A New Ids Large Signal Continuous Model For HEMT Devices Valid Under Static and Dynamic Conditions

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ABSTRACT

The solution to the problem of transconductance compression in HEMT devices can be found by means of a new continuous drain-source current (I_{ds}) model. The proposed model is able to reproduce the global I/V device behaviour under both static DC and dynamic pulsed operating conditions with an excellent fitting in all I/V regions, even in the case of using low and medium power HEMT devices. Being able of reproducing second and third order derivatives, the proposed model is also adequate for describing the nonlinear small-signal performance of these devices. Comparisons between experimental and simulated results, using the proposed model and other well-known models, demonstrate the validity of the new I_{ds} model for various gate widths, technologies and gate peripheries.

INTRODUCTION

In the last decade, several authors have presented various solutions [1-6] where the problem of obtaining an accurate model of the HEMT I_{ds} current source is overcome. Some of these models [2] present a considerable approach to the static I/V behaviour of the devices. Nevertheless, the fact of not defining these models in a continuous way limits their use in applications where either the CPU speed or higher order derivatives prediction (for intermodulation distortion, IMD, purposes) are important factors to be taken into account. Other authors do present continuous models for the static case of the I_{ds} non-linear current source [1-5]. But in most cases the presented new models are applied to low-power devices where the saturation current is not large enough to probe the model can accurately reproduce the different regions on the I/V plane (i.e. linear region, pinch-off region, etc).

In this paper, we are going to propose a new empirical continuous I_{ds} non linear large signal model capable of reproducing the HEMT different working zones in a natural way, considering the transconductance compression that occurs in these devices for gate voltage greater than a given value, and also reproducing the second and third order derivatives that have been shown responsible for the small-signal IMD.

Furthermore, it is important to point out that, the model will be able to reproduce not only the DC and small signal behaviour, but also the dynamic nonlinear pulsed characteristics taking into account the power output saturation when large input power is applied to the device. Thus, this new I_{ds} model will provide an accurate prediction of harmonics, as well as a way for intermodulation distortion modelling in large signal regime.

LARGE SIGNAL MODELLING

The starting point in the nonlinear HEMT modelling was the application of the MESFET models known at that moment (i.e. Curtice, Materka, etc. models) to the HEMT I/V characteristics. Obviously, these approaches, due to the particular behaviour of HEMT devices, did not provide enough accuracy. Although RF small signal MESFET and HEMT linear equivalent circuits may be considered the same, they are not so under DC, quasi-linear or pulsed operating conditions.

It is well known that the most important difference between MESFET and HEMT devices, as well as the principal feature of HEMTs, is the transconductance (g_m) compression. This effect may be clearly observed in HEMTs for gate voltage values greater than zero. The Curtice, Materka, etc. models are not able to simulate the transconductance compression. Hence, they can not be considered as an accurate approach.

A better aproach was modifying the conventional Curtice, Materka, etc models in order to obtain a better fitting of the static HEMT behaviour [4]. This is a valid approach for some devices. However, it has the problem of accurately simulating the I_{ds} characteristics for medium and high power devices and, in some cases, the discontinuities of the I_{ds} equation, and so, of its derivatives.

The new I_{ds} non-linear equation (1) is based on the modified Materka model [7], [8]. It is valid to describe the static and dynamic HEMT behaviour. Moreover, it fits the *pinch-off* region even in the case of high power devices [3] where the traditional models, e.g. Curtice, Tajima, etc., fail.

$$I_{ds} = I_{dss}.\left(v_{git_{eff}}\right)^{\left(E+K_E.v_{gi}\right)}.(1+\frac{S_S.v_{di}}{I_{dss}}).tanh\left(\frac{S_L.v_{di}}{I_{dss}.(1-K_G.v_{gi})}\right).e^{\left(-\frac{v_{gif_{lch}}{}^{\delta}}{\mu}\right)} \qquad (1)$$

Where:

$$v_{git_{eff}} = {}^{1}\!/_{(2.\eta)}.\left(\chi.v_{git} + v_{git_{lch}}\right),$$

$$v_{git_{lch}} = \ln\left(2.\cosh\left(\chi.v_{git}\right)\right),$$

$$v_{gif_{lch}} = \ln\left(2.\cosh\left(v_{gif}\right)\right),$$

$$v_{git} = v_{gi} - \left(V_P + \gamma.v_{di}\right),$$

And

$$v_{gif} = v_{gi} - V_{PF}$$

In the above expression, it appears a simple exponential term whose function consists on representing the g_m compression that appears for certain values of gate-source voltage (v_{gs}). The log(2cosh(x)) terms represent $|x|$ continuos functions, valid for higher order derivatives reproduction as it has been suggested by Pedro in [9]. In fact, most of the existing nonlinear models, for both MESFETs and HMETs, that are discontinuos at pinch-off, may be improved in their higher order derivatives prediction including terms for assuring smooth transitions. These terms could be either in the mentioned form or in the one Statz suggested for the charge equation, and that other authors [10-11] have recently included in their Ids equations.

MODEL VALIDATION

In order to validate the proposed I_{ds} model, the fitting to expression (1) of both DC and Pulsed I_{ds} [13] experimental current source of several devices has been carried out, establishing comparisons whit results obtained from other models [1-5]. We consider two quite different devices to probe the ability of the model to reproduce the I/V behaviour of any device without dependence neither on the technological process and size of device nor on the device working conditions (DC, pulsed, etc).

The first device is a 4*30 µm HEMT chip provided by the PML (PHILIPS) foundry; it is a low power transistor used in low noise applications. Figure 1 shows the experimental and fitted I/V DC characteristics for the proposed model and for the Shirakawa model [3]. One can observe an excellent agreement between experimental and fitted results, for both models.

In order to prove the proposed model is valid to fit not only the I_{ds} current source for low power devices, but also for medium and high power devices under dynamic operation, comparisons between I/V pulsed measurements and simulated results, obtained from our model and from other continuos models (generally of better performance than the non continuos ones) were carried out. As an example Figure 2 shows the comparisons between experimental and simulated results using our model and the model proposed by [3], that in Figure 1 seems to be a good approach, for a 6*150 µm HEMT device provided by the PML foundry. In this case, looking at the pinch-off region, we can see that our model arises as a better approach.

IMD PREDICTION

The predominant second and third order terms of the complete Ids Taylor-series expansion of our equation, responsible for the IMD small-signal behaviour, are shown in Figure 3 for Vds= 3 V (saturated region) for the previously mentioned 4*30 μm HEMT device. The parameters set for this device are included in Table 1.

As it can be seen, the transconductance higher order derivatives (Gm2 and Gm3) follow the behaviour of the ones experimentally extracted, using the technique proposed in [12]. Some differences are detected in Gm3 in the Vgs region above the point of maximum transconductance. This seems to be due to a stronger nonlinear behaviour than the one the few available continuos models predict in that region.

The measured coefficients and the ones reproduced by the model have been employed in a Volterra simulator to validate our model in small-signal nonlinear behaviour. We show in Figure 4 the carrier to intermodulation (C/I) performance versus the gate-source potential for two tones excitation at low frequencies (100 and 110 MHz), and high frequencies (10 and 10.01 GHz) with an input power level per tone of -20dBm. The results are quite good, supporting the Ids equation derivatives description. However, taking into account the results for MESFETs devices [14], the influence of Cgs derivatives should also be considered when we move higher in frequency.

CONCLUSIONS

A new nonlinear continuous model for the I_{ds} current source in HEMTs has been proposed. The validity of this model for DC behaviour, as well as for pulsed dynamic I/V conditions and small-signal IMD, has been shown. The ability of the model for assuming the most important and distinctive HEMT features, like the g_m compression and the consequent behaviour of its derivatives, has also been demonstrated from the agreement between experimental and simulated data.

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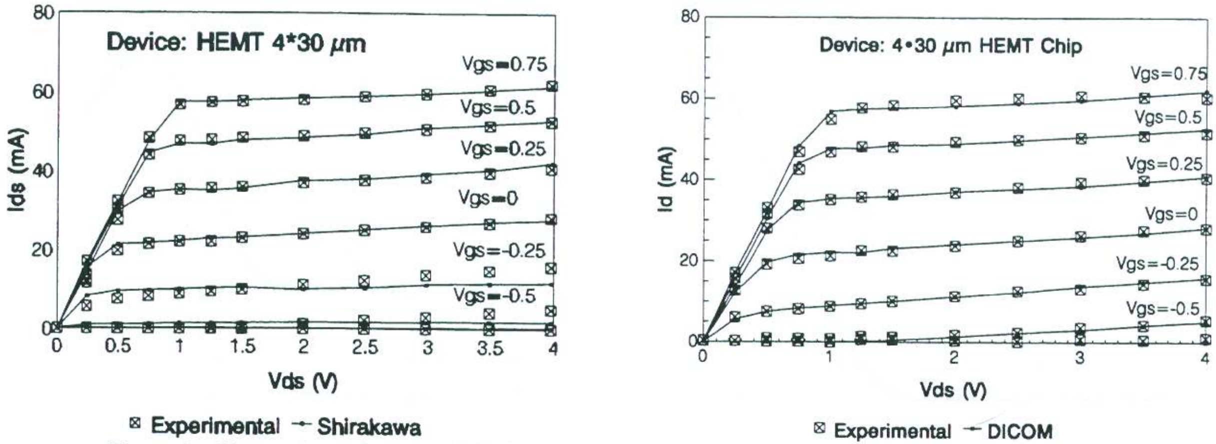

Figure 1.- Comparisons between DC I/V measurements and simulated results using the proposed model and another continuous model [3]

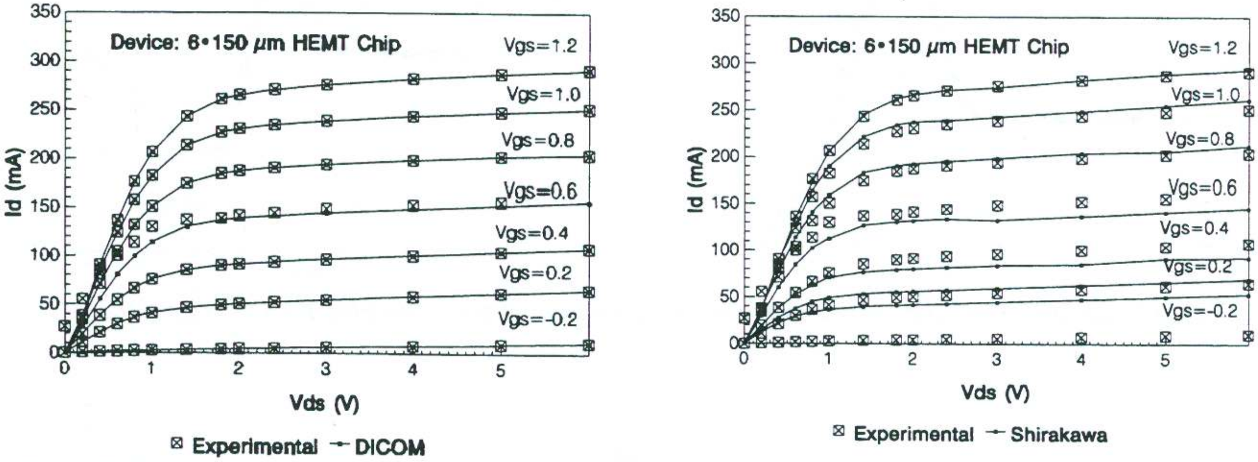

Figure 2.- Comparisons between pulsed I/V measurements and simulated results using the proposed model and another continuous model [3] for a medium power device.

Parameter	**4*30 μm HEMT**	**Parameter**	**4*30 μm HEMT**
I_{dss}	71.39 mA	S_L	474.3 mA/V
V_p	-0.43 V	K_G	0.5350 V^{-1}
γ	-0.07632	μ	1.293
E	1.134	δ	0.06301
K_E	-0.8828 V^{-1}	V_{PF}	0.6271 V
S_S	6.147 mA/V	$\eta \cong \chi$	4.3238

*Table 1. Parameters set for 4*30 μm HEMT.*

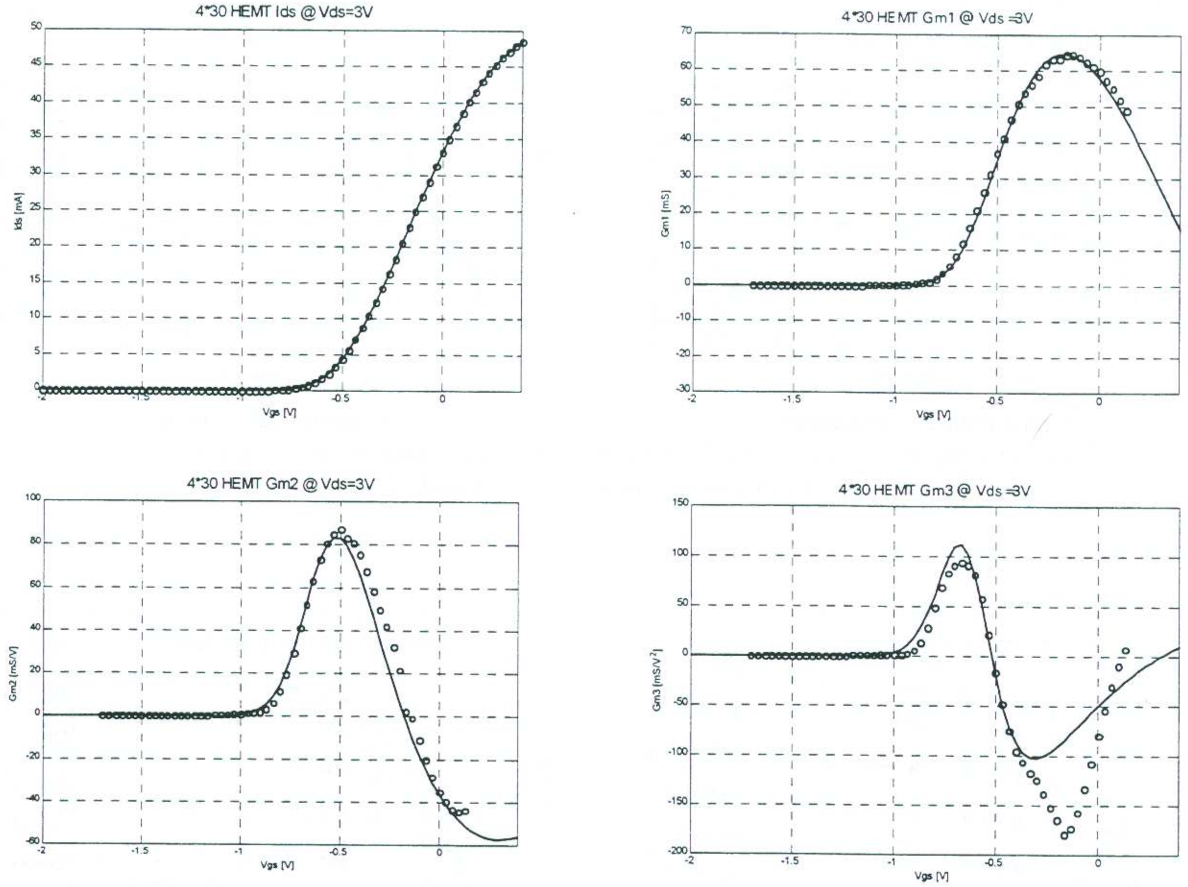

*Figure 3.- Ids, Gm1, Gm2 and Gm3 behaviour vs. Vgs. (o) Measured and (-) Modelled for a 4*30* μm HEMT .

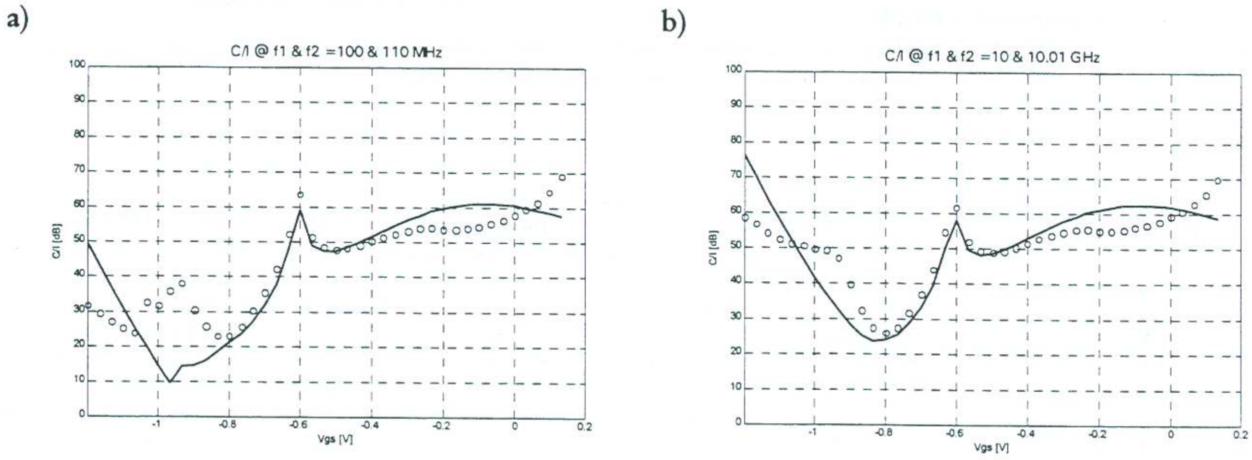

*Figure 4.- C/I behaviour vs. Vgs with (o) measured and (-) modelled derivatives for a 4*30* μm HEMT .
a) f1=100MHz & f2=110MHz. b) f1=10GHz & f2=10.01GHz.