Digital Predistorter Architecture with Small Signal Gain Control for Highly Nonlinear RF Power Amplifiers

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***Abstract*—In this paper, a digital predistorter (DPD) architecture is proposed for the linearization of highly nonlinear RF power amplifiers. This digital predistorter architecture uses a complexity reduced and a computationally efficient procedure to synthesis the predistortion function. Unlike conventional digital predistortion architectures that require more than one characterization to get a perfect match between the PA's nonlinearity and that of the DPD, the proposed architecture uses a single characterization and iteratively optimizes the predistortion function performance by controlling the predistorter's small signal gain. Experimental validation carried on a highly nonlinear RF power amplifier demonstrates the ability of the predistorter's small signal gain control to improve the linearity performance.**

I. Introduction

RF power amplifiers deployed in current wireless communications base stations are required to meet stringent linearity requirements while achieving the highest possible power efficiency. The linearity constraint, that consists in meeting the spectrum emission mask requirements, is due to the nature of the transmitted signals which have non constant envelops. In addition, the efficiency of the power amplifier needs to be maximized since it will dominate the running costs of the base stations in terms of DC power consumption and power dissipation. This calls for linearity versus efficiency trade-off. Such trade-off is very critical in the case of modern communication signals used in third generation (3G), 3G and beyond (3G+) and WiMAX systems. In fact, these communication standards employ advanced code division multiple access (CDMA) and orthogonal frequency division multiplexing (OFDM) techniques that result in time domain signals having high peak to average power ratio (PAPR). Accordingly, the use of brute force power amplifiers requires considerable back-off levels and will lead to poor power efficiency.

Currently, linearization techniques are being considered to extend the linear region of continuously driven power amplifiers. For a given linearity level, this reduces the required back-off and increases the achievable power efficiency [1]-[3]. Among the linearization techniques that have been reported in the literature, predistortion, and especially digital predistortion, is the most suitable for base station power amplifiers applications. In fact, feedforward systems are complex in nature and usually lead to low overall power efficiency due to the linear amplifier used in the distortion cancellation loop. In addition, feedback systems are very narrowband and are unable to handle the signal bandwidths used with base station power amplifiers and especially multi-carriers power amplifiers (MCPA). In contrast, predistortion technique presents inherent ease of implementation, low cost and good linearity versus efficiency trade-off in comparison with feedforward and feedback based linearizers. Furthermore, the use of digital predistortion, that has the ability to accurately synthesize the AM/AM and AM/PM compensation functions, makes possible the migration from mildly nonlinear power amplifiers to highly nonlinear power amplifiers. This further boosts the overall power efficiency of the linearized power amplifier.

The performance of digital predistortion systems fundamentally relies on the perfect match between the synthesized predistortion functions and the actual nonlinear characteristics of the power amplifier. Since the behavior of the power amplifier depends on the statistics and bandwidth of the input signal (continuous wave (CW), two tones, CDMA, etc,…) [4] as well as its average power [5]-[6], it is important to keep the same signal type and especially the same average power at the input of the power amplifier between the characterization and the linearization steps. The use of the instantaneous input and output waveforms based characterization technique reported in [4] ensures the first condition relative to the nature of the driving signal. For

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mildly nonlinear power amplifiers, the average power at the input of the PA does not vary following the introduction of the digital predistortion function. However, in the case of highly nonlinear power amplifiers, and due to the shape of the PA's AM/AM characteristic, the introduction of the predistortion function can considerably affect the average power of the transmitted signal. Recently, the authors briefly introduced in [7] an augmented digital predistorter architecture that does not affect the average power of the transmitted signal and thus maintains the same average power at the input of highly nonlinear power amplifiers between the characterization and the linearization steps. This is achieved by controlling the small signal gain of the predistorter.

In this paper, the predistortion function synthesis procedures involved with both the conventional DPD architectures and the proposed DPD architecture are compared. In Section II, the proposed predistorter architecture, which includes the small signal gain control, is described. Section III presents the advantages of the proposed digital predistorter over conventional digital predistorters. These advantages mainly focus on the synthesis procedure of the digital predistortion function. The performance of the proposed predistortion architecture is assessed experimentally in Section IV. The conclusions are presented in Section V.

II. Digital Predistorter Architecture With Small Signal Gain Control

The functional block diagram of the proposed predistorter is presented in Figure 1. Compared to a conventional DPD, the proposed predistorter adds a new control parameter, which is the predistorter's small signal gain, to optimize the predistortion function. The optimization criterion is the minimization of the average power variation through the digital predistorter. This will ensure identical behavior of the PA between the characterization and the linearization steps and thus a perfect match between the nonlinear characteristics of the PA and those of the DPD. Ultimately, this will lead to optimal linearity performance.

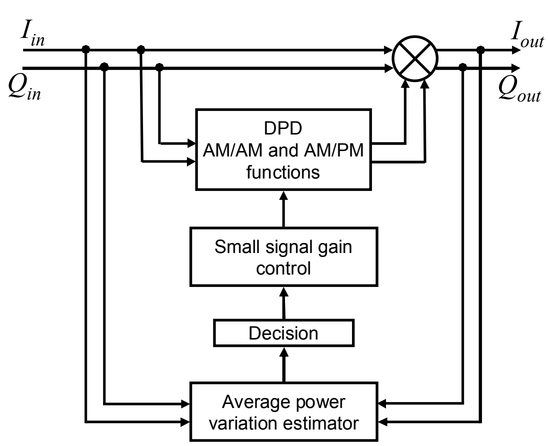

Figure 1. Functional block diagram of the proposed predistorter

First, the predistorter's input and output signals are used to estimate the average power variation through the predistorter. Second, a decision block is used to compare the estimated average power variation to a given threshold. The value of this threshold expresses the sensitivity of the PA behavior to the variation of the average input power. Then, if needed, an adjustment of the predistortion function is performed by controlling its small signal gain according to the equations presented in [7].

III. Synthesis of The Digital Predistortion Function

In this section, the procedure required to synthesize the digital predistortion function from the measured PA's input and output waveforms is described for conventional digital predistorters and for the proposed digital predistorter. Herein, the PA behavior variation due to changes in the signal average power is considered. Aging, bias and temperature drifts are considered to be long term variations and will be compensated for similarly in both cases using a new PA characterization.

For the synthesis of the predistortion function according to the conventional and the proposed approaches, the PA characterization is performed using the instantaneous input and output waveforms technique, and the measured data is processed identically to extract the PA behavior before the synthesis of the predistortion function. The data processing step also includes the delay and gain adjustment between the input and output paths.

In conventional digital predistorters, the predistortion function is directly synthesized from the processed data measured at the input and output of the PA. The small signal gain of the predistorter is set to unity and no control is applied to it. For a given DPD architecture, this defines a unique predistortion function that can be synthesized from the processed data. The predistorter is then applied upstream of the power amplifier and the performance of the linearized PA is evaluated in terms of adjacent channel leakage ratio or time domain error signal. Accordingly, this performance evaluation requires the down-conversion of the PA's output signal and its processing either to estimate the power level in the in-band and the adjacent channels or to generate the error signal. As long as the measured linearity does not meet the targeted specifications, a new characterization will be performed and the entire predistortion function synthesis procedure is repeated.

Contrary to conventional predistorters, the proposed digital predistorter adds one more degree of freedom in the synthesis of the predistortion function from the measured data. This is performed by controlling the small signal gain of the predistortion function. Accordingly, several predistortion functions that perfectly compensate for the measured PA nonlinearity can be synthesized from a single set of measurements. Figure 2 reports the AM/AM curves of such predistortion functions. First, a unity small signal gain ($SSG = 0$ dB) of the predistorter is chosen. Then, the predistortion function is synthesized and applied upstream of the power amplifier. The average power variation through the predistorter is used to control the adjustment of the predistortion function.

Accordingly, the proposed predistorter involves a synthesis procedure that significantly reduces the computational complexity in comparison with that of conventional predistorters. This is due to the following major advantages:

- The use of the small signal gain makes it possible to define several predistortion functions from a single set of measurements. Accordingly, the choice of the optimal predistortion function does not require a new PA characterization step but only an adjustment of the small signal gain of the DPD. In contrast, in conventional predistorters' schemes, each iteration involves a new characterization step.
- The feedback loop needed for the performance evaluation in the case of the proposed predistorter uses the digital signals at the input and output of the DPD. However, conventional predistorters require the feedback of the RF signal at the output of the power amplifier and its down-conversion and demodulation.
- The optimization of the predistortion function according to the proposed scheme is based on a quasi-direct solving approach according to the equations reported in [7]. These equations relate the average power variation through the DPD to the small signal gain adjustment. Conversly, such direct relations are not defined in the case of conventional digital predistorters.

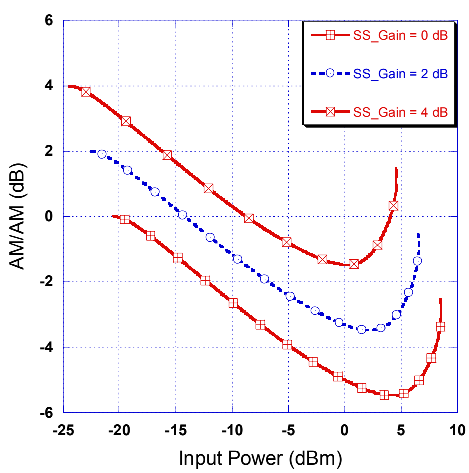

Figure 2. DPD's AM/AM characteristics vs. its small signal gain

IV. Experimental Validation

A highly nonlinear power amplifier operating around 1.95 GHz was considered in this work. The device under test was characterized under a 2-carriers WCDMA signal having a total bandwidth of 10 MHz. Several predistorters were then synthesized according to the DPD's small signal gain control approach described in this paper. The spectra measured at the output of the linearized amplifier for various DPD's small signal gains are presented in Figure 3. According to this figure, it is clear that the small signal gain control of the DPD can significantly improve the linearity performance of the linearized power amplifier.

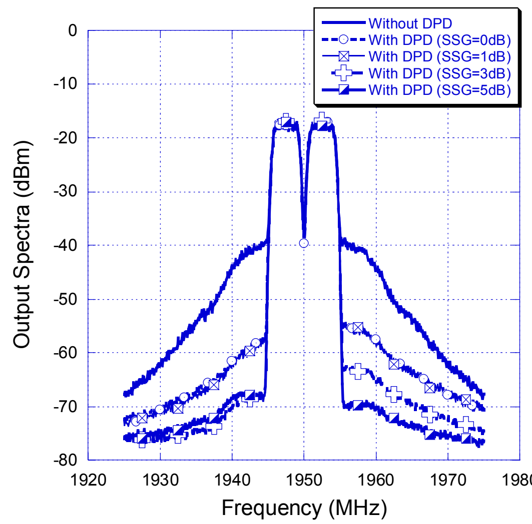

Figure 3. Measured spectra at the output of the PA vs. DPD's small signal gain

V. Conclusion

In this paper, a digital predistorter architecture suitable for highly nonlinear power amplifiers is presented. The advantages of the proposed predistortion function synthesis procedure over the conventional procedures are pointed out. It is shown that with a single characterization of the device under test, the predistorter's small signal gain control approach significantly improves the linearity performance of the linearized amplifier. Experimental validation demonstrates the ability of the proposed predistorter to improve the performance of the linearized amplifier by controlling the predistorter's small signal gain.

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REFERENCES

[1] A. Katz, “Linearization: Reducing distortion in power amplifiers,” *IEEE Micro.*, vol. 2, no. 4, pp. 37–49, December 2001.

[2] P. B. Kenington, High-Linearity RF Amplifier Design. Boston, MA; Artech House, 2000.

[3] F. H. Raab, P. Asbeck, S. Cripps, P. B. Kenington, Z. B. Popovic, N. Pothecary, J. F. Sevic, and N. O. Sokal, “Power amplifiers and transmitters for RF and microwave,” *IEEE Trans. Microwave Theory & Tech.*, vol. 50, no. 3, pp. 814-826, Mar. 2002.

[4] S. Boumaiza, and F. M. Ghannouchi, “Realistic power-amplifiers characterization with application to baseband digital predistortion for 3G base stations,” *IEEE Trans. Microwave Theory & Tech.*, vol. 50, no. 12, pp. 3016-3021, Dec. 2002.

[5] W. J. Jung, W. R. Kim, and K. B. Lee, “Digital predistorter using multiple lookup tables,” *Electron. Lett.*, vol. 39, no. 19, pp.1386-1388, Sep. 2003.

[6] O. Hammi, S. Boumaiza and F. M. Ghannouchi, “Multi-Branch Polynomial Model with Embedded Average Power Dependency for 3G RF Power Amplifiers,” *IEEE Canadian Conference on Electrical and Computer Engineering*, on CDROM, April. 2007.

[7] O. Hammi, S. Boumaiza and F. M. Ghannouchi, “On the Robustness of Digital Predistortion Function Synthesis and Average Power Tracking for Highly Nonlinear Power Amplifiers,” *IEEE Trans. Microwave Theory & Tech.*, in press.