A Comparative Overview of Digital Predistortion Behavioral Modeling for Multi-standards Applications

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***Abstract*— This work proposes a comparative study of three Digital predistortion (DPD) models, TPM (Two Path Memory based Volterra), GMP (Generalized Memory Polynomial), DDR (Dynamic Deviation Reduction) for multi standard system operation purpose. This paper is an extension of our previous work based on simulation data sets [1]. This assessment is conducted through measurements on a Silicon Bipolar Darlington Amplifier in two parts: the DPD models identification first, then their emulation with MATLAB in a specific measurements test bench to evaluate each DPD model with the power amplifier (PA).**

Keywords*— *Digital Predistortion, Nonlinear measurements, Behavioral modeling, power amplifier, GMP, DDR, TPM.

I. INTRODUCTION

Facing Power efficiency/Linearity compromise in telecommunication systems, DPD is an important technique to deal with non-linearity of the transmitter PA. Behavioral modelling based DPD is widely used today [2, 3], because the recent type of communication signals (e.g., LTE standards) are more sensitive to the non-linearity encountered in the amplification process (spread spectrum and high PAPR). Discrete time model based DPDs such as GMP [4] or DDR [5], are commonly used by communication systems suppliers. We observed in [1] trough simulations that performance of these type of models is biased by the signal used for determining DPD coefficients, consequently the variations occurring in incoming signal must be continuously monitored in order to readjust model coefficients. In system architecture point of view, the continuous coefficient update process results a complex and expensive feedback loop structure (Fig. 1).

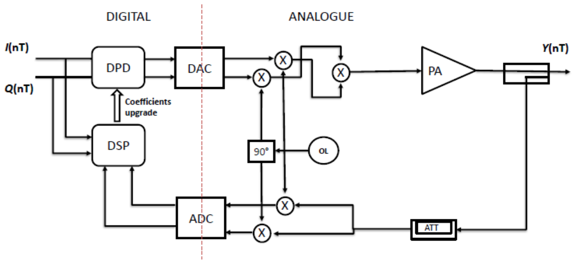

Fig. 1. General hardware architecture of DPD system

In order to reduce DPD architecture complexity and improve performance, it is desirable to obtain a DPD model that would perform equally well for a broad range of communication signal standards, using only a one-time coefficient update. This would considerably reduce the hardware complexity and cost by simplifying the regulation loop.

In this work, we compare the performances of three DPD model models; the two classical DPD models based on GMP and DDR formulations and the lastly introduced based TPM model approach. The DPD models are extracted and evaluated for a Silicon Bipolar Darlington Amplifier (AVAGO ADA-4543), operating at 3 GHz, with 12 dB of linear gain and 1 dB gain compression at 3 dBm output power.

In following, section II briefly recalls TPM DPD model equation; for sake of brevity we do not recall equations of GMP and DDR model which are well known [4, 5]. Next, we describe the coefficient identification procedures of the three DPD models in section III, and finally we present the DPD evaluation test bench and results in section IV and conclude.

II. TWO PATH MEMORY BASED VOLTERRA (TPM)

TPM model is a nonlinear continuous time integral model based on some physical observation that take into account the interaction between long-term memory and short-term memory effects. Short-term memory corresponds to the carrier frequency response of the amplifier. Whereas the long-term memory corresponds to the impact of the low pass filters in the biasing network and electro thermal circuit. The simplified equation of TPM model is shown below [6, 7, 8]:

$$x(t) = \left[1 + \int_0^\infty h_{LT}(|y(t-\tau)|, \tau) \,.\, |y(t-\tau)| dt\right]. \int_0^\infty h_{ST}(|y(t-\tau)|, \tau) . y(t-\tau) dt \quad (1)$$

Where $y(t)$ and $x(t)$ are respectively the input and output signal of the DPD (Indirect Learning technique); while $h_{ST}(y, \tau)$ and $h_{LT}(y, \tau)$ correspond to the nonlinear short-term and long-term responses of the PA.

In order to identify the model, the system is driven by a three-tone stimulus (one large and two adjacent small signal tones), illustration Fig. 2. Measurements of the gains between the three input-output tones [6], provide the data for determining the impulse responses $h_{ST}(y, \tau)$ and $h_{LT}(y, \tau)$ of (1).

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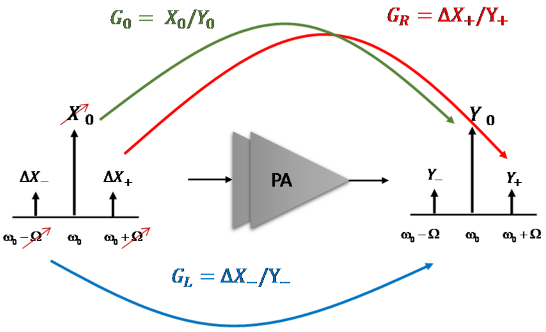

Fig. 2. Three-tone stimulus characterization (sweep large-signal tone power and frequency offset of adjacent small-signal tones, and measure inverse gains $G_o = X_o/Y_o$, $G_L = \Delta X_-/Y_-$ and $G_R = \Delta X_+/Y_+$)

III. Identification Procedure for DPD Models

A. GMP & DDR DPD models identification

In order to get data for GMP and DDR identification, the bench used is NI PXIe 5646R VST (Vector Signal Transceiver) from National Instrument, we drive the DUT with 42MHz OFDM signal, with a peak input power of 0 dBm corresponding to 5 dB gain compression. We have used in MATLAB LS techniques to identify the polynomials coefficients. The total number of coefficients is 56 for DDR and 24 for GMP, and the normalized mean square error (NMSE) is about -32 dB in both cases.

B. TPM model identification

The same equipment, NI PXIe 5646R VST, is used for characterization of the TPM model. The characterization procedure [7] is however significantly different from the previous models, as it uses a simple three-tone stimulus instead of the OFDM signal (Fig. 3). The large-signal tone have been swept in power from -20 dBm to 0 dBm corresponding to peak power considered in OFDM characterization for GMP and DDR models. Frequency of large-signal tone is also swept over 200 MHz of PA bandwidth, which is equivalent to the bandwidth covered by the OFDM output signal used for GMP and DDR model characterization. The power of the small-signal tones is maintained low at -30 dBm and their frequency offset to the large-signal tone is swept from 0 to 100 MHz.

The input-output gains of the three tones (G_o, G_L and G_R) are collected as a function of frequency and large-signal tone power. These are then processed following the algorithm described in [8] to get the two time-domain kernels of the model equation (1). The process uses an orthogonal series basis decomposition in the following form:

$$H(|y|,\Omega) = \sum_{k=0}^{K} \alpha_k \,.\, f_k(|y|) \qquad (2)$$

where $H(|y|,\Omega)$ represent a linear combination of the three measured gains. Then the power dependent basis functions $f_k(|y|)$ are represented by cubic splines, whereas the frequency dependent basis functions are decomposed in poles and residues using vector fitting method in Matlab. The basis functions ultimately form the two impulse responses model in (1), which are finally digitized using trapezoidal integration based on the identified poles and residues. The optimum number of spline functions found is 1 for both STM and LTM kernels, and the optimum number of poles was found to be respectively 3 for STM and 2 for LTM kernels. When recomposing the three measured gains (G_o, G_L and G_R), the NMSE is about -30 dB, comparable to DDR and GMP DPD models

IV. Comparison Test & Results

The DPD evaluation test bench is composed of a SMW200A VSG and a calibrated FSQ8 VSA, from Rhode & Schwarz (Fig. 3). The DPD models (GMP, DDR and TPM) operations are emulated on MATLAB/Simulink. During measurements, a modulated signal RF power sweep will be applied to the power amplifier under test up to its 1 dB CW gain compression point (P_{1dB}). For each average power point, a new IQ complex envelope is uploaded to the VSG alternatively for the non-predistorted and three predistorted configurations within Matlab.

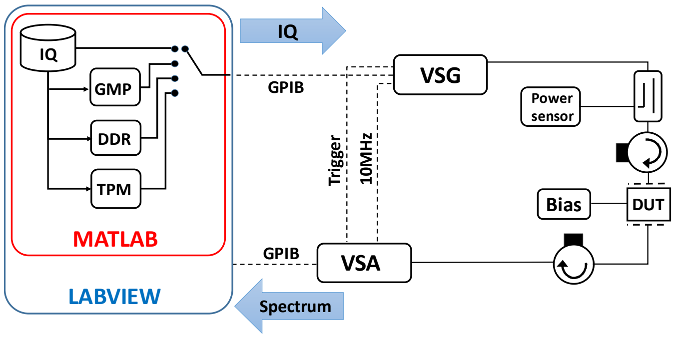

Fig. 3. Evaluation test bench for DPD models

We have considered evaluation of the DPD's for two test stimuli: the OFDM stimulus used for characterizing the GMP and DDR models and a different stimulus that is a 16QAM, for two input bandwidths. For illustration, we have represented in Fig. 4 the output spectra of the PA in the four evaluation configurations, for the 42 MHz OFDM signal, at -2 dB output power back-off (OBO) to P_{1dB}. We may observe similar linearization performance for the three DPD models.

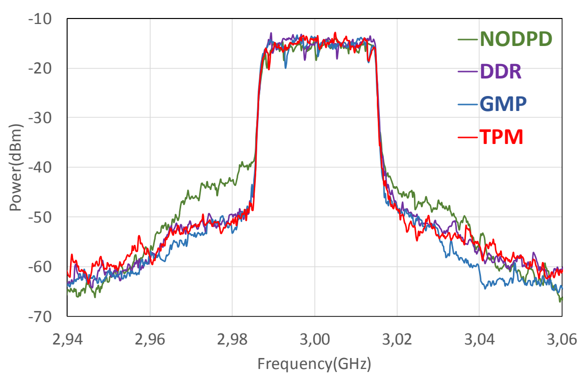

Fig. 4. 42 MHz OFDM signal predistorsion @ -2dB OBO

We have then measured ACPR (Adjacent Channel Power Ratio) in the four configurations as a function of OBO to P_{1dB}, which are represented in Fig. 5.

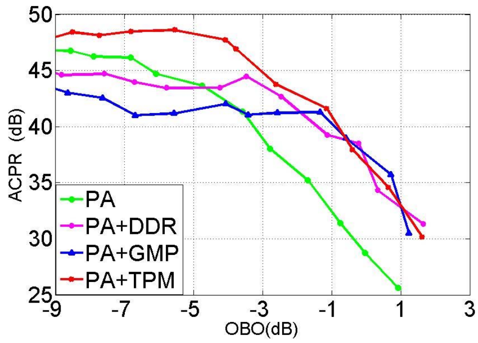

Fig. 5. ACPR for 42MHz OFDM test signal

We may observe similar ACPR improvements by all three DPD models, from -5 dB OBO upward. Below -5 dB OBO, the improvements are hindered by the noise floor of the VSA spectrum analyzer, which cannot accurately measure ACPR above 45dB. Although, we observe that performance of the TPM model is superior to the two other models in low power region. Indeed, in the low power region, ACPR performance is worse with GMP and DDR DPD than using PA without predistortion, which is not case with TPM model.

Next we have considered the application of a 16QAM stimulus for 42 MHz and 56 MHz input bandwidths. The coefficients of the three DPD models are kept unchanged. The goal is to observe agility of the DPD models without coefficient update. Fig. 6 and 7 show measured ACPR's of the four configurations, as a function of the PA output power back-off. Now we may clearly see a superior linearization performance of the TPM model versus the GMP and DDR models, especially in the low power region as well as at the larger bandwidth. GMP and DDR models would require a coefficient readjustment procedure in order to maintain good linearization performances, which is not the case for TPM. Without coefficient readjustment, linearization performances of the TPM model remain stable against variation of the signal power, the bandwidth and standard.

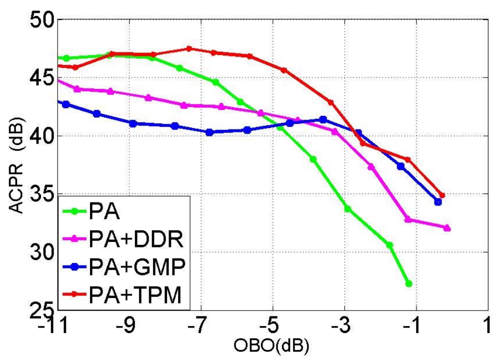

Fig. 6. ACPR for 42MHz 16QAM test signal

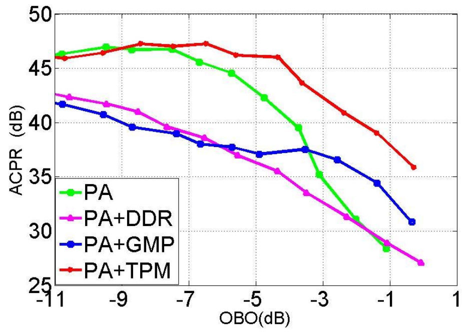

Fig. 7. ACPR for 56MHz 16QAM test signal

V. CONCLUSION

This work has presented a comparison of linearization performance between two commonly used DPD models (GMP & DDR), and a lastly introduced TPM DPD model. This comparison was made by achieving a series of measurements in the aim to verify the generality properties of the TPM model with respect to PA DPD application. The measurements has shown that TPM model maintain good linearization performances under a different stimulus conditions, without the need to readjust the coefficients. In the same conditions GMP and DDR model have shown need for coefficient update. This practical experimentation comes to sustain our previous observations based on behavioral simulations, and confirm the good potential of the TPM model as a "universal-signal" DPD design methodology that could simplify PA system design.

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