Contributions to HICUM
Parameter Extraction
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Outline

- Two point method for critical current $I_{CK}$
- Two point method for model parameter THCS
- Pitfall during extraction of QP0 and C10 from Gummel plot
Hicum Parameter Extraction
Two Point Method for Critical Current $I_{CK}$ (1)

- Assuming $ALHC=0$ the normalized injection width $w$ is given by:

$$i = 1 - \frac{I_{CK}}{I_{TF}} \quad \Rightarrow \quad w = \frac{w_l}{w_c} = \frac{i + \sqrt{i^2 + ALHC}}{1 + \sqrt{1 + ALHC}}$$

$$W = i$$

- Merging both base and collector transit time parts $\Delta T_{FB}$ and $T_{FCT}$ results in:

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

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

$$T_{FCT} = FTHC \cdot THCS \cdot w^2 \left[1 + \frac{2}{\frac{I_{TF}}{I_{CK}} \sqrt{i^2 + ALHC}}\right]$$
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Two Point Method for Critical Current $I_{CK}$ (2)

- $I_{TF}$ is given here by the measured $I_C$. There are two unknowns in second equ., the critical current $I_{CK}$ and model parameter THCS.

- Using a plot $\sqrt{((\Delta T_{FB}/THCS)-1)}$ vs. $I_{CK}/I_{TF}$ we may vary THCS until the characteristic is a straight line and extract $I_{CK}$ from slope.

- However, the better way is to use the two point equation.

\[
T_{FBC} = THCS \cdot w^2 \left[ 1 + \frac{2}{I_{TF} \sqrt{i^2 + ALHC}} \right]
\]

\[
\frac{\Delta T_F}{THCS} = 1 - \left( \frac{I_{CK}}{I_{TF}} \right)^2
\]

\[
I_{CK} = \sqrt{\frac{\Delta T_{F2} - \Delta T_{F1}}{I_{C1}^2 - I_{C2}^2}} = \sqrt{\frac{(\Delta T_{F2} - \Delta T_{F1}) I_{C1}^2 \cdot I_{C2}^2}{\Delta T_{F2} I_{C2}^2 - \Delta T_{F1} I_{C1}^2}}
\]
Hicum Parameter Extraction
Two Point Method for Critical Current $I_{CK}$ (3)

- Extracted $I_{CK}$ values are lower than values by Ardouin’s method.

<table>
<thead>
<tr>
<th>$V_{C}/V$</th>
<th>0.3</th>
<th>0.5</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{CK}$ / mA (Ardouin)</td>
<td>4.1</td>
<td>7.75</td>
<td>13.6</td>
<td>20.1</td>
</tr>
<tr>
<td>$I_{CK}$ / mA (Berkner)</td>
<td>2.65</td>
<td>5.79</td>
<td>8.77</td>
<td>11.38</td>
</tr>
</tbody>
</table>

Note: This example is based on the model file HICUM_EXTRACT (July 2001) from B.Ardouin (UNI Bordeaux) and the appropriate (synthetic) data in the setup nwa_mdlg/ft_vce.
Hicum Parameter Extraction
Two Point Method for Model Parameter THCS (1)

- The same principle may be used for THCS

\[
T_{FBC} = THCS \cdot w^2 \left[ 1 + \frac{2}{I_{TF} \sqrt{I_{C1}^2 + ALHC}} \right]
\]

\[
\frac{\Delta T_F}{THCS} = 1 - \left( \frac{I_{C2}}{I_{TF}} \right)^2
\]

- Using two measurement points \((\Delta T_{FB1} ; I_{C1})\) and \((\Delta T_{FB2} ; I_{C2})\) we have:

\[
THCS = \frac{\Delta T_{F1} - \Delta T_{F2} \left( \frac{I_{C2}}{I_{C1}} \right)^2}{1 - \left( \frac{I_{C2}}{I_{C1}} \right)^2}
\]
Hicum Parameter Extraction
Two Point Method for Model Parameter THCS (2)

- The parameter THCS shows asymptotically behavior too.
- The value for the curve $V_{CE} = 1V$ is $THCS = 70.38\text{pS}$.
- This is in accordance with the value $THCS = 70\text{ pS}$ used for creating the synthetic data.
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Model Parameters QP0 and C10 (1)

- QP0 and C10 may be extracted from Gummel plot measured at $V_{BC}=0$ using an optimization

$$\begin{align*}
\left( \frac{C10}{Q_{PT}} \right)_{meas} &= \frac{I_{Cmeas}}{\exp \left( \frac{V_{BE}}{V_T} \right)} \\
\end{align*}$$

- The calculated quantity is given by:

$$\begin{align*}
\left( \frac{C10}{Q_{PT}} \right)_{calc} &= \frac{C10}{QP0 + Q_{JE}} \\
\end{align*}$$

- The measured quantity is given by:

- However, the real device temperature effects via $V_T$ very strong the QP0 and C10 values, extracted from Gummel plot
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Model Parameters QP0 and C10 (2)

- Pitfall: a small $\Delta T$ results in a large $\Delta QP0$
- Conclusion: the actual device temperature must be known and used for $V_T$ calculation as accurate as possible

<table>
<thead>
<tr>
<th>$T_{\text{celcius}}$</th>
<th>$T_{\text{kelvin}}$</th>
<th>$k$</th>
<th>$q$</th>
<th>$vt$</th>
<th>$c10$</th>
<th>$qp0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>297.15</td>
<td>1.38E-23</td>
<td>1.602E-19</td>
<td>0.02559719</td>
<td>8.00E-32</td>
<td>6.60E-14</td>
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<tr>
<td>25</td>
<td>298.15</td>
<td>1.38E-23</td>
<td>1.602E-19</td>
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<td>1.66E-31</td>
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<td>1.38E-23</td>
<td>1.602E-19</td>
<td>0.02576948</td>
<td>1.41E-30</td>
<td>1.13E-12</td>
</tr>
</tbody>
</table>

$T=25C$  $T=26C$