A Compact Envelope-Memory Polynomial for RF Transmitters Modeling With Application to Baseband and RF-Digital Predistortion

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***Abstract*—In this letter, a compact envelope-memory polynomial based model, suitable for forward and reverse modeling of weakly nonlinear wireless transmitters and power amplifiers (PAs) exhibiting electrical memory effects, is presented. This model is implemented in a complex gain based architecture and takes advantage of the dependency of PA nonlinearity on the magnitude of the input signal. Contrary to conventional memory polynomials, the proposed model can be implemented in baseband, as well as in radio frequency, digital predistorters. A 100-W average power transmitter is used for experimental validation of the forward and reverse models. Both forward and reverse modeling results obtained with the proposed model are comparable to that of the conventional memory polynomial.**

***Index Terms*—Digital predistortion, memory effects, memory polynomial, model, power amplifier (PA), transmitter, 3G.**

I. Introduction

ACTUAL and emerging wireless communication systems, including third generation (3G), 3G and beyond (3G+), wireless local area network (WLAN) and worldwide interoperability for microwave access (WIMAX), use wideband signals that have high peak-to-average power ratios (PAPRs). The envelope variations of these signals are at the origin of the nonlinear distortions in the transmitter (Tx), especially the power amplifier (PA), and call for the use of a linearization technique to improve the achievable Tx power efficiency while meeting the linearity requirements. Moreover, the wide bandwidth of these signals emulates the electrical memory effects of the PA [1]. Thus, the modeling and compensation of nonlinear distortions and memory effects in wireless transmitters and PAs is becoming an unavoidable task in the design of high-performance radio systems.

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The behavioral modeling of nonlinear Tx/PAs exhibiting memory effects has been the topic of numerous research works over the last few years [2]–[7]. Several forward and reverse models have been proposed [2], [3]. Among these different models, the memory polynomial is one of the most powerful and robust models for both forward and reverse modeling of Tx/PAs' nonlinear behavior [4]–[7]. However, in its conventional form, the memory polynomial model (MPM) computes the actual baseband complex output sample, using the actual and preceding baseband complex input samples. The need for the preceding baseband complex input samples is an important limitation, particularly for RF-digital predistortion architectures [8], [9].

In this letter, a novel compact envelope-memory polynomial model (EMPM) that circumvents the above mentioned limitation of the conventional memory polynomial model is proposed. In this model, the nonlinearity of the PA is a function of only the magnitude of the input signal and not its complex value. Such an approach has been proven to be successful for the modeling and linearization of weakly nonlinear PAs and transmitters exhibiting mainly AM/AM and AM/PM distortions along with electrical memory effects [10], [11].

The proposed EMPM is suitable for forward and reverse modeling of nonlinear wireless Tx/PAs driven by modulated signals. The performance of this model in predicting and compensating for the nonlinear behavior of the device under test (DUT) is assessed experimentally. Section II introduces the envelope-memory polynomial model and highlights its major advantages compared to the conventional MPM. The performance of the proposed model in both forward and reverse modeling configurations is evaluated experimentally in Section III. The conclusions are presented in Section IV.

II. Proposed Envelope-Memory Polynomial Model

In the conventional memory polynomial model, the baseband complex output sample $[y_{MPM}(n)]$ is given as a function of the baseband complex input samples $[x(n), \cdots, x(n-M)]$, according to

$$y_{MPM}(n) = \sum_{i=0}^{M} \sum_{j=0}^{N} a_{ij} \cdot x(n-i) \cdot |x(n-i)|^{j} \tag{1}$$

where a_{ij} are the polynomial coefficients, N is the polynomial function order, and M is the memory depth. The orders of all polynomials herein are equal; however, these orders can be optimized separately.

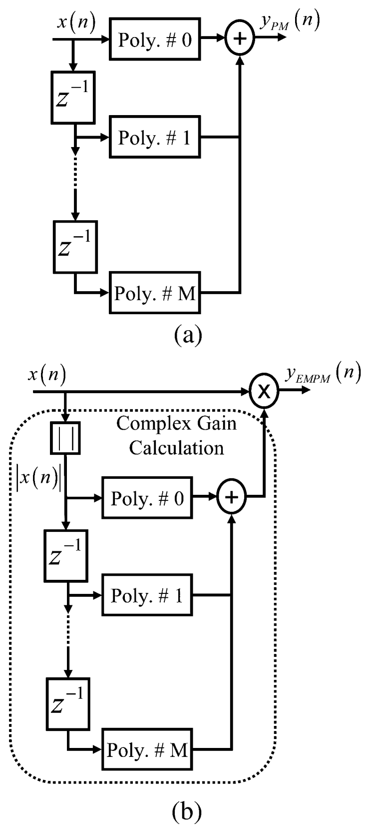

Fig. 1. Block diagram of memory polynomial models: (a) conventional model and (b) proposed model.

Conversely, for the proposed EMPM, the baseband complex output sample $(y_{EMPM}(n))$ is given by

$$y_{EMPM}(n) = x(n) \cdot \sum_{i=0}^{M} \sum_{j=0}^{N} \tilde{a}_{ij} \cdot |x(n-i)|^j \qquad (2)$$

where $x(n)$, N and M are as previously defined for the conventional model. $\tilde{a}_{ij}$ are the polynomial coefficients.

Block diagrams of both models are presented in Fig. 1, which clearly illustrates the fundamental difference between these two models. In fact, while the MPM uses the baseband complex input samples $[x(n), \cdots, x(n-M)]$ to compute the baseband complex output sample, $y_{MPM}(n)$, the baseband complex output sample, $y_{EMPM}(n)$, of the proposed EMPM is a function of the magnitude of the baseband complex input samples $[|x(n)|, \cdots, |x(n-M)|]$ and only the actual baseband complex input sample, $x(n)$.

According to Fig. 1, the proposed envelope-memory polynomial model has an architecture similar to the well established complex gain based digital predistorter (DPD). In fact, a complex gain value is first computed using the magnitude of the input samples, $x(n) \cdots x(n-M)$. Then, this complex gain is applied to the baseband complex input signal, $x(n)$, to generate the baseband complex output sample. Hence, for reverse modeling purposes (digital predistortion), the proposed model fits within the architecture of both baseband and RF-digital predistortion systems. To the best of the authors' knowledge, this is a unique DPD model that can be implemented in RF-digital predistortion systems and compensate for memory effects without requiring the full signal demodulation or access to knowledge of the I and Q baseband signals.

III. Experimental Validation of the Proposed Model

A. Device Under Test and Experimental Setup

The transmitter considered as the device under test in this work was made of an arbitrary waveform generator (AWG) (E4438C) and a 3G 100-W average power PA operating at 1960 MHz. During the characterization, modeling and linearization steps, the DUT was driven by a three-carrier wideband code division multiple access (WCDMA) signal that had a total bandwidth of 15 MHz and a PAPR of 10.6 dB. The DUT was characterized using the input and output baseband waveforms. The baseband input waveform was generated using Agilent Technologies' Advanced Design System Software and was downloaded into the AWG. The signal at the output of the DUT was downconverted and demodulated using a vector signal analyzer (E4406A) [12].

B. Forward Model Performance Assessment

The input and output baseband waveforms collected from the characterization step were first used to derive three models of the DUT: the conventional memory polynomial, the proposed envelope-memory polynomial, and the look-up table (LUT) based memoryless model. In order to assess the performance of these models in mimicking the behavior of the DUT, the memory effects detection method proposed in [13] was applied. This technique consists of removing the static nonlinearity and comparing, in the frequency domain, the residual nonlinearity due to memory effects measured at the output of the DUT with that predicted by the models.

The results are reported in Fig. 2, which shows the investigated spectra. This figure clearly establishes the proposed model's accuracy and robustness, which are comparable to those of the conventional MPM. The slight discrepancies between the models' predictions and the measurements at 20 MHz away from the central frequency were due mainly to the limited bandwidth (40 MHz) of the vector signal analyzer used in the characterization step.

C. Reverse Model Performance Assessment

The characterization results were also used to synthesize the reverse models (digital predistorters) that compensate for the nonlinearity of the DUT. In this step, three models were derived (conventional memory polynomial model, proposed envelope-memory polynomial model, and LUT based memoryless model). The measured spectra at the output of the linearized DUT using these reverse models are plotted in Fig. 3. This figure also shows the spectrum measured without applying any digital predistorter. This illustrates the ability of the proposed model to linearize the DUT and achieve similar performance to that of the conventional memory polynomial.

IV. Conclusion

In this letter, a novel compact EMPM is proposed for forward and reverse modeling of weakly nonlinear transmitters and

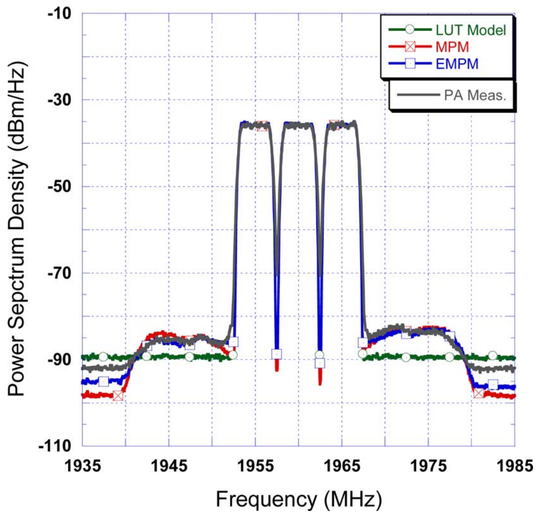

Fig. 2. Output spectra after static nonlinearity cancellation.

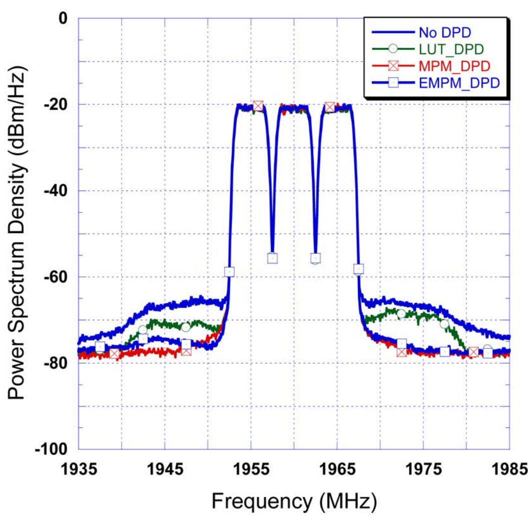

Fig. 3. Measured spectra at the output of the linearized DUT.

PAs that exhibit memory effects. Contrary to the conventional memory polynomial model, the proposed model estimates the complex gain of the device under test and predistorter based only on the magnitude of the input signal. Thus, the proposed EMPM can be used in baseband, as well as RF-digital, predistortion architectures. The performance of the proposed envelope-memory polynomial in both forward and reverse modeling of a device under test was assessed experimentally. It was shown that the proposed model performance is comparable to that of conventional memory polynomials.

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