A Measurement System for FET Derivative Extraction under Dynamic Operating Regime

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Abstract — **This paper presents a novel measurement system for derivative extraction under dynamic conditions based on the utilization of pulsed signals. This kind of characterization avoids unrealistic heating and trapping effects, making possible to realize the extraction process under conditions as close as possible to the device RF behaviour. The system principles and set-up are presented and described in order to provide reliable device modelling. Moreover, results of the derivative extraction process for an FLL177ME MESFET are presented with the aim of highlighting the existing differences between pulsed and traditional DC derivative characterization.**

I. INTRODUCTION

The development of accurate and upgraded models able of reproducing with precision the nonlinear RF/microwave device behaviour under real communication signals is an absolutely necessary key point in order to achieve designs with first-pass success.

The set of measurements required for device modelling was traditionally performed under static conditions (DC bias), which resulted in model inaccuracies. First, the DC power dissipated in the device could cause self-heating effects, being the temperature not constant during the characterization process. Secondly, microwave FETs could exhibit trapping effects that modified significantly the device characteristics with frequency. Finally, DC nonsafe operation areas (such as breakdown) could not be investigated with the purpose of obtaining nonlinear models with all the boundaries that could be reached under large-signal RF excitation.

All these drawbacks motivated the development of measurement techniques based on pulses, and several revolutionary works appeared proposing its utilization for I(V) or S-parameter characterization [1]-[3].

In the last years, a special interest has been generated in device linearity control and optimization, particularly when amplifying digitally modulated signals in modern communication systems. Consequently, a reliable derivative extraction process is really necessary in order to achieve an accurate nonlinear transistor characterization. Beyond small-signal intermodulation distortion (IMD), the extensive knowledge of derivatives permits to predict the large-signal IMD behaviour [4], being a truthful modelling of the device strong nonlinearities (cutoff, input junction conduction or saturated to linear region transition) an essential issue in the design process of non class-A power amplifiers. Current derivative extraction procedures are based on harmonic distortion measurements realized from a set of biasing points, being this technique not fully appropriate for RF simulation due to the device low frequency dispersion associated effects.

The goal of this paper is to describe a reliable derivative extraction system under dynamic regime that allows to perform nonlinear characterization thanks to a spectral-extraction measurement set-up using very short pulses. Since this class of extraction system takes into account the trap and thermal dynamical behaviour, a realistic device characterization is performed under working conditions as close as possible to the real-world ones.

II. MEASUREMENT SYSTEM

Given that the temperature time constants of FET transistors are very large compared with the RF cycle, the device temperature does not change under RF regime, being only dependent on the average power dissipated inside the own device. In the same way, when RF signals are applied, electron capture or emission effects caused by trap states have not enough time to occur during the RF cycle.

Based on these principles, the derivative extraction system presented in this paper makes possible to measure the device nonlinear behaviour starting from a DC quiescent point and travelling through the device full dynamic operation area by means of short pulsed signals.

The extraction procedure utilized in this work is based in the Maas & Crosmun model for FET gate/drain I/V characteristic [5], which expresses the drain current (principal source of intermodulation) as follows:

$$i_{ds} = G_1 v_{in} + G_2 v_{in}^2 + G_3 v_{in}^3 \qquad (1)$$

The complete measurement system was assembled as described in the diagram showed in Fig. 1.

The signal generator situated at the input of the system carries out the task of providing a pulse modulated RF signal to drive the device under test (DUT) through the RF path. The power level of this signal at the gate of the DUT must be low enough to ensure small-signal regime operation, but sufficient to provide quality measurements above the spectrum analyzer noise floor.

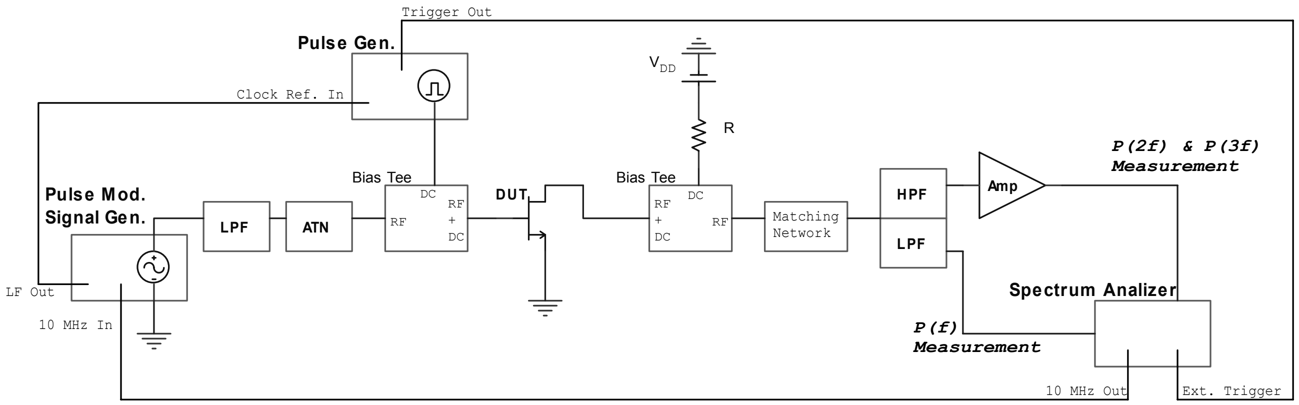


Fig. 1. Pulsed derivative extraction system for nonlinear device characterization.

The input low-pass filter grants a free-spurious signal, rejecting all possible undesired harmonics produced by the signal generator, and the 10 dB attenuator is employed to improve the adaptation condition at gate side.

Once a suitable pulse modulated RF excitation is selected, it is mounted over a pulsed DC component through the input bias tee, as can be seen in Fig. 2. The synchronism between RF and DC pulsed signals is an essential issue for a correct measurement process, so it is necessary to adjust carefully the generators' delay to avoid any error.

The shorter the pulses, the closer the device is to its real dynamic behaviour. Generated pulses must be shorter than thermal and trapping time constants, although pulsewidth must be large enough for quality measurement acquisition. In addition to it, the pulse period should ensure that the thermal state is only driven by the DC quiescent point.

Having in mind the limitations of the available measurement equipment, a pulsewidth value of 4µs was set, as well as a signal period of 10ms, obtaining in this way a duty-cycle really close to cero. In spite of a smaller pulsewidth would be more appropriate to ensure a correct characterization of certain specific devices, these values are perfectly suitable for almost all typical FETs used in communication systems [6].

Both the resistor *R* and the drain matching network ensure that the DUT sees a proper load value at fundamental frequency as well as DC, second and third harmonics, allowing to carry out the extraction process over any desired load-line, giving the feature to select the most interesting working conditions for each studied device.

At the output of the system, the low-pass path of the diplexer allows to measure directly the output power level at fundamental frequency, which will be employed in the calculation of the first derivative. In the other branch, the high-pass output and a high dynamic range amplifier adjust the signal to evaluate the output power level of second and third harmonics, which permits to extract second and third derivatives respectively.

Given that the signals directly obtained at the output of the derivative extraction system are pulsed too, it is obvious that the usual spectrum measurement technique can not be applied in this case. Therefore, an equipment with time-gated spectrum analysis capability [7] is required in order to extract the real spectrum of the RF signals from the measured pulsed ones. The time-gated technique makes possible to obtain spectral information about signals in the frequency domain that are separated in the time domain, since it allows to define a time window during which the measurement will be performed. This feature permits to specify the part of the signal that will be considered, excluding the rest, as can be appreciated in Fig. 3.

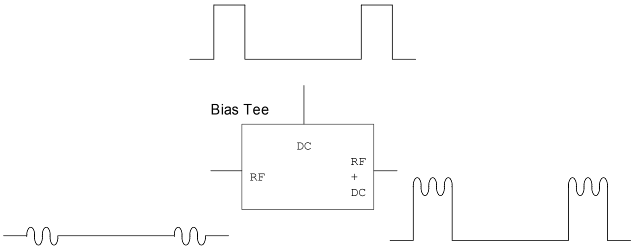


Fig. 2. Combination of pulse modulated RF signal with pulsed biasing.

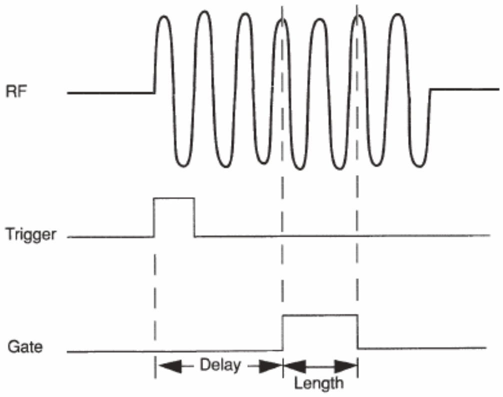


Fig. 3. Detail of time-gated spectrum analysis.

III. EXPERIMENTAL RESULTS

The usefulness of the proposed pulsed measurement system was then corroborated through the practical derivative extraction for a Fujitsu FLL177ME power MESFET.

The full process was performed for a load-line of 10Ω, as it makes possible a maximum signal excursion from cutoff to linear region when using this kind of device in PAs. In order to find the dynamical behaviour of the studied transistor, the pulsed derivative extraction was carried out from a class-C bias point (V_{gs}=-2.5V). Besides, the traditional DC characterization was completed with the purpose of obtaining the static device behaviour too. This last procedure was realized with the same measurement system than the dynamic case, but with no level change in the gate DC signal (i.e., no pulsed biasing).

Figure 4 shows the obtained results for both sets of extracted derivatives (DC and pulsed). In view of this, it is not difficult to appreciate the significant differences between static and dynamic nonlinear behaviours. As far as the authors are aware, no result of a pulsed derivative extraction of this kind has been published up to date.

As can be seen in these figures, the curves for the first, second and third derivatives have an evolution in agreement with the expected behaviour for a MESFET device [4]. It has also been corroborated that each derivative is coherent with the previous one, keeping the relation given by:

$$G_n = \frac{1}{n}\frac{dG_{n-1}}{dv_{in}} \qquad (2)$$

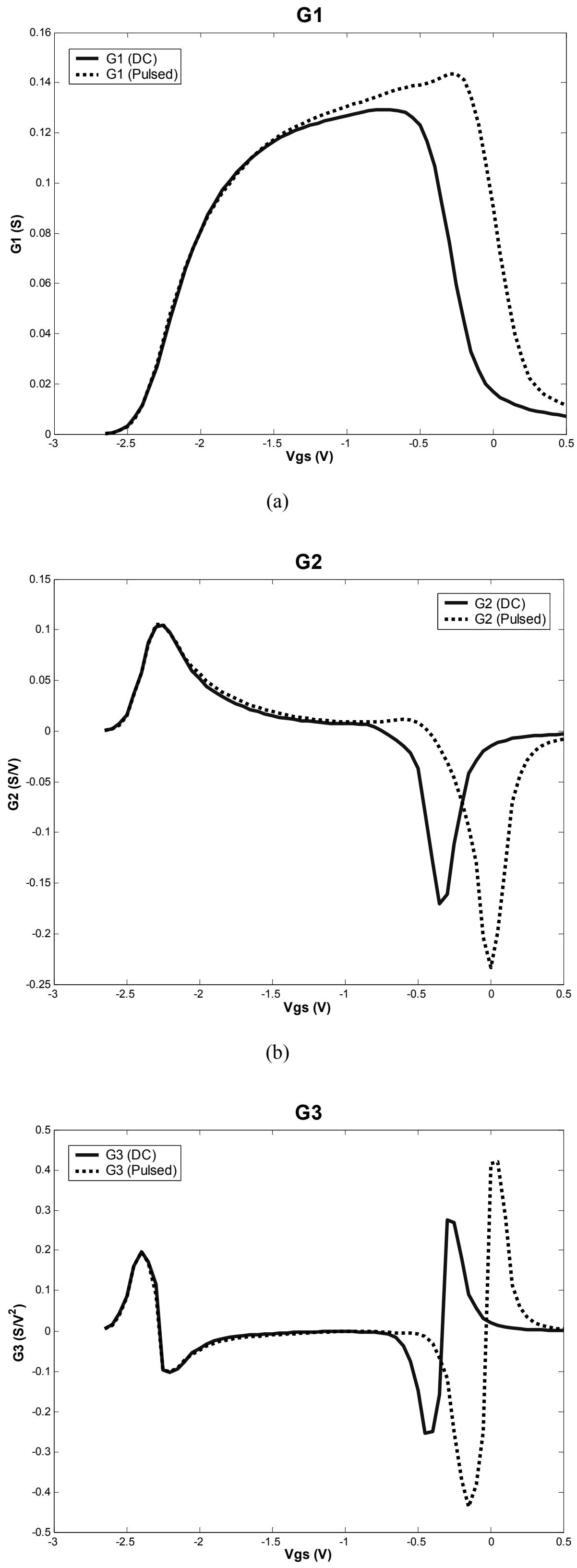
where n denotes the order of the derivative.

Finally, it is necessary to highlight how the derivatives extracted by pulsed measurements substantially differ from the DC ones, especially in the saturated to linear region transition, as it could be expected. Taking into account that this transition determines the position of the large-signal IMD sweet-spot in class-C operation, the use of the up to now available DC characterization process would result in an inappropriate estimation of this interesting point.

VI. CONCLUSION

The novel pulsed measurement system proposed in this paper opens new perspectives for FET nonlinear characterization. It could be a useful tool to upgrade the existing derivative extraction process, providing more accurate and reliable measurements when characterizing and modelling device RF behaviour.

Its effectiveness has been demonstrated with the practical characterization of a FLL177ME MESFET device, where significant improvement has been obtained in its extracted derivatives.



(a)

(b)

(c)

Fig. 4. First, second and third derivatives extracted under static (solid lines) and dynamic (dashed lines) conditions for a FLL177ME.

ACKNOWLEDGEMENT

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