On the correlations between model process parameters in statistical modeling

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Goal of the contribution

- to propose a simple method to establish mathematical relationships among correlated process and geometry-dependent model parameters (PGPs).
- The method needs to conform to syntax-based restrictions that have to be fulfilled in complex model libraries.

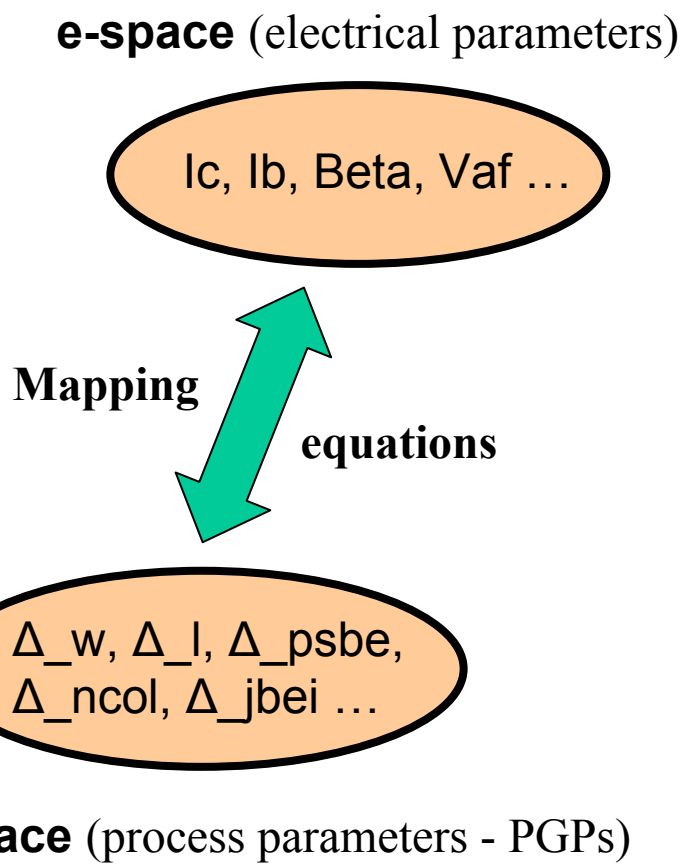
1. Statistical modeling

Results are applied to

- carry out sensitivity analysis in a particular design,
- generate case libraries for corner modeling,
- run Monte Carlo simulations,
- perform design centering and yield optimization with respect to natural process variations (using other tools – MunEDA, NeoLinear etc.).

2. Modeling flow for a *SINGLE DEVICE*

- Measured parameters evaluated from process control (PC) tests – e.g. Vth, Isat, Beta etc.
- Evaluated means $\mu(e_i)$ and standard deviations $s(e_i)$ of the electrical parameters e_i (often correlated) form an input e-space (i denotes i-th electrical parameter).
- There is a unique relationship between the e-space and the space of uncorrelated model process parameters p_j (p-space), where j denotes j-th process parameter.



2. Modeling flow for a *SINGLE DEVICE*

- This relationship is defined by mapping equations.
- Means $\mu(p_j)$ and standard deviations $s(p_j)$ of PGPs evaluated by Backward Propagation of Variance (BPV) [1,2,3].
- Precise modeling of the distributions of input e-parameters guaranteed.

Note that

- the resulting sets of $\mu(p_j)$ and $s(p_j)$ are obtained for *each device separately* and
- for a *single* device the obtained PGPs are *uncorrelated*.

REFERENCES

[1] C.C.McAndrew, J.Bates, R.T.Ida and P. Drennan, IEEE BCTM 1.2 (1997), p.28-31

[2] C.C.McAndrew, Proceedings ISQED'03 (2003)

[3] W.F.Davis, R.T.Ida, Proc. IEEE BCTM (1989), p. 262-265

3. Modeling flow for a *SET OF RELATED DEVICES*

The PGPs of all devices cannot be treated as independent. For instance:

- The epitaxial layer forms the base of substrate PNPs, lateral PNPs and the collector of vertical NPNs.
- Variations in gate oxide thickness affect the n- and p-type MOSFETs and also some capacitors.
- A mask defining a BJT emitter has an impact on several different types of BJTs.
- etc.

Necessity to introduce a correlation among related devices, i.e. among related sets of PGPs.

3. Modeling flow for a *SET OF RELATED DEVICES*

Let's have random variables
$x_i = \mathrm{N}(\mu_i, s_i^2)$ →

$$y = (x_i - \mu_i)/s_i$$

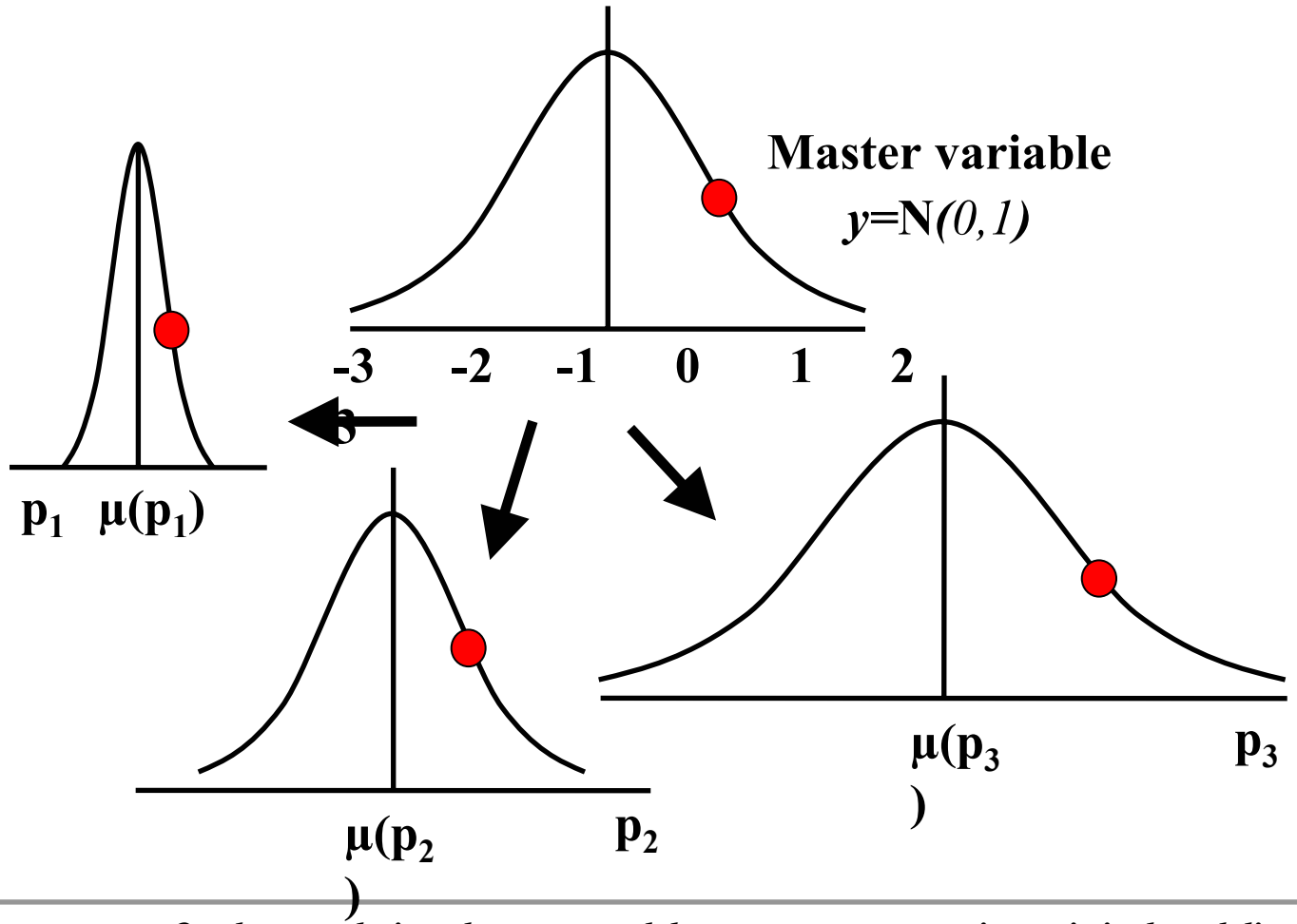
has a normalized
Gaussian distribution
$y = \mathrm{N}(0,1)$.

Let's have a **"master"** variable y with
normalized Gaussian distribution
$y = \mathrm{N}(0,1)$ →
Then *y-dependent* random variables

$$x_i = y^* s_i + \mu_i$$

with *specific* distributions $x_i = \mathrm{N}(\mu_i, s_i^2)$
can be generated.

3. Modeling flow for a *SET OF RELATED DEVICES*

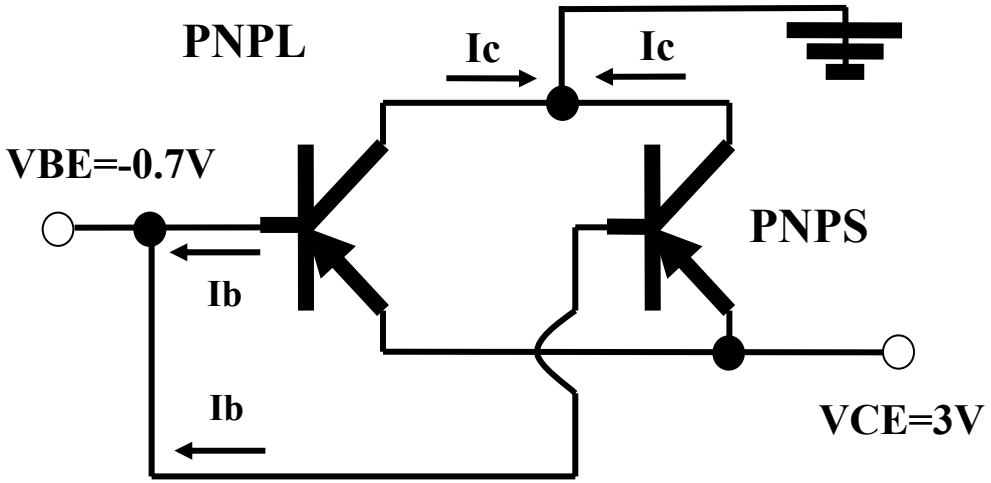


4. Simulation and results

As an example a substrate PNPS and a lateral PNPL were selected:

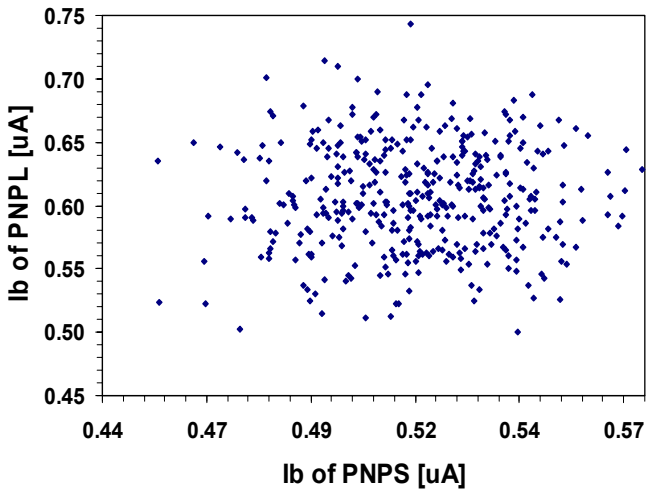
- Their base is the epitaxial layer.
- The emitters of both devices and the collector of PNPL are formed by the same mask and implant.

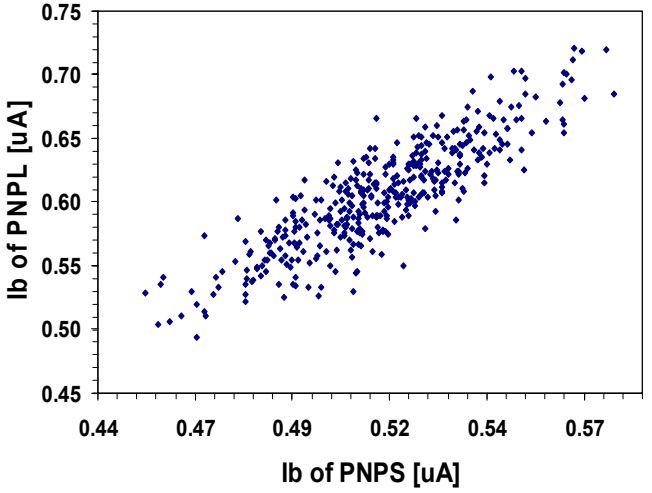
→ The correlation was introduced by means of the proposed transform.



4. Simulation and results

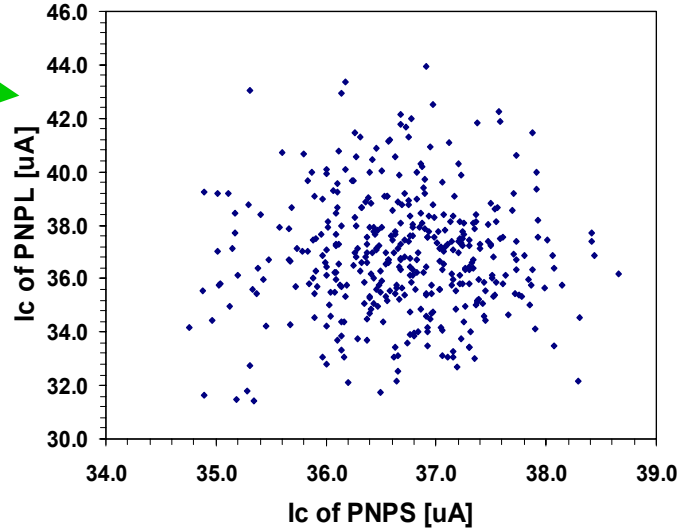
Simulated collector and base currents of PNPS and PNPL with **uncorrelated PGPs** (Monte Carlo).

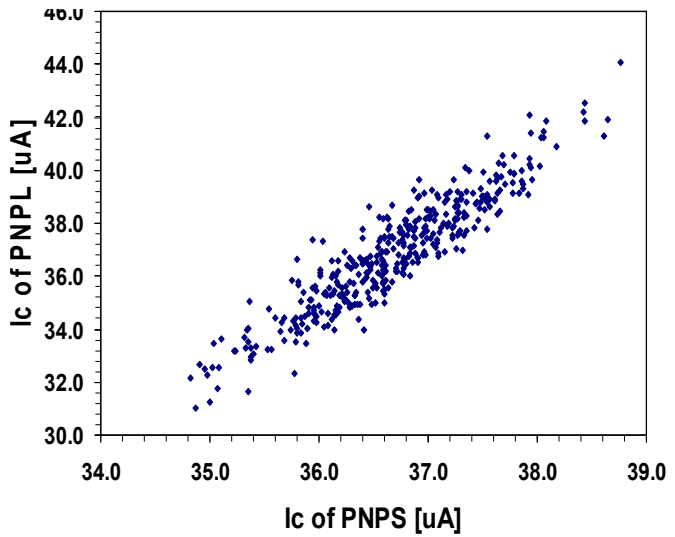




Simulated collector and base currents of PNPS and PNPL with **correlated PGPs** (Monte Carlo).

Too pessimistic modeling





Realistic modeling

Conclusions

- A straightforward transform was proposed and its impact on a design demonstrated.
- The implementation of correlations in the set of PGPs enabled realistic modeling. Random situations with a low probability of occurrence were eliminated.
- A design does not need excessive robustness.
- A new product is more competitive due to shorter development time and chip size reduction.