Nonlinear characterization and modeling approaches for Envelope Tracking RF PAs

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***Abstract*— The project consists in developing general techniques to model supply modulated RF power amplifiers (PAs). The aim is to build approaches capable of describing the device and PA behavior under modulation and envelope tracking operation. To do so, large-signal measurements have been carried out and models including the dynamic dependency of the RF input envelope and of the modulated supply voltage have been obtained. Further developments will be focused on using such approaches for digital predistortion of envelope-tracking PAs.**

***Index Terms*—Power amplifiers, behavioral modeling, large-signal network analysis, supply modulation, envelope-tracking**

I. INTRODUCTION

THE high number of applications and services offered through modern telecommunication platforms is increasingly demanding high-data rates connections and original system-level design approaches. This influences the way in which telecommunication signals are engineered: modern standards (e.g. 3G, LTE) implement large bandwidth signals (tens of MHz) and give origin to high peak-to-average modulated RF power. Such specifications affect the performance of RF power amplifiers, which account for the largest stake of the total power consumption of a transmitting system in both handset and base stations. Recent advancements in RF PA design include architectures in which the supply voltage is dynamically changed in order to minimize the output power back-off and enhance PA efficiency for high PAR signals. Some examples are envelope-tracking (ET) and envelope-elimination-and-restoration (EER) topologies. In order to make those techniques competitive, enhanced compensation and digital predistortion are needed. However, a number of aspects shall be taken into account with respect to standard PA topologies. First of all, supply modulation causes (un)wanted LF-to-RF conversion products. Furthermore, a dynamic bias unavoidably induces undesired memory effects when characterizing the RF-to-RF signal path. Such memory effects depend on the PA design, but also on its technology, which might be affected by low-frequency dispersive phenomena. As a consequence, custom predistortion techniques are essential within the system design, and challenges such as the identification procedure of a behavioral model for the PA, its mathematical description and the digital implementation of the PA inverse characteristic are open topics of research.

II. STATE OF THE PROJECT

The first aspect addressed in the project is related to the measurement set-up to be used in order to identify memory effects, especially considering the ones stimulated by a dynamic supply. To this aim, a large-signal network analyzer (LSNA) properly extended to measure low-frequency excitations has been used [1]. By means of the set-up in Fig. 1 it is possible to apply and measure simultaneously stimuli at both RF and LF in order to investigate the frequency response of the PA under compression and when driven by a dynamic bias voltage. Such transfer functions can be identified by applying a small signal modulation tone at low frequency around the dc value (obtaining dynamic biasing) through a LF module of the set-up, while a large tone is applied at the RF input of the amplifier [2]-[3]. At the RF output, two 1st order intermodulation products, up-converted at $f_0 \pm f_m$, can be simultaneously measured, together with the incident and scattered RF waves. By sweeping the frequency of the small signal applied, an evaluation of the up-conversion characteristic in the band around the carrier can be performed. With the same procedure, also the nonlinear impedance at the supply port of the PA can be measured, which is of key importance for the supply modulator designers and the interfacing with the PA. An example of the transfer functions measured is shown in Fig. 2-3. A modeling approach obtained

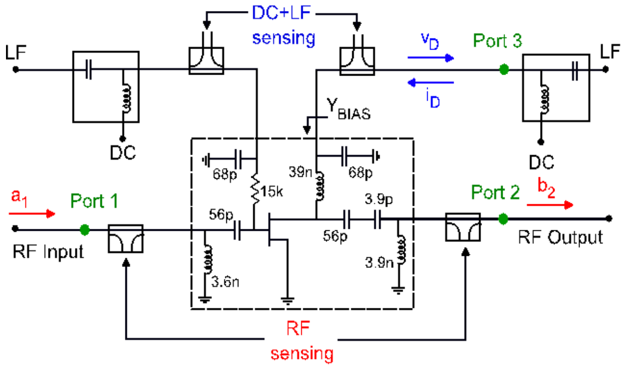

Fig. 1 – Block representation of the LF-extended LSNA measurement set-up and the DUT; the three ports and the electrical variables to be considered for the mixer-like characterization are highlighted.

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through the measurements described above has been now finalized and is under publication. This model allows to separately control the two inputs (RF and supply voltage) and opens the field to optimized predistortion for ET PAs. Other techniques using Nonlinear Vector Signal Analyzer (NVNA) by Keysight has also been tested and are under investigation with the purpose of measuring the time-domain response for modeling purposes è [4]; an example of pulsed X-parameters is shown in Fig. 4. Moreover, low-frequency load-pull at the supply port has been investigated [5].

III. FUTURE WORK

The models of RF output power and supply current will be used to design optimized digital predistortion algorithms under envelope-tracking operation, with the objective of minimizing the feedback, which it is usually implemented to set the predistortion coefficients. Furthermore, the approaches will be customized to be applied to Gallium Nitride PAs, which exhibit peculiar behavior especially if considering the low-frequency dispersion characteristics and their impact on the efficiency [6]-[7].

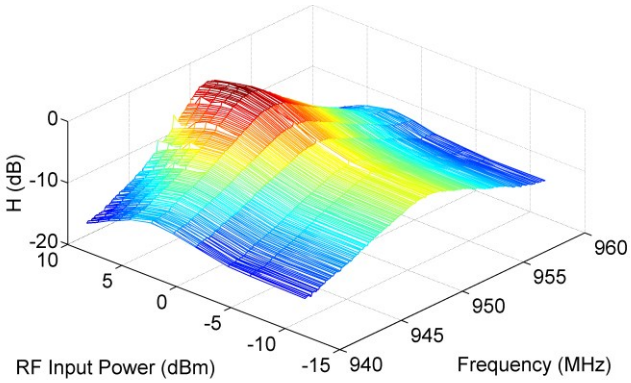

Fig. 2 –LF-to-RF transfer function measured around a carrier of 950 MHz by means of the LF-extended LSNA, applying a dynamic biasing around a drain bias dc voltage of 3.5V. RF input power:-10÷10 dBm, f_{MAX}=10 MHz, step: 100 kHz. The measurement set-up is shown in Fig. 1.

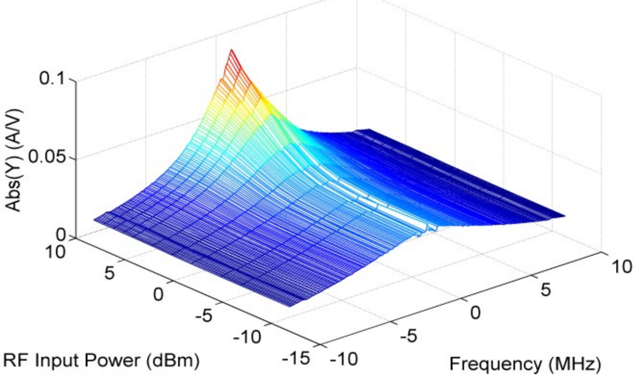

Fig. 3 –Nonlinear admittance measured around a carrier of 950 MHz by means of the LF-extended LSNA, applying a dynamic biasing around a drain bias dc voltage of 3.5V. RF input power:-10÷10 dBm, f_{MAX}=10 MHz, step: 100 kHz. The measurement set-up is shown in Fig. 1.

IV. IMPACT OF THE MTT-S FELLOWSHIP

The MTT-S fellowship gave me the opportunity to attend the IMS 2014 in Tampa. As a consequence, I got to know the many initiatives proposed by the MTT-S, and the possibility of building networks around my research interests. The economical contribution has been mainly invested in additional components for the measurement set-ups, as well as for the purchase of DUTs and boards manufacture. The remainder of the funds would also be used for future MTT-S co-sponsored conferences. The participation in these events greatly contributes to my willingness of pursuing a research career in RF and microwaves.

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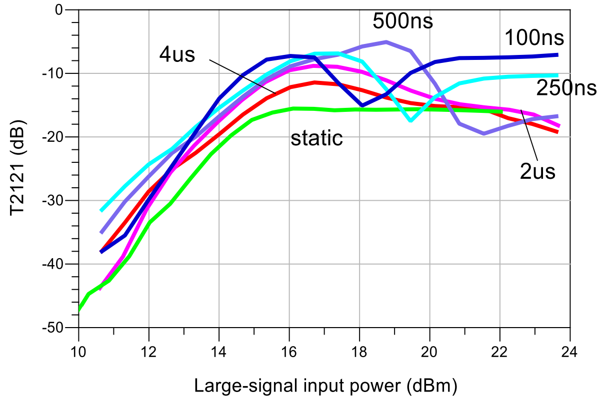

Fig. 4 - An example of pulsed X-parameter acquired at various time-delay from a RF pulsed wave, by means of the NVNA by Keysight. The device under test was a handset PA from RFMD [4].