A Low Complexity NARX Structure using Indirect Learning Architecture for Digital Pre-Distortion

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***Abstract* —In this paper, we demonstrate a nonlinear autoregressive with exogenous input (NARX) DPD technique which is more compact, less computationally intensive and less susceptible to errors caused by noise in the PA output compared to an equivalent memory polynomial based DPD. Experimental validation is performed with a 20 MHz LTE signal for a GaN Doherty power amplifier.**

***Index Terms* —power amplifier, nonlinear autoregressive with exogenous inputs, digital pre-distortion, indirect learning architecture**

I. Introduction

Digital pre-distortion (DPD) is the most cost effective way to linearize power amplifiers in communication systems. This is due to its high flexibility, lower complexity and high performance compared to the feedforward technique. Popular techniques which have been presented in the past include Volterra series techniques [1] and special case of Volterra series such as Hammerstein [2], memory polynomial [3]. These techniques are based on a finite impulse response (FIR) structure that depends on the systems current and past input signal. The other category of DPD techniques is based on infinite impulse response (IIR) structure in which the output not only depends on the current and past inputs but also the past outputs. One of the techniques used in this category is nonlinear autoregressive with eXogenous inputs (NARX) which is the special case of nonlinear autoregressive moving average with eXogenous inputs (NARMAX) [4] with no noise dependent model. The main advantage of the NARX model compared to Volterra series techniques is in its parsimony. This means less coefficients are required to model a system due to having access to past outputs in the forward path for the model. This results in a significant reduction in complexity and eases the implementation [4].

In this paper the main focus is to investigate the performance of NARX DPD by using indirect learning architecture and compare it with the memory polynomial technique. It can be shown that NARX DPD is less susceptible to measurement noise and impairments using indirect learning architecture compared to the memory polynomial [5]. The least square (LS) algorithm is used to estimate the NARX DPD coefficients. The performance of NARX DPD is experimentally validated and compared with memory polynomial (MP) technique in terms of NMSE, ACLR and number of floating points operations (FLOPs).

II. NARX DPD

The indirect learning architecture is shown in Fig. 1. Here coefficient estimation is performed in post-distortion and then the coefficients are copied to the forward path.

Despite the drawbacks of indirect learning, the main advantage is its coefficients can be estimated using a simple one-off algorithm, while direct learning requires some iteration to achieve the desired performance. This leads to lower complexity and needs less hardware resources.

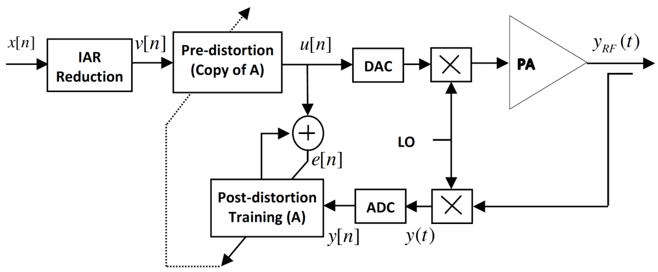

Fig. 1. Block diagram of the indirect learning architecture

In indirect learning the Instantaneous to Average Ratio (IAR) Reduction should be applied to the input signal to ensure high stability. In this case the normalized gain should be used as below,

$$G = \frac{\max(|y[n]|)}{\max(|x[n]|)} \tag{1}$$

For the N input-output data sequence, the post-distortion function in matrix form can be expressed by

$$u = \Psi c + e \tag{2}$$

where the basis function can be expressed by

$$\Psi = [A_1, \ldots, A_{M_a}, B_{10}, \ldots, B_{K0}, \ldots, B_{1M_b}, \ldots B_{KM_b}] \tag{3}$$

where $A_{M_a} = \sum_{m=1}^{M_a} u[n-m]$ and $B_{KM} = \sum_{k=1}^{K}\sum_{m=0}^{M_b} y(n-m)|y(n-m)|^{k-1}$

For the memory polynomial technique which is a special case of Volterra series, the basis function can be given by

$$\Psi = [B_{10}, \ldots, B_{K0}, \ldots, B_{1M_b}, \ldots B_{KM_b}] \quad (4)$$

It can be seen that the basis function of memory polynomial only depends on the output signal and hence it is prone to measurement noise and nonlinearity order, while the basis function of NARX DPD in (4) depends on both the input and output signals which creates more stability while finding the inverse of the basis function. Hence NARX DPD is less prone to measurement noise and impairments. The least square solution to estimate the coefficients $\hat{c}$ is given as

$$\hat{c} = (\Psi^H \Psi)^{-1} \Psi^H u \quad (5)$$

where $(\cdot)^H$ denotes complex conjugate transpose, and u is a vector of input samples. There is no difficulty to extract ($\hat{c}$) as both input and output samples of the power amplifier can be captured from the measurement. To ensure the stability of the identification algorithm, the inequality condition $\|y\|_2 \le F\|u\|_2$ needs to be met where $\|\cdot\|_2$ operator is the second order norm and F is a finite value. This is important as the past output samples of the pre-distortion function are not known. In [6], the output of the pre-distortion function can be initialized with a new predictive method.

III. Experimental Results

The experimental measurement of the NARX DPD is carried out by evaluating the adjacent channel leakage ratio (ACLR). A single carrier LTE with 20 MHz bandwidth centered at 2.63 GHz with IAR of 6 dB at 0.01% CCDF is applied in this experiment. To perform NARX training, 54690 samples have been captured.

The test bench includes an R&S vector signal generator SMU200A, a driver, RFHIC GaN Doherty power amplifier (RTP26010-N1) with typical gain of 40 dB in the forward path and IQ demodulator, ADC and capture board at the feedback path. All the signal processing and control are done in PC running with Matlab. In order to compensate the IQ imbalance due to the LO leakage, gain and phase error and DC offset are compensated offline and then the input and output data have been captured. Fractional delay compensation, using the Farrow structure is applied to compensate the delay and synchronize the input and output data.

Fig. 2 shows the power spectral density (PSD) comparison between the memory polynomial and NARX DPD when nonlinearity order K=5. It can be observed that the ACLR performance of NARX DPD with 20 and 25 coefficients outperforms memory polynomial with 30 coefficients. This shows that NARX DPD can be implemented with lower complexity and also is less prone to measurement noise and impairments. This is also theoretically true as shown in the previous section that the basis function of NARX DPD depends on both the input and output signals, this is in contrast to MP which its basis function depends on the output signal only and hence any measurement noise degrades the performance.

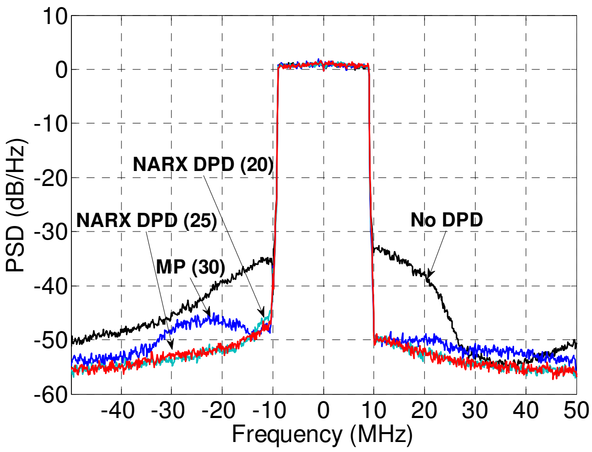

Fig. 2. PSD comparison between NARX DPD and MP when nonlinearity order K=5

V. Conclusions

In this work, we present an experimental validation for a NARX DPD using indirect learning. As outlined in the description of the structure of the NARX DPD in this paper, it is less susceptible to noise in signals used to train the DPD compared to Volterra series based techniques. Also evident from the ACLR data, using fewer coefficients the NARX DPD can achieve the same or better accuracy as a memory polynomial.

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