Spice-extraction with included temperature parameters using SGP model

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Overview

- Motivation
- Previous situation
- Targets of bachelor thesis
- Temperature parameters
- Heating equipment
- Way of temperature measurement
- Extraction results
- Summary
- Outlook

Motivation

- Better technical support for customers
- Customer requests for more detailled models up to 150 °C (automotive and lighting applications)
- Current SPICE models do not include temperature parameters
- Simulation results with default values for temperature parameter are less accurate at high temperatures

Previous situation

- Temperature parameters XTI, XTB, EG not included; simulation models are using default values

  due to:

- High time effort for measurements

- Missing Equipment for temperature measurements (heatable test sockets, heating element, temperature control)

Bachelor thesis (M. Nowottny, HAW Hamburg, Aug. to Oct. 2013)

- Analyzing the influence of temperature parameters (XTB, XTI, EG)
- Looking for a practicable method for including temperature parameters into SPICE models
- Construction / testing of suitable heating equipment
- Evaluating of suitable method for temperature measuring
- Performing of a real parameter extraction of a low VCEsat - transistor including temperature parameters
- Estimation of time effort for parameter extraction with included temperature parameters

Temperature parameters / influence (1)

- XTI temperature exponent for saturation current and
- EG Energy gap; main influence on saturation current:

$$IS(T) = IS(To)\left[\frac{T}{To}\right]^{XTI} \exp\left[\frac{EG}{UT(To)}\left(1-\frac{To}{T}\right)\right]$$

Temperature parameters / influence (2)

- XTB forward/reverse ß temperature coefficient, main influence on current gain and leakage saturation current :

$$BF(T) = BF(To)\left[\frac{T}{To}\right]^{XTB}$$

$$BR(T) = BR(To)\left[\frac{T}{To}\right]^{XTB}$$

$$ISE(T) = ISE(To)\left[\frac{T}{To}\right]^{-XTB}\left[\frac{IS(T)}{IS(To)}\right]^{1/NE}$$

$$ISC(T) = ISC(To)\left[\frac{T}{To}\right]^{-XTB}\left[\frac{IS(T)}{IS(To)}\right]^{1/NE}$$

Temperature parameters / influence (3)

- Influence on DC measurements:

  - Main influence of EG, XTI and XTB on current gain and output characteristic

- No influence on AC-measurements expected

  - fT, capacitances, switching times are not sensitive to changes of XTB, XTI and EG

- Examination focussed on DC behaviour

Transistor used for extraction

- Low saturation voltage (BISS) type, PNP
- Quick reference data:

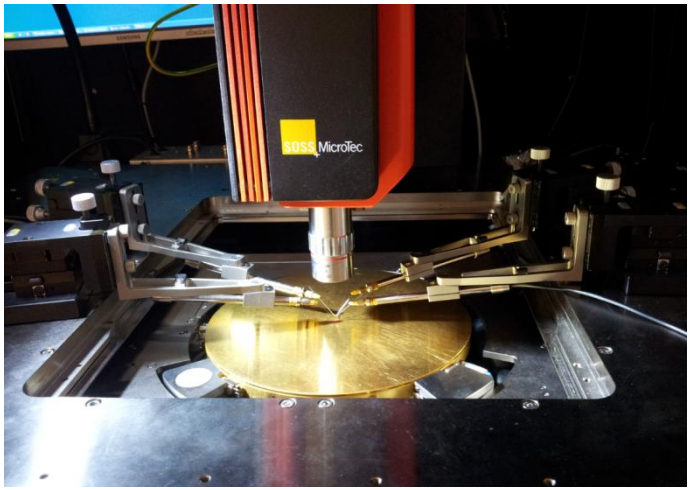
  - DC current: 5.7 A (max.)
  - VCEO: 12 V (max.)
  - Current gain: 335 @ V_{CE}=2V / I_C=2A (typ.)

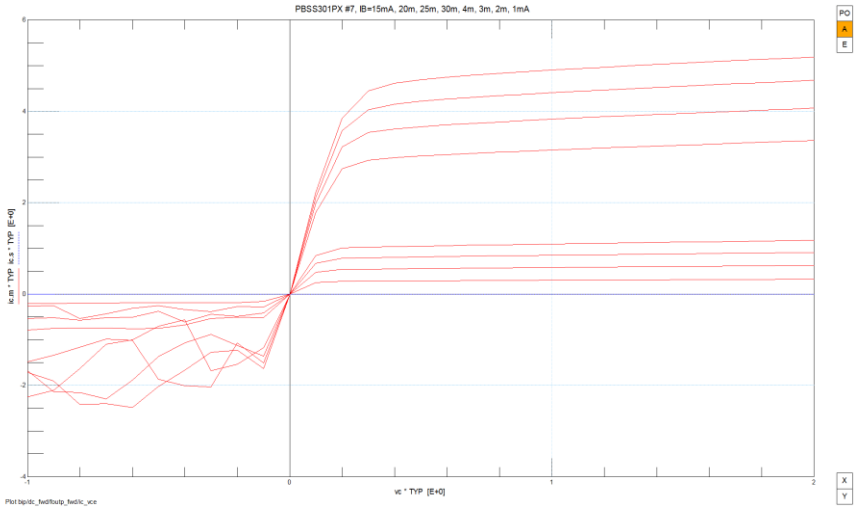
- Package: SOT 223
- Sales volume of BISS transistor family: 760 Mio. pcs. / 29 Mio. $ in 2012

Heating equipment (1)

Heatable temperature chuck (-40°C to 180 °C)

- Good temperature control, but poor measurement results (noise, oscillation)
- Differences between chuck and die temperature, depending on environment (air, nitrogen purging, shieldings etc.)

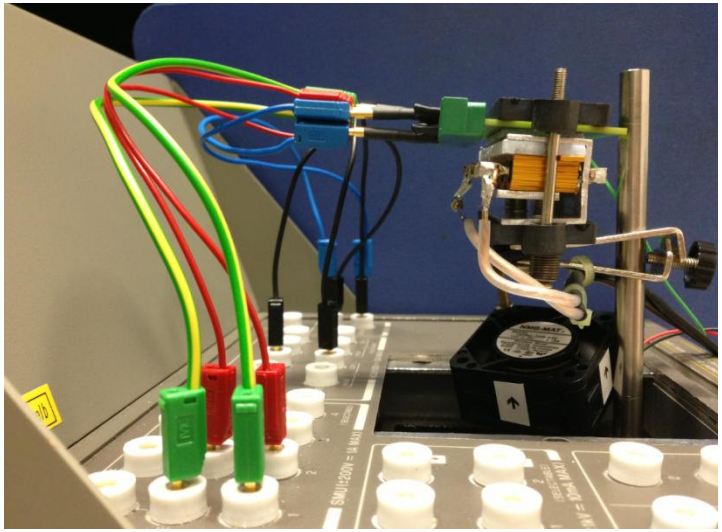




Heating equipment (2)

Self construction (25°C to 150 °C) with heating resistors

- Good temperature control, (Temp. controller, cooling fan, heating resistances, PT100, supplier: Farnell)



- Costs for equipment: About 250 €

Temperature mesurement (1)

Usage of thermocouple:

Measured temperature depends on sensor position inside heating block, not equal to die temperature / not reproducible

➔ Usage of internal base-emitter junction of BJT

BE voltage depends on temperature with temperature coefficient of –2 mV/K

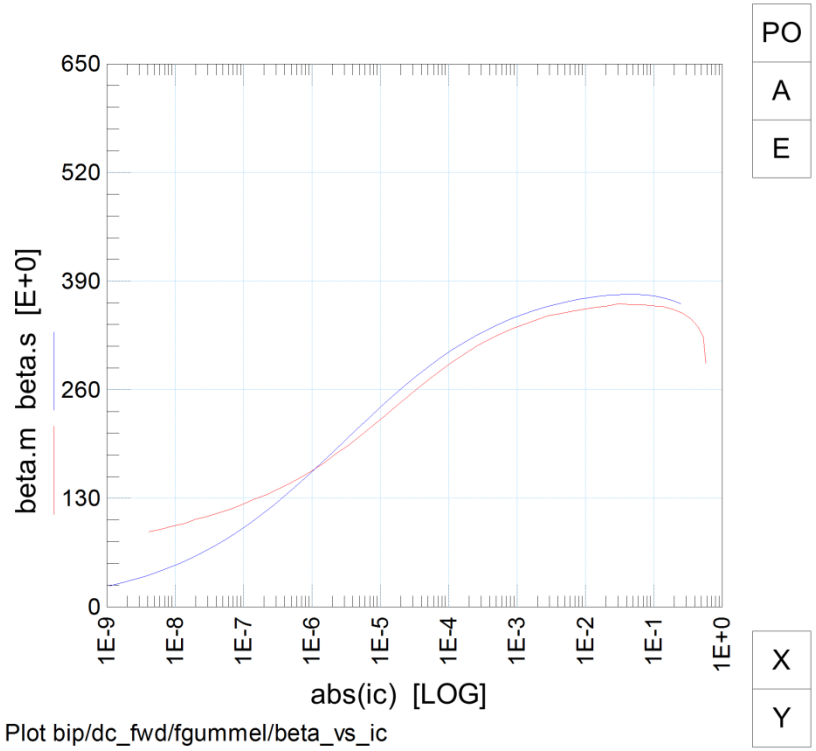
Temperature mesurement (2)

Usage of internal BE-Diode of BJT

- Measuring of calibration curve (BE-voltage vs. temperature) of DUT in furnace (measuring VBE@1mA each 25 °C)
- Correlation of BE-voltage to real die temperature
- Temperature adjustment by increasing controller settings until required BE-voltage for requested temperature is hit
- Accuracy of temperature controlling: Ca. 1-2 °C

Extraction results (1)

Current gain @ T=25°C

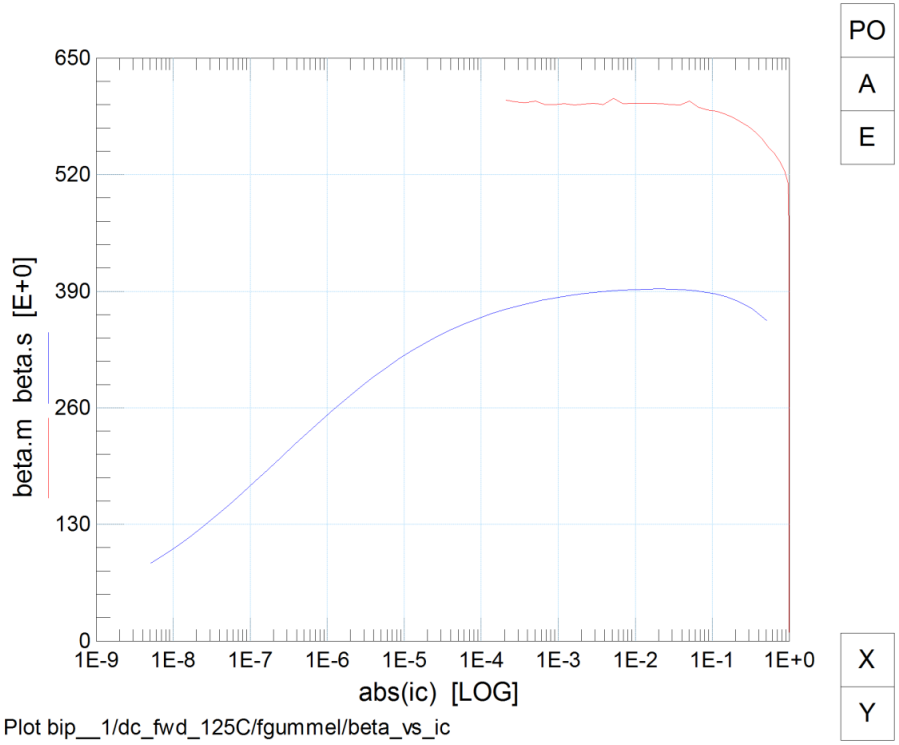


Default values:
XTB=0, XTI=3, EG=1,11

Red line: measured data
Blue line: simulated data

Extraction results (1)

Current gain @ T=125°C

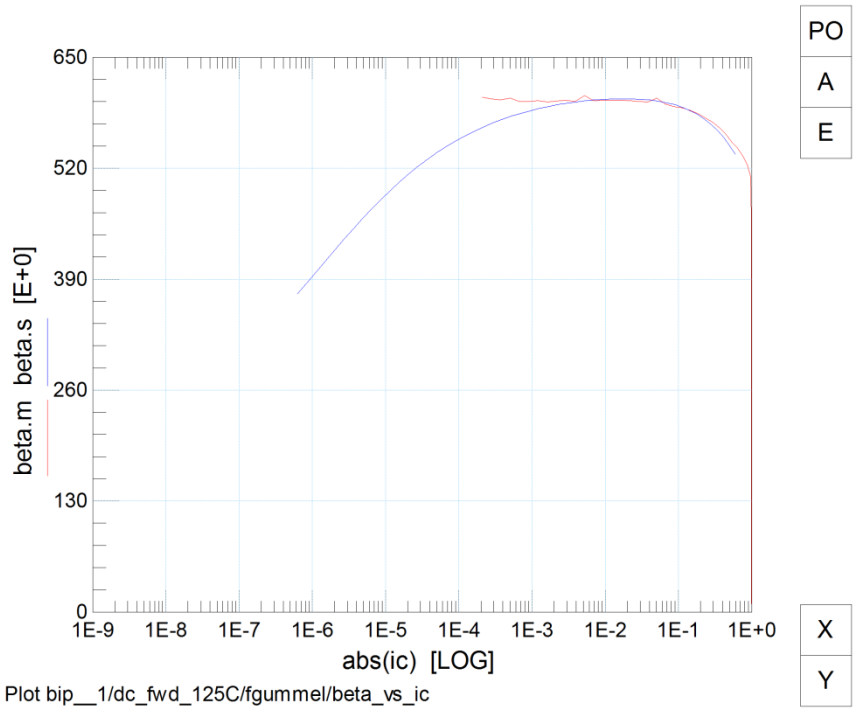


Default values:
XTB=0, XTI=3, EG=1,11

Red line: measured data
Blue line: simulated data

Extraction results (1)

Current gain @ T=125°C

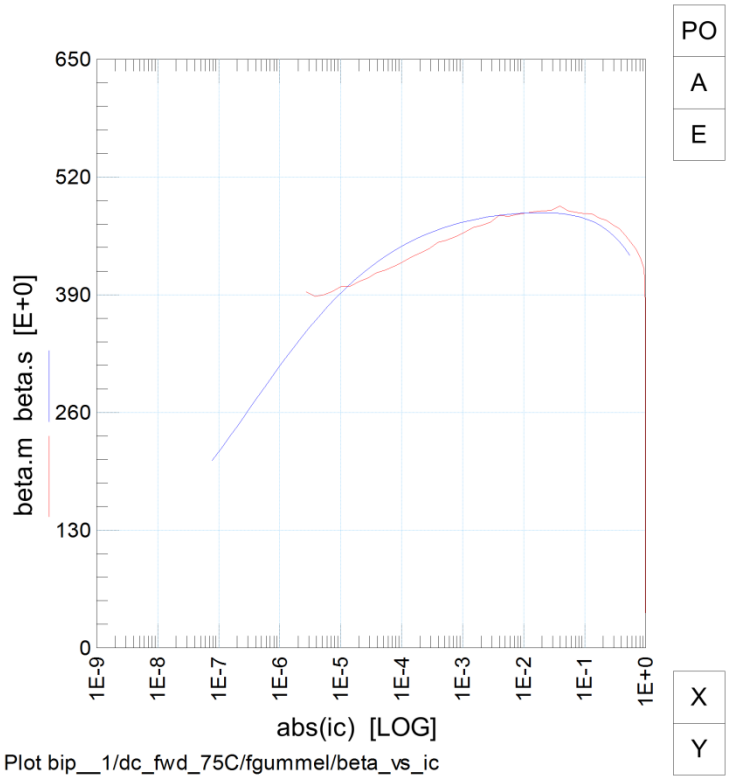


Tuned values:
XTB=1,46; XTI=1,94; EG=1,09

Red line: measured data
Blue line: simulated data

Extraction results (1)

Current gain @ T=75°C

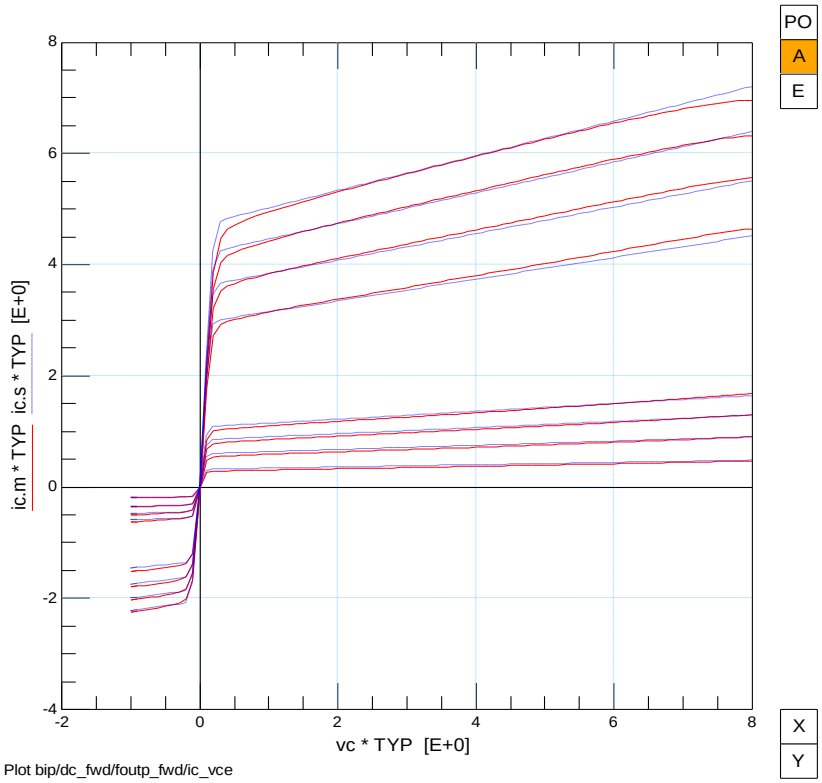


Tuned values:
XTB=1,46; XTI=1,94; EG=1,09

Solid line: measured data
Dashed line: simulated data

Extraction results (2)

Output characteristics @ T=25°C

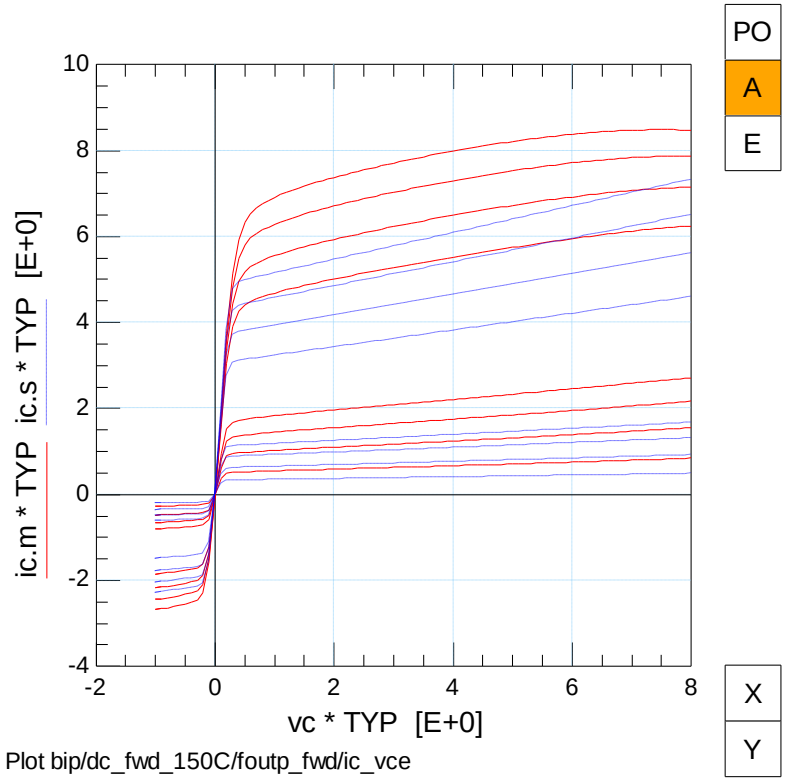


Default values:
XTB=0, XTI=3, EG=1,11

Red line: measured data
Blue line: simulated data

Extraction results (2)

Output characteristics@ T=125°C

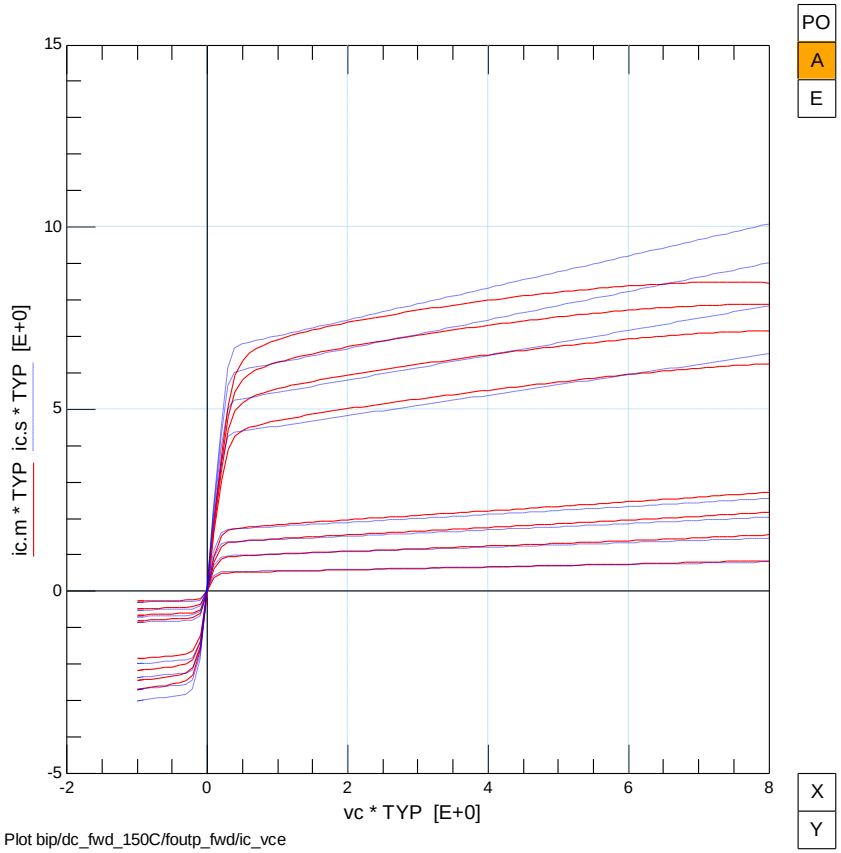


Default values:
XTB=0, XTI=3, EG=1,11

Red line: measured data
Blue line: simulated data

Extraction results (2)

Output characteristics @ T=125°C

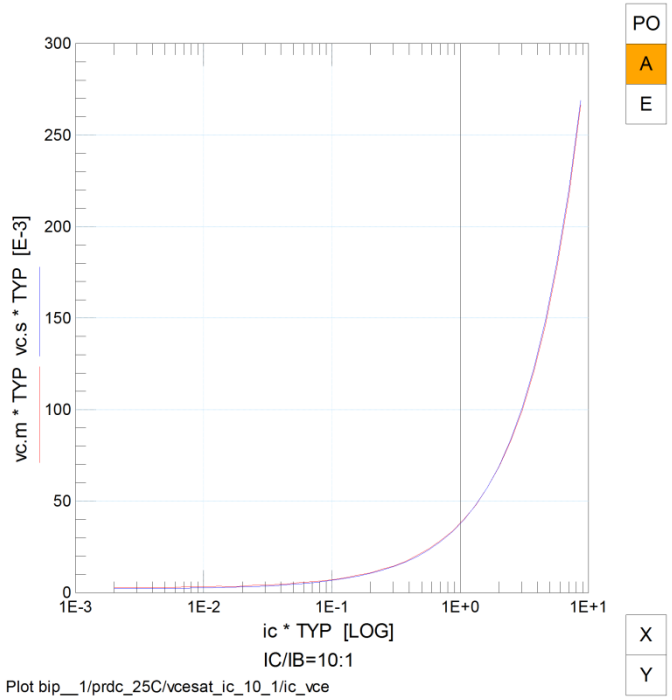


Tuned values:
XTB=1,46; XTI=1,94; EG=1,09

Red line: measured data
Blue line: simulated data

Extraction results (3)

Saturation voltage @ T=25°C

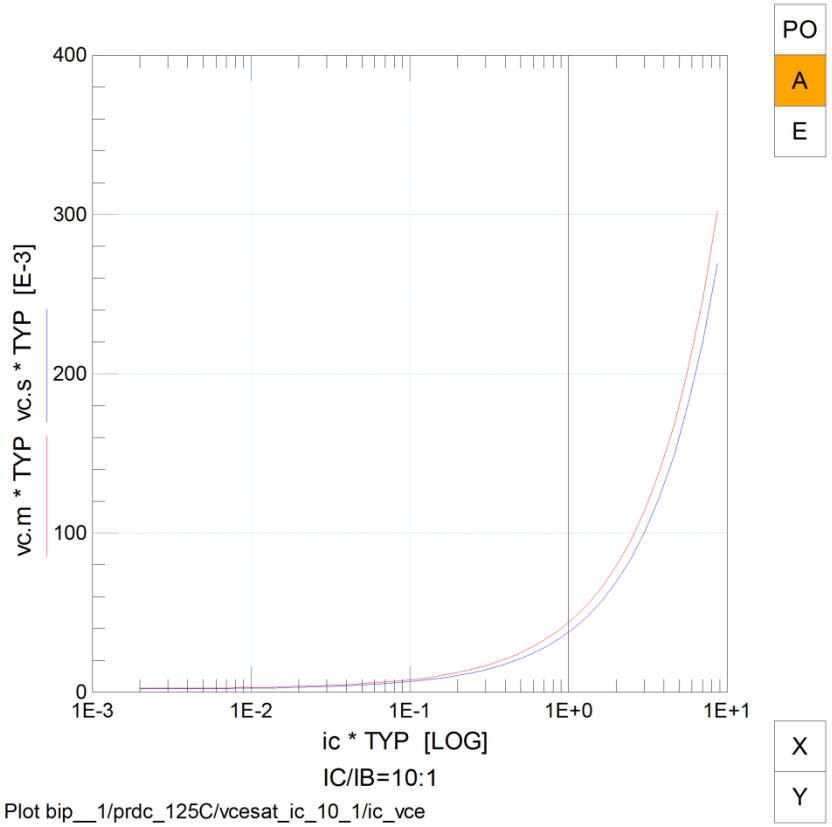


Default values:
XTB=0, XTI=3, EG=1,11

Red line: measured data
Blue line: simulated data

Extraction results (3)

Saturation voltage @ T=125°C



Default values:
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Red line: measured data
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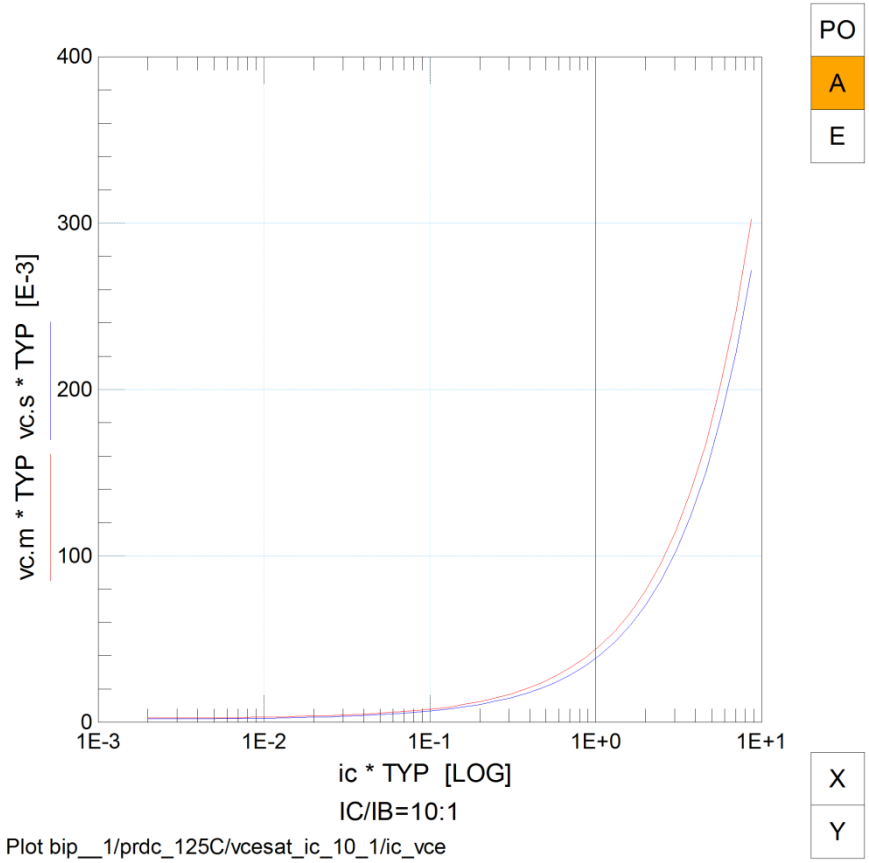
Extraction results (3)

Saturation voltage @ T=125°C



Tuned values:
XTB=1,46; XTI=1,94; EG=1,09

Red line: measured data
Blue line: simulated data

Way of working / extraction

- Doing standard measurements and parameter extraction @ 25°C
- Adding DC-measurements @ 125 °C
- Setting TEMP to measurement temperature (e.g. 125 °C)
- Fitting of XTI , using Gummel / hFE plot
- Fine tuning with EG (only minimum changes due to physical factor)
- Fitting of XTB, using output characteristics

Summary / Results

- Temperature measurements done by using a simple/cheap self construction and using internal BE-junction of DUT for sensor work well
- Good fitting of DC simulations by using two-point measurement (25 °C and additional 125°C) and tuning of XTB and XTI
- Saturation voltage simulations hardly sensitive to temp. Parameters

Outlook

- Verification of results at low temperatures (-25 °C)

- High time effort (2-3x higher) due to:
  - setting up temperature measurement equipment
  - additional furnace measurements

  => Changing furnace measurements by calculation of VBE ?

- Future extractions including temperature parameters, re-extraction of important and highrunner types for better customer support

Thank you for your Attention!