Adaptive Digital Predistorter based on Particle Swarm Optimization Algorithm

Rajbir Kaur and M.S. Patterh

Abstract--- An adaptive digital predistorter based on the PSO (particle swarm optimization) algorithm is developed and applied in LTE communication system. It can provide estimation and update adaptive digital pre-distortion filter coefficients. The performance of this method has been verified by means of simulation in MATLAB software. Significant reduction in distortion has been achieved. Simulation results show that wideband power amplifier have better performance based on proposed adaptive digital predistortion method.

Keywords--- Digital Predistorter, Particle Swarm Optimization, Linearization, Power Amplifier

I. INTRODUCTION

Radio Frequency (RF) High Power Amplifiers (HPAs) are one of the basic building blocks of modern wireless communication system. But most of these broadband wireless communication systems such as Universal Mobile Telecommunications System (UMTS) and Long Term Evolution-Advanced (LTE-Advanced) employ transmission formats such as wideband code division multiple access (WCDMA) or orthogonal frequency division multiplexing (OFDM) which have high peak-to-average power ratio (PAPR).The emphasis on higher data rates, spectral efficiency and cost reduction has driven the field towards linear modulation techniques such as quadrature phase shift keying (QPSK), quadrature amplitude modulation (QAM), wideband code division multiple access (WCDMA), and orthogonal frequency division multiplexing (OFDM)[1].The result is a complex signal with a non-constant envelope and a high PAPR. OFDM systems allow the transmission of high data rates over broadband radio channels without need of powerful channel equalizer. By using special modulation schemes, OFDM systems do not require a channel estimator. Thus OFDM systems are less complex as compared with a single carrier transmission system. But major disadvantage of OFDM signals is that they have very high PAPR. This high PAPR derives the PA into non-linear region and hence causes inter-modulation distortion (IMD), which causes spreading of power both within the band and in the adjacent frequency bands [2]. Linearization task can’t be accomplished successfully until the PA to be linearized is exactly modeled. In modern wireless communication systems, new modulation types are introduced in order to support more users by considering spectral efficiency. These new signals are sensitive to nonlinearity when they have high peak to average ratio. The main part in the system that causes nonlinearity is the power amplifier. For power amplifiers, between linearity and efficiency, there is a trade-off. However, by using predistortion techniques, both linearity and efficiency can be obtained. By this view, the signal at the output of amplifier becomes linear, AM/AM and AM/PM distortions are eliminated, the spectral regrowth is prevented and constellation of signals is given without deformation. Digital Predistortion (DPD) is one of the commonly used linearizing technique because of its robustness, moderate implementation cost and high accuracy. In DPD linearization technique, as shown in Figure 1, the predistorter (PD) is added in the front of the PA of a nonlinear device with extended nonlinear characteristics just opposite to the nonlinear characteristics of PA [3]. Over the past decade, extensive research has been carried out in DPD and many behavioral models have

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been developed, such as memory polynomial, generalized memory polynomial, and various simplified formats of Volterra-series-based models [4]. The DPD model coefficients are extracted using the least squares (LS) method, for which generally Quadratic Rotation Decomposition (QRD) or Singular Value Decomposition (SVD) algorithm is used in order to reduce the error. The evolutionary algorithms such as Bacterial Foraging Optimization (BFO), PSO, Genetic algorithm (GA), and Simulated

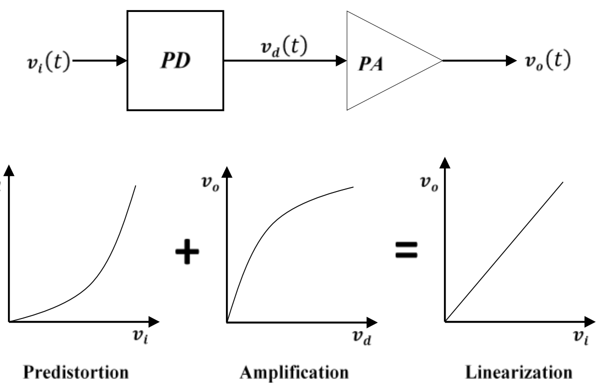

Fig. 1: DPD Process of Linearization

Annealing (SA) are getting popular because of their abilities to find the global minima in both continuous and non-continuous domains. PSO algorithm is an evolutionary computation technique which can be used in power amplifiers modeling and linearization applications [13]. So in present work, PSO algorithm have been used to find out the model coefficients for DPD and PA. The rest of the paper is organized as: section 2 is about memory polynomial model for DPD, section 3 is about PSO algorithm, section 4 is DPD design using PSO algorithm and section 5 is conclusion.

II. MEMORY POLYNOMIAL MODEL FOR DPD

The model used in present work to develop a polynomial model of a nonlinear system with memory is a truncation of the general Volterra series can be shown as [6-7]:

$$y(n) = \sum_{m=0}^{M} \sum_{k=1}^{K} c_{2k-1,m} \left| x(n-m) \right|^{2(k-1)} x(n-m) \quad (1)$$

Where $x(n-m)$ is the input complex base band signal, $y(n)$ is the output signal, $c_{2k-1,m}$ are complex valued parameters, M is the memory depth, K is the order of the polynomial.

The essence of DPD is that the amplitude and phase of input signals are preprocessed to compensate the AM/AM and AM/PM distortion brought by PA. For designing of the DPD, its architecture can be either direct learning architecture or indirect learning architecture. In direct learning architecture, first it must identify the PA nonlinear characteristics and then find the inverse characteristics of PA, which is quite a complex system. In indirect learning architecture, no need to find the inverse nonlinear characteristics of PA. Simply it is used for identifying the predistorter [8], so the indirect learning architecture has been used in present work for adaptive solution.

Due to the fact that the output of the model is linear with respect to its coefficients, it is possible to extract the nonlinear DPD model by using linear system identification algorithms. Due to its fast convergence and high accuracy, the LS estimation can be used for model extraction in DPD systems. To reduce the effects of the errors in the observations, the LS estimator generally needs more number of training sequences to find the best approximation of the DPD coefficients [4].

III. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) is a developed evolutionary technique. PSO is based on social interaction between independent particles and it uses social knowledge in order to find the global maximum or minimum of a generic function, the population fitness is improved by pseudo-biological operators, such as selection, crossover and mutation. Velocity update is the main PSO operator which takes best position into account during the iterations, resulting in a migration of the swarm towards the global optima [13].In the PSO, swarm intelligence is used to search the parameter space by controlling the trajectories of a set of particles according to a swarm-like set of rules. The position of each particle is used to compute the value of the function to be optimized. Consequently every position is a particular solution of the optimization problem. Hyper-space problem is Trans- versed by individual particles and are attracted by both the position of their best past performance and the position of the global best performance of the whole swarm [13-14].

Generally in PSO Algorithm, first we have to initialize the positions and associate velocities of all particles in the population randomly and evaluate the fitness value of all particles. Then to compute overall the personal best, personal best (p_{best}) of each particle iscompared with its current fitness value. If the current fitness value is better, then assign the current fitness value to p_{best} and assign the current coordinates to p_{best} coordinates. After this, determine the current best fitness value in the whole population and its coordinates. If the current best fitness value is better than global best (g_{best}), then assign the current best fitness value to g_{best} and assign the current coordinates to g_{best} coordinates. To *Calculate accelerations of the agents*, Update velocity (V_{id}^{t}) and position (X_{id}^{t}) of the d-th dimension of the i^{th}particle using the following equations [14-15]:

$$V_{id}^{t} = \omega(t) * V_{id}^{t-1} + c_1(t) \times rand1_{id}^{t} \times (pbest_{id}^{t-1} - X_{id}^{t-1} + c_2(t) \times (1 - rand1_{id}^{t}) \times (gbest_{d}^{t-1} - X_{id}^{t-1}) \quad (2)$$

$$V_{id}^{t} > V_{max}^{d} \, or V_{id}^{t} < V_{min}^{d}, then V_{id}^{t} = U(V_{min}^{d}, U_{max}^{d}) \quad (3)$$

$$X_{id}^{t} = rand2_{id}^{t} \times X_{id}^{t-1} + (1 - rand2_{id}^{t}) \times V_{id}^{t} \quad (4)$$

$c_1(t)$, $c_2(t)$ = time-varying acceleration coefficients with $c_1(t)$ decreasing linearly from 2.5 to 0.5 and $c_2(t)$ increasing linearly from 0.5 to 2.5 over the full range of the search, andw(t) = time-varying inertia weight changing randomly between *U*(0:4 ; 0:9) with iterations,$rand1$ and $rand2$ are uniform random numbers between 0 and 1, having different values in different dimension, *t* is the current generation number. The above equation has been introduced to clamp the velocity along each dimension to uniformly distributed random value between V_{min}^{d} and V_{max}^{d} if they try to cross the desired domain of interest. The maximum velocity is set to the upper limit of the dynamic range of the search ($V_{max}^{d} = X_{max}^{d}$).The minimum velocity ($V_{min}^{d}$) is set to ($X_{min}^{d}$).The fitness function evaluations of errant particles (positions outside the domain of interest) are normally skipped to improve the speed of the algorithm.

IV. DPD MODELING USING PSO ALGORITHM

In order to validate the proposed modeling techniques, a wideband PA input/output data has been taken. This PA was operated at 2.4GHz frequency and excited by an OFDM signal with 5 MHz bandwidth. To model the DPD using memory polynomial, the nonlinearity of the model i.e. the order of the polynomial, was truncated to 7. To consider the memory effects, the memory depth was taken as 3.The lower channel values of ACPR are measured at -10 MHz and -5 MHz, whereas upper channel values of ACPR are measured at 5 MHz and 10 MHz. To evaluate the PA and DPD model, the coefficients of memory polynomial has been calculated using PSO algorithm. To evaluate the model accuracy in the frequency domain, the spectra of PA modeled and the spectra of DPD using PSO algorithm have been plotted as shown in Fig 2 and Fig 3 respectively.

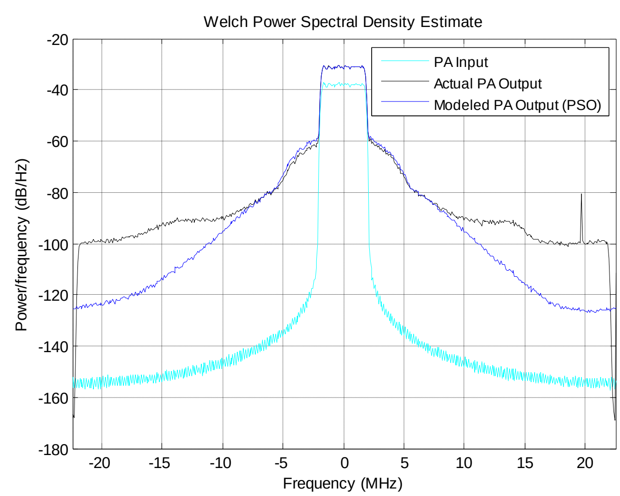

Fig. 2: Power Spectrum of Actual PA and Modeled PA Using PSO Algorithm

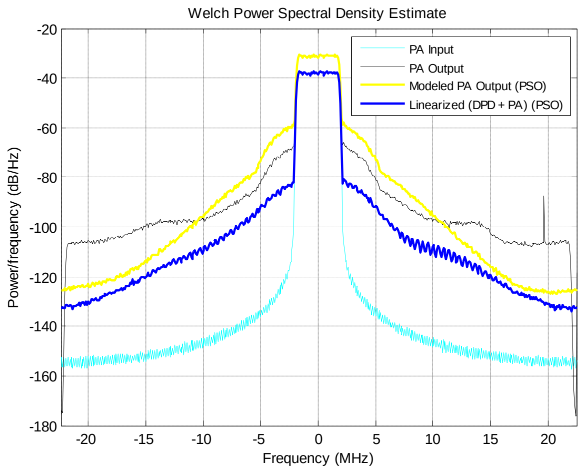

Fig. 3: Complete Power Spectrum of DPD Using PSO Algorithm

The measured value of ACPR for actual PA, modeled PA and modeled DPD using PSO algorithm are shown in Table 1.

Table 1: ACPR Measurements for Actual PA, Modeled PA and Modeled DPD using PSO Algorithm

Parameter	Actual PA	PA Modeled	DPD Modeled
Lower ACPR 2	-59.4759	-75.8102	-53.3235
Lower ACPR 1	-47.0499	-46.6465	-41.0010
Upper ACPR 1	-46.5342	-46.1182	-40.2545
Upper ACPR 2	-60.7407	-76.3273	-55.2835

V. CONCLUSION

Memory polynomial can be employed to model the DPD for nonlinear PA behavior with reasonable accuracy. The identification of memory polynomial coefficients becomes more complicated as the degree of non-linearity and memory length increases. In this paper different approach for memory polynomial coefficient identification has been developed using PSO algorithm. The adaptive scheme has the advantage of reducing the complexity and, at the same time, increasing the stability of digital predistortion. The effectiveness of this algorithm for modeling a DPD for non-linear PA with memory effects has been shown with modeling the DPD behavior for PA model.

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