LOW FREQUENCY DISPERSION AND OPERATION POINT DEPENDENCE MEASUREMENTS FOR NONLINEAR MICROWAVE MESFET MODELLING

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ABSTRACT

The present paper proposes an exhaustive comparison between the two methods of extracting the nonlinear parameters of the NE72084 transistor. For this purpose, we have developed a continuous and pulsed automatized set up along with a fitting program that permits us to obtain the total nonlinear transistor model. Furthermore, a software program that permits us to extract the total linear equivalent circuit measuring the scattering parameters in the 2-8 GHz frequency band at several polarization points in order to obtain the quasi-static nonlinear model has been developed. Simulations taking into account low frequency dispersion permit comparisons between the model obtained from pulsed measurements and the quasi-static approach. Experimental measurements show the agreement of the two different models.

Keywords: Low frequency dispersion, pulsed, quasi-static, nonlinear modelling.

1. INTRODUCTION

The expanding use of GaAs MMICs in both civil and military applications, has allowed the HEMT and MESFET to be incorporated in an increasing number of nonlinear circuits. To design these MMICs circuits, in home and commercial nonlinear programs, using harmonic balance or time-domain algorithms, are utilized. These simulation tools are very powerful but they need accurate large signal device models to improve the performance of these circuits and to minimize the number of design and fabrication cycles required. In spite of a great number of authors have made great efforts developing reliable large signal models for microwave HEMT and FET transistors, they remain a difficult challenge.

An important problem in dealing with the nonlinear modelling of these devices is their anomalous low frequency behaviour: the quasi-static approach is not fulfilled. The frequency dependence of transconductance and output resistance is due to the origin of this behaviour, trapping, surface state, etc, and implies that the DC characteristics are an over estimation of the device performance. Furthermore, the dynamic characteristics and the transconductance and output resistance are functions of the operation point. Consequently, changes in the equations and/or topology of the device's nonlinear circuit must be accomplished in order to have an accurate description of the transistor behaviour.

The typical way of modelling the nonlinear equation of the channel current is extracting the parameters of this equation from the small signal S parameters in the frequency band of interest at several polarization points (quasi-static approximation) [1]. Another way of obtaining the parameters of this current is using pulsed characteristics [2]. This method is only valid at each operation point and represents a better simulation of the real function of the transistor because it takes into account its real heating.

These methods do not predict a reliable behaviour of low frequency dispersion and DC operation. Recently, several authors have proposed models to solve these problems. A first approximation was to introduce a series resistor-capacitor path parallel with I_{ds} current source [3] and afterwards a more complete models have been developed. These last models change the resistor for a nonlinear current source. This nonlinear equation has similar characteristics to the typical I_{ds} current [4]. These models are able to predict the low frequency dispersion more or less exactly but do not solve the problem of the operation point dependence of the source parameters.

The work proposed in this paper is an exhaustive comparison between the two methods of extracting the nonlinear parameters of the transistor, mainly the I_{ds} equation. We have obtained the complete model of a packaged transistor NE72084 without the breakdown effect because our interest focus is mainly the I_{ds} current. For this purpose, we have developed a continuous and pulsed automatized set up along with a fitting program that permits us to obtain the access resistors R_g, R_s, R_d, the Schottky current parameters I_{ns} and α_s and the parameters of the nonlinear I_{ds} source. We can choose any form of the equation of the drain-source current. Furthermore, we have developed a software program based on the Dambrine [5] and Golio [6] methods that permit us to extract the total linear equivalent circuit measuring the scattering parameters in the 2-8 GHz frequency band at several polarization points in order to obtain the linear elements, the parameters of the nonlinear Schottky capacitor and the quasi-static characteristics.

MDS and SPICE simulations taking into account low frequency dispersion permit comparisons between the model obtained from pulsed measurements and the quasi-static approach and to show the polarization dependence of the output conductance. Experimental measurements of the transistor charged by 50 Ohms at the input and output ports show the agreement of the two different models.

2. NONLINEAR MODELIZATION

a) DC measurements: An automatized set up along with a fitting program permit us to obtain experimental DC measurements to calculate the access resistors R_g, R_s, R_d and the typical Schottky current parameters I_{ns} and α_s.

The R_s measurements are made injecting current by gate port sweeping V_{ds} and measuring V_{gs} and I_{ds}. The same method is used to measure R_d interchanging source for drain. Figure 1 presents experimental results of the R_s measurements for a NE72084 transistor. The R_g measurements are based in the Fukui method [7]. Likewise, the Schottky junction current source is measured injecting current by gate in source common configuration and the drain terminal open-circuit. The experimental results of figure 2 permit the extraction of the nonlinear equation of the Schottky junction current I_{ns} and α_s.

b) Pulsed measurements: In order to measure the continuous and pulsed characteristics of the transistors at any operation point and to obtain the nonlinear parameters of the actually known I_{ds} equations we have developed an automatized experimental set up along with an optimization program capable of fitting the experimental measurements to these nonlinear equations. The technical characteristics of the experimental system are:

- It is possible to control the frequency of the pulses.
- The range of the pulse width varies from 200 ns to 1000 ns.
- It is possible to vary the pulse rise time.
- Voltage ranges are: V_g: -10 volts to +10 volts (50 mA)
  V_d: -30 volts to +30 volts (500 mA)

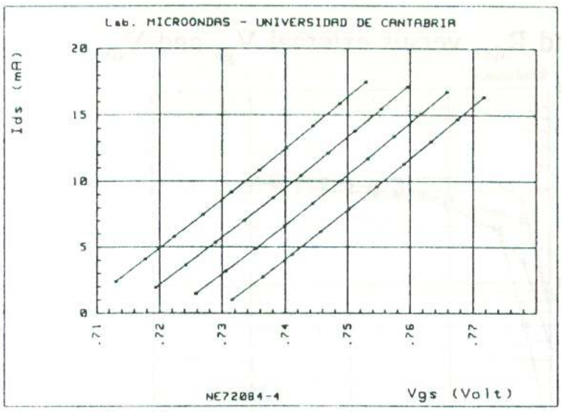

Fig. 1 - R_s measurements

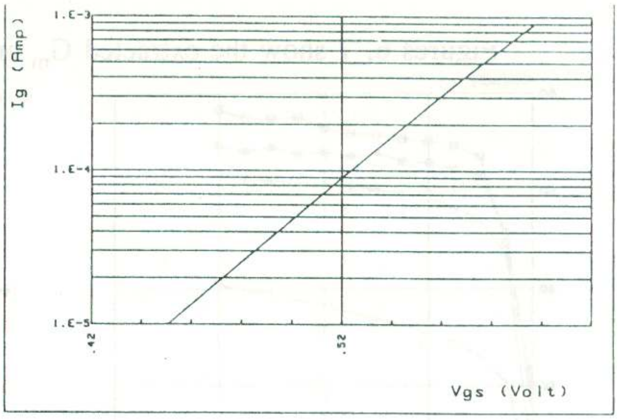

Fig. 2 - I_{gs} measurements

Figure 3 shows the experimental DC characteristics of the NE72084 FET transistor, the V_{gs} range is from -1V to 0.25V. The curves of the figure 4 represent the experimental and fitting results, the V_{gs} range is from -1V to 0V and the operation point is V_{gs}=-0.5V, V_{ds}= 5V. The nonlinear model used has been the quadratic Curtice model [1].

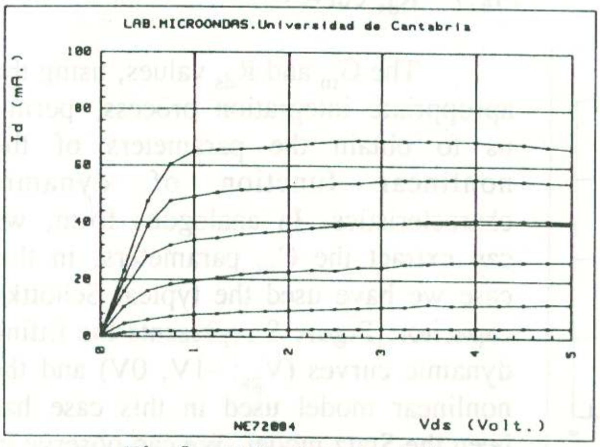

Fig.3 - DC characteristics

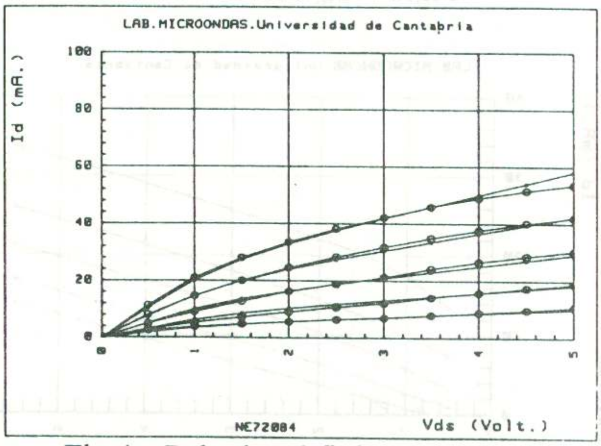

Fig.4 - Pulsed and fitting curves

Fitting   Exp.

c) Linear extraction: The measurements of the scattering parameters permit us to obtain the parameters of the linear equivalent circuits, valid at each operation point. Our interest frequency band has been 2 to 8 GHz. The measurements at several operation points will permit us to obtain the dynamic characteristic curves of the transistor. For this purpose, we have developed a linear extraction program based in the Golio [5] and Dambrine [6] methods modifying the algorithms to reduce the optimization error and also modifying the equivalent circuit to permit the calculation of packaging elements. Figure 5 shows the total linear equivalent circuit. The algorithms of interpolation using splines and the optimization method with constraints permit us to reach errors 50% less than the above mentioned methods.

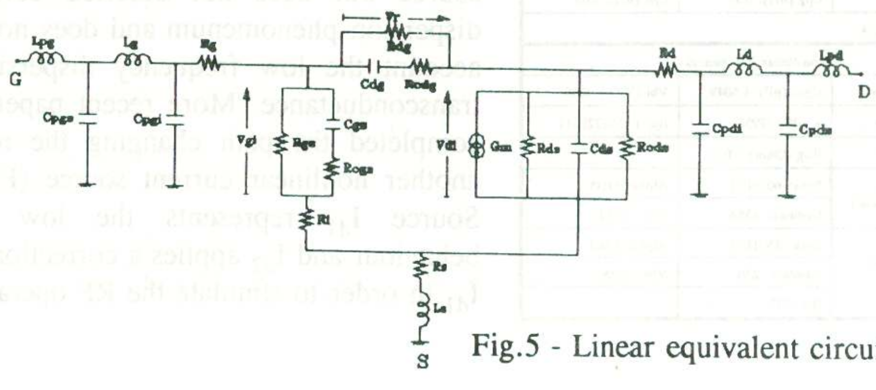

Fig.5 - Linear equivalent circuit

Figures 6, 7 show the extracted G_m and R_{ds}, versus external V_{gs} and V_{ds}.

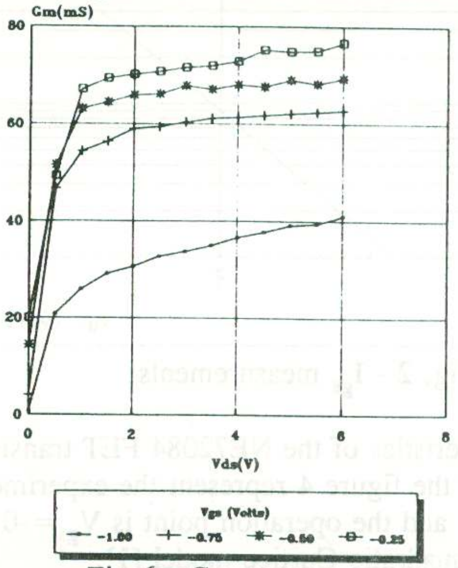

Fig.6 - G_m curves

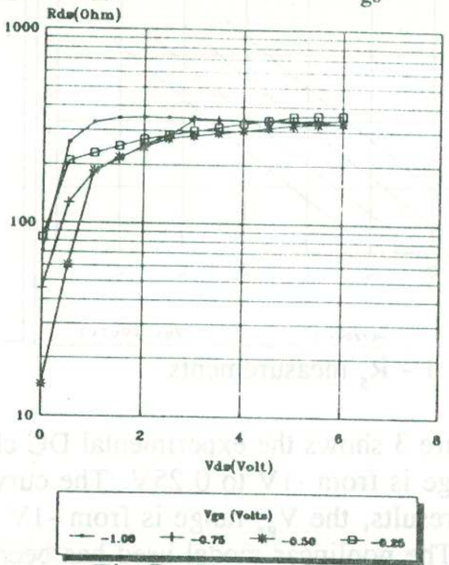

Fig.7 - R_{ds} curves

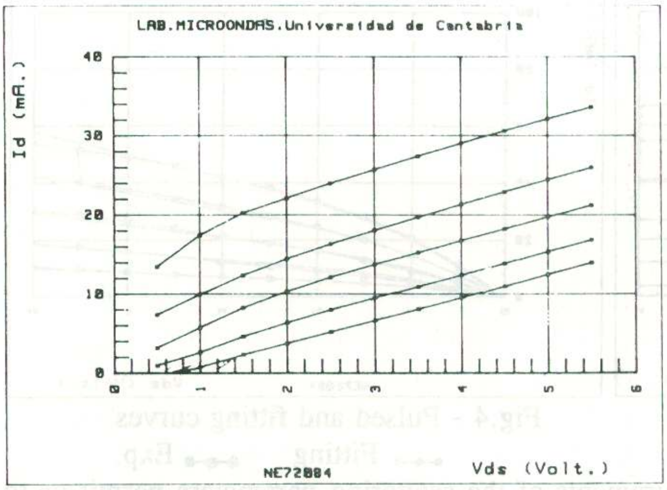

Fig.8 - Dynamic characteristics

The G_m and R_{ds} values, using the aproppriate integration process, permit us to obtain the parameters of the nonlinear function of dynamic characteristics. In analogous form, we can extract the C_{gs} parameters, in this case we have used the typical Schottky capacitor. Figure 8 represents the fitting dynamic curves (V_{gs}: -1V, 0V) and the nonlinear model used in this case has been the Statz model. We can observe in table I the total linear and nonlinear parameters of the transistor.

3. LARGE SIGNAL MODEL WITH LOW FREQUENCY DISPERSION

TABLE I

Linear Parameters		
Rg (Ohm): 4.26	Rd (Ohm): 2.63	Rs (Ohm): 2.62
Lg (nH): .213	Ld (nH): .157	Ls (nH): .037
Cdg (pF): .059	Cds (pF): .123	
Ri (Ohm): 5	Rcgs, Rcdg (Ohm): 0	Rcds (Ohm): 1E10
Package	Cpgs (pF): .067	Cpds (pF): .153
	Lpg (nH): .339	Lpd (nH): .205
Transit time (ps): 4		
Non-linear Parameters		
Cgs Schottky	Cgso (pF): 1.5049	Vbi (Volt.): .588
Igs Schottky	α_s: 30.477958	Ins: 1.155222E-11
Idg Linear	Rdg (Ohm): 1E10	
Ids Pulsed (Curtice Quadratic)	Beta: .6050E-2	Alpha: 1.035
	Lambda: .4554	Vto: -1.712
Ids Quasi-Static (Statz)	Beta: .1501E-1	Alpha: 1.387
	Lambda: .238	Vto: -1.506
	B= .033	

The most simple form of representing the low frequency dispersion is introducing a series resistor-capacitor path parallel to I_{ds} current [3]. Certainly this model is more exact than the static and quasi-static approaches with a simple current source but does not describe correctly R_{ds} dispersion phenomenum and does not take into account the low frequency dispersion of the transconductance. More recent papers [4] have completed the path changing the resistor for another nonlinear current source (Fig. 9). Source I_{d1} represents the low frequency behaviour and I_{d2} applies a correction to source I_{d1} in order to simulate the RF operation.

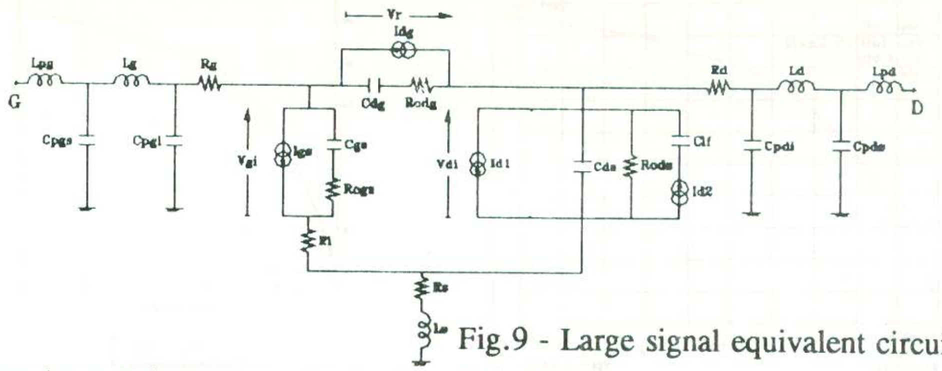

Fig.9 - Large signal equivalent circuit

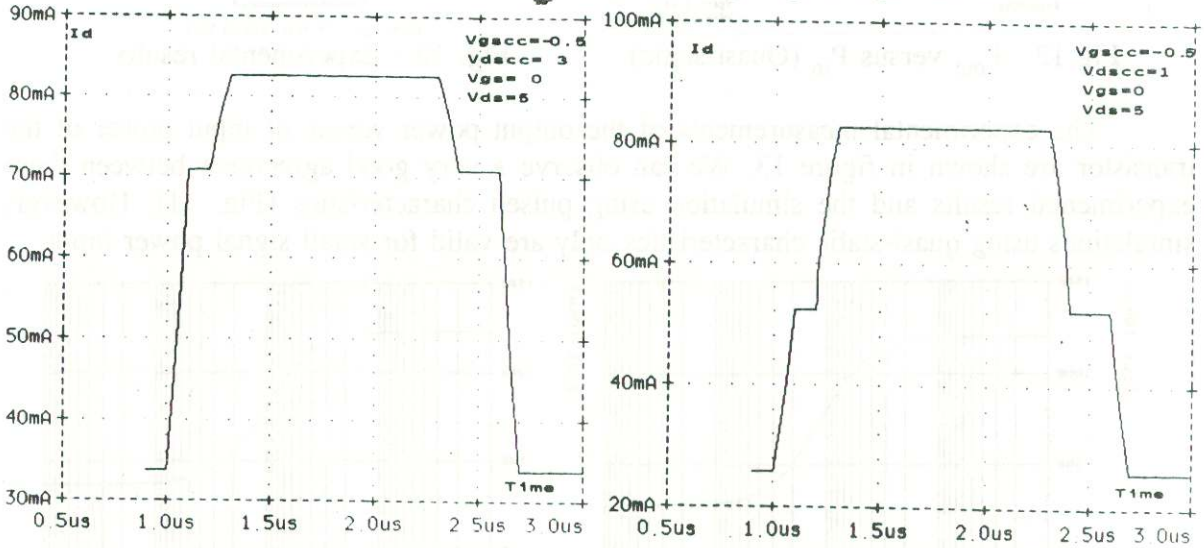

Fig.10 - Pulsed simulation

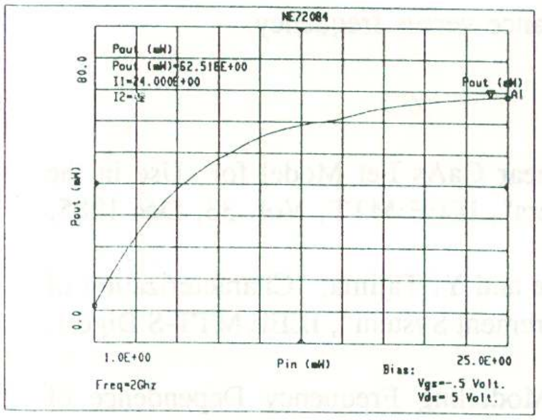

Fig.11 - P_{out} versus P_{in} (Pulsed)

Unfortunately, this model is not able to predict the operation point dependence. The quasi-static characteristics extracted from the S parameters at several bias points will only be valid around each operation point and the pulsed characteristics will only simulate the large signal behaviour in the same repose point of the measurements. To demonstrate that, we have simulated in the SPICE program a pulsed bank using the nonlinear equivalent circuit the figure 9 without the breakdown effect and linearizing the Schottky junction. The model used for the two sources has been Curtice quadratic. Fig.10 shows the same I_{ds} results for two different operation points.

4. SIMULATIONS AND EXPERIMENTAL RESULTS

In this part, we have made comparisons between the quasi-static approximation and the pulsed measurements. We can observe the operation point dependence of the output conductance. The simulations were carried out in MDS simulator program in 2-8 GHz frequency band and the operation point was V_{gscc}=-0.5V, V_{dscc}= 5V. Figure 11 represents the power output versus power input for a NE72084 FET transistor at 2GHz with 50 Omhs in the input and output ports using pulsed characteristics and figure 12 shows the same simulation but using the quasi-static curves. Figures 14 show the simulation of the real part of the output impedance at two different bias. We can observe the differences between them.

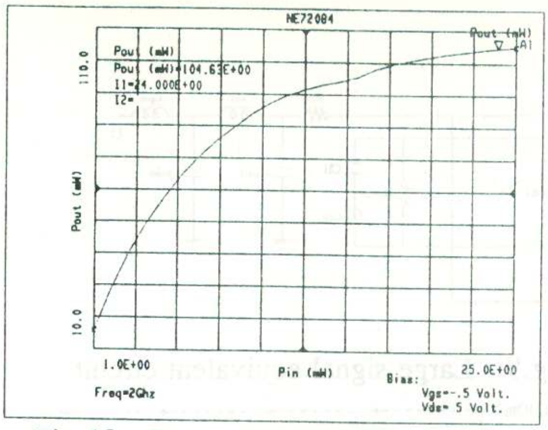

Fig.12 - P_{out} versus P_{in} (Quasi-static)

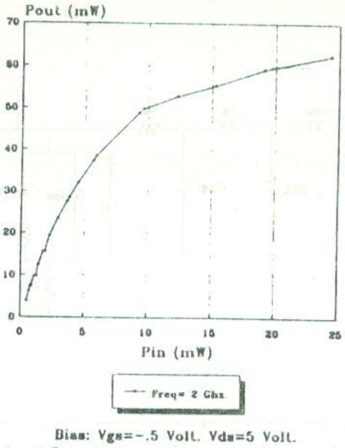

Fig. 13 - Experimental results

The experimental measurements of the output power versus of input power of the transistor are shown in figure 13. We can observe a very good agreement between these experimental results and the simulation using pulsed characteristics (Fig. 11). However, simulations using quasi-static characteristics only are valid for small signal power input.

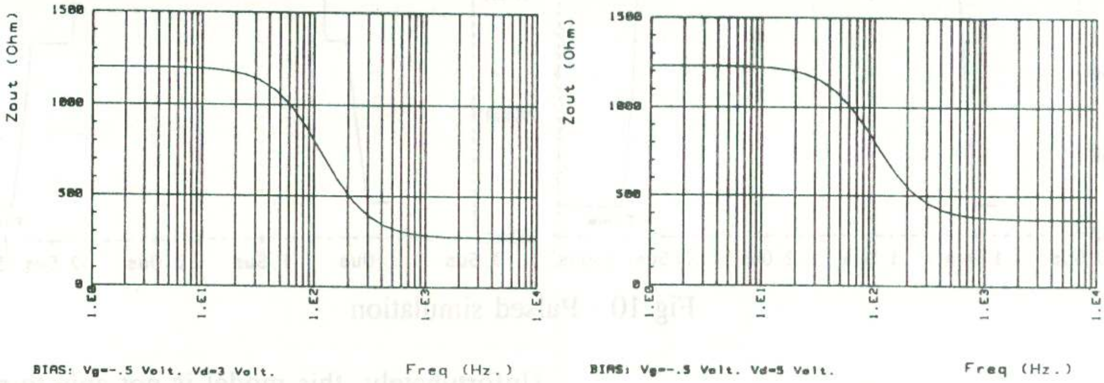

Fig.14 - Real part of the output impedance versus frequency.

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