Digital Tuning and Predistortion of Load-Modulated Balanced Amplifiers

Estefania Guillena, *Student Member, IEEE*, Pere Gilabert, Senior *Member, IEEE*

Abstract— This project shows the effect, in terms of linearity and efficiency, of the phase shift between the two control signals in a double input load-modulated balanced amplifier (LMBA), and presents the linearization of this amplifier through digital predistorsion based on an artificial neural network.

Keywords— load-modulated balanced amplifiers, power efficiency, digital predistortion, artificial neural network.

I. Introduction

Since 4G and now in 5G new radio, spectrally efficient orthogonal frequency division multiplexing (OFDM)-based waveforms have been introduced to meet the growing demand for data traffic, but at the price of significantly increasing the signal's peak-to-average power ratio (PAPR). Power efficient amplification of signals presenting high PAPR is one of the challenges that power amplifier (PA) designers have to face in order to avoid the power efficient degradation suffered when operating at large power back-off levels.

A possible high efficient topology based on dynamic load modulation principle is the load modulated balanced amplifier (LMBA) proposed by Quaglia and Cripps in [1]. A dual-input PA such as the LMBA, has several degrees of freedom that can be adjusted to optimize its power efficiency and linearity. In this project we have focused on evaluating and predicting the optimal relative phase shift (in terms of linearity) between the two input signals. Once the optimal phase shift has been selected, the linearization of the LMBA is performed using digital predistortion (DPD) based on an artificial neural network (ANN).

II. DUAL-INPUT POWER AMPLIFIER

The LMBA device used in this paper is described in [1] and has been donated by Roberto Quaglia from Cardiff University. This amplifier has two separate RF inputs: a) v_1 that controls the balanced amplifier (BPA) pair, based on two CGH40025F transistors from Wolfspeed, biased in class AB with $V_{GG,1}$ at -2.8 V corresponding to 80 mA of quiescent drain current; b) v_2 that controls the Control Signal Power (CSP) amplifier, also based on a CGH40025F, and biased in class C, with $V_{GG,2}$ at -5.3V. The complex BPA signal is defined directly as $x_1[n] = x[n]$, being x[n] the resulting signal after DPD linearization. While, the baseband complex CSP signal $x_2[n]$ is generated by using a shaping function that provides two degrees of freedom. One of the parameters can be tuned to allow some level of detroughing, while the other parameters control the shape of the AM/AM characteristic. In this work, the relationship between amplitudes is fixed and the effect of the phase shift between signals is analyzed. The CSP signal $x_2[n]$ is defined as

$$x_2[n] = x_{sf}[n]e^{i\Psi_{rel}} \qquad (1)$$

Where Ψ_{rel} is the relative phase (in radians) between the BPA and the CSP signals, and $x_{sf}[n]$ is defined as

$$x_{sf}[n] = A_s[n]\, K_0\, e^{i\,\phi_x} \qquad (2)$$

where $K_0 = \frac{max\{|x[n]|\}}{max\{|A_s[n]|\}}$, $\phi_x = phase\{|x[n]|\}$ and $A_s[n] = (|x[n]|)^2$.

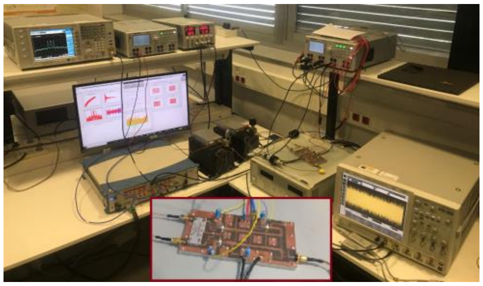

Fig. 1. Experimental setup.

III. Experimental results

The dual-input PA system was experimentally evaluated using a Matlab-controlled digital linearization test bench, as depicted in Fig. 1.

A. Phase shift between signals

We have carried out two measurement campaigns sweeping a 20 MHz LTE signal of 10 dB of PAPR, along a frequency range defined between 1.8 GHz and 2.5 GHz, in steps of 20 MHz and evaluating the power efficiency and linearity for different phase shifts, ranging from 0º to 350º. As described in [2], the relative phase shift between input signals has a significant effect on the LMBA linearity.

The variation of NMSE and ACPR can reach up to 10 dB between the best case (optimal phase shift) and the worst case (worst phase shift). In addition, a dependency of the optimal phase shift with frequency is observed.

In this project we are able to estimate the optimal phase shift between signals (to maximize linearity). Fig. 2 shows the optimal phase shift in terms of NMSE, and four different polynomial fittings of degrees 1, 3, 5 and a piecewise regression of degree 1. Fig. 3 shows the NMSE and ACPR obtained when considering the predicted phase shifts at different frequencies taking into account the four curve fitting strategies. The obtained results are compared with the original measured lower and upper bounds for NMSE and ACPR.

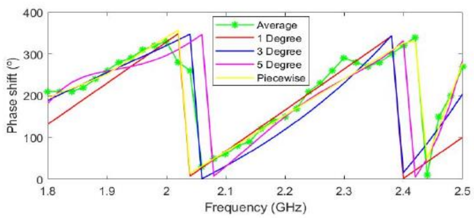

Fig. 2. Curve fitting of the optimal phase shifts targeting maximum linearity.

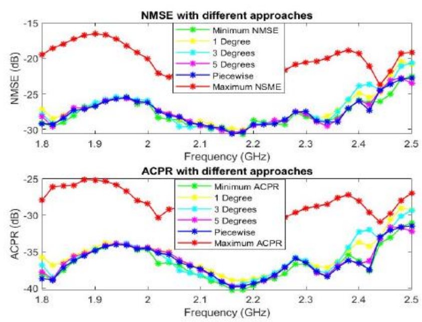

Fig. 3. NMSE and ACPR values obtained considering the predicted phase shifts taking into account different curve fitting approaches.

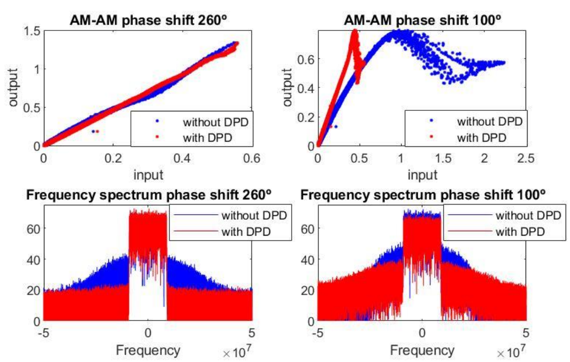

Fig. 4. AM-AM PA characteristics and output power spectra with and without optimal phase shift.

Although, with all the regressions we obtain linearity values close to optimal for the range between 1.8 and 2.4 GHz, the best results are found with the degree 1 polynomial fitting and with the piecewise regression. Finally, Fig. 4 shows the linearization of a 2 GHz signal, with OFDM-based 20 MHz bandwidth, using a Generalized Memory Polynomial (GMP) DPD considering the best (260º) and worst (100º) phase shift between LMBA input signals. Note that if the worst phase shift is selected, the LMBA cannot be linearized (i.e., meeting the -45dB of ACPR) even when applying DPD. Therefore, finding the optimal phase shift is vitally important to ensure linearability.

B. Artificial neural network DPD

Once the optimal phase shift has been selected, DPD is performed using an ANN. The selected neural network consists of 4 hidden layers, the first two layers contain 20 neurons and the last two contain 10 neurons. The input variables of the neural network are the in-phase and quadrature components of the signal and up to 9 delay taps of memory; and the signal's absolute value (envelope) and up to 4 delay taps of memory. The output is the in-phase and quadrature components of the predistorted signal. The training function used the Levenberg-Marquardt solver and the activation function in each neuron consisted in the tangent sigmoid function.

This network was previously trained with the LMBA input-output data and then implemented as an adaptive DPD following a direct learning approach. The linearization performance of ANN DPD is compared to the GMP DPD considering signals with different bandwidths: 20MHz, 60MHz and 200MHz. In all 3 cases DPD with ANN outperforms the GMP DPD, but in the case of using 20 MHz and 60MHz signals, the difference is very small, reaching the -45 dB of ACPR with the GMP with significantly less computational complexity than with ANN. However, at 200 MHz, the -45 dB threshold is only achieved with the ANN DPD, showing an important difference between both techniques. Fig. 5 and Table I shows a comparison of the linearization achieved with ANN and GMP when considering a 200 MHz bandwidth signal.

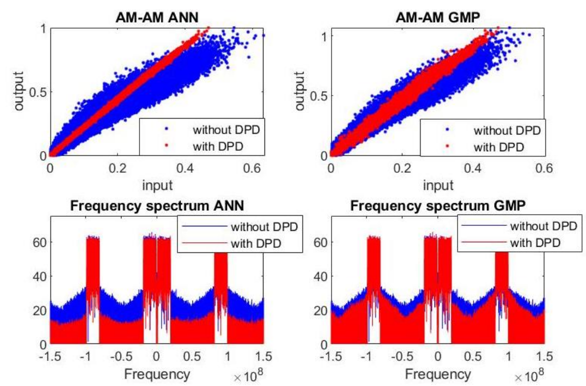

Fig. 5. AM-AM PA characteristics and output power spectra with ANN and GMP on a 200 MHz bandwidth signal.

Table I. LMBA Performance with ANN and GMP on a 200MHz Bandwidth Signal

DPD	NMSE	ACPR	Power out	Efficiency
ANN	-35.1 dB	-45.0 dB	34.1 dBm	23.8 %
GMP	-27.9 dB	-35.2 dB	33.7 dBm	22.6 %

IV. CONCLUSIONS

A. Future career plans

I finish this year my studies in Telecommunications Engineering and Aerospace Engineering, and next year I hope to start a master's degree in Telecommunications. I would like to do a Ph.D. program after completing the master's degree.

References

[1] R. Quaglia and S. Cripps, "A Load Modulated Balanced Amplifier for Telecom Applications," *IEEE Trans. on Microwave Theory and Tech.*, vol. 66, no. 3, pp. 1328–1338, Mar. 2018.

[2] E. Guillena, W. Li, P. Gilabert, G. Montoro, "Prediction of the Optimal Phase Shift between Control Signals in Dual-Input Power Amplifiers", in International Workshop on Integrated Nonlinear Microwave and Millimetre-wave Circuits, Mar. 2020