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Power Efficiency Improvement in OFDM System using SLM with Adaptive Nonlinear Estimator

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Abstract: OFDM is an increasingly popular multicarrier modulation technique for the next generation mobile radio communication system but Peak to Average Power Ratio (PAPR) is the major drawback of OFDM system. Most of the recent work is focused on reducing the PAPR of OFDM signal to enhance the performance. Here we propose a new technique for PAPR reduction, which improves the system power efficiency and maintains the better BER performance compared to the conventional SLM approach. The paper comprises of SLM, combined with Adaptive Nonlinear Estimator (ANE) which is a new major of non linear distortion caused by HPA. ANE estimates the mean square error between the OFDM signals before and after the nonlinear HPA and the signal having minimum mean square error among all OFDM signals is selected for final transmission.

Key words: OFDM . PAPR . SLM. ANE . HPA

INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has become a popular technique for transmission of signals over wireless channels and it has been adopted in various wireless standards such as digital audio broadcasting (DAB), digital video broadcasting (DVB-T), the IEEE 802.11a [1], local area network (LAN) standard and the IEEE 802.16a [2] metropolitan area network (MAN) standard. In OFDM system, high rate incoming signal is serial to parallel converted to N low rate data streams and each is sent over one of the N orthogonal subcarriers. Besides various advantages one of the major drawback of OFDM is that peak transmitted power can be substantially larger than the average power, when all the sinusoidal signals of N subcarriers are added constructively. The peak power is as large as N times the mean envelope power. This large amplitude fluctuation requires the linear high power amplifier (HPA) to avoid the irreducible bit error due to the nonlinear distortion.

Here, we study the performance of OFDM in the presence of a high power amplifier (HPA). Several researchers have been proposed schemes for reducing PAPR, such as amplitude clipping method [6], active constellation extension(ACE) [6], coding method , phase optimization , nonlinear companding transforms [11], interleaving [4], Selective Mapping (SLM) [7] and Partial Transmission Sequence (PTS) [24] 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 worst due to many defected signals. Block coding is another important method for PAPR reduction. This method can reduce the PAPR without any signal distortion. In the case of SLM technique, it was shown that this technique can achieve excellent PAPR reduction, it has a high signal processing complexity due to the use of multiple Inverse Fast Fourier Transform (IFFT) operations per OFDM block [8].

In this paper we have proposed a new idea for power efficiency enhancement which uses a high power amplifier after the SLM technique. In this paper we have considered an adaptive nonlinear pre-distorter, which linearize the operation of nonlinear HPA.

SYSTEM MODEL AND SLM TECHNIQUE

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 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.

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The PAPR of an OFDM signal will be

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

where Max $|x(t)|^2$ is the peak 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 $\sigma^2 = E[|X_n(t)|^2]/2$ [8]. the complementary cumulative distributed function (CCDF) of PAPR; i.e., the probability that PAPR exceeds a certain threshold $PAPR_0$ can be calculated as

$$\begin{aligned} CCDF[PAPR(x(t))] &= Pr(PAPR \succ PAPR_0) \\ &= 1 - (1 - e^{-PAPR_0})^N \end{aligned} \quad (3)$$

SLM TECHNIQUE

SLM method is a kind of phase rotation methods. Phase rotated data of the lowest PAPR will be selected to transmit. Figure 1 shows the block diagram of SLM scheme. Where U data sequence $x^{(u)} = [x_0^{(u)}, x_1^{(u)}, ...x_{N-1}^{(u)}]^T$ of length N (u = 0,1,..., U-1) are generated by multiplying original input X = $[X_0, X_1, ..., X_{N-1}]^T$ component-wise with predetermined phase sequences $P^{(u)}$, whose length is also equal to N. Then, IFFT is applied to each sequence, transforming the signal from the frequency domain to the time domain. As a result, the candidate sequence is given by [7]

$$x^{(u)} = IFFT(X \otimes P^{(u)}) \quad (4)$$

where

$$P^{(u)} = [P_0^{(u)}, P_1^{(u)}, ...P_{N-1}^{(u)}]^T (u = 0,1,U-1)$$

is the phase weighting sequence with

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

and usually selected from {±1} for avoiding the complexity for complex multiplications. The modified data for the u^{th} phase sequence $X^{(u)} = [X_0 P_{u,0}, X_1 P_{u,1}, ...X_{N-1} P_{u,N-1}]^T, u = 0,1,2....U-1$. 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

$$\hat{x} = \underset{0 \le u \le U}{\arg\min}[PAPR(x^{(u)})] \quad (5)$$

Here we have used SLM technique without explicit side information [8].

Efficiency of linear power amplifier: Efficiency of power amplifier η depends on the PAPR γ and the efficiency increases monotonically as the PAPR decreases. The specific relationship η= η(γ) depends on the class of the PA and on its particular design. The theoretical efficiency upper limits for class A and class B power amplifier are given [9].

$$\eta = K \exp(-k.\gamma\,[dB])$$

Where the efficiency is in %, the PAPR, γ is in dB and Values of K and k are given in Table 1.

NONLINEAR TRANSMITTER CHARACTERISTICS

The nonlinear distortion at the transmitter causes interferences both inside and outside the signal

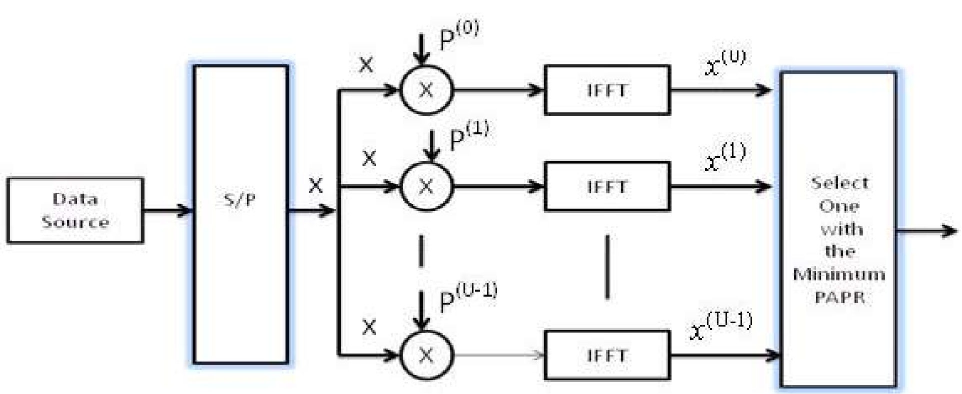
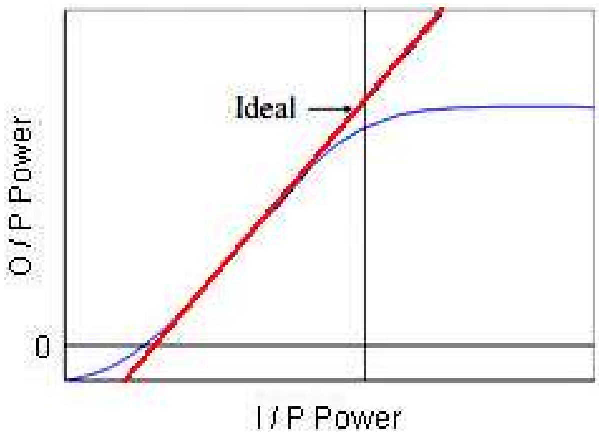


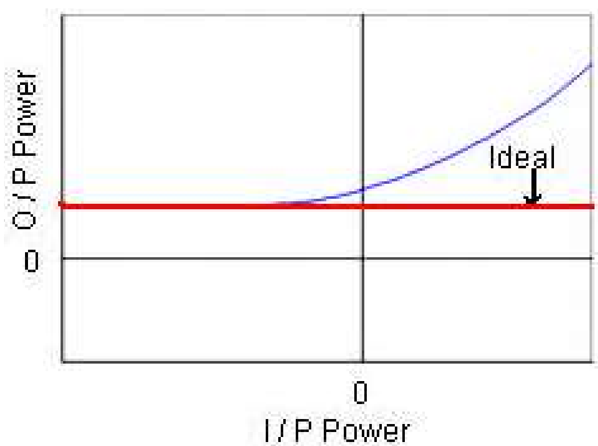
Fig. 1: Block diagram of SLM technique

Table 1:

Class	K	k
A	58.7%	0.1247
B	90.7%	0.1202



(a) AM-AM conversion



(b) AM-PM conversion

Fig. 2: AM/AM and AM/PM conversion characteristics of a SSPA

band-width. The inside component determines the amount of bit error rate degradation of the system, whereas the out-side component effects the adjacent frequency bands. In other words outside component increases the out of band radiation of the signal. The transmitter nonlinear distortion include signal clipping in the analog to digital (A/D) converter, signal clipping in the IFFT and FFT processors with a limited word length, amplitude modulation (AM)/AM and AM/phase modulation (PM) distortion in the radiofrequency(RF) amplifiers. The out-off-band (OBN) of OFDM signals increases due to nonlinear power amplifiers operating at lower back-offs. The high PAPR of OFDM requires high back-offs at the amplifiers[18].

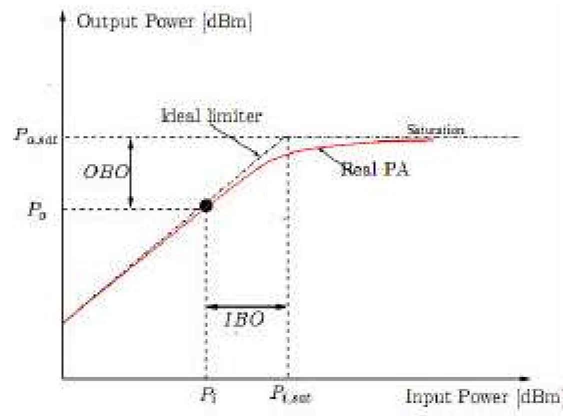


Fig. 3: Power amplifier response for IBO and OBO

In this paper, a memory less, time-invariant nonlinearity is assumed. The modulated OFDM signal is represented by

$$s[t] = A[t]e^{j\theta[t]} \quad (6)$$

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 signal of the HPA can be modeled as

$$s_{HPA}[t] = g(A[t]).e^{j\{\theta[t]+\Phi(A[t])\}} \quad (7)$$

$$s_{HPA}[t] = h[t].A[t].e^{j\{\theta[t]+\Phi(A[t])\}}$$

and

$$\hat{S}_{HPA}[t] = \hat{h}[t].A[t].e^{j\{\theta[t]+\hat{\Phi}(A[t])\}} \quad (8)$$

where h [t] and Φ (A[t]) are usually called real-valued functions of AM/AM and AM/PM conversion, respectively, $\hat{h}[t]$ and $\hat{\Phi}(A[t])$ are amplitude and phase offset estimated by the adaptive nonlinear estimator(ANE).

Here we assume the non-linear amplifier as Solid-State Power Amplifier (SSPA). Figure 2 shows the normalized characteristics of SSPA model.

The AM/AM and AM/PM conversion characteristics of a solid-state power amplifier (SSPA) can be expressed as [16].

$$g(A[t]) = \frac{vA[t]}{\left(1+\left[\frac{vA[t]}{A_0}\right]^{2r}\right)^{\frac{1}{2r}}} \quad (9)$$

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

where v≥0 is the small signal gain, A_0≥0 is the output saturating amplitude and r≥0 is a parameter to control

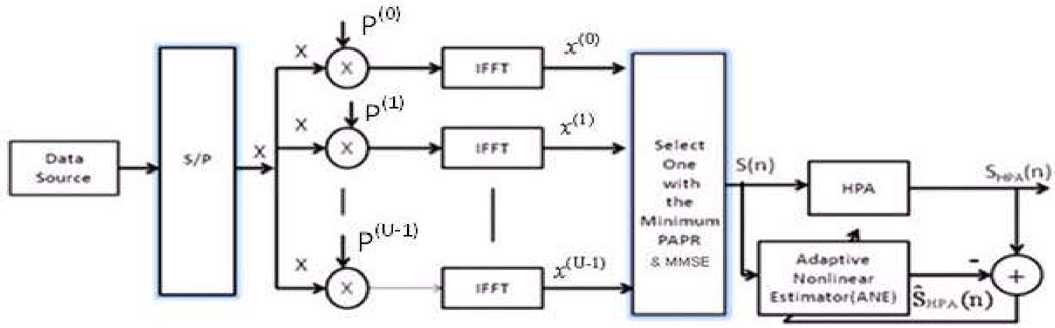


Fig. 4: Proposed block diagram of SLM scheme with adaptive nonlinear estimator

the smoothness of the transition from the linear region to the saturation level. If r is ∞, then it is called Hard limiter. The hard limiter is defined as

$$g(A(t)) = \big|_{r\to\infty} = \begin{cases} vA(t) & \text{if } vA(t) \le A_0 \\ A_0 & \text{otherwise} \end{cases} \tag{10}$$

Non-linear Effect on OFDM Signal

The nonlinear amplifier distortion of a SSPA depends on the back-off. Figure 3 shows a typical AM/AM response for an HPA, with the associated input and output back-off regions (IBO and OBO, respectively) [6].

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

$$IBO = 10\log_{10}\frac{P_{i,sat}}{\overline{P_i}} \tag{11}$$

and

$$OBO = 10\log_{10}\frac{P_{o,sat}}{\overline{P_o}} \tag{12}$$

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.

PROPOSED METHOD

A new technique using SLM combined with adaptive nonlinear estimator (ANE) method is proposed in this paper. Figure 4 shows the block diagram of the proposed method. Assume that the characteristics of AM / AM and AM / PM are independent of each other and can be estimated independently. The HPA model is considered for estimating the time varying property of HPA. due to the supply voltage variations and temperature change [13].

Figure 5 shows the HPA I/P as S(n), HPA O/P as $S_{HPA}(n)$ and ANE O/P is $\hat{S}_{HPA}[n]$ can be expressed as:

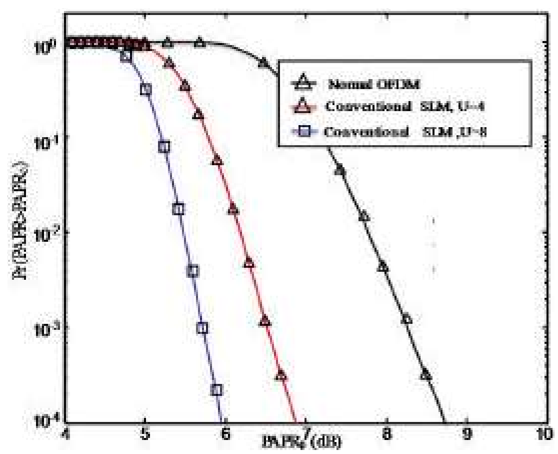


Fig. 5: CCDFs of SLM and normal OFDM

$$S(n) = A(n).e^{j\theta(n)}$$

$$\begin{aligned} S_{HPA}(n) &= g[A(n)].e^{j\{\theta(n)+\Phi_\Delta[A(n)]\}} \\ &= h(n).A(n).e^{j\{\theta(n)+\Phi_\Delta[A(n)]\}} \\ &= h(n).A(n).e^{j\theta_e(n)} \end{aligned} \tag{13}$$

and

$$\hat{S}_{HPA}(n) = \hat{h}(n).A(n).e^{j\{\theta(n)+\hat{\Phi}_\Delta[A(n)]\}} \tag{14}$$

Where A(n) and θ (n) represent the input signal amplitude and phase. h (n) and Φ_Δ [A(n)] are the real value amount of AM/AM and AM/PM at the HPA output at time n. $\hat{h}(n)$ and $\hat{\Phi}_\Delta[A(n)]$ are amplitude and phase offset estimated by the ANE respectively. Accordingly, similar to the derivation for updating the pre-distorter coefficient which is used to compensate the nonlinear distortion by HPA, the LMS algorithm the amplitude and phase offsets between the OFDM signals before and after the HPA is carried out.Therefore, the difference d(n) between the HPA output and ANE output is

$$d(n) = S_{HPA}(n) - \hat{S}_{HPA}(n) \tag{15}$$

We know that, the amplitude and phase are independent. Therefore, the amplitude difference $d_{gain}(n)$ is

$$d_{gain}(n) = |S_{HPA}(n)| - |\hat{S}_{HPA}(n)|$$
$$= |S_{HPA}(n)| - |\hat{h}(n).A(n)| \quad (16)$$

and Phase difference $d_{phase}(n)$ is

$$d_{phase}(n) = \theta_e(n) - \{\theta(n) + \hat{\Phi}_\Delta(n)\} \quad (17)$$

According to steepest descent algorithm, the update formulas for the ANE, $\hat{h}(n+1)$ and $\hat{\Phi}_\Delta(n+1)$ can be given as

$$\hat{h}(n+1) = \hat{h}(n) + \frac{1}{2}\mu[-\nabla_{gain}(n)] \quad (18)$$

and

$$\hat{\Phi}_\Delta(n+1) = \hat{\Phi}_\Delta(n) + \frac{1}{2}\mu[-\nabla_{phase}(n)] \quad (19)$$

The convergence time of the LMS adaptive algorithm depends on the step size μ. If μ is small, then it may take a long convergence time.However if μ is too large, the algorithm may never converge [8]. Therefore

$$h(n+1) = \hat{h}(n) + \mu_{gain}[|S_{HPA}(n)||P(n)| - \hat{S}_{HPA}(n)P^2(n)] \quad (20)$$

and

$$\hat{\Phi}_\Delta[A(n+1)] = \hat{\Phi}_\Delta[A(n] + \mu_{phase}\{\Phi_\Delta[A(n)] - \hat{\Phi}_\Delta[A(n)]\} \quad (21)$$

Where $\quad |\hat{S}_{HPA}(n+1)| = \hat{h}(n+1)|A(n+1)|$

is for amplitude and

$$\hat{\Phi}_\Delta(n+1) = \Phi_\Delta(n+1) + \hat{\Phi}_\Delta(n+1)$$

is for phase and this way, we can get the estimated output signal $\hat{S}_{HPA}(n+1)$. After updating amplitude and phase offset values, the estimated output signal $\hat{S}_{HPA}(n)$ is used to find OFDM signal with minimum nonlinear distortion. Then, the total minimum mean square error (MSE) is selected for the OFDM signal $S(n)$ (n = 0, 1, 2... LN-1) can be written as

$$MSE \approx \sum_{n=0}^{LN-1} |S(n) - \hat{S}_{HPA}(n)|^2 \quad (22)$$

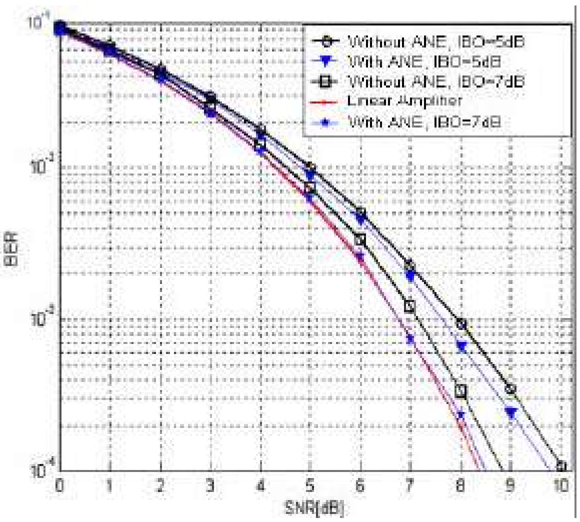


Fig. 6: BER Performance of original OFDM with and without ANE

$$\hat{v} = \text{argmin}\{MSE\}, \quad \text{for } v = 0,1,....U-1 \quad (23)$$

After calculating MSE, we can transmit the OFDM signal with minimum mean square error.

SIMULATION RESULTS

The performance improvement of our proposed scheme is evaluated by simulation. The number of subcarriers are assumed to be N = 128 and the applied signal modulation is 16-QAM.

CCDF performance: The CCDF shows the probability of an OFDM frame exceeding a given PAPR,

$$CCDF[PAPR(x(t))] = Pr(PAPR \succ PAPR_0)$$

Figure 5 shows the CCDF performance curve with SLM and without SLM. At probability 10^{-3} the PAPR of conventional SLM reduction can be reduced about 1dB for U=4 and at U=8 the PAPR become twice. ie 2dB.

BER performance: Figure 6 gives the BER performance of original OFDM with and without ANE. Simulation result shows that at 5dB IBO, the conventional OFDM method with ANE can achieve 0.2dB signal to noise ratio gain than conventional OFDM method without ANE. Meanwhile at IBO = 7dB the signal to noise ratio gain of conventional OFDM method with ANE becomes 0.5dB. This means that, more the input-back off (IBO), better is the BER performance. ANE makes a small improvement in the

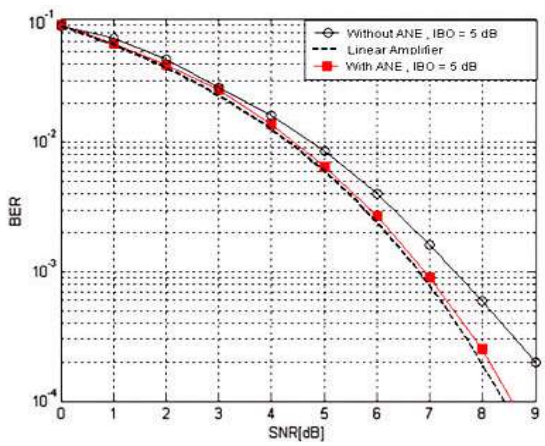


Fig. 7: OFDM using SLM method with and without ANE

BER performance. Consequently, it is clear that by using ANE at 7 dB IBO, BER performance closely matches with linear amplifier.

Figure 7 shows that the BER performance curve of OFDM using SLM method with and without ANE. It is clear from Figure 7 that at 10^{-3} BER 0.5dB SNR gain is achieved for IBO = 5dB with ANE. It can be observed that SLM method, with ANE at 5 dB IBO is closely matched with linear amplifier.

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 HPA using adaptive nonlinear estimator. The BER performance of OFDM system is investigated when HPA is combined with and without ANE and it is observed that ANE improves the BER performance. From the simulation results, it is shown that the necessary input back off is 5 dB in the SLM with ANE operation, to closely match with the linear amplifier. 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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