INTEGRATION the VLSI journal 57 (2017) 184–191

Contents lists available at ScienceDirect

INTEGRATION, the VLSI journal

journal homepage: www.elsevier.com/locate/vlsi

An adaptive digital predistortion for compensating nonlinear distortions in RF power amplifier with memory effects

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ARTICLE INFO

Keywords:
Power amplifier (PA)
Linearity
Digital predistortion (DPD)
Memory effect
Adjacent channel power ratio (ACPR)
Memory polynomial

ABSTRACT

In this paper, an adaptive digital predistortion based on a memory polynomial model is proposed in order to linearize the power amplifier with memory effect. The coefficients of the power amplifier model have been extracted using a least square method and those of predistortion have been identified by applying an indirect learning structure. Finally, the performance of digital predistortion has been demonstrated using the simulation of the power amplifier and the digital predistortion excited by a modulated 16 QAM signal in Matlab software. According to the simulation results, the criterion of adjacent channel power ratio (ACPR) declined by around 15 dB and the input/output power spectrum density of the power amplifier has quite similar curves. The linearized power amplifier output spectrum demonstrates the superiority of the proposed predistorter in eliminating the spectral regrowth which is caused by the memory effect in comparison to the other linearization methods.

1. Introduction

Power amplifiers, as an essential part, are utilized in wireless communication systems. A great amount of power is consumed in a transmitter by the radio frequency power amplifier, hence this element is known as a power hungry block [1]. Although power amplifiers are inherently nonlinear circuits, they have been aimed at amplifying communication signals linearly [2]. The nonlinear nature of this element produces in-band and out-of-band distortions. These distortions lead to adjacent channel interface and increase in error vector magnitude (EVM) [3]. In addition, many types of signal with diverse digital modulations such as code division multiple access (CDMA) for third generation and orthogonal frequency-division multiple access (OFDMA) for fourth generation have been introduced to improve spectrum efficiency and data transmission rate [4].

Because the signals have high peak to average power ratio (OFDM~10 dB) and a large back-off is required from the nonlinear region of the power amplifier for linear amplification, transmission of the non-constant envelop signals using linear power amplifiers has poor efficiency [5]. Thus, the power added efficiency (PAE) of power amplifiers is greatly diminished as a result of the large back-off so as to achieve sufficient linearity. Consequently, there is always a trade-off between linearity and efficiency as designing RF power amplifiers. In order to remove the compromise in the design of power amplifiers, several linearization techniques, such as feedback, feedforward and predistortion, can be employed to improve the linearity of power amplifiers without sacrificing efficiency [6]. Among the linearization techniques, the predistortion method has good performance and low cost [7]. Inserting a nonlinear model which has reverse transfer characteristic of the power amplifier before the power amplifier is the principal idea of linearization in the predistortion method as depicted in Fig. 1. This nonlinear model should be such that cascading power amplifier and predistortion creates linear response.

As seen in Fig. 1, the power amplifier has compressing input/output characteristic and the input/output characteristic of predistortion has an expanding behavior. This expanding characteristic can compensate for the nonlinearity of the power amplifier and theoretically, the relationship between the input and output of the system (PA+DPD) is highly linear. The predistortion can be divided into two types in accordance with the frequency in which it is implemented: 1. Analog Predistortion (APD) 2. Digital Predistortion (DPD).

The analog predistortion (ADP) works directly on the input signal of the power amplifier. The implementation of the analog predistortion is very simple but the predistortion works at a high frequency; hence it has low performance and limited adaptability [8]. There are many analog predistortion circuits that have simple and cost-effective structures [9–14]. The analog predistortion has several advantages in comparison with the digital predistortion, such as low cost and simple structure, but its capacity to improve linearity is less than that of the digital predistortion. Generally, the performance of the analog predis-

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http://dx.doi.org/10.1016/j.vlsi.2017.01.001
Received 3 July 2016; Received in revised form 23 October 2016; Accepted 2 January 2017
Available online 02 February 2017
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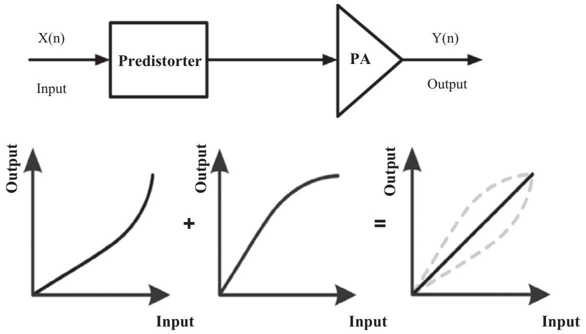

Fig. 1. Basic predistortion system.

tortion procedure is not comparable to the digital predistortion and most analog predistortion structures are exploited in a narrow band application. As an example, Mincheol Seo has proposed analog predistorter based on a Schottky diode but the improvement in spectral regrowth is very low [15]. One of the linearization methods always utilized in modern communication systems is the digital predistortion method [6,7,16–19].

Digital predistortion is one of the most effective methods of linearization, with low cost and high flexibility due to digital hardware implementation. The digital implementation greatly increases the accurate linearization capability [20]. The early linearization methods in literature utilized a memoryless structure in which predistortion compensated for the instantaneous nonlinear behavior of the power amplifier [21]. This behavior is characterized by amplitude modulation/amplitude modulation (AM/AM) and amplitude modulation/ phase modulation (AM/PM) terms. For instance in [22], Yunsung Cho has employed lookup table (LUT) rather than memroyless model, but the LUT could not efficiently eliminate distortion in an advanced wireless transmitter. However, when the bandwidth is augmented in most advanced systems, the memory effect of the power amplifier is not negligible. In order to obtain the best performance of DPD, the memory effect must be considered [23]. A proper model for accurate modeling of nonlinear dynamic systems is the Volterra series [24]. However, this model has many coefficients and the number of coefficients grows very quickly when the order of nonlinearity and memory depth increases; hence, the computational complexity of the model grows.

Lei Guan [25] has recently employed the Volterra series in order to model predistortion, however the complexity of model as well as the resource consumption increase. In order to overcome the complexity of the Volterra series, many models originating from Volterra series such as Wiener model [26], Hammerstein model [20] and memory polynomial model [27] have been proposed. Wiener and Hammerstein models, which are called two-box models, are appropriate for applications with low bandwidth. In Ref. [3], Jungwan Moon has proposed an Enhanced Hammerstein model, but this model and identification of coefficients are very complex. Memory effects are well considered in the memory polynomial model, and the coefficients of the model can be easily extracted using the least square method.

This paper proposes the use of memory polynomial to model the power amplifier and the digital predistortion. First, the memory polynomial function is utilized to model the power amplifier, and its coefficients are carefully extracted. Then, the coefficients of the digital predistortion are carefully identified using the memory polynomial model of the power amplifier and the indirect learning structure. In a predistortion design based on memory polynomial model, well compensated nonlinear distortion of the power amplifier and significant improvement in the amount of ACPR are observed.

This paper is organized as follows: In Section 2, the memory polynomial model and the indirect learning structure are described. Next, the design of the digital predistortion along with the least square method for extracting coefficients is completely expressed in Section 3. In Section 4, the simulation results of the power amplifier, the digital predistortion and a linearized system (PA+DPD) are reported. At the end of the section, the simulation results of the system are compared with some other works. Finally, the conclusion is presented in Section 5.

2. Memory polynomial model and indirect learning structure

2.1. Memory polynomial model

In this paper, the memory polynomial model has been proposed in order to model both the power amplifier and the digital predistortion. Kim and konstantinou proposed the memory polynomial model several years ago [28]. Owing to the complexity and accuracy of trade-off, this model is one of the most popular models for behavior modeling of predistortion. When the coefficients of Volterra series change to diagonal terms (i.e. removing all cross terms), the memory polynomial model is generated. The model is a two summation formula with two parameters: nonlinear order and memory depth. Therefore, this model has great flexibility. The baseband complex output signal (y_{MP}) of the memory polynomial model as a function of baseband complex input signal (x) can be described by the following equation:

$$y_{MP}(n) = \sum_{m=0}^{M} \sum_{k=1}^{K} \alpha_{mk} \,.\, x(n-m) \,.\, |x(n-m)|^{k-1} \tag{1}$$

where α_{mk} is the coefficients of the model and K and M refer to nonlinear order and memory depth, respectively. If we rewrite Eq. (1) as a generic formulation, the equation is written in this form:

$$y_{MP}(n) = \varphi_{\mathrm{MP}}(n) \,.\, \mathrm{A} \tag{2}$$

where $\varphi_{MP}(n)$ and A are defined as follows:

$$\varphi_{MP}(n) = \begin{bmatrix} x(n) \\ \vdots \\ x(n)\cdot|x(n)|^{k-1} \\ x(n-1) \\ \vdots \\ x(n-1)\cdot|x(n-1)|^{k-1} \\ \vdots \\ x(n-M)\cdot|x(n-M)|^{k-1} \end{bmatrix} \tag{3}$$

$$A = [\alpha_{01} \;\cdots\; \alpha_{0k}\; \alpha_{11} \;\cdots\; \alpha_{1k} \;\cdots\; \alpha_{MK}]^T \tag{4}$$

where $[\cdot]^T$ refers to transpose operator. According to Eq. (1), the dimension of this model is defined by nonlinear order and memory depth; thus, the memory polynomial model has two degrees of freedom. The block diagram of the memory polynomial model is depicted in Fig. 2. As illustrated in Fig. 2, the memory polynomial model can be understood as a combination of (M+1) polynomial

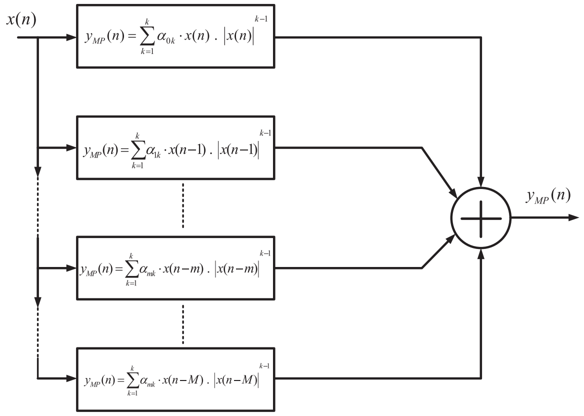

Fig. 2. The block diagram of the memory polynomial model.

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