TECHNISCHE UNIVERSITÄT DRESDEN

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Working Group Bipolar (Tr..)

I_T parameter extraction issues in HiCuM/L2 for very advanced HBTs

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Outline

1 Introduction

- Currently, weight factors in the GICCR charge integral are assumed to be constant over bias.
- Depending on the extraction method experimental determination of the transfer current related model parameters Q_{p0} and c_{10} may lead to issues for certain advanced devices .
- It is unclear whether this problem is caused by the method or the model formulation.

$$I_T = c_0 \frac{\exp(V_{B'E'}/V_T) - \exp(V_{B'C'}/V_T)}{\int_{x_l}^{x_u} h_g p dx} = c_{10} \frac{\exp(V_{B'E'}/V_T) - \exp(V_{B'C'}/V_T)}{Q_{p0} + h_{jEi}Q_{jEi} + h_{jCi}Q_{jCi} + Q_{f,T} + Q_{r,T}}$$

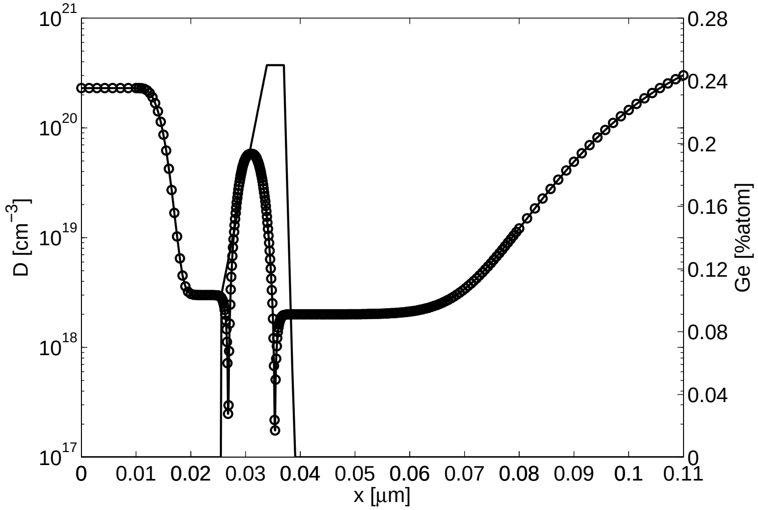
$$\text{with } h_g = \frac{\overline{\mu_{nB} n_{iB}^2}}{\mu_n(x) n_i^2(x)}$$

- Reproducing the issue by 1D device simulation allows to find the cause.

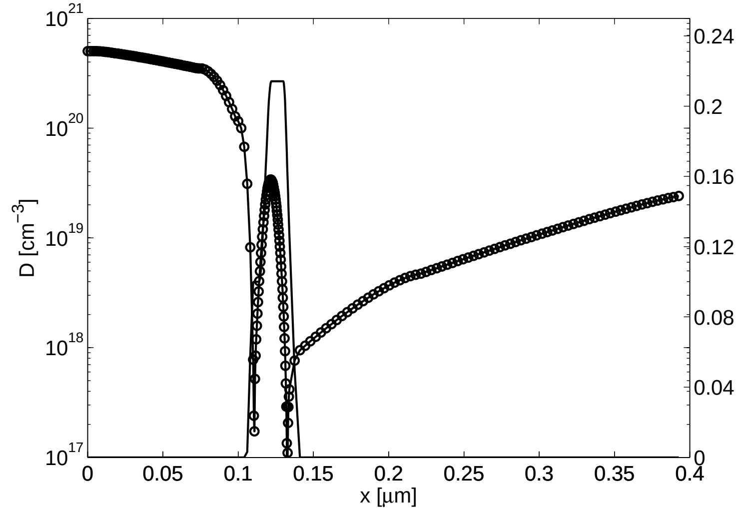
2 Doping profiles

- Two different reference profiles

’500 GHz’



’300 GHz’



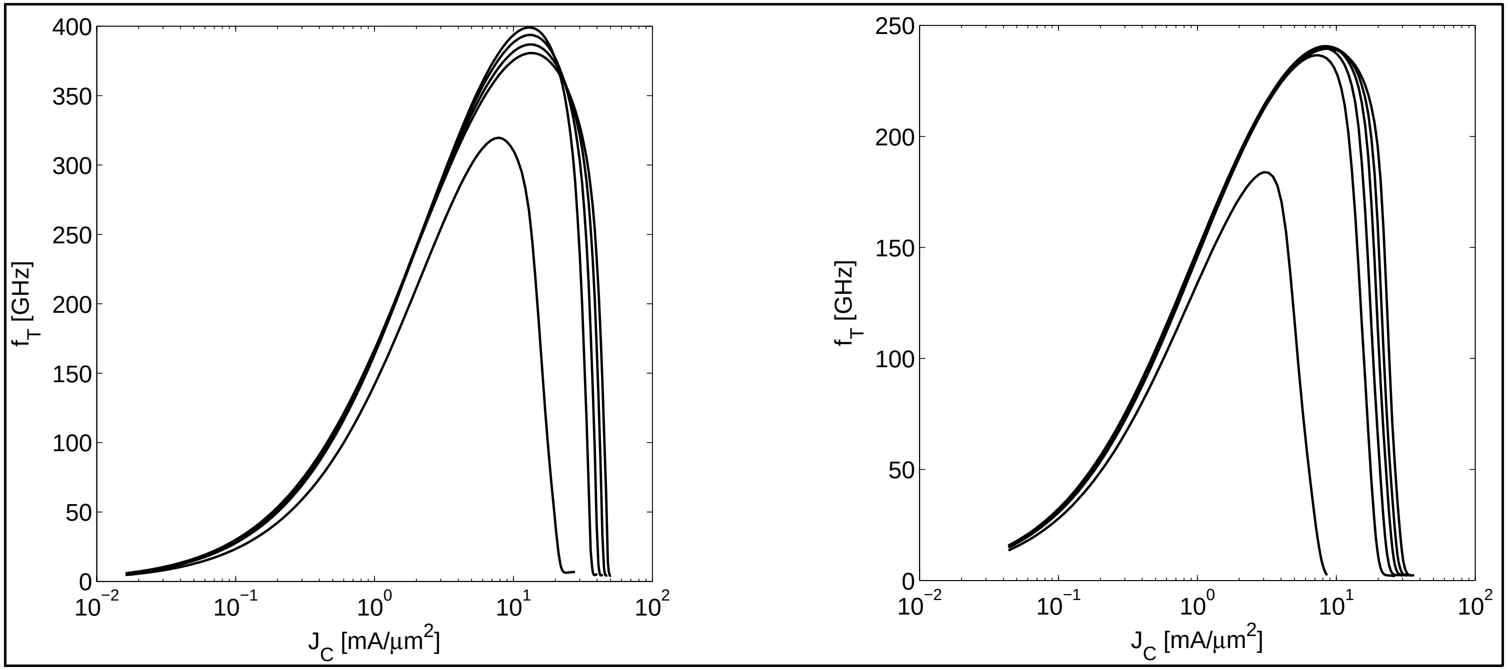
- all investigations based on 1D DD device simulation

- indicated fT values are for 1D HD/MC simulation

3 Transit frequency

- Transit frequency

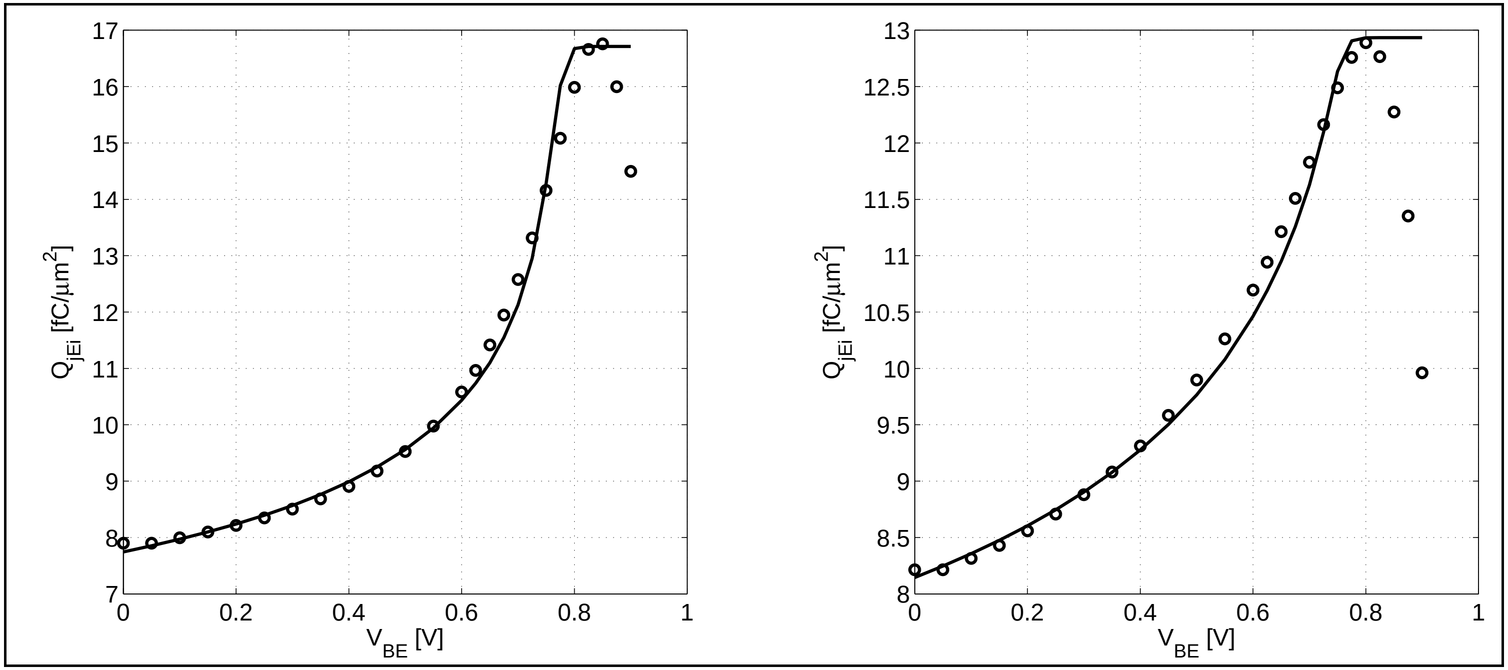
'500 GHz' '300 GHz'



- f_T vs. J_C @ V_{CE} = (0.6, 0.8, 1.0, 1.2, 1.5)V

4 Parameter extraction

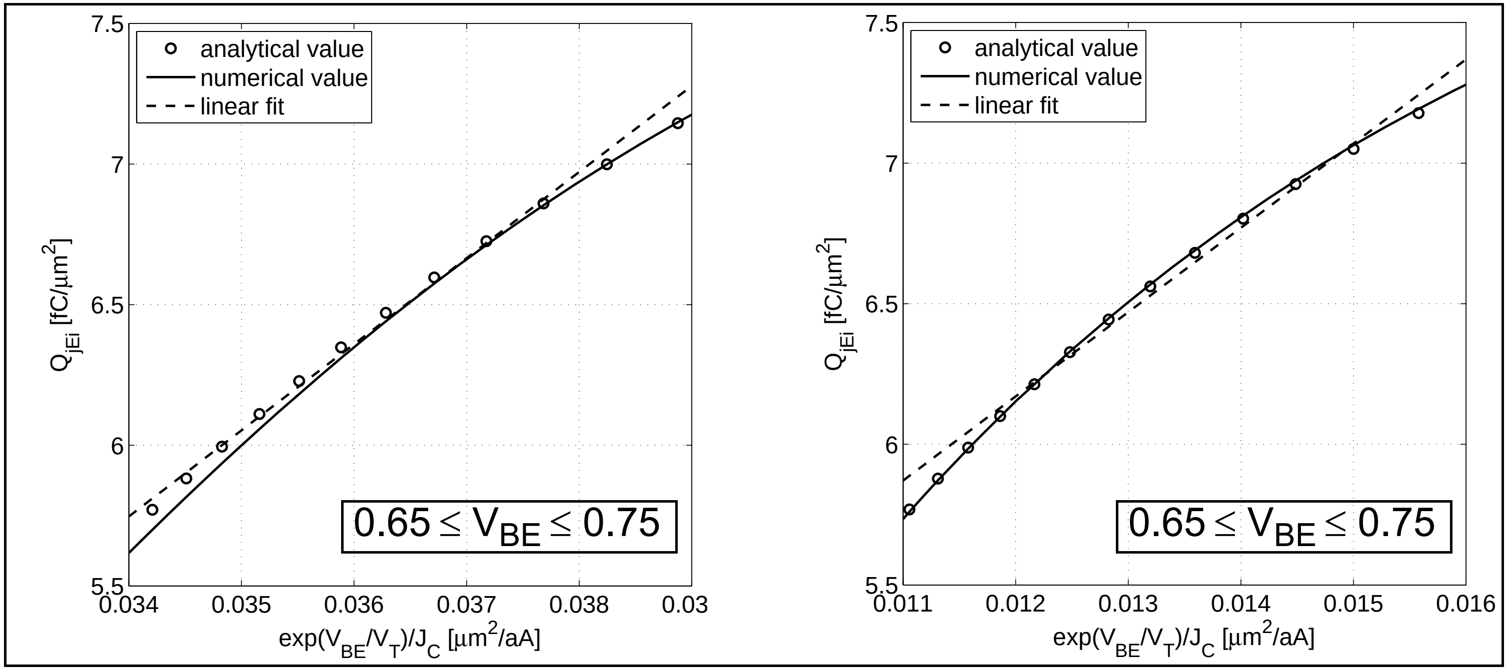
- 1st step: BE junction capacitance parameter extraction



- from extended HiCuM formulation, allows to analytically determine Q_{jEi}
- Note: $C_{j,max}$ is not directly measurable experimentally

4 Parameter extraction (cont'd)

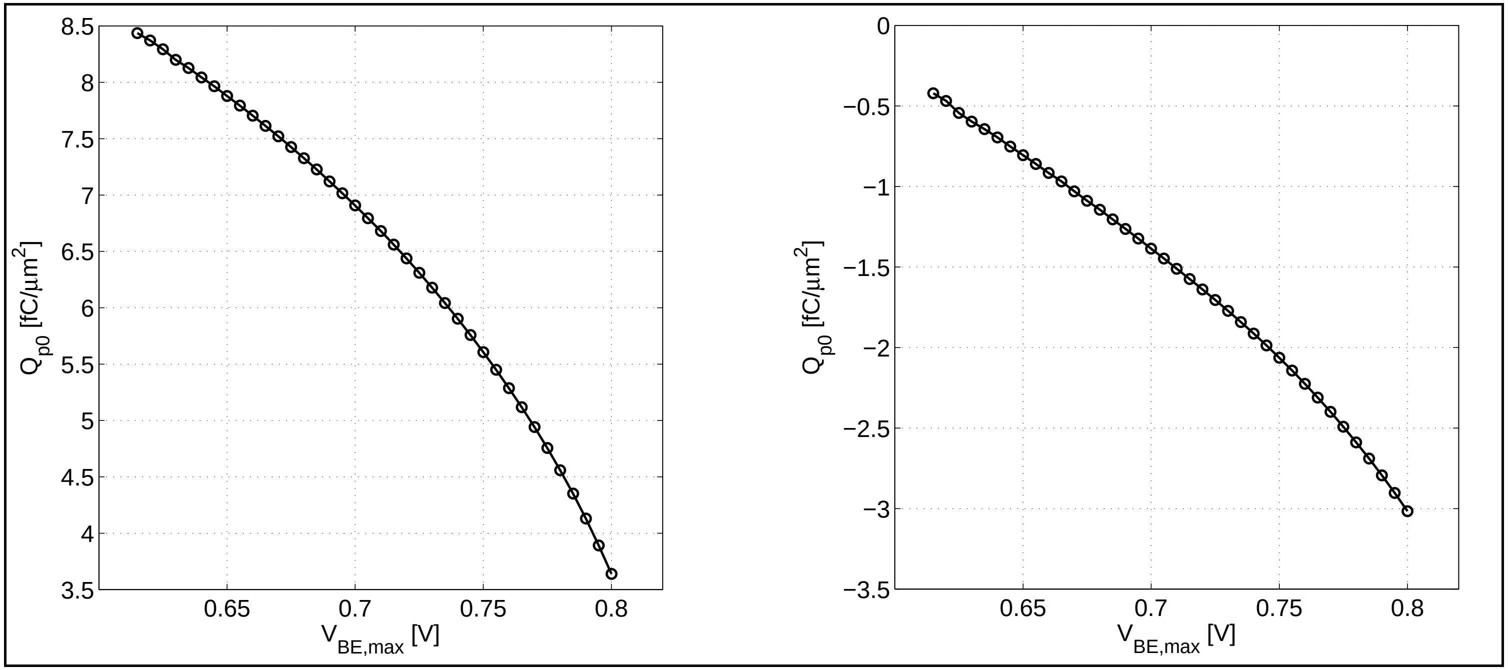
- 2nd step: c_{10} and Q_{p0} extraction



- $Q_{jEi} = \frac{c_{10}}{h_{jEi}} \frac{\exp(V_{BE}/V_T)}{J_C} - \frac{Q_{p0}}{h_{jEi}}$ @ V_{BC} = 0V and very low J_C
- Slope and intercept of Q_{jEi} vs. $\exp(V_{BE}/V_T)/J_C$ represent auxiliary parameters $c'_{10}=c_{10}/h_{jEi}$ and $Q'_{p0}=Q_{p0}/h_{jEi}$, resp.

4 Parameter extraction (cont'd)

- Q_{p0} variation over V_{BE} range (varied extraction intervals)



- Wide variation range of Q_{p0}!
- Linear fit of Q_{jEi} vs. $exp(V_{BE}/V_T)/J_C$ using increasing V_{BE} interval with fixed starting point and $V_{BE,max}$ as final value

5 Extraction results

- Extracted model parameters

parameter	500 GHz	300 GHz	100 GHz
C_{jEi0}	7.8440 fF/µm²	8.1670 fF/µm²	6.431 fF/µm²
V_{DEi}	0.7996 V	0.9488 V	0.9119 V
z_{Ei}	0.2145	0.2616	0.2107
a_{jEi}	2.1410	1.6030	1.5060
$Q_{p0,tech}$	**26.130 fC/µm²**	**35.186 fC/µm²**	**78.603 fC/µm²**
$Q_{p0,rSBi}$	**26.753 fC/µm²**	**33.275 fC/µm²**	**75.252 fC/µm²**
$Q_{p0,extr}$	4.6647 fC/µm²	**-2.576 fC/µm²**	8.665 fC/µm²
c_{10}	3.062 10^{-31} AC/µm^4	2.996 10^{-31} AC/µm^4	5.766 10^{-31} AC/µm^4
I_S	6.564 10^{-17} A/µm²	**-1.163 10^{-16} A/µm²**	6.6544 10^{-17} A/µm²
h_{jCi}	0.0886	0.7372 10^{-3}	1.053
h_{jEi}	1.0	1.0	1.0

- Direct extraction gives too low or negative value for ***Q_{p0}*****!**

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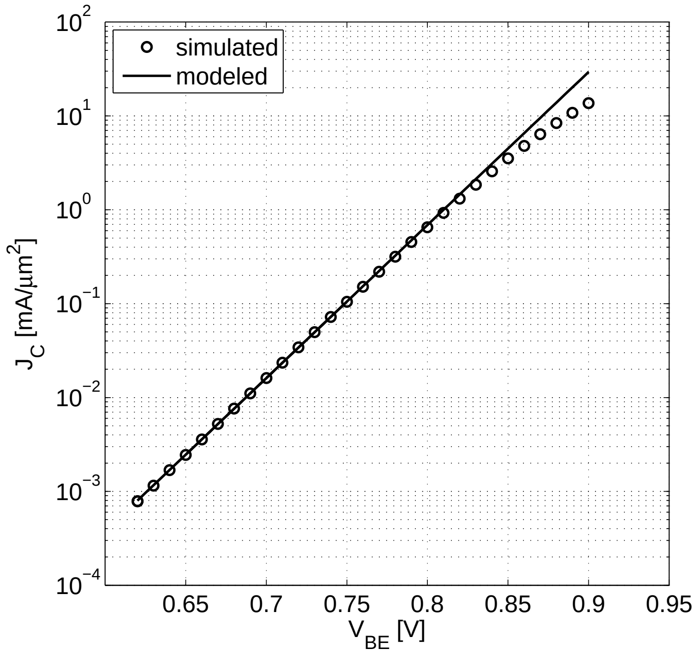
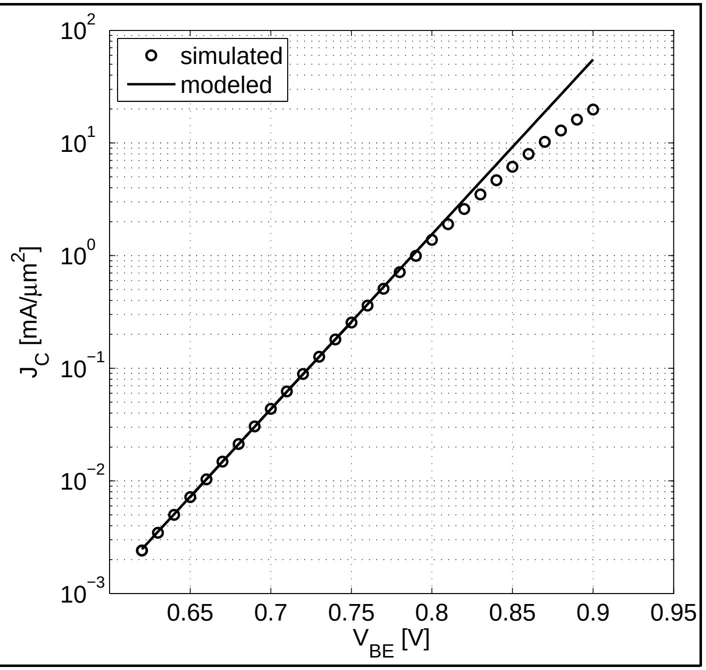
5 Extraction results (cont'd)

- Forward gummel plot @ V_{BC} = 0V

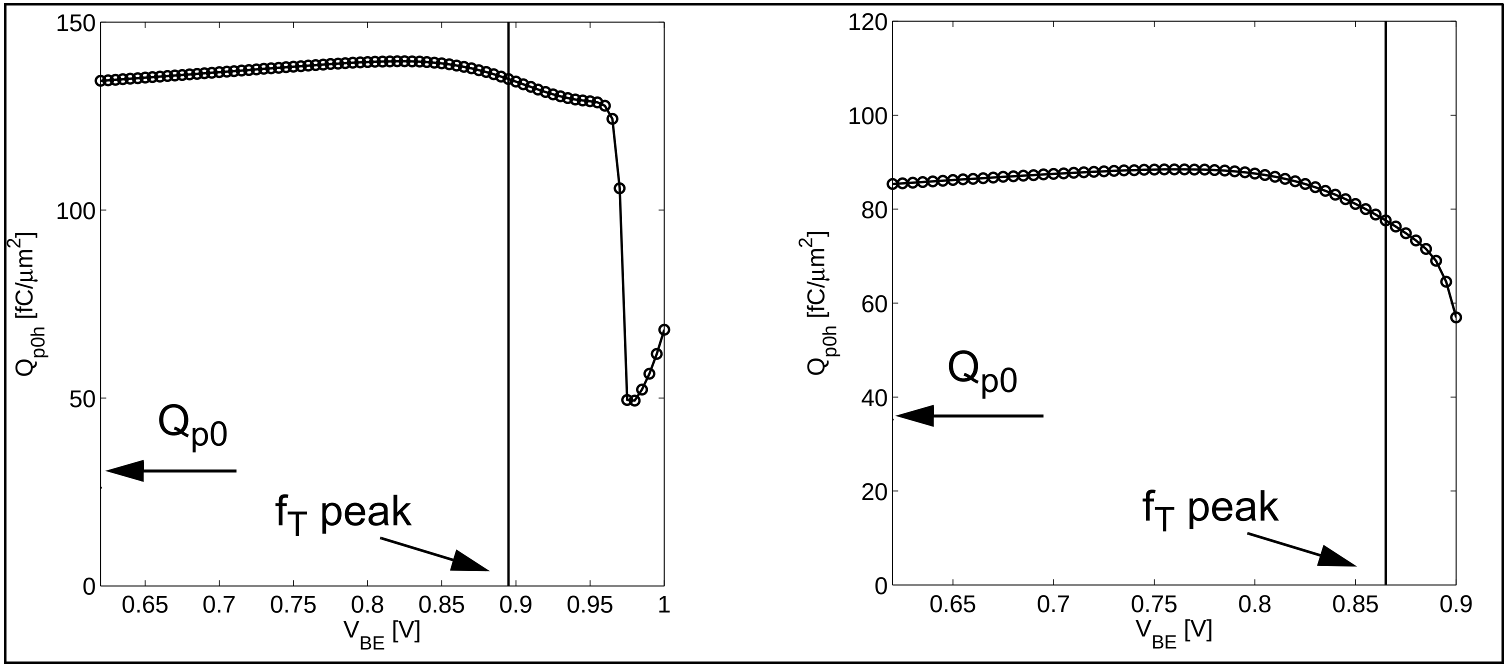




- Despite of the negative/non-physical value obtained for Q_{p0}, the fit in the gummel plot shows good conformance.

6 Results from device simulations

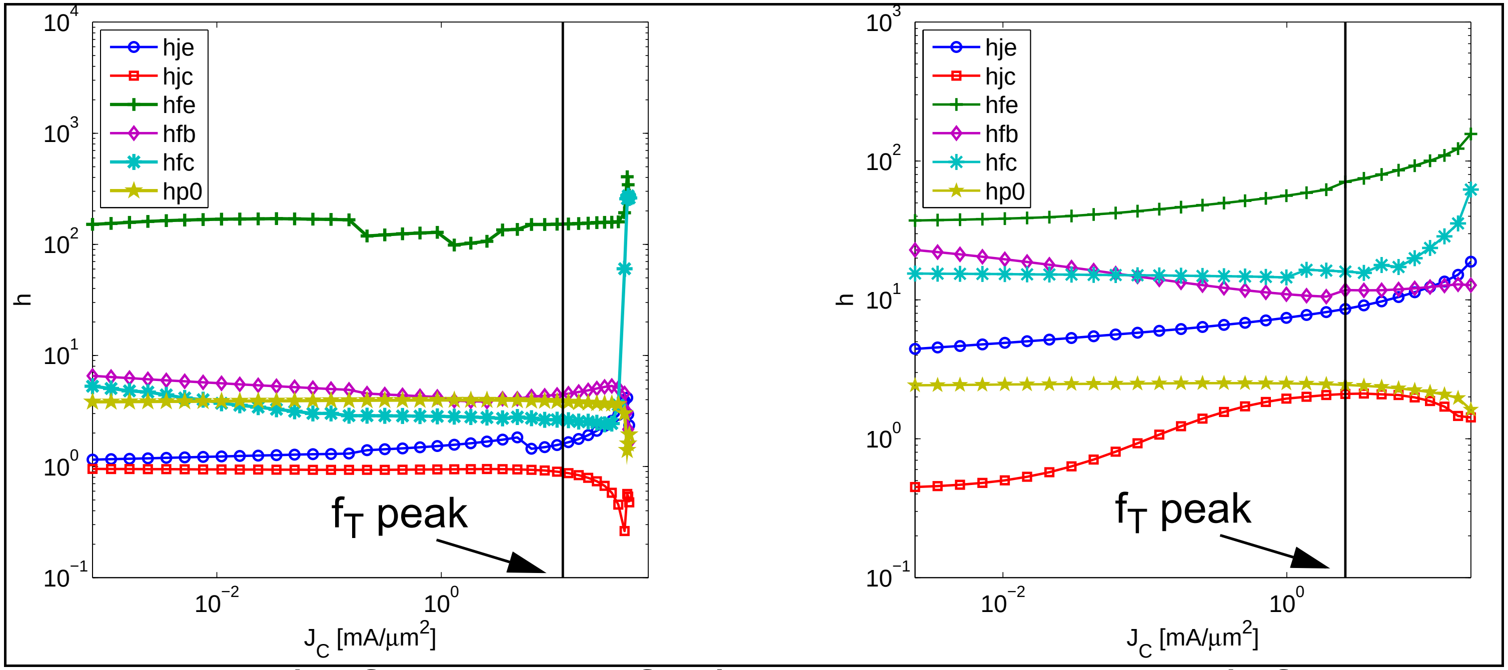
- Q_{p0h} from DEVICE simulations



- Q_{p0h} significantly larger than Q_{p0}
- distinctive bias dependence of Q_{p0h}

6 Results from device simulations (cont'd)

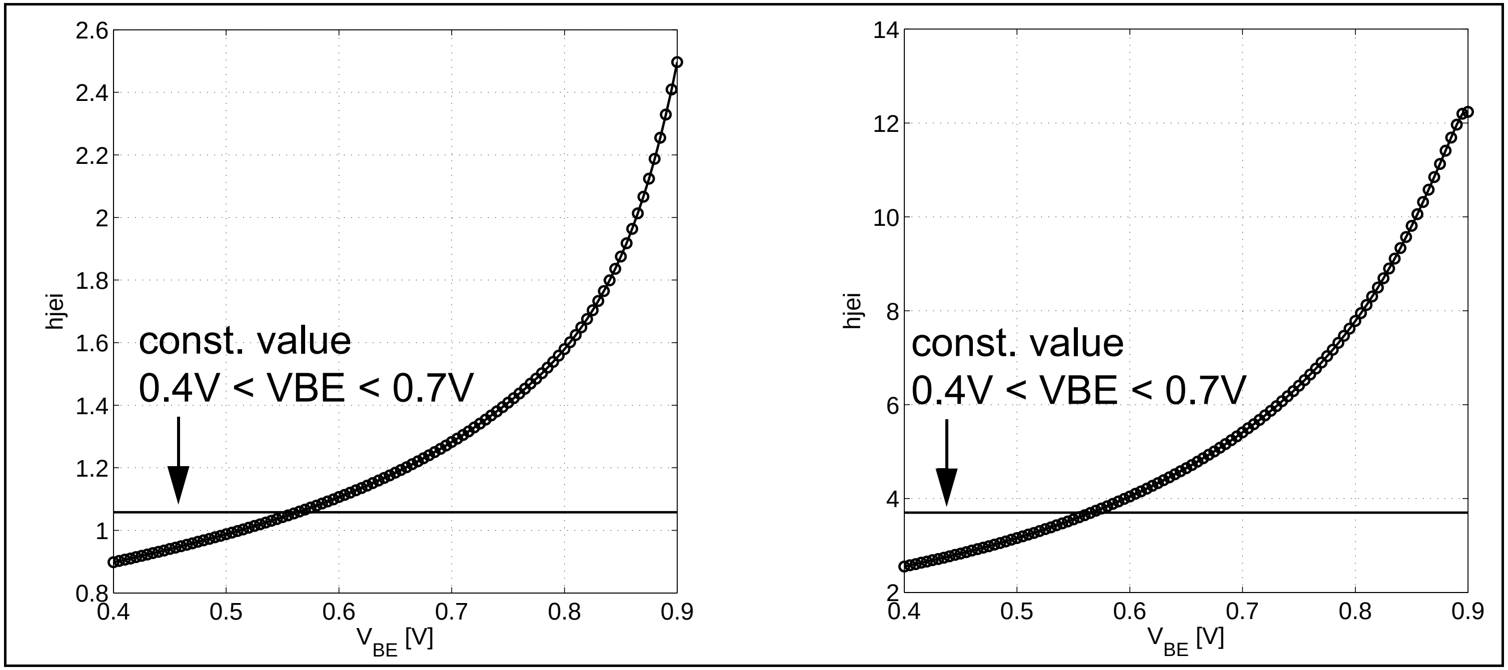
- weight factors from DEVICE simulations



- most weight factors are fairly constant up to peak f_T
- Q_{jEi} largest contribution in low-/medium bias range
  -> bias dependence of h_{jei} relevant

6 Results from device simulations (cont'd)

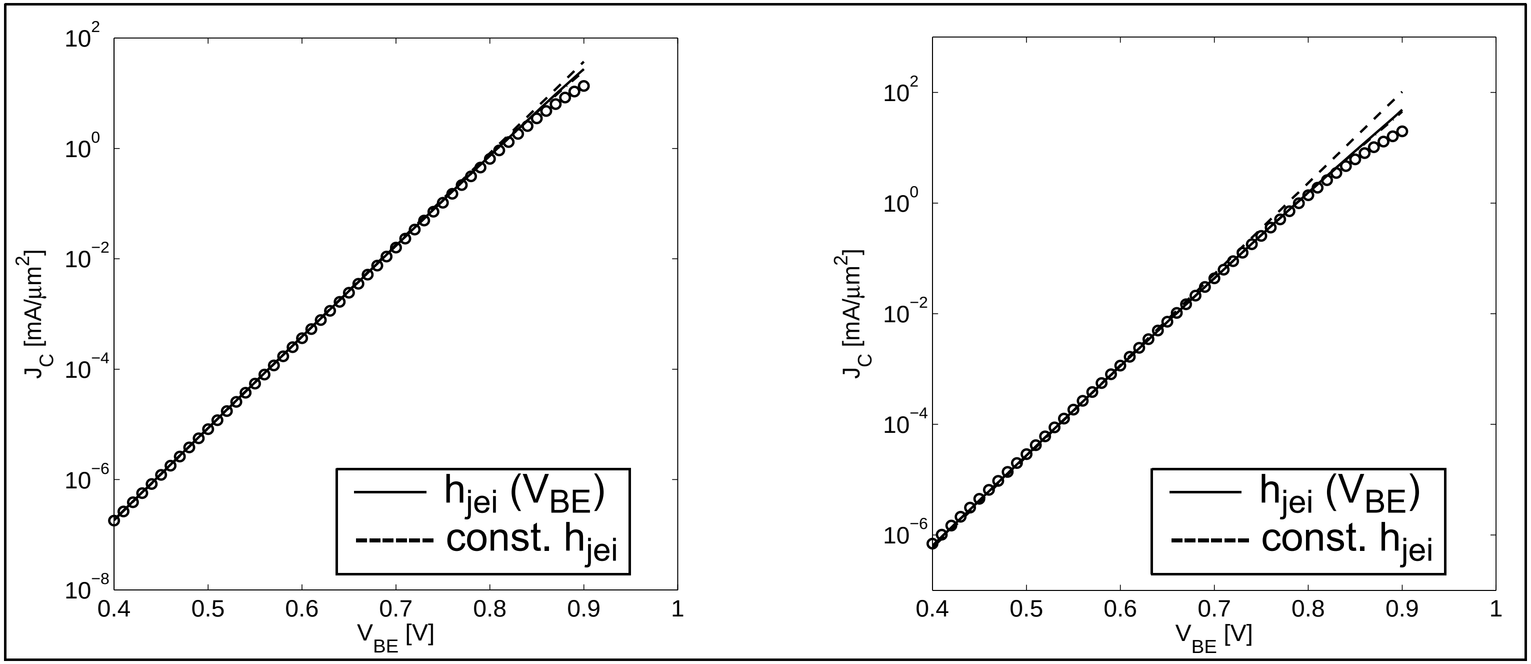
- calculation of Q_{jEih} and h_{jEi} from internal quantities



- $\Delta Q_{jEh} = Q_{jEih} = q \cdot A_E \int_{x_{me}}^{x_{Bn}} h_g \cdot (\Delta p - \Delta n) dx$ with $h_g = \frac{\mu_{nr} n_{ir}^2}{\mu_n(x) n_i^2(x)}$
- ***h_{jei}**$(V_{BE}) = Q_{jEih}(V_{BE})/(Q_{jEi}(V_{BE}) \cdot h_{p0})$*

7 Results from device simulations (cont'd)

- Insertion in GICCR



- Total weighted charge $Q_{p,T} = Q_{p0h} + Q_{jEih}$
- low-/medium bias cond.: only Q_{jEih} and Q_{p0h} significant
- $i_T = \frac{c_{10}}{Q_{p,T}}[\exp(V_{BE}/V_T) - \exp(V_{BC}/V_T)]$ with $c_{10} = (qA_E)^2 V_T \overline{\mu_{nB} n_{iB}^2}$

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8 Summary

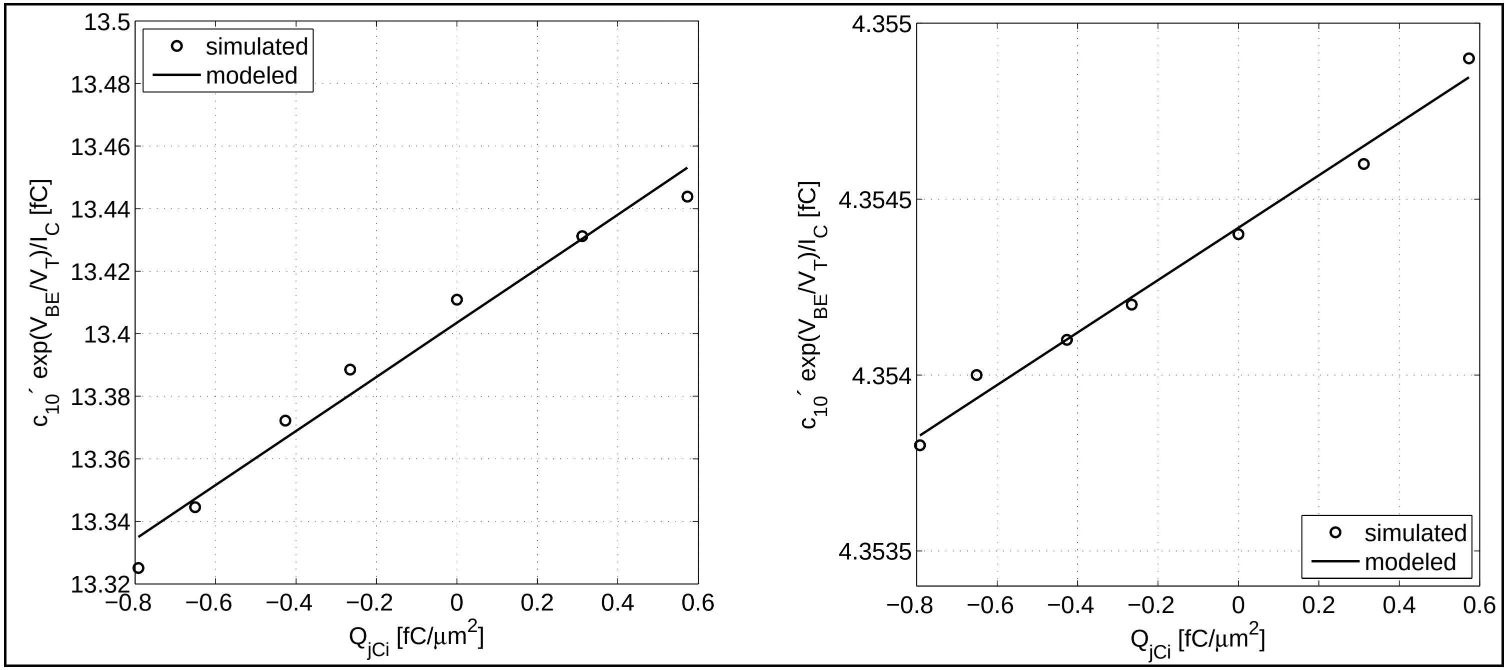
- Extracting Q_{p0} from I_C may not give accurate values.
- Ignoring the bias dependence of h_{p0} (or Q_{p0}) and h_{jEi} obviously leads to the observed extraction issue.
- Pros and cons of existing compact GICCR formulation to be investigated and evaluated on advanced HBT:
    - Keeping existing absolute charge term seems more favorable if bias dependence is mainly caused by Q_{p0h}

      => otherwise h_{p0}(bias) mixed with bias dependence of

      other weight factors

9 Appendix

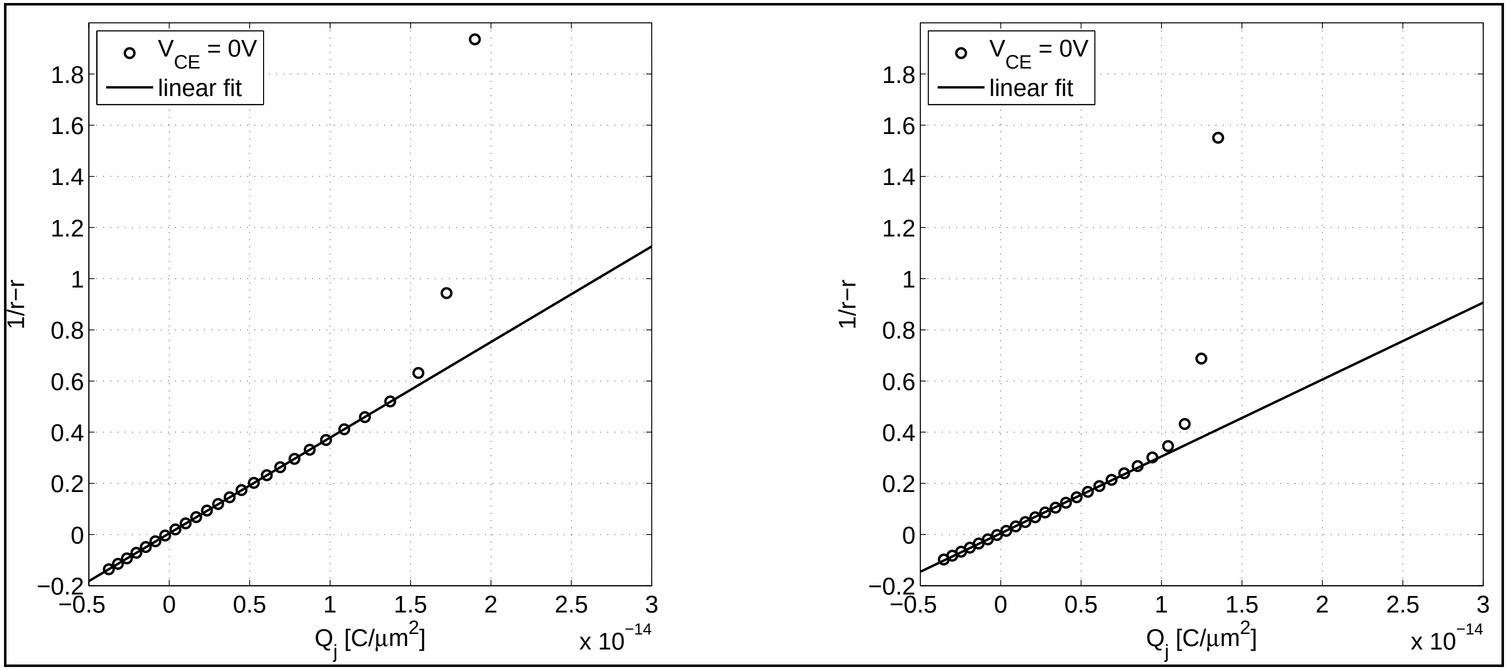
- 3rd Extraction step: h_{jci} determination



- $c'_{10}[\exp(V_{BE}/V_T)]/I_C$ plotted vs. Q_{jCi} is linear and the slope gives the auxiliary parameter $\boldsymbol{h'_{jCi}}=h_{jCi}/h_{jEi}$.
- h_{jEi} is currently set to 1 per default!

Appendix (cont'd)

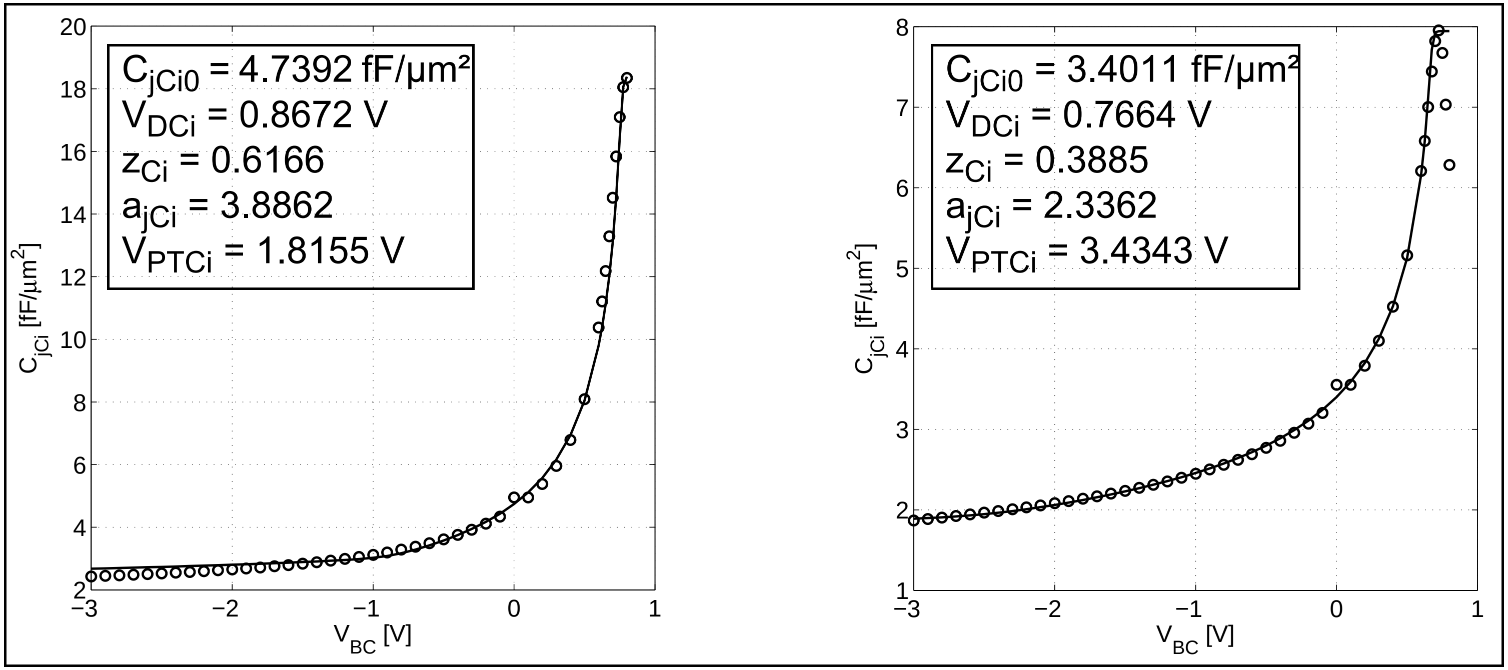
- Extraction of Q_{p0} from R_{SBi}



- $Q_j = Q_{jEi} + Q_{jCi}$ vs. $r = r_{SBi}/r_{SBi0}$ @ $V_{CE} = 0V$
- $\frac{1}{r} - r = \frac{Q_j}{Q_{p0}}$ -> Q_{p0} as the slope

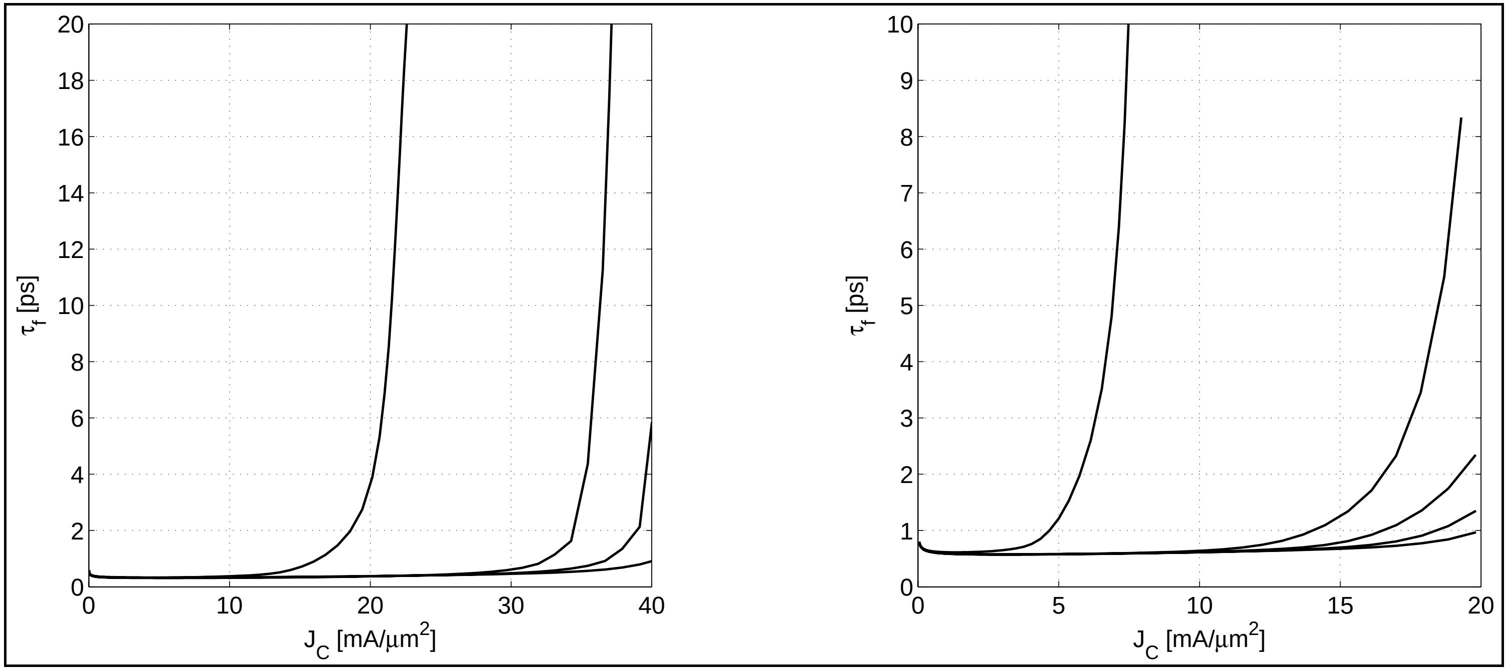
9 Appendix (cont'd)

- Internal BC capacitance



9 Appendix (cont'd)

- τ_f from DEVICE REGAP postprocessor



- $\tau_{0,\,500GHz}$ =0.3256 ps, $\tau_{0,\,300GHz}$ =0.5769 ps