

Application of HICUM Level0 v1.2 to Infineons B6CA Technologie

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Principal Bipolar/BiCMOS Modeling

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ATV PTP PFM EDA



Agenda

- Problems using VBIC
- Extraction procedure for HLO QS related model parameters
- Results in comparison with VBIC v1.2
- Summary

Introduction

- The goal of this investigation was to answer the following two questions:

Is the new bipolar compact model Hicup Level0 v1.2 able to model npn transistors of Infineon technologies with high breakdown voltages?

Is Hicup Level0 v1.2 able to become the follower of VBIC?

- The investigation was made under the following conditions:
 1. Simulator: Cadence Virtuoso Spectre version 7.1.1.239.isr15
16 Oct 2009
 2. ICCAP: 2009 650.400 Oct 6 2009
 3. Technology: B6CA, 0.5 μm Silicon BiCMOS, $f_{T_peak} = 5.5 \text{ GHz}$,
Supply voltage 5 / 12 V *

* Source: Infineon Technology Booklet 02.00

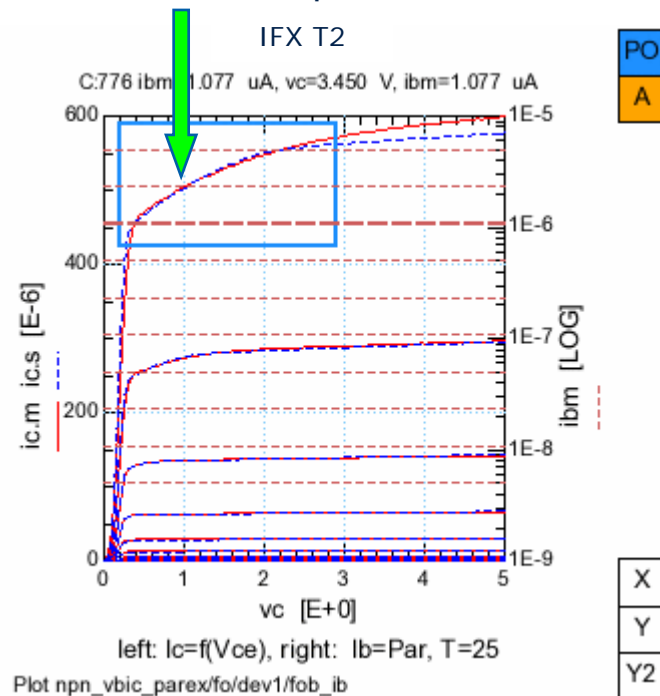
Problems using VBIC

We observed in the past the following problems using the VBIC 1.2 model:

- There is no model parameter combination RCI / GAMM, which is sufficient to model **both** the Ib and the Vb driven output characteristic
- If we use $RCI > 0$, ft shows a very sharp ft roll off, which does not fit to reality
- The appropriate TF increase affects the switch behavior
- Using $RCI > 0$ we observed a pole in CV simulations

Problems using VBIC

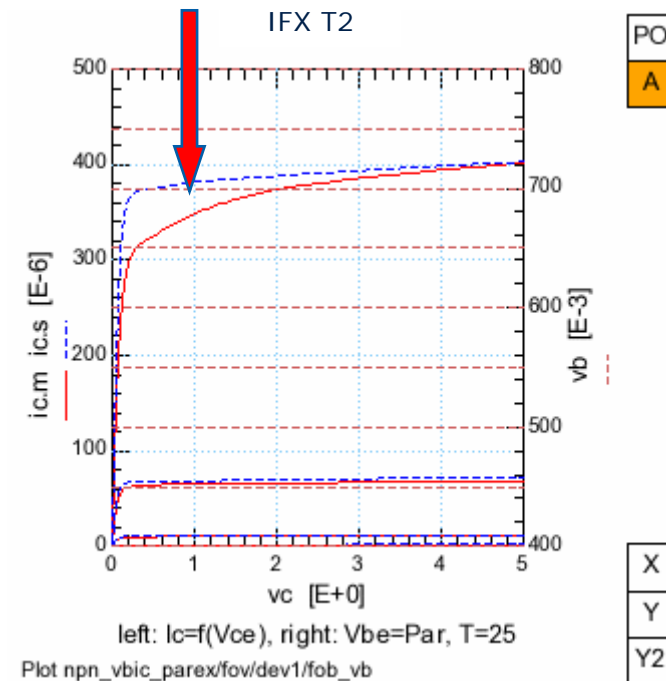
- Sufficient modeling of quasi saturation for I_b driven output characteristic



$I_c=f(V_{ce})$, $I_b=Par$

RCI=3838, GAMM=3351p, $V_0=3$, HRCF=1m

- Bad modeling of quasi saturation for I_b driven output characteristic



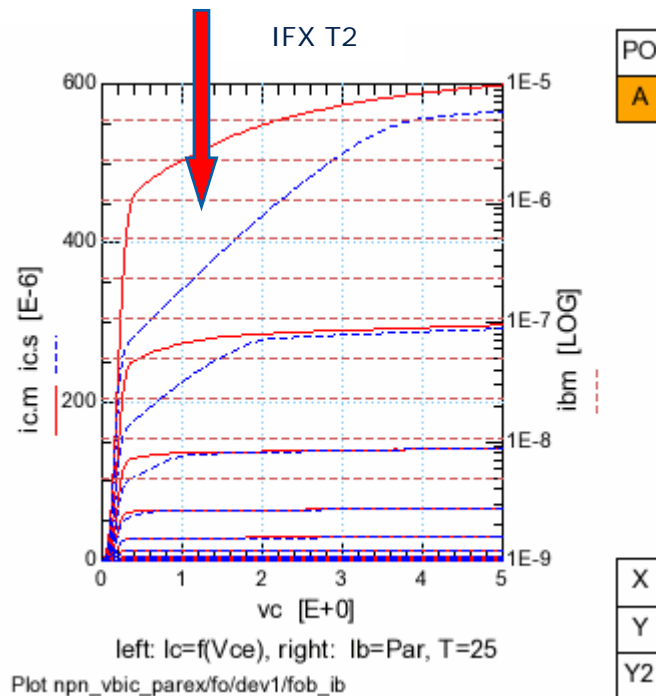
$I_c=f(V_{ce})$, $V_{be}=Par$

RCI=3838, GAMM=3351p, $V_0=3$, HRCF=1m

- Problem: There is no combination RCI / GAMM, which is sufficient for both cases

Problems using VBIC

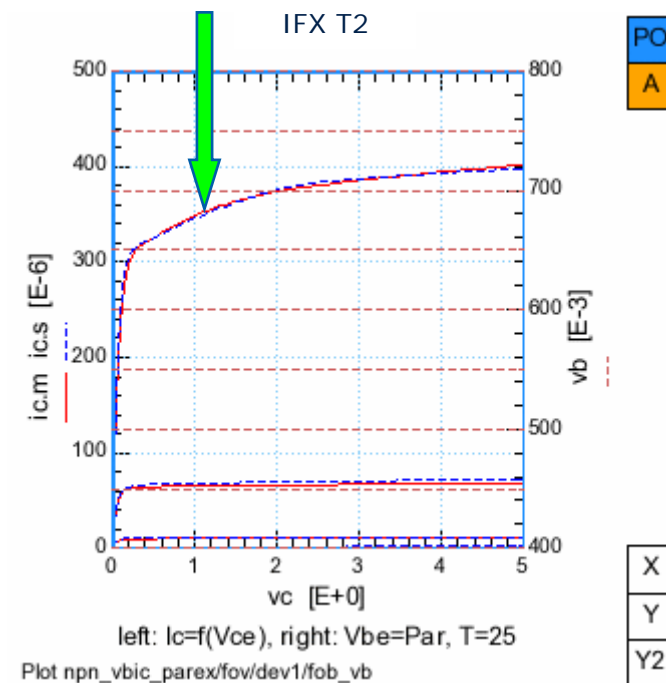
- Bad modeling of quasi saturation for I_b driven output characteristic



$I_c=f(V_{ce})$, $I_b=Par$

$RCI=6723$, $GAMM=1369p$, $V_0=3$, $HRCF=1m$

- Sufficient modeling of quasi saturation for I_b driven output characteristic



$I_c=f(V_{ce})$, $V_{be}=Par$

$RCI=6723$, $GAMM=1369p$, $V_0=3$, $HRCF=1m$

- Problem: There is no combination $RCI / GAMM$, which is sufficient for both cases

Agenda

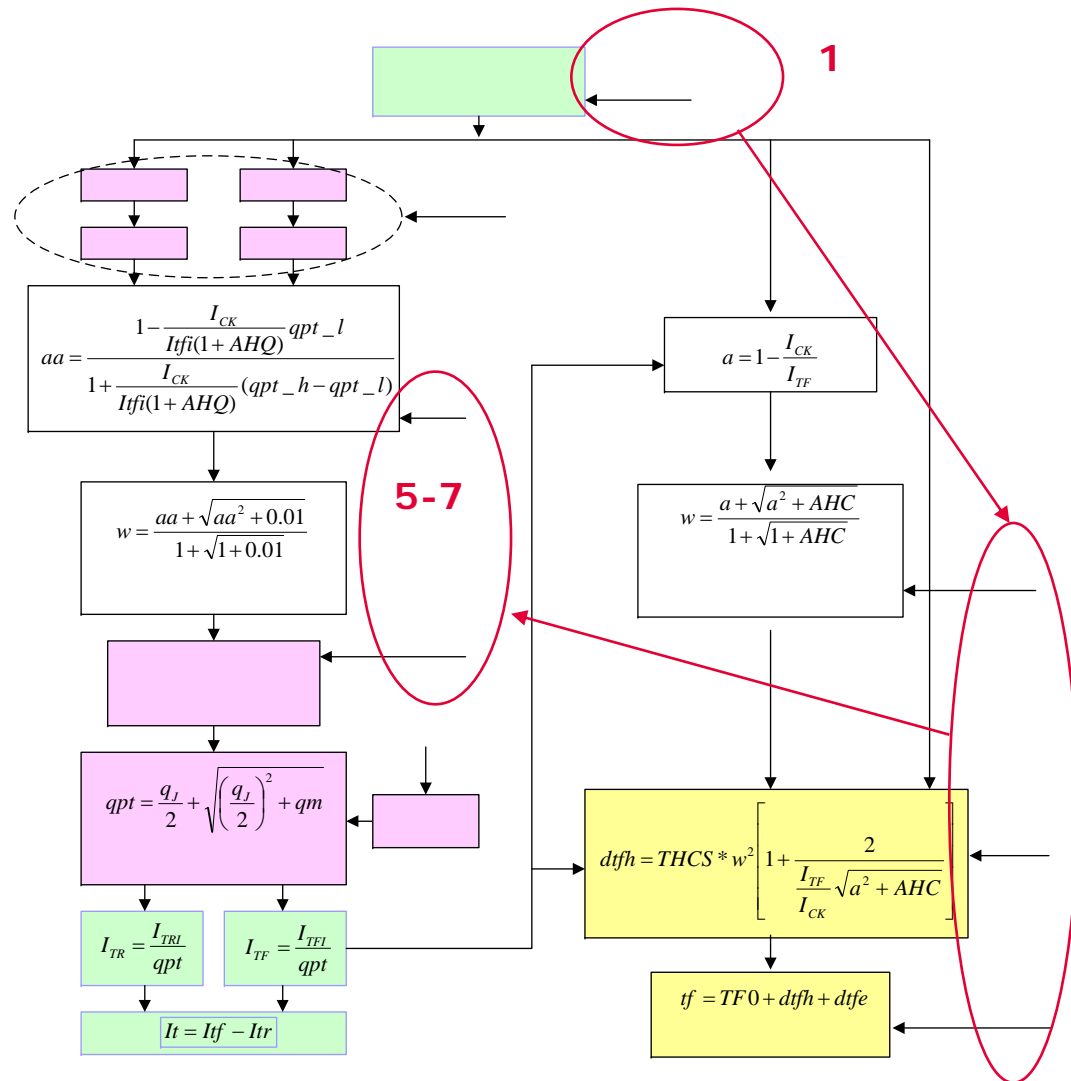
- Problems using VBIC
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Extraction procedure for QS related model parameters

■ The following extraction procedure was applied:

1. Calculate I_{ck} vs. V_c and optimize RC_{IO} , V_{LIM} , V_{PT}
2. Adjust A_{JE} and $THCS$
3. Optimize T_0 , T_{BVL} and DT_{OH} on $ft_{peak}(V_b)$
4. Optimize A_{HC} on ft roll off
5. Optimize A_{HCX} (A_{HQ}) below ft roll off inflection point
6. Optimize I_{QF} and I_{QFH} on forward output curves
7. Check I_c modeling on $ft=f(I_c)$ and $I_c=f(V_{be})$ curves

■ Precondition: junction capacitance parameters, series resistances R_E , R_{CX} , R_{bb} , fwd early voltage, self heating (RTH) have been extracted or calculated before



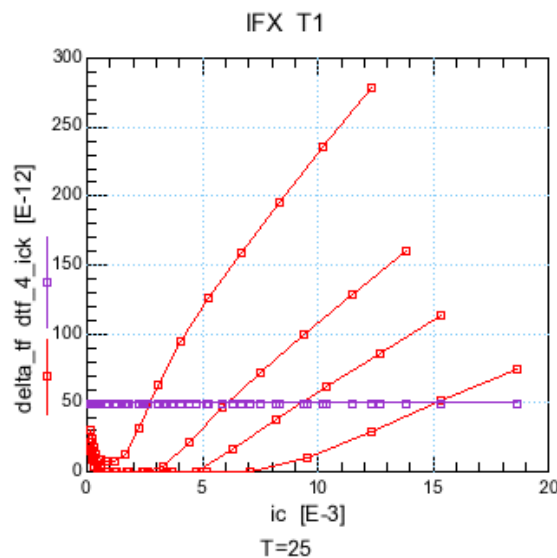
Calculation principle of transfer current and transit time for HLO v1.2

Extraction step by step

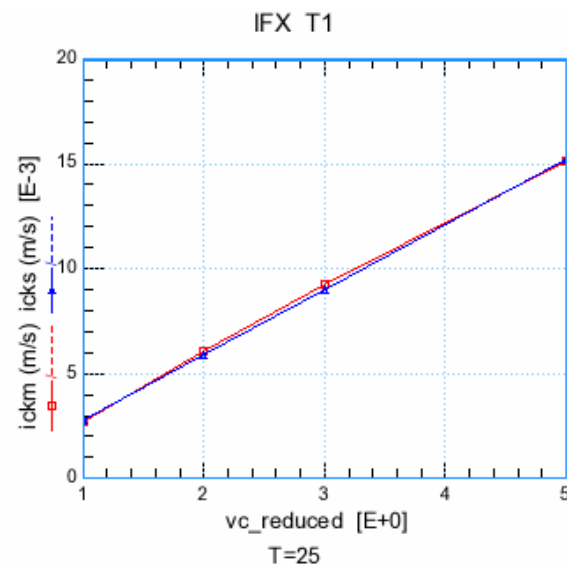
Step1



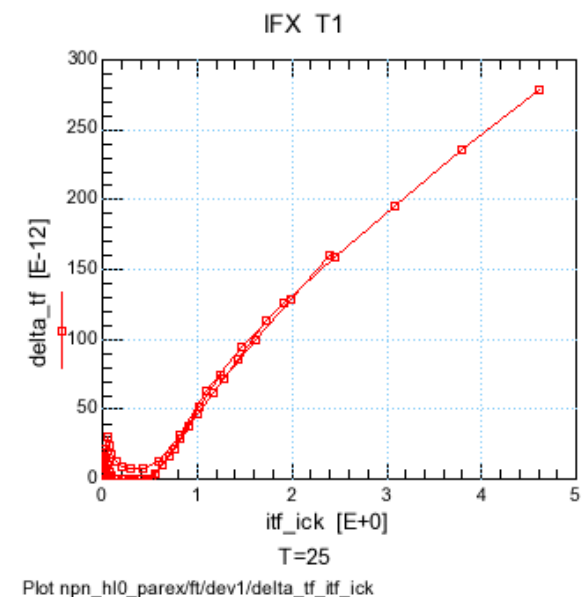
- Define a reasonable value for delta tf to calculate Ick(Vc)
- Extract RCI0, VLIM and VPT by optimization on Ick=f(Vc)
- The nearly linear Ick=f(Vc) indicates here, that the use of VPT for this technology is not necessary



$$\text{delta tf} = f(I_c, V_c)$$



$$I_{ck} = f(V_c)$$



$$\text{delta tf} = f(I_{tf}/I_{ck})$$

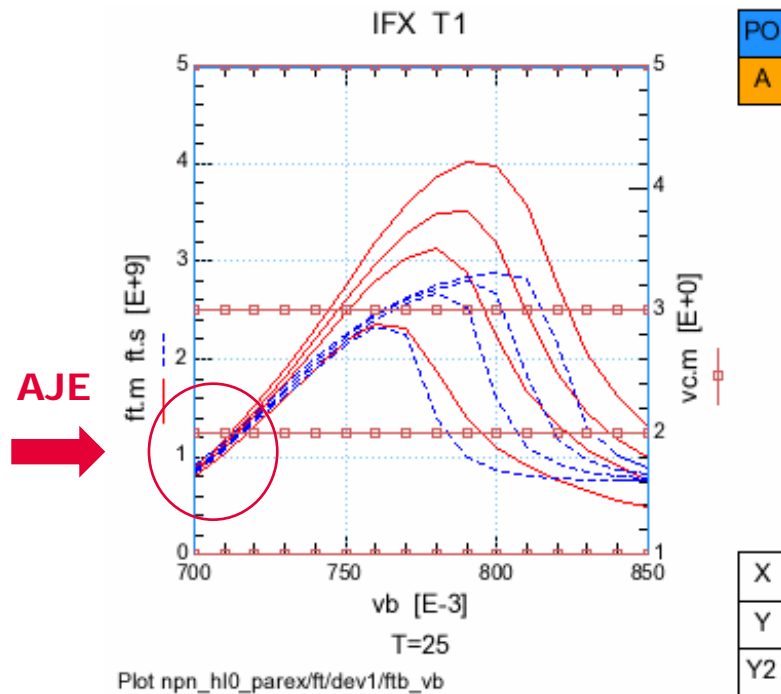
This extraction step is based on:

B.Arduin et.al. "Transit time parameter extraction for the Hicup Bipolar Compact model", BCTM2001

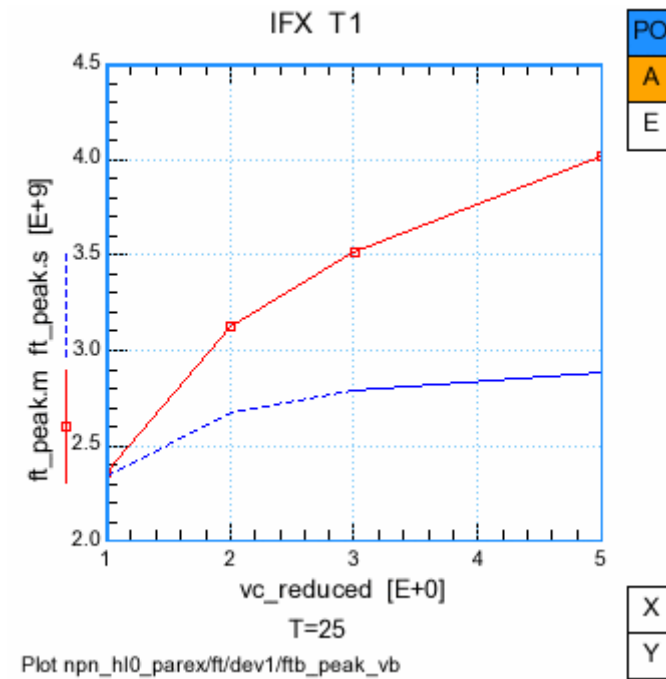
Extraction step by step Step2



- Adjust now AJE in the Vbe range, if necessary
- The other parts of ft are still wrong



$$f_T = f(V_b, V_c)$$



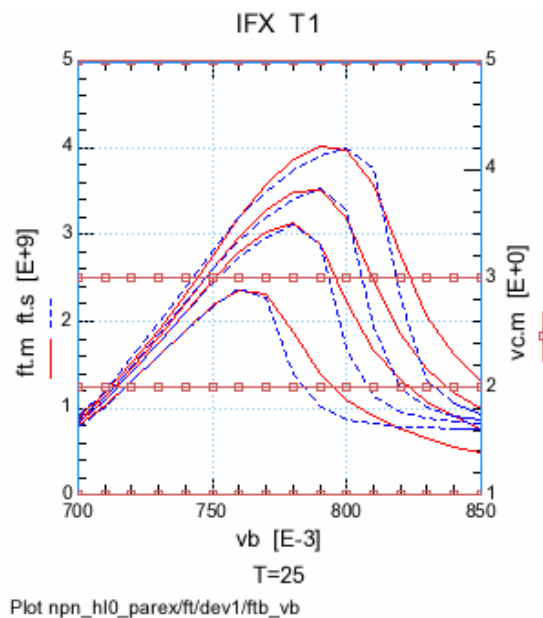
$$f_{T_peak} = f(V_c)$$

Extraction step by step

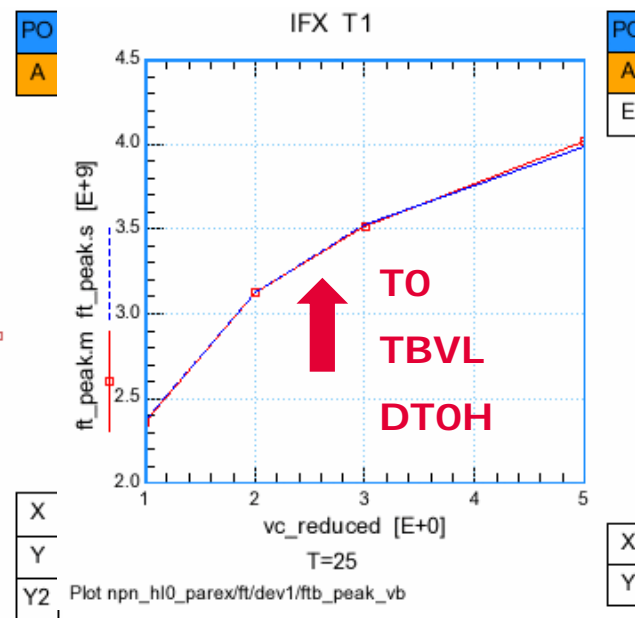
Step3



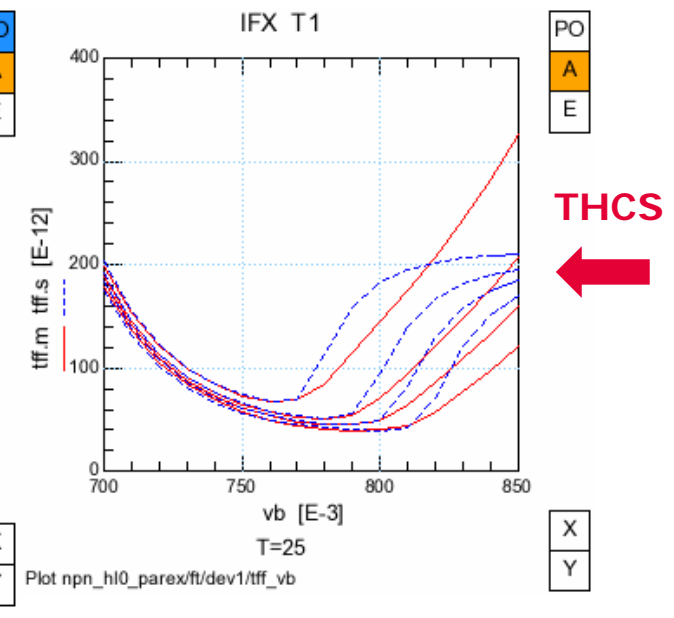
- Define a reasonable value for THCS (rule of thumb: 5 ...10 x tffmin)
- Optimize T0, TBVL and DT0H on $fT_{peak}=f(Vc)$, if necessary, go back to step2 and adjust AJE again
- DT0H is very useful for SiGe technologies to model the reduction of fT increase for high Vc . For the given Si technology, however, DT0H was not used.



$$fT=f(Vb, Vc)$$



$$fT_{peak}=f(Vc)$$



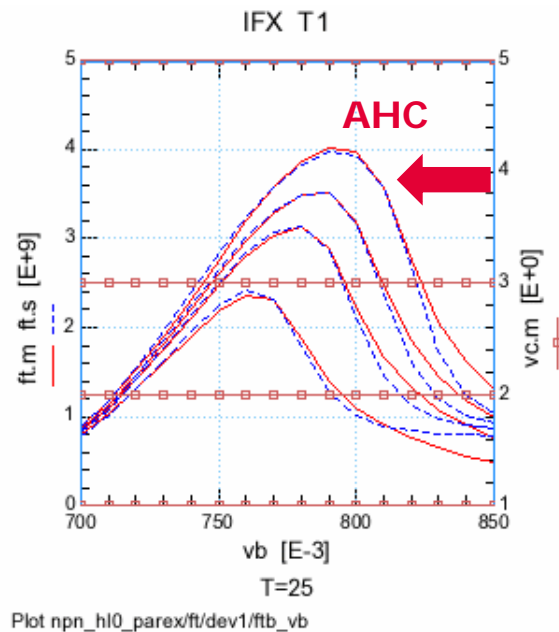
$$tff=f(Vb, Vc)$$

Extraction step by step

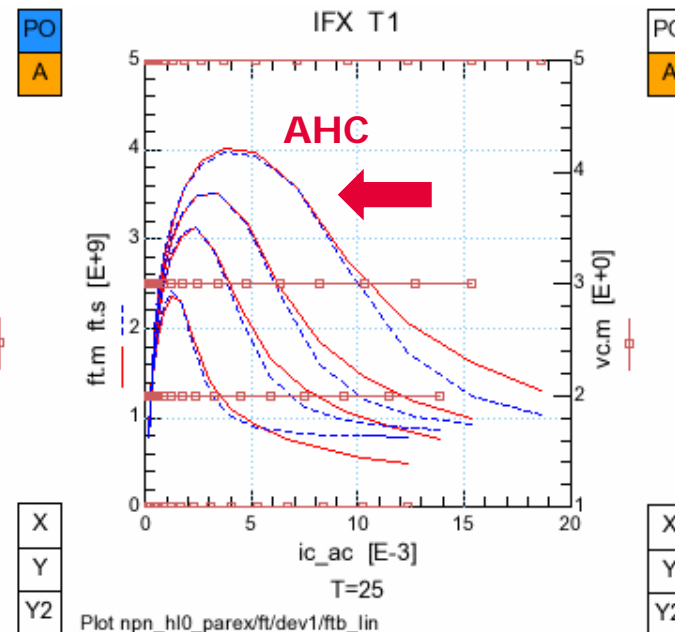
Step4



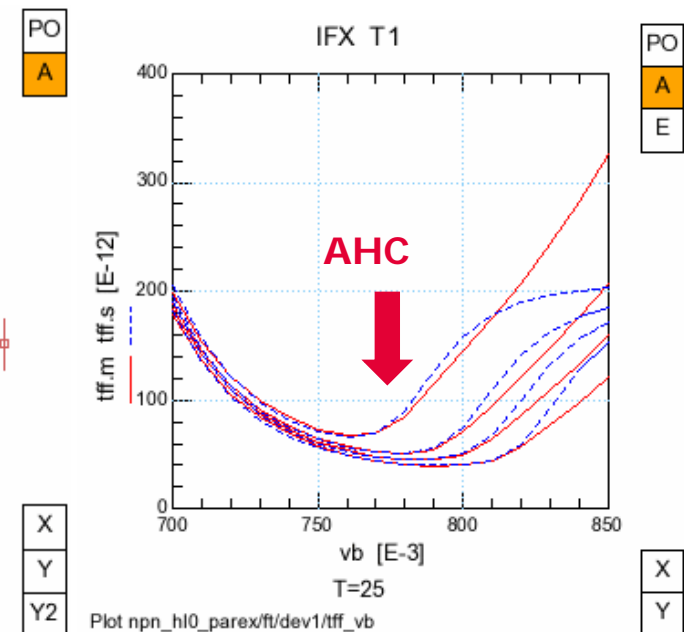
- Optimize the AC smoothing parameter AHC on the ft roll off before the inflection point



$$fT = f(Vb, Vc)$$



$$fT = f(Ic, Vc)$$



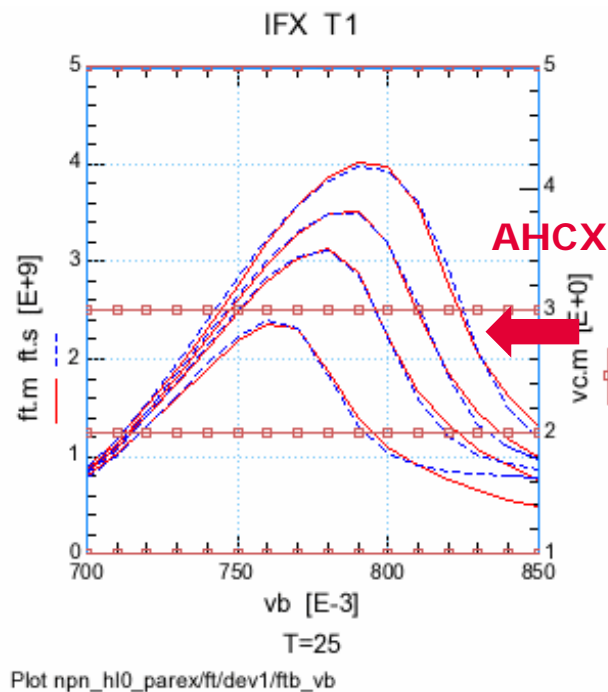
$$tff = f(Vb, Vc)$$

Extraction step by step

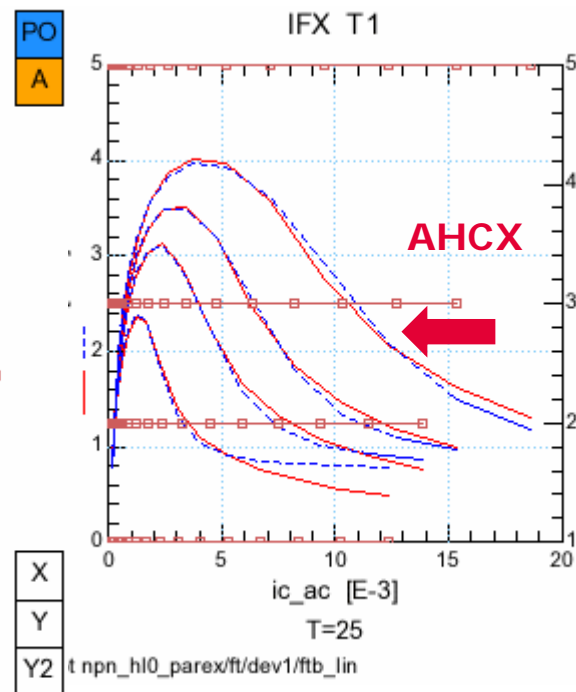
Step5



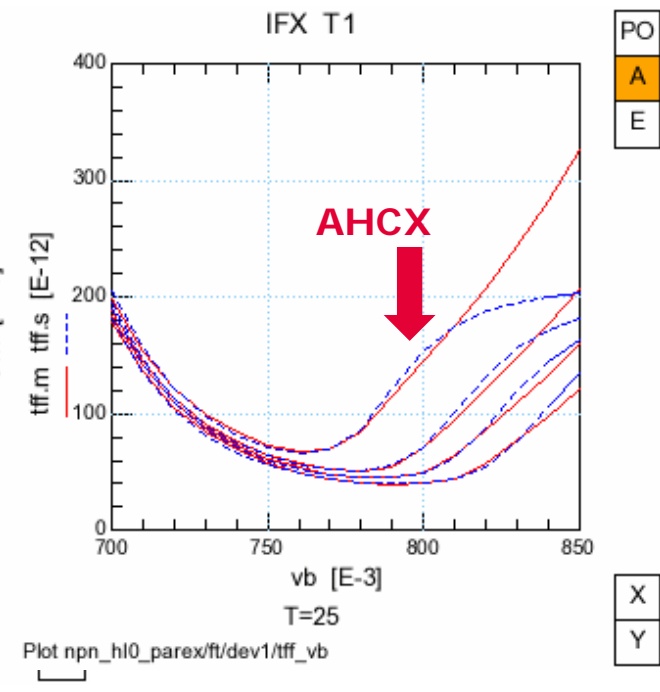
- Optimize the DC smoothing parameter AHCX (originally called AHQ) below ft roll off inflection point
- This give usually only a first guess for AHCX and must be further optimized on DC forward output and Gummel curves



$$f_T = f(V_b, V_c)$$



$$f_T = f(I_c, V_c)$$



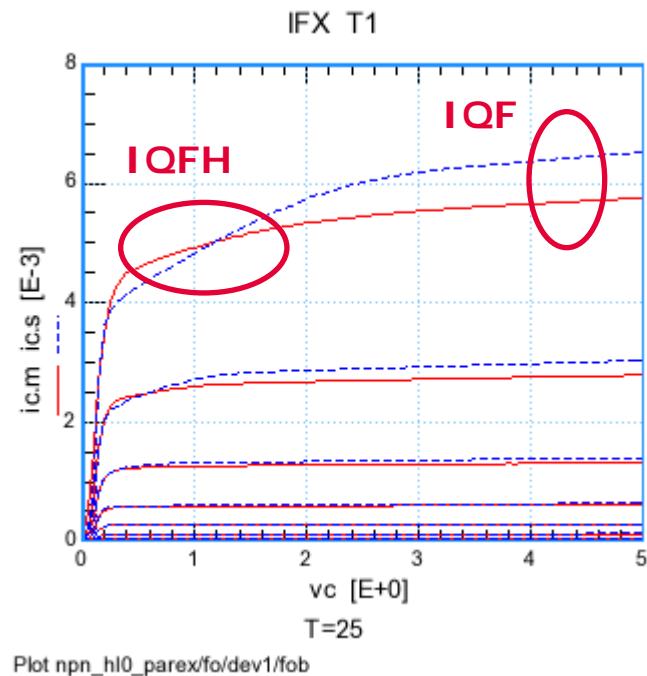
$$t_{ff} = f(V_b, V_c)$$

Extraction step by step

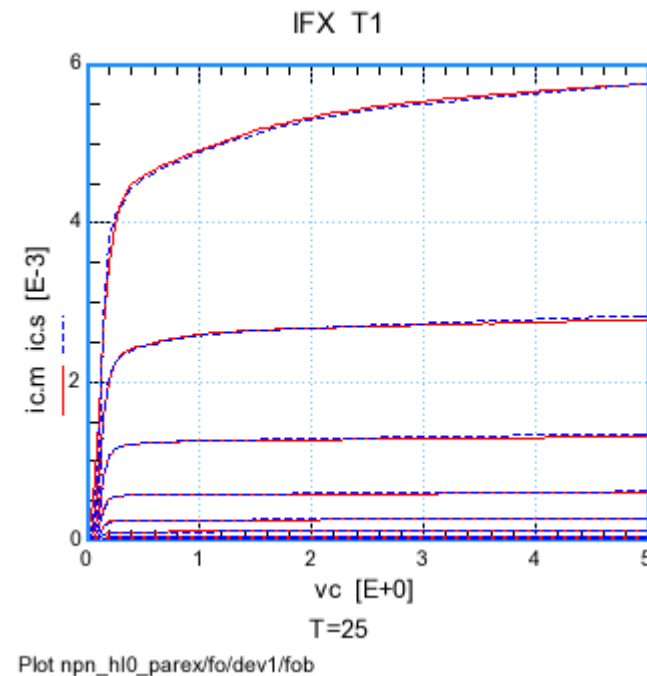
Step6



- Optimize IQF at FIQF=1 in the non-QS range of Ib driven forward output characteristic
- Optimize IQFH in the QS range Ib driven forward output characteristic



$I_c=f(V_c), I_b=Par.$



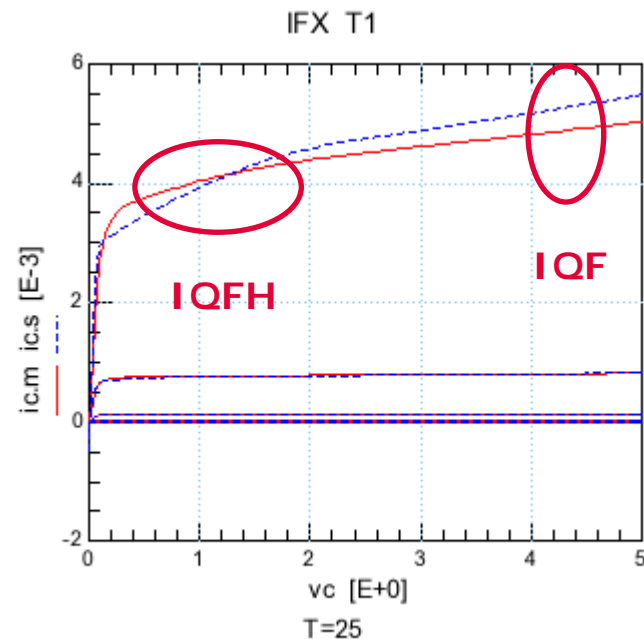
$I_c=f(V_c), I_b=Par.$

Extraction step by step

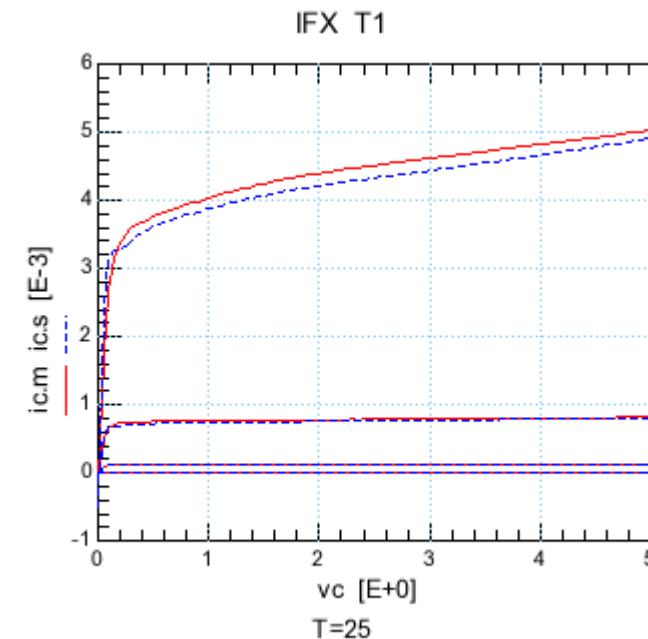
Step6



- Check IQF and IQFH on Vb driven forward output characteristic too, if necessary optimize together with Ib driven forward output characteristic



$$I_c = f(V_c), V_b = \text{Par.}$$



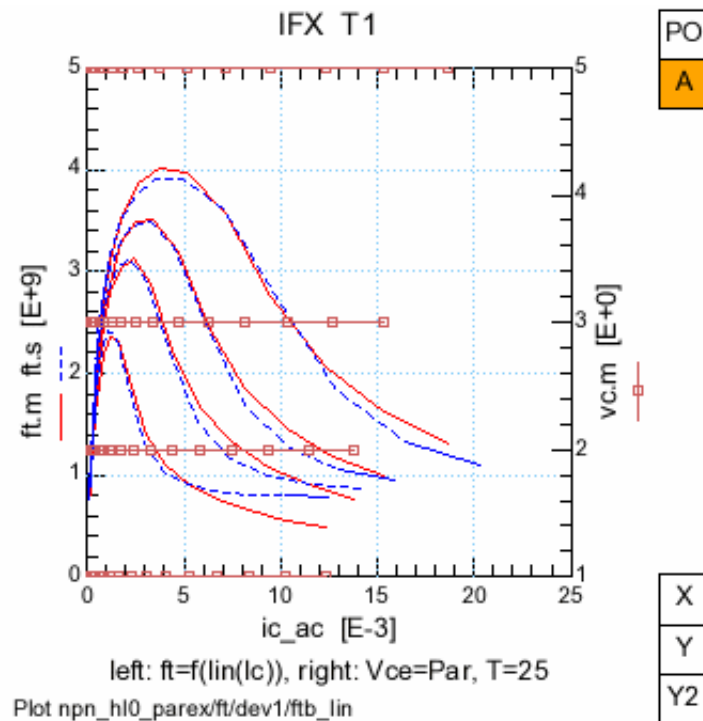
$$I_c = f(V_c), V_b = \text{Par.}$$

Extraction step by step

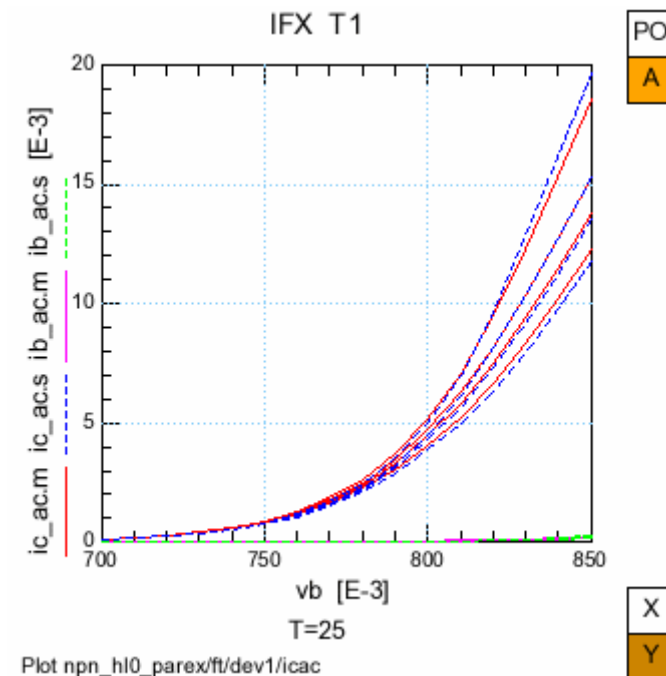
Step 7



- Check again the collector current modeling using the AC plots $f_t = f(\ln I_c, V_c)$ and $I_{c_ac} = f(V_b, V_c)$



$$f_t = f(I_c, V_c)$$



$$I_{c_ac} = f(V_b, V_c = \text{Par.})$$

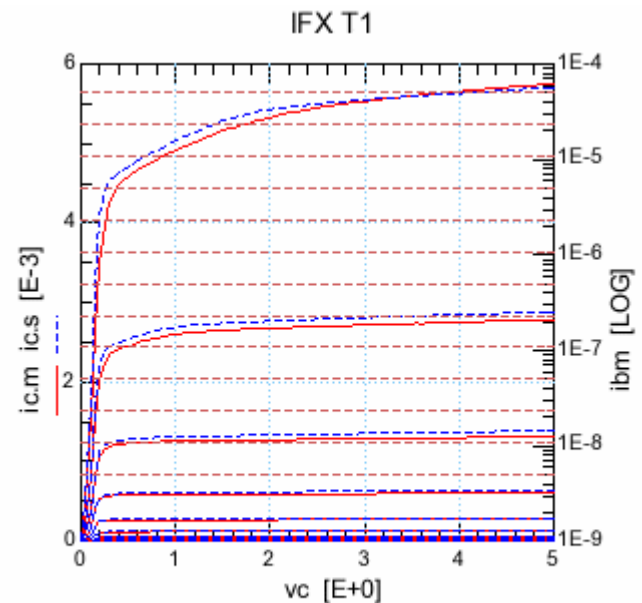
Agenda

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- Summary

Comparison with VBIC 1.2

- Base current driven output characteristic: both models allow a sufficient fit

VBIC v1.2

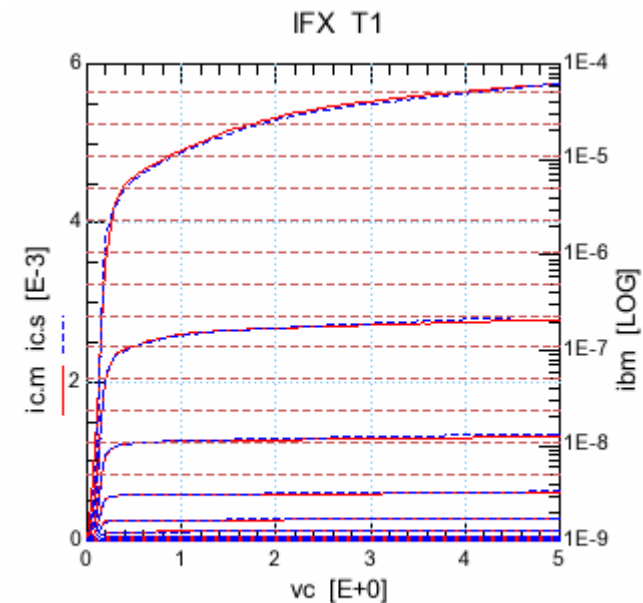


left: $i_c=f(V_{ce})$, right: $i_b=Par$, $T=25$

Plot npn_vbic_parex/fo/dev1/fob_ib

$i_c=f(V_c)$, $i_b=Par$.

HLO v1.2



left: $i_c=f(V_{ce})$, right: $i_b=Par$, $T=25$

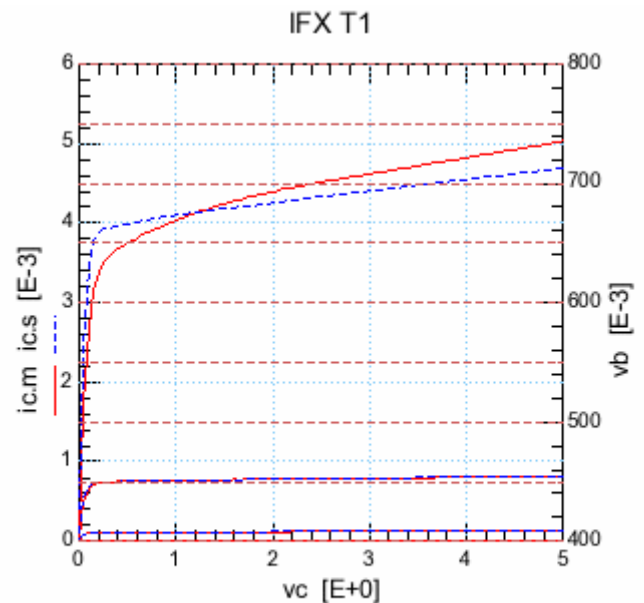
Plot npn_hlo_parex/fo/dev1/fob_ib

$i_c=f(V_c)$, $i_b=Par$.

Comparison with VBIC 1.2

- Voltage driven output characteristic: Sufficient fit for HLOv1.2, VBIC 1.2, however, fails

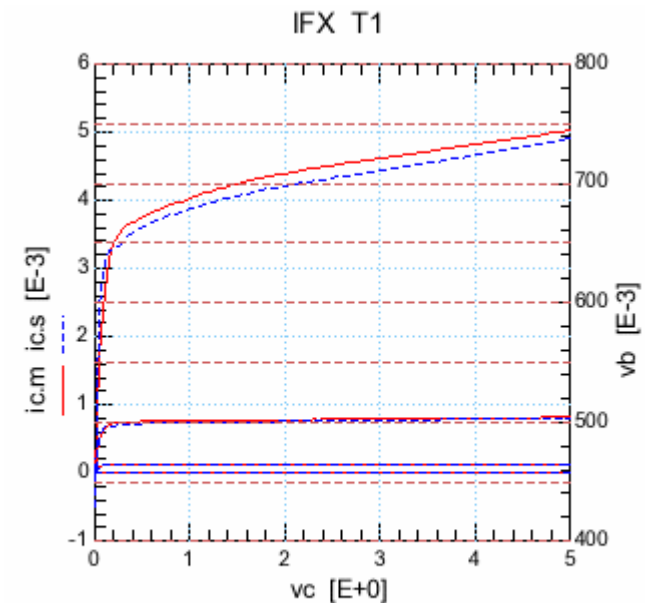
VBIC v1.2



left: $I_c=f(V_{ce})$, right: $V_{be}=\text{Par}$, $T=25$
Plot npn_vbic_parex/fov/dev1/fob_vb

$I_c=f(V_c)$, $V_b=\text{Par}$.

HLO v1.2



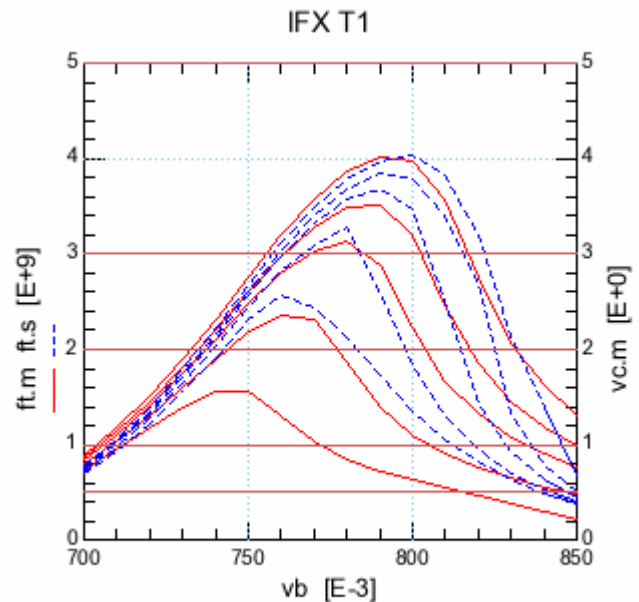
left: $I_c=f(V_{ce})$, right: $V_{be}=\text{Par}$, $T=25$
Plot npn_hlo_parex/fov/dev1/fob_vb

$I_c=f(V_c)$, $V_b=\text{Par}$.

Comparison with VBIC 1.2

- ft vs. Vb: HL0 v1.2 fits the voltage dependence good, VBIC as bad as SGP and, especially for small devices, a sharp decrease created by RCI is observed, which was optimized on fwd output characteristic

VBIC v1.2

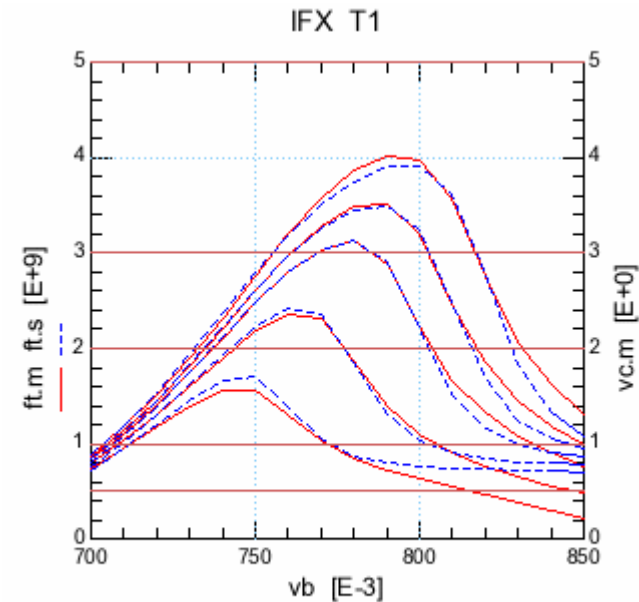


left: $f_T = f(V_{be})$, right: $V_{ce} = \text{Par}$, $T = 25$

Plot npn_vbic_parex/ft/dev1/ftb_vb

$$f_T = f(V_b, V_c)$$

HL0 v1.2



left: $f_T = f(V_{be})$, right: $V_{ce} = \text{Par}$, $T = 25$

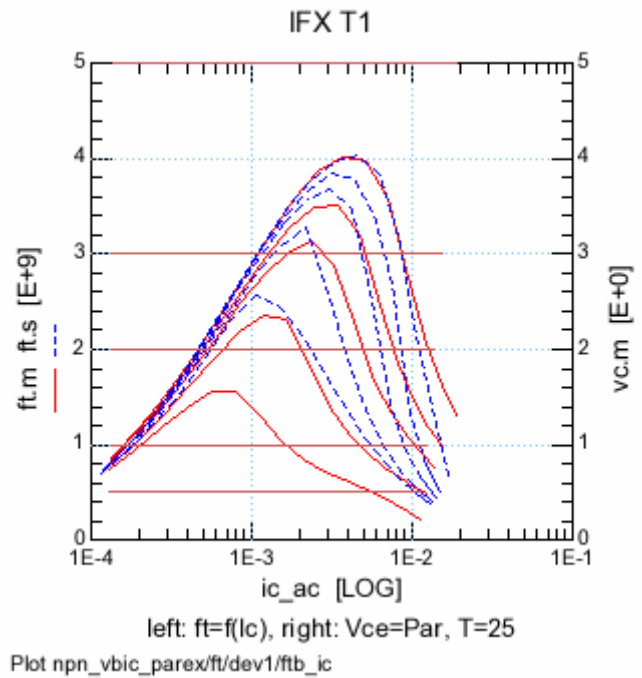
Plot npn_hl0_parex/ft/dev1/ftb_vb

$$f_T = f(V_b, V_c)$$

Comparison with VBIC 1.2

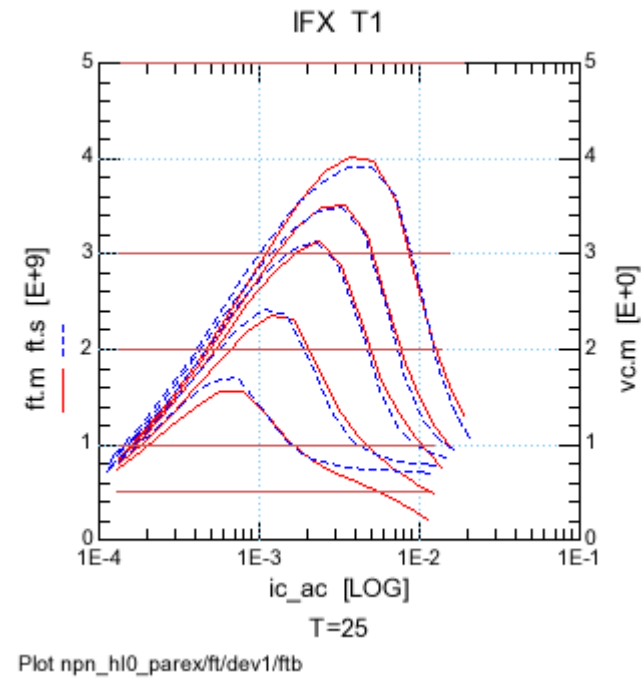
- ft vs. log(Ic): HLO v1.2 fits Ic axis nearly sufficient, VBIC as bad as SGP

VBIC v1.2



$$f_T=f(\log I_c, V_c)$$

HLO v1.2

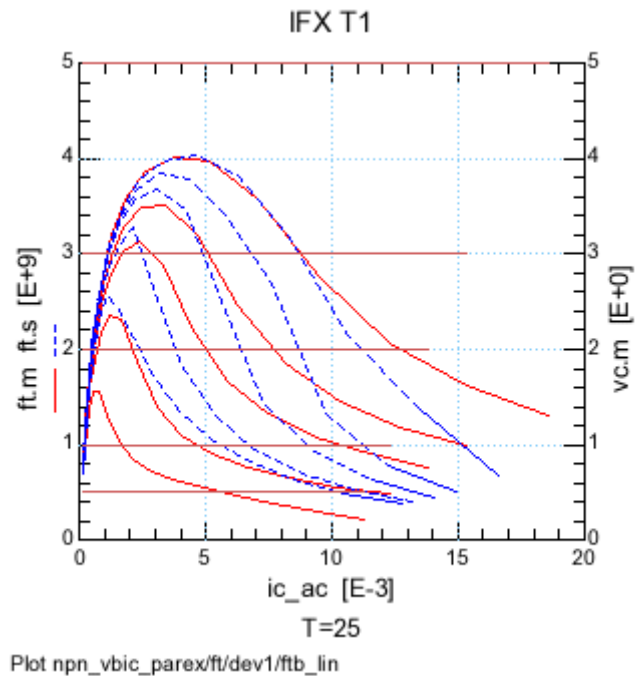


$$f_T=f(\log I_c, V_c)$$

Comparison with VBIC 1.2

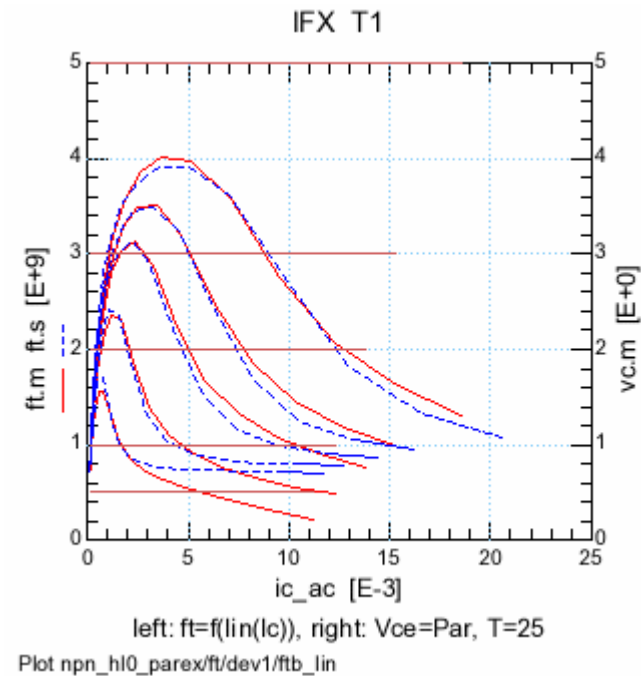
- ft vs. lin(Ic): HLO v1.2 fits Ic axis nearly sufficient, VBIC as bad as SGP

VBIC v1.2



$$fT = f(\text{lin } I_c, V_c)$$

HLO v1.2

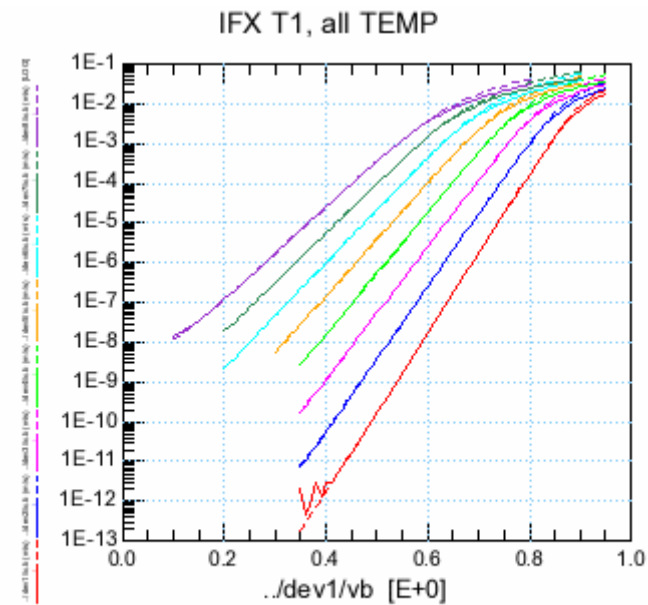


$$fT = f(\text{lin } I_c, V_c)$$

Comparison with VBIC 1.2

- Temperature behavior of I_c : both models allow sufficient fit

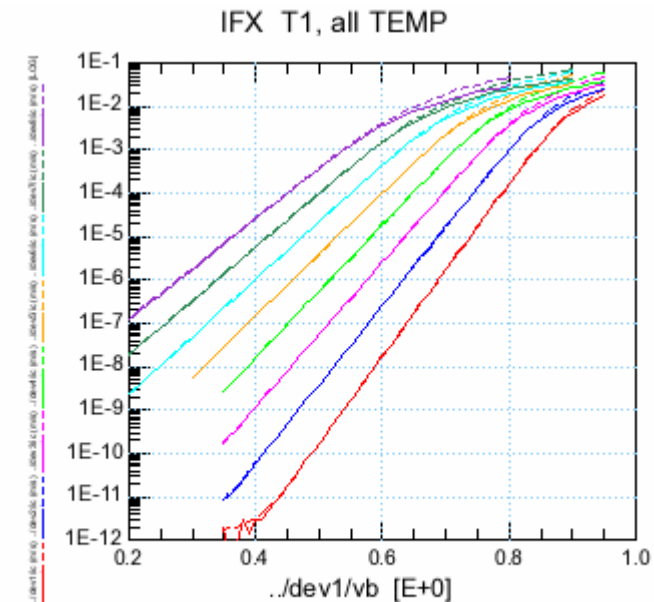
VBIC v1.2



$I_c = f(V_{be}, T), V_c=1V, T=-25$ (red), 0, 25, 50, 75, 100, 125, 150
Plot npn_vbic_parex/fg_temp/control/icb_all

$$I_c = f(V_b, T)$$

HLO v1.2



$I_c = f(V_{be}, T), V_c=1V, T=-25$ (red), 0, 25, 50, 75, 100, 125, 150
Plot npn_hlo_parex/fg_temp/control/icb_all

$$I_c = f(V_b, T)$$

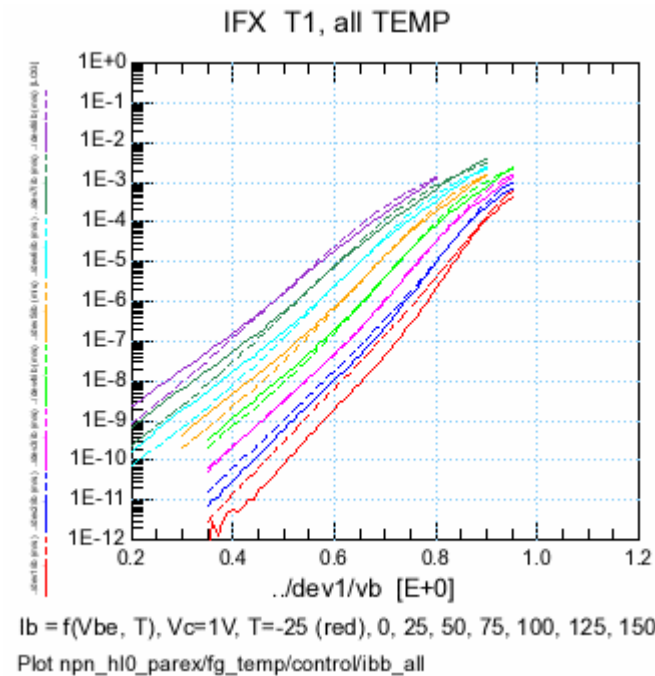
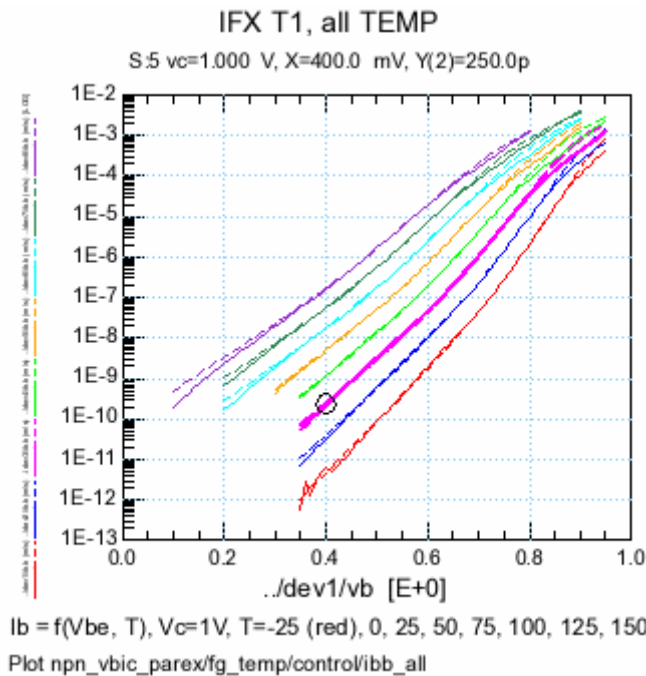
Comparison with VBIC 1.2

- Temperature behavior of I_b : VBIC allows to fit the non-ideal base current temperature dependence using XIN, HLO v1.2 not, because instead of an extra parameter a value of $mg=4.188$ is used

VBIC v1.2

$I_b = f(V_b, T)$

HLO v1.2



$$I_{BEN}(T) = I_{BEN}(T_{NOM}) \left[r T^{XIN} \exp\left(\frac{E_{ANE} \cdot (rT - 1)}{U_T}\right) \right]^{1/NEN}$$

$$I_{RES}(T) = I_{RES}(T_0) \left(\frac{T}{T_0}\right)^{\frac{1}{2} \left(3 - \frac{q \cdot FIVG}{k}\right)} \exp\left(\frac{1}{2} \cdot \frac{V_{GBE}}{V_T} \left(\frac{T}{T_0} - 1\right)\right)$$

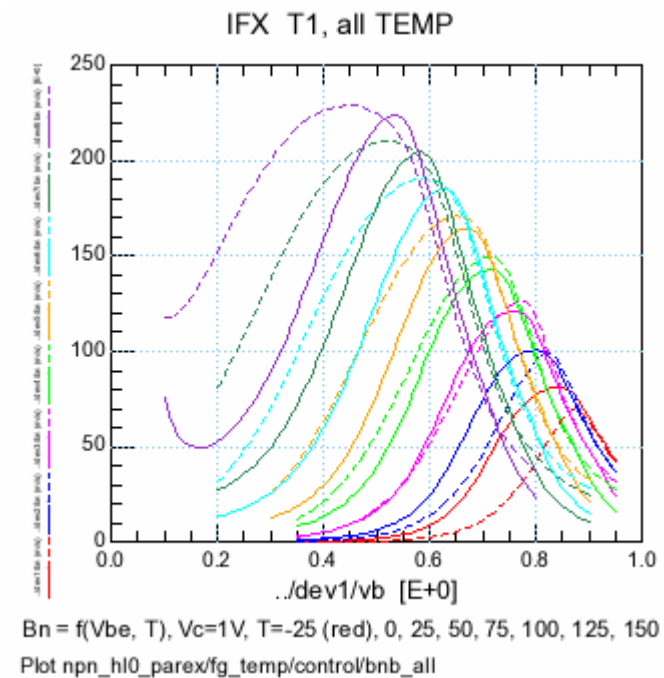
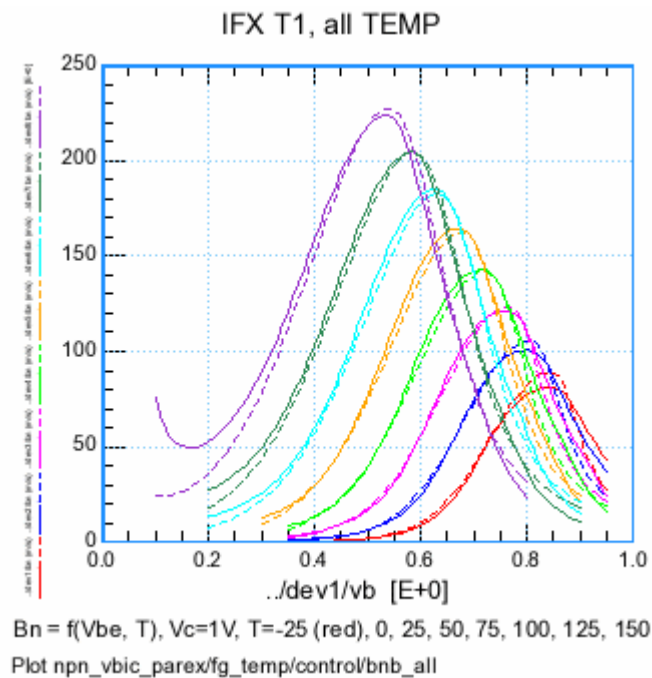
Comparison with VBIC 1.2

- Temperature behavior of B_n : VBIC allows to fit the beta increase temperature dependence sufficient, HLO v1.2 not

VBIC v1.2

$B_n = f(V_b, T)$

HLO v1.2



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Summary

- Hicup L0 v1.2 is able to model sufficient the following effects:
 1. QS of the voltage driven forward output characteristic
 2. QS of the current driven forward output characteristic
 3. ft voltage dependence and ft roll off
- This is an essential progress compared to HL0 v1.12 and an important advantage compared to VBIC 1.2
- Hicup L0 v1.2 is NOT able to model sufficient the temperature dependence of the non-ideal BE base current
- Request: An additional model parameter ZETARET must be introduced
- Two typing errors in the VHDL code must be corrected:
 1. AHCX -> AHQ
 2. ZETIQF -> ZETAIQF



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We partner.
We create value.



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