

GaN ASM-HEMT Modeling & Verification Workshop

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Application Engineer



Agenda

- Quick Start for IC-CAP
- Introduction to ASM-HEMT Model
- Introduction to CMC Modeling Kit (ASM-HEMT) in IC-CAP
- Export Model to ADS for Load-pull Simulation



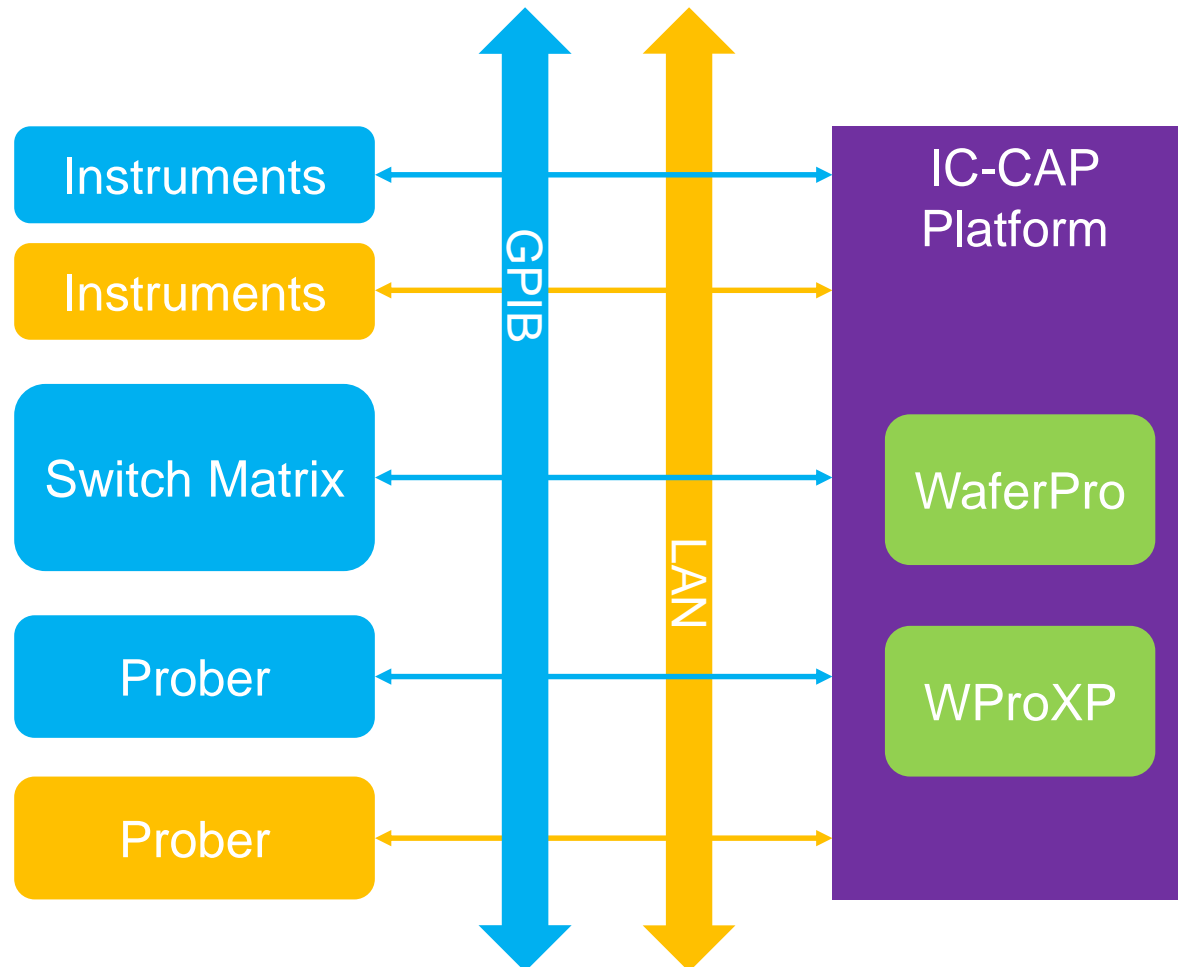
Quick Start for IC-CAP

What is PATHWAVE Device Modeling : IC-CAP

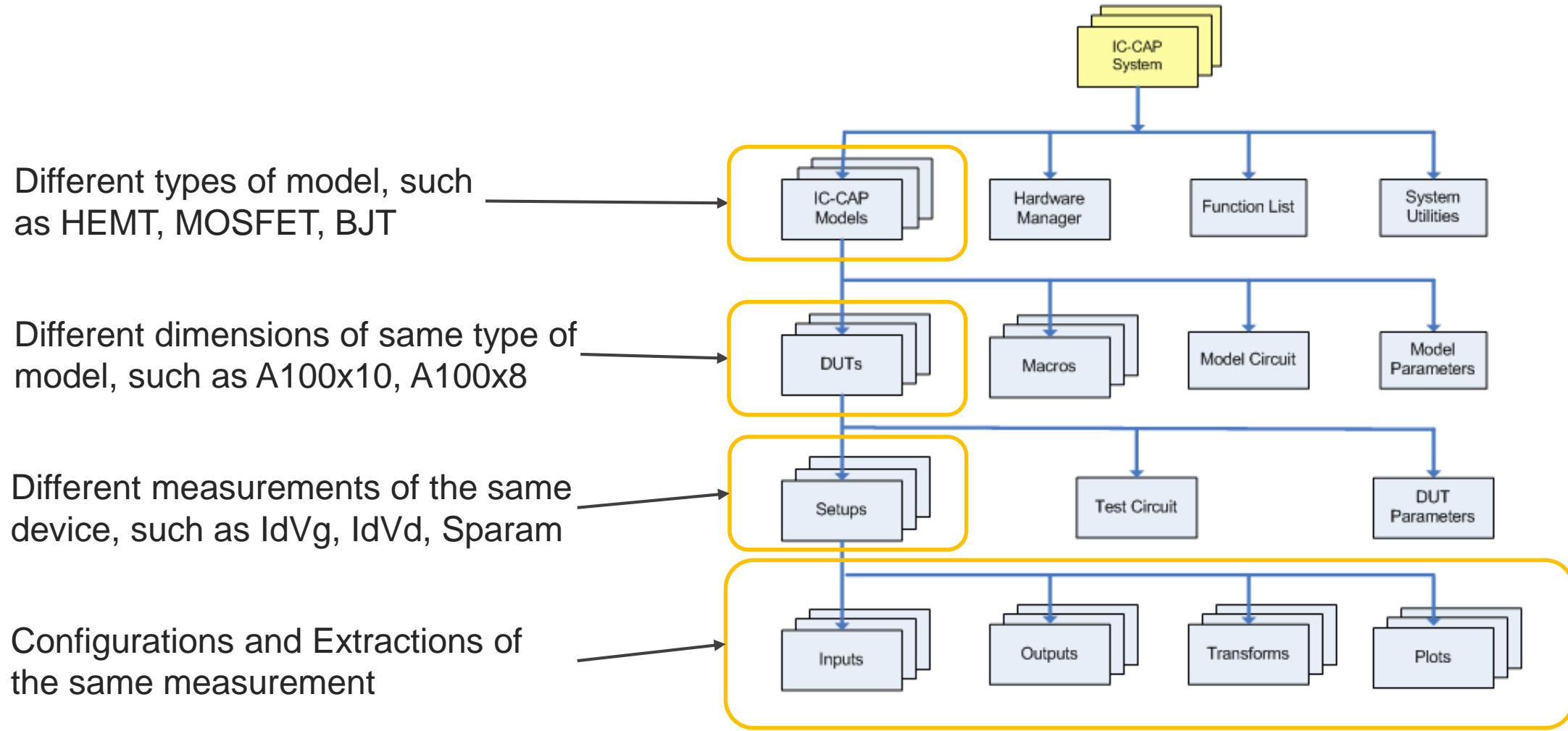
- **Integrated Circuit Characterization and Analysis Program**
- Integrate measurement and modeling on the same platform
- Support various simulators and python script
- Support customized GUI and extraction flow
- Suitable for highly customized modeling, such as RF and Power devices



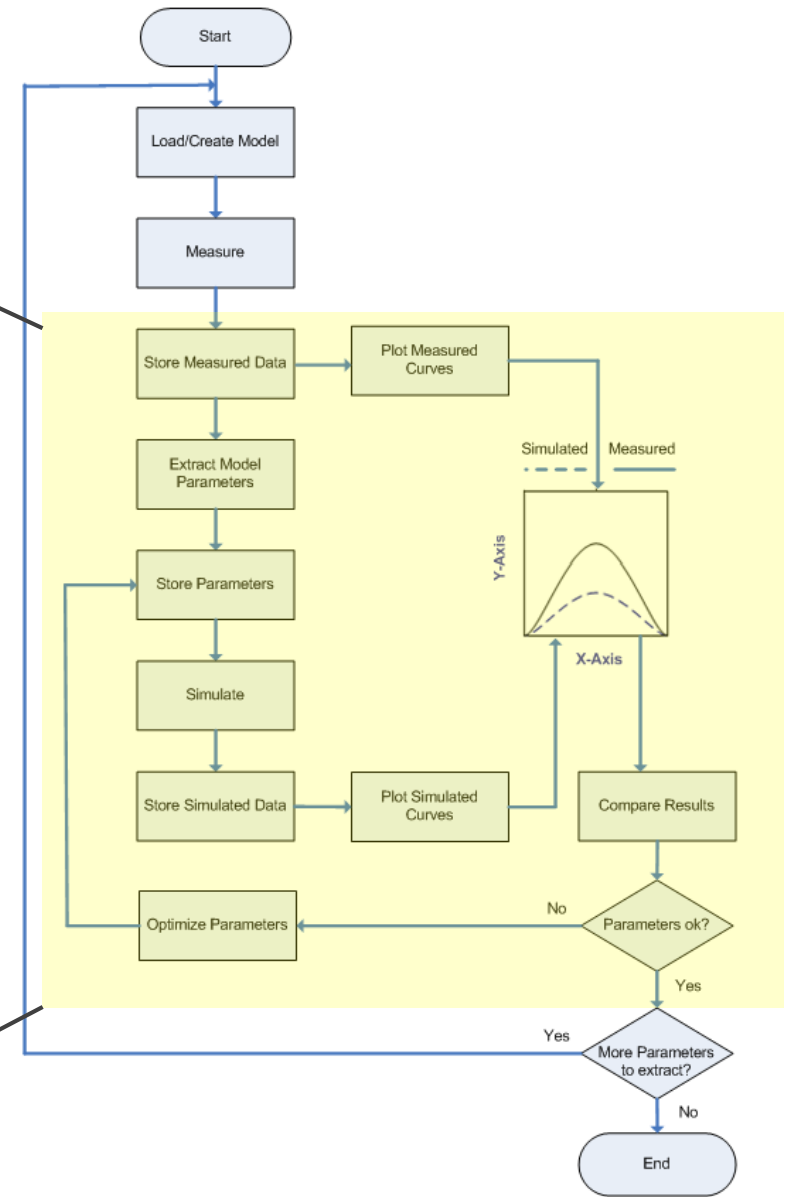
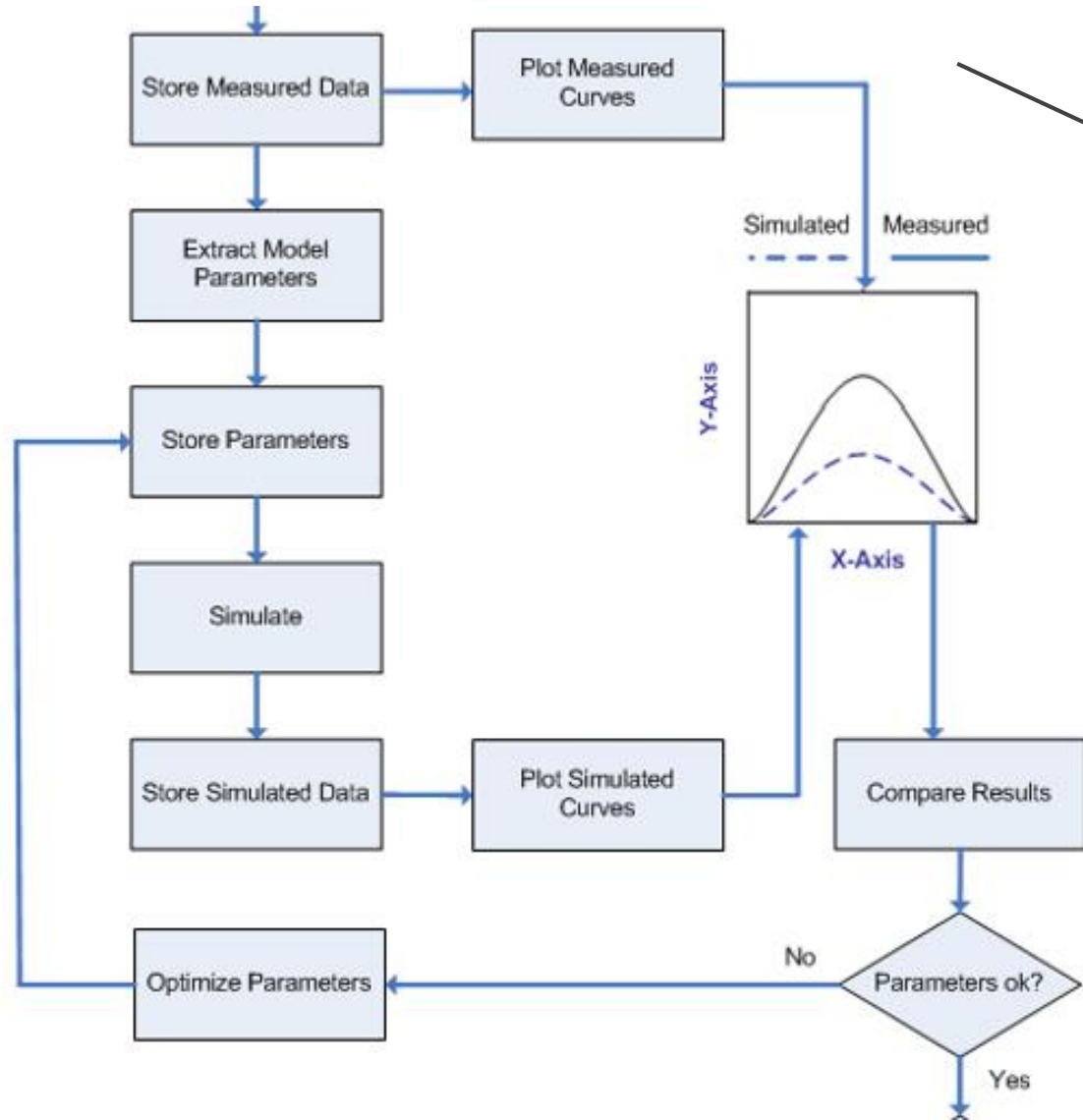
IC-CAP Measurement System



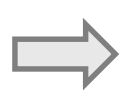
IC-CAP System Organization



Typical Modeling Flow



How Measurement Works



Inputs: Define the Stimulus/Bias to be applied

Outputs: Define the Data to be Measured

Input: va

Output: ia

Hardware Window

| Unit Table | |
|------------|------|
| HRSMU1 | SMU1 |
| HRSMU2 | SMU2 |
| HRSMU3 | SMU3 |
| HRSMU4 | SMU4 |

Define Unit Names in Setup to map to Unit Names defined in the Instrument Configuration settings in the Hardware Window

diode: (/diode/dc/idvd is Active):3

File Edit Measure Extract Simulate Optimize Data Tools Macros Windows Help

DUTs-Setups Circuit Model Parameters Model Variables Macros

Select DUT/Setup

dc

idvd

Measure / Simulate Instrument Options Setup Variables Extract / Optimize Plots

input: va

Mode: V

+ Node: A

- Node: GROUND

Unit: SMU1

Compliance: 100.0m

Sweep Type: LIN

Sweep Order: 1

Start: 300.0m

Stop: 1.000

of Points: 29

Input: vc

Mode: V

+ Node: C

- Node: GROUND

Unit: SMU2

Compliance: 100.0m

Sweep Type: CON

Value: 0.000

Output: ia

Mode: I

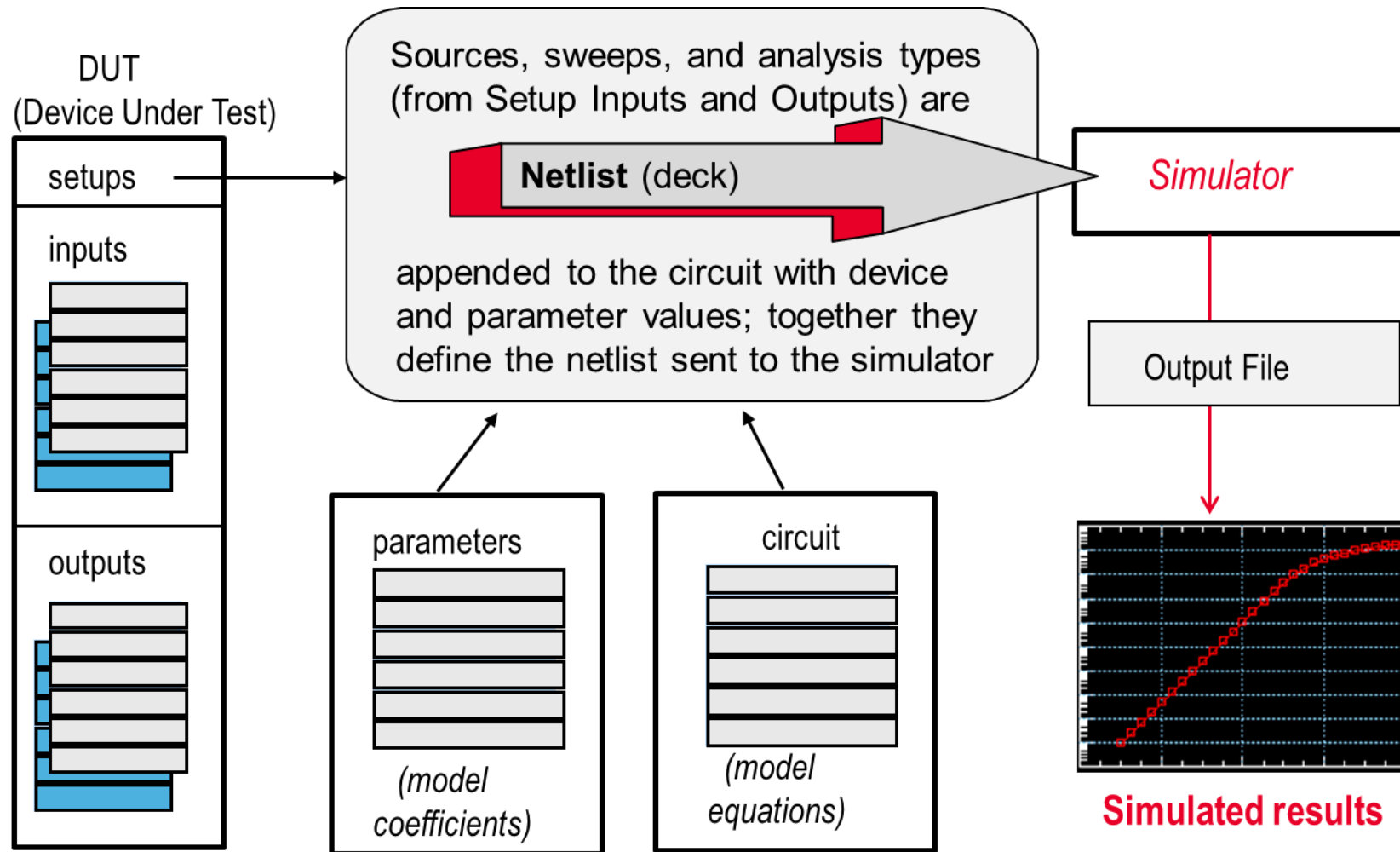
To Node: A

From Node: GROUND

Unit: SMU1

Type: B

How Simulation Works





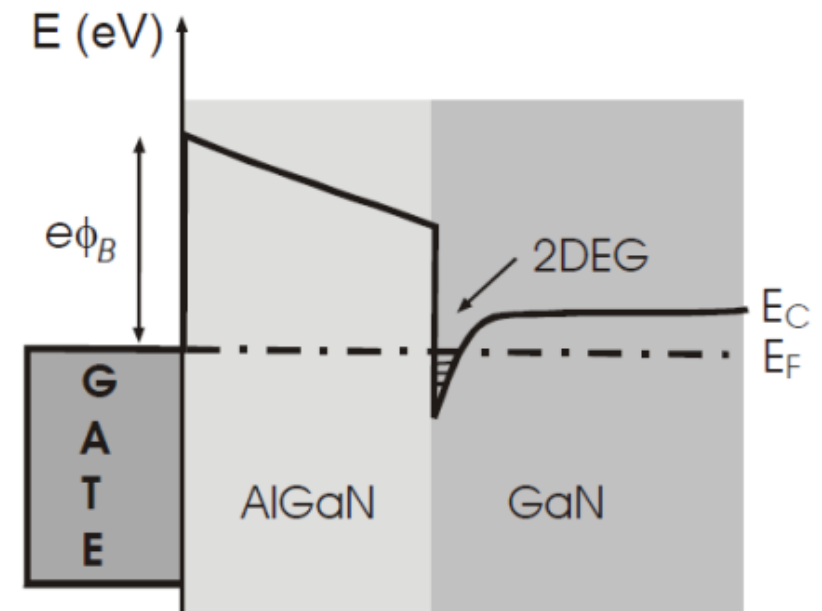
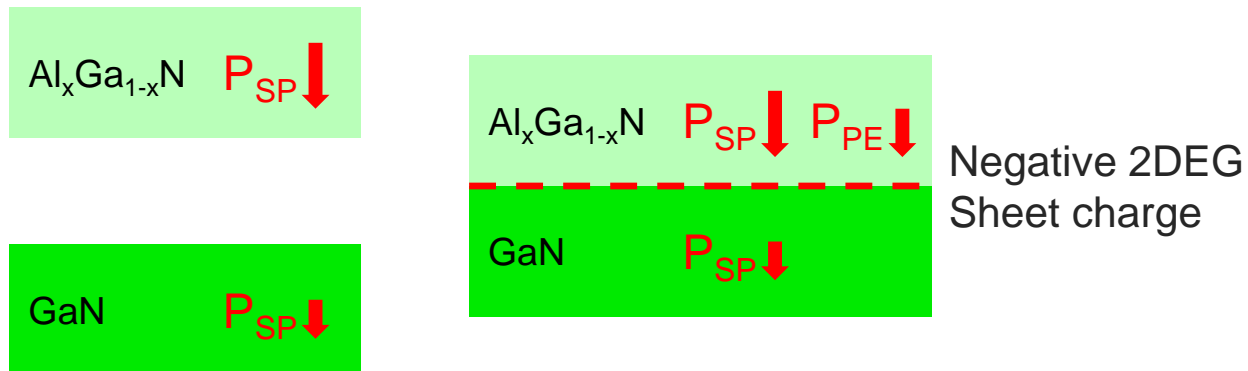
Introduction to ASM-HEMT Model

ADVANCED SPICE MODEL FOR HEMT

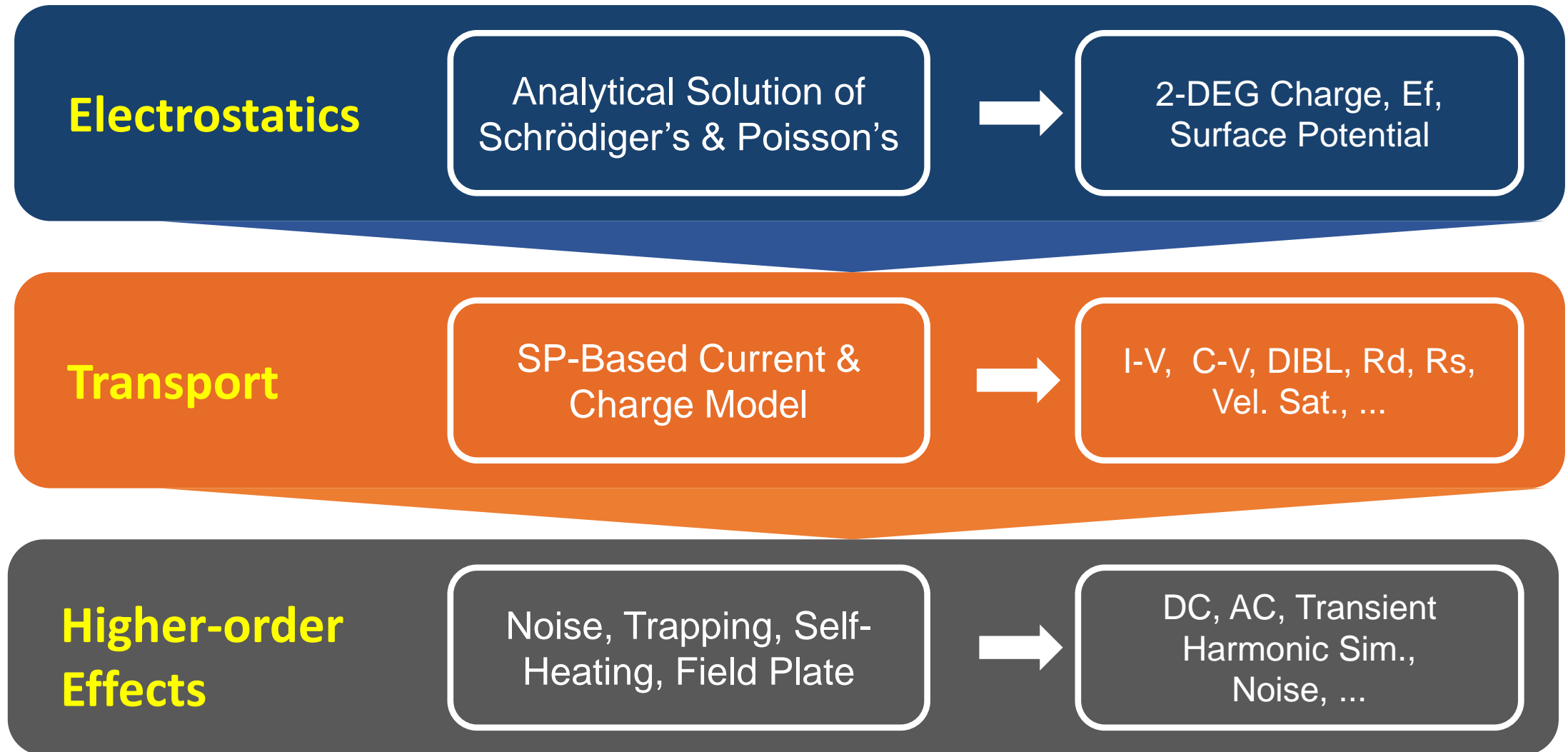
GaN HEMT Devices

HOW DOES A GAN DEVICE WORK?

- Difference between $\text{Al}_x\text{Ga}_{1-x}\text{N}$ and GaN **spontaneous polarization (P_{SP})** creates a sheet charge at the interface.
- Difference in lattice constants leads to mechanical strain and piezoelectric effect (**P_{PE}**)
- quantum well at the heterojunction interface → **2 Dimensional Electron Gas (2-DEG)**
 - very high mobility
 - Low resistance



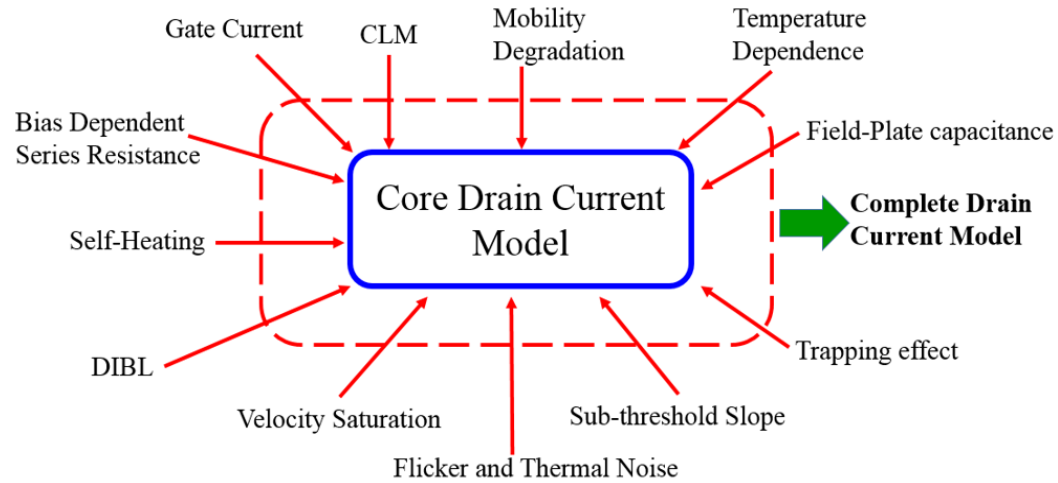
ASM-HEMT Model Overview



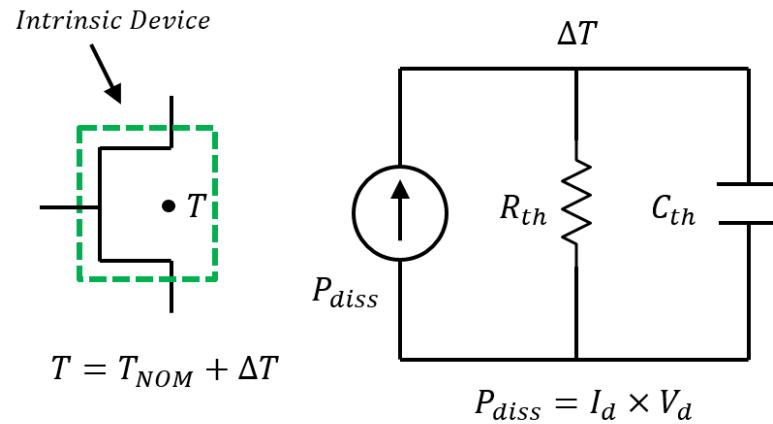
Advantages of Surface Potential-based Model

- Better Model Scalability – L, W, NF, Lsg, Ldg, Temperature etc.
- Better Temperature Scalability
- Device Insight
- Better Statistical Behavior
- Accurate Charges and Capacitances
- Less number of parameters – Easier parameter extraction
- Uses a single expression for all regions – Faster convergence, smooth derivatives
- Inherent Model Symmetry and Continuity

Core Model & Parameters



Real Device Effects Incorporated into the Model



Self-Heating Effect

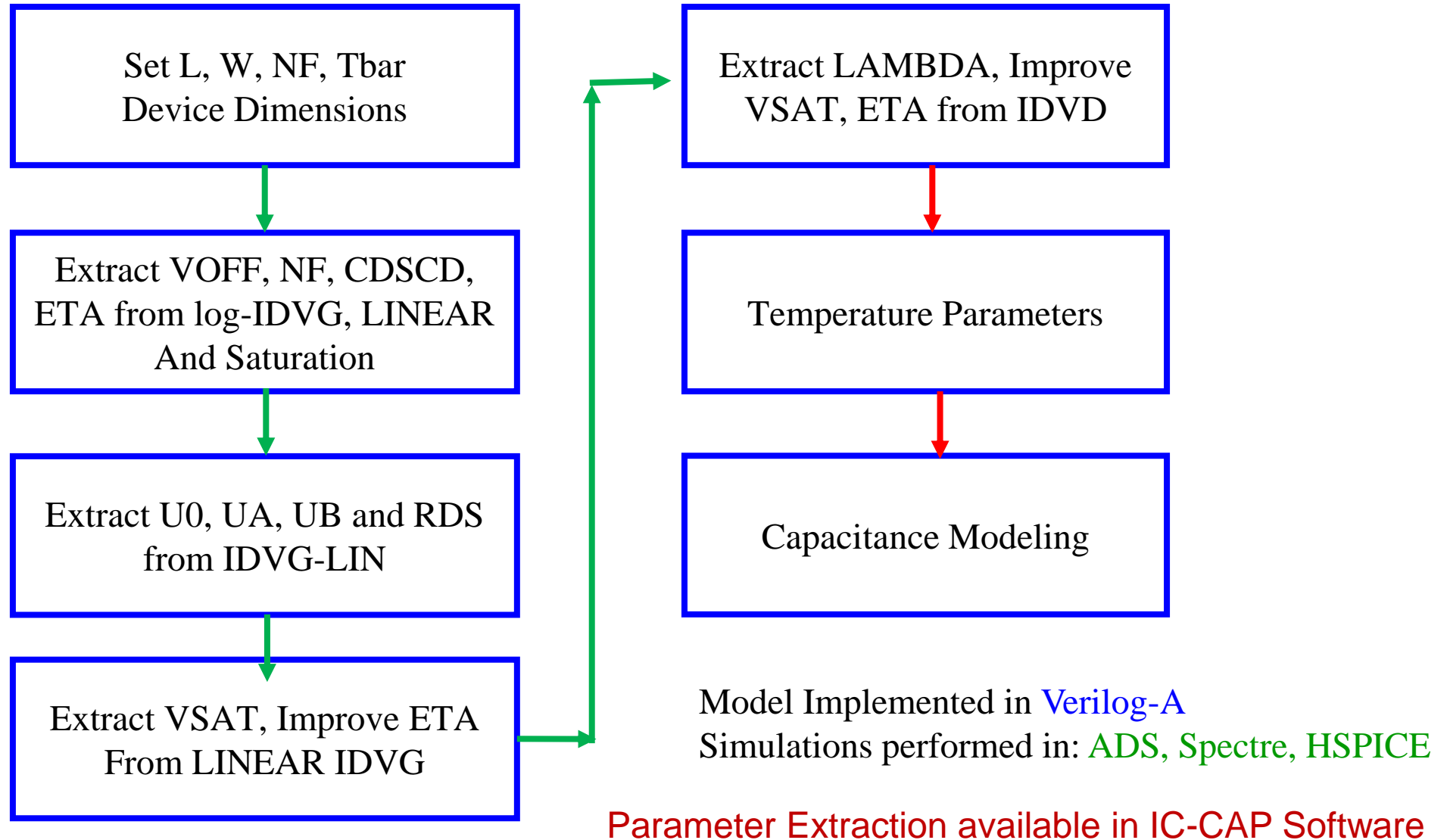
Core Model Parameters

| Parameter | Description | Extracted Value |
|---------------|---------------------------|-------------------|
| V_{OFF} | Cutoff Voltage | $-2.86 V$ |
| N_{FACTOR} | Subthreshold Slope Factor | 0.202 |
| C_{DSCD} | SS Degradation Factor | $0.325 V^{-1}$ |
| η_0 | DIBL Parameter | 0.117 |
| U_0 | Low Field Mobility | $33.29 mm^2/Vs$ |
| N_{SOACCS} | AR 2DEG Density | $1.9e + 17 /m^2$ |
| $V_{SATACCS}$ | AR saturation velocity | $157.6e + 3 cm/s$ |
| R_{TH0} | Thermal Resistance | 22Ω |

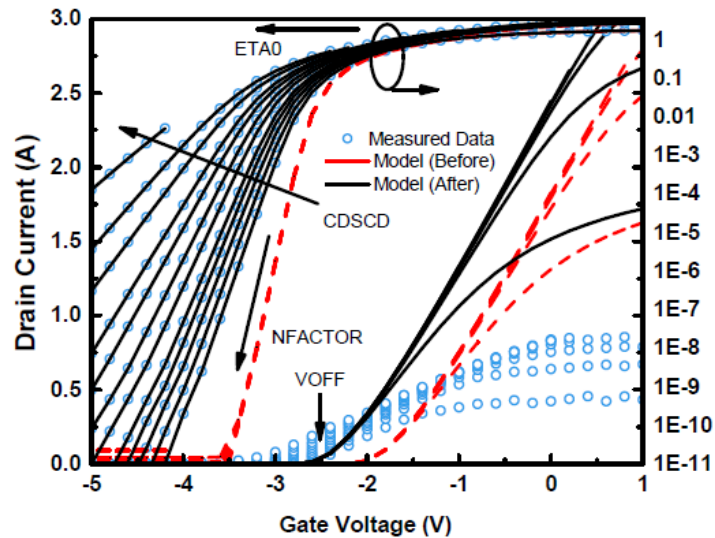
Core drain current expression

$$I_{ds} = \frac{\mu_{eff}}{\sqrt{1 + \theta_{sat}^2 \psi_{ds}^2}} \frac{W}{L} C_g N_f \left[V_{go} - \left(\frac{\psi_s + \psi_d}{2} \right) + V_{th} \right] \times \psi_{ds}$$

Model Parameter Extraction



Extraction from $I_d - V_g$ curves



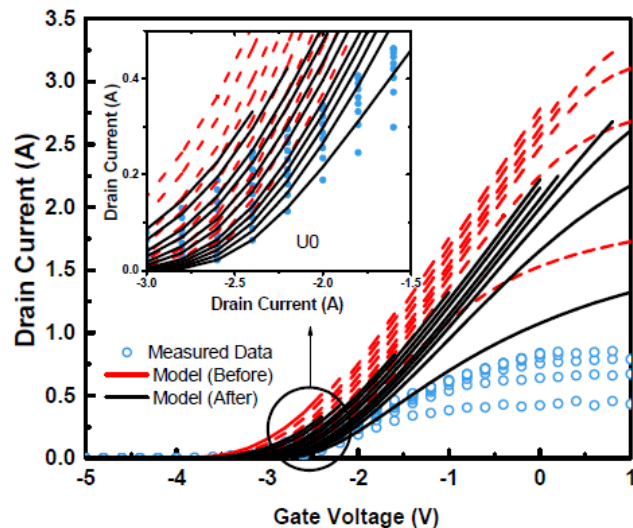
Start with $I_d - V_g$ characteristics in the log scale

η_{A0} – DIBL Parameter

$NFACTOR$ – Sub-threshold slope parameter

$CDSCD$ – Captures the drain voltage dependence on the sub-threshold slope.

$VOFF$ – Cut-Off Voltage

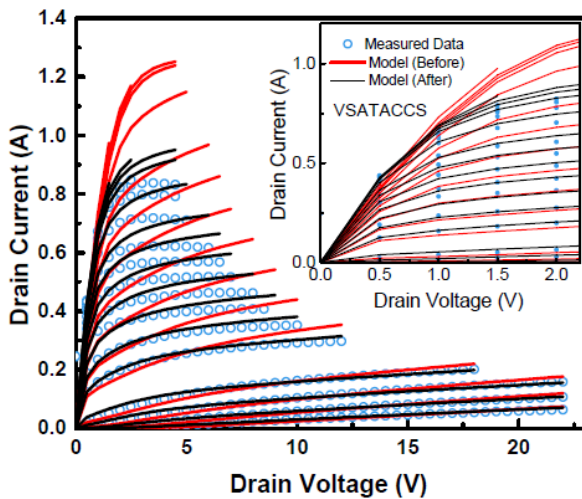
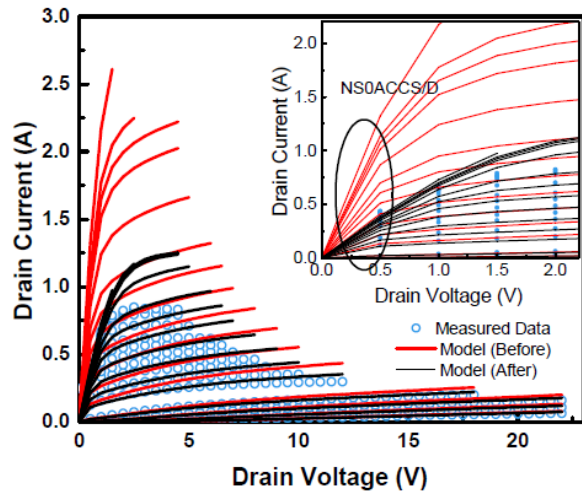


$I_d - V_g$ characteristics in the linear scale

$U0$ – Low field mobility

UA, UB – Mobility degradation parameters

Extraction from I_d - V_d curves



$I_d - V_d$ characteristics

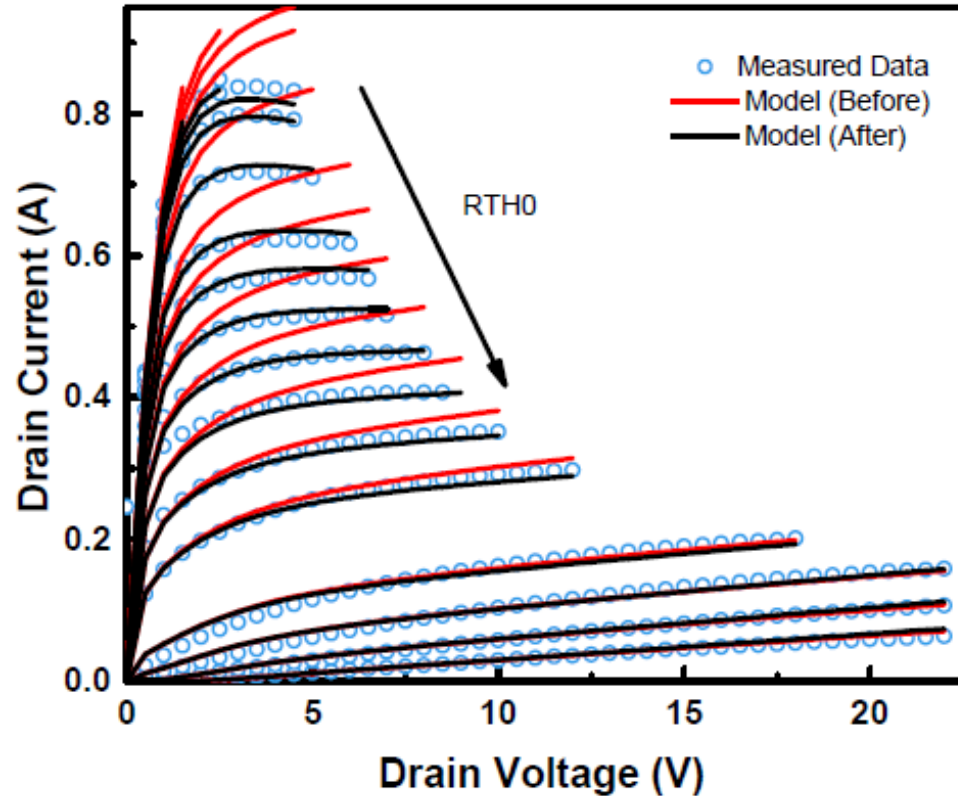
- **VSAT** – Velocity saturation parameter
- **UA, UB** – Mobility degradation parameters

Access Region Parameters extracted from $I_d - V_d$ characteristics:

- **NS0ACCS(D)** – 2DEG density in the access region.
- **VSATACCS** – Saturation velocity in the access region.
- **U0ACCS(D)** – Low field mobility in the access region.

$U0ACCS(D)$ independently tunes the access region resistance around $V_{ds} = 0$ and helps extract g_{ds} at that point.

Parameter Extraction – Self Heating



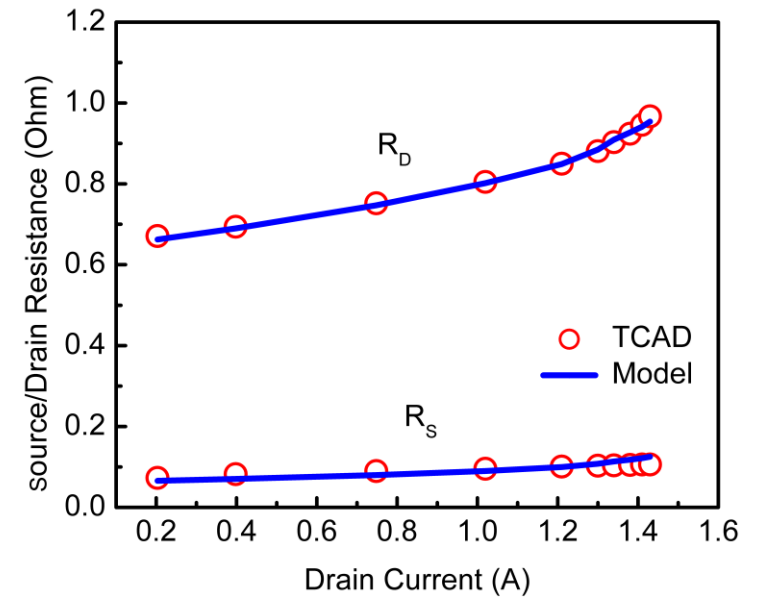
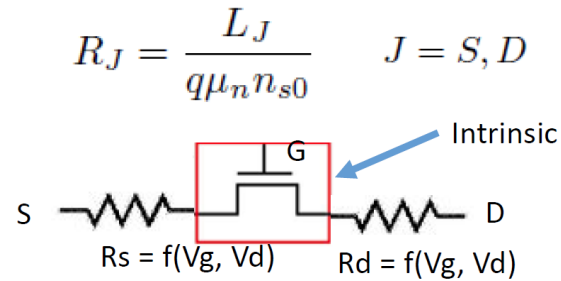
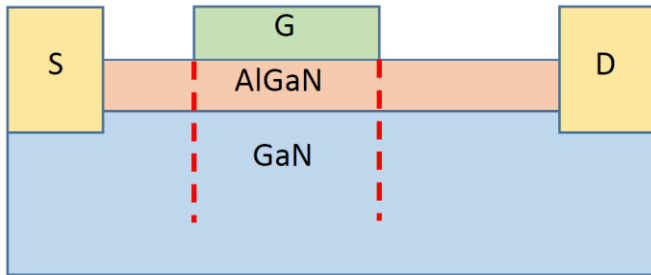
$I_d - V_d$ characteristics – Self Heating Parameters

- ***RTH0*** – Self heating resistance.
 - Decides the rate of temperature increase with increasing current.

Temperature dependence parameters to observe the effects of the temperature increase on IV characteristics:

- ***UTE*** – Temperature dependence of mobility
- ***AT*** – Temperature Dependence for saturation velocity

Nonlinear source/drain access region resistance model



$$I_{acc} = Q_{acc} \cdot v_s = Q_{acc} \cdot v_{sat} \cdot \frac{V_R / V_{Rsat}}{\left[1 + \left(\frac{V_R}{V_{Rsat}}\right)^\gamma\right]^{\frac{1}{\gamma}}}$$

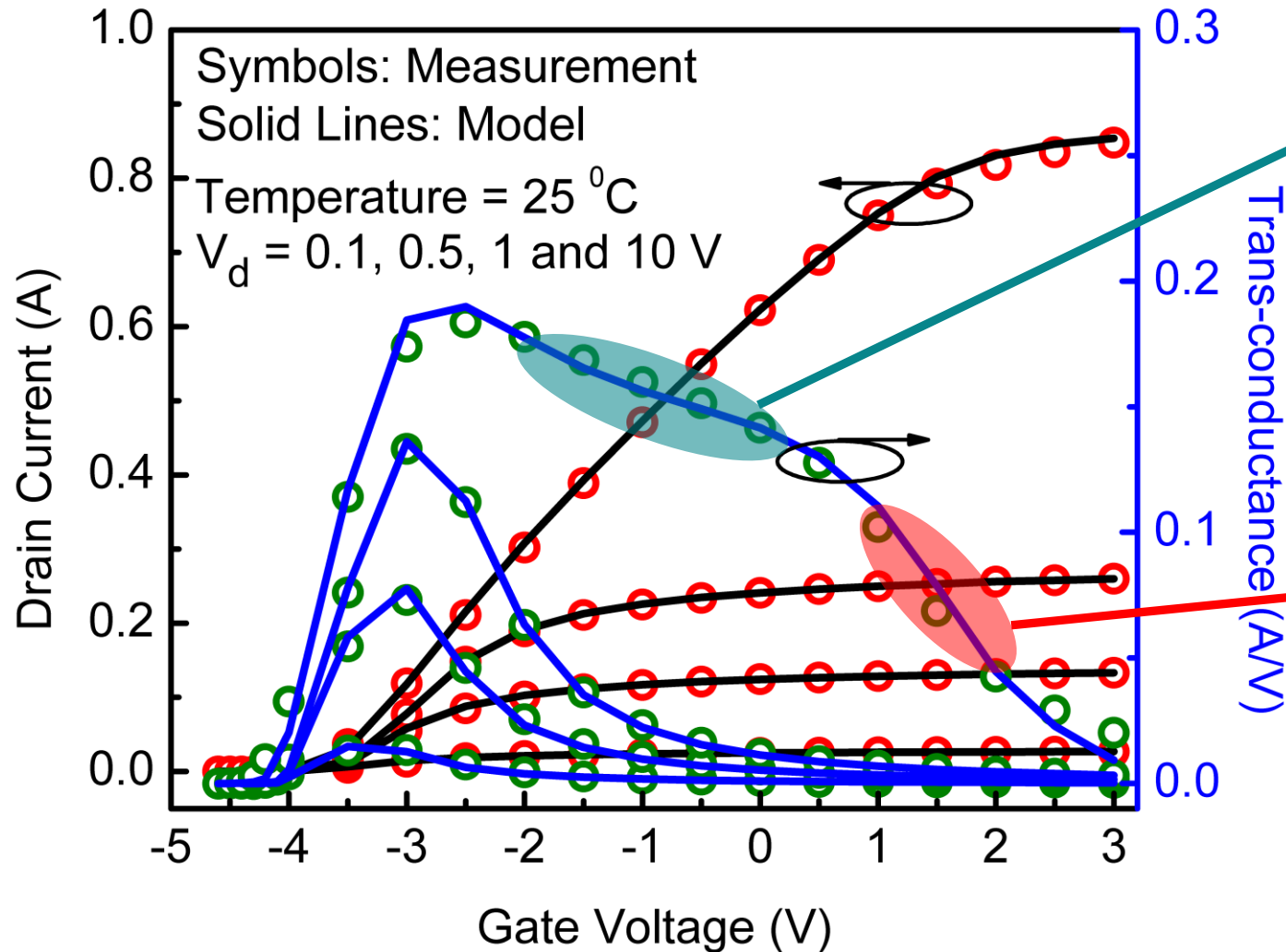
$$R_{d/s} = \frac{V_R}{I_{acc}} = \frac{R_{d0/s0}}{\left[1 - \left(\frac{I_d}{I_{acc,sat}}\right)^\gamma\right]^{\frac{1}{\gamma}}}$$

Nonlinear variation of source/ drain access resistances with I_{ds} .

Geometrically scalable

$$I_{ds,acc} = \frac{R_c}{W \cdot N_f} + \frac{L_{acc}}{W \cdot N_f \cdot q \cdot N_{S0ACCS} \cdot U_{0ACCS}} \times \left(1 - \left(\frac{I_{ds}}{W \cdot N_f \cdot N_{S0ACCS} \cdot V_{SATACCS}}\right)^2\right)^{-1/2}$$

$R_{d/s}$ Model – Effects on Transconductance g_m



The first slope in g_m
→ velocity saturation in the access region.

Second slope in g_m
→ self-heating in the device.

Reason: Self heating has significant impact at high gate and drain biases where the current is high.

Modeling of Temperature dependence

$R_{d/s}$ increases significantly with increasing temperature

Temperature dependence of 2-DEG charge density
in the drain or source side access region:

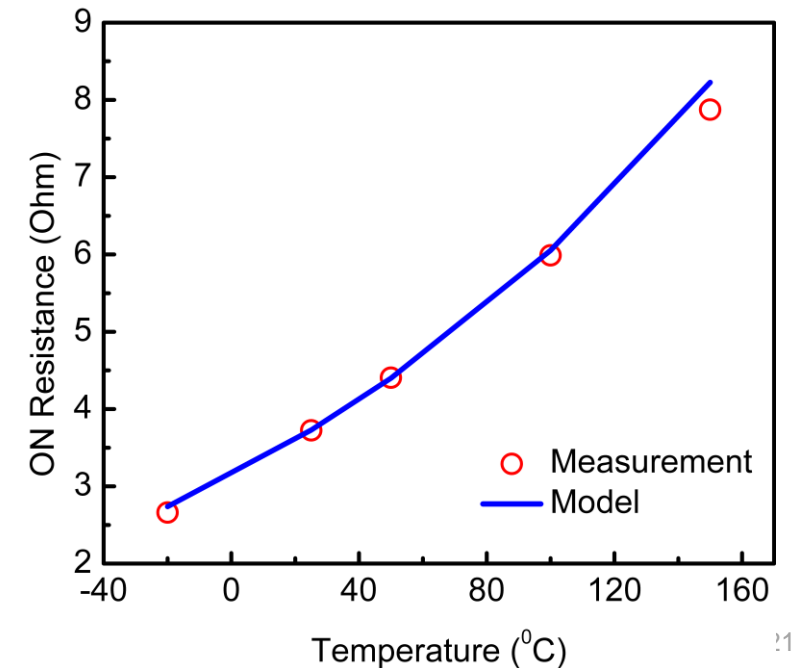
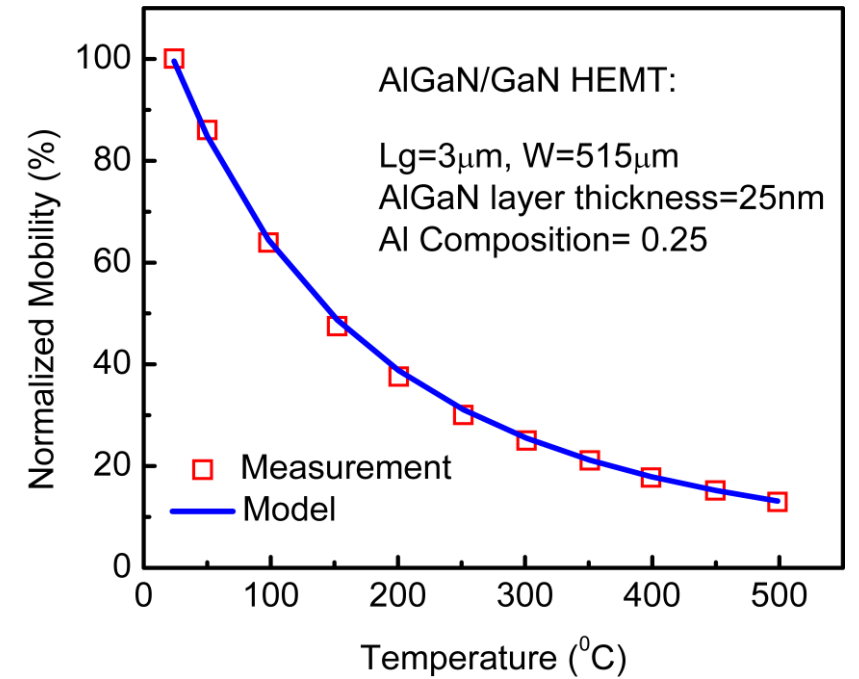
$$n_{s0}(T) = NS0ACC \cdot \left(1 - KNS0 \cdot \left(\frac{T}{TNOM} - 1 \right) \right)$$

Temperature dependence of Saturation Velocity:

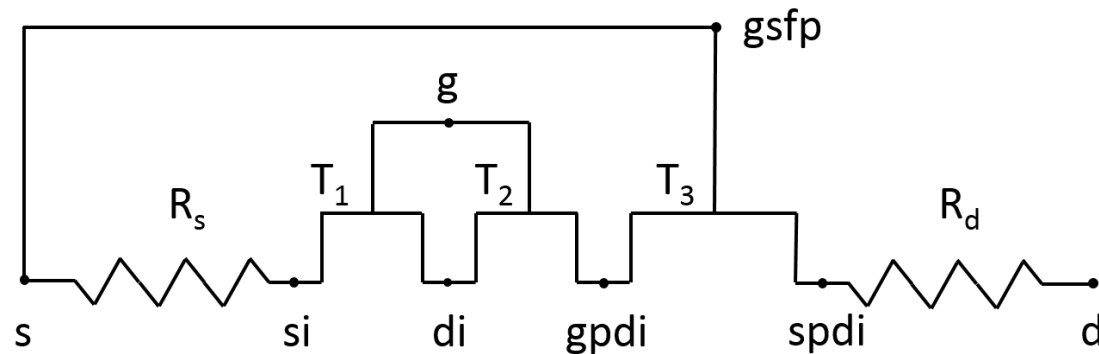
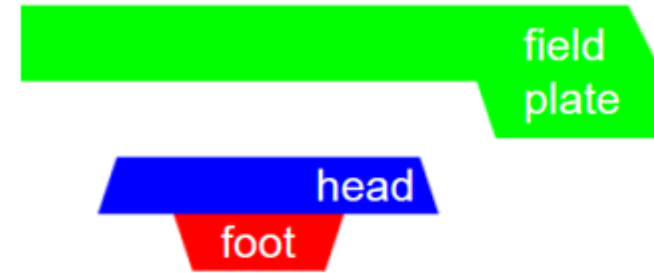
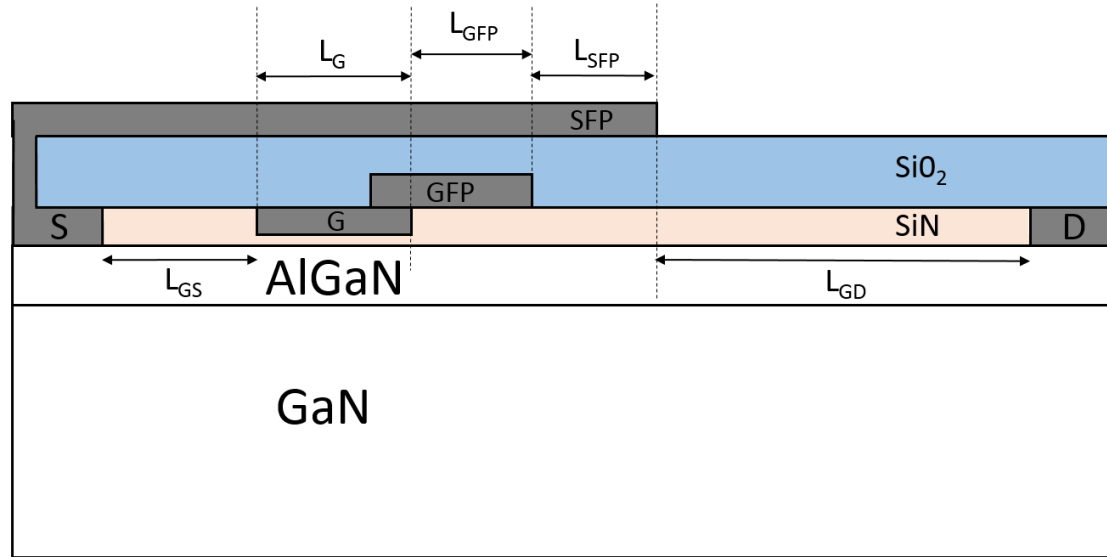
$$V_{sat}(T) = VSATACCS \cdot [1 + ATS(T - TNOM)]$$

Temperature dependence of electron Mobility:

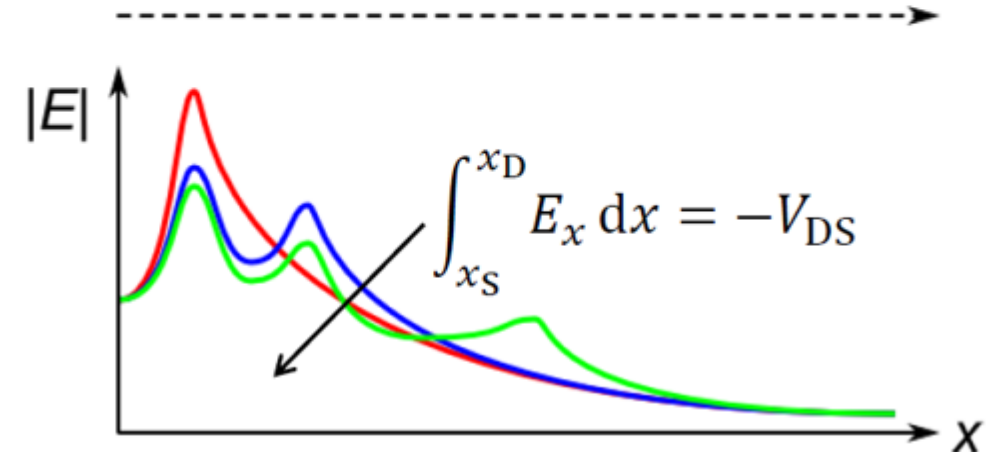
$$\mu_{acc}(T) = U0ACC \cdot \left(\frac{T}{TNOM} \right)^{UTEACC}$$



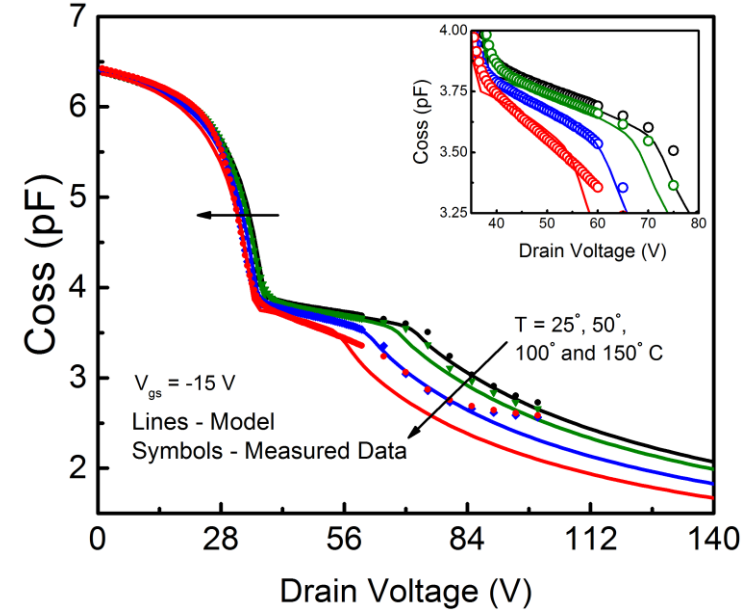
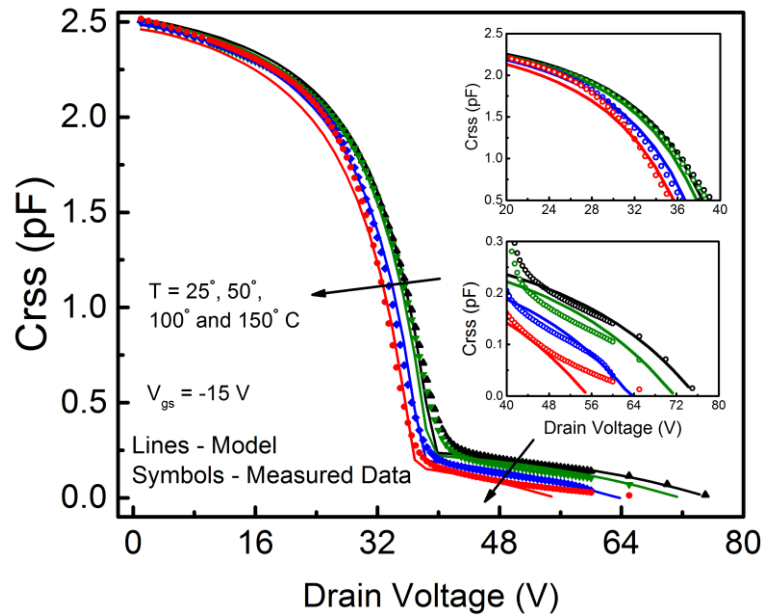
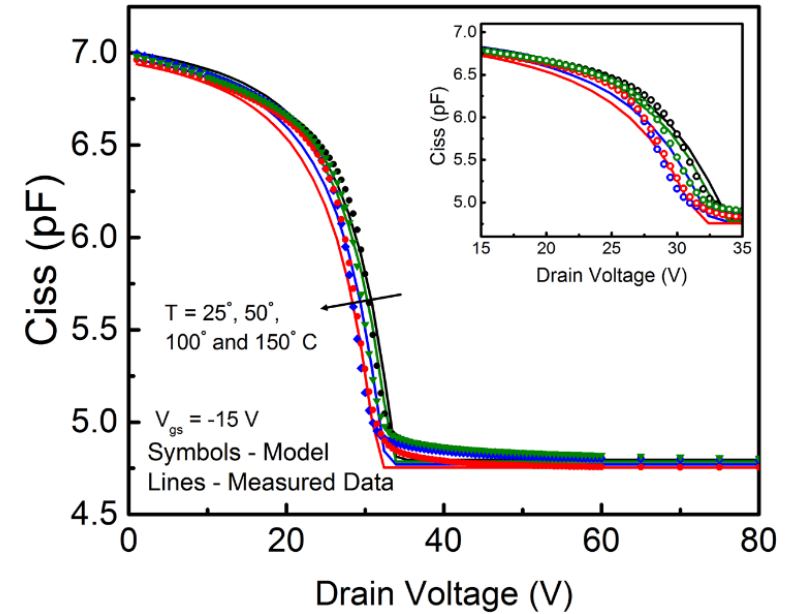
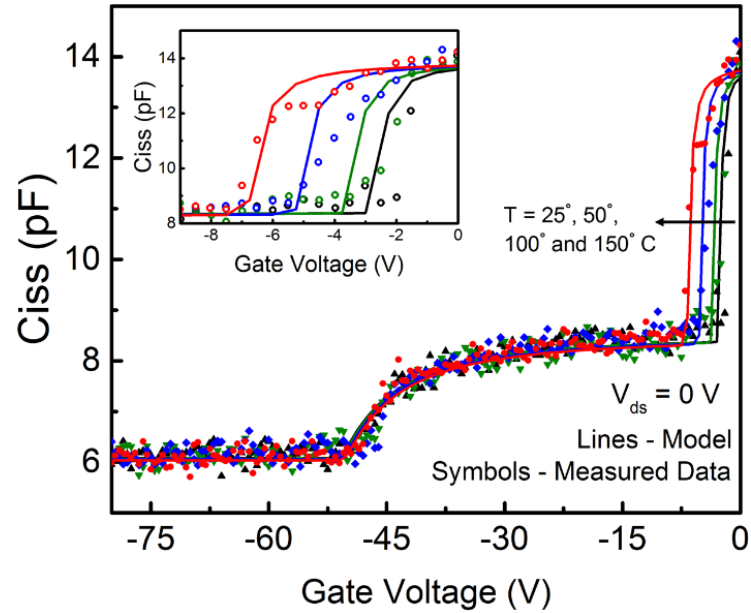
Modeling of Field-Plates in HEMTs



Affects capacitance and breakdown behavior.

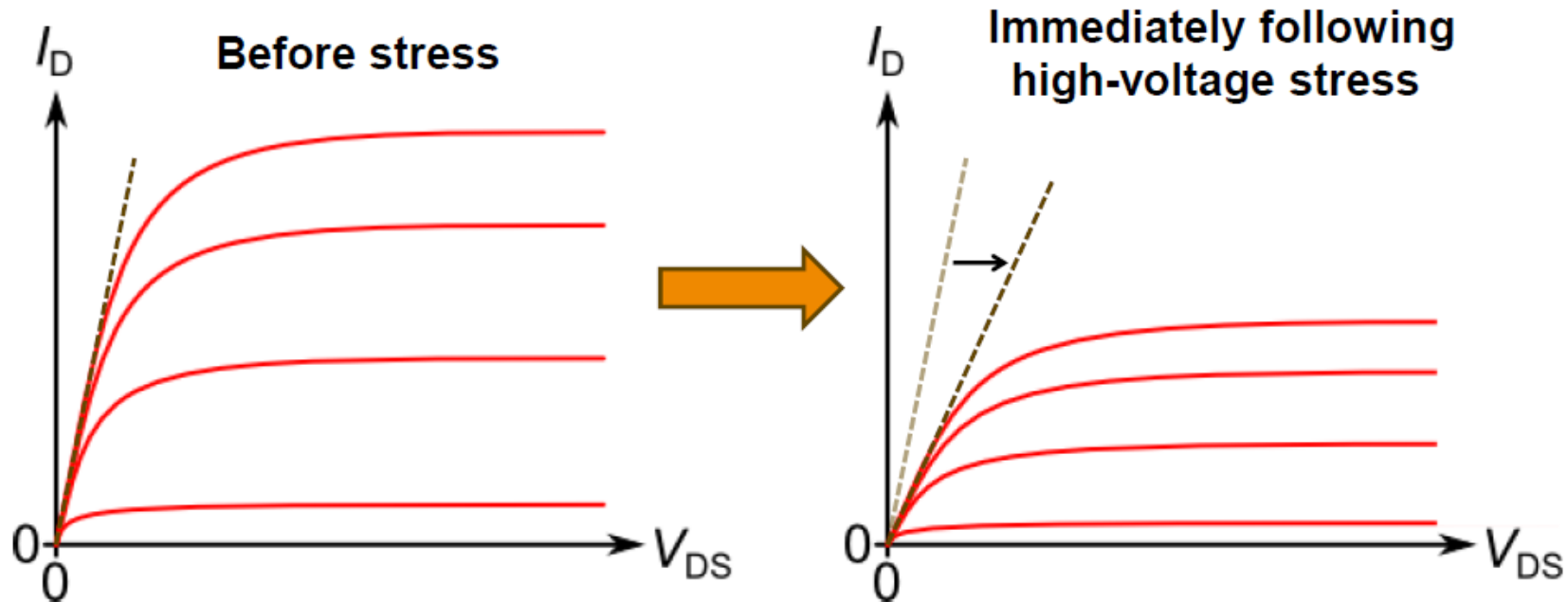


Field-Plate Capacitance Modeling

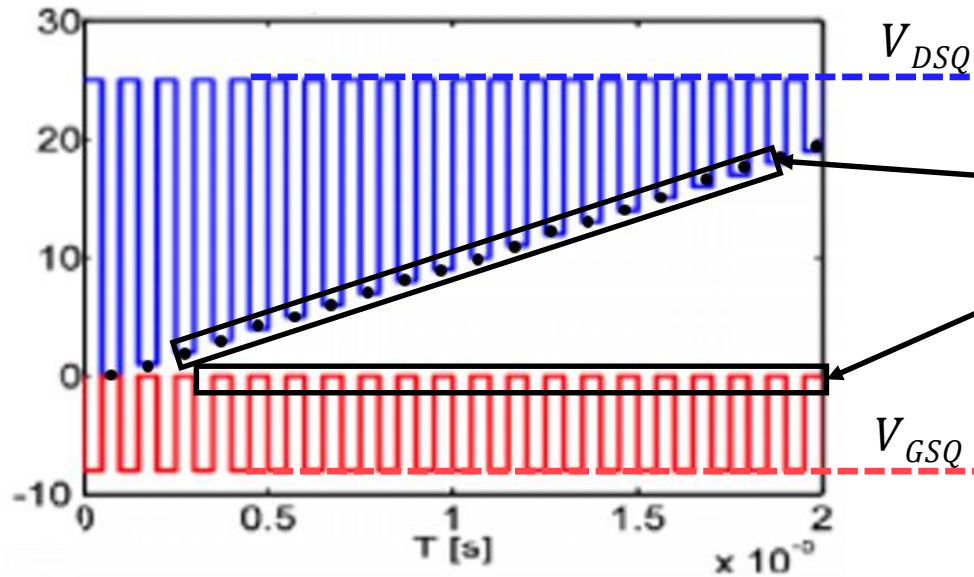


Current Collapse

- ▶ On-state current temporarily reduced following off-state stress



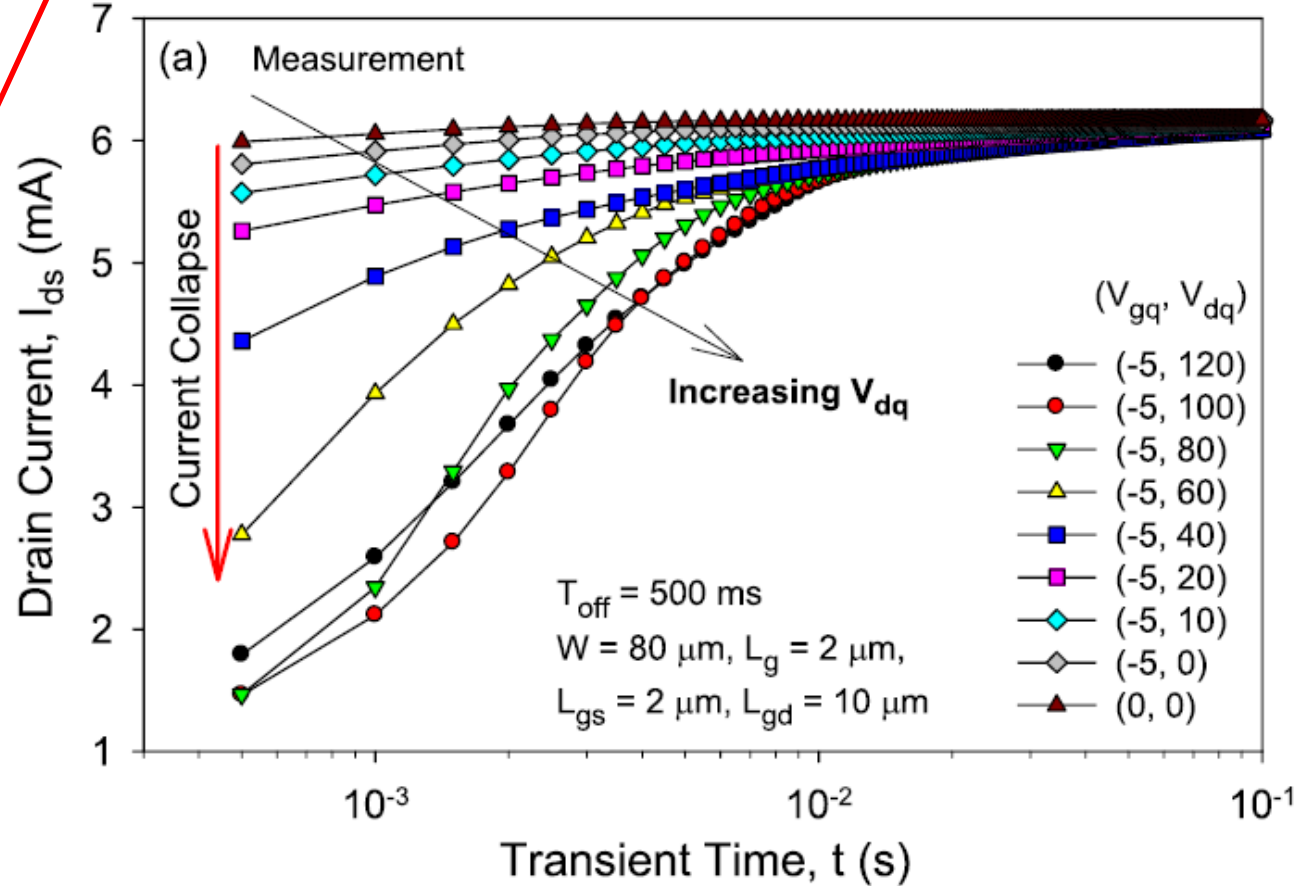
- ▶ Also known as **dynamic R_{on}**
 - On-state resistance depends on recent history of device biasing



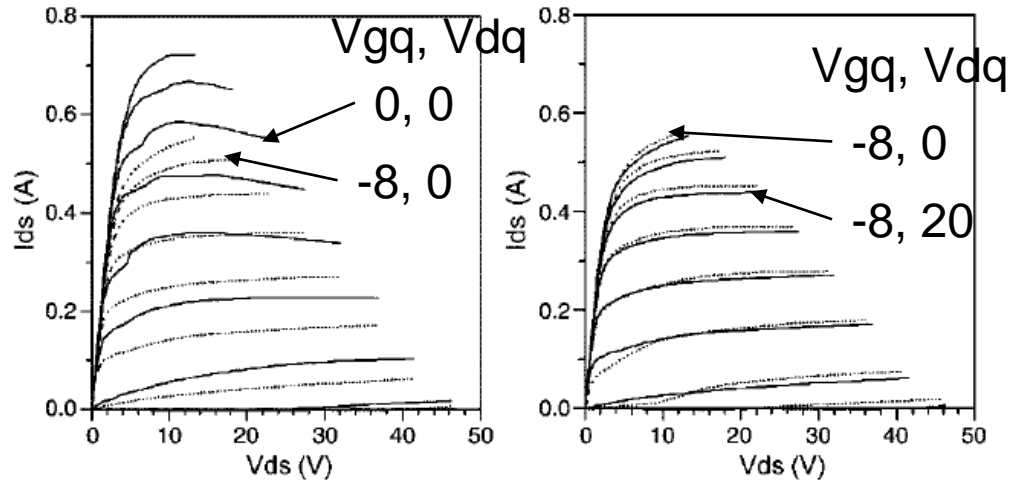
Quiescent Bias Condition

Measurement during pulse condition

Pulsed IV Measurements



Pulsed IV Measurements

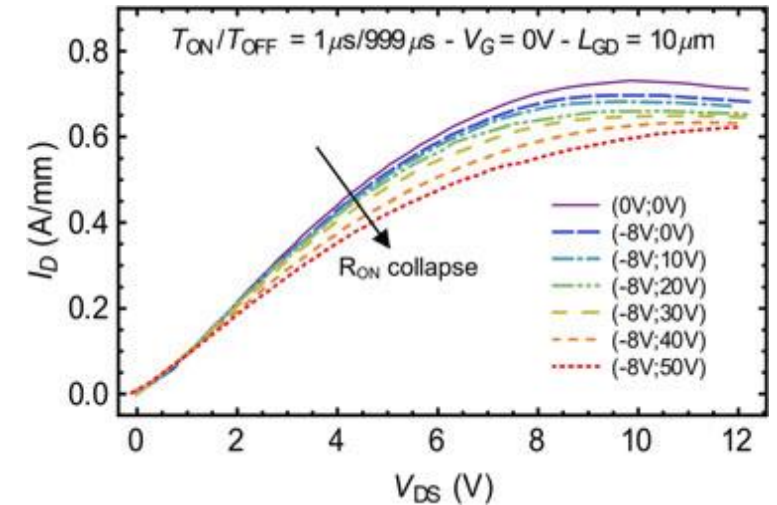


Gate-lag

- $V_{dq} = 0V$
- $V_{gq} = \text{Deep OFF condition}$:
A strong field through the AlGaN layer. No field through buffer (since $V_{ds} = 0$). Only surface traps activated.

Drain-lag

- $V_{dq} = \text{A significantly positive voltage}$
- $V_{gq} = \text{Deep OFF condition}$:
A strong field through the AlGaN layer as well as the buffer. Both surface and buffer traps activated.



R_{ON} Collapse:

Trapping reduces the 2DEG concentration and leads to an increased on-state resistance.

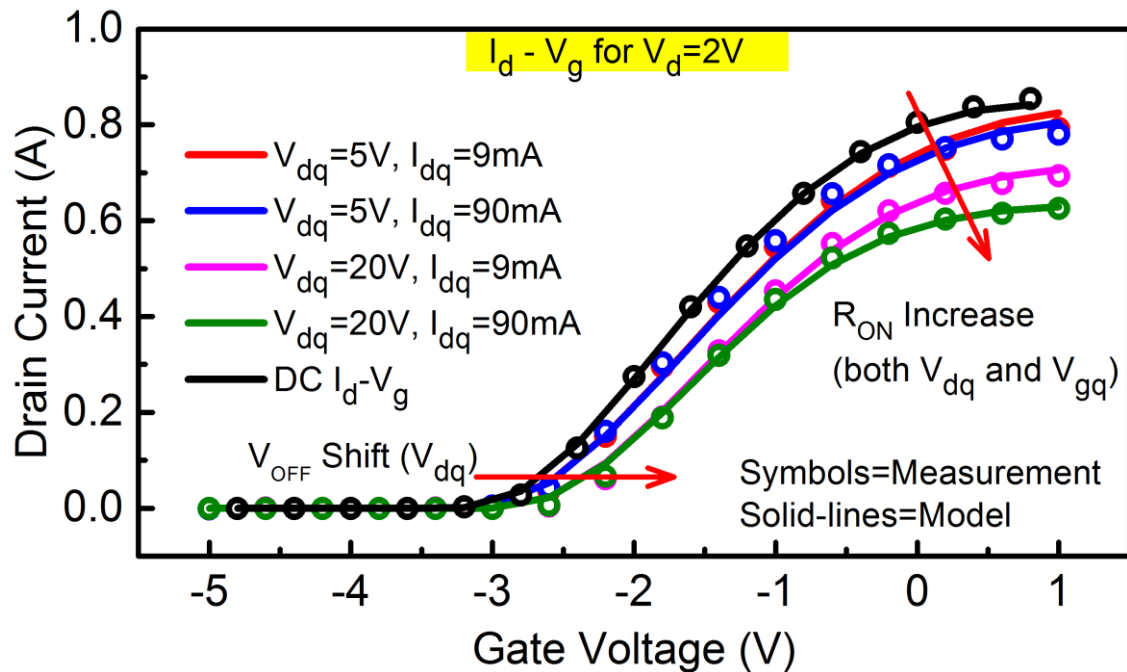
Trap Model

$$V_{\text{OFF}}(\text{Trap}) = V_{\text{OFF}} + (V_{\text{OFFTR}} \cdot V_{\text{trap2}})$$

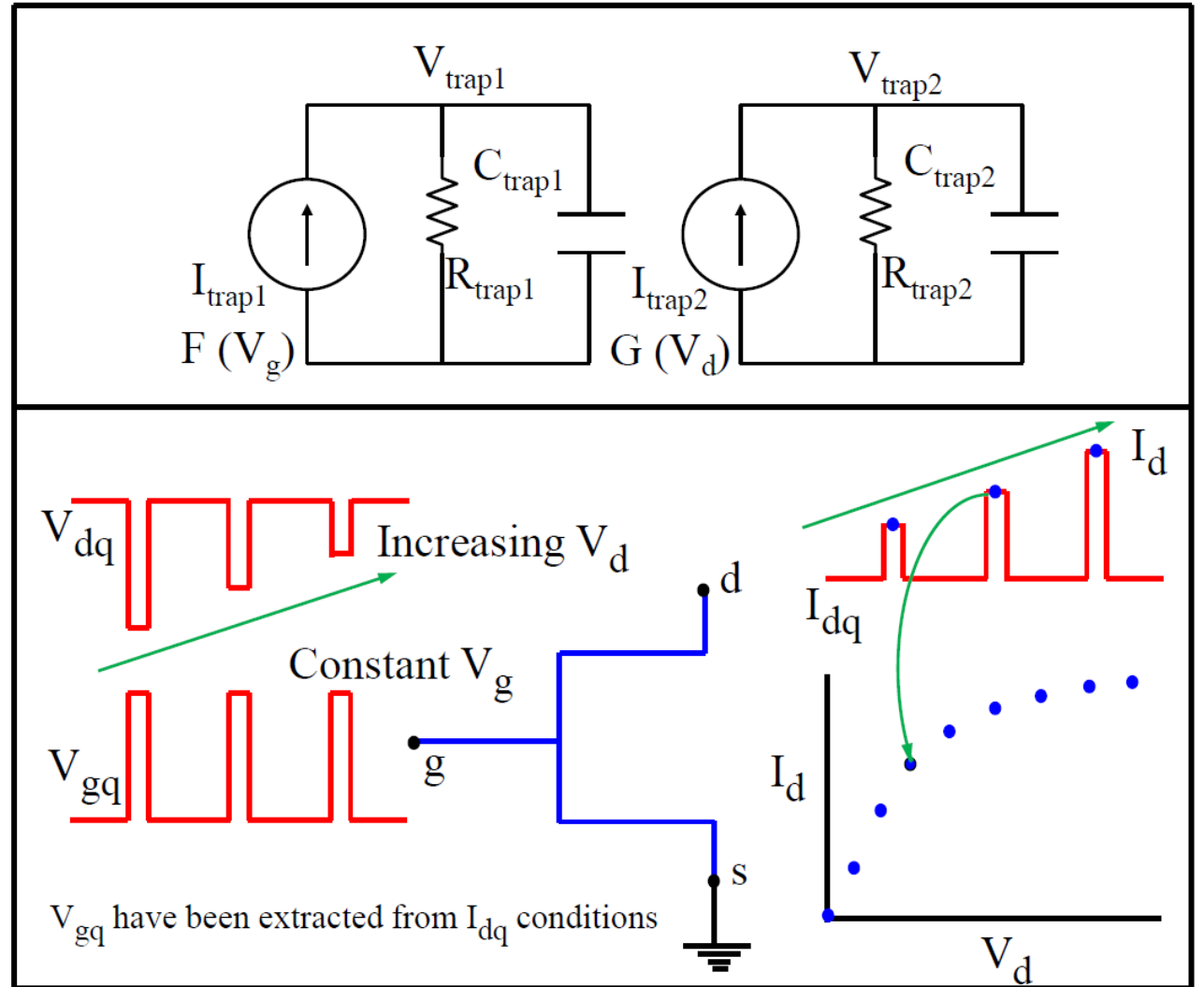
$$\eta_0(\text{Trap}) = \eta_0 + (\eta_{0\text{TR}} \cdot V_{\text{trap2}})$$

$$C_{\text{DSCD}}(\text{Trap}) = C_{\text{DSCD}} + (C_{\text{DSCDTR}} \cdot V_{\text{trap2}})$$

$$R_{\text{ds}}(\text{Trap}) = R_{\text{ds}} - (R_{\text{TR1}} \cdot V_{\text{trap1}}) + (R_{\text{TR2}} \cdot V_{\text{trap2}})$$



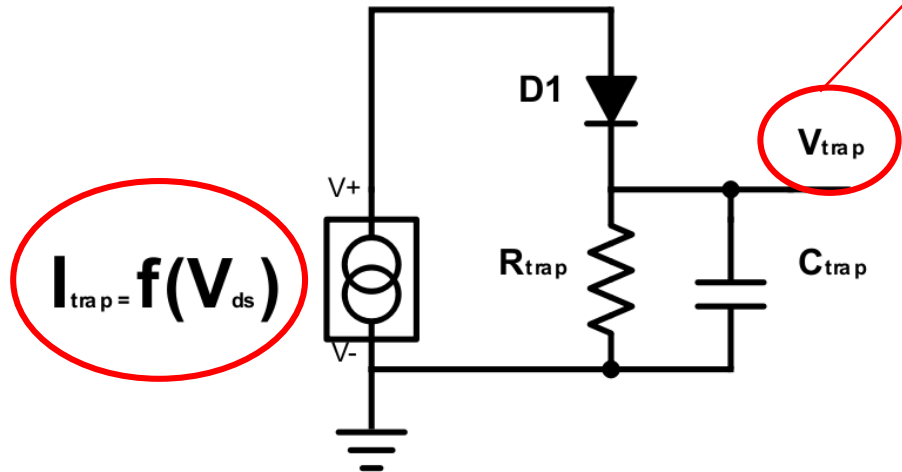
TRAPMOD=2



Pulsed-IV Scheme used to simulate the P-IV Characteristics in IC-CAP

Other Trap Models in ASM-HEMT

TRAPMOD=1



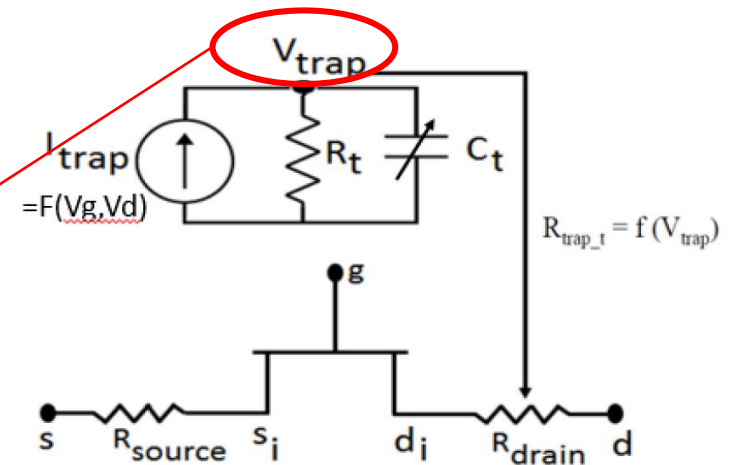
V_{trap} is then used to tune:

- Cut-off voltage
- DIBL
- Source and drain access resistances

TRAPMOD=3

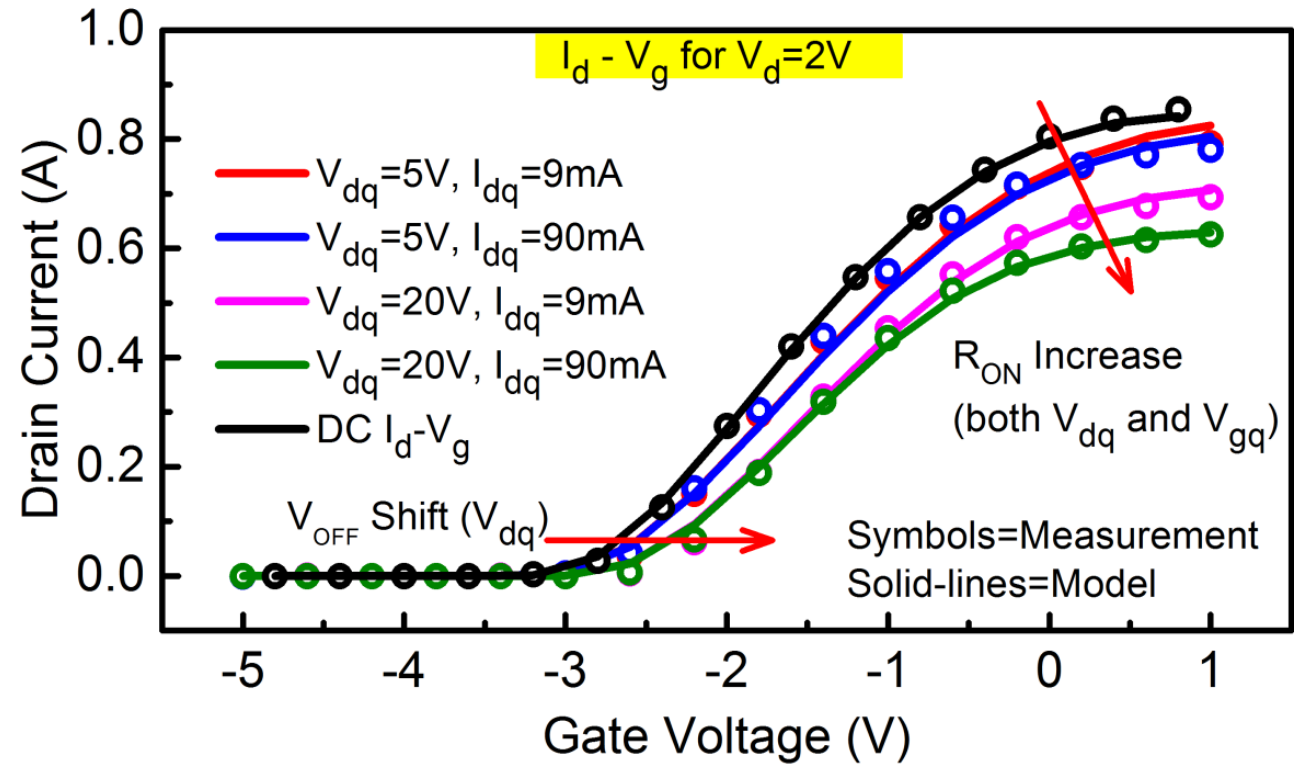
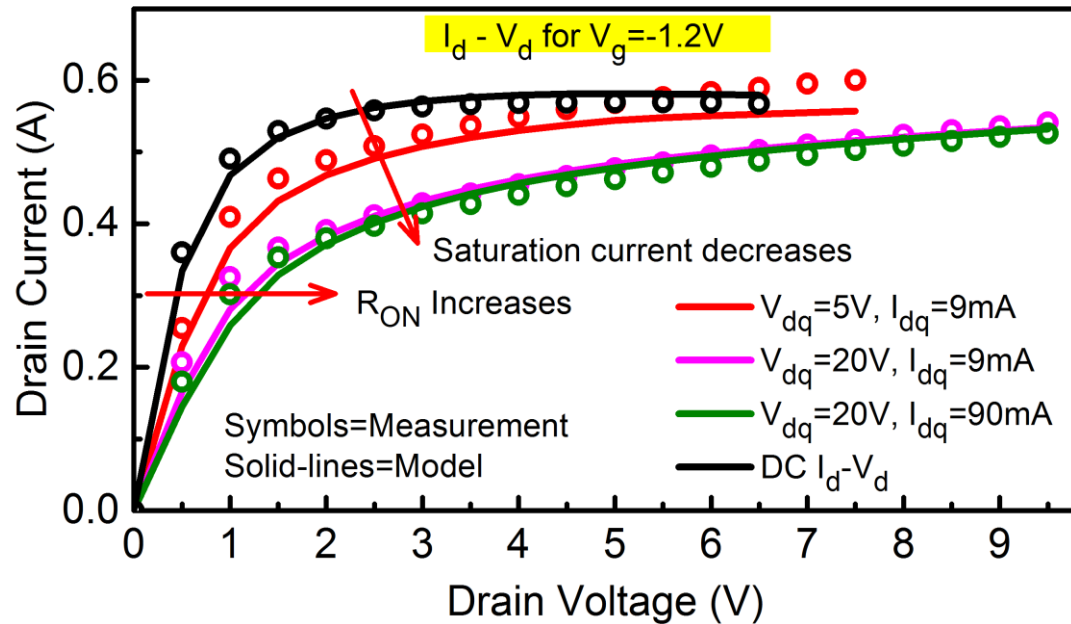
A single sub-circuit to capture the dependence on both V_g and V_d by using V_{gd} instead of V_{gs} and V_{ds} separately.

- V_{trap} is used to model the V_{gd} dependence on just the drain-side access region resistance.
- Recommended for modeling the GaN power device dynamic ON-resistance.
- An empirical temperature dependence is also included.



Trap Model

The trap model accurately captures Dynamic- R_{ON} and knee walkout.



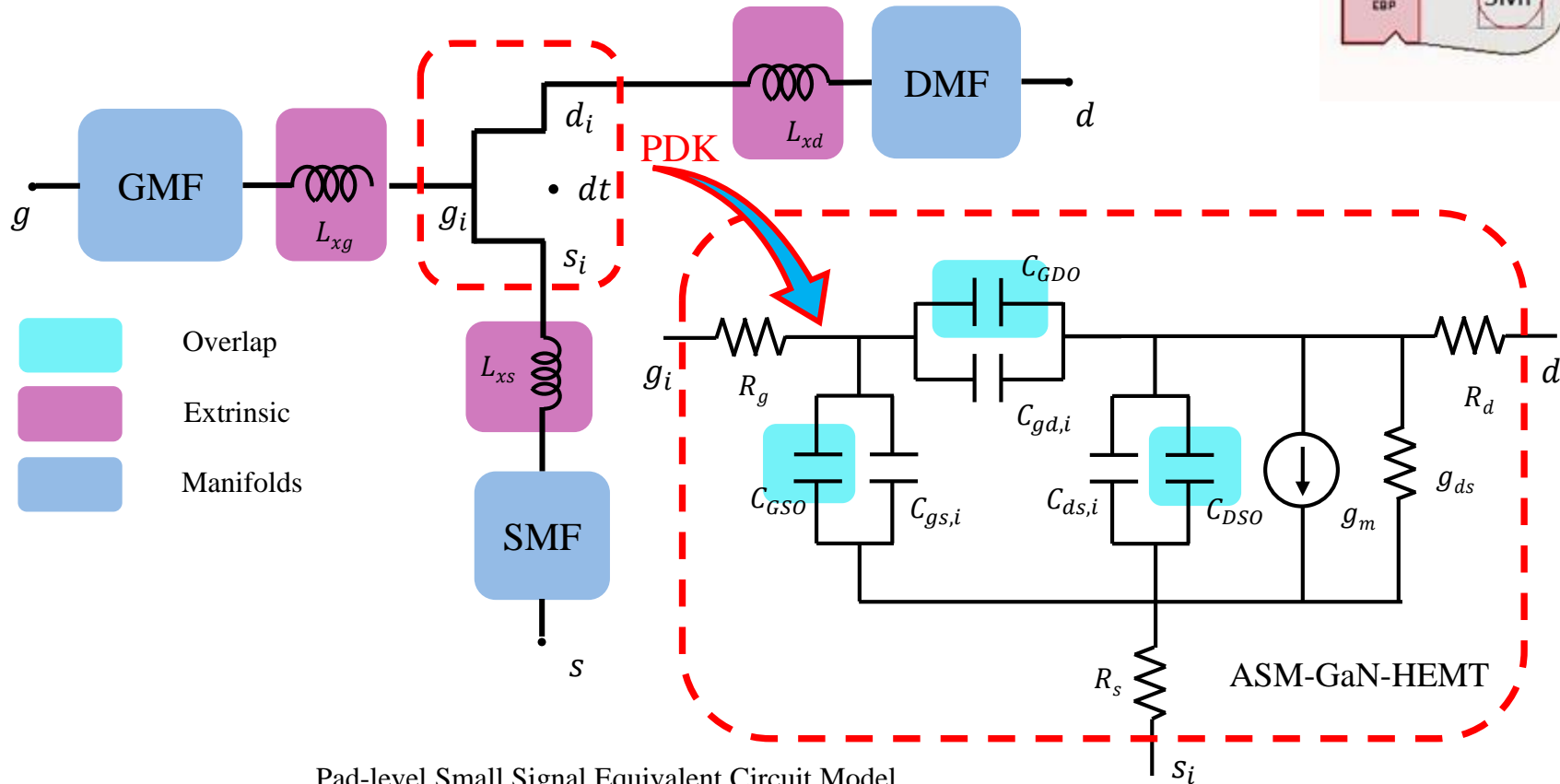
Pulsed – IV characteristics for multiple quiescent conditions

Knee walkout → linearity and efficiency

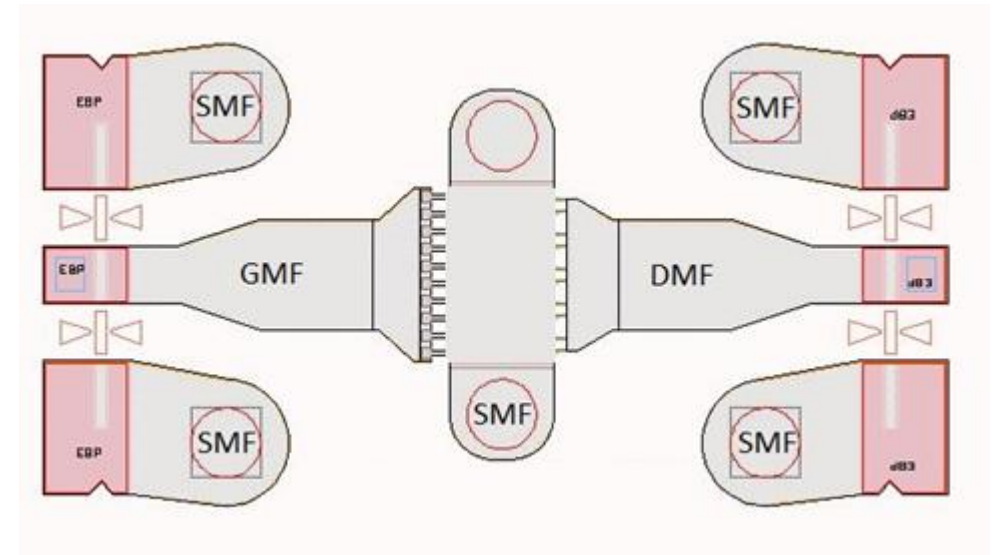
Pulse Width – 200 ns, Duty-cycle 0.02 %

RF Model & Extraction

- Model
 - Core surface potential based PDK
 - Access region resistances included in core
 - Bus-inductances in extrinsics



Pad-level Small Signal Equivalent Circuit Model



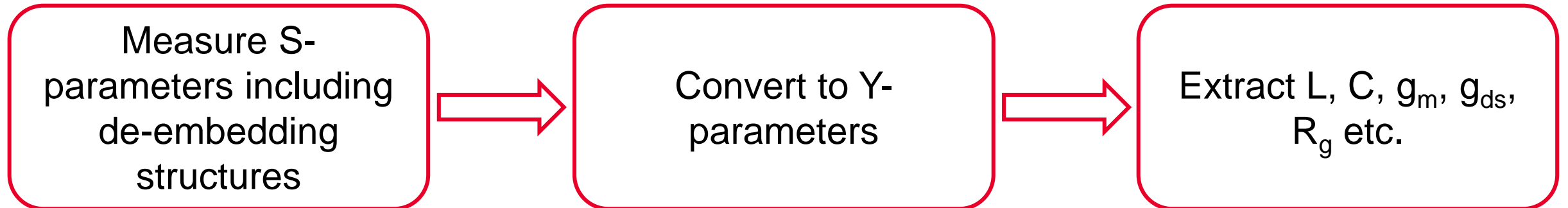
Device Layout

CGSO, CGDO, CDSO
bias-independent
capacitances

intrinsic capacitances:
 $C_{GS,i}$, $C_{GD,i}$ and $C_{DS,i}$
bias dependent

RF Model & Extraction

- Three step methodology
 - De-embed manifolds
 - Extract the intrinsic core model - Using low frequency Y-parameters
 - Extract Inductances - Using high frequency Y-parameters



RF Model & Extraction

[1]

Three step methodology

1. De-embed manifolds
2. Extract the intrinsic core model - Using low frequency Y-parameters
3. Extract Inductances - Using high frequency Y-parameters

[1]

$$Y_{11} = \frac{\omega^2 C_{gg}^2 R_g}{1 + \omega^2 C_{gg}^2 R_g^2} + \frac{j\omega C_{gg}}{1 + \omega^2 C_{gg}^2 R_g^2}$$

$$Y_{12} = -\frac{\omega^2 C_{gd} C_{gg} R_g}{1 + \omega^2 C_{gg}^2 R_g^2} - \frac{j\omega C_{gd}}{1 + \omega^2 C_{gg}^2 R_g^2}$$

$$Y_{21} = \frac{g_m - \omega^2 C_{gd} C_{gg} R_g}{1 + \omega^2 C_{gg}^2 R_g^2} - \frac{j\omega (C_{gd} + g_m C_{gg} R_g)}{1 + \omega^2 C_{gg}^2 R_g^2}$$

$$Y_{22} = g_{ds} + \frac{\omega^2 (C_{gs} C_{gd} R_g + R_g C_{gd} C_{gg} (1 + g_m R_g))}{1 + \omega^2 C_{gg}^2 R_g^2}$$

$$+ j\omega C_{ds} + \frac{j\omega C_{gd} (1 + g_m R_g) + j\omega^3 C_{gs} C_{gd} C_{gg} R_g^2}{1 + \omega^2 C_{gg}^2 R_g^2}$$

- The effect of **bus-inductances** is ignored at low frequencies (**assumption**)
- Drain & Source access region resistances ignored from hand analysis (**not an assumption, it is an advantage**)
- Ignore some terms at low frequency (~ 10 GHz) (**assumption**)
- Very simple – only need to adjust overlap capacitances & gate finger resistances (**advantage**)

$$[Y] \approx \begin{bmatrix} \omega^2 C_{gg}^2 R_g + j\omega C_{gg} & -\omega^2 C_{gd} C_{gg} R_g - j\omega C_{gd} \\ g_m - j\omega (C_{gd} + g_m C_{gg} R_g) & g_{ds} + j\omega (C_{ds} + C_{gd} (1 + g_m R_g)) \end{bmatrix}$$

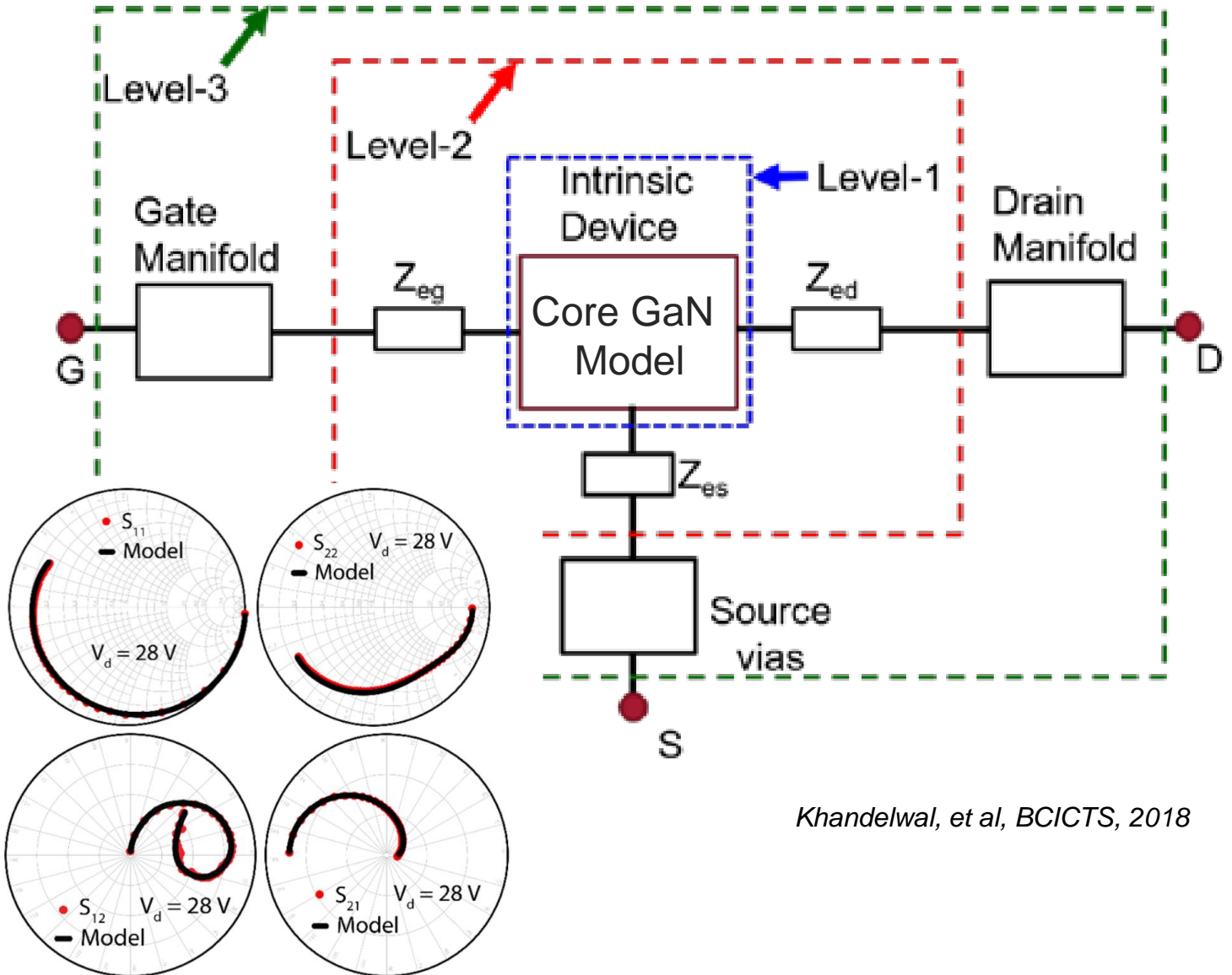
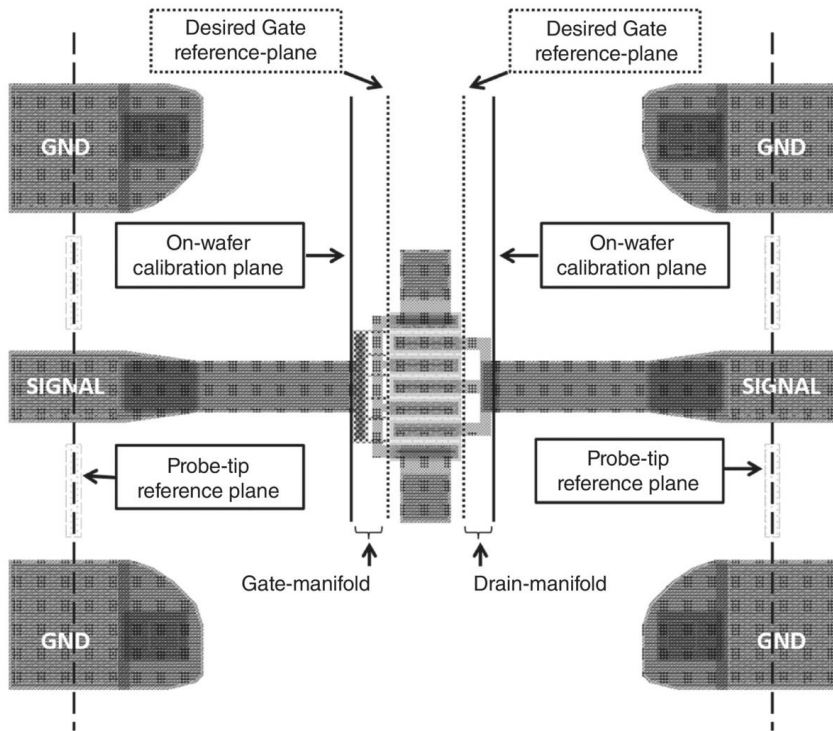
$$\begin{bmatrix} C_{gs} & C_{gd} & C_{ds} \\ g_m & g_{ds} & R_g \end{bmatrix}$$



$$\begin{bmatrix} (\text{Im}[Y_{11}] + \text{Im}[Y_{12}]) / \omega & -\text{Im}[Y_{12}] / \omega & \text{Im}[Y_{22}] / \omega - C_{gd} (1 + g_m R_g) \\ \text{Re}[Y_{21}] & \text{Re}[Y_{22}] & \text{Re}[Y_{11}] / (\omega^2 C_{gg}^2) \end{bmatrix}$$

[1] I. Kwon *et al.*, *IEEE Trans. Microw. Theory Techn.*, **50** (6), [2002]

RF Model & Extraction



*Nonlinear Circuit Simulation and Modeling,
Cambridge University press*

Khandelwal, et al, BCICTS, 2018



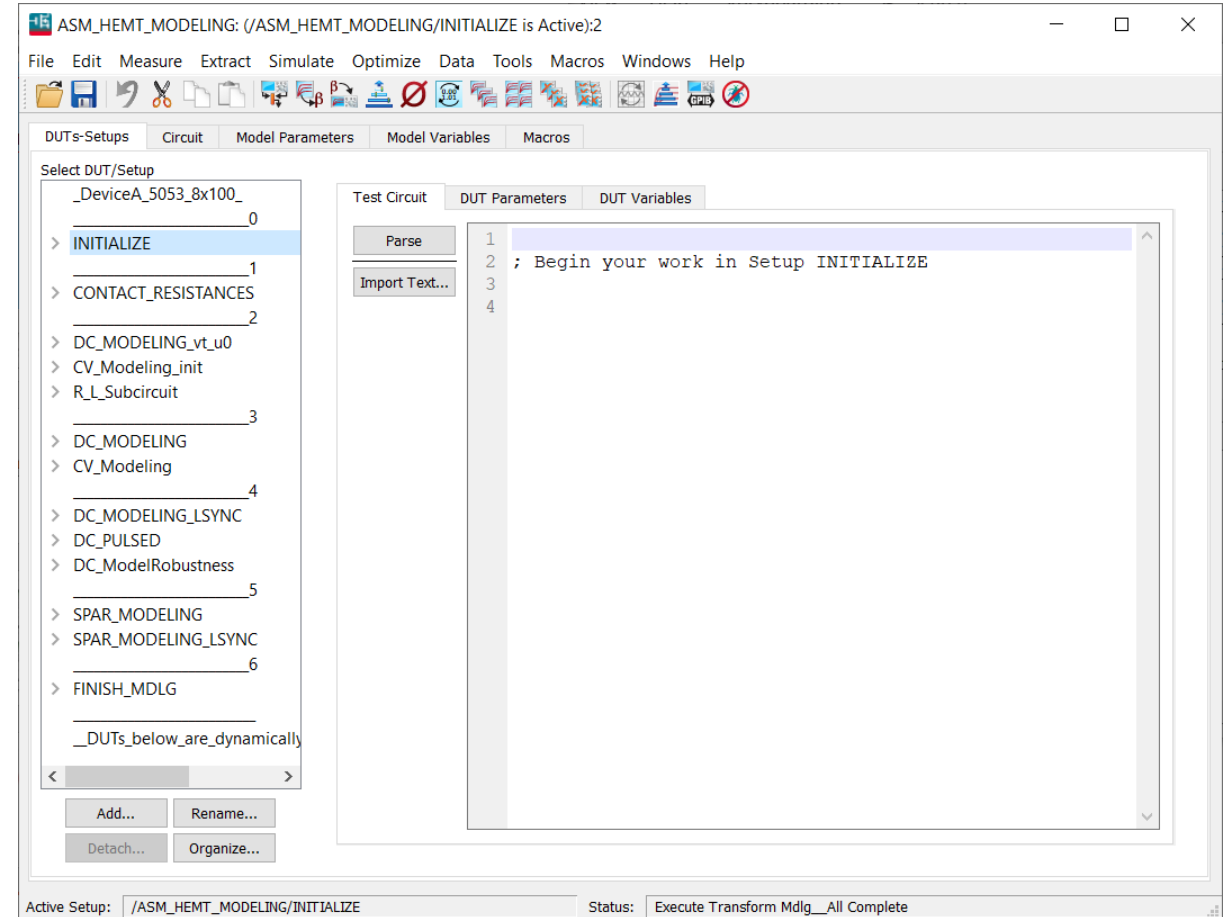
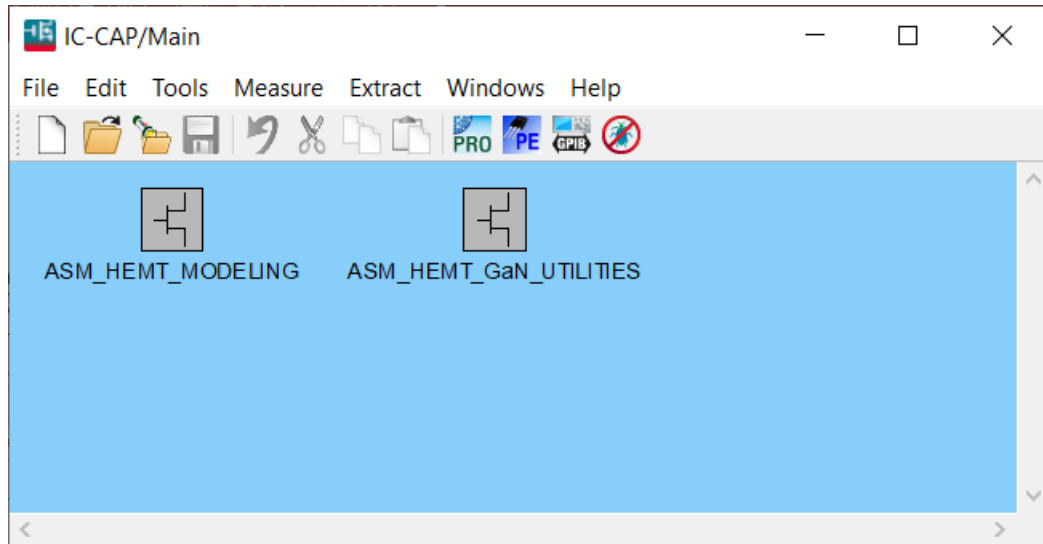
Introduction to CMC Modeling Kit (ASM-HEMT) in IC-CAP

Open Example Model Files

ASM-HEMT

ICCAP_2020_Update2 > examples > model_files > hemt > gancmc > asm-hemt

| Name | Date modified | Type | Size |
|----------------------------|----------------------|-------------|-----------|
| data | 12/25/2019 8:48 A... | File folder | |
| simulation | 12/25/2019 8:48 A... | File folder | |
| ASM-HEMT_GaN_UTILITIES.mdl | 8/17/2019 6:30 AM | MDL File | 1,657 KB |
| ASM-HEMT_Modeling.mdl | 8/7/2019 5:47 AM | MDL File | 39,636 KB |



Model Circuit and Parameters

Active Setup: /ASM_HEMT_MODELING/INITIALIZE Status: Execute Transform Mdlg_All Complete

```

27 ; -----
28
29 ;external Resistances for ASM HEMT model
30 R:RS S Si R=1m
31 R:RG G Gi R=1m
32 R:RD D Di R=1m
33 ;external Inductances for ASM HEMT model
34 L:LS Si Sii L=1p
35 L:LG Gi Gii L=1p
36 L:LD Di Dii L=1p
37
38 C:Cp11 G S C=1f
39 C:Cp22 D S C=1f
40 C:Cp12 G D C=1f
41
42 MAIN:Q1 Dii Gii Sii B DT
43
44 ; model name: asmhemt_1_0_1
45
46 model MAIN asmhemt_1_0_1 \
47 tnom =27.0 \
48 shmod =1 \
49 gatmod =1 \
50 rdsmod =0 \
51 rgatmod =0 \
52 trapmod =0 \
53 fp1mod =0 \
54 fp2mod =0 \
55 fp3mod =0 \
56 fp4mod =0 \
57 fnmod =0 \
58 tnmod =0 \
59 l =0.25e-6 \
60 w =200.0e-6 \
61 nf =1 \
62 ngcon =1 \
63 xgw =0 \
64 lsg =1.0e-6 \
65 ldg =1.0e-6 \

```

| Param Name | Min | Opt Min | Value | Opt Max | Max |
|---------------|-----|---------|--------|---------|-----|
| RTOTALPORT1 | | | 400.0m | | |
| RTOTALPORT2 | | | 400.0m | | |
| R_SOURCE | | | 50.00 | | |
| R_LOAD | | | 50.00 | | |
| X_LOAD | | | 0.000 | | |
| Temp_DC | | | 1.000a | | |
| CTERM_P1 | | | 1.000f | | |
| LTERM_P1 | | | 1.000a | | |
| CTERM_P2 | | | 1.000a | | |
| LTERM_P2 | | | 1.000f | | |
| RS.R | | | 1.000m | | |
| RG.R | | | 1.000m | | |
| RD.R | | | 1.000m | | |
| LS.L | | | 3.475p | | |
| LG.L | | | 11.72p | | |
| LD.L | | | 100.3f | | |
| Cp11.C | | | 1.000f | | |
| Cp22.C | | | 140.0f | | |
| Cp12.C | | | 8.000f | | |
| MAIN.TNOM | | | 25.00 | | |
| MAIN.SHMOD | | | 1.000 | | |
| MAIN.GATEMOD | | | 1.000 | | |
| MAIN.RDSMOD | | | 1.000 | | |
| MAIN.RGATEMOD | | | 1.000 | | |
| MAIN.TRAPMOD | | | 0.000 | | |
| MAIN.FP1MOD | | | 0.000 | | |
| MAIN.FP2MOD | | | 0.000 | | |
| MAIN.FP3MOD | | | 0.000 | | |
| MAIN.FP4MOD | | | 0.000 | | |

Initialize Modeling

DUTs-Setup Circuit Model Parameters Model Variables Macros

Select DUT/Setup
_DeviceA_5053_8x100_ 0

INITIALIZE

- README_FIRST
- LOAD_MEAS_DATA
- PROJECT_NAMING
- DEFINE_WORK_DIR
- INIT_MODELING

Measure / Simulate Instrument Options Set

Execute

Tune Fast...

Tune Slow...

Functions...

Select Transform:

- README_FIRST
- INIT_MODELING
- _optional_ 1
- Compare_with_Previous

CHECK THE SETTINGS

TEMPERATURE =====

| | | | | |
|----------|----------|--|--|--|
| TEMP /°C | TNOM /°C | | | |
| 25.00 | 25.00 | | | |

OK, Done

INSTANCE PARAMETERS =====

| | | | | |
|---|--|---|--|--|
| L (Channel Length) | W (Channel Width) | NF (Number Fingers) | NGCON (Number Gate Contacts) | |
| 150.0n | 100.0u | 8.000 | 1.000 | |
| LDG (Length of Drain-Gate Access Region) Default: 1u | LSG (Length of Source-Gate Access Region) Default: 1u | XGW (Distance Gate->Dev.Edge) Default: 0 | TBAR (Barrier Layer Thickness) Default: 25n | |
| 1.700u | 1.000u | 5.531u | 11.40n | |

MODEL SWITCHES =====

| | | | | |
|--|--|---|--|--|
| RGATEMOD: External (0) or Internal (1) Recommended: 1 | RDSMOD: External (0) or Internal (1) Recommended: 1 | SHMOD [0,1] (Self Heating off/on) Recommended: 1 | GATEMOD [0,1] (Gate Current Modeling off/on) Recommended: 1 | TRAPMOD [0,1,2,3] (Dyn.Trapping off/selection) Default: 0 |
| 1.000 | 1.000 | 1.000 | 1.000 | 0.000 |

FIELD PLATE SWITCHES =====

| | | | |
|---|---|---|--|
| FP1MOD [0,1,2] (Filed Plate Model1 off/selection) Default: 0 | FP2MOD [0,1,2] (Filed Plate Model2 off/selection) Default: 0 | FP3MOD [0,1,2] (Filed Plate Model3 off/selection) Default: 0 | FP4MOD [0,1,2] (Filed Plate Mode4 off/selection) Default: 0 |
| 0.000 | 0.000 | 0.000 | 0.000 |

MEASUREMENT CONTACT LOSSES (DC and Spar) =====

| | | |
|---------------------------------------|---------------------------------------|--|
| Port1 Contact Loss incl. Spar Testset | Port2 Contact Loss incl. Spar Testset | |
| 400.0m | 400.0m | Enter if already known, or apply later the Setups of DUT 'CONTACT_RESISTANCES' |

Check .mdm File Header for TEMP, TNOM, Rcontact etc.

The most important 1st step for successful device modeling is to reset the model parameters to default values (switch them 'off'). This means that after the first model parameters have been extracted, the simulation will only show the effect of these new parameters, AND NOT their effect overlaid by the still active parameters of the last modeling.
-> hit 'Reset Model Parameters', and then
-> hit 'Set Parameter Limits'.

Reset Model Parameters

Set Parameter Limits

Load Data for Modeling

Select DUT/Setup

- _DeviceA_5053_8x100_0
- INITIALIZE
 - README_FIRST
 - LOAD_MEAS_DATA
 - PROJECT_NAMING
 - DEFINE_WORK_DIR
 - INIT_MODELING
- CONTACT_RESISTANCES1
- DC_MODELING_vt_u02
- CV_Modeling_init
- R_L_Subcircuit

Measure / Simulate Instrument Options Se

Execute

Tune Fast...

Tune Slow...

Functions...

New...

Import Text...

View...

Rename...

Select Transform:

- HELP_HOW2USE1
- CLEAR_MEAS_DATA
- CLEAN_UP_SetupVars
- LOAD_MEAS_DATA
- VERIFY_MEAS_BIASES2
- _aux
- gui_Show_Biasings
- gui_ShowPlotAreaTools

prefix Dut name Setup name

_DeviceA_5053_8x100~DC_MODELING~ig_vgs__Input

IMPORT DATA

Selected .mdm data dir: /cygdrive/c/Users/cheschen/Desktop/RF_GaN_Modeling/iccip/data/DeviceA_8x100/Avail_Meas_Data/Data_for_Modeling

Deselect all DUTs

Clear all Meas. Data in Modelfile

HELP:
To manually load mdm files, first select DUT(s) from 'available Duts', then click into the first Setup in 'available DUT/Setups', and select the corresponding .mdm file from 'avail. mdm files'.

Click here, if mdm files are named Prefix~DutName~SetupName.mdm (no DUT/Setup and no mdm file selection is required)

Filename Wildcard File Suffix: .mdm

Apply

OK, Done

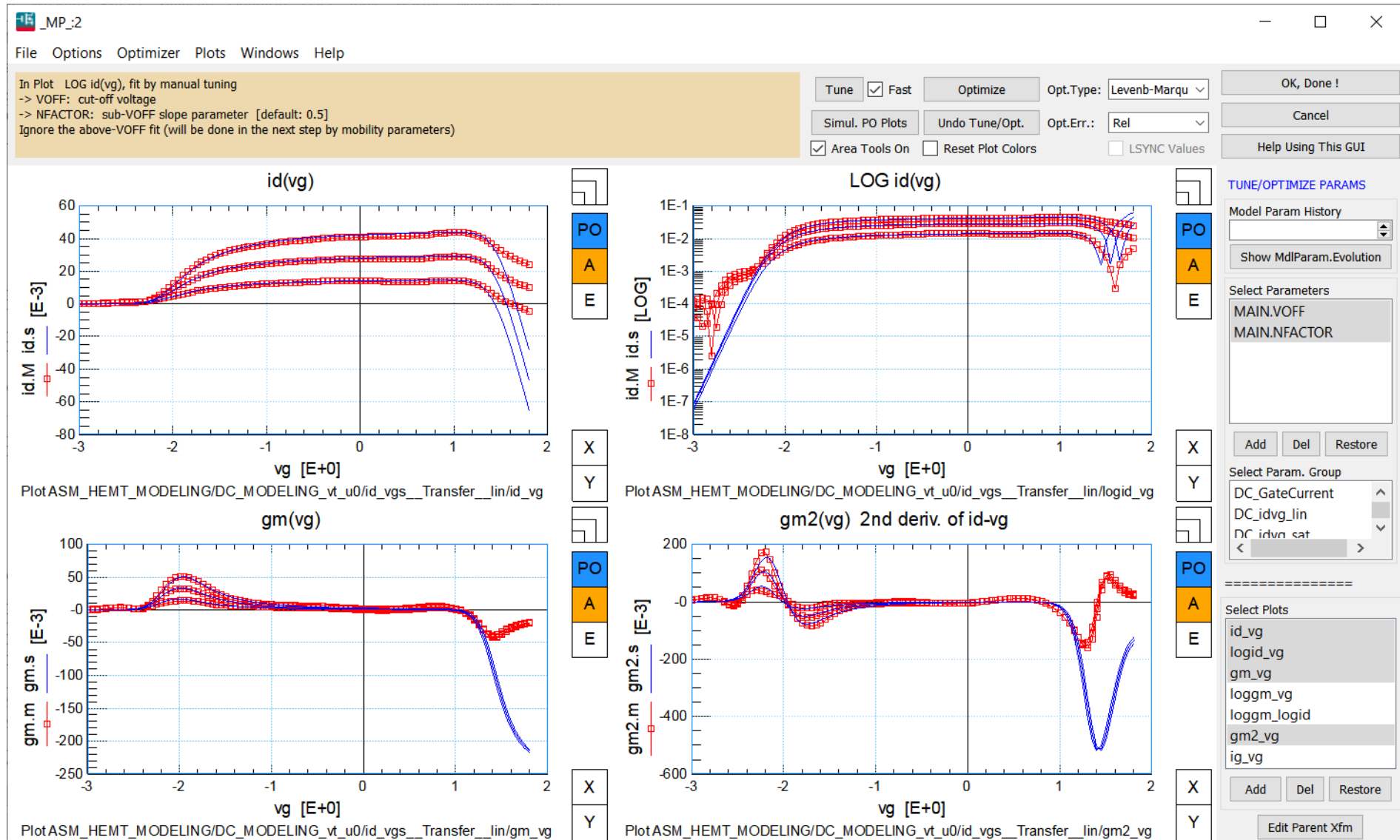
View .mdm Header Only, no Data Import

Load Automatically

Help

| available DUTs | available DUT/Setups | .mdm file loaded during this GUI session | status | avail. mdm files |
|-----------------------|-----------------------------------|--|--------|--|
| _DeviceA_5053_8x100_0 | CONTACT_RESISTANCES/DC_Meas_R | | | _DeviceA_5053_8x100~CONTACT_RESISTAI |
| INITIALIZE | CONTACT_RESISTANCES/DC_Meas_R | | | _DeviceA_5053_8x100~CONTACT_RESISTAI |
| CONTACT_RESISTANCES1 | DC_MODELING_vt_u0/id_vgs_Transfer | | | _DeviceA_5053_8x100~CV_Modeling_init~s |
| DC_MODELING_vt_u0 | CV_Modeling_init/spar_cap_vg_vd1 | | | _DeviceA_5053_8x100~CV_Modeling~spar |
| CV_Modeling_init | R_L_Subcircuit/Spar_bias | | | _DeviceA_5053_8x100~CV_Modeling~spar |
| R_L_Subcircuit | R_L_Subcircuit/Spar_sub | | | _DeviceA_5053_8x100~CV_Modeling~spar |
| DC_MODELING | DC_MODELING/ig_vgs__Input | | | _DeviceA_5053_8x100~CV_Modeling~spar |
| CV_Modeling | DC_MODELING/id_vgs__Transfer_lin | | | _DeviceA_5053_8x100~DC_MODELING_vt_u |
| DC_MODELING_LSYNC | DC_MODELING/id_vgs__Transfer_subV | | | _DeviceA_5053_8x100~DC_MODELING~id |
| DC_PULSED | DC_MODELING/id_vgs__Transfer | | | _DeviceA_5053_8x100~DC_MODELING~id |
| DC_ModelRobustness | DC_MODELING/id_vds__Output | | | _DeviceA_5053_8x100~DC_MODELING~id |
| SPAR_MODELING | CV_Modeling/spar_cap_vd_vg_low | | | _DeviceA_5053_8x100~DC_MODELING~id |
| SPAR_MODELING_LSYNC | CV_Modeling/spar_cap_vg_vd1 | | | _DeviceA_5053_8x100~DC_MODELING~ig |
| | CV_Modeling/spar_cap_vd_vg_T | | | _DeviceA_5053_8x100~R_L_Subcircuit~Spa |
| | CV_Modeling/spar_cap_vg_vdhigh | | | _DeviceA_5053_8x100~R_L_Subcircuit~Spa |
| | DC_MODELING_LSYNC/id_vds__Outpu | | | _DeviceA_5053_8x100~SPAR_MODELING~I |
| | DC_PULSED/idvd_vg0V0_vd0V0 | | | _DeviceA_5053_8x100~SPAR_MODELING~I |
| | DC_PULSED/idvd_vgm3V3_vd28V0 | | | _DeviceA_5053_8x100~SPAR_MODELING~! |
| | DC_PULSED/idvd_vgm8V0_vd28V0 | | | _DeviceA_5053_8x100~SPAR_MODELING~! |

GaN Modeling GUI



How to Use GaN Modeling GUI

| Name | Value |
|--------------|------------------------|
| UtilitiesLoc | ASM_HEMT_GaN_UTILITIES |

Select Plots

- id_vg
- logid_vg
- gm_vg
- loggm_vg
- loggm_logid
- gm2_vg
- ig_vg

Select Parameters

- MAIN.VOFF
- MAIN.NFACTOR

Add Del Restore

In Plot LOG id(vg), fit by manual tuning
 -> VOFF: cut-off voltage
 -> NFACTOR: sub-VOFF slope parameter [default: 0.5]
 Ignore the above-VOFF fit (will be done in the next step by mobility parameters)

Function Program2

```

3 GLOBAL_VAR UtilitiesLoc
4 |=====
5 !---define here which individual Plots (*no* MultiPlots!) and which Parameters you want to use for this m
6 Plots = 'id_vg, logid_vg, gm_vg, !loggm_vg, !loggm_logid, gm2_vg, !ig_vg'
7           ! Choices: Enter a comma-blanc separated list of Plots
8           !           -you can also include Plots of other Setups, using ../../Setup/Plot
9           !           -you can precede plot names with a ! to enter them to the Plot list of
10          !           but not as currently active targets for the PO, e.g. !idvg
11          !           -setting Plots="" will open a GUI to manually select from all Plots of
12 Parameters = "MAIN.VOFF, MAIN.NFACTOR"
13          ! Choices: Enter a comma-blanc separated list of ModelParameters or Model Variable
14          !           You can precede parameter names with a ! to enter them as candidates,
15          !           When linking to DutParameters: define Dutname.ParameterName
16          !           When linking to Variables: ModelVariables w/o any path, Dut and Setup
17          !           -Parameters = "" open the GUI without any Parameters predefined.
18          !           User can select parameters from the GUI by himself.
19          !           -Parameters = "n/a": show only MultiPlot incl. Comment, no PlotSelect
20          !           Useful when just displaying current extraction results,
21          !           -Parameters = "Compare": show only MultiPlot incl. Comment, no ParamSele
22 Comment = "In Plot LOG id(vg), fit by manual tuning
23 -> VOFF: cut-off voltage
24 -> NFACTOR: sub-VOFF slope parameter [default: 0.5]
25 Ignore the above-VOFF fit (will be done in the next step by mobility parameters)"
26          ! The Comment will be displayed on top left of the MultiPlot. Enter "" for 'no co
27          ! If the Comment starts with 'FF: ', it will be displayed with Fixed Font (Courie
28 PO_Error = "Relative"
29          ! Preset of PlotOptimizer error. Choices: "Relative", "Absolute", "" (keeps last
30 PO_ShowOnStartup = 0
31          ! Flag to enable showing the Plot Optimizer on MDL GUI startup or not? 0 - false,
32 |=====
33 mdlGuiStatus=GaN_ModelingGUI(PO_ShowOnStartup, Parameters, Plots, Comment, PO_Error)
34
  
```


How to Define Parameter Groups

The screenshot displays the 'Model Variables' interface with the 'Macros' tab selected. A search bar contains the letter 'F'. Below the search bar is a table of parameter groups. The row for 'PARAMGROUP_DC_idvg_lin' is highlighted with a red box. To the left, a 'Select Parameters' dialog shows a list of parameters including MAIN.VOFF, MAIN.NFACTOR, MAIN.U0, MAIN.UA, MAIN.UB, and MAIN.CDSCD. Below this dialog is a 'Select Param. Group' dialog with 'DC_idvg_lin' selected. An arrow points from the 'DC_idvg_lin' selection in the dialog to the highlighted row in the table.

| Name | Value |
|--------------------------------|--|
| PARAMGROUP_DC GateCurrent | MAIN.IGSDIO,MAIN.NJGS |
| PARAMGROUP_DC_idvg_lin | MAIN.VOFF, MAIN.NFACTOR, MAIN.U0, MAIN.UA, MAIN.UB, M... |
| PARAMGROUP_DC_idvg_sat | MAIN.ETA0, MAIN.VDSSCALE, MAIN.RTH0 |
| PARAMGROUP_DC_idvd | MAIN.LAMBDA, MAIN.VSAT, MAIN.DELTA, MAIN.THESAT |
| PARAMGROUP_ext_resistors | MAIN.RDSMOD, MAIN.RGATEMOD, RG.R, RS.R, RD.R |
| PARAMGROUP_int_resistors | MAIN.RDSMOD, MAIN.RGATEMOD, MAIN.RSHG, MAIN.RSC, MAI... |
| PARAMGROUP_Temp_DC | MAIN.UTE, MAIN.KT1, MAIN.AT, MAIN.KTGS |
| PARAMGROUP_Temp_int_resist | MAIN.KNS0, MAIN.ATS, MAIN.UTES, MAIN.UTED, MAIN.KRSC... |
| PARAMGROUP_Spar_Coverlap | MAIN.CGSO, MAIN.CGDO, MAIN.CDSO, MAIN.CBDO, MAIN.CBSO |
| PARAMGROUP_Spar_Cfringing | MAIN.CFG, MAIN.CFD, MAIN.CFGD, MAIN.CFGD0, MAIN.CFGD... |
| PARAMGROUP_Spar_Cdepletion | MAIN.CJ0, MAIN.VBI, MAIN.MZ, MAIN.AJ, MAIN.DJ |
| PARAMGROUP_Spar_BiasDependency | MAIN.VDSATCV, MAIN.CGDL |
| PARAMGROUP_Temp_Spar | MAIN.KTVBI, MAIN.KTCFG, MAIN.KTCFGD |
| PARAMGROUP_TrapMod1 | MAIN.TRAPMOD, MAIN.CDLAG, MAIN.RDLAG, MAIN.IDIO, MAI... |
| PARAMGROUP_TrapMod2 | MAIN.TRAPMOD, MAIN.CTRAP1, MAIN.RTRAP1, MAIN.CTRAP2... |
| PARAMGROUP_TrapMod3 | MAIN.TRAPMOD, MAIN.CTRAP3, MAIN.RTRAP3, MAIN.VATRAP... |
| PARAMGROUP_FieldPlate1 | MAIN.FP1MOD, MAIN.LFP1, MAIN.DFP1, MAIN.IMINFP1, MAI... |
| PARAMGROUP_FieldPlate2 | MAIN.FP2MOD, MAIN.LFP2, MAIN.DFP2, MAIN.IMINFP2, MAI... |
| PARAMGROUP_FieldPlate3 | MAIN.FP3MOD, MAIN.LFP3, MAIN.DFP3, MAIN.IMINFP3, MAI... |
| PARAMGROUP_FieldPlate4 | MAIN.FP4MOD, MAIN.LFP4, MAIN.DFP4, MAIN.IMINFP4, MAI... |
| PARAMGROUP_Quantum | MAIN.ADOSI, MAIN.BDOSI, MAIN.QM0I |

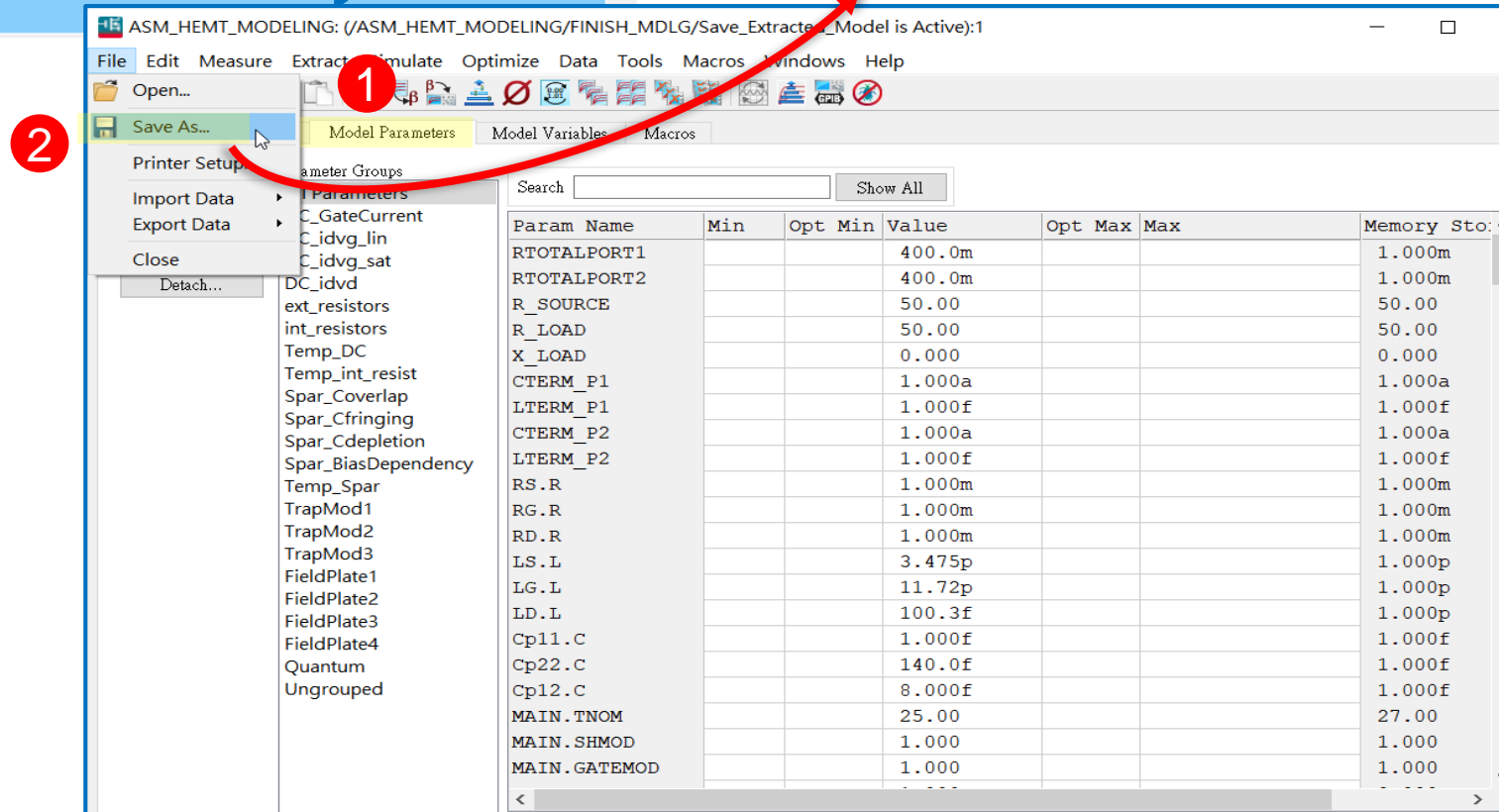
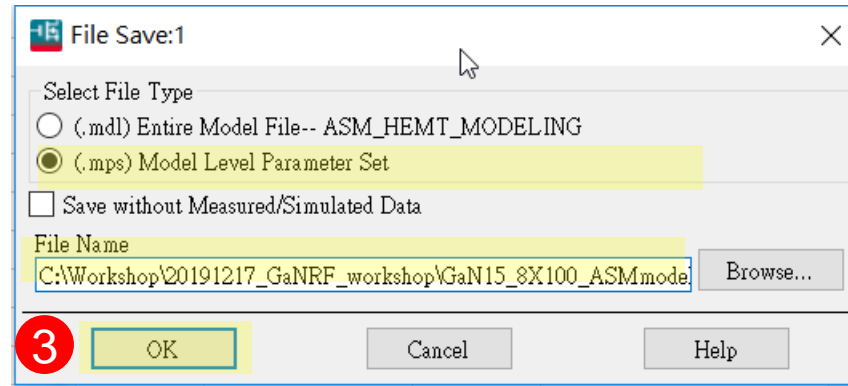
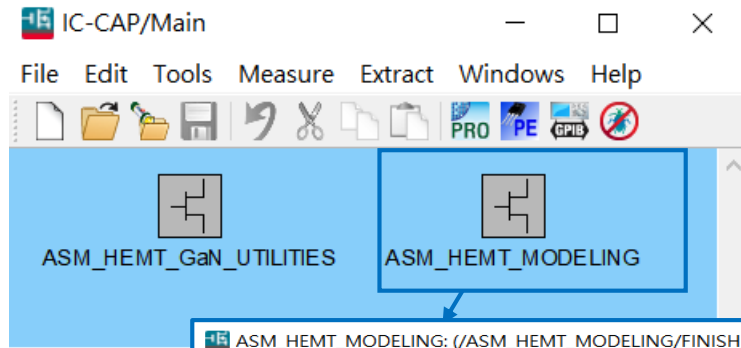


Live Demo for GaN Modeling GUI



Export Model to ADS for Load-Pull Simulation

Export model mps file



<<步驟>>

1. 點擊Model Parameters頁面

2. 點擊Save As

3. 選mps & 設置路徑 → 取得mps file

將Model導入ADS

File Edit Select View Insert Options Tools Layout Simulate Window DynamicLink DesignGuide Help

GENESYS Synthesis...
SPECTRASYS...
Encode Designs...
IC-CAP Import
LineCalc
Controlled Impedance Line Designer
Via Designer
Smith Chart...
Impedance Matching...
Model Composer
HSPICE Compatibility Component
Netlist Export
Spice Model Generator
User-Compiled Model
SnP Utilities

Any Device...
BJT Devices
Diode Devices
III-V FET Devices
MOS Devices
Power Devices
ASM HEMT...
PowerMOS_SiC...
IGBT...

Warning:4

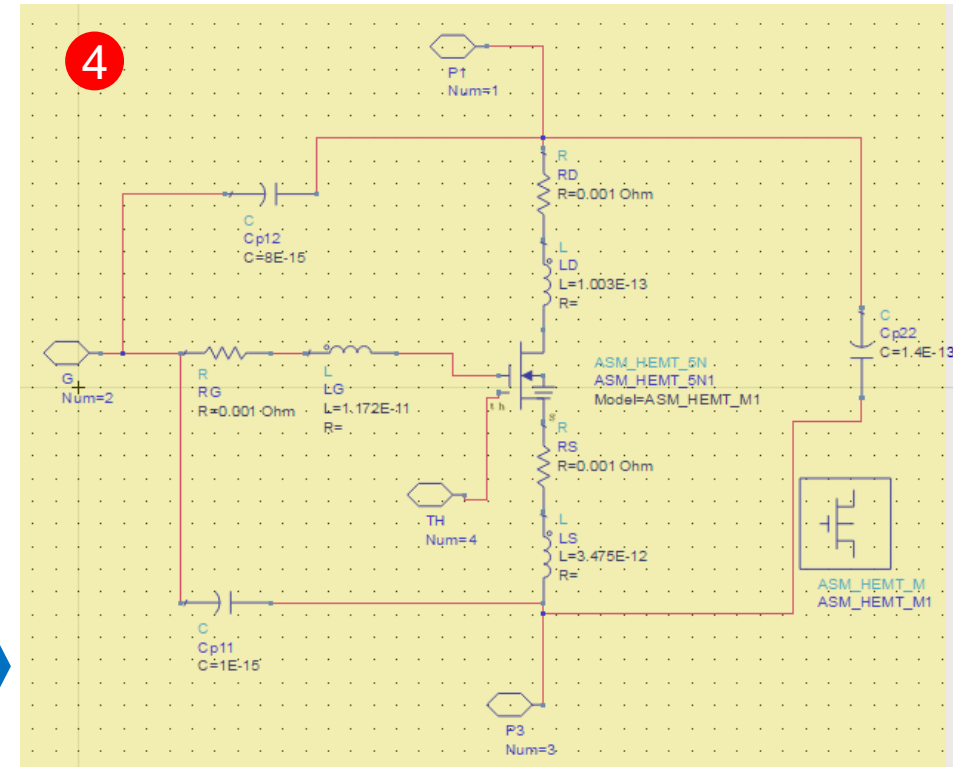
The File C:\Workshop\20191217_GaNRF_workshop\GaN15_8X100_ASMmodel.mps contained the following parameters which were not found in ASM_HEMT_M

Not Found:

```
RTOTALPORT1 = 400.0m
RTOTALPORT2 = 400.0m
R_SOURCE = 50.00
R_LOAD = 50.00
X_LOAD = 0.000
CTERM_P1 = 1.000a
LTERM_P1 = 1.000f
CTERM_P2 = 1.000a
LTERM_P2 = 1.000f
RS.R = 1.000m
RG.R = 1.000m
RD.R = 1.000m
LS.L = 3.475p
LG.L = 11.72p
LD.L = 100.3f
Cp11.C = 1.000f
Cp22.C = 140.0f
Cp12.C = 8.000f
```

ASM_HEMT_M
ASM_HEMT_M1

3



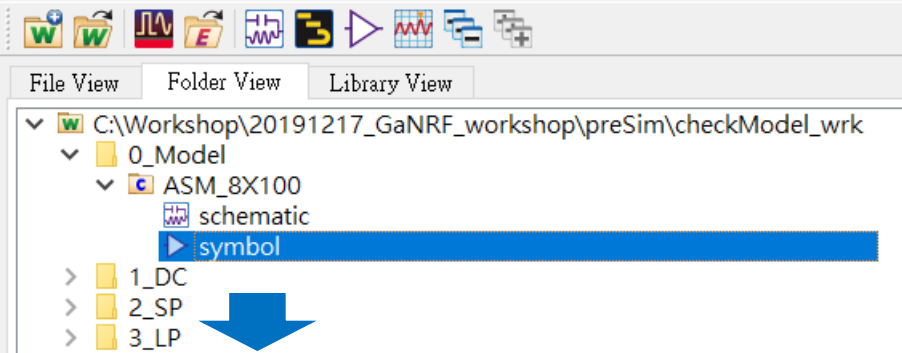
<<步驟>>

1. 創建schematic後,使用tools進行參數導入
2. 自動帶出 ASM_HEMT_M model card
3. 由于有外部參數,因此有Warning(需自行建構)
4. 自行建構外部參數與ASM_HEMT_5N連接

建立Symbol & 檢測基本電性

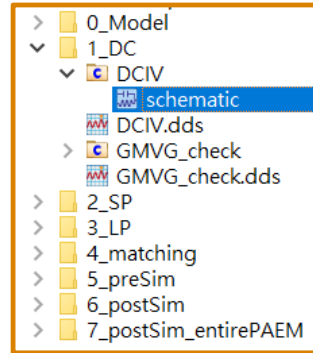
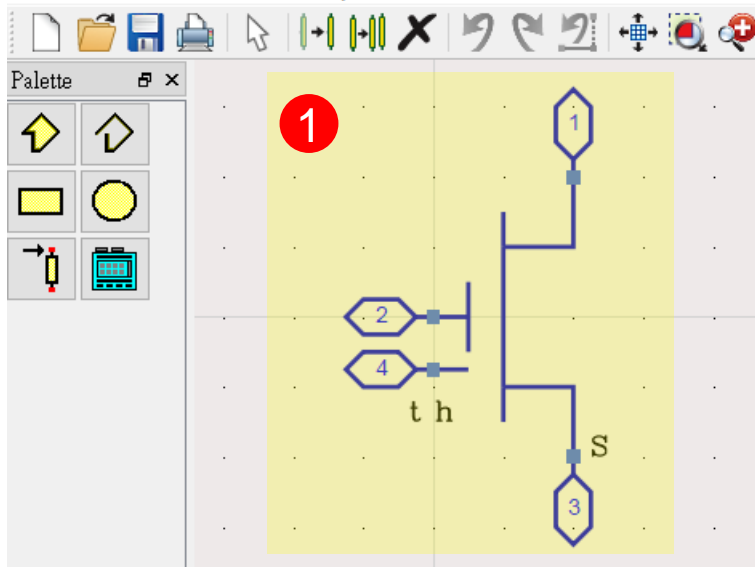
Advanced Design System 2020 (Main)

File View Options Tools Window DesignKits DesignGuide Help



ASM_8X100 [checkModel_lib:ASM_8X100:symbol] (Symbol):7

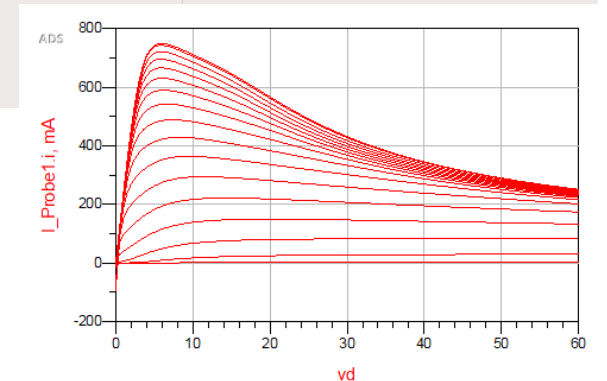
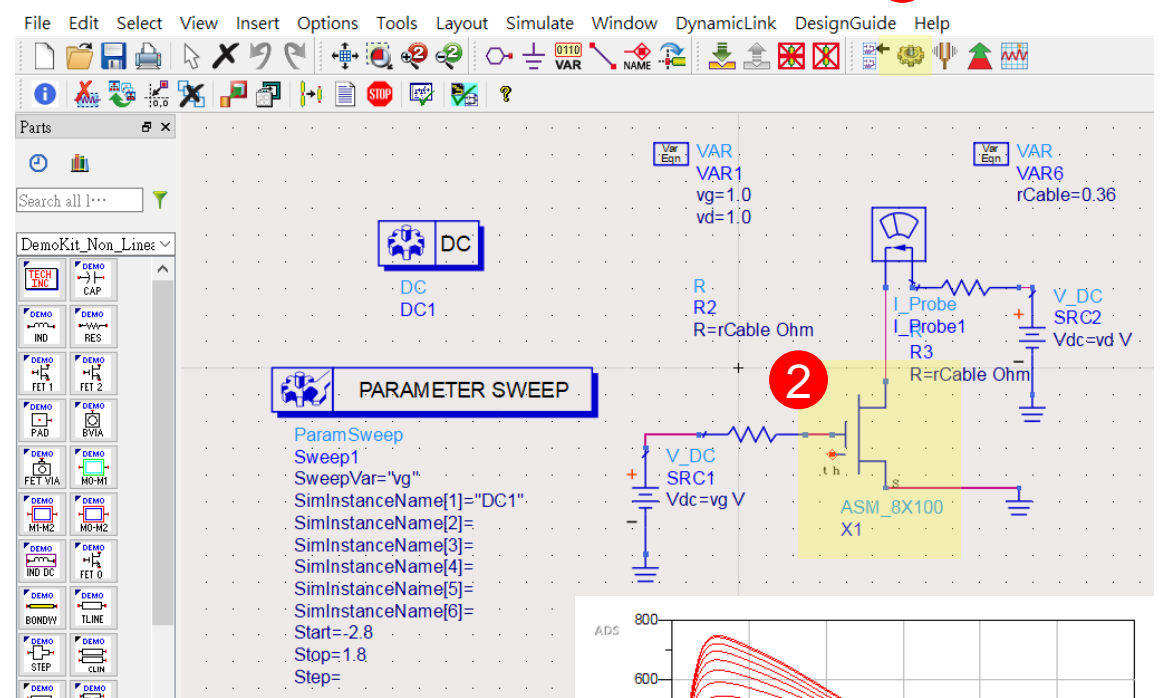
File Edit Select View Options Insert Tools Window Hel



<<步驟>>

1. 建立4T symbol
2. 放入schematic
3. 點擊simulation

DCIV [checkModel_lib:DCIV:schematic] (Schematic):8

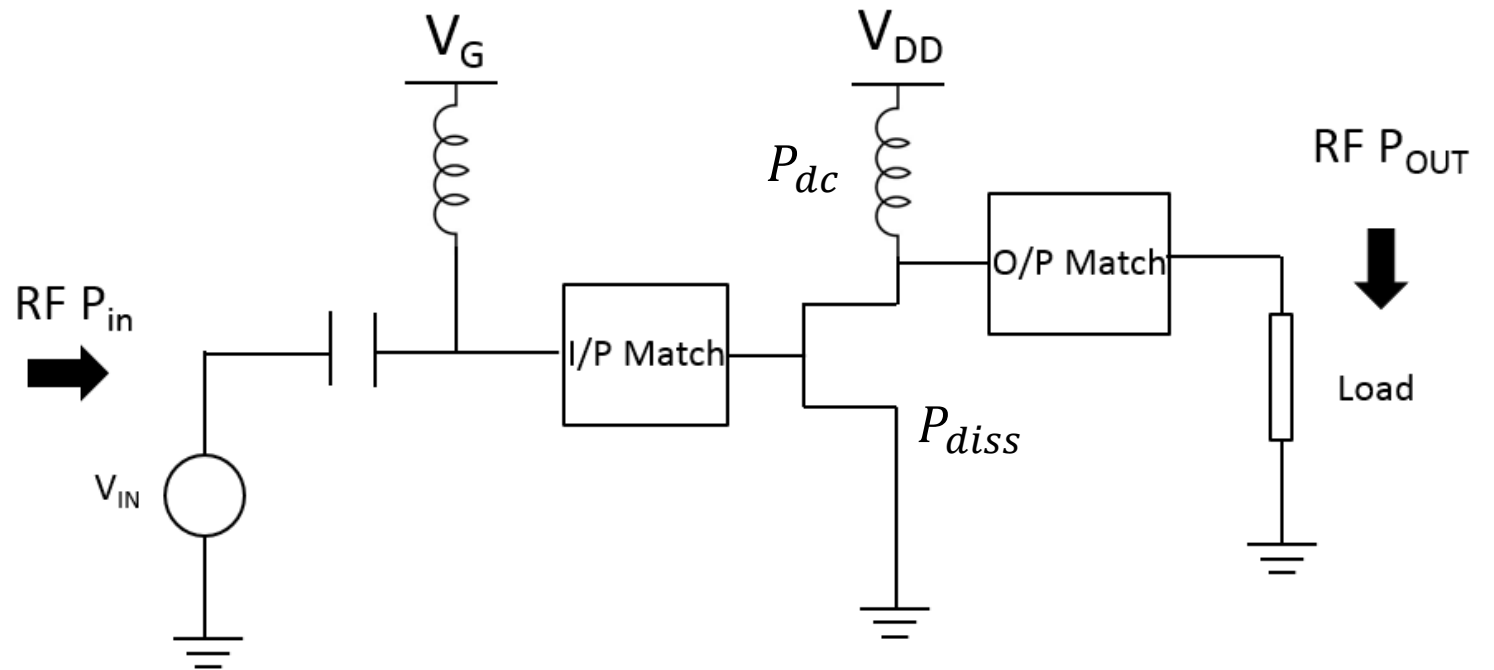


Power Amplifier Design Goals

$$\text{Gain} = \frac{P_{out}}{P_{in}}$$

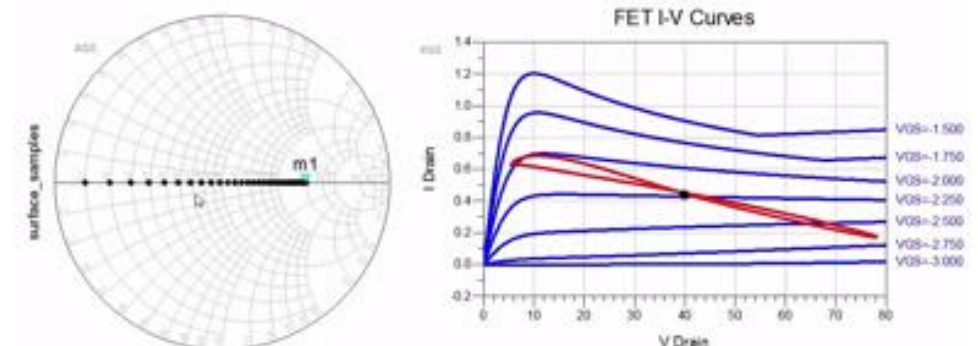
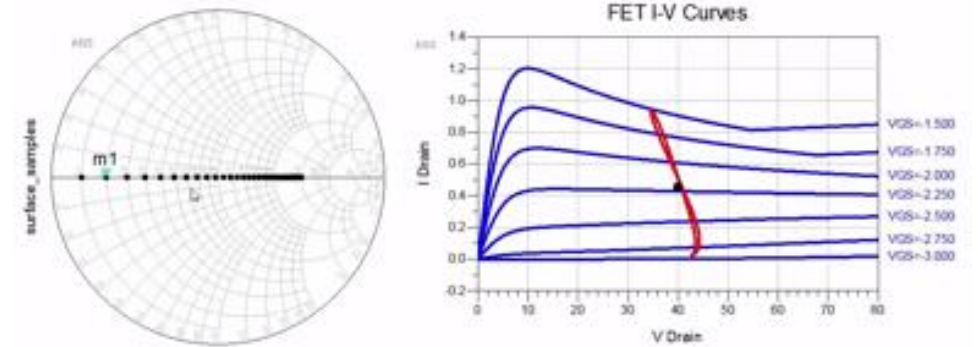
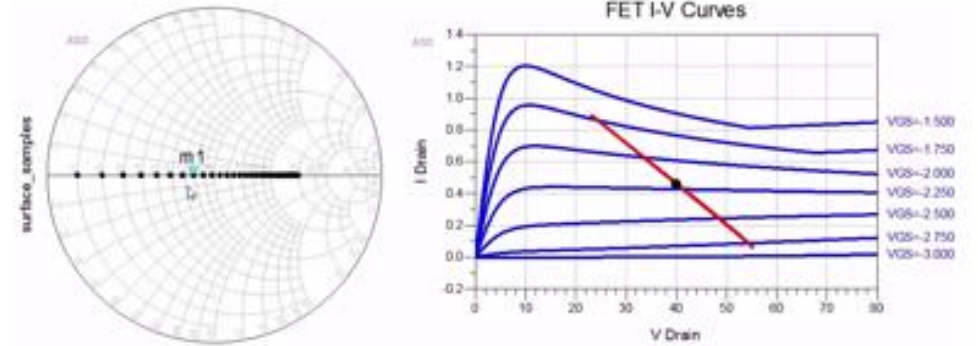
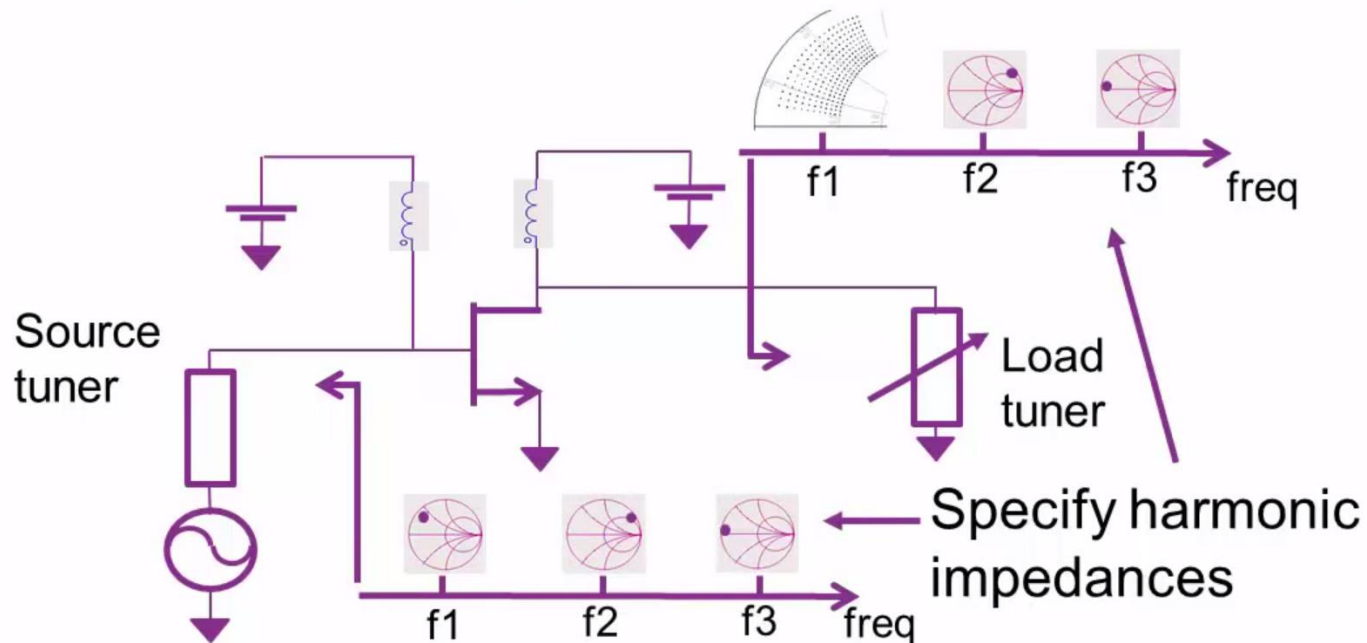
$$\text{PAE} = \frac{P_{out} - P_{in}}{P_{dc}}$$

$$\text{Drain Efficiency} = \frac{P_{out}}{P_{dc}}$$

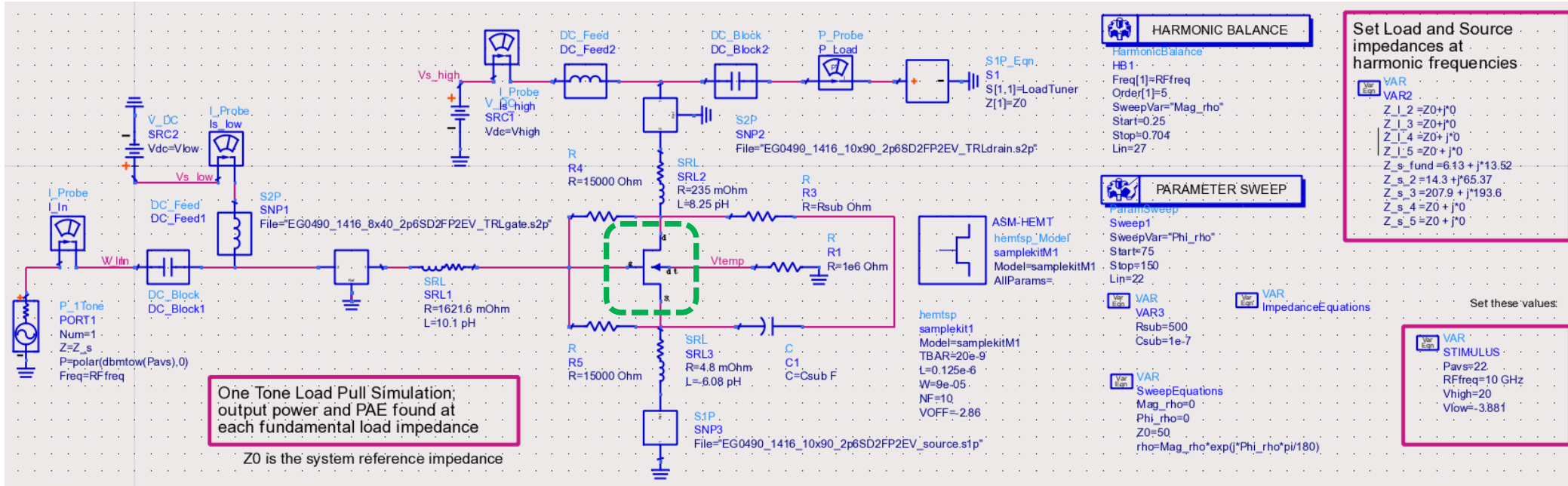


Load Pull Technique

- Determine Optimum load impedance for maximum Pout and PAE performance
- Specify matching networks
- Understand tradeoffs!

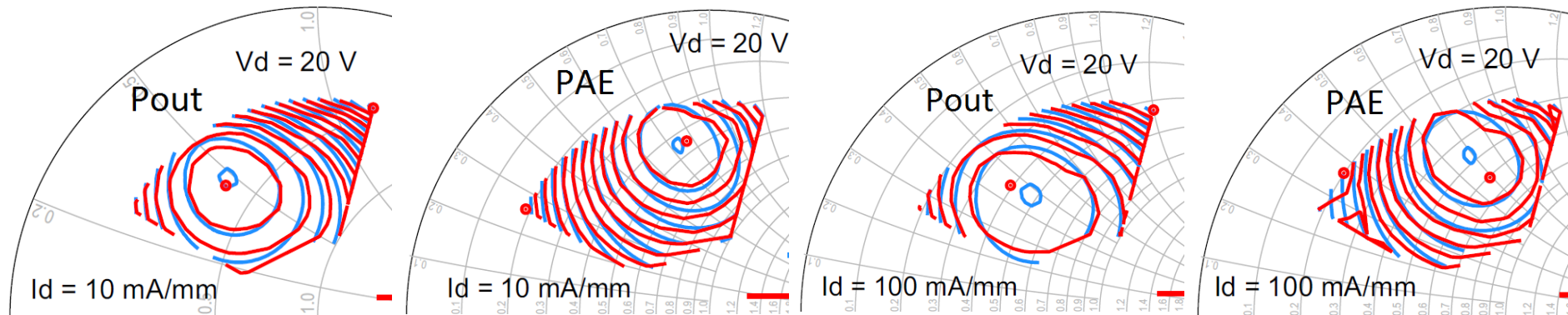


Large-Signal Model Validation



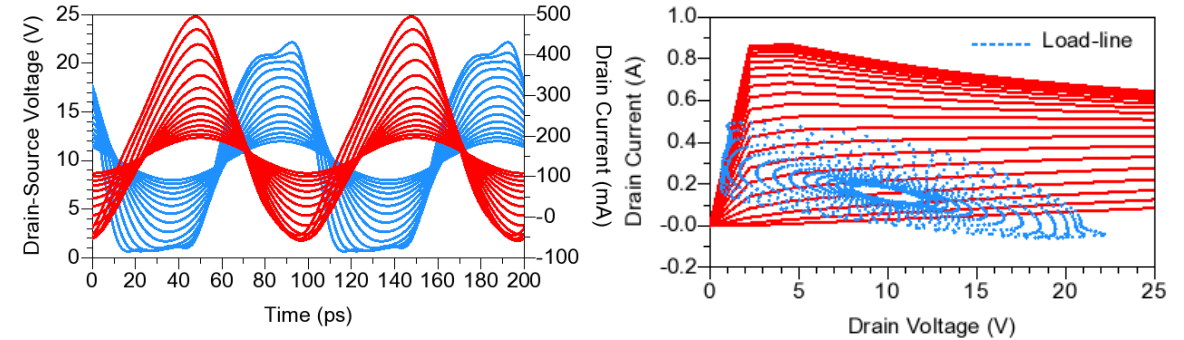
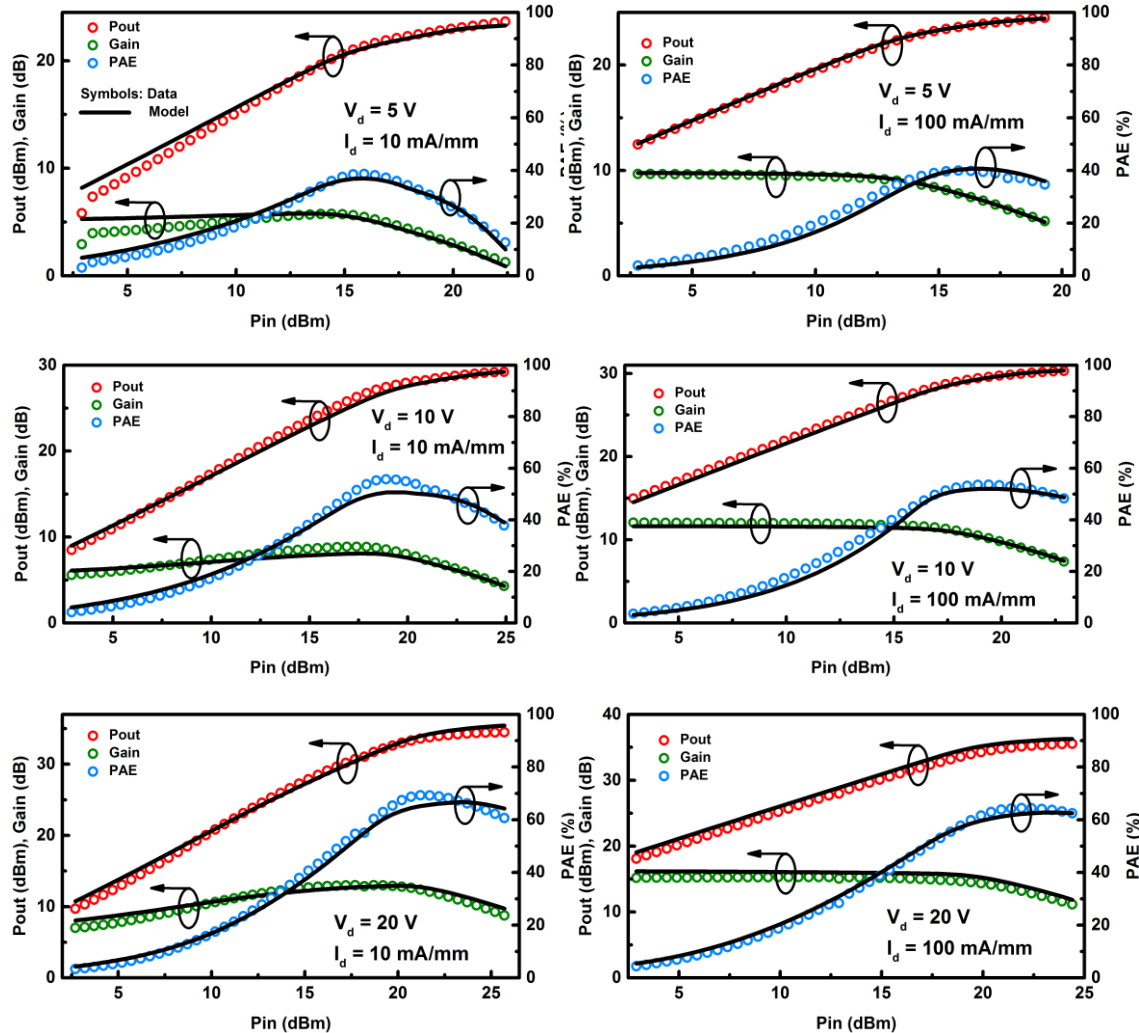
ADS Schematic for simulation of load-pull contours

22 dBm signal @ 10 GHz



Validation – Drive-up (HB)

Harmonic balance drive-up characteristics showing Pout, PAE & Gain



Time domain waveforms of drain voltage & current.
Load line contours spanning the IV plane

| | Frequency | 10 mA/mm | 100 mA/mm |
|-----------------------------|-----------|-------------------|-------------------|
| <i>Max. PAE</i> | f_0 | $22.46 + j38.54$ | $30.53 + j34.35$ |
| | f_1 | $40.61 - j93.39$ | $37.32 - j73.44$ |
| | f_2 | $11.39 - j0.07$ | $14.77 + j10.83$ |
| <i>Max. P_{OUT}</i> | f_0 | $19.57 + j22.83$ | $19.57 + j22.83$ |
| | f_1 | $253.48 - j65.72$ | $253.48 - j65.72$ |
| | f_2 | $15.66 - j31.21$ | $15.66 - j31.21$ |

[1] S. A. Ahsan et al., *IEEE J. Electron Devices Society*, Sep., [2017]



Live Demo for Load-Pull Simulation

Summary

- RF GaN modeling is challenging but extremely important.
- IC-CAP provides an easy-to-use kit for CMC GaN modeling.
- The tuned parameters can be easily imported to ADS for design and verification.

Let's work together to enable
first pass design success!

問卷填寫與抽獎

- 請點選會議訊息欄中的連結，或掃描右方QR Code，以進行問卷填寫。
- 相關欄位請確實填寫，以確保抽獎資格。
- 我們將從有效問卷中抽出10位，寄送小禮物。請留有效地址。
- 若您還有其他技術問題，請寄信至亞太區客戶服務中心：eesof-asia_support@keysight.com

• 感謝您的參與!

台灣繁體問卷:



大陸简体問卷: