A NOVEL TIME DOMAIN CHARACTERIZATION TECHNIQUE OF INTERMODULATION IN MICROWAVE TRANSISTORS. APPLICATION TO THE VIZUALIZATION OF THE DISTORTION OF HIGH EFFICIENCY POWER AMPLIFIERS

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ABSTRACT

Along with the increasing necessity of improving the large signal characterization of microwave transistors and the validation of nonlinear models, a novel characterization has emerged based on a time domain approach.

As explained and illustrated in this paper, this method allows the visualization and the accurate determination of amplifier distortions at low, medium and large RF power levels. The extraction of single tone and multitone voltage / current waveforms from a dedicated measurement system enhances the novel characterization technique proposed and the validation of non linear electrothermal model for CAD. Examples of measured and simulated results of GaAs FETs and GaInP/GaAs HBTs are given to demonstrate the great possibilities offered by the characterization procedure. Its use to optimizate trade-offs between efficiency and linearity of power amplifiers is clearly demonstrated by the display and the vizualization of the envelop and carrier distortions of the signals at both ports of power FETs and HBTs.

INTRODUCTION

GaAs MESFETs, heterostructure FETs and heterojunction bipolar transistors (HBT) are nowadays in strong competition for microwave power amplifiers [1], [2], [3]. Power amplifiers used in most communication systems must meet a number of requirements among which are efficiency and linearity. The research of good trade-offs between linearity and efficiency is something rather difficult also. The comparison in terms of linearity and efficiency between different kinds of transistors (FET and HBT) is not easy [4]. Clear conclusions or comments have not yet been established. A novel characterization method proposed in this paper can contribute very significantly to an extensive analysis of distortion'effects in high efficiency power amplifiers. The characterization procedure consists in measuring voltage / current waveforms at both ports of transistors driven by modulated microwave carriers. This method is based on harmonic mixing principle, frequency compression and translation. Such a characterization technique takes into account the time constants of transistors (i.e. time constant at low frequency mainly due to trap effects for FETs and to thermal effects for HBTs, and time constants at high frequency due to the distributed character of both kinds of transistors). This technique is an alternative of conventional load-pull method based on the use of classical vector network analyzers.

In the first part of this paper, basic foundations of the time domain waveform measurement system are presented. Special emphasis is made on the data processing for the vizualization of the performances of transistors driven by multitone excitations.

In a second part, measured and simulated results of HBTs and FETs are given and discussed. Topologies of nonlinear models of both kinds of transistors used for simulations are given.

Then as a conclusion, future investigations will be mentioned.

PART I : TIME DOMAIN WAVEFORM MEASUREMENT SYSTEM

The classical frequency domain large signal characterization of transistors by using a vector network analyzer and / or tuners and plotting load-pull contours does not provide an extensive insight into the operation mode of transistors. Voltage / current waveforms at both ports of transistors are required for that purpose.

Moreover, measured voltage / current waveforms can be directly confronted with simulated waveforms for an accurate validation of nonlinear models used in CAD.

The well-known microwave transition analyzer (MTA) is an alternative of vector network analyzer (VNA) [5], [6], [7]. This instrument allows measurement of time domain waveform. Nevertheless, two synchronized MTAs are required to have a four channel data acquisition unit capable of measuring the four power waves at both ports of transistors at the same time. This is necessary to keep the phase coherence between power waves waveforms at the DUT ports.

In other words, if only one MTA is used and commutations occur in the measurement system the phase reference is lost. Furthermore, absolute phases of every power waves (incident and scattered power waves) must be determined at each frequency component of interest, so that voltage / current waveforms can be extracted from measurements.

0-7803-4603-6/97/$5.00 (c) IEEE

In the general case (multitone excitations (figure 1)), one can write the following relationship :

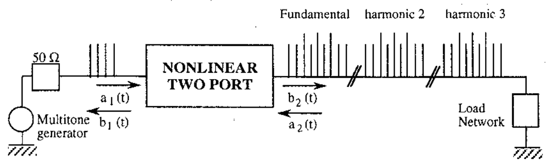

Figure 1

$$a_1(t) = \sum_n A_{1n} \cos\left(\omega_n t + \varphi_{1n}\right)$$

$$a_2(t) = \sum_m A_{2m} \cos\left(\omega_m t + \varphi_{2m}\right)$$

$$b_1(t) = \sum_m B_{1m} \cos\left(\omega_m t + \theta_{1m}\right)$$

$$b_2(t) = \sum_m B_{2m} \cos\left(\omega_m t + \theta_{2m}\right)$$

φ_{1n}, φ_{2m}, θ_{1m}, θ_{2m} must be accurately known in order to determine voltage / current waveforms.

$$\left.\begin{aligned} V_i(t) &= \left(a_i(t) + b_i(t)\right)\sqrt{Z_o} \\ I_i(t) &= \left(a_i(t) + b_i(t)\right)\frac{1}{\sqrt{Z_o}} \end{aligned}\right\} \quad i = 1, 2$$

Hewlett-Packard (Network Measurement and Description Group) has built a prototype four channel nonlinear network analyzer (prototype) using samplers connected to analog digital converters. The sampling process is based on the use of harmonic mixing principle. The frequency compression and translation which occurs inside the data acquisition unit is sketched in figure 2 (in the case of a microwave input two tone excitation). Llow frequency data (point C) are processed and error corrected to get time domain microwave signal at the transistor ports (on wafer probe tips).

In order to be able to optimize load impedance required to maximize the power added efficiency and / or the linearity of the transistor under test, the data acquisition unit must be coupled to harmonic load-pull facilities.

The block diagram of the whole measurement tool is given in figure 3.

Error corrections in magnitude are performed using a TRL calibration procedure and a power calibration. Error corrections in phase are achieved by following a specific phase calibration technique based on the use of a standard reference generator (step recovery diode) preliminary characterized by using a "nose to nose" calibrated sampling scope [8].

The principle of active loops running respectively at the three first harmonics of the signal transmitted by the transistor are used to control and optimize separately and independently load impedances at harmonics [9].

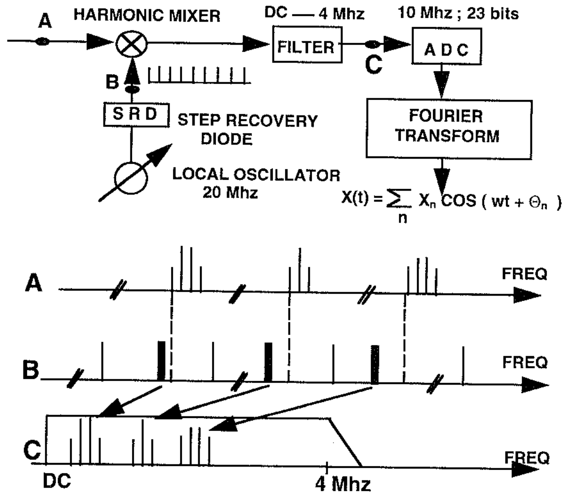

figure 2 : frequency compression and translation

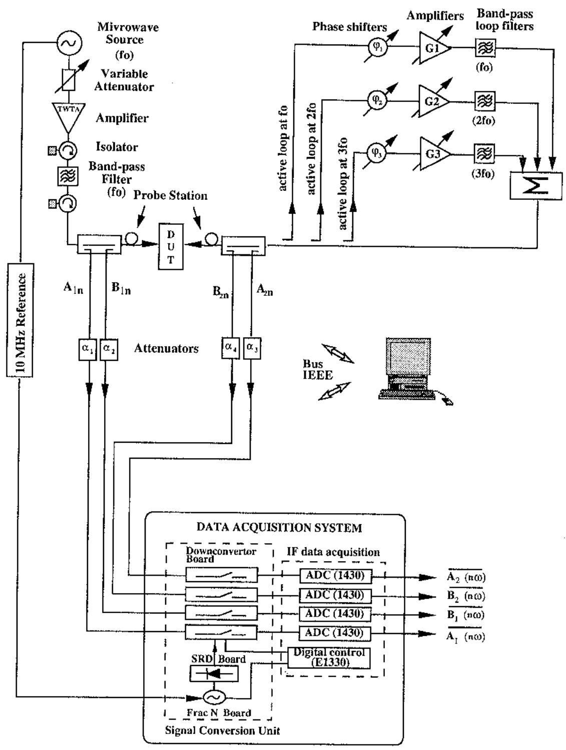

Figure 3 : block diagram of the measurement system

PART II : SIMULATED AND MEASURED INTERMODULATION RESULTS OF HBTs AND FETs

HBT and FET models

Nonlinear HBT and FET models have been extracted from pulsed I/V and pulsed S parameter measurements [10]. This technique allows an isothermal characterization of transistors. Figure 4 shows a nonlinear electrothermal model of HBT. (modified Ebers-Moll). Both the convective nonlinear elements of this model and the base-emitter capacitance are temperature dependant. Figure 5 shows a nonlinear model of FET. The main drain current source is modelled by a modified Tajima model. The pulsed measurement procedure followed for the extraction of the nonlinear model of the FET was completed at a DC quiescent bias point where the thermal state and the trapping state of the transistor are very similar to those obtained during the large signal simulation and characterization. This ensures appropriate modelling conditions required for an accurate comparison between measurements and simulated data.

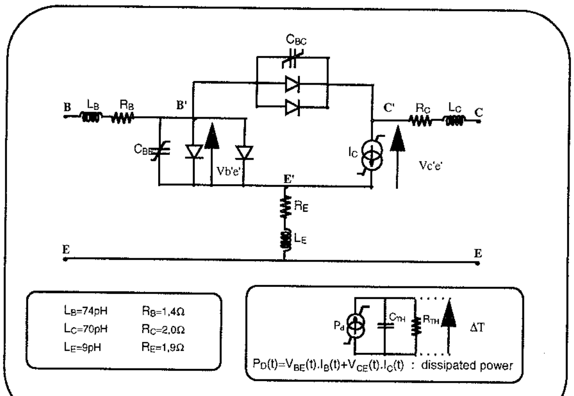

figure 4

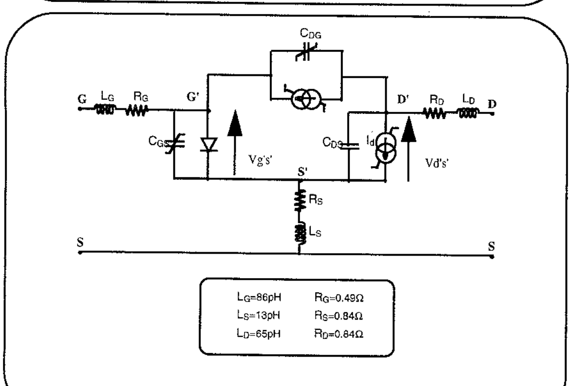

figure 5

Time domain intermodulation results

A 240 μm^2 GaInP/GaAs HBT and a 600 μm GaAs FET (Thomson Foundry) were measured at L-band under class B operation mode. A two tone excitation (frequency ω_1 and ω_2) was applied at the input of these devices. The center frequency was $\frac{\omega_1 + \omega_2}{2} = 1.8$ GHz and the frequency difference was $(\omega_1 - \omega_2) = 100$ kHz . The frequency compression and translation which occurs inside the data acquisition unit reduces considerably the ratio between the carrier frequency and the envelop frequency.

At microwave (point A of figure 2) $\frac{\omega_1 + \omega_2}{2(\omega_1 - \omega_2)} = 18000$

while at low frequency (point C of figure 2) $\frac{\omega_1' + \omega_2'}{2(\omega_1' - \omega_2')} = 20$.

The low frequency signal at point C represents an image of the microwave signal. This frequency translation and compression principle allows a visual inspection of both the carrier and the envelop distorsions. Figure 6 shows the measured time domain voltage and current waveforms at both ports of the HBT. One can note the clipping of the envelop of these signals at high RF level. The phase shift at the origin which is characteristic of a suppressed carrier amplitude modulated signal can also be observed. A good agreement between simulated results (figure 7) and measurements is obtained. This feature validates the nonlinear electrothermal model of the HBT.

Measurements of a 600 μm^2 GaAs FET were also performed under class B operation mode. Figure 8 shows the measured voltage / current waveforms obtained for this device.

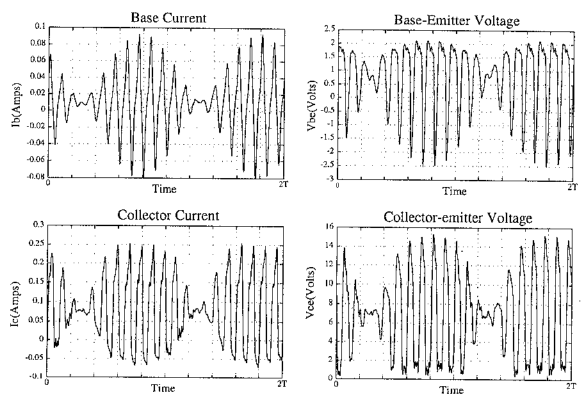

Figure 6 : Intermodulation measurement results under two - tone excitation

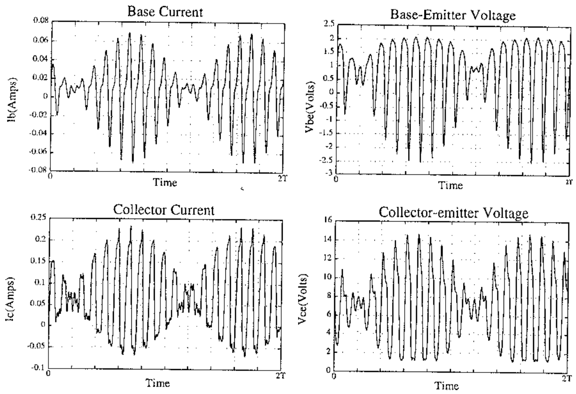

Figure 7 : Intermodulation simulation results under two - tone excitation

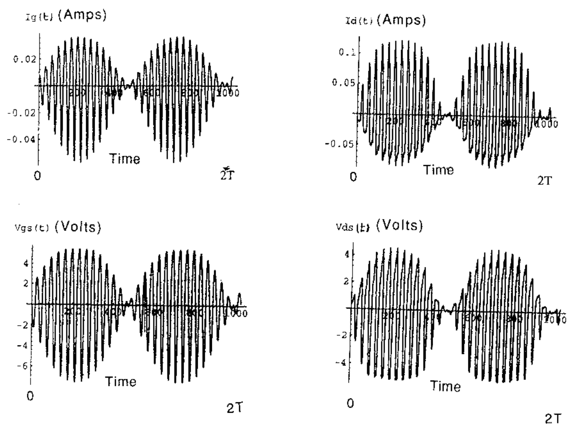

Figure 8 : Intermodulation measurement results of a FET

CONCLUSION

A novel time domain characterization procedure of high frequency transistor has been presented in this paper. It allows the visualization of carrier and envelop distorsions of microwave modulated carriers. This novel time domain characterization approach provides a key step in the validation procedure of nonlinear models of microwave transistors. It is also of great interest for the optimization of trade offs between linearity and efficiency in radiocommunication power amplifiers. Constant power added efficiency loci superimposed to constant third order intermodulation loci will be presented in the final paper. The correspondence between voltage / current waveforms and the optima points of these loci will be allow a novel approach of the dertermination of trade-offs between Power Added Efficiency (PAE) and linearity. Moreover, this will enforce time domain and frequency domain correlations. Future investigations concern the measurements of multitone carriers and the coupling of measured data with circuit envelop simulators for system level simulation and design. Another topic concern the time domain measurements of pulsed microwave signals for radar application. Some main investigations expected will be discussed in the final paper.

ACKNOWLEDGMENTS

The authors would like to thank J. VERSPECHT and M. VANDEN BOSSCHE (Hewlett-Packard NMDG Brussels) who provide the vectorial "nonlinear network" analyzer for the measurements of high frequency time domain waveforms.

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