Large-signal switching behavior: distributed lateral effects

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Rohde & Schwarz

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OUTLINE

- Introduction
- Compact modeling approaches
- Model evaluation by 2D transient simulation
- Conclusions

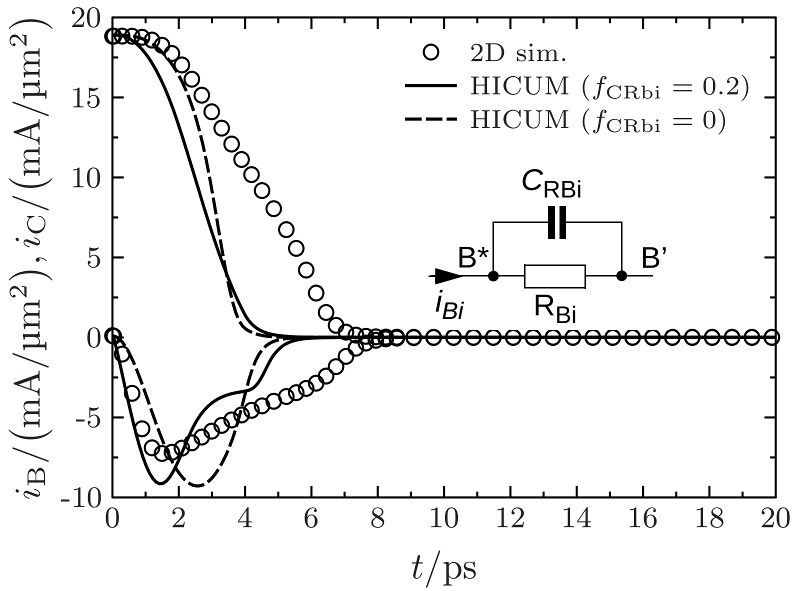
Introduction

- Recent developments in HBT technology (SiGe, InP) are attractive for mm- and sub-mm-wave applications
- For high-speed/-frequency applications, the high transconductance makes HBTs preferable over MOSFETs, especially for drivers, PAs, oscillators
- Design of such circuits requires accurate large-signal (l.s.) compact models

- Experimental verification of l.s. models restricted to 13 GHz!
  - using PNA-X and 5 harmonics for pulse reconstruction in time domain

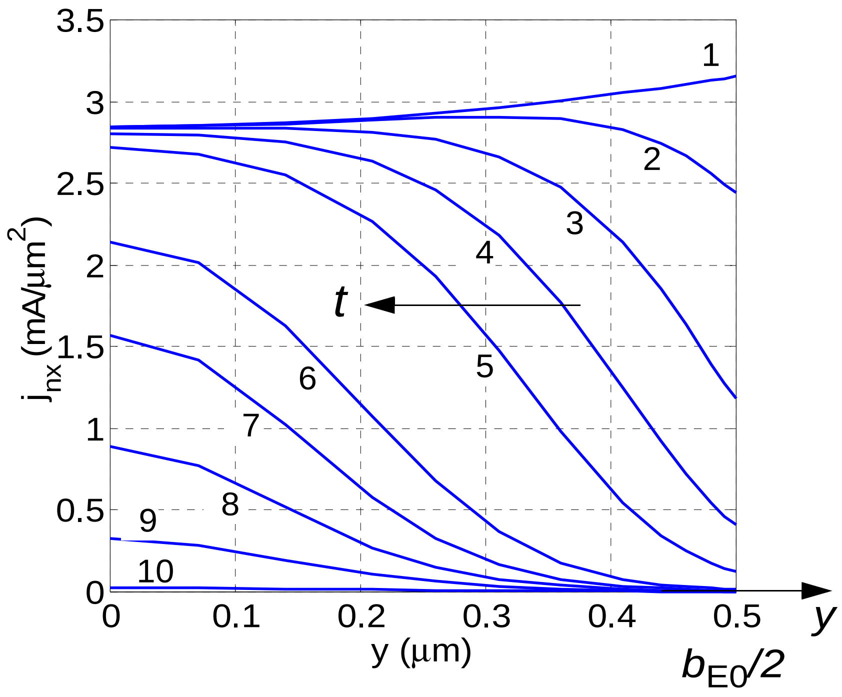
=> Investigation of high-speed l.s. switching behavior needs to be based on TCAD

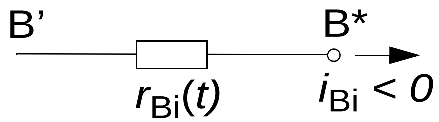
- Existing compact (lumped) models can show significant deviations, especially during turn-off, due to lumped R_{Bi}



=> investigate and evaluate options for improving accuracy

High-speed turn-off process



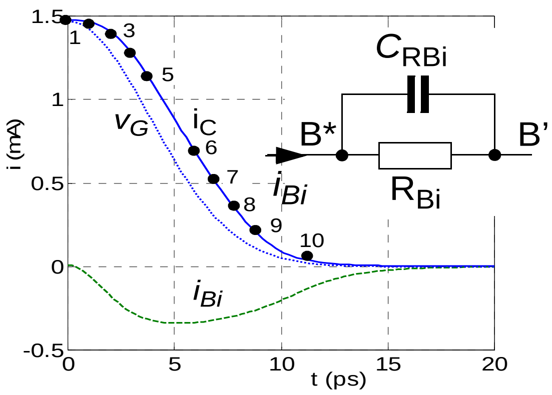


- discharge of internal transistor from the E window edge/perimeter

=> causes (strong) dynamic emitter current crowding (ECC)

- ECC is a distributed effect
  dynamic ECC cannot be captured by *lumped* internal base resistance

- Standard ECC equivalent circuit with parallel C_{RBi} is valid only for small-signal operation!



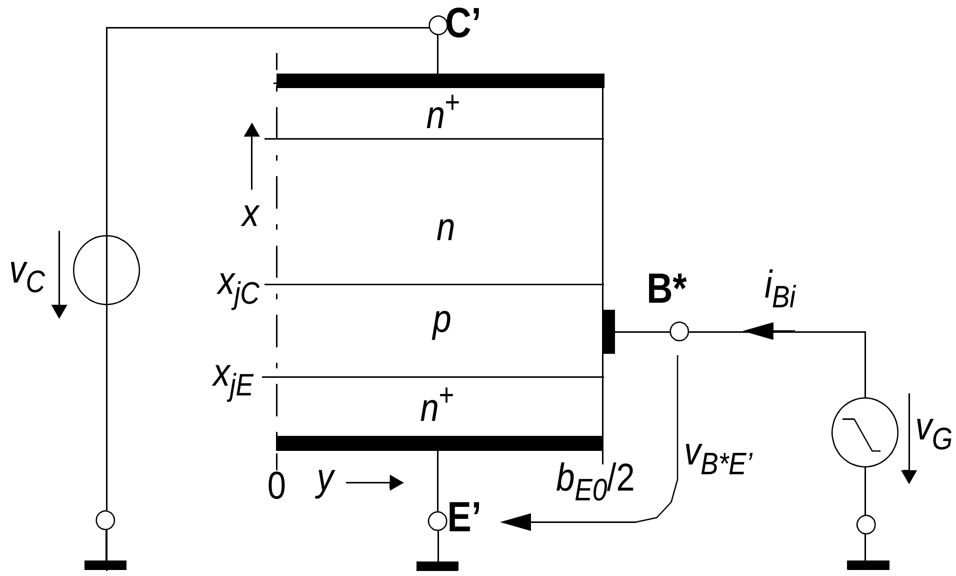
=> need computationally efficient representation of distributed charging and discharging effects (lateral NQS effects)

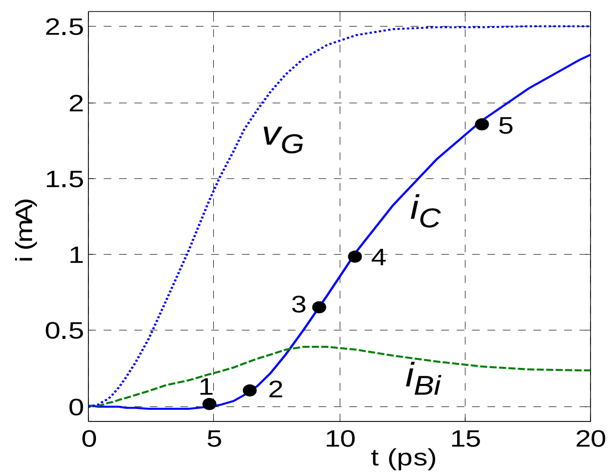
Device simulation

2D device simulation of the internal transistor only (SiGe HBT)

- no BE perimeter junction
- half structure (due to symmetry)

- smooth pulse v_G to avoid artificial spikes
- adjustable maximum frequency contained in pulse
  - 50 GHz (max. frequency)





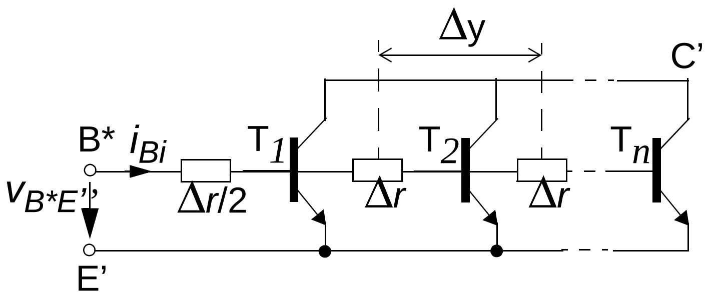
- simulated emitter widths: 0.1, 0.2, 0.4 μm

=> used as reference for evaluating compact representations of internal base

Compact modeling approaches

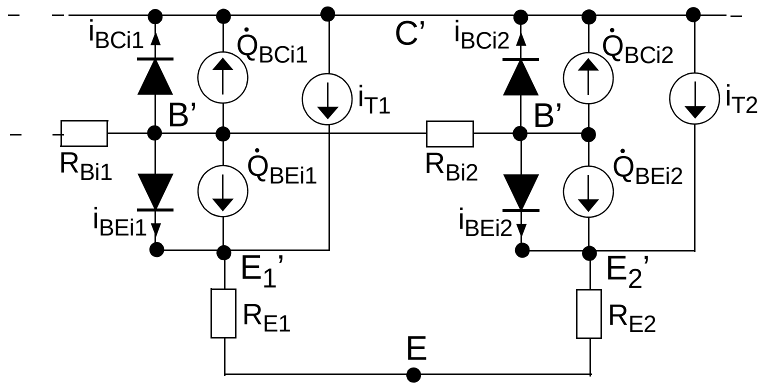
Equivalent circuits for the internal transistor

- 10-transistor model (reference)

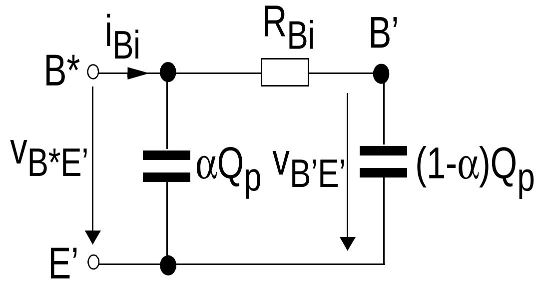


$$\Delta r = r_{SBi}(y)\frac{\Delta y}{4l_{E0}}$$

- 2-transistor model variants
  - **equal** distribution of E area
  - **non-equal** distribution
    0.4:0.6 (area); 0.15:0.5 (R_{Bi})



- 1-transistor model (preferred)
  - lateral charge partitioning across R_{Bi}

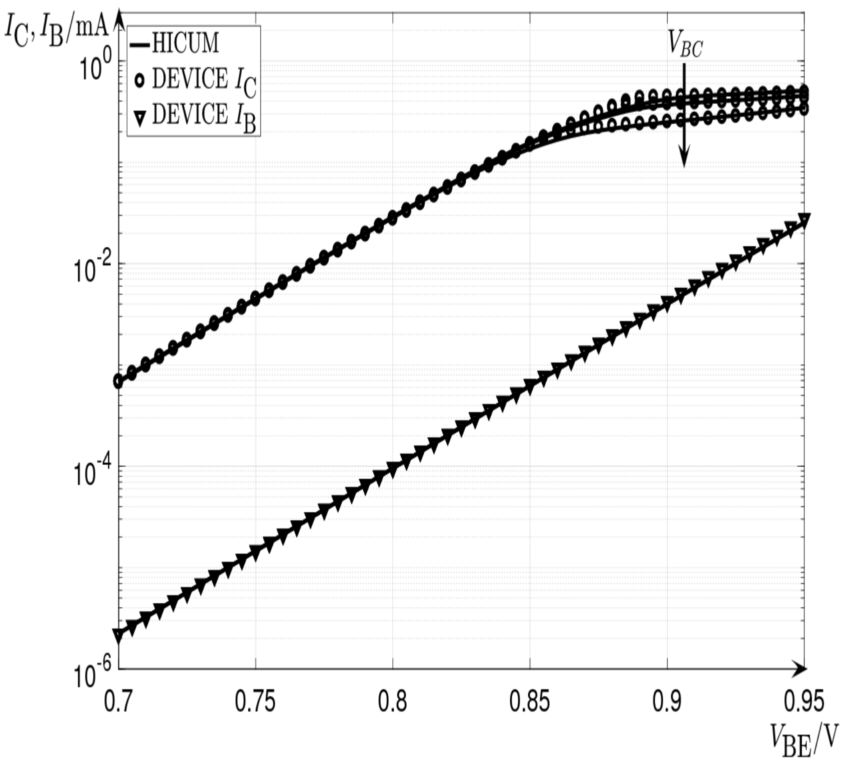


Model parameters generated from HICUM/L2

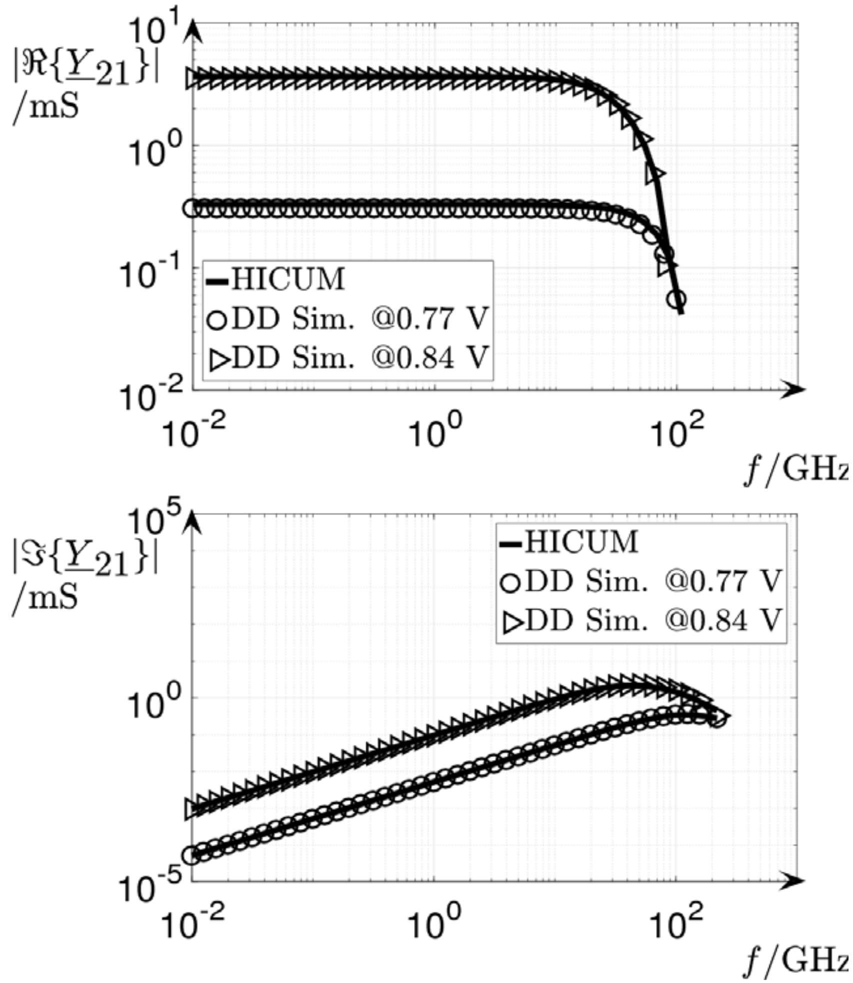
HICUM/L2 results

Verification against 2D device simulation

Gummel characteristics



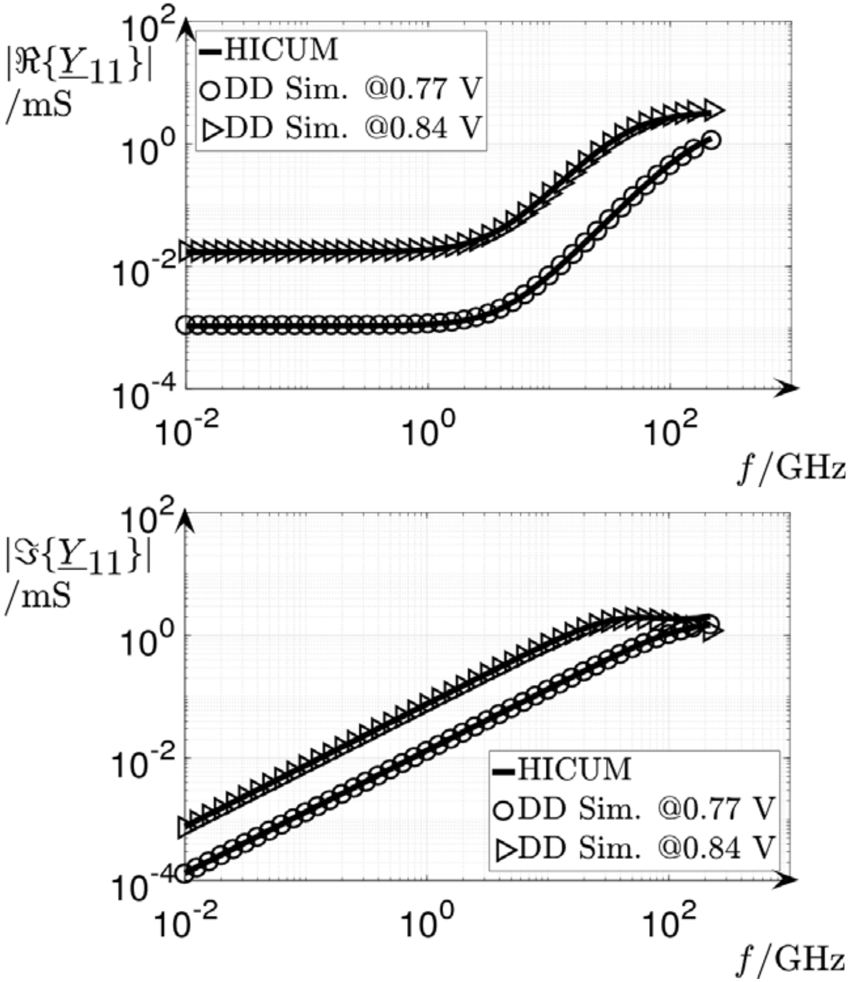
transconductance



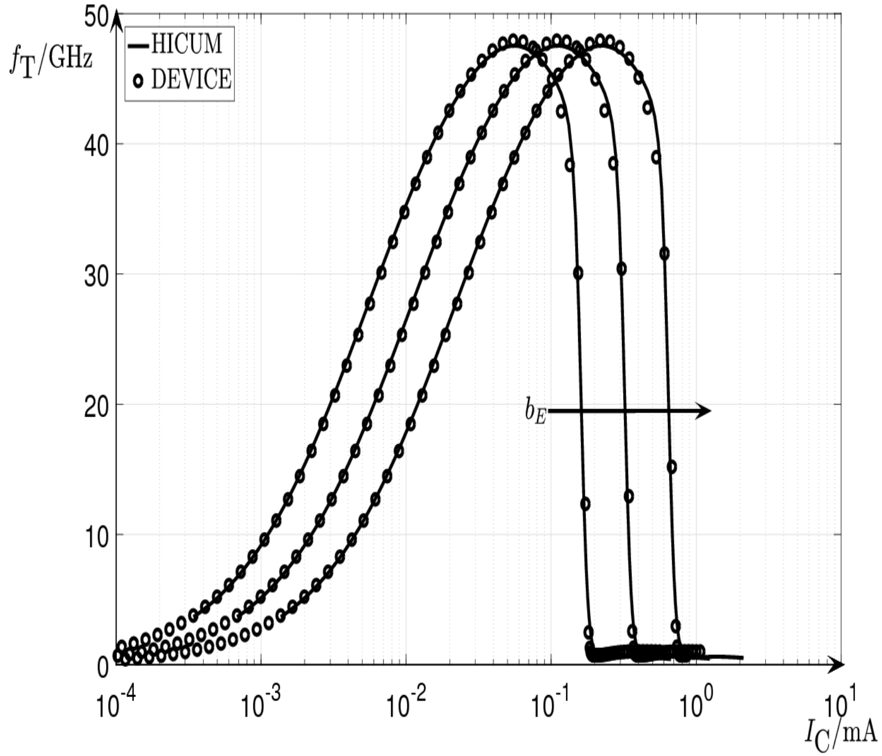
HICUM/L2 results

Verification against 2D device simulation

input admittance



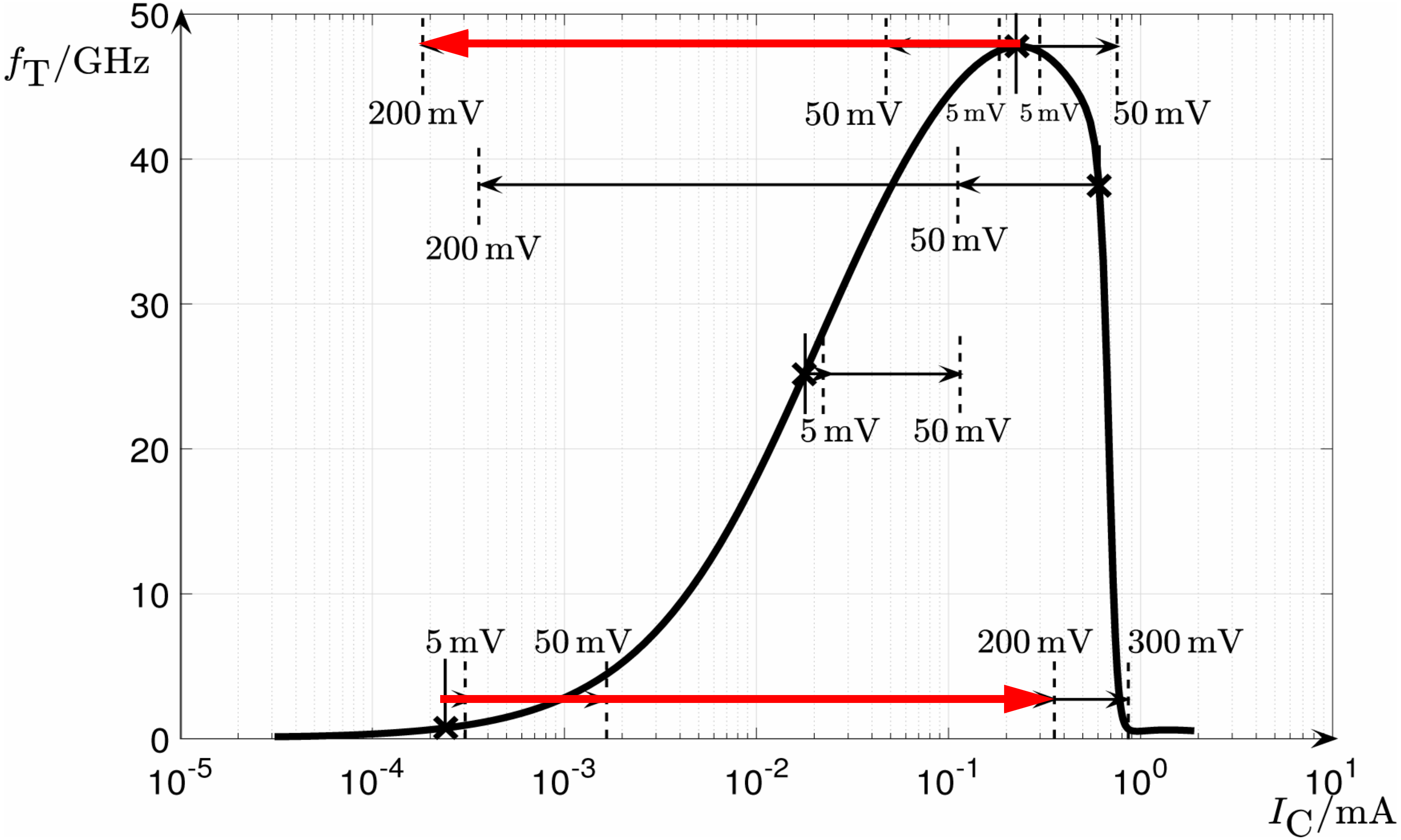
Transit frequency



=> **excellent agreement for DC and quasi-static characteristics**

Quiescent operating points

... and investigated switching amplitudes

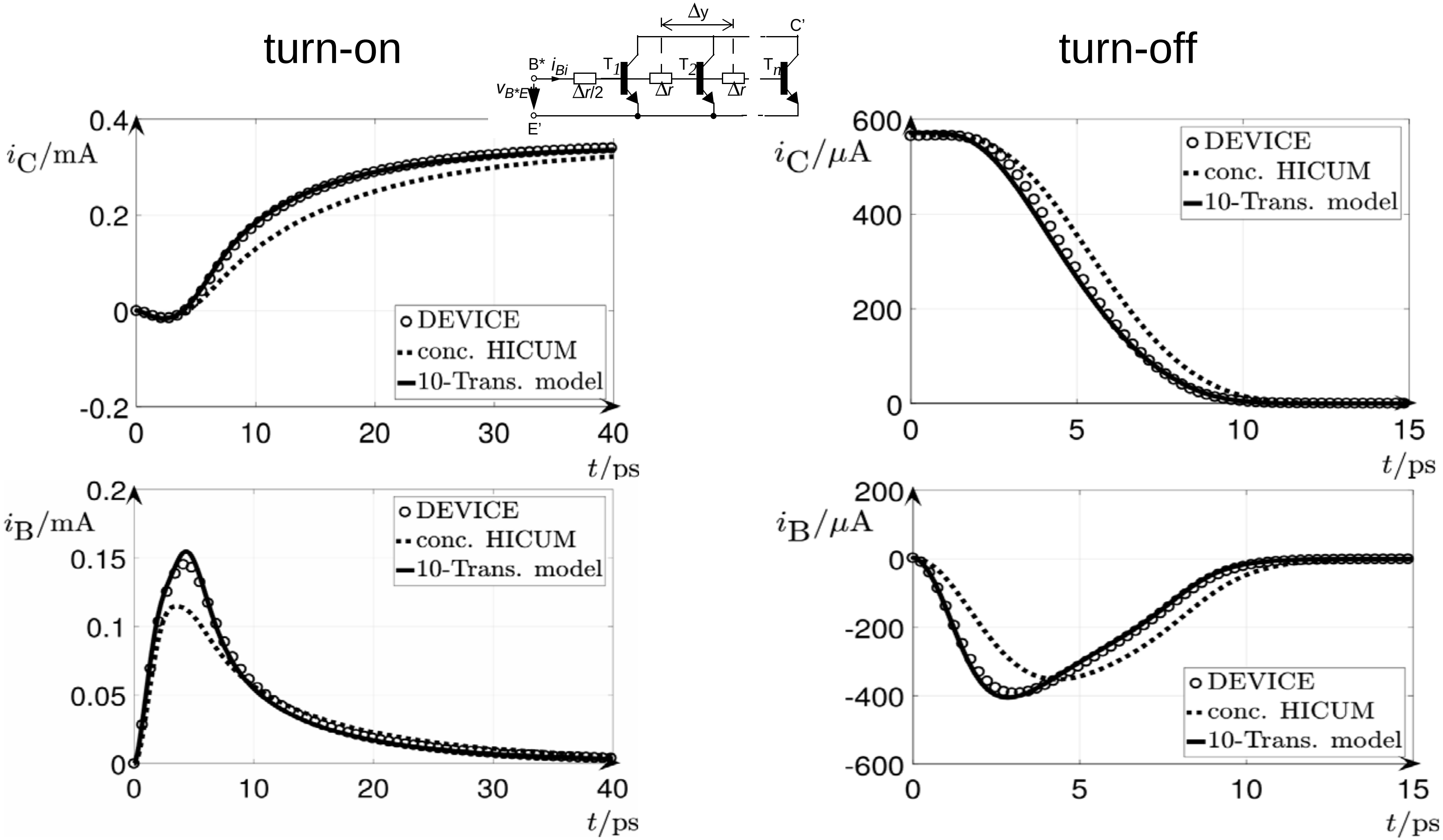


- different bias regions and switching amplitudes covered

Selected case here: ΔV = 200 mV for b_{E0} = 0.4 µm

Model evaluation by 2D transient simulation

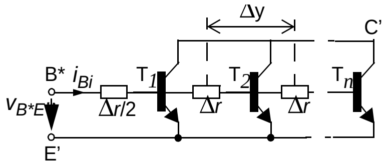
10-transistor model (reference)



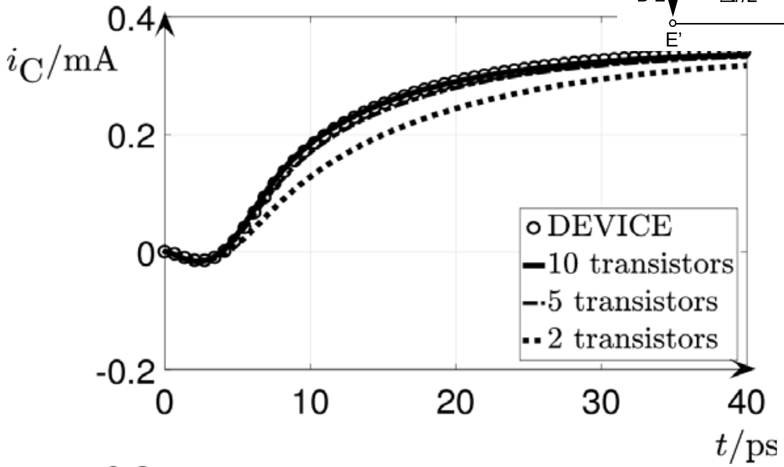
=> distributed model agrees well with TCAD

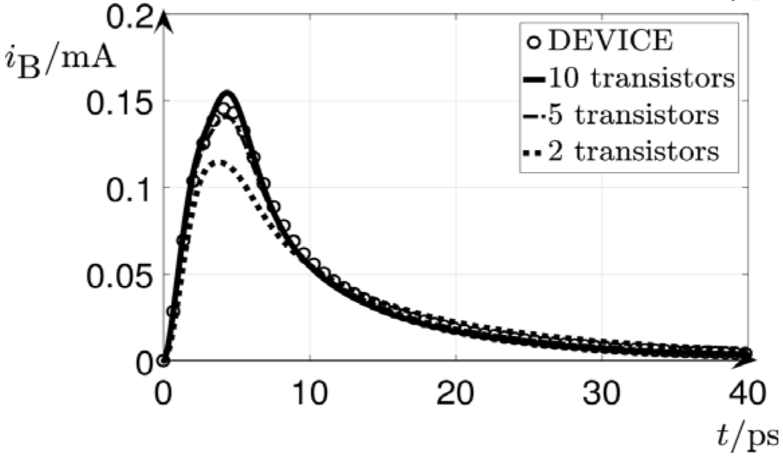
- larger deviations for compact (lumped) model

n-transistor models (n = 2, 5, 10)

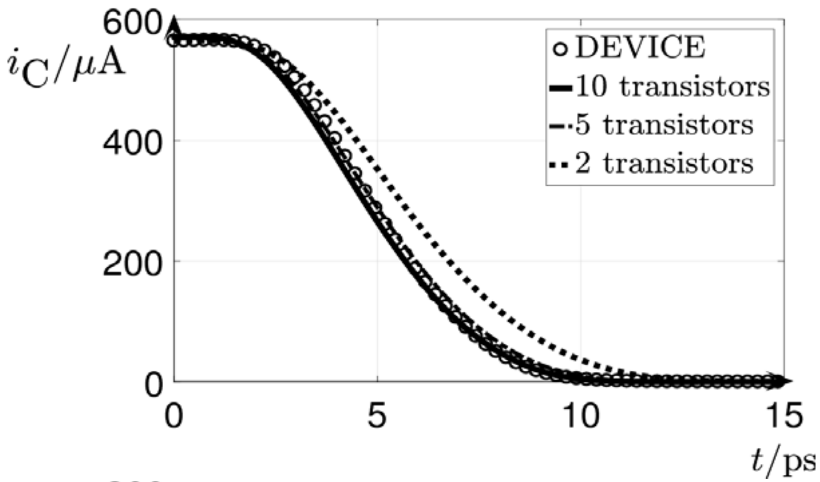


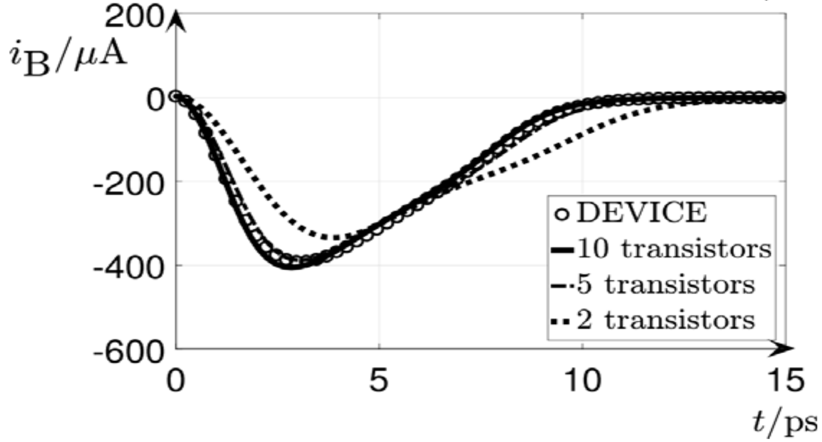
turn-on





turn-off



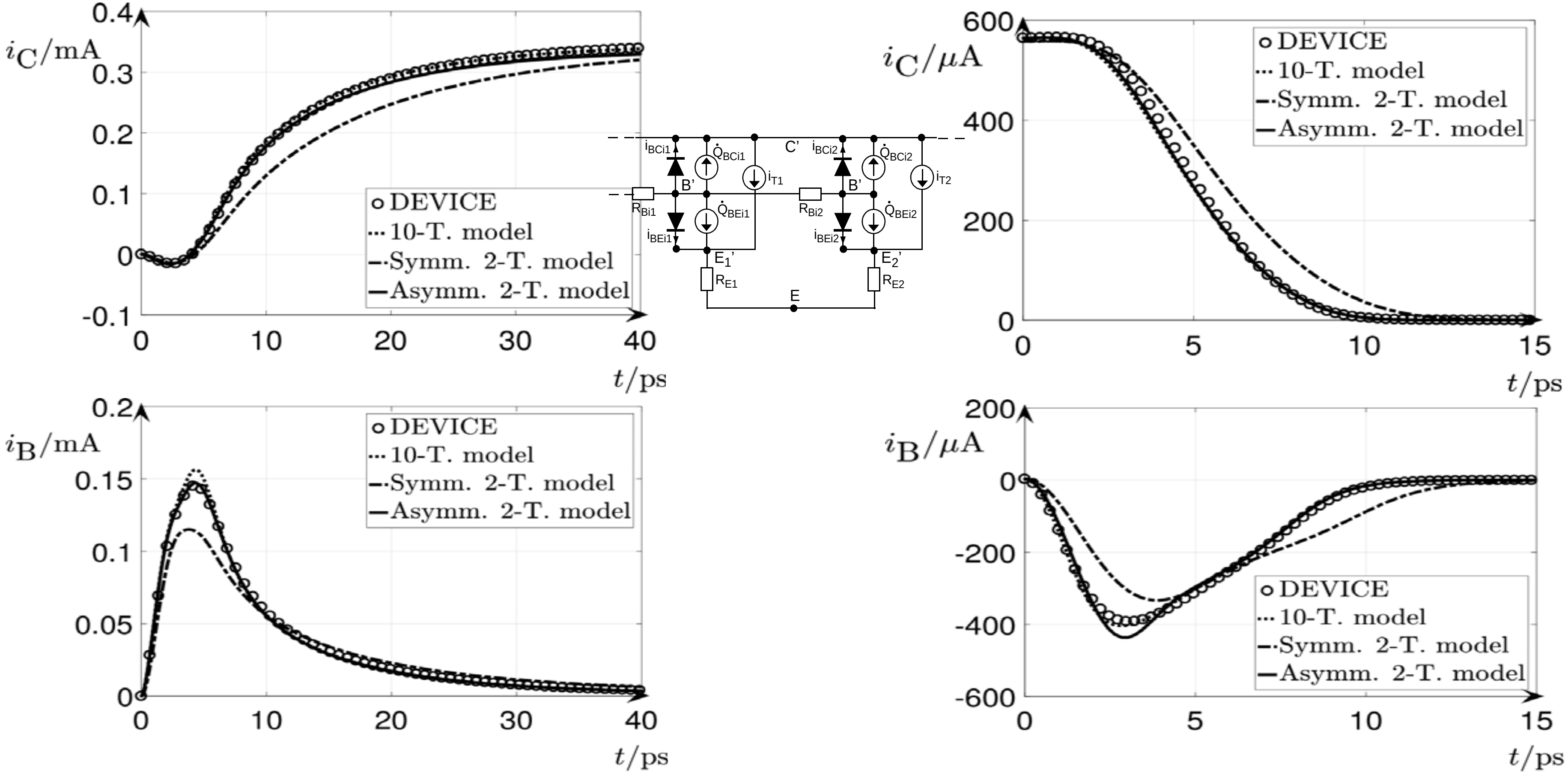


=> need **at least n = 5** for capturing time dependent behavior

- deviations of equidistributed 2-transistor model similar to 1-transistor model

Non-equidistributed 2-transistor model

turn-on turn-off

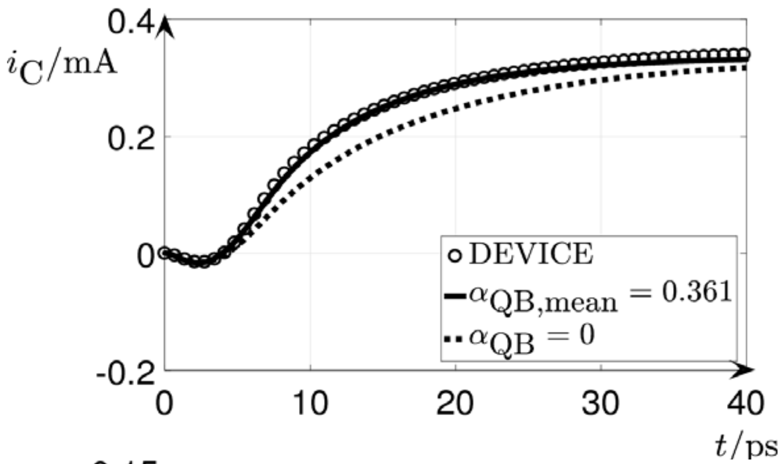


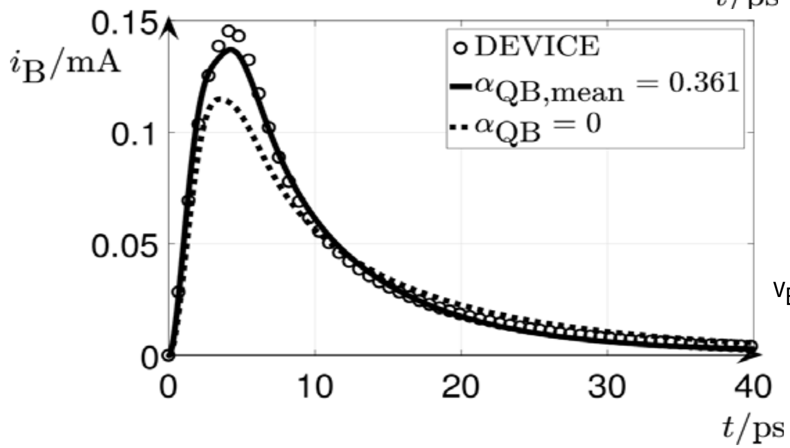
=> **significant improvement due to non-equidistributed A_E and R_{Bi}**

- bias & freq. independent partitioning, but computational effort still too large

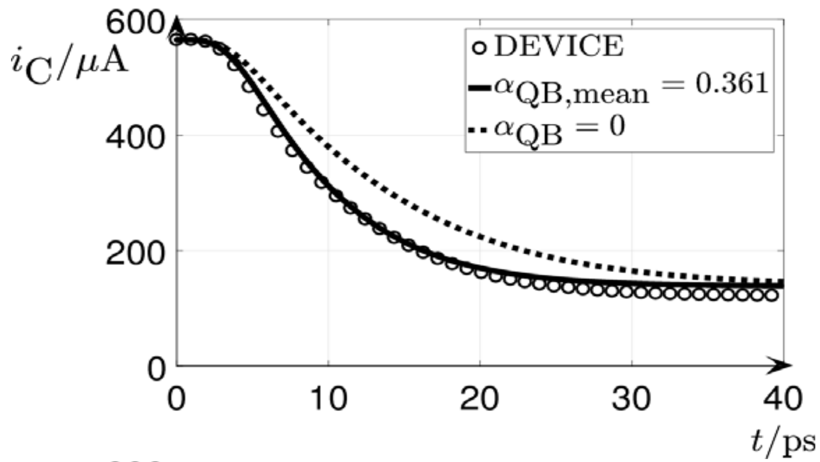
Charge partitioning across internal base resistance

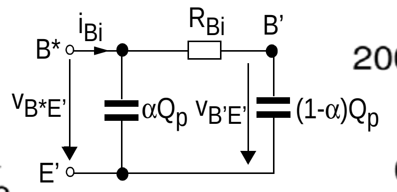
turn-on

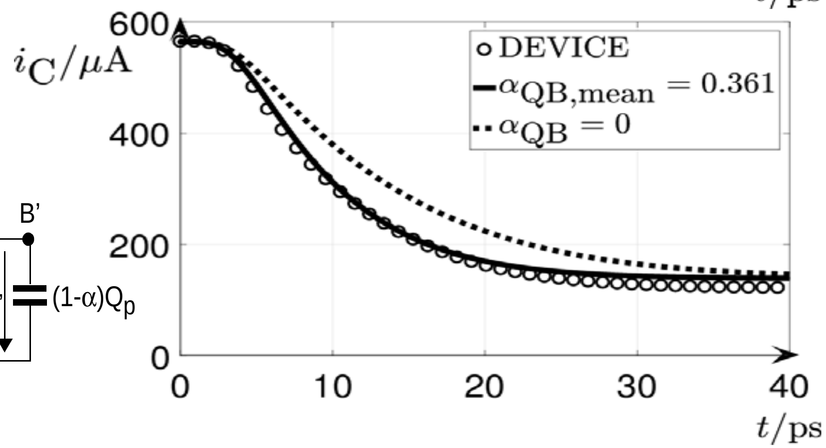




turn-off







=> excellent agreement for compact CP-R_{Bi} model => **preferred solution!**

- partitioning factor depends on bias!

Conclusions

- Existing (standard) approach (R_{Bi}, C_{RBi}) for describing dynamic emitter current crowding (ECC) valid only for small-signal operation
- Compact (lumped) model shows visible deviations for large-signal ECC operation, especially for turn-off switching
- Investigated alternatives for describing dynamic large-signal ECC
  - 10-transistor model => accurate, but **computationally far too expensive**
  - equidistributed 2-transistor model => **similar deviations as 1-transistor model**
  - non-equidistributed 2-transistor model
    => similar accuracy as 10-transistor model, but **computationally still too expensive**
  - lateral charge partitioning across R_{Bi}
    => **accurate and computationally efficient**, but **partitioning factor is bias dependent**

=> pursue lateral charge partitioning approach

Future work

- Develop physics-based formulation for partitioning factor
- Verify charge partitioning model for wide range of voltage swings

Acknowledgments

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