Determining Timing for Isothermal Pulsed-bias S-parameter Measurements

Anthony Parker, Jonathan Scott, James Rathmell and Mohamed Sayed

Abstract—**S-parameters measured under pulsed conditions are shown to vary from their steady-state values with pulse measurement width and pulse repetition rate. A method is presented for determining suitable timing for isothermal, pulsed-bias, pulsed-RF, S-parameter measurement of GaAs devices. Variation of S-parameters with wafer temperature and with measurement duration and duty cycle are correlated.**

I. Introduction

Pulsed-bias, pulsed-RF measurement of devices has been possible for some time. A device is switched briefly to the bias point where RF measurements are made. These measurements are interleaved with long quiescent periods where no RF is applied. The technique has been used to measure instantaneous FET characteristics with control over channel temperature, established during the quiescent period, and is known to yield data unavailable from inferior tests.[1], [2] The aim is usually to measure S-parameters in an interval short enough that the device does not heat up, and at intervals spaced sufficiently to fully recover from the perturbation of measurement.

Recently, a method for selecting appropriate bias-pulse durations has been reported.[3] The method reported in [3] is intended for situations where only the bias characteristics are sought, since it assumed a system that can carry out a complex measurement in a short period of time.[4] We demonstrate a method applicable when pulsed-S-parameter data are to be gathered. We correlate the variation of S-parameters with measurement duration and duty cycle against a change in wafer temperature.

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II. Measurements

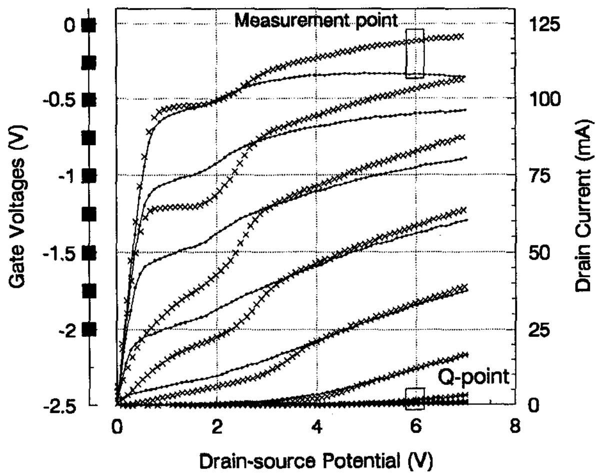

Fig. 1. Drain characteristics of an HP GaAs FET measured with $2\mu s$ (×) and 10ms (•) pulse durations. Note that the gate-voltage steps corresponding to the characteristic traces are plotted on the left-hand y-axis.

Using the equipment described in [4], we measured a Hewlett-Packard 250μm-wide GaAs FET under pulsed conditions. The drain characteristic is shown in figure 1. The low-frequency dispersion is clearly visible in the data gathered at 10ms/point (timing typical of low-frequency Semiconductor Parameter Analysers such as the industry-standard HP4145). Note that the characteristic is quite different when measured at $2\mu s$/point with 10ms quiescent interval. We then measured the device S-parameters in $2\mu s$ and 10ms pulses at the point $V_{ds} = 6$V, $V_{gs} = 0$V (which measurement point we designate as "{6,0}"). The quiescent point was

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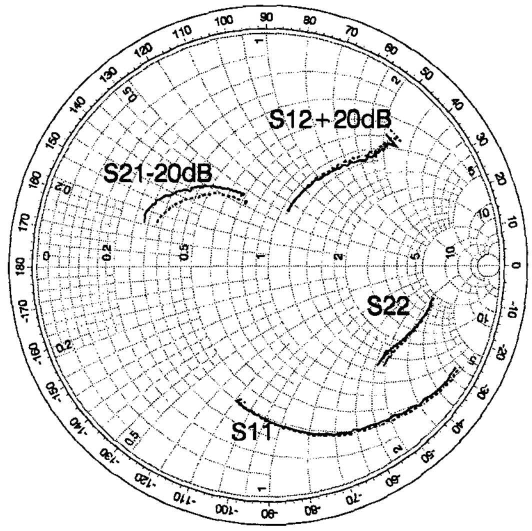

Fig. 2. S-parameters for the GaAs FET from 2–10GHz with pulse measurement times of 2μs (solid lines) and 10ms (dotted lines). The quiescent interval was 10ms in both cases. Note that S_{21} has been scaled down by 20dB, and S_{12} up by 20dB, for plotting clarity.

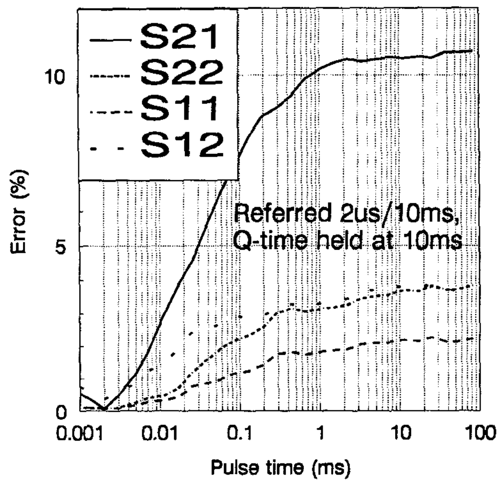

Fig. 3. Average discrepancy from 2–10GHz between S-parameters of the GaAs FET measured in 2μs pulses spaced 10ms and the S-parameters measured with a range of pulse intervals but the same quiescent interval of 10ms.

{6,-2}, and measurement pulses were spaced 10ms apart. (We designate this timing as "[2μ,10m]" and "[10m,10m]" .) Figure 2 shows the result of this S-parameter measurement. The change in the S-parameters, particularly S_{21}, is evident.

In order to determine the sensitivity to timing we measured the device's S-parameters while varying the pulse duration and holding the quiescent time interval (interpulse spacing) constant at 10ms. For each measurement, we calculated the discrepancy between the parameters we obtained and those found in the "reference" case of {6,0}/[2μ,10m], shown in figure 2. The discrepancy or error has been calculated as the average over all frequencies of the complex distance between each S-parameter. (We measured at 51 frequencies equispaced between 2 and 10GHz.) The result is plotted in figure 3. Observe firstly that the traces flatten out above 1ms, indicating that the values of the parameters have settled to their steady-state values after the transition between quiescent and pulse points. This implies that there is little to be gained in this instance from settling intervals greater than 1ms. The channel reaches equilibrium after this interval. The traces also flatten out for small intervals. Note that the curves dip to zero error as they pass the reference point {6,0}/[2μ,10m]. The fact that the traces are only just levelling out at the 1μs point suggests that 1μs is only barely short enough for isothermal characterisation of this device. (Bias networks set a lower limit of $\approx$ 1μs for these tests. The RF equipment lower limit is just under 500ns, and the PIV limit 100ns.)

The conclusions in the preceding paragraph rest on the assumption that the interpulse interval—10ms—is sufficiently long. Consider now the plot of figure 4. Here the pulse time is held short, and the quiescent interval varied. The traces now settle for quiescent times in excess of about 200μs, although there is a small change as duty cycle extends from 1% to below 0.1%. This confirms that the choice of 10ms was sound. The tentative conclusion is that a pulse of duration below 2μs with a duty cycle below 1% will yield isothermal S-parameter data.

Can the limits of the region in pulse-time/quiescent-time space where device time constants affect the values of the S-parameters be quickly delineated by taking a single slice through the surface? For example, can the required bound-

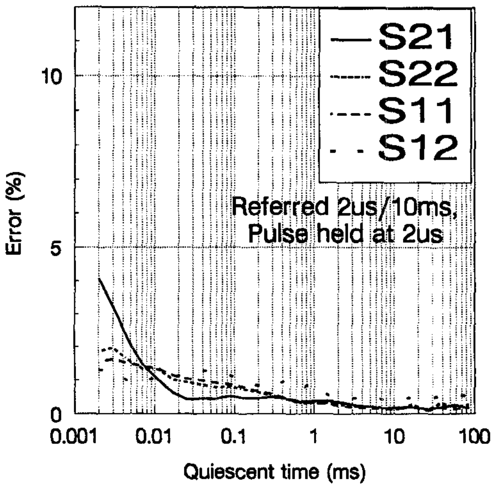

Fig. 4. Average discrepancy from 2–10GHz between S-parameters of the GaAs FET measured in $2\mu s$ pulses spaced 10ms and the S-parameters measured with a range of quiescent intervals but the same pulse interval of $2\mu s$.

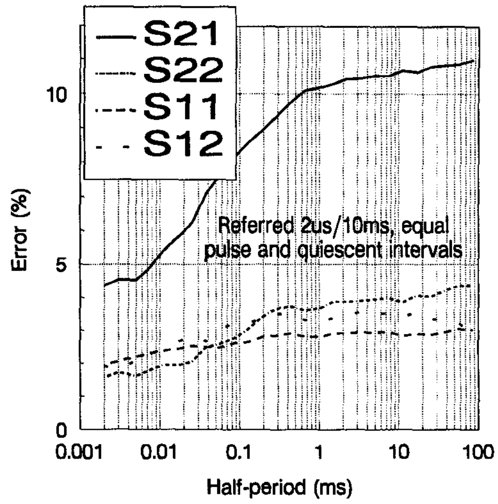

Fig. 5. Average discrepancy from 2–10GHz between S-parameters of the GaAs FET measured in $2\mu s$ pulses spaced 10ms and the S-parameters measured with quiescent and pulse intervals varying but held equal.

aries be found from the slice $t_p = t_q$? (All the graphs here are effectively slices through a 3-dimensional surface equivalent to figure 2 of [3], but with S-parameter error as the z-axis.) Figure 5 is the $t_p = t_q$ slice. The traces flatten out above 1ms, suggesting that this is a safe interval, but are still changing about two microseconds.

It should be noted that S-parameters accumulated during this test are not themselves useful; what is useful is a region where the traces level out, betraying a desirable timing interval. A final measurement with maximised short pulse and minimised long quiescent interval is desired to efficiently obtain the isothermal parameters corresponding to the selected quiescent point.

If it were possible to continue reducing t_p and t_q, we might determine both the pulse and spacing intervals from the slice of figure 5. However, we will show that this would yield an unnecessarily pessimistic estimate. Figure 6 is the full, 3-dimensional surface (corresponding to S_{21} only) showing parameter variation with pulse and quiescent duration. In practice we seek to avoid making the measurements required to obtain this plot; even with the system described in [4] this measurement takes several hours. For visualisation purposes we present it here.

The complete surface reveals that a constant $t_p + t_q$ slice most closely approximates the fall line to the optimal point, but without a priori knowledge of the sum, there will be no faster method than to take a small number of slices, such as the initial two we used here.

III. Comparison with Results obtained with a Thermal Chuck

Direct heating of the device during isothermal measurement should be able to cause a change in S-parameters similar to that occurring between isothermal and steady-state measurement. Table I compares values of S-parameters measured isothermally at 20C and 100C with steady-state parameters measured at 20C; the latter resemble the isothermal 100C set quite closely. The pulsed drain characteristics at 100C are plotted in figure 7 along with the 20C steady-state characteristics from figure 1. Note that the dc and 100C pulsed-I/V curves intersect near {6,0}. We infer that the observed changes are a result of change in device channel temperature.

S-parameters @3GHz	Isothermal 20C	Isothermal 100C	Steady-state 20C
S_{11}	$0.919\angle 2.36$	$0.946\angle 2.36$	$0.937\angle 2.38$
S_{12}	$0.0360\angle 0.561$	$0.0398\angle 0.592$	$0.0377\angle 0.612$
S_{21}	$6.15\angle$-1.08	$5.46\angle$-1.05	$5.45\angle$-1.04
S_{22}	$0.671\angle 1.85$	$0.666\angle 1.83$	$0.681\ \angle 1.83$

TABLE I

COMPARISON OF S-PARAMETERS AT 3GHZ MEASURED ISOTHERMALLY AT 20C AND 100C WITH STEADY-STATE S-PARAMETERS MEASURED AT 20C. ANGLES ARE IN RADIANS.

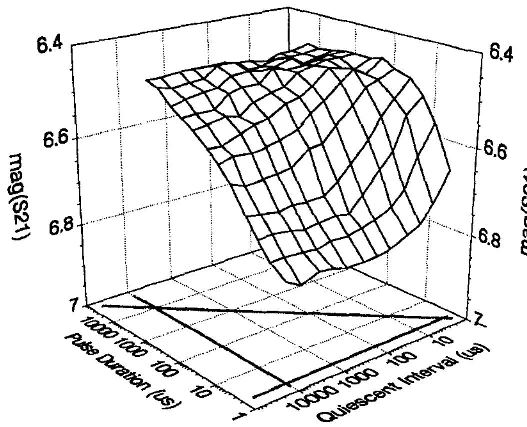

Fig. 6. Magnitude of S_{21} from 2.5–3.5GHz as a function of pulse and quiescent duration. The trajectories of the 2D slices previously considered are shown projected onto the xy-plane below the data surface.

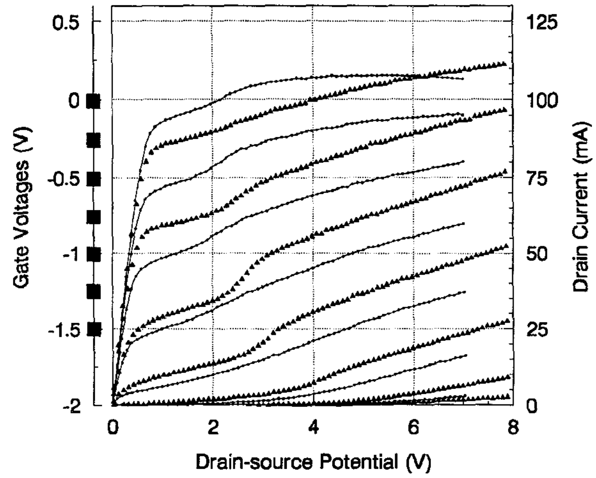

Fig. 7. Drain characteristics of the FET measured at 100C with 2μs pulses ($\triangle$) and at 20C with 10ms pulses ($\bullet$). Again the gate-voltage steps corresponding to the characteristic traces are plotted on the left-hand y-axis.

IV. CONCLUSION

Typically two curves, derived from S-parameters, allow identification of the pulse and interpulse intervals required to assure that S-parameters represent isothermal operation in a device. This is considerably faster than taking a whole 3-dimensional surface, and easier than determining the fall line on the fly.

REFERENCES

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[4] Jonathan Scott, Anthony Parker and Mohamed Sayed, "RF, Pulsed-IV, Device Measurement System in VXI" *Workshop on Applications of Radio Science*, Canberra, June 25–27, 1995.