Large Signal Model for Analysis and Design of HEMT Gate Mixer

R. Allam, C. Kolanowski, D. Theron, and Y. Crosnier

Abstract— **This paper examines the problem of modeling HEMT's for calculations of conversion gain and intermodulation. An accurate and simple large signal model of discrete HEMT's has been developed. The nonlinear elements of the model are assumed to depend exclusively on the gate-source voltage. The interpolation of the measured data, using polynomial expressions, provides a description of the HEMT's nonlinearities in a CAD software. Based on the model, a hybrid HEMT gate mixer has been built. The accuracy of the model has been verified, and we obtained good agreement between the measured and simulated results.**

I. Introduction

The GATE mixer is an attractive configuration for millimeter wave HEMT mixers because it requires low LO level and provides conversion gain. Recently, the analysis of microwave nonlinear networks has been of great interest. Different empirical models have been developed by many authors [1]–[3] for the simulation of HEMT's in nonlinear circuits. These models are used to predict gain, intermodulation, noise, etc., for circuits such as amplifiers, mixers, and multipliers. However, a single model is unable to properly describe all of these various circuits. In this investigation, a simple nonlinear model is presented for gate mixer based on its specific working type.

This model is based on the experimental values of the dynamic parameters measured in the microwave frequency range. The Dambrine procedure [4] is used to determine the transconductance, output conductance, and gate-source capacitance at different biasing conditions. These elements are extracted from S parameters measured in the 1–40 GHz range. Then, they are used for the determination of nonlinear microwave model.

II. The Nonlinear Model

It is directly derived from the microwave small signal equivalent circuit and takes into account as main nonlinearities: the drain current generator I_{DS} (transconductance G_m and output conductance G_d) and the gate-source capacitance C_{GS}. The other circuit elements are assumed to be linear. The equivalent circuit of the HEMT is shown in Fig. 1. Most conventional nonlinear characterizations are based on the DC measurements of the drain current I_{DS} as a function of the drain-source V_{DS} and the gate-source V_{GS} bias voltages. This method is not satisfactory because thermal and trap effects may modify the microwave behavior of the HEMT.

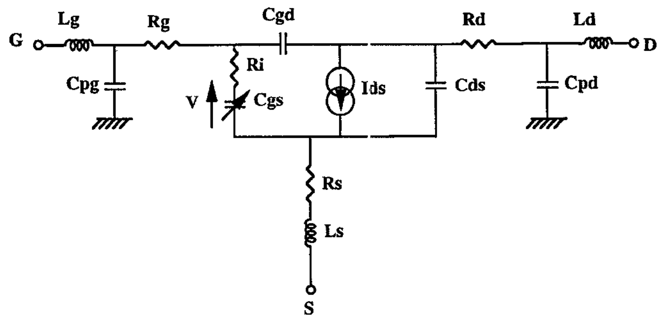

Fig. 1. Nonlinear model used.

In the gate mixer, the RF and LO signals are applied to the gate and the IF frequency is taken from the drain. The gate is usually biased near its turn-on voltage. The drain is biased in saturation regime. In the gate mixer, the profile of the transconductance versus V_{GS} is the dominant factor in the frequency conversion process. In this configuration, the drain is usually short circuited for the LO and RF frequencies and senses only the IF. As a consequence the voltage variations at this electrode are very small and V_{DS} remains very close to the quiescent value V_{DS0}. For that reason, the nonlinear elements of the model may be assumed to depend exclusively on V_{GS}. Based on this assumption, the nonlinearities are defined as follows: The drain current function is

$$I_{\mathrm{DS}} = \int_{V_p}^{V_{\mathrm{GS}}} G_m(V_{\mathrm{GS}}, V_{\mathrm{DS0}})dV_{\mathrm{GS}} + G_d(V_{\mathrm{GS}}, V_{\mathrm{DS0}}) \times [V_{\mathrm{DS}} - V_{\mathrm{DS0}}] \tag{1}$$

where

V_{GS}: internal gate voltage
V_{DS}: internal drain voltage
V_{DS0}: quiescient internal drain voltage
V_{P}: internal pinch-off gate voltage

$G_m(V_{\mathrm{GS}}, V_{\mathrm{DS0}})$, $G_d(V_{\mathrm{GS}}, V_{\mathrm{DS0}})$ are the RF transconductance and RF output conductance determined from the device measurements. We described $G_m(V_{\mathrm{GS}}, V_{\mathrm{DS0}})$ and $G_d(V_{\mathrm{GS}}, V_{\mathrm{DS0}})$ by using polynomial expressions. The polynomial order is chosen to give the best fit with the measured values:

$$G_m(V_{\mathrm{GS}}, V_{\mathrm{DS0}}) = (a_0 + a_1 \times V_{\mathrm{GS}} + a_2 \times V_{\mathrm{GS}}^2 + \cdots a_n \times V_{\mathrm{GS}}^n)F(V_{\mathrm{GS}}) \tag{2}$$

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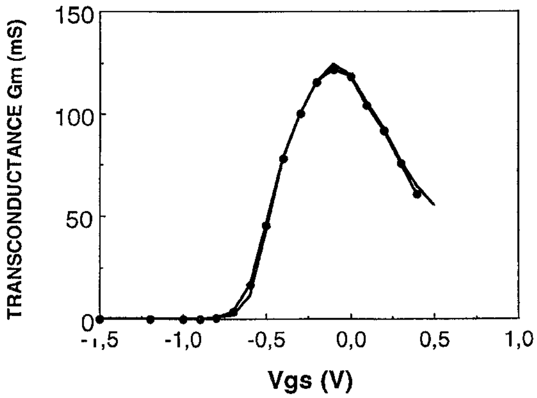
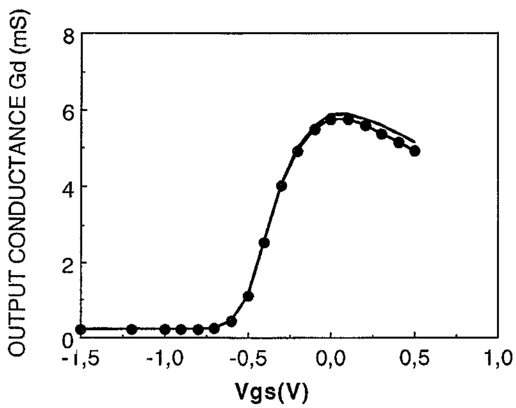
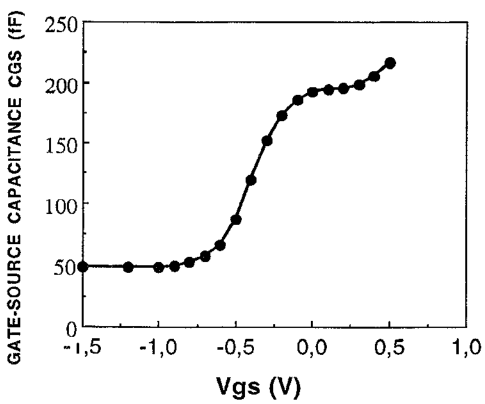


(a)



(b)



(c)

Fig. 2. Comparison between measured (—•—) and modeled (—) nonlinearities data as a function of gate voltage for: (a) transconductance, (b) output conductance, and (c) gate-source capacitance.

$$G_d(V_{\rm GS}, V_{\rm DS0}) = (b_0 + b_1 \times V_{\rm GS} + b_2 \times V_{\rm GS}^2 + \cdots b_n \times V_{\rm GS}^n)F(V_{\rm GS}) \quad (3)$$

Attention must be paid to the fact that these polynomial representations have to be quasi constant below the pinch-off gate voltage V_p. This is achieved owing to the function $F(V_{\rm GS})$:

$$F(V_{\rm GS}) = 0.5 \times [1 + \mathrm{TANH}((V_P - V_{\rm GS}) \times 40] \quad (4)$$

TABLE I
CONSTANT PARAMETERS OF THE PM HEMT

Rg	Rd	Rs	Ri	Lg	Ld	Ls	Cgd	Cds	Cpg	Cpd
1.2Ω	5.7Ω	3.8Ω	2.5Ω	65pH	60pH	5pH	34fF	15fF	15fF	25fF

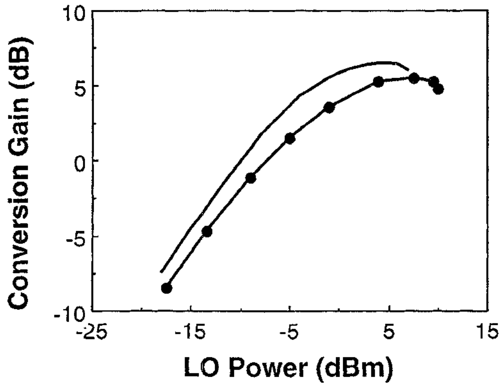


Fig. 3. Gate mixer conversion gain as a function of local oscillator power: simulated (—) and measured (—•—).

The gate charge is modeled by

$$Q_{\rm GS} = \int_{V_p}^{V_{\rm GS}} C_{\rm GS}(V_{\rm GS}, V_{\rm DS0})dV_{\rm GS} + K \times V_{\rm GS} \quad (5)$$

with

$$C_{\rm GS}(V_{\rm GS}, V_{\rm DS0}) = (c_0 + c_1 \times V_{\rm GS} + c_2 \times V_{\rm GS}^2 + \cdots c_n \times V_{\rm GS}^n)F(V_{\rm GS}) \quad (6)$$

where K corresponds to the constant value of $C_{\rm GS}$ below pinchoff and $C_{\rm GS}$ ($V_{\rm GS}$, $V_{\rm DS0}$) is determined from the characterization of the device.

III. Verification of Large Signal Model

This nonlinear modeling was applied to the gate mixer design. The LO, RF, and IF frequencies chosen for this test were 24.5, 28.5, and 4 GHz, respectively. The device was a 0.25-μm-gate-length pseudomorphic HEMT from DAIMLER-BENZ with six fingers of 20 μm each. The constant parameters of the PM HEMT model are listed in Table I. Comparisons between the measured and simulated transconductance, output conductance, and gate-source capacitance are shown in Fig. 2. A good fit is observed. The RF and LO combination was realized externally by means of a coupler. The HEMT input was matched to 50-Ω the RF and LO frequencies. The output load was a resistor close to 100 Ω at the IF frequency and a short circuit for LO and RF frequencies. The circuit was designed with a harmonic balance simulator MDS by Hewlett-Packard. Simulation results are presented and compared to the measured data in Figs. 3 and 4, where we can find satisfactory agreement.

IV. Conclusion

In this paper, an improved large signal model for HEMT gate mixer is presented. The model has been used to predict

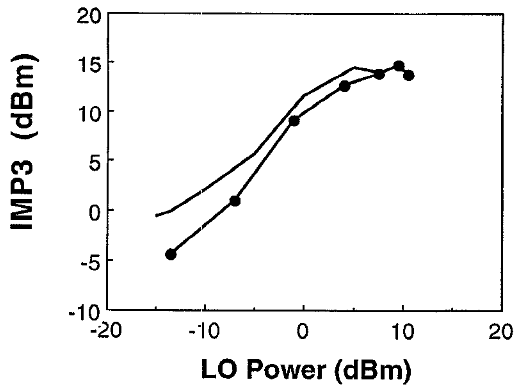


Fig. 4. Comparison between simulated (—) and measured (—•—) output third-order intermodulation product.

the conversion gain and third-order intermodulation versus LO power. The suitability of the model has been verified by excellent agreement between the measured and simulated performances. The model can be also applied to many other FET structures: GaAs MESFET, Multi-Channel HEMT's, ... etc.

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