LARGE SIGNAL DYNAMIC PROPERTIES OF GAAS MESFET/HEMT DEVICES UNDER OPTICAL ILLUMINATION.

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ABSTRACT

This paper is the result of an extensive investigation on the large signal dynamic behaviour (Pulsed I/V) of unipolar GaAs devices, in the overall I/V plane, when varying the incident optical input power. We have observed a hyperbolic dependence with the gate voltage along with a quasi-logarithmic dependence with the optical power. An empirical equation has been developed in order to take into account both effects, and the successive simulations show a very good agreement with the experimental data for different foundries and technological process.

INTRODUCTION

The increasing integration of hybrid and monolithic circuits has reinforced the need of accurate large signal device models to improve the performance of these circuits and to minimise the number of design and fabrication steps required. Therefore, it is very important for efficient CAD tools to have good modelling approaches able to predict the small and large signal non-linear dynamic behaviour of GaAs devices.

The distinct advantages of optical transmission systems and the increasing use of microwave frequencies within general communication systems, coupled with the ability to integrate microwave and optical components onto a single slice of GaAs have stimulated considerable interest in the development of microwave opto-electronic systems. The optical circuits are advantageous because they can be integrated into the microwave circuits without interfering with them, they have low losses and small dimensions, short reaction time and wide band. The optical signal can be returned to the electrical domain using a depletion photo-detector but this option requires additional processing steps. Another possibility is to use the optical signals to control or introduce signals directly into microwave devices. Direct illumination on the microwave or millimeter-wave monolithic circuit is very attractive for versatility of applications associated with the optical fiber communication and control systems. The GaAs FET, the basic building block of MMIC's, can be used as a photo-detector embedded on the monolithic chip itself, and thus serves as an optical port. Then, it is significant to examine optical-microwave interaction on a FET in a monolithic circuit and how is the variation of the FET model parameters due the illumination.

It is well known that when we have an illuminated GaAs device, an interesting absorption effect takes place at the Gate-Drain and Gate-Source spacing and a free carrier photoexcitation occurs at the active area level. In fact these devices exhibit both photoconductive and photovoltaic effects that can be conveniently amplified by using external buffer resistors. This means that the static DC curves as well as the small signal equivalent circuit parameters change when optical energy goes into the device and many laboratories have studied this problem and shown many industrial applications [1][2].

However the true large signal behaviour [3][4] is governed by the dynamic pulsed I/V characteristics that depends on the quiescent bias point. As far as we know there is not any report on the effects of optical illumination on this bias dependent dynamic behaviour that is responsible of the output power and efficiency capabilities of these electron devices. This paper details the most important research conclusions obtained from an extensive study of the different optical extractions, fitting and optimisation procedures, in terms of DC and Pulsed measurements, applied to an F20 6*50 μm GEC-MARCONI MESFET transistor. The result of this study will give us a starting point for optical large signal modelling of these devices along with the knowledge of the optical laws for the most dependent parameters.

OPTICAL MEASUREMENTS SETUP

The experimental test setup consists in a Pulsing system [5] and a laser diode pigtailed coupled to a wafer probe station. The material of the devices is GaAs therefore an optical wavelength of 830 nm is used to illuminate its active region. The computer controlled optical incident power can be varied between 0.01 and 10 mW, thus covering most of applications. Edge effects were carefully investigated because optical absorption can be dependent on the spot aperture and position.

OPTICAL LARGE SIGNAL DYNAMIC PROPERTIES

Several authors [6][7] have demonstrated the importance of non-linear characterisation of transistors from pulsed measurements. The DC curves allow us to know the DC behaviour and the temperature of the quiescent operating points in RF operation, and the pulsed measurements take into account the transistor self-heating that change internal parameters as electron mobility, ionization breakdown or schottky barrier characteristics. Also low frequency dispersion, mainly on the transconductance and output conductance, associated with deep levels traps and surface state, greatly affects the dynamic of the transistor.

Fig.1 shows the aspect of the dynamic I/V curves for a classical GEC-Marconi F20 MESFET device biased in a class AB point. The two sets of curves are for dark and 2mW laser operation. We can observe, as we can expect from physical considerations, that both curves do not intersect in the quiescent bias point because the static behaviour changes with optical absorption. Furthermore, we can observe a useful change in the drain slopes along with the normal increment of the drain current. Fig.2 shows the overall increment of the drain current as a function of the gate and drain voltage. It is very interesting to note that this extra current is more important for gate voltages close the high gain points in the linear region, thus decreasing monotonically when approaching to the saturated regime.

Fig.3 shows the dynamic drain current in excess as a function of the gate voltage and optical power in the saturated region. The surface plot shows a logarithmic dependence with the optical power and a hyperbolic tangent form with the gate voltage. So it is no difficult to put these main dependencies in a structured analytical expression for the multibias dynamic Ids current source:

$$\begin{aligned} Ids &= FNL\,(Vgs, Vds, Vgso, Vdso, Pl) = \\ &= FNL[\,K1.Tanh(Vgs)\,, Vds\,,\, K2.Tanh(Vgso)\,, Vdso\,,\, Log(Pl)\,] \end{aligned} \tag{1}$$

where Vgs, Vds and Vgso, Vdso are respectively the instantaneous and static control voltages, and Pl the incident optical power.

In this work is used the MESFET equivalent circuit given by T. Fernández et al. [7] where the Ids current is modelled by two non-linear sources. One of them is a bias point dependent non-linear equation and the other one represents the differences between DC and Pulsed characteristics at every bias point. The equation for the dynamic Ids current given in [7] is modified as Allemando and Bonnaire [8] in order to guarantee the continuity of the derivatives and accurately predict intermodulation distortion. In this way it is given by:

$$Ids = Idss\left\{\frac{1}{2a|Vt|} * \left[a\,(Vgi - Vt) + \log\{2 * \cosh[a\,(Vgi - Vt)]\}\right]\right\}^{(E+KeVgi)} * \ (1 + Ss\,Vdi)\ * tanh\left(\frac{Sl\,Vdi}{1 - Kg\,Vgi}\right) \qquad (2)$$

with : $Vt = Vto + \gamma\ Vdi$

where Vgi, Vdi are the internal instantaneous voltages, E, Ke and Kg are constant and Idss, Vt0, γ, a, Ss and Sl are bias (Vgso,Vdso) dependent parameters in order to fit the Pulsed I/V dynamic behaviour.

The influence of the optical illumination over this equation has been analysed and it is not difficult to find the appropriate variations and to identify what are the most sensitive parameters. For example, the Fig.4 shows the variation of the Idss parameter versus the optical power for three quiescent gate voltages and the same quiescent drain voltage. We can observe that not only the absolute value but also the slopes are different when changing the optical power and the internal dissipated DC power. Furthermore as well as the other parameters is different when changing the drain voltage. The variation of this parameter presents a logarithmic form versus the incident optical power and then it can be modelled as:

$$Idss = Idss1(Vgso, Vdso) + Idss2(Vgso, Vdso) * \log(1 + Idss3(Vgso, Vdso) * Pl) \qquad (3)$$

where these three new parameters are functions of quiescent bias point. Fig.5 shows this dependence for other parameter, Vt0, when the device biased in the saturation region (Vdso=5V) and the optical power and gate voltage swing the whole range. In the same way Fig.6 shows the dynamic optical dependence when the device is biased in the linear region. The Vt0 parameter can be modelled versus the optical power by an anti-logarithmic function as:

$$Vt0 = Vt01(Vgso, Vdso) + Vt02(Vgso, Vdso) * Pl^{Vt03(Vgso,Vdso)} \qquad (4)$$

Analogous process must be realised with the other optical power and bias dependent parameters. Fig.7 and Fig.8 show the close fit of this modelling approach for two different quiescent bias point at two different optical powers.

The same measurements have been done for HEMT D02AH PML devices, with an analogous behaviour excepting the gain compression phenomena. These results will be presented at the conference time.

CONCLUSION

An exhaustive investigation on the dynamic properties of GaAs MESFET/HEMT devices under optical absorption has been carried out. We have shown the main dependencies and the way of integrating this behaviour into any classical analytical equation for the drain current. The results can be easily extended to HEMT devices. Numerical simulations show good agreement with the experiment.

ACKNOWLEDGMENTS

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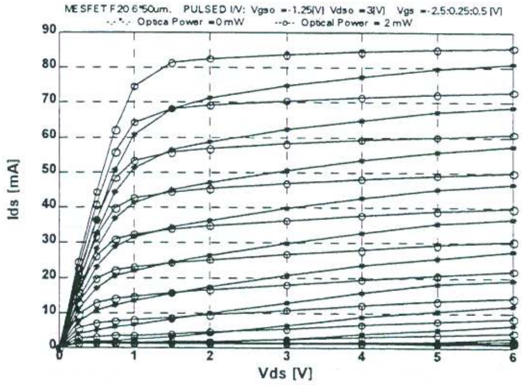

Fig 1: Dynamic I/V curves.

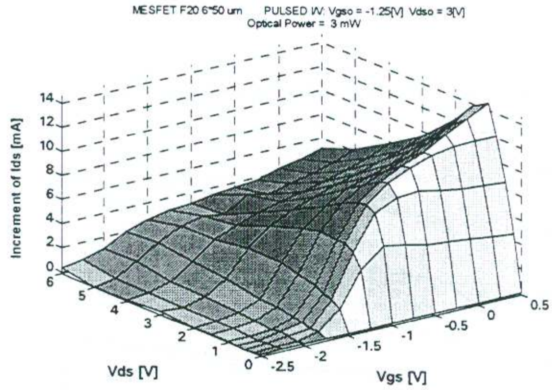

Fig 2: Increment of Ids versus bias.

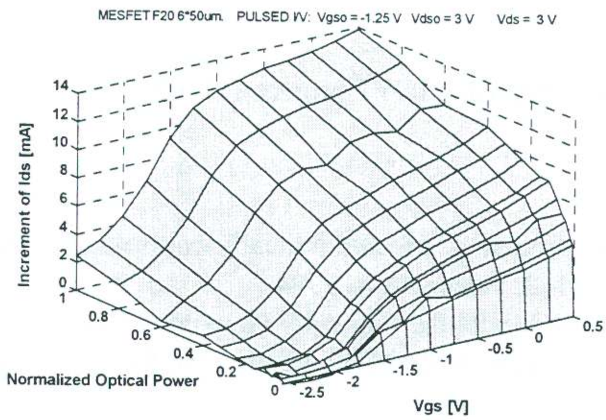

Fig. 3: Increment of Ids versus Optical Power and Vgs in the saturated region.

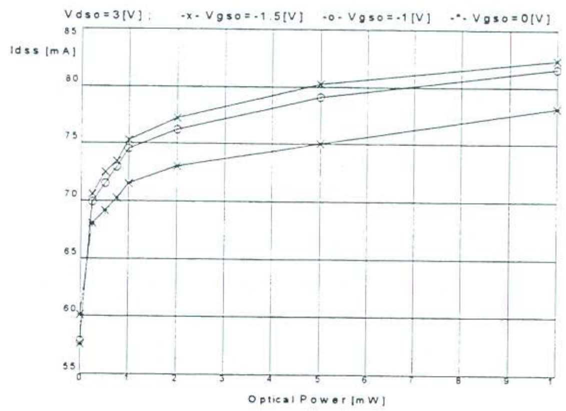

Fig 4: Idss parameter versus the optical power for three different quiescent bias points.

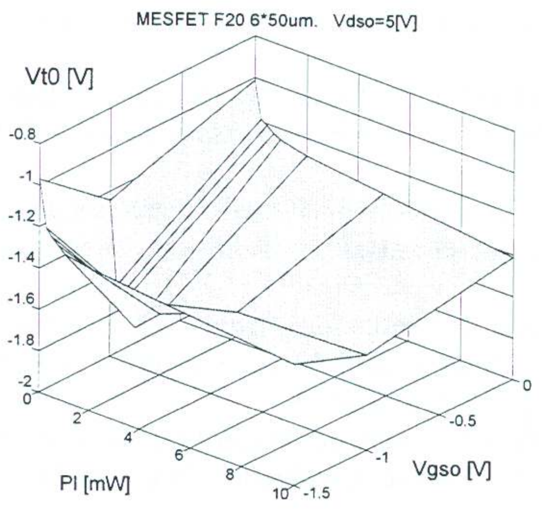

Fig.5: Variation of the parameter Vt0 versus optical power and gate voltage in the saturated region (Vdso=5[V]).

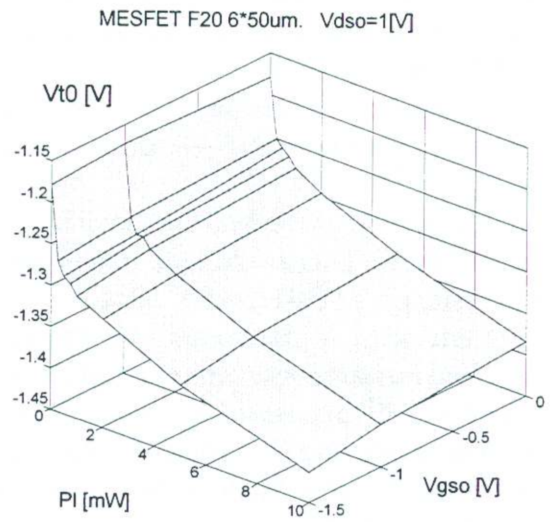

Fig.6: Variation of the parameter Vt0 versus optical power and gate voltage in the linear region (Vdso=1[V]).

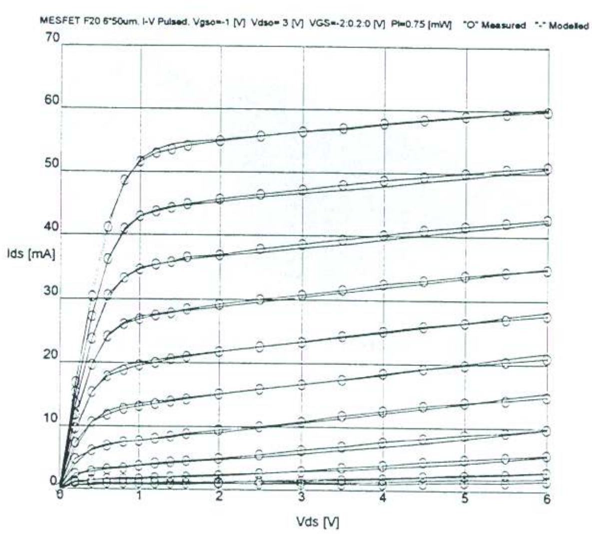

Fig.7: Experimental and simulated pulsed curves at Vgso=-1[V] and Vdso=3[V]. Optical power = 0.75mW.

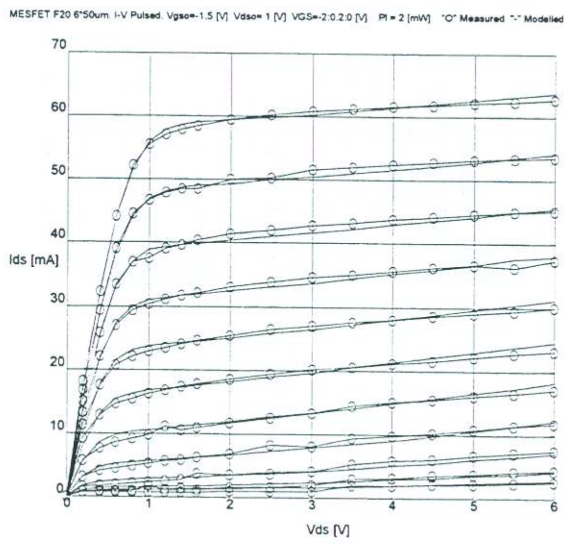

Fig.8: Experimental and simulated pulsed curves at Vgso=-1.5 [V] and Vdso=1[V]. Optical power= 2 W.