LV MOS Model for Circuit Surfer

Arbeitskreis MOS-Modelle und Parameterextraktion Crolles, May 2003

Wolfgang Kraus

wolfgang.kraus@hno.atmel.com

Atmel Germany

Contents

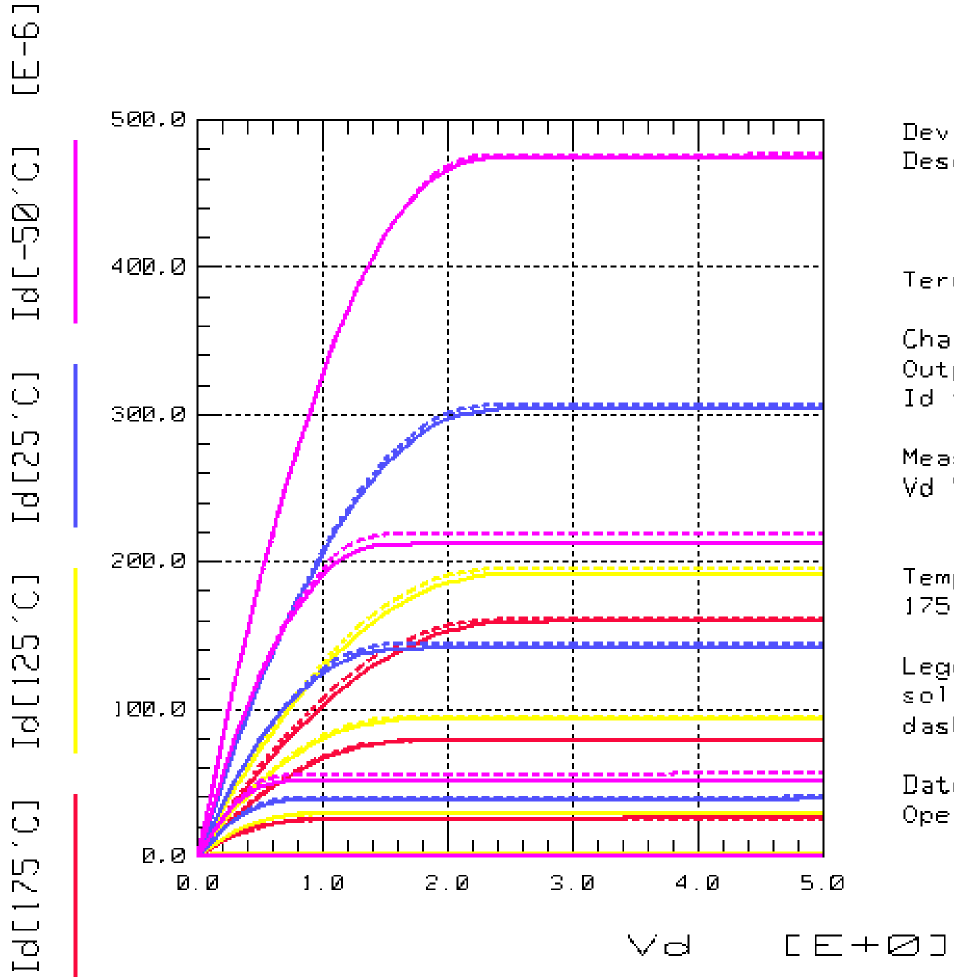
- Motivation
- Typical case model
- Construction of corner models
- Principal Component Analysis on corner models
- Final statistical MOS model
- Conclusions
- References

Motivation

Background information :
Circuit Surfer is a Tcl/Tk application between schematic entry and simulator to run statistical simulations for yield estimation/improvement.
Characterization service offered by the creator PDF/SOLUTIONS.

Objectives :

- Can we create suitable models by our own?
- Test a method to create statistical models early in process life cycle



Device: NMOS
Description: Medium voltage
N-channel enhancement
MOSFET
W = 40 um L = 40 um
Terminals: d g s b nb hw

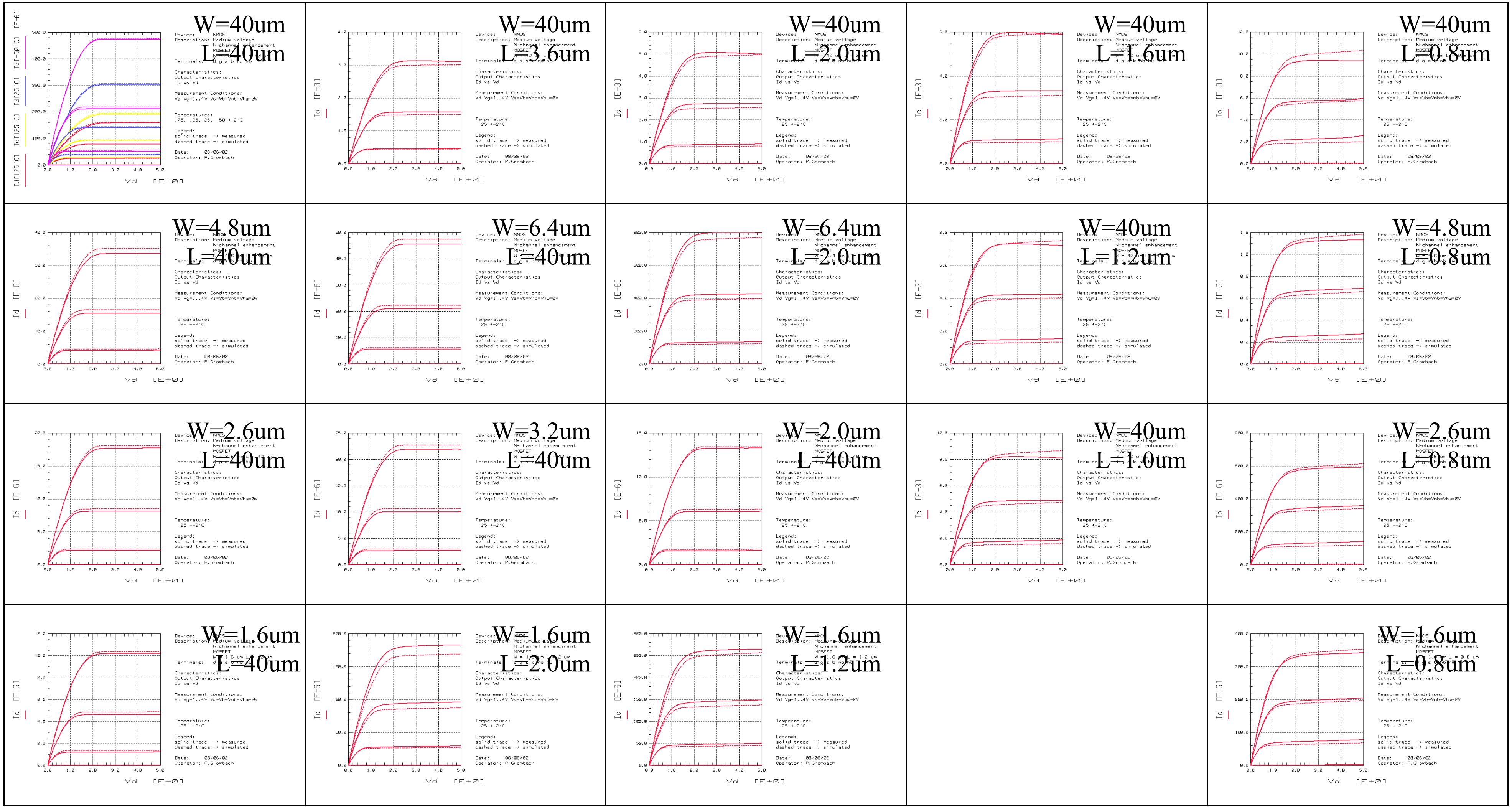
Characteristics:
Output Characteristics
Id vs Vd

Measurement Conditions:
Vd Vg=1..4V Vs=Vb=Vnb=Vhw=0V

Temperatures:
175, 125, 25, -50 +-2'C

Legend:
solid trace -> measured
dashed trace -> simulated

Date: 06/06/02
Operator: P.Grombach


W=40um
L=40um
W=40um
L=3.6um
W=40um
L=2.0um
W=40um
L=1.6um
W=40um
L=0.8um
W=4.8um
L=40um
W=6.4um
L=40um
W=6.4um
L=2.0um
W=40um
L=1.2um
W=4.8um
L=0.8um
W=2.6um
L=40um
W=3.2um
L=40um
W=2.0um
L=40um
W=40um
L=1.0um
W=2.6um
L=0.8um
W=1.6um
L=40um
W=1.6um
L=2.0um
W=1.6um
L=1.2um
W=1.6um
L=0.8um

```
simulator lang=spectre
// * Technology:         Smart-I.S.1
// * Maskset:            25201
// * Lot:                N08817
// * Wafer:              07
// * Device Description: Medium voltage (5V) N-channel enhancement MOSFET
// * Simulator:          SPECTRE v4.4.6.011302
// *************************************************************
// * $RCSfile: mnem11.sts,v $
// * $Date: 2002/08/09 09:31:41 $
// * $Revision: 1.1 $
// * $Name:  $
// *************************************************************
subckt MNEM11 d g s b nb hw
parameters  L=0 W=0
xm d g s b nb hw macro w_ex=W l_ex=L
subckt macro subd subg subs subb subnb subhw
parameters                                            \
w_ex  = 0          l_ex   = 0                               \
mn1 subd subg subs subb ekvnmos w=w_ex l=l_ex
model ekvnmos ekv                                           \
type  = n               update      = 2.6       tnom  = 25  \
tox   = 16.5n + tox_skew      xj    = 193n                        \
vto   = 0.9+vtn_skew                                        \
.
.
.

gamma = 0.845                phi   = 0.6       kp    = 122u      \
pb    = 736m                 pbsw  = 208m            pbswg = 800m      \
tlev  = 0               tlevc       = 0        xqc = 0.4
ends macro
ends MNEM11
```

Construction of corner models

- small dataset of 1st E-test data on Vth and Idsat used
- construct 6 process corners [1]
- modify selected parameters of typical model to match process corners
- TOX set to process spec limits
  VTO, KP, WETA, LETA, DL, DW modified
- result : 7 models for each device, 15 parameters modified
- result : 7X15 statistical data matrix

Construction of corner models

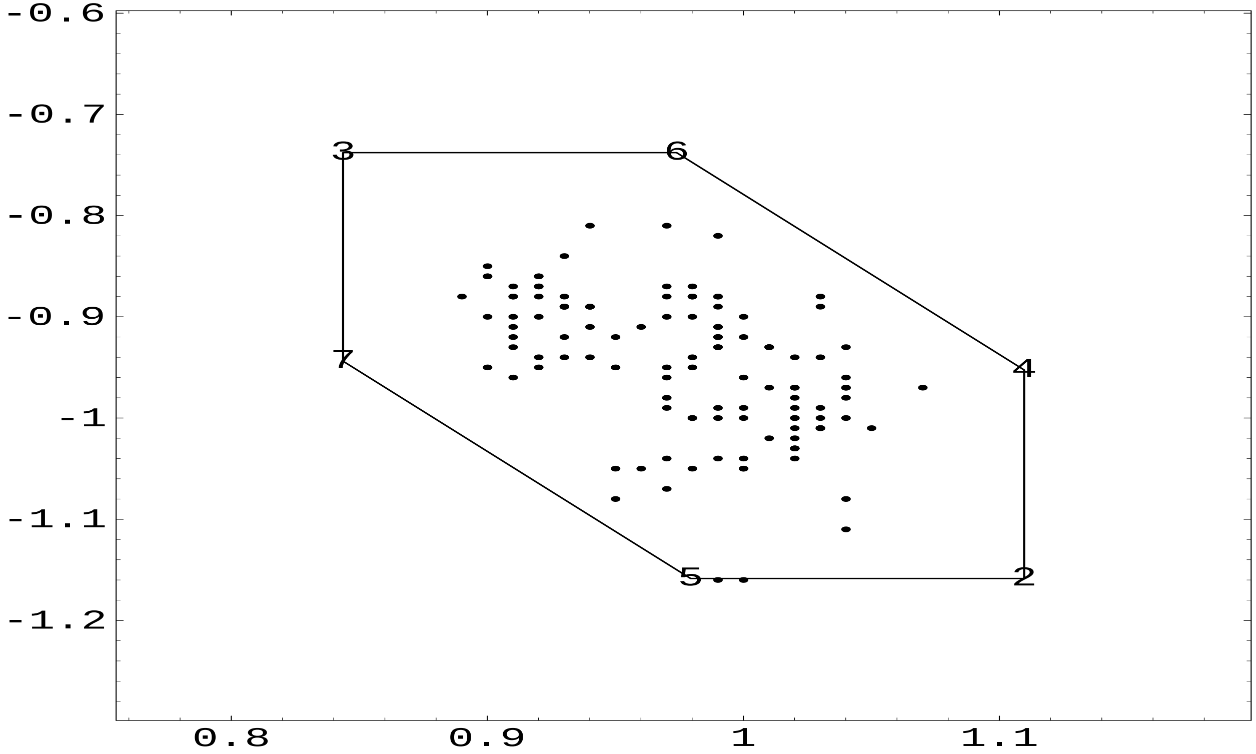


Figure 1: Threshold voltage of PMOS vs NMOS, w/l=1.6/0.8

Construction of corner models

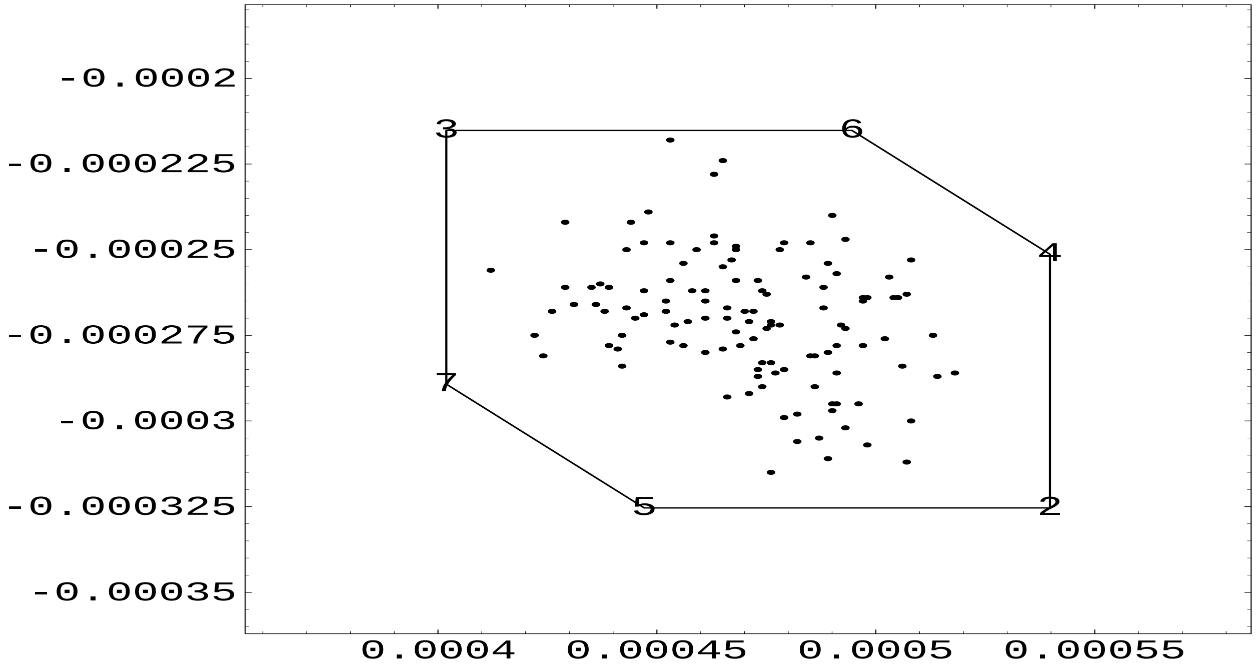


Figure 2: saturation current of PMOS vs NMOS, w/l=1.6/0.8

Construction of corner models

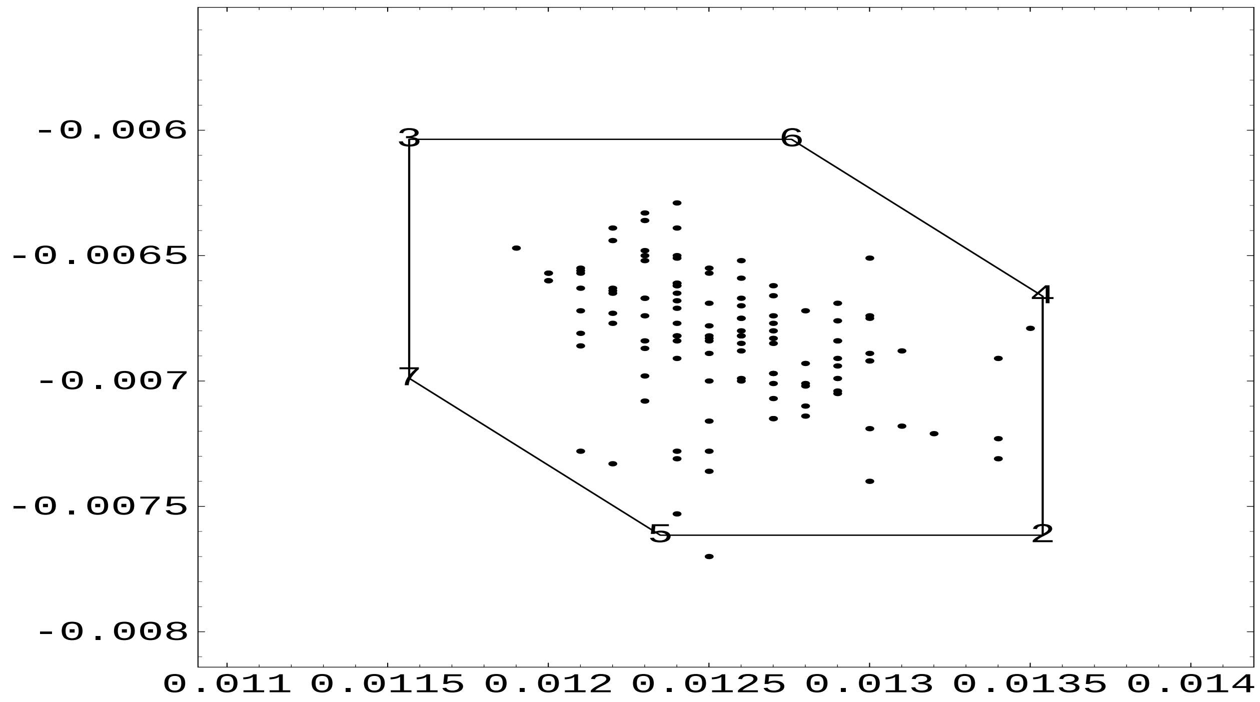


Figure 3: saturation current of PMOS vs NMOS, w/l=40/0.8

Construction of corner models

Partial statistical data matrix :

corner	TOX/nm	VTOn/V	VTOp/V
TT	16.5	0.953	-0.98
SS	18.25	1.028	-1.107
FF	14.75	0.873	-0.846
SM	18.25	1.028	-1.023
MS	18.25	0.977	-1.107
MF	14.75	0.923	-0.846
FM	14.75	0.873	-0.93

Principal Component Analysis

- do singular value decomposition (SVD) of normalized data matrix [2]
- interpretation of SVD:
  transformation to independent variables
  arranged in order of decreasing significance
- retain most important singular values [3]
- tune principal components to counteract bias towards process extremes [3]
- denormalize principal components

Principal Component Analysis

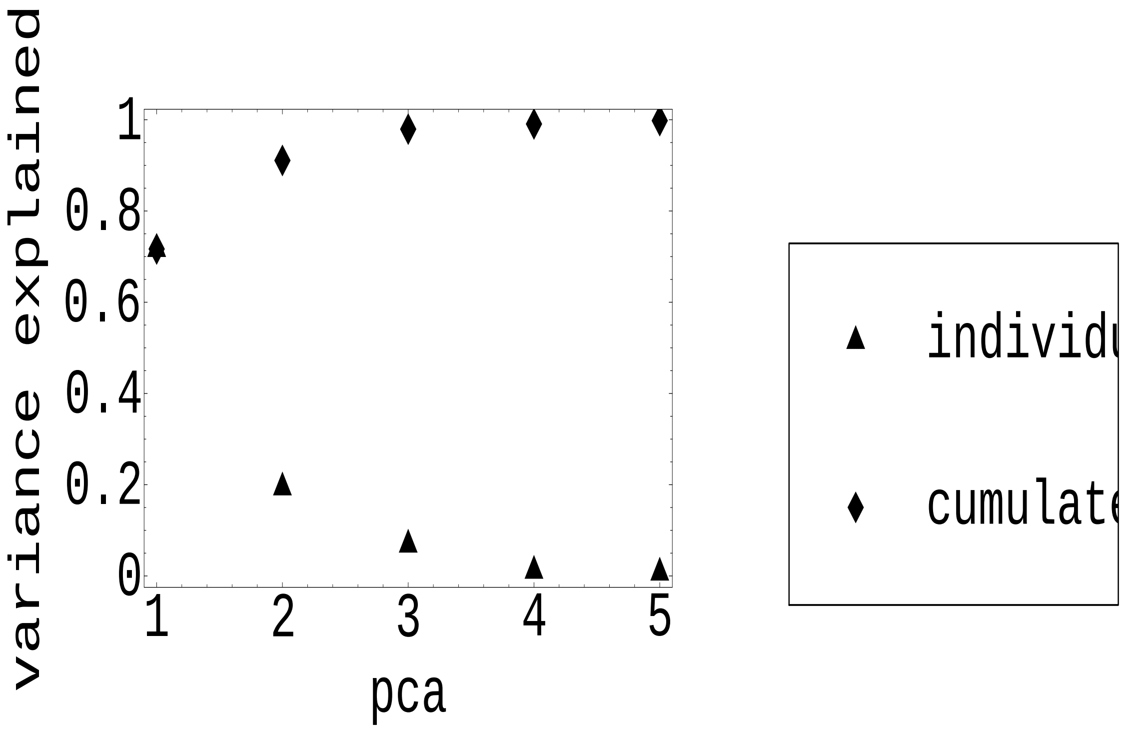


Figure 4: individual and accumulated first 5 principal components

Principal Component Analysis

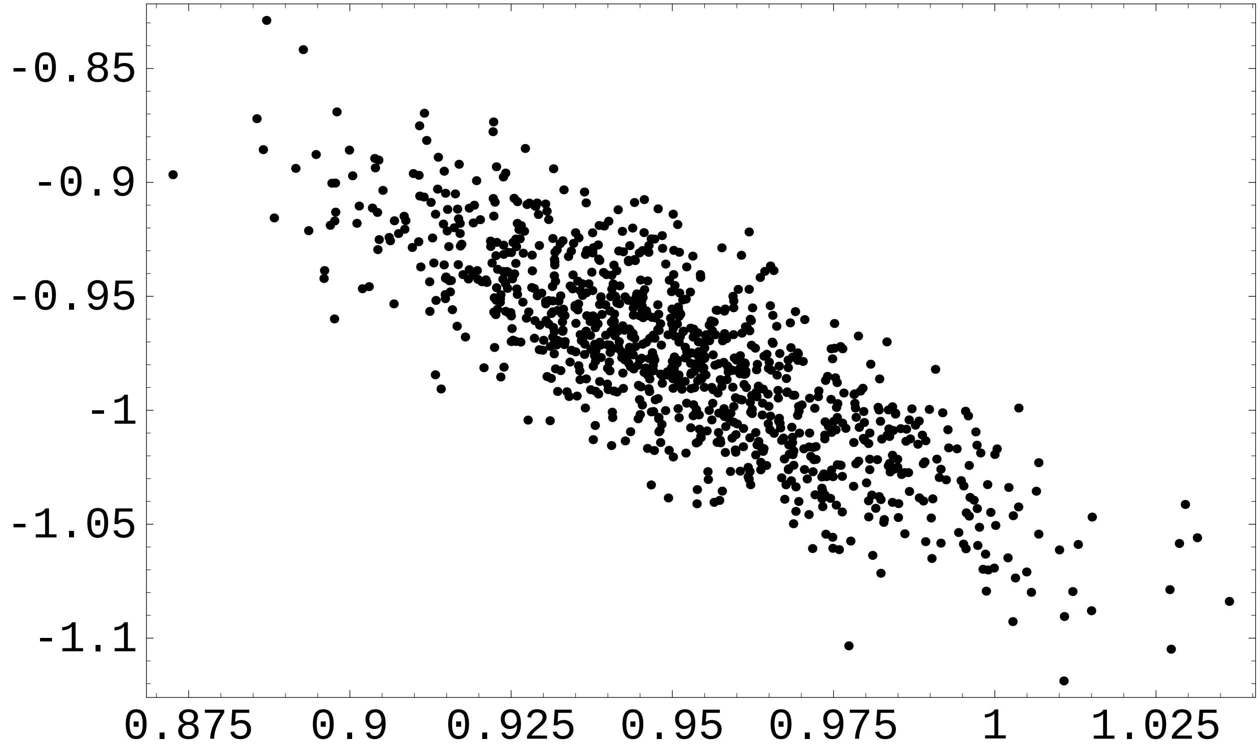


Figure 5: Vth scatter diagram using 3 principal components

Principal Component Analysis

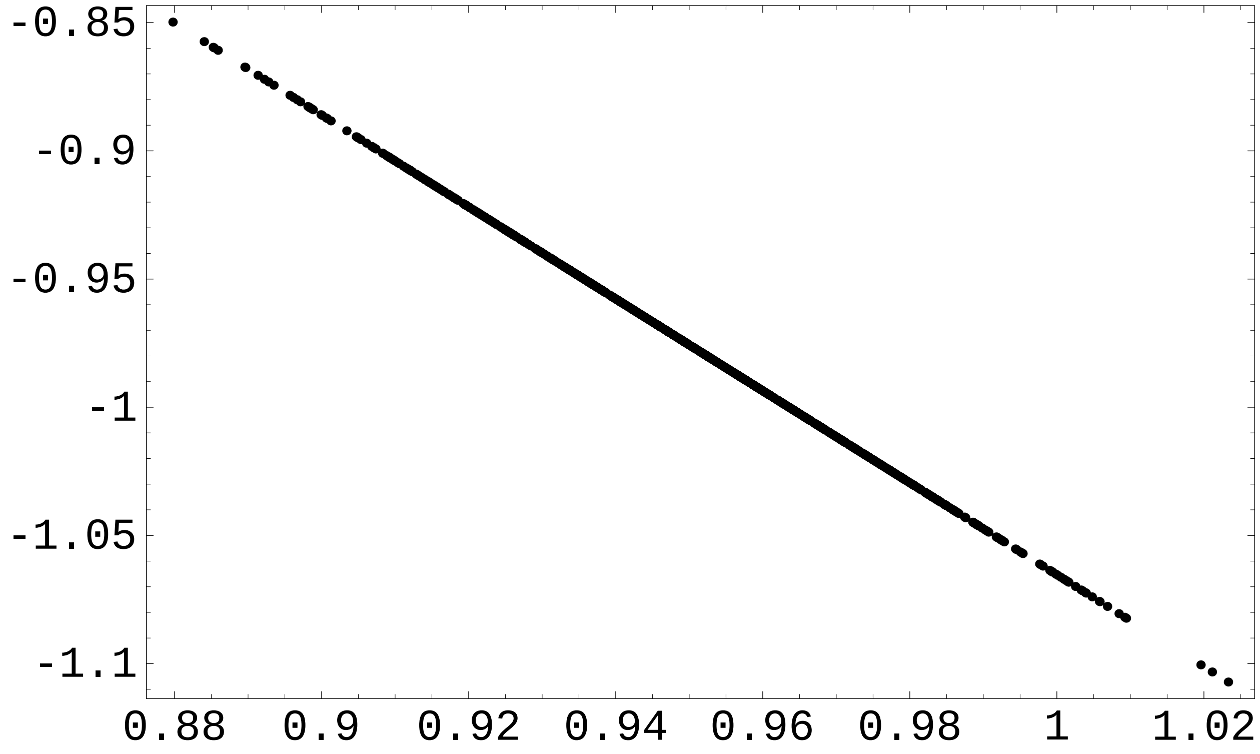
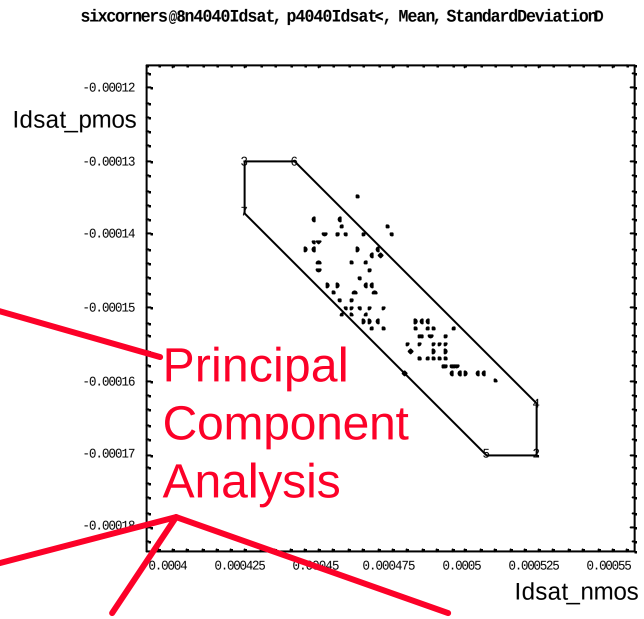


Figure 6: Vth scatter diagram using 1. principal component

Statistical Device Model



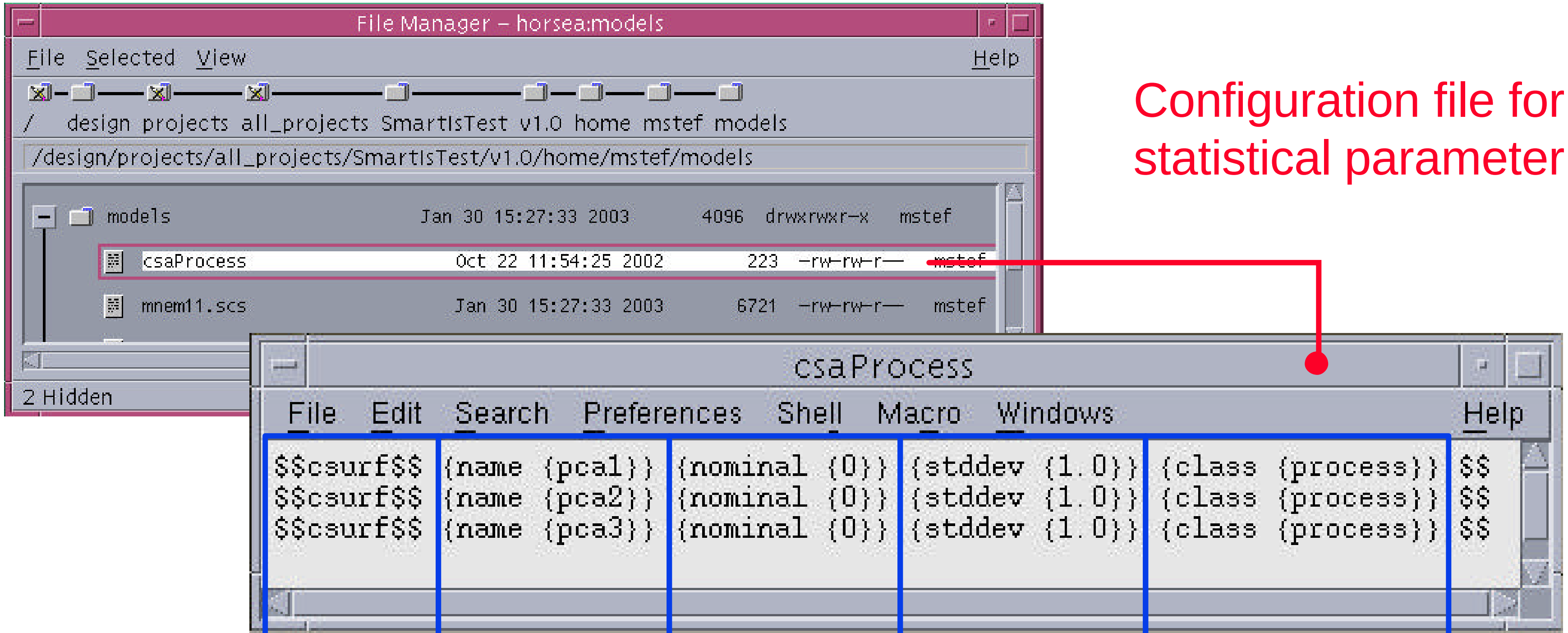

```
simulator  lang=spectre

parameters pca1=0
parameters pca2=0
parameters pca3=0
...
subckt MNEM11 d g s b nb hw
parameters   L=0 W=0
xm d g s b nb hw macro w_ex=W l_ex=L
subckt macro subd subg subs subb subnb subhw                   \
parameters                                                     \
w_ex     = 0                                                   \
l_ex     = 0                                                   \
...

...


Tox      = 16.5n    + 1.0e-9*(-0.694834*pca1 + 0.0696463*pca2 + 0.00962222*pca3)\
vto      = 0.9      + 1.0   *(0.0234071*pca1 + 0.0101704*pca2 - 0.00486807*pca3)\
kp       = 122u     + 1.0e-6*(4.16713  *pca1 - 0.429151 *pca2 - 0.0545855 *pca3)\
weta     = 0        + 1.0   *(0.0491942*pca1 + 0.173216 *pca2 + 0.113016  *pca3)\
leta     = 0.345    + 1.0   *(0.109925 *pca1 - 0.0411565*pca2 - 0.0198766 *pca3)\
dl       = -150e-9 + 1.0e-9*(31.2471  *pca1 + 11.8618  *pca2 + 8.31984   *pca3)\
dw       = -260e-9 + 1.0e-9*(27.5304  *pca1 + 10.0648  *pca2 + 8.46852   *pca3)\
...
xqc      = 0.4
ends macro
ends MNEM11
```

Circuit Surfer Setup: Parameter Setup



Configuration file for statistical parameter

Circuit Surfer ident.	Parameter name	Mean	Standard-deviation	Parameter classification: Process or Mismatch

Assumption: N(0,1)-distribution

Conclusions

- It is possible, to generate statistical models early in process life cycle.
- The statistical models are expected to need retuning after process maturation.
- Principal component analysis has been demonstrated based on worst case models.
- The resulting models can be used for:
  - statistical simulation with Circuit Surfer
  - nominal simulation w.o. Circuit Surfer
  - corner simulation w.o. Circuit Surfer

References

[1] D. Foty, MOSFET MODELING WITH SPICE, Prentice Hall PTR, Upper Saddle River, NJ 07458

[2] J. E. Jackson, A User's Guide To Principal Components, JOHN WILEY & SONS, INC., New York

[3] K. Singhal and V. Visvanathan, Statistical Device Models from Worst Case Files and Electrical Test Data, IEEE Trans. on Semiconductor Manufacturing, vol. 12, no. 4, Nov. 1999

[4] Circuit Surfer User Guide, v2.5, Cadence, May 2002