the phase weighting sequence with

$$\left|B_n^{(u)}\right| = 1 (n = 0,1,N-1)$$

and usually selected from $\{\pm 1\}$ for avoiding the complexity for complex multiplications. The modified data for the u^{th}phase sequence

$X^{(u)}=[X_0 B_{u,0}, X_1 B_{u,1}, \ldots X_{N-1} B_{u,N-1}]^T$,

u=0,1,2….U-1.After the PAPR comparisons among the U data sequence $x^{(u)}$, the optimal mapped one $\hat{x}$ with the minimum PAPR is selected for transmission. then

$$\hat{x} = \arg \min_{0 \le u \le U} [\mathrm{PAPR}(x^{(u)})] \tag{10}$$

PAPR reduction effect will be better U is increased.SLM method can effectively reduce PAPR without any signal distortion. Here we have used SLM technique without explicit side information [5].

3.2 Voltra Series Model

Fig.3 shows the block diagram of the proposedmethods SLM with VSM. This method, reduce PAPR and the compentions the nonlinearities (out-of-band radiation). In proposed method , a sequence of the I/P data sequence is multiplied by each of the predetermined sequences, called phase sequences, to yield alternative I/P symbolsequences. Then, the PAPR is calculated for different sequences in the time domain generated after the IFFT for the phase rotated symbol sequences and the sequence with the minimum PAPR is selected [h] after this VSM is applied to the OFDM signals.

The OFDM signal before and after HPA respectively x(t), r(t) and VSM o/p z(t) can be expressed as

$$x(t) = A(t).e^{j\theta(t)}, \tag{11}$$

where t is the time index before serial/parallel conversion, A(t) the amplitude of the transmit signal and θ(t) is the phase.The output samples of the HPA can be written as

$$z(t) = f[A(t)].e^{j\{\theta(t)+\Psi[A(t)]\}}, \tag{12}$$

$$z(t) = h(t).A(t).e^{j\{\theta(t)+\Phi(A(t))\}}$$

where h [t] and Φ (A[t]) are usually called real-valued functions of AM/AM and AM/PM conversion of solid-state power amplifier (SSPA), respectively.The combination of a given memory less HPA and the corresponding VSM will result in

$$r(t) = g(f[A(t)]).e^{j\{\theta(t)+\Psi[A(t)]+\Phi[f(A(t))]\}}$$

The third–order volterra series model is expressed in a matrix form as

$$d(t)=hx^T(t) \tag{13}$$

where d(t) is the output of the volterra series model predistorter, the superscript T denotes the transpose of the matrix, h is the volterra kernel vector and x(t) is the input vector , which are defined by

$$h = [h_0^{(1)}, h_1^{(1)}, \ldots\ldots\ldots, h_{N-1}^{(1)}, h_{000}^{(3)}, h_{001}^{(3)}, h_{002}^{(3)}, \ldots\ldots\ldots, h_{klm}^{(3)}, \ldots\ldots, h_{(N-1)(N-1)(N-1)}^{(3)}, \tag{14}$$

$$x(t) = [x(t), x(t-1), \ldots\ldots, x(t-N+1)], |x(t)|^2 x(t), |x(t)|^2 x(t-1), |x(t)|^2 x(t-2), \ldots, x(t-N+1)]^2 x(t-N+1)]] \tag{15}$$

Here, t is the current sample time and N is the system memory length in the discrete time form. The overall system output y(t) is given by

$$Y(t) = \sigma(d(t)) \tag{16}$$

Where σ is a nonlinear system function with memory and the vector d(t) is given by

$$d(t)=[d(t),d(t-1),\ldots\ldots,d(t-M+1)] \tag{17}$$

Here, M is the memory duration of the nonlinear system.

The output r(t) of the training volterra series model is given by

$$r(t) = hy^T(t) \tag{18}$$

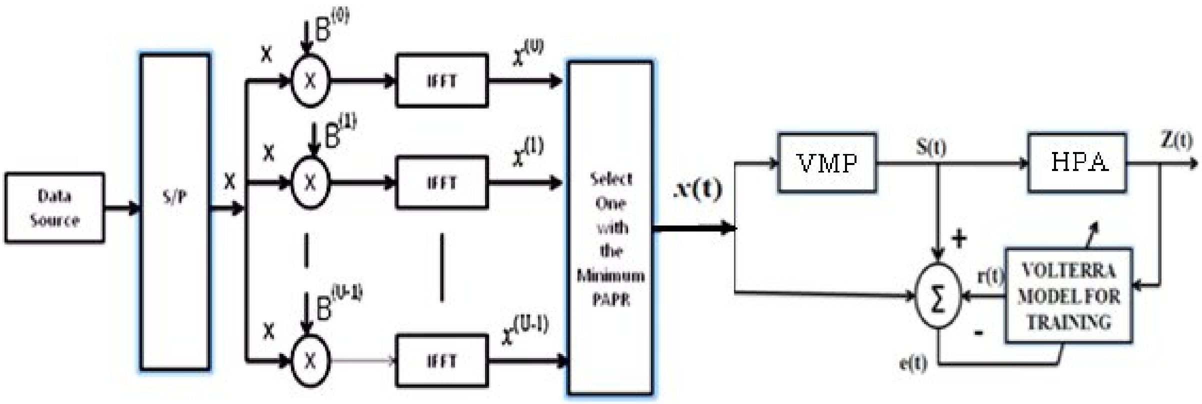

Fig. 3 Block diagram of proposed method

Where y(t) is the vector of the sampled output of the overall system defined by

$$\begin{aligned} y(t) = [&y(t), y(t-1), \ldots\ldots, y(t-N+1)], |y(t)|^2 x(t), \\ &|y(t)|^2 y(t-1), |y(t)|^2 y(t-2), \ldots.., y(t-N+1)]^2 y(t-N+1)]] \end{aligned} \tag{19}$$

If the volterra series models satisfy the following conditions

$if\ \ x(t) \neq y(t), \quad then\ d(t) \neq r(t)$ and

$$if\ \ x(t) \neq y(t), \quad then\ d(t) = r(t) \tag{20}$$

Then, as e(t)=d(t)-r(t) approaches zero,y(t) approaches x(t), thus so does y(t) to x(t).
The kernel update of the training volterra series system follows the modified recursive least square(RLS) algorithm. The kernel vector at the sample time t is updated by

$$\hat{h}^{(t)} = \hat{h}^{(t-1)} + k(t)\sigma^*(t) \tag{21}$$

Where $\sigma(t)$ is called the innovation that represents the information contained in the current desired output value which cannot be predicted by the previous kernel vector and is defined by

$$\begin{aligned} \sigma(t) &= d(t) - \hat{h}^{(t-1)} y^T(n) \\ &= \hat{h}^{(t-1)} (x(t) - y(t))^T \end{aligned} \tag{22}$$

and k(t) is the time varying gain vector defined by

$$k(t) = \frac{\lambda^{-1} P(t-1) y^T(t)}{1 + \lambda^{-1} y^*(t) P(t-1) y^T(t)} \tag{23}$$

The matrix P(t) is updated as follows:

$$P(t) = \lambda^{-1} P(t-1) - \lambda^{-1} k(t) y^*(t) P(t-1) \tag{24}$$

The output y(t) of the overall system is used as the input to the training volterra series model. The contents of the training volterra series model are copied into those of the volterra series model pre-distorter. To compare the performance of the indirect and p^{th} order pre-distorters.Then, the total minimum mean square error (MSE) is selected for the OFDM signal, can be written as

$$MSE = \frac{\sum_{k=1}^{K} |x_k(t) - r(t)|^2}{\sum_{k=1}^{K} |x_k(t)|^2} \tag{25}$$

where K is the number of total data, $x_k(t)$ is the desired detector output of k^{th} data and $r_k(t)$ is the k^{th} compensated output. After calculating MSE, we can transmit the OFDM signal with minimum mean square error.

4 Simulation Results

This section presents simulations results conducted to examine the performance of the proposed scheme. Table1 summarizes the system parameters used in the simulation.

Table I
The Parameter for Simulation

Parameter	Value
Modulation	QPSK
Number of data sub-carriers	256
Number of pilot sub-carriers	4
Number of FFT Points	256
Number of candidate sequence(U)	4,8,16
HPA Model	SSPA
IBO(dB)	5
Number of controls smoothness HPA	p =2
Channel	AWGN

4.1 PAPR Performance

Fig.4 shows the CCDF performance curve of normal OFDM, conventional SLM (CSLM) and the proposed method at different values of U. For U=4 the proposed method can reduce PAPR more than the CSLM by 0.7dB and also the graph shows , as U increases more PAPR reduction is achieved.

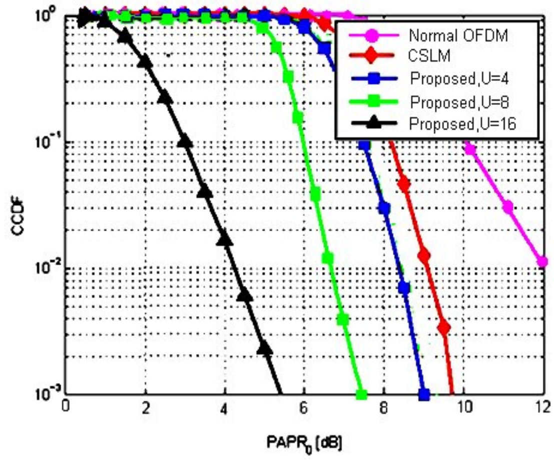

Fig. 4 PAPR Performance of an OFDM signal

4.2 BER performance

Fig.4 gives the BER performance of normal OFDM, CSLM and proposed method. Simulation result shows that at U=8, the proposed method can achieve 1.2dB signal to noise ratio gain than the CSLM. Meanwhile at U = 16 the signal to noise ratio gain of the proposed method becomes 1.8dB. This means that, more the U, better is the BER performance.

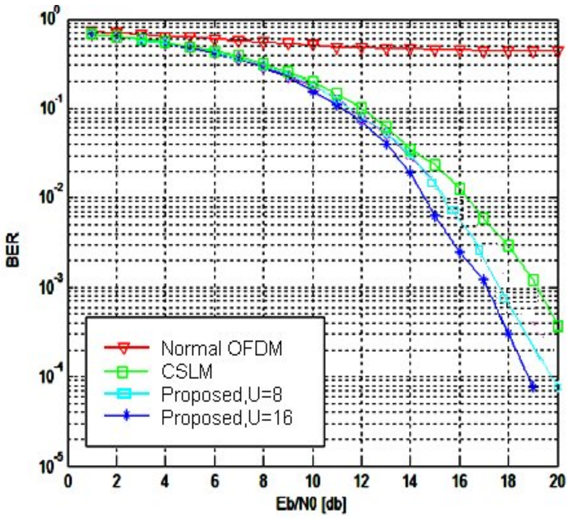

Fig. 5 BER Performance of an OFDM signal

5 Conclusion

In this paper, we have proposed a technique for PAPR reduction of OFDM signals to improve the power efficiency with the combination of SLM and VSM. From the simulation results, it is shown that the proposed method has better PAPR and BER performance than the normal OFDM signal,VSM and conventional SLM method. The main advantage of the proposed combination is to reduce PAPR which improves power efficiency and improvement in BER performance is achieved over conventional technique.

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