How to avoid negative slope in the Hicum Level0 collector current ?

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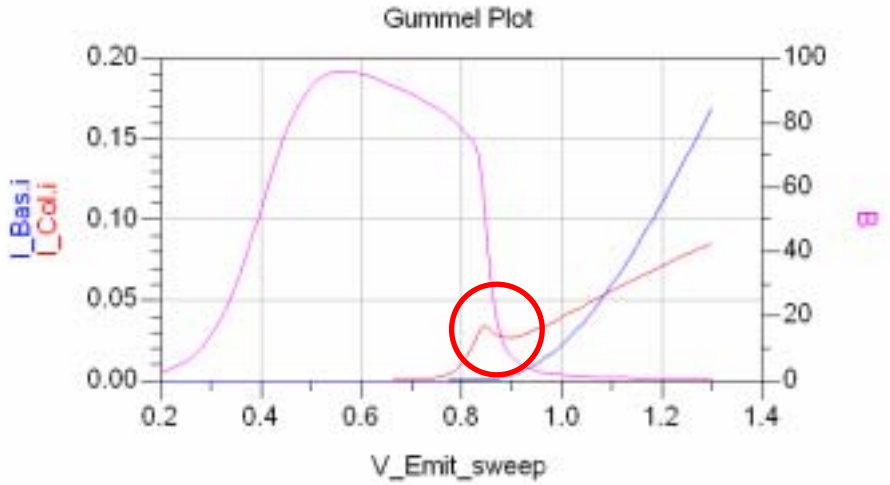
AKB 2006
at
XFAB Erfurt
27.10.2006

The problem: negative slope in Ic



red = Ic

blue = Ib

magenta = Beta

- Negative slope in Ic may appear if HL0 parameter IQFH is low, resp. TFH is high
- Simulation conditions

1. HL0 v1p11, va-version
2. ADS 2005
3. IQFH=14m, THF=1e-20
4. Circuit: fg_0

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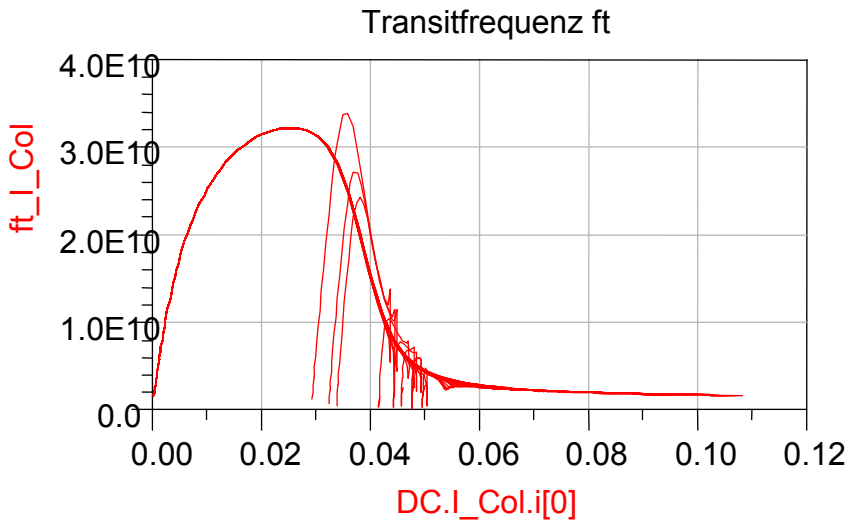
The result during MC simulation



- Ambiguous relation between Ic and Vb
- Convergence problems in Monte Carlo simulation, if IQFH is varied
- The only work around: don't use IQFH for Monte Carlo simulations

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HL0 transfer current

$$I_{TF} = \frac{I_{TFL}}{1 + \frac{\Delta q_{FH}}{q_{PT}}} \quad \Rightarrow \quad I_{TF} = \frac{I_{TFI}}{q_{PT} + \Delta q_{FH}}$$

$$q_{PT} = \frac{q_J}{2} + \sqrt{\left(\frac{q_J}{2}\right)^2 + q_M}$$

$$q_J = 1 + \frac{q_{JCI}}{VEF} \qquad q_M = \frac{I_{TFI}}{IQF} + \frac{I_{TRI}}{IQR}$$

- Denominator consist of a sum of two normalized charges
- qpt is nearly appropriate to SGP
- dqfh is intended to model the high current beta roll off

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Simplification of dqfh

$$\Delta q_{FH} = \left[wl^2 + TFH \frac{I_{TFL}}{I_{CK}} \right] \frac{I_{TFL}}{IQFH}$$

$$\Delta q_{FH} = wl^2 \frac{I_{TFL}}{IQFH}$$

$$I_{TF} = \frac{I_{TFI}}{q_{PT} + \Delta q_{FH}} = \frac{I_{TFI}}{\underbrace{q_{PT}}_{Term\ A} + \underbrace{wl^2 \frac{I_{TFL}}{IQFH}}_{Term\ B}}$$

- 1st assumption: setting TFH=0 could solve the problem (Note, that TFH=0 creates an simulation error and use e.g. TFH=1e-20)
- However, the problem still exist: negative slope in Ic appears, if IQFH is chosen low enough
- A critical minimum value for IQFH however may not defined, because it depends on the model parameter IS via ideal current ITFI .

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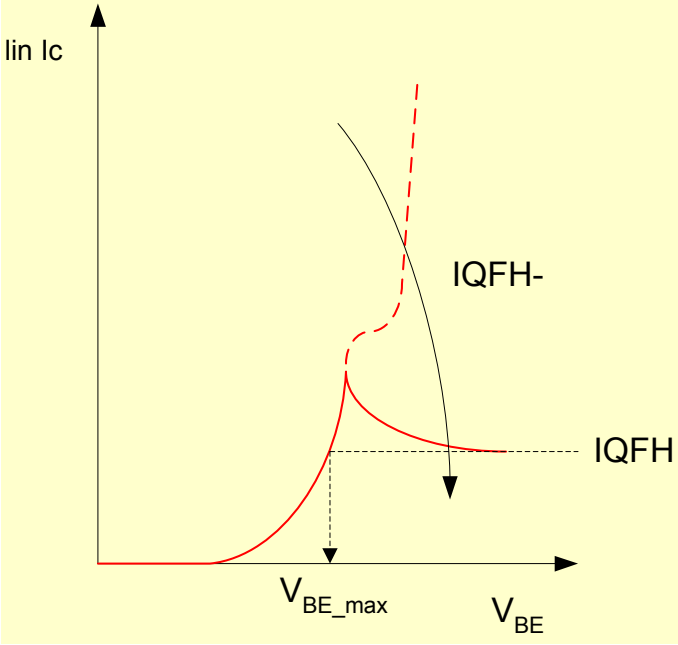
HL0: critical maximum V_{BE}

$$V_{BE\max} = V_T \ln\left(\frac{IQFH}{IS}\right)$$

resp.

$$IQFH_{\min} = IS \exp\left(\frac{V_{BE\max}}{V_T}\right)$$



- At least, we may define as a rule of thumb a critical maximum V_{BE} , until which no negative slope will appear in collector current
- However, this does not really solve the problem

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HL0: different OP dependencies

$$I_{TF} = \frac{I_{TFI}}{q_{PT} + \Delta q_{FH}} = \frac{I_{TFI}}{\underbrace{q_{PT}}_{Term\ A} + wl^2 \underbrace{\frac{I_{TFL}}{IQFH}}_{Term\ B}}$$

$$q_{PT} = \frac{q_J}{2} + \sqrt{\left(\frac{q_J}{2}\right)^2 + q_M}$$

$$wl = \frac{al + \sqrt{al^2 + AHC}}{1 + \sqrt{1 + AHC}}$$

$$q_M = \frac{I_{TFI}}{IQF} + \frac{I_{TRI}}{IQR}$$

$$al = 1 - \frac{I_{CK}}{I_{TFL}}$$

- The problem appears because of the different operating point dependencies of term A and B
- wl depends on ITFL and ICK (Vce)

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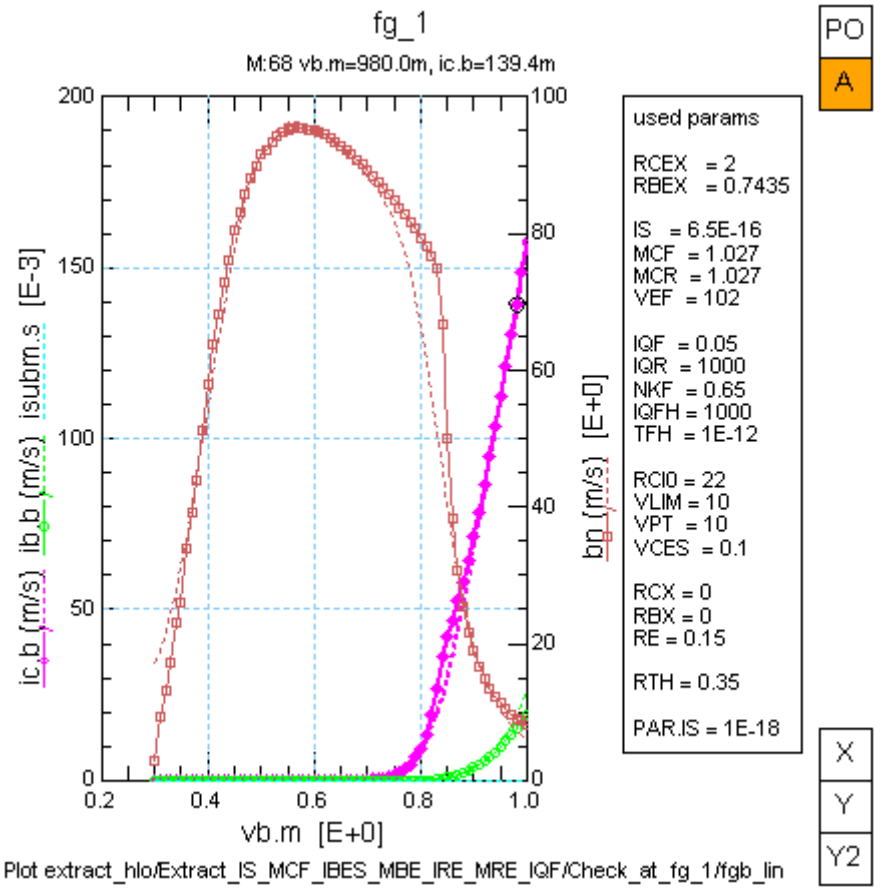
HL0: use of VBIC equation for qpt

$$I_{TF} = \frac{I_{TFI}}{q_{PT}}$$

$$q_{PT} = \frac{1}{2}\left[q_J + (q_J)^{1/NKF} + 4q_M\right]^{NKF}$$

- Use of VBIC qpt-equation
- Introduction of NKF allows a steeper beta decrease,
- Advantage: valid range for NKF may easy defined in Verilog a



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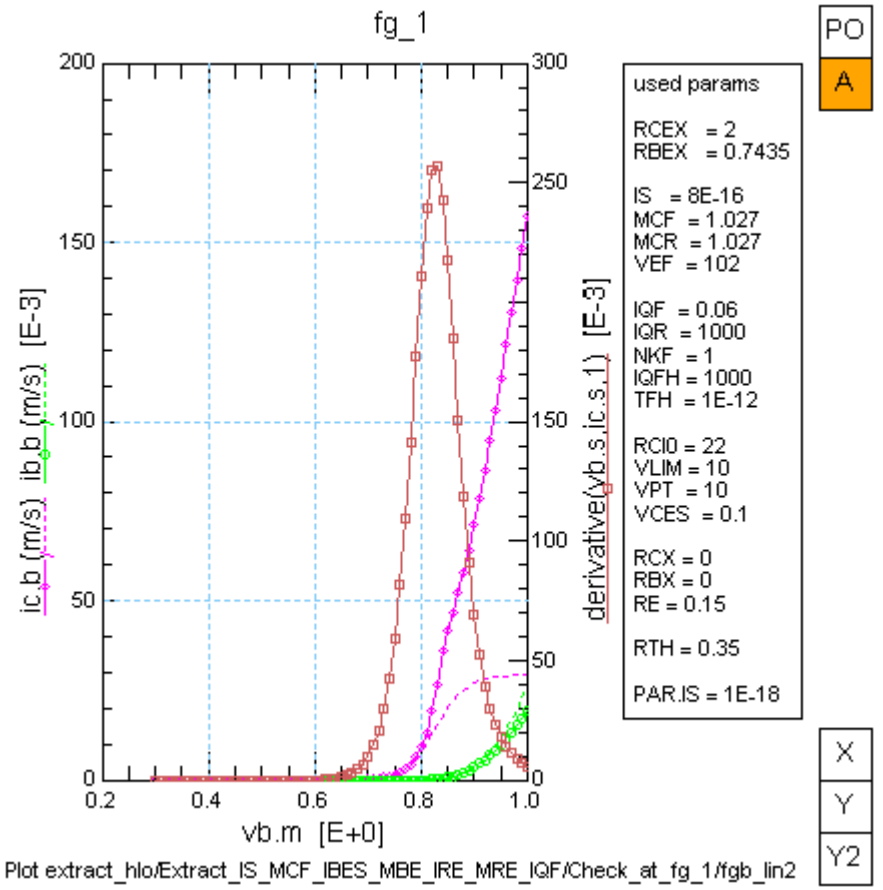
HL0: NKF valid range

- Advantage : valid range for NKF may be easy defined in Verilog A
- In this way, negative slope of Ic may be avoided, if base is vb driven
- Disadvantage: does not work for Ib condition at the base



parameter real nkf 0.5 from [0:1]

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Summary

- The possibility of a negative slope may create serious problems using the HL0 model, especially during MC simulations
- The use of the VBIC qpt equation does not solve the problem
- Several other modification of the dqfh term where investigated, but not succesful
- A solution to avoid negative slope in Ic of HL0 is still an open problem
- Further investigation is necessary

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