Advanced behavioral modeling of RF/Microwave circuits for active antenna system simulation

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Summary

A methodology for the prediction of the active antenna system performance is presented. It is based on the simulation of the power amplifier at system level, drastically reducing the simulation time for the calculation of large scale architecture. Initially, the in-house behavioral model of the power amplifier is extracted from measurement data. PA models are connected to phased-array antenna which is described through multiport S-parameter matrix. Simulation results at system level are presented to analyze dispersion of magnitude and phase at antenna's excitation ports and power consumption.

1. Introduction

The increased risk of impairments resulting from ever-increasing architecture complexity of communication systems requires high circuit model quality. An accurate simulation of the RF chain is needed in order to reduce the cost of prototyping, and optimize system performance. In the chain, the nonlinear Power Amplifier (PA) is one of the most challenging circuits to model. On one hand, circuit-level simulation and lookup table models are not suitable anymore for optimized subsystem design and accurate system analysis. On the other hand, antenna designers are facing new challenges: theoretical beam steering is modified when connecting the antenna to the rest of the systems in the radio chain. The connection of the antenna to the different systems of the chain introduces phase errors that may change the initial beam-steering angle. For example, the presence of digital step attenuators (DSA) and digital phase shifters (DPS) used for the analog beamforming will introduce losses that need to be considered at the design stage. In addition, the connection of a PA at each port of the antenna introduce load-pull effects that may degrade the PA behavior while coupling effects between the antenna elements may reduce the antenna performances. Therefore, a tool enabling the analysis of this effect, based on accurate behavioral models, is necessary to improve beam steering.

2. Power amplifier behavioral modelling

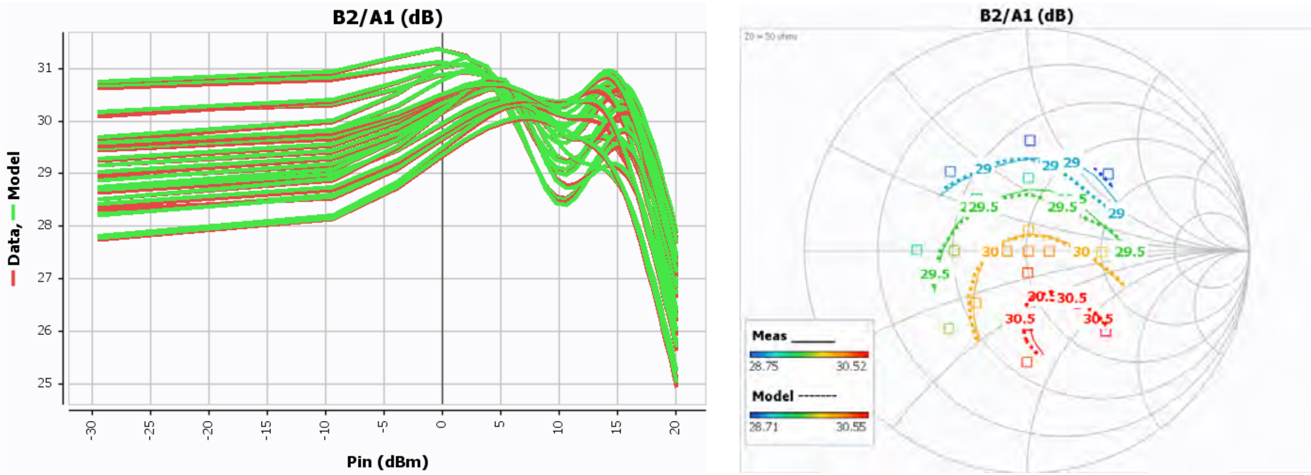
Different techniques have been developed for the extraction of the behavioral models aiming for a compromise between accuracy and calculation time. The methodology presented in this paper is based on bilateral modeling techniques of power amplifiers in mismatched conditions and high frequency memory effects. One of its main advantages is that models can be easily extracted using data provided by commercial harmonic balance (HB) simulator or from measurement data. The methodology for the prediction of PA behavior in system-level simulations will be illustrated through an off-the-shelf PA.

The behavioral modeling formalism with the potential for handling load impedance mismatch has been introduced in [1] under the names of the "polyharmonic distortion" model (PHD model). In our article, PA is described thanks to a reduction of PHD model and the model's capabilities are extended to PA's operating bandwidth, in order to take into account High Frequency memory effects [2]. Indeed, we are making the assumption that an amplifier can be viewed as a nonlinear two-port circuit and can be described as follow:

$$\begin{pmatrix}\tilde{b}_1\\ \tilde{b}_2\end{pmatrix} = \begin{pmatrix}S_{11}(|\tilde{a}_1|,\Omega) & S_{12}(|\tilde{a}_1|,\Omega)\\ S_{21}(|\tilde{a}_1|,\Omega) & S_{22}(|\tilde{a}_1|,\Omega)\end{pmatrix}\cdot\begin{pmatrix}\tilde{a}_1\\ \tilde{a}_2\end{pmatrix} + \begin{pmatrix}0 & S_{12}^{\Delta}(|\tilde{a}_1|,\Omega)\\ 0 & S_{22}^{\Delta}(|\tilde{a}_1|,\Omega)\end{pmatrix}\cdot\begin{pmatrix}\tilde{a}_1^*\\ \tilde{a}_2^*\end{pmatrix} \quad (1)$$

where $\tilde{b}_1$, $\tilde{b}_2$ and $\tilde{a}_1$, $\tilde{a}_2$ are respectively the reflected and incident power waves at the two ports, $S_{11}(|\tilde{a}_1|,\Omega)$ are the nonlinear Scattering functions that depend only on the incident wave's magnitude and Ω the frequency offset from carrier. Thus, equation (1) ensures the validity of the bilateral model of nonlinear part at operating frequency.

Figure 1 (a) presents PA gain according to input power at 3.6 GHz for several output impedance. Measurement data and model are well matched. Same results are displayed on Smith chart in figure 1 (b) for fixed input power of 12 dBm. Gain contours are well reproduced by the model on the characterization area.



(a) (b)

Figure 1. Model vs. data of PA gain function of input power (a) and PA gain function of output impedance (b)

3. Active antenna system design and simulation results

Using an in-house simulation environment, an active antenna system is designed by connecting PA blocks at each port of antenna S-parameter matrix. The in-house simulation engine is able to compute in a reasonable time the response of each PA blocks depending on active VSWR presented at each port of the antenna. Simulations results allow analyzing dispersion of magnitude (Figure 2) and phase at the antenna's ports and to update the radiation pattern in consequence. By sweeping carrier frequency and beam steering in the in-house simulator, system impairments and performances can be analyzed before system integration.

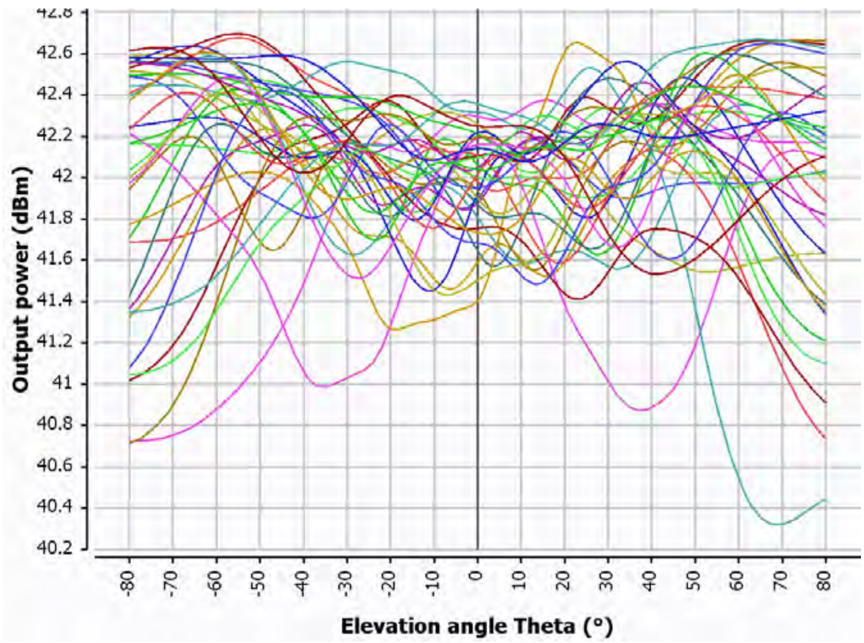


Figure 2. Output power of each PA function of elevation angle θ

References

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