# A Measurement Set-up and Methodology Combining Dynamic Biasing and Baseband Predistorsion for High Efficiency and Linear Amplifier Design

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***Abstract* — This paper presents a time domain envelope measurement system that enables the study and the optimization of high efficiency and linear power amplifiers by applying both envelope tracking and digital base band predistorsion techniques. A main focus of this paper is the description of the set up architecture along with its capability to achieve in depth investigations on the dynamic behavior of envelope tracking amplifiers (ET PAs). To reach optimal efficiency and linearity performances ET PAs need to be accurately characterized under dynamic operating conditions in order to perform a well suited control of RF input envelope and bias voltage tracking signals. The proposed set up is applied here to a 10 W GaN Power amplifier from Cree at 3.6 GHz**

***Index Terms* — Power Amplifiers, Envelope tracking, Microwave test bench, linearity and efficiency characterization.**

## I. INTRODUCTION

Great efforts have been accomplished over the past decade to design high efficiency and linear microwave power amplifiers. The achievement of both high efficiency and linearity performances is a real challenge in the case of the amplification of signals having large envelope variations. Such signals are used in communication systems requiring good spectral efficiency and propagation channel robustness.

High efficiency is of prime importance for designing power amplifiers because it results in DC power saving and thermal management improvement which in turn results in improved transistor reliability thanks to reduced self heating effects. Linearity is obviously required to ensure acceptable signal integrity. Many power amplifier design techniques demonstrating good trade offs between efficiency and linearity have been reported. [1], [2], [3], [4], [5], [6].

Amongst these techniques, dynamically biased power amplification appears as a very promising approach and remains an important subject of investigations when it has to be applied to high power, high DC current microwave amplifiers with high data rate modulation schemes.

In this context, a measurement set up dedicated to power amplifier efficiency and linearity optimization by an appropriate management of base band signals that feed the RF carrier modulator and the PA biasing circuits can be a useful tool for power amplifier designers.

In Part II of the paper the proposed time domain envelope measurement set up is described. In part III, it is shown how the measurement system is applied to a 10 Watt, S Band, GaN amplifier to achieve efficiency and linearity enhancements. The methodology used for the extraction of a dynamic drain bias law is explained. Then envelope tracking technique is applied and demonstrates significant efficiency improvements. After that a digital predistorsion is applied to the ET PA to enhance linearity performances.

To conclude future trends are mentioned.

## II. TEST BENCH DESCRIPTION

The block diagram of the set up that we have developed is given in Fig. 1.

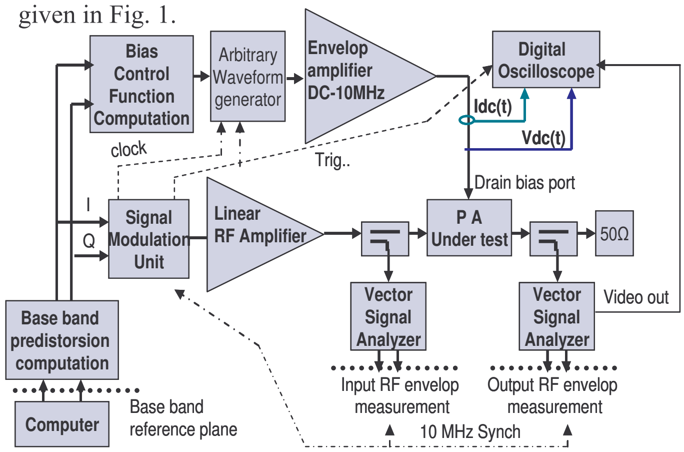


Fig. 1. Block diagram of the test bench.

The base band measurement signal is generated by the measurement software which runs on the computer controlling the whole set up and loaded in I / Q ports of the signal modulation unit. The output RF signal of the signal modulation unit is linearly amplified and feeds the input of the power amplifier under test (AUT) .Input and output signals of the AUT are measured by using vector signal analyzers. The magnitude of the base band measurement signal is loaded in an arbitrary waveform generator (AWG) to feed the drain bias circuits of the power amplifier under test. The output signal of the AWG is amplified by using a linear DC-10 MHz (70V – 2A) amplifier. We do not take into account in the following the poor efficiency of this envelope amplifier. We use this linear envelope amplifier for the moment to develop our test bench methodology as explained in part III of the paper. Later, this envelope amplifier will be obviously substituted by a high efficiency switch mode amplifier. Current and voltage probes connected to a sampling scope are used for drain bias voltage and current measurements. Clock synchronization and envelope trigger signals are carefully controlled in order to ensure a proper time alignment between the RF envelope signal and the drain biasing signal driving the amplifier under test.

## III. Application to Efficiency and Linearity Enhancements of a 10 W GaN Amplifier

A 10 W GaN amplifier from Cree (CGH40010F-TB) has been used as a device under test. The carrier frequency is 3.6 GHz. A QAM 16 modulation scheme has been applied. A picture of the amplifier is shown in Fig. 2.

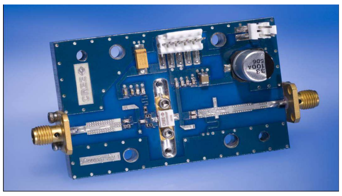

Fig. 2. Photograph of the amplifier under test before removing large capacitances of the drain bias circuit.

Large capacitances of the drain bias circuit have been removed in order to enable envelope tracking signal injection. In a first step, dynamic AM/AM characteristics of the amplifier under test driven by a 100 Ks/s QAM 16 signal at 3.6 GHz are recorded for different fixed DC drain bias voltages varying from 11V to 28V. Corresponding measurement results are shown in Fig. 3.

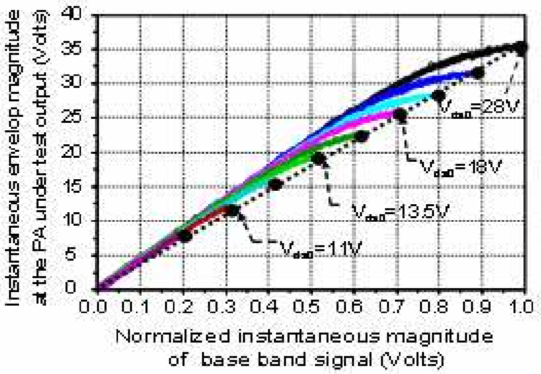


Fig. 3. Dynamic AM/AM at different DC drain bias voltage for 100Ks/s QAM 16 stimuli.

Characteristics plotted in Fig. 3 are magnitude of the instantaneous output envelope voltage of the 50 Ω loaded amplifier under test versus the normalized magnitude of the instantaneous envelope voltage of the base band signal generated by the computer. A drain bias law versus magnitude of the base band signal generated by the computer is extracted from measurements given in figure 3. The coordinates of the points of the targeted drain bias function are taken to keep constant gain and high drain efficiency as indicated by points and dotted line in Fig. 3. The extracted drain bias law versus the magnitude of the input signal envelope is plotted in Fig. 4.

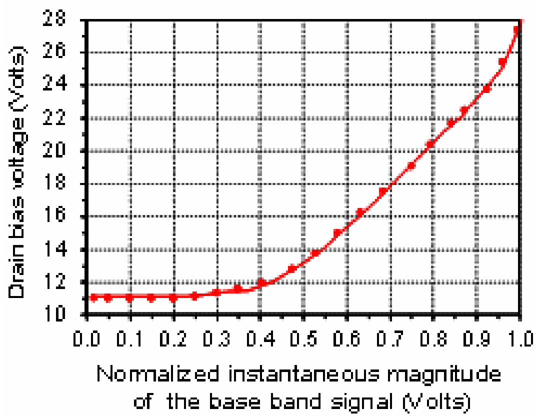


Fig. 4. Drain bias law versus magnitude of the input base band signal generated by the computer.

In a second step, the dynamic envelope tracking signal is applied to the drain bias port of the amplifier under test thanks to the computer controlled AWG and the linear envelope amplifier as sketched in Fig. 1. Appropriate time alignment between RF signal envelope and drain bias signal are achieved. The dynamic envelope characteristics obtained when envelope tracking is applied to the amplifier under test is plotted in Fig. 5.a and Fig. 5.b.

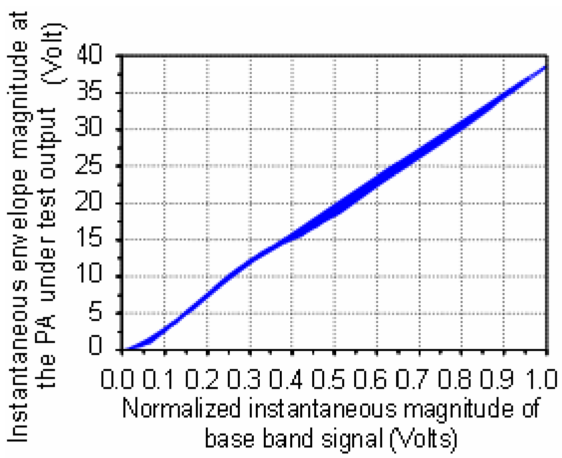


Fig. 5.a. Instantaneous complex envelope characteristic obtained when envelope tracking is applied.

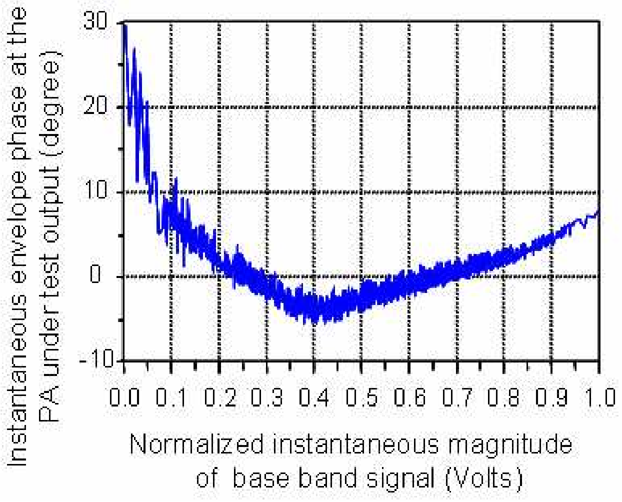


Fig. 5.b. Instantaneous complex envelope characteristic obtained when envelope tracking is applied.

The drain efficiency and linearity performances of the amplifier under test with and without applying envelope tracking are illustrated in Fig. 6.

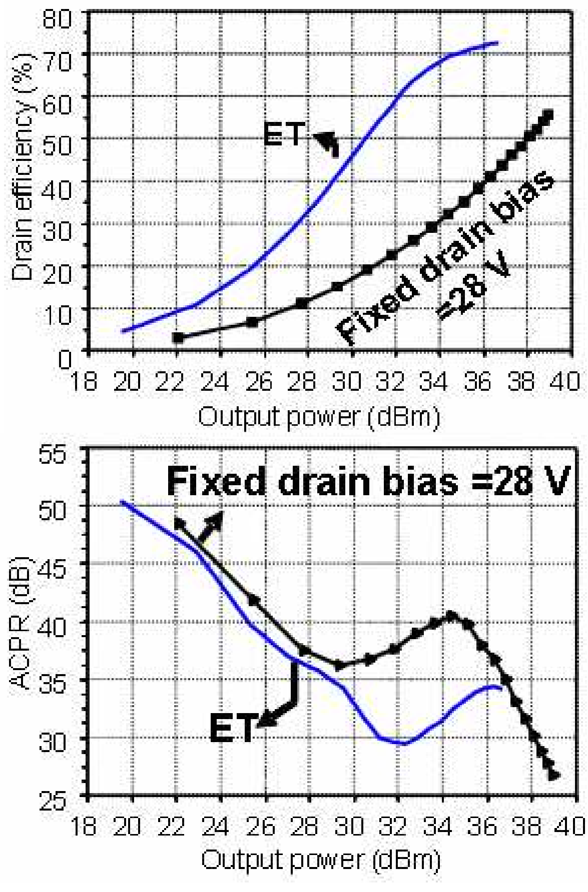


Fig. 6. Drain efficiency and linearity of the power amplifier under test ►►► without Envelope tracking, ▬ with envelope tracking.

Significant efficiency improvements are reached but linearity performances must be enhanced. Linearity performances seem to be affected here by the envelope tracking technique because drain bias variations generate larger AM/PM conversion compared to fixed drain bias conditions.

In a third step, a simple first order base band predistorsion technique (DPD) is applied. It consists in extracting and inverting spline functions fitting the average of measured dynamic AM/AM and AM/PM characteristics of the ET amplifier as illustrated in Fig. 7. The principle of the base band predistorsion method used has been reported in [7][8].

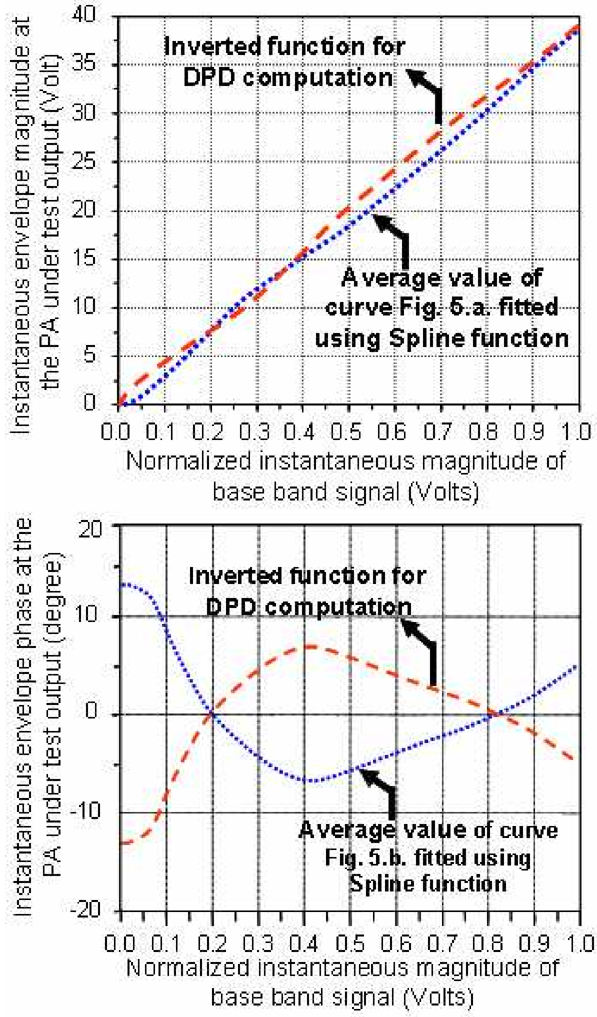


Fig. 7. Spline functions fitted for DPD computation.

When both ET and base band predistorsion techniques are applied, the efficiency and the linearity performances of the 10 W GaN amplifier under test are given in Fig. 8.
Fig. 9. Shows drain voltage and current bias waveforms recorded at maximum PA output power.

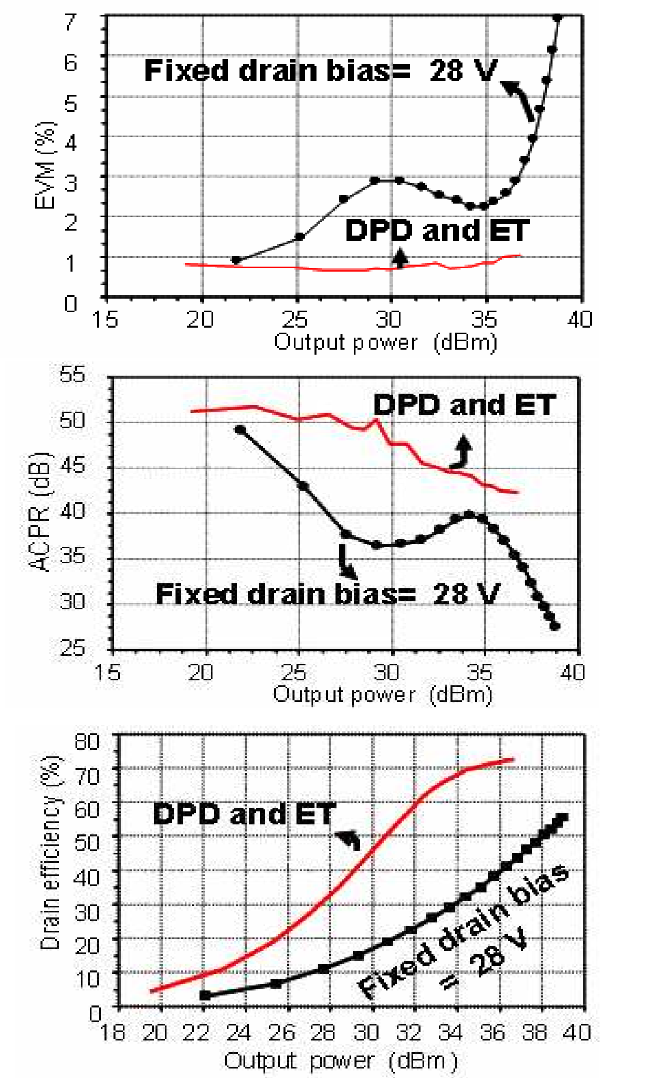


Fig. 8. Drain efficiency and linearity performances of the ET amplifier when a base band predistorsion is applied.

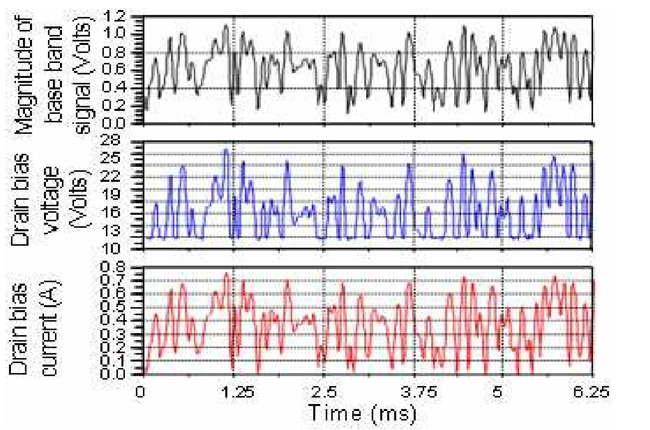


Fig. 9. Drain current and voltage bias waveforms at maximum PA output power.

## VII. Conclusion

This work demonstrates great potentialities of the presented set up and its associated computer controlled signal processing and characterization methodology to provide helpful measurements for PA designers .The use of two vector signal analyzers and a sampling scope enables accurate characterization and control of the time alignment of RF signal envelope and time varying bias voltage signal. Efficiency measurement results shown here concerns the amplifier under test alone. DC consumption of the envelope amplifier is not taken into account. In a next step a high efficiency switch mode envelope amplifier will be used and wider envelope bandwidth signals will be applied and processed.

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