Time-Domain Measurement System Using Track & Hold Amplifier Applied to Pulsed RF Characterization of High Power GaN Devices

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Abstract — **We propose in this paper a time-domain test bench for the pulsed characterization of a high Power GaN Amplifier. Our findings are based on a Track and Hold Amplifier for the down-conversion of RF spectra using the sub harmonic sampling principle. The use of wideband THA to replace samplers or mixers enables reducing component density in an analog domain. It permits direct digitization of entire pulsed RF spectrum, bringing more flexibility in the receiver's performance by enhancing the dynamics and bandwidth. This test bench is capable of completely extracting the phase, amplitude and pulse profile of the RF signal. Power characteristics, phase and amplitude information for multiple bursts of pulses of a 50 W GaN HEMT Nitronex (NPTB00050B) power amplifier have been measured using the proposed calibrated measurement system. The low frequency memory effects (thermal and trapping) of high power GaN amplifier were also measured.**

***Index Terms* —Track and Hold Amplifiers, GaN power amplifiers, Sub harmonic sampling, dispersive effects, time-domain measurement.**

I. Introduction

The electrical characteristics of Wide Band Gap semi-conductors make them a prime candidate for use in the design of high power amplifier. To extract its inherent properties, and optimize low frequency memory effects occurring in non-linear high power GaN devices, it is necessary to characterize them in a time-domain with modulated signals. Time-domain measurement of multisines [1], [2] for radio communications and pulsed modulated signals for radar applications [3] have been performed using the sub-sampling principle like LSNA. The main drawback of using the sub-sampling principle is its very low bandwidth due to the attenuation of high frequency spectral components of a comb generator operating at 20 MHz. Another system with an 8 bits dynamic range and enlarged bandwidth of 160 MHz has been realized exhibiting promising results [5]. Specific configurations of the sampler based instrument allow increasing the bandwidth using a complex clock circuitry [4]. The challenge to optimize the bottleneck (bandwidth and dynamic range) and reduced analog IF circuitry still exists.

In this paper, we propose a time-domain test setup that includes a commercially available THA (InPHI 1321TH) with increased dynamic range and bandwidth to accurately characterize the pulse profile of PA under fast pulsing conditions. The working principle, characterization of THA and its advantages over a sampler are displayed in the section II of this paper. In the next section (section III) the sub-harmonic sampling scheme used in the demodulation of phase and amplitude is discussed. Next a 50 W GaN PA is characterized to demonstrate the potential capabilities of the proposed bench and finally a comparison between the measurements of the proposed time-domain system and a vector signal analyzer (FSQ) is made.

II. Characteristics of Track and Hold Techniques

Down conversion of RF signal is the key component in time domain analysis. Until recently, the major instrument used for sampling based down conversion of microwave spectra into IF spectra has been the sampler. The gain conversion of the sampler is very low -37 dB while the maximum input power to the sampler is limited to -15 dBm making it necessary to include an IF circuitry comprising of Linear power amplifiers (around 55 dB gain) and a low pass filter before sending this data to ADC. The linearity of IF circuitry is highly important for not contaminating the actual data.

In order to reduce the analog circuitry in the IF path a broadband Track and Hold Amplifier (THA) has been used. To illustrate the working principle of THA, an ADS simulation was performed. The block diagram of the ADS schematic is presented in Fig. 1.

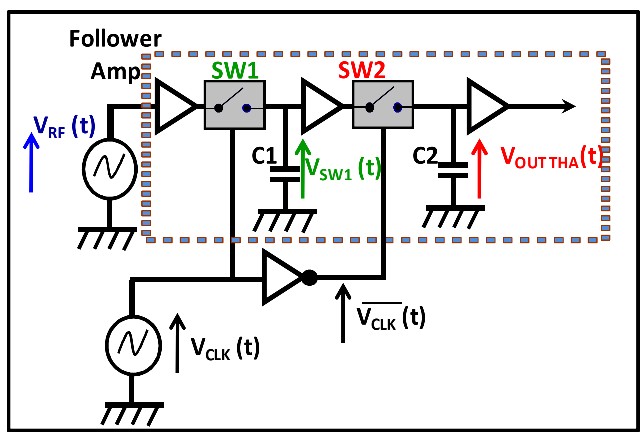

Fig. 1. Block diagram of THA schematic in ADS

A transient analysis of THA was performed with a CW RF signal at 2.5 GHz. Two ideal switches (SW1 & SW2) driven by 400 MHz differential clocks (i.e. T_{clock}=2.5ns) were used. In Fig.2 it can be seen that during negative half of clock cycle (T_{clock}) SW1 is tracking the RF signal where as it holds on to the voltage level reached by hold capacitance C1 during the switch to positive half. SW 2 driven by an inverted clock performs similar function for each half of inverted clock cycle, but it tracks and holds the voltage level at the output of SW 1.

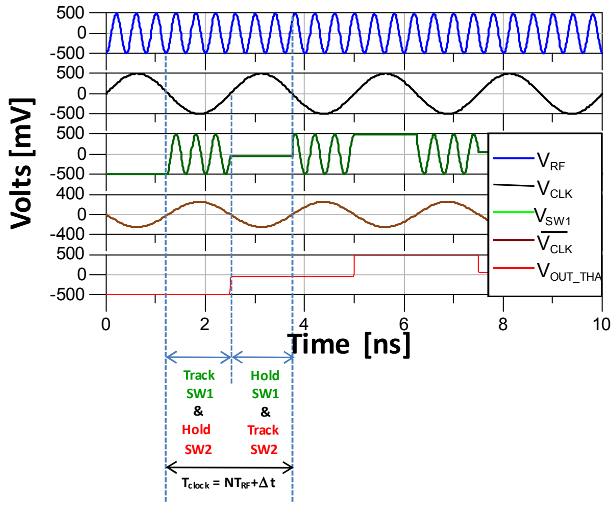

Fig. 2. Sampling principle for THA (ADS simulation)

The output of the THA (V_{OUT_THA}) has ideal gain conversion equal to unity corresponding to the RF signal due to the use of emitter follower amplifiers at the output of each switch. It can be observed that the THA follows the sub-sampling principle described by the following equation:

$$T_{clock} = NT_{RF} + \bullet t \quad (1)$$

With N=6, T_{RF}=0.4ns and •t =0.1ns.

Using this sub-sampling principle V_{OUT_THA} could directly be digitized by ADC without using any IF circuitry.

Complete characterization of THA in terms of power and linearity was performed using the measurement system described in Fig. 3.

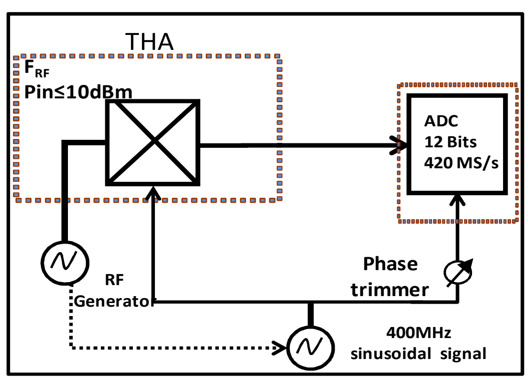

Fig. 3. Block diagram of Track & Hold Amplifier characterization test bench

THA and ADC share the same sinusoidal clock without the IF analog circuitry thus reducing circuit complexities. A phase trimmer is provided on the ADC clock path to make sure that the ADC sample falls within the hold interval of the THA as shown in Fig. 4.

Fig. 5 depicts the measured conversion gain of the commercially available wide band THA (13GHz BW&2GS/s). The gain conversion obtained by THA is much higher than the gain conversion of samplers.

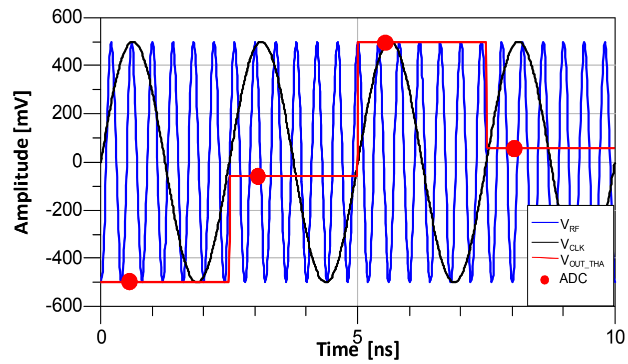

Fig. 4 . Sampling interval for THA & ADC (ADS simulation)

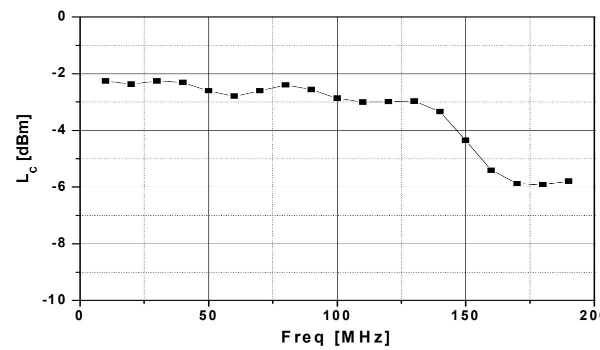

Fig. 5. Output power & Gain conversion of THA @ P_{in}=0dBm

For linearity analysis 1dB compression point (Fig. 6), third order intercept point and IMD was measured using the ADC acquisition.

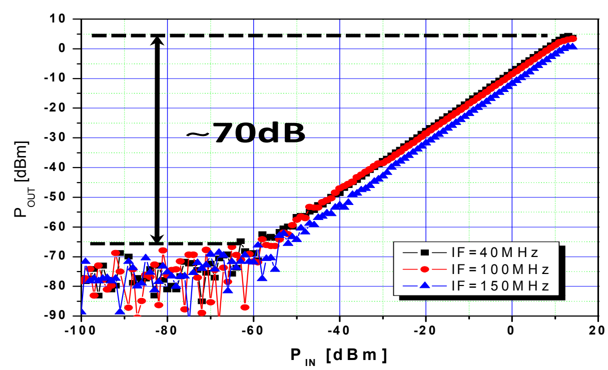

Fig. 6. 1dB compression point of THA @ different CLK frequencies

The measured value for 1dB compression point was P_{1dB} = 6 dBm (P_{IN}=12dBm) and a much higher dynamic range of 70 dB is achieved. The TOI point calculated from the measurement is around 10 dBm which is almost similar to the dynamic range of ADC. It ensures that if maximum input power to the THA is kept lower than 5 dBm, the system (THA+ADC) response would always be linear. An IMD level of 40 dBc was measured almost 10 dB below the maximum saturation level of THA thus ensuring that the IM contribution could be neglected as long as it is in the linear region of THA.

III. THA BASED TIME DOMAIN PULSED MEASUREMENT SYSTEM

The pulsed RF signal generated by the R&S SMBV100A is linearly amplified and feeds the input of the power amplifier under test (AUT). Input and output signals are sequentially measured by using two directional couplers, a switch and a 13GHz bandwidth 2 GS/s THA plus a dual Channel 420MS/s, high dynamic range (12 bit) analog-to-digital converter (ADC). A common clock of 400 MHz (sinusoidal) is fed into the THA and the ADC synchronized by a 10 MHz reference. The pulsed RF signals are directly sampled by the THA and the ADC. A power calibration is then performed using a pulsed power-meter as power reference. A phase calibration similar to the one described in [8] is performed to directly sample the pulsed RF signals at the AUT reference planes πin and πout. Complete block diagram of the measurement system is described in Fig. 7.

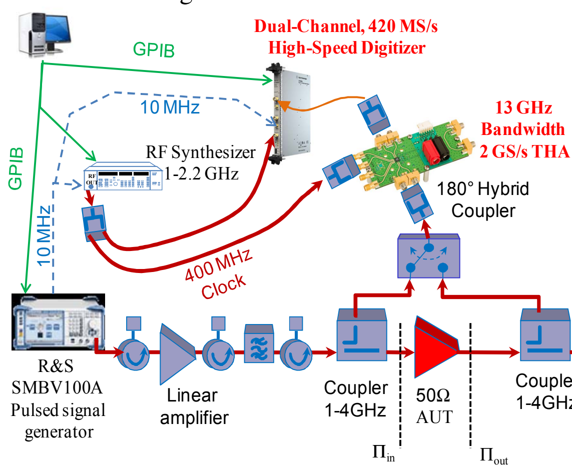

Fig. 7. Block diagram of Measurement System

A. *Sub harmonic sampling/Quadrature sampling.*

Magnitude and Phase demodulation encoded high frequency carrier signal was always a problem but by reducing the complexity of the IF circuitry, the boundary between analog to digital conversion and digital computation has been increased [6]. This direct RF sampling eliminates the need for IQ mixing if the digitizer samples using the following relation:

$$T_{ADC} = NT_{RF} + T_{RF}/4$$

Where N=6 (2)

Using this relation the in-phase and quadrature components could easily be extracted.

B. *Pulsed Measurements*

In this section, a 50W GaN Nitronex power amplifier was driven by a pulsed signal with optimal quiescent current of 330 mA and drain voltage of 28V. A burst of eight pulses was applied to the AUT operating at frequency of 2.5 GHz with a common sinusoidal clock (THA + ADC) of 400MHz. The pulse period was equal to 10 us with 10% duty cycle. The time-domain waveform was sequentially captured at both ports of AUT.

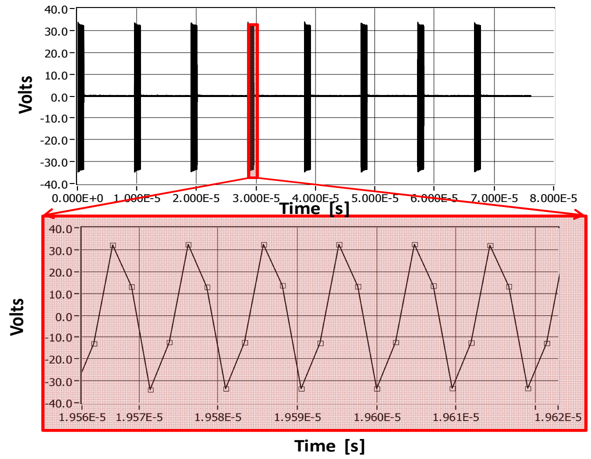

Fig. 8. Measured time-domain pulsed output waveform

Fig.8 depicts the time-domain waveform at the output of AUT for an output power of 45 dBm. It could be noticed that each period of the sampled RF signal within the pulse has exactly 4 samples at the same time instants. Based on this data the in-phase and quadrature components were computed and the phase (Fig. 9) and amplitude (Fig. 10) information was demodulated from the signal. The harmonic components at the input and output are eliminated by the narrow band directional couplers used in the measurement system described in Fig.7. As the signal within pulse width is continuous therefore almost a constant phase could be seen where during the off state of the pulse only noise is measured. A small decrease in the envelope amplitude is noticed during the pulse which is due to thermal and trapping effect.

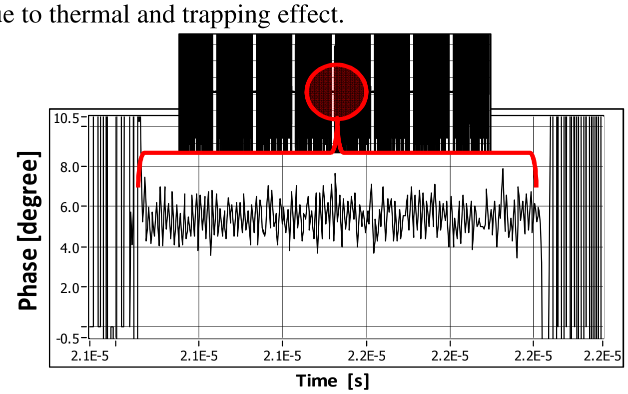

Fig. 9. Demodulated Phase within each pulse at saturation

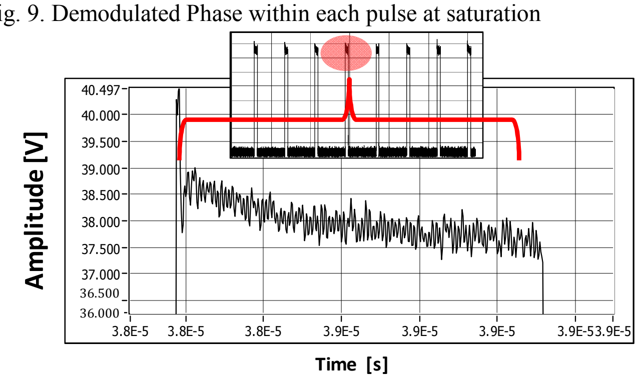

Fig. 10. Demodulated pulse amplitude at saturation

C. Measurement analogy of proposed system and Vector Signal Analyzer

This section depicts the analogy between the proposed measurement setup and the conventional Vector signal Analyzer based on mixing principle. Similar test bench was used as described in Fig.7 where only the THA was replaced by R&S FSQ26 and its sampling frequency was set to the maximum value of 326.4MHz. Identical power and phase calibration procedures were applied to both systems. Fig 11 demonstrates the measured output power and gain of the same AUT under same biasing conditions as mentioned earlier and it could be noticed that similar power characteristics are obtained.

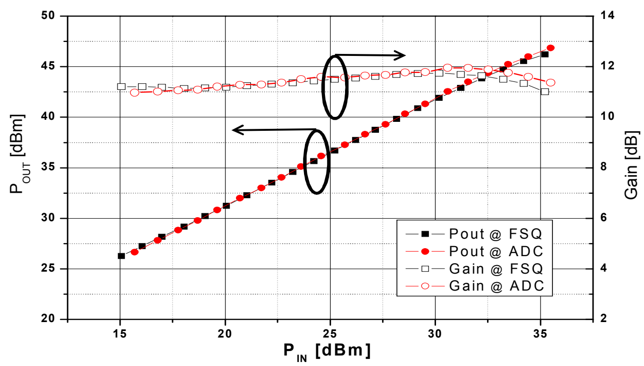

Fig. 11. Comparison of Pout & Gain for AUT

The phase and amplitude information of the same AUT at the saturation were measured with the VSA and are presented in Fig. 12. It's observed that identical characteristics are obtained using the two different instruments validating the measured result of THA. The decreasing pulsed magnitude envelope measured with the two systems confirms the presence of low memory effects.

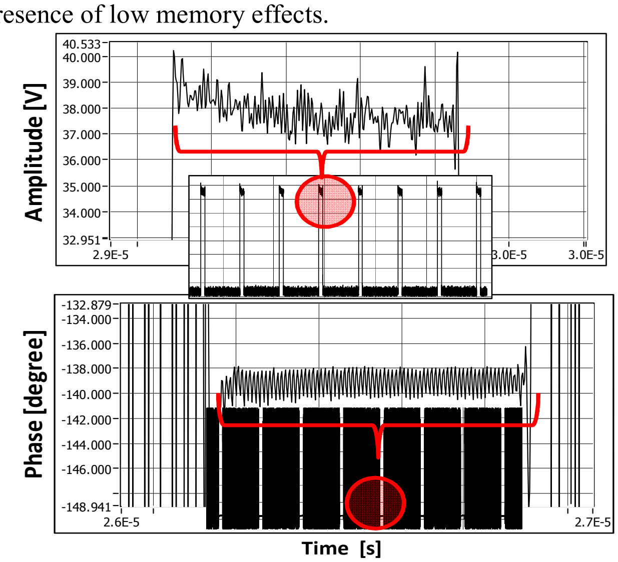

Fig. 12. Amplitude and Phase Demodulation using VSA

IV. Conclusion

This paper presents a time-domain test bench for pulsed characterization of high Power GaN Amplifier. It is based on the use of THA, the working principle of which is demonstrated. It highlights the advantages of wideband THA over the sampler for the conventional sub-sampling principle. The reduction of component density in analog domain and direct digitization of entire RF spectrum brings more flexibility in the receiver's performance. A much improved bandwidth of 200 MHz with 12 bits enhanced dynamic range is achieved. The use of the sub-harmonic sampling enabled us to extract the in-phase and quadrature components without the use of digital mixers. The measurements of test bench were validated by comparing two different receivers (THA+ADC, VSA). Similar power, envelope magnitude and phase information under pulsed condition of the same GaN high power amplifier were obtained. The decreasing magnitude of the pulsed envelope reveals the presence of low memory effects occurring in the nonlinear device.

Future work would consist of building a four channel time-domain measurement system based on THA to measure pulse to pulse stability [7] of high power amplifier under different load conditions.

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