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Artificial techniques applied to the improvement of the previous signals in the power amplifiers

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Abstract

A rapid evolution in electronic systems has been experienced in recent years, and one of the fields where this development has been notorious is the telecommunication systems in which users demand more and better services and with higher data transfer speeds. This has generated the need to develop new devices, algorithms and systems that manage to satisfy the requirements demanded y new technologies. An example of the above is the front-end of telecommunication systems. Systems need to be more efficient, but some elements of the systems, as the power amplifier, present nonlinearity when operating in its most efficient region, causing that it has to make a commitment between efficiency and linearity. This paper presents a comparison of different artificial neural network architectures, as a behavioral modeling method, to perform digital predistortion of power amplifiers.

Keywords: Comparative study; Neural networks ;digital pre-distortion ; RF amplifiers.

1. Introduction

The power amplifier (PA) is one of the most important devices within the communications system, because it is

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the one that provides the energy to the signal that is sought to be transmitted. However, this makes it the device with the highest power consumption in the system. If the efficiency of the system is a priority, then it is necessary to make the PA as efficient as possible. However, as shown in Figure 1, when the PA is working most efficiently, it is operating in its non-linear region, which means that the linearity of the PA is low, therefore, its output signal is distorted [1].

Since the amplifier alone cannot provide both efficiency and linearity, some methods or techniques have been developed to improve PA linearity without sacrificing efficiency [2]. There are different methods that are classified in three main groups: Feedforward [3], Feedback [4] and Predistortion [5]. Within predistortion there is the digital predistortion technique [6] and this is the one that will be shown in this study due to the advantages it offers, such as: great versatility to perform behavior modeling, flexibility of the predistortion method, signal treatment via software, among others [7]. The inverse model can be performed by means of PA behavior modeling using mathematical series, neural networks or any algorithm that allows a non-linear dynamic model. This inverse model modifies the input signal to make the PA output signal more linear [8]. In this study, neural networks will be used to model the amplifier and a comparison of different neural networks will be made.

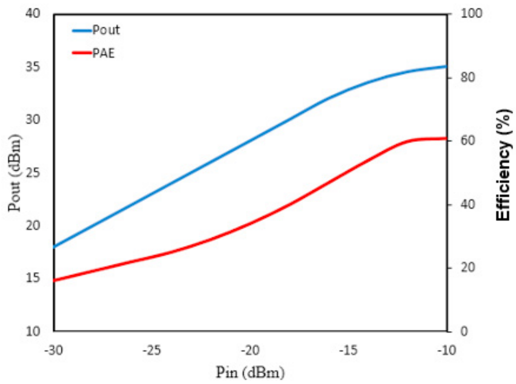

Fig. 1. Output power and efficiency of an AB amplifier

2. Methods

The process to perform the digital predistortion technique consists of 6 main stages: I) signal generation, II) PA input and output capture, III) data processing to obtain AM-AM and AM-PM characteristics, IV) behavior modeling, V) predistortion and VI) predistortion validation [9] [10] [11] [12]. To carry out this method, it is necessary a vector signal generator, a PA operating in the high efficiency region, an equipment to capture the obtained signals and, if necessary, a preamplifier to bring the PA to the desired operation region. Figure 2 shows the block diagram of the measurement bench.

2.1 Signal Generation

The signal used is a 5 MHz wide LTE with a PAPR of 7.5 dB and a center frequency of 2.1 GHz. The spectrum of the generated signal is shown in Figure 3. This signal will be sent to the generator through its IQ values [13].

2.2 PA Input and Output Capture

For creating the amplifier's behavior model, the input and output signals of the PA are necessary. Figure 4 shows the spectrum of both captured signals.

It can be seen that the spectrum of the output signal is an amplified and distorted version of the input signal.

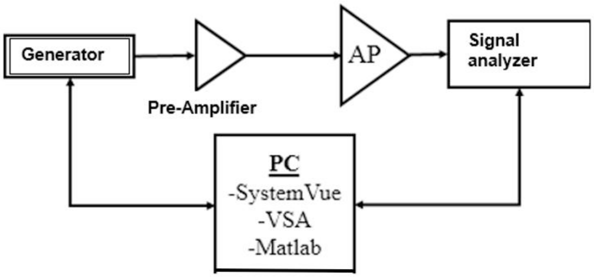

Fig. 2. Measuring bench diagram.

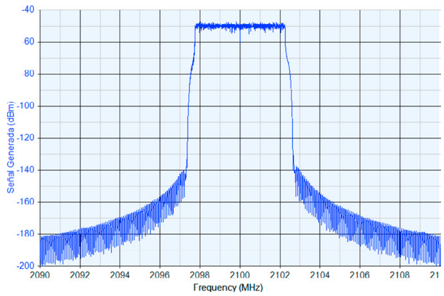

Fig. 3. Five MHz LTE broadband signal generated.

2.3 AM-AM and AM-PM characteristics

The AM-AM characteristic represents amplitude distortion of the PA. It can be represented as Pin-Pout or Pin-Gp, where Pin, Pout and Gp represent input power, output power and PA gain respectively. The AM-PM characteristic is the phase distortion of the PA, i.e. the phase difference between the output signal and the input signal. These characteristics show the non-linearity and memory effects of the PA [14], so they are used as a guide to check if the modeling that was done is correct. The AM-AM and AM-PM characteristics of the stage II and standardized signals are shown in Figures 5 and 6 respectively. The normalization of the signals is done because one is interested in the behavior of the PA and not in the gain. The dispersion that exists between the points, at low input power, is due to the memory effects of the PA.

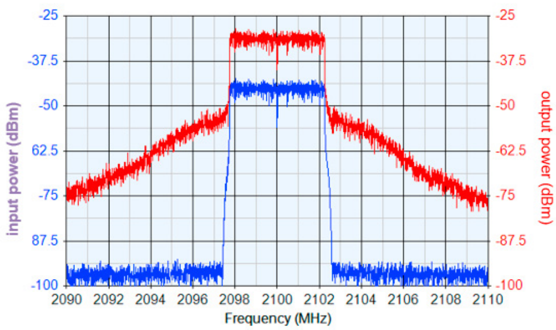

Fig. 4. Input signal (blue) and output signal (red) from the PA.

2.4 Behavioral Modeling

Modeling is the crucial stage of the pre-distortion technique, since a model that is able to reproduce the non-linearity and memory effects of the PA will be able to considerably reduce the spectral re-growth of the PA output signal. That is why, in the literature, many studies search for a robust modeling technique that allows reducing the unwanted effects [5], [12]. In this study, 4 neural networks will be used as modeling method, one with feedforward architecture and 3 with recurrent architecture. The feedforward network is the RVFTDNN (Real-Valued Focused Time-Delay Neural Network) while the networks with recurrent architecture are the FC2HLANN (Full Connected Two Hidden Layers Neural Network), M2HLANN (Modified Two Hidden Layers Neural Network) and NARX (Nonlinear Autoregressive Network with eXogenous inputs). The FC2HLANN and M2HLANN neural networks are modifications of the 2HLANN feedforward network [14] which is a network with two hidden layers, the first one with a linear activation function and the second one, a nonlinear.

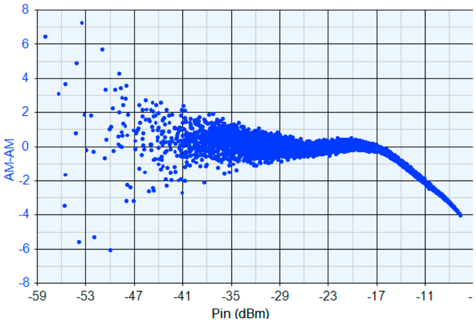

Fig. 5. Standardized AM-AM characteristic.

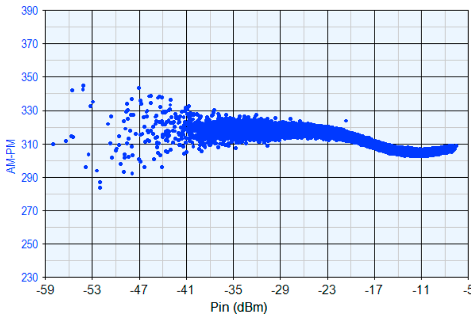

Fig. 6. Standard AM-PM characteristic

The configuration of input delays, output delays, neurons in the first layer and neurons in the second layer of the FC2HALNN network used for comparison is 2, 3, 4 and 25, respectively. For the M2HLANN network, the configuration of input delays, output delays, neurons in the first layer and neurons in the second layer is 3, 4, 2 and 20, respectively. Finally, the NARX network has as a main characteristic that it does not use the present inputs of the input signals. It only works with the delays of these signals and that provides it a great capacity to model non-linear behavior [14]. The network configuration used for the comparison is 1 and 2 delays in the input and output, respectively, as well as 25 neurons.

2.5 Pre-distortion

Once the inverse behavior model is obtained, the pre-distortion of the generated signal in the baseband is performed. The way to pre-distortion the signal will depend on the type of model that is being used. Figure 7 shows the scheme to be applied in the case of using the fee-forward type neuronal networks; while, for the recurrent neuronal networks, the baseband treatment must be performed, as shown in the scheme of Figure 8. Once the predistortion is performed, the IQ values are again sent to the vector signal generator and the predistortion is validated.

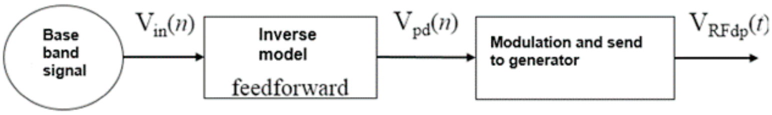

Fig. 7. Feedforward pre-distortion scheme.

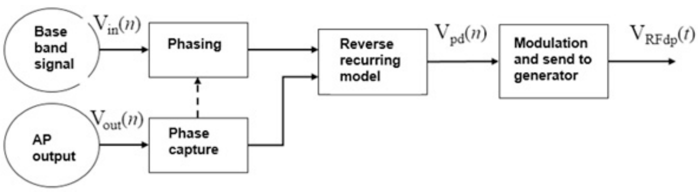

Fig. 8. Diagram of recurrent pre-distortion.

2.6 Pre-Distortion Validation

The validation consists of quantifying the reduction of the spectral enhancement of the output signal of the Doherty PA model RTH21007-10 and comparing it against the output signal of the PA without pre-distortion. The spectral enhancement is quantified by measuring the adjacent channel power (ACPR). Figure 9 shows the power spectrum of the output signal with and without predistortion using the RVFTDNN. A reduction of the spectral enhancement of the PA can be observed, which results in a successful reduction of distortion (non-linearity).

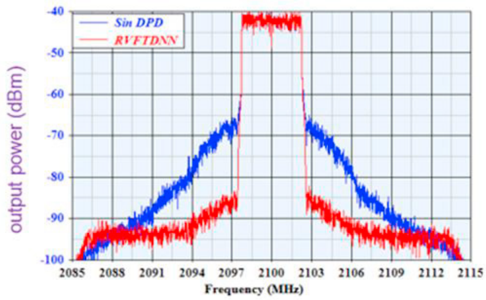

Fig. 9. Resulting spectrum of digital pre-distortion.

3. Results

Different neural network architectures were compared, as a method to model a PA, and these models were used to perform digital pre-distortion. Of the four neural network architectures studied, all four were able to correctly model the behavior of the PA as shown in Table 1, where the normalized mean square error (NMSE) of each model can be observed. The results shown in Table 1 indicate how different are the model response and the PA response. This parameter is calculated as shown in equation 1 [2]. Where: xi: PA response and yi: Model response.

$$NMSE[dB]=10\log_{10}\left[\frac{\sum |x_i-y_i|^2}{\sum x_i^2}\right] \quad (1)$$

Table 1. NMSE of behavior modeling.

	NMSE (dB)	N° Delays		N° Neurons	
		Entry	**Exit**	**1st layer**	**2nd layer**
RVFTDNN	-34.98	10	-	24	16
FC2HLANN	-37.14	3	2	3	16
M2HLANN	-38.012	2	3	1	22
NARX	**-38.603**	**1**	**2**	**4**	**16**

Finally, Figure 10 shows the AM-AM characteristic obtained with the RVFTDNN network and Figure 11 shows the power spectrum of the amplifier output signal with and without pre-distortion. The reduction of distortion obtained using the RVFTDNN network is notably higher compared to the other analyzed networks.

4. Discussion

Within power amplifier linearization techniques, digital pre-distortion is one of the most used techniques for research due to the advantages it offers. One of the most important parts of this technique lies in the correct modeling of the behavior of the amplifier to be linearized, that is why many modeling methods are reported in the literature and each one with different advantages and disadvantages. In the case of neural networks, there are several architectures that are proposed for PA models. In this case, RVFTDNN, FC2HLANN, M2HLANN and NARX networks were used because they present good results both in literature and in implementation. When performing the AP behavior modeling, all the neural networks showed a really low NMSE, indicating that the models were able to reproduce the PA behavior. However, in order to correctly perform digital pre-distortion, it is indispensable that the neural networks have a good generalization in order to predict the behavior at values, in the input signal, different from the values with which it was trained [4]. Because there is no definitive way to measure the generalization of a neural network, tests of each architecture with different number of delays and neurons were performed until the neural networks with the best generalization were found.

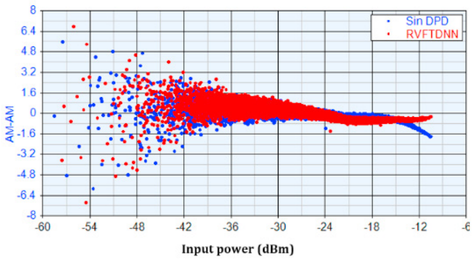

Fig. 10. AM-AM resulting from digital pre-distortion.

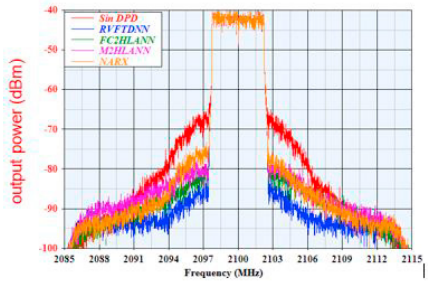

Fig. 11. Resulting spectrum of digital pre-distortion.

5. Conclusions

A comparative analysis of different architectures of the RVFTDNN, FC2HLANN, M2HLANN and NARX neural networks was carried out. The capabilities of each were compared to perform behavioral modelling of a Doherty power amplifier. Regarding the AP behavior modeling. The architecture that presented the lowest modeling NMSE was NARX with -38,603 dB, however, it was the one with the poorest digital pre-distortion results. From the results obtained in the modeling tests, it was observed that the recurrent networks showed better capabilities to model non-linearity and memory effects. This is due to the fact that the network has more information that allows it to reproduce these behaviors. The digital predistortion was successfully carried out with the 4 networks analyzed. Unlike the results obtained in the modeling, the network that showed better results in the predistortion was the RVFTDNN network. While the network that presented the poorest results was the NARX network.

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