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X-Parameter Modeling of Power Amplifier for Pre Distortion Applications

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Abstract — **This paper presents X- parameter technique for modeling a high power, wide band and PA with memory effects, which can be used in development of Pre-distortion Technique. The model is extracted for a WCDMA signal. The resulting nonlinear X-parameter model has been validated with the characteristics of its hardware counterpart. The model has been implemented in the SystemVue simulator.**

Keywords – **Behavioral model, Memory effects, S-Parameters, SystemVue, X-parameters.**

I. Introduction

Introduction of 3G and 4G technologies has imposed stringent constraints on the RF designers for designing Power amplifiers (PA) which should meet performance requirements in terms of power efficiency and good linearity. Due to broadband nature of 3G and 4G signals, frequency dependent behavior of PA is encountered, i.e., memory effects. Memory effects are defined as distortion phase and amplitude changes over the modulation bandwidth, which obvious character is spectrum asymmetry. Memory effects based on the existence of behavioral model can be divided into three categories like memory-less behavioral model [1], linear (short-term) memory effects behavioral model [2] and nonlinear (long-term) memory effects [3] behavioral model. For accurate modeling of PA, Memory effects cannot be ignored. RF design engineers are faced with the sometimes daunting task of evaluating and selecting devices for PA design. Also during the past designers relied on linear data or extrapolation techniques to predict the PA model. Large signal S-parameters are widely used for extracting the PAs behavioral model but for this time invariant property of PA characteristics is generally assumed [5]. The research on nonlinear S-parameters has begun during last two decades. People would like to develop a characterizing framework similar to S-parameter, which could describe nonlinear systems like S-parameter did in linear systems. These more than two decades effort of researchers has result in the development theoretical basis for X-parameters. This paper presents the use of X-parameters for PA model extraction, via the black-box modeling technique. Rest of the paper is organized as fellows. Section II presents the theoretical background of X-parameters, In Section III, in the SystemVue has been used to extracted and validate the extracted model. We draw our conclusion in Section IV.

II. Theoretical Background of X-Parameters

X-parameters have emerged as new category of nonlinear network parameters for high-frequency design. These parameters were introduced by Agilent Technologies and are functionality included in N5242 Nonlinear Vector Network Analyzer[6][7], and the W2200 Advanced Design System in 2008. X-parameters can be applied to both large-signal and small-signal conditions, for linear and nonlinear components. Mathematically X-parameters can be regarded as superset of S-parameters [8]. And for small signals X-parameters are reduced to S-parameters. X-parameters have overcome a key challenge in RF engineering like nonlinear impedance differences, harmonic mixing. X-parameters seem to be helpful in solving this cascading problem by measuring the X-parameters of a set of components individually and then calculating the X-parameters of the cascaded system. Calculations based on X-parameters are usually performed within a harmonic balance simulator environment [9]. X-parameters are based on the poly harmonic distortion modeling work of [10] and [11]. X-parameter format and underlying equations are open and documented in several IEEE papers [12] and has been discussed under as:
In its usual notations S-Parameters can be written as

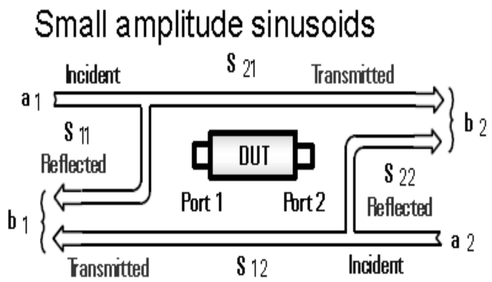

Fig.1. Representation of S-parameters for small signal sinusoids

$$b_1 = S_{11a1} + S_{12a2} \quad (1a)$$

$$b_2 = S_{21a1} + S_{22a2} \quad (1b)$$

Where

$$S_{ij} = \frac{b_i}{a_j}\bigg|_{\substack{a_k=0\\ k\neq j}} \quad (2)$$

S-parameter measurements require that the S-parameters of the device do not change during the measurement.

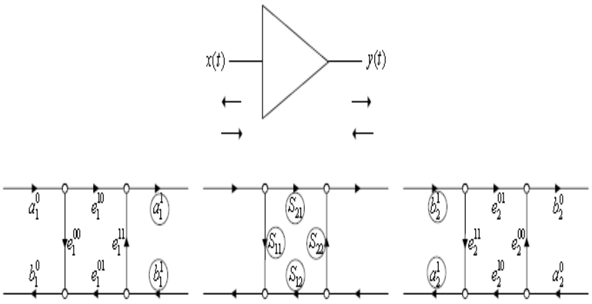

Fig.2. Traditional measurement of S-parameters

To solve, traditionally we use a forward and reverse sweep (2 port error corrections). If the S-parameters change ,when sweeping in the forward and reverse directions when performing 2 port error correction, then the resulting computation of the S-parameters are invalid. In general eq. 1 can be written as

$$b_i = \sum_k S_{ik} \cdot a_k \tag{3}$$

Expanding eq. 3 in matrix form, we get

$$\begin{bmatrix} b_1^{fwd} & b_1^{rev} \\ b_2^{fwd} & b_2^{rev} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1^{fwd} & a_1^{rev} \\ b_2^{fwd} & a_2^{rev} \end{bmatrix} \tag{4}$$

or

$$\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} = \begin{bmatrix} b_1^{fwd} & b_1^{rev} \\ b_2^{fwd} & b_2^{rev} \end{bmatrix} \begin{bmatrix} a_1^{fwd} & a_1^{rev} \\ b_2^{fwd} & a_2^{rev} \end{bmatrix} \tag{5}$$

So, correct value of S_{22} is generally asked by the designers because the match changes with input drive power and frequency. To find correct value of S_{22}, it is traditionally measured at a frequency slightly offset from the large input drive signal. But it still does not provide the exact solution. So, for large signals, X-parameters are the better solution.

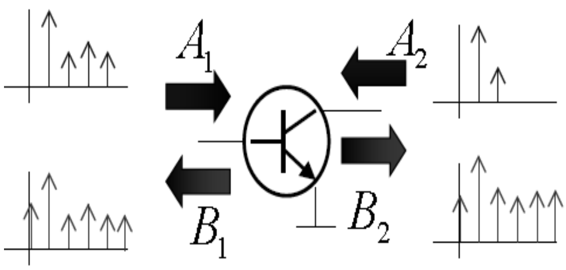

Fig.3. Representation of X-parameters

The X-parameters provide a mathematically correct mapping of the 'A' and 'B' waves at ports, input powers, harmonics, DC bias, etc (as shown in Fig.3). The X-parameters provide a mathematically correct mapping of the 'A' and 'B' waves at ports, input powers, harmonics, DC bias, etc, etc. For linear and nonlinear system X-Parameters can be written as (Agilent Technologies)

$$B_{1k} = F_{1k}\left(DC, A_{11}, A_{12}, \ldots, A_{21}, A_{22}, \ldots\right) \tag{6}$$

$$B_{2k} = F_{2k}\left(DC, A_{11}, A_{12}, \ldots, A_{21}, A_{22}, \ldots\right) \tag{7}$$

$$b_{ij} = X_{ij}^{(F)}\left(|A_{11}|\right)P^{j} + \sum_{k,l \neq (1,1)} \left(X_{ij,kl}^{(S)}\left(|A_{11}|\right)P^{j-l} \cdot a_{kl} + X_{ij,kl}^{(T)}\left(|A_{11}|\right)P^{j+l} \cdot a_{kl}^{*} \right) \tag{8}$$

Where
i= output port index
j = output frequency index
k = input port index
l = input frequency index
i.e. $|A_{11}|$ represents Large signal drive to the PA input port 1 at their fundamental frequency 1 and $X_{21,21}^{T}$ means output port 2, output frequency 1(i.e. fundamental frequency), input port 2 and input frequency 1(i.e. fundamental frequency).

III. X-Parameter Modeling of PA

Fig. 4 shows the snapshot of the set up used for extracting the model of PA using X-Parameters. The model has been developed using Agilent SystemVue software. The spectrum of the input signal to the PA and its output are shown in Fig. 5. The model has been extracted using memory polynomial given by eq. 8.

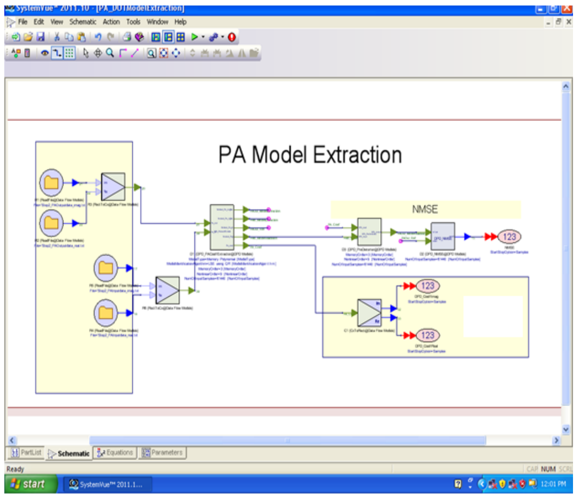

Fig.4. Snapshot of Set-up used for Extraction of PA Model using X-Parameters

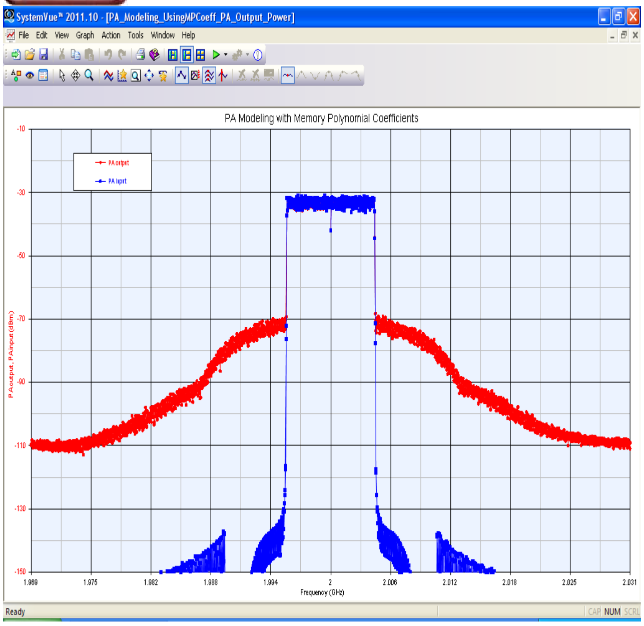

Fig.5. Input and Output Spectrum of PA

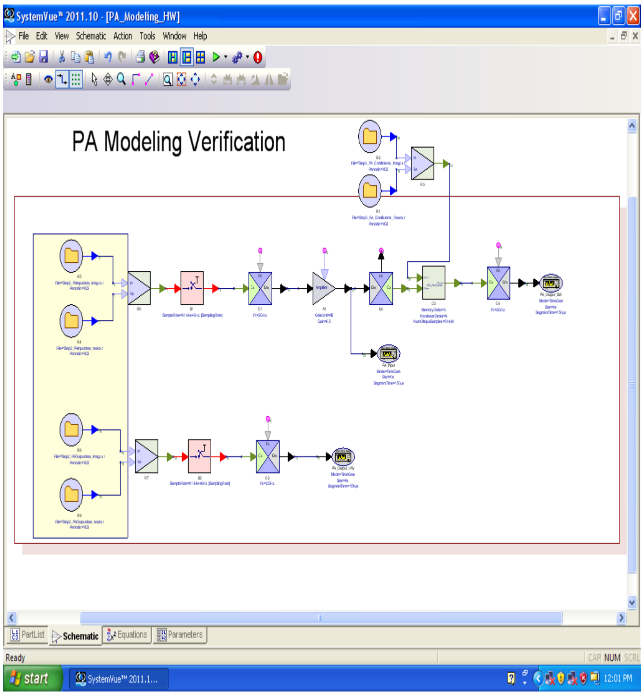

Fig.6. Snapshot of Set-up used for Verification of PA Model using X-Parameters

Comparison of input and output spectrum shows the non-linear behavior of PA and the effect of this non-linear behavior in spreading of the in-band and out-of-band frequency components. For valediction of the extracted model, it has been compared with its hardware counterpart by using the verification set-up shown in Fig.6 and the results have been shown in Fig. 7.

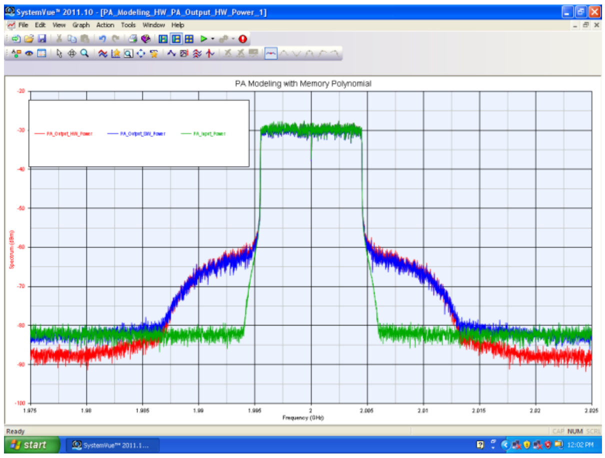

Fig.7. Input and Output Spectrum of actual PA and X-Parameter Modeled PA

Fig.7 shows that the modeled PA has almost similar characteristics as that of its hardware counterpart. The characteristics of the modeled PA slightly deviate only for higher harmonics, which are generally ignored for pre-distortion applications.

IV. Conclusion

The paper presents modeling and simulation PA with memory effects. Memory effects have been identified from X-parameter simulations. The extracted memory model has been validated with its hardware model. Comparison of result shows the valediction of the extracted model. The extracted model can be useful in development of linearization techniques such as pre-distortion for wide bandwidth communication signals with high peak-to-average ratios.

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AUTHOR'S DETAIL

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The first author has over 13 year of teaching experience. She has done her B. Tech and M.Tech. from Nagpur and Punjab respectively. Presently she is working at Punjabi University and also pursuing Ph.D. from this university. She has number of publication in reputed journals. Her area of research is communication engineering.

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