AdMOS GmbH Advanced Modeling Solutions

Flicker Noise Extraction for Scalable MOS Simulation Models

Dr. Thomas Gneiting

AdMOS GmbH

thomas.gneiting@admos.de

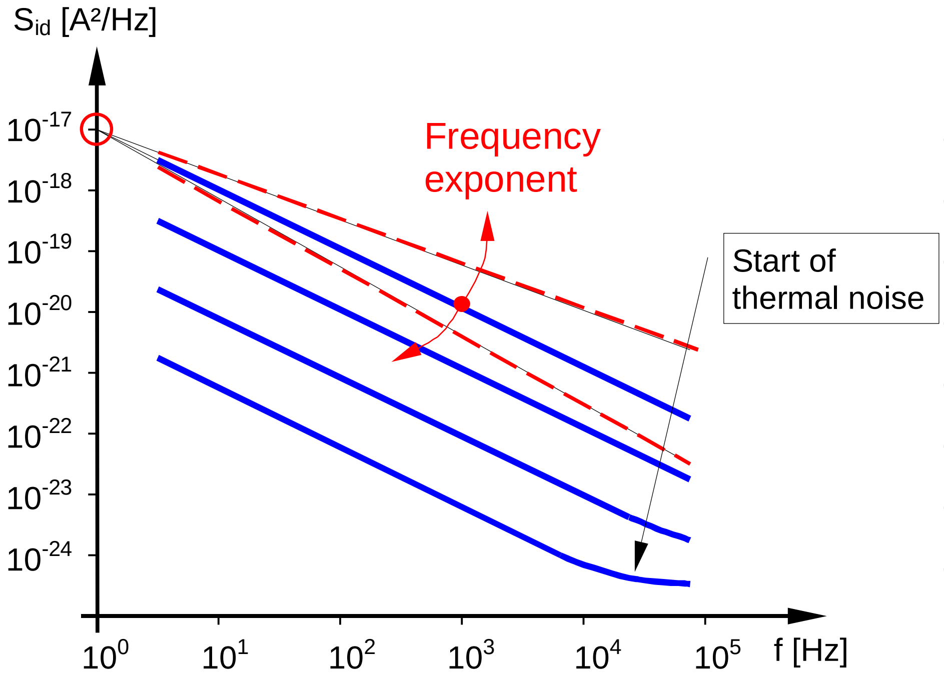
AdMOS GmbH Advanced Modeling Solutions

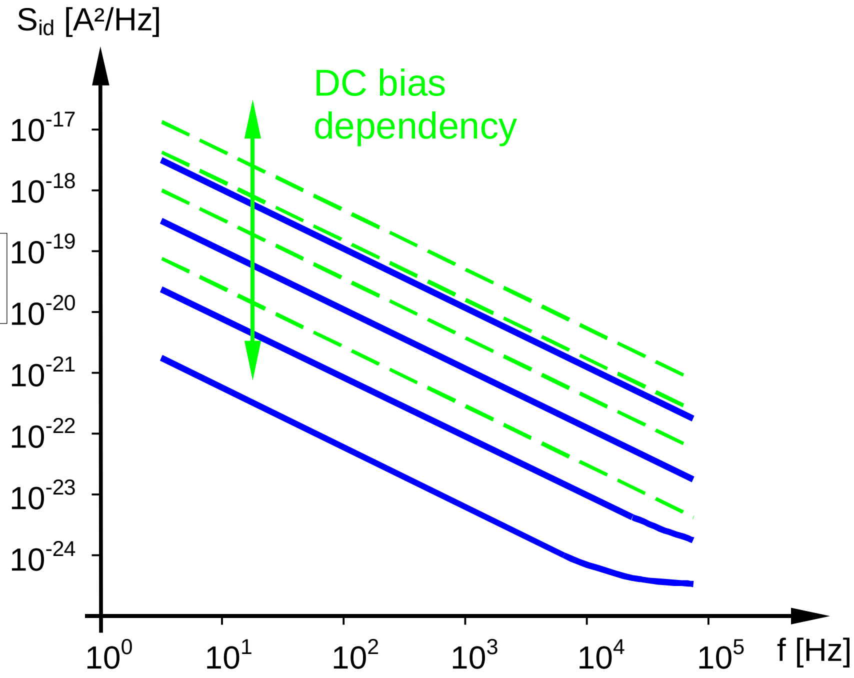
Content

- Flicker noise equations in modern MOS models
- Noise simulation in different simulators
- Steps in parameter extraction using a PSP example
- Problems to be solved
- Summary

Common Flicker Noise Models

The most MOS simulation models provide the following 2 principal degrees of freedom to adjust the flicker noise behavior.





+ Dimension dependency

BSIM3 Flicker Noise

AdMOS GmbH Advanced Modeling Solutions

NOIMOD=1,4,5

$$S_{id}(f)=\frac{KF\cdot I_{DS}^{AF}}{C_{OX}\cdot L_{eff}^{2}\cdot f^{EF}}$$

"classic" SPICE model

NOIMOD=2,3,6

BSIM3 model

$V_{gs}>V_{th}+0.1$:

$$S_{id}(f)=\frac{k_B\cdot T\cdot q^2\cdot \mu_{eff}\cdot I_{DS}}{C_{oxe}\left(L_{eff}-2*LINTNOI\right)^2\cdot A_{bulk}\cdot f^{EF}\cdot 10^8}\cdot$$

$$\left(NOIA\cdot\log\left(\frac{N_O+2\cdot 10^{14}}{N_l+2\cdot 10^{14}}\right)+NOIB\cdot(N_O-N_l)+\frac{NOIC}{2}\cdot\left(N_O^{\,2}-N_l^{\,2}\right)\right)$$

$$+\frac{k_B\cdot T\cdot I_{DS}^{\,2}\cdot\Delta L_{CLM}}{W_{eff}\left(L_{eff}-2*LINTNOI\right)^2\cdot f^{EF}\cdot 10^8}\cdot\frac{NOIA+NOIB\cdot N_l+NOIC\cdot N_l^{\,2}}{\left(N_l+N^*\right)}$$

$V_{gs}<V_{th}+0.1$:

$$S_{id}(f)=\frac{S_{li'mit}\cdot S_{wi}}{S_{li'mit}+S_{wi}},\qquad S_{wi}(f)=\frac{NOIA\cdot V_{tm}\cdot I_{DS}^{\,2}}{W_{eff}\cdot L_{eff}\cdot f^{EF}\cdot 4\cdot 10^{36}}$$

BSIM4 Flicker Noise

FNOIMOD=0

$$S_{id} = \frac{KF \cdot I_{DS}^{AF}}{C_{OX} \cdot L_{eff}^{2} \cdot f^{EF}}$$

"classic" SPICE model

FNOIMOD=1

Inversion:

$$S_{id,inv}(f) = \frac{k_B \cdot T \cdot q^2 \cdot \mu_{eff} \cdot I_{DS}}{C_{oxe}\left(L_{eff} - 2 * LINTNOI\right)^2 \cdot A_{bulk} \cdot f^{EF} \cdot 10^{10}} \cdot$$

$$\left(NOIA \cdot \log\left(\frac{N_O + N^*}{N_l + N^*}\right) + NOIB \cdot \left(N_O - N_l\right) + \frac{NOIC}{2} \cdot \left(N_O{}^2 - N_l{}^2\right)\right)$$

$$+ \frac{k_B \cdot T \cdot I_{DS}{}^2 \cdot \Delta L_{CLM}}{W_{eff}\left(L_{eff} - 2 * LINTNOI\right)^2 \cdot f^{EF} \cdot 10^{10}} \cdot \frac{NOIA + NOIB \cdot N_l + NOIC \cdot N_l{}^2}{\left(N_l + N^*\right)^2}$$

SubVth:

$$S_{id}(f) = \frac{S_{id,inv}(f) \cdot S_{id,subVt}(f)}{S_{id,inv}(f) + S_{id,subVt}(f)}, \qquad S_{id,subVt}(f) = \frac{NOIA \cdot k_B \cdot T \cdot I_{DS}{}^2}{W_{eff} \cdot L_{eff} \cdot f^{EF} \cdot N^{*2} \cdot 10^{10}}$$

AdMOS GmbH Advanced Modeling Solutions

PSP Flicker Noise

Local model:

$$S_{fl}(f) = \frac{q \cdot \Phi_T^{\,2} \cdot \beta \cdot I_{DS}}{f \cdot C_{ox} \cdot G_{vsat} \cdot N^*} \cdot \left[\left(NFA + NFB \cdot N^* + NFC \cdot N^{*2} \right) \cdot \ln\left(\frac{N_m^* + \Delta N / 2}{N_m^* - \Delta N / 2} \right) \right.$$

$$\left. + \left(NFB + NFC \cdot \left[N_m^* - 2 \cdot N^* \right] \cdot \Delta N \right) \right]$$

Fixed frequency exponent of 1!

Scaling equation:

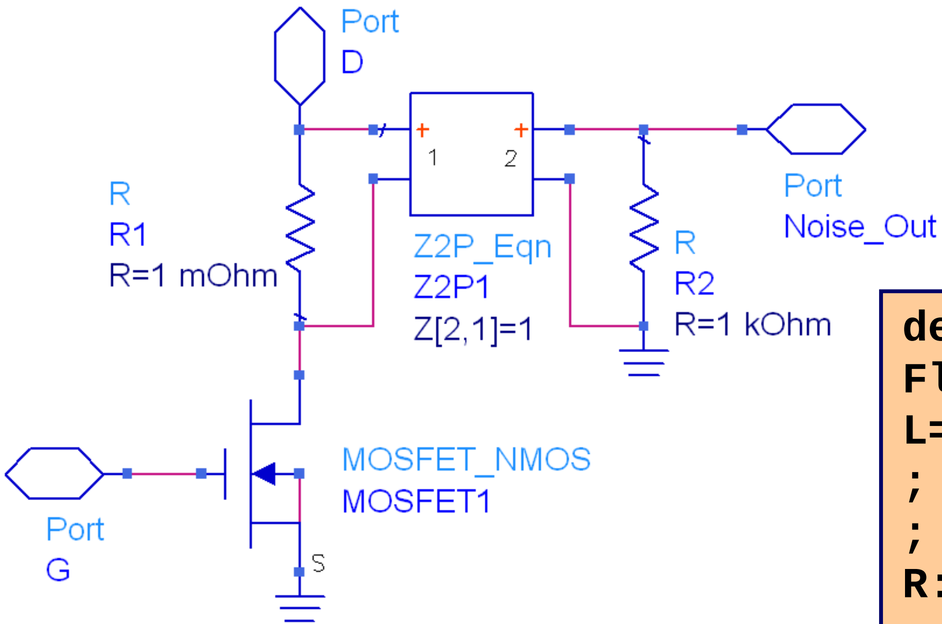
$$NFA = NFALW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$NFB = NFBLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$NVC = NFCLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

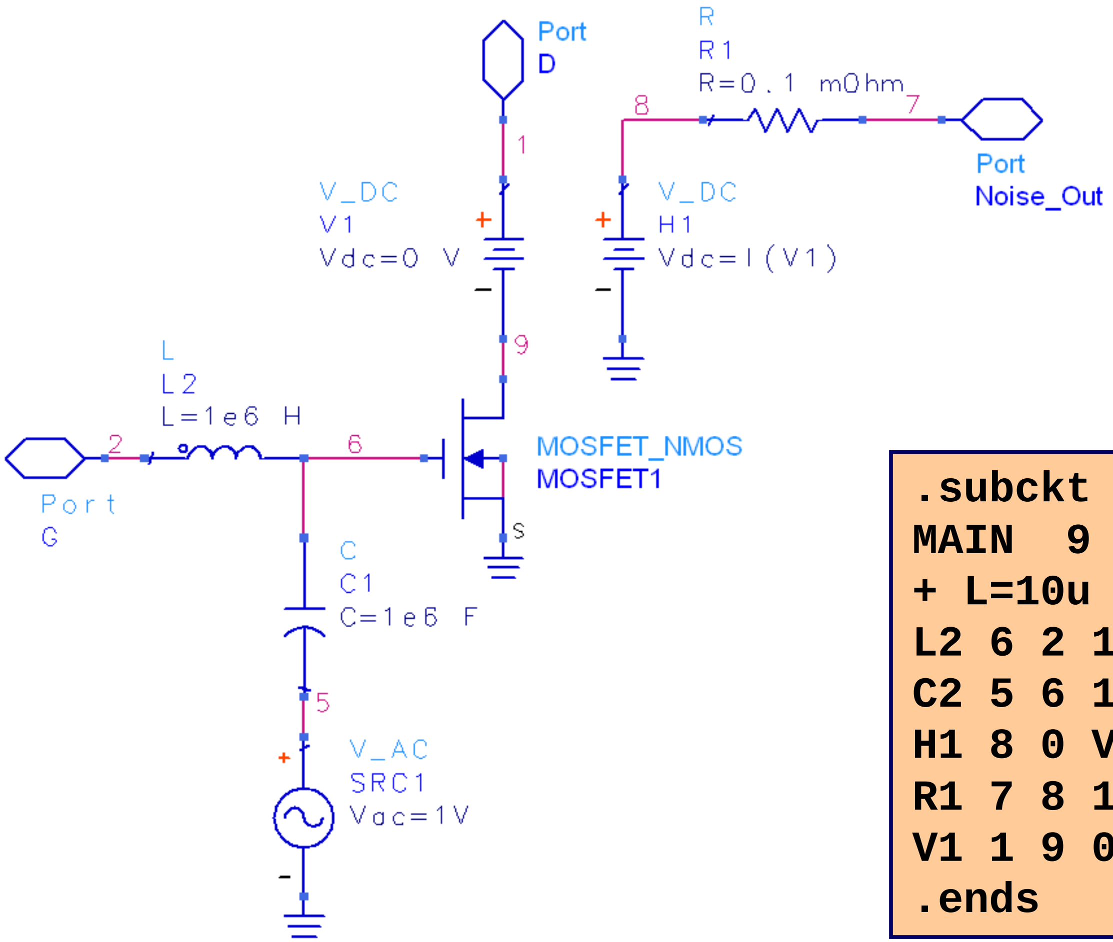
AdMOS GmbH Advanced Modeling Solutions

Noise in ADS




```
define noise_circ (D G OUT)
Flicker_Noise:MAIN D1 G 0 0 \
L=10u W=10u Mult=1
;
; sense the noise current
R:Rdummy D D1 R=1m   Noise=no
;
;convert noise current into an
identical voltage
Z_Port:v D1  D OUT 0 Z[2,1]=1
R:Raux   OUT 0 R=1k  Noise=no
;
end noise_circ
```

Noise in Spice, HSPICE



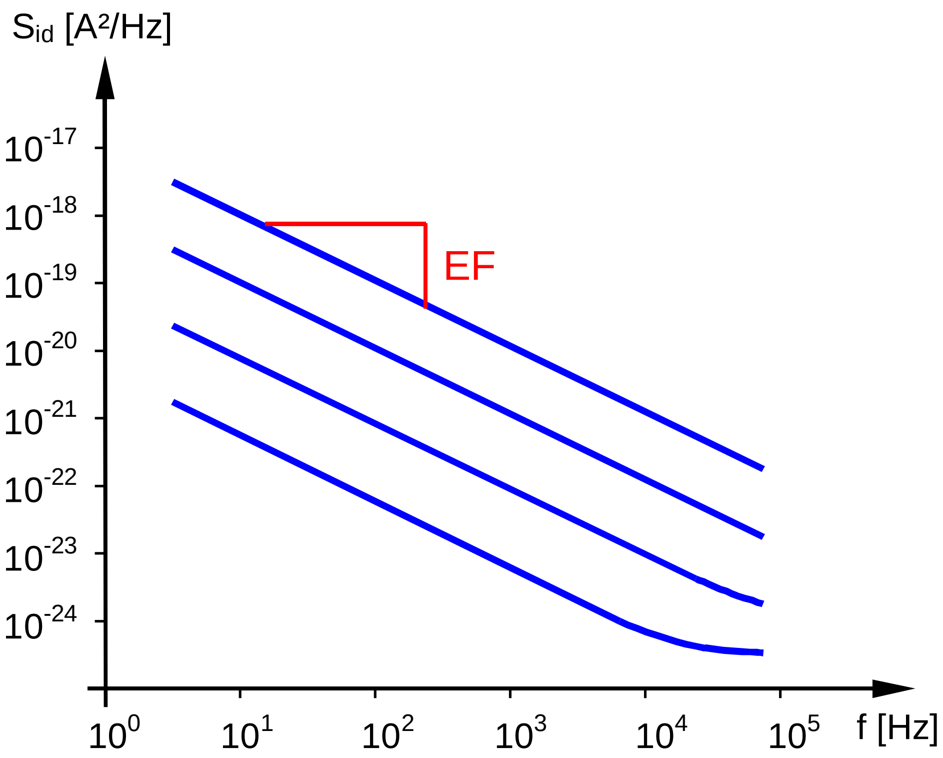

```
.subckt noise_circ 1 2 5 7
MAIN  9 6 0 0 Flicker_Noise
+ L=10u W=10u NF=1
L2 6 2 1000000
C2 5 6 1000000
H1 8 0 V1 1
R1 7 8 1e-4
V1 1 9 0
.ends
```

Content

- Flicker noise equations in modern MOS models
- Noise simulation in different simulators
- Steps in parameter extraction using a PSP example
  - Measurement (see paper from IHP, Falk Korndörfer)
  - Determination of the frequency exponent *)
  - Determination of bias dependency *)
  - Extraction of parameters for scalable noise models shown with an example using the PSP model
- Problems to be solved
- Summary

*) Based on the work of Knoblinger, Grabinski, Sischka

Frequency Exponent (1)



If the model provides a frequency exponent, it can be derived from the slope of the measured curves in logarithmic representation:
(Example for SPICE model, the other models behave similar)

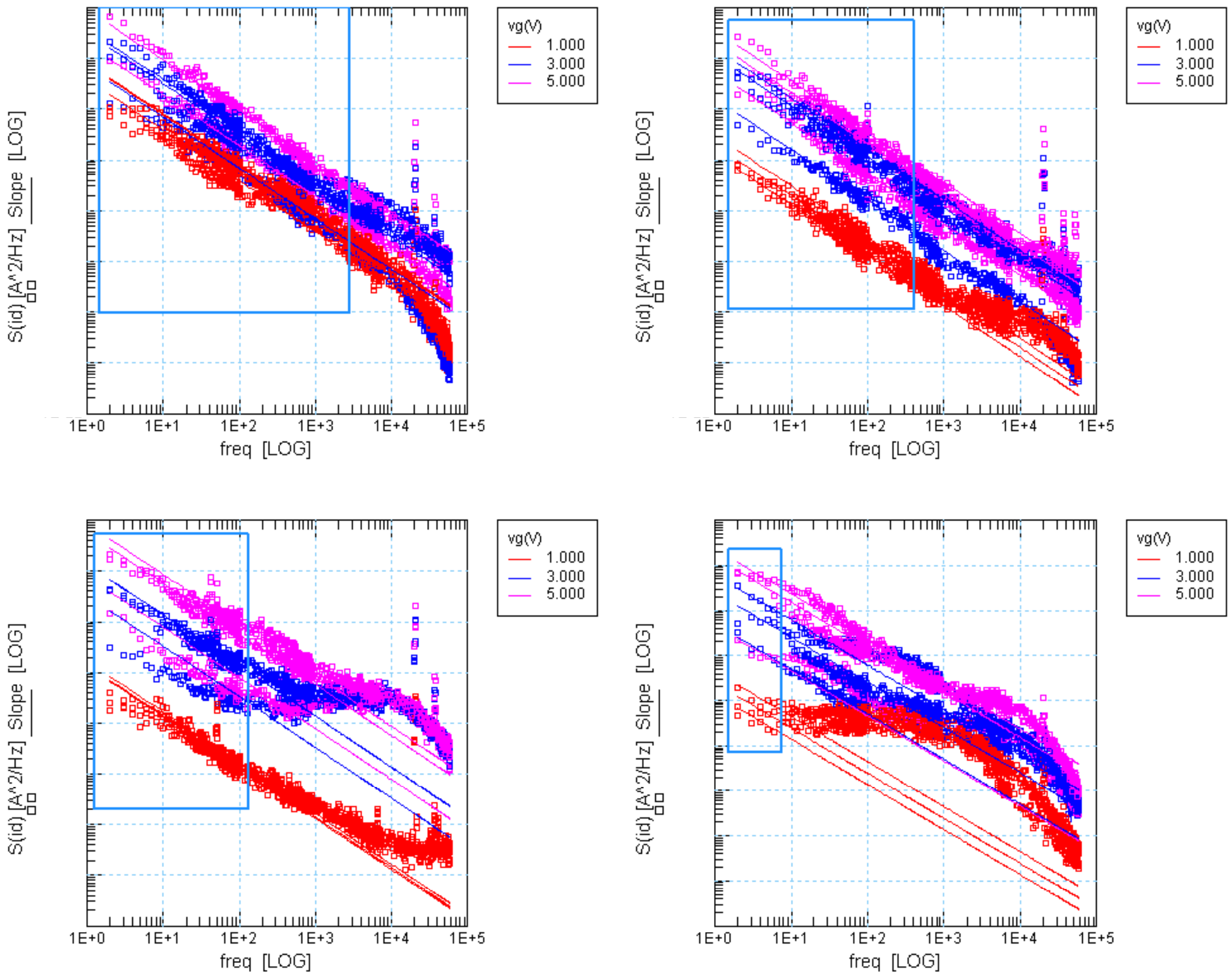
$$S_{id}(f) = \frac{KF \cdot I_{DS}^{\;AF}}{C_{OX} \cdot L_{eff}^{\;2} \cdot f^{\,EF}}$$

$$S_{id}(f) = con \cdot f^{\,-EF}$$

$$\log\left(S_{id}(f)\right) = \log(con) - EF \cdot \log(f)$$

$$y = c + m \cdot x$$

Frequency Exponent (2)



In the real world:

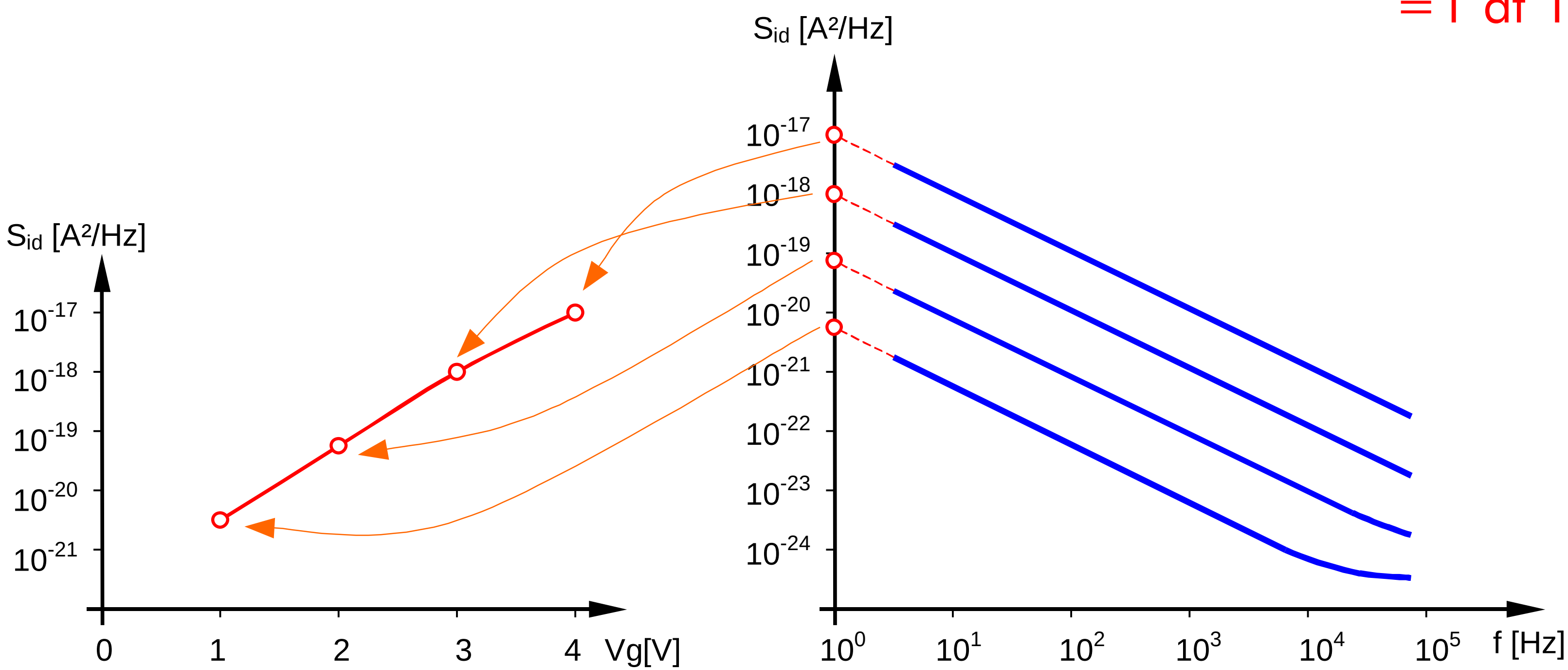
- ➢EF must fit several devices with diff. L, W simultaneously
- ➢Take into account only parts of the curves due to measurement restrictions.

DC Bias dependency (1)

Once the slope is given, the noise values at 1Hz can be determined by extrapolating the measured curve to 1Hz.

(Example for SPICE model, the other models behave similar)

$$S_{id}(f) = \frac{KF \cdot I_{DS}^{AF}}{C_{OX} \cdot L_{eff}^{2} \cdot \underbrace{f^{EF}}_{=1 \text{ at } 1\text{Hz}}}$$



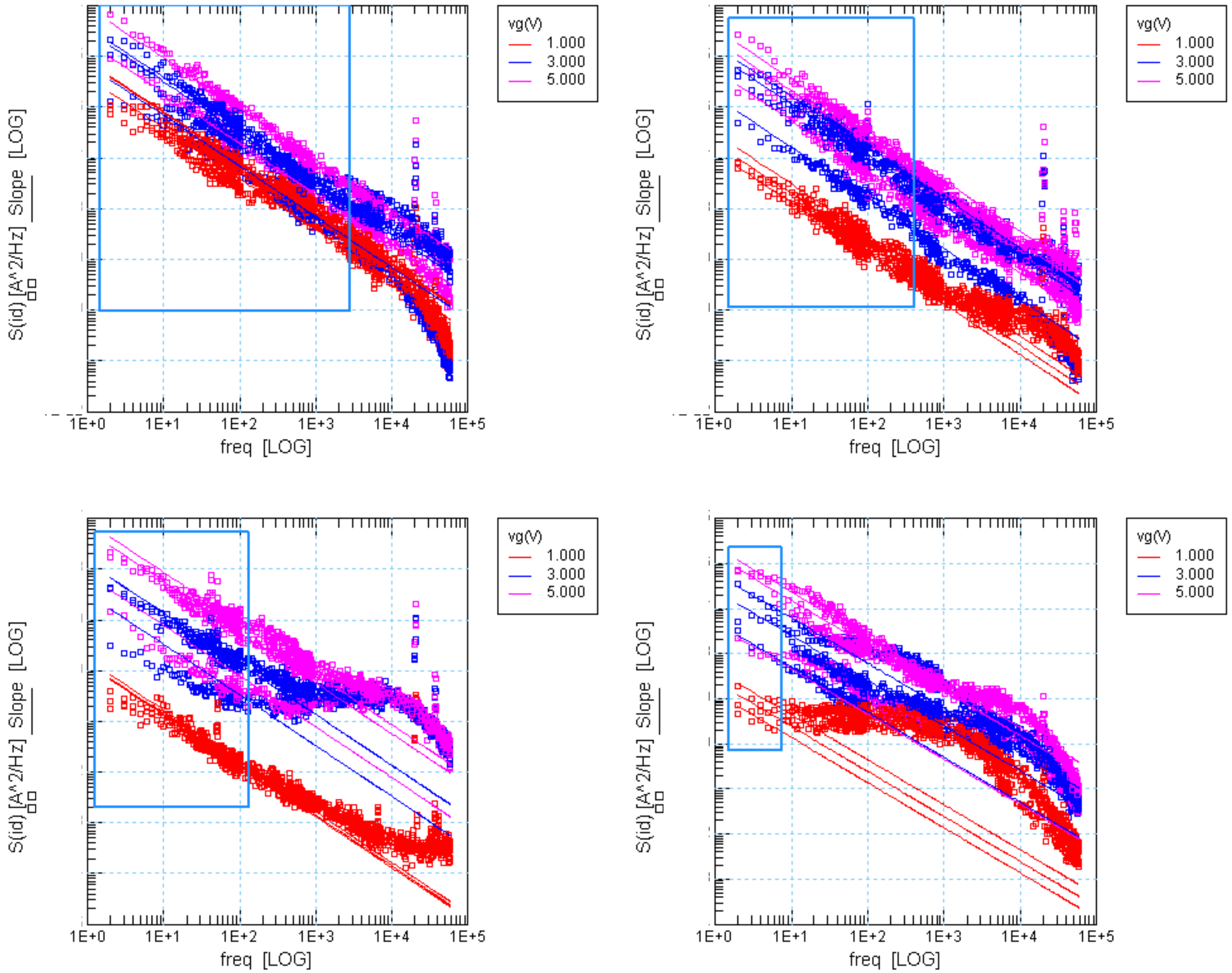
DC Bias dependency (2)

3 Steps:

- Select range of curves to determine slope
- Make curves slopeless
- Apply linear fitting to the selected range of the curve and determine cross-point at 1Hz

DC Bias dependency (2)

AdMOS GmbH Advanced Modeling Solutions



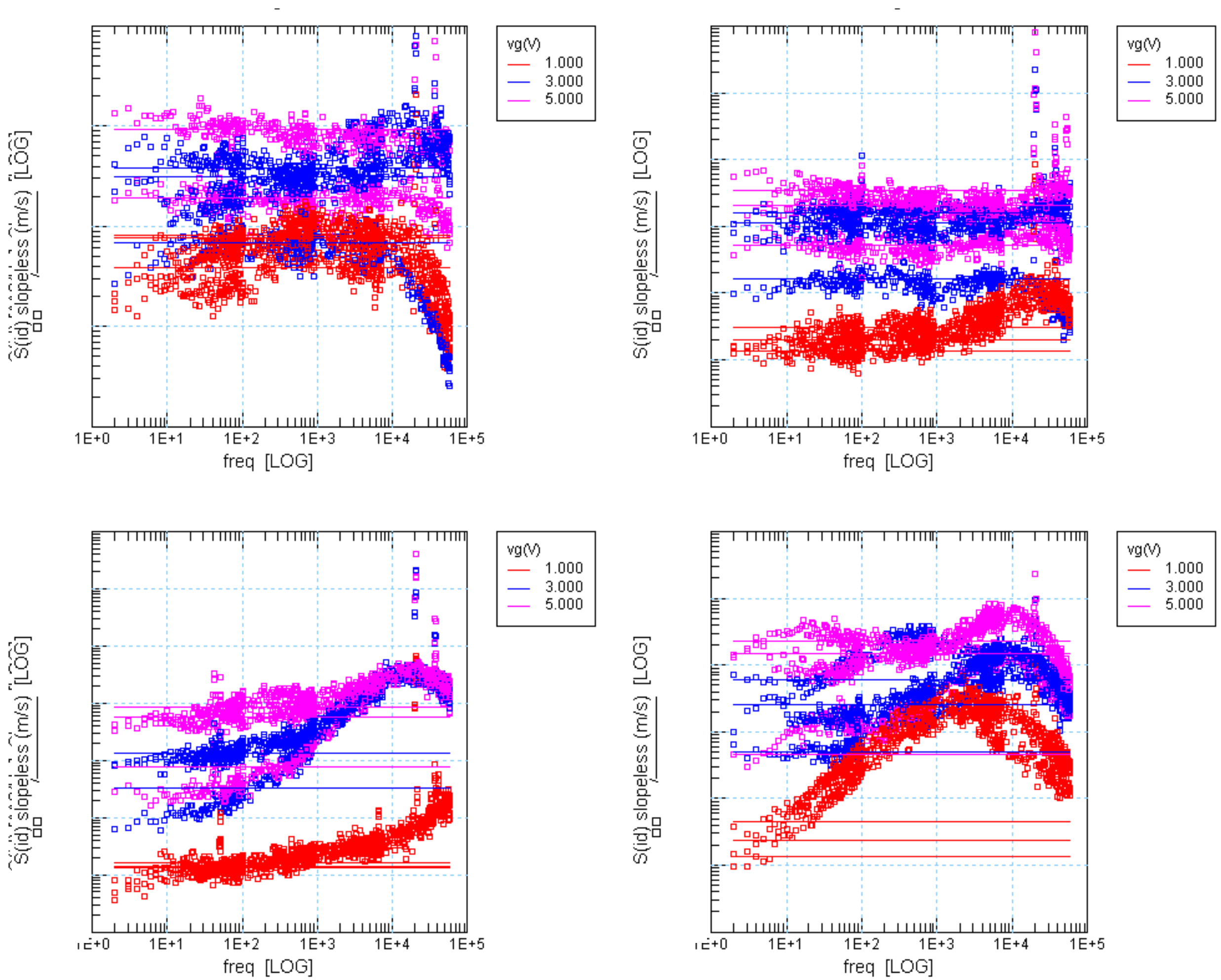
3 Steps:

➢Select range of curves to determine slope

➢Make curves slopeless

➢Apply linear fitting to the selected range of the curve and determine cross-point at 1Hz

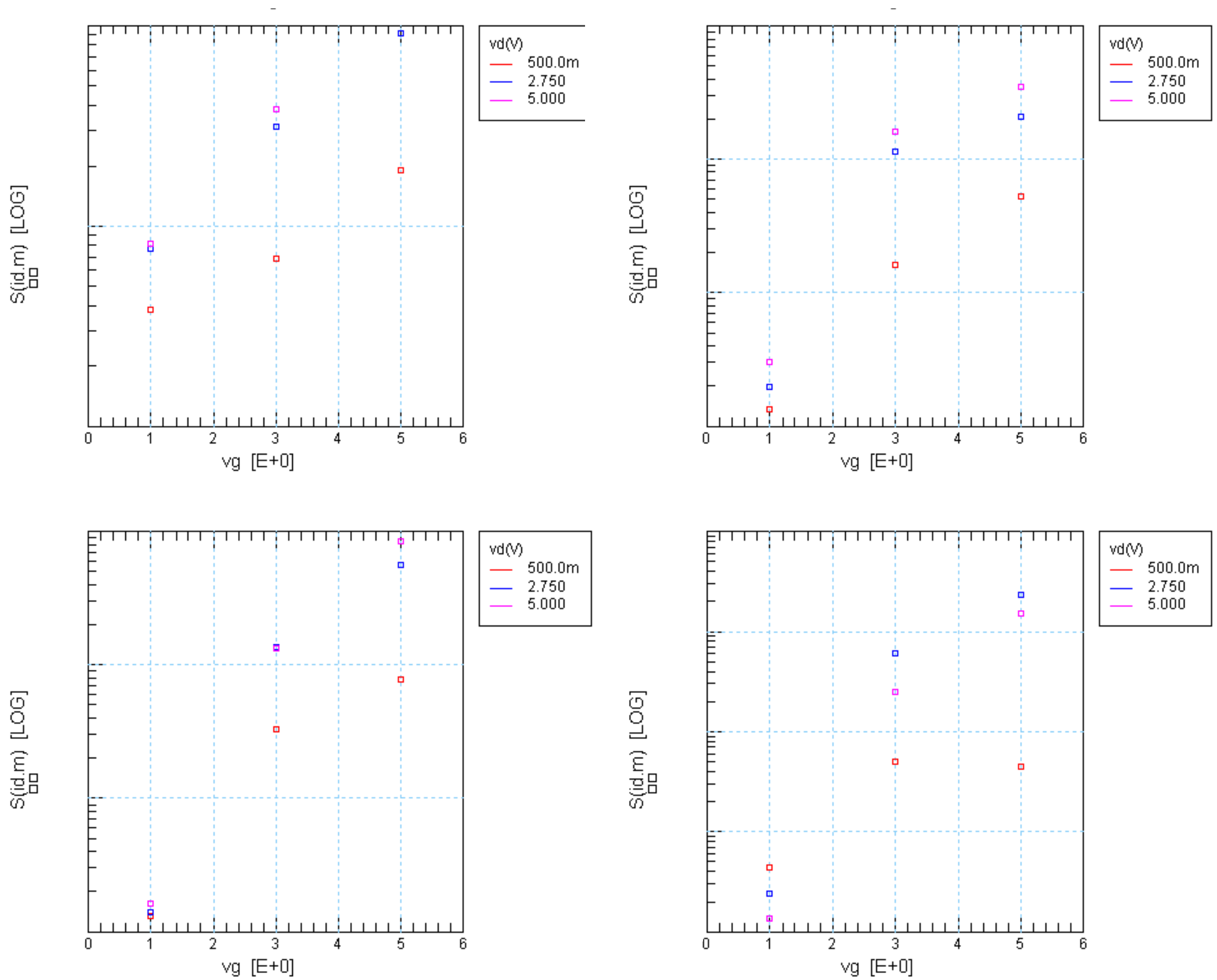
DC Bias dependency (2)



3 Steps:

- Select range of curves to determine slope
- Make curves slopeless
- Apply linear fitting to the selected range of the curve and determine cross-point at 1Hz

DC Bias dependency (2)



3 Steps:

- ➢Select range of curves to determine slope
- ➢Make curves slopeless
- ➢Apply linear fitting to the selected range of the curve and determine cross-point at 1Hz

Parameter Extraction – PSP (1)

S_{id}(f=1Hz) @ diff Vg, Vd, L, W

Solver S_{fl}(1Hz)=f(Parameter, Dimensions, DC Bias)

PSP:
PSP1020 Par.
L, W, MULT
VG, VD

Iterative Solution using a modified Levenberg-Marquardt algorithm

Noise parameters

PSP:
NFALW, NFBLW, NFCLW

Parameter Extraction – PSP (2)

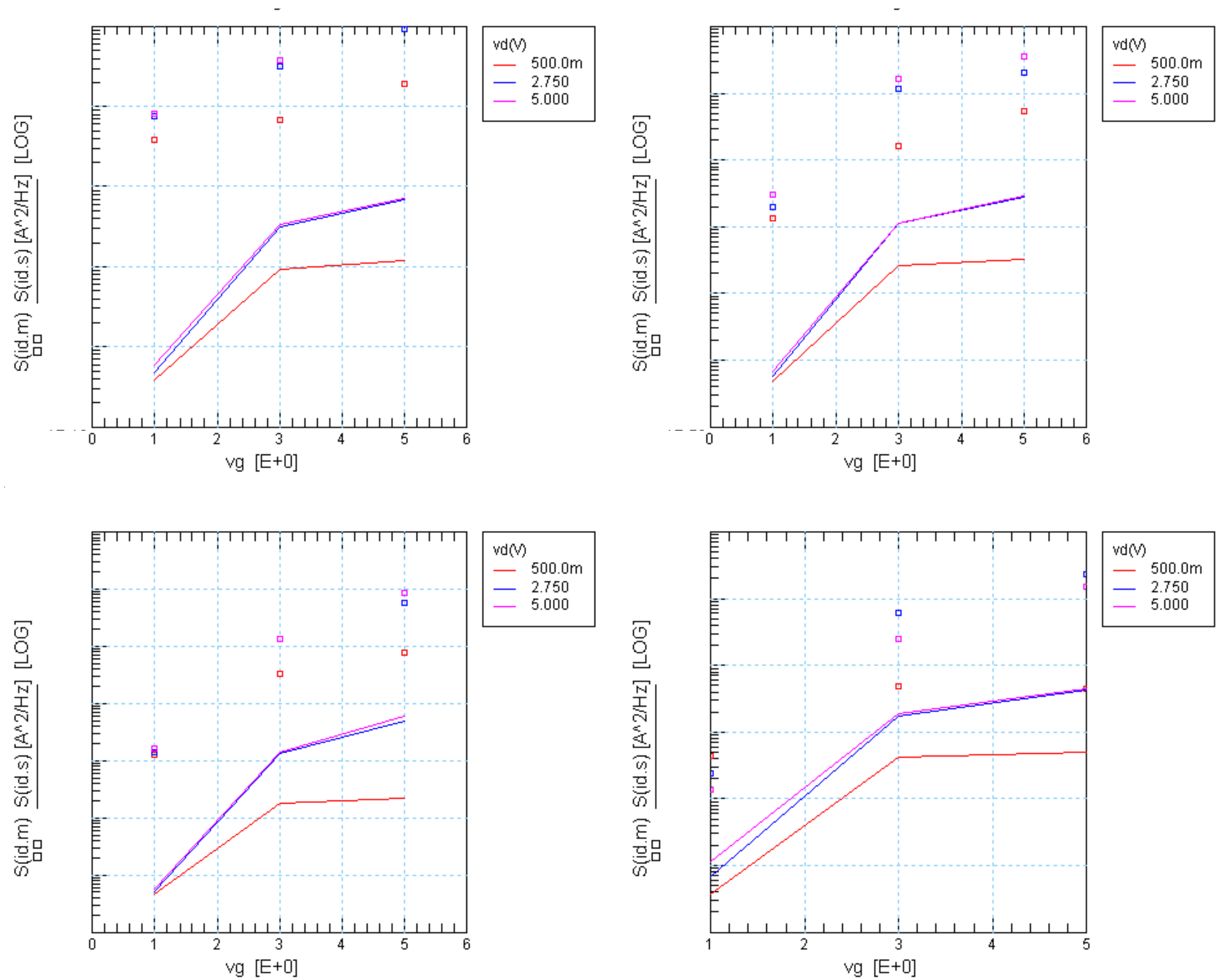
Example parameter extraction process:

1. Simulation with default values of NFALW, NFBLW, NFCLW

2. Perform extraction in ca. 1s and repeat simulation

AdMOS GmbH Advanced Modeling Solutions

Parameter Extraction – PSP (2)

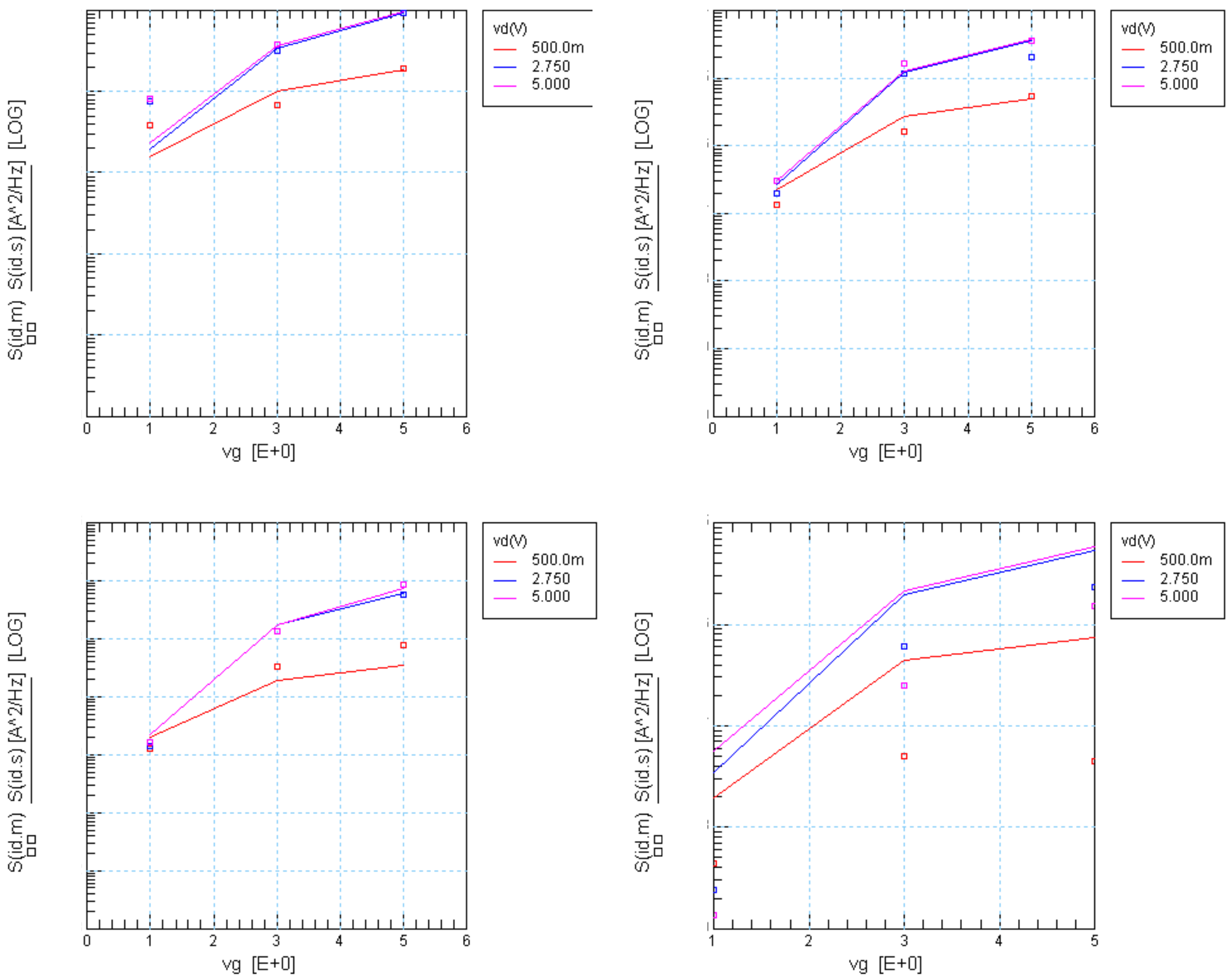


Example parameter extraction process:

1. Simulation with default values of NFALW, NFBLW, NFCLW

2. Perform extraction in ca. 1s and repeat simulation

Parameter Extraction – PSP (2)



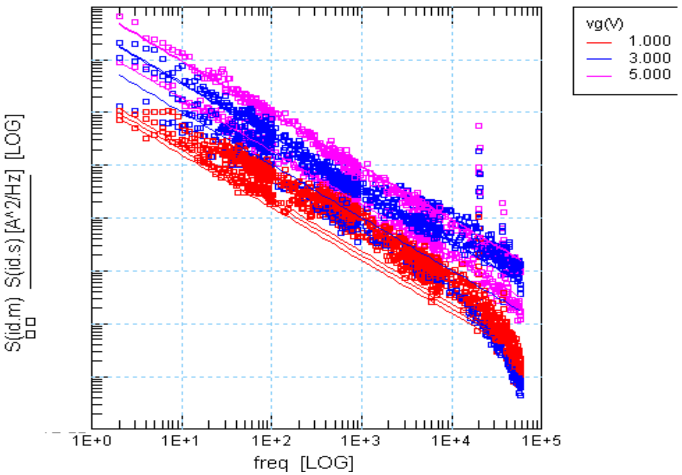
Example parameter extraction process:

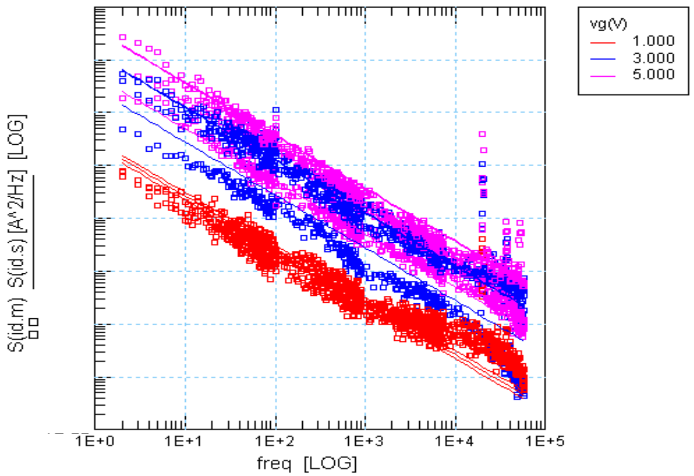
1. Simulation with default values of NFALW, NFBLW, NFCLW

2. Perform extraction in ca. 1s and repeat simulation

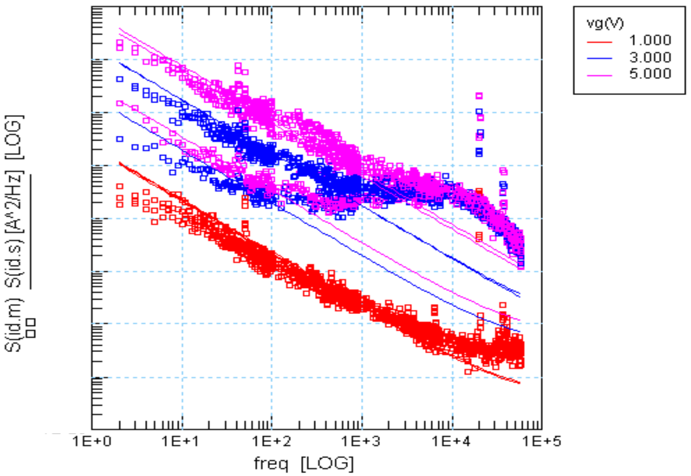
AdMOS
AdMOS GmbH Advanced Modeling Solutions

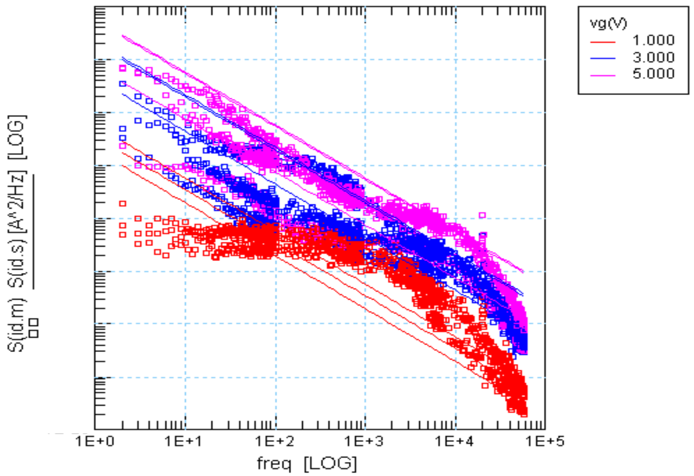
Parameter Extraction – PSP (3)





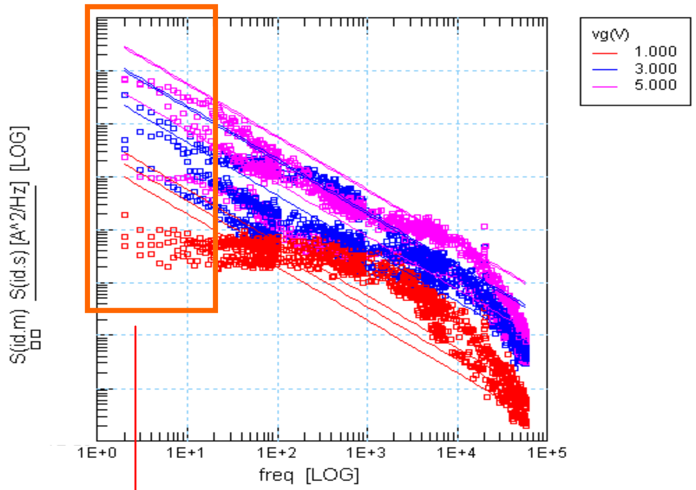
Final result for 4 different transistor dimensions.





AdMOS GmbH Advanced Modeling Solutions

Problems to be solved



Fitting for small device cannot be improved in this area without the distortion of the other devices.

The scalability of the simulation models is still not good enough.

The PSP scaling equation:

$$NFA = NFALW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$NFB = NFBLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$NVC = NFCLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

does not allow to modify parameters independently for L and W. Actually, only the product L·W is taken into account.

Summary

- Together with the measurement of flicker noise (presented by Falk Korndörfer, IHP), the shown extraction strategy is the basis of a complete noise modeling method.
- The very effective simultaneous extraction of flicker noise parameters for different devices with different dimensions is the key improvement of this tool.
- The shown methodology for PSP was implemented for common MOS models (BSIM3, BSIM4) and can be easily extended to other models like HiSIM2 etc.
- The co-operation between IHP and AdMOS resulted in a commercial available Flicker Noise Modeling Tool. For details, please see:
  www.admos.de → Products → Flicker Noise System