Latest improvements in modelling for GaN and GaAs foundry processes with the support of ADS capabilities
Presentation outline

- UMS Introduction.
- Foundry Offer: GaAs and GaN processes.
- Why good models & Design Kits are needed?
- NL modeling for GaAs and GaN.
- Electro-thermal modeling for GaN.
- Noise and linearity modeling and validation.
- Stack for E/M.
- Other topics and coming improvements.
UMS at a glance

- European source of RF MMIC solutions, GaAs and GaN foundry services

- Industrial facilities in:
  - Ulm (Germany): GaAs & GaN technology development and production
  - Villebon (France): product development, back-end production and support

- Long heritage of supplying to most demanding applications
Our Markets

- Defence & Security
  - Phased Array Radar
  - Electronic Warfare
  - Communications

- Space
  - Communications
  - Earth Observation
  - Scientific Missions

- Automotive ISM
  - Long Range Radar
  - Short Range Radar
  - Industrial Sensors

- Telecom
  - Point to Point
  - VSAT Terminal
  - Base Stations
Product offer
From DC up to 110GHz

Asic

- Power Amplifiers up to 200W
- Very Low Noise Amplifiers
- Mixed signal functions
- Multichip modules

20 RF designers

Catalogue

~ 200 Products

Technology Platform

GaAs

GaN

SiGe

Plastic & Hermetic packages

Date / Ref doc
**Foundry & Services Offer**

<table>
<thead>
<tr>
<th>Design</th>
<th>Technology</th>
<th>Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools (PDK) and support</td>
<td>pHEMT and HBT GaAs</td>
<td>Wafer and die</td>
</tr>
<tr>
<td>Foundry training</td>
<td>HEMT GaN</td>
<td>On wafer test</td>
</tr>
<tr>
<td>Multi Project Wafers</td>
<td>Schottky</td>
<td>Known Good Die</td>
</tr>
<tr>
<td>Early access mode</td>
<td>MESFET</td>
<td>Packaging</td>
</tr>
</tbody>
</table>

**Comprehensive support**
Foundry Offer

Open processes

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Technology/Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1GHz</td>
<td><strong>GaN</strong> GH25_10 HEMT GaN (0.25µm)</td>
</tr>
<tr>
<td>2GHz</td>
<td><strong>GaAs</strong> PH25 Low Noise pHEMT (0.25µm)</td>
</tr>
<tr>
<td>5GHz</td>
<td><strong>GaAs</strong> PH15 Very Low Noise pHEMT (0.15µm)</td>
</tr>
<tr>
<td>10GHz</td>
<td><strong>GaAs</strong> PH10 Very Low Noise High Gain pHEMT (0.1µm)</td>
</tr>
<tr>
<td>20GHz</td>
<td><strong>GaAs</strong> PPH25 Power pHEMT (0.25µm)</td>
</tr>
<tr>
<td>50GHz</td>
<td><strong>GaAs</strong> PPH25X High Power pHEMT (0.25µm)</td>
</tr>
<tr>
<td>100GHz</td>
<td><strong>GaAs</strong> PPH15X High Power pHEMT (0.15µm)</td>
</tr>
<tr>
<td></td>
<td><strong>InGaP</strong> HB20P Power InGaP HBT</td>
</tr>
<tr>
<td></td>
<td><strong>InGaP</strong> HB20M VCO InGaP HBT</td>
</tr>
<tr>
<td></td>
<td><strong>InGaP</strong> HP07 MesFet (0.7µm)</td>
</tr>
<tr>
<td></td>
<td><strong>InGaP</strong> BES 100 Schottky Diode Technology</td>
</tr>
<tr>
<td></td>
<td><strong>InGaP</strong> ULRC Passive components</td>
</tr>
</tbody>
</table>
PDK: UMS added values

- Fully **scalable** and accurate models $\rightarrow$ First pass success

- Passive devices:
  - Inductor, capacitor, resistor, line.

- Active devices:
  - FETs: linear, non-linear and noise,
  - Parallel and series switches.
  - Schottky diodes and varactors.

- Data available for spread analysis.

- Accurate models $\Rightarrow$ no need for FET sampling
UMS PDK added values

With Keysight ADS 2012-2016

- Schematic and layout library (auto-layout capability)
- Stack definition for E/M simulations
- Design Rule Check capability
**FET NL modeling**

**Technical measurement of pulsed I-V & S-Parameters for nonlinear modelling**

- A fast pulse with a low duty cycle is used to move gate and drain biases from a chosen steady quiescent bias to another point on the I-V plane.

- S-parameters measurements are performed in pulses.

- It is closer to the operational behavior.

- The thermal and traps conditions are set by the quiescent biasing condition.
NL Model

\[ i_D(V_{GS}^{mod}, V_{DS}^i, \tau), \]

\[ V_{GS}^{mod} = V_{GS}^i + dV_{traps} + dV_{th} \]

\[ Id(V_{GS}^i) = P_1 \cdot g(V_{GS}^i)^{P_2} - A \cdot g(V_{GS}^i) \text{ with } 2 \leq P_2 < 3 \]

- Gate capacitances are described by gate charges
- Thermal effects controlled by Vth (for GaN)
  \[ (dV_{th} = K_{th} \cdot [(T_B - T_B^*) + R_{th}(T_B) \cdot P_D - R_{th}(T_B^*) \cdot P_D^*]) \]
- Drain lag or traps taken into account

[1] C. Chang and al. Nonlinear Transistor Modeling for industrial 0.25µm AlGaN-GaN HEMTs
EuMW 2013
Temperature evaluation techniques for $R_{th}$ validation

<table>
<thead>
<tr>
<th>Technique</th>
<th>GH25 - 8 x 125 µm $T_b = 130 , ^\circ C / P_{diss} = 4 , W/mm$</th>
<th>PPH25X - 10 x 55 µm $T_b = 95 , ^\circ C / P_{diss} = 1 , W/mm$</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR microscopy</td>
<td>$10 , ^\circ C/W$</td>
<td>$89 , ^\circ C/W$</td>
</tr>
<tr>
<td>Thermoreflectance</td>
<td>$11 , ^\circ C/W$</td>
<td>$96 , ^\circ C/W$</td>
</tr>
<tr>
<td>Raman spectroscopy</td>
<td>$12.5 , ^\circ C/W$</td>
<td>$118 , ^\circ C/W$</td>
</tr>
<tr>
<td>3D Thermal simulation</td>
<td>$17.5 , ^\circ C/W$</td>
<td>$149 , ^\circ C/W$</td>
</tr>
</tbody>
</table>

Thermal measurements $\Rightarrow$ Thermal model validation 3D $\Rightarrow$ $T_j$ evaluation $R_{th}$ ($T_c$)

$\approx + 70 \%$
GaN GH25 lag or traps effect

✓ Asymmetrical time constant for emission and capture are taken into account through the filter structure below implemented in the model.

✓ Constants may be adjusted to fit with observation of the Drain lag.

✓ Gate lag less pronounced is not taken into account.

NL Model Cgs and Cgd

- Gate Charges described by equations and validation.
Validation of the NL models

- Power load pull simulation / measurements

Load pull – 8x75μm / 10GHz / 30V@100mA/mm  
Measurements versus model simulations under same input and output load conditions.

At MMIC level. On a X band PA.
Video Tutorials

Plextek RFI is has a growing library of video tutorials on various aspects of Microwave/MMIC design. They feature examples of past design IP that we can use to help develop custom products for our clients with reduced risk and timescales.

Videos can be viewed by clicking the individual links below, or by visiting the Plextek RFI YouTube channel

**An X-band MMIC PA designed on a UMS GaN Process using Keysight ADS**

In this video Stuart Glynn describes the design of an X-band GaN PA using a GaN process from UMS, on keysight’s ADS simulator

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Measured</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>GHz</td>
<td>9 to 11.5</td>
<td></td>
</tr>
<tr>
<td>SS Gain</td>
<td>dB</td>
<td>~ 13</td>
<td></td>
</tr>
<tr>
<td>IRL</td>
<td>dB</td>
<td>&gt; 8</td>
<td></td>
</tr>
<tr>
<td>ORL</td>
<td>dB</td>
<td>&gt; 8</td>
<td></td>
</tr>
<tr>
<td>$P_{sat}$</td>
<td>dBm</td>
<td>~ 7W (38.5dBm)</td>
<td>+29dBm drive</td>
</tr>
<tr>
<td>PAE at $P_{sat}$</td>
<td>%</td>
<td>~ 42</td>
<td>+29dBm drive</td>
</tr>
<tr>
<td>LS gain flatness</td>
<td>dB</td>
<td>± 0.5</td>
<td></td>
</tr>
</tbody>
</table>
GaAs – PH10 – for E band

- E band design requires noise model
- E-band measurements of 4 noise parameters is challenging.
  -> Extrapolation from 2-40GHz may be preferred!

=> The model has been validated through up to E-Band MMIC design.

\[ \langle \text{ind}^2 \rangle = 4 \cdot k \cdot T \cdot Gm \cdot P \cdot \Delta f \]
GaAs Modeling: PPH15X-20. Power comparison

2-port Nonlinear hot model vs power measurements(TV110840)

Vds=6V – Ids=60mA

Zload=Zopt Pout

Freq=9GHz
GaAs modeling PPH15X-20: linearity

Linearity comparison for Zload=Zopt IMR3 @low level

8x75µm @ 10GHz & 6V-150mA/mm Zs=50Ohm

2-port Non linear hot model
UMS designed a 8W 6-8GHz PA using the NL model and targeting linearity optimization.

- Signal pre-distortion increases significantly
- The linearity, but a good linearity is also reached without the DPD.

- 5.5-7.5GHz, 25V 340mA
- $\text{Psat} > 39\text{dBm}$
- Gain 18dB
- C/I3 = 34dBc à 10dB back-off
- MSE woDPD = -27dB @30dBm
- MSE withDPD< -50dB @30dBm
- QFN molded package
EM Simulations

- Stack for Momentum or 3D EM simulations
- Cases analysed with Keysight R&D Support (special thanks to Vincent Poisson! :)
  - Inductors, device which includes an air-bridge.
  - Via-holes.
  - Capacitors, investigation around edge effect.
Air bridge – Momentum EM model

No layout manipulations to get the physical 3D EM air bridge modeling!

Thanks to DPC overlap with EL air bridge

Very accurate modeling of the inductance!
Via hole – real 3D model (automatically generated for EM)

No layout manipulations to get the physical VIA HOLE 3D EM modeling!

-> reduction of port number for EM simulation
MIMCAP – DRM and MICRO PHOTO

- The following pictures (from the left to the right) highlight the DRM process description and the cross section photo particular of a MIMCAP.

- Since the Momentum estimation seems to be lower than the measurements, first idea was try to estimate the parasitic capacitance of the crossing PO (red ellipse) to be added in the substrate model.
The plates area in the bridge direction need to be enlarged by 1.46 um due to the parasitics.
• **5% to 8%** of mismatch between the test structure measurements and the simulations.

• Even after the addition of the calculated parasitics, the model seems to be **not enough accurate.** Other contributors have to be considered.
PARASITIC ESTIMATION ON 400fF MIMCAP

- Since the PO is build on PI by deposition, it is reasonable to consider that the parasitics estimation has to be considered in addition to other parasitics hanged to the other three sides of the top plate.

- Under this assumption we can try to guess the following:

\[ C_{tot} = C_{teor} + C_{par1} + 3C_{par2} = 325.6 \text{fF} \]

![Diagram showing parasitic estimation](image)

**Effective Capacitance**

![Graph showing effective capacitance](image)

**Error Capacitance %**

![Graph showing error capacitance](image)
MIMCAP - 4pF TEST STRUCTURE CHECK

Effective Capacitance (F)

Error Capacitance (F)
Other important topics

- **DRC as Design Rule Check:**
  - Possibility for the designer to check and correct layout violations.
  - Gain of time.

- **Co-simulation …**
  - Possibility to mix processes at the same elevation.

- **Next steps:**
  - Electro-thermal capabilities of ADS Eth: alignment with UMS electro-thermal data in progress.
  - Maximum ratings: calculation by designers. Verification of maximum ratings by designers may take a long time. Hot spot identification by simulation investigated.
Questions?

Thank you for your attention!