THE INFLUENCE OF PULSE SEPARATION AND INSTRUMENT INPUT IMPEDANCE ON PULSED IV MEASUREMENT RESULTS

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ABSTRACT

Pulsed current-voltage (IV) characterization has arisen as a method that can be used in many cases to obtain more accurate large-signal device characterization. The accuracy of pulsed IV measurements requires the use of a sufficiently short pulse length and a sufficiently large pulse separation. For a small class of devices, if the pulse separation used is too short, the steady-state condition at the quiescent bias point may not be reached between pulses. In this case, the measurement results depend on the actual steady-state condition achieved, which is not the steady-state condition of the desired quiescent bias point and is dependent on several factors, including instrument input impedance. It is shown in this work that a longer pulse separation must be used in measurements involving devices with significant trapping effects (such as a GaAs MESFET) for quiescent bias points near pinch-off, while a shorter pulse separation is often acceptable for Class A quiescent bias points and for devices with minimal trapping effects (such as a Si MOSFET). The normalized difference unit is used to allow numerical analysis of the IV results.

I. INTRODUCTION

Pulsed current-voltage (IV) characterization has arisen as a method for more accurate RF large-signal characterization of devices [1]-[3]. Traditional static DC IV, or "curve tracer" measurements, are often insufficient for describing the RF large signal behavior of devices because thermal and trapping effects are dependent on the trace location and not on the quiescent bias point. In pulsed IV measurement, short pulses with small duty cycles are taken from a quiescent bias point to the desired measurement locations throughout the IV plane. The shortness of the pulse length allows measurement at each location before slow processes can occur at the measurement location. The large separation of the pulses allows steady-state thermal and trapping conditions to be reached at the quiescent bias point before each pulse [4].

In this work, a comparison of the pulsed IV results obtained using different models of a Dynamic i(V) Analyzer (DiVA), manufactured by Accent Optical Technologies, shows that noticeably different IV measurement results can be obtained for some devices and quiescent bias condition combinations due to instrument impedance differences. This is illustrated for a GaAs MESFET using a model D265 when compared to the D210 and D225 results. It is concluded that this difference is device-related and due to an insufficiently small pulse separation and the fact that the input impedance of the D210 and D225 models differs from the D265 input impedance. In addition, it is found that for a pinch-off quiescent point on a low-trapping device (a Si MOSFET), the difference between the curves is much smaller for a 1 ms pulse separation and that the measurement results in this case do not show improvement as the pulse separation is increased further.

II. THE NORMALIZED DIFFERENCE UNIT

The difference between two sets of IV curves can be expressed numerically by the normalized difference unit, defined in [5] and [6] as

$$NDU = \frac{1}{N}\left(\frac{\sum_{i=1}^{N}\left|I_{DS1i} - I_{DS2i}\right|}{\left|I_{DSmean}\right|}\right), \qquad (1)$$

where N is the number of measured points in each set of curves and I_{DS1i} and I_{DS2i} are the drain-source current at the ith (V_{GS}, V_{DS}) points of measurement[1] on the two current-voltage characteristics and I_{DSmean} is the average of the current values over all measured points from both characteristics, given by

$$I_{DSmean} = \frac{1}{2N}\sum_{i=1}^{N}(I_{DS1i} + I_{DS2i}).$$

This metric can be used to compare any two sets of IV curves made using the same settings. Typical uses include pulsed-static and measured-modeled comparisons. In this work the NDU is used to compare pulsed IV results with different pulse separation settings.

III. GaAs MESFET EXPERIMENTAL RESULTS

The impetus for this study arose from a comparison of IV analyzers which appeared to show an inconsistency in one of the instruments for a GaAs MESFET. It was initially discovered that, for a pulse separation of 1 ms, two different-model pulsed IV measurement instruments had very different IV results. A numerical comparison using the normalized difference unit (NDU) [5],[6] was performed for identical pulsed IV measurement settings using a quiescent bias point near pinch-off for a GaAs MESFET known to have slow trapping effects. It is shown with the aid of the NDU that as the pulse separation is increased; the difference between the results of the two IV analyzers vanishes, indicating that the initial measurement was not performed under correct characterization conditions.

A comparison between pulsed IV measurements with identical settings on three different instruments using the NDU is shown in Table I. The device-under-test for this experiment was a TriQuint CLY-5 GaAs MESFET, and the quiescent bias point used was V_{GS} = -2.2 V, V_{DS} = 0 V, near pinch-off. The main diagonal of the table (numbers in boldface) indicates the repeatability for each instrument, while the other NDU values correspond to a comparison of results between different instruments. The instruments being compared are the Accent Dynamic i(V) Analyzers (DiVA) models D210, D225, and D265.

The NDU values corresponding to the comparisons between repeated measurements on each instrument (main diagonal) indicate that the NDU expressing such repeatability is on the order of 0.02 or lower. Thus any larger number suggests a bona-fide difference in the IV curves. The D210 and D225 results compare reasonably well. However, the comparisons of the D265 to the other instruments yield relatively high NDU values (over 0.15 in all cases), indicating that the measurement results are much different. Fig. 1 shows the D225 and D265 results.

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[1] While the concepts are here discussed for FET devices, the same approach applies to bipolar devices with appropriate changes in terminology.

TABLE I: NDU VALUES COMPARING PULSED IV RESULTS FOR THREE DiVA MODELS

	D210	D225	D265
D210	**0.0076**	0.032	0.151
D225	0.037	**0.013**	0.175
D265	0.15	0.173	**0.02**

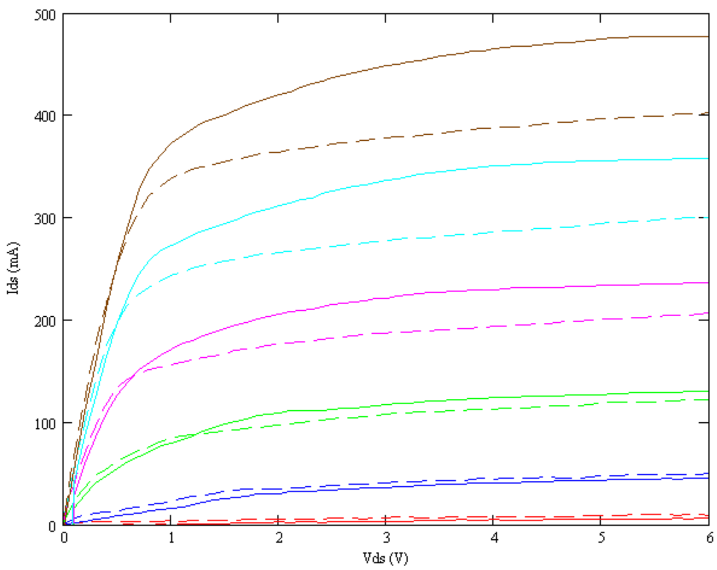

Fig. 1. Initial DiVA D265 (Solid Lines) and D225 (Dashed Lines) Pulsed IV Results for Quiescent Bias Point (V_{GS} = -2.2 V, V_{DS} = 0.0 V, labeled with a "X"), Pulse Separation = 1 ms (NDU = 0.156)

In response to this problem, an experiment was performed in which identical measurement settings were used with pulse separation values of 1, 10, 100, and 1000 ms. The settings for the measurement are as follows:

<u>Pulsed IV Measurement Settings</u>

- V_{GS} from -2.2 V to -0.7 V in steps of 0.3 V
- V_{DS} maximum = 6 V
- I_{DS} maximum = 500 mA
- Instantaneous Power Limit = 2.5 W
- Bias Point V_{DS} = 0 V
- Bias Point V_{GS} = -2.2 V
- Average Over: 16 samples
- V_{DS} step size = 0.1 V
- Pulse Length = 0.2 µs
- Pulse Separation = 1, 10, 100, 1000 ms

The IV curves corresponding to a 1000 ms separation are displayed in Fig. 2. Fig. 3 shows a plot of the NDU between the D225 and D265 results against pulse separation, along with the repeatability "noise floor" of NDU = 0.02 (the maximum NDU value between D265 results in Table I. The NDU between the measurements made on the two instruments decreases from a 0.156 for a separation of 1 ms to 0.028 for a separation of 1000 ms. The plot in Fig. 3 is an indication that for the 100 and 1000 ms pulse separation settings, the D265 and D225 differ by an amount that can be attributed to instrument-to-instrument repeatability, being slightly higher than measurement repeatability on the same instrument, and not due to non-steady-state conditions. It also shows that there is no significant difference between the results from using a 100 ms separation and a 1000 ms separation, an important conclusion. Thus, it appears that for this GaAs MESFET, accurate results (pertaining to the separation) will be achieved by using a separation of 100 ms.

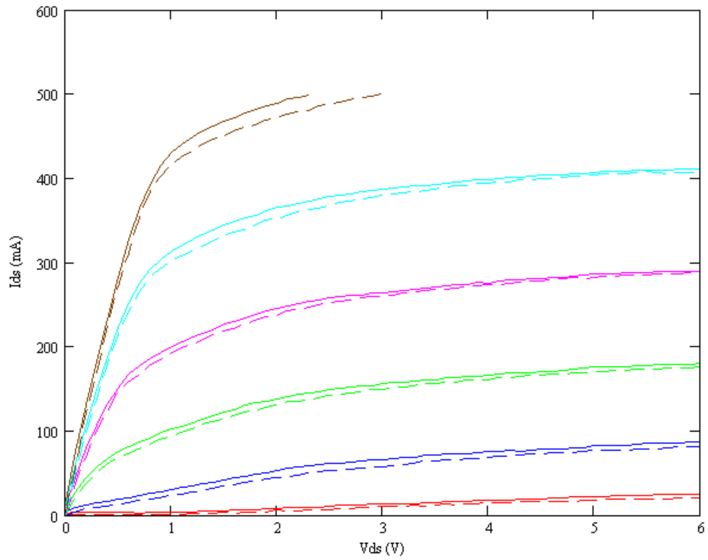

Fig. 2. D225 (Solid Lines) and D265 (Dashed Lines) Measured Pulsed IV Curves for the GaAs MESFET with a pulse separation of 1000 ms and a quiescent bias point of V_{GS} = - 2.2 V, V_{DS} = 0 V (marked with an "X") (NDU = 0.028)

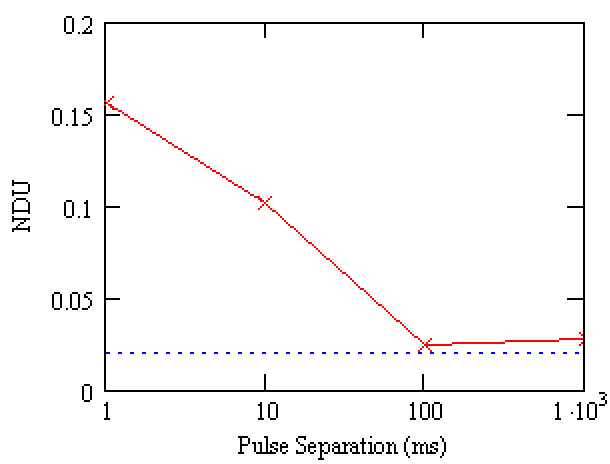

Fig. 3. NDU Comparing D225 and D265 Pulsed IV Results Versus Pulse Separation (Solid Line) and Estimated Instrument Repeatability NDU Level (Dotted Line)

The cause of the difference in results is analyzed in this paper and shown to be due to an insufficiently short pulse separation, which does not allow the quiescent bias steady-state condition to be reached between pulses. If the pulse separation used in measurement of the GaAs MESFET is not sufficiently long, the results of the measurement will vary based on the input impedance of the instrument. The input impedance of the D225 at the drain port for this measurement was 10 Ω, while the input impedance for the D265 was 23.5 Ω [7]. Thus the results differ for a pinched-off bias point due to differing impedances in the path of the electrons attempting to return to the pinched channel and "reset" the trapping condition. For the 1 ms separation, neither analyzer reaches the quiescent bias point steady-state. The different input impedances cause the actual steady-state condition achieved by the two devices to be different based on the amount of traps in the channel that can be reset during the separation period. The problem is accentuated for this device due to the fact that it is implemented using the Dual Implant One Metal (DIOM) technology, causing it to be very susceptible to surface states. It is suspected that similar behavior could be observed in unpassivated SiC and GaN FETs.

The experiment was also performed for a quiescent bias point near pinch-off with a Mitsubishi RD07MVS1 Power Si MOSFET, a device expected to have very little trapping from previous MOSFET experiments [5]. The D225 and D265 pulsed IV results are shown in Fig. 4 to have results that compare much better than the curves pertaining to the pinch-off quiescent bias point for the GaAs MESFET. As a confirmation that the 1 ms pulse separation is sufficient in this case, an increase in the pulse separation does not cause a closer correspondence in the results (Fig. 5). Thus it seems that the 1 ms pulse length provides optimal results in the case of this device for which thermal effects are dominant.

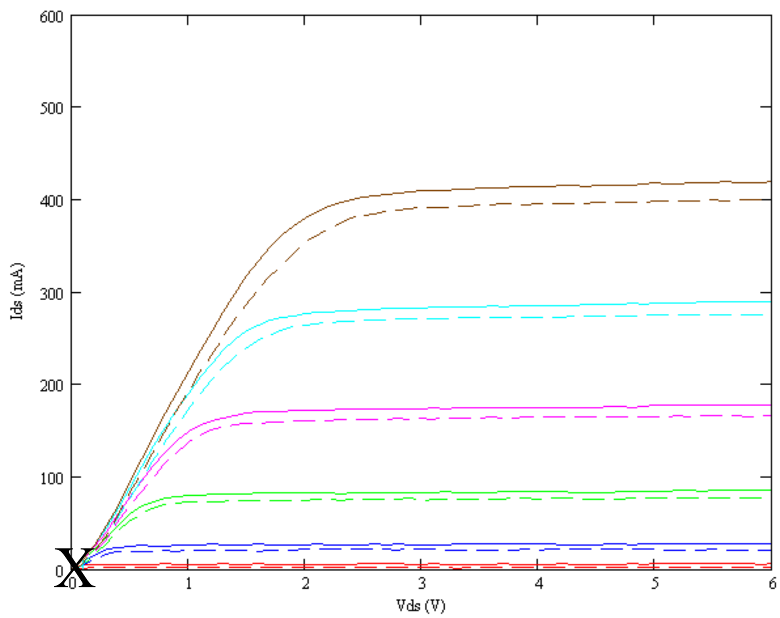

Fig. 4. D225 (Solid Lines) and D265 (Dashed Lines) Measured Pulsed IV Curves for the Si MOSFET with a pulse separation of 1 ms and a quiescent bias point of V_{GS} = 2 V, V_{DS} = 0 V (marked with an "X") (NDU = 0.084).

Therefore, while a pulse separation of 1 to 10 ms is sufficient for accurate pulsed IV measurement on most devices, a longer pulse separation may be required for particular devices with large surface-state trapping effects when a quiescent bias point near pinch-off is used. While the current voltage measurement takes longer, a significant increase in accuracy is obtained.

V. CONCLUSIONS

The results of this experiment show the importance of using a proper separation between pulses in pulsed IV measurement. For a small class of devices with significant trapping effects, if a proper separation of pulses is not used, the steady-state condition will not be that of the desired quiescent bias point; additionally, this steady-state condition differs from instrument to instrument depending on the measurement port input impedance. A longer pulse separation is necessary when attempting to measure pulsed IV characteristics corresponding to a quiescent bias point near pinch-off in high-trapping devices such as GaAs MESFETs. This is because the trap states take an extremely long time to reset due to the fact that the channel is pinched off between measurements. In such a situation, the number of traps that can be reset during the pulse separation is governed by the port input impedance of the measurement instrument. In the case of the GaAs MESFET, it was found that satisfactory agreement between results obtained on instruments with different input impedances was obtained for a pulse separation of 100 ms. It was found, however, that a separation of 1 ms was acceptable for measurements of an example Si MOSFET device in which trapping effects are negligible.

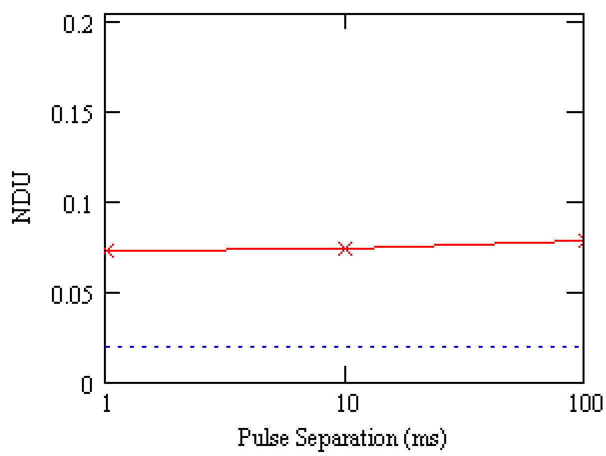

Fig. 5. NDU Versus Pulse Separation for the GaAs MESFET Pulsed IV Measurements with Quiescent Bias Point (V_{GS} = -1 V, V_{DS} = 3 V).

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