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Time Domain Harmonic Load-Pull of an AlGaN/GaN HEMT

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Abstract — **This paper describes the time domain measurements up to 2.5 Watts of an AlGaN/GaN HEMT performed on an innovative measurement setup dedicated to high power characterizations. The key characteristics of our setup are presented, allowing us to reach time domain waveforms for high power transistors under source-pull and harmonic load-pull conditions. The capability of our setup to acquire time domain waveforms versus the fundamental and first harmonic matching conditions is shown.**

Index Terms — **active circuits, harmonic distortion, LSNA, nonlinearities, power measurement, time domain measurement.**

I. Introduction

The struggle for the best RF high power amplification pushes the microwave transistors very close to their limits. Nonlinear operation modes are required for the active devices in order to meet the requirements. Even if nonlinear models in a good CAD software are mandatory points, there is a strong need for high power functional time domain characterization of active devices.

We are building a new measurement setup devoted to the measurement of large microwave transistors up to 18 GHz. After a short description of our setup including its innovative features, we propose here our early 2.5 Watts time domain measurements performed on a GaN device under source pull and harmonic load pull conditions.

II. A Time Domain Bench for High Power Mismatched Transistor Characterization

This is a completely new setup in our lab, each element has been chosen for being able to handle high power measurements : the Large Signal Network Analyzer (LSNA), the 'wave probes', the tuners.

The innovative LSNA measurement system from NMDG/Maury/Agilent is especially well suited for large signal characterizations of nonlinear devices [1] with high power levels due to its programmable attenuators on each channel. This system has a real 4-paths acquisition scheme, thus the complete electrical status of a dual port nonlinear device is captured in one shot, without any effect of the source or load mismatch. This equipment, after calibration, plots the time domain waveforms of the DUT.

We have replaced classical couplers or reflectometers by some 'wave probes'. The wave probes are small loops of RF cable coupled very close to the device, it has been shown that this approach provide well-suited performances for LSNA measurements in terms of coupling and directivity factors. The wave probes principle is described on [2]. These wave measurements taken very close to the device allow getting all the RF nonlinear information with negligible losses between the device and the tuner.

We are using at the device input a Focus motorized tuner and at the output a Focus motorized harmonic tuner. The input tuner can be seen in combination with the RF source as a new generator with matching capabilities, allowing us to feed optimally the RF power into the device. The output tuner offers, in addition with the classical fundamental tuning capability, a mean to control the phase of a 2F0 quasi short-circuit. This feature helps to optimize the output characteristics of a high power transistor driven in nonlinear regime.

The complete bench organization is proposed Fig. 1. One can notice that this on-wafer bench is designed to handle pulsed measurements, but this nice feature is not described in this paper. We mainly want to point out that the wave probes are localized very close to the DUT, before the tuners. This innovative key feature allows modifying the matching conditions of the device without any effect on the LSNA calibration and accuracy. It makes possible to study efficiently the time domain waveforms of the DUT versus the input and output matching condition.

III. Nonlinear Measurements

All the LRRM calibration [3] process with a LSNA can be performed with the wave probes. Even if we have a quite small coupling value, around – 45 dB on the band 1 – 18 GHz, the calibration 'on wafer' is completely usable in terms of absolute amplitude, absolute phase and linearity. Of course, we can choose this coupling value by changing the distance between the wave probe and the RF line. Nevertheless, for high power measurements, this value is well suited [2]. In fact, with this coupling value, an important advantage is that we do not need to activate the step attenuators at the LSNA input channels. With the classical coupling method, these step attenuators have to be put at ten or twenty dBs or more. So, for high power measurement, we still can take benefit of all the LSNA dynamic range.

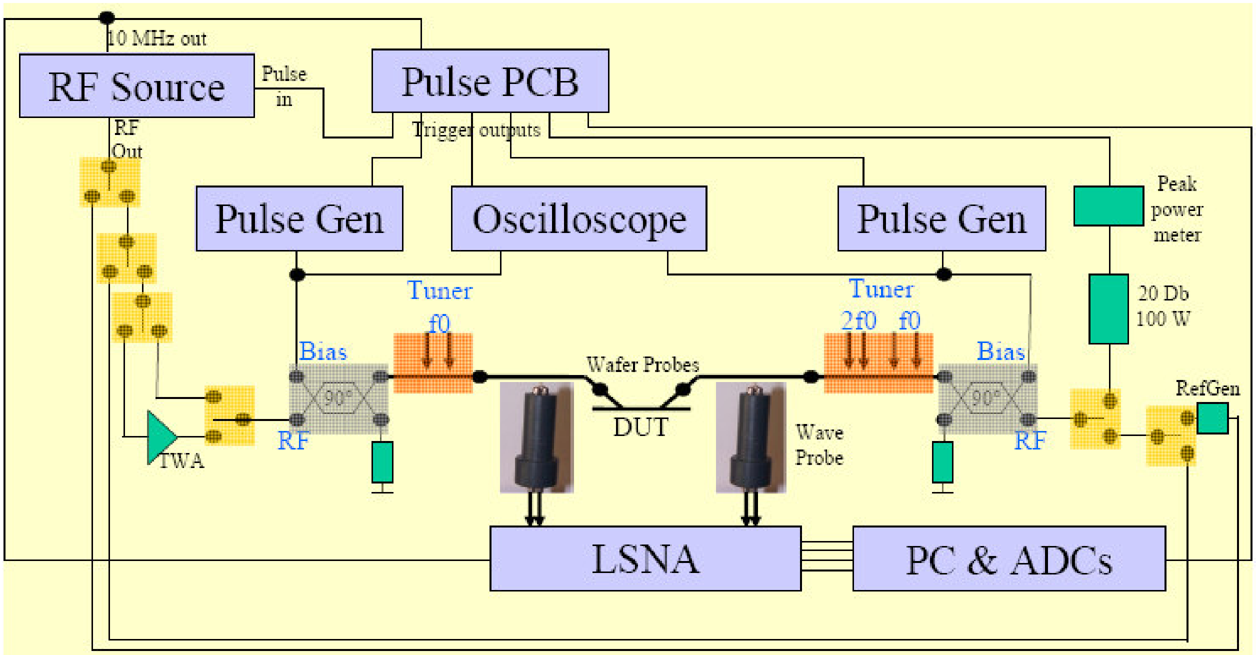

Fig. 1. Complete bench organization.

The measurements we propose have been done on wafer with an AlGaN/GaN HEMT 4x125 µm (grid length : 0.25 µm, pitch : 35 µm).

The measurement fundamental frequency is 2 GHz, and with our calibration procedure we can look at the influence of up to eight harmonics. The excitation is in mode ‘Continuous Wave’. We have moved the fundamental tuners in order to reach the area of the highest F0 power in the load.

The matching conditions on both accesses, including all the connected equipments, are directly obtained from the LSNA measurements and cross-checked with the feed-back of the tuners calibration.

As a first measurement result, we propose to study the effects of the tunable 2F0 short-circuit. This nice feature provided by the harmonic tuner is suitable with our LSNA measurement setup due to the fact we get the RF samples before the tuners. Such work has already been done in an active load-pull environment, but with much more difficulties [4]. We have done on Fig. 2 a comparison of the current and voltage slopes at the output of the DUT with and without the 2F0 matching. We can observe how matching the 2F0 improves the waveform slopes in terms of linearity. This improvement is not so significant in term of output power, but dramatically changes the nonlinear behavior of the transistor. This is a key feature to check the nonlinear accuracy of a transistor model and to monitor the device operating class.

The second measurement is a sweep of the input power (Fig. 3). We are able to evaluate the power gain, the power added efficiency and the output power versus the input power (as a classical load-pull system) but in addition we get the visualization of time domain waveforms and extrinsic load lines very near of the DUT planes (at the probe tips plane). The 2F0 tuner was in its optimal position for output power level at the -1dB compression point. One can notice that the bias point was optimized too because the time domain slopes enter simultaneously in conduction and breakdown regions.

V. Conclusion

The results we propose in this paper validate our approach with the wave probes close to the DUT. We are able to perform an entire LSNA LRRM calibration and high power transistor measurements have been performed under CW RF and DC bias. We have presented some first and promising results, and we will now move to larger devices and to pulsed regime.

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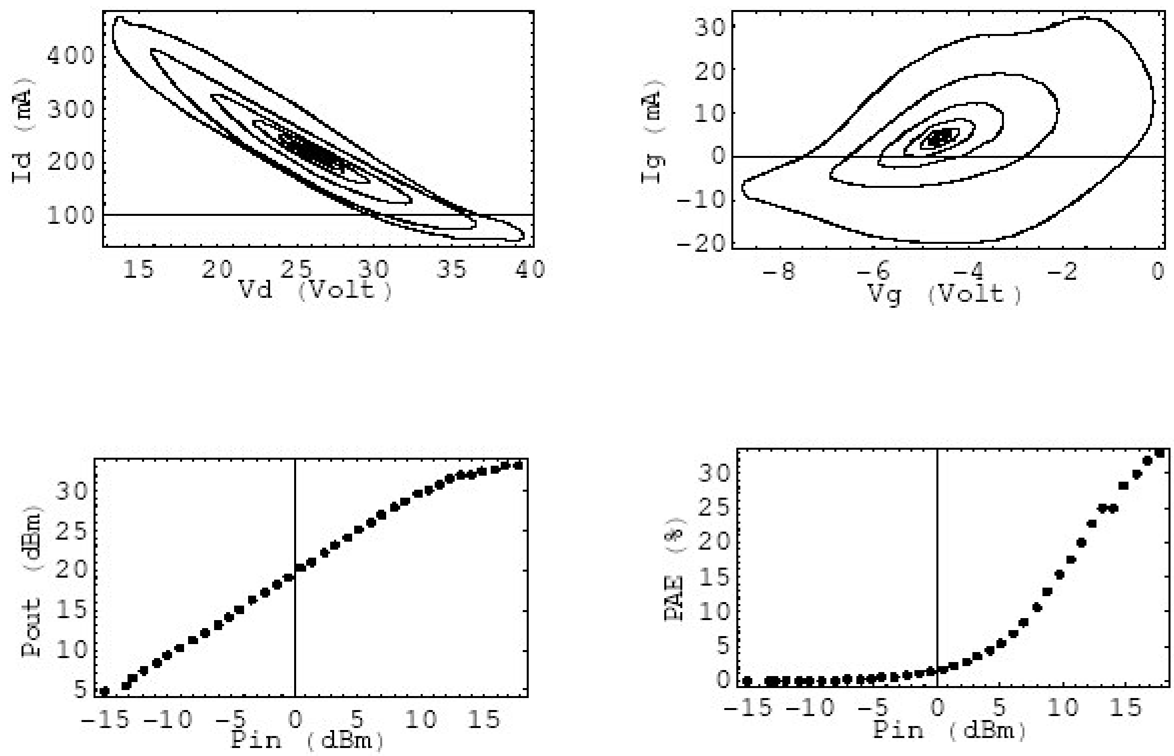

Fig. 3. Load and source lines, output power and PAE for a sweep of input power.

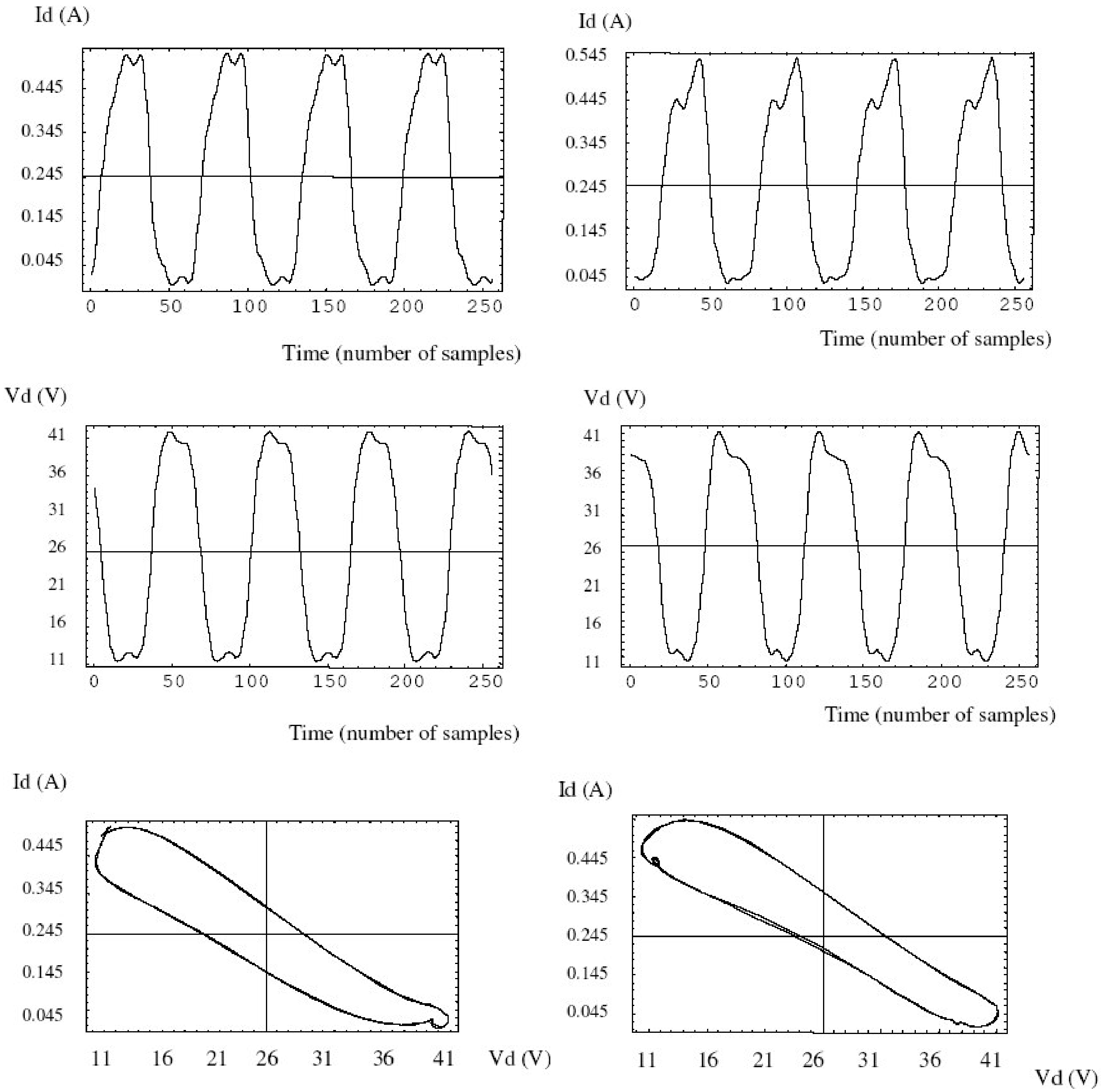

Fig. 2. Comparison of time domain slopes with (left) and without (right) $2f_0$ matching.