HICUM/L2 Models for SiGe-HBTs in IHP 0.13µm BiCMOS Technology

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Agenda

- HBTs for IHP’s 0.13 SiGe BiCMOS technology SG13
- Scaled HICUM/L2 model for the low-voltage HBT
- Scaled HICUM/L2 model for the high-voltage HBT
  - issue 1: base current as function of $V_{CB}$
  - issue 2: avalanche breakdown simulation
- Design kit implementation
  - issue 3: incompatibility ADS $\Leftrightarrow$ Spectre
HBT Portfolio in IHP SG13

- **Low-voltage HBT npn13p**
  - BVCEO = 1.7V, $f_T/f_{max} = 250/300$ GHz
  - layout configurations: BEC, CBEBC

- **High-voltage HBT npn13v**
  - BVCEO = 3.7V, $f_T/f_{max} = 45/120$ GHz
  - layout configuration: CBEBC

- **Status Q1/2011**
  - npn13p and npn13v currently in qualification
Model Parameter Extraction npn13p

- HBT size and configuration
  - layout: BEC
  - scaling:
    - drawn emitter length scaling: 0.36\,\mu m – 0.96\,\mu m
    - drawn emitter width: 0.12 \,\mu m

- Extraction environment
  - ICCAP 2009
  - simulator: ADS2008
  - model call in circuit: "... model MAIN HICUM2_22 ..." → only HICUM/L2.22?
  - scaling with XMOD’s Smach
Scaled Model Results DC

Gummel Characteristics $V_{CB} = -0.5V, 0V, +0.5V$

Output Characteristics $V_{BE} = 0.6(0.05)1.0V$
Scaled Model Results RF

\[ f_T (V_{BE}) \]
\[ V_{CB} = -0.5(0.5)1.5V \]
Issue: \( f_T @ \) High \( V_{BE}, V_C \)

- Could not model transit frequency in the very high-current range for high \( V_{CE} \) and \( V_{CB} \)
- Actions
  
  fine-tuning of transit time parameters (esp. \( thcs \))
  
  \( \rightarrow \) lead to no satisfying solution
Scaled Model Results RF II

S parameter
HBT: 0.12x0.84µm²
V_{BE} = 0.87(0.02)0.93V
V_{CB} = 0V
f = 500MHz ... 50GHz
Model Parameter Extraction npn13v

- HBT size and configuration
  - Layout: CBEBC
  - Scaling:
    - Drawn emitter length scaling: 1µm – 5µm
    - Drawn emitter width: 0.18 µm

- Extraction environment
  - ICCAP 2009
  - Simulator: ADS2008
  - model call in circuit: "... model MAIN HICUM2_22 ..."
  - scaling with XMOD’s Smach
Results for npn13v (1x0.18x2µm²)

Gummel Characteristics
$V_{CB} = -0.5V, 0V, +0.5V$

Output Characteristics
$V_{BE} = 0.6(0.05)0.9V$

$I_C (V_{BE})$
$V_{CE} = 0.5(1.0)4.5V$

$f_T (V_{BE})$
$V_{CB} = -0.5, 0, +1, +2, +3V$
Issue 1: Base Current

- Could not model
  - base current above $V_{BE}=0.8\,V$
  - base current @ $V_{CB}=-0.5\,V$
- Introduction of $tbhrec$
  - excess BC recombination time $tbhrec$ leads to good fit in the range $0.7\,V < V_{BE} < 0.8\,V$
- Open issue:
  - base current increase for $V_{CB} = -0.5\,V$
  - base current for $V_{BE} > 0.9\,V$

$I_B (V_{BE})$
$V_{CB}=-0.5, 0, +0.5\,V$

$tbhrec = 0$

HBT: HV-HBT
Layout: $1\times(0.18\times2)\,\mu m^2$
$I_B (V_{BE})$
$V_{CB}=-0.5, 0, +0.5\,V$

$tbhrec = 600s$
Issue 2: Avalanche Current I

- Simultaneous simulation of $I_B$ direction change at high $V_{BE}$ and in the temperature range -40°C up to +125°C not possible
  - relevant parameter: temperature coefficient for the avalanche factor $\alpha_{fav}$

HBT: HV-HBT
Layout: 8x(0.18x2)µm²
$I_B (V_{CE})$
$V_{BE}=0.6(0.05)0.9V$

$\alpha_{fav} = -0.15 \, K^{-1}$

HBT: HV-HBT
Layout: 1x(0.18x2)µm²
Issue 2: Avalanche Current II

- Compromise
  - change of avalanche temperature coefficient $\alpha_{faV}$ → good temperature dependence but bad fit at $V_{BE} > 0.75V$

HBT: HV-HBT
Layout: 8x(0.18x2)$\mu$m²
$I_B (V_{CE})$
$V_{BE} = 0.6(0.05)0.9V$

$\alpha_{faV} = -0.08 \text{ K}^{-1}$
Models for Design Kit

- For the design kit IHP offers model cards for different simulators
  - in Spectre syntax for Cadence and ADS users
  - in HSPICE syntax

- Extraction environment
  - ICCAP 2009 (Spectre 6.2)
  - HICUM/L2v...; scaling with XMOD’s Smach
  - Simulator: ADS2008 (... model MAIN HICUM2_22 ... → HICUM/L2.22)
  - ADS delivers most stable and fast simulation results but main target are Cadence users

- Main issue
  - I could not create a HICUM/L2 model card for Spectre which reproduces the ADS simulations
    - scaled model did not work at all
    - even non-scaled HICUM ADS simulations did not agree with simulations under Spectre
Modeling Variants for HBT Type 0.12x0.84 μm² I

- ICCAP Environment
- ADS simulation with Verilog-A source code
  - L2.23 (`#load "veriloga", "../..hicumL2V2p23.va"`)  
    - same results with L2.24
- Results identical to version with ADS internal HICUM

\[ I_C(V_{CE}) = 0.6(0.05)1.0V \]
\[ f_T(V_{BE}) = -0.5(0.5)1.5V \]

\[ CJE(0V) = cjei0 + cjep0 + cbepar = 9.7fF \]
\[ CJC(0V) = cjci0 + cjcx0 + cbcpar = 9.0fF \]
Modeling Variants for HBT Type 0.12x0.84 µm² II

- ICCAP Environment
- Simulator
  - standard ADS with model call “... HICUM ...”
  - ADS in ICCAP “spmodeads” (circuit in native Spectre syntax)
- Simulation results differ from previous ADS amongst others by
  - all capacitances are too low
  - stronger avalanche current

\[ I_C(V_{CE}) \]
\[ V_{BE} = 0.6(0.05)1.0V \]

\[ f_T(V_{BE}) \]
\[ V_{CB} = -0.5(0.5)1.5V \]
Modeling Variants for HBT Type 0.12x0.84 μm² III

- ICCAP Environment
- Simulator
  - standard ADS with model call “... HICUM ...”
  - ADS in ICCAP “spmodeads” (circuit in native Spectre syntax)
- Partial adaption to previous ADS by
  - increase capacitance parameters
  - adjust avalanche parameter $q_{avl}$

$I_C (V_{CE})$
$V_{BE} = 0.6(0.05)1.0V$

$f_T (V_{BE})$
$V_{CB} = -0.5(0.5)1.5V$

$C_JE(0V) = c_{jei0} + c_{jep0}$
$+ c_{bepar} = 9.7fF$

$C_JC(0V) = c_{jci0} + c_{jcx0}$
$+ c_{bcpar} = 9.0fF$
Modeling Variants for HBT Type 0.12x0.84 µm² IV

- ICCAP Environment
- Spectre6.2 with internal HICUM and with Verilog-A
  'adhl_include “../../../../hicumL2V2p24.va”'
- Simulation results differ from ADS amongst other by
  - $C_{BC}$ still too low
  - stronger avalanche current
  - kinks in the $S_{ij}(\text{freq}, V_{CE})$ functions

\[ I_C (V_{CE}) \]
\[ V_{BE} = 0.6(0.05)1.0V \]

\[ f_T (V_{BE}) \]
\[ V_{CB} = -0.5(0.5)1.5V \]