IMPROVING UNDERSTANDING OF THE RF CIRCUIT BEHAVIOUR OF CONTEMPORARY SEMICONDUCTOR DEVICES THROUGH FAST-SAMPLING *I*(*V*) CURVE TRACER MEASUREMENTS.

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ABSTRACT

Most contemporary semiconductor devices exhibit dynamic *I*(*V*) behaviour that is different from the static (or dc) behaviour - in some cases markedly different. Commercial fast-sampling dynamic curve tracer instrumentation shows how devices ranging from diode structures to pseudomorphic high electron mobility transistors (PHEMTs) and heterojunction bipolars (HBTs) will behave in practical RF circuits. Examples of dynamic behaviour include the inability to cut-off some HBTs, which may lead to the power-added efficiency being highest at low supply voltages; highly non-diode-like flow of gate current and negative drain current flow in E-mode GaAs FETs; broadband negative differential conductivity in some PHEMTs, which complicates the circuit designers job of achieving stable circuits; the reduction of dispersion in high-voltage SiC FETs, and, by analysis of drain current transients, separation of the percentage contributions to dispersion in FETs and HEMTs made by deep levels and self-heating as a function of bias and operating point.

INTRODUCTION

Although in recent years there has been a general awareness that the dynamic *I*(*V*) characteristics of modern semiconductor devices may be different from their dc characteristics, the degree and diversity of these differences can be surprising. From a circuit engineer's point of view, devices should ideally be dispersionless - but they never are. Although some contemporary PHEMTs exhibit little dispersion for small gatewidths, generally dispersion is present in all devices and is a fact of life which has to be accommodated. The issue has importance to the fidelity-to-practice of non-linear device models for use in circuit simulators - a problem which becomes progressively more acute the more demanding become the specifications of circuits, especially power amplifiers for mobile services (including base stations).

A particular problem in measuring the high-speed *I*(*V*) characteristics of RF and microwave devices is keeping them stable, and in constructing instrumentation with sufficient bandwidth to excite two-port devices with synchronized fast pulses while preventing oscillation. A wide range of devices can now be measured with an instrument in which these difficulties have been solved, and which can be used by non-specialists (see [1]).

ENHANCEMENT MODE GAAS FET EXAMPLE

Figure 1 gives an example application: the upper frame shows the dc characteristics (thin lines) for an enhancement-mode GaAs FET compared with dynamic drain current characteristics measured with 100nsec pulses about a bias point of V_{DS} = 2V, V_{GS} = 0V. The two sets of curves are quite different. The lower frame shows the associated dc gate conduction characteristics. Under both dc and pulsed conditions the gate-source voltage is iterated to assure that, despite the passage of gate current, the correct pre-set value is maintained for each parametric curve. The gate current is decidedly non-diode like, and is not easily fitted by any of the commonplace large-signal models. Furthermore, the drain current for high positive V_{GS} and low V_{DS} is negative - a fact which is not easily accommodated by some large-signal models either (negative drain current is simply a result of forward gate conduction current flowing out of the drain, which is counter to the normal direction of drain current flow). Overall, despite the obvious attraction of E-mode devices for some circuit applications, care must be taken in creating a model of the device for inclusion in non-linear circuit simulators, and the gate current flow is too large to be ignored in practical circuits. To add to the complication, the characteristics are dependent upon the bias point about which they are measured.

ASPECTS OF DEVICE BEHAVIOUR UNCOVERED BY A FAST-SAMPLING CURVE TRACER

Many other aspects of device behaviour have been uncovered which are either surprising or present severe difficulties for generating non-linear device models for circuit simulators. In addition to those listed in the Abstract, the effects observed include

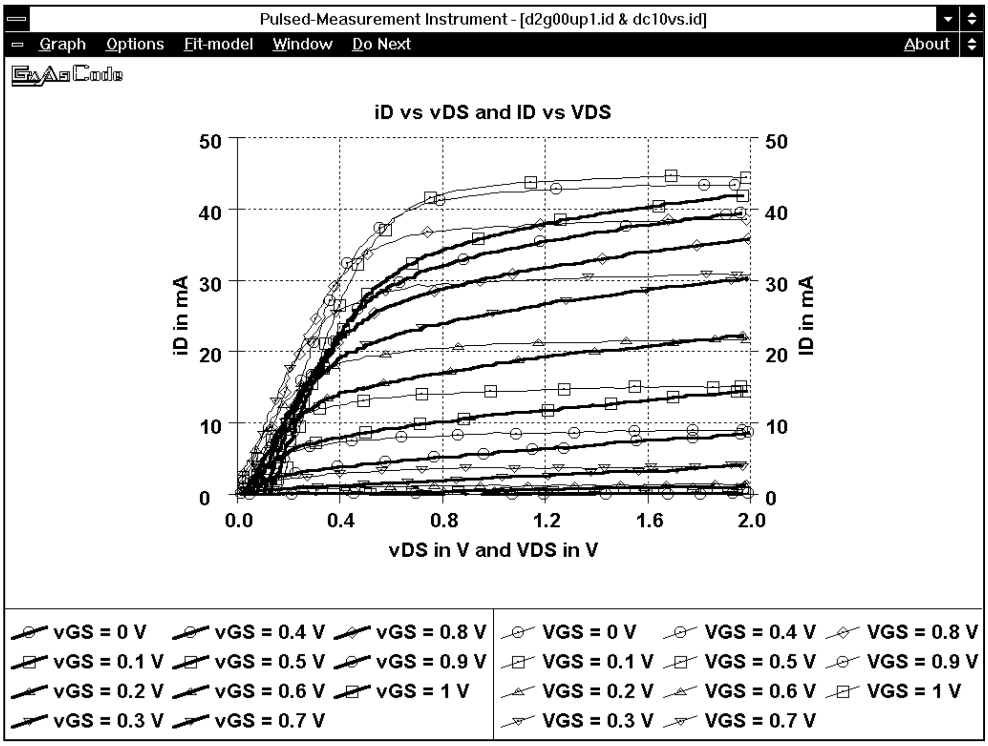
- large dispersion in bipolar transistors arising from self-heating;
- dramatic differences between the dynamic and static (or dc) breakdown characteristics of GaAs FETs.
- bipolar characteristics which are unstable unless the device is attached to a heatsink;
- drain current which is a two-valued function of V_{DS} in GaAs FETs where the current curls back on itself;
- negative differential conductivity in bipolars which is a rate effect probably arising from the operating-point dependence of the transistor's frequency response.

NEGATIVE DIFFERENTIAL CONDUCTIVITY IN BIPOLARS

An example of the phenomenon of negative differential conductivity in bipolars is given in Figure 2, which are results for a small microwave silicon mixer BJT. Negative differential conductivity occurs only for bias points like that shown, and only at base currents below bias. Nevertheless, the effect is real and legitimate. It occurs when the measurement is made at a fast enough rate (i.e. short enough pulse) to be comparable with the intrinsic response time of the transistor, which is a function of the operating point.

CONCLUSIONS

The static (or dc) behaviour of most semiconductor devices differs, in some cases markedly, from the dynamic behaviour. To characterise and model such devices for use in RF circuits fast-sampled measurements must be made. A commercial fast-sampling curve tracer has been used to uncover important aspects of device behaviour which are surprising and in some cases present severe difficulties for generating non-linear device models for circuit simulators.



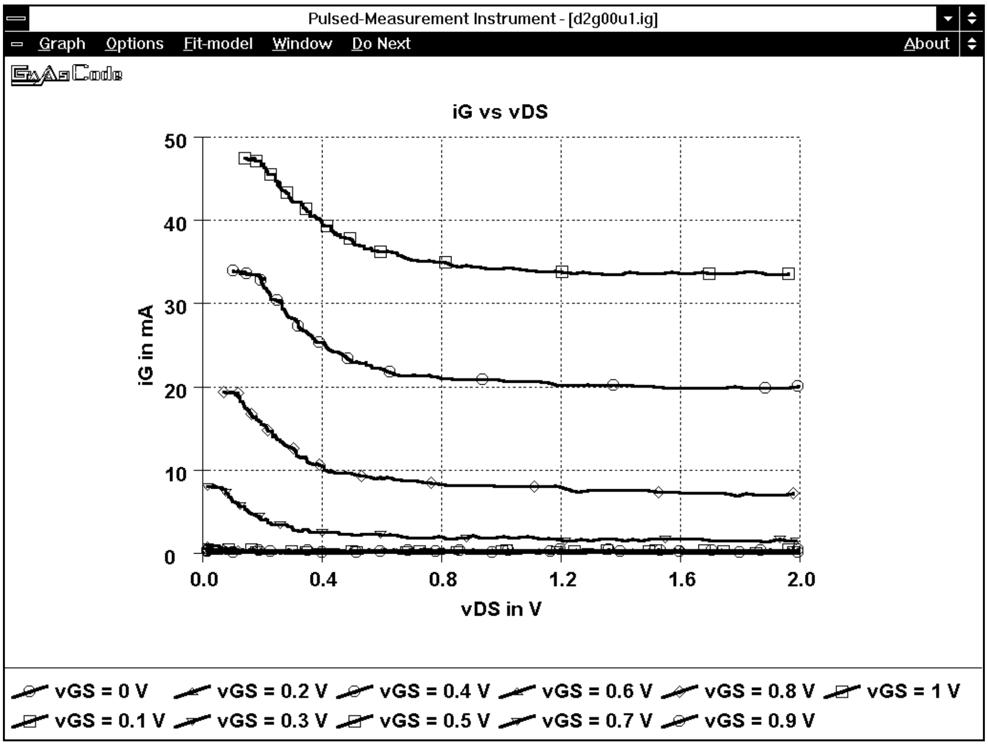


Fig. 1: E-mode GaAs FET characteristics. Upper frame: dynamic drain current (thicker lines) measured about a bias point of V_{DS} = 2V, V_{GS} = 0V compared with dc (thinner lines). Lower frame: gate conduction measured with 1µsec pulses about the same bias point.

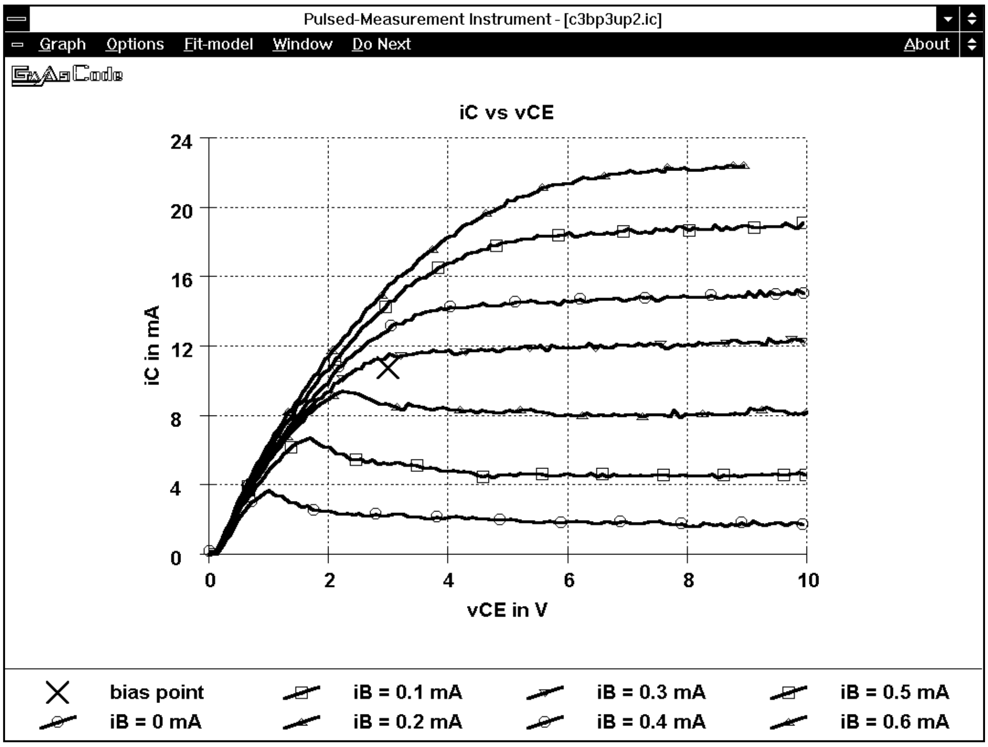


Fig. 2: Characteristics of a small microwave silicon mixer BJT measured using 200nsec pulses. Note the negative differential conductivity of the curves below the bias point.

REFERENCE

[1] P.H.Ladbrooke, N.J.Goodship, J.P.Bridge and D.J.Battison "Dynamic I(V) measurement of contemporary semiconductor devices", May 2000, Microwave Engineering Europe, pp23-33.