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Performing and Analyzing Pulsed Current-Voltage Measurements

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This article describes the methods used for pulsed measurements that reduce stress on power devices during characterization

Pulsed IV analysis allows the development of more accurate nonlinear models for RF and microwave device operation. An analysis of pulsed IV waveforms allows better exploitation of measurement capabilities to produce accurate results. Static and dynamic IV measurement waveforms produced by a commercially available pulsed IV analyzer are examined. Because transistors can become unstable during any type of IV measurement, the use of bias tees allows a frequency-dependent impedance to be presented. However, it is shown that care must be used when using bias tees in pulsed IV measurement to choose a bias tee with an inductor time constant significantly higher than the pulsing frequency but significantly lower than the frequency at which oscillations develop.

Introduction

Pulsed current-voltage (IV) measurements have emerged as a preferred method of obtaining current-voltage characteristics for active devices such as field-effect transistors (FETs), high electron mobility transistors (HEMTs) and bipolar junction transistors (BJTs) [1]. In traditional static, or curve tracer, measurements, IV characteristics are measured by increasing drain-source (or collector-emitter) voltage from zero to the maximum value for each value of gate-source voltage (or base current). In pulsed IV measurements, pulses are made from a static quiescent bias point determined by the user to the necessary locations throughout the IV plane [2]. Such measurement more accurately resembles radio-frequency and microwave operation, due to the fact that temperature and trapping effects do not have sufficient time to occur at the voltages and currents being measured, but are wholly dependent upon the quiescent bias point [3].

A popular commercial instrument for performing pulsed IV testing is the Dynamic IV Analyzer (DIVA) manufactured by Accent Optoelectronics, that allows measurement with pulse lengths as low as 0.1 µs [4]. To allow users to better understand the method of pulsed IV measurement, a study has been performed of the voltage waveforms at the gate and drain ports of a model 265 DIVA. The analysis is easily performed for any pulsed IV system by using an oscilloscope with its two channels connected to the gate and drain channels of the pulsed IV system.

From these measurements, it can be seen how the system performs pulsed IV measurements in a way to provide isothermal (constant temperature) and isodynamic (constant trap occupancy) conditions.

Devices can become unstable during IV measurement, causing the measured characteristic to change [5]. It may be possible to avert such problems by using bias tees (e.g. terminated in 50 ohms) in conjunction with a pulsed IV analysis system; however, the time constants of the inductor and capacitor in the bias tee must be chosen so that the capacitor is seen as a short circuit and the inductor as an open circuit at the frequency of oscillation, while the opposite is true for the frequency content of the pulses. Pulsed IV waveforms taken through bias tees are examined and the effects of bias tees on device characteristics are demonstrated.

	Pulse Duration	Pulse Separation	Voltage Range	Current Range
Gate Port:	200 ns to 1 ms	500 µs to 1 s	–15 V to +10 V	0 to 180 mA
Drain Port:	100 ns to 1 ms	500 µs to 1 s	0 V to +65 V	0 to 2 A

Drain Current Limit	Gate Output Impedance	Gate Current Resolution	Drain Output Impedance	Drain Current Resolution
<250 mA	50 Ω	±0.25 mA	100 Ω	±3.25 mA
>250 mA	50 Ω	±0.25 mA	10 Ω	±32.5 mA

Table 1 · Accent DIVA D265 specifications (4).

Pulsed IV Measurement Basics

There are two major types of processes causing inaccuracy of static DC IV results. Self-heating of the device causes inaccuracy of typical DC IV measurements. It is well-known that the channel temperature TC of a transistor is given by the equation

$$T_C = \theta P_D + T_A \qquad (1)$$

where θ is the thermal resistance of the device (not necessarily a constant), P_D is the power dissipated in the channel, and T_A is the ambient temperature at which the measurement is performed. P_D is given by the product of the drain voltage and drain current at which the thermal state is set. In static DC IV measurement, the dwell time at each point is sufficiently long that the thermal state is set for each point on the trace. However, in RF operation, the frequency of operation is so high that the thermal state is set by the quiescent bias point.

Trapping effects, a second cause of DC IV inaccuracy, are dependent upon the surface states and deep levels in the semiconductor material [6]. As with thermal conditions, the minimum time constant of the trapping conditions is such that trapping is dependent upon the quiescent bias point in RF operation. Note that this quiescent point could change under RF drive in some classes of power amplifiers (e.g. Class B).

Due to these thermal and trapping conditions, it can be concluded that pulsed IV measurement from a quiescent bias point will provide a more accurate set of RF IV curves for a transistor. To obtain an accurate characteristic, a pulse length should be used that is short enough to provide an IV measurement under isothermal (quiescent thermal) and isodynamic (quiescent trapping) conditions. The range of pulse lengths available should allow accurate device characterization. Scott gives 2 µs as a maximum pulse length for isothermal and isodynamic measurements of an example FET device [7].

Static and Pulsed IV Waveforms

Measurement of the static and pulsed IV waveforms of a DIVA model D265 was performed by connecting the channels of an oscilloscope to the gate and drain channels of the instrument. Manufacturer specifications for the D265 model are shown in Table 1, showing the available range of measurement parameters. First, a static IV measurement waveform was obtained using the following settings for the DIVA unit:

- V_{DS} from 0 to 6 V
- V_{GS} from –1.5 V to –1 V in 0.5 V steps
- V_D maximum = 6 V
- I_D maximum = 500 mA
- Instantaneous Power Limit = 1.4 W
- Average over: 16 samples
- Sweep Rate = 1 V/s

Figure 1 shows the resultant measurement waveform. For each gate voltage, the drain voltage is swept from its minimum to maximum value. The gate voltages are stepped in order from minimum to maximum values.

Next, analysis of pulsed IV measurement waveforms was performed using the following DIVA parameter settings:

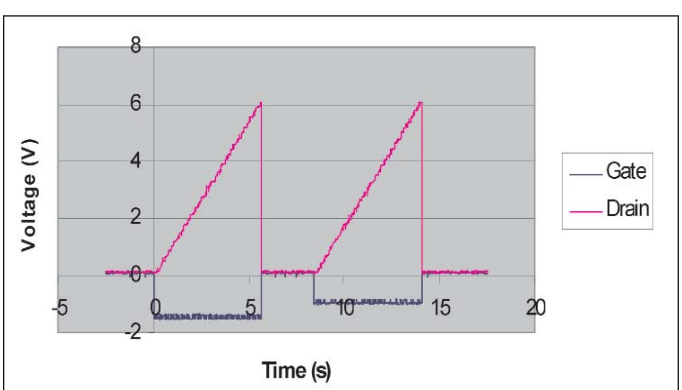

Figure 1 · Static measurement results for drain (top) and gate (bottom) voltages.

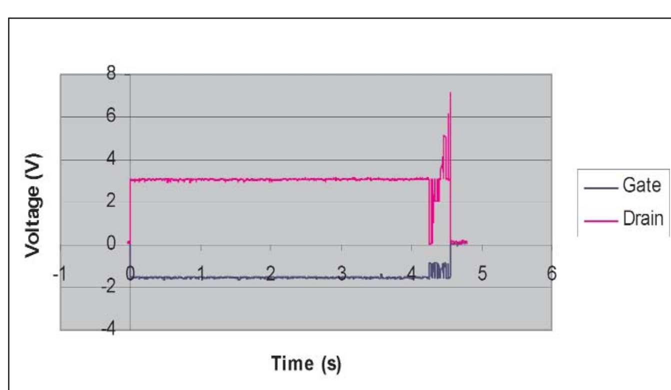

Figure 2 · Measured drain and gate voltages versus time (zoomed out).

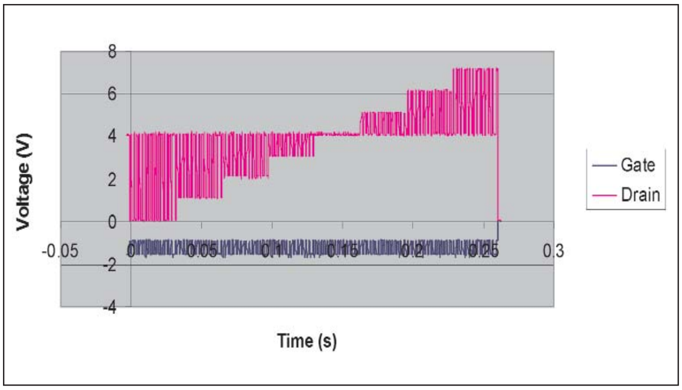

Figure 3 · Zoomed-in plot of DIVA pulsing. V_{DS} is swept from 0 to 7 V for a gate voltage of –1 V.

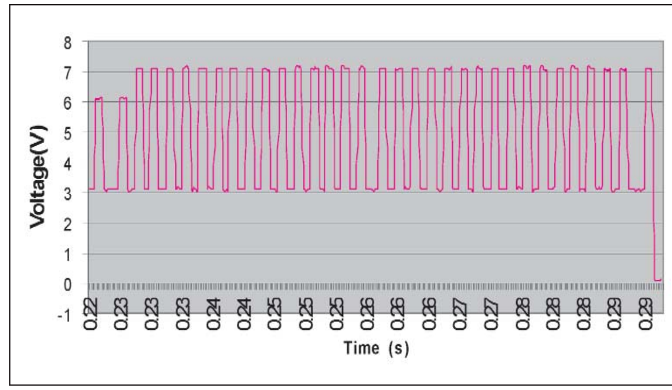

Figure 4 · Two series of DIVA 265 drain voltage pulsing; first value receiving 17 pulses.

- V_{GS} from –1.5 V to –1 V in 0.5 V steps
- V_{DS} maximum: 6 V
- I_D maximum: 500 mA
- Instantaneous Power Limit: 1.4 W
- Bias Point V_{DS} = 3 V
- Bias Point V_{GS} = –1.6 V
- Average over: 16 samples
- V_{DS} step size = 1 V
- Pulse Length (µs) = 1000
- Pulse Separation (ms) = 1

A zoomed-out view of the waveform is shown in Figure 2. The quiescent bias point of V_{GS} = –1.6 V, V_{DS} = 3 V is set and held for over 4 seconds before the pulsing is performed. Abernathy gives the typical thermal time constant of a GaAs MMIC device as 156 µs [7]; therefore, 4 seconds should be more than sufficient time for conditions to reach steady-state. Following the setting of the quiescent point, the pulsing is performed, followed by which the voltages are returned to zero.

A zoomed-in view of the pulsing shows the sequence in which voltages are measured. In this measurement, V_{DS} was swept from 0 to 7 V with a V_{DS} step size of 1 V and a gate voltage of -1 V. The quiescent bias point (from which the pulses are taken) is V_{GS} = -1.6 V, V_{DS} = 4 V. The resultant waveform is shown in Figure 3. For each gate voltage, the drain voltage is pulsed from the quiescent voltage to each V_{DS} value to be measured, from lowest to highest voltage. The gate voltage is also pulsed from the quiescent gate voltage to the gate voltage to be measured. After pulsing to all specified values of drain voltage for the minimum gate voltage, the process is repeated for the next gate voltage, until the measurements have been performed for all specified drain and gate voltages. An averaging setting of 16 samples was used for this measurement, so 16 pulses occur for each combination of gate and drain voltages. Figure 4 shows a plot of drain pulses to further illustrate this point.

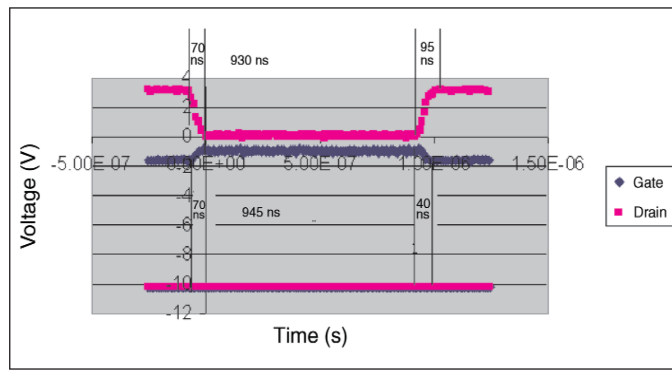

Figure 5 · DIVA drain and gate pulsing results with rise and fall times.

Figure 5 shows a measured DIVA drain and gate pulse for a nominal pulse length of 1 µs. The drain voltage rise time (it is actually falling) was measured by the oscilloscope as 70 ns (23.33 ns/V). The gate voltage rise time was also 70 ns (116 ns/V). The time for which the pulse maintained its value was 930 ns for the drain and 945 ns for the gate. If half of the rise and fall times are added to the hold times, the pulse length is 1.0125 µs for the drain and 1.000 ns for the gate. These are both very close to the desired pulse length of 1 µs. The drain voltage appeared to be removed slightly before the gate voltage. The drain voltage displayed a fall time of 95 ns (31.667 ns/V), while the gate fall time was 40 ns (66.67 ns/V). According to literature published by the manufacturer, the measurement is performed near the end of the pulse [4].

Measurement with Bias Tees

The DIVA is designed so that the external use of bias tees is not necessary to bias the device. However, situations often exist in which the 10 or 100 ohm input impedance of the DIVA places the device in an unstable situation. In this case, it may be desired to use bias tees in order to achieve stability. A study was performed con-

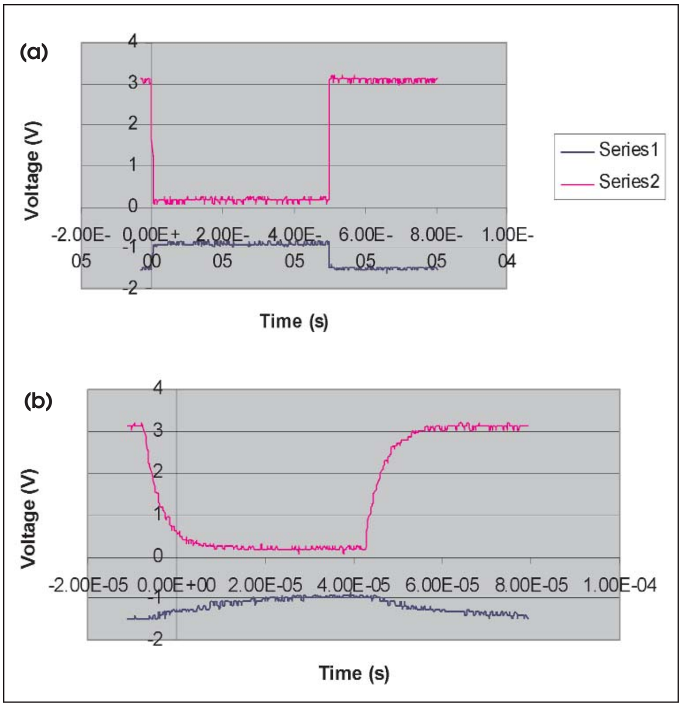

Figure 6 · DIVA pulse waveshapes: (a) without bias tees and (b) with bias tees, for a pulse length of 50 µs.

cerning the effect of bias tees on the accuracy of DIVA D210 results. In this experiment, pulsed IV measurements were performed for different pulse lengths on a TriQuint CLY-5 GaAs FET with and without the bias tees inserted between the ports of the DIVA and the ports of the device. The drain and gate of the device were connected to the RF + DC ports of the bias tees and the instrument ports were connected to the DC ports.

An RL distortion in the pulsed IV waveform can be observed for the case when the bias tees are connected. Figure 6 shows the waveforms for a pulse length of 50 µs without and with bias tees. The point of departure from the quiescent voltage toward the voltage to be measured and the departure for the return occur 50 µs apart in both cases; however, the rise and fall times are lengthened due to RL distortion in the case where bias tees are used. The accuracy of the result remains unaffected as long as the first RL distortion does not extend into the region in which the measurement is made. However, as the pulse length is decreased beyond about 20 µs, distortion begins to be visible in the IV results. Figure 7 shows the pulsed IV results for pulse lengths of 1000 and 5 µs. For the 1000 µs curves, the results appear identical, while for a pulse length of 5 µs, the results are affected. From this experiment, it was determined that the lower inductor time constant of the two bias tees used is about 20 µs. This indicates that for pulsed IV measurements performed with a pulse length greater than 20 µs, the bias tees can be included with no effect on the results. Theoretically, this cutoff pulse length can be calculated if the bias tee inductance values are known. The time constant of an inductor is given by

$$\tau = L/(2\pi R) \tag{2}$$

where R is the resistance seen by the inductor terminals, which is usually obtainable or known.

To avoid oscillation due to device instability in transistor measurements, it is proposed that a bias tee be constructed or selected which has an inductive time constant less than the desired pulse length but that has a capacitive time constant less than the frequency of oscillation. By this method, the RF port of the bias tee can be terminated in an impedance that places the device in a stable region, and this impedance can be shown to the frequency of oscillation while pulsed IV measurements are successfully performed.

Conclusions

Examination of the waveforms used by a standard pulsed IV measurement system allows a user to become familiar with the methods and rationale behind pulsed IV measurements. The pulsed IV waveforms examined can provide the capability of isothermal and isodynamic transistor measurements for more accurate RF characterization. Bias tees can be used to allow pulsed IV measurements to be performed on transistors in some cases; however, a pulse length that is higher than the period of oscillation must be used. In addition, the pulse length must be greater than the inductor time constant of the bias tee.

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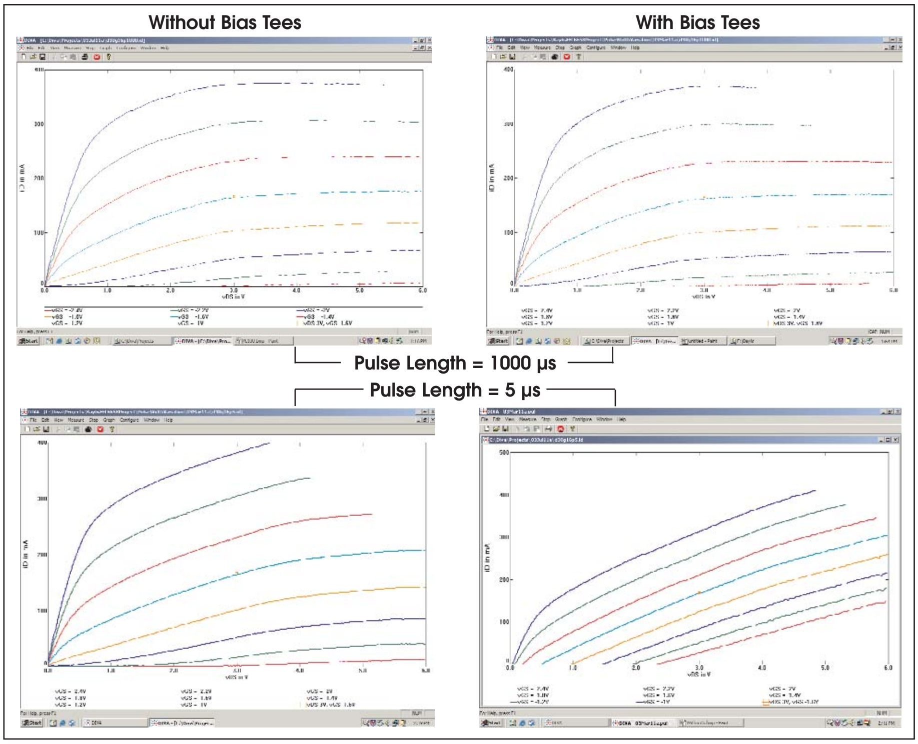

Figure 7 · DIVA pulsed IV results with and without bias tees at pulse lengths of 1000 and 5 µs.

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