Enabling Baseband and Radio-Frequency Characterization of Power Amplifiers Using a Wideband Nonlinear Measurement Platform.

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Abstract—**The use of efficiency-enhancing techniques and wideband modulations schemes induces nonlinear memory effects in radio-frequency of power amplifiers.**

This work focused on the development of a custom measurement setup to enable combined baseband and radio-frequency characterization of such effects. It extends the capabilities of a commercial vector network analyzer platform by enabling synchronized current and voltage measurements on the supply terminal of the amplifier.

Index Terms— **Large signal network analysis, nonlinear measurements, behavioral modeling, three-port behavioral modeling.**

I. INTRODUCTION

BEHAVIORAL models are needed in order to evaluate the realistic performance of power amplifiers (PA) within radio-frequency (RF) transmitters and to improve their characteristics. These models are typically identified by measuring the response of the device under test (DUT) to different types of stimuli, such as continuous wave (CW), pulsed or multitone signals.

Advanced measurement capabilities enable the formulation of new large-signal behavioral models that take into account long-memory effects. In fact, in case of modulated signals, the nonlinear distortion in the PA produces spurious low-frequency components. These, in turn, interact with various physical mechanisms such as low-frequency dispersion in the characteristics of some types of electron devices (e.g. Gallium Nitride devices), self-heating or bias modulation (either intentional or self-induced). The global effect is the non-linear dependence of the PA output signal from the past values of the input.

In this context the RF PA can be modeled as a three-port electrical network. Its operating condition is fully known once two physical quantities, such as voltage and current or incident and scattered waves, are measured for each port. The first two ports are respectively the input and output ones, whereas the third port represents the connection between the PA and the power supply circuitry. In fact, spurious baseband components due to non-linear distortion will be superimposed to the existing dc bias.

The measurement hardware used during this project was made available by Keyisght Technologies in Aalborg, Denmark.

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II. MEASUREMENT SETUP

The proposed setup is based on a commercial non-linear vector network analyzer (NVNA) platform. It can measure error-corrected absolute amplitude and phases of RF envelopes at the input and the output of the PA while at the same time acquiring absolute amplitude and phases of the baseband signals on the supply port (Figure 1). The automatic acquisition and post-processing of all the data was controlled by custom software developed during the course of this project.

A. *RF measurements*

As in a classic vector network analyzer, RF signals are picked off using directional couplers, downconverted to baseband with a mixer and finally digitized. However, in this setup, all the components in a given frequency bandwidth (here 12.5 to 50 MHz maximum, set by the digitizers) around a single RF carrier are measured at the same time, giving the possibility of reconstructing periodic time-domain waveforms of modulated signals.

B. *Baseband measurements*

Microwave directional couplers usually present very low directivity characteristics at low frequencies and so are poorly suited for supply-port measurements. After comparing different solutions, a custom fixture based on commercial oscilloscope voltage and current-clamp probes was developed. The fixture provides a fixed reference plane for the third port and, using external impedance adapters, allows to interface the probes with the 50 Ω -matched internal baseband receivers of the NVNA, featuring the same measurement bandwidth as RF ones.

III. CALIBRATION

Calibration procedures are needed to compensate for all the systematic sources of error in the measurement setup: delays, attenuations, non-ideal directivity of couplers, mismatching effects, amplitude and phase distortion in the acquisition channel.

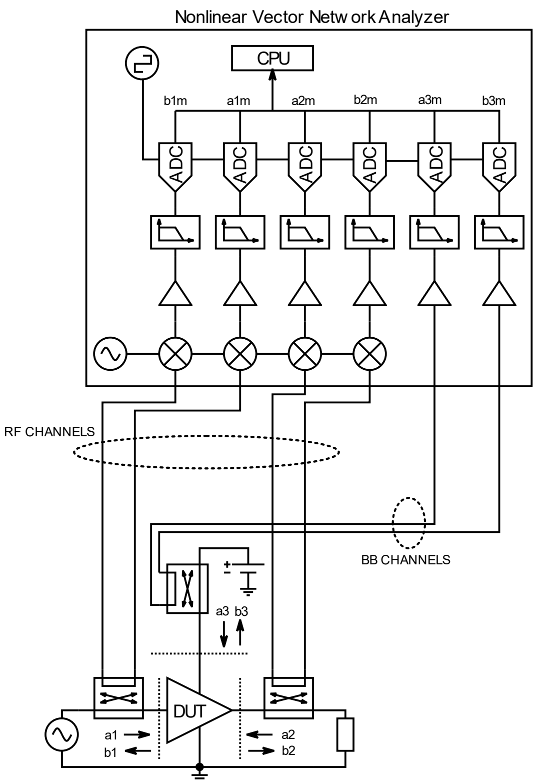

Fig 1: The proposed three-port measurement setup

Assuming a linear behavior of all the employed test-set, the mapping between measured waves (“m” apex) and the ones at the DUT ports can be expressed in the frequency domain as a 6-by-6 complex-valued matrix for each of the measured phasors (“k” index).

$$\begin{bmatrix} a_{1,k}^m \\ b_{1,k}^m \\ a_{2,k}^m \\ b_{2,k}^m \\ a_{3,k}^m \\ b_{3,k}^m \end{bmatrix} = \begin{bmatrix} \alpha_{1,k} & \beta_{1,k} & 0 & 0 & 0 & 0 \\ \gamma_{1,k} & \delta_{1,k} & 0 & 0 & 0 & 0 \\ 0 & 0 & \alpha_{2,k} & \beta_{2,k} & 0 & 0 \\ 0 & 0 & \gamma_{2,k} & \delta_{2,k} & 0 & 0 \\ 0 & 0 & 0 & 0 & \alpha_{3,k} & \beta_{3,k} \\ 0 & 0 & 0 & 0 & \gamma_{3,k} & \delta_{3,k} \end{bmatrix} \begin{bmatrix} a_{1,k} \\ b_{1,k} \\ a_{2,k} \\ b_{2,k} \\ a_{3,k} \\ b_{3,k} \end{bmatrix} \quad (1)$$

The calibration needs to estimate the coefficients in Equation 1 for each of the measured frequency components to yield correct reconstruction of the signals at three PA ports.
The procedure consists of the different steps:

1) *Relative Calibration*
   Using acquisitions of pre-characterized passive loads, the relative errors between the two electrical quantities measured on each of the ports are compensated.
2) *Absolute amplitude and phase calibration*
   Using a calibrated power meter and a known phase reference, the linear distortion introduced in the measurement channel is removed.
3) *Alignment*
   Measured waveforms on the different ports are synchronized to provide a complete characterization of the amplifier. A cross-frequency alignment procedure is needed to get coherent baseband and RF acquisitions.

The procedure was implemented in the control software and each step was independently validated.

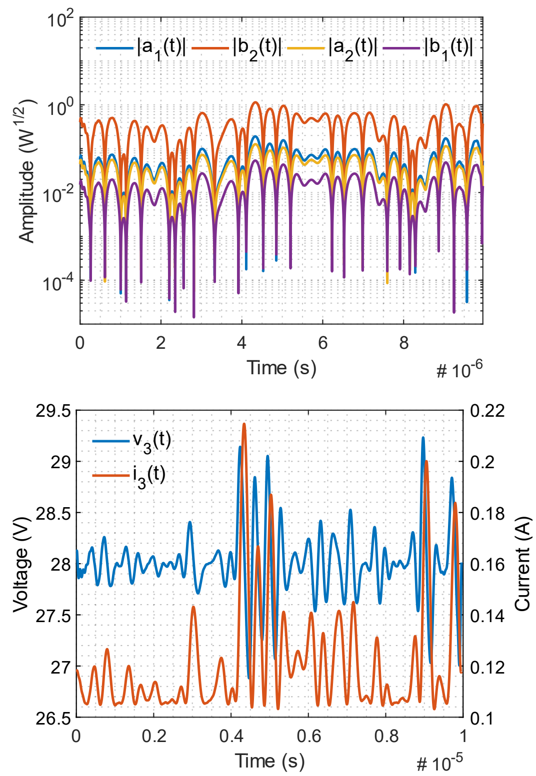

Fig 2: Measurement of a DUT response to a multitone signal

IV. RESULTS

The proposed setup can automatically acquire calibrated measurements of the relevant electrical quantities on the three ports of the PA, enabling new modeling and characterization techniques. An acquisition of the combined RF and baseband response of a commercial PA using a 5-MHz-wide random phase multitone excitation signal is reported in Figure 2.

V. CONCLUSIONS

A. *Career plans*

After my Master’s degree, I decided to pursue a PhD degree in electronic engineering at the University of Bologna, Italy.
Some of the research topics will be nonlinear measurement platforms and behavioral modeling techniques for RF PAs. The MTT-S scholarship has given me the chance of developing an original project that motivated me to continue with this further degree.

B. *Impressions on MTT-S Sponsored Conference*

Thanks to the MTT-S scholarship, I have attended the 12th European Microwave Integrated Circuits Conference (EuMIC) in October 2017. It was an occasion of getting to know state-of-the-art research results directly from people working in the field. I gained more insight in the topics I was already familiar with and I had the chance of getting to discover different ones. This inspired new techniques and approaches that I could employ in my own research projects.