A Low-Rate Identification Scheme of High Power Amplifiers

Ziming Wang, John Dooley, Keith Finnerty, Ronan Farrell
Callan Institute
School of Electrical and Computer Engineering
National University of Ireland Maynooth
Maynooth, Co. Kildare, Ireland

***Abstract*—A novel low-rate identication method for high power ampliers with memory-effect is presented. It is demonstrated that the required bandwidth of the feedback signal is not required to be greater than twice the signal modulation bandwidth, but is instead determined by the number of feedback samples and the degree of freedom of coefcients in the behavioral model. As the experimental measurements and extracted power amplier model show, this method can achieve a much better NMSE accuracy of modeling power amplier with nonlinear memory-effects compared with previously published approaches**

Keywords*—*Identification, feedback bandwidth, high power amplifier (HPA), sampling rate.

I. Introduction

It is commonly accepted that the bandwidth of digital predistortion has to be much wider than that of the original signal modulation bandwidth, often three to seven times wider. In terms of the feedback signal from the output of a nonlinear PA to perform digital pre-distortion, there is a similar requirement for signal bandwidths of multiples of the original modulated signal. In the case of a 100 MHz instantaneous modulation bandwidth which will be required in the forthcoming Long Term Evolution Advanced (LTE- Advanced) systems, the demanding feedback bandwidth requirement creates a big cost for a high speed analog-to digital(ADC) device. For instance, a 500MHz feedback bandwidth will be required for the 100M LTE-Advanced signal in conventional digital predistortion(DPD) scheme based on memory polynomial. Meanwhile, the clock jitter has been proved to be a considerable source of performance degradation in wideband DPD systems [1]. So the sampling rate of ADC device in feedback path is becoming a block to the identification and predistortion scheme of wideband HPA.

To answer this problem, [2], [3], [4] are proposed to introduce a low-rate modeling method by a multi-dimensional Volterra kernel interpolation where the kernels are estimated using at least the Nyquist-rate of the original forward signal. This method is only usable to weakly nonlinear systems because it down-samples the forward signal to low-rate samples for the estimation process which leads to the loss of nonlinear memory variables in the PA model. To extend the low-rate identification method to high power amplifiers(HPA) in which the nonlinear memory-effect is very sensitive, [5] employs a feedback model to generate high rate feedback samples by means of estimating a band-limited model. However, all of these methods mentioned above [2]-[5] try to utilize the incomplete spectral information as a result of the filtering in the feedback signal path. This in turn leads to inaccuracy in the feedback sample values.

In the past, the problems of low-rate identification algorithms have been the loss of memory variables in the behavioral model and the loss of high frequency intermodulation distortion information in feedback samples. In this paper, we present a High Power Amplifier model with high-rate forward samples and low-rate feedback samples. This model enables an extraction setup, which preserves all of the memory variables of the behavioral model. Performing the model extraction in this way allows us to sample the high frequency intermodulation distortion by a low-rate ADC in the feedback path.

II. Multi-rate Characterisation of Nonlinear System with Memory-effect

In order to introduce a universal low-rate identification approach, we define a nonlinear polynomial model that is general enough to incorporate several different modelling scenarios.

The general memory polynomial model representation is given here as:

$$PD(n) = \sum_{i}^{Q} \omega_i(n)\phi_i\big[x(n), x(n-1), ..., x(n-t)\big] \qquad (1)$$

where x(n) and PD(n) is the input and output of predistorter, $\omega_i(n)$ is the *i*th complex coefficient at time n, Q is total number of terms, and $\phi_i\big[\,\cdot\,\big]$ is a memory nonlinear function of the input sequence [i.e., x(n),x(n-1),...,x(n-t)], being differentiable with respect to the input sequence. Note that this memory polynomial model is linear with respect to the coefficients $\omega_i(n)$.

The augmented matrix using general memory polynomial model with full feedback bandwidth is written in (2) and shown in Fig. 1a. Here,the feedback samples are denoted by $\hat{y}(\cdot)$.

$$A^{(a)} = \Big[\phi\big[x(\tau_1), x(\tau_1 - 1), \ldots, x(\tau_1 - t_1)\big], \quad x(\tau_1) - \hat{y}(\tau_2)\Big], \qquad (2)$$

$$where \quad \tau_1 = \quad \tau_2 = (t_1 + 1) : 1 : end; \quad t_1 = T_m/\Omega_s$$

Since the memory length of the PA to be modeled is fixed, despite reducing the sampling rate of the ADC on the feedback path, enough information is present to extract the model once the sampling rate of the forward signal remains the same. So the novel low-rate model is written in (3). Previously presented models have used high rate input and output data, and low rate input and output data as shown in Fig.1a and Fig.1b respectively where Ω_s and Ω_f indicate high sampling rate and low sampling rate. The method presented in this paper does not aim to compromise the sample rate of the feedforward signal, but instead only reduces the required performance of the feedback signal capture rate as shown in Fig. 1c.

$$A^{(c)} = \Big[\phi\big[x(\tau_1), x(\tau_1 - 1), \ldots, x(\tau_1 - t_3)\big], \quad x(\tau_1) - \hat{y}(\tau_2)\Big],$$
$$where \quad \tau_1 = (t_3 + 1) : N : end; \quad \tau_2 = (t_1 + 1) : 1 : end$$
$$t_3 = t_1 = T_m/\Omega_s \tag{3}$$

As shown in this augmented matrix representation, the input sequence of general nonlinear polynomial is a set of input date $x(\cdot)$ running at Ω_s which is sequential from τ_1 to $\tau_1 - t_3$. That means there are full set of memory variables in each row of the augmented matrix. So the problem of loss of nonlinear memory-effects due to the reduction of feedback sampling rate has been solved through this method.

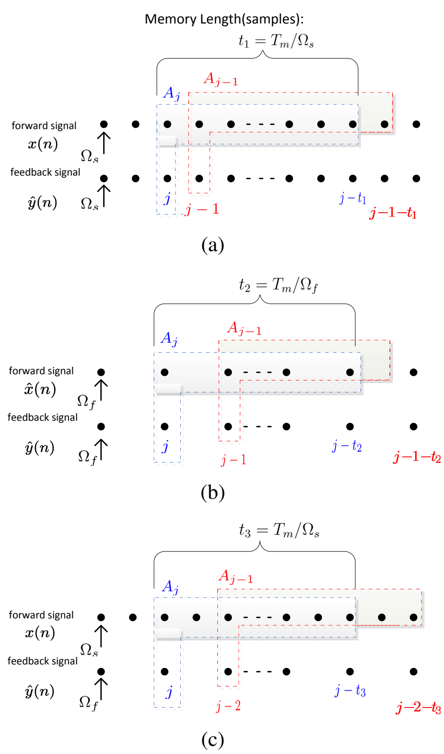

Fig. 1: Augmented Matrix
(a)Nonlinear identification with full feedback bandwidth
(b)Weakly nonlinear identification with half feedback bandwidth
(c)Nonlinear identification with half feedback bandwidth

The computation of PA identification or predistortion parameters is often carried out by solving an over-determined system of equations with the Least Squares (LS) method [6]. Because the number of equations or feedback samples is much more than that of the parameters, the typical selection process for behavioural model training data involves the selection of partial data samples. In the past, due to the loss of nonlinear memory effects in the behavioral model, the training data have to be consecutive. Fortunately by means of the way to build the behavior model proposed in this paper, the consecution of training data is unnecessary.

The new scheme of sampling high frequency intermodulation distortion by low-rate ADC is done by removing the requirement for the bandwidth of the anti-alias filter to be matched directly to the sampling rate of the ADC. Assume the sampling rate of each channel in two-channels of a time-interleaved ADC is f , so the whole sampling rate is 2f . If the bandwidth of the anti-alias filter is the same as that of the time-interleaved ADC but there is only one channel of the time-interleaved ADC working for sampling intermodulation distortion at f. What we obtain are the same samples as one channel of the time-interleaved ADC. The magnitude of each sample in this structure is accurate in the time domain, even though the transformed spectrum in the frequency domain will exhibit aliasing. Sufficient information of high order intermodulation distortion is present in the low rate sampled time domain signal.

III. Results

To validate this model an experimental testbench and software simulation were assembled. The testbench comprised of a Rohde & Schwarz SMU200A, a 10W 20MHz Class AB power amplifier and a Rohde & Schwarz FSQ. The datasets recorded by the FSQ were used to extract the general purpose model presented in equation (3). In simulation test, an ARCTAN PA Model is selected[7],[8]. The PA input $x(t)$ and output $y(t)$ are assumed to obey an ARCTAN model where M indicate the length of linear memory-effect and N indicate the length of nonlinear memory-effect.

A. MATLAB Simulation

In terms of PA model test, $N = 2$, $\gamma_1 = 18$,$\gamma_2 = 1.8$, $M = 2$, $\zeta_1 = 1.17$, $\zeta_2 = 0.17$. And the Fig. 3 shows the AM-AM curve of ARCTAN model, and Fig. 2 shows the spectrum of LTE input signal and PA output signal. As the test result of PA model shown in TABLE I, the method proposed in this paper achieved a much better performance of modeling a PA with memory-effect than the method in [4].

$$y(t) = \sum_{i_1=1}^{N} \{(\gamma_{i_1} tan^{-1}(z(t - i_1)))e^{j\angle z(t-i_1)}\}$$
$$z(t) = \sum_{i_2=1}^{M} \zeta_{i_2} |x(t - (i_2 - 1))| \tag{4}$$

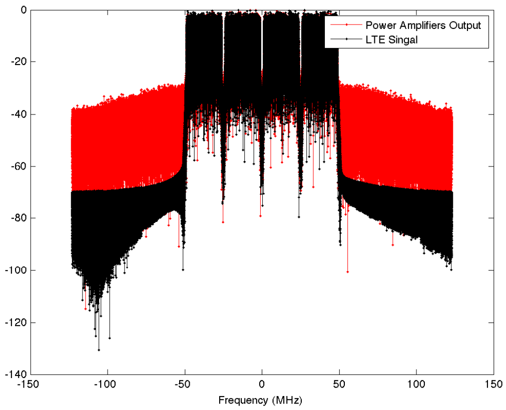

Fig. 2: The Spectrum of LTE Input and PA Model Output

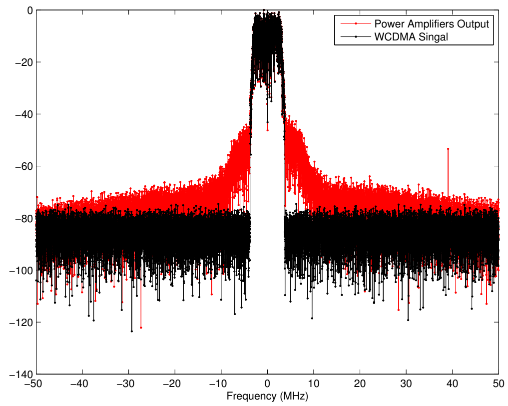

Fig. 4: The Spectrum of WCDMA Input and Class AB PA Output

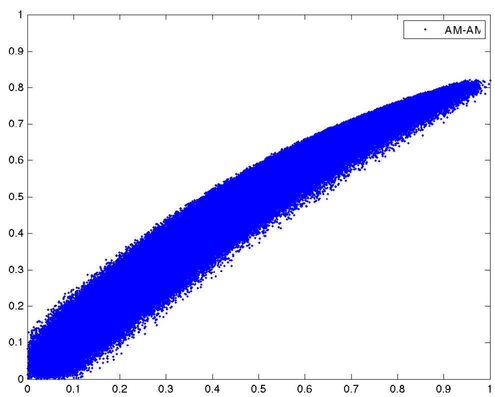

Fig. 3: The AM-AM Curve of PA Model

B. Experimental Results

In terms of test under the 10W Class AB power amplifier, the spectrum and NMSE test result are shown in Fig. 4 and TABLE II.

IV. Conclusion

As the experimental measurements and power amplifier model show, this method achieve a much better NMSE accuracy of modeling power amplifier with nonlinear memory-effects than the method proposed in the past.

TABLE I: NMSE Test Result of PA Model

Sampling Rate(MHz)	Proposed Method	Method in [4]
245.76	-53.7815dB	-53.7815dB
122.88	-51.4631dB	-29.0943dB
81.92	-51.1929dB	-19.1391dB
61.44	-50.7453dB	-17.6845dB

TABLE II: NMSE Test Result of Class AB PA

Sampling Rate(MHz)	Proposed Method
100	-50.1771dB
80	-50.1621dB
70	-49.8901dB
60	-48.0506dB

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