Jan Verspecht bvba

Mechelstraat 17
B-1745 Opwijk
Belgium

email: contact@janverspecht.com
web: http://www.janverspecht.com

Advanced Time Domain Loadpull Technique for Characterization of Microwave Power Transistors

Jan Verspecht, Fabien De Groote and Jean-Pierre Teyssier

ESA Microwave Technology and Techniques Workshop
May 6-7 2008, Noordwijk, The Netherlands

Advanced Time Domain Loadpull Technique for Characterization of Microwave Power Transistors

Jan Verspecht(1), **Fabien De Groote** (2), **Jean-Pierre Teyssier** (3)

(1) Jan Verspecht b.v.b.a.
Mechelstraat 17, B1745 Opwijk, Belgium
Email: contact@janverspecht.com

(2) Verspecht-Teyssier-DeGroote s.a.s.
IUT GEII, 7 rue Jules Valles, 19100 Brive, France
Email: degroote@brive.unilim.fr

(3) XLIM
123, avenue Albert Thomas, 87069 Limoges CEDEX, France
Email: teyssier@brive.unilim.fr

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].

ADVANCED CLASSIC LOADPULL

An example of an advanced classic loadpull setup is depicted in Fig. 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 impedances. 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.

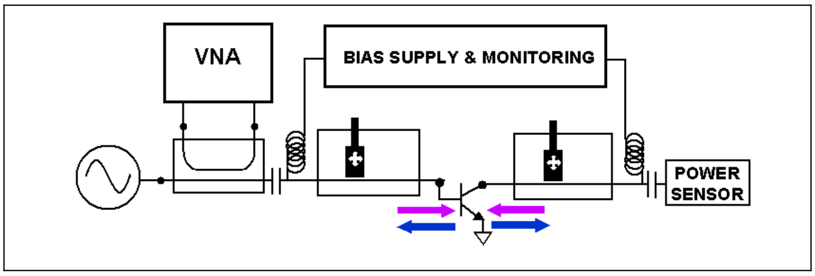

Fig. 1. Schematic of a classic loadpull setup.

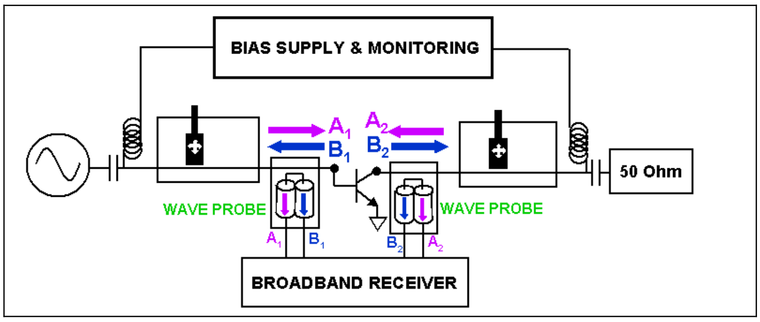

Fig. 2. Schematic of a modern loadpull setup

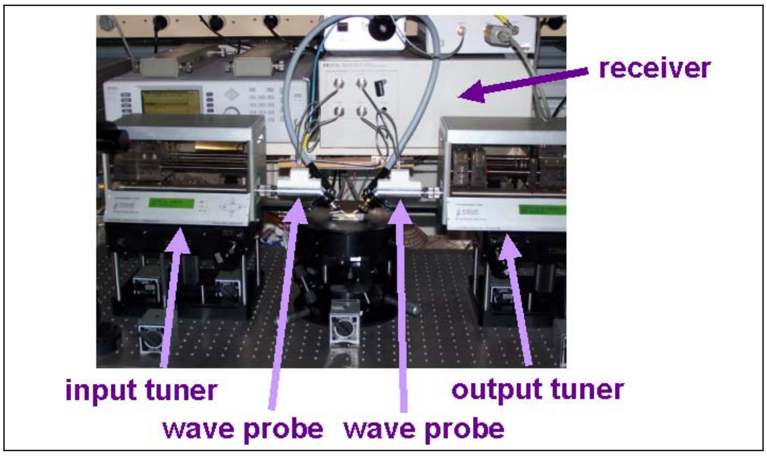

Fig. 3. Picture of the measurement setup at XLIM, France.

ADVANCED TIME DOMAIN LOADPULL

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

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.

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 presented 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 GaN high electron mobility transistor (HEMT), corresponding to a power sweep at 2 GHz, are shown in Fig. 4. The corresponding dynamic loadlines are shown in Fig. 5.

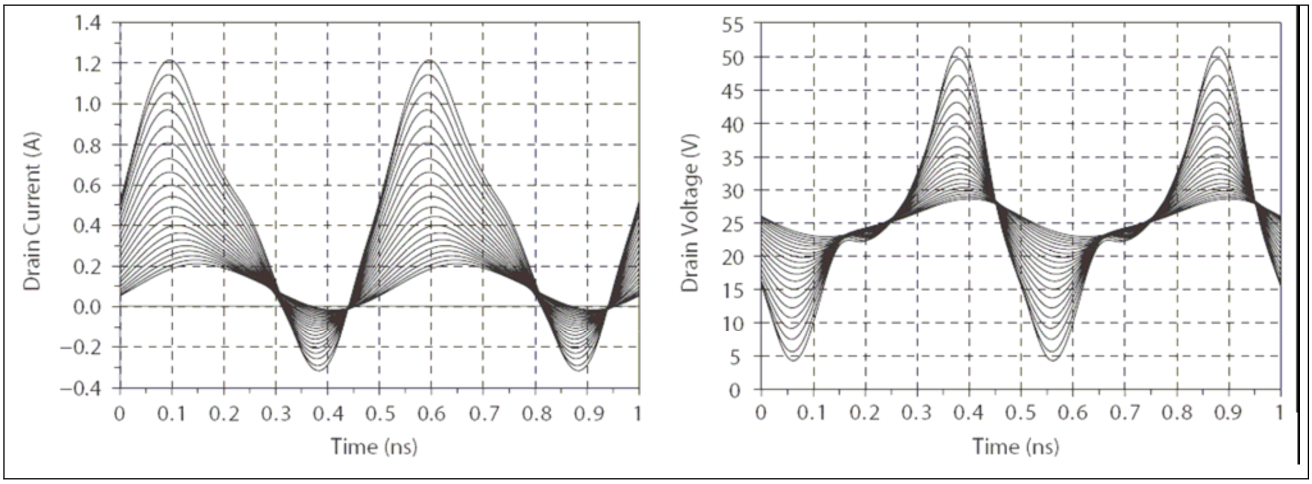

Fig. 4. Drain voltage and current waveforms

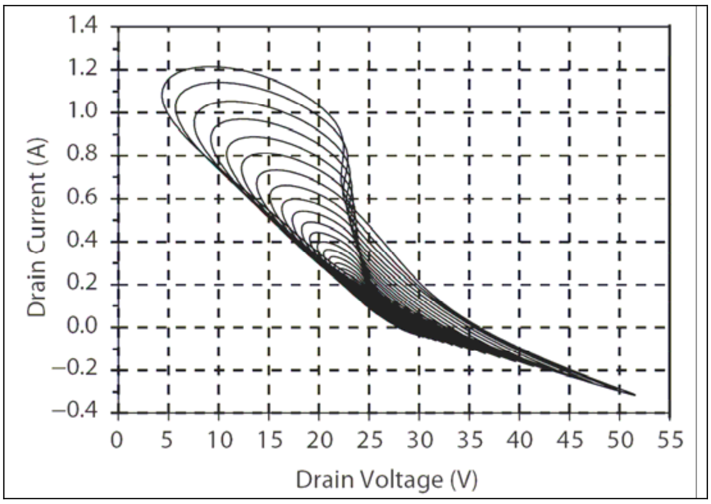

Fig. 5. Example dynamic load line

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 a loop coupler with an very tiny loop; the loop being significantly smaller than a quarter wavelength of the highest frequency to be measured . The principle was published more than sixty years ago [7] [8] [9] [10]. The loop introduces virtually no insertion loss, yet has a directivity that is sufficient for all loadpull applications. The simple principle of the wave probe is explained in the following. Fig. 6 depicts a loop coupler that 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 electric 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. If the loop is dimensioned such that it has the same amount of electric and magnetic coupling, there is destructive interference between the electrically and magnetically induced currents in the left arm, whereas there is constructive interference in the right arm. Thus, 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 coupling effect of a wave probe is effectively localized, in contrast to classical distributed couplers.

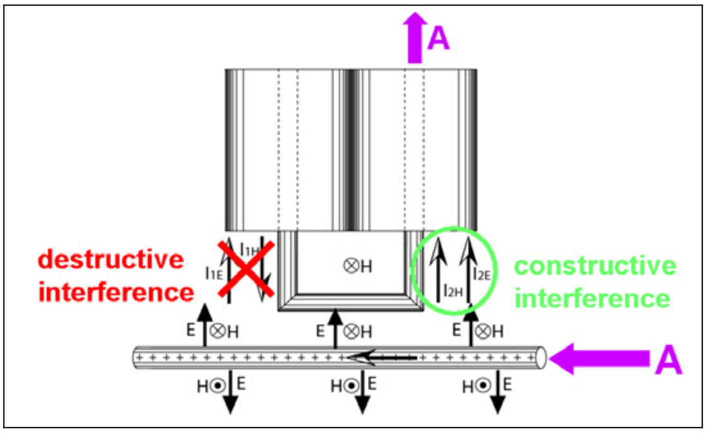

Fig. 6. Loop coupler structure inserted near waveguide center conductor

Probably the most important characteristic of the wave probe is its directivity. The directivity of a coupling structure is the quantitative measure for its ability to separate the two waves traveling in the transmission line structure. In Fig. 6, for example, the directivity is given by the ratio between the power measured at the right output of the wave probe and the power measured at the left output of the wave probe, under the assumption that there is only a wave traveling to the right on the main structure (as it is the case in Fig. 6). The simple wave probe that we have constructed has a minimum directivity of 12 dB at 20 GHz and a significantly higher directivity at lower frequencies. This is sufficient for loadpull applications. Another important characteristic of the coupling structure is the coupling factor versus frequency. Fig. 7 depicts the coupling factor versus a wide band of frequencies, for different distances between the wave probe and the center conductor of a transmission line structure. These measurement results show a coupling factor that increases with frequency, until about 10 GHz. The coupling factors range from about -20 dB to -40 dB. The increase of the coupling factor for higher frequencies can be beneficial for harmonic measurements. This can be explained by the fact that losses in cables and connectors increase with frequency and by the fact that power levels of harmonics are lower than the power level of the fundamental. The wave probe can automatically boost the power of the higher frequency harmonics relative to the power of the lower frequency fundamental. This power leveling effect increases the dynamic range for the harmonics. In our example, to be presented in the following, we use a coupling factor of the wave probe between -50 dB and -40 dB in the S-band [2-4 GHz]. The outputs of the wave probe are directly connected to RF samplers that can handle a maximal input power of about -10 dBm. As such, the setup used for the example can handle power levels upto 40 dBm (10 Watt). We can control the distance between the wave probe and the center conductor of the transmission line, which allows to optimize the setup for a specific power level.

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. The basic ideas of the calibration procedures are described in [3].

CONCLUSIONS

Three pieces of LSNA technology will soon become readily available: wave probes, broadband receivers and extended VNA 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

The authors thank Alcatel-Thales III-V Lab for providing the transistor used for generating the examples of this paper, as well as Focus Microwaves for providing support related to the wave probes.

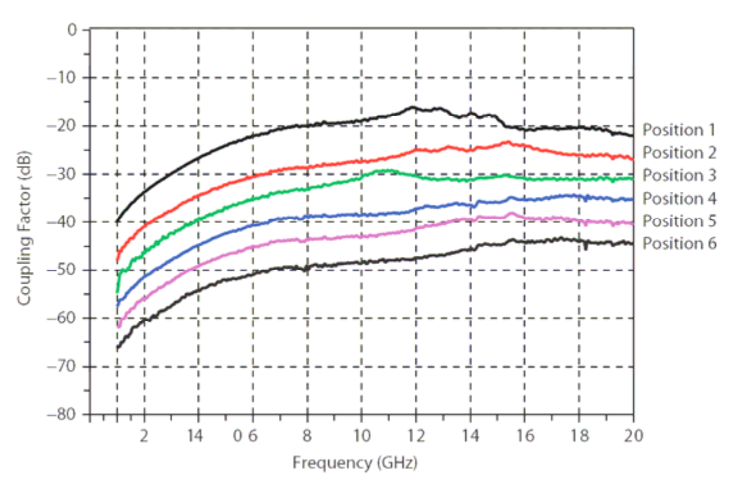

Fig. 7 Coupling value for a wave probe for different positions above the main line

REFERENCES

[1] F. De Groote, Jan Verspecht, Christos Tsironis, Denis Barataud, Jean-Pierre Teyssier, “An improved coupling method for time domain load-pull measurements,” *65th ARFTG Conference Record*, USA, June 2005. [Online] Available: http://www.janverspecht.com

[2] F. De Groote, Olivier Jardel, Jan Verspecht, Denis Barataud, Jean-Pierre Teyssier, Raymond Quéré, “Time Domain Harmonic Load-Pull of an AlGaN/GaN HEMT,” *66th ARFTG Conference Record*, USA, December 2005.

[3] Jan Verspecht, “Large Signal Network Analysis,” *IEEE Microwave Magazine*, Vol.6, No.4, pp.82-92, USA, December 2005. [Online] Available: http://www.janverspecht.com

[4] Christophe Charbonniaud, Jean-Pierre Teyssier, Raymond Quéré, “Time-domain pulsed large-signal non-linear characterization of microwave transistors,” *Conference Record of the 33rd European Microwave Conference*, Vol.1, pp.241-244, October 2003.

[5] T. Williams, J. Benedikt, P.J. Tasker, “Application of a Novel Active Envelope Load Pull Architecture in Large Signal Device Characterization,” *Conference Record of the 35th European Microwave Conference*, October 2005.

[6] Jan Verspecht, “The Return of the Sampling Frequency Convertor,” *62nd ARFTG Conference Record*, USA, December 2003. [Online] Available: http://www.janverspecht.com

[7] H. Early, “A wide-band directional coupler for wave guide,” Proceedings of the IRE, 1946.

[8] H. Riblet, “A mathematical theory of directional couplers,” Proceedings of the IRE, vol. 35, no. 11, pp. 1307–1313, Nov. 1947.

[9] H. Riblet and T. Saad, “A new type of waveguide directional coupler,” Proceedings of the IRE, vol. 36, no. 1, pp. 61–64, Jan. 1948.

[10] R. Schwartz, P. Kelly, and P. Lombardini, Criteria for the design of loop-type directional couplers for the l band,” Microwave Theory and Techniques, IEEE Transactions on, vol. 4, no. 4, pp. 234–239, Oct 1956.