A Simple RF Power Amplifier Behavior Model for System Level Parameters Estimation

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ABSTRACT

In this paper, a nonlinear behavior model of an RF power amplifier, based on two polynoms extracted from measured AM-AM and AM-PM characteristics, is tested to estimate principal parameters at system level such as the gain, IP3 (or IMD3) and ACPR.

The same signal excitation for characterization and simulation is guaranteed by the connected-solutions bench (provided by Agilent Technologies) permitting real comparisons. For the experiments, we use a STMicroelectronics PPA (pre power amplifier), with 17.7dB of gain, +6dBm of maximum power output and less than –50dBc of ACPR. The frequency band of interest corresponds to 1920-1980MHz for WCDMA applications.

The proposed model can be extended to other signals and can be easily implemented into a simulator used by RF designers. It permits having all system level power amplifier characteristics well predicted with less time consuming.

1. INTRODUCTION

An accurate and representative power amplifier (PA) distortion characterization is a key factor to evaluate and to predict the performance of amplifiers and particularly their nonlinear behavior. Traditionally, the required PA linearity is guaranteed by backing off the amplifier, i.e. the operating point is backed off from the saturation level to the more linear region of the amplifier characteristics. However by doing so, the efficiency of the amplifier is decreased significantly, since the amplifier is operating more efficiently when the input signal is driven near the 1dB compression point. In another hand, in such a way, the PA introduces non linearities which should be predicted.

Behavior models provide simplified models of the essential nonlinear behavior at circuit level or system level of simulation. The main advantage of the behavioral modeling is the compact representation in the hierarchy used in simulation at the next level of abstraction. The simplification means that the model will execute more quickly, and will use less memory than if an entire complex subsystem was simulated, for example at the transistor level.

To estimate models with nonlinear effects, several methods have already been developed: Volterra Series [1] and Artificial Neural Network (ANN) [2] principally, differential equations, harmonic balance, transient simulation and behavioral model [2] extracted from measurements. For most of authors, a nonlinear system can be represented by Volterra kernels [3]. However, the computation of the Volterra kernels for nonlinear systems is often difficult and time-consuming for strongly nonlinear devices. About ANN, one potential problem with this technology is that it provides accurate models at the higher input levels, but they do not behave like polynomials for small input signals [4].

In many applications involving modeling of nonlinear systems, it is convenient to employ a simpler model. Moreover, simple behavioral model can be used easily in a digital communication system simulation. The PA block is often represented by AM/AM and AM/PM functions. Usually, the AM/AM and AM/PM are measured by sweeping the input power at a single tone in the center frequency of the passband of the PA and these measurements are not sufficient to model the PA behavior in particular applications. Recently, some new statistical techniques were, for example, developed to analyze the effects of nonlinear distortion on a WCDMA or CDMA signal (used in the 3G standards), and also to predict ACPR (Adjacent Channel Power Ratio) from the AM-AM and AM-PM characteristics [5-6]

Our final aim is to facilitate the use of a behavioral model of PA into a simulator used by designers. The parameters of this model must be easily extracted from simple measurements. These observations lead us to conclude that a fifth order polynomial interpolation [7] of nonlinear parameters is then sufficient and precise enough to describe the PA behavior. Using such a polynomial model permits easily the estimation, with good agreements, of the power amplifier parameters at system level. Indeed, we don't take into account electrical characteristics. In this way, time consuming is decreased and it allows to evaluate quickly and accurately the component specifications.

2. MEASUREMENTS APPROACH

Distortion Suite (Agilent Technologies) is the software we use for AM/AM and AM/PM measurements. This software provides a measurement of the Input/Output waveform relationship of a PA stimulated with complex signals. Output power levels used may be large enough to cause distortion or compression of the amplifier output stages, and the software characterizes this distortion or compression with AM/AM and AM/PM curves.

Therefore, characterization is made with complex signals and not CW signals like usually. Why do not use CW signals? CW signals are insufficient for testing all amplifier distortions. Indeed, the response of a nonlinear device depends on the nature of a complex signal, which excites it in a generally nonlinear way. Complex signals differ in time from CW signals, and hence the resulting distortion will be different. The consequence of this fact is that the ACPR of the same amplifier is different when stimulated by different modulation formats.

2.1 Bench setup

The equipment shown in figure.1 contains, for characterization measurements, a VSA (Vector Signal Analyser DC-6GHz) E89640 for the output signal analyses (spectral and time domain), a generator source E4437B which can generate CDMA formats, linked to the simulator ADS (Agilent). For the CW measurements, we also use a VNA (Vector Network Analyser).

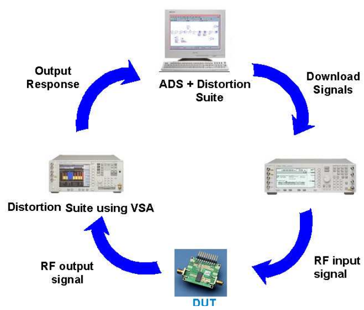

Figure 1:Connected-Solutions bench setup

The principal advantage of this bench is having the same excitation signal for measurements and simulations [8].

2.2 Proposed Model

The fifth-order memoryless nonlinearity can be described by the Taylor series:

$$y(t)=\alpha_0+\alpha_1*x(t)+\alpha_2*x(t)^2+\alpha_3*x(t)^3+\alpha_4*x^4+\alpha_5*x(t)^5$$

where x(t) is the input passband signal, y(t) is the output passband signal, and α_I are the Taylor series coefficients.

In this paper, the model is represented by the AM/AM and AM/PM thank to two fifth order polynoms (see figure 2).

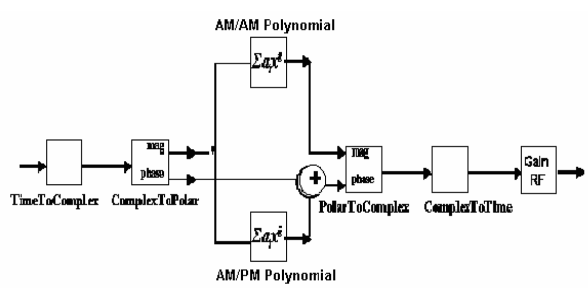

Figure 2: Amplifier Polynomials Behavior Model

The input signal is transformed into complex envelop signal which can be expressed as:

$$V(t) = I(t) + j*Q(t)$$

with I(t) and Q(t), respectively the real and imaginary part of the voltage. Then these two parts are used to compute the magnitude and the phase of the input envelop signal. The normalized coefficients of the polynomials representing the AM/AM and the AM/PM are used to compute the magnitude and phase of the output envelop signal. The input magnitude is used to be transformed by AM/AM polynomial and by AM/PM polynomial. The phase difference is calculated between the input phase and the AM/PM response. The two parts are then transformed into an output complex signal and finally transformed in time domain. The output is, at the end, multiplied by the power amplifier gain.

2.3 Polynomial coefficients extraction

We start the measurements of amplitude conversion and phase conversion by sufficiently sweeping the input power to reach the compression of the PA. We estimate the 1dB compression at nearly –3dBm input level power.

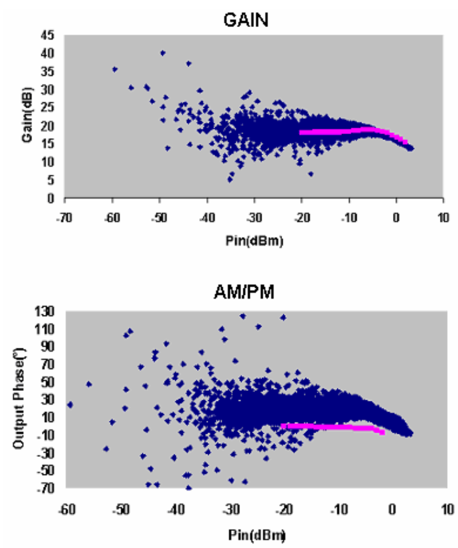

Figure 3: amplifier gain and phase conversion measurements by VSA (dark points) for WCDMA signal and by VNA (light curve) for a CW signal test

The AM/AM and AM/PM responses are measured by the VSA in the time domain. Then, fifth order polynomial fitting is computed.

These two polynoms with AM/AM and AM/PM coefficients represent the fundamental part of the PPA behavioral model which can be easily implemented into a simulator such as ADS.

3. PARAMETERS VALIDATION RESULTS

Commonly used parameters for radio-frequency amplifiers at system level are:

-Power/Voltage gain which is the ratio of output power/voltage (delivered to the load) to the input power/voltage (available from the source). The power gain will be equal to the voltage gain of the amplifier only if the input and output impedances are the same.

-Amplitude compression **(AM/AM)** and phase compression **(AM/PM)**. These two characteristics are used to predict the impact of the amplitude compression.

-Third-order intercept point (IP3):

The nonlinearity of radio frequency circuits is often expressed in terms of the third-order intercept point (*A*IP3).

Assuming two interferers very close to the desired frequency, a non-linear output from the amplifier will generate inter-modulation products. The most important of the products is the third order product since it falls directly in the frequency band of interest.

-**ACPR** and/or EVM, are the parameters of the quality of the modulation. This last parameter (ACPR) is detailed in the last part of this paper.

Gain and IIP3 can be estimated, from polynoms coefficients, with following relations:

$$Gain(dB)=20*\log(\alpha_1)$$
$$A_{IP3}^2 = 4/3*\alpha_1/\alpha_3$$

Gain has been measured and results are compared to the simulated gain in figure 4.

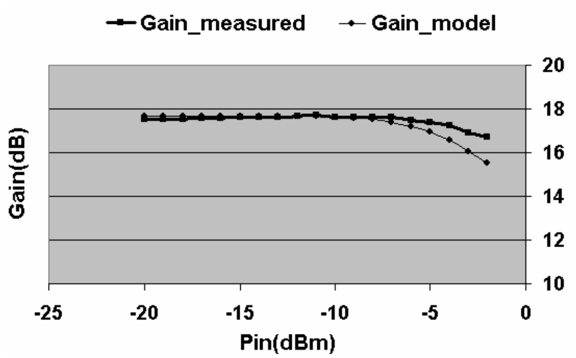

Figure 4: Simulated and Measured Gain

The power amplifier polynomial model gives accurate predictions in linear part, but a difference appears in nonlinear part.

IIP3 value measured by the VSA is +18dBm. In figure 5, the simulated result can be viewed in spectral domain for the same two-tones test.

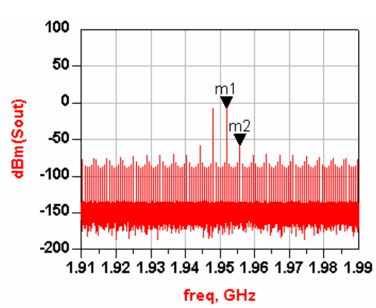

Figure 5: Output at fundamental and third order in spectral domain

The marker 1 gives the output power at the fundamental frequency. The marker 2 gives the third order output power value at 2f2-f1.

As we've said the polynomial model offers the possibility to estimate the parameters of Gain and IP3 without simulation or measurement. We can also use the formula in §2.2 to extract the results from the polynomial model coefficients.

In table 1, we compare the formula to the results given by the model simulations and the measurements.

Parameters	Measured results	Estimated results	Model results
GAIN(dB)	17.7	17.8	17.65
IIP3(dBm)	18	18.31	18.25

Table 1: Comparison between model and estimation results

Good agreements are obtained between the results given by the power amplifier model and the results from the gain and IP3 formula. The error does not exceed 5% in comparison with the measurements.

4. VALIDATION WITH ACPR PARAMETER

Digital modulation analysis on the PA was also performed to obtain key parameters such as spectral regrowth, adjacent channel power ratio (ACPR). The spectral regrowth seen at the output arises from the digital modulation "spreading" of the input signal due to the distortion in the PA.

The ACPR is calculated by integrating the spectral regrowth data (a power spectral density plot) over two finite frequency ranges (the in-band and adjacent channels) to obtain their respective powers. The ACPR is the ratio of (adjacent channel power/in-band channel power) and is usually specified in dB. For designers, the goal is to reduce the ACPR as much as possible so as not to cause interference in the adjacent channel. This is an important modulation quality parameter.

The ACPR results given by the model depend certainly on the input level signal used to build the model. In figure 6, we can see the input level signal influence during the AM/AM and AM/PM acquisition.

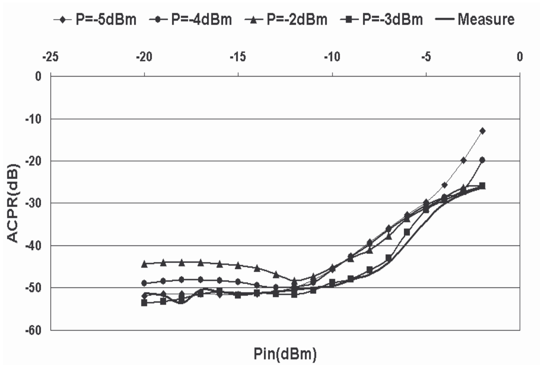

Figure 6: ACPR simulated at different Pin compared to the measure

We can see clearly that the ACPR results given for –3 dBm input level corresponds the best to the ACPR measured. This input level is precisely the 1dB compression point. Therefore it's very important to select the right input level to reach the power amplifier saturation and perform the model.

We can notice in figure 6, that with a model built from –2dBm input level, the ACPR is the worst in linear part. Indeed, at this level, the saturation is already reached, that's why the ACPR value is so high. About the other levels, the compression is not yet reached: the ACPR results in linear part are similar but for the nonlinear part, the ACPR is overestimated.

In conclusion, the input level choice must be at the 1dB point compression, that means clearly between the linear and nonlinear part to improve the results.

5. CONCLUSION

In this paper, we propose a simple behavioral model for RF power amplifiers permitting to describe accurately and with less time consuming, the parameters at system level. A good agreement has been demonstrated between Gain, IP3, ACPR results and dynamical measurements. With such a model, measurements are reduced only to the AM/AM and AM/PM characteristics. The establishment of the power amplifier specifications can be done by saving time and permitting to reduce the "time to market". Eventually, other parameters like IPX and IMDX (X=2,3,..7) can be estimated too.

6. ACKNOWLEDGEMENTS

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