CHARACTERIZING THE GATE TO SOURCE NONLINEAR CAPACITOR ROLE ON FET IMD PERFORMANCE

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ABSTRACT

This paper discusses the gate to source nonlinear capacitor contribution on small signal intermodulation distortion (IMD) performance of FET devices. The second and third order coefficients for the Cgs(Vgs) Taylor-series expansion, experimentally extracted with a simplified one-sided version of our previously proposed test set-up, are shown to be responsible for some detected differences on IMD behavior at high frequencies.

INTRODUCTION

It has been accepted as a law in [1], that reproducing the small-signal second and third order IMD on a FET is only possible if its model not only describes the nonlinear I/V and Q/V characteristics, but also their respective derivatives up to the same order. As a mild nonlinear device, either successive numeric differentiations or least squares fittings of the commonly measured characteristics have been proved to be inadequate for extracting these derivatives. Maas et al. solved this problem in [2] and [3] for the predominant nonlinearity, Ids(Vgs), with a direct and simple technique based on harmonic measurements at drain side, an effective procedure later extended in [4] for the complete bidimensional Ids(Vgs,Vds) Taylor-series expansion. The reported experimental extractions have permitted to evaluate the Ids equations for IMD purposes since then, and have led to important conclusions on bias and load control for low nonlinear distortion. The reactive nonlinearities have been considered of secondary or minor effect; however, not disposing of a procedure for extracting their power-series terms has determined the nowadays incapacity for evaluating the extent of its minor role as it has been recently considered in [5].

In this paper we intend to show the accurate role Cgs(Vgs) nonlinear capacitor plays on IMD performance in the saturated region, extracting its second and third order Taylor-series coefficients versus Vgs through a simplified procedure of the one recently proposed in [6] for the complete bidimensional Qg(Vgs,Vgd) expansion. The modified test set-up, its corresponding direct formulation, and the solution to the detected problems in [7] for the region where the Cgs(Vgs) relative importance is too small, conforms a trustful technique for getting its second and third order derivatives and analyzing its responsibility, along with Ids(Vgs,Vds), in the IMD performance versus bias and load at high frequencies, something reported in previous significant works [8] and [9]. The proposed extracting procedure has been thought as a complementary step in the small-signal nonlinear description of FET devices.

CHARACTERIZATION PROCEDURE

We consider the nonlinear currents topology for the widely accepted equivalent circuit of Fig. 1 where Cgs(Vgd) dependence is not taken into account, and Cgd is assumed linear, a common practice for applications in the saturated region. Having made a previous extraction either of Maas transconductance description or Pedro complete Ids expansion, the Taylor-series coefficients for Cgs(Vgs),

$$\mathrm{Cgs(Vgs)} = \mathrm{Cgs1} + 2.\mathrm{Cgs2.vgs} + 3.\mathrm{Cgs3.vgs}^2 \qquad (1)$$

can be extracted from second and third harmonic measurements in gate with the help of a test set-up as the one shown in Fig. 2. The second and third harmonic amplified power levels are referred to the first harmonic reflected power level via the directional coupler, in order to define two IMD ratios. With these ratios, we can determine the absolute values for the second and third order nonlinear transfer functions $H_2(\omega1,\omega1)$ and $H_3(\omega1,\omega1,\omega1)$ relating the phasors for the second and third order harmonic components of the gate current to the excitation phasor as it is shown below,

$$|H_2(\omega1,\omega1)| = \frac{|\mathrm{Is}(2\omega1)|}{|\mathrm{Vs}(\omega1)|^2 / 2} = |\mathrm{Yin}(\omega1)|.\sqrt{\frac{\mathrm{IMR}(2\omega1)}{2.\mathrm{Pavs}(2\omega1).\mathrm{Re}\{\mathrm{Zs}(2\omega1)\}}} \qquad (2)$$

$$|H_3(\omega1,\omega1,\omega1)| = \frac{|\mathrm{Is}(3\omega1)|}{|\mathrm{Vs}(\omega1)|^3 / 4} = \frac{|\mathrm{Yin}(\omega1)|}{2.\mathrm{Pavs}(\omega1)}.\sqrt{\frac{\mathrm{IMR}(3\omega1)}{\mathrm{Re}\{\mathrm{Zs}(\omega1)\}.\mathrm{Re}\{\mathrm{Zs}(3\omega1)\}}} \qquad (3)$$

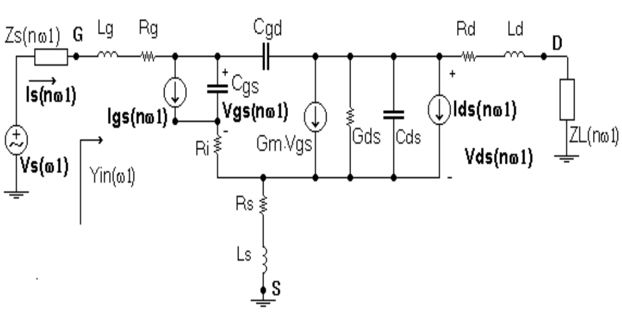


Fig. 1 - Nonlinear currents topology for a saturated FET.

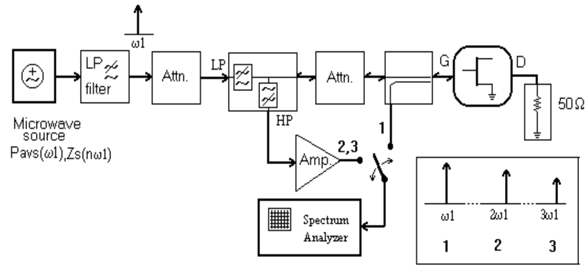


Fig. 2 – Test set-up for Cgs(Vgs) characterization.

These second and third order nonlinear transfer functions are easily related to the second and third order coefficients of both nonlinearities through Volterra-series analysis, and let us extract Cgs2 once we know Gm2, Gmd and Gd2 (or simply G2 for Maas extraction) as we show in (4),

$$\mathrm{Cgs2} = \frac{\left\{ \begin{array}{l} |H_2(\omega1,\omega1)|.\angle\alpha_2(\omega1,\omega1) - K_{\mathrm{Isds}}(2\omega1). \\ .\left[K^2_{\mathrm{Vgs}}(\omega1).\mathrm{Gm2} + K_{\mathrm{Vgs}}(\omega1).K_{\mathrm{Vds}}(\omega1).\mathrm{Gmd} + K^2_{\mathrm{Vds}}(\omega1).\mathrm{Gd2}\right] \end{array} \right\}}{j.2.\omega1.K_{\mathrm{Isgs}}(2\omega1).K^2_{\mathrm{Vgs}}(\omega1)} \qquad (4)$$

where from the first order equivalent circuit, and applying linear circuit analysis techniques,

$$K_{\mathrm{Vgs}}(\omega1) = \mathrm{Vgs}(\omega1) / \mathrm{Vs}(\omega1) \qquad K_{\mathrm{Vds}}(\omega1) = \mathrm{Vds}(\omega1) / \mathrm{Vs}(\omega1)$$

and for the second order one,

$$K_{\mathrm{Isds}}(2\omega1) = \mathrm{Is}(2\omega1) / \mathrm{Ids}(2\omega1)\Big|_{\mathrm{Igs}(2\omega1)=0} \qquad K_{\mathrm{Isgs}}(2\omega1) = \mathrm{Is}(2\omega1) / \mathrm{Igs}(2\omega1)\Big|_{\mathrm{Ids}(2\omega1)=0}$$

In an analogous way, Cgs3 can be extracted with the previous knowledge of Gm3, Gm2d, Gmd2 and Gd3 (G3 for the one-sided case), and all the second order coefficients.

EXPERIMENTAL EXTRACTION AND SIMULATION RESULTS

The extracted Cgs2 and Cgs3 for a MESFET NE72084 are shown in Fig. 3 for Vds=3V and -2 < Vgs < 0V. It can be appreciated that Cgs2 ≅ 0.5*dCgs1/dVgs, and Cgs3≅ 0.33*dCgs2/dVgs even for Vgs near 0V where their relative contribution is the smallest. We detected that a careful extraction of Rs is the key for a successful Cgs characterization, and that some important remarks derived from quasilinear analysis could give us a complementary technique for extracting the extrinsics.

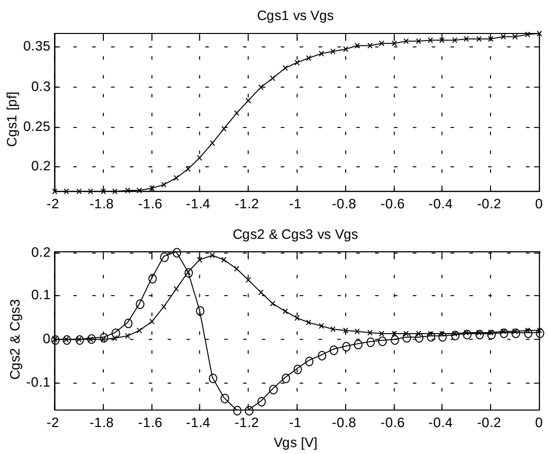


Fig. 3 - Extracted Cgs1, Cgs2 (x) and Cgs3 (o) for V_{DS}=3V and -2V<V_{GS}<0V

These results confirm the exponential nature of FET behavior near pinch-off and the expected incapacity of the classical Schottky junction capacitance equation for reproducing the derivatives and thus characterizing this nonlinearity for IMD purposes.

In Fig. 4 we show the evolution of the carrier to third order intermodulation ratio (C/I) with frequency and Vgs for a 50 ohm load, for both Cgs linear and nonlinear; confirming the growing significance of Cgs(Vgs) IMD role when the frequency increases in the microwave region and certain bias shift of the sweet spot (the relevant peak for Vgs in the high gain region, valid for low distortion designs). The highest value in Fig. 4(b) corresponds to the strongest cancellation between the 3ωo load current components due to Ids and Cgs nonlinearities.

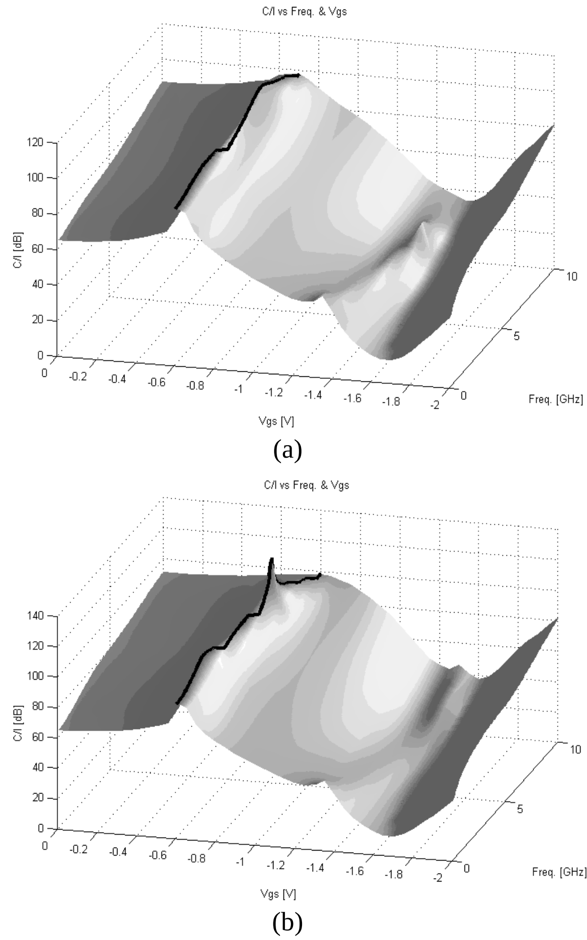
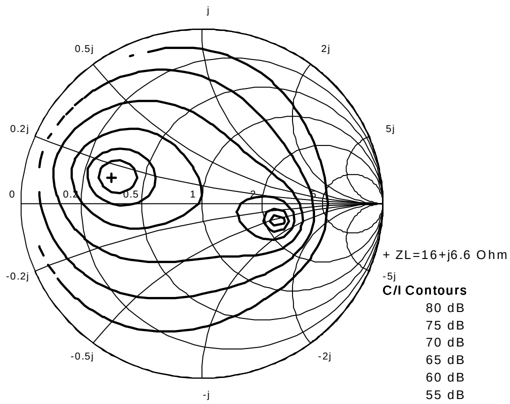


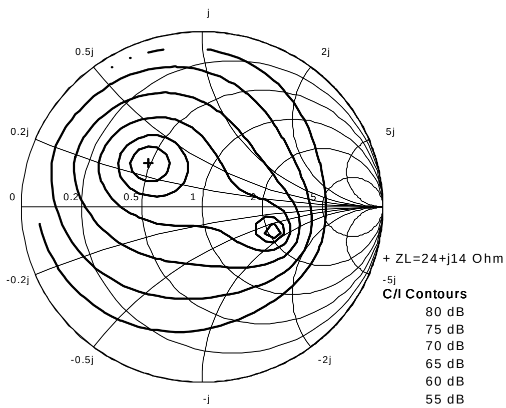
Fig. 4 - C/I behavior vs. Frequency and Vgs for one tone excitation. Vds=3V.(a) Cgs linear.(b) Cgs nonlinear.

The simulated C/I load-pull contours in Fig. 5 for the complete Ids(Vgs,Vds) expansion with Cgs either linear or nonlinear, gives us some further insight into its IMD role with load condition control. Both, the output impedance at the fundamental frequency for maximum C/I and the circles, undergo some rotation, sometimes difficult to be corrected experimentally, even at a frequency not too high.

The Cgs derivatives in the saturated region are expected to provide us with additional tools for source-pull second harmonic control of small-signal IMD, not only in amplifiers but also in active gate mixers, something to be shown in future works both with simulations and experiments. Other nonlinear phenomena, as AM/PM conversion, could also have a better description.



(a)



(b)

Fig.5 -C/I Load-Pull Contours (Two tones: f1=2, f2=2.01GHz) Vds=3V,Vgs=-0.2V. (a) Cgs linear and (b) Cgs nonlinear

CONCLUSIONS

In this paper, the experimentally extracted second and third order derivatives for Cgs(Vgs) in a MESFET are used in Volterra simulations to prove its increasing role on FET IMD performance with frequency. These derivatives will provide the designers with the capability of evaluating how the small-signal nonlinear distortion due to this nonlinearity is described by either the existing or new models, as well as an improvement in the load or source-pull control (at the fundamental and harmonics) for IMD cancellation purposes.

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