

Performance of a Predistorter Based on Saleh Model for OFDM Systems in HPA Nonlinearity

Mohammad Mehdi Shammasi, S. Mostafa Safavi

Electrical Engineering Department, Amirkabir University of Technology

Tehran, Iran

m.shammasi@gmail.com, msafavi@aut.ac.ir

Abstract— Orthogonal Frequency Division Multiplexing (OFDM) is an attractive technique for wireless communication applications. However, it suffers from high nonlinear distortion in nonlinear devices such as high power amplifiers (HPA) due to large peak to average power ratio (PAPR) of the OFDM signals. A predistorter based on inverse of the Saleh model is proposed to compensate for the nonlinearity. In this paper, we investigate the BER performance of an OFDM system in a nonlinear environment with and without the use of the proposed predistorter. Optimum values of amplifier output back off (OBO) are calculated for different scenarios and effect of modulation order and number of subcarriers on system performance are studied. Results show that use of predistorter can significantly enhance the system performance by reducing the needed OBO and increasing HPA power efficiency. Other simulations were performed to investigate the effect of modulation order and number of subcarriers on the system performance.

Keywords— OFDM, HPA, Nonlinearity, Saleh model, Predistorter

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has gained much attention for high speed digital communications and has been used in different communication applications such as Digital Video Broadcasting (DVB), Asymmetric Digital Subscriber Line (ADSL), Wireless Local Area Network (WLAN) and Wimax, for its ability to mitigate severe multipath fading and efficient implementation using fast Fourier transform (FFT) and inverse FFT (IFFT) [1]. In spite of many advantages, OFDM systems show a great sensitivity to amplifier nonlinearity due to large Peak to Average Power Ratio (PAPR) of the transmitted signals. The nonlinear distortion at the transmitter causes both in-band and out-of-band noise and adjacent channel interference (ACI), which may become intolerable if not controlled [2],[3].

In order to prevent nonlinear distortion, the simplest method is to back off signal power sufficiently from the saturation point of the High Power Amplifier (HPA) to the linear region. This will however reduce the efficiency of the HPA. Other methods include reducing the PAPR of OFDM signal i.e. by clipping and coding. Each method has its advantages and drawbacks. Another method is to eliminate the nonlinear effects of the HPA by predistorting the signal prior to HPA. By “Predistorter”, we mean a device cascaded before the power amplifier with the purpose of canceling the distortion caused by the HPA. The predistorter can be implemented by different strategies. Assuming that the transfer function of a HPA is correctly modeled *a priori* by some methods, the predistorter can be then implemented as a direct inverse of the HPA characteristics.

In [4] different types of predistortion techniques is evaluated experimentally, however, the research lacks an evaluation of predistorting based on inverse saleh model.

In this paper, we consider a Traveling Wave Tube Amplifier (TWT) with characteristics based on measurements done by Kaye et al. [5]. We propose a predistorter based on Saleh model. Saleh model is the most suitable model for TWTAs. Then we study BER performance variation according to OBO values for the OFDM system in nonlinear environment with and without the use of predistorter. We present the optimum values of OBO needed in each case and we also study the effect of modulation order and number of subcarriers in BER performance. It should be noted that the nonlinear distortion is independent of the channel environment and the channel is assumed to be AWGN.

II. SYSTEM DESCRIPTION

The overall system architecture is presented in Fig. 1. The model consists of an OFDM transmitter, a predistorter, the high power amplifier, the AWGN channel and the OFDM receiver.

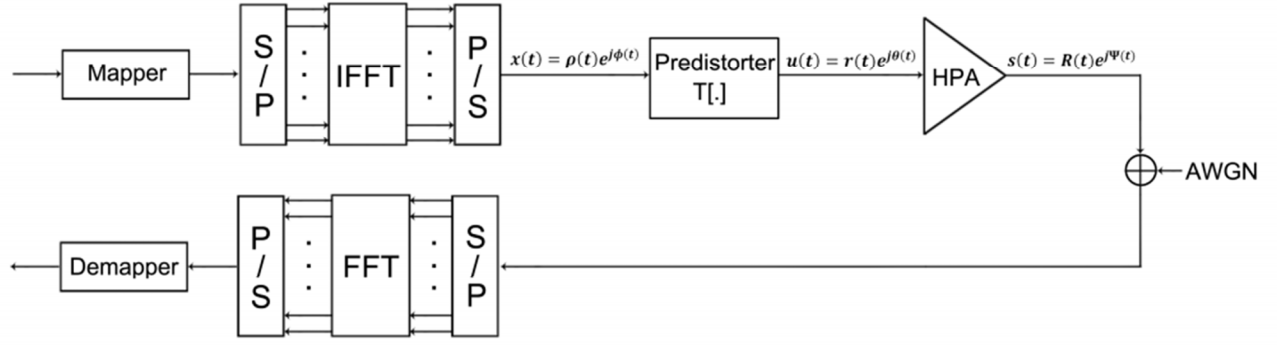


Figure 1. Block diagram of the overall OFDM system with HPA and Predistorter

A. OFDM System

The block diagram of OFDM system is shown in Fig. 1. The complex envelope of a baseband OFDM signal is:

$$x(t) = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j2\pi f_k t} \quad (1)$$

Where $f_k = k/T$ is the k 'th subcarrier frequency and T is the symbol duration. The samples of $x(t)$ taken at times $t = nT/N$ are expressed as:

$$x[n] = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j2\pi nk/N}, \quad n = 0, 1, \dots, N-1 \quad (2)$$

Which is identical to inverse Fourier transform (IFFT) of X_k . Where X_k s are the modulated data symbols mapped by a desired constellation in the mapper.

B. The High Power Amplifier

The high power amplifier used here is a TWT. TWT amplifiers exhibit nonlinear distortion in both amplitude (AM-to-AM conversion) and phase (AM-to-PM conversion). We have used experimental data presented in [5] to model the TWTA. Fig. 2 shows the AM/AM and AM/PM characteristics of the TWTA according to [5].

C. Predistorter

The predistorter is used for compensation of HPA's nonlinear effects as in the Fig. 1.

For the signal at the output of HPA the following conditions must be satisfied [6]:

$$R(t) = A[r(t)] \quad (3)$$

$$\Psi(t) = \theta(t) + \Phi[r(t)] \quad (4)$$

Where $r(t)$ and $\theta(t)$ are the amplitude and phase of signal at the input of HPA, $A[.]$ and $\Phi[.]$ are the AM/AM and

AM/PM transfer functions of the HPA. For the predistorter to completely compensate the nonlinearity, we should have: $x(t) = s(t)$, so:

$$r(t) = A^{-1}[\rho(t)] \quad (5)$$

$$\theta(t) = \phi(t) - \Phi[r(t)] \quad (6)$$

The most suitable analytical representation for TWT amplifiers is Saleh model. For the Saleh model AM/AM and AM/PM conversions are: [7]

$$\text{AM/AM: } A[r(t)] = \frac{\alpha_a r(t)}{1 + \beta_a r^2(t)} \quad (7)$$

$$\text{AM/PM: } \Phi[r(t)] = \frac{\alpha_\phi r^2(t)}{1 + \beta_\phi r^2(t)} \quad (8)$$

Where α_a & β_a are the AM/AM parameters and α_ϕ & β_ϕ are the AM/PM parameters of the Saleh model.

The inverse function of $A[.]$ only exist for $\rho(t) \geq \sqrt{\frac{\alpha_a^2}{4\beta_a}}$, so we should restrict the input of the predistorter, so that its amplitude doesn't exceed $\sqrt{\frac{\alpha_a^2}{4\beta_a}}$.

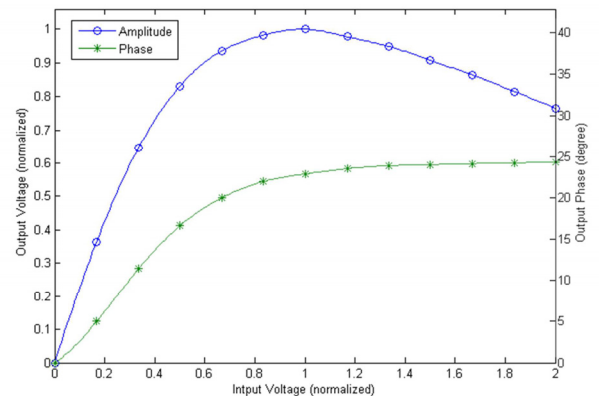


Figure 2. AM/AM and AM/PM characteristics of the TWTA [5]

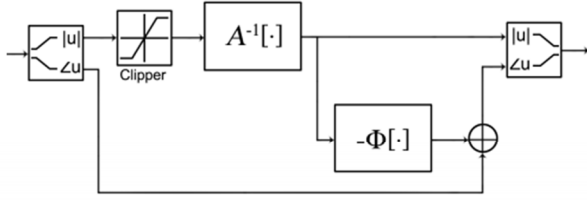


Figure 3. Block diagram of the predistorter system

At the output of predistorter we have:

$$r(t) = \begin{cases} \frac{\alpha_a - \sqrt{\alpha_a^2 - 4\beta_a \rho(t)^2}}{2\beta_a \rho(t)}, & 0 < \rho(t) < \sqrt{\frac{\alpha_a^2}{4\beta_a}} \\ A^{-1}\left(\sqrt{\frac{\alpha_a^2}{4\beta_a}}\right) = \frac{1}{\sqrt{\beta_a}}, & \rho(t) \geq \sqrt{\frac{\alpha_a^2}{4\beta_a}} \end{cases} \quad (9)$$

$$\theta(t) = \phi(t) - \frac{\alpha_\phi r^2(t)}{1 + \beta_\phi r^2(t)} \quad (10)$$

A block diagram of the predistorter system is illustrated in Fig. 3.

In case of ideal predistortion (i.e. the assumption of Saleh model for HPA was exact) the overall HPA + predistorter system acts like a soft limiter, it doesn't change the phase of input signal, but its amplitude is clipped by $\sqrt{\frac{\alpha_a^2}{4\beta_a}}$. In this case ideal predistortion is described by the following AM/AM and AM/PM functions:

$$\text{AM/AM: } F_A(\rho(t)) = \begin{cases} \rho(t), & 0 < \rho(t) < \sqrt{\frac{\alpha_a^2}{4\beta_a}} \\ \sqrt{\frac{\alpha_a^2}{4\beta_a}}, & \rho(t) > \sqrt{\frac{\alpha_a^2}{4\beta_a}} \end{cases} \quad (11)$$

$$\text{AM/PM: } F_\psi(\rho(t)) = 0 \quad (12)$$

Since Saleh model isn't the exact representation of the HPA (in our case, it has a RMS error of 0.01 for amplitude and 0.469 for phase [7]), there is some performance degradation compared to ideal predistortion.

As mentioned, OFDM signals have a high PAPR thus the signal may be clipped in some points which results in signal distortion and BER degradation. So sufficient values of output back off (OBO) should be considered for better BER performance.

III. SIMULATION RESULTS

First of all it should be noted that since in our simulations the HPA model is normalized, the power of one OFDM symbol should be also normalized to 1. The Saleh parameters

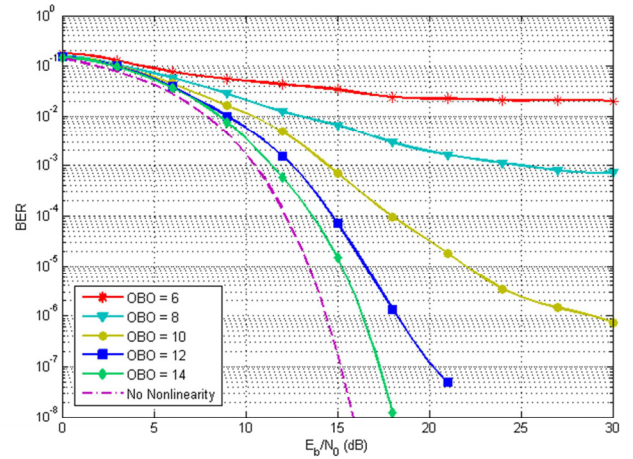


Figure 4. BER of HPA only system according to several OBO values. (Modulation = 16QAM, Number of subcarriers = 512)

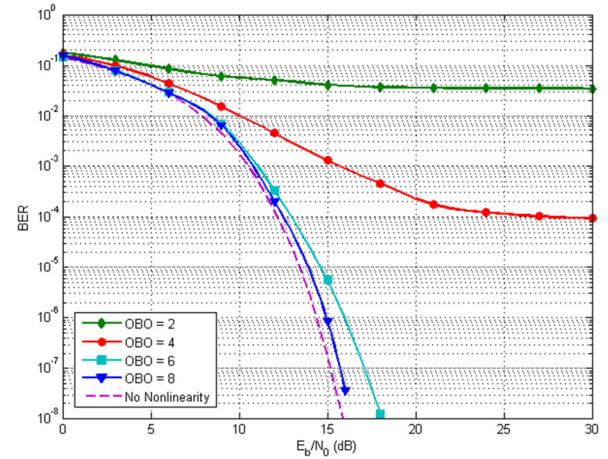


Figure 5. BER of HPA + Predistorter system according to several OBO values. (Modulation = 16QAM, Number of subcarriers = 512)

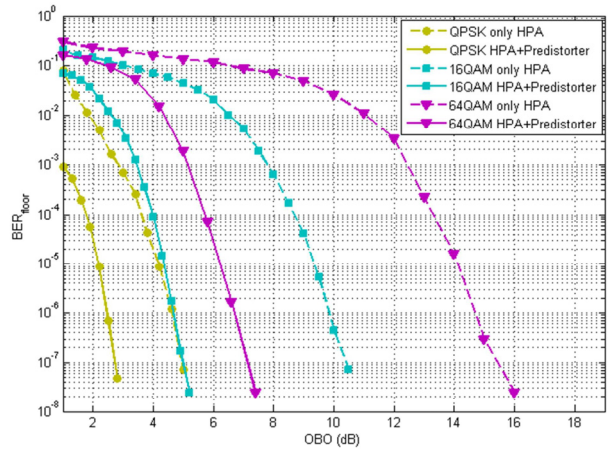


Figure 6. BER_{floor} vs. OBO for HPA and HPA + Predistorter and different modulations. (Number of subcarriers = 512)

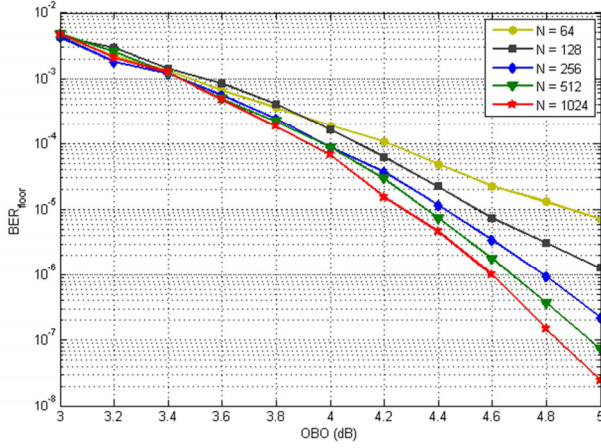


Figure 7. BER_{floor} vs. OBO for HPA + Predistorter and different number of subcarriers (Modulation = 16QAM)

that fits the data presented in [5] are: $\alpha_a = 2.1587$, $\beta_a = 1.1517$, $\alpha_\phi = 4.033$, $\beta_\phi = 9.1040$. The channel is assumed AWGN.

Fig. 4 shows the BER performance of an OFDM system with HPA when no predistorter is used according to different values of OBO. The number of subcarriers is 512 with 16QAM modulation. The more the OBO increases the better BER performance in cost of lower power efficiency of HPA.

Fig. 5 shows the same system, but this time with the use of predistorter. Compared to system without predistorter, lower OBO values are required to obtain a good BER performance, which results in higher HPA power efficiency.

To obtain an OBO value that makes a good balance between BER performance and HPA power efficiency a useful performance measure is the total degradation (TD) defined by [8]:

$$TD = OBO + \Delta \quad (13)$$

Where OBO is the output power back off of the HPA and Δ represents the increment in the signal to noise ratio E_b/N_0 , which is required to maintain a given BER level assuming that no nonlinear distortion exists.

Optimum OBO values corresponding to the minimum TD has been obtained from further simulations and listed in Table 1 for a reference BER of 10^{-5} . The results are for a 512 subcarrier OFDM system with QPSK, 16QAM and 64QAM modulations in HPA only and HPA+Predistorter cases. Optimum OBO values corresponding to an ideal predistortion is also presented. It can be seen that since the Saleh model is not the exact model of the HPA, our system with predistorter acts poorer than an ideal predistortion and the corresponding OBO values are higher.

Table 1. Optimum OBO values (dB) corresponding to the minimum TD for a 512 subcarrier OFDM system (Reference BER = 10^{-5})

Modulation format	HPA only	HPA + Predistorter	Ideal predistorter
QPSK	7	4.5	4.2
16QAM	12.5	6.1	5.9
64QAM	17.2	7.9	7.4

According to Fig. 4 and Fig. 5, for a specific value of OBO, it is a point in which increasing the SNR would no longer increases the BER performance and there is a floor for bit error rate of the system (BER_{floor}).

Fig. 6 shows BER_{floor} ($SNR = \infty$) vs. OBO plots for different modulations and for HPA only and HPA+Predistorter cases in a 512 subcarrier OFDM system. The use of predistorter significantly reduces the OBO needed for a specific BER_{floor} . Increasing the modulation order will result in a higher PAPR thus higher values of OBO are needed to maintain a specific BER performance.

Fig. 7 shows BER_{floor} vs. OBO of the system with predistorter according to several number of the OFDM subcarriers (64, 256, 512 and 1024) and for 16QAM modulation. In this case BER_{floor} decreases when number of subcarriers increases. Although increasing the number of subcarriers increases PAPR, it is shown in [9] that for small clipping levels the power of clipping noise for each OFDM symbol is independent of the number of subcarriers. Thus, since the clipping noise will distribute among larger number of subcarriers, amount of noise in each subcarrier is lower which results in better BER performance.

IV. CONCLUSIONS

This paper represents a predistorter based on inverse of the Saleh model. BER performance according to different OBO values is studied and optimum OBO values are presented for different scenarios in a system with 512 subcarriers. It was shown that since Saleh model isn't the exact representation of the HPA, our predistorter system performs poorer than an ideal predistorter, though it still decrease the needed OBO and increase amplifier power efficiency. Effects of modulation order and number of subcarriers on floor of bit error rate were investigated. It was shown that while increasing modulation order degrades system performance, increasing number of subcarriers enhances it.

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