Large Signal Pulsed RF And DC Load Pull Characterization of High Voltage 10W GaAs-GaInP HBTs

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***Abstract* — This paper presents an on-wafer set up for the characterization of high voltage (26V) power HBTs under simultaneous large pulsed RF signal and pulsed DC test conditions. Both RF power profiles and DC current/voltage profiles are measured thanks to the use of a pulsed VNA (for RF) and a sampling scope (for DC). Typically the pulse width range is (300 ns – 300 ms) and a 10% duty cycle is applied. RF power performances and DC consumption of the transistors under test are recorded at different time positions within the pulse width .This enables to investigate the effects of transient thermal aspects on RF power characteristics. S Band Measurements of 10 Watt (20 finger 2*70mm² GaAs-GaInP HBTs from Thales TRT and UMS foundry) with specific gold radiator are reported in this paper.**

I. INTRODUCTION

High power transistors operating at high bias voltages (equal or higher than 26 V) are very attractive for their use in base stations for cellular networks, satellite communication systems and radar applications. Due to their high power handling capability and good reliability, GaAs - GaInP HBTs offer a very attractive solution. Along with different technologies which enable large breakdown voltages (up to 65V), the thermal management is a very crucial feature to handle, specifically in the case of large size multi-finger active cells in which gain collapse phenomena due to current concentration on single fingers must be avoided.

In order to design optimized architectures of very large power amplifiers, accurate electro-thermal models of HBTs are of prime importance [1]. Such models are basically derived from multi-bias S-parameter and I/V measurements. The implementation of accurate models in CAD packages in combination with envelope simulations lead to deep analyses of transient thermal aspects which, in turn appear to be very useful for any PA design procedure. An important feature in the overall design procedure of high power SSPAs lies in the validation or in the refinement of such models. For that purpose, the large signal characterization on which this paper focuses is actually very useful. Here, a pulsed load pull set up is proposed . Since it is accurately calibrated for vector measurements, it provides valuable and enhanced information compared to large signal CW measurements as it enables to investigate thermal aspects and associated time constants engaged in power transistors.

The set up architecture is presented in the first part of this paper. In the second part, measurements of S Band 10W HBTs are reported and discussed. Comparisons between measurement results of HBTs designed with a thin gold radiator or with a thick gold radiator are presented afterwards.

II. SET-UP DESCRIPTION AND MEASUREMENT PRINCIPLE

The large signal characterization system that we have developed makes use of a pulsed VNA which includes pulse modulators [2].

A pulse modulator connected at the output of the microwave source is used to create the stimulus signal while four other pulse modulators connected on the measurement channels are used to achieve narrow measurement time windows. The so called measurement time windows can be delayed in order to scan the pulse response of the device under test (DUT), from the beginning to the end of the pulse stimulus duration. In fact, the heterodyne principle of VNAs along with a narrow 500 Hz band pass filtering performed at IF, permits vector measurements of power wave ratios at the center spectral line of the Sin(x)/x spectral shape of pulsed signals. Therefore power characteristics, AM/AM and AM/PM of a DUT can be recorded versus both the input R.F power level and the time position within the pulse width.

The biasing of the transistor under test is also pulsed by using a DC pulse generator, RF and DC pulses are obviously synchronized. Voltage and current probes are connected to the DC paths of bias tees and a sampling

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scope is used for the measurements of the DC current and voltage waveforms at different RF power levels.

The set up arrangement for signal conditioning , load impedance tuning and DC and RF data acquisition is sketched in Fig.1.

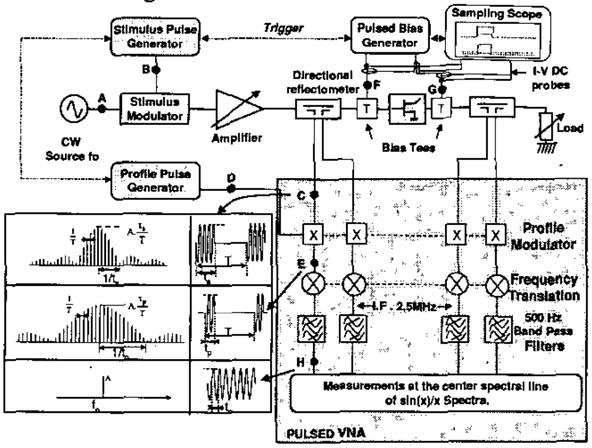

Fig. 1. Block diagram of the set-up

The principle of the pulse profiling (measurement time window) is given in Fig.2.

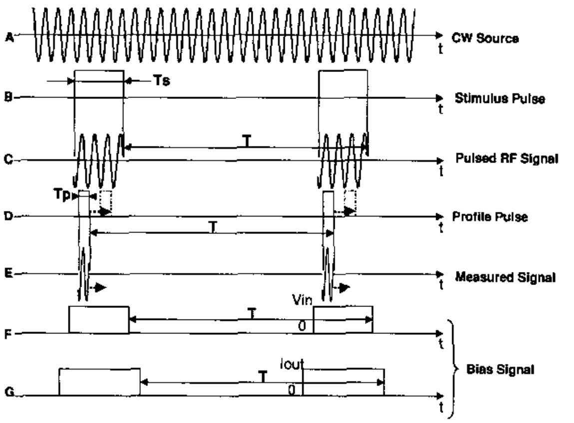

Fig. 2. Pulsed RF and pulsed bias signal representation

An on-wafer conventional TRL or SOLT calibration procedure is performed before measurements. This calibration procedure is achieved under pulsed RF conditions. The measurements of the calibration standards are done at the center frequency of the signal (sin(x)/x spectra). An absolute power calibration is also made by using a peak power meter. During this absolute power calibration routine, in order to get an error corrected value of the power at the DUT reference plane for an on-wafer probe contact, the power sensor is connected to the input of the reflectometers and reciprocity relationships are used to determine power levels at the DUT reference planes[1]. This is definitely more accurate than applying a de-embedding correction between reflectometer connected planes and probe tip planes.

When a narrow acquisition window width (τp) is applied with a repetition rate T, the power P(f0) measured by the VNA at the center frequency of the sin(x) /x spectra permits the determination of the pulse power Pp using the following relationship :

$$P_p = P(f0)\left(\frac{T}{\tau_p}\right)^2 \qquad (1)$$

II. On wafer measurement results of 10 Watt High voltage HBTs

GaAs-GaInP HBTs are well known for having many advantages in power amplification at microwave frequencies due to their high gain and high power density. For a full exploitation of their high power handling capabilities, thermal management must be optimized. The aim of these measurements is to demonstrate the impact of gold radiator as thermal shunt on RF performances. As comparison, two similar transistors (HBTs 20 finger $2*70mm^2$ GaAs-GaInP) from Thales TRT and UMS were characterized, one with a thin gold radiator and an another one with a thick gold radiator.

Measurements were performed at 2.2GHz. The RF pulse width was set to 300mS and the repetition rate to 3ms (duty cycle of 10%). It assumes that it lets the transistor come back to a same thermal state between two successive RF pulse. A 30mS acquisition window width was fixed and several measurements were performed from the beginning to the end of the RF pulse. On one hand, the collector-emitter voltage was not pulsed and set to a DC value of 24V, on the other hand, the base-emitter voltage was pulsed from 0V to 1.22V. The equivalent internal impedance of this base biasing generator was set to 14Ω. The load impedance was tuned to obtain the best trade-off between the maximum power added efficiency and the maximum output power.

Firstly, for the transistor with just a thin gold radiator, the RF output power decreases by 1W from the beginning to the end of the pulse and power added efficiency decreases from 60% to 50%. On Fig.3, AM/PM characteristics (carrier phase shift within the pulse), power added efficiency and RF power are given.

Secondly, with a thicker radiator as thermal shunt on a similar transistor, we can see on Fig.4 as a result that the thermal behavior is really improved.

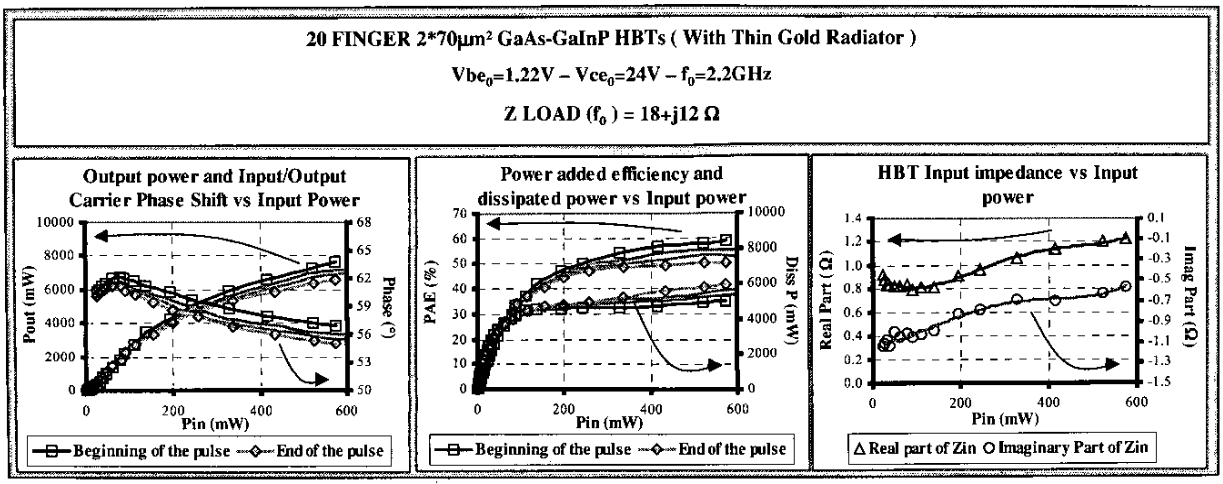

Fig. 3. Measurements of 20 finger 2*70mm² GaAs-GaInP HBTs with thin gold radiator.

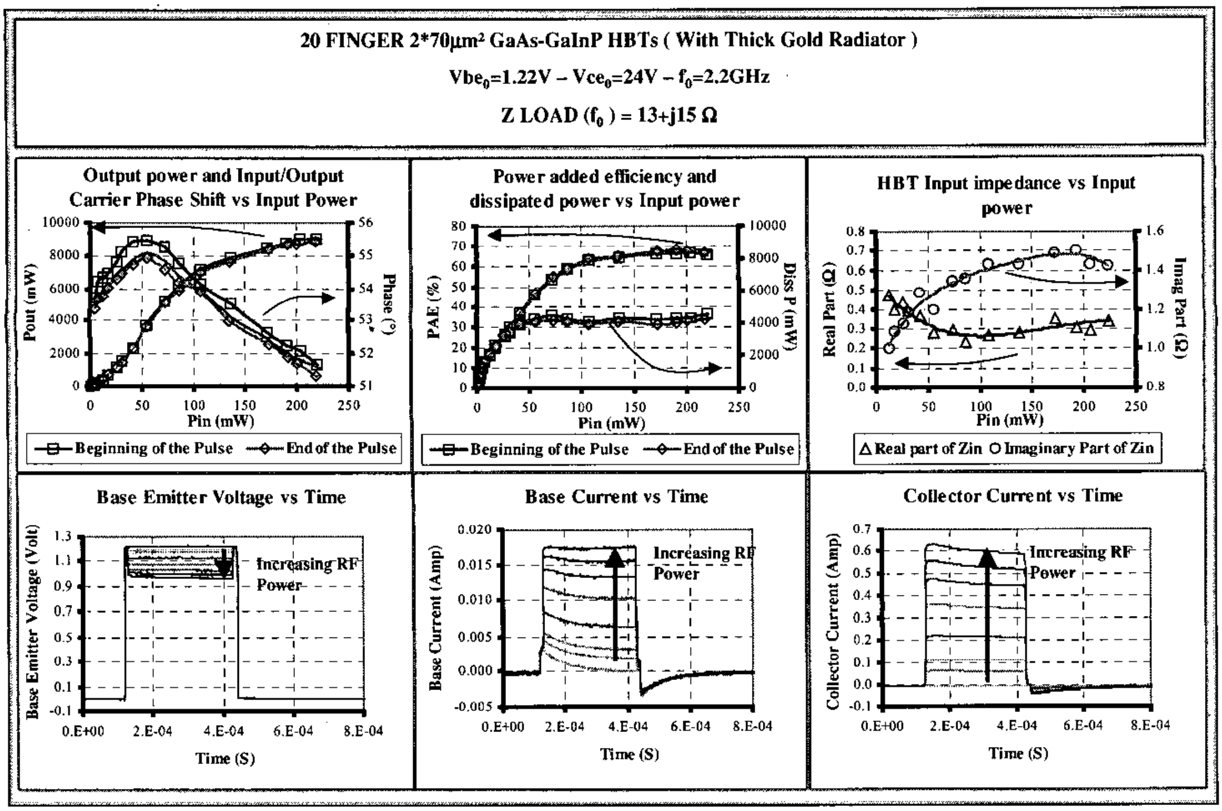

Fig. 4. Measurements of 20 finger 2*70mm² GaAs-GaInP HBTs with thick gold radiator.

For measurements shown on Fig.4, the setup kept the same configuration. The transistor was characterized under the same pulsed and bias conditions. The only main difference lies in the fact that the load impedance tuning was refined. Here the waveforms of the DC pulses were recorded by a sampling scope. The results show that the collector-emitter current decreases while the base-emitter current increases within the RF pulse at high output RF power due to the thermal effect. Nevertheless, the RF performances stay constant within the RF pulse for high power levels. We can notice that compared with the transistor which uses a thin gold radiator, the transistor with a thick gold radiator has a higher power gain due to a lower base resistor.

V. Conclusion

A fully automated and calibrated measurement setup for a complete RF large signal and DC pulsed characterization of power transistors has been presented. The use of a pulsed VNA permits a control on both repetition rate and RF pulse width as well as profile acquisition window. It enables an accurate transistor characterization. Therefore, an important application of this measurement tool lies in the deep validation and the refinement of nonlinear models of large size multi finger transistors. This first step is obviously necessary for the management of further high powered amplifiers. The output power targeted is up to 30W. A second interesting point concerns the measurement of AlGaN transistors. This set-up in which pulsed aspects are combined with high DC voltage levels is also very interesting for the validation of nonlinear models which are taking into account thermal and trapping effects. Furthermore, such characterizations are quite useful for the optimization of power amplifier behavior for modern radar applications.

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