Advanced Measurement Technologies for Characterizing Power Transistors

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ABSTRACT — **Advanced measurement technologies for characterizing power transistors are introduced. The basic idea is to upgrade existing loadpull set-ups such that they are able to measure the time domain voltage and current waveforms at both transistor terminals. The upgrade is based on the combination of three technologies: low-insertion loss loop couplers ("wave-probes"), broadband microwave receivers and open source calibration software.**

***Index Terms* — Loadpull, time domain measurement, loop coupler, broadband receiver, power transistor, dynamic loadline.**

I. Introduction

A complete characterization of microwave power transistors has always presented specific challenges. In general two methods are being used: a first method uses pulsed bias measurements, often combined with small signal S-parameter measurements. This method is typically used by the transistor modeling society. A second method are so-called loadpull measurements, whereby one presents a whole range of output impedances to the transistor terminal, together with a large signal input signal, and one measures several output characteristics of the device like e.g. output power, adjacent-channel-power ratio (ACPR), power gain, … . Loadpull measurements are typically used by amplifier designers to find the optimal operating conditions of the transistors for meeting specific amplifier requirements. Loadpull measurements are also often used to verify large-signal transistor models. In this paper we present a simple novel loadpull measurement setup with extended capabilities. We believe that the enabling technology that was developed for the new setup will soon result in readily available loadpull setups with full pulsed bias and radio-frequency (RF) measurement capability, essentially combining the capabilities of the 2 methods mentioned above [4].

II. Advanced Classic Loadpull

An example of an advanced classic loadpull setup is depicted in figure 1. A load and a source tuner are placed as close as possible to the device-under-test (DUT), the power transistor. The two tuners provide a whole range of possible input and output imdepances. The input signal is provided by a synthesizer, often boosted by a power amplifier. A vector network analyzer (VNA) and a power meter are used to measure the RF signals. A bias supply and monitoring system is also present. The transistor performance under large signal excitation and with realistic load and source impedances is determined by using the power meter and VNA measurements, the measured bias voltages and currents and, finally, the S-parameters of the tuners. Note that these S-parameters are a function of the tuner settings, they are different for each realized input or output impedance. These S-parameter functions are determined a priori by a time consuming tuner calibration procedure.

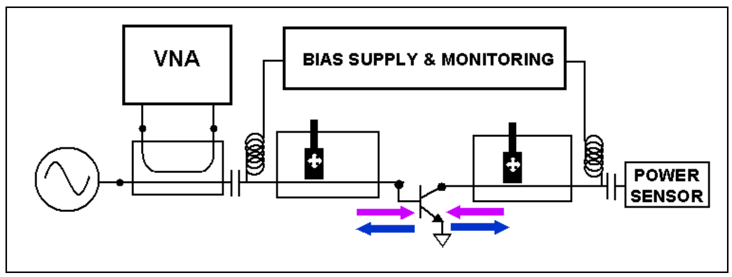

Figure 1. Schematic of a classic loadpull setup.

III. Simple Modern Loadpull

A schematic of a modern loadpull setup [1][2], which is the subject of this paper, is shown in figure 2, a picture of the system realized at XLIM, France, is shown in figure 3.

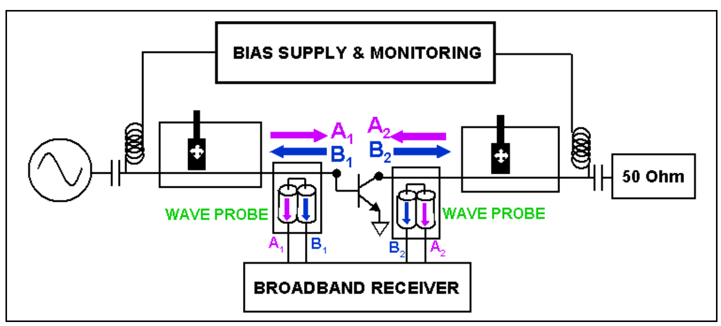

Figure 2. Schematic of a modern loadpull setup

The main difference with classic loadpull techniques is that the RF signals are sensed between the DUT and the tuners, whereas in a classic loadpull setup the tuner is placed in between the DUT and the RF signal sensors. The new sensing method is realized by using a low-insertion loss loop coupler structure, also called a "wave probe". The outputs of the wave probe, the sensed incident and reflected traveling voltage waves, are connected to a broadband microwave receiver, which measures the phase and amplitude of the fundamental as well as of all significant harmonics.

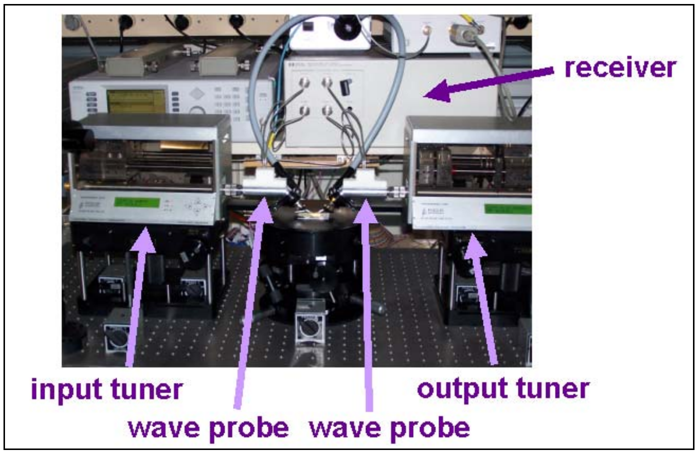

Figure 3. Picture of the measurement setup at XLIM, France.

IV. Advantages of Modern Approach

The modern setup has many advantages when compared with the classic approach. Probably the most significant advantage is that the RF signals are sensed between the tuner and the DUT. As a result the measured RF signals completely determine the RF signals at the DUT terminals, it is not necessary to know the S-parameters of the tuner. In fact the information on the impedances represented by the tuner can be derived from the RF signal measurements. As such the new setup no longer requires any a priori characterization of the tuners. A second advantage is that the setup allows to determine the amplitudes and the phases of the fundamental as well as all significant harmonics of the RF signal. As such the data can easily be transformed into the time domain. Converting the traveling voltage waves in a current/voltage representation and plotting the time domain drain current versus the time domain drain voltage results in a representation of the so-called dynamic loadline, a popular tool for amplifier design. An example of measured time domain drain voltage and drain current waveforms at the terminals of a Thales-Tiger 2 x 100µm GaN HEMT, corresponding to a power sweep at 4 GHz, are shown in figure 4. The corresponding dynamic loadlines are shown in figure 5.

V. Enabling LSNA Technology

The modern loadpull setup is based on the use of three pieces of "Large Signal Network Analyzer" (LSNA) technology [3]: the wave probe, the broadband RF receiver and the use of extended VNA calibration procedures. We expect that these three pieces will soon become readily available.

The wave probe is actually a loop coupler structure with a tiny loop (significantly smaller than a quarter wavelength) [1]. The loop is exposed to the electro-magnetic fields of the RF signals as they travel through the waveguide structure. The loop introduces virtually no insertion loss, yet has a directivity that is sufficient for all loadpull applications. The basic principle of the tiny loop coupler is explained in figure 6.

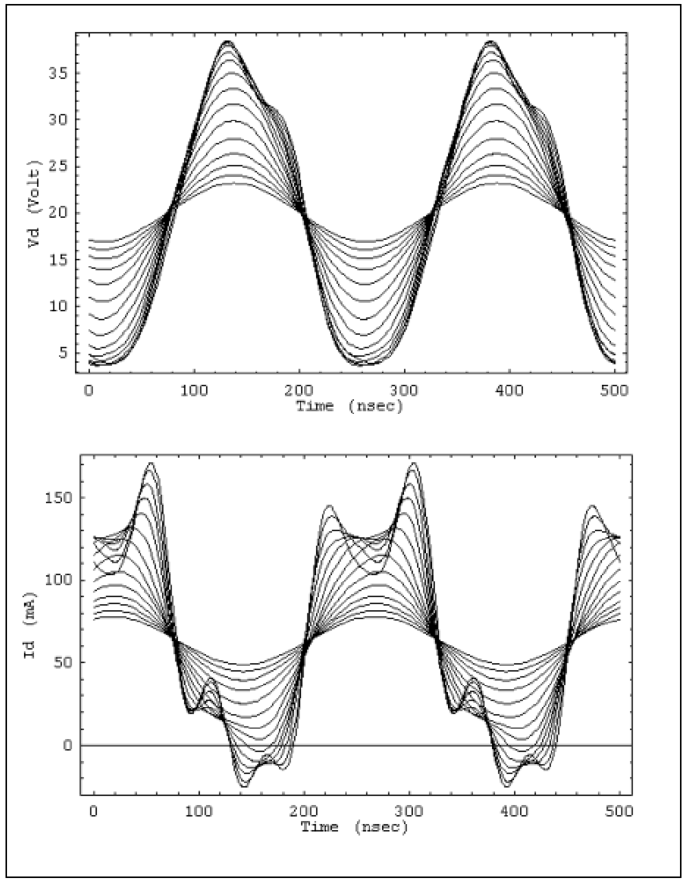

Figure 4. Drain voltage and current waveforms

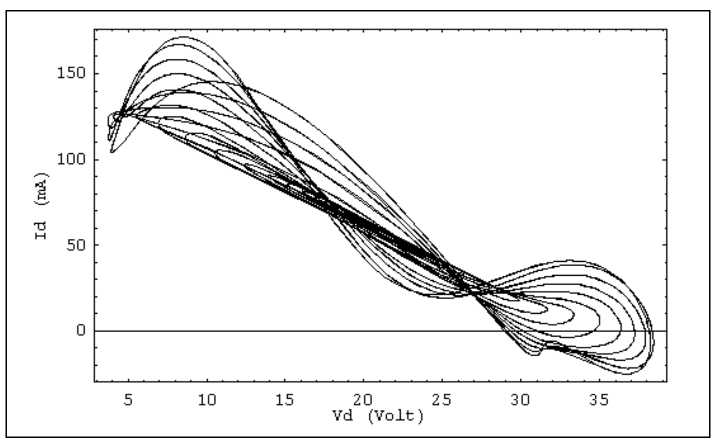

Figure 5. Example dynamic load line

Figure 6 depicts the loop coupler as it is positioned close to the center conductor of a waveguide structure. Note that the ground of the waveguide is not represented. Assume that a traveling voltage wave (denoted by A) is traveling from right to left inside the waveguide. The electrical field caused by the charge on the center conductor induces a current in the left arm of the wave probe that is in phase with the current induced in the right arm. The magnetic field, on the other hand, induces two currents in both arms of the wave probe that are in opposite phase. As a result there is destructive interference between the electrically and magnetically induced currents in the left arm, whereas there is constructive interference in the right arm. Finally a signal is only generated in the right arm and not in the left arm of the wave probe, thereby demonstrating the directivity of the structure.

The broadband receiver is based on a 4-channel sampling frequency convertor [6]. The basic idea is to sample the RF signal at a rate that is slightly offset from a subharmonic of the fundamental frequency. As a result the intermediate frequency (IF) output of the sampler contains low frequency copies of the fundamental as well as the harmonics. The sampling process preserves the amplitude as well as the phase relationship between all of the spectral components. The IF output signals are digitized by standard analog-to-digital convertors with a typical bandwidth of 25 MHz.

The third piece of enabling LSNA technology is a set of extended VNA calibration procedures based on open source software. The basic ideas of the calibration procedures are described in [3].

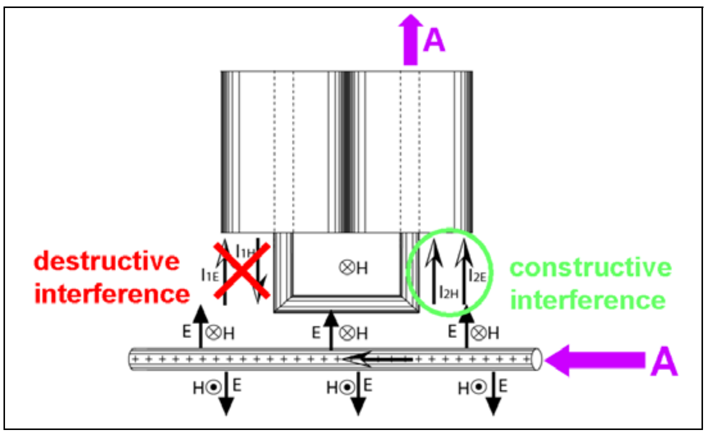

Figure 6. Loop coupler structure inserted near waveguide center conductor

VI. Conclusions

Three pieces of LSNA technology will soon become readily available: wave probes, broadband receivers and open source calibration procedures. The combination of this technology will enable to upgrade existing loadpull setups towards new measurement capability: amplitude and phase of harmonics, time domain voltage and current waveforms, dynamic loadlines, elimination of time consuming tuner calibrations.

At the same time we firmly believe that these three pieces of LSNA technology will make even more advanced time domain loadpull setups like the ones described in [4] and [5] more readily available to a broad number of microwave engineers.

Acknowledgements

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