Application of deep learning methods to the mitigation of nonlinear effects in communication systems

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***Abstract*—This work focused on the application of deep learning techniques at digital predistortion for power amplifiers. Artificial neural networks and Random Forest were approached as workarounds for PA modeling and Volterra kernels selection. Results from this research are presented in this work. Furthermore, the student explains his future career plans and intention to attend to a MTT-S Sponsored Conference.**

***Index Terms*—Signal Processing, Power Amplifiers, Digital predistortion, Deep Learning, Random Forest, Artificial Neural Networks.**

I. Introduction

DIGITAL communications standards evolution has led to new challenges in the mobile communications industry, regarding power amplifiers (PAs) power consumption and nonlinearities. Namely, orthogonal frequency division multiplexing (OFDM) is a widely used modern modulation technique which is characterized by a high peak-to-average power ratio (PAPR). Considering the fact that PAs are one of the most power consuming elements in a wireless communication scenario, their energy efficiency is essential. Hence, it is a widespread practice to work with PAs at their peak power, i.e., in their saturation zone, where their maximum power efficiency is achieved. At this point, PAs begin to behave nonlinearly, particularly when high PAPR modulated signals are fed as input. These nonlinearities lead to undesired consequences such as in-band distortion and spectral regrowth. Digital predistortion (DPD) have emerged as a workaround to this efficiency-linearity trade-off. This linearization technique is based on the idea of transforming the input signal in order to avoid the appearance of nonlinearities at the output, achieving at the same time energy efficiency and linear behavior.

In order to compensate nonlinearities, a model of the PA behavior is required. Thanks to their accurate performance, Volterra series has become the most popular modeling technique at DPD. However, this series is formed of a high number of components, since the series was originally infinite. Therefore, reducing its computational requirements has been a topic of interest during the past years [1]. Next chapter presents experimental results of a random forest component selection technique.

II. Experimental Setup and Results

During this scholarship, different deep learning techniques for the PA modeling were studied. Firstly, a complex artificial neural network based on Wirtinger Calculus [2] was developed. For this matter, the equations of regular artificial neural networks (ANN) were extended with the corresponding chain derivatives to obtain the update equation for complex weights. Convergence issues known as the vanishing gradient problem were encountered in the practical implementation of the abovementioned technique.

After this approach, a Random Forest technique was applied to Volterra kernels selection. Random Forest [3] is an ensemble learning method, that is, a machine learning algorithm based on generating models and aggregating their results. Random forests perform good generalization results since they are formed of a significant amount of decision trees, solving in this way their overfitting drawback. Decision trees are simple models characterized by a hierarchical structure based on recursively dividing the input on subsets and making predictions by using the mean of each subset that is why they tend to overfit. Decision trees were used to divide the input dataset regarding whether a Volterra kernel had been used in the model or not. After that, their predictions about the linearization normalized mean square error (NMSE) were used to identify each of the regressors importance.

TABLE I
INPUT DATA TO THE RANDOM FOREST ALGORITHM

t	Φ_1	Φ_2	...	Φ_n	*NMSE (dB)*
1	0	1	...	1	-45.8
2	0	0	...	1	-41.1
⋮	⋮	⋮	⋮	⋮	⋮
N	1	1	...	0	-35.9

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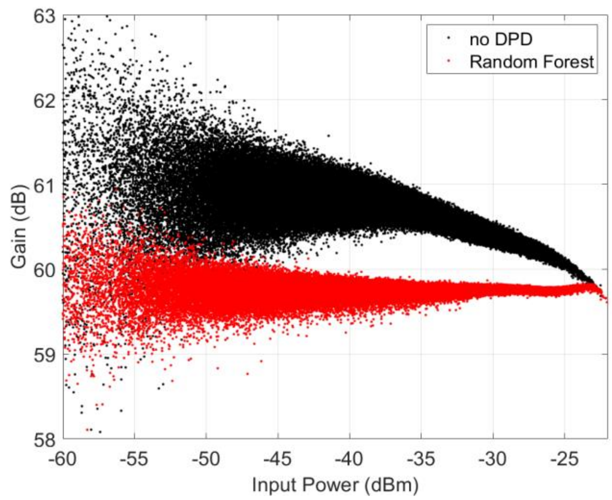

Fig. 1. AM/Gain characteristics of a PA without DPD and with DPD composed of the 25 most relevant coefficients identified by Random Forest.

The validation of the technique was executed over a 30 MHz 5G-NR signal acquired on a testbench with the following components. It was formed of a SMU200A vector signal generator from Rohde & Schwarz, which is followed by two cascaded Mini-Circuits TVA-4W-422A+ preamplifiers. The output is supplied to the device under test, which consists on the evaluation board of the Cree's GaN CGH40010, whose output signal is measured with a PXA-N9030A vector signal analyzer from Keysight Technologies. The PA operating point was fixed to +27.5 dBm of average output power which corresponds to 1.2 dB of gain compression. The input dataset was built by using 5000 DPD models obtained by randomly pruning a generalized memory polynomial of 13th order and maximum memory depth of 15. Each one of them was applied to one OFDM symbol and the linearization NMSE was used as the output vector. Table I shows the structure of the input dataset.

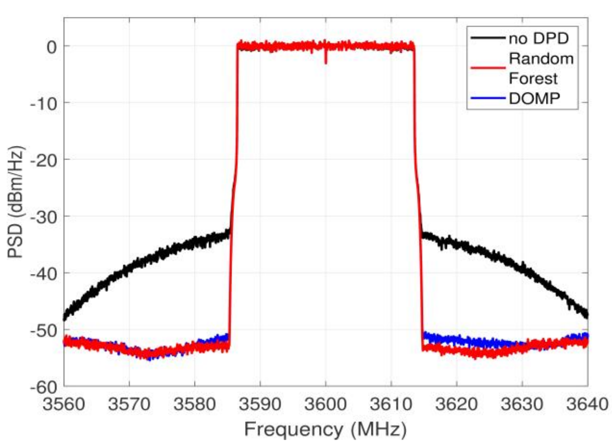

Fig. 2. Power spectral density of the signal without DPD and with 25-coefficient DPDs attained with Random Forest and DOMP.

AM/Gain characteristics for the PA without DPD and with a DPD of the 25 most important coefficients, according to the random forest, are illustrated in Fig. 1., where the linearization of the DUT is clearly observed. Fig. 2. shows the power spectral density in the same situation adding the results for the doubly orthogonal matching pursuit (DOMP) [4] sorting technique with the same number of coefficients, where a spectral regrowth reduction is observed with respect to the case without DPD, achieving a similar performance with both algorithms.

Results of the aforementioned research have been submitted to the IEEE Topical Conference on RF Power Amplifiers (PAWR) [5] within the Radio Wireless Week (RWW) Conference to be held in San Antonio, Texas in 2020 and at the time of this report, decisions are still to be made.

The adaptability of Volterra series to the power dependence has also been investigated. For that, a novel formulation of a Volterra series in which the kernels have a polynomial dependence on the average signal power was derived [6]. These results are expected to be presented in the APMC 2019.

III. Conclusion

A. *Future career plans*

The student is expected to graduate his B.Sc. Degree in Electrical Engineering at the University of Seville in September 2019. Being a part of the MTT-S organization and getting an insight into investigation had a major impact on the student's life. Future research options such as continuing his studies in a master's degree including a Ph.D. program are being considered. After his graduation date, the student intends to start his career in the industry in order to get a personal experience that will allow him to enrich his background as well as decide on future plans.

B. *Impression on MTT-S Sponsored Conference*

The student has not been able to assist to any MTT-S Sponsored Conference yet. However, he intends to assist to the 2019 Asia-Pacific Microwave Conference (APMC 2019) and he is certain that a conference of such an importance will be an unforgettable experience.

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