# A METHOD FOR CHARACTERISING FREQUENCY DISPERSION AND THERMAL EFFECTS INDEPENDENTLY IN GaAs FETs

**J Rodríguez Tellez*, A Mediavilla**, T Fernández** , A Tazón****
*University of Bradford, West Yorkshire, BD7 1DP, UK
e-mail: J.Rodrigueztellez@bradford.ac.uk
**Universidad de Cantabria, E.T.S.I.I.T, Avda Los Castros s/n 39005, Santander, Spain
e-mail: media@dicom.unican.es

## ABSTRACT

Static, pulsed and liquid crystal measurement results are presented for a 900μm gate-width MESFET. The results indicate clearly that the device has a much slower thermal response time than was previously thought. The data indicate that the differences observed between the static and pulsed IV characteristics of the device are due to frequency dispersion and not to thermal effects, as is sometimes assumed.

## INTRODUCTION

Over recent years a number of articles advocating measurement of the characteristics of MESFETs under pulsed conditions as a means of eliminating the self-heating effect introduced by conventional dc based measurements have been proposed Selmi and Ricco (1), Fernández et al (2). In the majority of cases, systems with narrow pulse widths (<1μs) and long repetition rates (approximately 1kHz) are proposed in order to eliminate the self-heating effect. The reasons for these test conditions have not however been explained satisfactorily. In addition the assumption Selmi and Ricco (1) that the differences between the IV characteristics of the device acquired under static and pulsed conditions are due to the self-heating effect is, in the case of the MESFET, incorrect. In this paper these two points are considered using a variety of measurement approaches.

## MEASUREMENTS AND DEVICES

To corroborate the general results presented in this paper the IV characteristics of a MESFET were measured using a variety of systems. These were:

(i) dc method with different delay time. In this test the output characteristics of the device were measured with the HP4145A semiconductor analyser. This equipment enables the static dc measurements to be performed with different delay times (this is the time allowed at each bias point before the drain current is measured) so that the effect of the self-heating can be investigated.

(ii) pulsed method: For this test the output characteristics of the device were measured using the system shown in Fig. 1 Fernández et al (3). In this system the gate or the drain (or both) can be pulsed so that the device is turned on for a short period of time and the drain current measured during the on period. If the pulse width is sufficiently narrow and the period is sufficiently long, then the self-heating effect can be eliminated from the measured data. The series connected dc supplies enable the initial or static conditions of the device to be specified and this is a possible way of controlling the amount of self-heating which takes place in the device. For the purposes of this paper however the pulsed results presented were obtained with the device biased from a static point of view at $V_{GS} = -1V$, $V_{DS} = 0V$. This corresponds to the device being switched fully off thereby ensuring no internal heating at the static point.

The question of how narrow the pulses need to be to ensure no self-heating takes place was investigated by performing pulsed measurements with different pulse widths and varying repetition rates. In addition the device was coated with liquid crystals J. Rodríguez et al (4) and its temperature recorded with a VCR. This enabled the temperature of the device to be recorded in real time as the different pulsed tests were performed. Since the VCR records at 25 frames/second, the possibility of missing a temperature condition, arising from a rapidly occurring transient, was minimised by not synchronising the VCR recording with the electrical tests and by allowing the tests to run for a long period of time (minutes in some cases). The captured video information was then analysed on a frame-by-frame basis. This enabled a thermal-time response curve to be constructed for the device and the onset of heating to be detected, This test enabled the results from the electrical testing to be cross-checked.

The device utilised as the test vehicle was a 0.5μm gate-length, -0.8V pinch-off MESFET with a total gate-width of 900μm (5). This was implemented with a 4-finger (225μm gate-width/finger) structure. To facilitate the liquid crystal thermal work the device was bonded to a 0.63mm thick alumina substrate. The bond wires were kept as far away from the active device as possible to ensure that the liquid crystal layer thickness was thin enough (<3μm) for it not to affect the thermal properties of the device significantly.

To determine the minimum pulse width required to cause the device to heat, a liquid crystal with a temperature range of 27°C to 35°C was employed (6). This is relatively close to ambient temperature and it is possible to observe the onset of heating at a stage before it has a significant effect on the electrical characteristics. The pulse width was then adjusted until the onset of heating could be detected. The pulse repetition rate was made large (300ms) so that the response of the device to a single transient could be observed,. The results of this exercise are shown in Fig. 2. This shows the temperature of the device when a 20ms wide pulse is employed. This was the narrowest pulse width which increased the temperature of the device above the 27°C liquid crystal threshold point. For these results the gate-source terminal was pulsed from -1V to 0V with the drain-source held at a constant $V_{DS}$ of 4V. From a thermal point of view, keeping the drain terminal at a fixed potential does not present a problem since the drain-source resistance of the device is very high when it is switched off. The pulsed drain current was measured as 73mA. Although below 27°C the liquid crystal does not exhibit a colour, it was noticed that a pulse width of 2.5ms was the minimum pulse width which caused the liquid crystal to flow slightly due to heat convection. For this case, the pulsed drain current was, as before, 73mA. Although these results indicate that the onset of heating occurs with pulse widths of approximately 2.5ms such heating does not affect the drain current significantly. In fact a pulse width of 10ms was necessary before the drain current dropped by 0.2% of the nominal pulsed drain current. Further confirmation of the relatively slow thermal response time of the device was obtained by measuring under static conditions the output characteristics of the device with the HP4145A with different delay times. For the $V_{GS} = 0V$, $V_{DS} = 4V$ point, the results of this are shown in Fig. 3. This again shows that no changes to the drain current occur until a delay of 10ms is applied. More interestingly it shows that even after a one second delay the drop in $I_{DS}$ is only 1mA. Delay times larger than one second were not found to alter the drain current. This indicates that one second is sufficient time for the device to reach equilibrium conditions from a thermal point of view. Notice from Fig. 3 that the 50°C base temperature arises from the heating caused by the previous $V_{DS}$ bias points included in the measurements. Fig. 3 represents the last point in the $V_{GS} = 0V$, $V_{DS}$ (0 to 4V) curve.

## PULSED RESULTS

Fig. 4 shows a number of curves measured under pulsed conditions with pulse widths of 1μs and a period corresponding to 1kHz. In view of the previous results such a narrow width pulse does not introduce any self-heating effects into the measured drain current. The static or dc curve measured with a one second delay is also shown for comparison purposes. These curves all correspond to the $V_{GS} = 0V$ case.

Curve 1 corresponds to the situation where only the drain terminal is pulsed from the static point of $V_{DS} = 0V$ and the gate terminal is held constant at a $V_{GS}$ of 0V. Curve 2 corresponds to the case where the gate terminal is pulsed from $V_{GS} = -1V$ to 0V and the drain terminal is swept in a dc manner from 0 to 4V. Curve 3 corresponds to the case where the gate and the drain terminals are pulsed from the static positions of $V_{GS} = -1V$ and $V_{DS} = 0V$. From a thermal point of view these three situations are the same since the initial or static conditions of the device corresponds to the off case and the pulse conditions are the same. This being true, curves 1, 2 and 3 should coincide and the fact that they do not, suggests that the differences between the curves are due to frequency dispersion effects. The difference between curve 1 and 2 being due to the frequency dependency of the device output conductance and the difference between curve 2 and the static curve is due to the self-heating and frequency dependency of the device transconductance. For the latter case, the self-heating effect is small since, as was seen previously, at $V_{DS} = 4V$ the self-heating effect only changes the drain current by 1mA. This is quite a small change compared to the changes introduced by frequency dispersion effects. Also notice that in the linear region the pulsed curves coincide. This suggests that no self-heating is taking place and re-inforces the dispersion idea since it is known that frequency dispersion is most apparent in the saturation region. Notice also that, when both terminals of the device are pulsed (Curve 3), the characteristics differ from those obtained when either terminal is pulsed independently. This is understandable because of the complex dependency and interaction of the device transconductance and output conductance on frequency and operating point (and hence thermal effects). The frequency dependency observed with the output conductance and transconductance using this pulsed measurement system agrees quite well with the results presented in reference J. Rodríguez et al (7) which were acquired using a small-signal swept frequency system.

## CONCLUSIONS

In summary the following main points emerge from the work presented in this paper.

(i) The pulsed measurement idea does not need to be implemented with particularly small width pulses in order to ensure no self-heating effects. For the device considered here pulse widths of the order of a few ms as opposed to pulses in the μs range are sufficient to ensure this providing the period is made sufficiently large.

(ii) For small and medium size transistors a pulsed measurement system may not be needed at all in order to measure the IV characteristics of the device with no self-heating. This, of course, is only true if the acquisition criterion and can be used to determine the extent of the self-heating problem.

and

(iii) The results presented show that the self-heating effect on the electrical characteristics of the device is relatively small compared with the effect of frequency dispersion.

The differences observed between the characteristics of the device measured under pulsed and static conditions are to a large extent due to the frequency dependency of the device transconductance and output conductance and are not related to thermal effects. The procedure presented here enables the two phenomena to be investigated separately.

## ACKNOWLEDGEMENTS

The authors would like to thank the Spanish Ministry of Education and Science for their financial support of this work under the Acciones Integradas program.

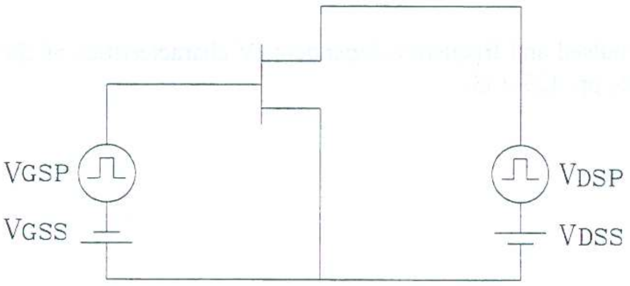

Figure 1 Pulse Measurement System

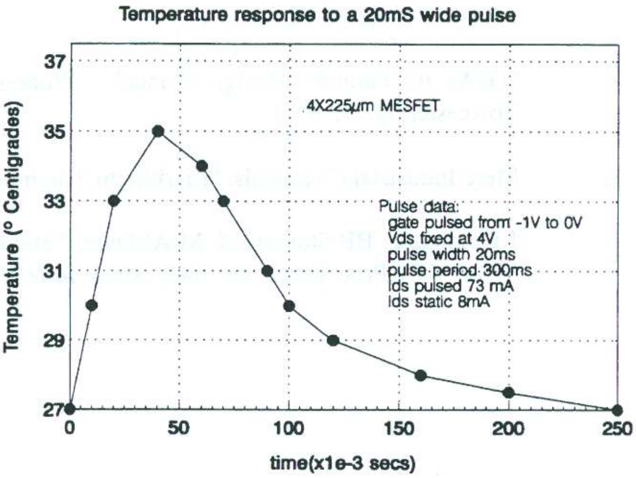

Figure 2 Thermal Response of Device

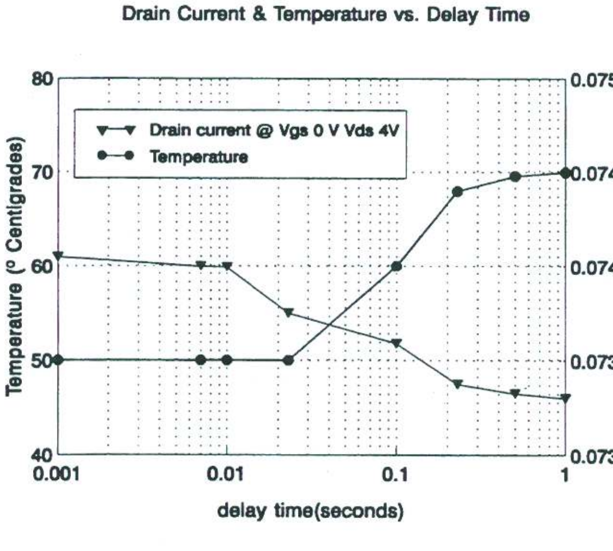

Figure 3 Drain Current as function of delay time

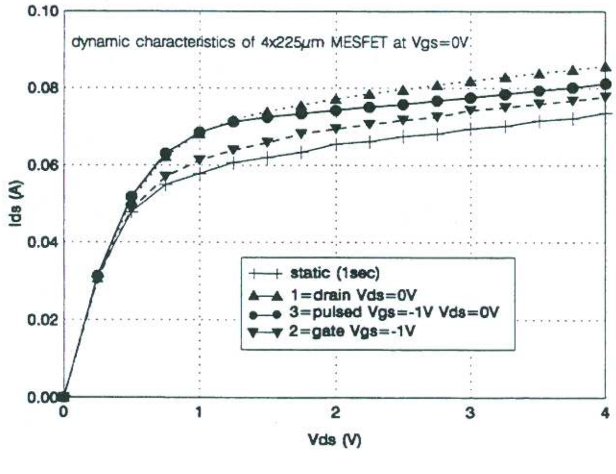

Figure 4 Drain Current under Pulsed and Static Conditions

## REFERENCES

1. Selmi, L & Ricco, B, "Modelling temperature effects of the dc-IV characteristics of GaAs MESFETs", IEEE Trans. 1993, ED-40, (2), pp. 273-277.

2. T Fernandez, Y Newport, J Zamanillo, A Tazon & A Mediavilla, "Extracting a bias-dependent large-signal MESFET model from pulsed I/V measurements", IEEE Trans on Microwave Theory & Techniques, Vol. 44, No. 3, March 1996, pp. 372-378.

3. T Fernandez, Y Newport, JN Zamanillo, A Mediavilla & A Tazon, "High-speed automated pulsed IV measurement system", 23rd European Microwave Conf., Madrid, Sept. 93, pp. 494-496.

4. J Rodriguez, S Laredo & RW Clarke, "Self-heating in GaAs FETs-a problem?", Microwave Jnl, Vol. 37, No. 9, Sept. 94, pp. 76-92.

5. "GaAs IC Foundry Design Manual - Process F20/F14", GEC Marconi Materials Technology, Caswell, Towcester, NN12 8EQ.

6. Merc Industrial Chemicals, "Licritherm Thermochromic Materials", Product Information Sheet.

7. J Rodriguez, BP Stothard & M Al-Daas, "Static, pulsed and frequency-dependent IV characteristics of GaAs FETs", IEE Proc. Pt. G, Vol. 143, No. 3, June 1996, pp. 129-133.