

Characterization and Modeling of Lateral PNP Bipolar Transistor in CMOS Process

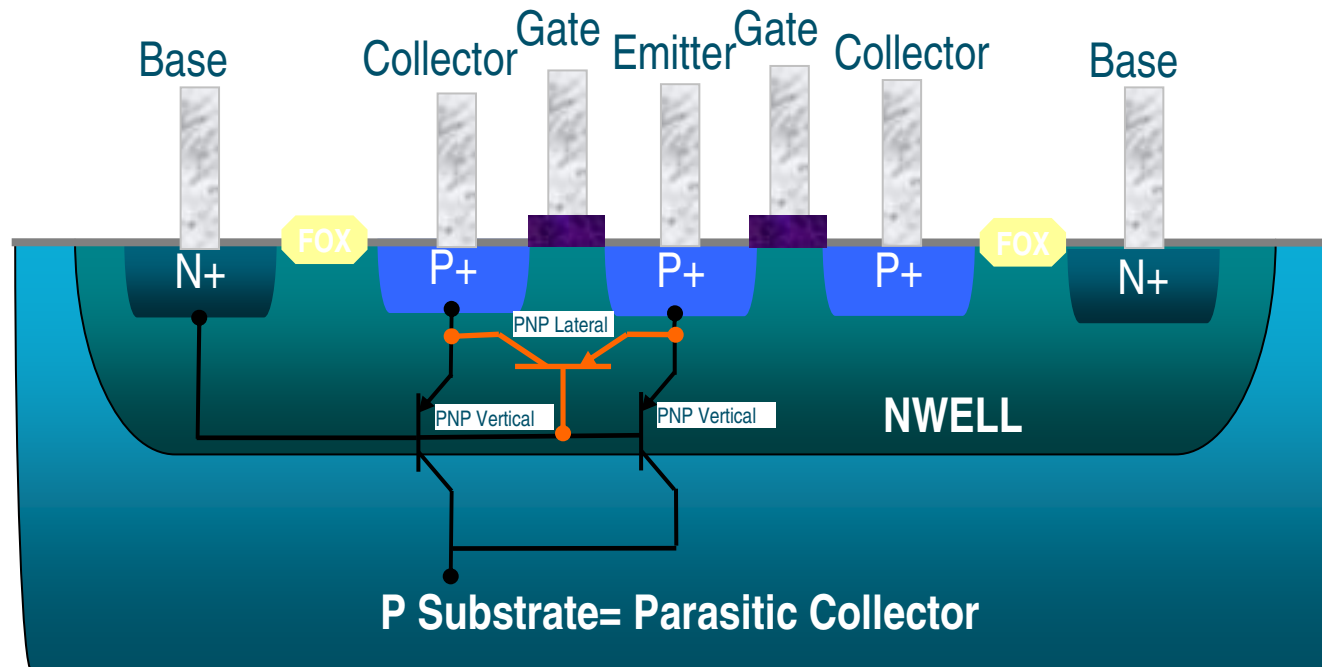
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Bipolar Arbeitskreis, 6 May 2011, Munich, Germany

Outline

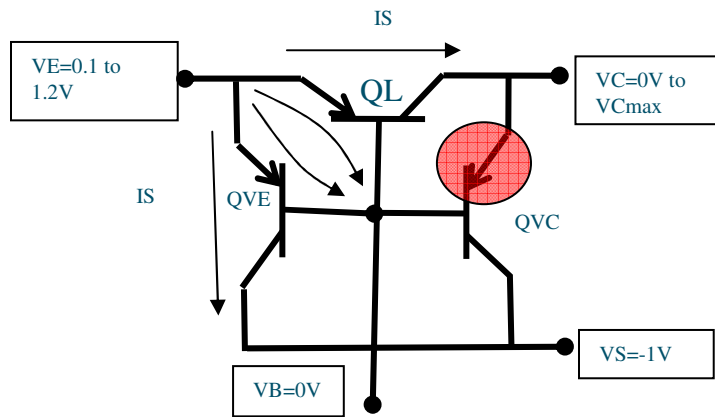
- Cross-Section and Model Network
- Characterization
- Parameter Extraction
- DC Results
- Summary

Cross Section

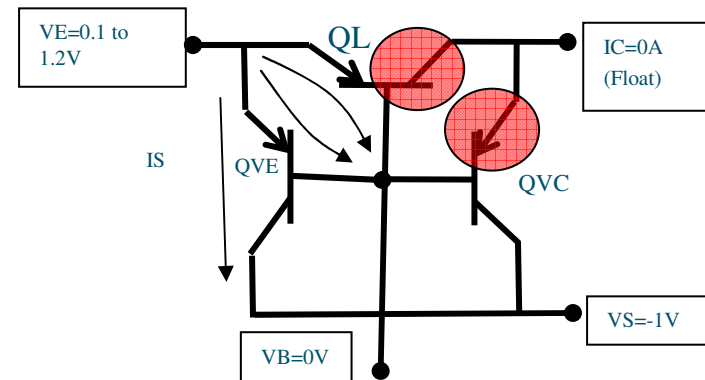


- Main PNP lateral bipolar transistor (P+/NWell/P+)
- Two parasitic PNP vertical bipolar transistor between (P+/NWell/PSUB)

Characterization: Forward Gummel (Lateral PNP)



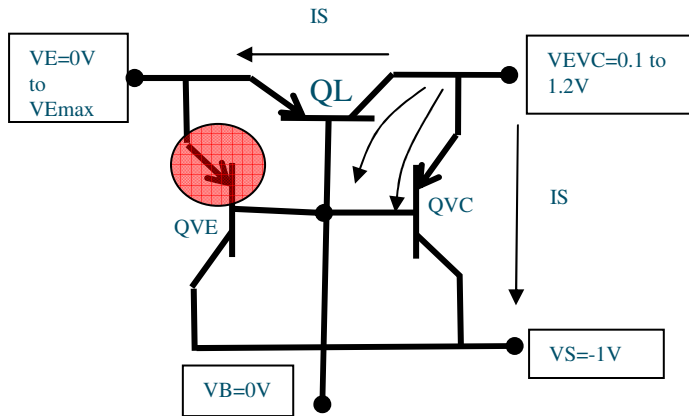
Forward Gummel of QL



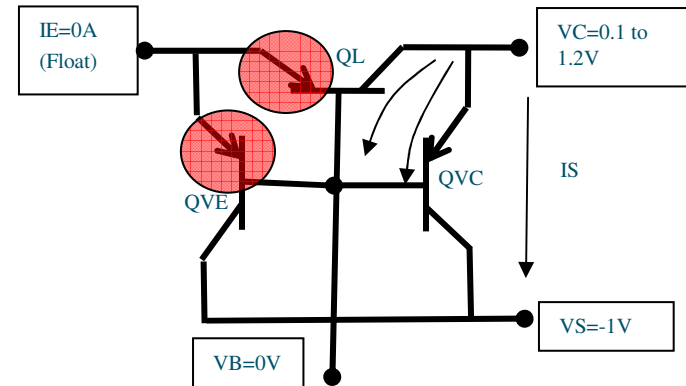
Forward Gummel of QVE

Besides the main transistor QL, two vertical parasitic transistors under the emitter (QVE) and the collector (QVC) are included in the model. All the three transistors are represented by the Berkeley SPICE Gummel-Poon (SGP) model.

Characterization: Reverse Gummel (Lateral PNP)



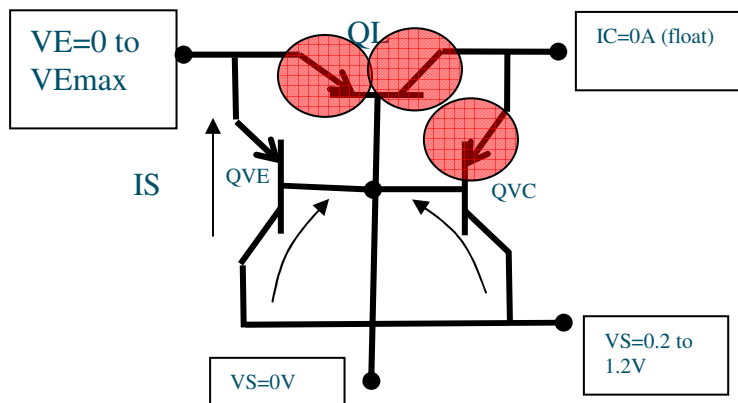
Reverse Gummel of QL



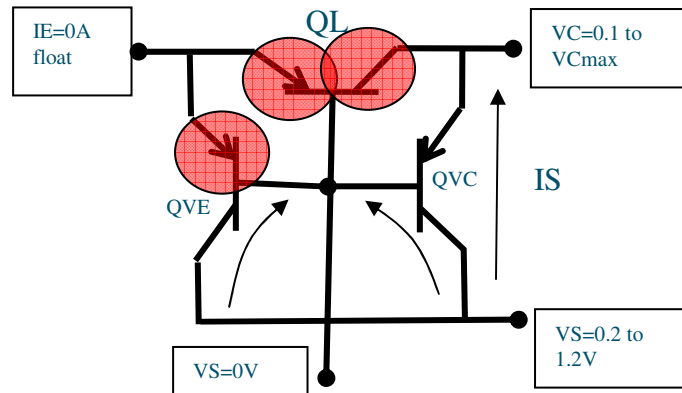
Forward Gummel of QVC

Total collector current is combination of transfer current of lateral bipolar (QL) and transfer current of vertical bipolar (QVC).

Characterization: Reverse Gummel (Vertical PNP)



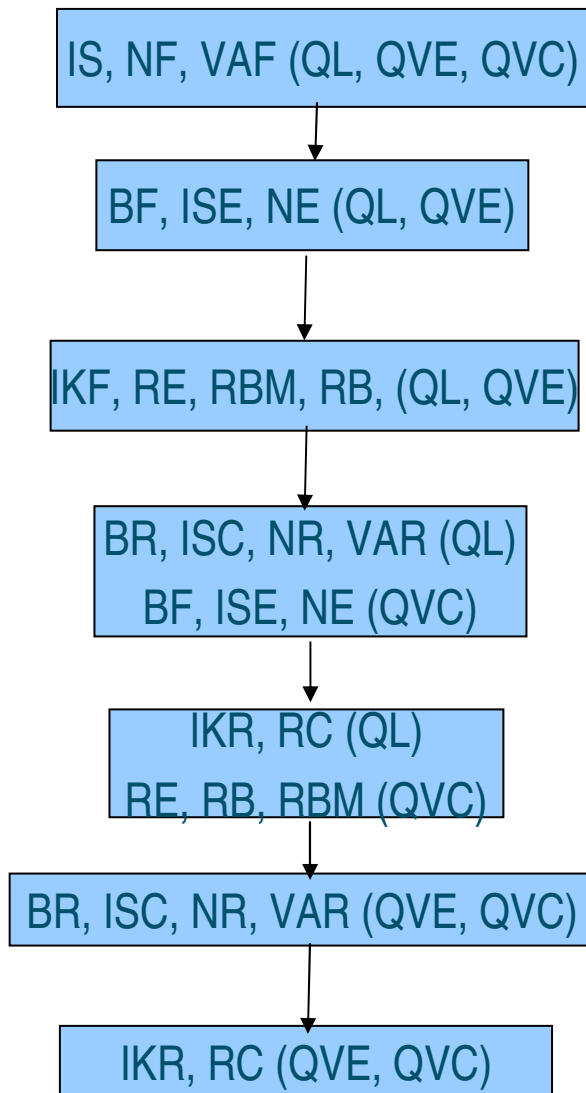
Reverse Gummel of QVE



Reverse Gummel of QVC

Substrate-base leakage current of each vertical transistor is half of the total base current

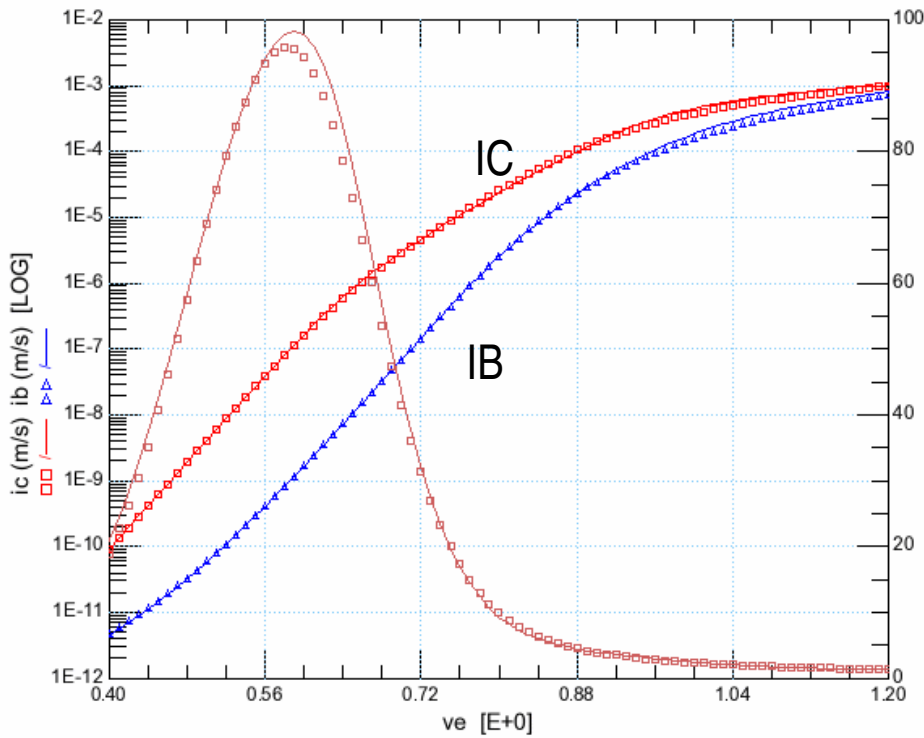
Parameter Extraction Flow



- If reverse early VAR is sufficiently large, VAR extraction is necessary prior to extraction of NF. ($NF_{eff} \sim NF + V_t/VAR$)
- Base-Emitter junction of QL is common to QVE and base-collector of QL is common to base-emitter of the QVC. So base-emitter current extraction is depending on collector saturation current of other bipolar QVE and QVC.
- It is recommended that all collector saturation current (IS) of QL, QVE and QVC has to be extracted first, before any base-emitter current extraction.

Model Result: Forward Gummel (After Extraction and Optimization)

Forward Gummel Plot of lateral PNP bipolar transistor

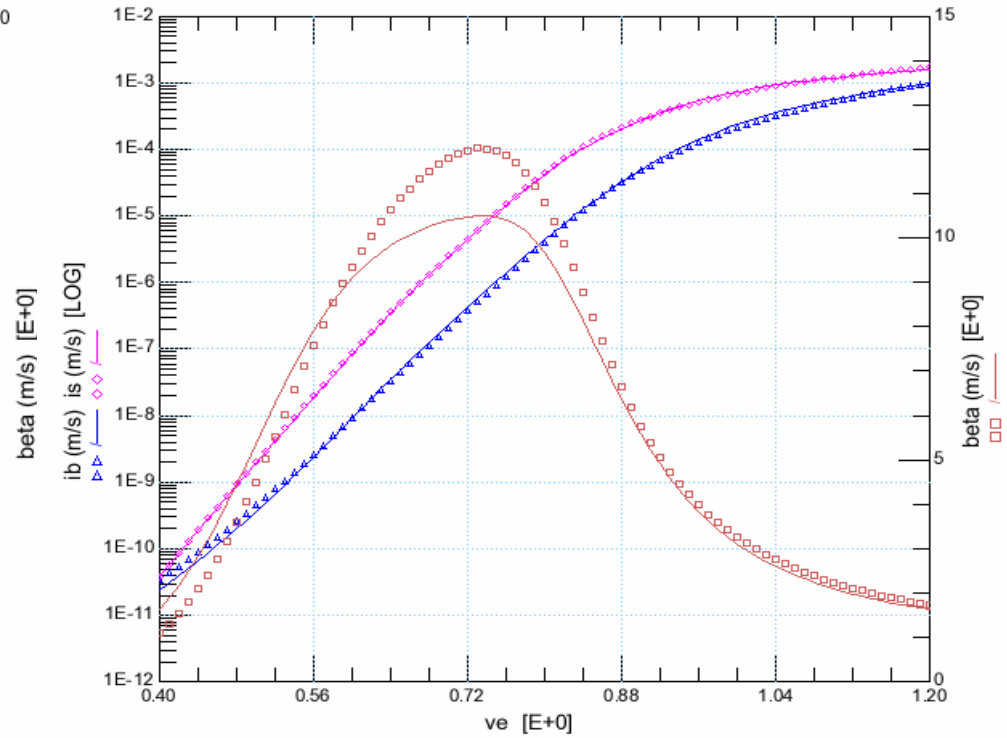


Symbol= measured
Solid line = model

QL: IS= 25.88a NF= 1.022 BF= 2.075K ISE= 3.691f NE= 2.315

QVE: IS= 3.190a NF= 1.005 BF= 26.01 ISE= 16.32a NE= 1.419

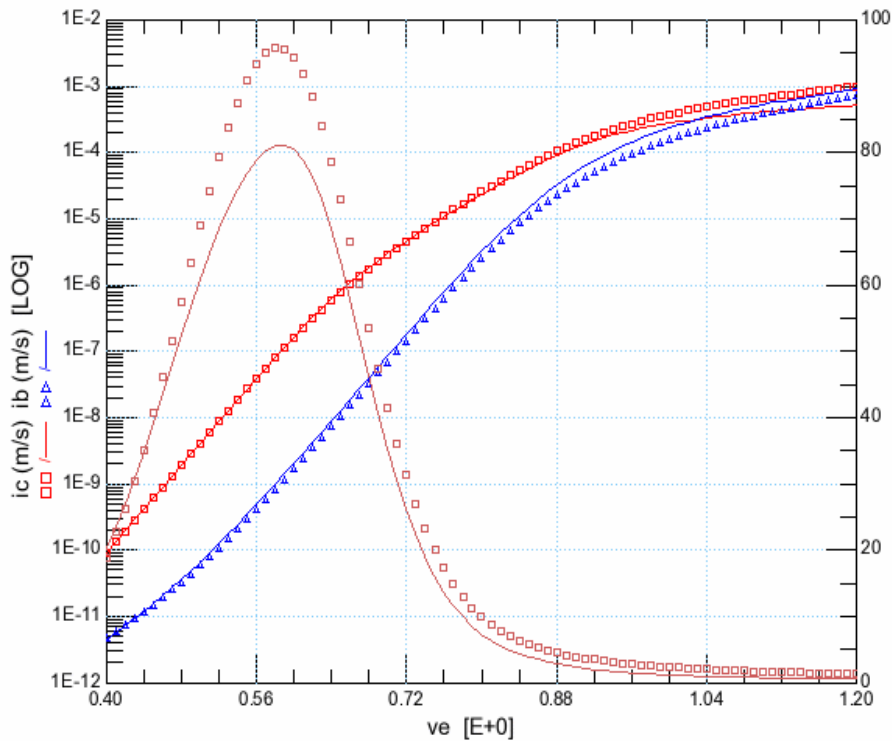
Forward Gummel Plot of vertical PNP bipolar transistor



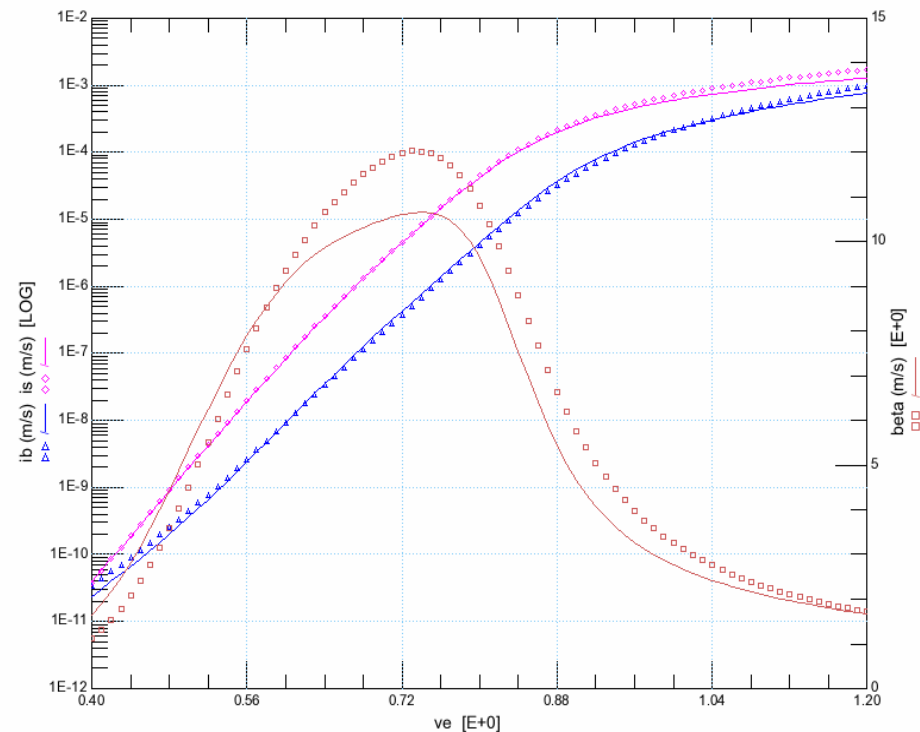
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Model Result: Forward Gummel (After Tuning)

Forward Gummel Plot of lateral PNP bipolar transistor



Forward Gummel Plot of vertical PNP bipolar transistor



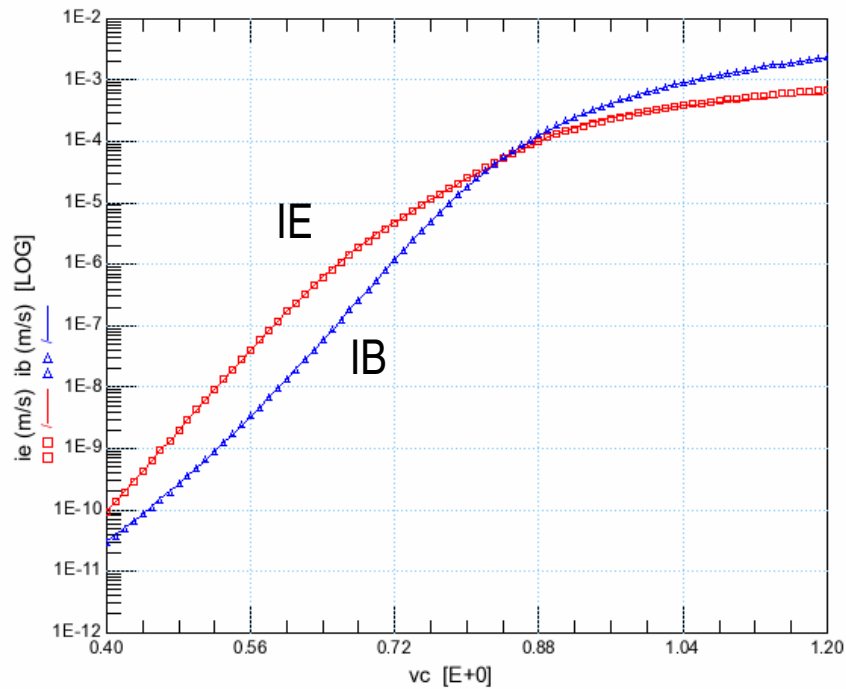
Symbol= measured
Solid line = model

QL: IS= 25.88a NF= 1.022 **BF= 200** ISE= 3.691f NE= 2.315

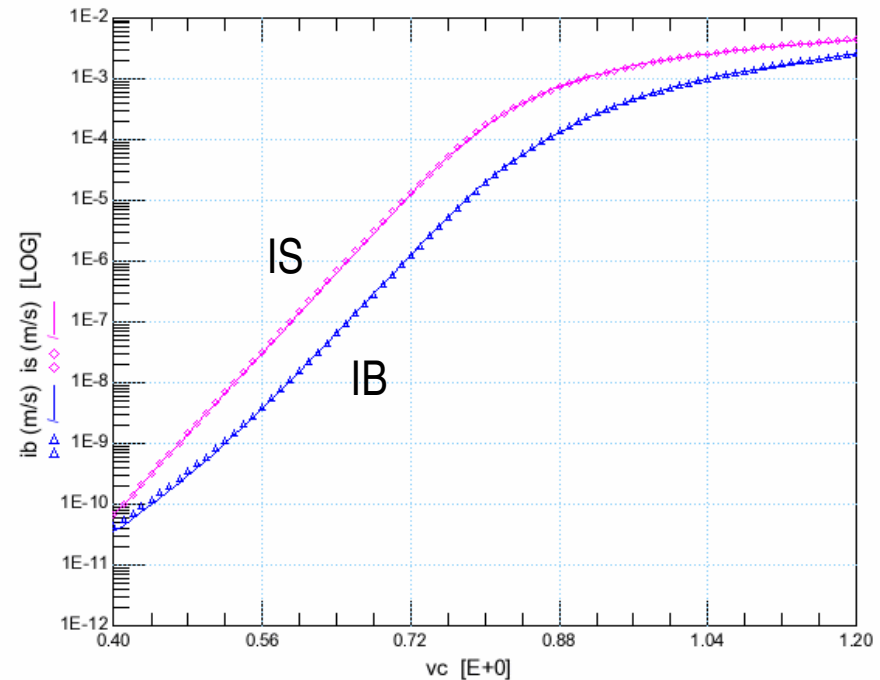
QVE: IS= 3.190a NF= 1.005 **BF= 73** ISE= 16.32a NE= 1.419

Model Result: Reverse Gummel

Reverse Gummel Plot of Lateral PNP bipolar transistor



Forward Gummel Plot of Vertical PNP bipolar transistor

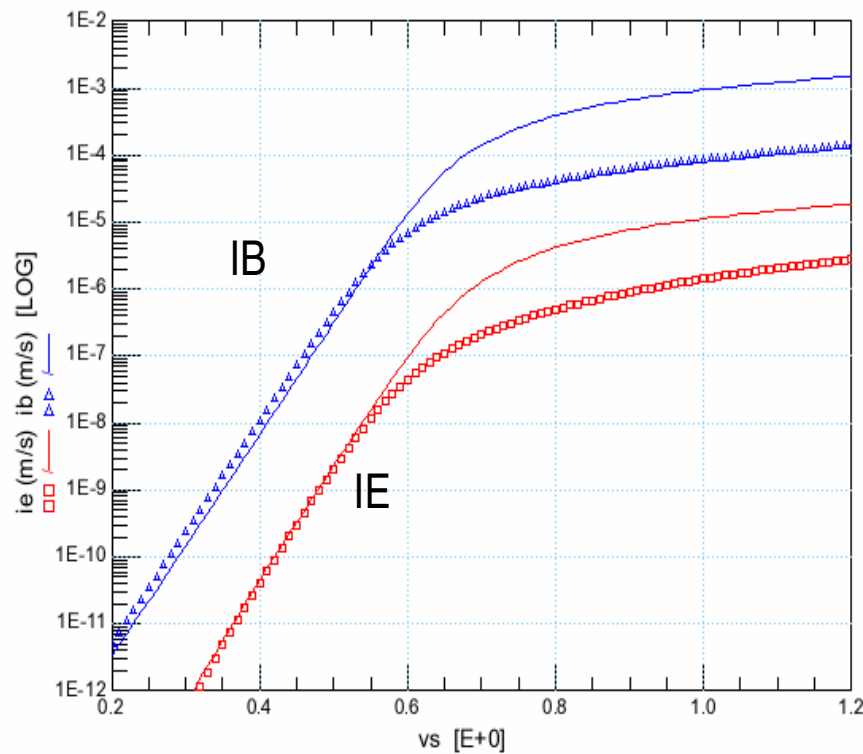


Symbol= measured
 Solid line = model

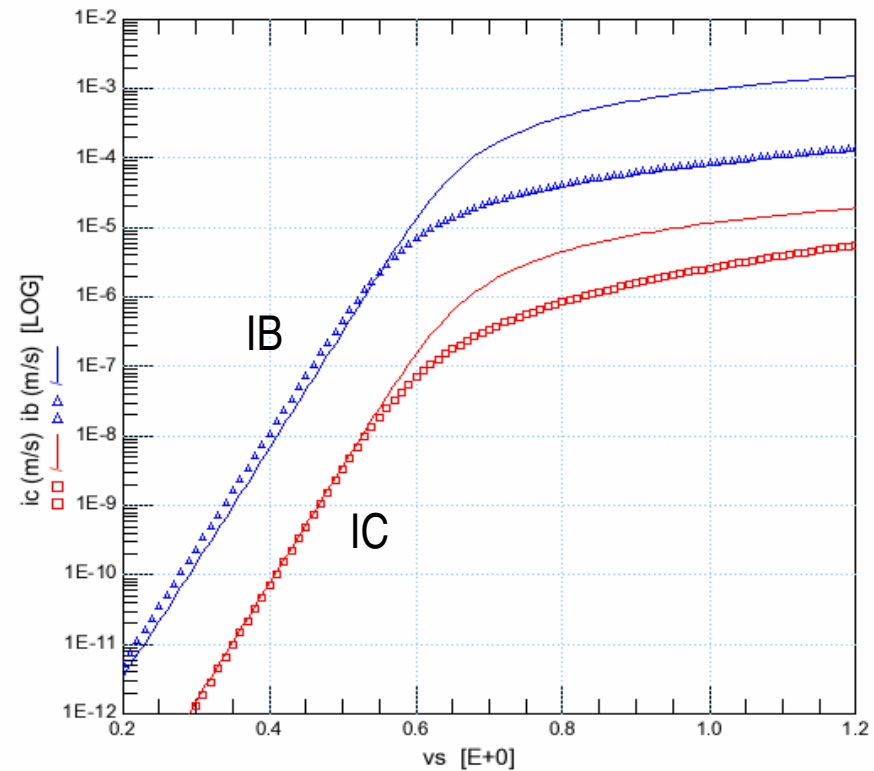
- Simultaneous good fit of Reverse Gummel of lateral PNP and forward Gummel plot of vertical PNP at the collector side

Model Result: Reverse Gummel (Vertical PNP)

Reverse Gummel Plot of Vertical PNP bipolar transistor at Emitter side



Reverse Gummel Plot of Vertical PNP bipolar transistor at Collector side



Symbol= measured

Solid line = model

- Model can predict reverse leakage current of each transistor very accurately
- Insufficient high current effect model

Summary

- A complete lateral PNP transistor is modeled with a main SGP transistor (QL) and two additional vertical parasitic transistors under the emitter (QVE) and the collector (QVC)
- Standardize extraction of model parameter for three SGP Bipolar sub-circuit network
- Proposed model can valid any combination of bias ranges