AN ENHANCED ACTIVE LOAD-PULL SYSTEM FOR HIGHLY MISMATCHED POWER TRANSISTOR MEASUREMENTS

J.M. COUPAT, Ph. BOUYSSE, J.M. NEBUS, J.P. VILLOTTE

IRCOM - Faculté des Sciences de Limoges - URA CNRS n° 356
123, Avenue Albert-Thomas - 87060 LIMOGES Cédex (FRANCE)

ABSTRACT

The experimental characterization of highly mismatched power transistors has always been a very difficult task to achieve. Practically, it is not within the capabilities of mechanical tuning systems because of the inherent losses of these devices. Active load-pull systems allow to simulate highly reflective load impedances close to the edge of the Smith chart by driving the output of the device with a large available power source. However, in such conditions, experience shows that the transistor under test may be quickly damaged if the phase adjustement of the output injected power wave is not carefully and properly monitored. That means that classical active load-pull systems "suffer from" poor reliability for the measurement of highly mismatched power components. We propose in this paper a novel load-pull technique providing an attractive solution to these problems. It consists in performing fine an accurate electronic load perturbations around initial mismatches. The associated measurement set-up is described. Measurement results of silicon bipolar power transistors are given.

INTRODUCTION

Since Y. TAKAYAMA has published the principle of active load-pull technique (1976) [1], active load-pull systems have been widely developped and used in many microwave labs for the nonlinear characterization of transistors. (FETs, silicon bipolar transistors, HBTs, HEMTs). [2], [3], [4], [5], [6], [7]. Although, much work report on medium power transistor measurements by load-pull techniques [2], [3], [4], [5], [6], [7], results of power transistors (several watts) have never been published to our knowledge. The measurement of high power transistors is a very difficult task because such components are generally highly mismatched. It cannot be done by mechanical tuning systems because of their inherent losses. It cannot be easily done by using classical active load-pull systems which requires large power sources driving the output of the DUT. Moreover experience shows that the DUT may be quickly damaged if the phase adjustement of the power wave injected at the output port of the DUT is not properly monitored. We propose in this paper a novel active load-pull technique allowing to overcome the above limitations. The main difference between the novel active load-pull technique and the classical one lies in that an appropriate mismatched power source is used to drive the output port of the DUT.

The proposed technique allows an accurate characterization of highly mismatched power transistors. (reflection coefficients of loads larger than O.9). Futhermore the novel technique is safer on devices.

I - THE CLASSICAL AND THE NOVEL ACTIVE LOAD-PULL TECHNIQUES - MAIN DIFFERENCES AND IMPROVEMENTS

Let us consider an arbitrary nonlinear two-port device described in terms of fundamental frequency power waves (figure 1).

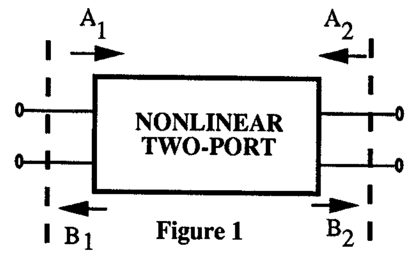

Figure 1

I.1 - The DUT characterization by a classical active load-pull technique

Classical 50 Ohm coherent power sources are used to drive both ports of the DUT : (figure 2).

Principle

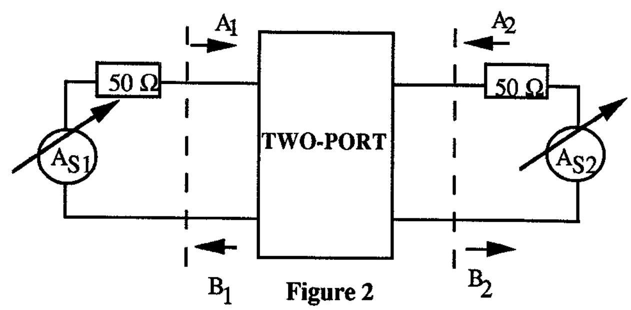

Figure 2

Any load impedance of the Smith Chart can be electronically imposed on the DUT by amplitude and phase shifting the output injected power wave A_2.

OF1

CH3277-1/93/0000-0245$01.00 © 1993 IEEE

Hardware implementation

A simplified block diagram of the method is sketched in figure 3.

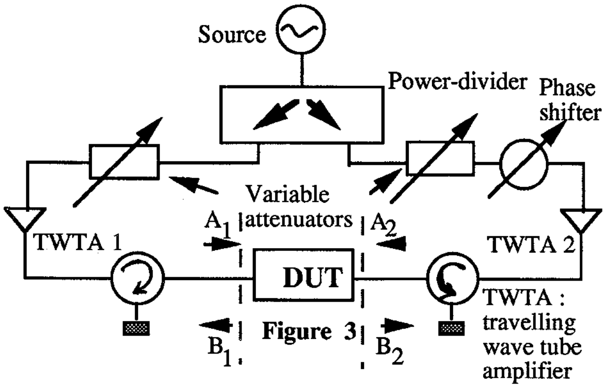

Figure 3

Second and third harmonics are approximatively terminated in a 50 Ohm load as long as large bandwidth isolators are connected to both ports of the DUT. By using such a characterization technique, the electronically simulated load impedances (A_2/B_2) are uniformely distributed around the internal 50 Ohm impedance of the output power source driving the device. (see illustration figure 4).

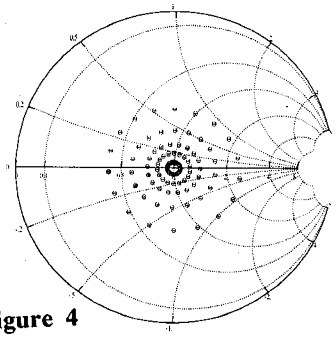
Figure 4

If the above technique is well-suited for the measurement of weakly mismatched components, it is not appropriate to the characterization of highly mismatched power transistors because it "suffers from" the following main drawbacks :

- the distribution of measurement points is not suitable to finely scan any particular limited area close to the edge of the Smith chart, where the best amplification capabilities of highly mismatched power transistors are reached.

- Large available power sources driving the output of the DUT are required to simulate highly reflective loads. In these conditions, if the phase adjustement of the output injected power wave is not properly controlled, experience shows that the D.U.T. may be damaged.

I.2 - The DUT characterization by the novel active load-pull technique

An attractive solution allowing to overcome the main limitations of the classical technique consists in using a mismatched power source to drive the output port of the device (figure 5).

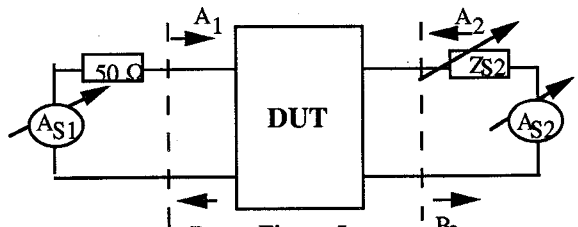

Figure 5

When the output power source is turned off, the DUT is loaded by Z_{S2}.

By amplitude and phase shifting the signal supplied by the output power source variable load impedances located around Z_{S2} are simulated.

Hardware implementation

An adjustable complex internal impedance of the output power source can be obtained by using a simple assembly which consists of a directional coupler terminated in a sliding short circuit (figure 6).

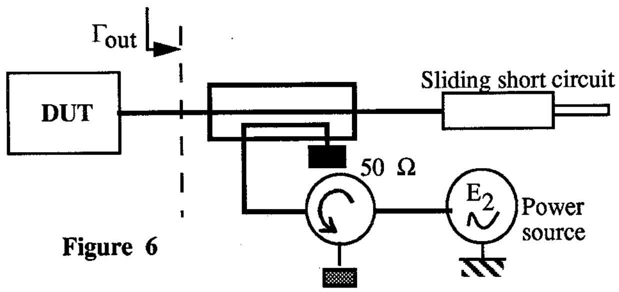

Figure 6

When the power source is turned off, the initial load impedance (Γ_{out}) "seen" by the DUT can be adjusted anywhere on a circle which depends on the inherent losses and coupling factor of the directional coupler (see illustration figure 7).

Practically, by using a 6 dB coupler, we may present an initial Γ_{out} having a radius of 0.7 and describing a full circle on the Smith chart.

By using a 10 dB coupler a radius of 0.8 is obtained.

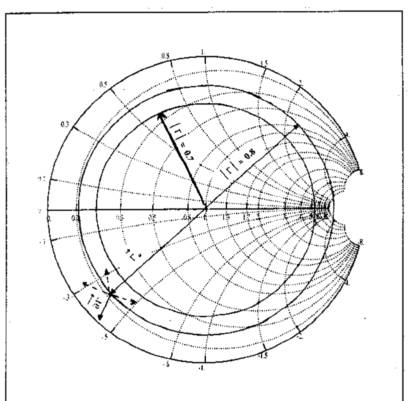
Figure 7

Let's assume an initial setting : $\Gamma_{out} = \Gamma_o$.

The output power source (A_{S2}) is now turned on.

By amplitude and phase shifting the power wave supplied by this source, vector perturbations $\vec{\partial\Gamma}$ are superimposed to the initial adjustement : $\vec{\Gamma_o}$ (figure 7).

$$\vec{\Gamma_{out}} = \vec{\Gamma_o} + \vec{\partial\Gamma}$$

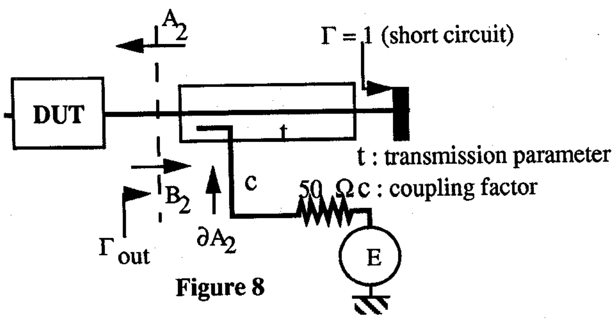

Figure 8

As the power waves b_2 (supplied by the DUT) and ∂a_2 (supplied by the output power source) are coherent waves, the principle of superposition can be applied.

Therefore, we can write the following relationships.

$$A_2 = |t|^2 e^{j\theta} B_2 + C e^{j\varphi} \partial A_2$$

$$\frac{A_2}{B_2} = |t|^2 e^{j\theta} + C e^{j\varphi} \frac{\partial A_2}{B_2}$$

$$\boxed{\vec{\Gamma_{out}} = \vec{\Gamma_o} + \vec{\partial\Gamma}}$$

By using such a technique, an example of load contours obtained is given in figure 9.

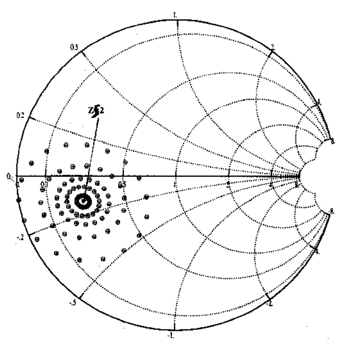

Figure 9

It is clearly illustrated that any particular area of the Smith Chart can be finely and accurately explored.

This technique is particularly valuable and efficient for the characterization of highly mismatched power transistors.

As we can finely control load-variations close to the edge of the Smith Chart, power transistors with very low output impedances (in the order of the ohm) can be accurately characterized by using this novel technique.

II - THE MEASUREMENT SYSTEM AND EXPERIMENTAL RESULTS

II.1 - Measurement system

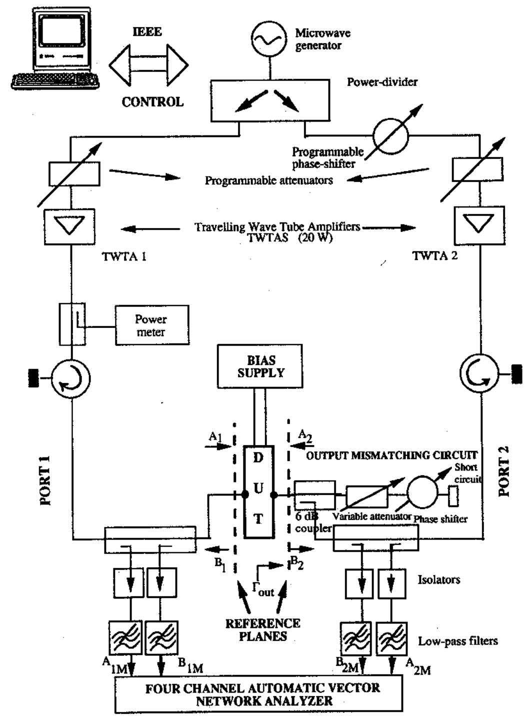

Figure 10

It uses two separate 20 watt travelling wave tube amplifiers to drive both ports of the system, allowing measurements of up to 10 watt CW power transistors.

The new technique previously described is applied at port 2 of the system.

The system is fully error corrected for reflection coefficients, transmission coefficients, input and output powers.

II.2 - Experimental results

Measurement results of silicon bipolar transistors are given. They illustrate the capabilities of our system.

A medium power silicon bipolar transistor (MOTOROLA XP 4001) was characterized at 2 GHz under class AB operation. An output power of 360 mw is obtained.

A power silicon bipolar transistor (MOTOROLA XP 4004) was characterized at 1.7 Ghz under class A operation. An output power of 3 watts is reached.

Both transistors are used in a common emitter configuration and biased at a constant base current.

Figure 11 shows constant added power loci of the Motorola XP 4001.

Figure 12 illustrates the set of load impedances simulated for the characterization of the Motorola XP 4004.

The distribution of measurement points proves the accuracy and efficiency of the characterization technique.

Figure 13 gives constant added power loci of the transistor Motorola XP 4004 for a fixed input power of 350 mW. It has to be noticed that all points are measurement points. They don't result from any kind of fitting routine.

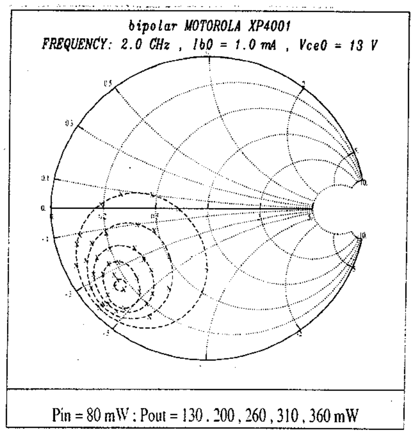

Figure 11

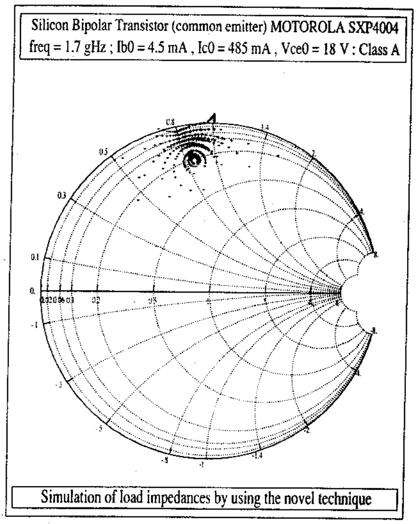

Figure 12

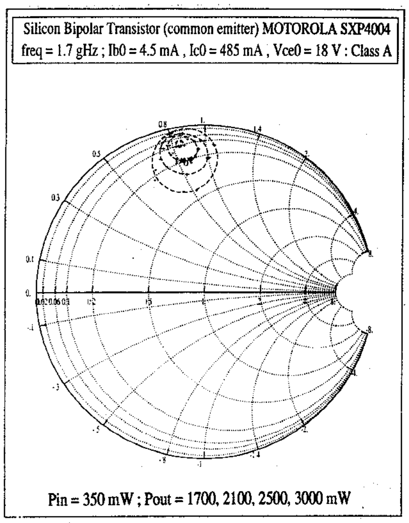

Figure 13

CONCLUSION

The novel load-pull technique proposed in this paper reveals to be very efficient and accurate for the characterization of highly mismatched power devices resulting from multi-chips association. Fine and repeatable electronic load variations are achieved. The associated measurement system is capable of measuring high power-low impedance (several watts-one ohm) power devices. The system which covers at the present time the 1 - 18 Ghz frequency bandwidth can be extended either in the RF domain or the millimeter wave domain. Furthermore, this novel technique is particularly well-suited for the measurement of very high power transistors (several tens of watts) under CW or pulsed mode operation [8]. Therefore, one of its main use is in the optimization of power amplifiers for mobile communication systems and radar applications.

Acknowledgements : The authors would like to thank Pr. J. OBREGON for his constant guidance and suggestions throughout this work.

REFERENCES

[1] **Y. TAKAYAMA,** "A new load-pull characterization method for microwave power transistor". IEEE-MTT-S Symposium Digest - pp 218-220 - June 1976.

[2] **R.S. TUCKER, P.D. BRADLEY,** "Computer-aided error correction of large-signal load-pull measurement". IEEE Transactions on Microwave Theory and Techniques - MTT - 32, pp 296-300 - March 1984.

[3] **M. PIERPOINT, D. POLLARD, J.R. RICHARDSON,** "An automated measurement technique for measuring amplifier load-pull and verifying large-signal device models".IEEE MTT-S Symposium Digest - pp 625-628 - 1986.

[4] **K. KOTZEBUE, T.S. TAN, D. Mc QUATE,** "An 18 to 26.5 GHz waveguide load-pull system using active load tuning".IEEE MTT-S Symposium Digest - pp 455-456, 1987.

[5] **J.M. NEBUS and al,** "Optimized CAD of power amplifiers for maximum added power or minimum third order intermodulation using an optimization software coupled to a single tone source and load-pull set-up". IEEE MTT-S Symposium Digest - pp 1049-1052, 1988.

[6] **F.M. GHANNOUCHI, R. LAROSE, R.G. BOSISIO,** "A new multiharmonic loading method for large signal microwave and millimeter-wave transistor characterization". IEEE Transactions on Microwave Theory and Techniques, Vol. 39, n° 6, pp 986-996 - June 1991.

[7] **D.A. TEETER and al,** "Large signal characterization and numerical modeling of the GaAs/Al GaAs HBT". IEEE MTT-S Symposium Digest - pp 651-654, 1991.

[8] **D.D. POULIN, J.R. MAHON, J.P. LANTERI** "A high power on-wafer pulsed active load-pull system". IEEE MTT-S Symposium Digest - pp 1431-1434, 1992.