# On pulsed RF measurements

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# Motivation

- Improved SiGe HBT performance within the DOT5
  → new spectrum of sub-millimeter-wave applications [1]
- Higher performance due to down-scaling
- Issue: DC and S-par measurements are more affected by self-heating → device temperature variation is generally unknown → model parameter extraction difficult
- Solution: Pulsed DC and S-par measurements
  - Pulse width smaller than thermal time constant of transistor
    → no significant change in temperature during measurement
  - Exploration of save operating area (SOA)

[1] E. Ojefors, J. Grzyb, Y. Zhao, B. Heinemann, B. Tillack, and U. R. Pfeiffer, "A 820GHz SiGe chipset for terahertz active imaging applications," in Solid-State Circuits Conference Digest of Technical Papers (ISSCC), 2011 IEEE International. IEEE, Feb. 2011, pp. 224–226.

# Outline

1. Introduction
2. Experimental Setup
3. System Validation
4. Results and Discussion
5. Extraction of $C_{TH}$
6. Measurement vs simulation
7. Conclusions

# 1. Introduction

## Parameters

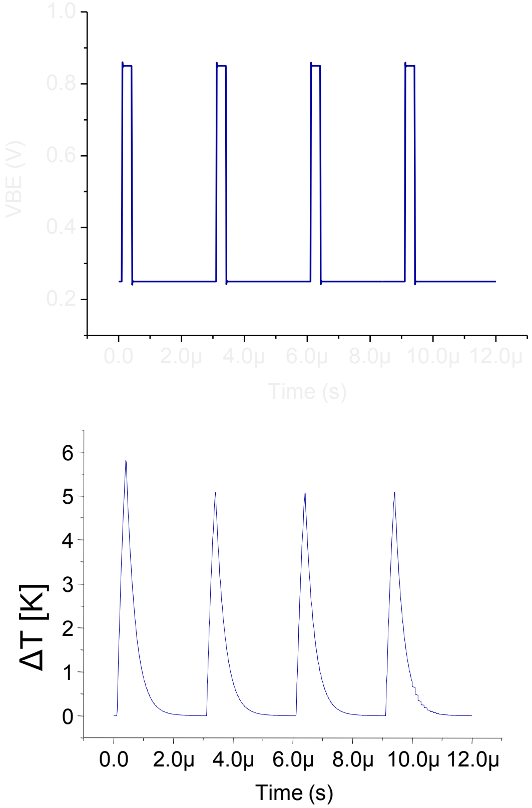
- Duty cycle D
- Pulse width $T_w$
- Pulse period $T_p$

$$D = \frac{T_p}{T_w} \cdot 100$$

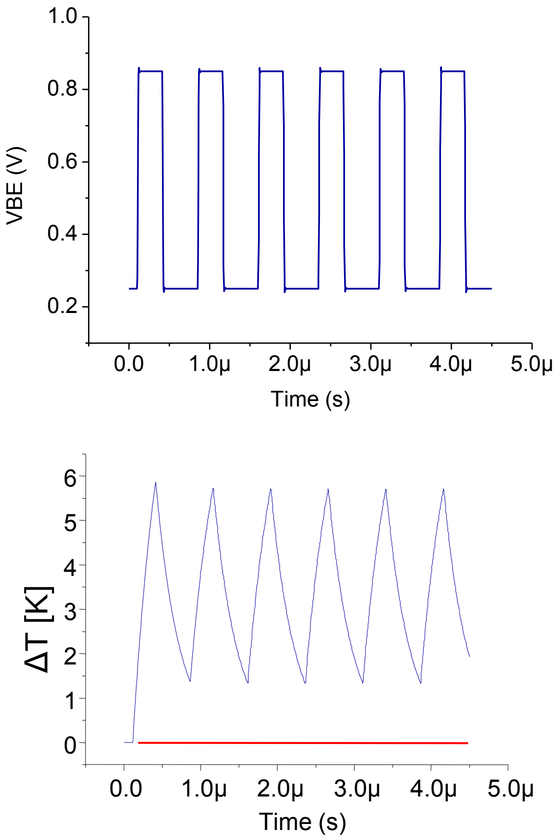
- Generally: 0.1%<D<10%

**Trade-off isothermal behavior and measurement accuracy**

## Small duty-cycle



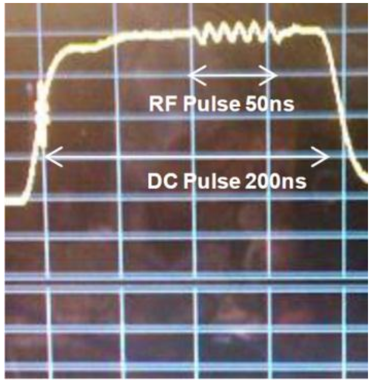
## High duty-cycle

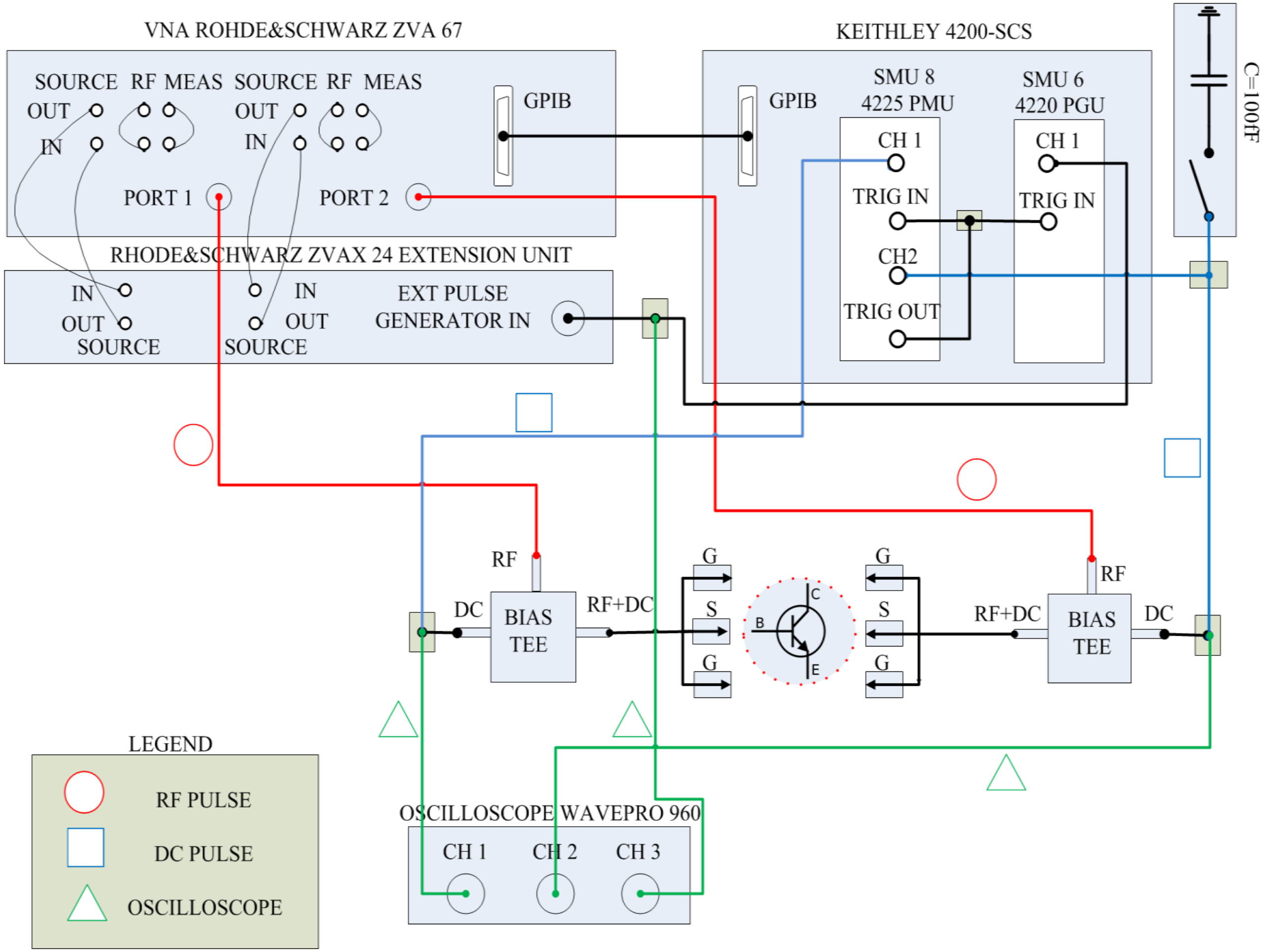


# 2. Experimental Setup

**Pulsed measurement system characteristics:**

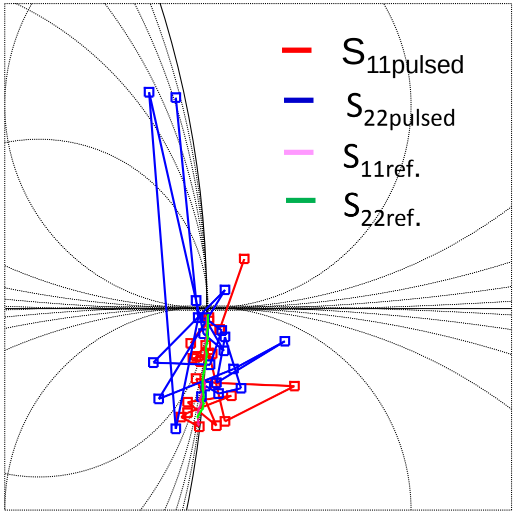
- Pulse width
  $Tw_{min} \geq 80$ns DC
  $Tw_{min} \geq 100$ns RF
- $T_{rise}$ and $T_{fall} \geq 20$ns
- Frequency
  f [500MHz – 45GHz]
- Duty-Cycle
  D [0.01% - 50%]
- Current resolution [µA]

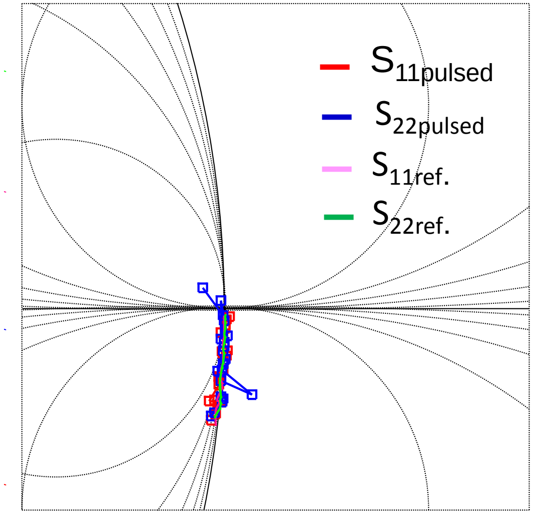


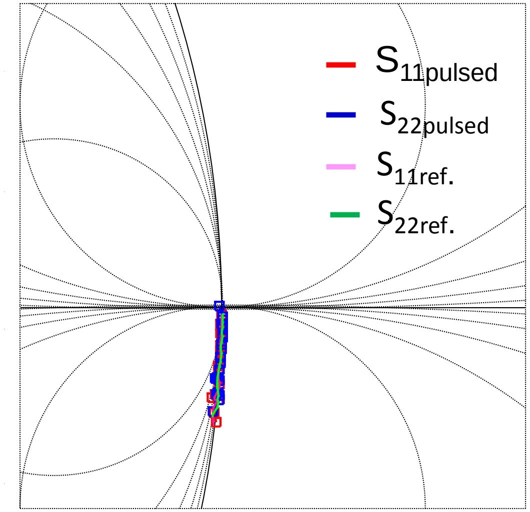


# 3. System Validation

## Measurement of an OPEN (4.5fF) with f [500MHz – 45GHz]


Duty cycle= 0.1%


Duty cycle= 1%

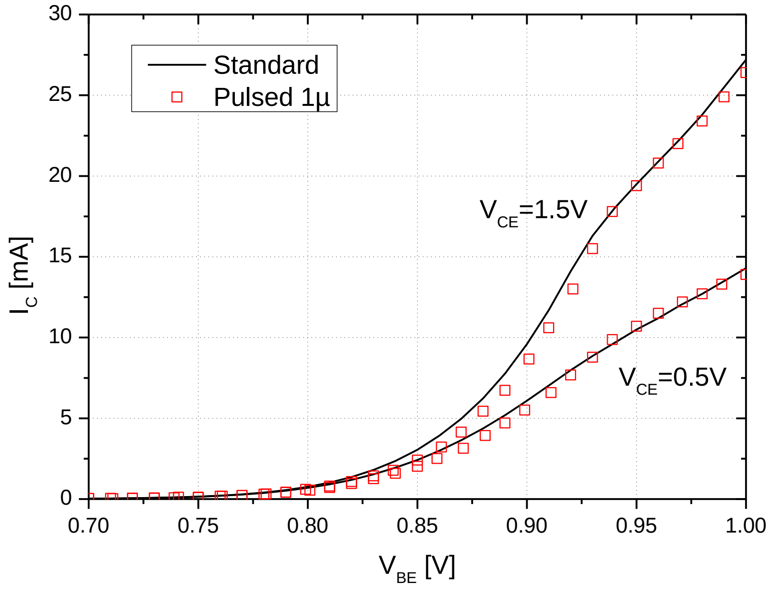

Duty cycle= 5%

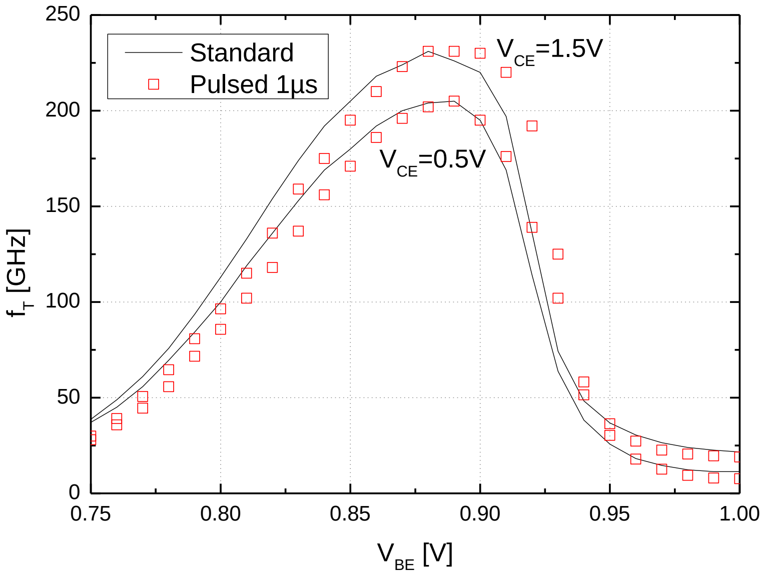
Using D of 5% conventional and pulsed S-parameter measurement are in very good agreement

# Transistor measurement of a SiGe HBT

Technology process of STMicroelectronics: $f_T$=230GHz $f_{max}$=290GHz

Device geometry: $W_E$= 0.23 µm $L_E$ = 5.0 µm

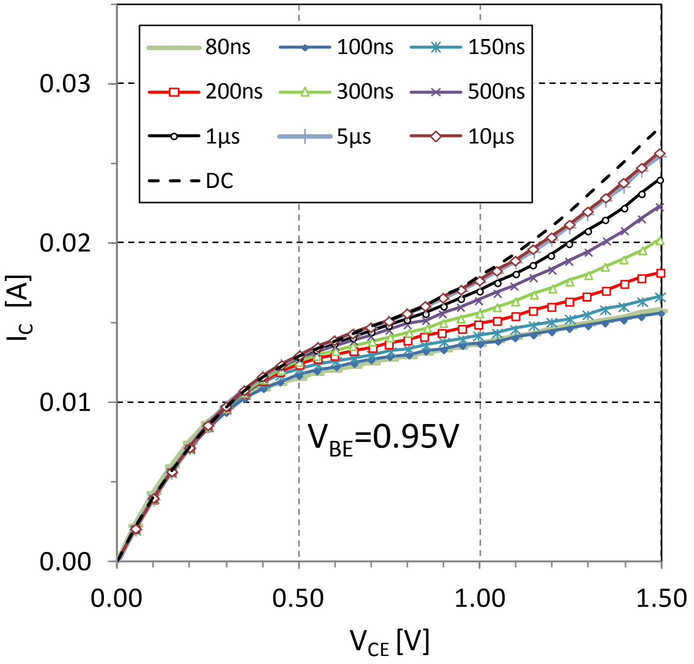




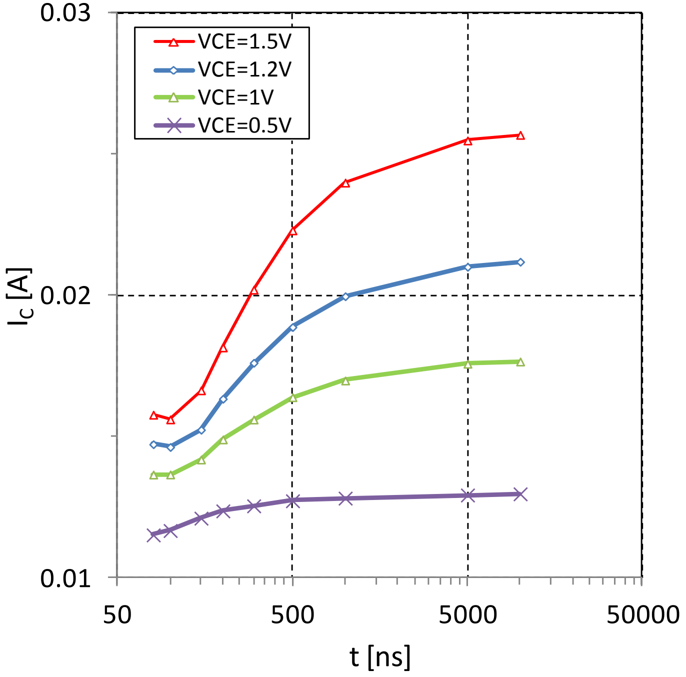
Pulsed I(V) and pulsed RF characteristics in good agreement with conventional measurements

# 4. Results and Discussion

## Pulsed I(V) for SiGe HBT with $W_E$= 0.27 µm $L_E$ = 5.0 µm

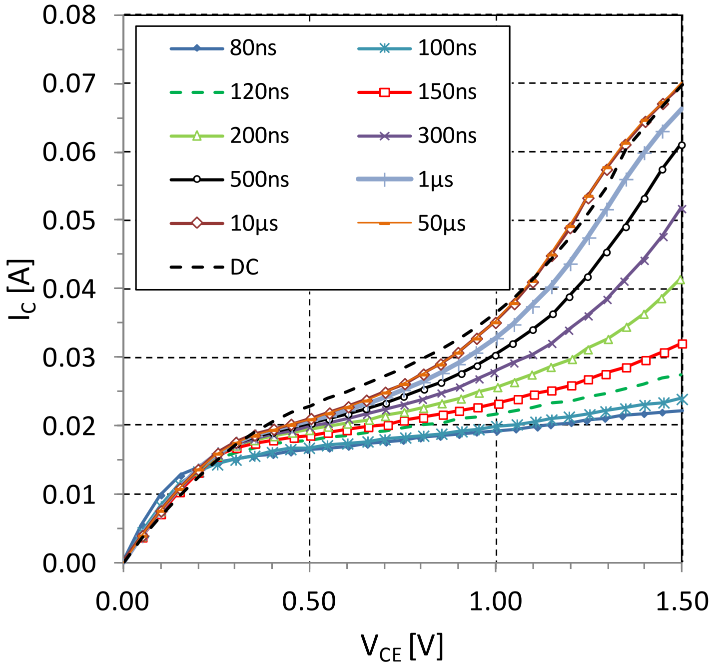


Collector current $I_C$ vs. collector emitter voltage $V_{CE}$

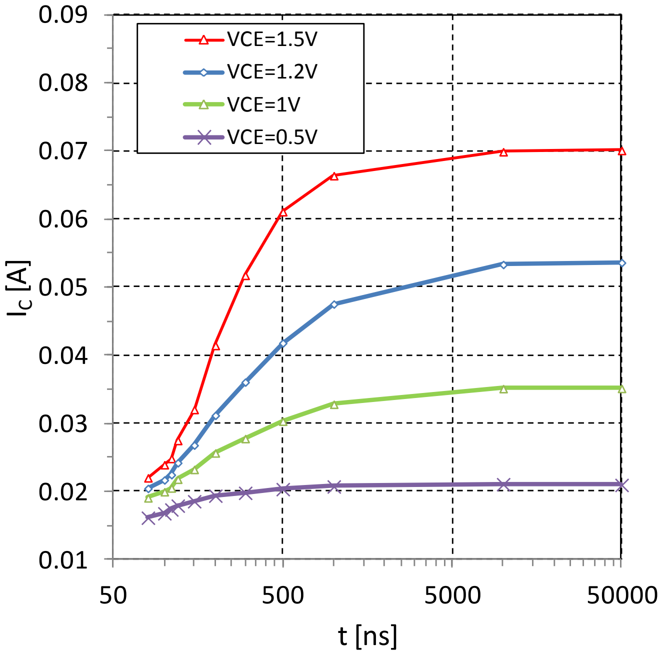


Collector current $I_C$ vs. pulse width t

# Pulsed I(V) for SiGe HBT with $W_E$= 0.84 µm $L_E$ = 5.0 µm

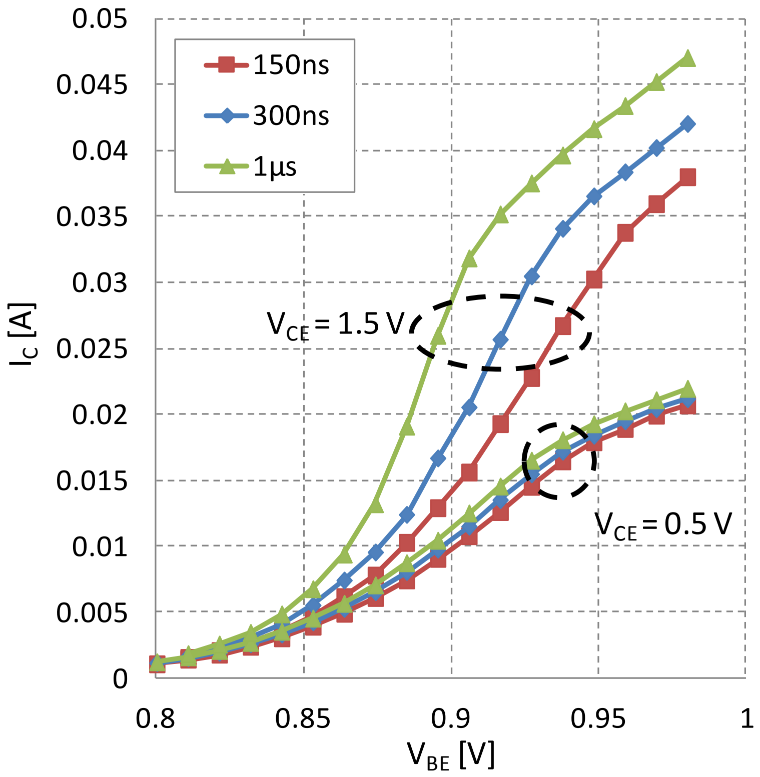


Collector current $I_C$ vs. collector emitter voltage $V_{CE}$

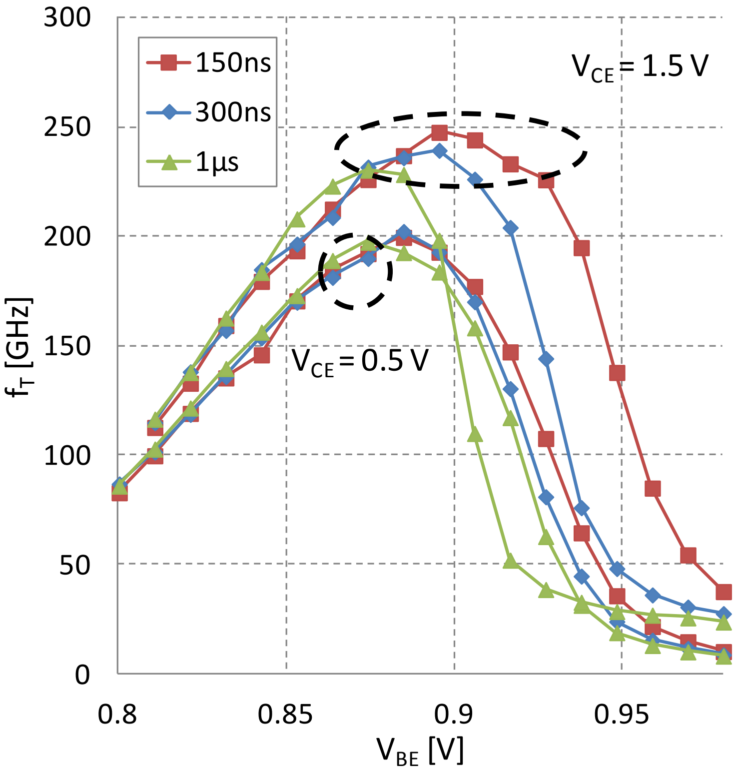


Collector current $I_C$ vs. pulse width t

# Pulsed I(V) and pulsed RF for SiGe HBT with $W_E$= 0.84 µm $L_E$ = 5.0 µm

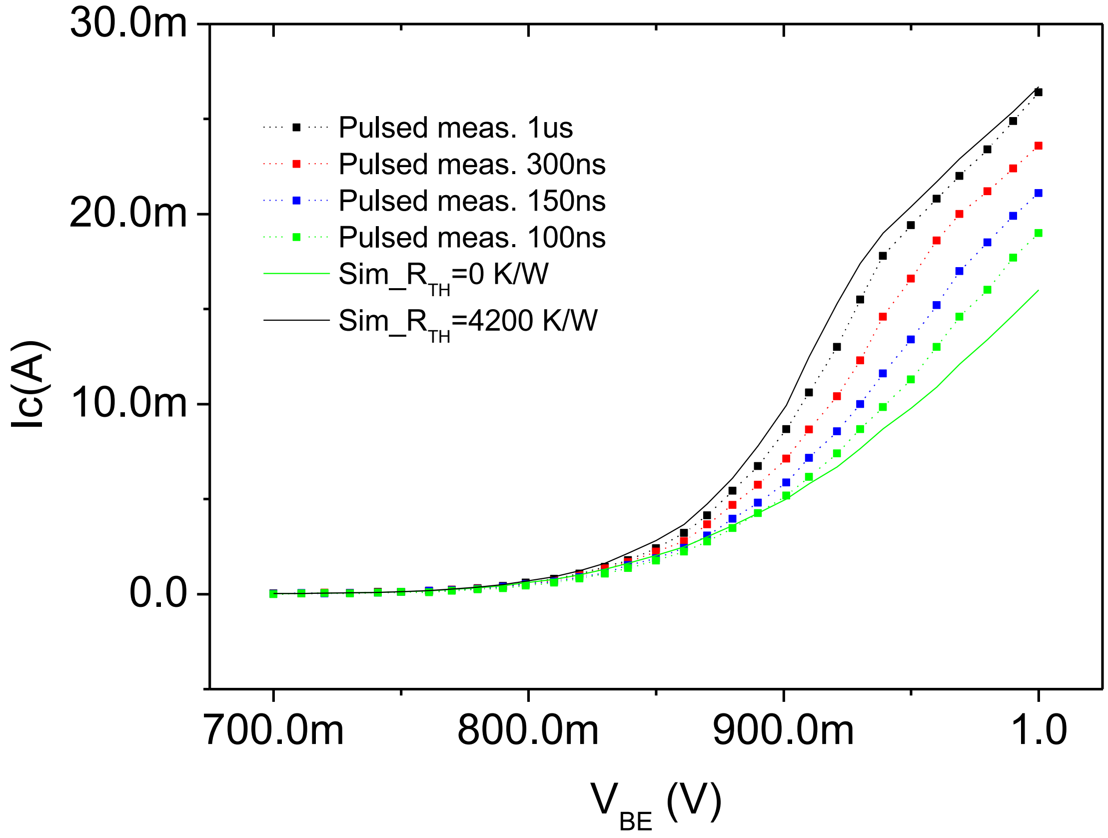


Collector current $I_C$ vs. base emitter voltage $V_{BE}$



Transit frequency $f_T$ vs. base emitter voltage $V_{BE}$

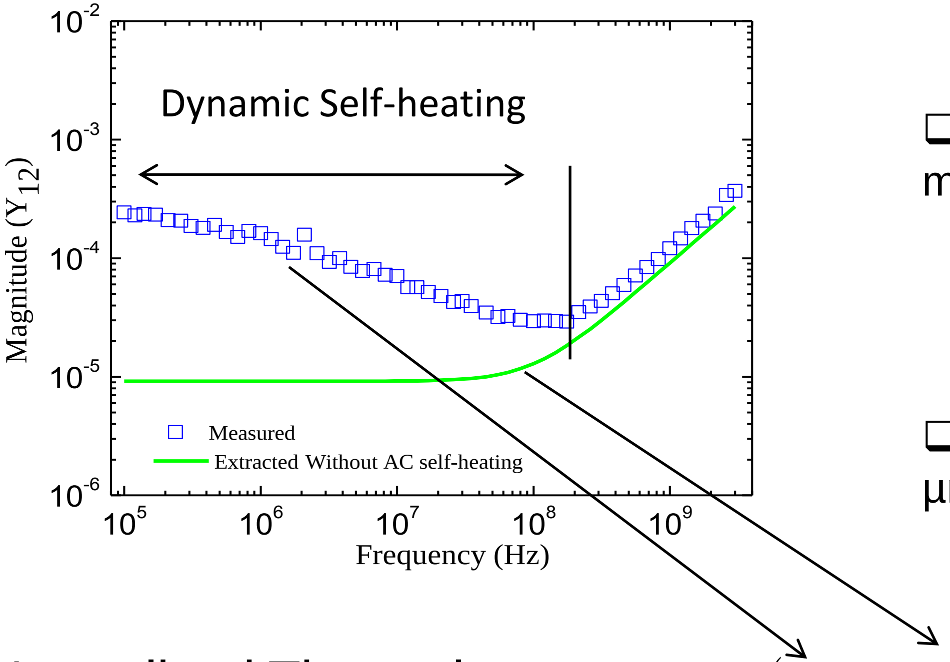
# Isothermal measurement?



For a pulse width of 100ns self-heating has been significantly reduced

# 5. Extraction of $C_{TH}$

## A) $C_{TH}$ extraction from low freq. Y-parameters



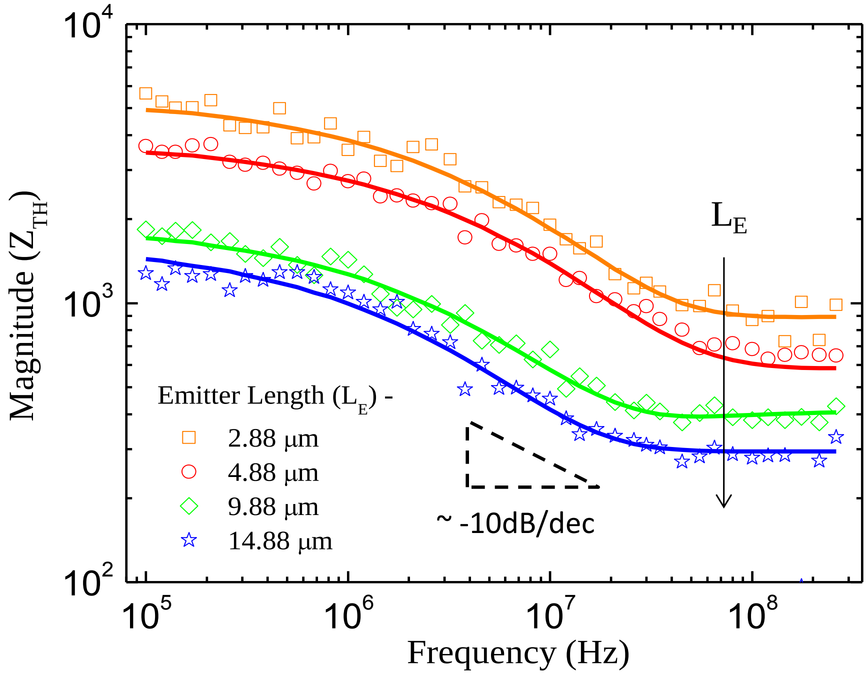
❑ Low frequency S-parameter measurements :

- 100 kHz – 3 GHz,
- $V_{CE}$ = 1.5 V
- $V_{BE}$ = 0.95 V

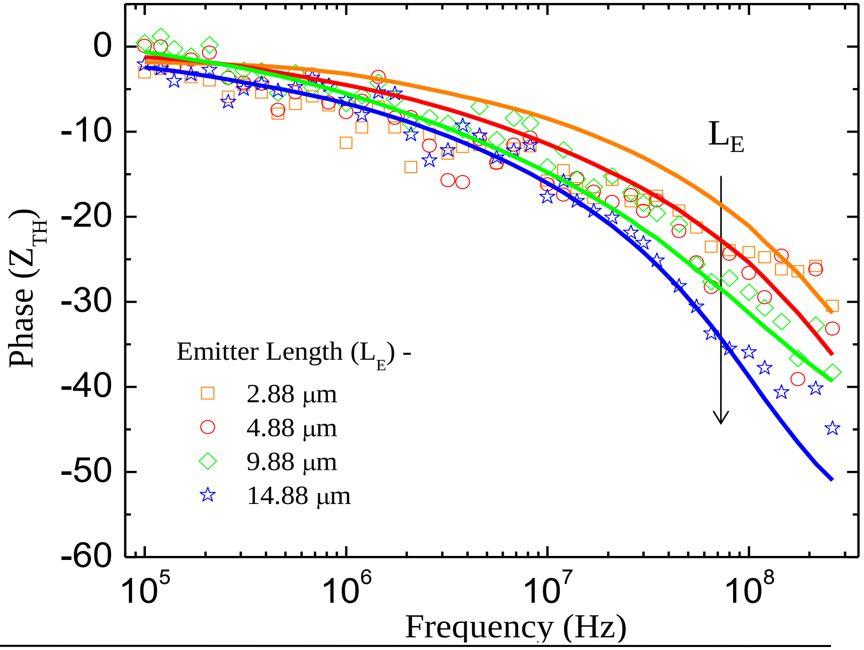
❑ DUT : $L_E$*$W_E$ = 9.88*0.15 µm²

Normalized Thermal Impedance →

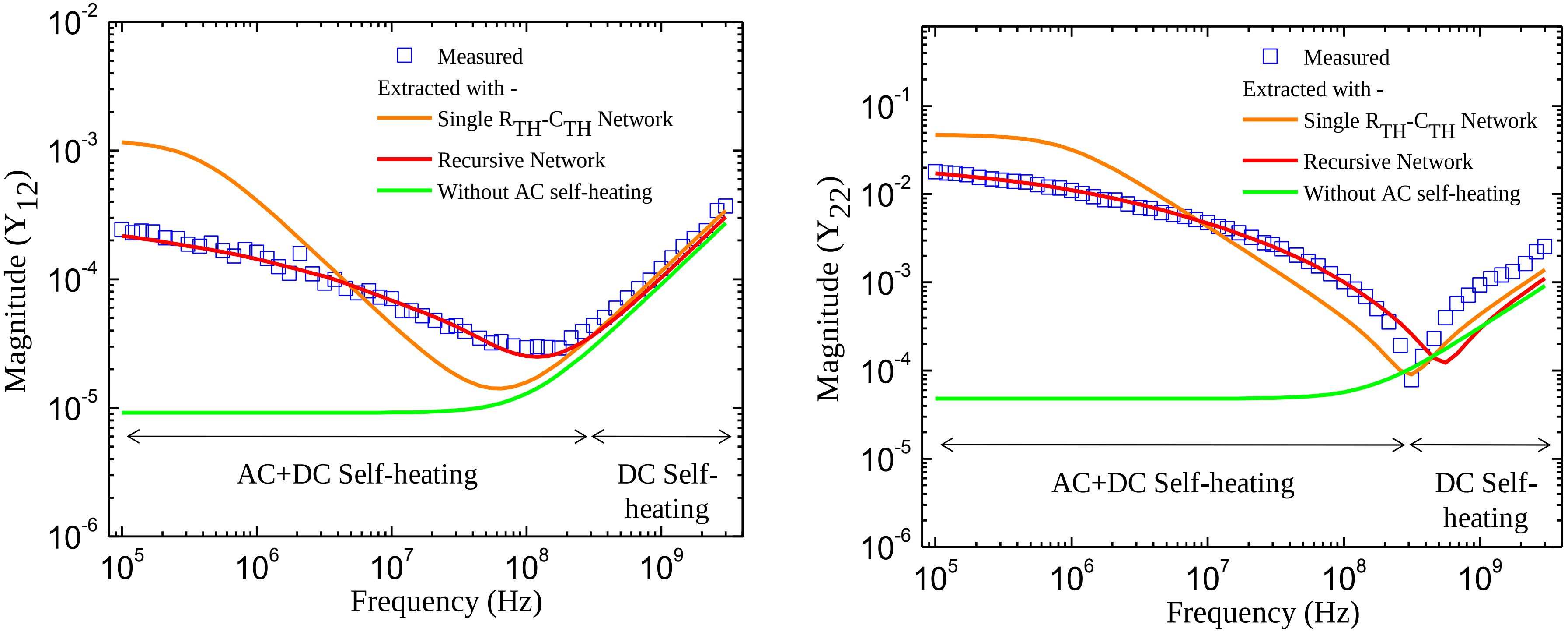
$$Z_{TH}(\omega)=\frac{\left(y_{12}(\omega)-y_{12}^{AC}\right)}{\left(y_{12}^{DC}-y_{12}^{AC}\right)}\cdot\frac{\left(I_C+V_{BE}y_{12}^{DC}+V_{CE}y_{22}^{DC}\right)}{\left(I_C+V_{BE}y_{12}(\omega)+V_{CE}y_{22}(\omega)\right)}$$



- Frequency domain magnitude and phase of thermal impedance for different geometry of transistor



- Symbols – measured
- Lines – extracted with Recursive electro-thermal network

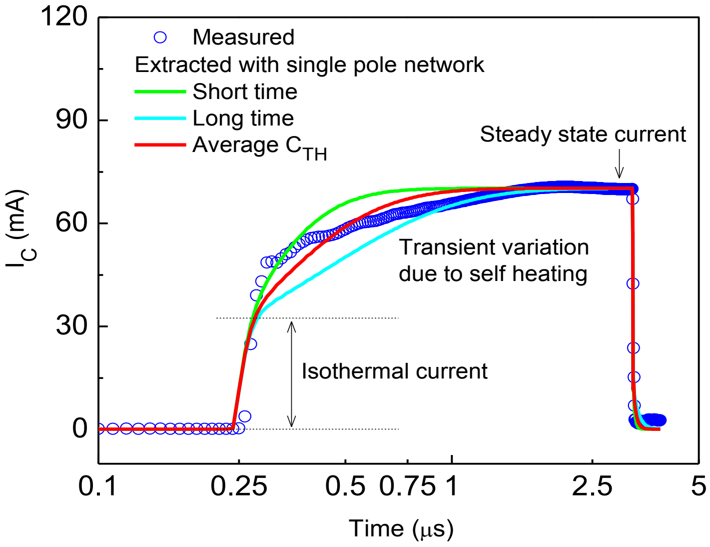


Comparison of thermal modeling of y-parameters with HiCuM compact model simulation connecting the electro-thermal network at temperature node:

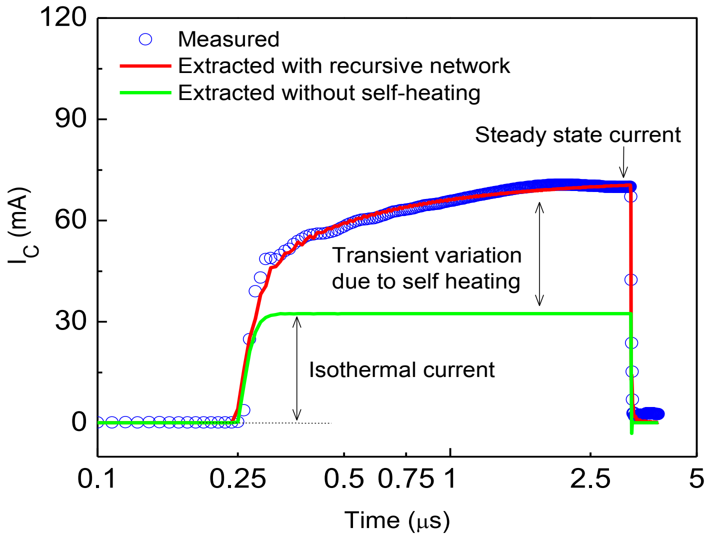
1. Single R-C network, 2. Recursive network and 3. only with Thermal resistance

# B) From Pulsed I(V) Measurements

Comparison between measurements and HiCuM L2 simulation. ($A_E$ = 15 x 0.27 µm²)

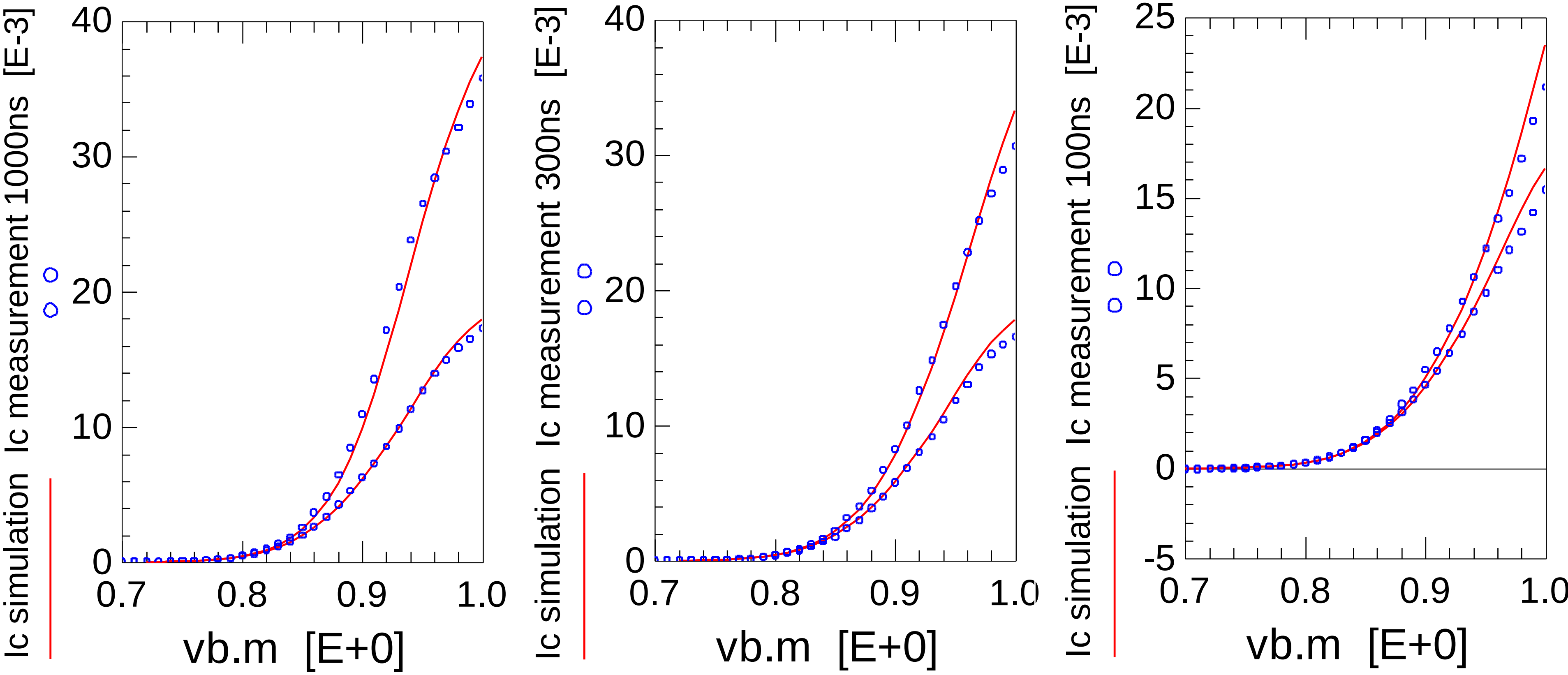


Thermal modeling with single pole network



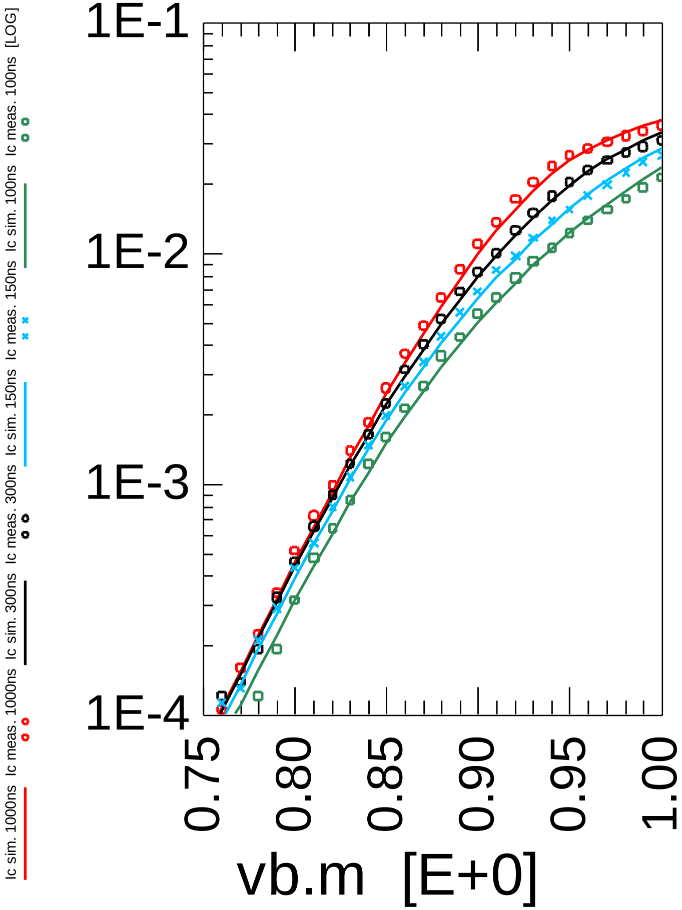
Thermal modeling with recursive network

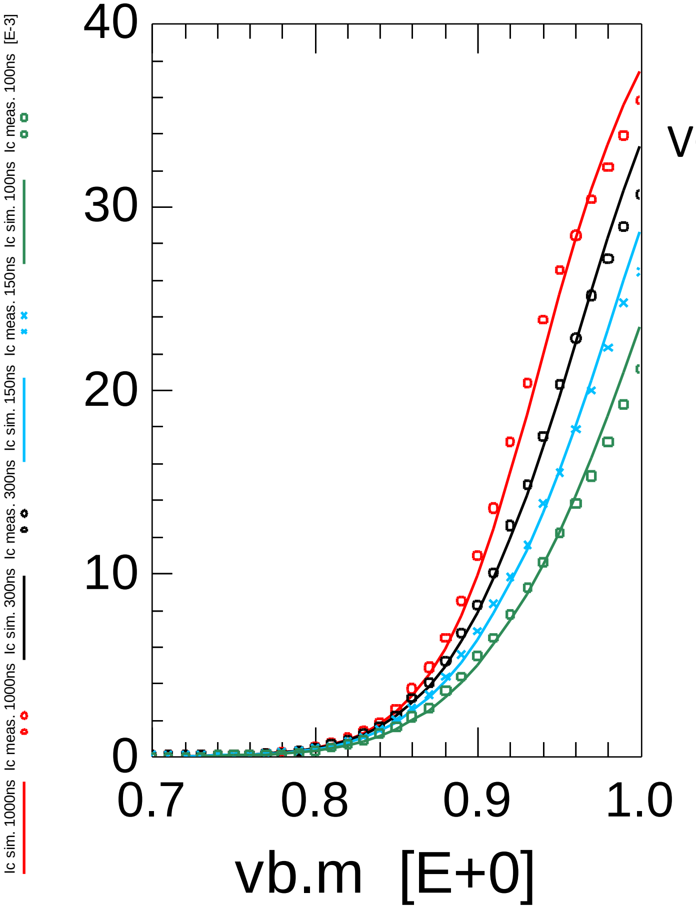
# Measurement vs simulation (1/3)



VCE=0.5V & 1.5V

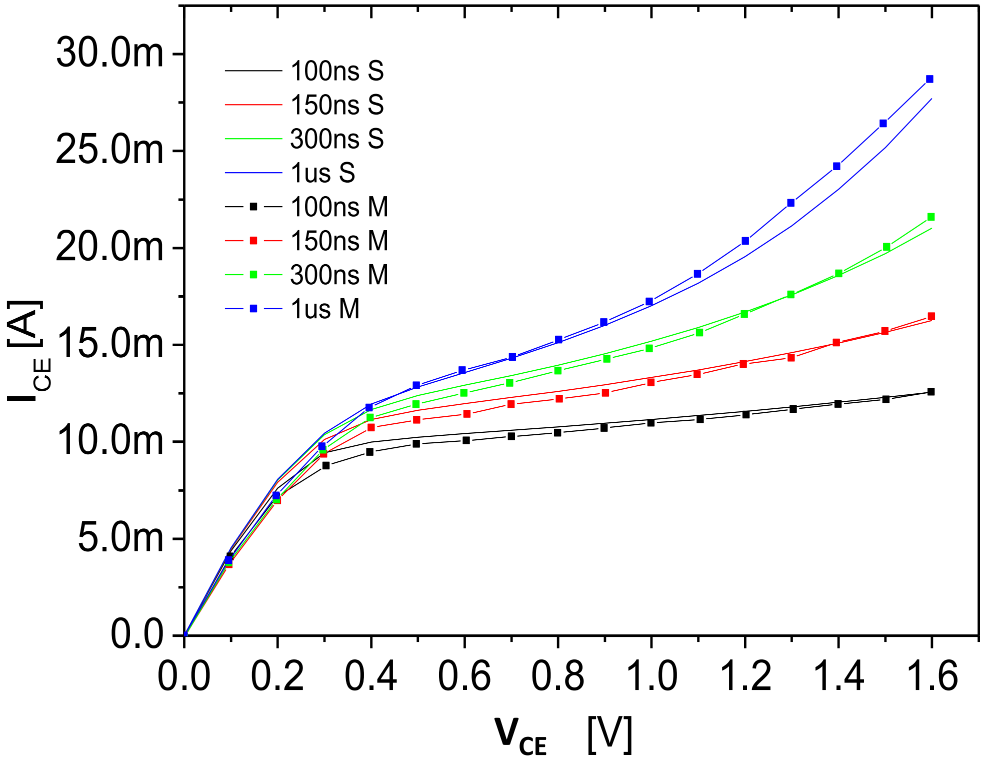
# Measurement vs simulation (2/3)





VCE=1.5 V

# Measurement vs simulation (3/3)



# 6. Conclusions

- State of the Art Pulsed I(V) pulsed RF System validated with conventional measurements
- Self-heating can be significantly decreased and SOA expanded
- Pulsed measurements help separating thermal effects from electrical effects (e.g. Self heating ↔ Avalanche)
- Extraction procedure to achieve physical model parameters is much easier

# Acknowledgment

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