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# How to improve ICCAP's ability to generate scaled model parameters

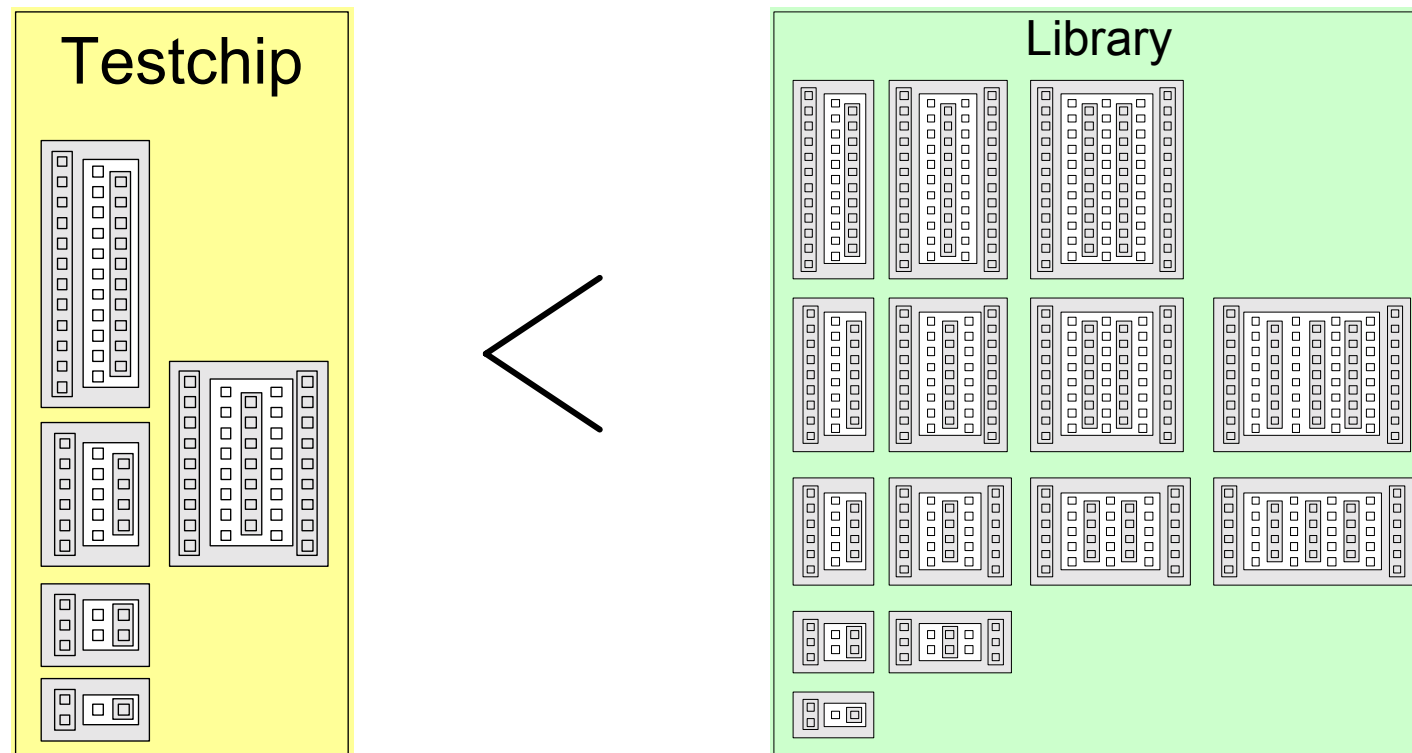
by  
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Infineon Technologies, Munich

# Why model parameter scaling ?

## Testchip devices vs. Library devices

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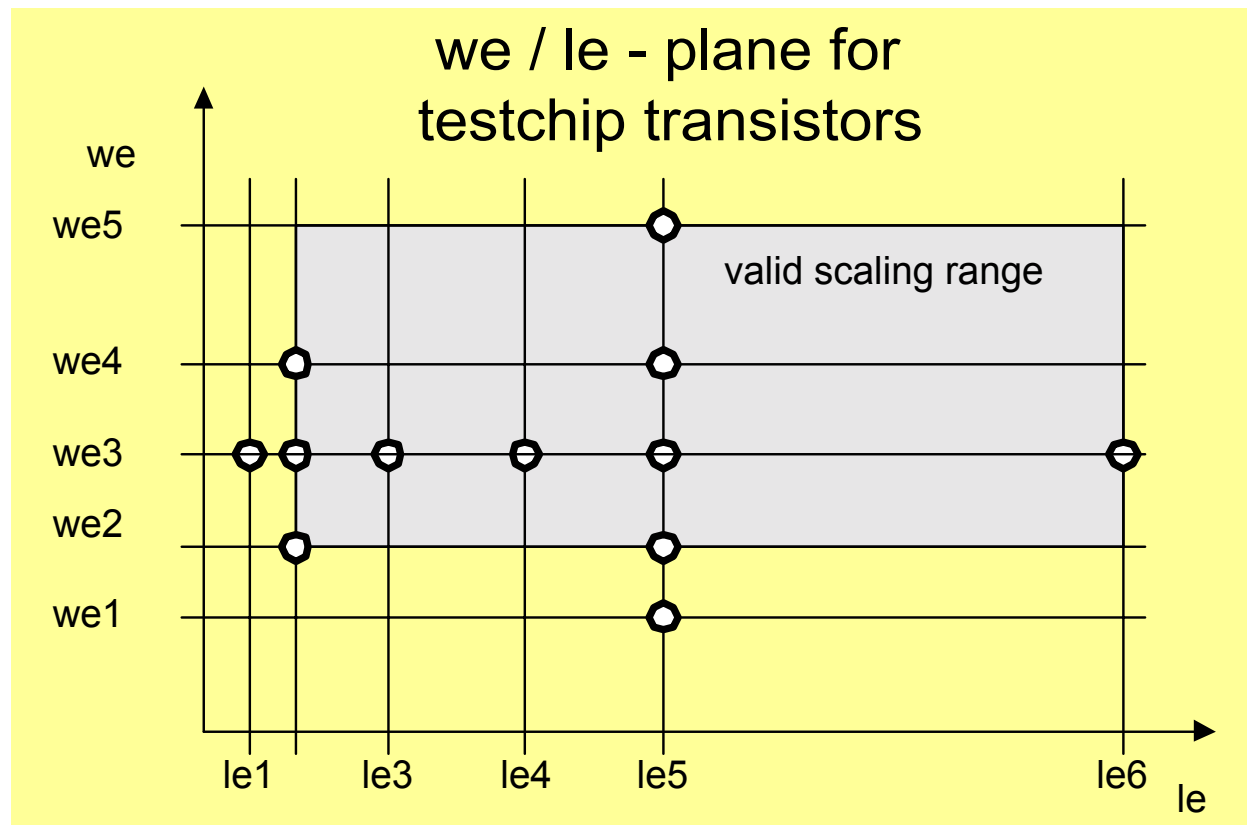
- Number of testchip devices < number of library devices
- The modeling engineer needs to calculate the model parameters for all the other unknown devices in the library



# Why model parameter scaling ?

## Testchip devices in the we / le plane

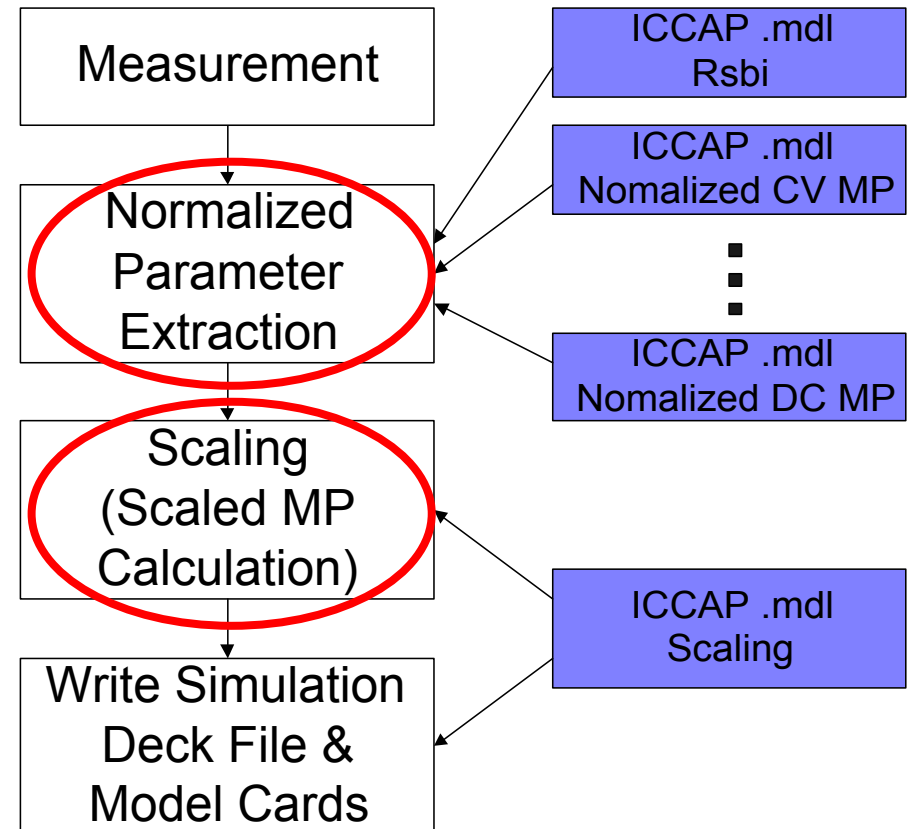
- Testchip transistors realized only at certain points in the we / le plane, library devices are allowed in the whole valid range



# What is “scaling model parameters” ?

## General Flow

- Process of scaling model parameters consists of four main steps
- The second step may be realized in two different ways:
  1. normalizing absolute model parameters, which are extracted for each test device before (traditional method) or
  2. normalizing the measurement values
- First method will be shown more detailed as an example for linear scaling



# What is “scaling model parameters” ?

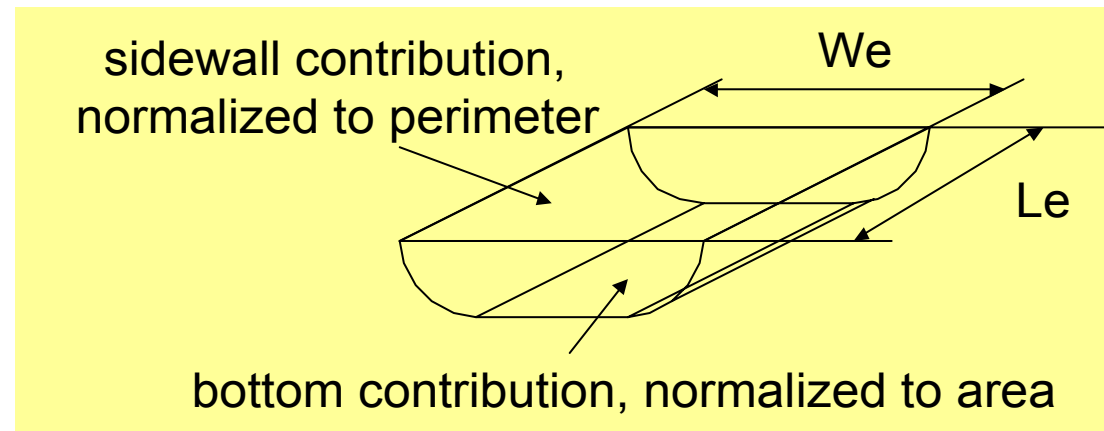
## Example for extraction of normalized parameters (1)

- Taking into account the different contributions of the perimeter and bottom emitter area, the following scaling approach is often very useful:

$$IS = is\_a * Ae + is\_p * Pe$$

$$\text{with } Ae = We * Le, Pe = 2 * (We + Le)$$

- Dividing by Ae we get:  $IS / Ae = is\_a + is\_p * Pe / Ae$

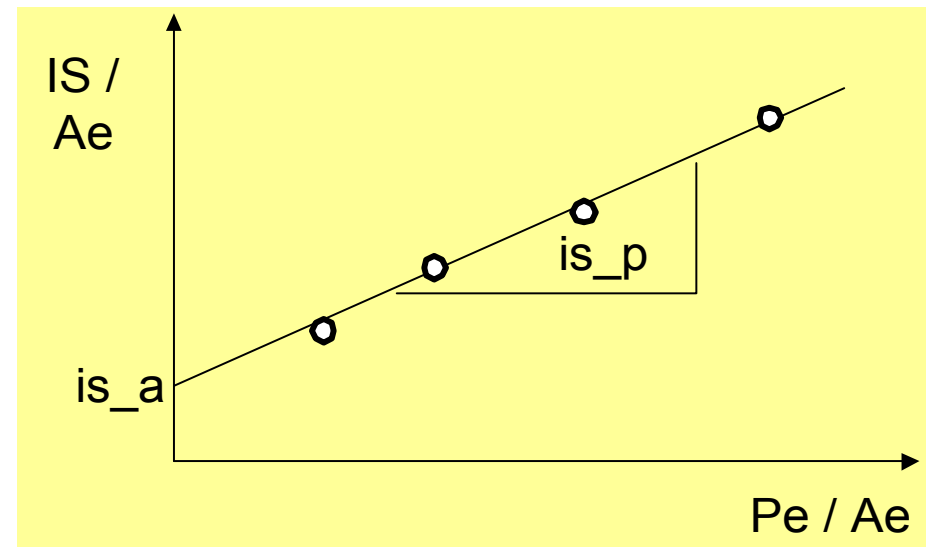


# What is “scaling model parameters” ?

## Example for extraction of normalized parameters (2)

- Pre-Condition: extracted IS model parameters for all testchip devices
- A linear fit gives the normalized parameters  $is\_p$  (A/ um ) and  $is\_a$  ( A / um<sup>2</sup>)
- Using the normalized parameters, we can calculate the scaled model parameter IS for each geometry

$$IS / Ae = is\_a + is\_p * Pe / Ae$$



Definition: “Normalized parameters” are parameters, which are normalized to geometrical transistor dimensions, e.g. emitter area or perimeter or P/ A ratio etc.

# What is “scaling model parameters” ?

## Scaling definition

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- From previous example, we found three essential preconditions for scaling model parameters:
  - a) the scaling equation
  - b) the geometrical information for the devices (W and L) and
  - c) the normalized parameters.

$$IS = is\_a * Ae + is\_p * Pe$$

**Definition: “Scaling model parameters” may be defined as the calculation of model parameters for unknown devices, based on scaling equations, geometrical values and normalized parameters.**

- The three preconditions may be fulfilled on different levels

# What is “scaling model parameters” ?

## Scaling levels

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- Main criteria for scaling level definition is:  
Where are the scaling equations defined ?

- **Scaling level 1:**  
scaling equations defined in a user specific scaling-program

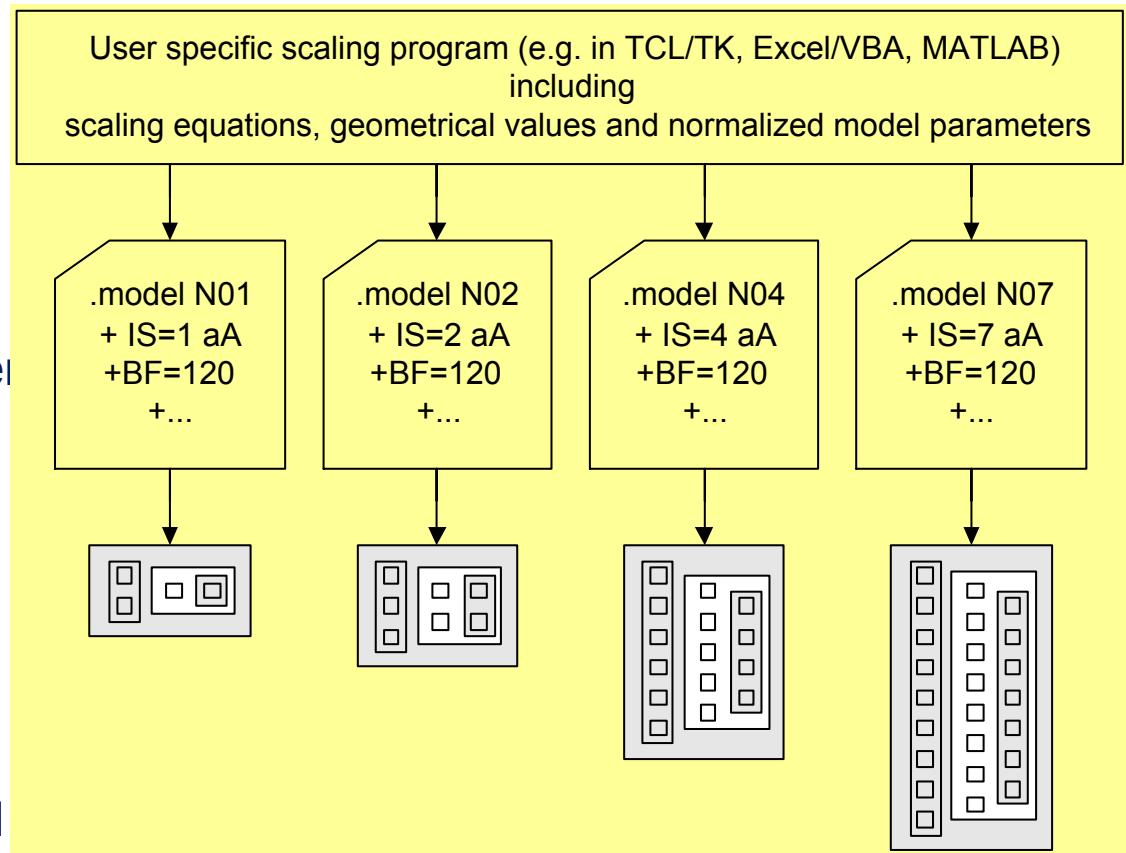
- **Scaling level 2:**  
scaling equations are defined on the model card

- **Scaling level 3:**  
scaling equations defined inside the model CODE

# What is “scaling model parameters” ?

## Scaling level 1

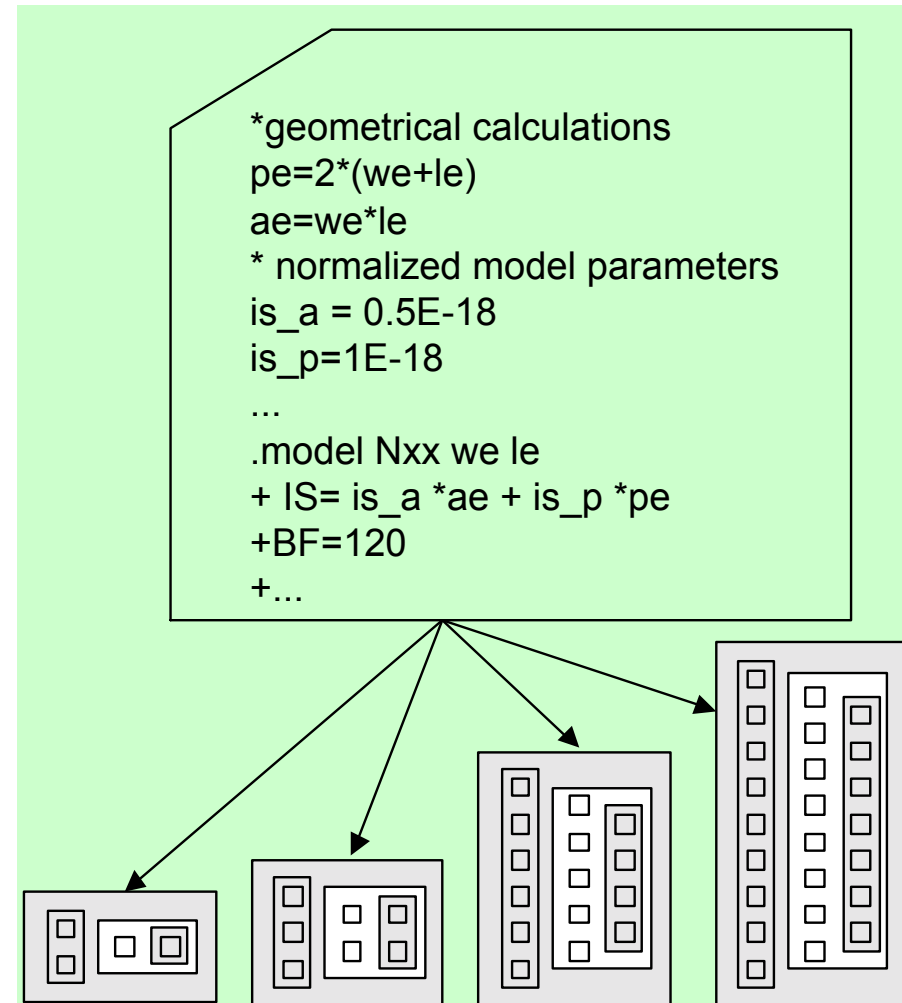
- The scaling equations, the geometrical dimensions and the normalized parameter values are defined in a user specific scaling program.
- Principle: **one** model card for **one** device
- Example: traditional used for BJT modeling



# What is “scaling model parameters” ?

## Scaling level 2

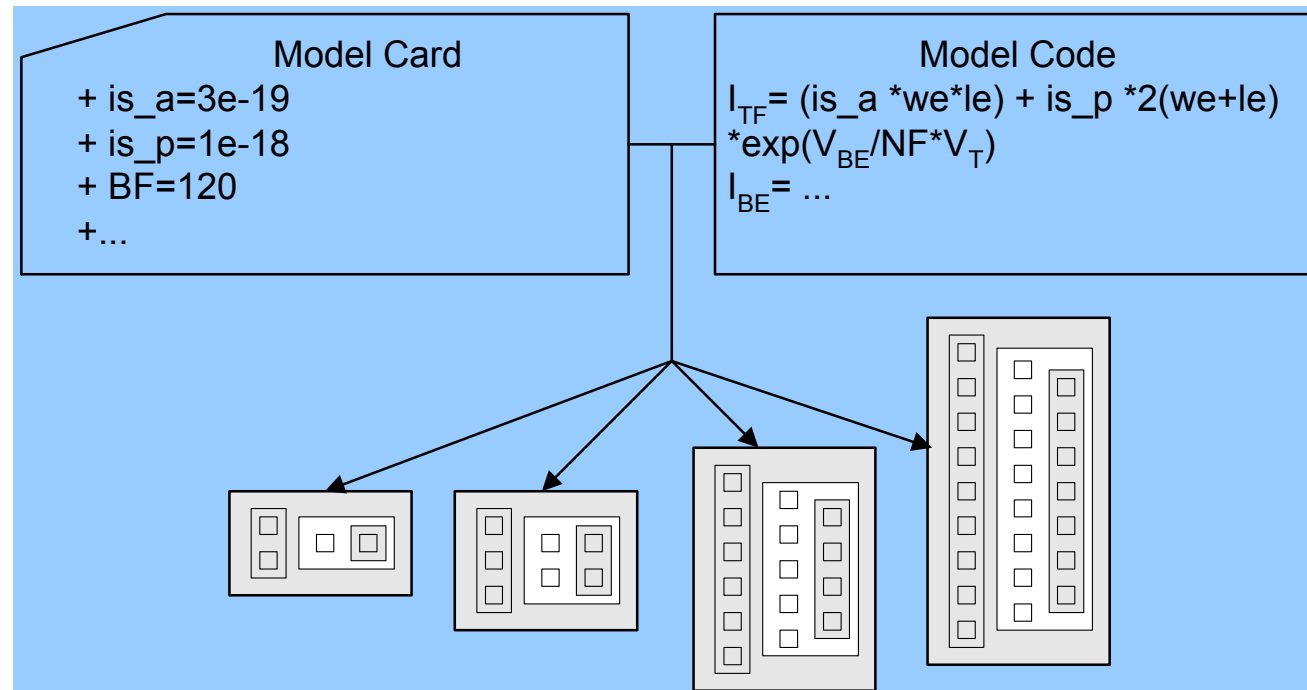
- Scaling equations and normalized parameters are defined on the model card
- The geometrical information (W, L) taken over from the model call in the netlist (e.g. model Nxx we=1.2 le=8.4), additional geometrical calculations realized on the model card
- Principle: **one** model card for **all** devices
- Example: BJT modeling and RF-MOS modeling



# What is “scaling model parameters” ?

## Scaling level 3

- Scaling equations are defined inside the model code
- Normalized parameters delivered by the model card
- Geometrical information (W, L) delivered by the model call
- Principle: **One** model card for **all** devices
- Example: BSIM model and other MOS models



# What is “scaling model parameters” ?

## Scaling level summary

	Scaling Level 1	Scaling Level 2	Scaling Level 3
Scaling equations realized in:	user specific scaling program	Model card	Model CODE
Normalized parameters defined in:	user specific scaling program	Model card (or in an additional file)	Model card
W and L defined in:	user specific scaling program	Model call argument	Model call argument
Other geo values and geo equations defined in:	user specific scaling program	Model card	Model card

# How to improve ICCAP ?

## New tables

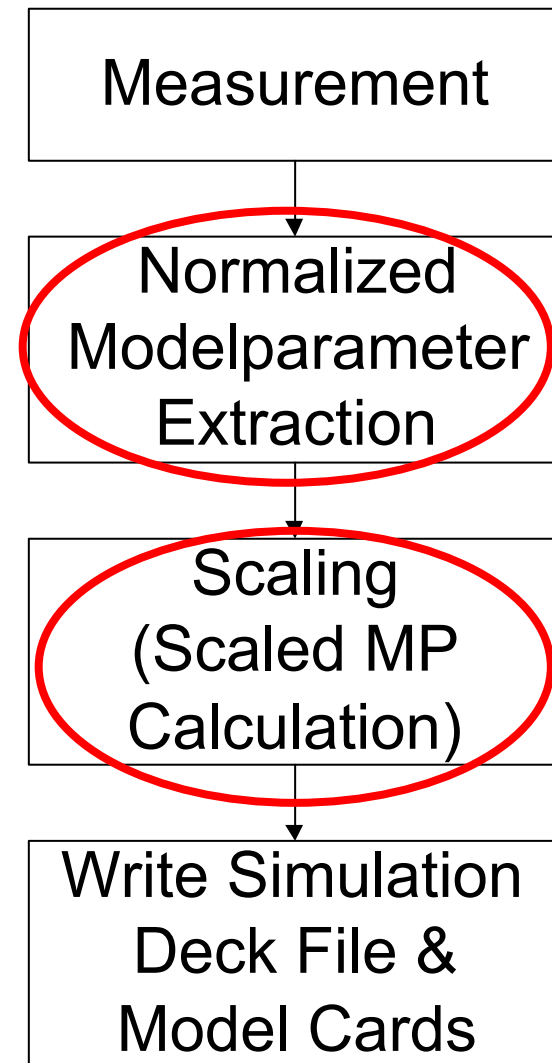
- To support these three different scaling levels in ICCAP we need:

- an extended model parameter table

- a new geometry table and

- a new normalized parameter table

- These new tables will be useful for both the normalization and the scaling step of the procedure



# How to improve ICCAP ?

## Extended model parameter table (1)

Result of a transform, e.g.  $=calc\_ce$

String =calc\_ce Result of an equation, e.g.  $=is\_a*aer+is\_p*per$

Model Parameters Number

	min			main			max		
name	n01	n02	n10	np01	np02	np10	slider		
write 2 file	y	no	no	y	y	y	slider		
q1.area	1	1	1	1	1	1	slider		
ce	1E-15	2E-15	3E-15	4E-15	7E-15	10E-15	slider		
cb	1E-15	2E-15	3E-15	4E-15	7E-15	10E-15	slider		
rcex	80	40	30	20	15	7	slider		
rbex	1000	500	300	200	100	80	slider		
nnp.is	1E-18	2E-18	3E-18	4E-18	7E-18	10E-18	slider		
nnp.bf	230	220	200	198	195	194	slider		

## How to improve ICCAP ?

### Extended model parameter table (2)

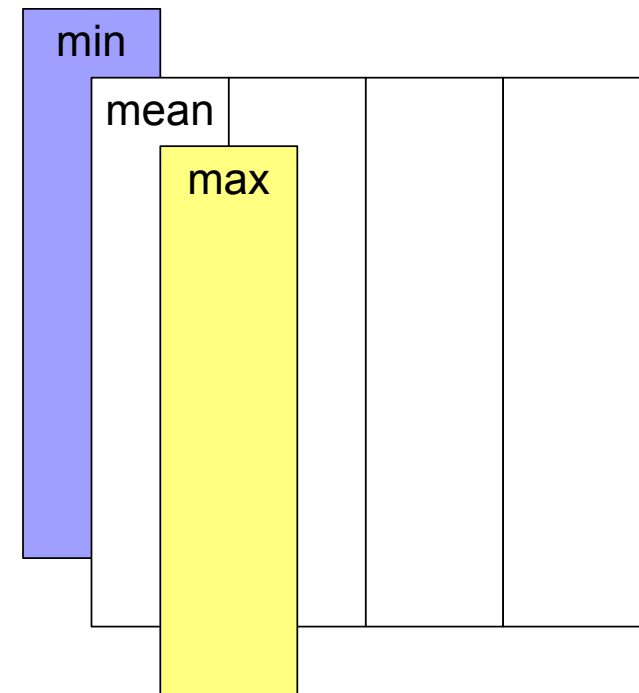
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- One column for each transistor offers the possibility to hold more than one model parameter set at the same time in ICCAP
- This model parameter table will be used to define the scaling equations
- All cells of the model parameter table spread sheet must be able to contain a number, a string, an equation or the result of a transform
- Addressing the cells must be possible using the names, defined in the first column
- Additional model variables are necessary for selection of the parameter set, which will be used for simulation run

# How to improve ICCAP ?

## Extended model parameter table (3)

- An import request is the “Triple table”
- That means, there are two additional tables of the same dimension behind the model parameter table
- These tables may be used for min- and max-value definitions for all model parameters
- This feature is useful e.g. for the definition of optimizer boundaries, for realization of corner models, for fast and slow models etc.
- The min- and max- table may be called on the top by appropriate buttons on the main table



# How to improve ICCAP ?

## New geometry parameter table (1)

Equation or Transform output

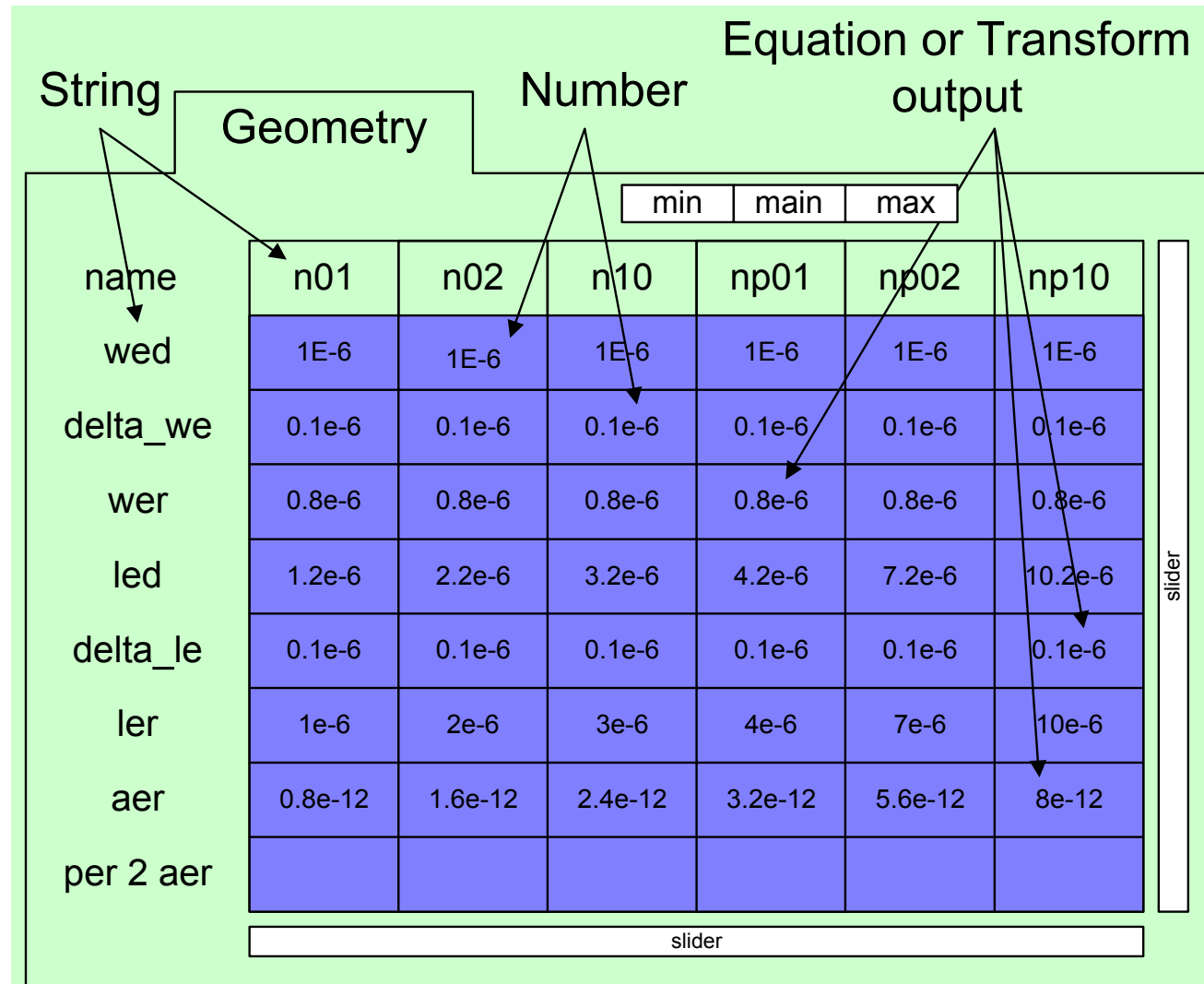
String      Geometry      Number      output

	n01	n02	n10	np01	np02	np10
name						
wed	1E-6	1E-6	1E-6	1E-6	1E-6	1E-6
delta_we	0.1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6
wer	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6
led	1.2e-6	2.2e-6	3.2e-6	4.2e-6	7.2e-6	10.2e-6
delta_le	0.1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6
ler	1e-6	2e-6	3e-6	4e-6	7e-6	10e-6
aer	0.8e-12	1.6e-12	2.4e-12	3.2e-12	5.6e-12	8e-12
per 2 aer						

min    main    max

slider

slider



## How to improve ICCAP ?

### New geometry parameter table (2)

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- Again, all cells of the geometry parameter table must be able to contain a string, a number, an equation or the result of a transform.
- Important: the number of columns, used in the geometry table, defines the number of columns for both the normalized parameter table and the model parameter table
- The calculated geometrical values must be available for calculations in the model parameter table by a column / row index or (better) by the name of the geometrical value, e.g. `wem` for emitter width real
- The geometry table must be designed as a triple table too

# How to improve ICCAP ?

## New normalized parameter table (1)

String      Normalized Parameters      Number      Equation or Transform output

				min	main	max	
name	n01	n02	n10	np01	np02	np10	slider
bf_m	18	18	18	22	22	22	
bf_n	230	178	178	140	140	140	
is_a	5e-19	5e-19	5e-19	5e-19	5e-19	5e-19	
ise_m	5e-15	5e-15	5e-15	5e-15	5e-15	5e-15	
ise_n	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16	
rsbi	4000	4000	4000	4000	4000	4000	
rcex_m	2	2	2	5	5	5	
rcex_n	80	80	80	95	95	95	
							slider

# How to improve ICCAP ?

## New normalized parameter table (2)

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- Number of columns is the same as for the geometry table
- Normalized parameter table must be a spread sheet too, because for different device groups or for single devices different normalized parameters may be necessary
- The cells must be simply available for calculations in the model parameter table by a column / row index or (better) by the name of the normalized parameter, e.g. is\_a for the normalized area component of the saturation current
- All cells of the normalized parameter table spread sheet must be able to contain a string, number, an equation or the result of a transform
- The normalized parameter table must be designed as a triple table

# How to improve ICCAP ?

## General requirements for all new tables

- All new tables must be designed as a spreadsheet
- All three new tables must have the same dimensions
- The number of columns for all tables is defined by the geometry table
- Access to the cells must be possible by row / column index and / or by row / column names
- All cells must be able to contain a string, number, an equation or the result of a transform
- Triple table design is requested to save e.g. min, mean and max values
- The plot program must be able to plot any data in the tables against each other (same size provided)

Result of a transform, e.g. =calc\_ce

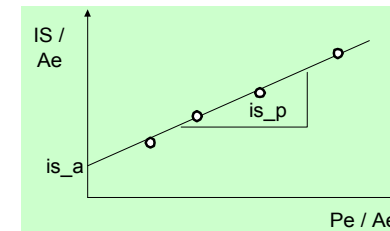
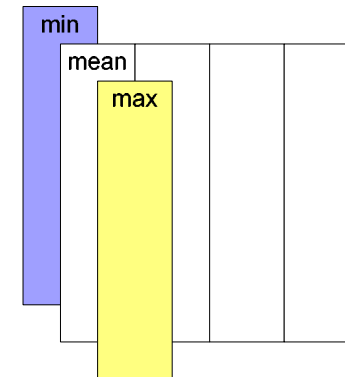
String

Model Parameters

Number

Result of an equation, e.g. =is\_a\*aer+is\_p\*per

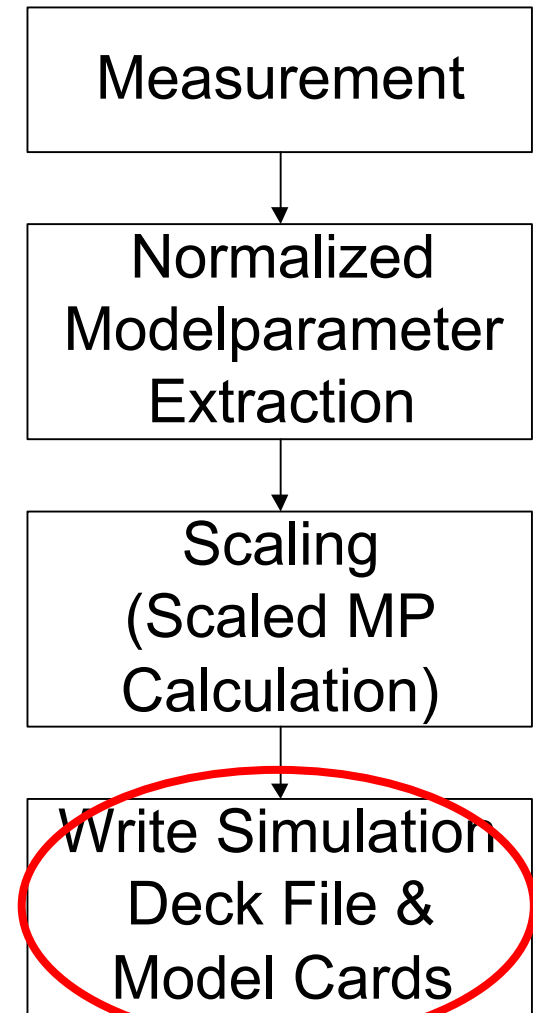
name	n0*	n02	n10	np01	np02	np10
write 2 file	y	no	no	y	y	y
q1.area	1	1	1	1	1	1
ce	1E-15	2E-15	3E-15	4E-15	7E-15	10E-15
cb	1E-15	2E-15	3E-15	4E-15	7E-15	10E-15
rcex	80	40	30	20	15	7
rbex	1000	500	300	200	100	80
npr.is	1E-18	2E-18	3E-18	4E-18	7E-18	10E-18
npr.bf	230	220	200	198	195	194



# How to improve ICCAP ?

## Requirements for creating the models cards

- The model cards must be created using a transform, including header, parameter section and subcircuit definition
- For writing the model cards it must be possible:
  1. to select a subset of transistors for writing, using a switch on the model parameter table
  2. to change the letter case (main.is -> MAIN.IS)
  3. to format the numbers (2.3122e-13 -> 2.3e-13)
  4. to change the notation. A new model variable "Use\_exponential\_notation" is necessary to avoid problems reading the prefixes m, M,  $\mu$  etc. in the scs-file by spectre



# How to improve ICCAP ?

## Summary

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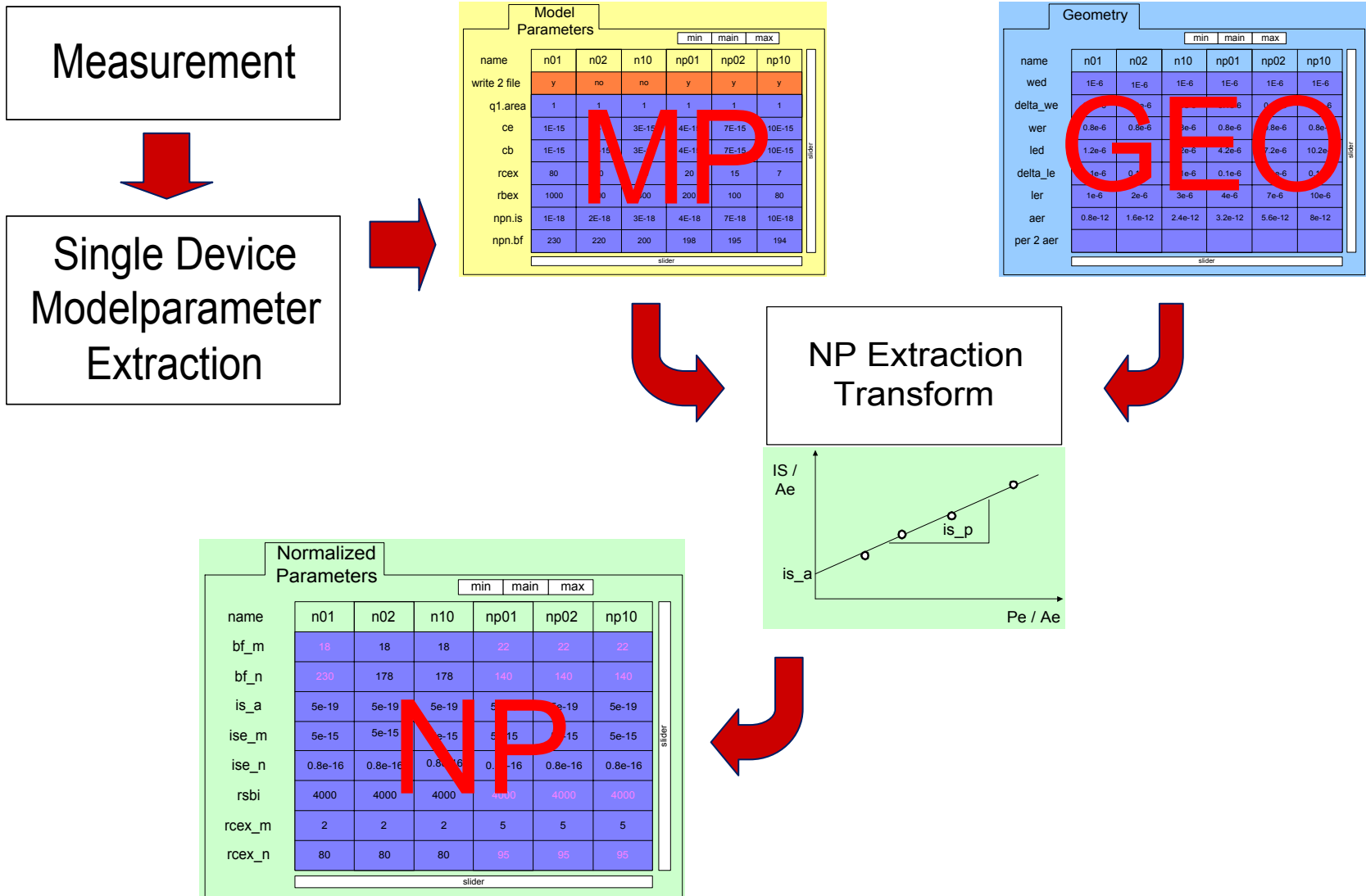
- Some definitions are made for the scaling problem discussion: “Normalized parameters”, “Scaling model parameters”
- We defined three different “Scaling Levels”

1. ICCAP’s ability for creating scaled model parameters may be improved by introduction of three new tables: a geometry , normalized parameter and an extended model parameter table.

1. This will result in a better support of the following tasks for all three scaling levels:
- a) Analyzing measured data to find out scaling equations,
  - b) Definition of geometrical transistor dimensions,
  - c) Extraction of normalized parameters,
  - d) Calculation of scaled model parameters and
  - e) Creating the model cards.

# Appendix: How to use the new tables ?

## Normalized Parameter Extraction (1)



# Appendix: How to use the new tables ?

## Normalized Parameter Extraction (2)

Measurement



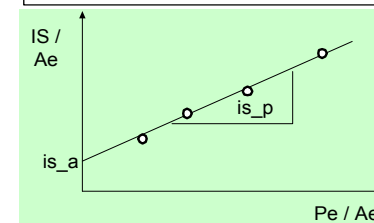
Measurement Normalization

Geometry

	min	main	max			
name	n01	n02	n10	np01	np02	np10
wed	1E-6	1E-6	1E-6	1E-6	1E-6	1E-6
delta_we	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6
wer	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6
led	1.2e-6	1.2e-6	1.2e-6	4.2e-6	7.2e-6	10.2e-6
delta_le	1e-6	0.1e-6	1e-6	0.1e-6	0.1e-6	0.1e-6
ler	1e-6	2e-6	3e-6	4e-6	7e-6	10e-6
aer	0.8e-12	1.6e-12	2.4e-12	3.2e-12	5.6e-12	8e-12
per 2 aer						



NP Extraction Transform



Normalized Parameters

	min	main	max			
name	n01	n02	n10	np01	np02	np10
bf_m	18	18	18	22	22	22
bf_n	230	178	178	140	140	140
is_a	5e-19	5e-19	5e-19	5e-19	5e-19	5e-19
ise_m	5e-15	5e-15	5e-15	5e-15	5e-15	5e-15
ise_n	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16
rsbi	4000	4000	4000	4000	4000	4000
rcex_m	2	2	2	5	5	5
rcex_n	80	80	80	95	95	95

# Appendix: How to use the new tables ?

## Model Parameter Scaling (Level 1)

Geometry						
	min	main	max			
name	n01	n02	n10	np01	np02	np10
wed	1E-6	1E-6	1E-6	1E-6	1E-6	1E-6
delta_we	0.1e-6	1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6
wer	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6
led	1.2e-6	3.2e-6	4.2e-6	7.2e-6	2e-6	
delta_le	0.1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6	
ler	1e-6	2e-6	3e-6	4e-6	7e-6	10e-6
aer	0.8e-12	1.6e-12	2.4e-12	3.2e-12	5.6e-12	8e-12
per 2 aer						

**GEO**

Normalized Parameters						
	min	main	max			
name	n01	n02	n10	np01	np02	np10
bf_m	18	18	18	22	22	22
bf_n	230	1	178	22	22	140
is_a	5e-19	5e-19	5e-19	5e-19	5e-19	5e-19
ise_m	5e-15	5e-15	5e-15	5e-15	5e-15	5e-15
ise_n	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16
rsbi	4000	4000	4000	4000	4000	4000
rcex_m	2	2	2	5	5	5
rcex_n	80	80	80	95	95	95

**NP**



$$IS = is\_a * Ae + is\_p * Pe$$



Model Parameters						
	min	main	max			
name	n01	n02	n10	np01	np02	np10
write 2 file	y	no	no	y	y	y
q1.area	1	1	1	1	1	1
ce	1E-15	2E-15	3E-15	15	10E-15	
cb	1E-15	2E-15	3E-15	15	7E-15	
rcex	80	40	30	0	7	
rbex	1000	50	10	0	100	80
npn.is	1E-18	2E-18	3E-18	4E-18	7E-18	10E-18
npn.bf	230	220	200	198	195	194

**MP**

Simulation & NP Correction

Write Simulation Deck File with one model card for one device

# Appendix: How to use the new tables ?

## Model Parameter Scaling (Level 2)

Geometry						
	min	main	max			
name	n01	n02	n10	np01	np02	np10
wed	1E-6	1E-6	1E-6	1E-6	1E-6	1E-6
delta_we	0.1e-6	1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6
wer	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6
led	1.2e-6	3.2e-6	4.2e-6	7.2e-6	2e-6	
delta_le	0.1e-6	0.1e-6	0.1e-6	0.1e-6	0.1e-6	
ler	1e-6	2e-6	3e-6	4e-6	7e-6	10e-6
aer	0.8e-12	1.6e-12	2.4e-12	3.2e-12	5.6e-12	8e-12
per 2 aer						

**GEO**

Normalized Parameters						
	min	main	max			
name	n01	n02	n10	np01	np02	np10
bf_m	18	18	18	22	22	22
bf_n	230	1	178	22	22	140
is_a	5e-19	5e-19	5e-19	5e-19	5e-19	5e-19
ise_m	5e-15	5e-15	5e-15	5e-15	5e-15	5e-15
ise_n	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16	0.8e-16
rsbi	4000	4000	4000	4000	4000	4000
rcex_m	2	2	2	5	5	5
rcex_n	80	80	80	95	95	95

**NP**



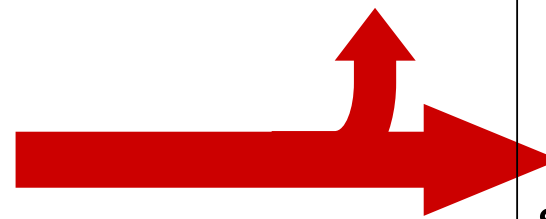
$$IS = is\_a * Ae + is\_p * Pe$$

Simulation & NP Correction



Model Parameters						
	min	main	max			
name	n01	n02	n10	np01	np02	np10
write 2 file	y	no	no	y	y	y
q1.area	1	1	1	1	1	1
ce	1E-15	2E-15	3E-15	15	10E-15	
cb	1E-15	2E-15	3E-15	15	7E-15	
rcex	80	40	30	0	7	
rbex	1000	50	10	0	100	80
npn.is	1E-18	2E-18	3E-18	4E-18	7E-18	10E-18
npn.bf	230	220	200	198	195	194

**MP**



Write Simulation Deck File with scaling equations