Experiences with Using

the ASM-HEMT Model for III/IV HEMTs

SisConsult
Ingenieurbüro - Engineering Office
Dr.-Ing. Franz Sischka
Consulting Services
for Electronic Device
Measurements,
Data Verification
and Modeling
www.SisConsult.de

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Outline

- **Introduction to the Model**
- DC Modeling
- S-Parameter Modeling
- **Conclusions**

The Concept of the ASM Model

1. Starting Point: ideal device

physics-based core channel-charge
and surface-potential calculations

2. Adaption for Simulation Speed:

approximated equations for terminal current and charge

3. Adding of additional models for real device effects.

The Concept of the ASM Model in Details

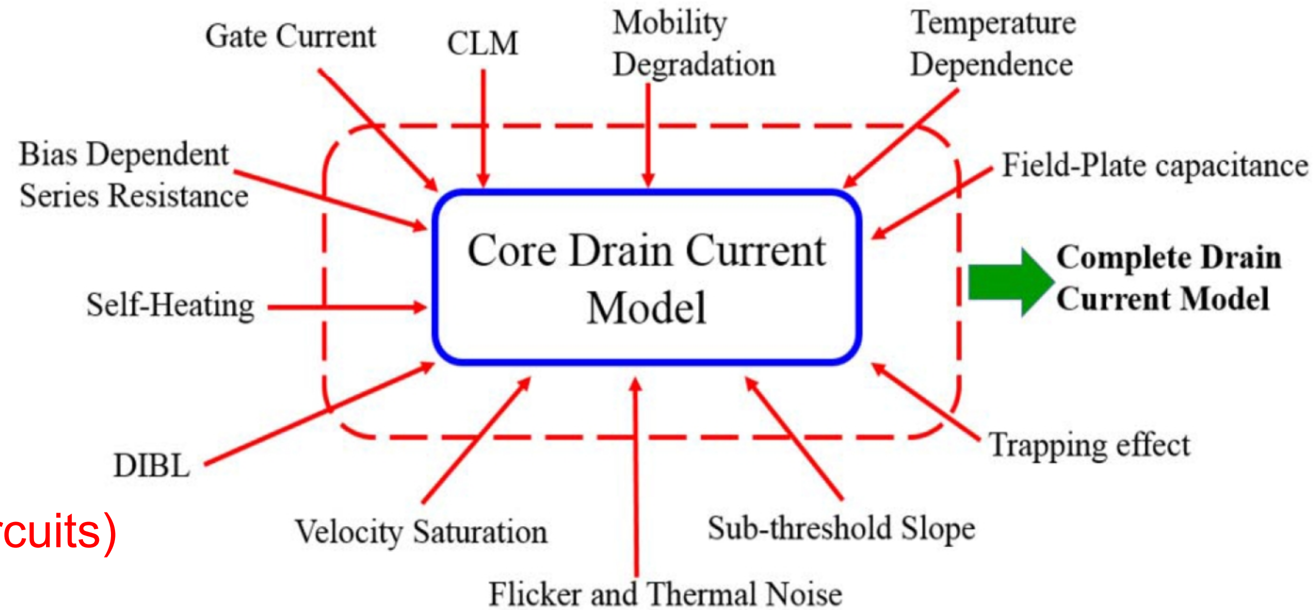
S.Khandelwal:

- The ASM-GaN-HEMT is a physics-based model.
  The core of it is the formation of the *ideal*, 2-dimensional charge density, described by:
  -> transcendental equations based on Schrödinger, Poisson, Fermi.

- To achieve simulation speed, these complex equations are approximated by a single, unified and highly accurate expression, resulting in a fully analytical solution for Id, and *still ideal device*.

- to cope with real devices, several *effects are added* to the ideal core model:

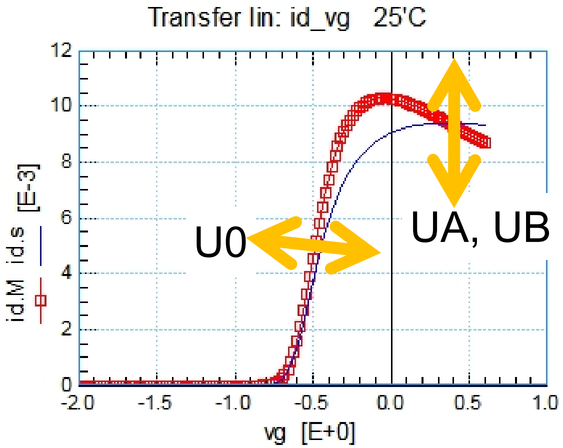
- gate current
- mobility field dependence
- drain-induced barrier lowering
- subthreshold-slope degradation
- non-linear series resistances
- channel-length modulation
- velocity saturation effect
- self-heating effect
- temperature dependence
- trapping (by RC network sub-circuits)
- flicker and thermal noise



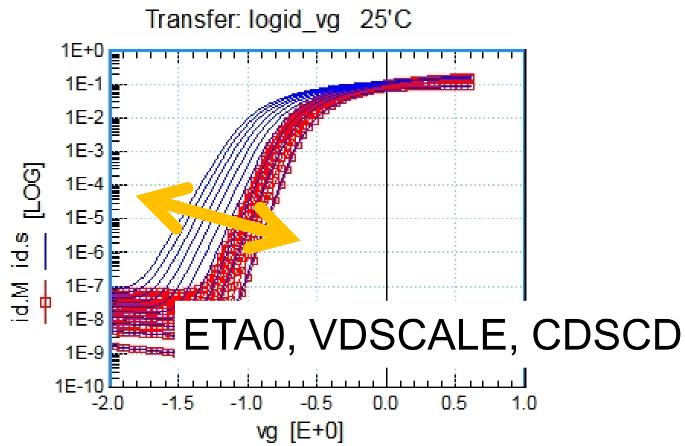
from ASM-HEMT 101.0.0 Technical Manual

Added Real-Device Effects in Details

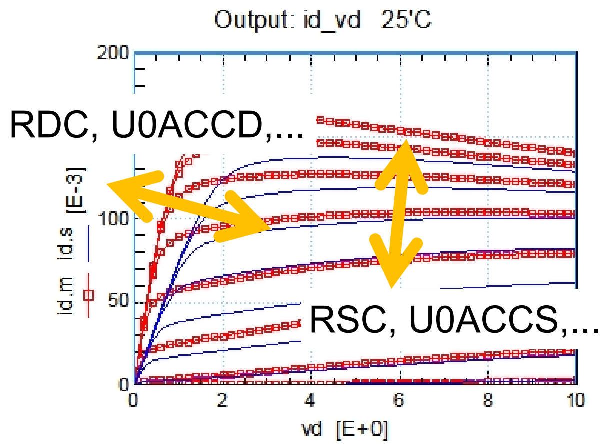
Mobility Dependence



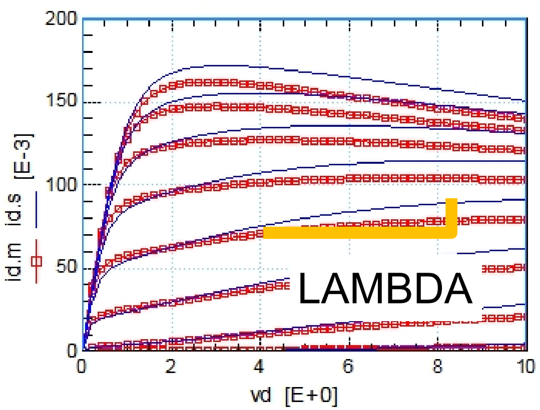
Drain Induced Barrier Lowering (DIBL) and Sub-Threshold Slope Degradation



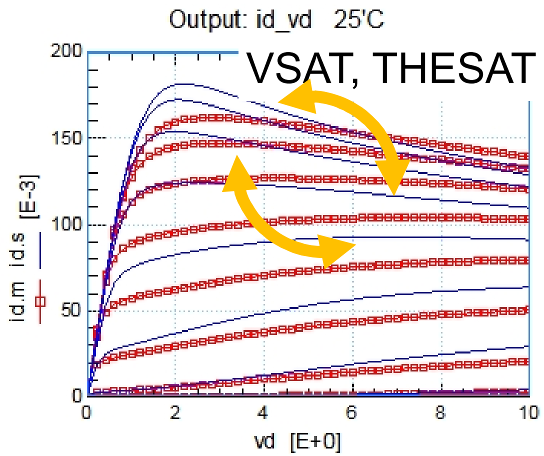
Nonlinear RD & RS



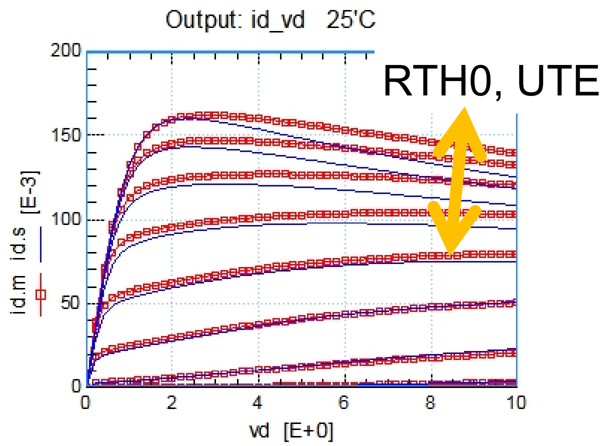
Channel Length Modulation (CLM)



Velocity Saturation



Self-Heating



Added Real-Device Effects in Details (Cont'd)

Charge is modeled by DC !!!

No Specific Parameters for Bias-Dependence of S-Parameter Capacitances !!!

You may achieve pretty the same DC fitting by two or more different DC parameter sets, but only one of them is fitting the S-parameters and its capacitances !

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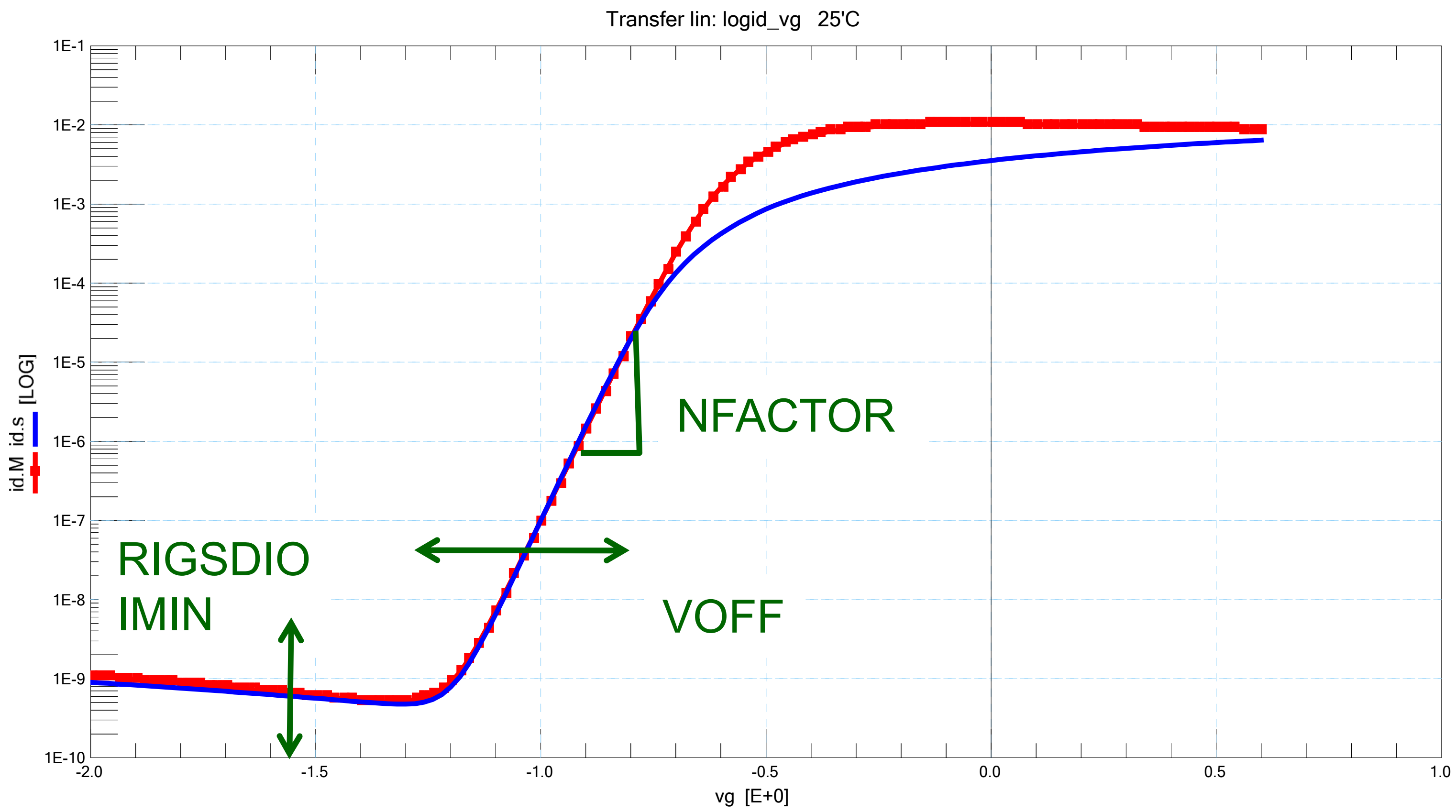
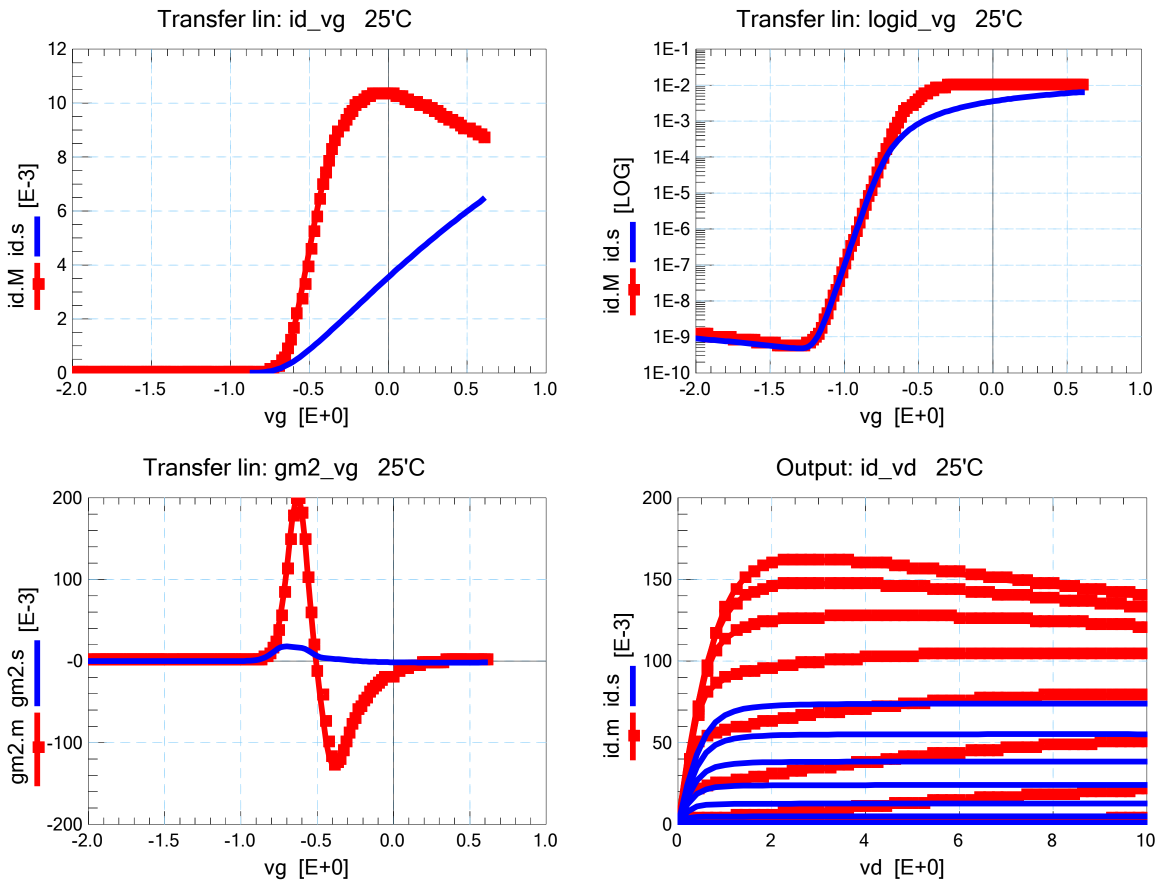
DC Modeling id-vdlin: **Sub-Threshold**



measured
modeled

DC Modeling id-vdlin: **Above Threshold**

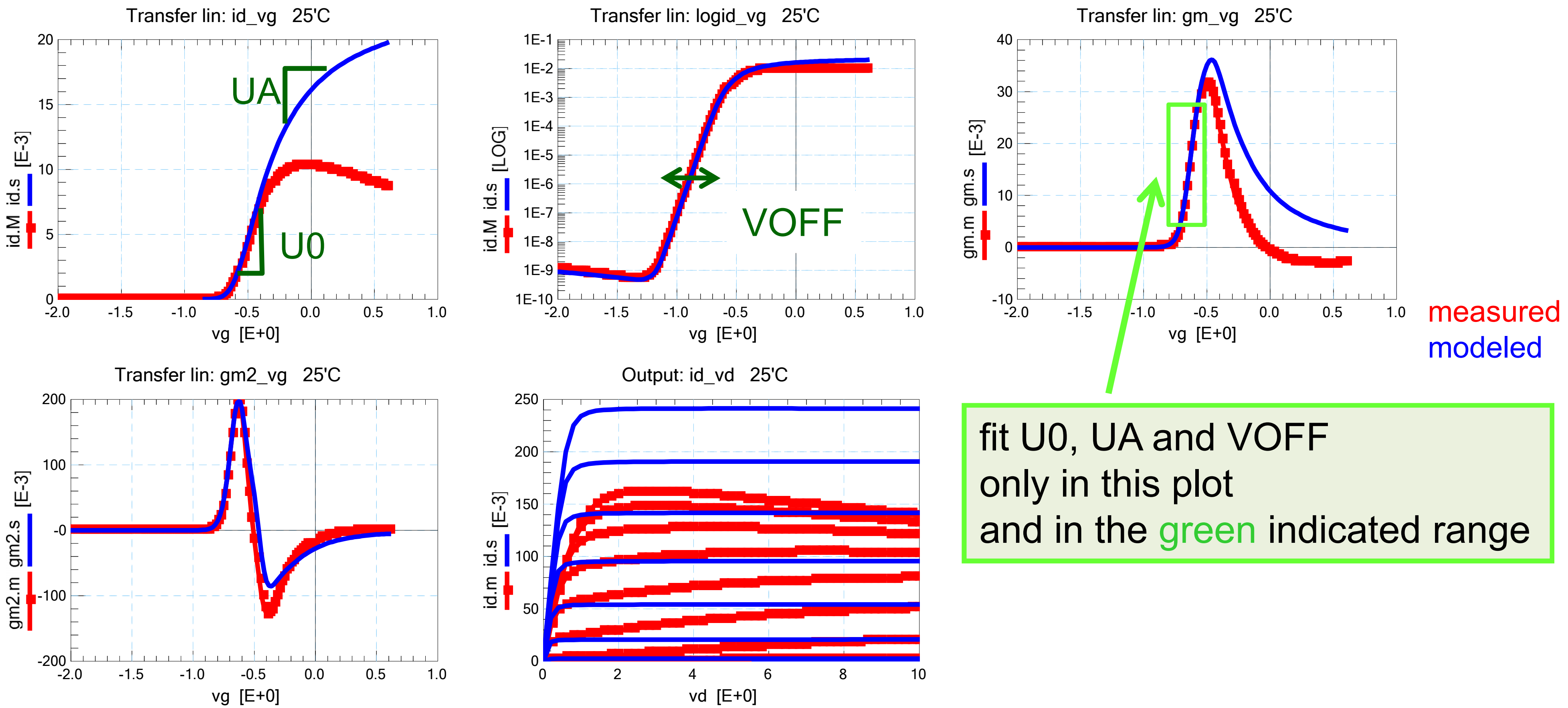
Starting Condition:



measured
modeled

DC Modeling id-vdlin: **Above Threshold**

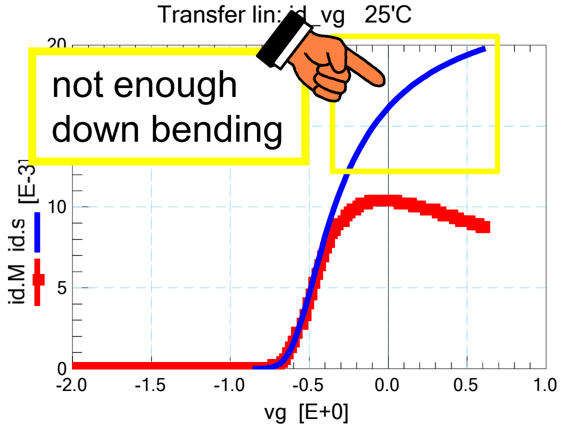
Step 1:

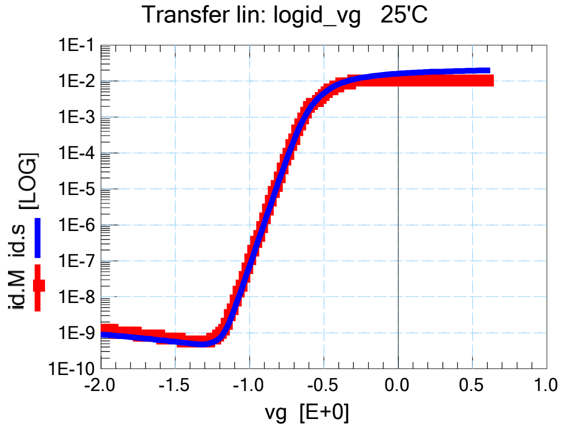


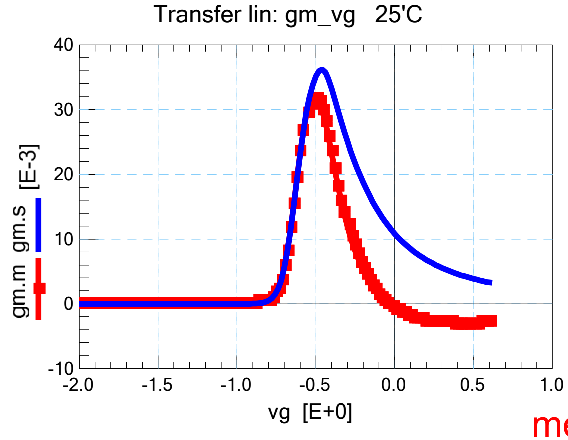
DC Modeling id-vdlin: **Above Threshold**

Step 2:

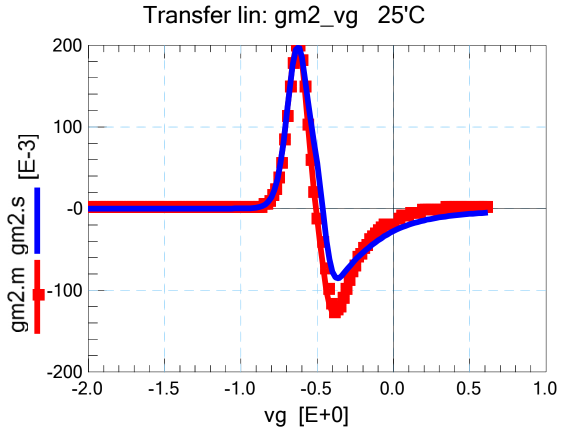
Inspect id-vg and the knee of id-vd:
- ➢ If id is not bent enough in id-vg, and if also id-vd measurement shows id-compression for high id range, tune also UB.
- ➢ Otherwise, keep UB = 0.

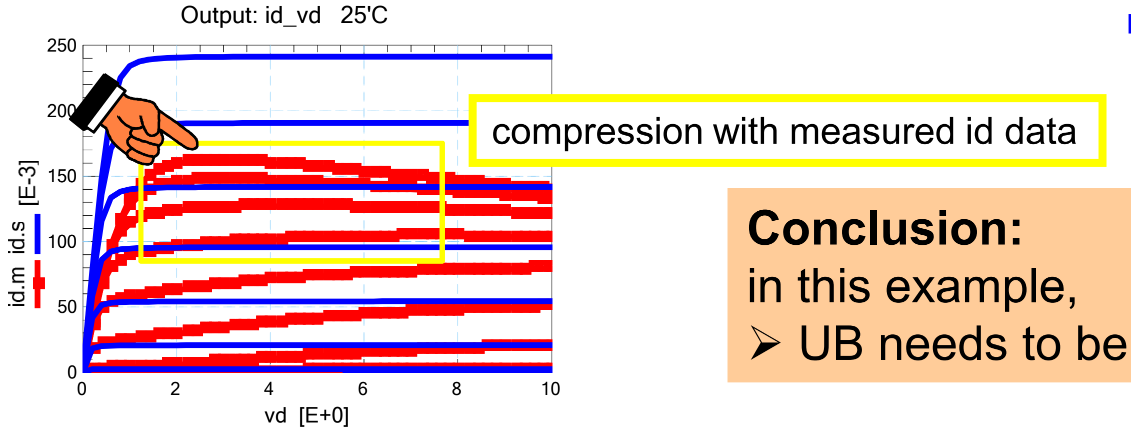






measured
modeled



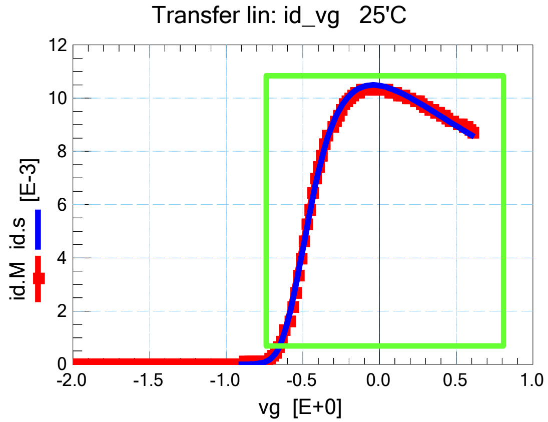


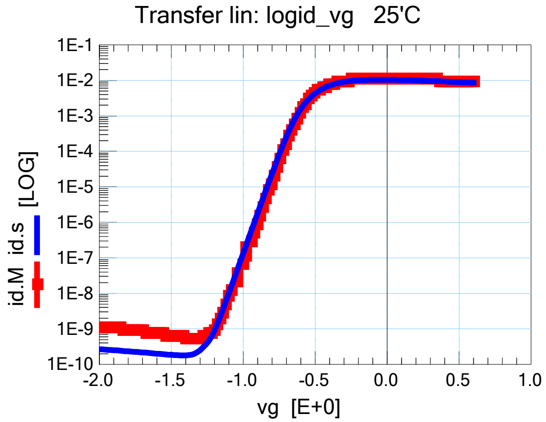
Conclusion:
in this example,
- ➢ UB needs to be tuned !!!

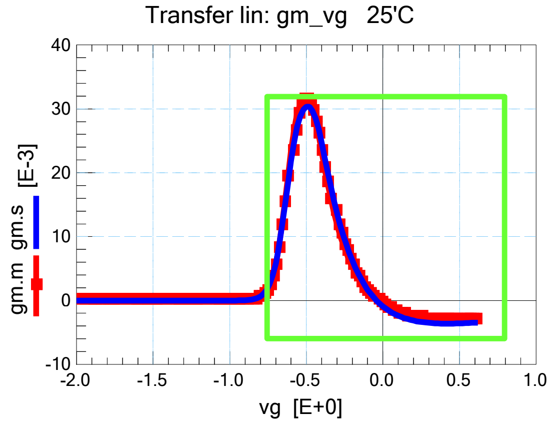
DC Modeling id-vdlin: **Above Threshold**

Step 3:

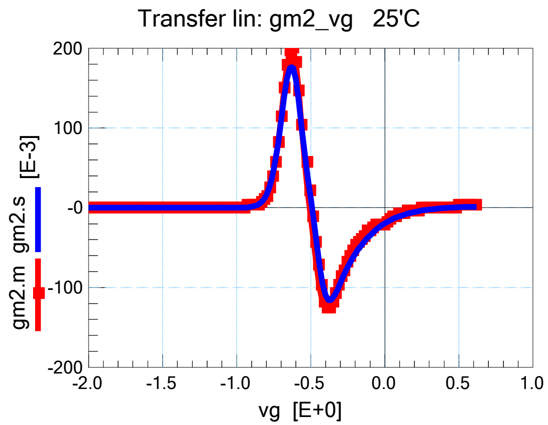
- Tune UB in both, id_vg and gm_vg plots,
  and keep an eye on id-vd plot.
- If you cannot fit id_vg completely,
  tune UB so that the end points at MAX(vg) match

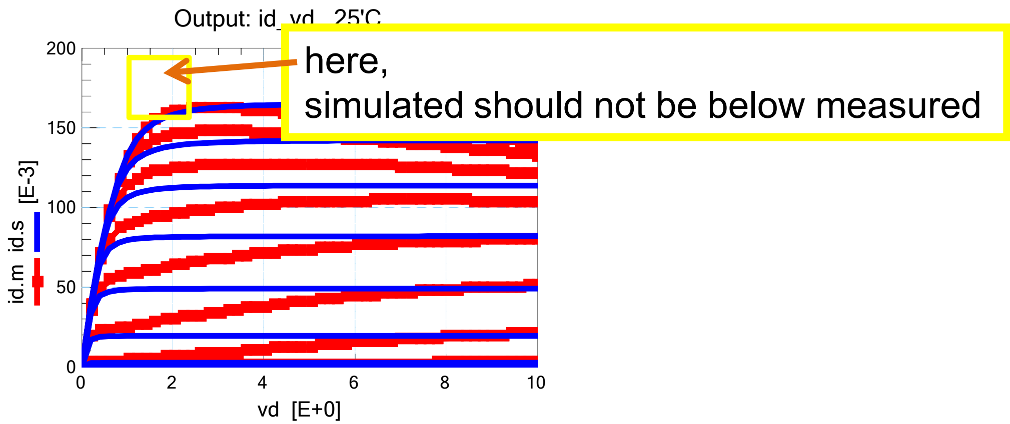






measured
modeled





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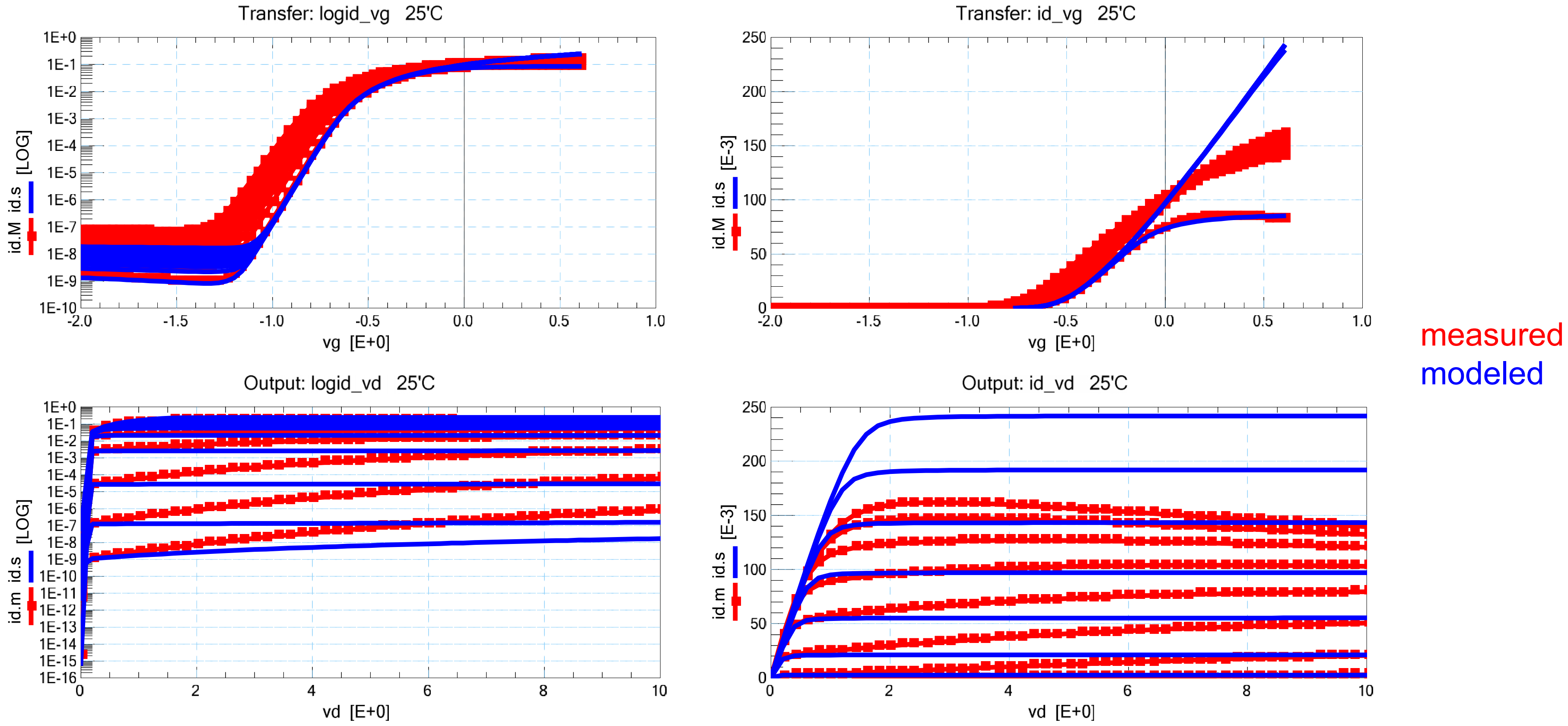
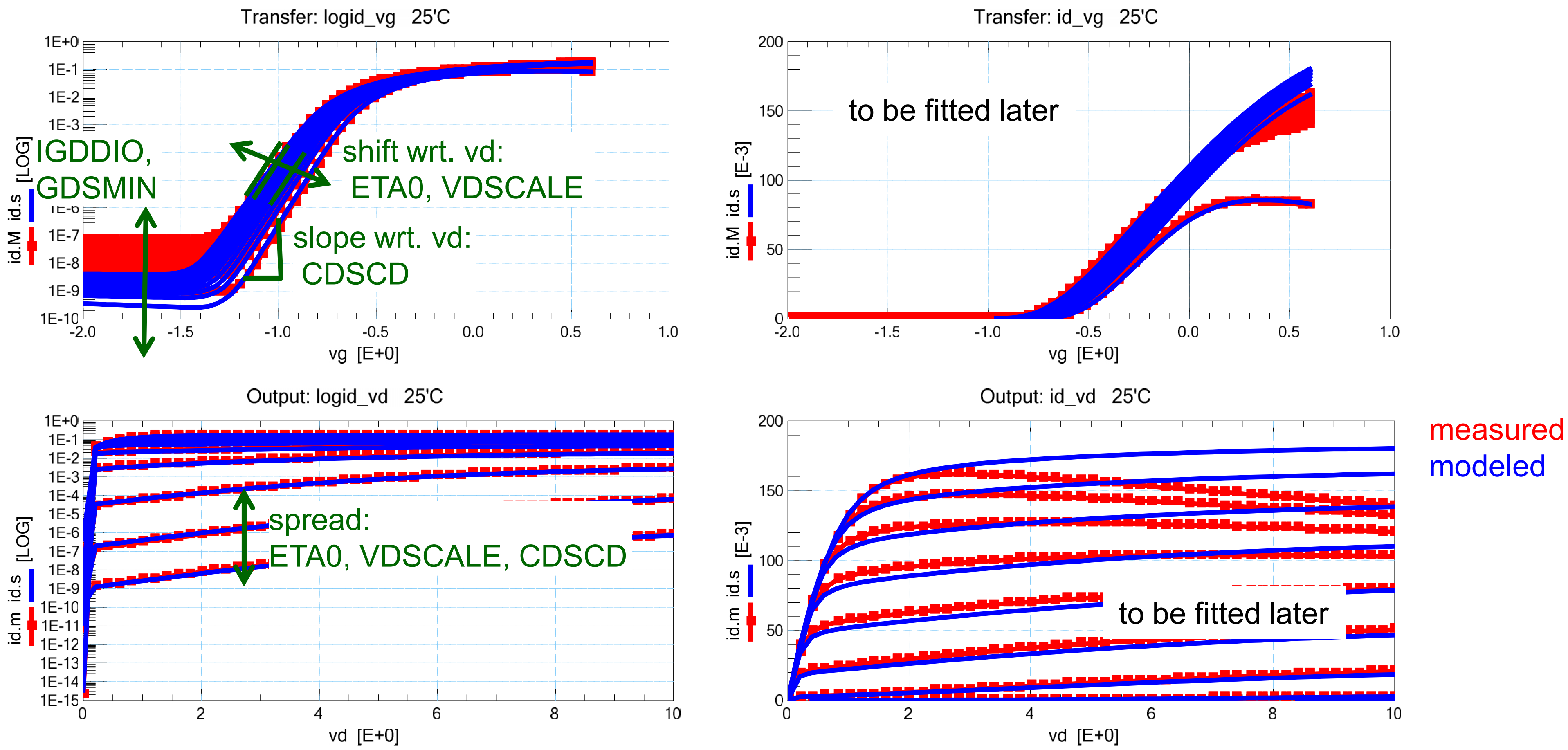
DC Modeling id-vg: **Sub-Threshold**

Starting Condition:

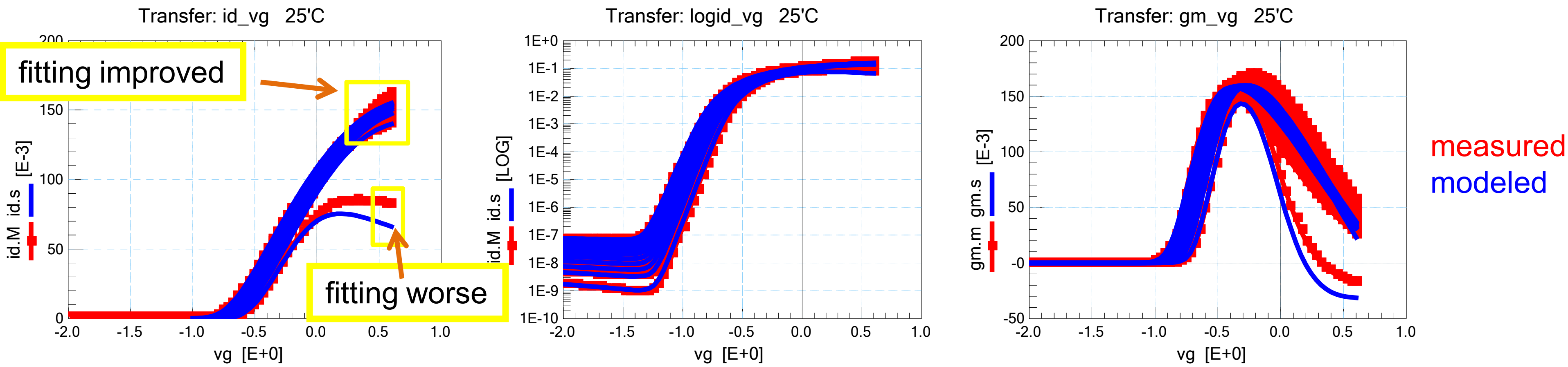


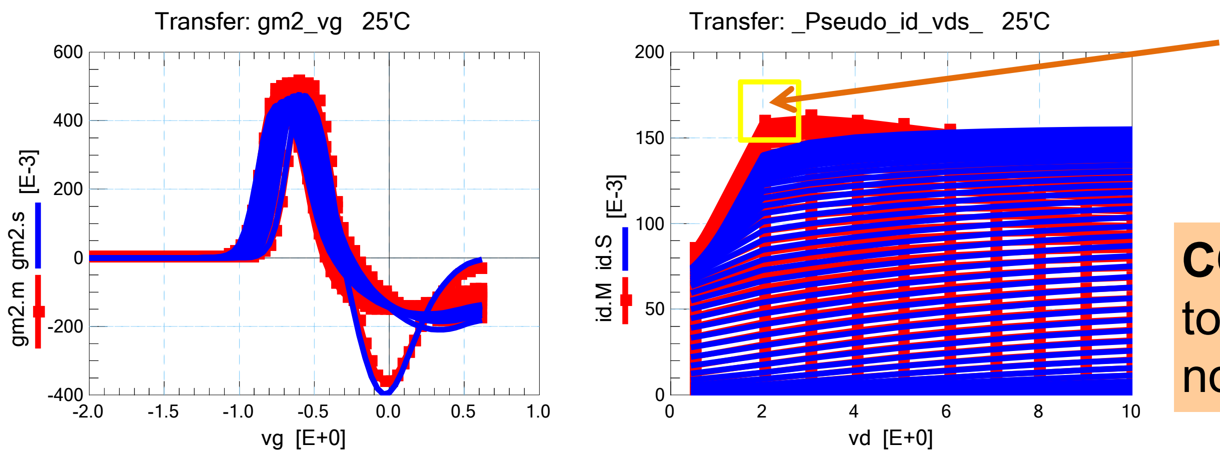
DC Modeling id-vg: **Sub-Threshold**



DC Modeling id-vg: **Above Threshold**

Fine-Tune Mobility Parameters U0, UA, UB



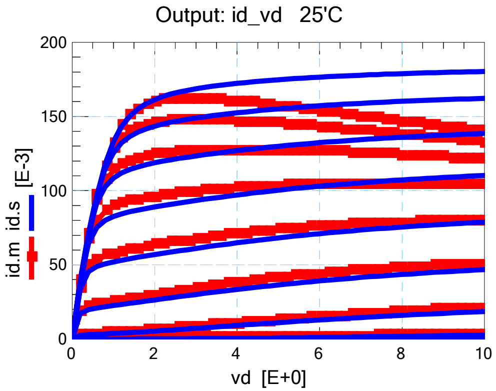


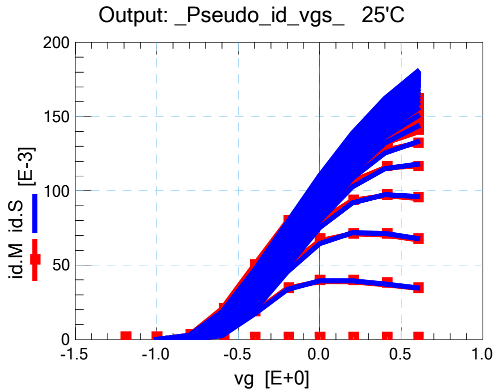
fitting worse:
simulated curve (blue) should
not be below measured (red)

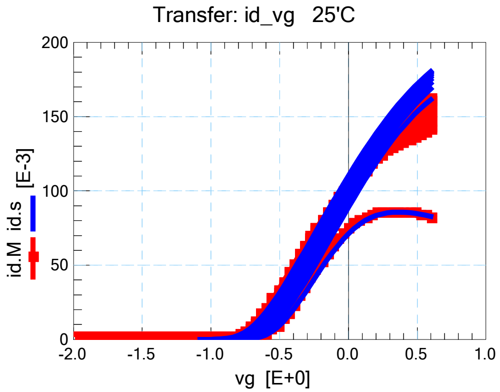
CONCLUSION:
to be fitted later by
nonlinear RS & RD

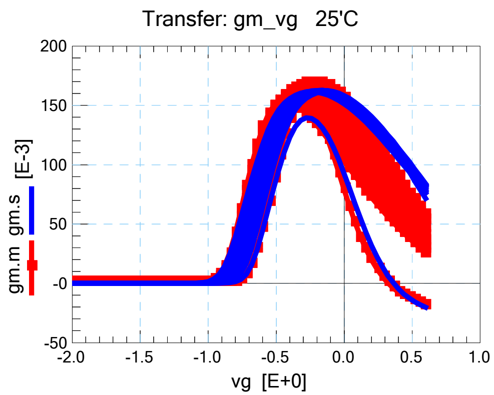
DC Modeling   id-vd Modeling

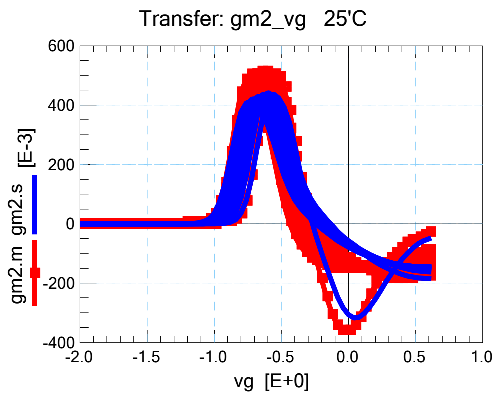
Starting Condition:





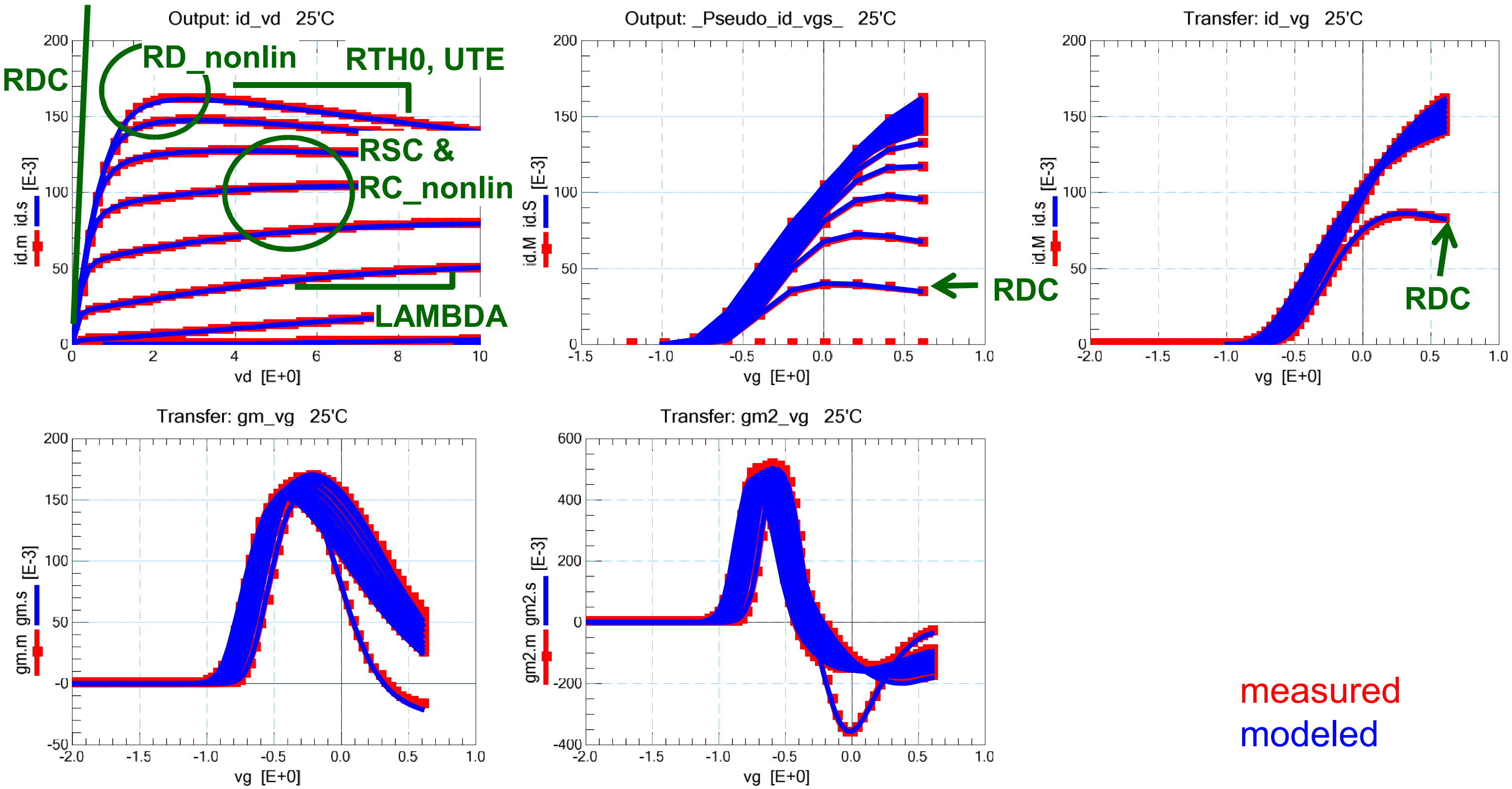




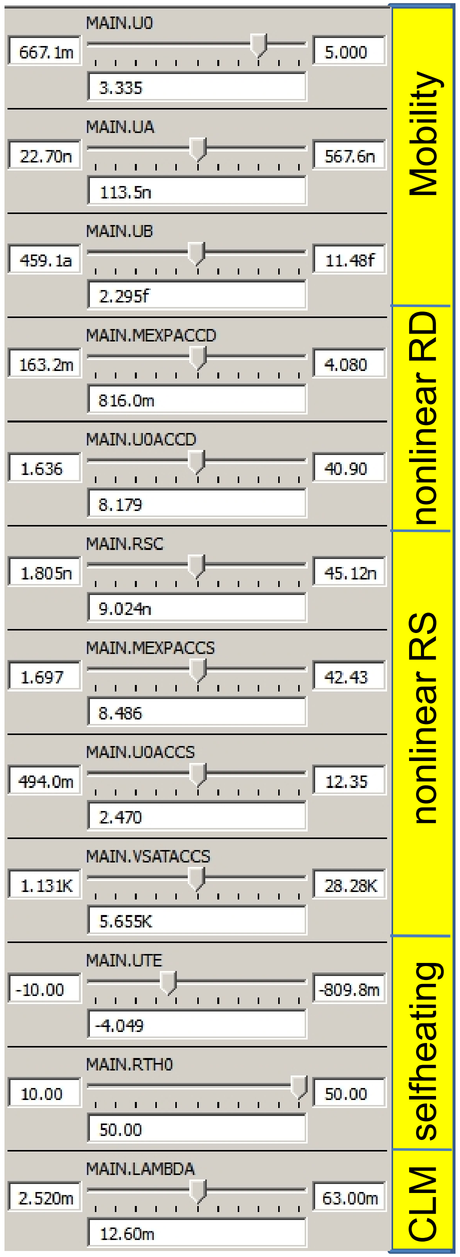


measured
modeled

DC Modeling   id-vd Modeling



measured
modeled



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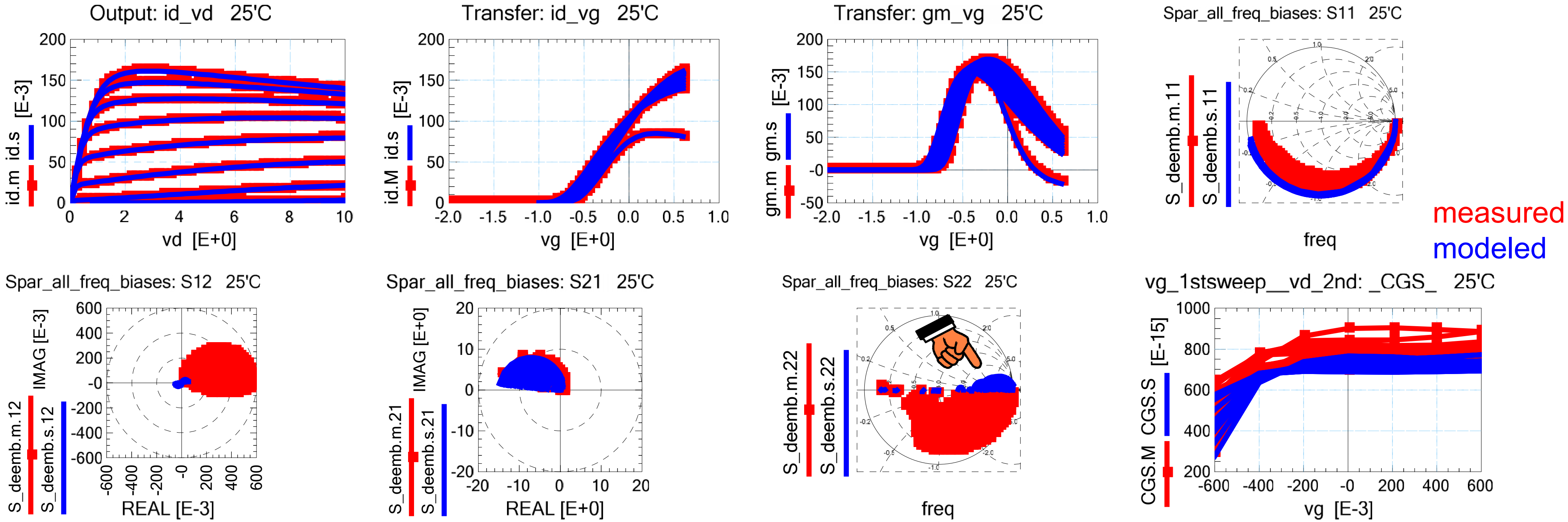
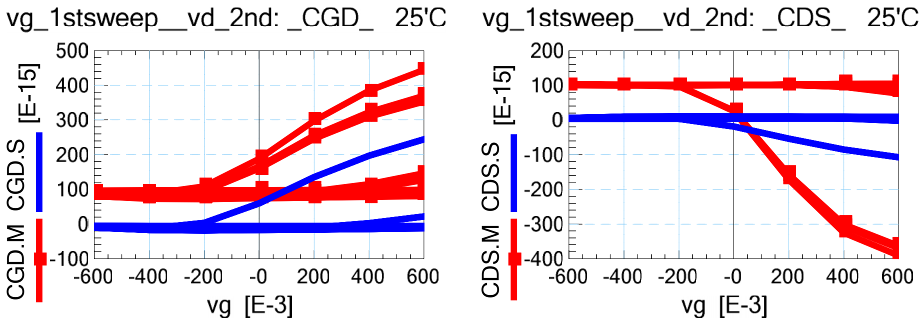
DC Modeling

Verification of DC Parameter Values by Inspection of S-Parameters





- S11 & S21 look physical
- but, S12 too small (due to simulated CGD~0 ?)
- S22 is inductive (!!), and CDS~0
- however, bias-dependency of capacitances is OK

ASM model offers parameters for capacitance offset shift (CGSO, CGDO, CDSO)

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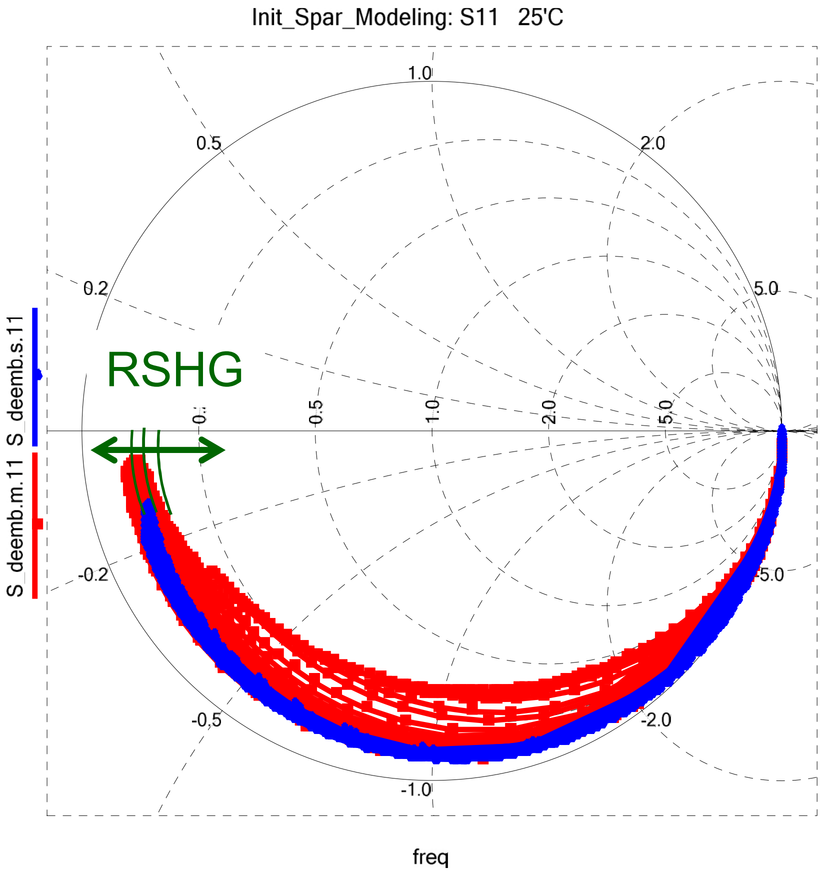
S-Parameter Modeling

Gate Sheet Resistance RSHG from S11-Parameters



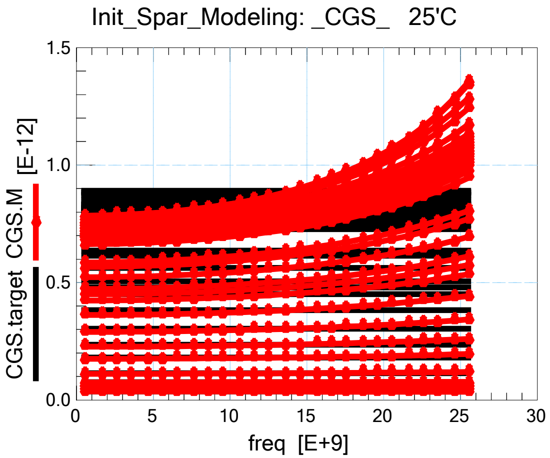
measured
modeled

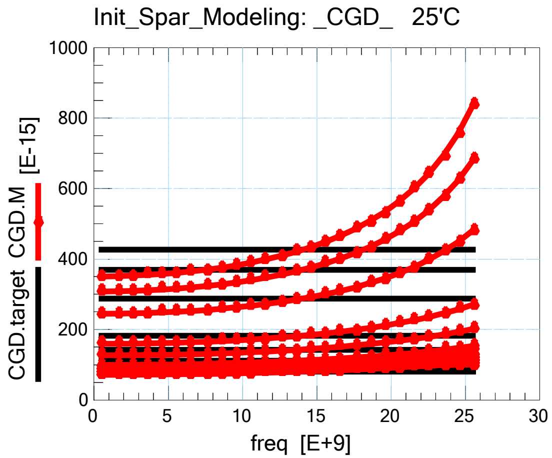
S-Parameter Modeling   Series Inductors LG, LD, LS

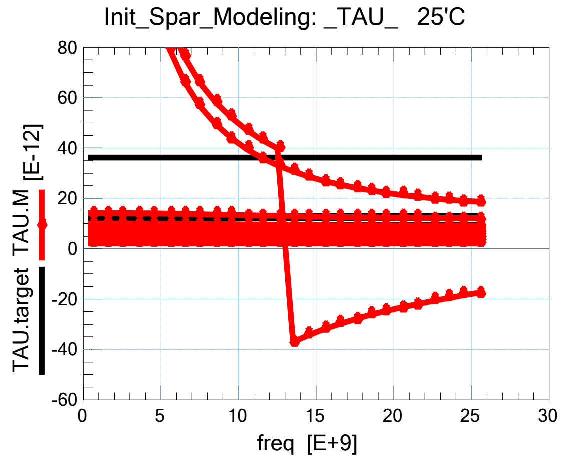
➢Meas. Data Manipulations:
Strip-off S-Parameters from external inductors, convert to Y, interpret as 'inner PI' schematic, calculate CGS, CGD, TAU, GM, CDS.

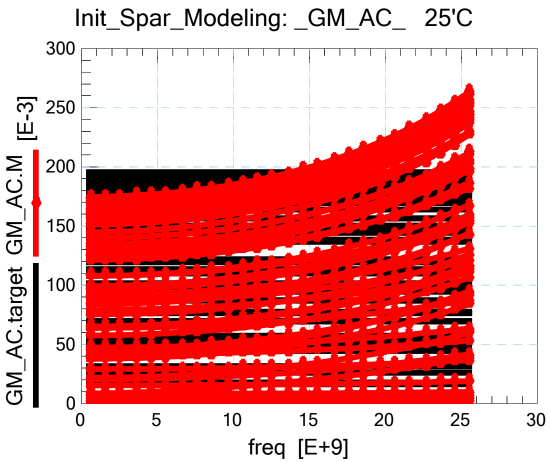
➢Then, tune external inductors to make the stripped-off PI components as freq-independent as possible.

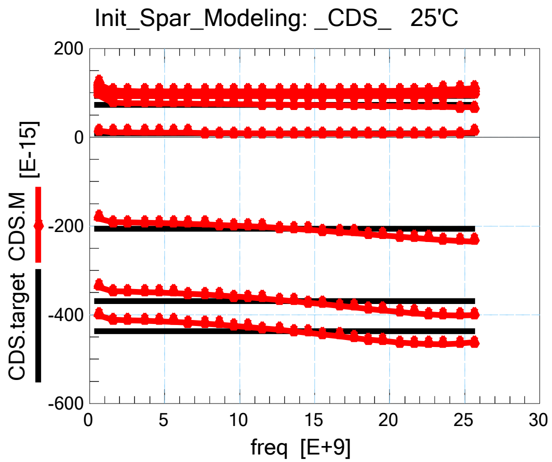
For details see the appendix !

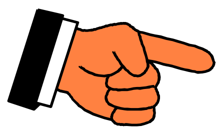












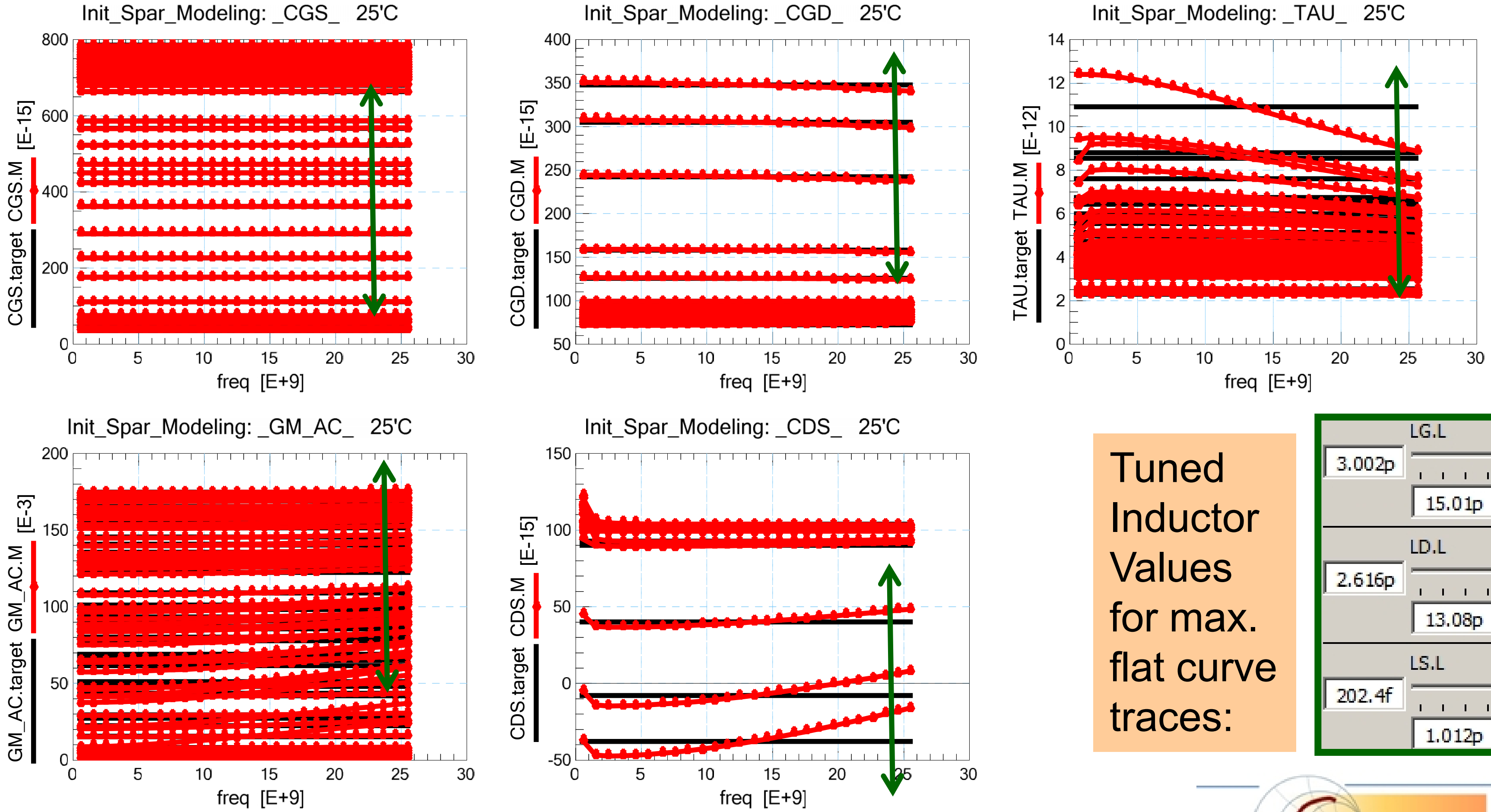
Starting Condition:
LG=LD=LS=0

S-Parameter Modeling

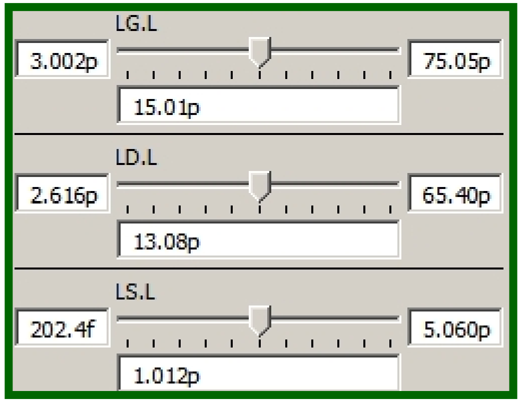
Series Inductors LG, LD, LS

➢Meas. Data Manipulations:
Strip-off S-Parameters from external inductors, convert to Y, interpret as 'inner PI' schematic, calculate CGS, CGD, TAU, GM, CDS.
➢Then, tune external inductors to make the stripped-off PI components as freq-independent as possible.

For details see the appendix !

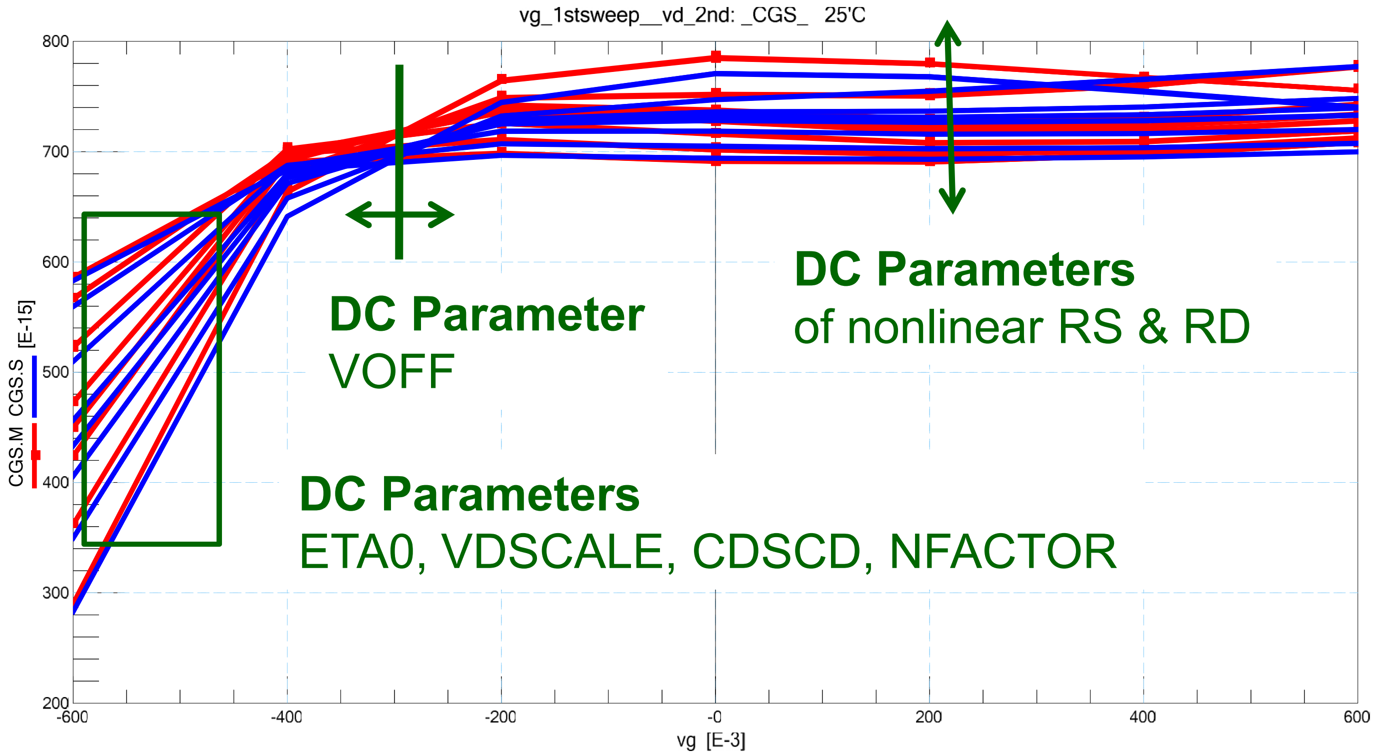


Tuned Inductor Values for max. flat curve traces:



S-Parameter Modeling Gate-Source Capacitance

Adjust **Offset Capacitance Parameter CGSO** (Gate Source Overlap Cap.)



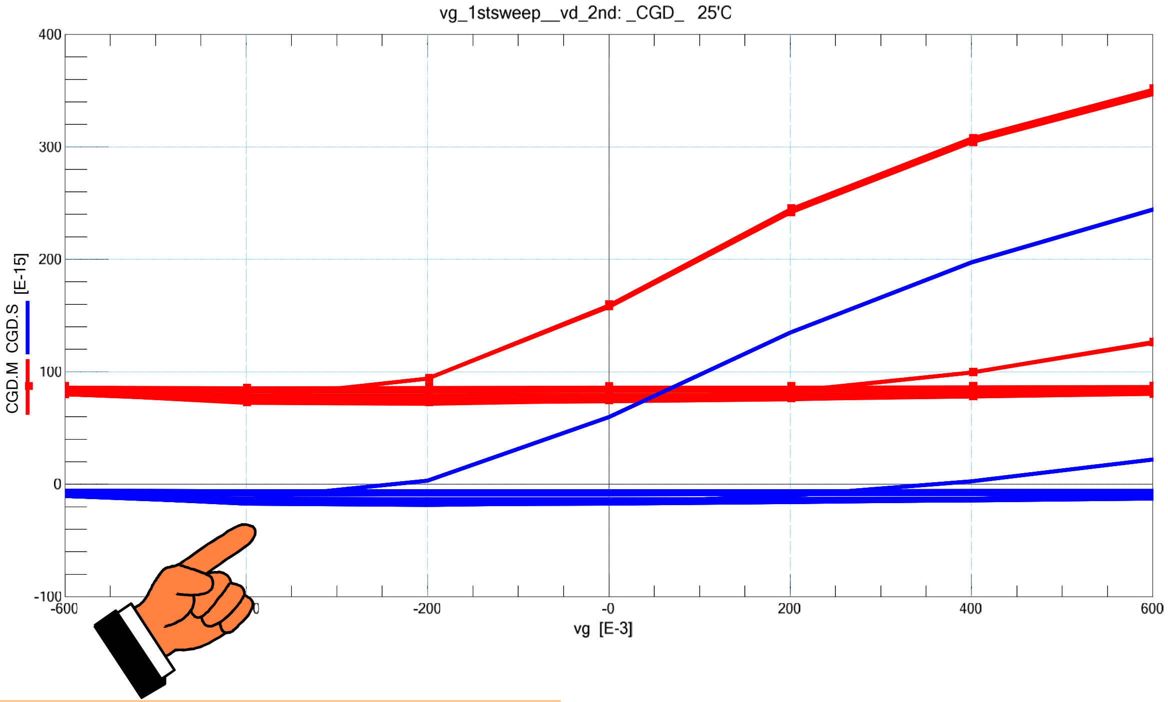
measured
modeled

Notice:

CGSO, CGDO, CDSO belong to the intrinsic core model.
The bias-dependency of the capacitances is fitted by the DC parameters.

S-Parameter Modeling   Gate-Drain Capacitance

Starting Condition:

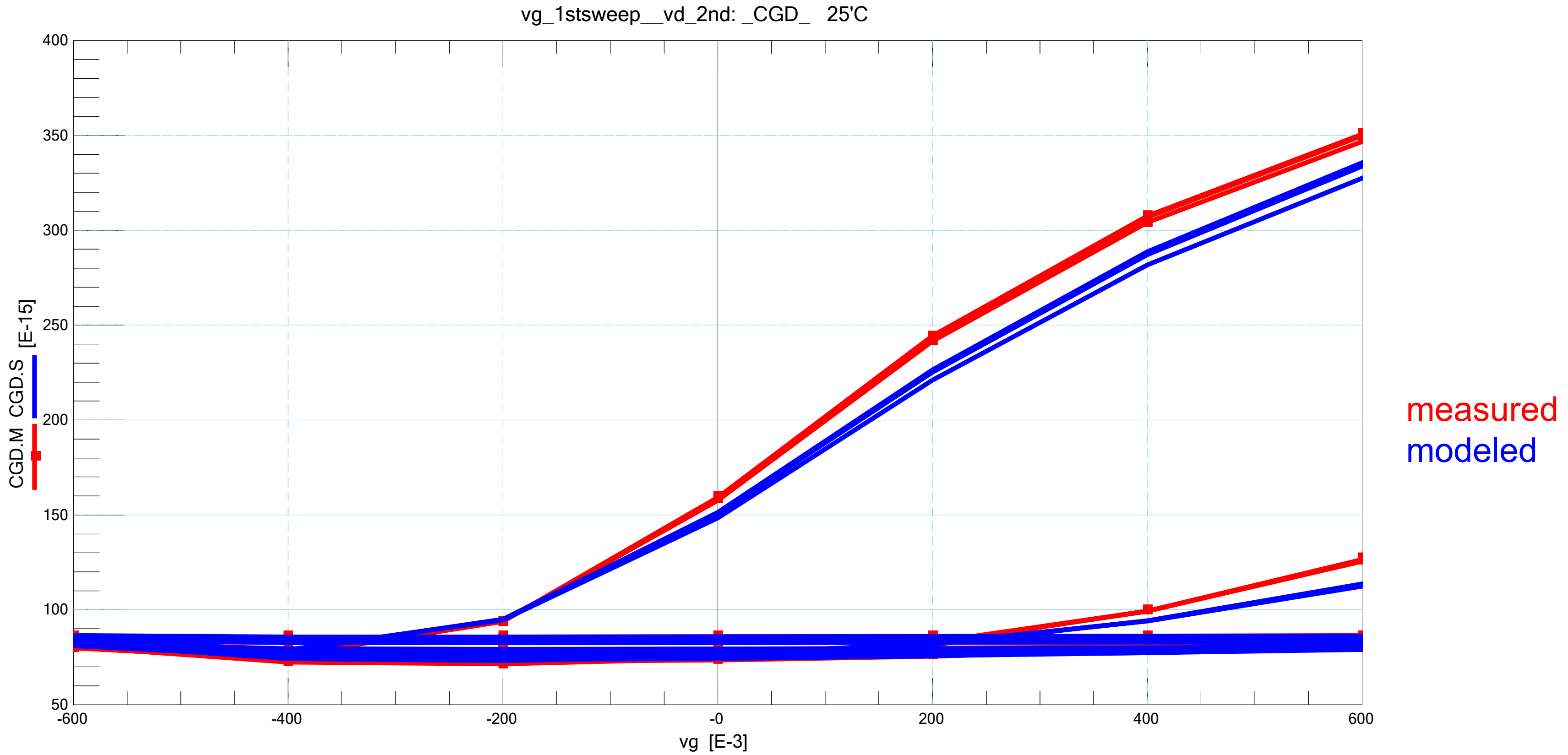


measured
modeled

- unphysical !!!
- negative capacitance !
- need to add offset capacitance

S-Parameter Modeling Gate-Drain Capacitance

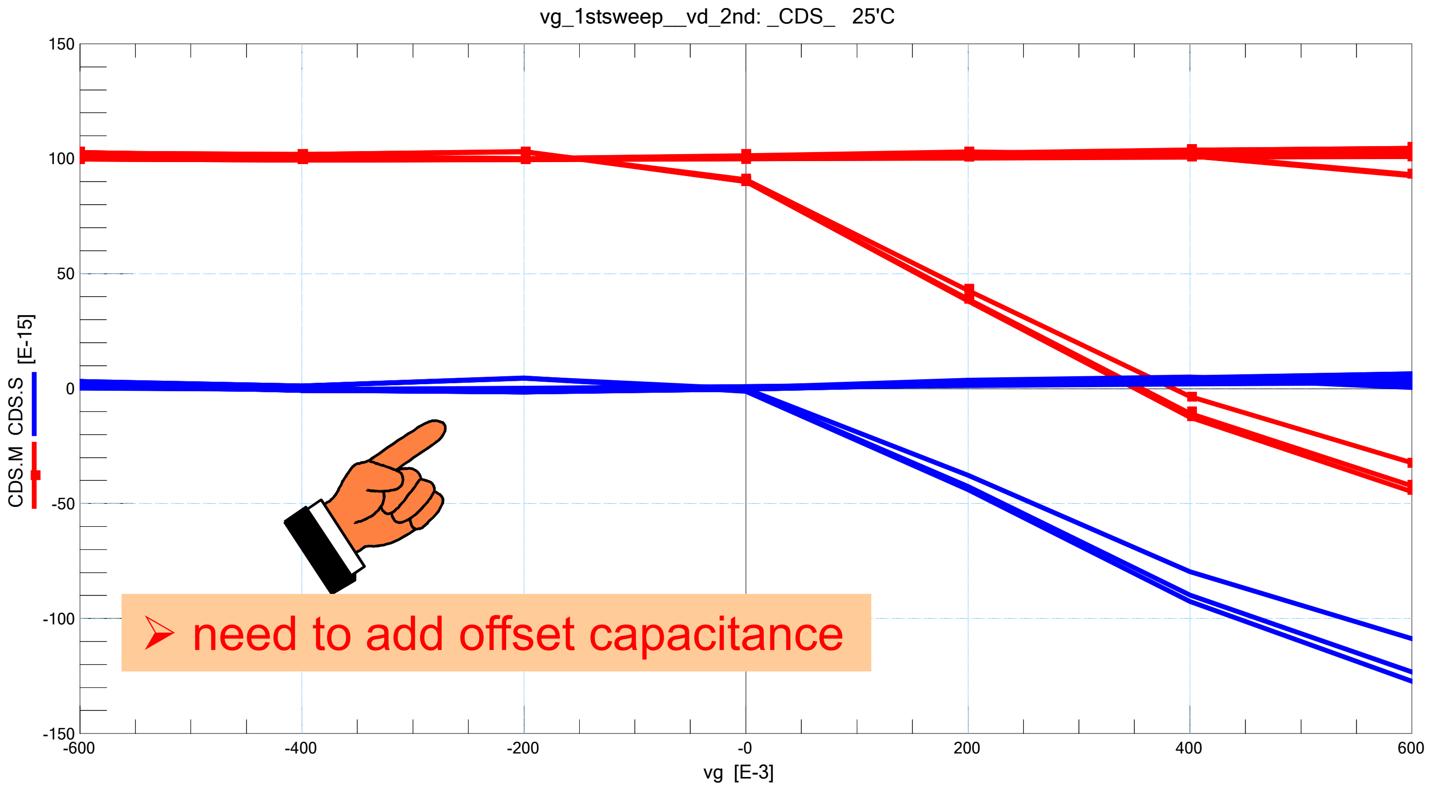
Offset Capacitance Parameter CGDO adjusted



S-Parameter Modeling

Drain-Source Capacitance

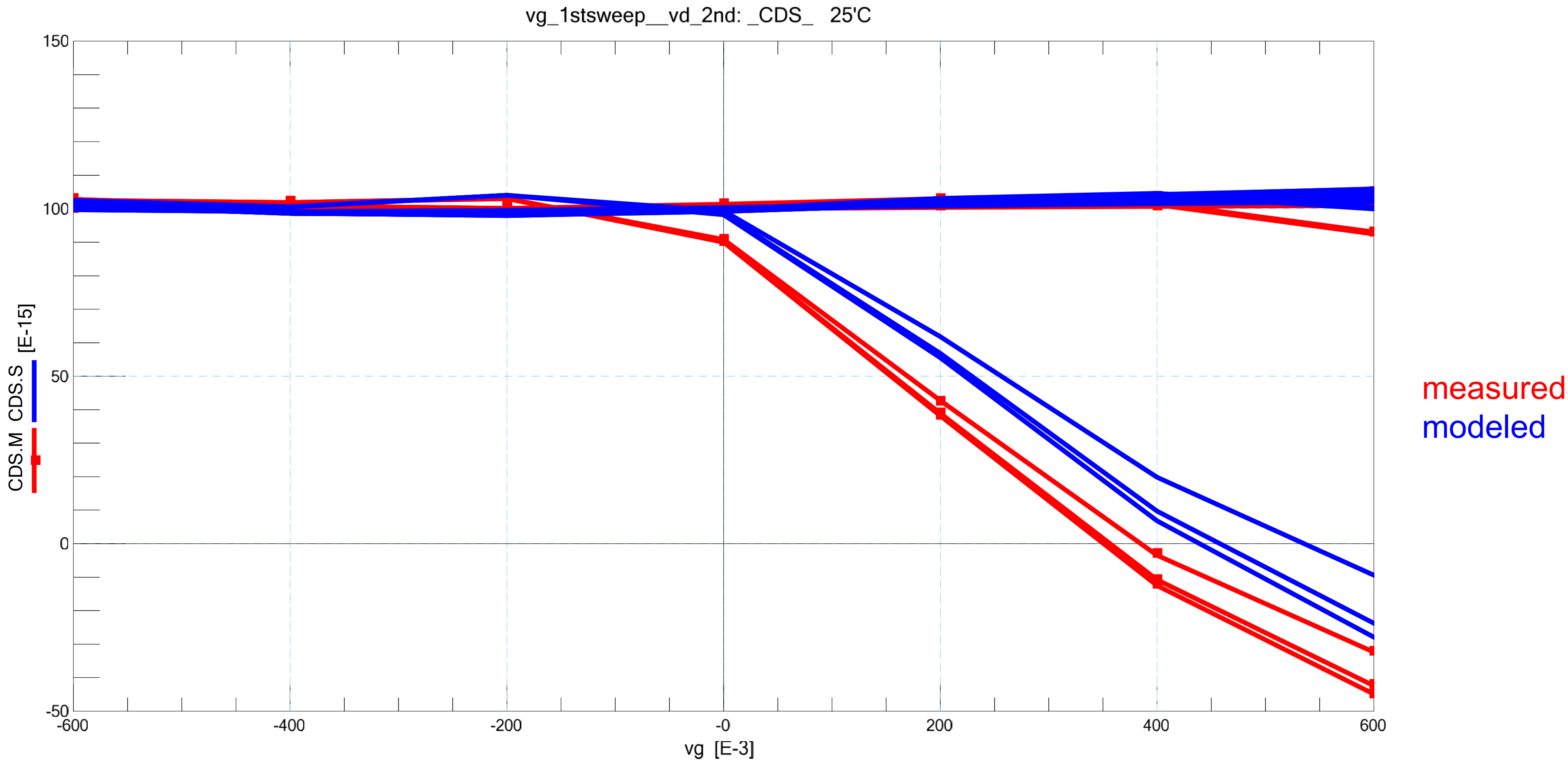
Starting Condition:



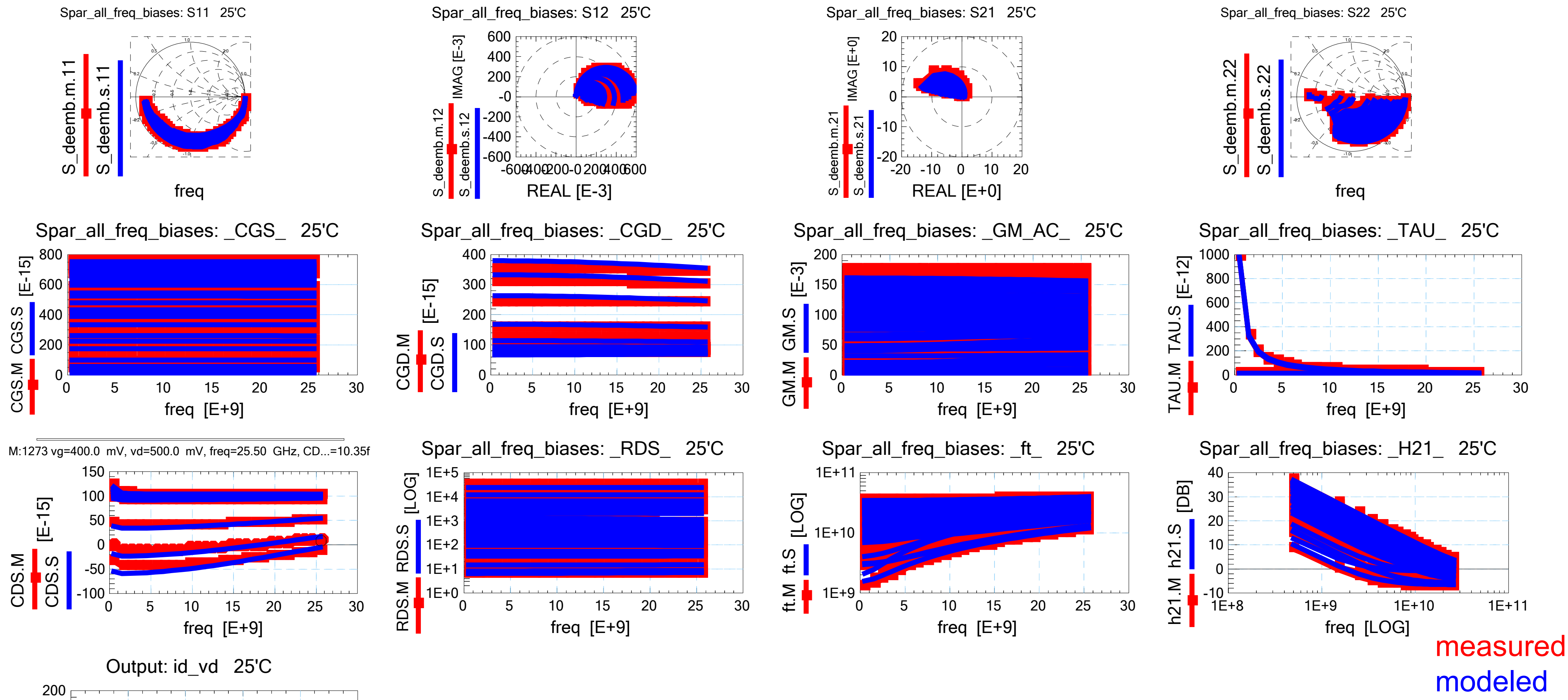
measured
modeled

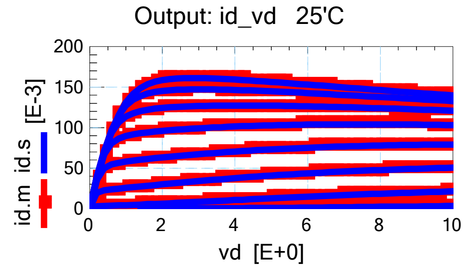
S-Parameter Modeling   Drain-Source Capacitance

Offset Capacitance Parameter CDSO adjusted



Final Fit





- ➢ All fittings achieved by DC parameters (!),
- ➢ plus parameters for bias-independent offset capacitance
- ➢ plus fitted external inductors

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Conclusions

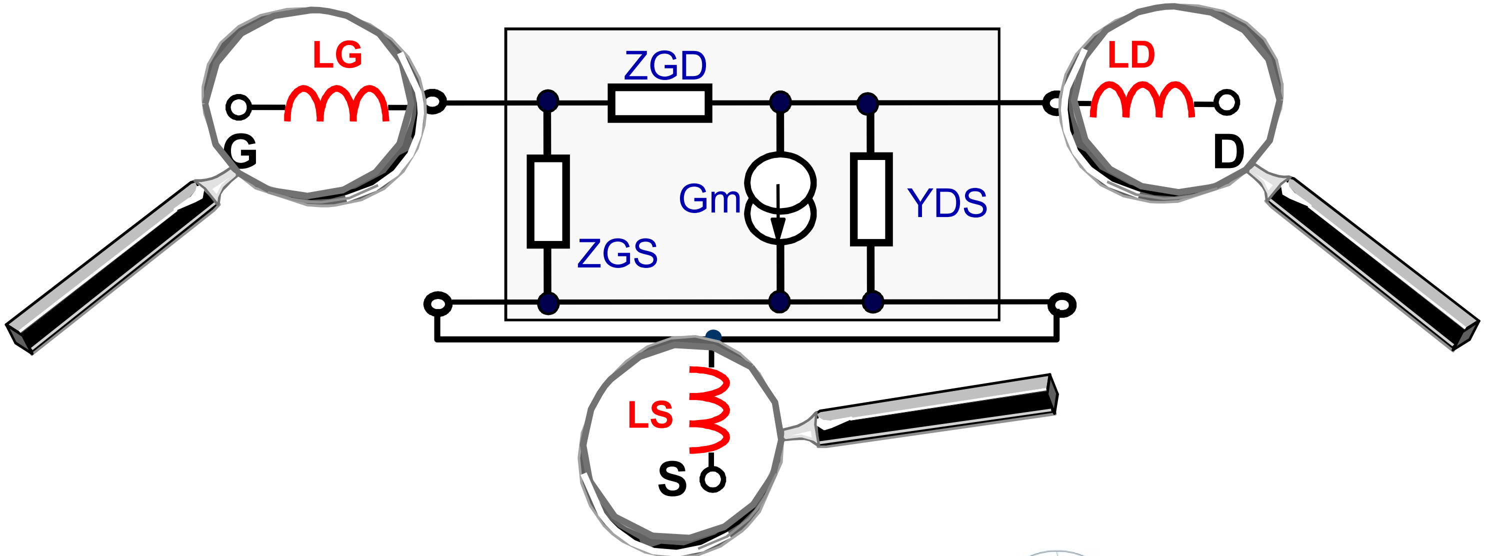
Compared to the EEHEMT and the Angelov model,
the ASM-HEMT model is the most physics-based model.

As a consequence, once its parameter values do fit both,
DC and S-Parameters, the model can be applied
to reliably predict device performance also outside the modeling ranges.

The compromise in the current model version is that,
typically, the S-Parameter capacitance fitting
is more challenging compared to mathematical models (like EEHEMT).

APPENDIX:

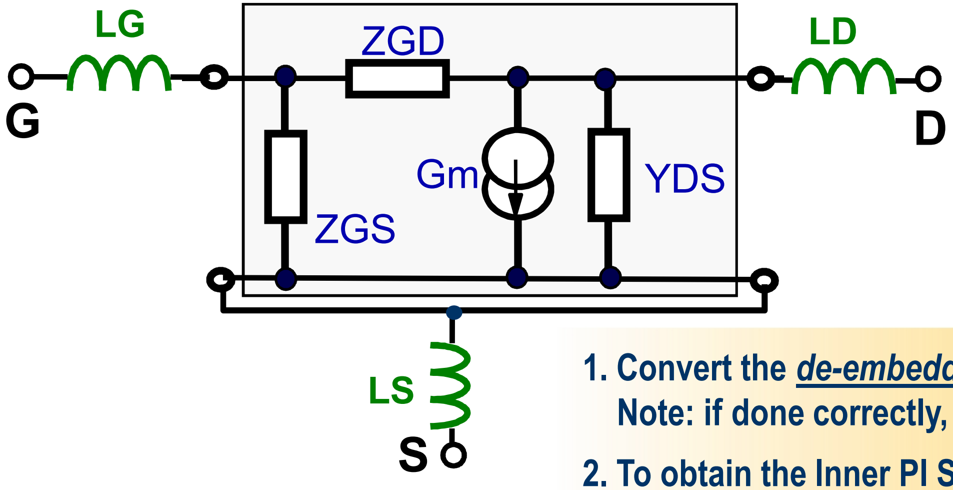
How to Obtain the MOS/MESFET/HEMT Transistor Inductor Values *from De-Embedded* S-Parameter Measurements



Important Pre-Consideration:

The de-embedded S-Parameter measurements
do no longer include the contact pad parasitics
(like pad capacitances, line inductances),
but they still include the inner transistor inductances
and -of course- the capacitances and the transistor's GM.

By applying the following procedure,
these inner inductances can easily be modeled correctly.



The Procedure:

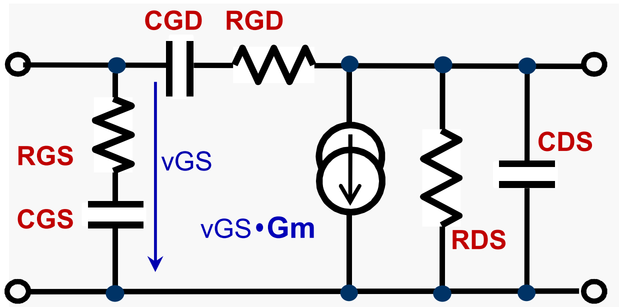
1. Convert the *de-embedded* S-parameters to Z, and strip-off the remaining external inductors.
   Note: if done correctly, the inner PI Schematic component values become frequency independent.

2. To obtain the Inner PI Schematic, convert further to Y-parameters and calculate the complex impedances, admittances and Gm:

ZGS	= 1 / (Y.11 + Y.12)	Impedance Port1 → GND
ZGD	= 1 / (-Y.12)	Impedance Port1 → Port2
Gm	= Y.21 - Y.12 = GM • $e^{-j \cdot 2PI \cdot freq \cdot TAU}$	Voltage → Current Amplification
YDS	= Y.22 + Y.12	Admittance Port2 → GND

3. Finally, get

RGS = REAL(Z_10)	CGS = - 1 / (IMAG(Z_10) • 2PI • freq)
RGD = REAL(Z_12)	CGD = - 1 / (IMAG(Z_12) • 2PI • freq)
GM = MAG(Gm)	TAU = - PHASE(Gm) / (2PI • freq)
RDS = 1 / (REAL(Y_20))	CDS = IMAG(Y_20) / (2PI • freq)



quasistatic approach

Note: In Spice transistor models (like EEHEMT, Angelov, ASM-HEMT and also the MOS models), the inner-PI schematic components *(capacitors, resistors and GM)* are modeled frequency-independent. By tuning the values of the external **inductors**, this prerequisite can be fulfilled. In other words, the measured inner capacitors and GM are then only DC bias dependent (see next slide !)

Warning: this method cannot be applied to bipolar transistor modeling due to the inner Base node and the non-negligible resistor RBB'.

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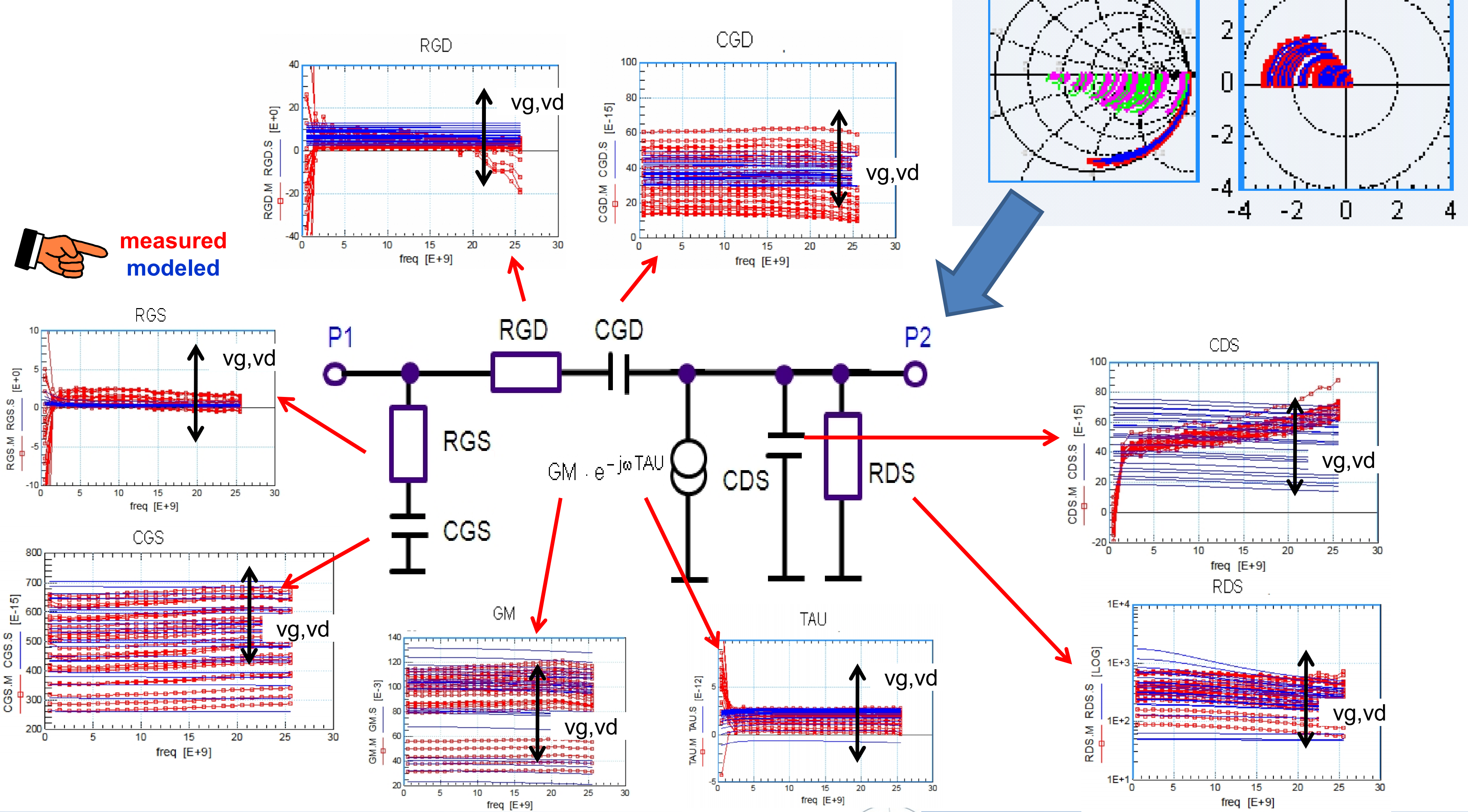
Inner PI Component Plots vs. Frequency

with accurately subtracted external inductors



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Dr.-Ing. Franz Sischka

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eMail: franz.sischka@SisConsult.de