Proposal for modeling the barrier effect in the bipolar compact model

Hicum L0

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Modeling the barrier effect in Hicum L0

- SiGe-Transistors show often a kink in the high base current region, called the “barrier effect”
- The effect was investigated by different authors, e.g. Tiwari [1], Peter et.al., [2], Sadovnikov et. al. [3]
- Cressler and Niu gave a nice summary about this effect, they wrote:

“The sudden increase in $J_B$ accompanying the barrier onset in a SiGe HBT is the result of the accumulation of holes in the base region due to HBE (heterojunction barrier effect)” [4, p.241]
Modeling the barrier effect in Hicum L2

- In HICUM L2 the three current dependent $T_{FT}$ parts and the appropriate charges are calculated separately.

**Base Part** $\Delta T_{FB}$

$$\Delta T_{FB} = (1 - FTHC) \cdot THCS \cdot w^2 \left[ 1 + \frac{2}{I_{TF} / I_{CK} \sqrt{i^2 + ALHC}} \right]$$

**Collector Part** $T_{FCT}$

$$T_{FCT} = FTHC \cdot THCS \cdot w^2 \left[ 1 + \frac{2}{I_{TF} / I_{CK} \sqrt{i^2 + ALHC}} \right]$$

**Emitter Part** $\Delta T_{FE}$

$$\Delta T_{FE} = TEF0 \left( \frac{I_{TF}}{I_{CK}} \right)^{GTE}$$
This allows to use the absolute base charge $Q_{bf}$ for modeling the barrier effect.

The additional base current, created by the barrier effect, is calculated by the following approach [5]:

\[
I_{bh_{\text{rec}}} = \frac{Q_{bf}}{TBHREC}
\]

with the new model parameter TBHREC.
In Hicum L0 v1.12, however, base and collector charge are merged into one current dependent charge component.

Additional, we have to decide between two different high current charge components:

- \( d_{qfh} \) is used for the transfer current \( I_{TF} \)
- \( dqfh \) is used for the total minority charge \( qf \)

\[
I_{TF} = \frac{I_{TFL}}{q_{PT}}
\]

\[
I_{TFL} = \frac{I_{TFL}}{q_{PT}}
\]

\[
a = 1 - \frac{I_{CK}}{I_{TF}}
\]

\[
al = 1 - \frac{I_{CK}}{I_{TFL}}
\]

\[
w = \frac{a + \sqrt{a^2 + AHC}}{1 + \sqrt{1 + AHC}}
\]

\[
wI = \frac{al + \sqrt{al^2 + AHC}}{1 + \sqrt{1 + AHC}}
\]

\[
d_{qfh} = THCS * w^2 * I_{TF}
\]

\[
daqfh = \frac{wI^2 + TFH I_{TFL}}{I_{CK}} I_{TFL} I_{QFH}
\]

\[
qf = qf_0 + dqfh + dqef
\]

\[
I_{TF} = \frac{I_{TFL}}{1 + \frac{d_{qfh}}{q_{PT}}}
\]
Modeling the barrier effect in Hicum L0

To model the barrier effect, we have to multiply the ideal BE current with a operating point dependent factor $f_{\text{Barrier}}$

$$I_{jbe} = I_{be} \cdot f_{\text{Barrier}} + I_{re}$$

- If no barrier effect appears (low $V_{be}$), we need $f_{\text{Barrier}} = 1$
- If barrier effect appears (high $V_{be}$), we need $f_{\text{Barrier}} > 1$
- This could be realized normalizing the charge $dq_{fh}$ to $qf_0$, like:

$$f_{\text{Barrier}} = 1 + \frac{dq_{fh}}{qf_0}$$

However, this overestimates the increase of IB, because only the base component of $dq_{fh}$ is responsible for the IB increase
That is why we have to split \( dqfh \) using a multiplier \((1 - FTHC)\). We end up with the following approach:

\[
f_{\text{Barrier}} = 1 + \frac{(1 - FTHC) \times dqfh}{qf_0}
\]

\[
I_{jbe} = I_{be} \times f_{\text{Barrier}} + I_{re}
\]

Note: The model parameter \( FTHC \) is used here in the same meaning as in Hicum L2.
Modeling the barrier effect in Hicum L0 Results

Ib=f(Vbe), Vc=1V
FTHC=1
no barrier effect

Ib=f(Vbe), Vc=1V
FTHC=0.95
with barrier effect
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Results

I\(_c\) = f(V_{be}), V_c = 1V

FTHC = 1, IQFH = 357\(\mu\)A

no barrier effect

I\(_c\) = f(V_{be}), V_c = 1V

FTHC = 0.95, IQFH = 393\(\mu\)A

with barrier effect

IQFH is slightly adjusted
Modeling the barrier effect in Hicum L0
Summary

- SiGe-Transistors show often a kink in the high base current region, called the “barrier effect”

- This effect is modeled in HICUM L2 using the base minority charge $Q_{fb}$ and the additional model parameter TBHREC

- In HICUM L0 this way is blocked, because base and collector part of the minority charge are merged in the charge $dqfh$

- A possible solution of the problem is to use a multiplier $f_{Barrier}$ for the ideal base current. It is defined using a fraction of $dqfh$ only.

- The model parameter $FTHC$, known already from HICUM L2, was introduced as the split factor. It may be extracted fitting the base current in the high $Vbe$ range.
Modeling the barrier effect in Hicum L0

References


