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# Mixed-Signal SoC Characterization for Power Amplifier DPD Feedback Loop Compensation

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## Abstract

The main objective of this paper is to present a calibrated mixed-signal characterization measurement system with an application case focusing a power amplifier (PA) digital pre-distortion (DPD scenario. This system allows to extract behavioral models radio-frequency (RF) mixed-signal components or devices, ranging from analog-to-digital converters (ADC), digital-to-analog converters (DACs) and integrated system-on-a-chip (SoC) integrated receiving and transmitting blocks, which are extracted in a scattering parameters notation and called D-parameters. It is developed on a modular PXI platform from National Instruments (NI) and will be used to improve the overall performance of a DPD feedback loop.

*Index Terms* – Mixed-signal, D-parameters, digital pre-distortion, and power amplifier linearization.

## 1. Introduction

Nowadays, the linearization of base-station power amplifiers (PAs) plays an important role to increase the PA efficiency and overall system performance, especially by employing digital processing schemes known as digital pre-distortion (DPD) onto the PA input signal. For this reason, DPD applications capable of measuring PAs DPD are really interesting to study the power amplifiers behavior and enhance their performance. Furthermore, one of the real challenges in the development of 4G/5G communication systems is that with the continuous increase of signals' bandwidth and carrier-aggregated conditions, there is a need to utilize higher speed data converters (RF ADCs and DACs) or integrated RF mixed-signal SoCs operating directly at RF bands. Due to this situation, these kind of devices can no longer be assumed to be ideal and their artifacts need to be taken into account in the system design process.

A mixed-signal measurement system based on a modular PXI platform from National Instruments (NI) already discussed in [1-3] will be revisited in its general details and architecture. This mixed-signal measurement system allows to have RF ADC/DACs or integrated RF mixed-signal SoCs behavioral models in common RF/Microwave circuit and system simulators.

For this purpose, a wideband integrated SoC receiver is characterized in two different models of operation focusing its RF performance and RF-to-IF behavior. This characterization is composed of a NIST-compatible calibration and measurement procedures to provide amplitude and phase representations of its internal functioning (called D-parameters$^{TM}$) [1]. The mixed-signal integrated SoC receiver is then applied in a hardware-in-the-loop DPD feedback path use case, [4], in order to linearize a representative 4G/5G and carrier-aggregated base-station PA. DPD feedback loop is operated into subsampling limitations and digital processing schemes are employed in order to improve the overall performance, just possible because of the utilization of this specific mixed-signal characterization procedure.

In a nutshell, this paper demonstrates how a mixed-signal measurement system can be exploited to extract an RF mixed-signal SoC model and apply it onto a PA DPD scenario in order to improve the complete system performance.

## 2. Mixed-Signal SoC Characterization Revisited

To proceed with the proposed approach, an integrated mixed-signal SoC wideband receiver Linear Technology® LTM9003 has been chosen [5]. This is an RF-to-digital receiver subsystem that includes a high performance 12-bit analog-to-digital converter (ADC), a bandpass filter (BPF), intermediate frequency (IF) amplifier and a high linearity RF down-converting mixer. As shown schematically in Figure 1, in this case the device under test (DUT) is composed of a commercially available PA followed by a coupler to obtain a sample of the output signal into the feedback loop and terminated by a COTS mobile unit duplexer. The characterized mixed-signal SoC is employed in the feedback loop of this PA DPD chain.

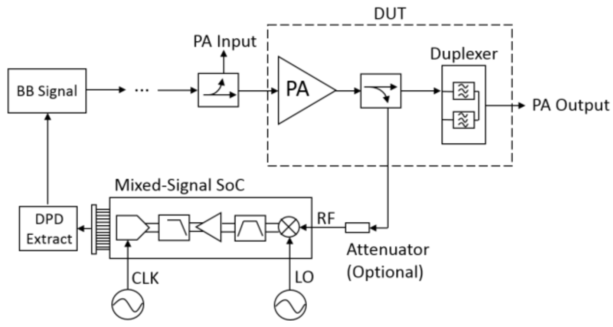


**Figure 1.** PA digital pre-distortion test setup.

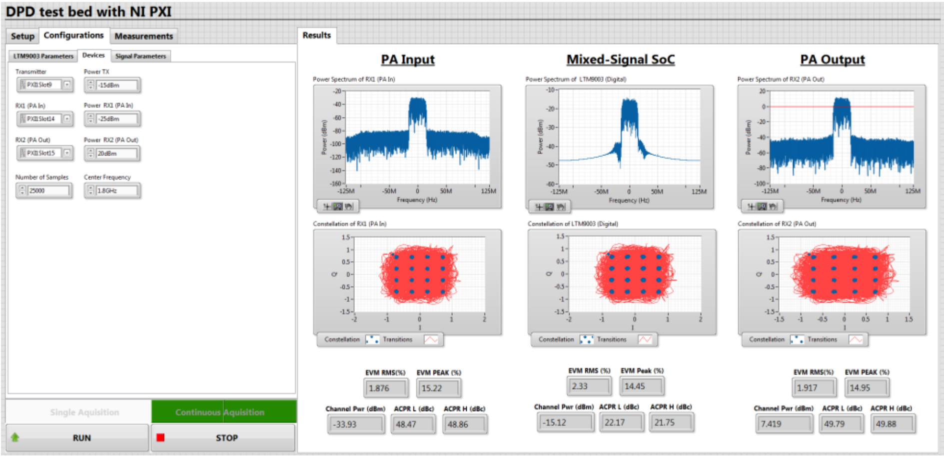


**Figure 2.** LabVIEW front-panel frame for the DPD application.

As can be seen, the setup consists in RF transmitter (TX NI 5793), which generates the baseband signal. The signals generators (SG NI 5652) are responsible to generate the LTM9003 LO and CLK signals. After that, a coupler is connected to RF transmitter, before PA input. Then, the coupler is connected to RF receiver (NI 5792) to read the PA input (incident wave) and it is connect to PA input. In PA output other coupler is used, which is connected to the duplexer and to the LTM9003 RF port. In the duplexer output port, the linearized total output signal to be radiated to the air interface can be obtained through another PXI receiver (NI 5792) emulating an antenna. Afterwards, the LTM9003 digital port is read (throughout an FPGA module) and the DPD extract model is applied in LabVIEW software.

## 3. DPD Model Extraction Strategy

The proposed architecture allows to measure in real-time the input-output performance of a close to real base-station PA chain, and obtain common measures as error vector magnitude (EVM), channel power and adjacent channel power ratio (ACPR), which are mandatory figures of merit for all wireless communication standards. LabVIEW application front panel is shown in Figure 2 showing different frames of the software side of the developed system.

## 4. Measurement Results

(To be included in the final version …)

## 5. Conclusion

This paper presents a PA DPD laboratory test bench working in a real-time fashion, which takes profit from an a priori mixed-signal SoC characterization procedure to correct DPD feedback's loop behavior. By using this approach we were able to get valid PA functioning under stringent conditions when operating at subsampling rates in the DPD feedback loop component. It was also demonstrated how a mixed-signal characterization system can be extended to more practical situations as in the PA DPD application under evaluation using COTS components.

## 6. Acknowledgements

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