POWER AMPLIFIER LINEARISATION USING PRE-DISTORTION WITH MEMORY

G. Baudoin(1), P. Jardin(1), R. Marsalek(1,2)

(1) ESYCOM – ESIEE (Equipe systèmes de communications)
2, Boulevard Blaise Pascal, BP99, 93162 Noisy-le-Grand Cedex, France
g.baudoin@esiee.fr, p.jardin@esiee.fr, marsaler@esiee.fr

(2) Department of Radio Electronics, Brno University of Technology
Purkynova 118, Brno, 602 00, Czech Republic
tel. (42) 05 41 14 91 64, fax (42) 05 41 14 92 44

Abstract

The method for power amplifier digital adaptive baseband pre-distortion with memory is proposed and applied to compensate the nonlinearity of power amplifier (with or without memory) driven with OFDM signal.

I. Introduction

The nonlinearities present in power amplifiers (PA) cause the amplitude and phase distortions of the PA output signal. These distortions are at the origin of undesirable spectral regrowth and constellation point's deformation if the PA input is a signal with non-constant envelope. Many techniques for compensations of the nonlinearities and their effects were proposed [1]. Our work is focused on the Adaptive baseband digital pre-distortion technique. Its principle is to distort the PA input signal in that way that the nonlinearities in overall system (predistorter + PA) are negligible.

To compensate the PA distortion, the global system (predistorter+PA) must behave as the linear system with gain G_0. This gain depends on the Peak Back Off (PBO) representing the difference between PA saturation power and the maximal PA output power to transmit. In this paper, the adaptive pre-distortion method with memory, based on recursive post-distortion function calculation is presented.

II. PA modeling

The behavior of a memoryless PA can be completely characterized by its AM/AM and AM/PM curves. These characteristics give the PA output power and phase, respectively, as the functions of PA input power for the case of single-tone PA input signal. For the wideband signals used in modern communication systems like UMTS, the PA memory effect cannot be ignored. In such case, Volterra [4] or Wiener-Hammerstein systems can model the PA behavior. These models are in general too complex for practical use, so it's possible to work with theirs simplified versions – for example the polynomial with memory.

All the derivations in this paper will be done in baseband equivalent domain. Let z_n is the complex envelope of the modulated signal at sample n and A is the non-linear operator representing the PA behavior such as :

- For the memoryless PA
  $\mathrm{A}\left(z_n\right) = AM(|z_n|^2)\exp(j(\arg(z_n) + PM(|z_n|^2))$ where $AM(|z_n|^2)$ and $PM(|z_n|^2)$ are the AM/AM and AM/PM characteristics, respectively. This operator can be modeled like in [2].

$$A(z_n) = \sum_{k=0}^{P-1} a_k z_n |z_n|^{2k} \tag{1}$$

- For the PA with memory, we adopt the polynomial model with memory in a form

$$A(z_n) = \sum_{k=0}^{N-1} \sum_{l=0}^{L} a_{k,l} z_{n-ln_0} \left| z_{n-ln_0} \right|^k \tag{2}$$

  An example of model having such form is given in [3].

III. Adaptive polynomial pre-distortion method with memory based on post-distortion

In the classical predistorter adaptation approach (Figure 1a), the pre-distortion operator F_{pre} is calculated by minimization of the criterion between the PA attenuated output signal z_{pa} and predistorter input z. The ideal pre-distortion operator is then defined as : $\mathrm{A}\left(\mathrm{F}_{pre}(z)\right) = G_0 z$ or $\mathrm{F}_{pre}(z) = \mathrm{A}^{-1}(G_0 z)$. As A is the non-linear operator, F_{pre} cannot be calculated directly from z_{pa} and z. Hence, some form of iterative algorithm has to be used.

As shown in [2], the post-distortion operator (F_{post}) calculation doesn't require the iterative approach, although expression for F_{post} et F_{pre} are identical. Thus in this paper, the technique for adaptive predistorter (with memory) calculation based on postdistorter calculation is shown.

The principle of the method is depicted on Figure 1b. $\mathrm{F}_{\mathrm{pre}}^{(\mathrm{n})}$ is the pre-distortion operator at sample n, $z_{p,n}$ and $z_{pa,n}$ are the PA input and output at same sample instant. The post-distortion operator $\mathrm{F}_{\mathrm{post}}^{(\mathrm{n})}$ is obtained by minimization of the least squares criterion:

$$J(n) = \sum_{l=1}^{n} \lambda^{n-l} \left| z_{p,l} - F_{post}^{(n)}\left(z_{pa,l}\right) \right|^2 \tag{3}$$

where λ is forgetting factor.
The polynomial pre(post)-distortion operator with memory was chosen :

$$\mathrm{F}\left(z_n\right) = \sum_{k=0}^{N-1} \sum_{l=0}^{L} f_{k,l} z_{n-ln_0} \left| z_{n-ln_0} \right|^k = \mathbf{f}^{\mathbf{T}} \mathbf{v}_{\mathbf{n}} \tag{4}$$

with n_0 being the elementary delay , $\mathbf{f}^{\mathbf{T}} = (f_{0,0} f_{1,0} \cdots f_{N-1,0}\; f_{0,1} f_{1,1} \cdots f_{N-1,1} \cdots f_{0,L} f_{1,L} \cdots f_{N-1,L})$ and $\mathbf{v}_{\mathbf{n}} = (z_n, z_n|z_n| \; ..., z_n|z_n|^{N-1}, z_{n-n_0}, z_{n-n_0}|z_{n-n_0}|, ..., z_{n-n_0}|z_{n-n_0}|^{N-1}, z_{n-Ln_0}, z_{n-Ln_0}|z_{n-Ln_0}|, ..., z_{n-Ln0}|z_{n-Ln_0}|^{N-1})^{\mathbf{T}}$.

The criterion $J(n)$ is therefore a quadratic function of the coefficients $f_{post\,k,l}^{(n)}$ belonging to $\mathrm{F}_{\mathrm{post}}^{(\mathrm{n})}$. It has unique minimum – solution of linear equations set. In the implementation, the recursive least squares algorithm (RLS) is used for $\mathrm{F}_{\mathrm{post}}^{(\mathrm{n})}$ calculation.
The pre-distortion operator at sample $n+1$ is its equivalent post-distortion operator at sample n.

$$\mathrm{F}_{\mathrm{pre}}^{(\mathrm{n+1})} = \mathrm{F}_{\mathrm{post}}^{(\mathrm{n})} \tag{5}$$

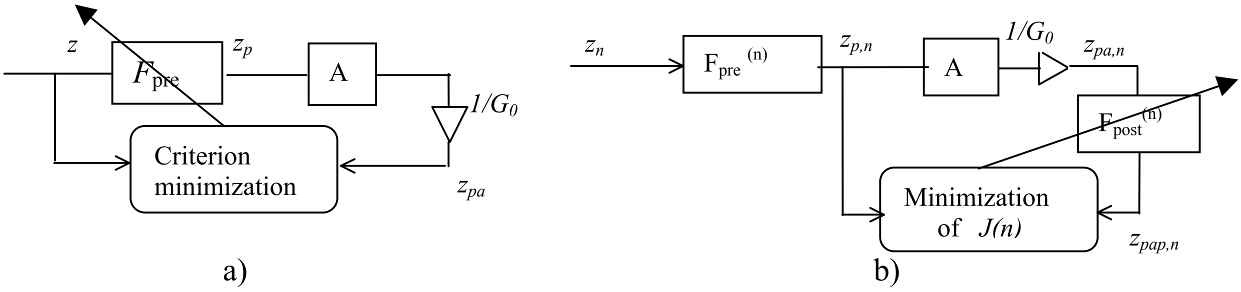


Figure 1: Classical pre-distortion approach (a), schematic of pre-distortion calculation based on post-distortion (b)

IV. Results for OFDM input signal

The above-described algorithm was tested with HIPERLAN 2 type modulated OFDM signal (64 subcarriers with 16QAM mapped symbols). The oversampling with factor 16 was used to cover the spectral regrowth caused by the PA nonlinearity.

As the first step, the PA model defined by Saleh [1] with $AM(|z|) = 2 \cdot |z| / (1 + |z|^2)$ and $PM(|z|) = \pi / 3 \cdot |z|^2 / (1 + |z|^2)$ served as the baseband PA model. Such model doesn't correspond to the application kept in view (OFDM and HIPERLAN 2) but serves as the common reference in many PA linearization domain publications.

Furthermore the PA input and output signals obtained from real amplifier working in class AB at the frequency of 1.45 GHz given by Diaz et al. in [3] were used for the tests. These OFDM type signals were obtained by subsampling the signal around central frequency f_0=5MHz and sampling at $4f_0$.

The identification of PA model having form as in eq. 2 is possible using these steps:

- Complex envelope calculation, conversion to baseband domain resulting in PA baseband input $z_{in,n}$ and output $z_{out,n}$ signals
- Least squares estimation on $z_{out,n}$ - $A(z_{in,n})$ to obtain PA coefficients $a_{k,l}$, based on equation similar to eq. 3 (with $\lambda=1$)

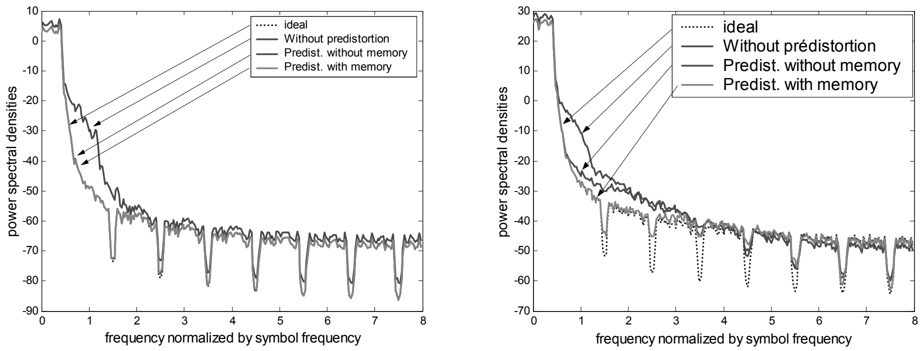
The polynomial with 6 coefficients (N=6) as the postdistorter operator F_{post} was considered during the experiments. Two cases were tested – memoryless predistorter (L=0) and predistorter with memory (L=1, n_0=1). The RLS algorithm initial conditions were set as follows: the initial pre-distortion polynomial $F_{post}^{(0)}(z) = z$ (corresponds that there is no predistorter at the adaptation start), the first « Kalman gain » set to 10^5 Id (Id means identity matrix), forgetting factor λ=0.99.

The power spectral densities of signals with and without pre-distortion for both above mentioned PA models are shown in Figure 2. In Figure 3, the instantaneous error between desired and actual PA output amplitude and the constellation diagram for PA model with memory are shown. Note that PBO was set to 0.96dB for all the presented results.

V. Conclusions

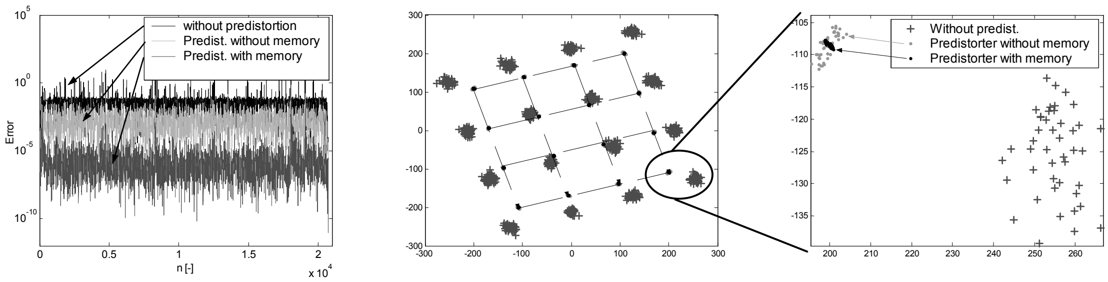
The proposed pre-distortion method based on polynomial with memory as the predistorter is able to take into the account the memory effects of power amplifiers driven with wideband input signals. The method was successfully tested on the classical memoryless Saleh model as

well as on the PA model with memory, identified from real measured OFDM signals at the input and output of class AB power amplifier.
One advantage of this method is its relative simplicity in comparison with more complex predistorters based for example on Volterra models.



a) b)

Figure 2 : Power spectral densities without and with pre-distortion (Saleh model (a), PA with memory [3] (b))



a) b) c)

Figure 3 : Instantaneous error between desired and actual PA output amplitude (a), constellation diagram (b) and its zoom (c) for PA with memory

References

[1] P.B. Kennington, "High linearity RF Amplifiers design", Artech House 2000.

[2] R. Marsalek, P. Jardin, G. Baudoin, "From post-distortion to pre-distortion for power amplifiers linearization", to appear in *IEEE Communication Letters,* 2003.

[3] J.I. Diaz, C. Pantaleon, I. Santamaria, "Nonlinearity Estimation in Power Amplifiers Based on Subsampled Temporal Data", *IEEE Transactions on Instrument and Measurement*, vol. 50, No.4, August 2001

[4] CH. H. Cheng, E.J. Powers, "Optimal Volterra Kernel Estimation Algorithms for a nonlinear Communication System for PSK and QAM inputs", *IEEE Transactions on Signal processing*, vol. 49, No. 1, January 2001