Methods for Selecting the Best Replicas of a Concurrent Dual-band Polar Volterra Series Applied in Power Amplifier Modeling

Bianca L. De Oliveira[1], Luis Schuartz[1] and Eduardo G. Lima[2]

[1]Group of Integrated Circuits and Systems (GICS) - Electrical Engineering Department Federal University of Parana, Curitiba, Brazil
bianca.limaoli@ufpr.br

***Abstract*— Mathematical modeling of the Volterra series with polynomial truncations and memory truncations was developed in *Matlab* software to represent the model of nonlinear dual-band concurrent power amplifiers efficiently and accurately. From the study performed in a previous paper of the polar dual-band concurrent Volterra series with thirty-two truncations, all combinations of replicas were made from the determination of some truncation factors. The replicas were divided into four divisions with polynomial and memory truncation factors to be determined and fixed truncation factors at their minimum values, totaling 15 replicas. Thus, in this paper, the four replicas that reproduce the amplifier model with the highest efficiency and accuracy were analyzed and chosen from the combinations of the fifteen replicas by comparing the best NMSE (*normalized mean square error*) values. The contribution of this article is to present two methods for, given a certain number of replicas, choosing which are the best among the 15 available.**

I. Introduction

The power amplifier (PA) in the transmission chain acts by increasing the energy of the input signal, propagating radio frequency signals over large distances. Regardless of the class of operation, the amplifier should be efficient, but the amplifier ends up generating distortions in the signal due to its nonlinear characteristics, which can compromise the information that is transmitted. When the amplitude of input signal increases the system starts to present nonlinear characteristics, as is the case with power amplifiers. For the PA to exhibit the greatest possible efficiency it must act in the nonlinear region, making its representation more complex. These nonlinear systems have input and output characteristics that can be approximated by a polynomial [1].

The Volterra series is a technique for modeling nonlinear power amplifiers and can improve the accuracy of models to obtain satisfactory results. However, the series can have a large number of generated parameters depending on the desired accuracy, increasing the computational complexity and the simulation time of the model. Using the normalized mean square error (NMSE) metric, it is possible to measure the accuracy of the behavioral models of the Volterra series from the measured and estimated results.

II. Polar Volterra series

A. Single-band Volterra series

The single-band Volterra series represents a nonlinear system with memory, where the amplifier is treated as a system of an input $x(n)$ and an output $y(n)$. In the conventional Volterra series, the complex output of the amplifier is obtained using values between the complex input and its complex conjugate. Most of the contributions obtained are out-of-band intermodulation contributions [1]. The polar Volterra series manipulates with specific truncations and individually the amplitude and phase components of the input signal, representing the even and odd combinations of the signal [2]. In this work the extension of the polar Volterra series to the dual-band case is addressed.

B. Dual-band polar Volterra series

The dual-band Volterra series performs the modeling of the amplifier only for harmonic frequencies of the desired frequency, simplifying the single band Volterra series by considering only the important terms [2].

C. Four-truncation double-band polar Volterra series

From the dual-band Volterra series, the four-truncation dual-band Volterra series was developed, where two truncations are polynomial and two are memory truncations. In this model, it was possible to reduce the NMSE values by increasing the accuracy [2].

D. Ten-truncation double-band polar Volterra series

From the four-truncation Volterra series, the ten-truncation Volterra series was developed. In this model, some polynomial and memory truncation values were set to their minimum values [3]. Thus, the series reduced the number of generated coefficients without reducing the accuracy of the model.

III. SIMPLIFICATIONS IN THE POLAR VOLTERRA SERIES OF 32 TRUNCATIONS

The thirty-two truncation polar Volterra series was developed from the four-truncation Volterra series. The series was divided into four parts that in total have 15 replicas [4]. In this model, it was possible to present all combinations of replicas, of which each replica adopts different polynomial truncation values and memory truncation values. The complex band 1 output at present time, y_1 (n), for the Four-truncation double-band polar Volterra series is calculated from:

$$\sum_{p_1=1}^{P_1}\sum_{r=1}^{p_1}\sum_{q_1=0}^{M_1}\cdots\sum_{q_r=q_r-1}^{M_1}\sum_{q_{r+1}=0}^{M_1}\cdots\sum_{q_{p_1}=q_{p_1-1}}^{M_1}\sum_{p_2=1}^{P_2}\sum_{s=1}^{p_2}\sum_{l_1=0}^{M_2}\cdots\sum_{l_s=l_{s-1}}^{M_2}\sum_{l_s=l_{s+1}}^{M_2}\cdots\sum_{l_{2s-1}=l_{2s-2}}^{M_2}\sum_{l_{2s}=0}^{M_2}\cdots\sum_{l_{s+p_2-1}=l_{s+p_2-2}}^{M_2}\sum_{l_{s+p_2}=0}^{M}\cdots\sum_{l_{2p_2-1}=l_{2p_2-2}}^{M_2} h_{p_1,r,q_1,\dots,q_{p_1},p_2,s,l_1,\dots,l_{2p_2-1}}$$
$$\prod_{j_1=1}^{r} a_1(n-q_{j_1}) \prod_{j_2=r+1}^{p_1} a_2(n-q_{j_2}) \qquad (1)$$
$$\prod_{k_1=1}^{s}\exp(j\theta_1(n-l_{k_1}))\prod_{k_2=s+1}^{2_s-1}\exp(-j\theta_1(n-l_{k_2}))$$
$$\prod_{k_3=1}^{p_2-s}\exp(j\theta_2(n-l_{k_3}))\prod_{k_4=1}^{p_2-s}\exp(-j\theta_2(n-l_{k_4}))$$

where the amplitude is represented by $a_n(.)$, the input phase by $e^{j\theta(.)}$ and $h(.)$ are the Kernels, and P_j and M_j are polynomial truncation and memory truncation, respectively. From equation (1), it was possible to obtain the remaining 14 replicas for the 32 truncations model from different values of polynomial and memory truncations for each division.

For the first division the replicas have one truncation to be determined and three at their minimum values. For the second division the replicas have two truncations to be determined and two fixed. For the third division the replicas have three truncations to be determined and one fixed, and in the fourth division there are no fixed truncations [4]. The 15 replicas are represented by the output complex y1(n) calculated by:

$$y_1(n) = y_{r_1}(n) + y_{r_2}(n) + y_{r_3}(n) + \dots + y_{r_{15}}(n) \qquad (2)$$

In this paper the thirty-two truncation dual-band concurrent polar Volterra series had its fifteen replicas compared using two different methods to determine which of the fifteen replicas are the best to adequately model the amplifier, thus simplifying the mathematical modeling.

In the first applied method each of the 15 replicas was simulated individually. In the first step the replica that generated the best NMSE result was chosen. In the second step, the best chosen replica is removed, leaving 14 replicas, which are simulated and compared to obtain the second replica with the best NMSE value. In the third step, the best replicas chosen in the first and second steps are removed, leaving 13 replicas, which are simulated and compared, thus obtaining the third replica with the best NMSE value. The process is repeated with 12 replicas to choose the fourth-best replica.

In the second method, in the first step, all 15 replicas were individually simulated and compared to obtain the best replica among the 15. In the second step, 14 different models are simulated, each with 2 replicas, and necessarily in all 14 models one replica is the best chosen in the first step and the other replica varies, with one of the 14 remaining replicas being chosen in each of these 14 models. The process was done until the 4 best replicas were obtained.

IV. SIMULATION RESULTS

The results of the application of the two methods were obtained in the *Matlab* software. It is possible to verify the results of the application of the two comparison methods. For method 1 the best replicas obtained were: R8, R13, R14, and R3. The NMSE values for the WiFi and LTE band of these replicas are shown in Table 1. For method 2 the best replicas obtained were R8, R9, R10, and R2. The NMSE values for the WiFi and LTE band of these replicas are presented in Table 2.

TABLE 1: METHOD 1 NMSE VALUES

Replica	Coefficient	WiFi band (dB)	LTE band (dB)
R8 and R13	15	-32.9	-31.8
R8,R13 and R14	22	-35.1	-32.2
R8, R13, R14 and R3	15	-32.9	-31.8

TABLE 2: METHOD 2 NMSE VALUES

Replica	Coefficient	WiFi band (dB)	LTE band (dB)
R8 and R9	22	-35.1	-32.2
R8,R9 and R10	19	-35.4	-25.1
R8,R9,R10 and R2	19	-35.4	-25.1

From the comparison of the two methods, it is possible to see that method 2 had a better performance than method 1. This happened because method 2 is more complex, keeping the best replicas previously chosen and adding 1 new best replica. Model 1, on the other hand, tests only models with 1 replication.

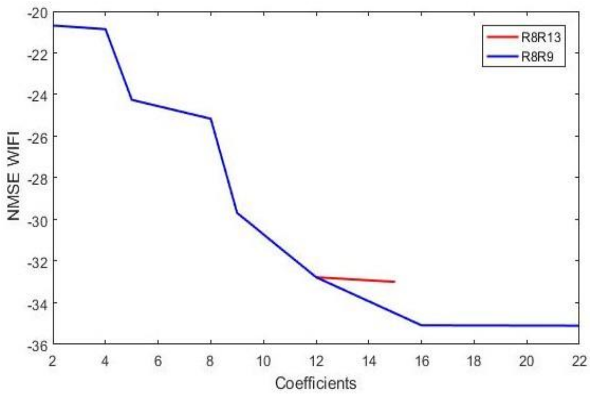

Fig. 1 Two replica models for WiFi band.

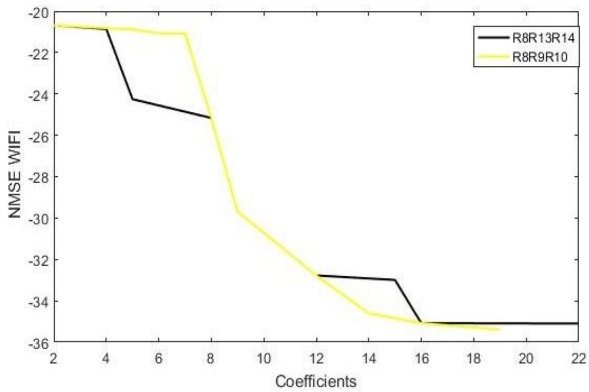

Fig. 2. Three replica models for WiFi band.

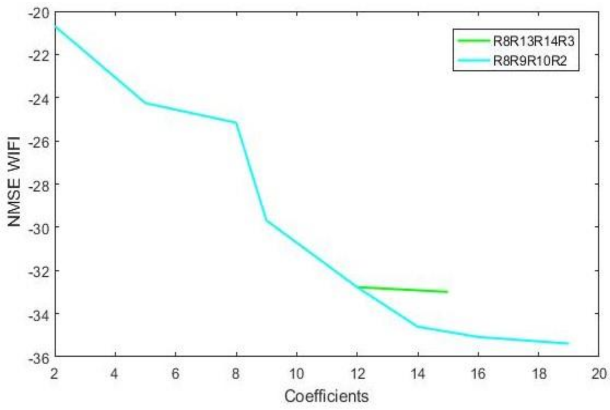

Fig. 3. Four replica models for WiFi band .

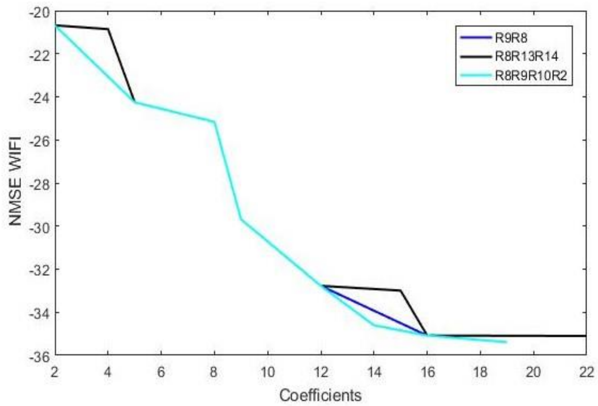

Fig. 4. Best replica models for WiFi band.

In Fig. 1, Fig. 2 and Fig. 3 it is possible to compare the NMSE values for both methods applied for different amounts of replicates. Figure 4 shows the best NMSE values for different amounts of replicas used with Method 2, where by increasing the number of replicas from 2 (R8 and R9) to 3 (R8, R9 and R10) there was an improvement of 0.3 dB, and by increasing to 4 replicas (R8,R9,R10 and R2) the improvement was 0.034 dB over the 2 replicas.

V. CONCLUSIONS

This paper introduces simplifications to the thirty-two truncation polar Volterra series for behavioral modeling of power amplifiers. In the full model of the series it was noted that it would not be necessary to simulate 15 replicas to make the PA representation. Thus, 2 methods were used to reduce the number of replicas in the series. The first method was the simplest, always choosing a best replica from the best NMSE value obtained and the second more complex method proved to be more efficient by choosing a best replica in each step and keeping the best replicas defined in the previous steps. Thus, from method 2 it was possible to obtain the four best replicas representing the power amplifier without reducing the accuracy and reducing the simulation time of the model.

Acknowledgment

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior -Brasil (CAPES) -Finance Code 001, by National Council for Scientific and Technological Development (CNPq) Fundação Araucária de Apoio ao Desenvolvimento Científic e Tecnológico do Estado do Paraná under the Program PIBITI UFPR 2020 and Fundo Nacional de Desenvolvimento da Educação (FNDE).

References

[1] S. Benedetto, E. Biglieri, and R. Daffara, “Modeling and performance evaluation of nonlinear satellite links a Volterra series approach”, IEEE Trans. Aerosp. Electron. Syst., vol. 15, no. 4, pp. 494507, Jul. 1979.

[2] B. L. Oliveira, L. Schuartz and E. G. Lima, “Polar Volterra series applied in modeling of competing dual-band power amplifiers”, in SIM2020, 2020. p. 1-4.

[3] B. L. Oliveira, L. Schuartz and E. G. Lima, “Polar Volterra series with independent truncations applied in modeling of competing dual-band power amplifiers ”, in SeMicro-PR2020, 2020. p. 1-4.

[4] B. L. Oliveira, E. G. Lima and L. Schuartz, “Modified Polar Volterra series with thirty-two independent truncations applied in modeling of competing dual-band power amplifiers.”, in EMICRO/SIM, 2021. p. 1-4