Memetic Algorithm for Digital Pre-Distortion of WiMAX Power Amplifier Based on a Memory Polynomial Model

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***Abstract*- Digital Pre Distortion (DPD) is one of the fastest and cost effective digital processing technique to mitigate the distortions in Power Amplifier (PA) caused by nonlinearity and memory effects. This paper presents a general DPD architecture for wideband PA systems based on a direct learning approach with constrained feedback bandwidth. The proposed scheme is based on evaluating the Power Spectral Density (PSD) of the PA and DPD output signal. The coefficients of PA and DPD are optimized iteratively in order to minimize the output PSD around the pre specified frequency. In this work, a stochastic optimization algorithm called Memetic Algorithm (MA) is used to optimize the coefficients of PA and DPD. This approach encourages scientific discussions and technological innovations toward an effective solution for reducing DPD system implementation complexity and cost. The study evidences prove that MA produces promising results for Worldwide Interoperability of Microwave Access (WiMAX) signal.**

***Keywords*- Power Amplifier, Memory Polynomial, Digital Pre-Distortion, Memetic Algorithm, radio frequency, WiMAX, Power Spectral Density**

I. INTRODUCTION

Modern wireless communication systems like WiMAX, LTE, are continuously developing in data rate and bandwidth to support more users and provide more data services [1]. To further fully utilize the frequency spectrum and support the significant increase of the modulated signal bandwidth, concurrent dual-band amplifiers have been developed recently [2]. As the bandwidth increases, it poses stringent requirements on the PA linearity, efficiency and memory effects. The importance of memory effects started to be recognized in PA/linearizer papers in the late 1980s [3-4]. DPD is a widely used technique to compensate the nonlinearity and memory effect of radio frequency (RF) PA [15, 16].

To effectively developed DPD at first an accurate PA model must be developed and the nonlinear characteristics of the PA are accurately modeled. DPD correctly inverted the nonlinear characteristics of the modeled PA so that the overall system response to a signal flowing serially through the cascade of DPD+PA can become linear as shown in figure 1 [2, 13, 14].

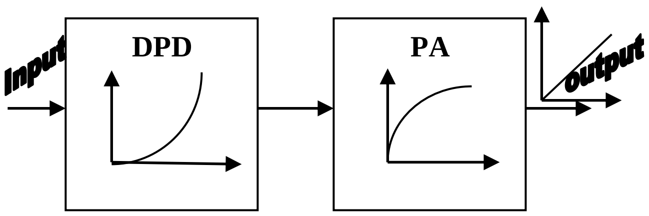

Fig. 1: Basic concept of DPD+PA

A model of a PA is a mathematical representation that provides the ability to predict the system performance. To defines the memoryless non linear PA in mathematically model $V_{in}{}^{n}(t)$, $V_{out}(t)$ and G_n are for input, output and gain respectively [3, 17, 18]

$$V_{out}(t) = \sum_{n=1(odd)}^{2n-1} G_n V_{in}{}^{n}(t) \tag{1}$$

Equation 1 is described as odd quintic polynomial:

$$V_{out}(t) = G_1 V_{in}(t) + G_3 V_{in}{}^{3}(t) + G_5 V_{in}{}^{5}(t) \tag{2}$$

Solving quintic polynomial (2) and filtered out the out of band products the developed equation (3) is

$$\begin{aligned}
&\left(G_1V_1+\frac{3}{4}G_3V_1^3+\frac{3}{2}G_3V_1V_2^2+\frac{11}{16}G_5V_1^5+\frac{30}{16}G_5V_2^4V_1+\frac{30}{8}G_5V_1^3V_2^2\right)\cos\omega_1 t+\\
&\left(G_1V_2+\frac{3}{4}G_3V_2^3+G_3\frac{3}{2}V_1^2V_2+\frac{11}{16}G_5V_2^5+\frac{30}{16}G_5V_1^4V_2+\frac{30}{8}G_5V_2^3V_1^2\right)\cos\omega_2 t+\\
&\left(\frac{3}{4}G_3V_1^2V_2+\frac{20}{16}G_5V_1^4V_2+\frac{15}{8}G_5V_2^3V_1^2\right)\cos\left(2\omega_1-\omega_2\right)t+\\
&\left(\frac{3}{4}G_3V_1V_2^2+\frac{15}{8}G_5V_1^3V_2^2+\frac{20}{16}G_5V_2^4V_1\right)cos\left(2\omega_2-\omega_1\right)t+\\
&+\frac{10}{8}G_5V_1^3V_2^2\cos\left(3\omega_2-2\omega_1\right)t+\frac{10}{8}G_5V_2^3V_1^2\cos\left(3\omega_1-2\omega_2\right)t
\end{aligned} \quad (3)$$

Now the Volterra series model is widely used to represent a non-linear system. Being a nonlinear dynamic system, the DPD is described by Volterra theory, where complex Base band input signal $(X(n))$ and output signal $(y(n))$ are related as [2, 16, 19]

$$y(n)=\sum_{k=1}^{\infty}\sum_{n_1}\cdots\sum_{n_k}h_k(n_1,n_2,\cdots n_k)\prod_{r=1}^{p}X(n-n_r)\prod_{q=p+1}^{k}X(n-n_q)^{*} \quad (4)$$

In (4), $h_k(n_1,n_2,\cdots n_k)$ are the Volterra kernels. To compute Volterra series parameters becomes complicated when the order of the polynomial increased [13, 20]. Also it is difficult to characterize the non-linear Volterra system by the system's unit impulse response. Therefore, some special cases of Volterra series are considered: Two-box, three-box or parallel-cascade modeling approach can be used to modeling PA and DPD with memory effects based on Wiener model, Hammerstein model, Parallel Hammerstein model. In this work Three-Box Wiener Hammerstein model as shown in figure 2 has been used [4, 16, 21]. In this model memory less nonlinear system (polynomial model) is followed by and preceded by linear time invariant (LTI) system

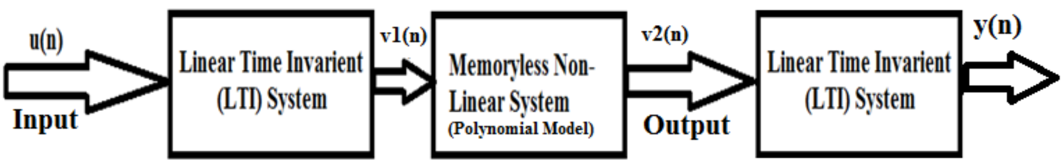

Fig. 2: Three-Box Wiener Hammerstein Model

The output $\left(y(n)\right)$ of Three-Box Wiener Hammerstein model can be written as

$$y(n)=\sum_{l_2=0}^{L-1}a_{l_2}\sum_{p=1}^{P}b_p\left[\sum_{l_1=0}^{L-1}a_{l_1}u(n-l_1-l_2)\right]^{p} \quad (5)$$

In (5), a_l coefficients are the impulse response value of the LTI system and L (odd numbers) presents the maximum depth of delays caused by memory effect. b_p coefficients of the memory less nonlinear system (polynomial model) presenting the nonlinearity and P is the maximum order used in the polynomial model [3, 16].

II. MEMETIC ALGORITHMS

MA is one of the new techniques which imitate the nature and culture. Dawkins represented a new idea of gene-centered view of evolution. He coined a new expression "meme" which means a behavior is passed from one individual to the other [5, 8]. In MA two learning methods are used: the first is Lamarckian learning and the second one is baldwinian learning [7, 12]. In Lamarckian Learning, individuals learn during their lifespan and keep the values of local search improvement. In selection mechanism, fitness of individuals gets evolved according to their local search improvements. Therefore, best improvements are transferred to next generation in genotype. In baldwinian learning, local search is applied to individual and fitness value of individual is calculated by the use of local learning however local improvements are not part of genotype, so local search improvements are passed indirectly to offspring. Whitley et al. argued that Lamarckian Learning is much more faster than baldwinian learning but results of Lamarckian Learning can cover to local optima faster than Baldwinian Learning [7, 9, 13]. It also mimics natural evolution process but it may be different from GA in performing individual learning which is also known as meme(s) [11, 12]. The flow diagram and pseudo code of MA is shown in figure 3

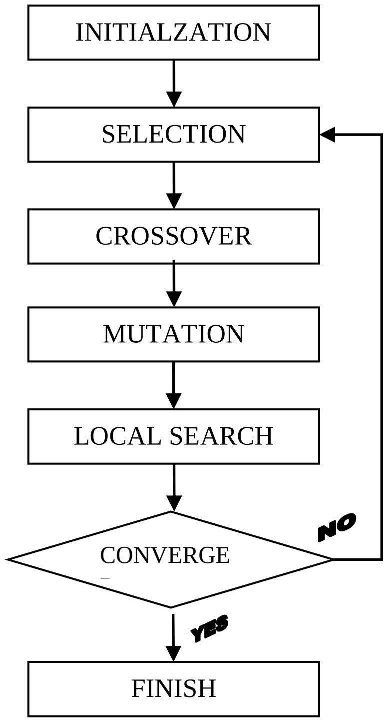

Fig. 3a: Flow diagram of Memetic Algorithm

Algorithm: Memetic Algorithm (MA)

Initialize population
Calculate fitness of population
while Best individual (chromosome) does not meet the criteria **do**
  Select parents
  Crossover operation in order to get offsprings
  Mutation operation over population
  Individual learning is proceed (local search)
  Determine fitness of population
end while

Best individual is the solution of problem

Fig. 3b: Pseudo code of Memetic Algorithm

III. RESULTS AND DISCUSSION

A WiMAX PA of 10 MHz used for the experimental validation. The PA and DPD were characterized by measuring its input and output baseband complex waveforms using the standard experimental setup [11]. The AM-AM, AM-PM and PSD characteristics for actual PA, modeled DPD using MA depicted in figures 4, 5 and 6 respectively. MA is implemented using the indirect learning architecture based parameter estimation of memory polynomial based digital predistorter.

The AM-AM characteristics and AM-PM characteristics for actual PA (black), modeled PA using MA (red) are shown in figure 4 and figure 5 respectively. The AM-AM characteristics curve of modeled PA using MA is very close with the actual PA. This shows the accuracy of the modeled PA using MA. PSD characteristics for PA input (sea green), PA output (black) and modeled PA using MA (red) are shown in figure 6. PSD characteristics of modeled PA using MA are very close to actual PA output PSD.

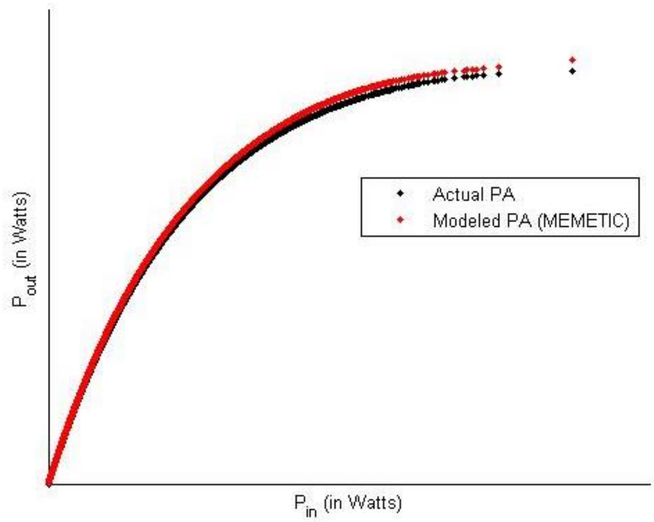

Fig. 4: AM-AM characteristics for actual PA and modeled PA using MA

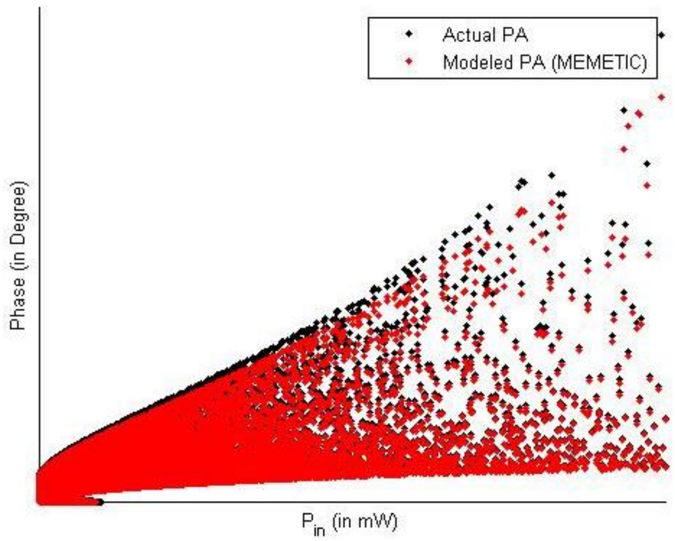

Fig. 5: AM-PM characteristics for actual PA and modeled PA using MA

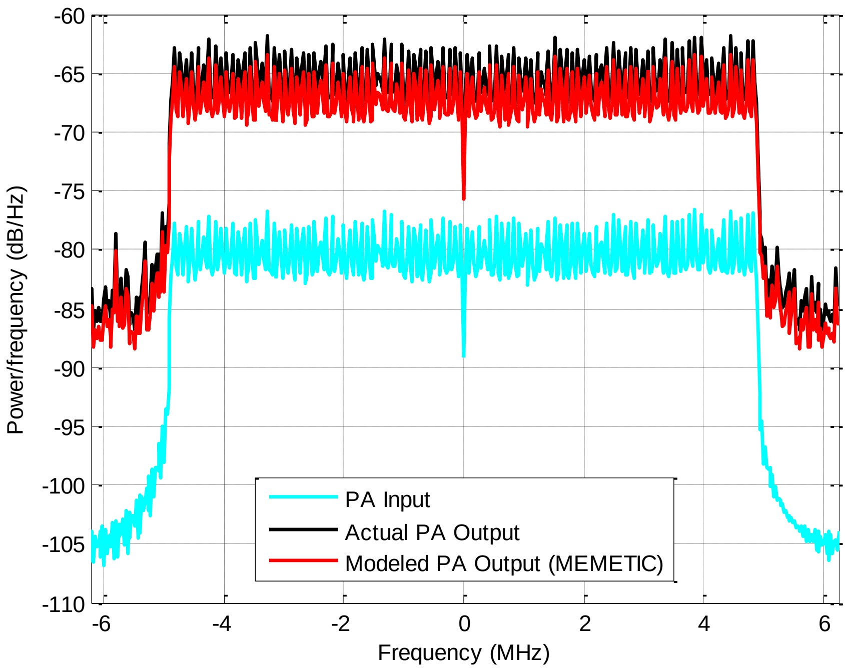

Fig. 6: PSD characteristics for PA input, PA output and modeled PA using MA

The inverse AM-AM characteristics for actual PA (black) and modeled DPD using MA (red) are shown in figure 7. The AM-AM characteristics curve of modeled DPD using MA is very close with the inverse AM-AM characteristics for actual PA. This shows the accuracy of the modeled DPD using MA based on memory polynomial. PSD characteristics for PA input, PA output and modeled (DPD+PA) using MA are shown in figure 8.

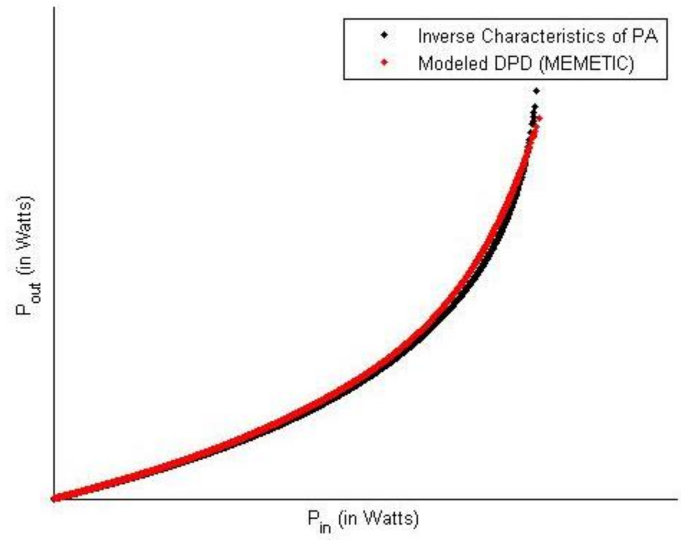

Fig. 7: Inverse AM-AM characteristics for actual PA and AM-AM characteristics modeled DPD using MA

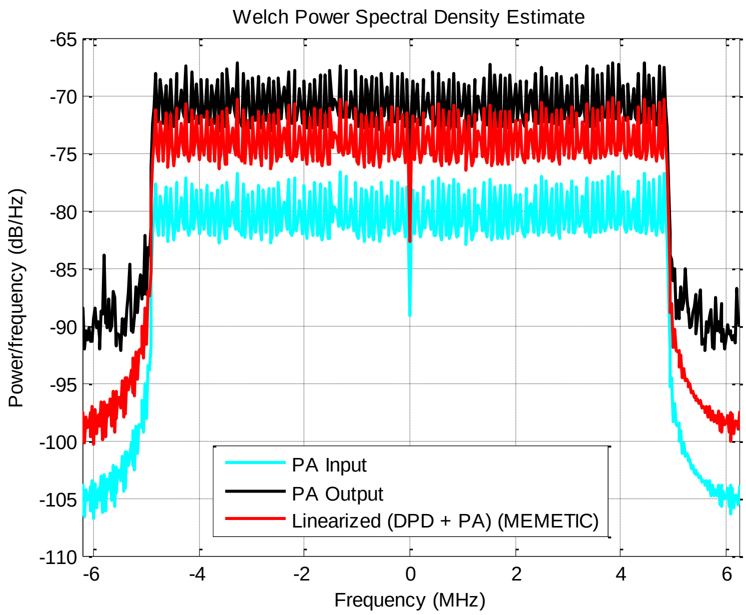

Fig. 8: PSD characteristics for PA input, PA output and modeled (DPD+PA) using MA

In figure 8, the PSD of the modeled (DPD+PA) using MA is shown same as the PSD of the PA output. But the adjacent channel power ratio (ACPR) level of modeled DPD has decreased more than PA output PSD.

IV. CONCLUSIONS

In this paper, The PA and DPD model extraction solution based on a stochastic optimization technique MA using memory polynomial has been introduced. Measurements confirm that this technique is easy to implement and results show a good ACPR reduction, significant improvement in non linearity & efficiency and compensate the more amounts of memory effects.

The novelty in this method is based on a WiMAX PA of 10 MHz. The future research should be on the implementation of this technique using modified MA and another more stochastic evolutionary algorithm.

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