Broadband characterization of Gallium Nitride RF amplifiers and transistors under modulated excitations

Alberto Maria Angelotti, Student Member, *IEEE* and Alberto Santarelli, *Member, IEEE*

***Abstract*—This document reports the research undertaken during the past months under the support of the MTT-S Graduate Fellowship. Working towards the development of advanced state-spaces model for Gallium Nitride radio frequency power amplifiers, two major characterization milestones were reached. First, a novel setup for wideband active load pull, leveraging on existing VNA equipment, was developed and demonstrated. Second, a method for the characterization of memory effects**

***Index Terms*—gallium nitride, rf power amplifiers, nonlinear microwave measurements, behavioral modeling, large signal network analysis.**

I. Introduction

The fifth generation (5G) of wireless telecommunications networks at achieving Gb/s transmission capacity, using spectrum frequencies higher than current standards and accessing wider modulation bands (hundreds of MHz to GHz). The design and optimization of transmitter systems for 5G, however, is significantly impacted by the presence of memory effects in the power amplifier (PA).

A particular case of interest is that of PAs based on Gallium Nitride (GaN) High-Electron-Mobility-Transistors (HEMTs). These devices display nonlinear memory behaviors due to trapping of charge carriers in the semiconductor crystal lattice defects. The time-varying terminal voltages and temperature influence the trapped charge, which in turn dynamically modifies the transistor characteristics.

Novel characterization techniques of such effects under realistic 5G-like excitations are crucial for the design of RF transmitters, in order to achieve efficient signal amplification with broadband linearity. Such capabilities can then be leveraged on for the development of advanced (e.g., state-space-like) models for the long-memory behavior of the PA behavior. This will ultimately enable simulation, digital predistortion and overall optimization of PAs in transmitters.

The following sections introduce two major milestones in the development of that were achieved during the past few months and resulted in two publications [1][2] to be presented at International Microwave Symposium 2020.

II. Wideband Active load pull

Wideband active load pull (WALP) has been proposed as a technique to characterize microwave transistors and to optimize power amplifier performance under operating conditions that closely mimic 5G communication applications [3]. The method allows to set, for a given device under test (DUT), a user-prescribed load reflection coefficient profile across a wide modulation bandwidth (BW) at fundamental and harmonic frequencies.

In the setup developed at the University of Bologna (Fig.1), a first vector signal generator (VSG) excites the DUT at the input using a periodic multitone signal that closely emulates the statistical and spectral properties of standard waveforms. A second VSG injects another multitone signal which actively synthesizes the required load reflection coefficient across the bandwidth of interest.

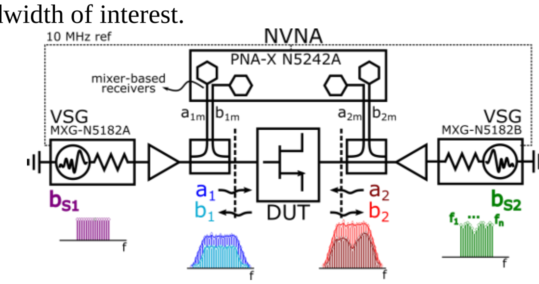

Figure 1: The developed wideband active load pull setup.

The computation of the correct output-injected signal to synthesize the required load uses a multi-variable optimization procedure that leverages on calibrated vector network analyzer (VNA) acquisitions. The iterative algorithm uses a combination between a modified secants' method and a novel procedure that estimates the large signal output match of the DUT. Fast and stable convergence of the method was validated on different DUTs (Fig.2).

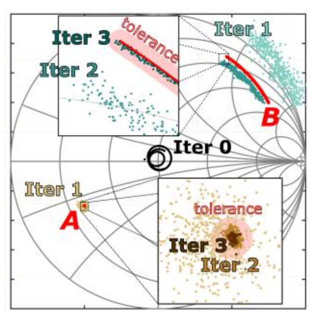

Figure 2: Convergence of the WALP algorithm on a packaged PA excited by a 80-MHz wide random phase multitone signal at 1 GHz on two different load profiles (A-B).

This approach [1] differs from existing ones in that it does not use full waveform measurements, enabling WALP on

A.M. Angelotti is pursuing a PhD degree with the Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi", University of Bologna, Bologna, Italy (e-mail: alberto.angelotti@unibo.it).

A. Santarelli is associate professor with the Department of Electrical, Electronic and Information Engineering "Guglielmo Marconi", University of Bologna, Bologna, Italy (e-mail: alberto.santarelli@unibo.it).

widespread standard hardware. These broadband load emulation capabilities will allow to characterize the impact of charge trapping on single-stage PAs for 5G applications at an early stage of the design cycle, before having to implement any actual matching circuit.

III. Broadband EVM Characterization of Long-Memory in GaN Transmitters

Error vector magnitude (EVM) is a fundamental metric for evaluating the broadband linearity of PAs in telecom transmitters. Recent advances [4] in nonlinear measurement techniques have enabled its accurate estimation using standard VNA hardware, instead of the typically employed wideband vector-signal-analyzers.

The framework uses the best linear approximation (BLA) of PA to estimate: the full nonlinear dynamic input-output response is represented as a sum of the response of a linear-time-invariant (LTI) system and a nonlinear distortion residual, which is directly related to the EVM. The LTI approximation of the system is optimal in the least square sense for a given class of modulated signals sharing the same gaussian probability density function (pdf) and power spectral density (PSD) as 5G waveforms.

In [2] the dependency of the EVM and the BLA on the large-signal operating point (LSOP) of the PA was studied. In particular, different frequency spacings of the 5G-like multitone excitation are tested on a GaN PA. In this way, it possible to probe charge trapping effects across a variety of time-scales while, differently from previous methods, faithfully reproducing LSOPs close to the final application.

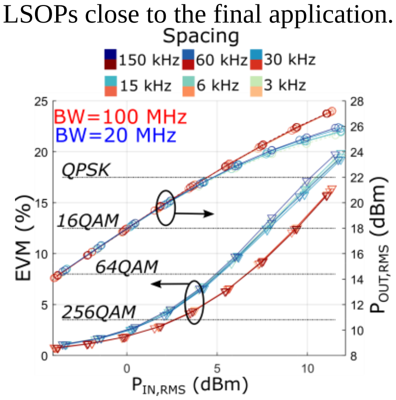

Figure 3: EVM vs Power Curves for two different bandwidths and spacings on a GaN PA at 5.5GHz.

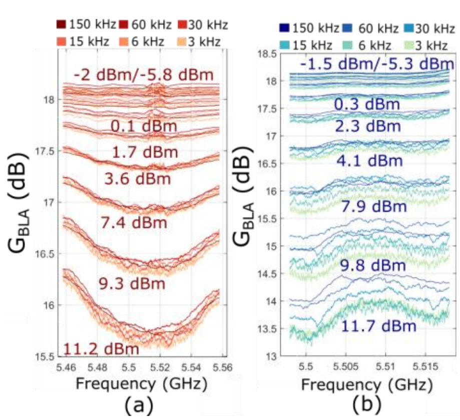

Figure 4: BLA for two different bandwidths (a-b), spacings and power levels on a GaN PA at 5.5GHz.

Results are reported in Fig.3-4. The EVM seems to be mostly unaffected by the tone spacing, while some dependence of the BLA on the spacing is seen for the 20 MHz bandwidth at higher power levels. The complex dependence of the BLA on the input power and signal bandwidth highlight that, due to the excitation of high-order Volterra Kernels, conventional Wiener-Hammerstein (e.g. memory polynomial) models are not sufficient to describe the PA behavior.

This experimental study confirms the need for the development of advanced (e.g. state-space) models for GaN amplifiers in telecom applications.

IV. Further Work

The newly developed WALP and EVM characterization capabilities will be used to study and benchmark novel modeling and digital predistortion architecture tailored for the compensation of long-memory effects in
GaN PAs.

V. Career Plans and Impact Statement

A. Career Plans

After completing my PhD next Spring, I yet have to make any specific long-term plan but I would certainly value any position that will allow me to continue to further my research interests in nonlinear microwave measurements and characterization. In this respect, either applying for an academic post-doc or looking for an industrial research position in the field are both viable choices.

B. Impact Statement

The MTT-S Graduate Fellowship has been a great opportunity for pursuing a challenging but rewarding research project that ultimately helped my personal and professional growth.

Even though I did not have the possibility of attending IMS 2019 in person, the support of the fellowship allowed me to develop several original research lines, resulting in significant publications in the field.

References

*[1] **A.M. Angelotti** , G. Gibiino, T. S. Nielsen, D. Schreurs and A. Santarelli "Enhanced Wideband Active Load-Pull with a Vector Network Analyzer Using Modulated Excitations and Device Output Match Compensation," to be presented as part of IMS 2020.*

*[2] **A.M. Angelotti** , G. Gibiino, C. Florian, and A. Santarelli "Broadband Error Vector Magnitude Characterization of a GaN Power Amplifier using a Vector Network Analyzer," to be presented as part of IMS 2020.*

[3] M. Marchetti, M. J. Pelk, K. Buisman, W. C. E. Neo, M. Spirito, and L. C. N. de Vreede, "Active harmonic load–pull with realistic wideband communications signals," IEEE Trans. Microw. Theory Techn., vol. 56,no. 12, pp. 2979–2988, Dec 2008.

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