EDI CON 2016 Electronic Design Innovation Conference

Non-Linear and Noise Modeling of a 0.15um GaN Die Family

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Agenda

- Introduction
- 0.15 um Device Technology
- Characterization & Modeling Methods
- 0.15 um Device Noise Models
- 0.15 um Large Signal Models
- Summary

Introduction

- GaN has many design wins in high power applications and also useful for LNAs
- Reduced gate length processes, such as 0.15um, have emerged to address higher frequencies (e.g. > 10 GHz)
- This talk will focus on advanced models developed for a family of 0.15 um GaN die addressing both low noise and high power applications

Introduction: Modelithics-Qorvo GaN Library for Die & Packaged Devices

V1.8 Library Now Available via Modelithics Website Request High quality model library software w/ version control and frequent updates.

- 17 Die and 43 Packaged Devices
- Quick access to model datasheets
- Many example & reference projects
- Easy click thru installer
- Supports Keysight ADS or NI/ AWR DE

Free for Qorvo customers

- **Features:**
  - Scaling of operating voltage
  - Ambient temperature and self heating affects
  - Intrinsic voltage/current node access for waveform optimization
  - Switch to turn on/off bond wires for die models as applicable
  - Noise and small-signal models
  - Advanced thermal sensing

} *For some devices*

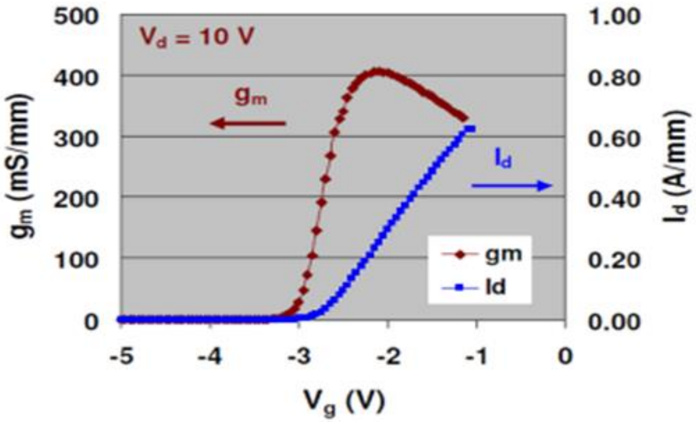
Modelithics® Qorvo

0.15 um GaN Technology

- Qorvo's production released QGaN15 process utilizes AlGaN/GaN epitaxial layers grown on high thermal conductivity SiC substrate.
- DC Id-max is 1.15 A/mm, DC gm-max = 425 mS/mm and pinch-off voltage is -3.1V at Vds of 10V.
- Gate-to-drain device breakdown voltages exceeds 75V, measured at Id = 1mA/mm and Vgs = - 6.0V, with ft of > 32 GHz and F_{max} of 160 GHz.

Key performance parameters of QGaN15

Parameter	Unit	Nominal
Idss (Vgs=0,Vds=5V)	mA/mm	800
I_{max} (Vgs=1, Vds=5)	mA/mm	1150
GM_{max}	mS/mm	425
Vp	V	-3.1
BVGD@ Id=1mA/mm, Vgs= -6V	V	75
Ft@20V, 100 mA/mm	GHz	32.5
F_{max}@ 20V, 100 mA/mm	GHz	160

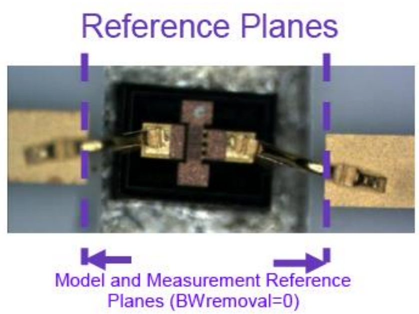


[1] S. Nayak, M-Y. Kao, H-T Chen, T. Smith, P. Goeller, W. Gao, J. Jimenez, S. Chen, C. Campbell, G. Drandova, R. Kraft, “0.15um GaN MMIC manufacturing technology for 2-50 GHz power applications,” 2015 *International conference on compound semiconductor manufacturing technology,* Scottsdale, Arizona

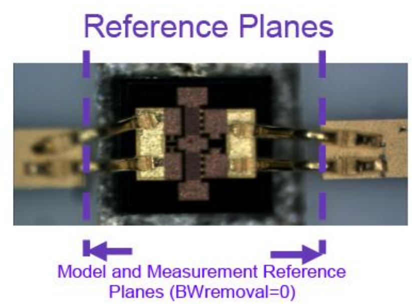
0.15 um GaN Die Model Overview

Small-Signal /Noise and Non-Linear Models were Developed for 6 Discrete Die Transistors (2 to 15 W)

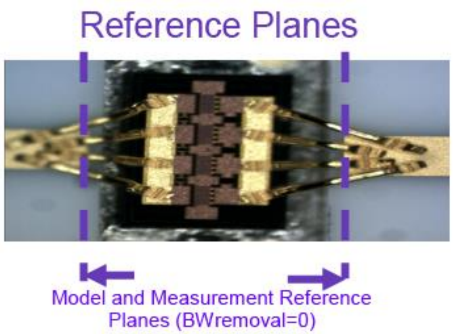
TGF2942 (2W)



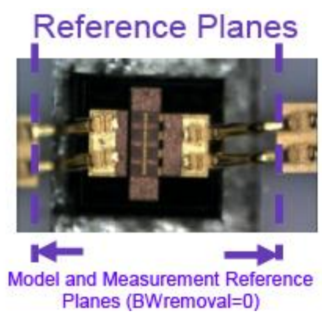
TGF2935 (4W)



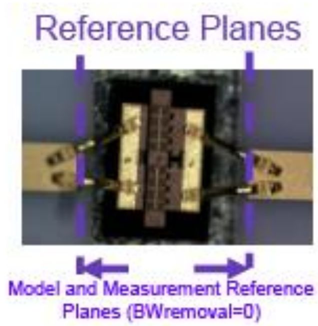
TGF2936 (8W)



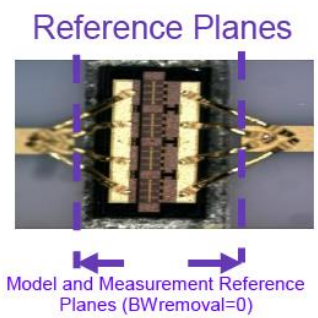
TGF2941 (4W)



TGF2933 (8W)

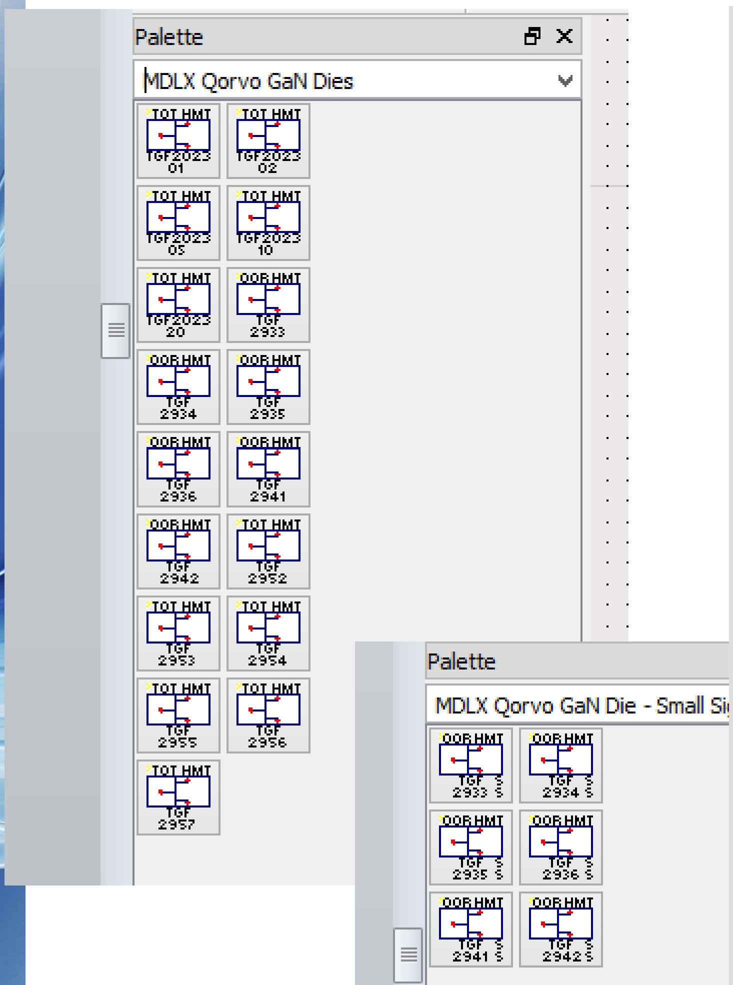


TGF2934 (15W)

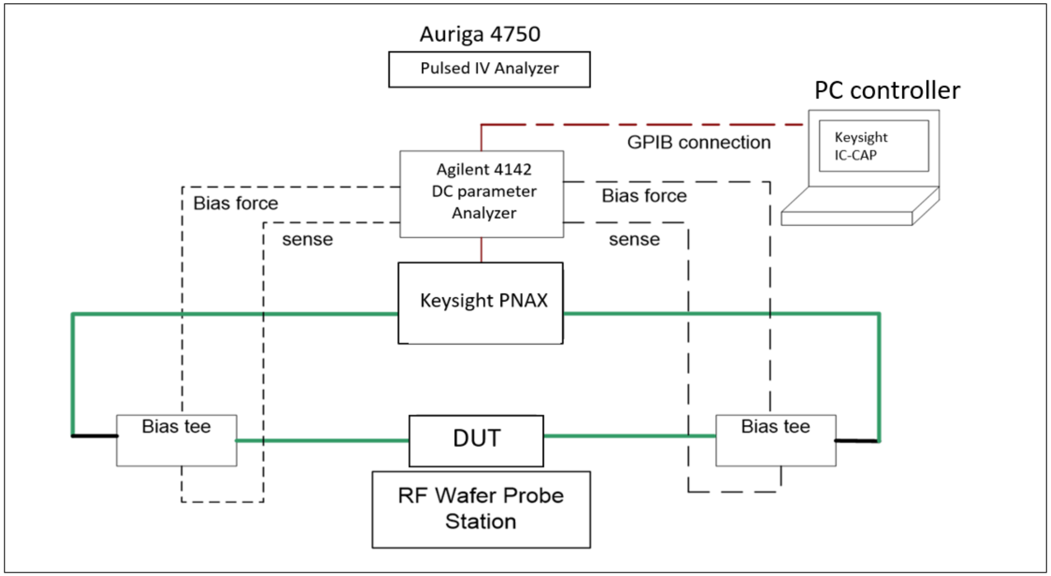


0.15 um GaN Die Model Overview

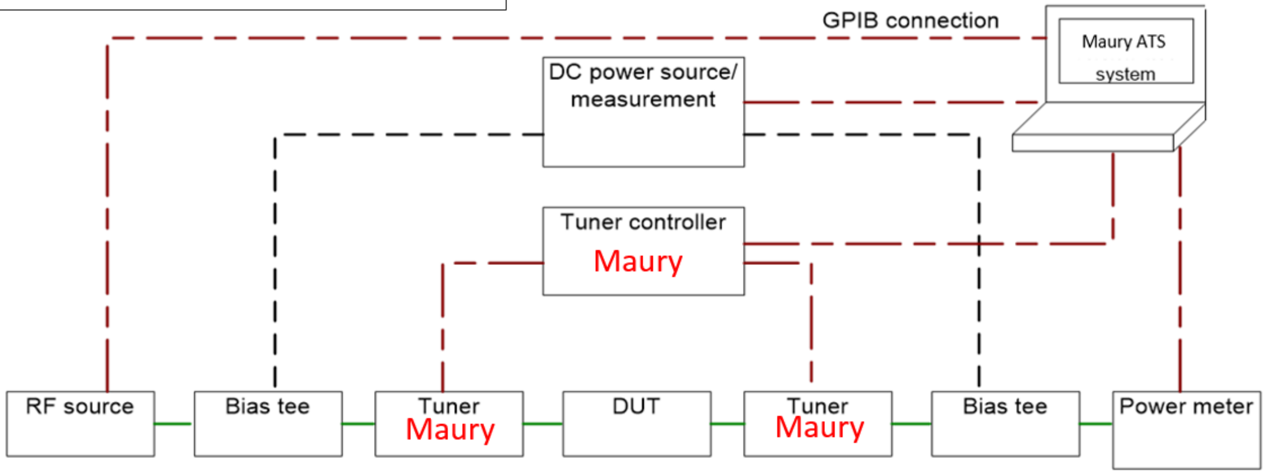
Small-Signal /Noise and Non-Linear Models as Setup in ADS



Standard Test Configurations for NL Transistor Model Development and LS Validations



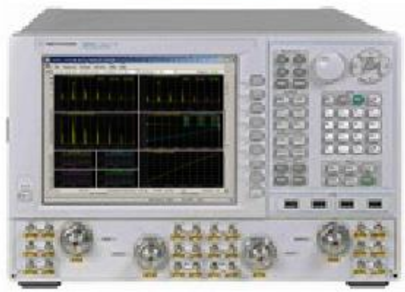
Optional: Pulsed RF/Bias



Noise Testing Bench

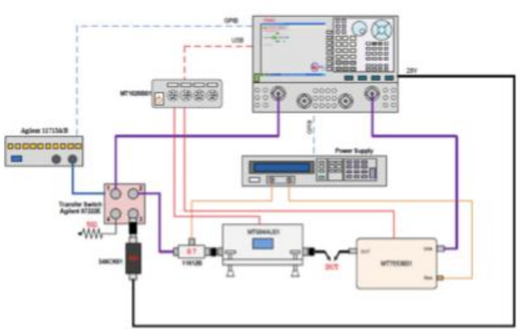
Keysight PNAX/ Maury Microwave ATS Based Noise Parameter System

KEYSIGHT TECHNOLOGIES
Solutions Partner



Keysight Technologies' PNA-X Series Nonlinear Vector Network Analyzer (NVNA)

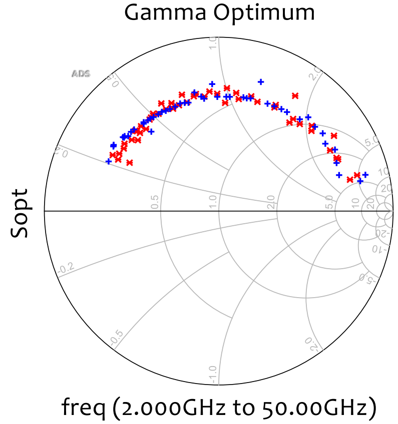
Maury Microwave
Your Calibration, Measurement & Modeling Solutions Partner!

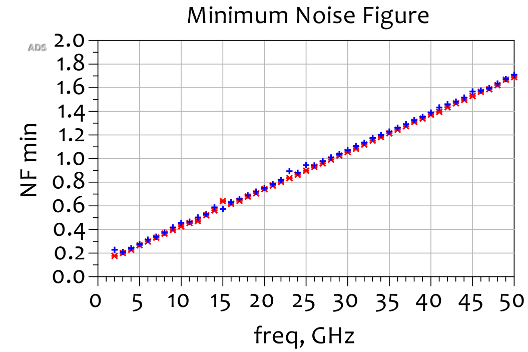


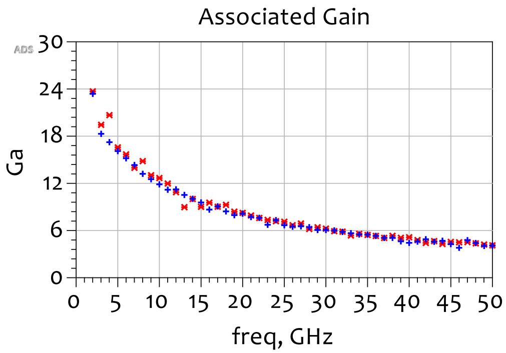
Test Setup Block Diagram

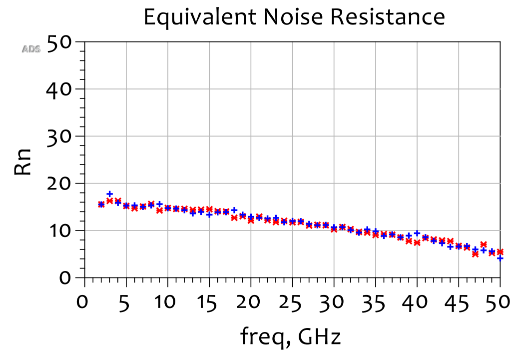
- PNA-X with 50 GHz low noise receivers (OPT. 29)
- Maury NP kit (noise receiver module, switch box)
- Maury tuners
- Maury ATS Noise software
- 50 GHz noise source

Noise Parameter Benchmark using golden standard device in 2-50 GHz band before GaN15 noise measurements









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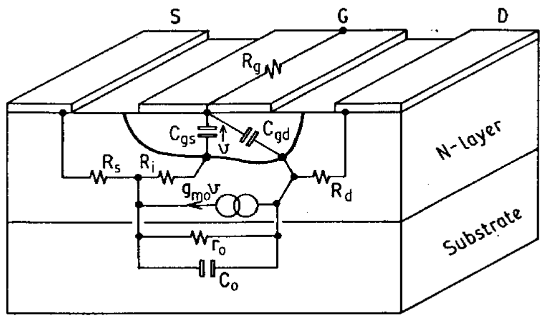
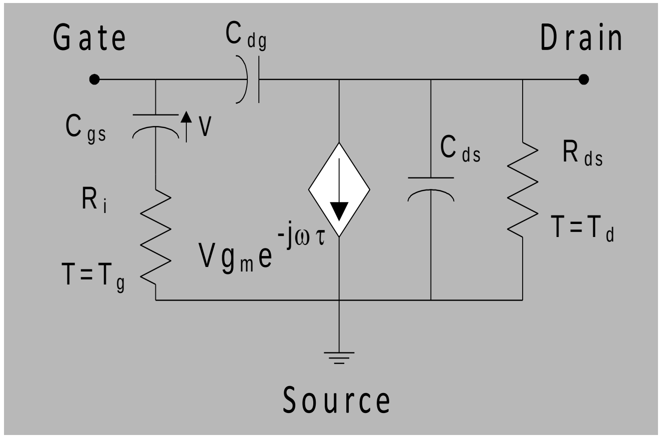
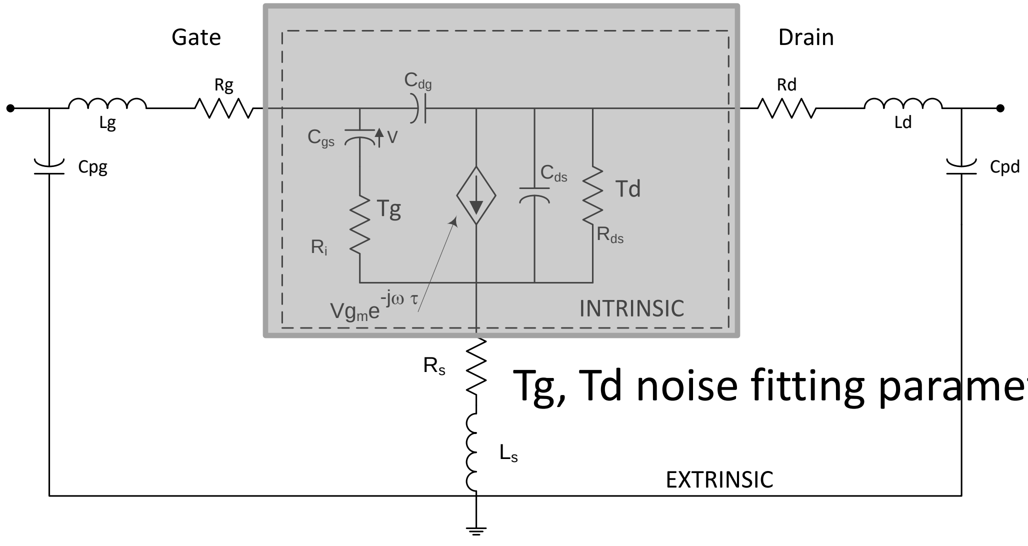
Small-signal/Noise Modeling



From P.H. Ladbrooke, *MMIC Design: ...,* Artech House, 1989



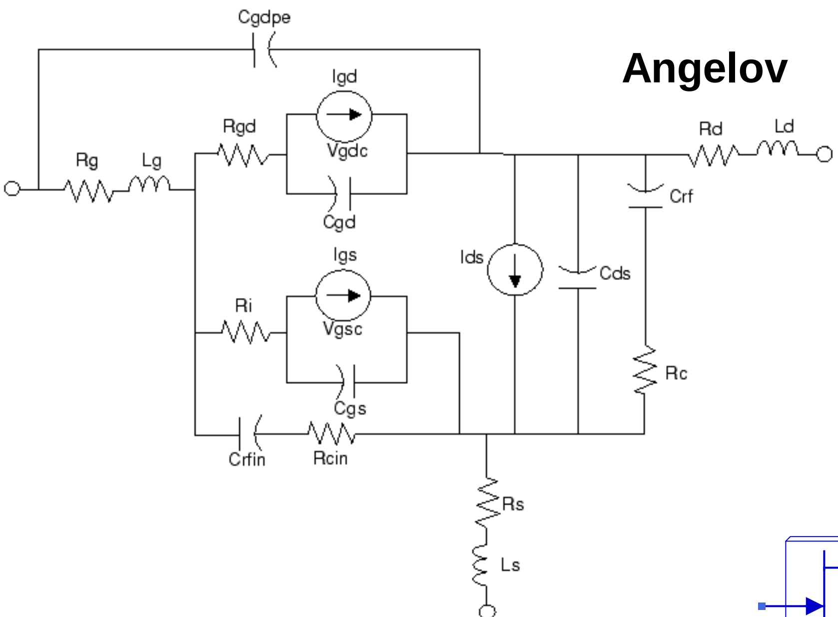
M. Pospieszalski, “Modeling of Noise Parameters ...,” 1989 IEEE Trans.on Microwave Theory and Tech.



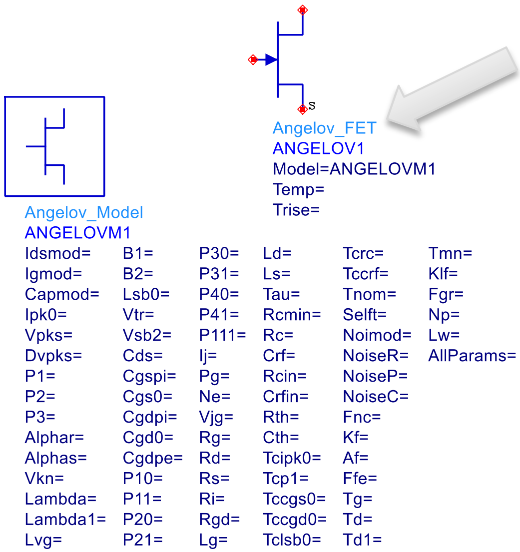
Tg, Td noise fitting parameters

Non-linear Modeling

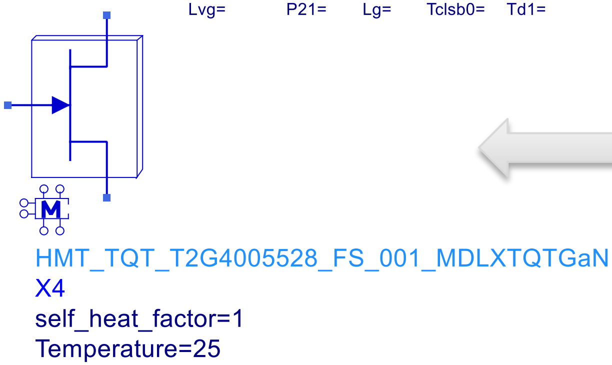
We use a modified Angelov model implemented with Verilog-A Code for NL GaN Modeling



+ electro-thermal (Rth-Cth) circuit



ADS Angelov Model Template and Model Parameter 'card'



Modelithics Symbol For Specific GaN Device Model

Example Model Features

Model Features *Small-Signal*

- Broadband (DC to 40GHz)
- Small-signal model
- Bias selectable: VDS=12V, 20V and 28V
- Measurement Validations:
  - Multi-biased S-parameters (25C)
  - Multi-biased Noise Parameters (2 to 26GHz)

Recently extended to 35 GHz

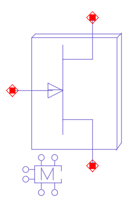
Model Features *Large-Signal*

- Broadband (DC to 40GHz)
- Large-signal model (Angelov-based)
- Bias scalable: VDSQ (12V to 28V)
- Temperature scalable: (25C to 85C)
- Advanced model feature: enabling intrinsic I-V sensing
- Measurement Validations:
  - Pulsed I-V (25C to 85C)
  - Multi-bias S-parameters (25C to 85C)
  - Multi-bias Noise Parameters (2 to 26GHz)
  - Single Tone Power and Load Pull (10GHz)

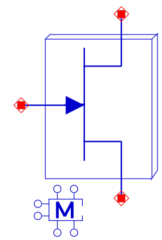
Technical Notes

- Model is optimized for 12V, 20V and 28V operation.
- Model Parameters:
  - **Bias:** for setting the operating bias point of the model. List of Biases:

Bias	VDSQ (V)	IDSQ (mA)	Noise Validation
1	12	20	✓
2	12	40	✓
3	20	20	
4	20	40	✓
5	28	20	
6	28	40	



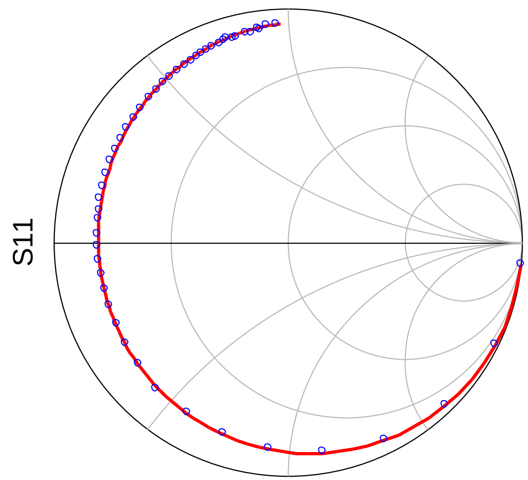
HMT_QOR_TGF2942_SS_001_MDLXQorvoGaN
X4
BiasCondition=2 - 12V, 40mA
BWremoval=0 - Bond wire effect in model

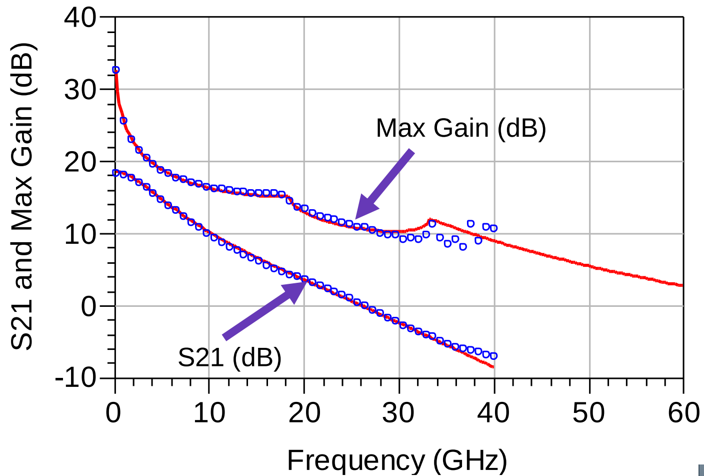


HMT_QOR_TGF2933_001_MDLXQorvoGaN
X3
VDSQ=28
self_heat_factor=1
Temperature=25
BWremoval=1 - Bond wire effect removed

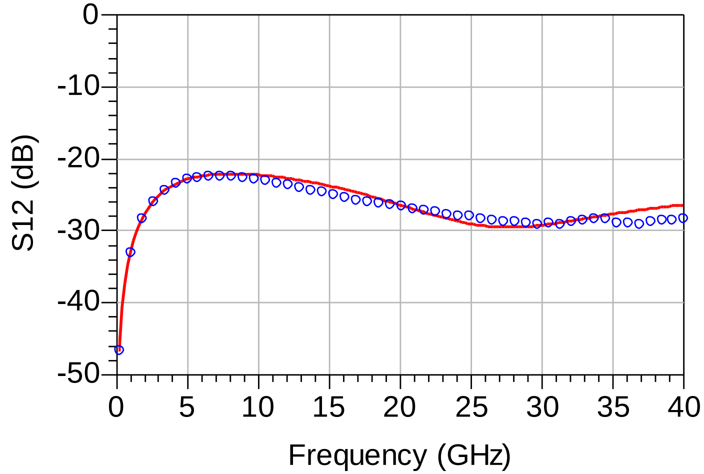
Example SS/Noise Model Performance

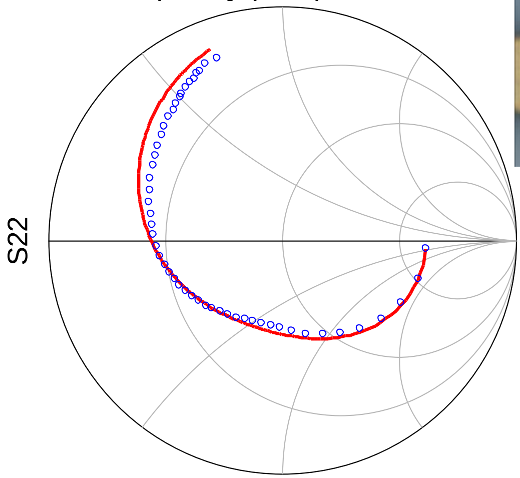
S-Parameters Model vs. Measured: Bias 2, VDS = 12V, IDS = 40mA, 25C

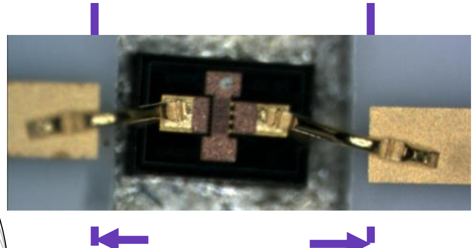




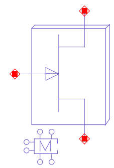
Model:
HMT-QOR-TGF2942S-SS-001







Model and Measurement Reference Planes (BWremoval=0)

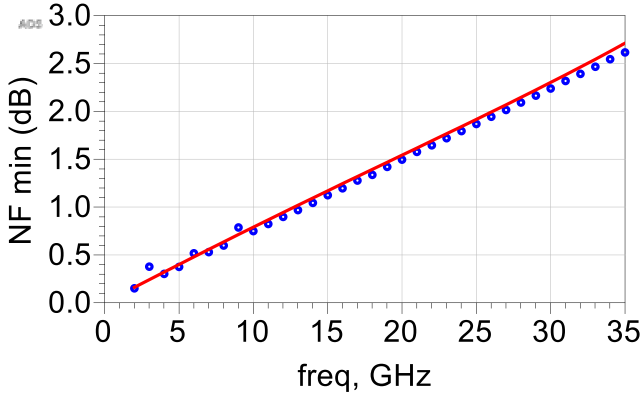


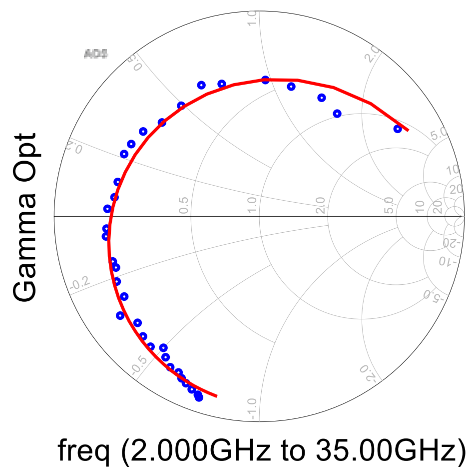
HMT_QOR_TGF2942_SS_001_MDLXQorvoGaN
X4
BiasCondition=2 - 12V, 40mA
BWremoval=0 - Bond wire effect in model

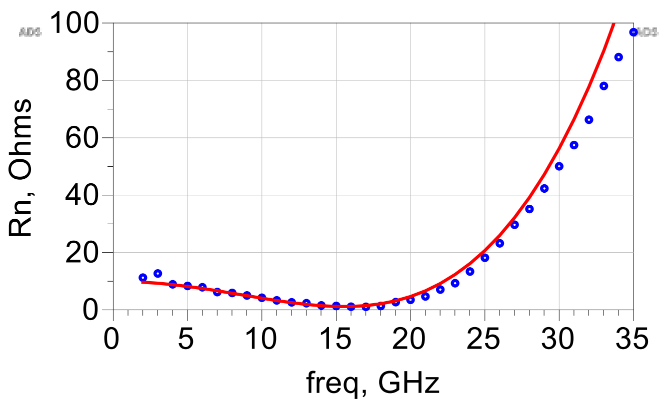
Legend: Red Solid lines - Model data, O Symbols - Measured data
Simulated at 25C with the frequency range from 0.2 - 40GHz. 50Ω Smith Charts

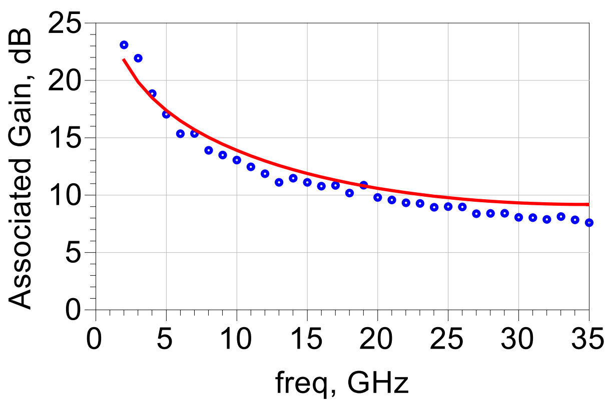
Example SS/Noise Model Performance

Noise Model vs. Measured: Bias 2, VDS = 12V, IDS = 40mA, 25C

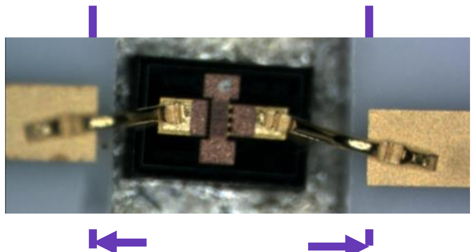




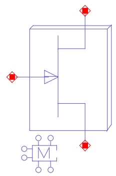




Model:
HMT-QOR-TGF2942-SS-001



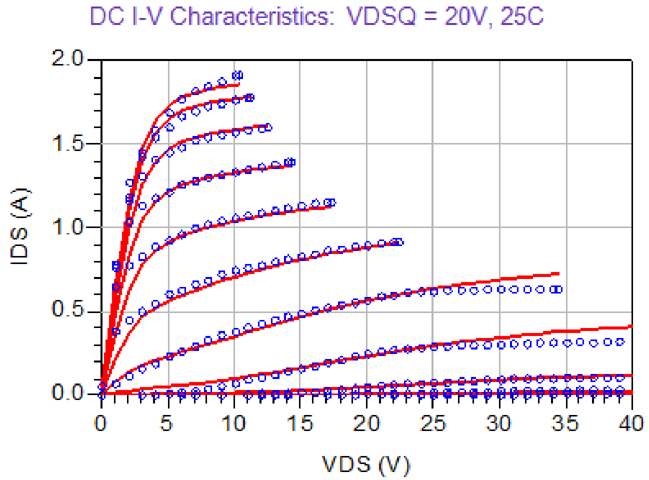
Model and Measurement Reference Planes (BWremoval=0)



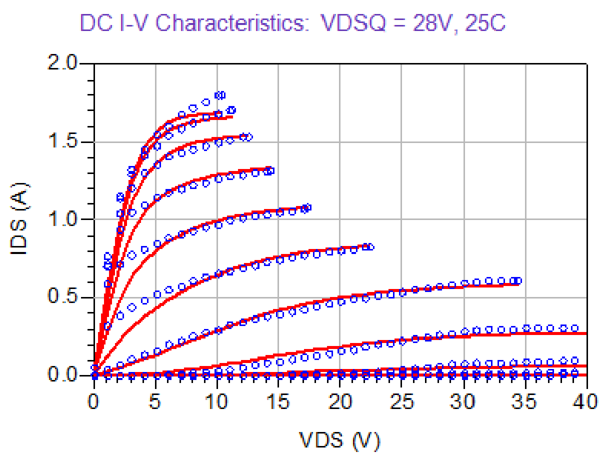
HMT_QOR_TGF2942_SS_001_MDLXQorvoGaN
X4
BiasCondition=2 - 12V, 40mA
BWremoval=0 - Bond wire effect in model

Legend: Red Solid lines – small-signal model, O symbols – measured data
Simulated at 25C with frequency range from 2 – 35 GHz. 50-Ohm Smith Charts

Example LS/Non-Linear Model Performance – Pulsed IV Curves

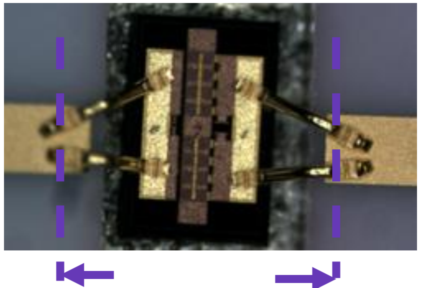


Legend: Red Solid lines - Model data, O Symbols - Measured data
Simulated at 25C with VGS varying from -4 to 1V in steps of 0.5V,
VDS varying from 0 to 40V in steps of 1V. Model self_heat_factor= 0 and VDSQ = 20V.

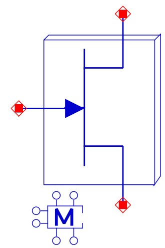


Legend: Red Solid lines - Model data, O Symbols - Measured data
Simulated at 25C with VGS varying from -4 to 1V in steps of 0.5V,
VDS varying from 0 to 40V in steps of 1V. Model self_heat_factor= 0 and VDSQ = 28V.

Model:
HMT-QOR-TGF2933-001



Model and Measurement Reference Planes (BWremoval=0)

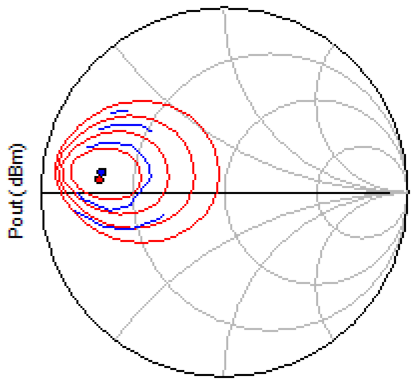


HMT_QOR_TGF2933_001_MDLXQorvoGaN
X3
VDSQ=28
self_heat_factor=0
Temperature=25
BWremoval=0 - Bond wire effect in model

Example LS/Non-Linear Model Performance – 10 GHz Load-Pull

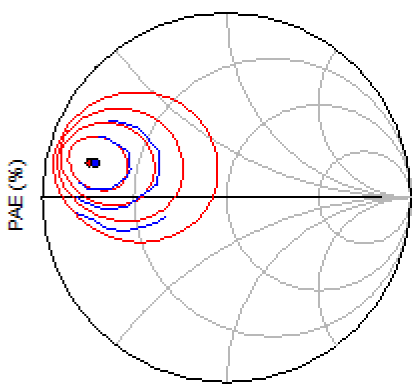
Load Pull Validation: Frequency = 10GHz
VDS = 20V, IDS = 80mA,
Input Power = 27dBm, Z0 = 50Ω Center, 25C

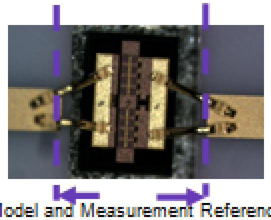
Power Tuning (1dB contour step)



P3dB ~8W

Efficiency Tuning (10% contour step)





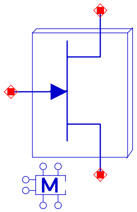
Model and Measurement Reference Planes (BWremoval=0)

Test Bench Reflection Coefficient:

GammaS=0.771<-177°
GammaS2=0.708<137°
GammaS3=0.428<93°
GammaL2*=0.753<82°
GammaL3*=0.434<9°

*Fundamental tuning only. Harmonic impedances are not tuned

Model:
HMT-QOR-TGF2933-001



HMT_QOR_TGF2933_001_MDLXQorvoGaN
X3
VDSQ=20
self_heat_factor=0.10
Temperature=25
BWremoval=0 - Bond wire effect in model

Legend: Red Solid lines – Model, Blue Solid lines – Measured.
Pulsed Biased conditions for measurements: duty cycle = 10% with pulse length = 100us.

Example LS/Non-Linear Model Performance – 18 GHz Load-Pull

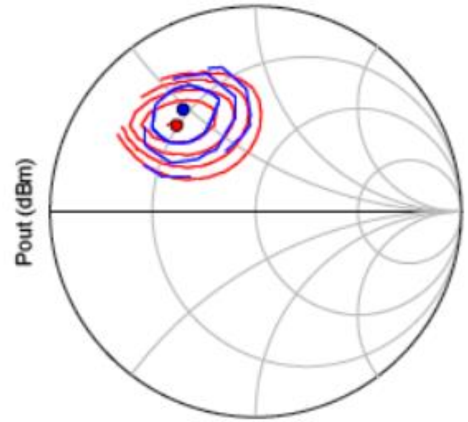
HMT-QOR-TGF2942-001

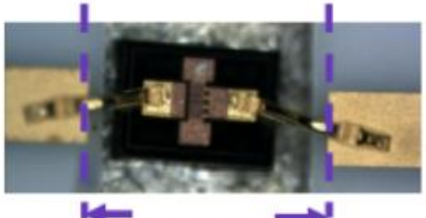
Load Pull Validation: Frequency = 18GHz
VDS = 28V, IDS = 20mA,
Input Power = 25dBm, Z0 = 50Ω Center, 25C

Model:
HMT-QOR-TGF2942-001

P3dB ~2W

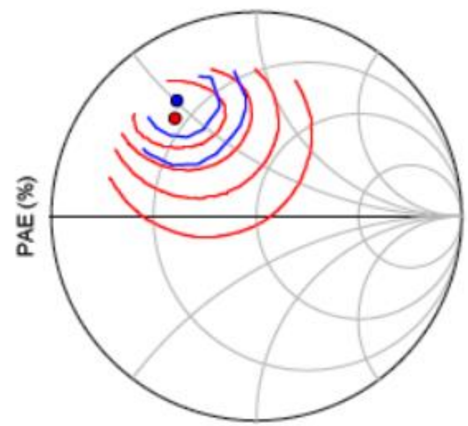
Power Tuning (0.5dB contour step)





Model and Measurement Reference Planes (BWremoval=0)

Efficiency Tuning (10% contour step)



Test Bench Reflection Coefficient:

GammaS=0.572<-166°
GammaS2=0.402<115°
GammaS3=0
GammaL2*=0.233<110°
GammaL3*=0

*Fundamental tuning only. Harmonic impedances are not tuned

Legend: Red Solid lines – Model, Blue Solid lines – Measured.

Example LS/Non-Linear Model Performance – 10 GHz Power Sweep

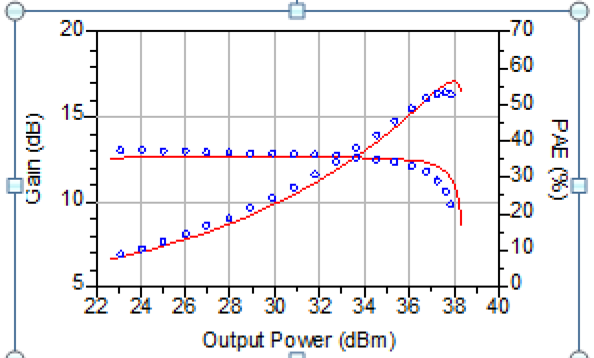
6-8 Watt die

Single Tone Power Sweep: Frequency = 10GHz
VDS = 20V, IDS = 80mA, 25C

<u>Load Condition: Power Tuned</u>

Model Simulated to 31dBm Input Power
Measured Data Simulated to 28dBm Input Power

Transducer Gain and Power Added Efficiency (PAE)

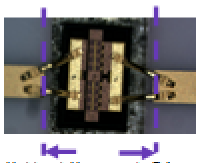


Legend: Red Solid lines - Model data, O Symbols - Measured data

<u>Load Condition: Power Tuned</u>
Test Bench Reflection Coefficient:

GammaS=0.771<-177°
GammaS2=0.708<137°
GammaS3=0.428<93°
GammaL=0.748<173°
GammaL2*=0.753<82°
GammaL3*=0.434<9°

*Fundamental tuning only. Harmonic Impedances are not tuned.

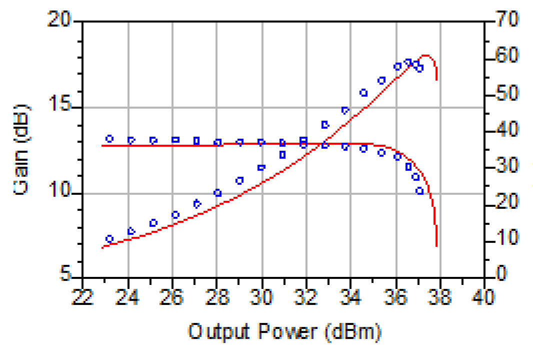


Model and Measurement Reference Planes (BWremoval=0)

<u>Load Condition: PAE Tuned</u>

Model Simulated to 31dBm Input Power
Measured Data Simulated to 27dBm Input Power

Transducer Gain and Power Added Efficiency (PAE)



Legend: Red Solid lines - Model data, O Symbols - Measured data

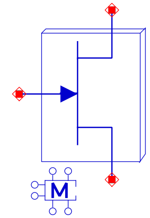
Pulsed Biased conditions for measurements: duty cycle = 10% with pulse length = 100us.

<u>Load Condition: PAE Tuned</u>
Test Bench Reflection Coefficient:

GammaS=0.771<-177°
GammaS2=0.708<137°
GammaS3=0.428<93°
GammaL=0.792<167°
GammaL2*=0.774<81°
GammaL3*=0.442<4°

*Fundamental tuning only. Harmonic Impedances are not tuned.

Model:
HMT-QOR-TGF2933-001



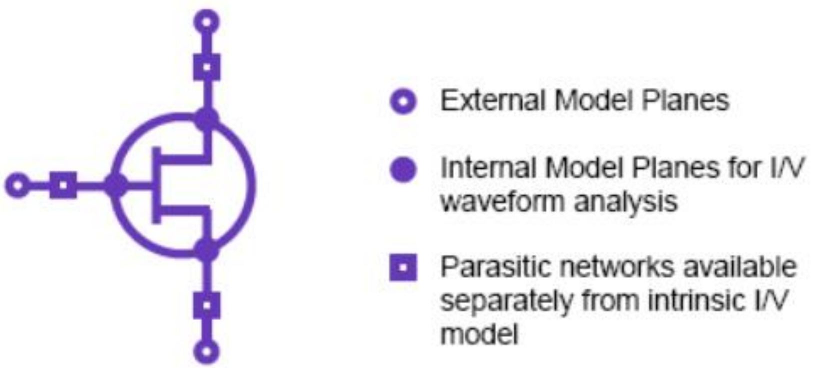
HMT_QOR_TGF2933_001_MDLXQorvoGaN
X3
VDSQ=20
self_heat_factor=0.10
Temperature=25
BWremoval=0 - Bond wire effect in model

Advanced Model Feature

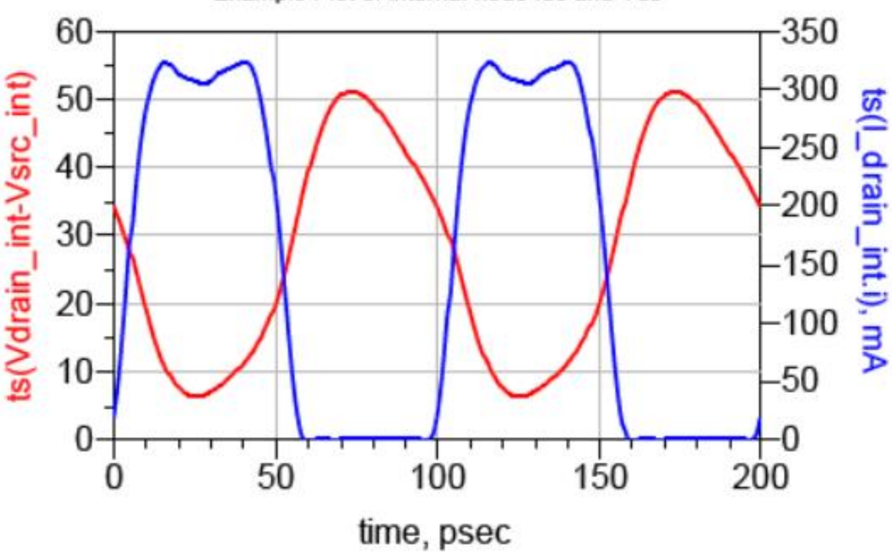
Access to intrinsic I-V planes enables waveform engineering
For advanced modes of operation (eg. Class F, J)

Advanced Model Features: Intrinsic Voltage/Current Sensing

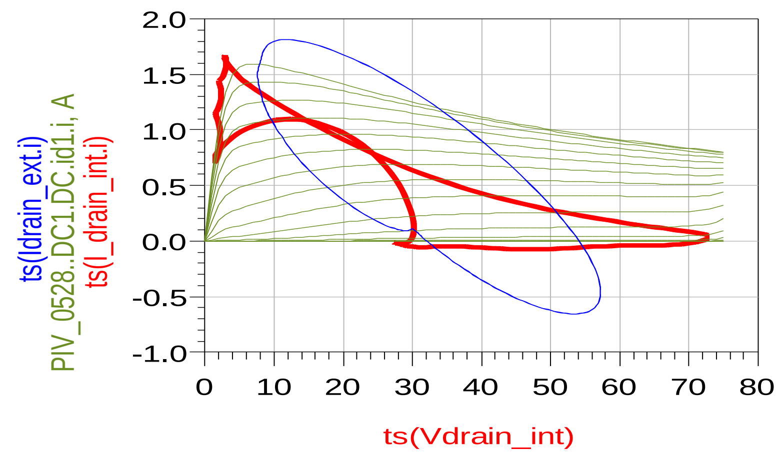
Get Vds and Ids model data near current generator intrinsic planes while tuning.



Example Plot of internal node Ids and Vds



Intrinsic sensing – red;
external sensing -- blue



The dynamic loadline stays within the boundary of the device I-V plane

Summary

- A set of state-of-the-art non-linear and noise models have been advanced for a family of 0.15 um GaN die devices.
- The models are validated for S-parameter performance through 40 GHz, noise parameter prediction through 35 GHz and large-signal power performance at 10 and 18 GHz.
- Advanced LS models provide confidence for first-time-right design
- The models demonstrated are part of the Modelithics Qorvo GaN Library available for free use by Qorvo approved customers by request at:

  http://www.modelithics.com/mvp/Qorvo

How To Get GaN Library Support

- **Contact Modelithics for GaN model support**
  - Download support
  - License support
  - Installation support
  - How to use specific features, etc.
  - support@modelithics.com

- **For product application specific support**
  - Email Qorvo applications engineering
  - info-products@qorvo.com

THANK YOU!