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Presented at the 38th European Microwave Conference
European Microwave Week 2008 - Amsterdam, The Netherlands

Pulse Profiling for AlGaN/GaN HEMTs Large Signal Characterizations

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***Abstract*— This paper deals with pulsed LSNA measurements of high power AlGaN/GaN transistors performed in a multi-harmonic passive load-pull environment. Time domain waveforms are acquired during a 150 ns window. This measurement window is moved across the 20µs duration of pulses, the period is 1 ms. Phase and gain drifts of transistor characteristics versus time during the pulses are obtained and discussed.**

I. Introduction

High power transistors are prone to long term memory effects; these effects consist in the device self-heating and, especially for FET devices and new GaN devices, the so-called trapping effects [1] [2] [3] [4] [5]. In a general manner, these low frequency memories seriously affect the transistor behaviour: the gain is usually reduced; the linearity is also poor for wideband modulated signals. So, pulsed measurement capabilities are a key point for modern amplifier design [6] [7] [8].

The particular case of RADAR power amplifier applications, with high power pulses applied to the devices, is more sensitive to the drift of characteristics during the pulses [9]. As the device heats and the traps fills during the power shot, the gain and the phase significantly change. As a result, the data processing of reflected waveforms is more complicated and the RADAR target images are noisier.

The LSNA (Large Signal Network Analyser) type of instrument has already proved its major interest, as the direct view of the device time domain waveforms is an invaluable tool for RF power amplifiers designers [10] [11] [12] [13]. A recent improvement of this equipment has shown that time domain pulsed measurements can be achieved with duty cycle up to 10000, without the usual dynamical desensitization of many RF measurement systems. This pulsed LSNA is synchronized with a pulsed IV (PIV) biasing subsystem, including two pulsed generators and an oscilloscope. A new improvement of this system now allows performing pulse profiling, with the measurement accuracy kept. Such pulse profiling measurements in a load-pull environment have already been carried out, but with a regular VNA, i.e. with measurement dynamical losses, limited duty cycle and without time domain capabilities [14].

We will first describe the measurement setup with the pulse profiling capability; then some GaN transistor measurement results will show the setup capabilities and will be discussed. Finally, some conclusions and many perspectives of this innovative measurement system are proposed.

II. Pulsed and Pulse-Profile LSNA Measurements

The LSNA sampling process of CW large signals can be explained in the time domain as a stroboscope. It allows, in a one-shot measurement, to acquire both the fundamental and harmonic frequencies data for all the incident and reflected waves. Thanks to sophisticated but robust calibration algorithms, the time domain current and voltages slopes versus time or the load cycles can be drawn at the reference planes.

We have proposed a new approach for the pulsed measurements; it looks like a second-level stroboscope. This is the so-called Time Domain Approach (TDA) for RF pulses measurements. It is based on a progressive acquisition of all the required data points before sending them to the Fast Fourier Transform (FFT) of the LSNA. Inside every pulse, a defined number of samples is stored, and put together with the precedent ones. This principle, shown in Fig. 1, is a stroboscope approach, because the RF sampler shots are lightly shifted compared to the observed RF frequency. The computation of all the related frequencies of the system – RF signals, RF samplers, Analog-Digital Conversion (ADC) acquisition – is a key point, to be sure of the phase coherence between the samples to be put together before the FFT [15].

This method implies the total acquisition time directly depends on the measurement duty cycle but this fact has in theory no consequence on the dynamic of the considered system because there are no relative long-term jitters. To ensure that, the TDA needs a common reference for the triggers of the ADCs and for the RF receiver; all the frequencies must be very accurately synthesized in order to ensure exact ratios and phase shifts. A dedicated digital board with counters and dividers has been designed to generate all the triggers we need to work in pulsed mode (fig.2), this board is driven by a very precise frequency synthesizer (called FracN) to generate the clocks. All the devices to be synchronized in pulsed mode (the RF source, the ADCs, the PIV subsystem) are connected to this board as shown in fig. 3.

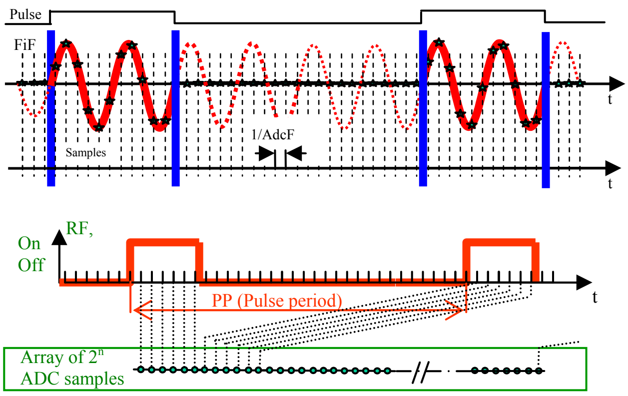

Fig. 1 Sampling acquisition of the RF signal during pulses: the phase of the first sample of next pulse is linked with the phase of the last sample of the previous pulse. The data array is filled with ADC results during the pulses

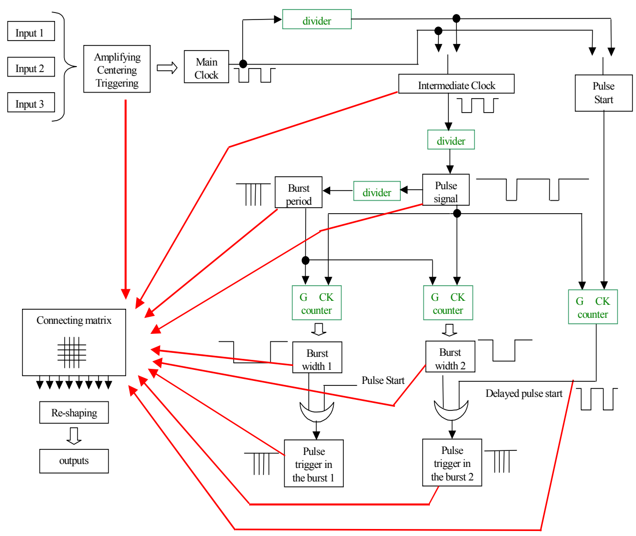

Fig. 2 The dedicated digital board for the triggers and delays

The pulse profile capability has been added to the measurement system. This has been performed with a simple additional trigger delay setting. This delay can be adjusted with respect to the sampling phases. For our particular measurement example, we have decided to acquire 2 samples during each pulses (fig. 4), the pulse duration is set to 20 µs, and the period is 1 ms (fig. 5). As we took 16384 sample points for the FFT, one measurement needs 16384 /2 × 1ms = 8.192 s. A sweep on the delay parameter allows getting time domain measurements during the pulses versus time.

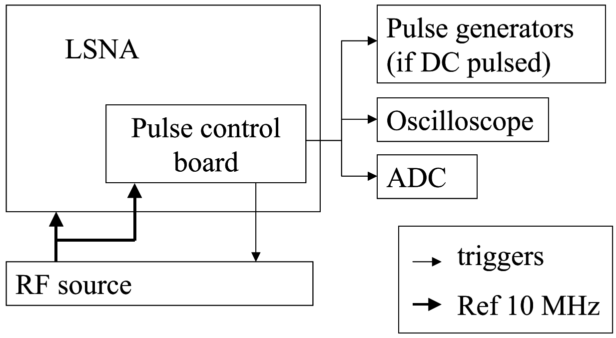

Fig. 3 The trigger signals and reference clocks

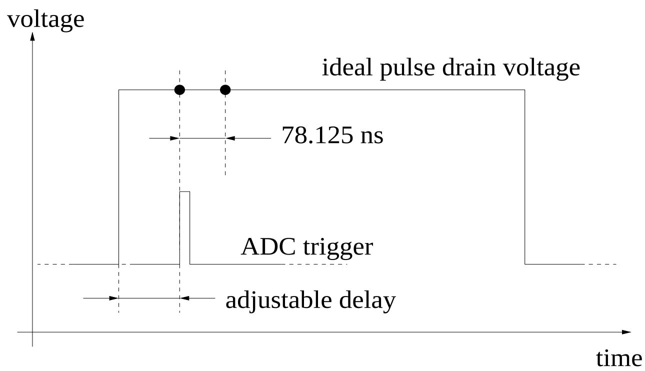

Fig. 4 Pulse profiling with 2 samples

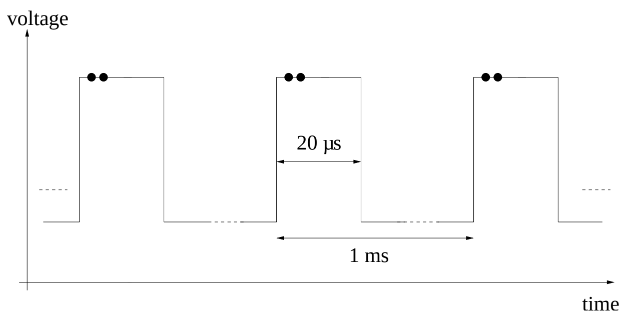

Fig. 5 Pulse parameters

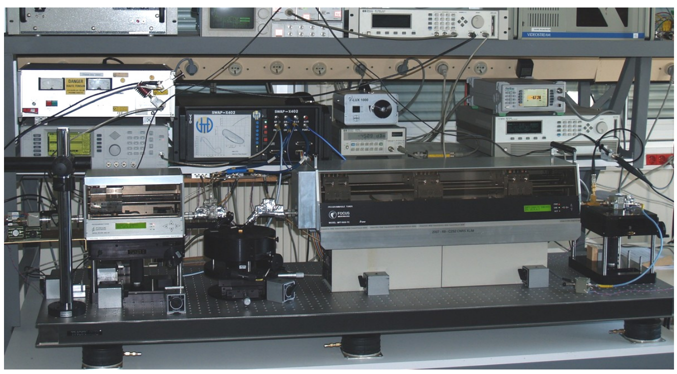

Fig. 6 Our complete setup

Note that our on-wafer measurement system for profile pulsed time domain measurements (shown on fig. 6) features several up-to-date techniques: wave probe couplers, MPT multi-harmonic tuner, hybrid bias tee.

III. Profile Pulsed Measurements Results

The device under test (DUT) is an AlGaN/GaN HEMT from III-V Lab and 1 mm gate width. We have performed 4 sets of RF time domain profiles, at a large (6 dB) and very large (10 dB) compression factors, in order to have a strong nonlinear behaviour. We do not have optimized the fundamental or harmonic load impedances for optimum gain or efficiency. The fundamental frequency is 2 GHz, and we have measured harmonic frequencies up to 12 GHz. During the pulses, the drain bias is 25 Volts, and outside the pulses the gate is pinched-off and the drain is either 40 Volts or 0Volts. It means that, outside the pulses, there is no device self-heating but the traps are filled or not.

The profile sweep starts from 800 ns after the beginning of the pulses. This is a limit of our RF sampling system. As the device drifts very fast at the beginning of the pulse, we acquire points each 78.125 ns up to 1.5 µs, and after we reduce the acquisition density. We present here the power gain and the phase of S21 versus time for the four measurement configurations: fig. 7 and fig. 8.

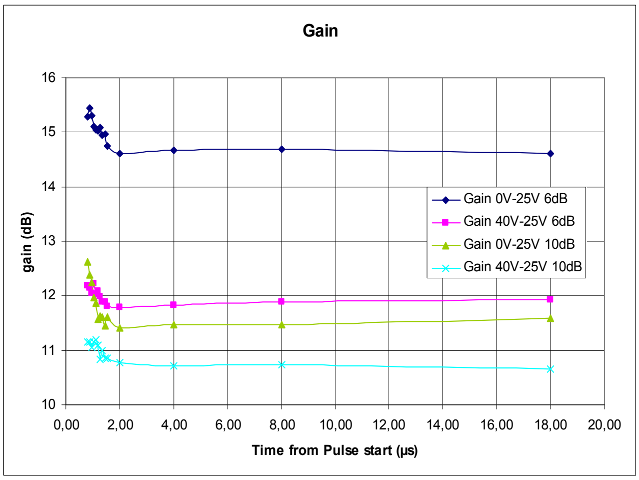

Fig. 7 2 GHz Gain versus time within the 20 µs Pulse

These measurement results are in good agreement with the knowledge of pulse power amplifiers designers: the amplifier characteristics are shifting during the pulses. At this step, it is difficult to explain in details these results: we are facing a complex dynamical nonlinear system with coupled inter-dependant phenomena. The self-heating changes the device physics, but the traps also affect the device and the traps behaviour depends on the temperature…

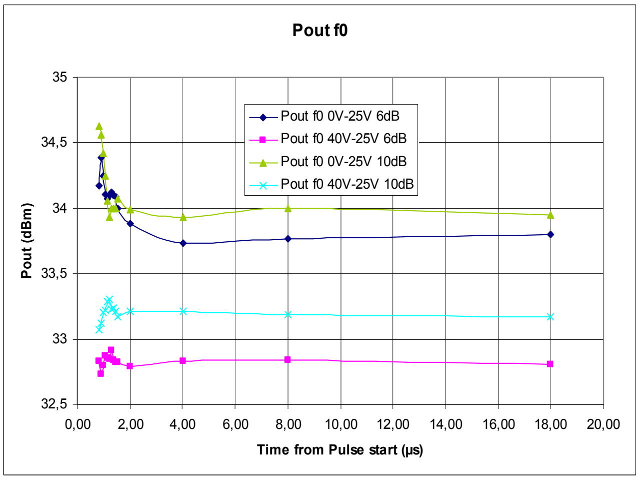

Fig. 8 2 GHz S21 Phase versus time within the 20 µs Pulse

It appears here that the transistor characteristics become relatively stable after 4 µs; and the phase shift can be as high as 4°. Moreover, there is no big difference between results with prefilled traps (40 Volts drain bias outside pulses) and the other ones. As we are working at high saturation, even when we start from (supposed) empty traps (0 Volts drain bias outside the pulses), the traps are filled very quickly by the pulse bias (25 Volts) and the large RF signal.

Many other results are provided by our setup: for each acquisition point proposed on fig 7&8, we dispose of the time domain waveforms, i.e. the amplitudes and phases at the harmonic frequencies.

Our hardware setup for time domain pulse profiling measurements will be improved, in order to get only one sample per pulse and to be able to start measurements earlier in the pulse.

IV. Conclusions & Perspectives

We now dispose of a new measurement facility for the deep investigation of pulsed RF signals. The combination of time domain waveforms and pulse profiling offers outstanding measurement means for RF designers dealing with RADAR power amplifiers.

This new tool will be very efficient for a better understanding of the long-term memory effects of large transistors. Many studies will be launched: change of time domain waveforms versus time, effects of fundamental frequency and harmonic frequencies loads on the drifts, effects of the starting points of the pulses, effects of the power amplifier operating regime. This tool will help for optimizing the pulse power amplifiers in terms of flatness of characteristics, and to check or optimize the non linear models of transistors including thermal and trapping effects.

Acknowledgment

The authors want to thanks Alcatel-Thales III-V Lab for providing the test GaN device.

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