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

by
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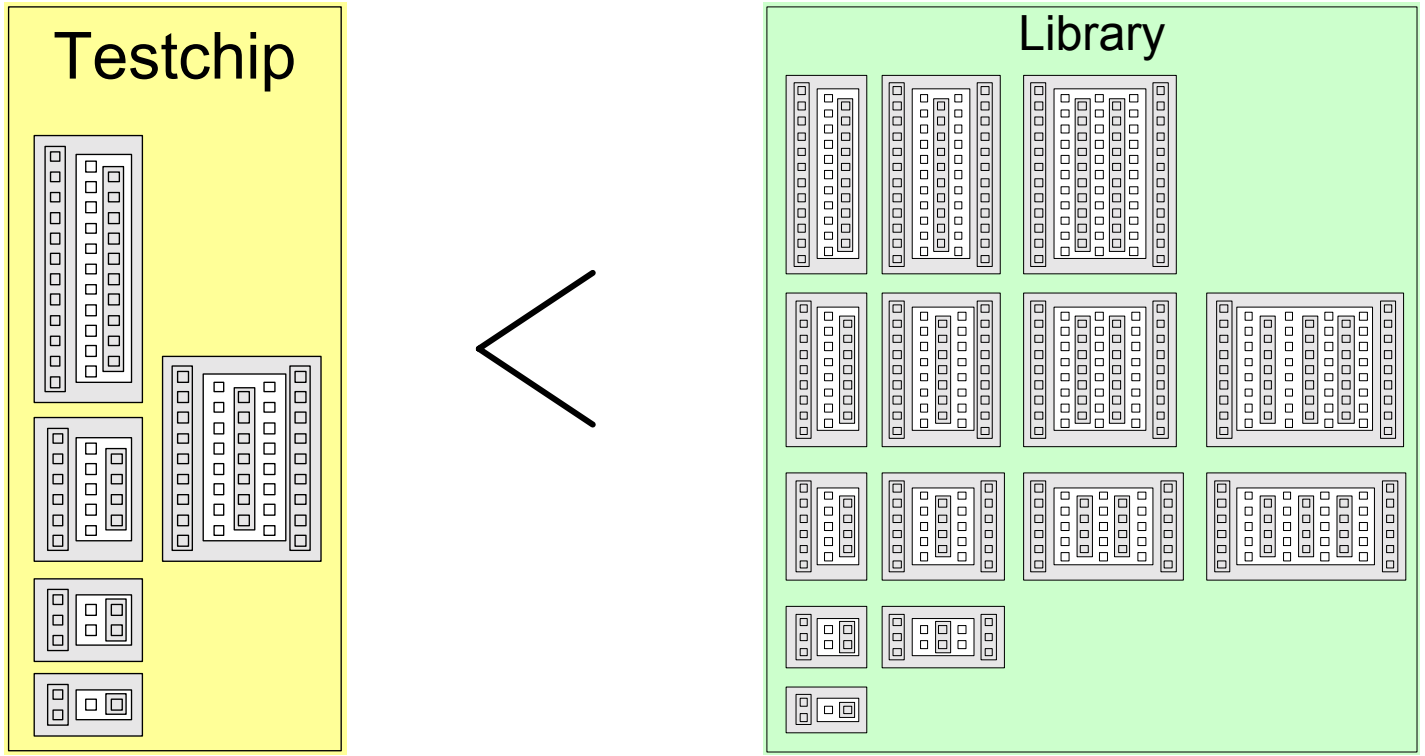
Why model parameter scaling ?
Testchip devices vs. Library devices

- 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



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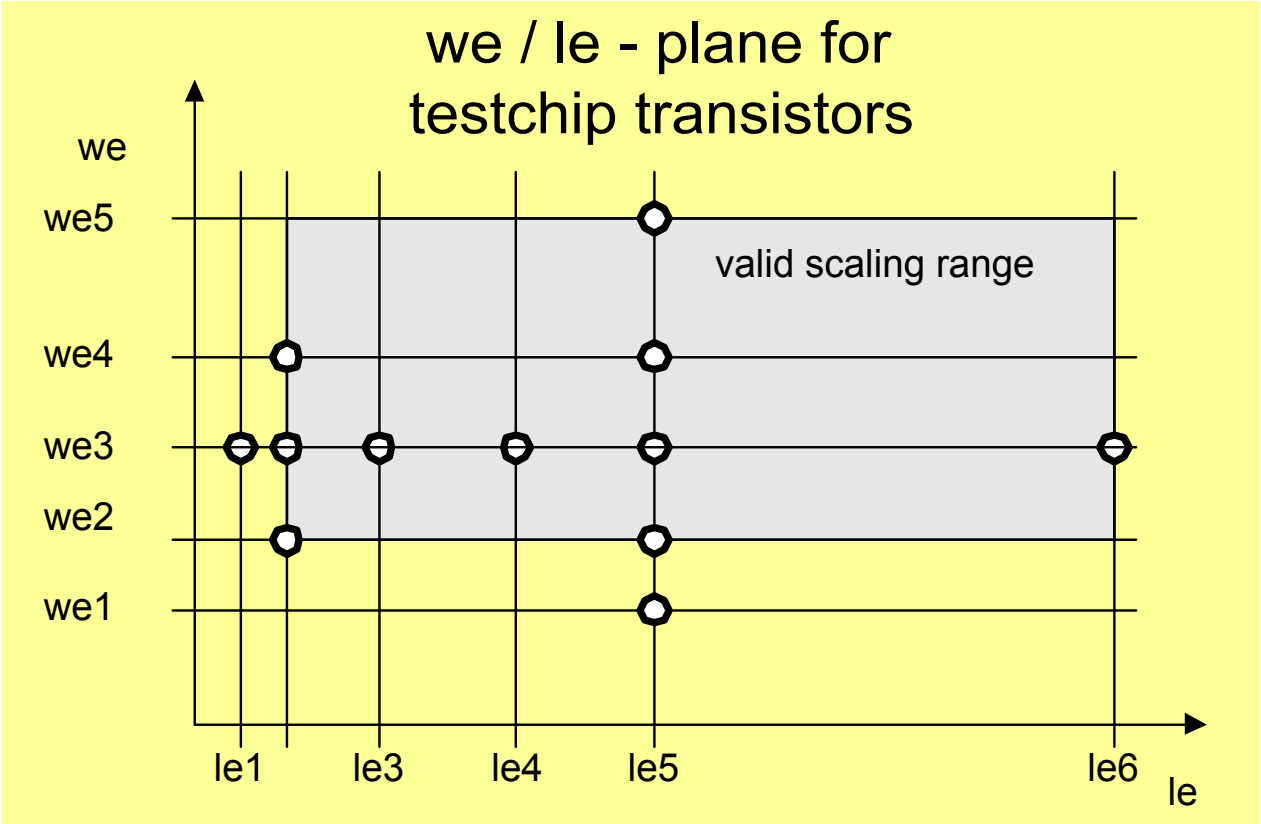
Why model parameter scaling ?
Testchip devices in the we / le plane

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



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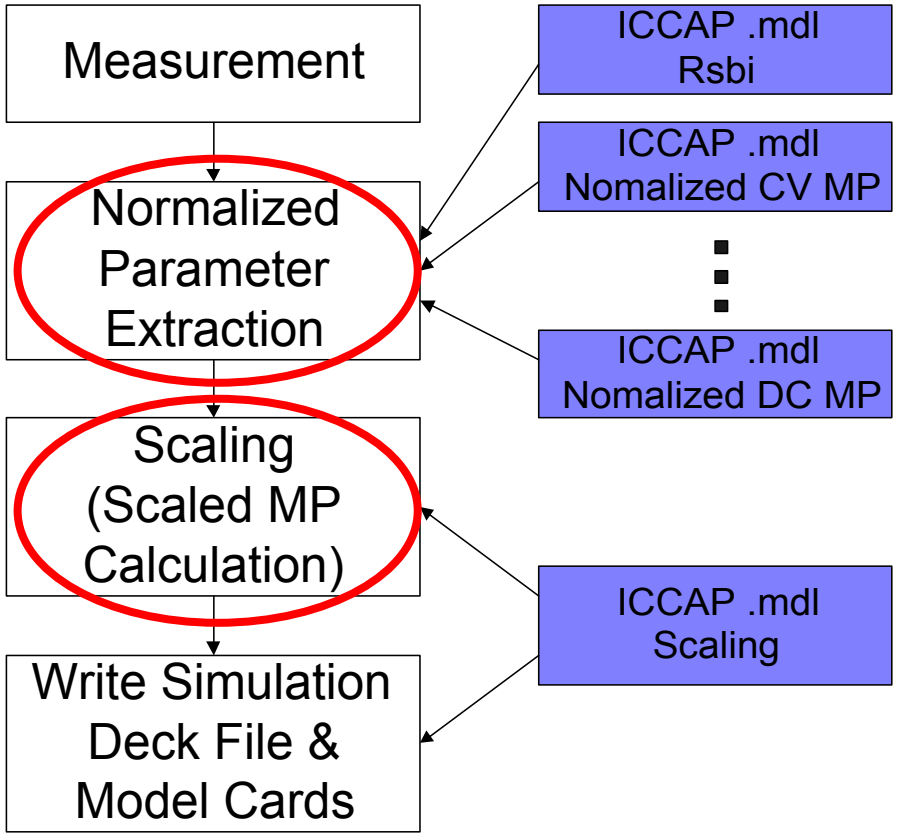
What is "scaling model parameters" ? General Flow

- 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



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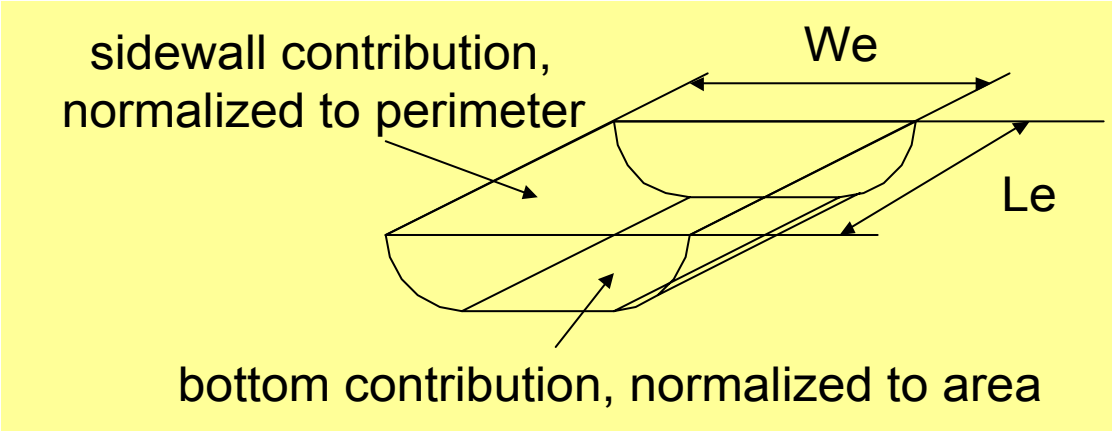
What is "scaling model parameters" ?
Example for extraction of normalized parameters (1)

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

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

  with $Ae = We * Le$, $Pe = 2*(We+Le)$

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



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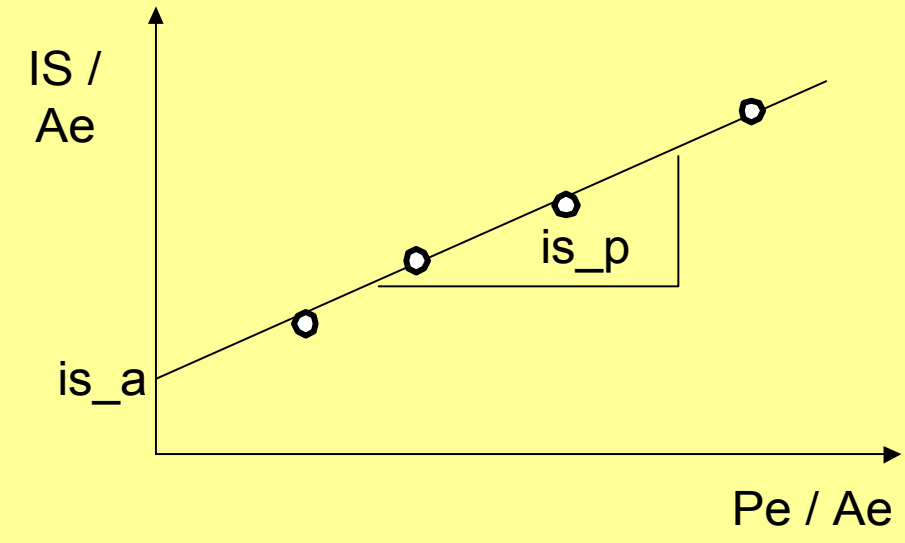
What is "scaling model parameters" ?
Example for extraction of normalized parameters (2)

- 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 / um2)
- 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

- 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

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What is “scaling model parameters” ?
Scaling levels

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

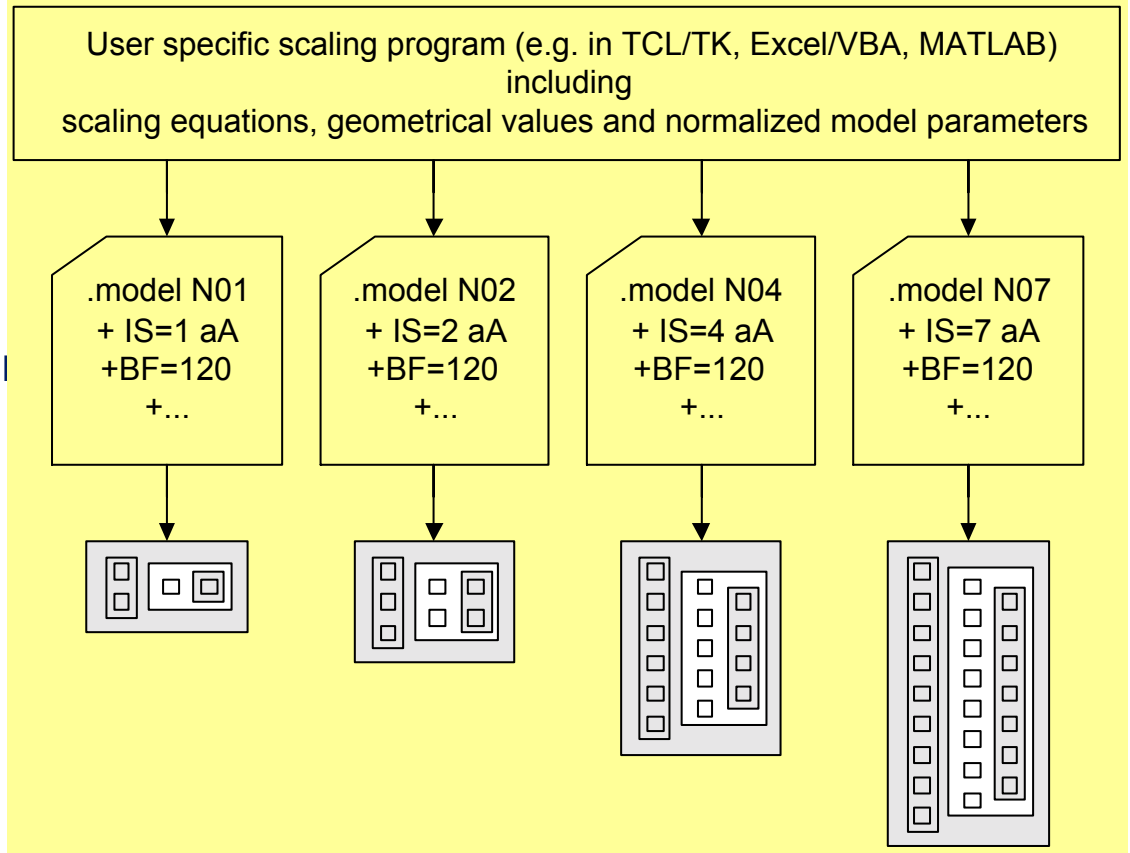
- **Scaling level 1**:
  scaling equations defined in a user specific scaling-program

- **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



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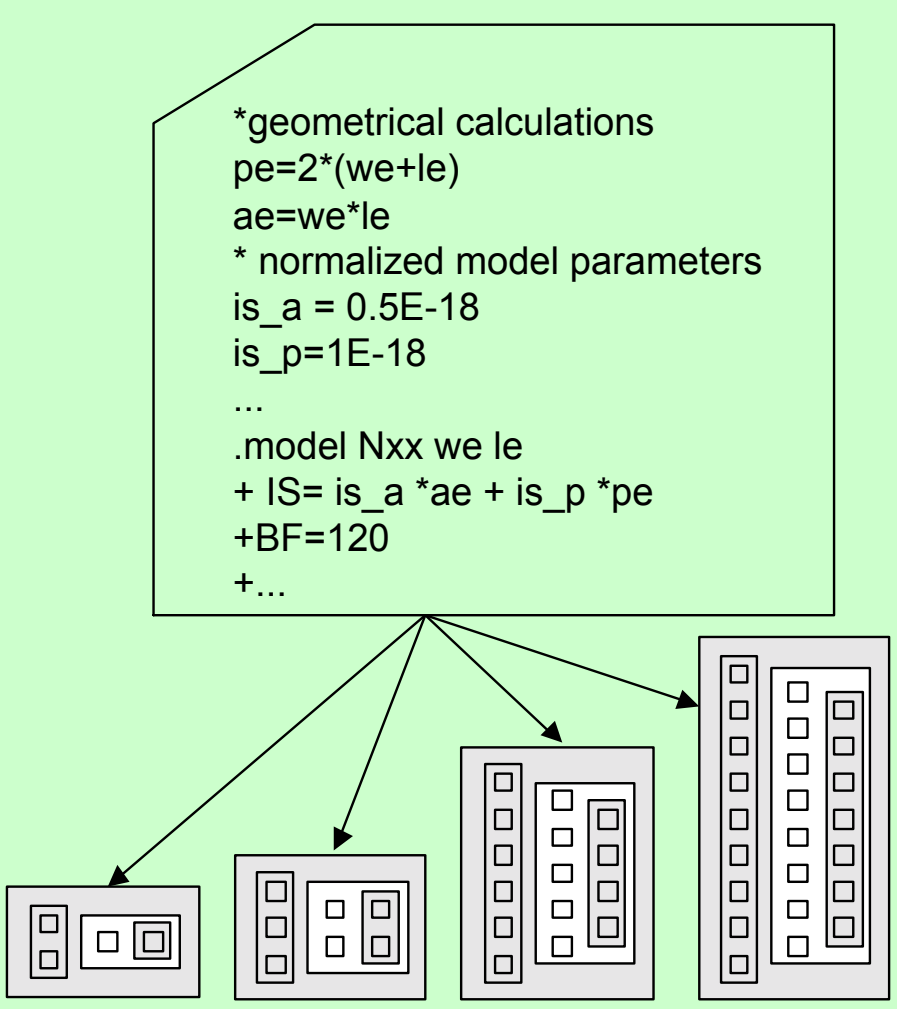
What is “scaling model parameters” ?
Scaling level 2

- 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 cal-culations realized on the model card
- Principle:
  one model card
  for **all** devices
- Example: BJT modeling and RF-MOS modeling



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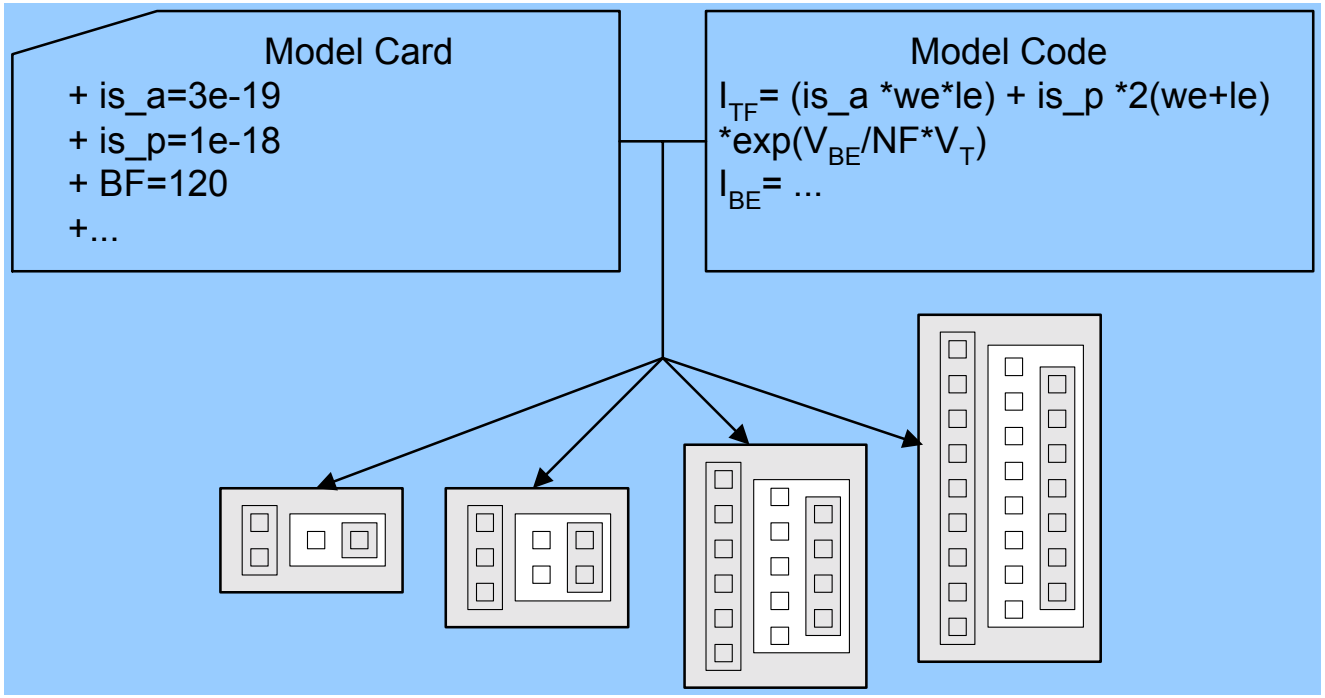
What is “scaling model parameters” ?
Scaling level 3

- 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

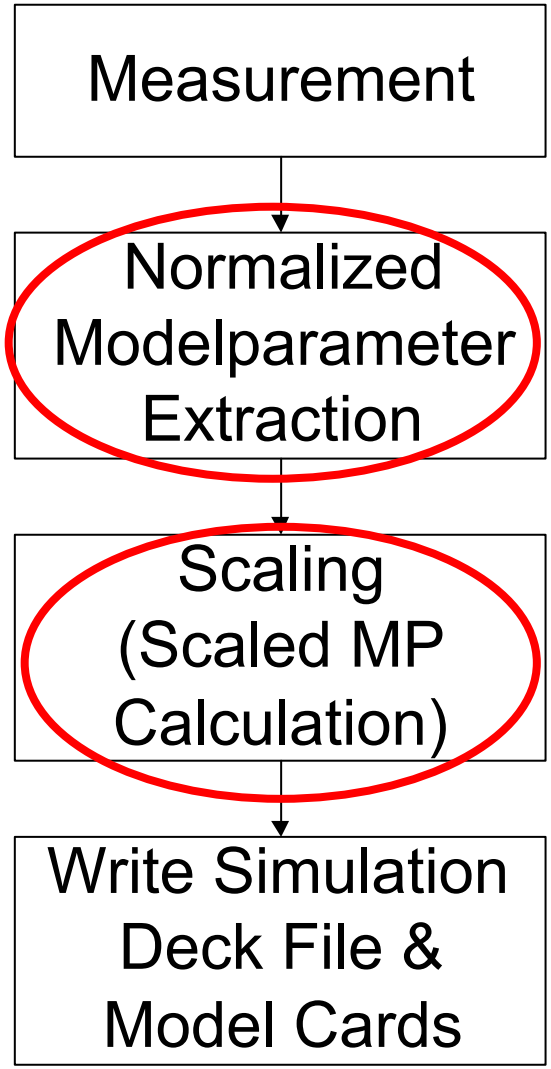


What is “scaling model parameters” ?
Scaling level summary

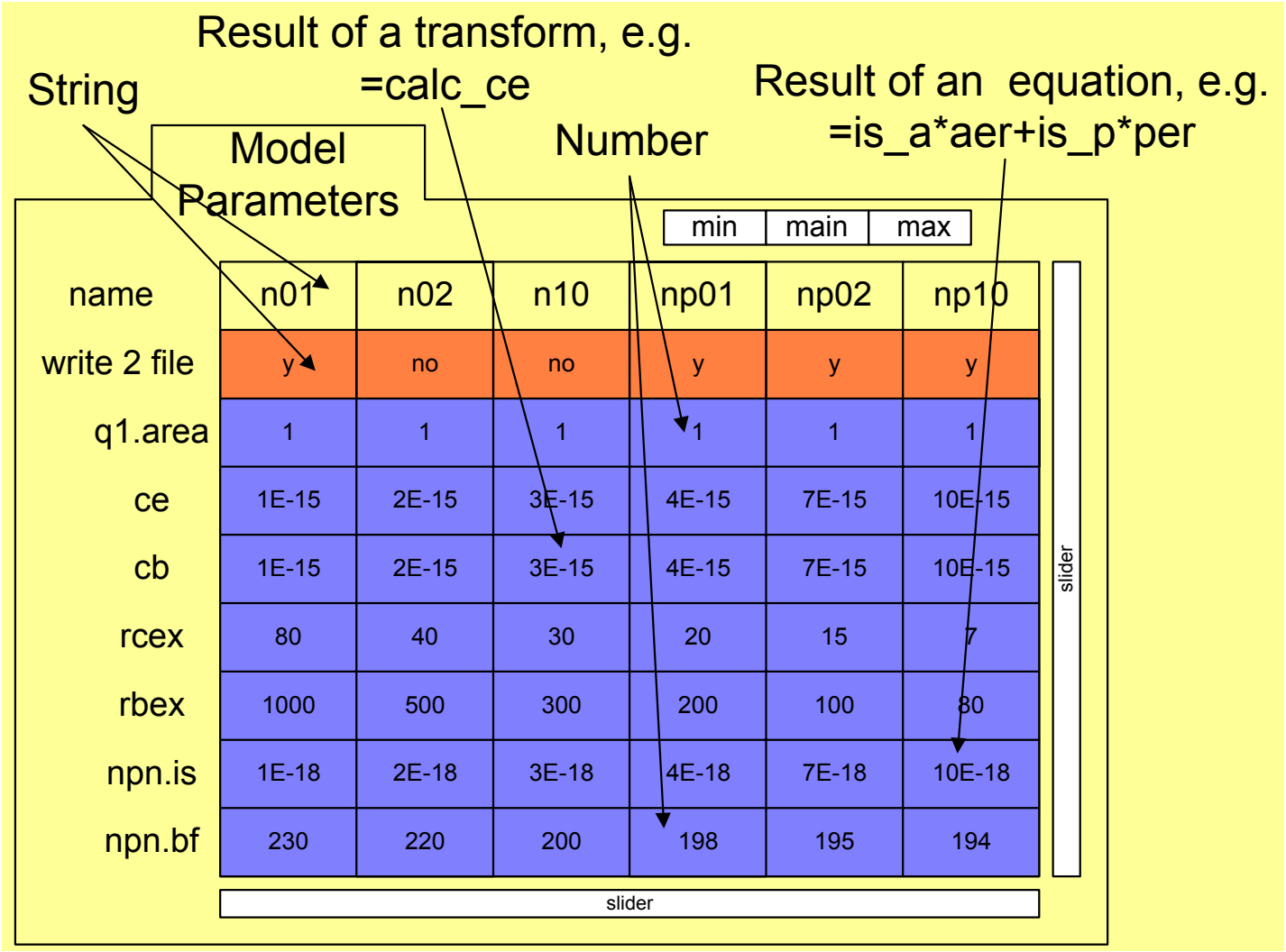
	Scaling Level 1	Scaling Level 2	Scaling Level 3
Scaling equations realized in:	user specific scaling program	Model card	Model CODE
Normalized parameters defined in:	user specific scaling program	Model card (or in an additional file)	Model card
W and L defined in:	user specific scaling program	Model call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

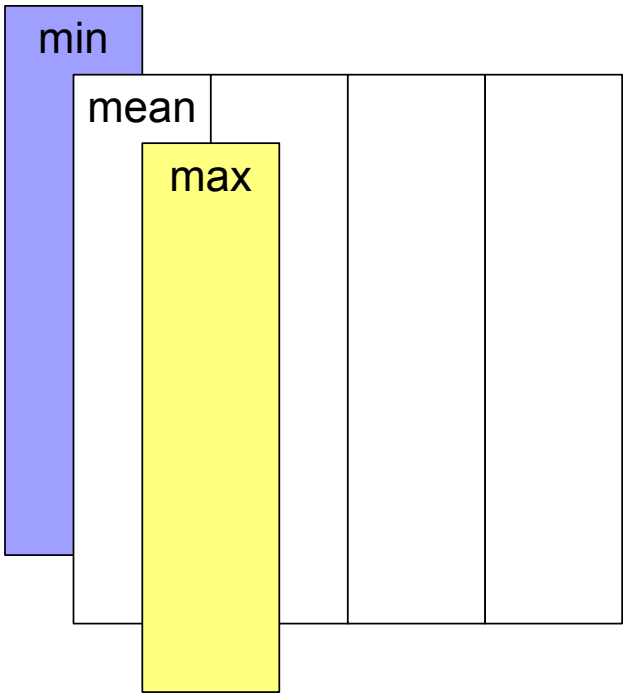


How to improve ICCAP ?
Extended model parameter table (2)

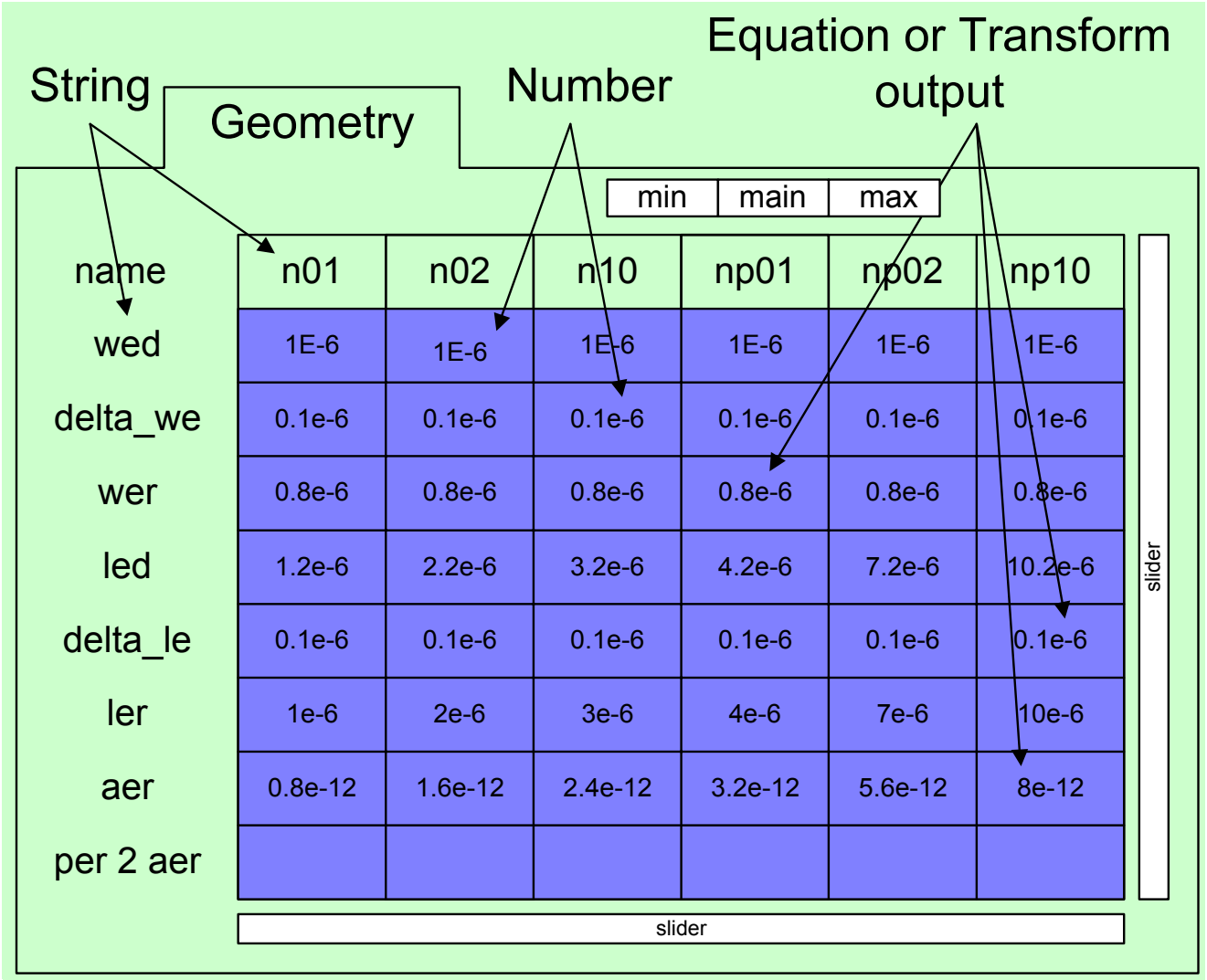
- One column for each transistor offers the possibility to hold more than one model parameter set at the same time in ICCAP
- This model parameter table will be used to define the scaling equations
- All cells of the model parameter table spread sheet must be able to contain a number, a string, an equation 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



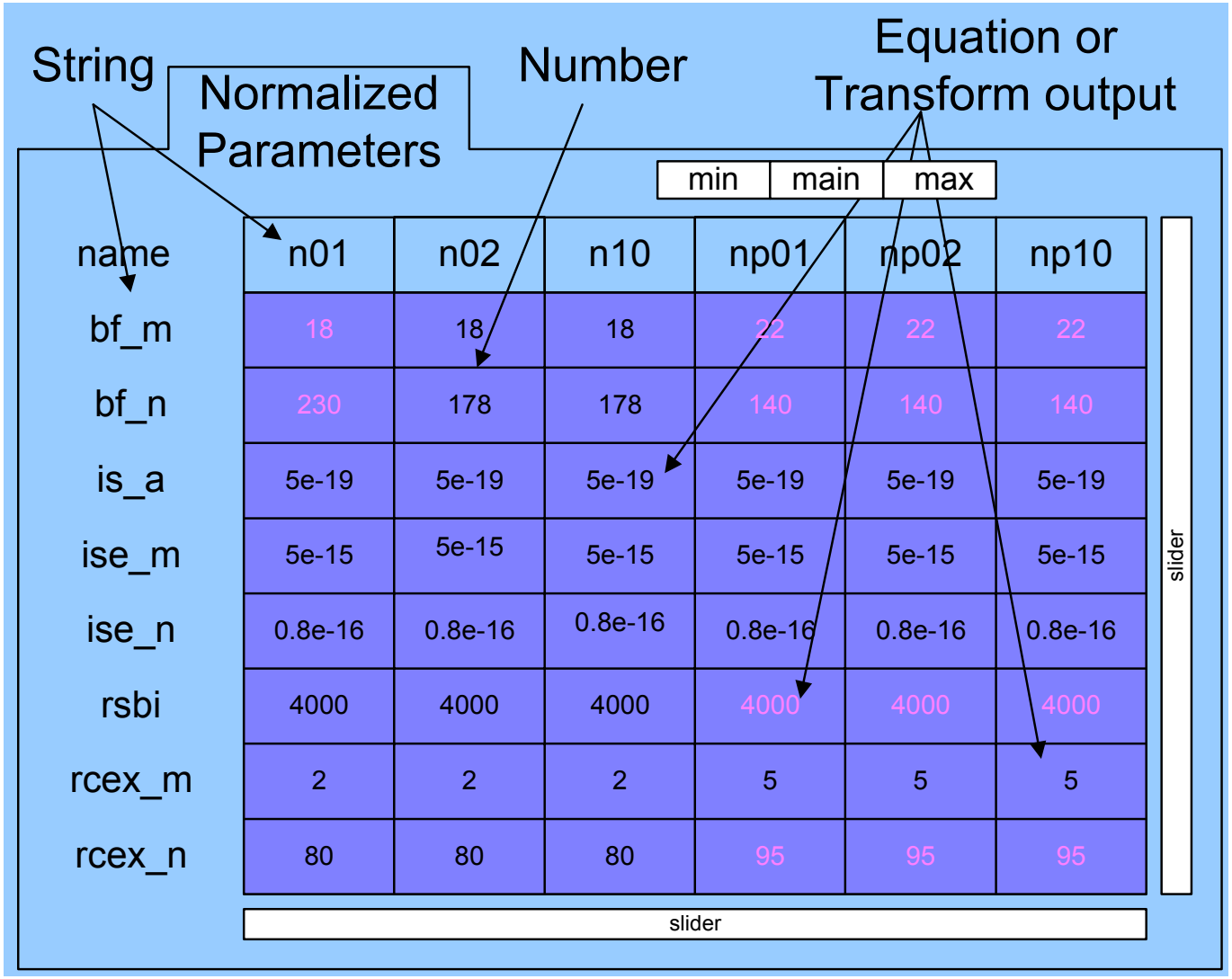
How to improve ICCAP ?
New geometry parameter table (1)



How to improve ICCAP ?
New geometry parameter table (2)

- 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. wer for emitter width real
- The geometry table must be designed as a triple table too

How to improve ICCAP ?
New normalized parameter table (1)



How to improve ICCAP ?
New normalized parameter table (2)

- 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

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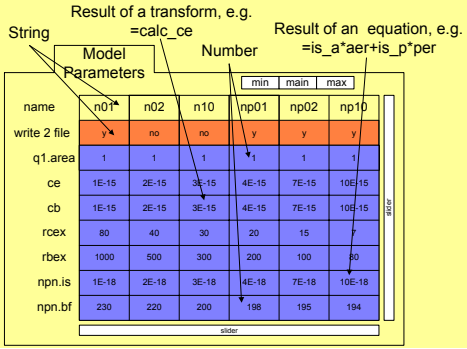
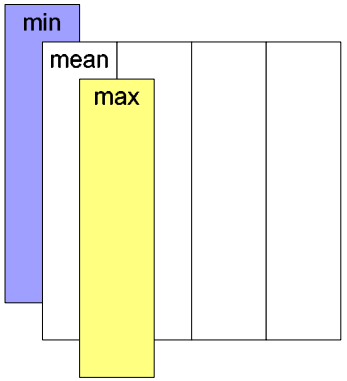
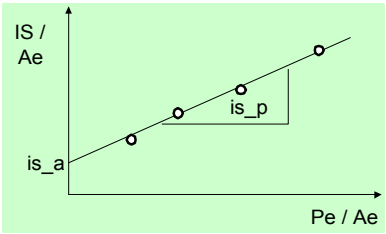
How to improve ICCAP ?
General requirements for all new tables

- 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)







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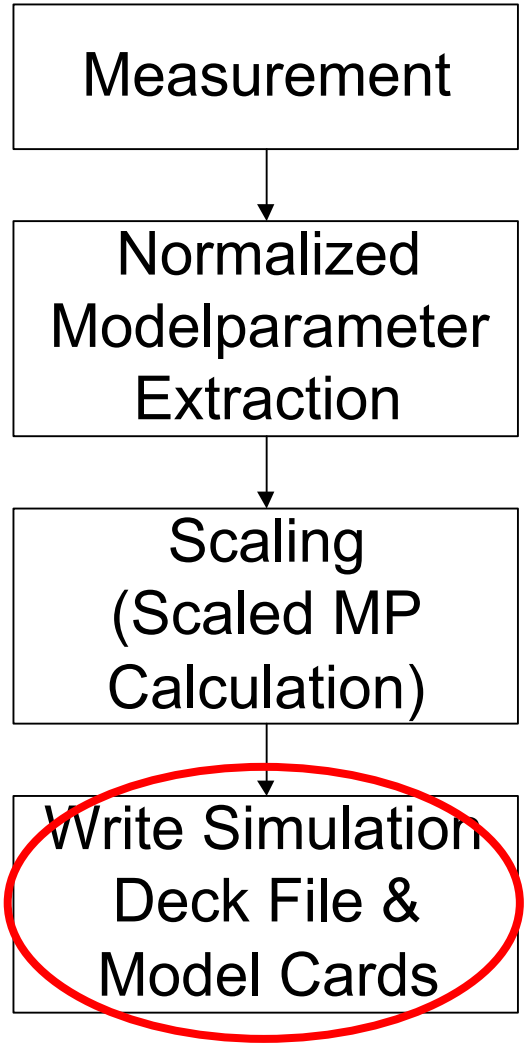
How to improve ICCAP ?
Requirements for creating the models cards

- 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, µ etc. in the scs-file by spectre



How to improve ICCAP ?
Summary

- 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)

Measurement

Single Device Modelparameter Extraction

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		3E-15	4E-15	7E-15	10E-15
cb	1E-15		3E-	4E-15	7E-15	10E-15
rcex	80			20	15	7
rbex	1000		200	200	100	80
npn.is	1E-18	2E-18	3E-18	4E-18	7E-18	10E-18
npn.bf	230	220	200	198	195	194

slider

MP

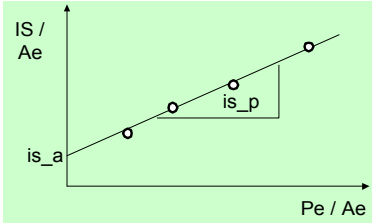
Geometry

	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						
wer	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6	0.8e-6
led	1.2e-6			4.2e-6	7.2e-6	10.2e-6
delta_le				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						

slider

GEO

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	5	e-19	5e-19
ise_m	5e-15	5e-15	e-15	5	15	5e-15
ise_n	0.8e-16	0.8e-16	0.8	0.	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

NP

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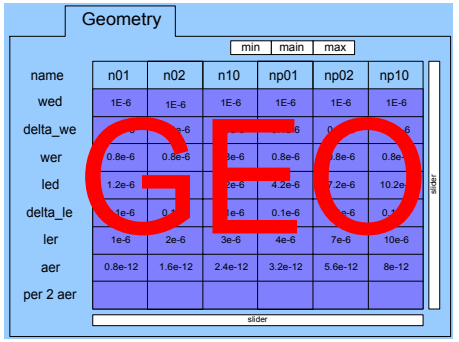
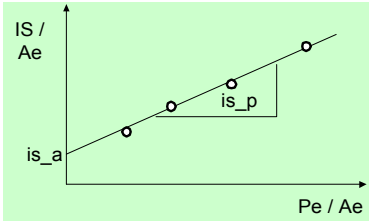
Appendix: How to use the new tables ?
Normalized Parameter Extraction (2)

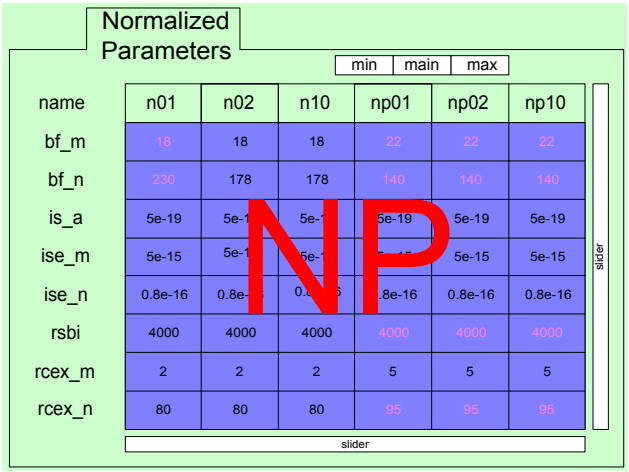
Measurement

Measurement Normalization

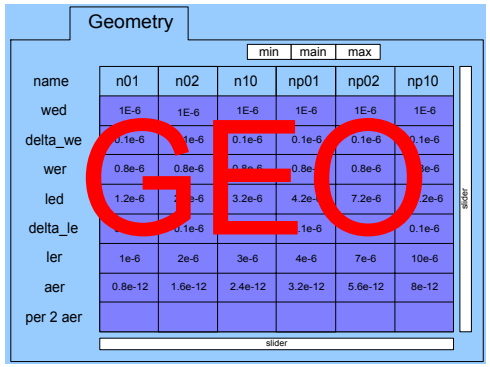


NP Extraction Transform





Appendix: How to use the new tables ?
Model Parameter Scaling (Level 1)



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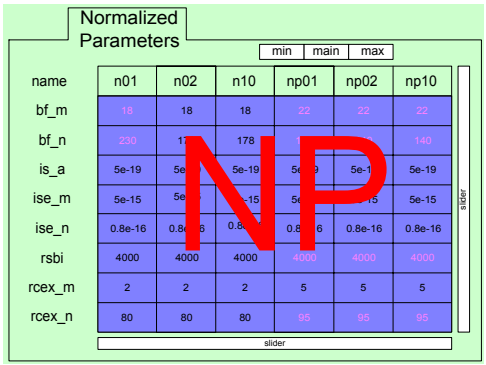
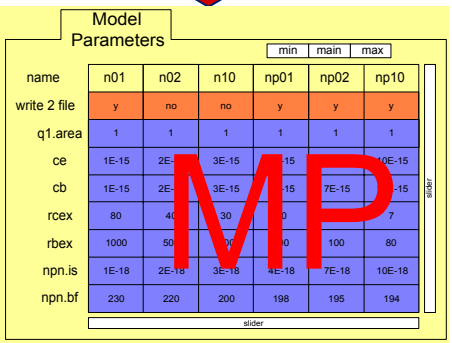


NP

IS = is_a * Ae + is_p *Pe



MP

Simulation
&
NP
Correction

Write Simulation Deck File with one model card for one device

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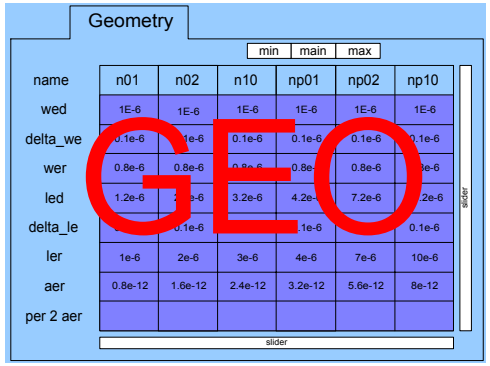
Appendix: How to use the new tables ?
Model Parameter Scaling (Level 2)



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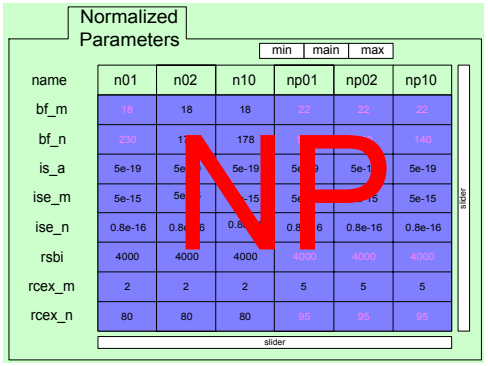

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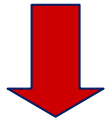
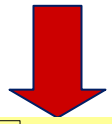
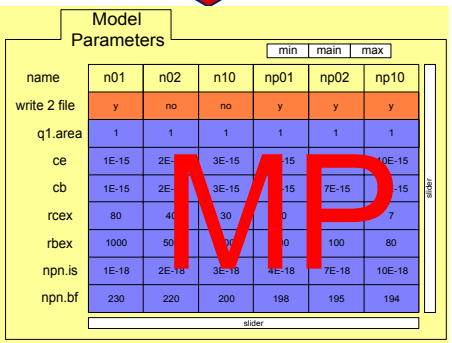


IS = is_a * Ae + is_p *Pe

Simulation
&
NP
Correction





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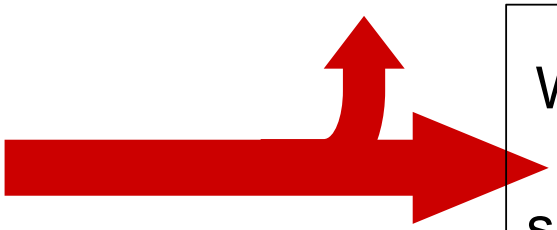

Write Simulation
Deck File with
scaling equations

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