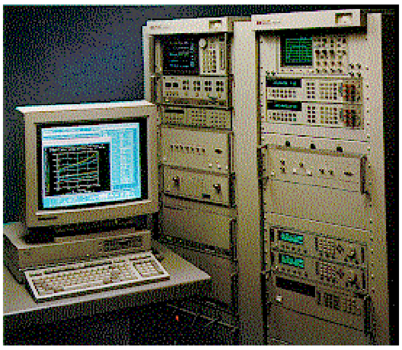
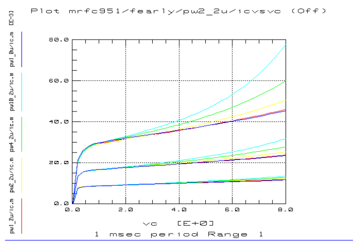
Slide 1

Introduction To
Pulsed DC and S-Parameter Measurements





Franz_Sischka@agilent.com

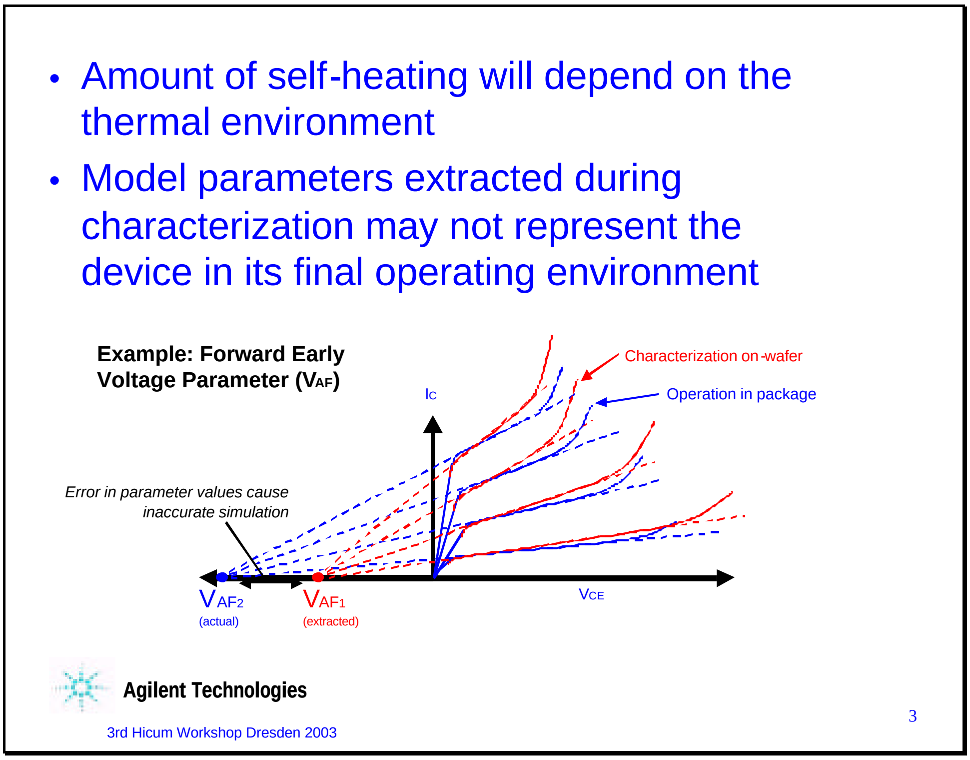
Agilent Technologies

Slide 2

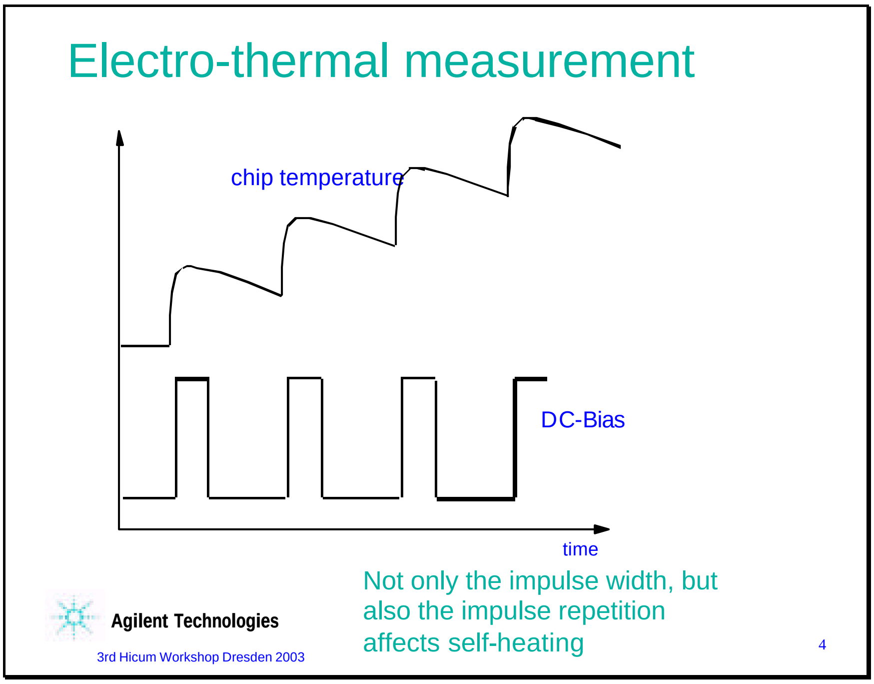
Electro-thermal modeling strategy

- Problem:
  - DC and S-par measurements are affected by self-heating.
  - Under non-pulsed conditions the temperature varies and is generally unknown.
- Solution:
  - Isothermal, pulsed measurements: accurate extraction of the electrical parameters at several constant temperatures.
  - Accurate Temperature Parameter extraction:
    RTH extracted using steady-state measurements.
    CTH extracted by measuring current vs. pulse width.

Slide 3



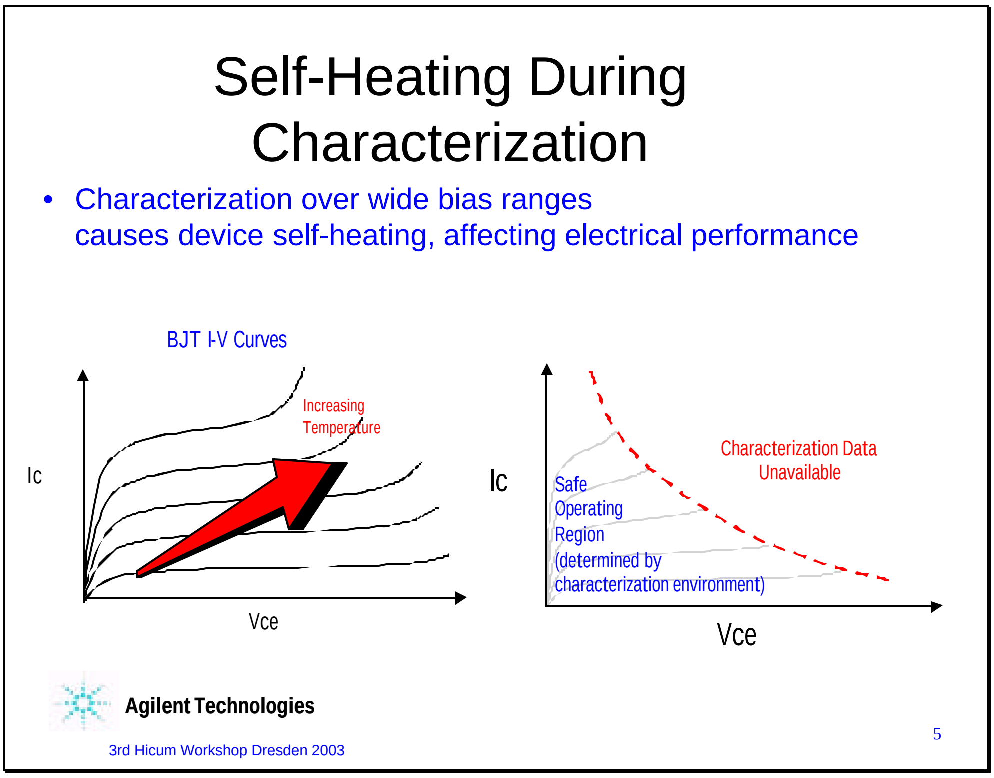
Slide 4



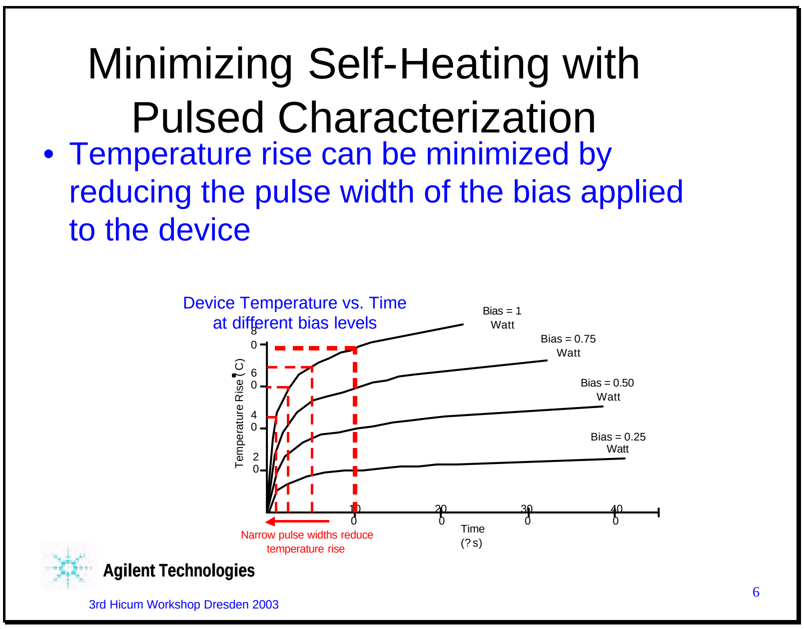
Self-heating can cause a major challenge to modeling, because as a general rule, we have to account for self-heating effects already at currents above ~10mA (for typical Vmax = 5V) for packaged devices, and for on-chip measurements using a thermochuck, the critical current is about 50mA.

A solution is to apply pulsed DC measurements. This provides isothermal measurement conditions, and allows to extract the model parameter values which are correct for the modeling temperature TNOM.
However, if these pulses exceed a few microseconds, self-heating might already occur.

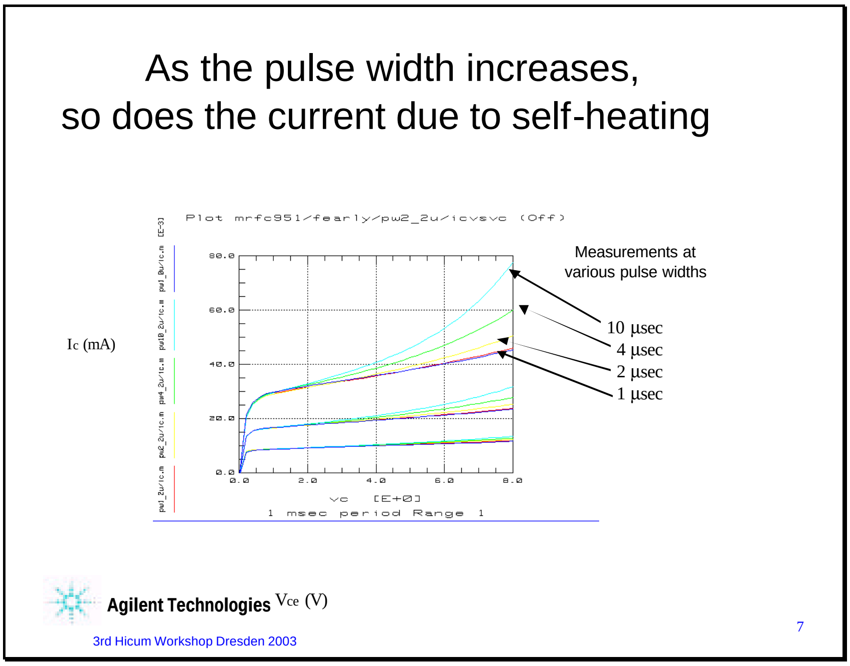
Slide 5



Slide 6



Slide 7



When measuring transistors with higher Drain or Collector currents, self-heating may occur. This means for an output characteristics, for example, that the traces at high Collector or Drain voltages belong to a hotter device than those of low voltages. For modeling, the main problem hereby is that later, the simulator models assume a constant temperature TNOM over the full output characterization sweep (!), and what we measure as a selfheating would be possibly modeled by an avalanche effect!

The slide above gives an example for a packaged bipolar transistor, measured with different pulse widths. It can be seen that only pulses in the millisecond range can lead to isothermal measurement results.

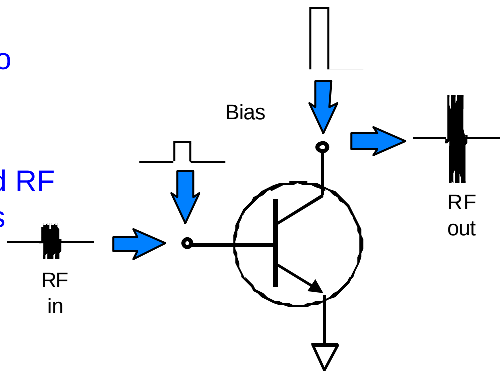
In order to avoid self-heating, the 100us of the Agilent 4142 and 415x are not short enough. The pulsed measurements of the 4142 and 415x are targeted for production test. For some of these tests, a CW mode would damage the device, and therefore, pulse measurements are performed instead. It is important to note that these pulsed measurements are not intended to prevent from self-heating, but rather from damaging the DUT! Therefore, these kind of pulsed measurements do usually not help much for modeling. If the DUT is later also measured by a NWA, it is even worse to apply these pulses for DC, because the device will definitively heat-up during the lengthy NWA measurements. And, in this case, the DC parameters apply to relatively cold (but not isothermal) measurements, while the biased NWA measurements are hot device measurements. In this case, it might no wonder when no curve fit can be achieved for both DC and S-parameters.

Self-heating can easily be verified when measuring the BETA of bipolar transistors or ROUT of MOS transistors once with a forward sweep (from low to high voltage), and a second time in reverse sweep. If both traces are different, self-heating might have occurred (Import the data of setup 1<forward> into setup 2<reverse>). The same experiment can be performed when applying the 100us pulsed measurements to the device. If self-heating occurs, we might end up with 4 different beta curves, depending on the sweep and pulse conditions.

Slide 8

Implementing the Complete Solution: Pulsed Characterization with NWAs

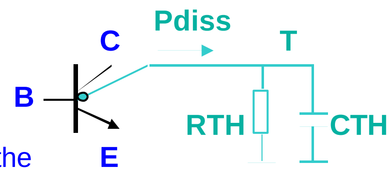
- Pulsing the bias to the device minimizes temperature rise due to self-heating
- Pulsed I-V and Pulsed RF characterization allows isothermal parameter extraction



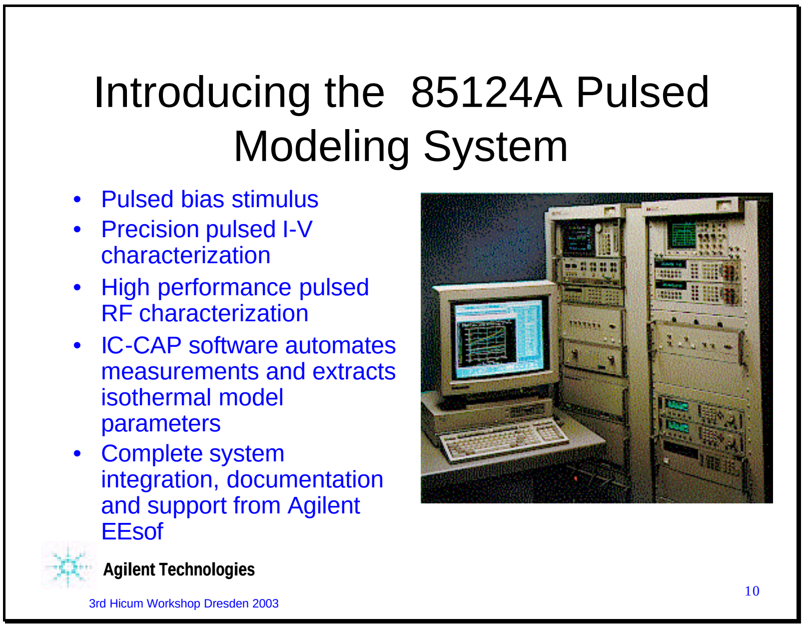
Slide 9

Electro-thermal SIMULATION

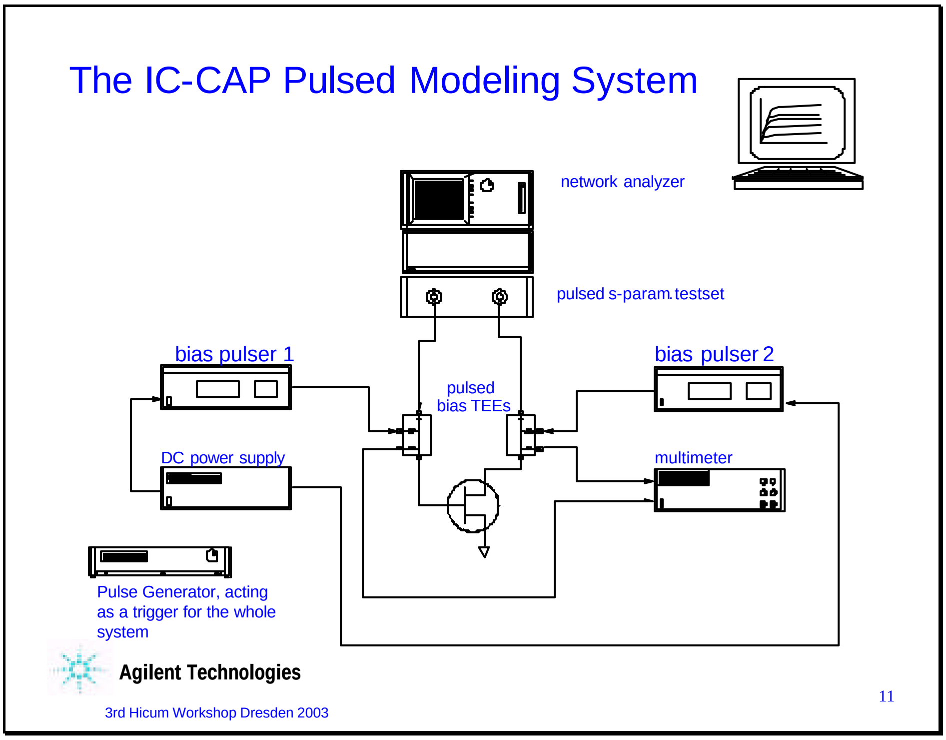
- Due to the internal architecture, simulators usually follow a concurrent approach.
- A temperature node is added to the model: voltage and temperature nodes are evaluated simultaneously.
- The device thermal model is described using thermal capacitances and resistances.
- Simulation results now include temperature and dissipated power.



Slide 10



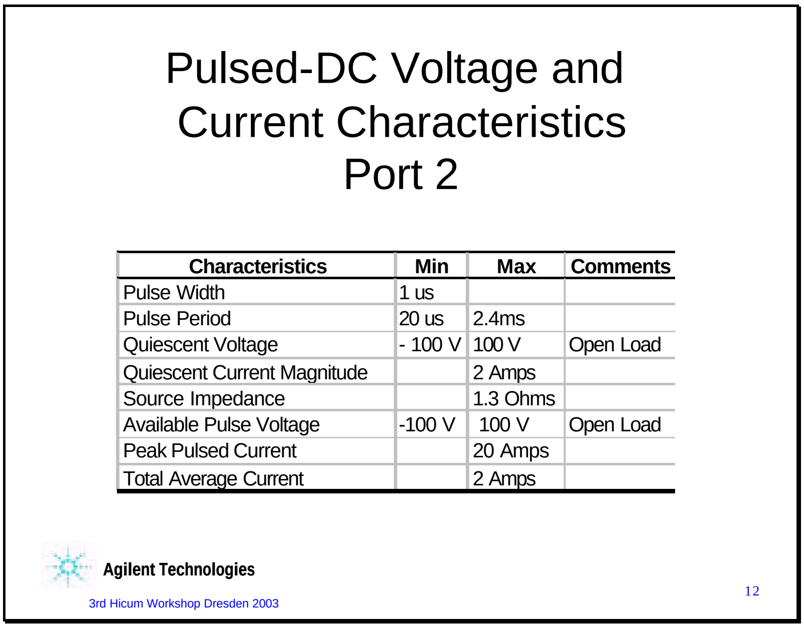
Slide 11



When measuring a transistor, the DC measurements are usually performed in fast sweep mode, i.e. pretty fast in time. On the other hand, performing the biased RF measurements (network analyzer), the underlying DC bias has to be kept constant during the whole frequency sweep, incremented and again constant for the next frequency sweep. This means that the RF measurements may have been performed at completely different chip temperatures than the DC measurements. And while the possibly cooler DC measurements served to extract the DC model parameters, we may run into problems when extracting the remaining RF parameters, which refer to hotter measurement conditions.

To avoid this, a complete measurement setup has been configured for IC-CAP as the Agilent 85124A Pulsed Modeling System. This system allows 1us pulsed measurements from DC up to 40GHz. The slide above gives an overview of the system .

Slide 12

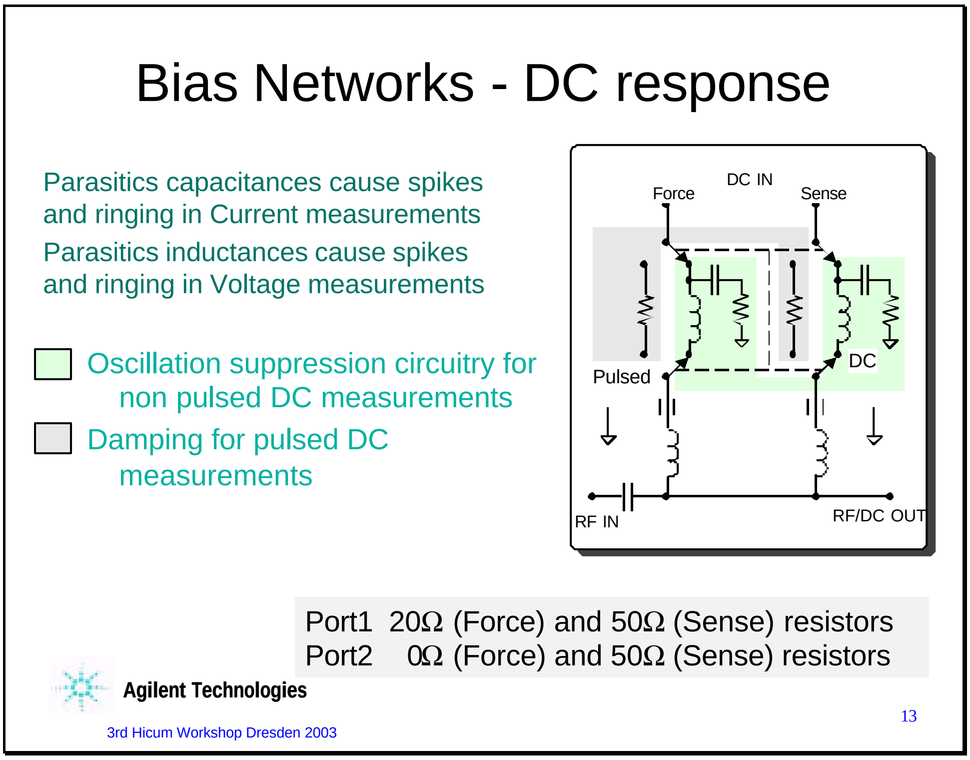


Pulsed-DC Voltage and Current Characteristics Port 2

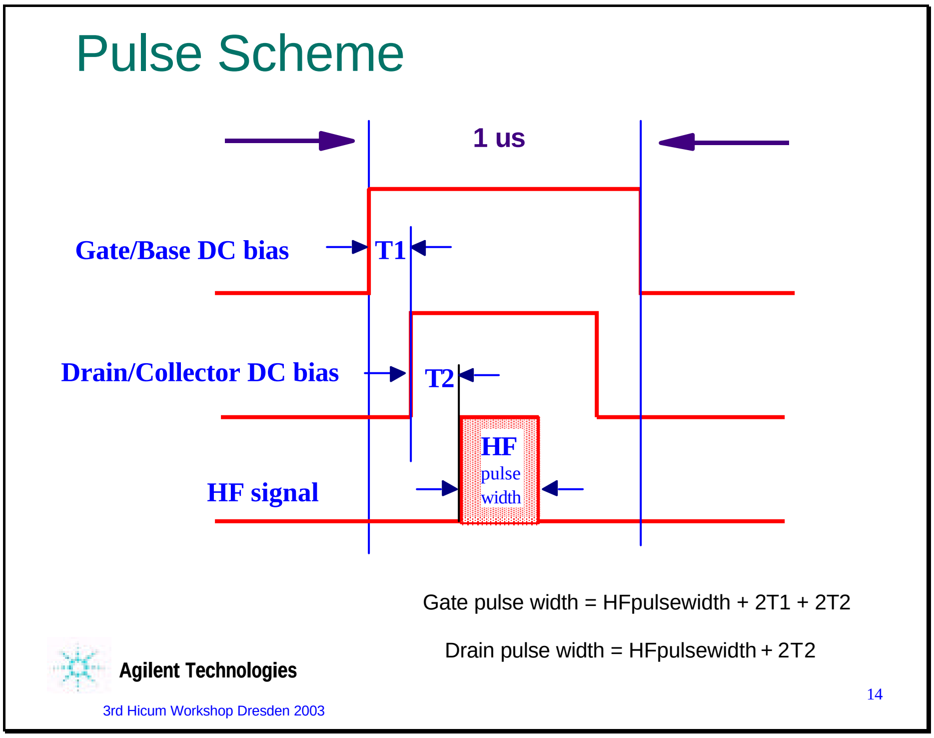
Characteristics	Min	Max	Comments
Pulse Width	1 us		
Pulse Period	20 us	2.4ms	
Quiescent Voltage	- 100 V	100 V	Open Load
Quiescent Current Magnitude		2 Amps	
Source Impedance		1.3 Ohms	
Available Pulse Voltage	-100 V	100 V	Open Load
Peak Pulsed Current		20 Amps	
Total Average Current		2 Amps	

Agilent Technologies
3rd Hicum Workshop Dresden 2003
12

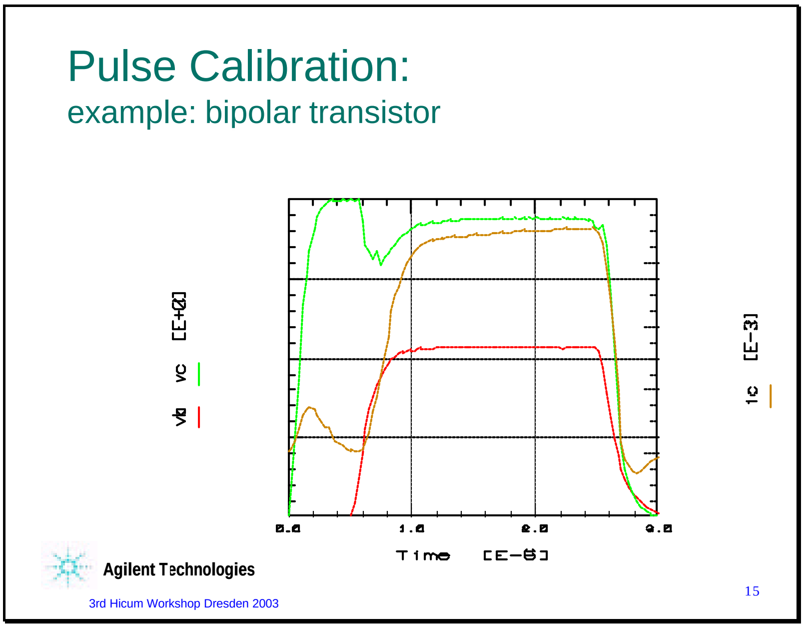
Slide 13



Slide 14



Slide 15



This specific IC-CAP Setups treats the pulsed system like an oscilloscope.
The goal is to evaluate the best sampling time for the pulsed icvce measurements.
In details:

- we measure the time performance of the pulses, and therefore, we use the Input 'Time'.
- first, we bias for max vB and max vC.

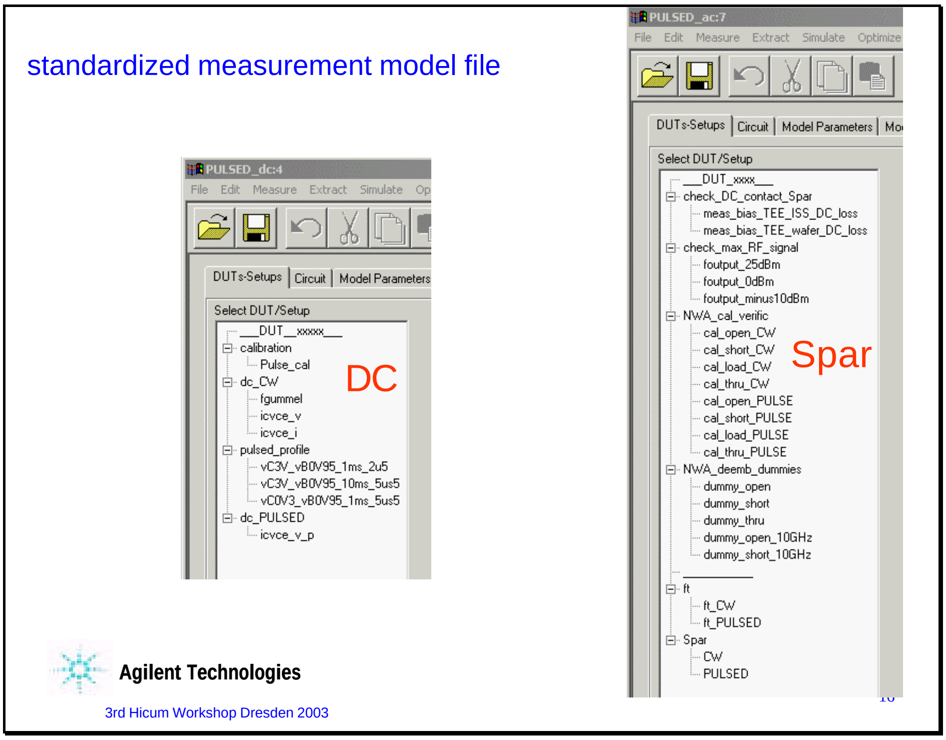
The timing specifications for the pulsed systems are in the Instrument Options:

- The Collector voltage is turned on first:
  PSMU2 Pulse Delay: 0s,   PSMU2 Pulse Width: 2.5us
- Then, the Base voltage is switched on:
  PSMU1 Pulse Delay: 500ns,   PSMU1 Pulse Width: 2us

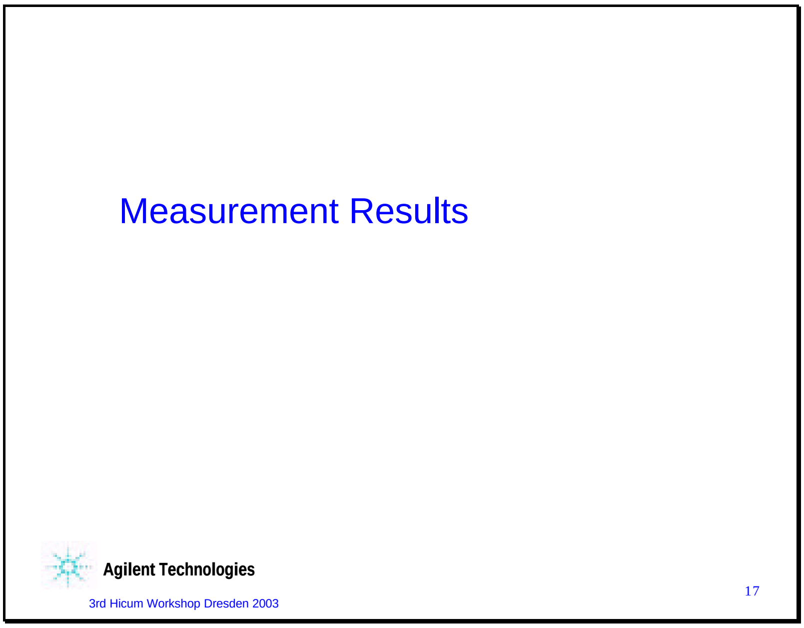
So, both, Base and Collector voltage, will be turned off simultaneously after 2.5 us.

The impulse repetition period is 1ms, and specified also in the Instrument Options.

Slide 16

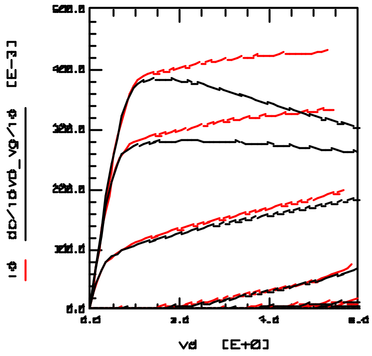


Slide 17

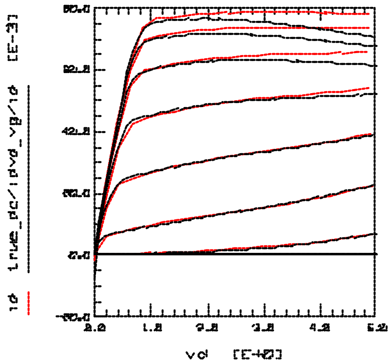


Slide 18

Self-heating effects
Example 1: PHEMT Id-Vd



Non pulsed



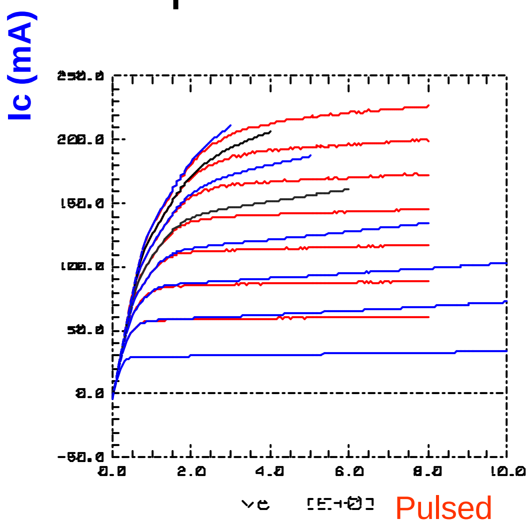
Pulsed

- Self-heating effect is clearly visible even at relatively low power

Slide 19

Self-heating effects
Example 2: BJT Ic-Vce

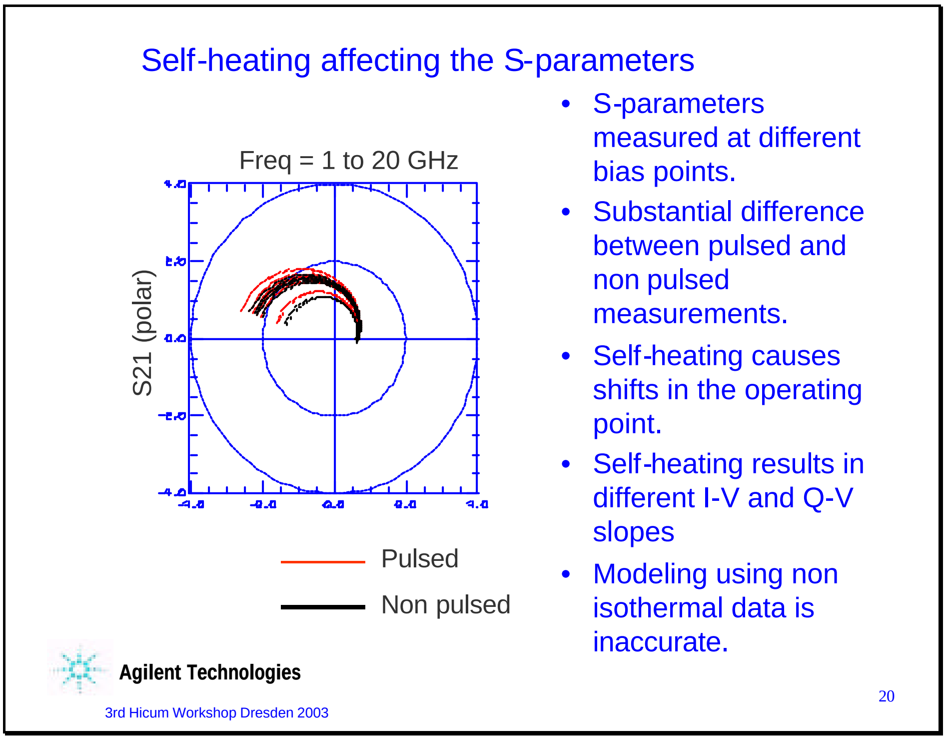
- Ic traces measured at constant Ib.
- Self-heating: the temperature is bias dependent.
- Early effect, quasi-saturation, high injection cannot be distinguished from self-heating.
- Modeling using conventional parameter extraction is inaccurate.



Pulsed

Non pulsed

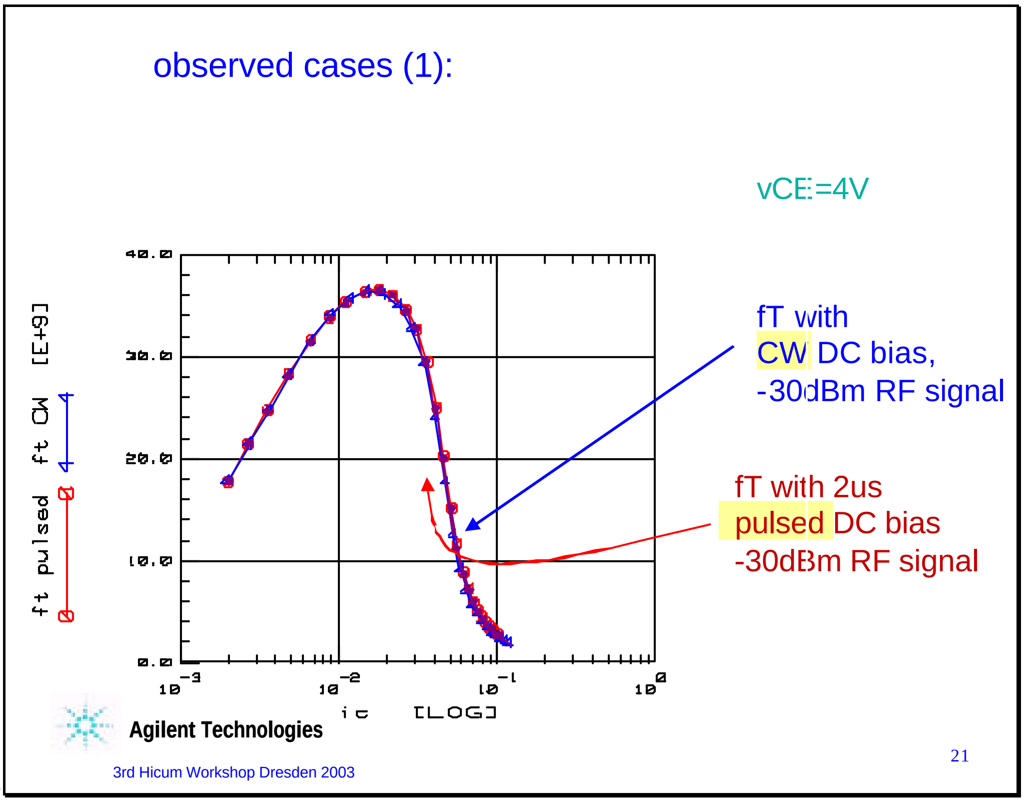
Slide 20



The S21-parameters in this slide depict a transistor measured in pulsed mode (1us pulse for DC and NWA) compared to a conventional CW measurement.

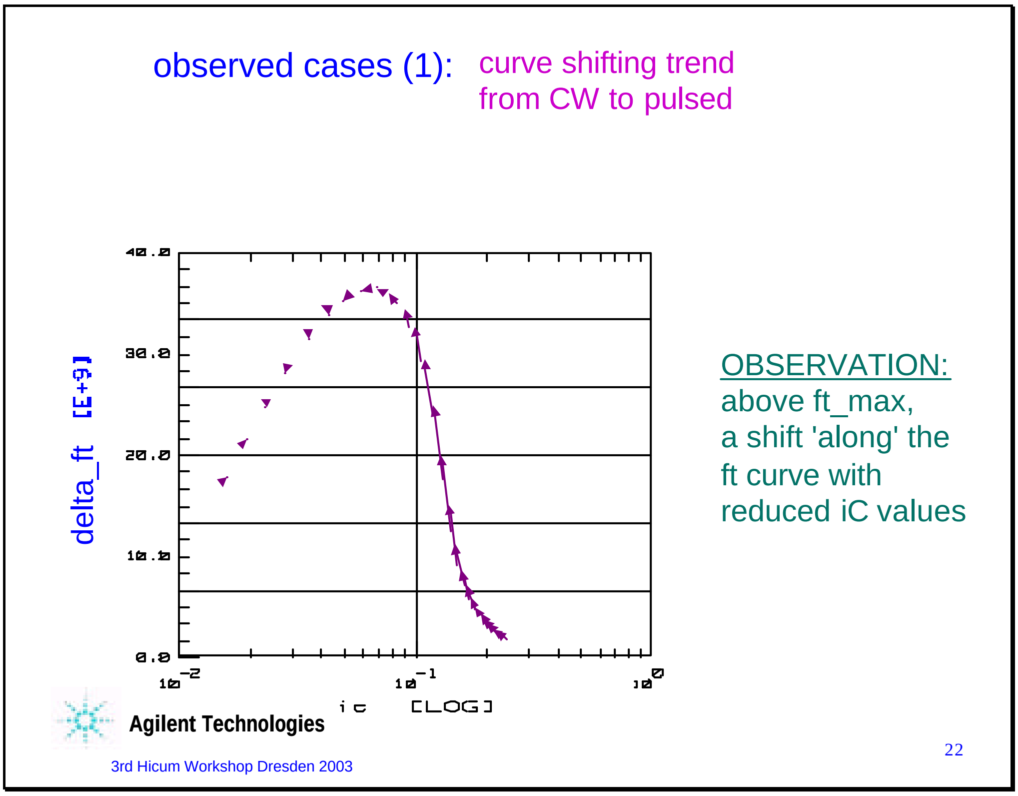
Three different transistor types were measured, and pulsed and non-pulsed S-parameters were obtained. The next slides show the effect of self-heating related to the plot ft_vs_ic.

Slide 21

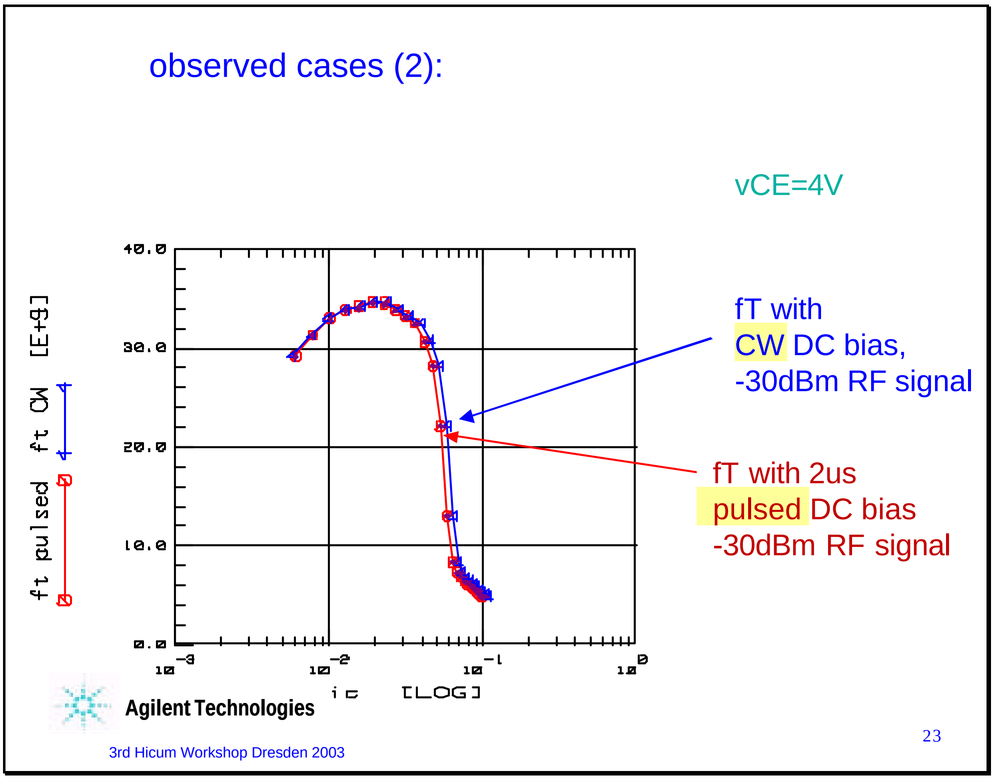


e

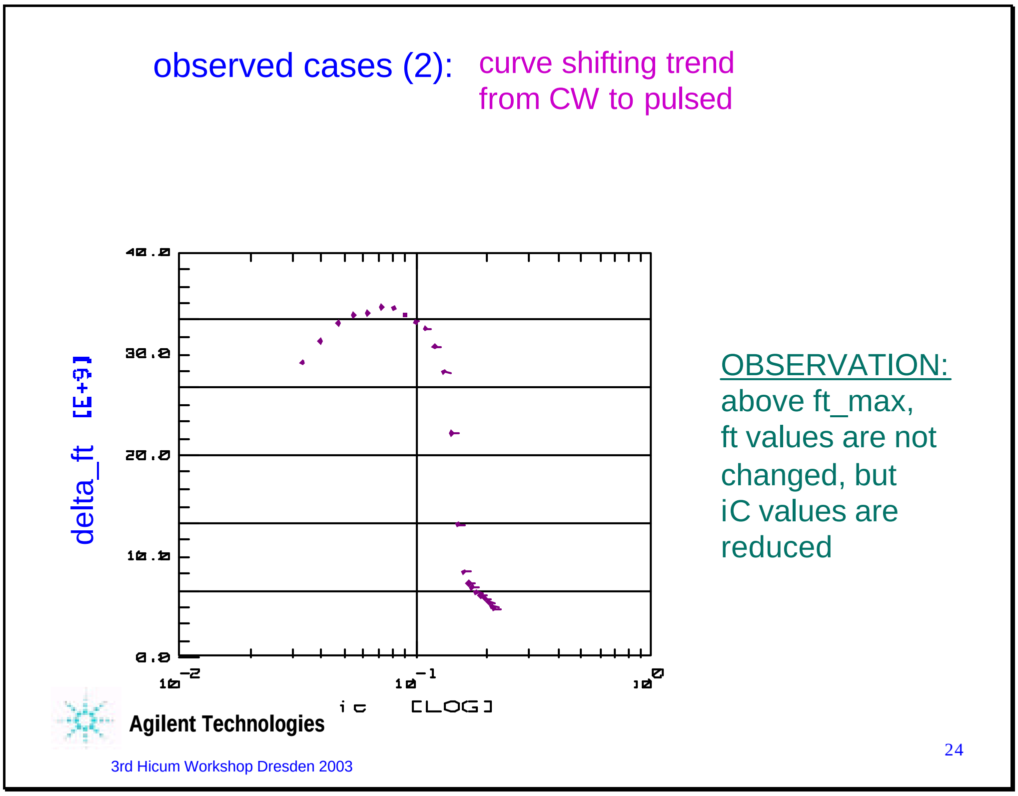
Slide 22



Slide 23

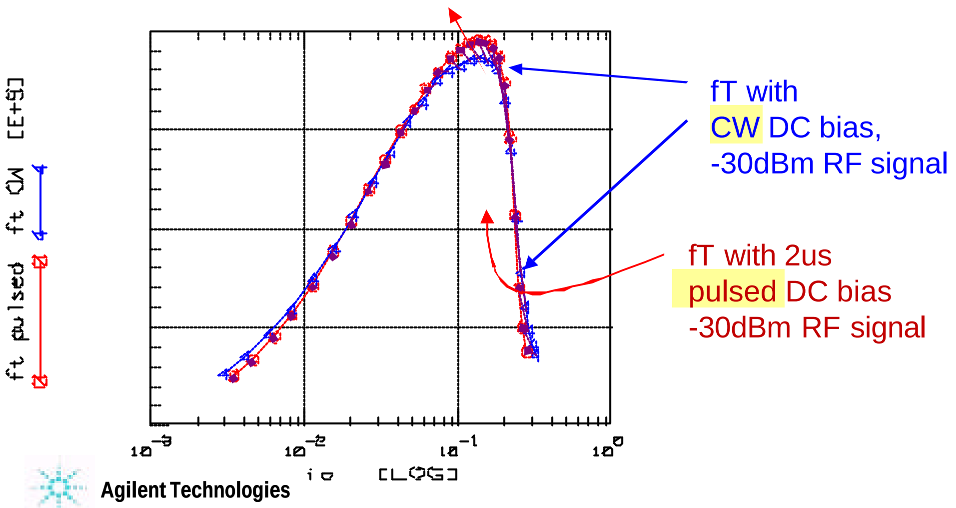


Slide 24



Slide 25

observed cases (3):

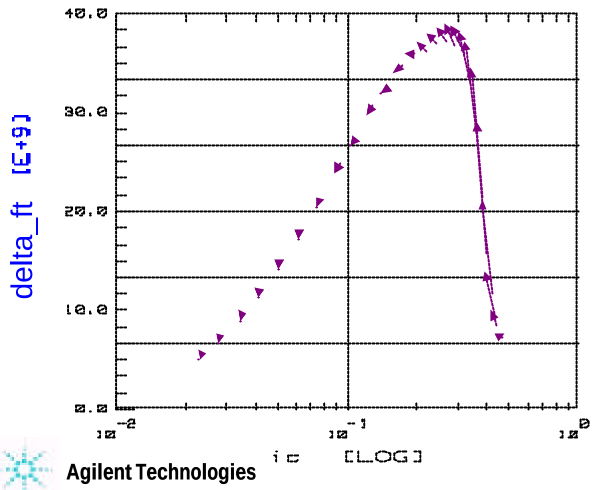


Agilent Technologies

3rd Hicum Workshop Dresden 2003

Slide 26

observed cases (3): curve shifting trend from CW to pulsed



OBSERVATION:
around ft_max,
ft is increased, while
iC is reduced

above ft_max,
a shift 'along' the
ft curve with
reduced iC values

Agilent Technologies

3rd Hicum Workshop Dresden 2003

Slide 27

CONCLUSIONS

•Particularly for modeling ft, pulsed measurements help separating thermal effects from the Avalanche effect.

•Applying pulsed modeling systems gives physical model parameters.