ACCURATE NONLINEAR RESISTIVE FET MODELING FOR IMD CALCULATIONS

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ABSTRACT

This work discusses the nonlinear modeling procedures required for intermodulation distortion (IMD) calculations of MESFETs biased in the resistive (linear) region. An automatic full two-sided characterization of Ids(Vgs,Vds) is compared against the previously published extraction of Ids(Vds) in this problematic region. It is shown that this one-sided Taylor series extraction is insufficient for most applications of the FET in its triode zone, and thus an alternative method is proposed.

INTRODUCTION

In a now classic paper [1] Maas proposed the GaAs MESFET as an appropriate device for RF and microwave mixing applications, when it is biased in the so-called "linear" or triode zone. The fundamental argument is the high linearity (e. g. low intermodulation distortion, IMD) that can be obtained if the FET's gate controlled resistor-like operation is used in resistive mixers or MESFET switches. However, soon it was recognized that the device's "linear" zone was not so linear as it was ideally expected, which motivated the publication of a method for an IMD model extraction [2],[3]. That model assumes that, in the triode zone, the bi-dimensional nature of drain source current, Ids(Vgs,Vds), can be approximately ignored and thus only the dependence of Ids on the output voltage, Vds, was characterized.

The main objective of this paper is to show that this oversimplified modeling procedure is insufficient for many applications, and to propose a complete set-up that enables the full Taylor series Ids(Vgs,Vds) coefficients independent extraction.

ACCURATE NONLINEAR CHARACTERIZATION

To study the impact of the various Ids(Vgs,Vds) Taylor series coefficients on the IMD performance of the MESFET voltage controlled channel resistance, we started by the general connection topology represented in Fig. 1. In cold FET mixers [1], [3], [4], the device is connected in a common source configuration with $I_1(\omega)=0$ ($I_2(\omega)$ plays the role of local oscillator). In FET bi-directional switches the channel resistance is either used in series (common gate configuration with $I_2(\omega)=I_3(\omega)=0$ or $I_2(\omega)=I_1(\omega)=0$), or in parallel (common source configuration with $I_2(\omega)=I_1(\omega)=0$) [2].

In the case that will be analyzed next, the MESFET is under characterization and mounted in a common source configuration, driven at the gate and drain terminals. Therefore, $I_1(\omega)=0$, and $Y_1(\omega)$ is simply composed by the device's source parasitics.

It is assumed that in the quiescent point (two fixed DC values for MESFET switches and a time varying bias point for MESFET mixers) Ids(Vgs,Vds) can be expanded in a Taylor series as:

$$\begin{aligned} Ids(Vgs,Vds) &= Ids_{DC} + Gm.vgs + Gds.vds + Gm2.vgs^2 + Gmd.vgs.vds + Gd2.vds^2 + \\ &+ Gm3.vgs^3 + Gm2d.vgs^2.vds + Gmd2.vgs.vds^2 + Gd3.vds^3 + \ldots \end{aligned} \quad (1)$$

In this way, and applying the Nonlinear Currents Method of Volterra series [5], to the multi-port circuit of Fig. 1, it can be shown that 1st order control voltages are:

$$Vgs^{(1)}(\omega) = Z_{42}.I_2(\omega_1) + Z_{43}.I_3(\omega_2) \quad (2)$$

$$Vds^{(1)}(\omega) = Z_{52}.I_2(\omega_1) + Z_{53}.I_3(\omega_2) \quad (3)$$

(where Z_{ij} are various impedance parameters that were used to describe the network), and thus 2nd order drain currrent at $(2\omega_2)$ is given by:

$$Ids^{(2)}(2\omega_2) = [Z_{43}^2.Gm2 + Z_{43}.Z_{53}.Gmd + Z_{53}^2.Gd2] \,.\, I_3(\omega_2)^2 \quad (4)$$

while 3rd order drain current component at $(3\omega_2)$ is:

$$\begin{aligned} Ids(3\omega_2) &= [Z_{43}^3.Gm3 + Z_{43}^2.Z_{53}.Gm2d + Z_{43}.Z_{53}^2.Gmd2 + Z_{53}^3.Gd3] \,.\, I_3(\omega_2)^3 + \\ &+ [2.Gm2.Vgs(2\omega_2).Vgs(\omega_2) + Gmd.Vgs(2\omega_2).Vds(\omega_2) + \\ &+ Gmd.Vgs(\omega_2).Vds(2\omega_2) + 2.Gd2.Vds(2\omega_2).Vds(\omega_2)] \end{aligned} \quad (5)$$

Since, for Vds=0, Ids=0 independent of Vgs, all drain current derivatives in respect to Vgs must also be zero: Gm=Gm2=Gm3=0. However, as long as cross dependence of Ids on Vgs and Vds is concerned, nothing similar can be said, and so Gmd, Gm2d and Gmd2 should, in principle, be expected to present non null values. Therefore, the previously published model extraction procedure is implicitly neglecting Z_{43}.Gmd in comparison to Z_{53}.Gd2 in 2nd order Ids (4) and neglecting $[Z_{43}^2.Gm2d + Z_{43}.Z_{53}.Gmd2]$ in comparison to Z_{53}^2.Gd3 in 3rd order Ids (5).

There are at least two reasons to discuss these approximations. First, since a cold FET mixer is recognized to be reasonably linear for RF $[Vds(\omega_2)^n \approx 0]$ but still presents a useful frequency conversion efficiency $[Vgs(\omega_1).Vds(\omega_2) \neq 0]$, it should not be expected that Gd2 (output nonlinearity) dominates 2nd order distortion performance over Gmd (input-output nonlinearity), nor Gd3 over Gm2d and Gmd2. In fact, since Gmd can be defined as the derivative of Gds in respect to Vgs, it is the coefficient of (1) that describes (in a weak nonlinearity sense) the channel resistance control imposed by Vgs, exactly the phenomenon used in a resistive FET mixer.

And second, at VHF, where such a model is usually extracted, the device is almost unilateral, except for the current-series feedback created by the parasitic MESFET source resistance, Rs. Thus, Z_{43} represents the gate voltage developed by channel current in Rs. On the other hand, Z_{53} represents the voltage developed across the channel resistance, Rds=1/Gds, and so Z_{43}/Z_{53} should present a similar ratio to Rs/Rds. At $V_{DS}=0$ Rds is only a few ohms, and so it is not clear that $Z_{43} << Z_{53}$.

EXPERIMENTAL RESULTS

To prove these qualitative arguments, a 6x50μm MESFET from a GEC Marconi F20 process wafer was fully characterized in its triode and saturated regions using an automatic double sided set-up, based on the one proposed in [6]. Measured values of Gds, Gmd, Gd2, Gm2d, Gmd2 and Gd3 for $-2.3V<V_{GS}<0V$ and $V_{DS}=0$ are presented in Fig. 2 and Fig. 3.

For comparison purposes, Fig. 2 also shows Gd2 and Gd3 coefficients that would be obtained with the previous one-sided simplified approach.

The obvious differences between the Gd2 and Gd3 pairs seen in Fig. 2 are really a measure of the impact of all other coefficients. Since, in a practical application, embedding device admitances, and transimpedance gains between ports, are much different from the conditions used for model extraction (e. g. microwave frequencies against VHF used in the set-up, or unmatched input/output terminations) the use of only Gd2 and Gd3 to predict cold FET IMD behavior would be very inaccurate. This clearly justifies the need for the now proposed complete resistive FET two-sided characterization procedure.

CONCLUSIONS

The one-sided Taylor series characterization for the drain source nonlinear current has been proven to be inaccurate for IMD prediction on FET devices in cold operation. A complete two-sided description, able to include the important cross terms, has been suggested to properly evaluate the small-signal nonlinear behaviour of these devices in this problematic region; giving us the possibility of correctly describing important applications such as resitive mixers, switches, etc.

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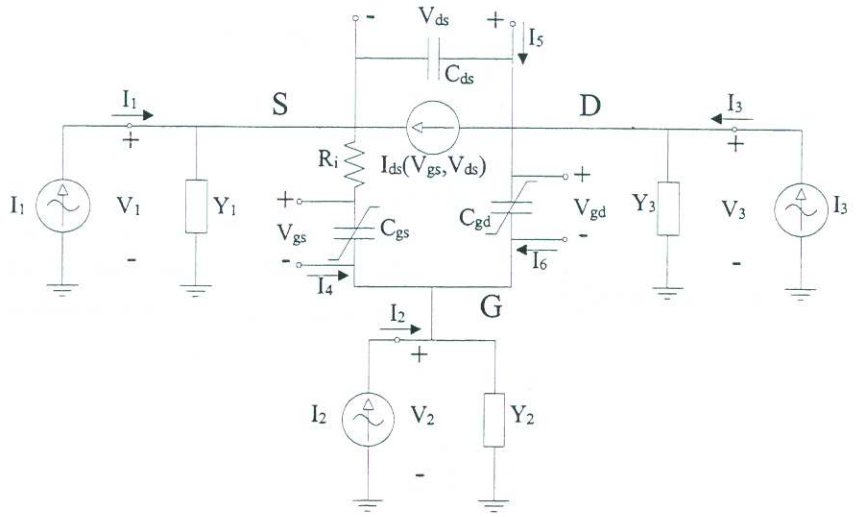

Fig. 1 - Equivalent circuit model of general FET topology.

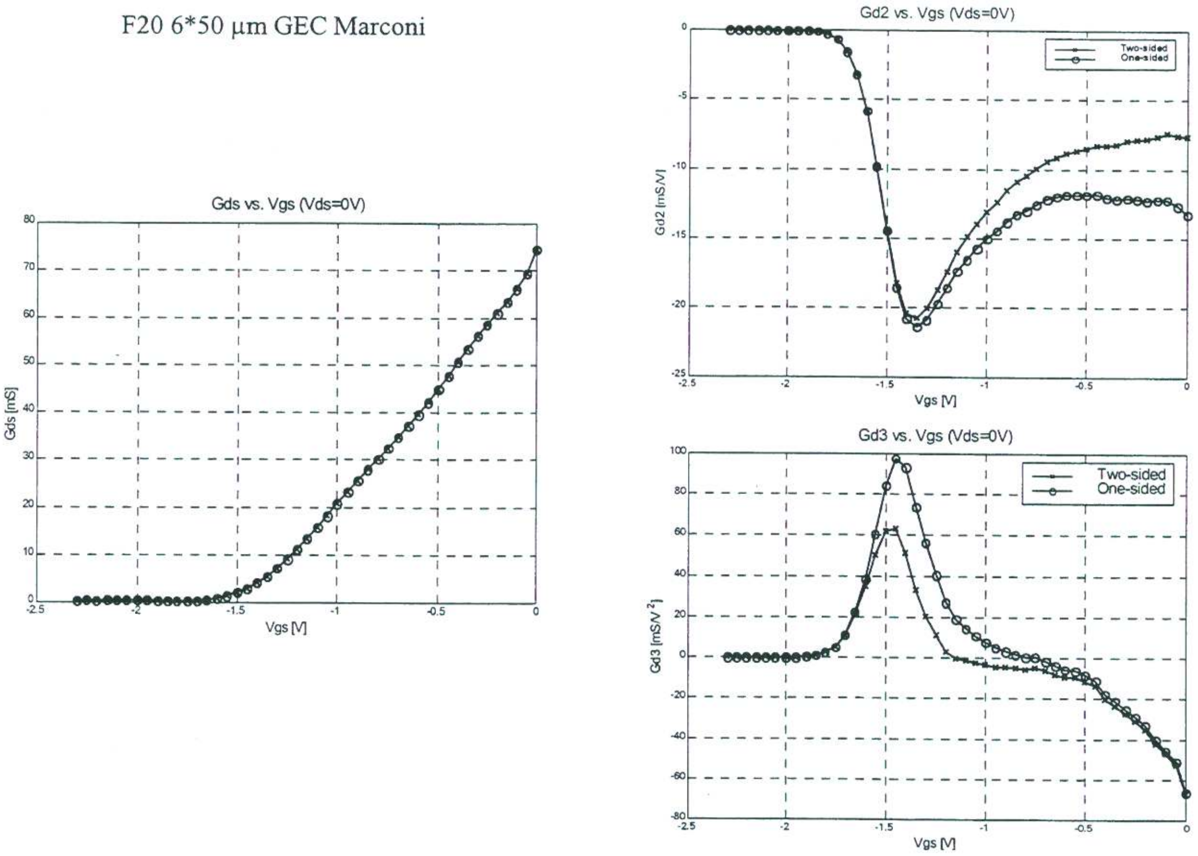

Fig. 2 - Extracted Gds, Gd2 and Gd3 for the one-sided and two-sided characterizations @ $V_{DS}=0$ and $-2.3V<V_{GS}<0V$.

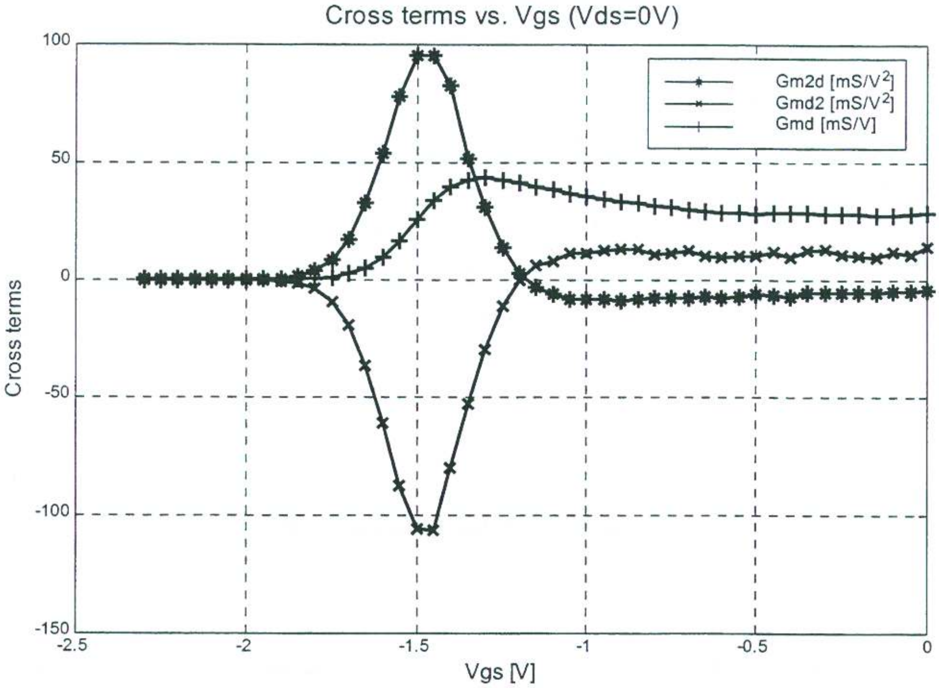

Fig. 3 - Extracted Gmd, Gm2d and Gmd2 @ $V_{DS}=0$ and $-2.3V<V_{GS}<0V$.