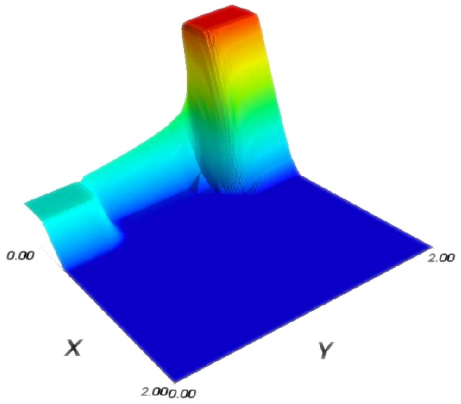
XMOD Technologies
74 Rue G. Bonnac
Tour 1, 1er Etage
33 000 Bordeaux
Tél: +33 56 11 04 34
e-mail: ardouin@xmodtech.com

XMOD TECHNOLOGIES

- Company presentation -

Bertrand ARDOUIN



Brief Resume

Bertrand ARDOUIN

Born in 1972

Master & Ph.D. In EE from University Bordeaux, IMS (IXL), France

Former Student of Thomas Zimmer

Co-founder of XMOD Technologies in 2002, R & D Director

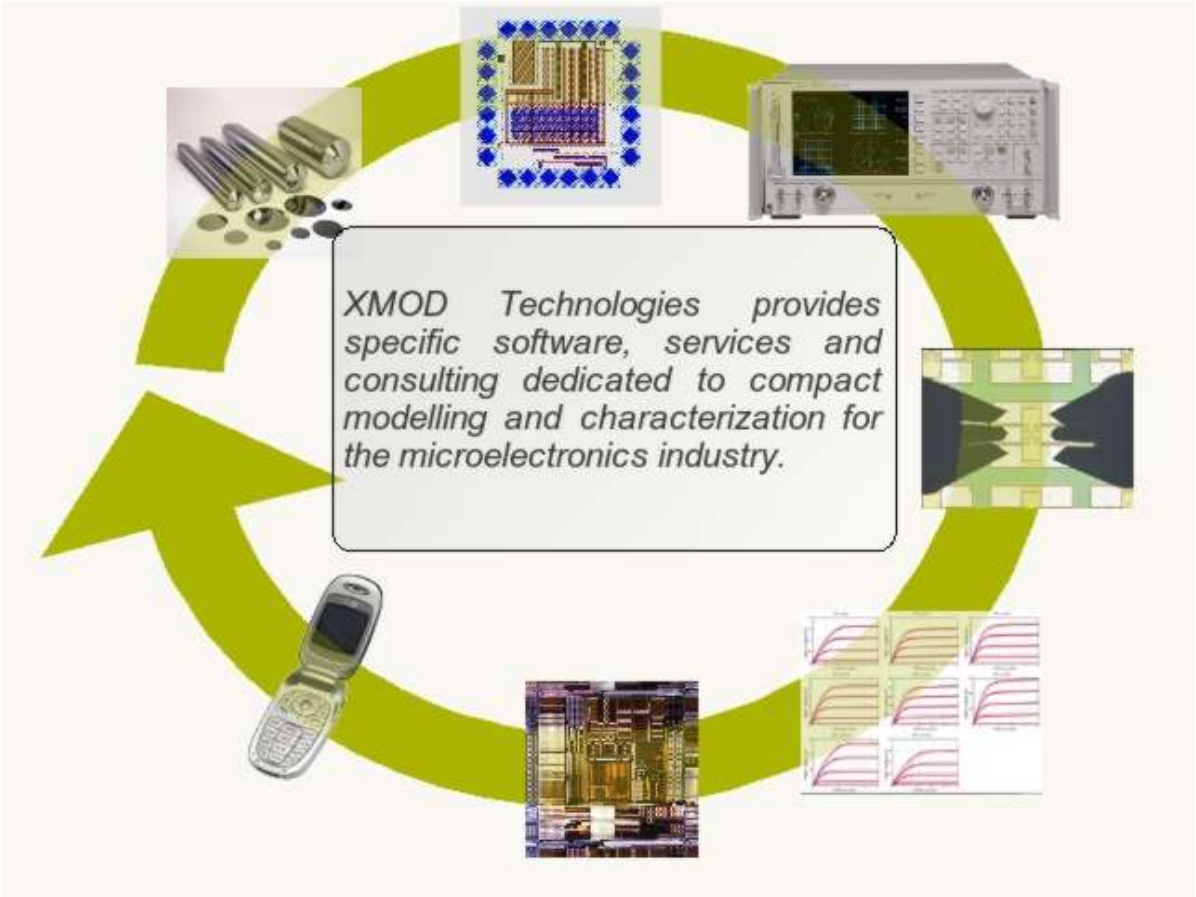
Managing Director of XMOD Technologies

Working fields:

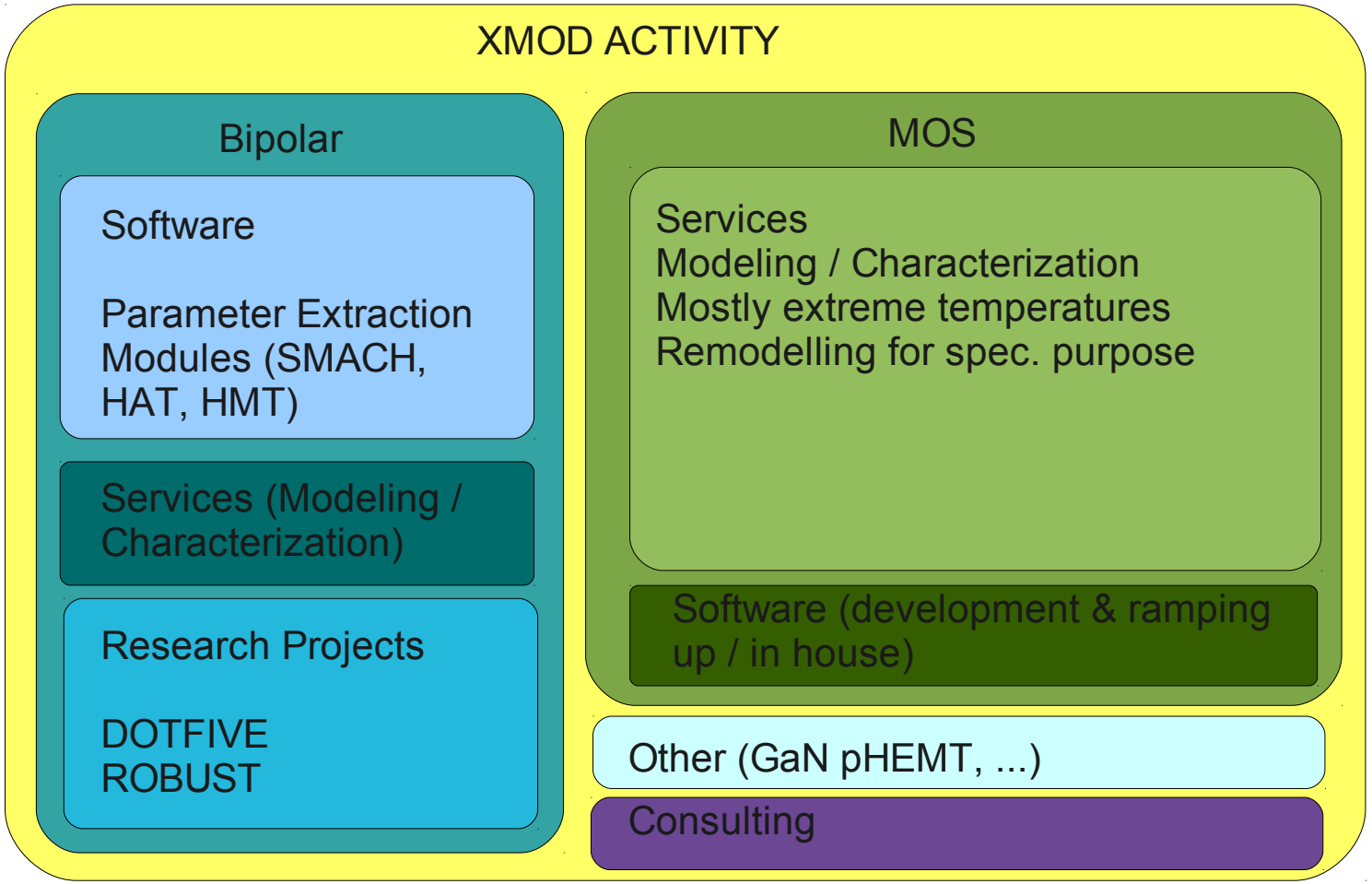
- Compact Modeling & characterisation of SiGe HBTs, CMOS, ...
- On wafer DC, CV & HF measurements / De-embedding, 1/f noise
- Cryogenic & very high temperature measurements
- Software development (3 generations of extraction toolkits)
- Compact Models (SGP, HiCUM, VBIC, BSIM3, BSIMSOI, PSP, EKV, Angelov, various diodes, varactors, resistors & MiM cap models)

BCTM CAD/modeling sub-committee member

Overview


XMOD Technologies provides specific software, services and consulting dedicated to compact modelling and characterization for the microelectronics industry.

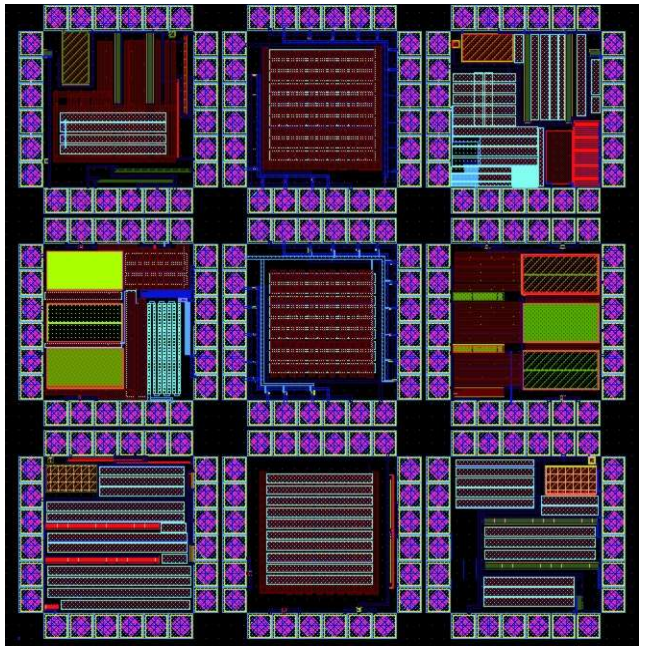
Overview


XMOD ACTIVITY
Bipolar
Software
Parameter Extraction Modules (SMACH, HAT, HMT)
Services (Modeling / Characterization)
Research Projects
DOTFIVE
ROBUST
MOS
Services
Modeling / Characterization
Mostly extreme temperatures
Remodelling for spec. purpose
Software (development & ramping up / in house)
Other (GaN pHEMT, ...)
Consulting

Examples

Test Chip Design

- Design done either by customer (following XMOD recommendations) or by XMOD (in collaboration with our partner for layout)
- Evaluation of existing Test Chip (wrt target application)
- improvement and/or re-design of Test Chip to meet specific needs
- Design of test chip from scratch
- Special skills for
  - high frequencies / de-embedding (up to 110GHz)
  - Bipolar test structures
  - specific needs



Picture:

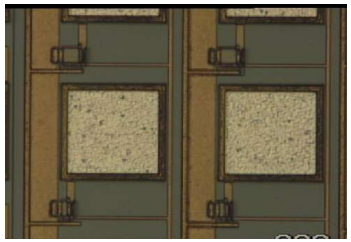
Example of a special test chip design for cryogenic applications

Examples

On Wafer Characterization

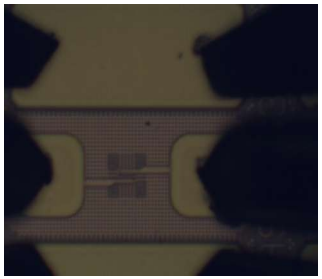
- DC, CV and S parameters (up to 110GHz)
- 200 mm wafers
- Accurate de-embedding
- 1/f Noise
- Extreme temperatures
- Liquid nitrogen 77K to 300°C

Semi-automatic prober



MOS transistors in DC pads

Cryogenic prober for 77K measurements

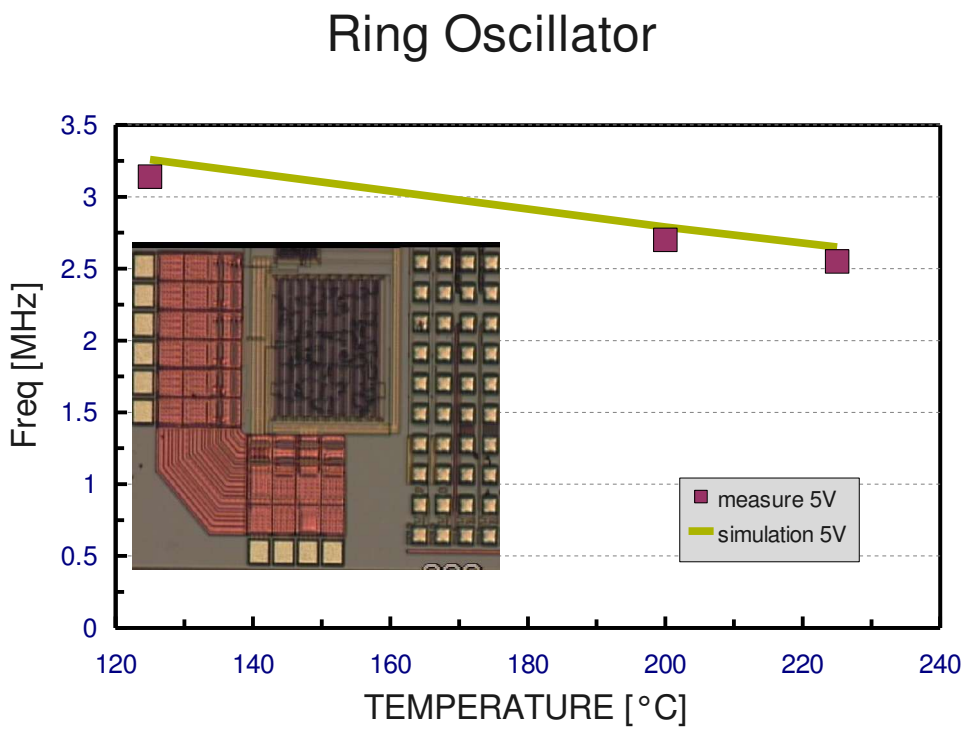


HBT in GSG RF pads

Examples

Parameter Extraction and model kit generation

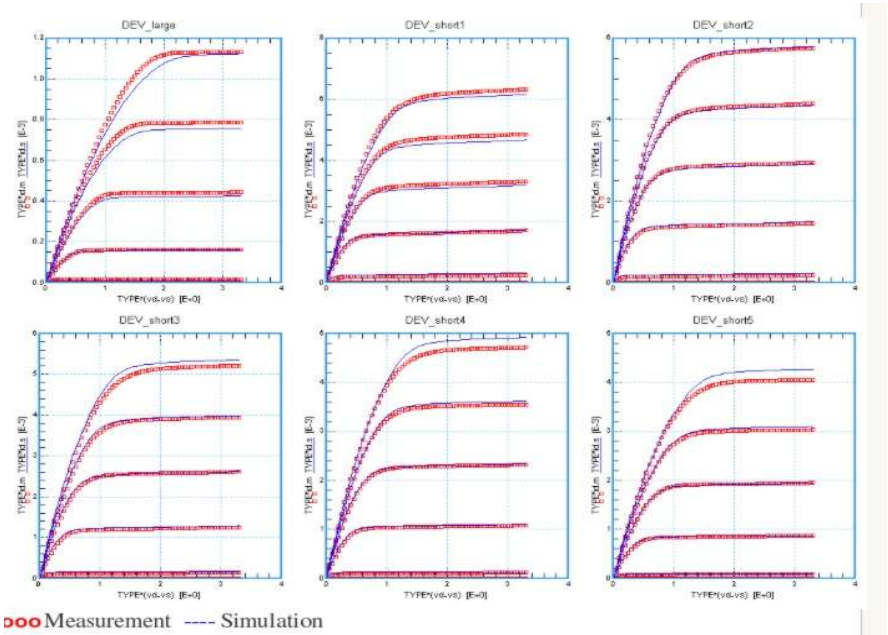
- **Example 1:** Re-modelling of foundry CMOS process up to 225 °C
  Verification of ring oscillator up to 225 °C

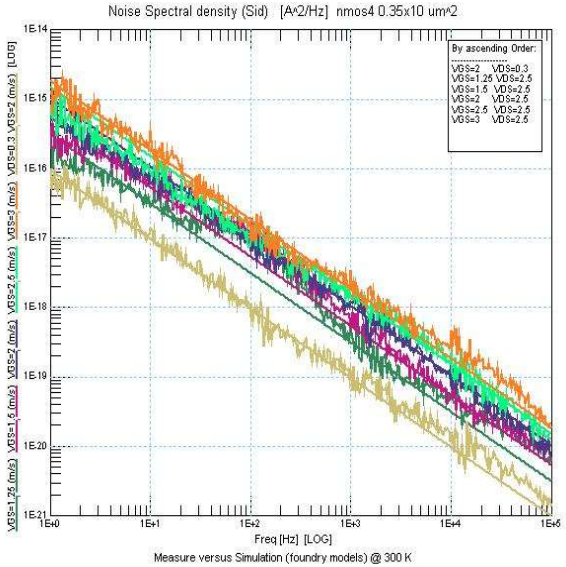


Examples

Parameter Extraction and model kit generation (Cont.)

- **Example 2:** Re-modelling of foundry process for 77K applications



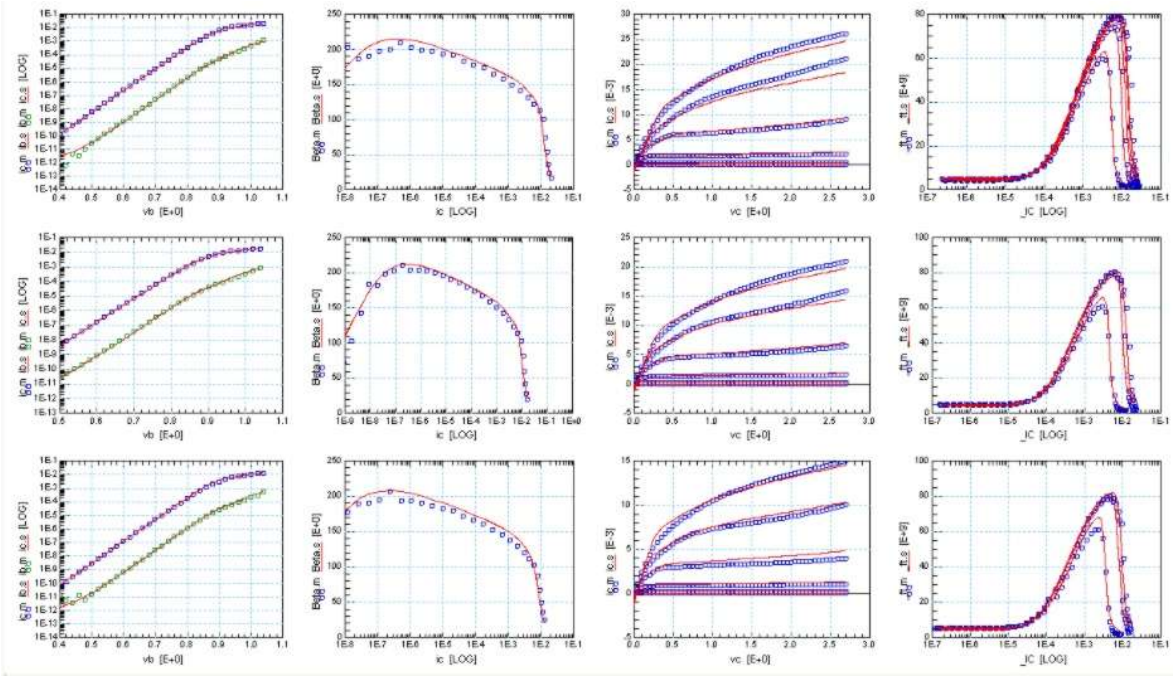


Examples

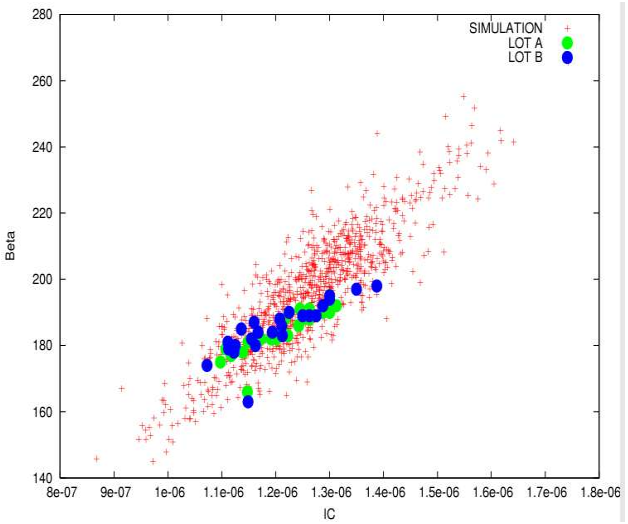
Parameter Extraction and model kit generation (Cont. 2)

- **Example 3:** HiCUM Scalable & Statistical model - 80GHz SiGe HBT process

Scalable model Simulations versus measure (3 different transistors size)



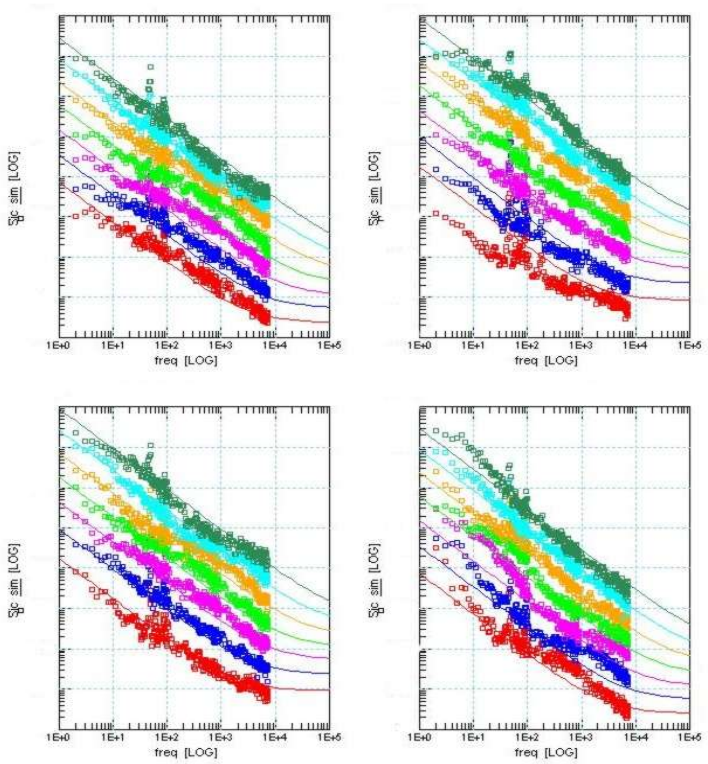
Monte Carlo simulation vs PCM measurements

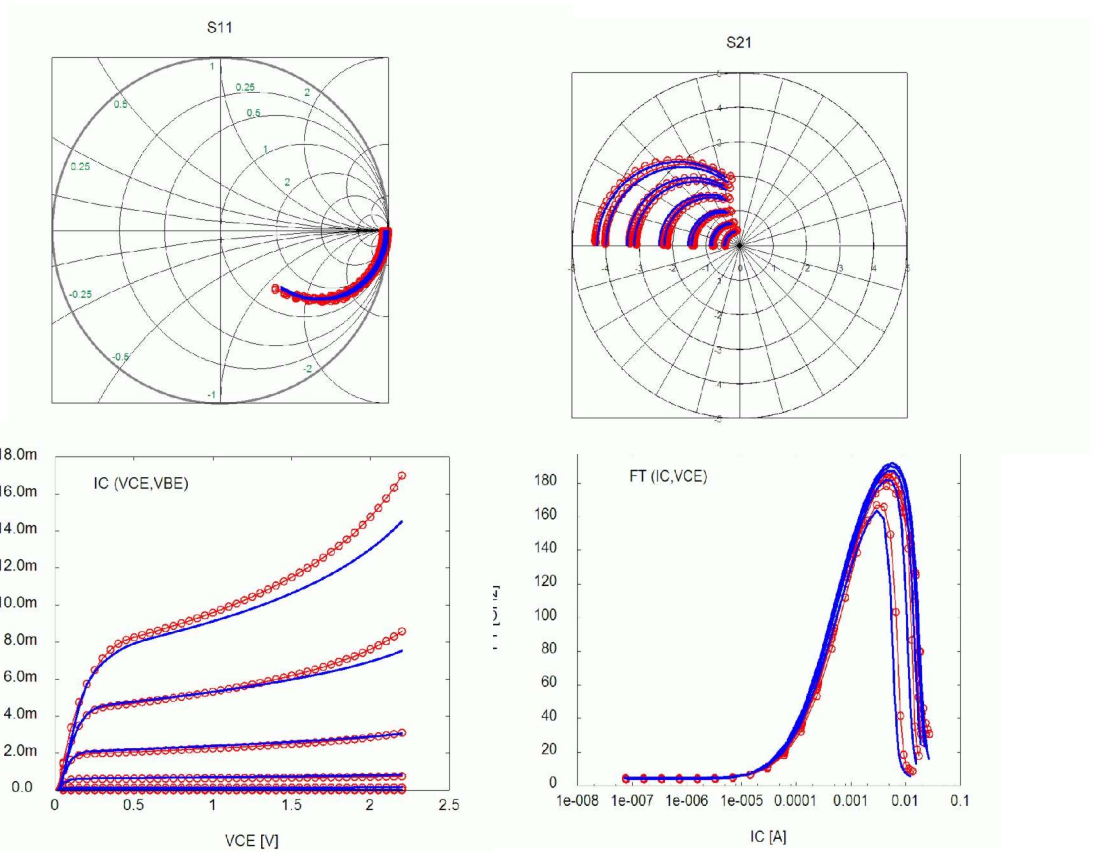


Examples

Parameter Extraction and model kit generation (Cont 3)

- **Example 4:** HiCUM Scalable 200GHz SiGe HBT process
  Freq 100MHz -> 48.7 GHz





Extra Slides

HiCUM Transfer Current Equation:

$$I_{TF} = \frac{C10}{QP0 + HJEI\ \ Q_{jei} + HJCI\ \ Q_{jci} + HFE\ \ Q_{fe} + Q_{fB} + HFC\ \ Q_{fc} + Q_{r,T}} \left[\exp\left(\frac{V_{BE}}{V_T}\right) - \exp\left(\frac{V_{BC}}{V_T}\right) \right]$$

Problem at low current densities:

- **C10/QP0 = IS but no unique solution**
- **QP0 can be obtained only from Tetrodes (e.g., relative to QJ estimate → intrinsic transistor definition)**
- **Impact of QfB (high currents) depend on QP0**
- **Adjusting QP0 for high currents compromises low currents**
- **In most Advanced HBTs: missing factor for QfB → need tuning of QP0 but irrelevant with RsBI0 variations**

Extra Slides

HiCUM Transfer Current Equation modified:

Introduce new parameters (in the netlist / no need for modified code):

J_S, QP00, KSIGE, V_AR0, V_AF0, H_FE0, H_FC0

These become “frontend” for :

C10, QP0, HJEI, HJCI, HFE, HFC

$$\mathrm{C10} = \mathrm{J\_S} * \mathrm{Q\_P00} * AE^2 * \mathrm{K\_SIGE}$$

$$\mathrm{QP0} = \mathrm{Q\_P00} * \mathrm{K\_SIGE} * AE$$

$$\mathrm{HJEI} = \frac{\mathrm{K\_SIGE}}{\mathrm{V\_AR0}} * \frac{AE}{AE0} = \frac{\mathrm{K\_SIGE}}{V\_AR}$$

$$\mathrm{HJCI} = \frac{\mathrm{K\_SIGE}}{\mathrm{V\_AF0}} * \frac{AE}{AE0} = \frac{\mathrm{K\_SIGE}}{V\_AF}$$

$$\mathrm{HFE} = \mathrm{H\_FE0} * \mathrm{K\_SIGE}$$

$$\mathrm{HFC} = \mathrm{H\_FC0} * \mathrm{K\_SIGE}$$

Extra Slides

HiCUM Transfer Current Equation modified:

$$I_{TF} = \frac{\mathrm{C10}}{\mathrm{QP0} + \mathrm{HJEI}\ Q_{jei} + \mathrm{HJCI}\ Q_{jci} + \mathrm{HFE}\ Q_{fe} + Q_{fB} + \mathrm{HFC}\ Q_{fc} + Q_{r,T}} \left[\exp\left(\frac{V_{BE}}{V_T}\right) - \exp\left(\frac{V_{BC}}{V_T}\right) \right]$$

VBC<<1 Qr,T ~ 0

Introduce new “front end” parameters:

$$I_{TF} = \frac{\mathrm{J\_S}\ \mathrm{Q\_P00}\ AE^2\ \mathrm{K\_SiGe}}{\mathrm{Q\_P00}\ \mathrm{K\_SiGe}\ AE + \mathrm{K\_SiGe}\frac{AE}{AE0}\ \frac{Q_{jei}}{\mathrm{V\_AR0}} + \mathrm{K\_SiGe}\frac{AE}{AE0}\ \frac{Q_{jci}}{\mathrm{V\_AF0}} + \mathrm{H\_FE0}\ \mathrm{K\_SiGe}\ Q_{fe} + Q_{fB} + \mathrm{H\_FC0}\ \mathrm{K\_SiGe}\ Q_{fc}} \quad [\mathrm{Exp}]$$

After simplification:

$$I_{TF} = \frac{\mathrm{J\_S}\ AE}{1 + \frac{Q_{jei}}{\mathrm{Q\_P00}\ AE0\ \mathrm{V\_AR0}} + \frac{Q_{jci}}{\mathrm{Q\_P00}\ AE0\ \mathrm{V\_AF0}} + \mathrm{H\_FE0}\ \frac{Q_{fe}}{\mathrm{Q\_P00}\ AE} + \frac{Q_{fB}}{\mathrm{K\_SiGe}\,\mathrm{Q\_P00}\ AE} + \mathrm{H\_FC0}\ \frac{Q_{fc}}{\mathrm{Q\_P00}\ AE}} \quad [\mathrm{Exp}]$$

From Absolute Charges (Q) to normalized charges (q), if Qjei and Qjci propotionnal to AE0

$$I_{TF} = \frac{\mathrm{IS}}{1 + \frac{q_{jei}}{\mathrm{V\_AR0}} + \frac{q_{jci}}{\mathrm{V\_AF0}} + \mathrm{H\_FE0}\ q_{fe} + \frac{q_{fB}}{\mathrm{K\_SiGe}} + \mathrm{H\_FC0}\ q_{fc}} \quad [\mathrm{Exp}]$$

Extra Slides

HiCUM Transfer Current Equation modified:

Comparison to SGP/VBIC possible until TF0 is constant with current:

$$\frac{q_{fB}}{\mathrm{K\_SiGe}} \sim \frac{TF0 \quad I_{TF}}{\mathrm{Q\_P00} \quad \mathrm{KSIGE}} \sim \frac{I_{TF}}{I_{KF}}$$

$$I_{KF} \sim \mathrm{Q\_P00}\frac{\mathrm{KSiGe}}{TF0} = \frac{\mathrm{Q\_P0}}{TF0}$$

Q_P0 (or QP0) does not appear anymore in the final equation, but it is implicit in qfB nevertheless its influence is moved towards higher currents, its know equivalent to the IKF knob

We can tune high currents effects without modifying low currents