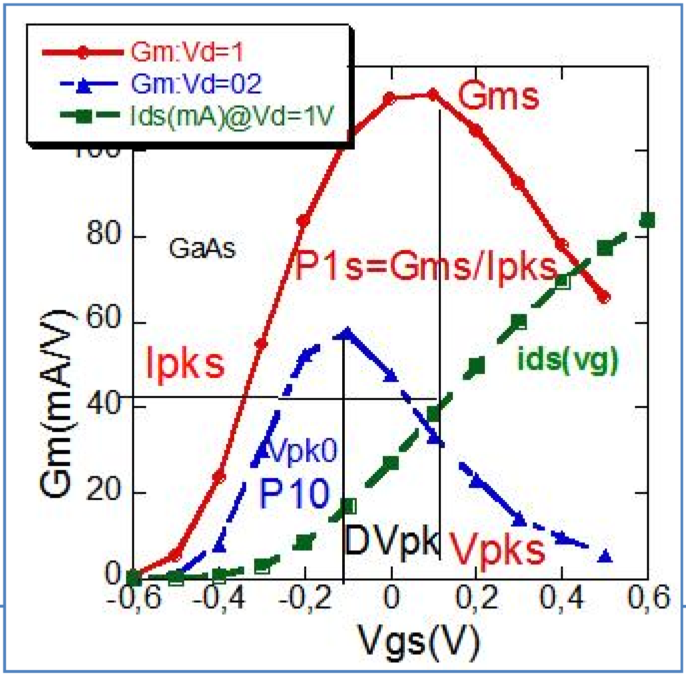
Angelov GaN Modeling

- ➢ Parameter Influence
- ➢ Parameter Extraction Strategy



sketch by courtesy of Prof. I.Angelov

Franz Sischka, Dec. 2020

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Outline

- **Introduction to the Angelov Model**
- **Step-by-Step Modeling Sequence**

    Resistances RG, RD, RS

    DC Input Characteristic ig-vgs

    DC Transfer Characteristic id-vgs

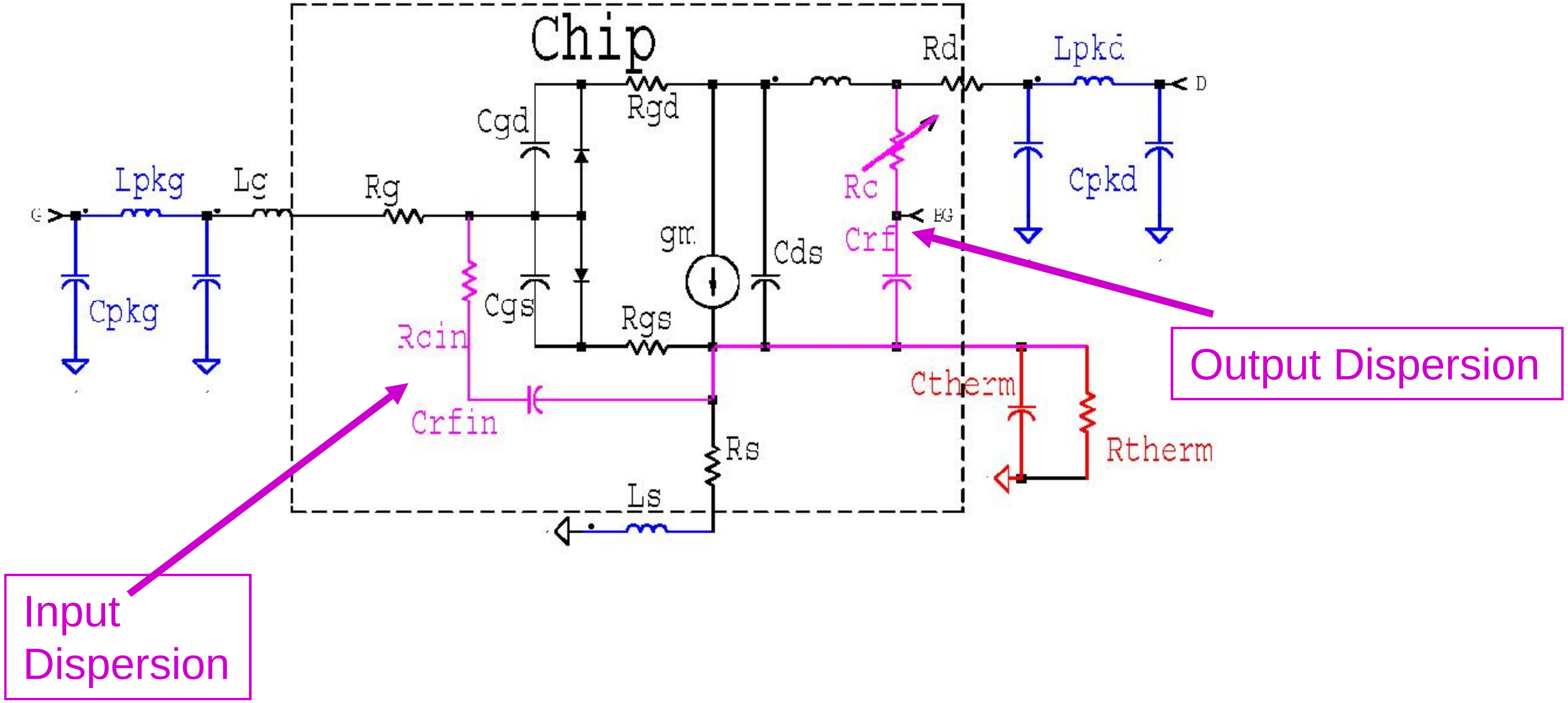
    DC Output Characteristic id-vds

    Thermal Modeling

    S-Parameter Modeling

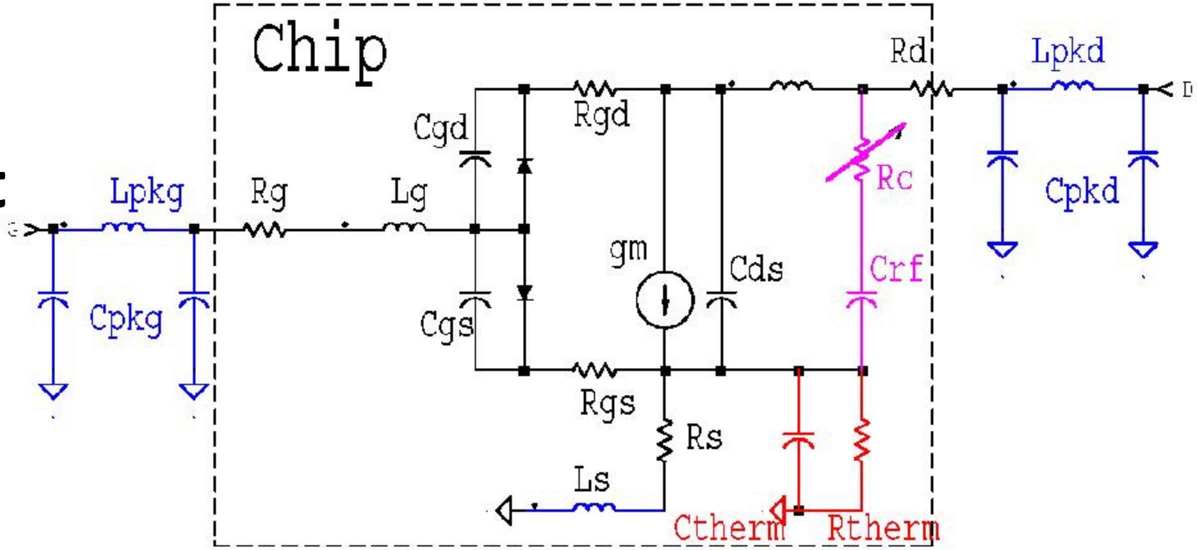
- **Modeling Results**

Angelov Model Circuit

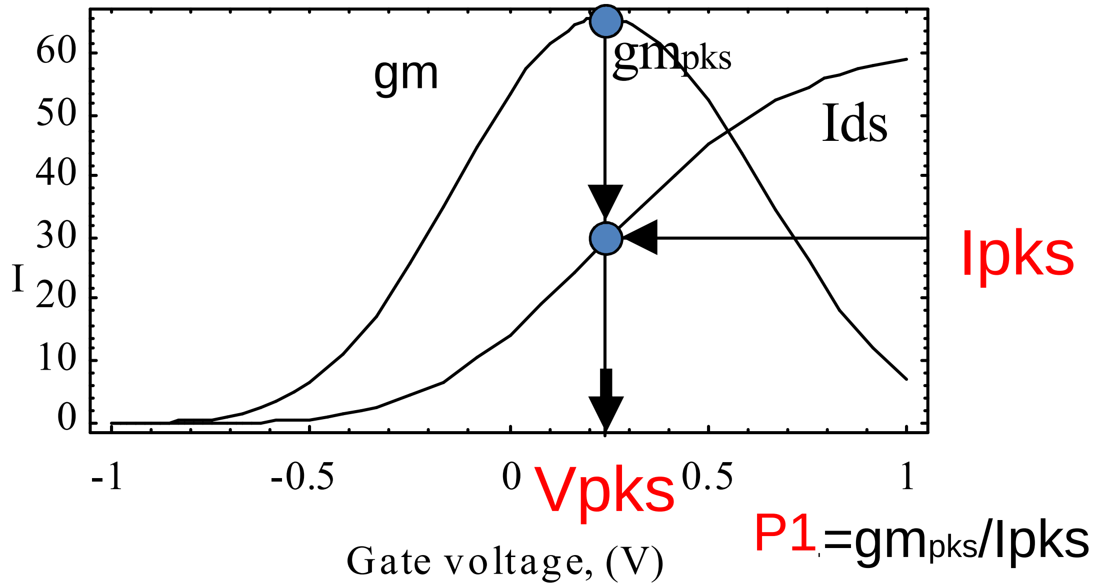


FET

Equivalent Circuit



The Angelov model features parameter initialization from measurement inspections



Ids equations

FET Current source:
The ideal case is if we can split:
Ids = f1(Vgs)*f2(Vds)

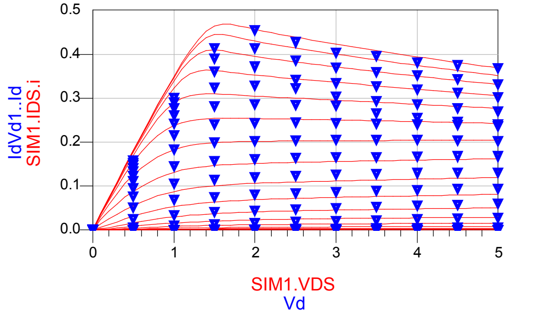
$$I_{ds} = I_{pk}(1+\tanh(\Psi_p))\tanh(\sim V_{ds})(1+ a V_{ds} + a_{sb}.e^{V_{dg}-V_{tr}});$$

$$\cdot_p = P_{1m}((V_{gs}-V_{pk0}) + P_2(V_{gs}-V_{pks})^2 + P_3(V_{gs}-V_{pkm})^3);$$

$$P_{1m} = g_{mpk} / I_{pk};$$

$$V_{pk}(V_{ds}) = V_{pk0} + \Delta V_{pks}\tanh(\sim_s V_{ds}) - V_{sb2}(V_{dg}-V_{tr})^2;$$

$$\sim = \sim_r + \sim_s[1+\tanh(\cdot_p)]; P_{1m} = P_{1s}(1+B_1/\cosh(B_2.V_{ds}));$$



High Power FET Measured&Model

$$I_{ds} = I_{dsp} - I_{dsn};$$

Symmetric model

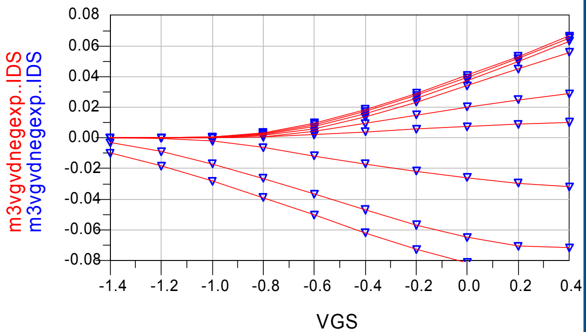
$$I_{dsp} = I_{pk}(1+\tanh(\Psi_p))(1+\tanh(\sim V_{ds}))(1+ a V_{ds} + a_{sb}.e^{V_{dg}-V_{tr}});$$

$$I_{dsn} = I_{pk}(1+\tanh(\Psi_n))(1-\tanh(\sim V_{ds}))(1- a V_{ds});$$

$$\cdot_p = P_{1m}((V_{gs}-V_{pk0}) + P_2(V_{gs}-V_{pks})^2 + P_3(V_{gs}-V_{pkm})^3);$$

$$\cdot_n = P_{1m}((V_{gd}-V_{pk0}) + P_2(V_{gd}-V_{pks})^2 + P_3(V_{gd}-V_{pkm})^3);$$

$$\sim = \sim_r + \sim_s[1+\tanh(\cdot_n)];$$

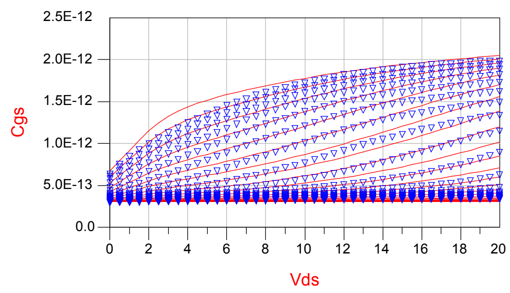


Symmetrical model
Meas.&Model

Gate Charge

- Capacitance implementation

$$1->\frac{\partial V_{gs}}{\partial t};\frac{\partial V_{gd}}{\partial t};2->I_{gs}=\frac{\partial V_{gs}}{\partial t}C_{gs};I_{gd}=\frac{\partial V_{gd}}{\partial t}C_{gd};$$



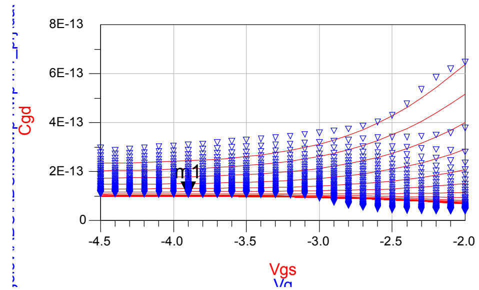
$$C_{gs}=C_{gsp}+C_{gs0}.(1+\tanh[\cdot_1]).(1+\tanh[\cdot_2])$$

$$\cdot_1=P_{10}+P_{11}.V_{gs}+P_{111}.V_{ds};\cdot_2=P_{20}+P_{21}.V_{ds};$$

$$C_{gd}=C_{gdp}+C_{gd0}.(1+\tanh[\cdot_3]).(1+\tanh[\cdot_4]+2P_{111})$$

$$\cdot_3=P_{30}-P_{31}.V_{ds};\cdot_4=P_{40}+P_{41}.V_{gd}-P_{111}.V_{ds};$$

P_{111} -high voltage effects for C_{gs}&cross-coupling for C_{gd}



$$Q_g=Q_{gs}+Q_{gd};$$

- Charge implementation

$$Q_{gs}=\int C_{gs}(V_{gs},V_{ds})dV_{gs}=C_{gsp}.V_{gs}+C_{gs0}.(V_{gs}+Lc1)Th2;$$

$$Q_{gd}=\int C_{gd}(V_{gs},V_{gd})dV_{gd}=C_{gdp}.V_{gd}+C_{gd0}.(V_{gd}+Lc4)Th3;$$

$$Lc1=\frac{\log[\cosh[\cdot_1]]}{P_{11}},Tn2=\tanh[\cdot_2];Lc4=\frac{\log[\cosh[\cdot_4]]}{P_{41}},Tn3=\tanh[\cdot_3]$$

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- Introduction to the Angelov Model
- **Step-by-Step Modeling Sequence**

Resistances RG, RD, RS	
DC Input Characteristic	ig-vgs
DC Transfer Characteristic	id-vgs
DC Output Characteristic	id-vds
Thermal Modeling	
S-Parameter Modeling	

- Modeling Results

Angelov Modeling Flow:

-1- RS, RD

-2- ig(vg)

-3- id(vg)

-4- id(vd)

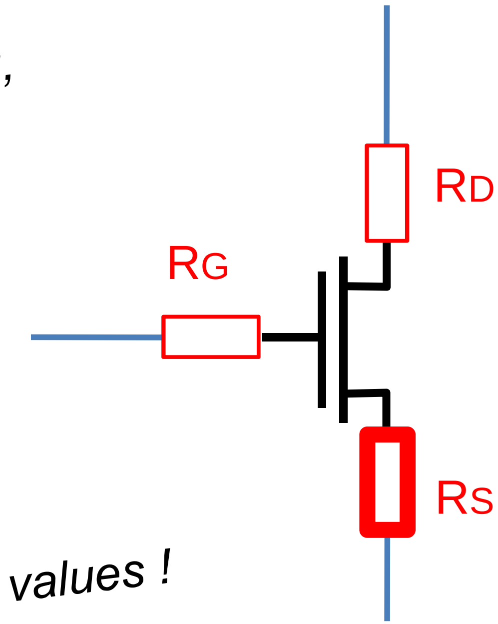
-5- S-parameters: RG, Inductors

capacitors from vd-vd and vd-vg biasing

-6- Nonlin-RF: fine-tuning & verification

Resistances RG, RD, RS

The accurate extraction of the external resistors is extremely important for a successful device modeling, because they strongly affect the remaining inner model performance.



Of particular importance is RS: a wrong RS value affects basically all DC parameter values !

As a best-practice,
the external resistors values are extracted applying different extraction methods.

FROM DC:

- **RD** from id-vd linear range
- **RS** from id-vd: distribution of id curves for vd in saturation
  or from DC Flyback measurement

FROM S-PARAMETERS:

- **RS**, **RG**, **RD** from ColdFET (Dambrine*)

Once these resistors are modeled, and during the remaining modeling steps:
- RS should be changed only very little
- RG will be tuned to fit S11
- RD will be tuned to fit id-vd in the linear range

* G.Dambrine et.al., 'A New Method for Determining the FET Small-Signal Equivalent Circuit', IEEE Trans.Microwave Theory and Techniques, vol.36, nr.7, July 1988

➢ **Step-by-Step Modeling Sequence**

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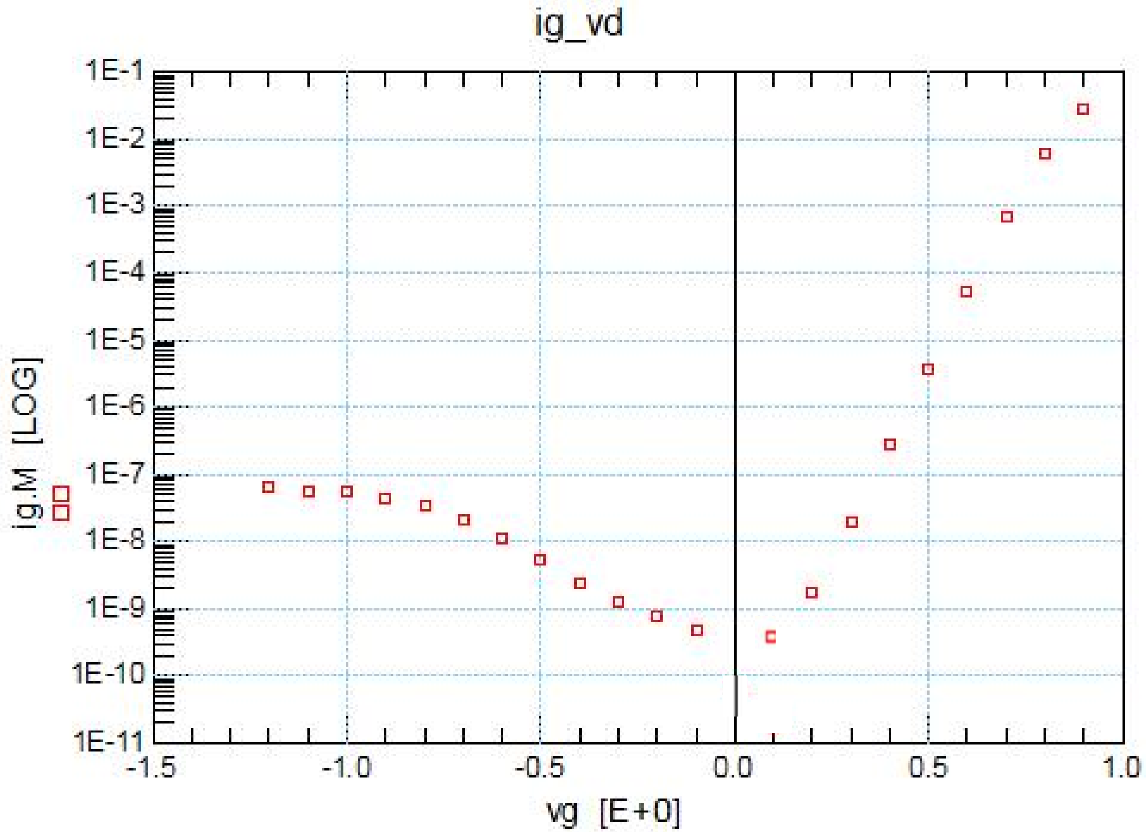
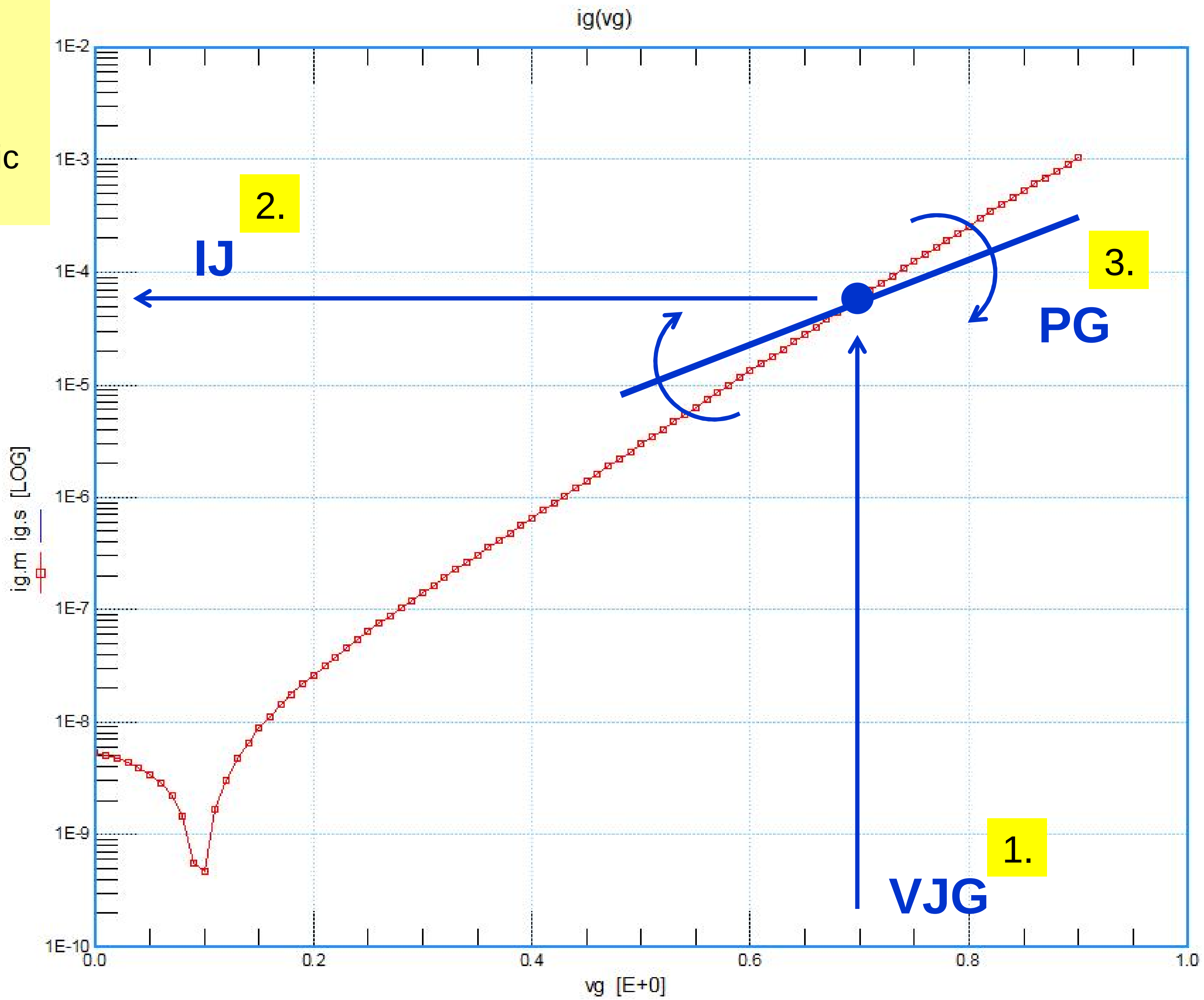
DC Input Characteristic

ig vs. vg



ig vs. vg

Modeling the diode characteristic for vg>0



- **Step-by-Step Modeling Sequence**
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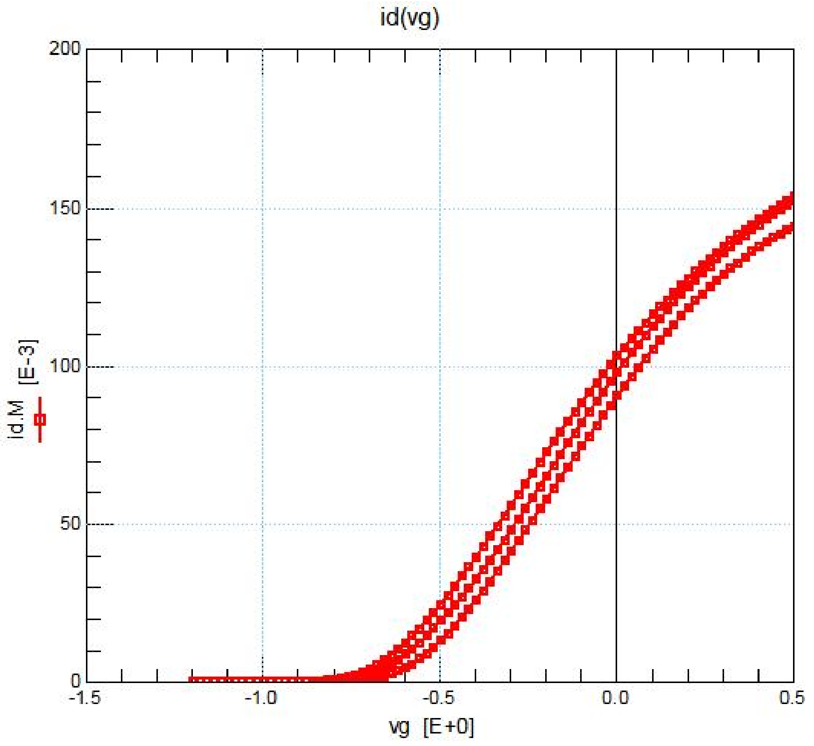
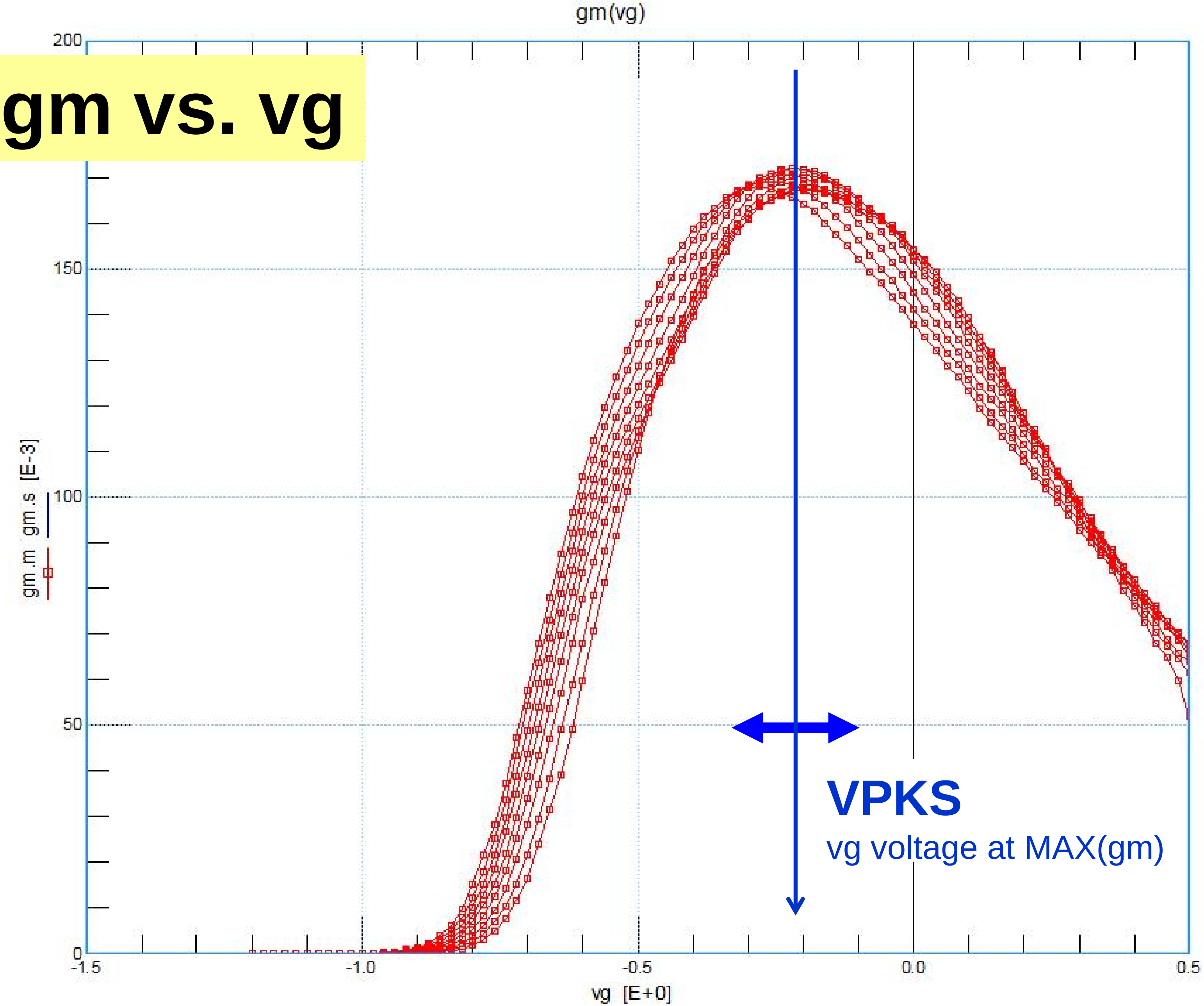
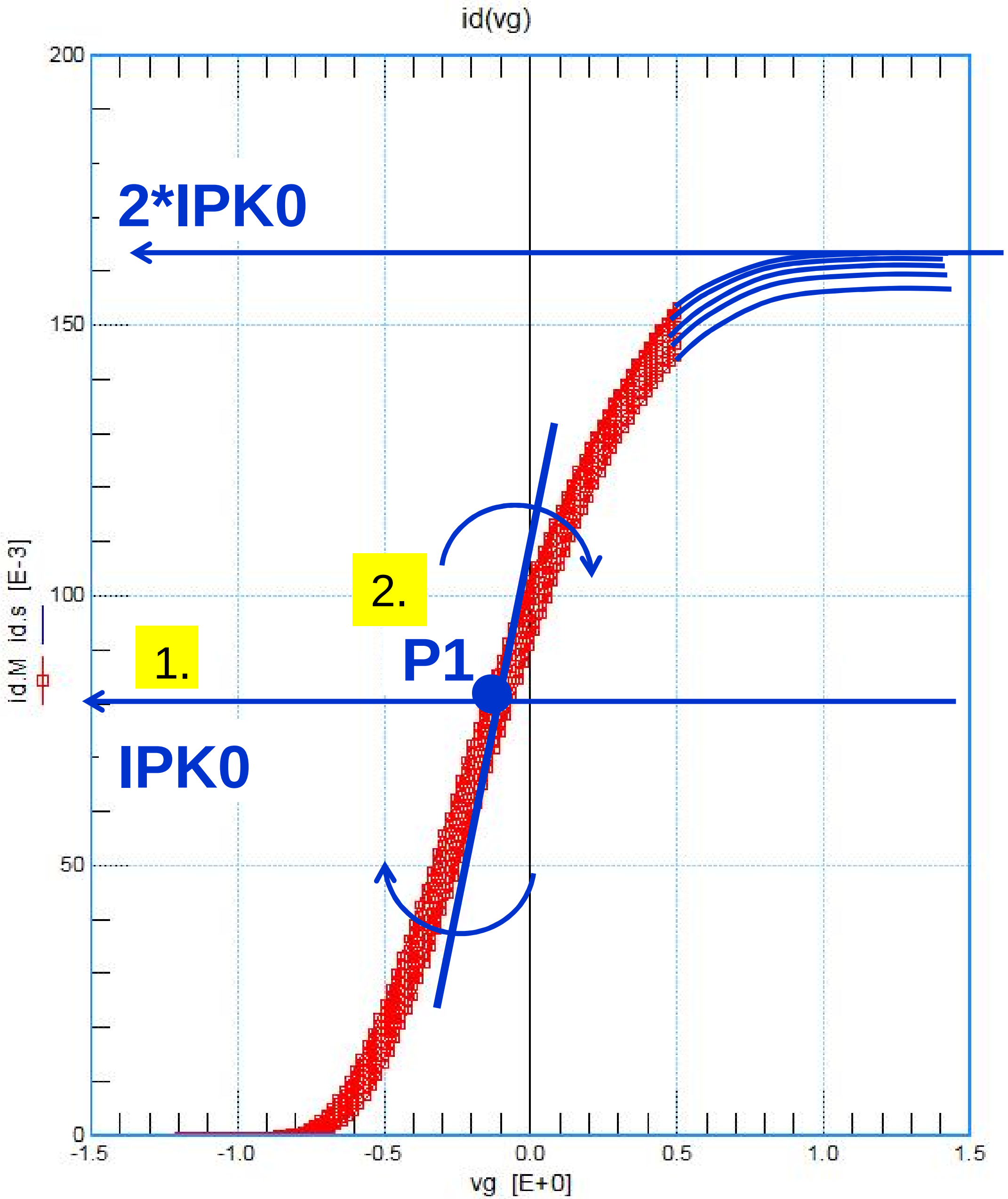
DC Transfer Characteristic
id vs. vg



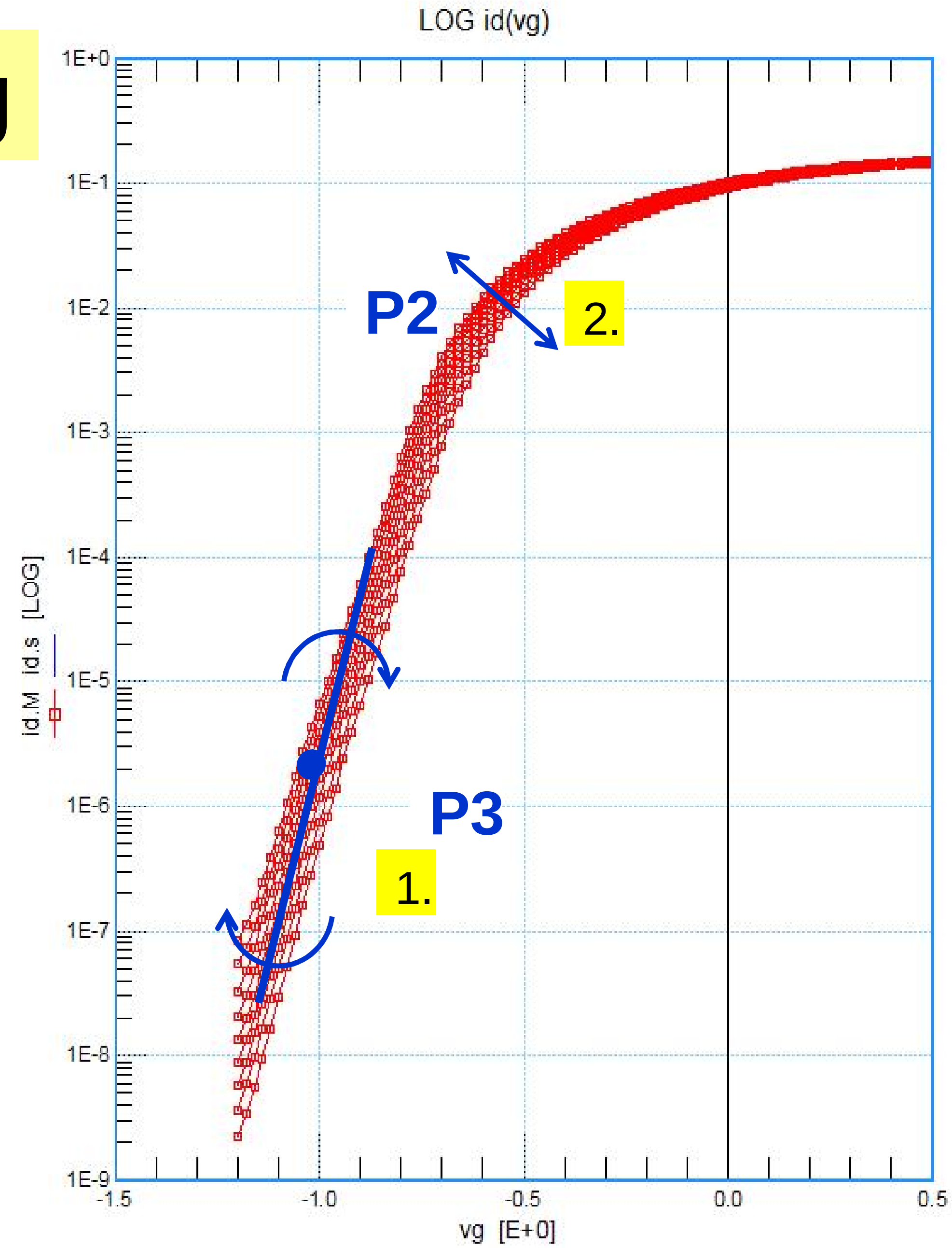
gm vs. vg


gm(vg)
200
150
100
50
0
-1.5
-1.0
-0.5
0.0
0.5
vg [E+0]
gm.m gm.s [E-3]
VPKS
vg voltage at MAX(gm)

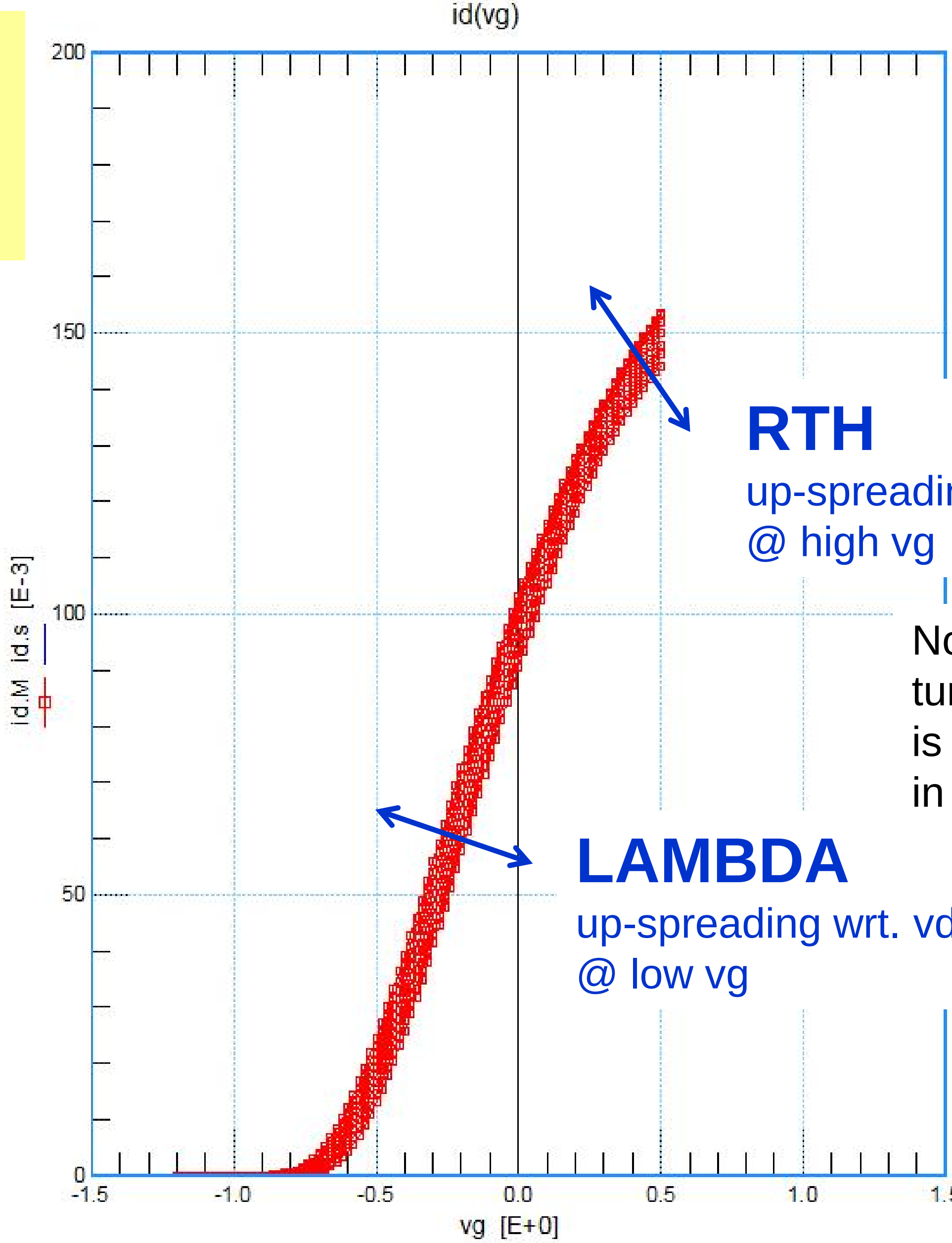
id vs. vg


id(vg)
2*IPK0
2.
1.
P1
IPK0
200
150
100
50
0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
vg [E+0]
id.M id.s [E-3]

LOG(id) vs.vg


LOG id(vg)
1E+0
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
id.M id.s [LOG]
-1.5
-1.0
-0.5
0.0
0.5
vg [E+0]
P2
2.
P3
1.

id vs. vgs
Effect of vds



RTH

up-spreading wrt. vds,
@ high vg

LAMBDA

up-spreading wrt. vds,
@ low vg

Note:
tuning RTH and LAMBDA
is usually more obvious
in Setup id-vd

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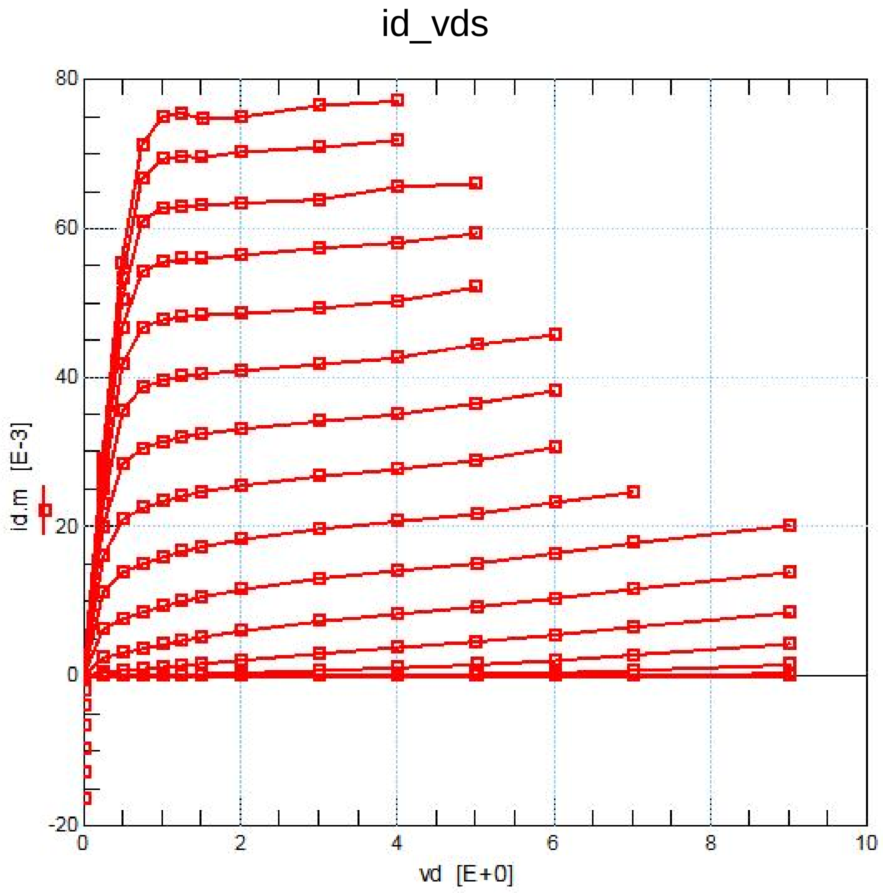
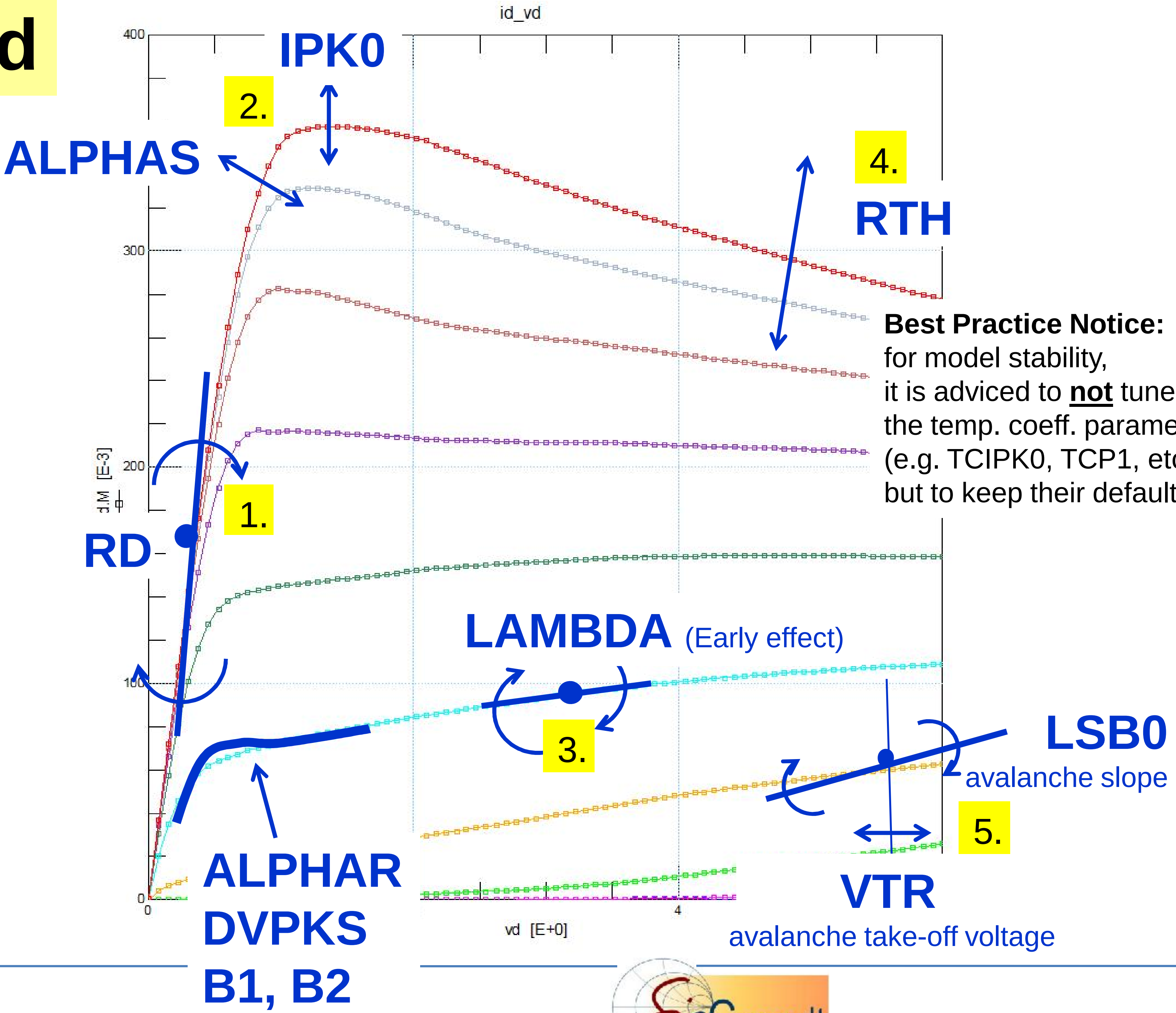
DC Output Characteristic id vs. vd

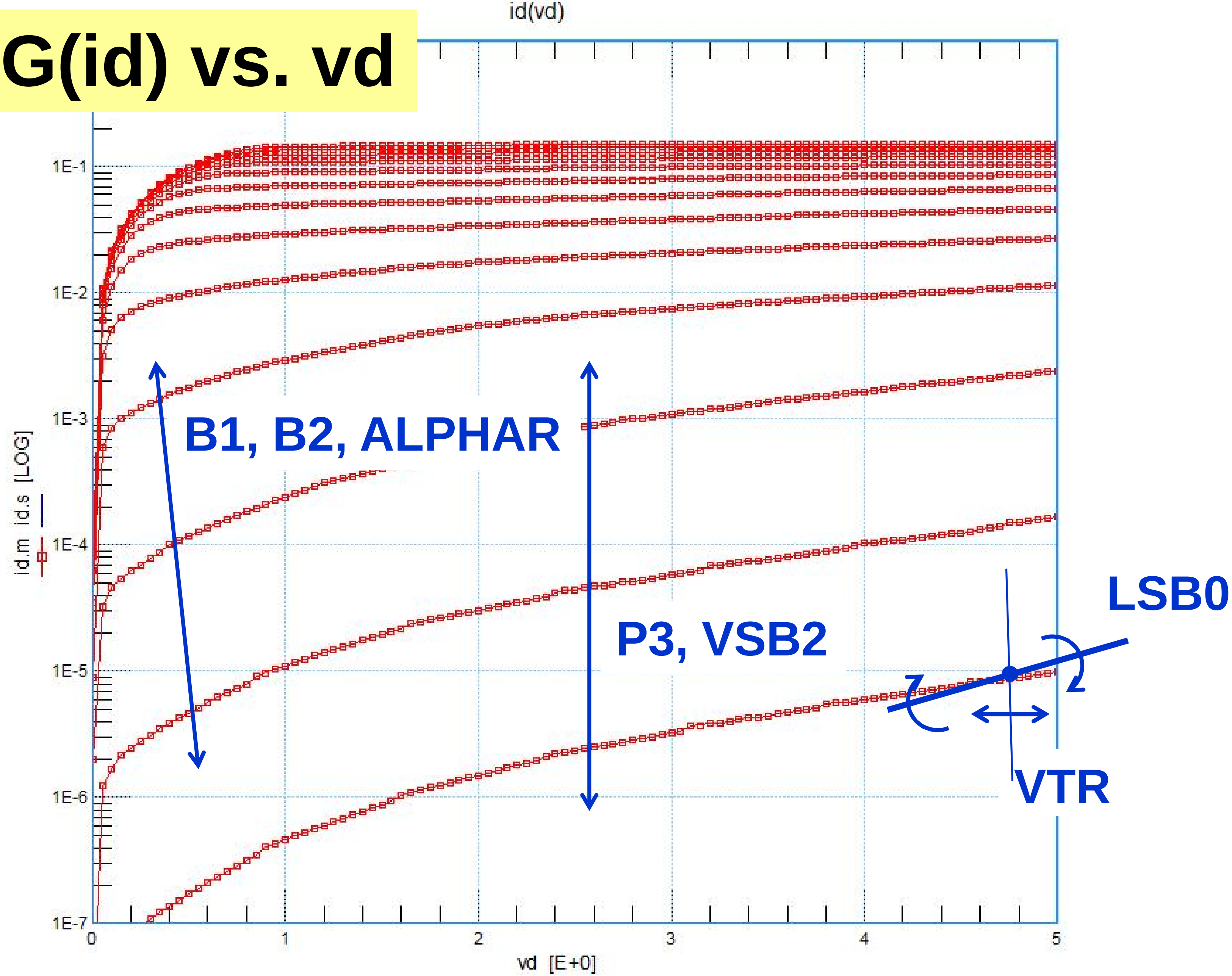


id vs. vd



Best Practice Notice:
for model stability,
it is adviced to **not** tune
the temp. coeff. parameters
(e.g. TCIPK0, TCP1, etc),
but to keep their default values.

LOG(id) vs. vd



id(vd)
1E-1
1E-2
1E-3
1E-4
1E-5
1E-6
1E-7
id.m id.s [LOG]
0
1
2
3
4
5
vd [E+0]
B1, B2, ALPHAR
P3, VSB2
LSB0
VTR

- **Step-by-Step Modeling Sequence**
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A Note on Thermal Modeling

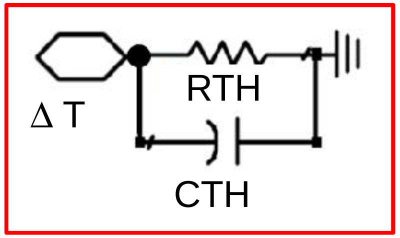
Device Temperature Rise

$\Delta T = RTH * Dissipated\_Power$

Device Temperature

$T_{Dev} = TEMP + \Delta T$

thermo-electrical circuit
for the self-heating modeling



CTH models the thermal storage

Usually: RTH * CTH = 1ms

If you don't know CTH, set CTH = 1E-3 / RTH

Never set CTH=0 !!!

Otherwise, your model is thermally faster than electrically !

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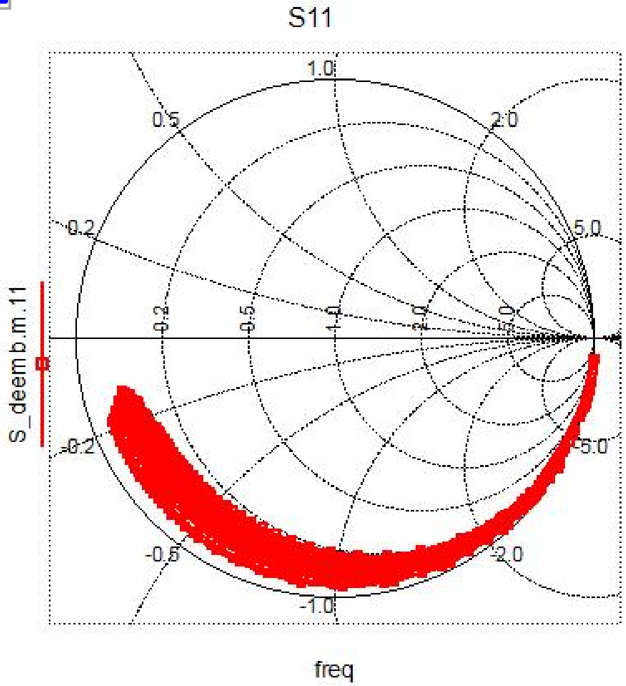
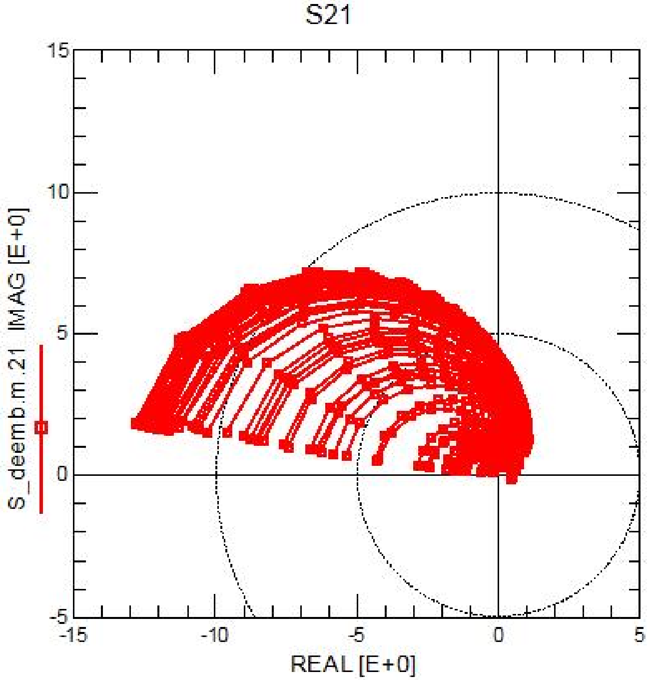
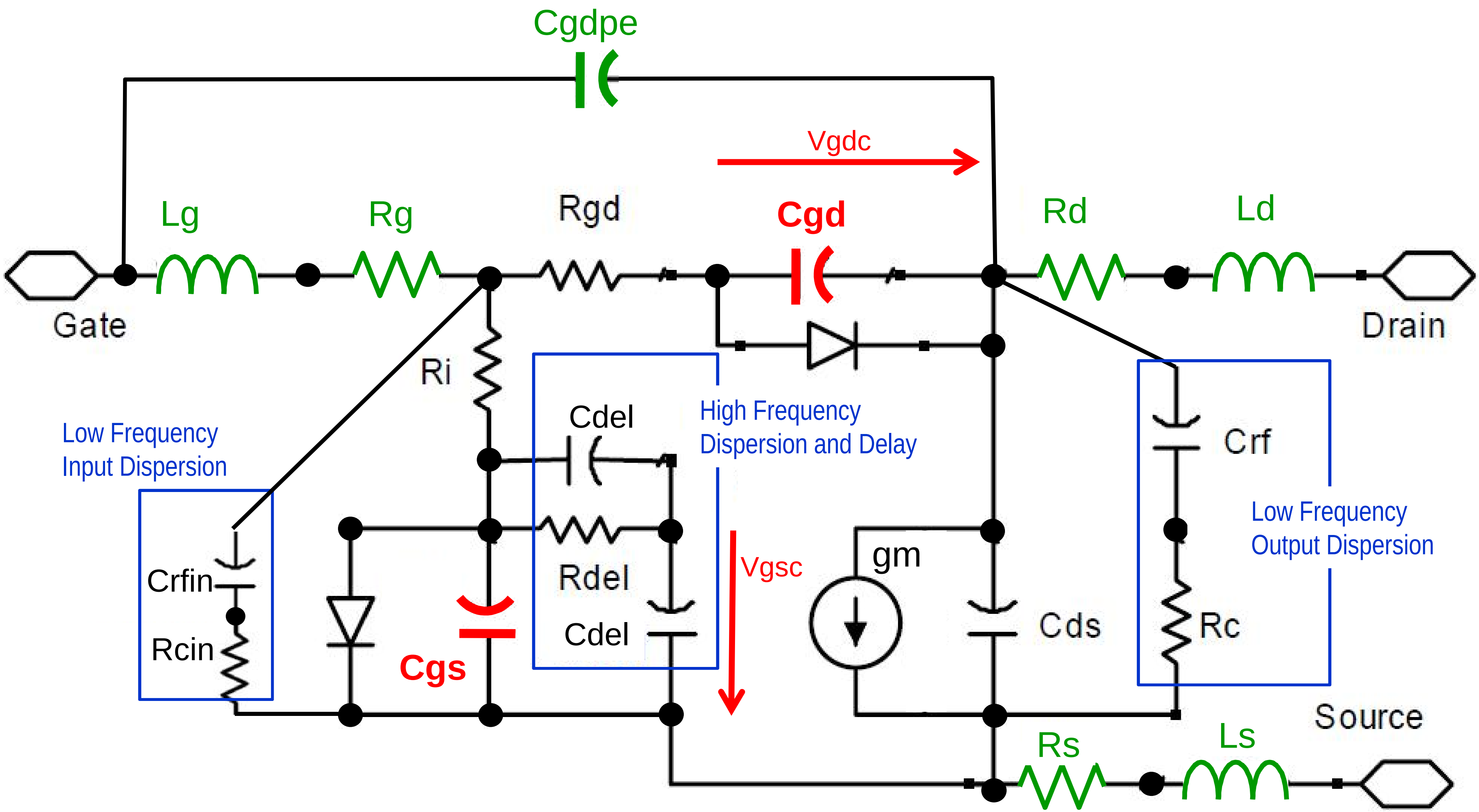
S-Parameter Modeling



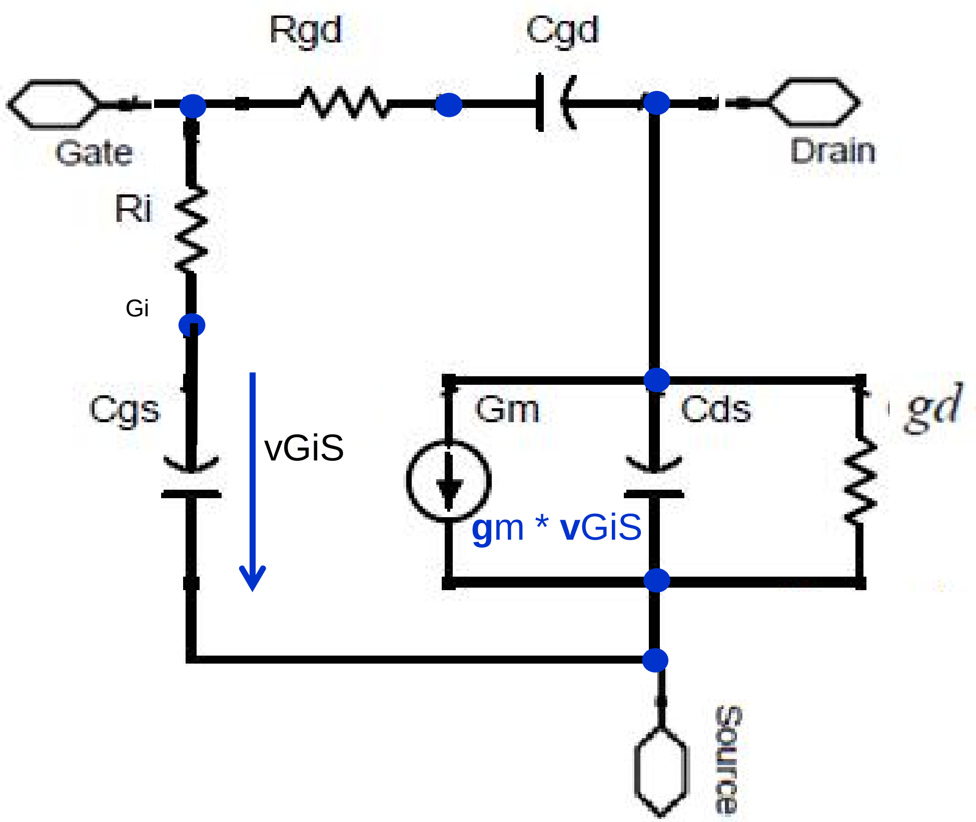


Full AC Schematic



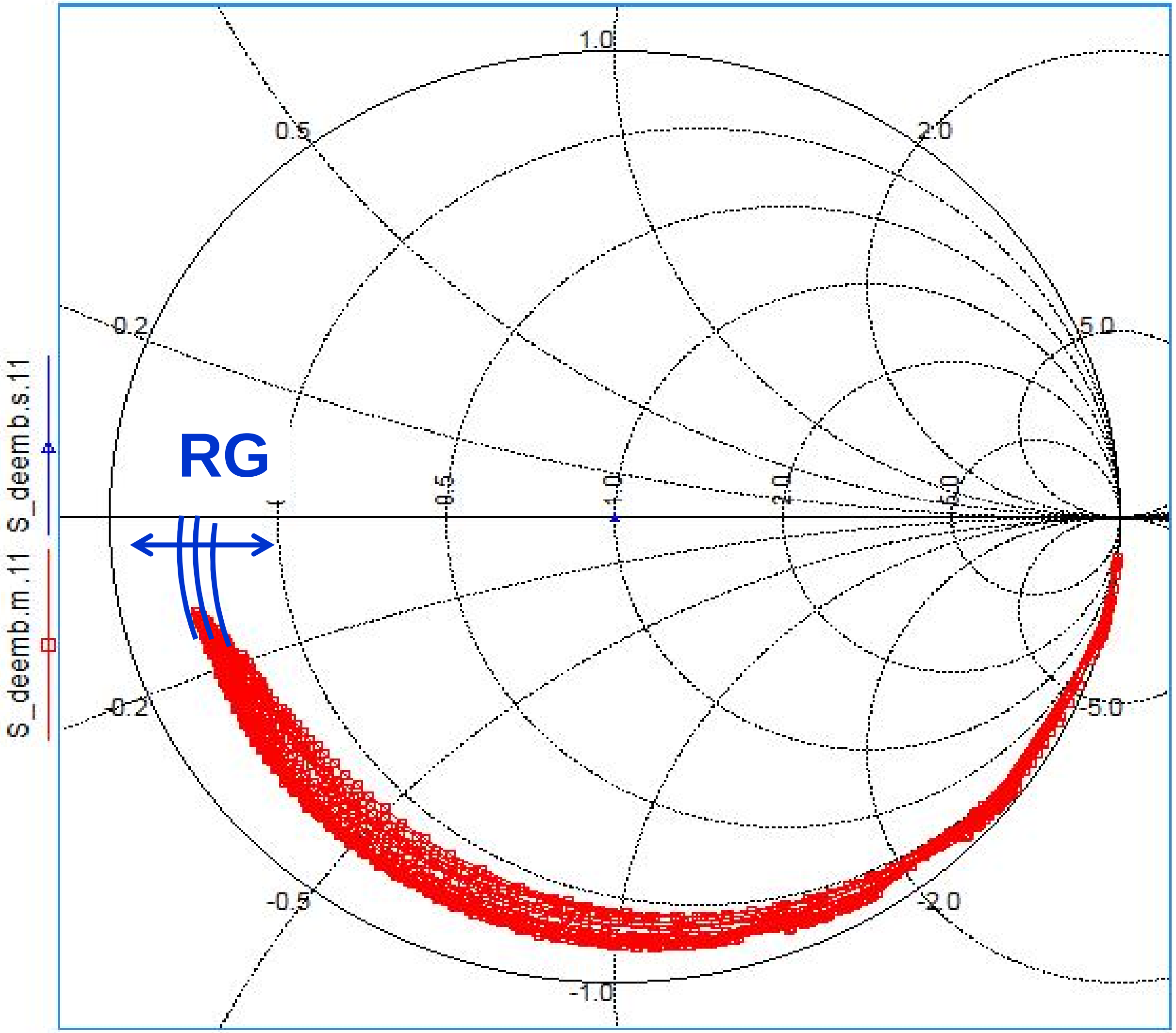
Note: Vgsc and Vgdc are the internal node control voltages
for the bias-dependent capacitances **Cgs** and **Cgd**

Simplified Inner PI AC Schematic



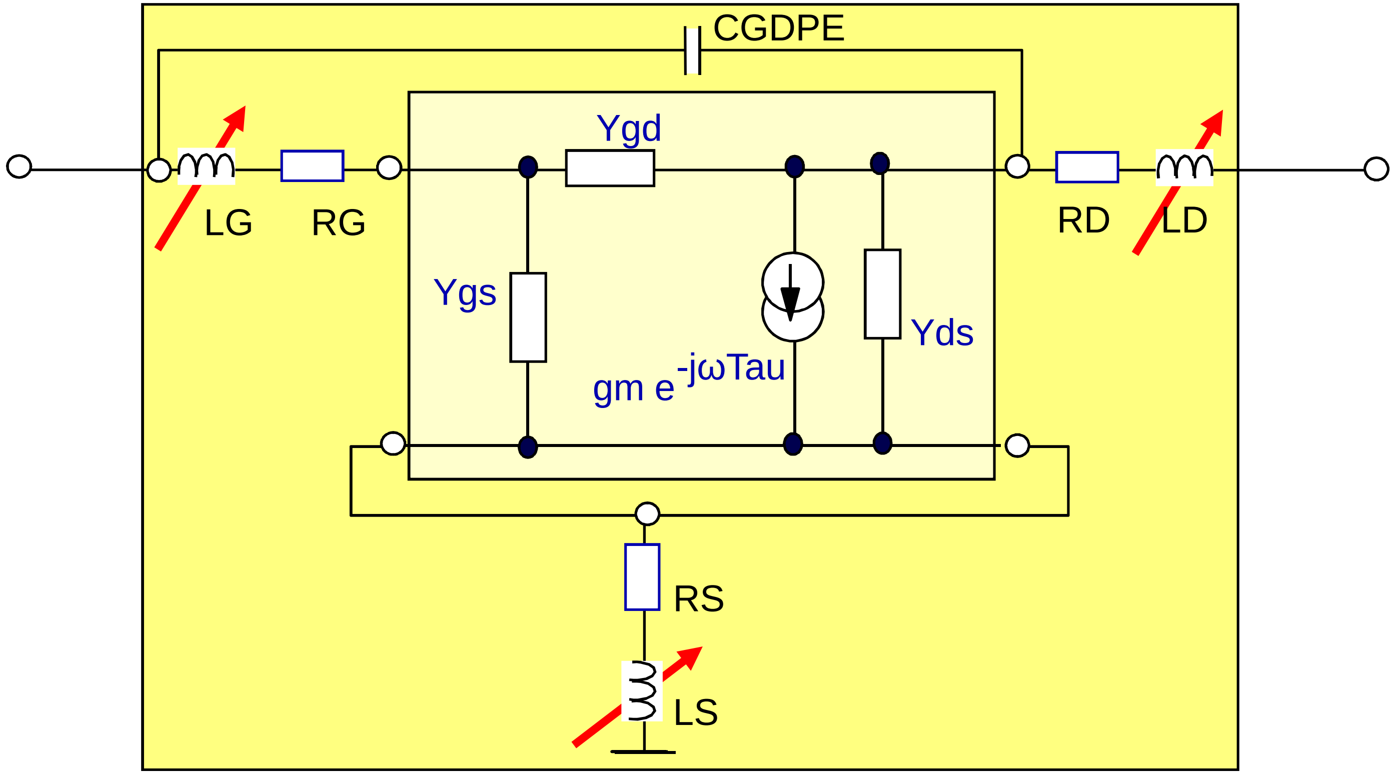
RG

S11



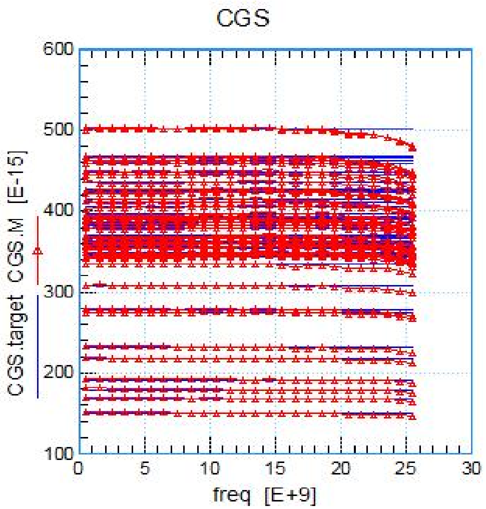
Adjust the extrinsic inductors LG, LD and LS

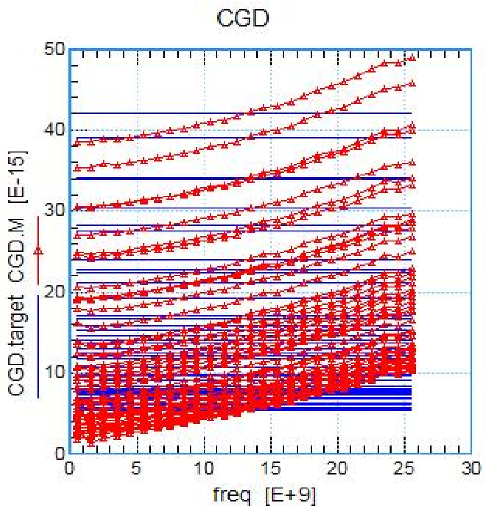
to make intrinsic parameters as freq. independent as possible

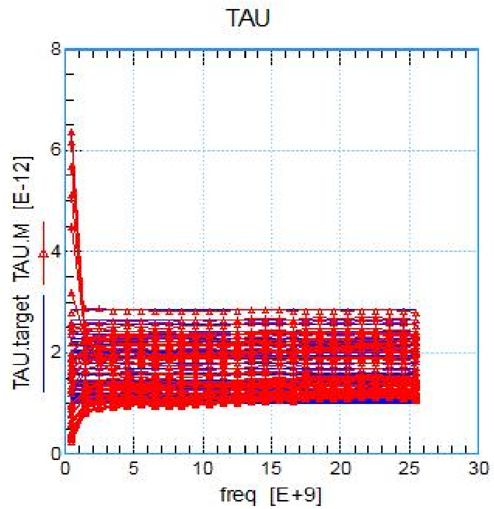


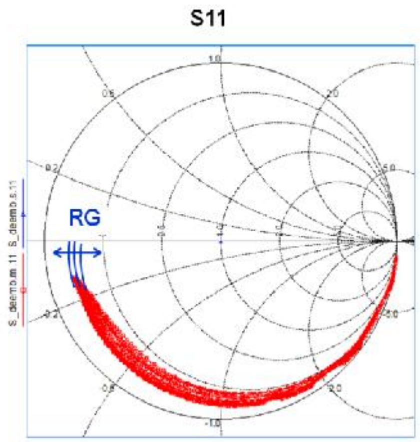
For details, see next slide

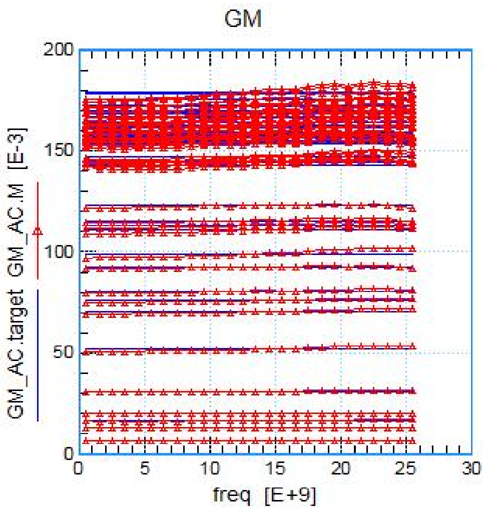
External Inductors

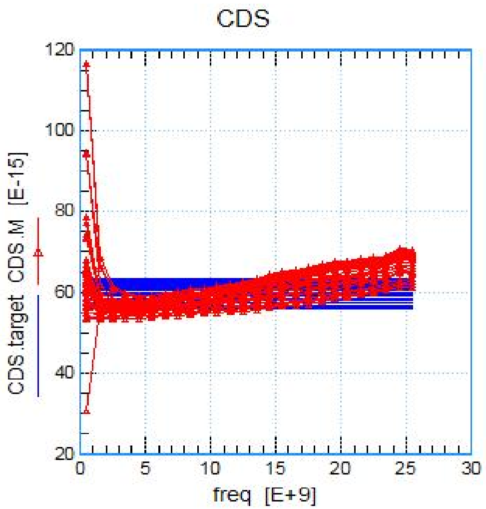












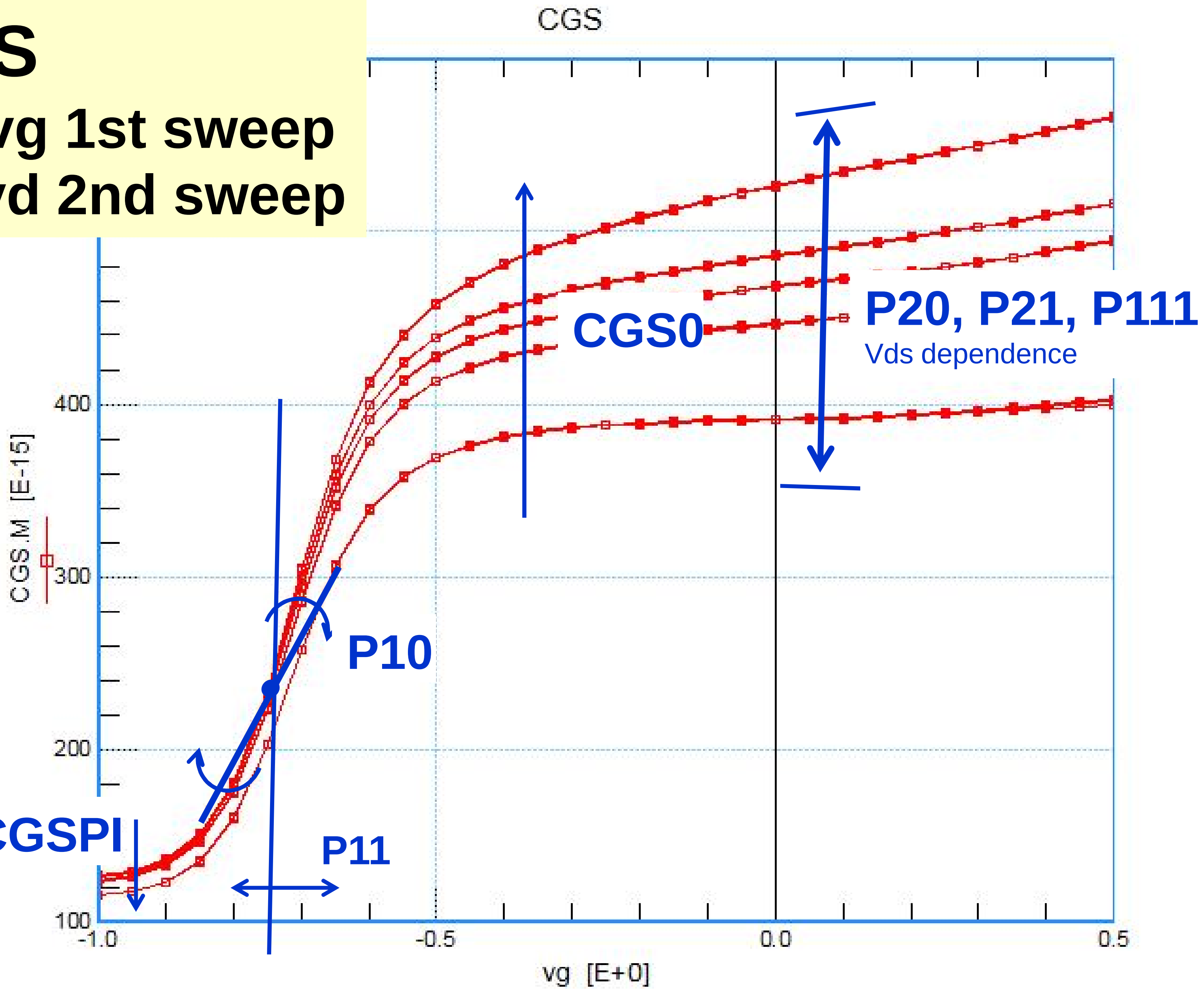
adjust extrinsic
LG, LD, LS

(and also RG, but keep an eye on simulated S11!**)**

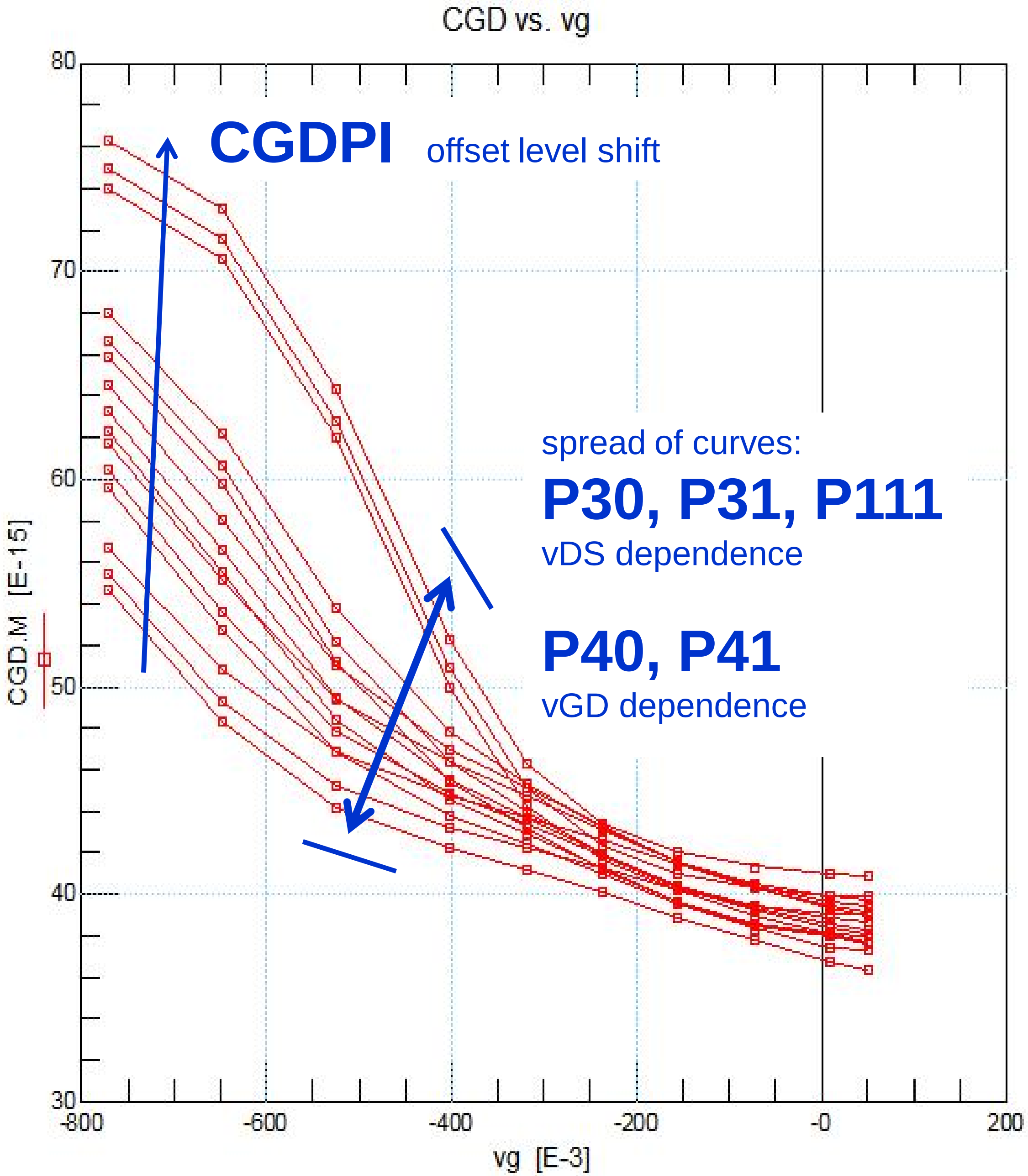
to make the intrinsic parameters as freq. independent as possible

Note: RD and RS have been fitted in DC id-vd

CGS
@ vg 1st sweep
vd 2nd sweep

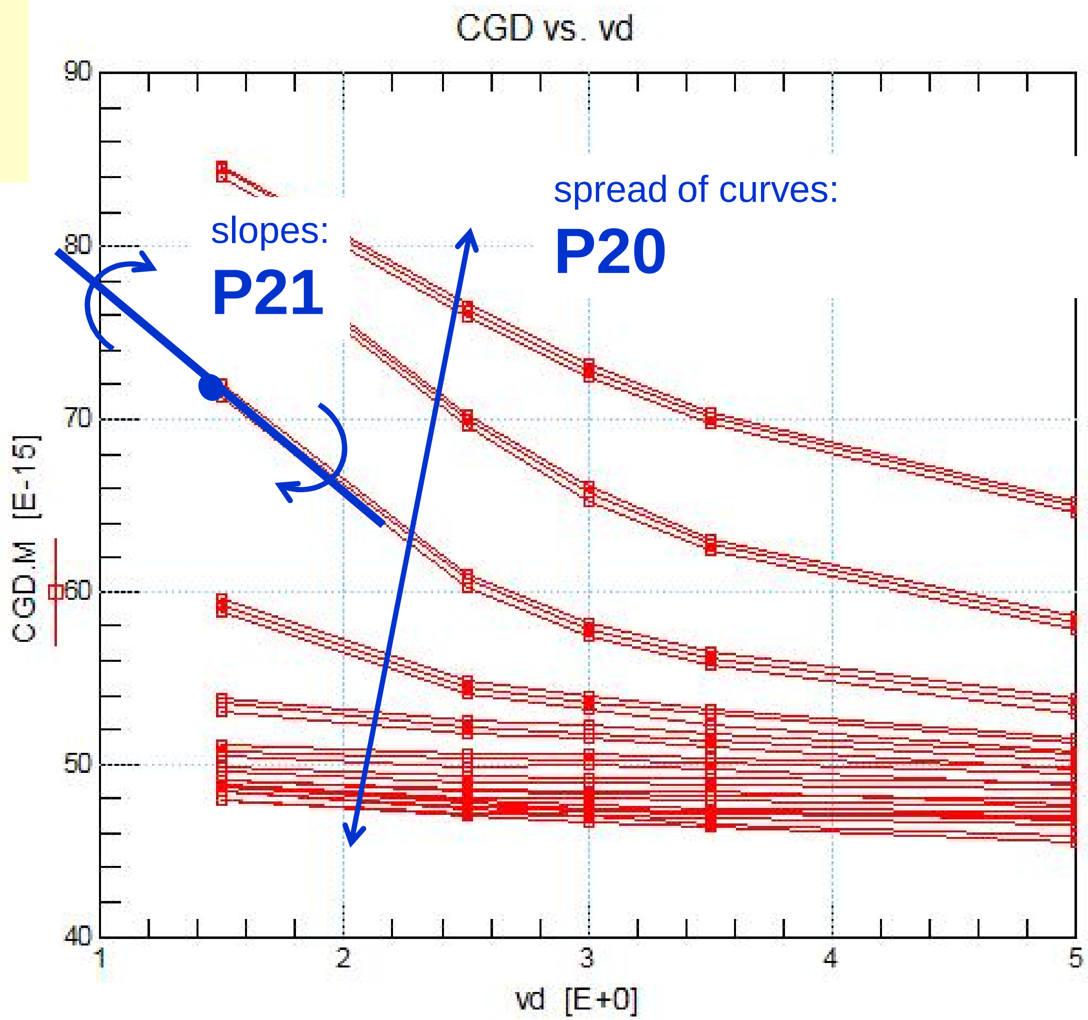


CGD
@ vg 1st sweep
vd 2nd sweep



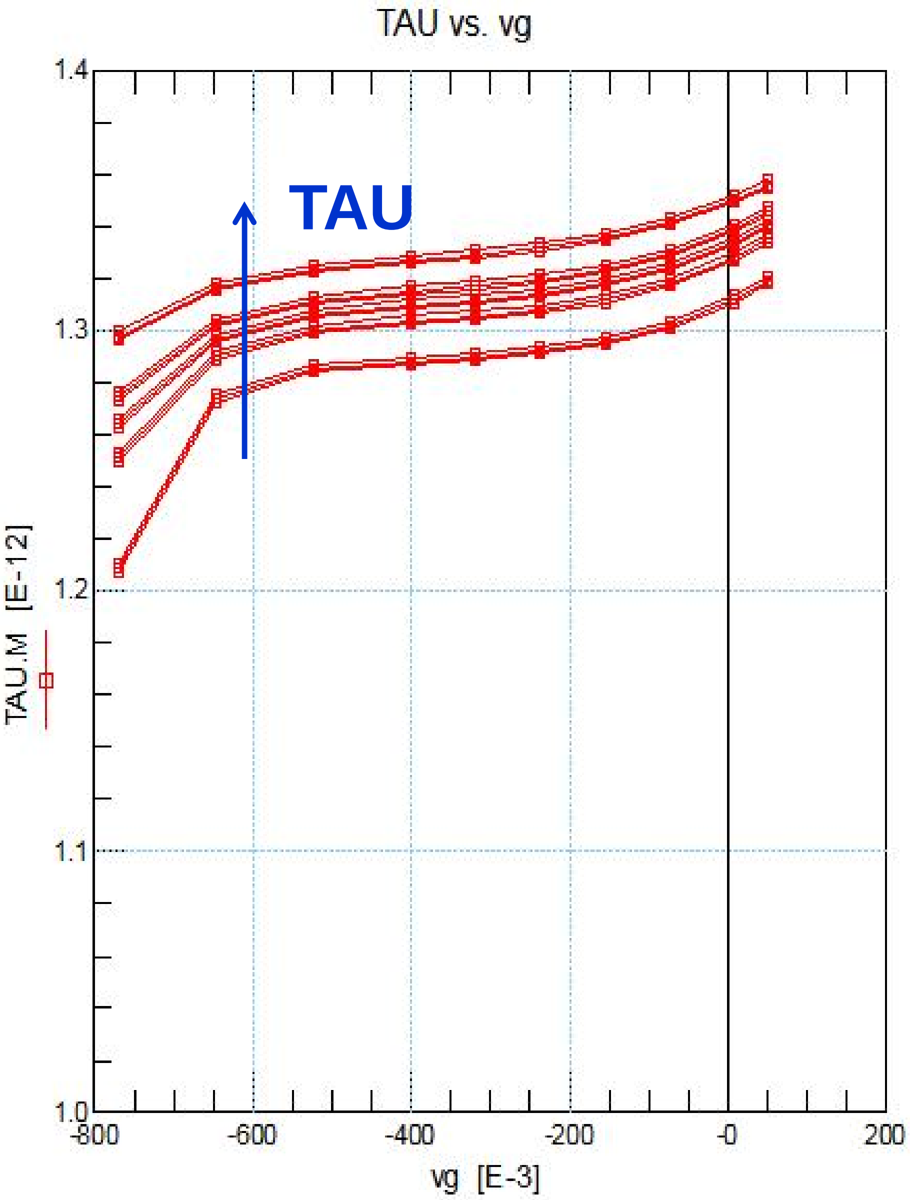
CGD

@ vd 1st sweep
vg 2nd sweep



TAU

@ vg 1st sweep
vd 2nd sweep



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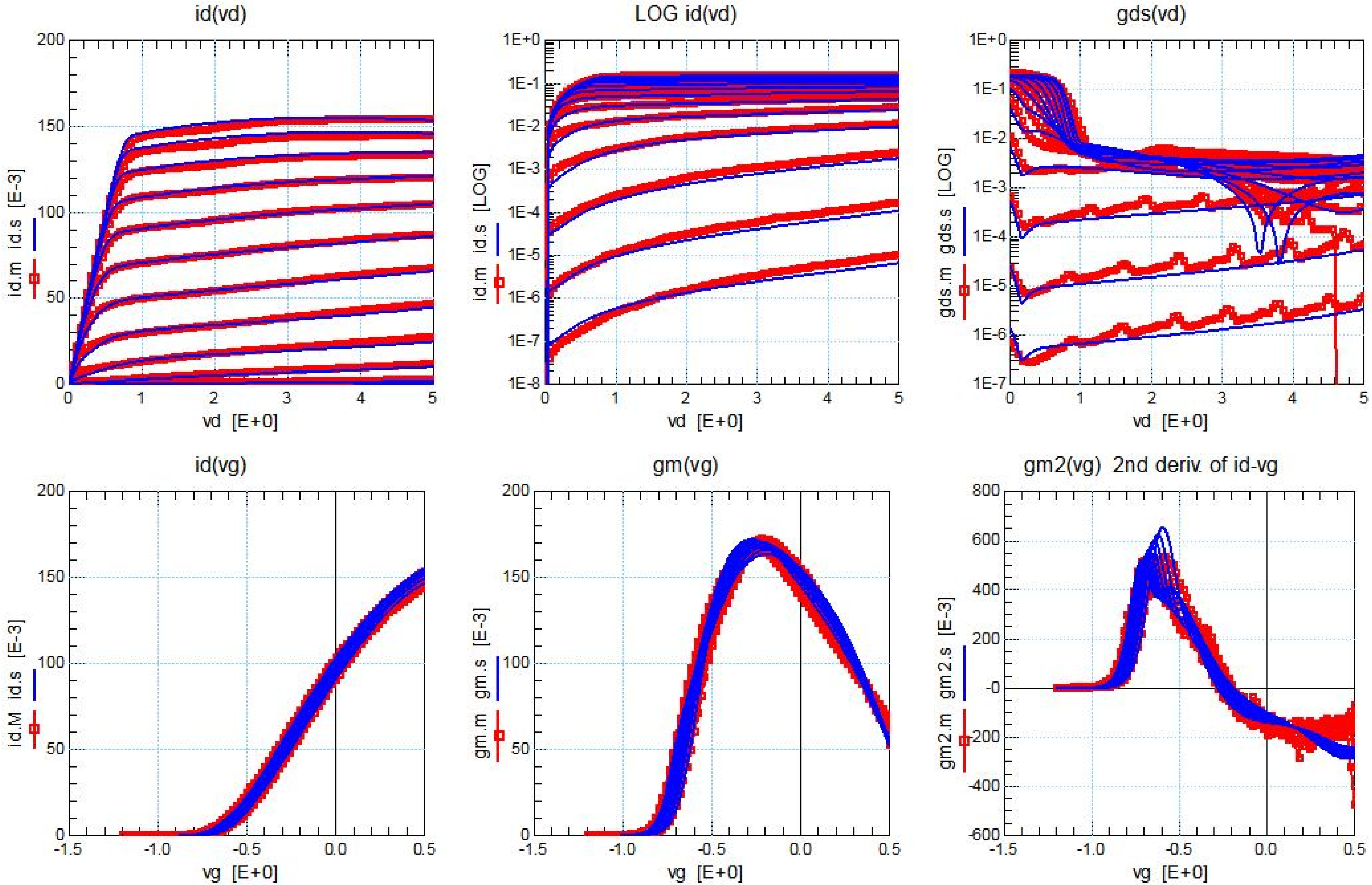
  Thermal Modeling

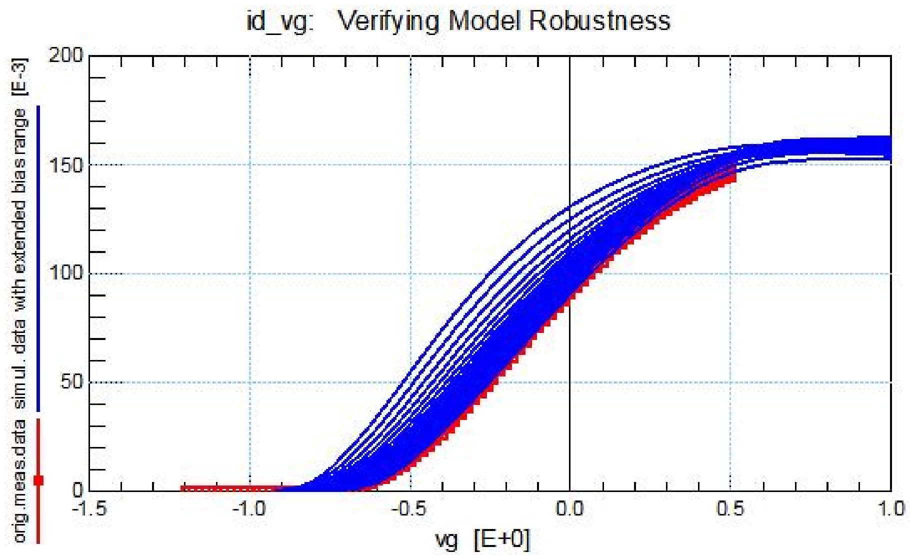
  S-Parameter Modeling
- **Modeling Results**

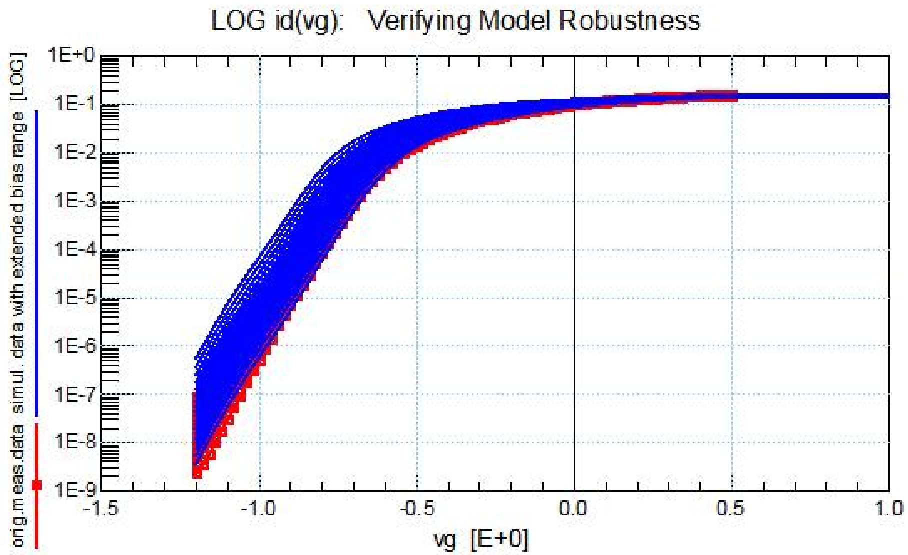
DC Modeling Result

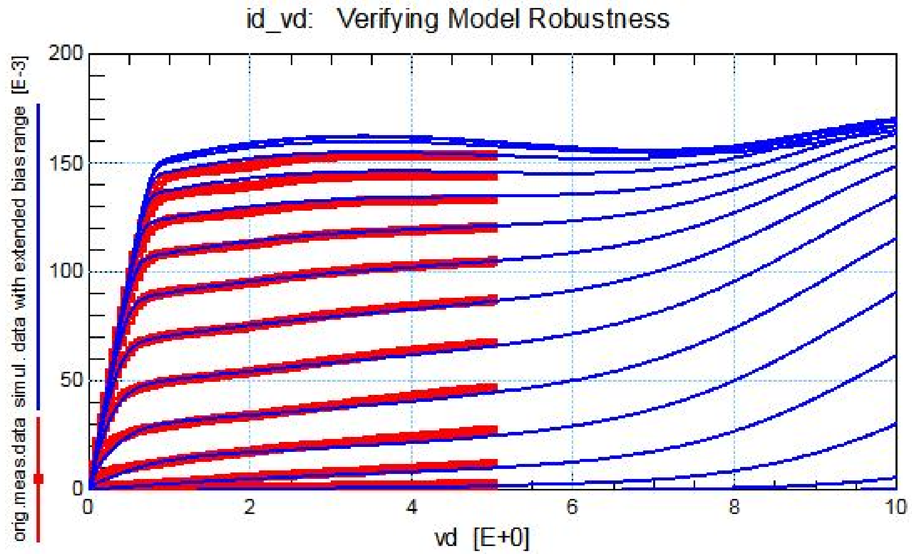


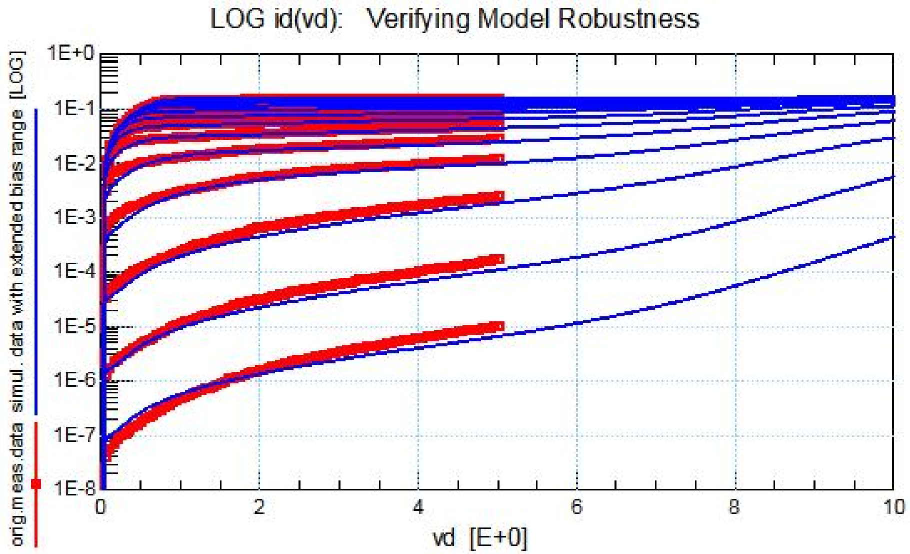
Model Robustness Check

measurements
extended simulation range

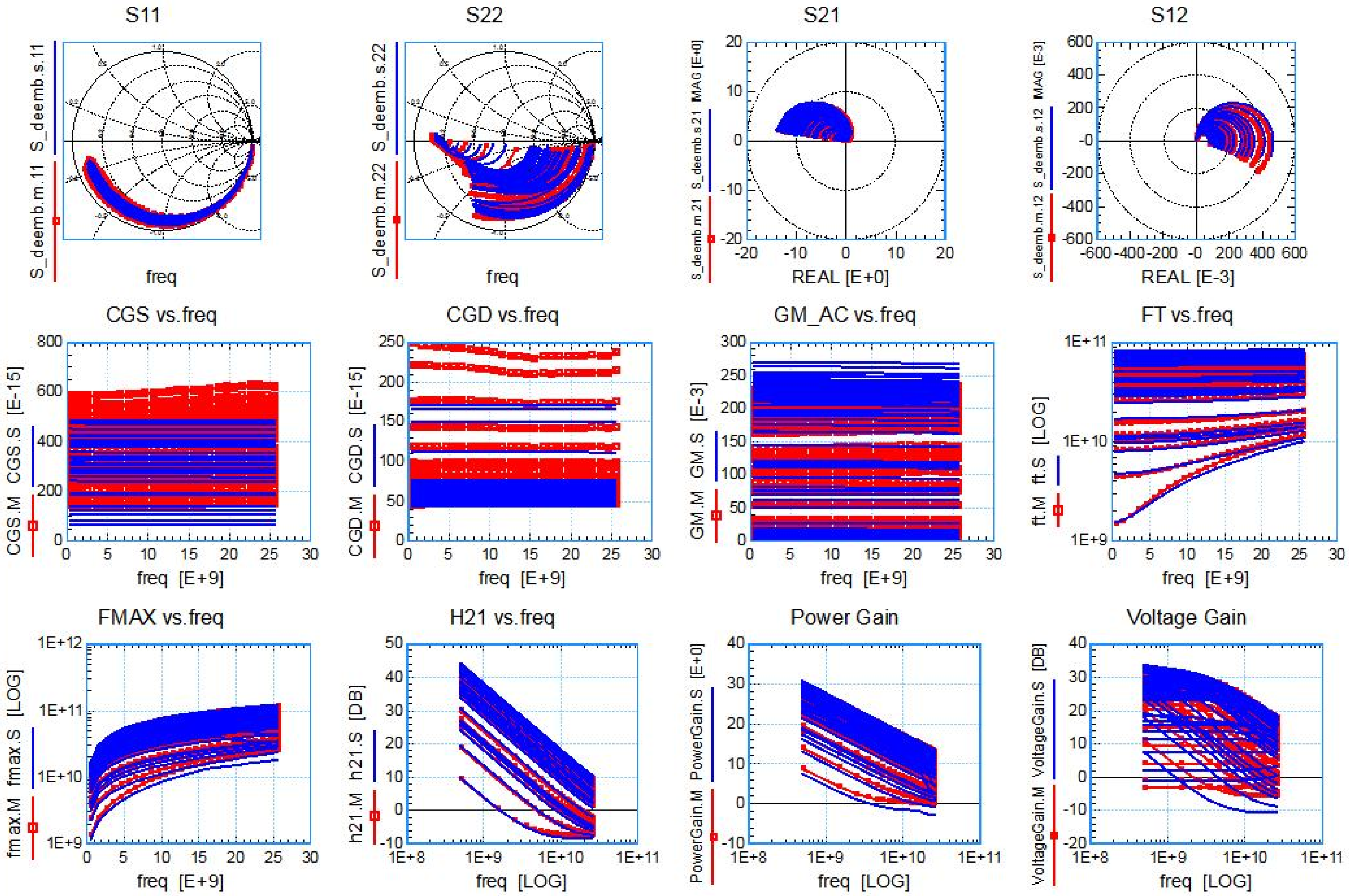








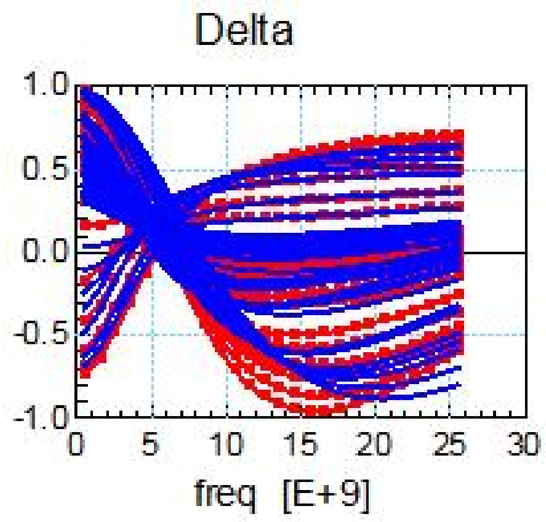
S-Parameter Modeling Result

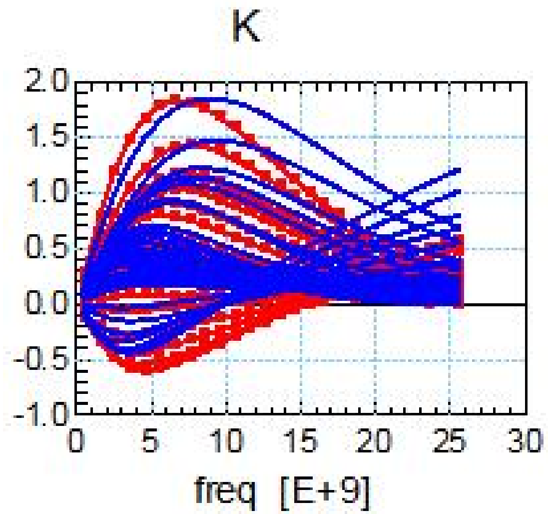


Stability K-Factor Check

$$\Delta = S_{11} \cdot S_{22} - S_{12} \cdot S_{21}$$

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2 \cdot |S_{21} \cdot S_{12}|}$$





The Stability Factor K, together with its determinant Δ part, are a good measure to check the fitting of simulated to measure data of all four S-parameters, in a single plot.

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