Applications of a Customized Angelov Model to Build a High Power GaN Model Library

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Modelithics and Qorvo are collaborating to provide designers with free access to state-of-the-art high accuracy models for a growing number of power GaN transistors. The available and planned GaN model library supports simulation-based design flows for GaN power amplifiers (PAs) with output power requirements from 5W to over 500W. This talk will summarize the library content, features and device as well as circuit level “closed loop” PA validations of the new models.
Agenda

• Introduction
• Device Validation Example
• PA Application Examples
• New Model Features
• Summary
Motivation for Model-Enabled PA Designs

• Demonstrate the effectiveness of a growing GaN model library for supporting PA designers

• These models provide advantages to designers who want quick turn-around designs, but may not have measured load-pull data at target frequencies.

• The availability of a complete circuit model can be very useful in guiding post-fabrication adjustments, if needed, to improve or fine tune bench performance.
Non-Linear Models for Qorvo GaN Die Packaged Devices

V1.6.4 Library Now Available via Modelithics Website Request
– 11 Die and 27 Packaged Devices (> 15 more models coming)
– Actively maintained software w/ version control and updates.
– Quick access to Model datasheets within the library
– Many example & reference projects
– Model support directly from Modelithics
– Easy click thru installer

**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
– Updated and new model features in development
GaN Die & Package Library
Device Element Palates
IV Characteristics

Self_heat_factor=1.0  
(100% Duty)

Self_heat_factor=0.1  
(10% Duty)

Self_heat_factor=0.01  
(1% Duty)

HMT_TQT_TGF2023_2_01_001_MDLXTQTGaN  
X5  
VDSQ=28 V  
BWremoval=1 - Bond wire effect removed  
self_heat_factor=1  
Temperature=25

Simulated at 25°C and 85°C with VGS sweep. VDSQ of 12V and 28V.  
Pulse width = 0.5us, duty cycle = 0.05%
Intrinsic Waveform Sensing

Intrinsic sensing – red; external sensing -- blue

Intrinsic IV sensing at Current generator

Red – class A; Blue – class AB; Pink – class B
Example Device Level Validations

- Broadband S-parameters (DC to 3 GHz)
- Large-signal model (Angelov-based)
- Temperature scalable (25°C to 85°C)
- Advanced model feature enabling intrinsic I-V sensing
- Measurement validations:
  - Pulsed I-V
  - Multi bias S-parameters
  - Power drive-ups using TriQuint data (1 and 1.5 GHz)

Power Tuning (1 dBm contour step)

Efficiency Tuning (10% contour step)

<table>
<thead>
<tr>
<th>Load Pull Summary</th>
<th>Max. Power Load Impedance (ohms)</th>
<th>Max. Power Value (dBm)</th>
<th>Max. PAE Load Impedance (ohms)</th>
<th>Max. PAE Value (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>1.721 + j*0.285</td>
<td>54.8</td>
<td>1.887 + j*1.526</td>
<td>79.7</td>
</tr>
<tr>
<td>Model</td>
<td>1.562 + j*0.489</td>
<td>54.9</td>
<td>1.697 + j*1.459</td>
<td>83.1</td>
</tr>
</tbody>
</table>

Pulsed bias conditions for measurements: duty cycle = 20% with pulse length = 200 μs.

Single Tone Power Sweep: Frequency = 1 GHz, VDS = 36 V, ID = 600 mA (25°C)

Transducer Gain and Power-Added Efficiency (PAE) vs Output Power

Impedances (ohms) presented to the device during power drive-up test:
- ZL fundamental = 1.67 + j*2.02
- ZL second harmonic = 2.68 + j*3.84
- ZL third harmonic = 4.88 + j*2.37
- ZL fundamental = 1.46 + j*0.18
- ZL second harmonic = 4.82 + j*1.13
- ZL third harmonic = 13.50 + j*10.01

Legend: Red: Model, Blue: Measured data (provided by TriQuint)

Pulsed bias conditions for measurements: duty cycle = 20% with pulse length = 200 μs.
### 3dB-Compression Output Power, Gain and PAE

<table>
<thead>
<tr>
<th>Device</th>
<th>Goal</th>
<th>Sim</th>
<th>Meas</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2G6000528-Q3</td>
<td>Capable of 10W</td>
<td>Operation: class AB</td>
<td>Q. Bias: 28V/50mA</td>
</tr>
</tbody>
</table>

| Gain (linear) | 20dB +/-1 at 2.4GHz | 17dB +/-1 at 2.4GHz | ✓ |
| Power         | 10W                | 10W                | ✓ |
| PAE           | 50%                | 50%                | ✓ |

### Return Loss under 35dBm Output

Markers = measured
Solid = simulated, using EM simulation
### Design Spec

<table>
<thead>
<tr>
<th>Device</th>
<th>Goal</th>
<th>Sim</th>
<th>Meas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T2G4005528-FS</strong></td>
<td>Capable of <strong>65 W</strong></td>
<td>Operation: class AB</td>
<td><strong>Q. Bias:</strong> 28V/200mA</td>
</tr>
<tr>
<td><strong>Gain (linear)</strong></td>
<td><strong>16dB +/-1</strong> at 3.5 GHz</td>
<td><strong>17dB +/-1</strong> at 3.5 GHz</td>
<td>✓</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td><strong>65 W</strong></td>
<td><strong>65 W</strong></td>
<td>✓</td>
</tr>
<tr>
<td><strong>PAE</strong></td>
<td><strong>60%</strong></td>
<td><strong>60%</strong></td>
<td>✓</td>
</tr>
</tbody>
</table>

#### 3.5 GHz Eval Board

- **board**: 25-mil Rogers RO3210™

VdsQ = 28 V, IdsQ = 200 mA, frequency = 3.5 GHz. Comparison for transistor model cascaded with the built-in TL modeled matching networks (red lines), AXIEM modeled matching networks (green line), and measured (blue symbols) power amplifier power sweep.
**PA Example #3**
*(Modelithics, Qorvo)*

### Design Spec

<table>
<thead>
<tr>
<th>Device</th>
<th>Goal</th>
<th>Sim</th>
<th>Meas</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2G6003028-FS</td>
<td>Capable of 30W</td>
<td>Operation: class AB</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Q. Bias: 28V/200mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gain (linear)</td>
<td>14dB +/-1 at 5.8GHz</td>
<td>14dB +/-1 at 6GHz</td>
<td>✓</td>
</tr>
<tr>
<td>Power</td>
<td>30W</td>
<td>30W</td>
<td>✓</td>
</tr>
<tr>
<td>PAE</td>
<td>50%</td>
<td>50%</td>
<td>✓</td>
</tr>
</tbody>
</table>

**5.8 GHz PA Design**

- 25-mil RO3210

**Power Amplifier Power & PAE**

**Power Amplifier S-Parameters**

- **Legend:** Red: Model, Blue: Measured data

See Modelithics Application Note 049: Analysis of a 30 W Power Amplifier Utilizing Modelithics’ TriQuint T2G6003028-FS model in Agilent ADS
## PA Example # 4 (Qorvo)

<table>
<thead>
<tr>
<th>Design Spec</th>
<th>Goal</th>
<th>Sim</th>
<th>Meas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device: T2G6000528-Q3</td>
<td>Good PAE at P3dB &gt; 40 dBm From 5 to 5.8 GHz</td>
<td>Operation: class AB</td>
<td>Q. Bias: 32V/50mA</td>
</tr>
<tr>
<td>Gain (linear)</td>
<td>13 dB</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>Power</td>
<td>10 W</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td>PAE</td>
<td>55%</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

- **Solid lines** – Simulation
- **Dashed lines** – Measured data

### Performance Metrics

- **Gain (linear)**: 13 dB
- **Power**: 10 W
- **PAE**: 55%

### Frequency Responses

- **Gain vs Pout at 5.4 GHz**
- **P3dB vs Frequency**
## PA Example #5 (Modelithics/Ivan B.)

### Design Spec

<table>
<thead>
<tr>
<th>Device</th>
<th>Goal</th>
<th>Sim</th>
<th>Meas</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2G6003028-FL</td>
<td>Capable of 30 W</td>
<td>Operation: Continuous class F</td>
<td>Q. Bias: 28V/200mA</td>
</tr>
</tbody>
</table>

### Gain (linear)

- 17dB+/-2 ✓

### Power

- 25 W ✓

### PAE

- >60% ✓

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**Output Power (dBm), PAE (%) at +34 dBm input, and linear S21dB**

![Wave forms at intrinsic generator](image.png)

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**1.8-2.2 GHz Eval Board**

![Eval Board](image.png)
Class J Design Flow – Keysight

- Matthew Ozalas from Keysight Technologies created a class J PA Design example using a device model from Modelithics GaN Library, taking advantage of the models’ intrinsic IV nodes
- For more details visit Keysight’s YouTube channel “How to Design an RF Power Amplifier: Class J” at [http://keysight.com/find/eesof-how-to-videos](http://keysight.com/find/eesof-how-to-videos)

Screenshots from YouTube and available Interactive PA Design Utility in ADS workspace
New Model Features

- Enhanced Sensing of Intrinsic Voltages and Ids current that removes the effects of Cgd in addition to Cds and other parasitics.
- Parasitic Network remains available to allow the user to incorporate the effects of the parasitics into the output matching network.
- Enhanced Thermal Modeling for Peak Temperature Prediction for Pulsed Operation
- Sensing of Peak and Average Temperature Rise due to Self-Heating effects.
The simulated $T_{ch}$ matches the datasheet very well, which proves that the RTH model works fine vs. various duty cycles and pulse widths.
Summary

- Demonstrated successful first-pass simulation-based PA designs using a new Qorvo GaN Model Library
- Upcoming releases will include an enhanced model format for
  - improved intrinsic I/V sensing
  - enhanced electrothermal models
  - channel temperature sensing
- The Library is free to Qorvo approved designers, request at:
  [http://www.modelithics.com/mvp/Qorvo](http://www.modelithics.com/mvp/Qorvo)
Thank You!