Behavioral Modeling Accuracy for RF Power Amplifier with Memory Effects

Chokri Jebali, Noureddine Boulejfen, Ali Gharsallah, and Fadhel M. Ghannouchi

Abstract—In this paper, a system level behavioural model for RF power amplifier, which exhibits memory effects, and based on multi-branch system is proposed. When higher order terms are included, the memory polynomial model (MPM) exhibits numerical instabilities. A set of memory orthogonal polynomial model (OMPM) is introduced to alleviate the numerical instability problem associated to MPM model. A data scaling and centring algorithm was applied to improve the power amplifier modeling accuracy. Simulation results prove that the numerical instability can be greatly reduced, as well as the model precision improved with nonlinear model.

Keywords—power amplifier, orthogonal model, polynomial model , memory effects.

I. INTRODUCTION

IN wireless communication, the need for higher capacity motivated the study of CDMA that was originally perceived to provide a capacity that was orders of magnitude higher than other alternatives, such as analog band splitting or digital TDMA. In system level simulation, behavioral model are applied to model the PA nonlinearities. Behavioral models for transmitters/ PAs may be classified into three categories depending on the memory effects existence. Memoryless nonlinear system, quasi-memoryless nonlinear systems, and nonlinear systems with memory.

The actual radio generation uses wideband signals, which lead to focus the research to the nonlinear system with memory rather than memoryless system. For a nonlinear system with long term memory effects, where the system response depends not only on the input envelope amplitude, but also its frequency. In high power amplifier(HPAs), such effects may be generated from thermal effects, as well as long time constants in dc-bias networks. It was shown in [1], that a high power amplifiers with memory effects exhibits two tone intermodulation distortion (IMD) which depends on the tone spacing. Wideband signals also tend to induce memory effects in the PA. In several cases, memoryless predistortion can be ineffective. Therefore, an accurate representation of the

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memory effects in nonlinear transmitter/PA is crucial to linearization efforts.

II. CHARACTERIZATION AND MODELING OF POWER AMPLIFIERS

The power amplifier are characterized by experimental means, to provide information on the PA characteristics such as intermodulation (third and/or fifth order), nonlinearity, and memory effects. Based on measurements, we can carry out several information regarding the nonlinearity of the PA to match an appropriate application. However, when changing the input statistics will not change the frequency response of the DUT. Non linear PA may exhibit a different frequency response when measured with several input signals. White noise signal may yield a different frequency response from that of single tone excitation. Indeed, an input independent representation is desired. Behavioral modeling can provide a compact representation of the PA characteristics using a relatively set of parameters. The power amplifier may be modeled based on circuit diagram with values of the components as the model parameters. Also, it can be modeled using a polynomial model. The goal in any case, is to offer an accurate model for the DUT. The complexity task associated with the most comprehensive model for dynamic nonlinear system, represented by the Volterra model, is reduced by other models. As the parameters number of the Volterra series increases exponentially with the nonlinear order and the memory depth, several models derived and have been offered to resolve this problem[2]-[6]. Although, the complexity of this model, it demonstrate high accuracy in modeling mildly nonlinear PAs. Therefore, for high nonlinear PA, this model is limited by the complexity in terms of number of parameters. To alleviate this complexity, and simplify the Volterra model, different methods have been proposed [7]-[9]. In general, nonlinear power amplifiers PAs generate spectral regrowth, and/or spectral broadening, which creates adjacent channel interference.

It is desirable to design an efficient transmitters/power amplifiers while keeping the spectral emissions below the spectral emission limits. It is advisable to consider that the characteristics of the input signal of the PA as well as specific parameters of the transmitters/ PA. In order to obtain the power spectrum at the output of the transmitter, it is required

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to run several simulations to model the input signal and the power amplifier characteristics.
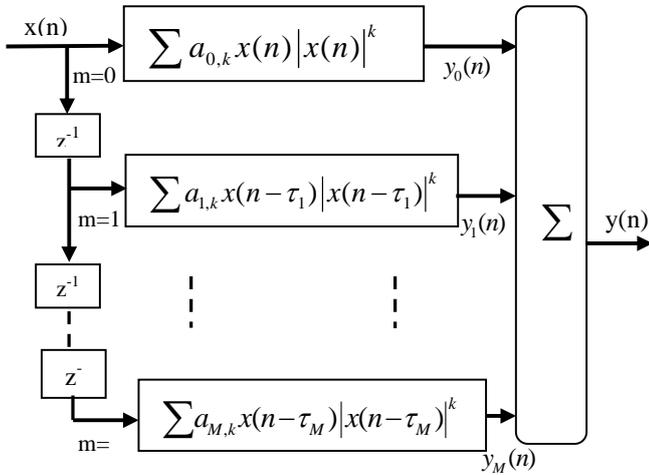

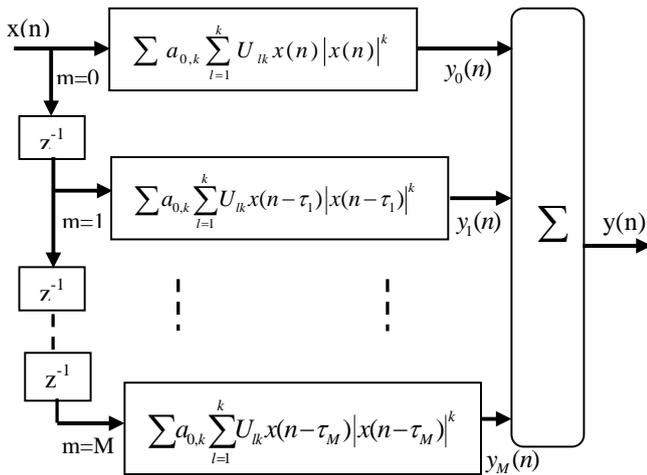Fig. 1 Structure of Memory Polynomial Model

Fig. 2 Structure of Memory Orthogonal Polynomial Model

A. Memory polynomial Model

The memory polynomial model (MPM) [2], introduces pairs of delayed samples of the input signal, with an kth order to describe the nonlinearity and the memory effects, as depicted in Fig. 1. Where its input output relationship is expressed by

$$\tilde{y}_{MPM}(n) = \sum_{m=0}^{M} y_m(n) \qquad (1)$$

$$\tilde{y}_{MPM}(n) = \sum_{m=0}^{M}\sum_{i=1}^{K} a_{im} \cdot x(n-m) \cdot \left| x(n-m) \right|^{l-1} \qquad (2)$$

Where, $x(n)$ is the input measurement, $\tilde{y}_{MPM}(n)$ is the output measurement, k is the polynomial order, M is the memory depth, a_{im} the coefficient of the model.

B. Memory Orthogonal polynomial Model

The orthogonal memory polynomial model [10], uses a set of basis functions to significantly improve the identification accuracy and the orthogonality of the polynomial terms within each branch, as shown in fig.2. This results a reduction of the conditioning of the matrix to be inverted in the LS identification. The orthogonal model's output is described by:

$$\tilde{y}_{OMPM}(n) = \sum_{m=0}^{M} y_m(n) \qquad (3)$$

$$\tilde{y}_{OMPM}(n) = \sum_{m=0}^{M}\sum_{i=1}^{K} a_{im} \cdot \sum_{l=1}^{i} U_{li} \cdot x(n-m) \cdot \left| x(n-m) \right|^{l-1} \qquad (4)$$
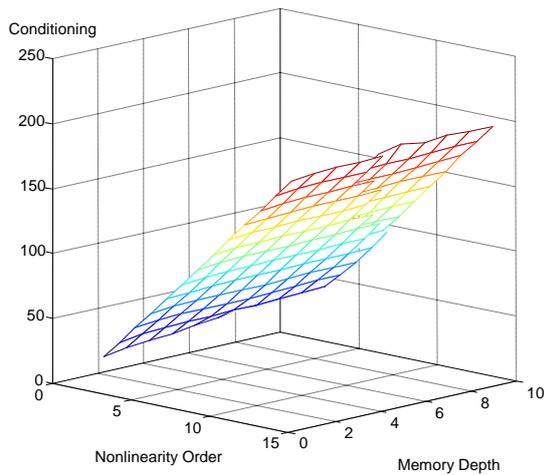
where U_{li} is given by:

$$U_{li} = \begin{cases} (-1)^{l+i} \cdot \dfrac{(i+l)!}{(l-1)!(l+1)!(i-l)!} & \text{for } l \le i \\ 0 & \text{for } l > i \end{cases} \qquad (5)$$
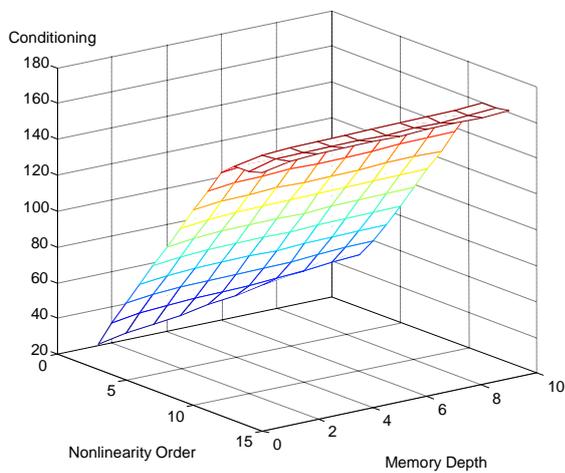
The identification of the polynomial coefficients is given by the Least Square Method (LS) in transforming equations to a matrix form.

III. MATH EXPERIMENT RESULT

The results reported in this section show that both considered memory polynomial models lead to similar performances, both in time domain and frequency domain. Herein, a comparison of the complexity and identification robustness of these models is carried out. It was demonstrated that for the same DUT driven by a given signal, the memory polynomial model MPM, and the orthogonal polynomial model OMPM have the same parameters such as nonlinearity order and memory depth.

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(a)

(b)

Fig. 3 Comparison of the condition number of (a) Before Pre-processing memory polynomial model (MPM), (b) Before Pre-processing orthogonal memory polynomial model (OMPM)

This is due to their similar formulations. Therefore, both models have the same number of basis functions, which lead to the same number of coefficients. The performance of the memory polynomial model MPM is not satisfactory, especially, as soon as the nonlinearity order and the memory depth increase. Indeed, the basis functions associated with the orthogonal memory polynomial model OMPM generate higher computational complexity also, which increases proportionally with the nonlinearity order [11].

Bad conditioning of the vandermonde matrix leads to high computationally consuming matrix inversion process[11]. The pseudo-inverse calculation is very sensitive to slight disturbances. This results to an inaccurate results when finite

precision calculation is required. A data pre-processing technique requires to be applied on the input waveform for the condition number improvement of the inversion matrix. The numerical instability can be reduced provided that there is a pre-processing of the signal $x(n)$, which modifies its distribution. The signal pre-processing approach performed in this paper consists of centering and scaling the input data stream [12], As given by:

$$x'(n) = \frac{x(n) - \bar{x}}{\sigma_x} \qquad (6)$$

where $\bar{x}$ and σ_x are the mean value and the standard deviation of the signal, $x(n)$, respectively. $x(n)$ and $x'(n)$ are the original input waveform and the pre-processed input waveform. The resulting signal is scaled to standard deviation and centered at zero mean. This results a values spreading reduction, while the accuracy of the subsequent numeric computations is improved.

In other hand, for the orthogonal polynomial model OMPM, input signal normalization was applied to improve the conditioning of the vandermonde matrix, as given by:

$$x'(n) = \frac{x(n)}{\max |x(n)|} \qquad (7)$$

Figure 3, shows the condition number values for both the MPM and the OMPM model before data pre-processing. To give a quantitative measure of the polynomial model accuracy, the Normalized Mean Square Error (NMSE) was used to assess the performance of the considered models. These have been calculated but the results are not provided in this document. Figure 4 illustrates the significant improvement achieved by pre-processing the input data based on pre-processing procedure. Consequently, if we consider a given polynomial model, data pre-processing is an unavoidable step in parameter identification. In fact, it is substantial to consider this aspect while evaluating the relative computational complexity of the considered models. Indeed, introducing a signal pre-processing technique that centers and scales the measured data, where the calculation of the mean value and the standard deviation of the input waveform is used for the model identification. Accordingly, the OMPM model leads to significantly lower numerical instability of the matrix inversion (Vandermonde matrix), which translates into a more robust pseudo-inverse calculation. It is clear that the pre-processing required for the OMPM model is less computationally demanding than that of the MPM model.

IV. CONCLUSION

In this paper, we have proposed an accurate multi-branch polynomial models for RF power amplifiers that exhibits strong memory effects. By comparing the precision of two model MPM and OMPM, we prove that the numerical instability can be greatly reduced based on data scaling and centring algorithm. Accordingly, model precision improved by nonlinear memory models is carried out. This conclusion yields a good tradeoff between models precision and complexity.

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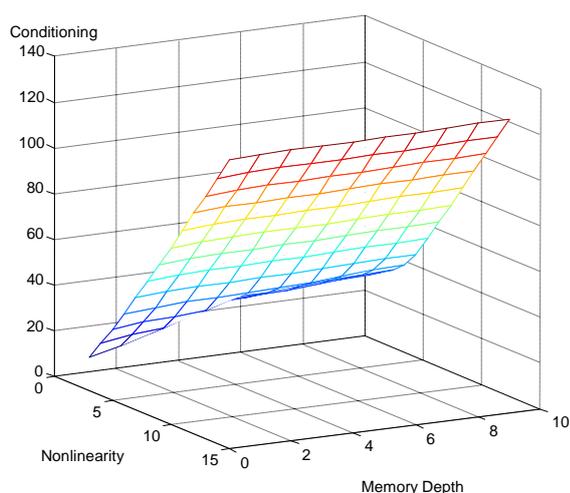
(a)
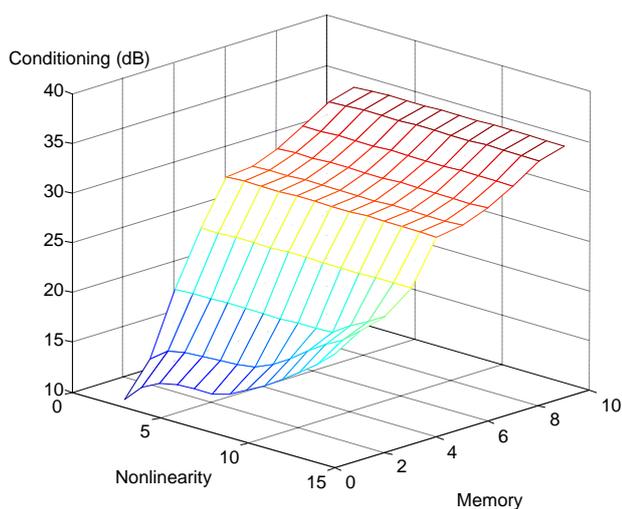
(b)

Fig. 4 Comparison of the condition number of (a) After Pre-processing memory polynomial model (MPM), (b) After Pre-processing orthogonal polynomial model (OMPM)

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