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Title	**Hybrid Predistortion Algorithm for HPA Non-linearity Mitigation**
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Re:	Extracts from WiMAGIC, Work Package 4, Task 4.3
Abstract	Time – frequency approach for the mitigation of high power amplifier nonlinearity
Purpose	To be discussed and approved for use in IEEE 802.16m SDD
Notice	
Release	
Patent Policy	

Hybrid Predistortion Algorithm for HPA Non-linearity Mitigation

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Introduction

In this contribution we propose a hybrid digital predistortion technique for mitigating the high power amplifier (HPA) nonlinearities in an OFDMA system that conforms to the set of system requirements stipulated for the IEEE 802.16m standard that is under development. The term *hybrid* refers to the fact that the proposed technique uses both time and frequency domain signal processing. This is in contrast to the usual approach to predistortion where all signal processing is carried out in one or the other domain. Specifically, the proposed method performs the HPA nonlinearity estimation task in the frequency domain and the compensation task in the time domain, as discussed in detail in [1]. The method has been simulated using a set of system parameters drawn from the 802.16m Evaluation Methodology Document (EMD) [2].

Nonlinearity Model in Time and Frequency Domais

To test the effectiveness of the proposed algorithm by computer simulation, we create a test environment where the HPA is modeled using the Rapp-2 model as specified in the EMD. Thus, the AM/AM conversion characteristic of the amplifier is represented as

$$y(t) = \frac{x(t)}{\left(1 + \left|\frac{x(t)}{C}\right|^{2s}\right)^{\frac{1}{2s}}} \qquad (1)$$

and a perfect phase response is assumed. Here, the parameter C determines the output saturation amplitude, and the parameter s is the degree of nonlinearity. The proposed method is based on estimating the coefficients of the polynomial representation of the inverse of the AM/AM response. To demonstrate the main idea, we will use the above model with parameters (C,s)=(1,2). Therefore, the inverse functions is

$$x(t) = \frac{y(t)}{(1 - y(t)^4)^{1/4}} \qquad (2)$$

and has the power series expansion

$$x(t) = c_1 y(t) + c_2 y(t)^5 + c_3 y(t)^9 + c_4 y(t)^{13} + c_5 y(t)^{17} + c_6 y(t)^{21} + c_7 y(t)^{25} \ldots \qquad (3)$$

Fourier transform duality governs that the powers in one domain are converted to the convolutions in the other domain. Using this principle, the frequency domain equivalent of the time-domain series expansion can be represented as

$$X = c_1 Y + c_2 Y * Y * Y * Y * Y + ... \qquad (4)$$

where X=X(f) is the Fourier transform of x(t) and Y=Y(f) is the Fourier transform of y(t). Notice that, in this example, all terms except those with power 4n+1 (where n= 0,1,2,3....) are absent in the time domain. However, the success of the method does not require that the time-domain response have any special feature other than being invertible.

The major task of the proposed predistortion technique is to estimate the coefficients c_1, c_2,… using X(f) and Y(f) as data. This is accomplished by sending a known training sequence x(t) and observing the HPA output y(t). In this phase, the predistortion element is removed from the signal path. From x(t) and y(t), the frequency domain functions X(f) and Y(f) are obtained by FFT, which is an integral element of any OFDM system. Once we have the coefficients c_1, c_2,… at hand, the predistorter, which is simply the time-domain inverse function in the power series form, is placed into the signal path before the HPA. The estimation algorithm runs continually to improve estimation accuracy and track any time variation of the HPA nonlinearity.

Implementation of the hybrid predistortion algorithm for IEEE 802.16m

The basic idea of the proposed hybrid predistortion technique is to estimate the HPA nonlinearity in the frequency domain and perform the predistortion in the time domain. We now discuss the implementation details specific to the 802.16m application.

We consider a system working in the TDD mode. The estimation phase for this is shown in Figure 1.

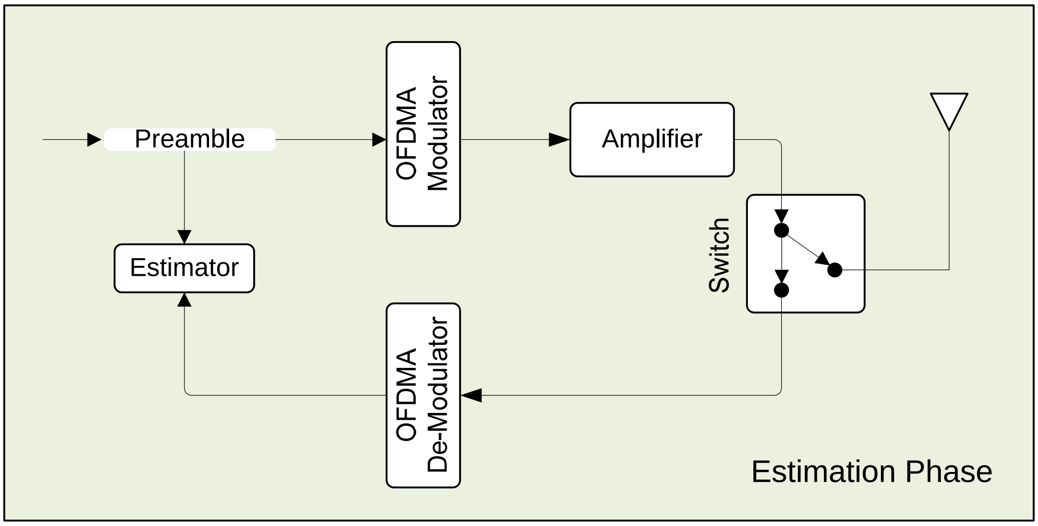

Figure 1: Estimation Phase. *(The receiver is active during preamble transmission)*

During the estimation phase, the predistorter is removed from the signal path and a known preamble specified in the standard is transmitted. In normal TDD operation the receiver is switched off during transmission. However, in the estimation phase, we keep the receiver on during transmission, so as to be able to observe the HPA output generated in response to the transmitted preamble. The transmitter needs to send the boosted preamble *(in the simulations we have used a gain in the range of 20-23 dB)* so as to capture the nonlinear response across the entire dynamic range of the HPA.

The compensation/predistortion phase of the proposed method is shown in Figure 2.

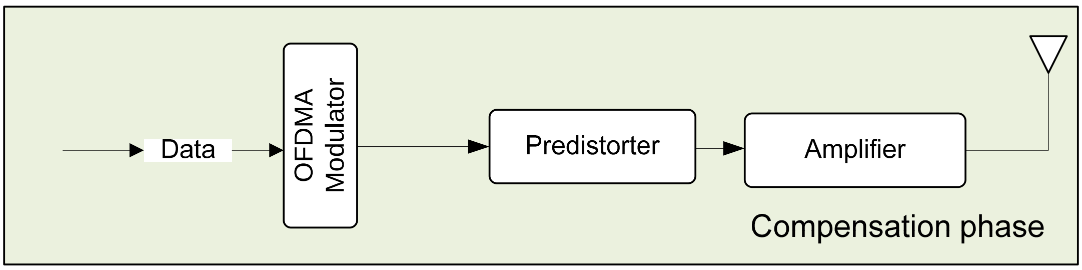

Figure 2: Compensation phase

The good point about this preamble approach is that the transmitter need not to be stopped during the transmission for the estimation purpose. Therefore any change in the amplifier model can be easily tracked in real-time system operation.

In Table 309 of IEEE 802.16d standard, the preamble sequences for downlink frame structure are defined. As an example one of the various preambles provided in standard is shown in the table below.

Table 1: Preamble from the IEEE 802.16d/e standard

Preamble
A9F7 AC1B D0A4 BD69 4D3E DC29 91CC 3B2D 24BF 26A2 2346 F8DB 3702 02CD… A25D 382D 4119 AAC6 76E3 20A9 38A9 5762 C407 8689 B602 4E47 7F0E DA8F 5631… 06F0 D70E BE3E 006F 75B5 0B53 7D

The preamble shown above is the hexadecimal representation of the 568 bits that modulate the subcarriers according to the formula

$$\begin{aligned} Re\{PreamblePilotsModulated\} &= 4.\sqrt{2}.\left(\frac{1}{2}-W_k\right) \\ \text{Im}\{PreamblePilotsModulated\} &= 0 \end{aligned} \quad (5)$$

Simulation Results

We have performed simulations using the above preamble sequence. Figure 3 shows the HPA response with and without predistortion.

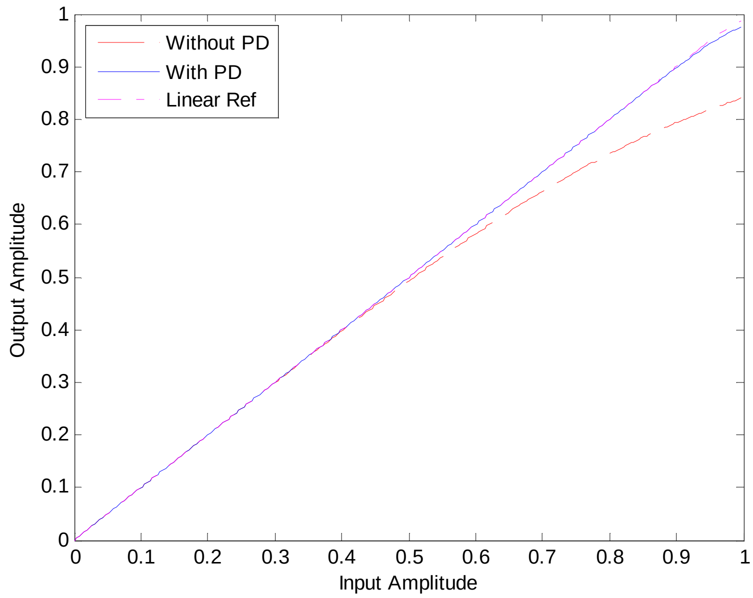

Figure 3: Linearization of amplifier

A major concern in wireless systems is out-of-band emissions, which cause interference to other users and systems. A benchmark parameter in this sense is the amount of output power back-off (OBO) required by the HPA to meet the spectral emission requirements. Figure 4 shows the comparison of the output spectrum for various values of OBO with and without predistortion. In this figure, the benchmark response may be taken as the 15dB OBO without predistortion. There is a regulation defined by FCC [3] for adjacent channel interference, which is also cited by the 802.16m EMD. In the IEEE 802.16e standard [4] a spectral mask is defined as a reference, which is shown in Figure 4 with the dark blue line

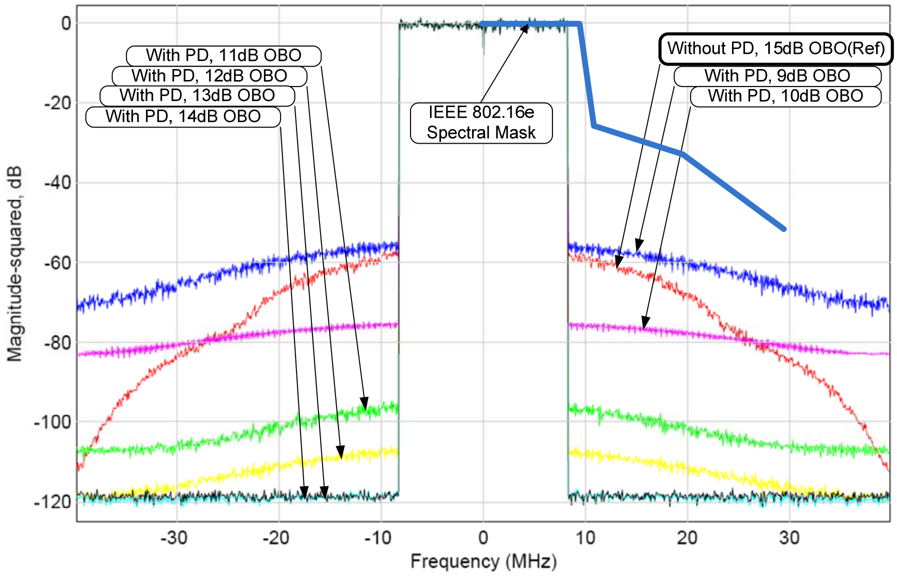

Figure 4: Output power spectral density for various OBO values with and without predistortion.

The performance of the predistorter, in terms of the null suppression is shown in Table 2:

Table 2: Suppression of the null-subcarriers, at the edges of the band.

OBO (dB)	**Relative suppression of nulls at the band edges (dB)**
15	60
12	60
10	38
9	20

References

[1] S.Ali, G.Markarian, E.Arikan, “Novel Predistortion Algorithm for OFDMA”, 2008, unpublished.

[2] J. Zhuang, L. Jalloul, R. Novak, and J. Park, "Draft IEEE 802.16m Evaluation Methodology," IEEE 14th December 2007.

[3] FCC, "Amendment of Parts 1, 21, 73, 74 and 101 of the Commission's Rules to Facilitate the Provision of Fixed and Mobile Broadband Access, Educational and Other Advanced Services in the 2150-2162 and 2500-2690 MHz Bands." vol. FCC 04-258, FCC, Ed.: FCC, 2004.

[4] Contributors, "IEEE 802.16e-2005 Standard," IEEE Task Group e 2005.