Cadence AWR Design Environment Empowers RF PA Design and Simulation

RF Design Solutions for High-Power Amplifiers

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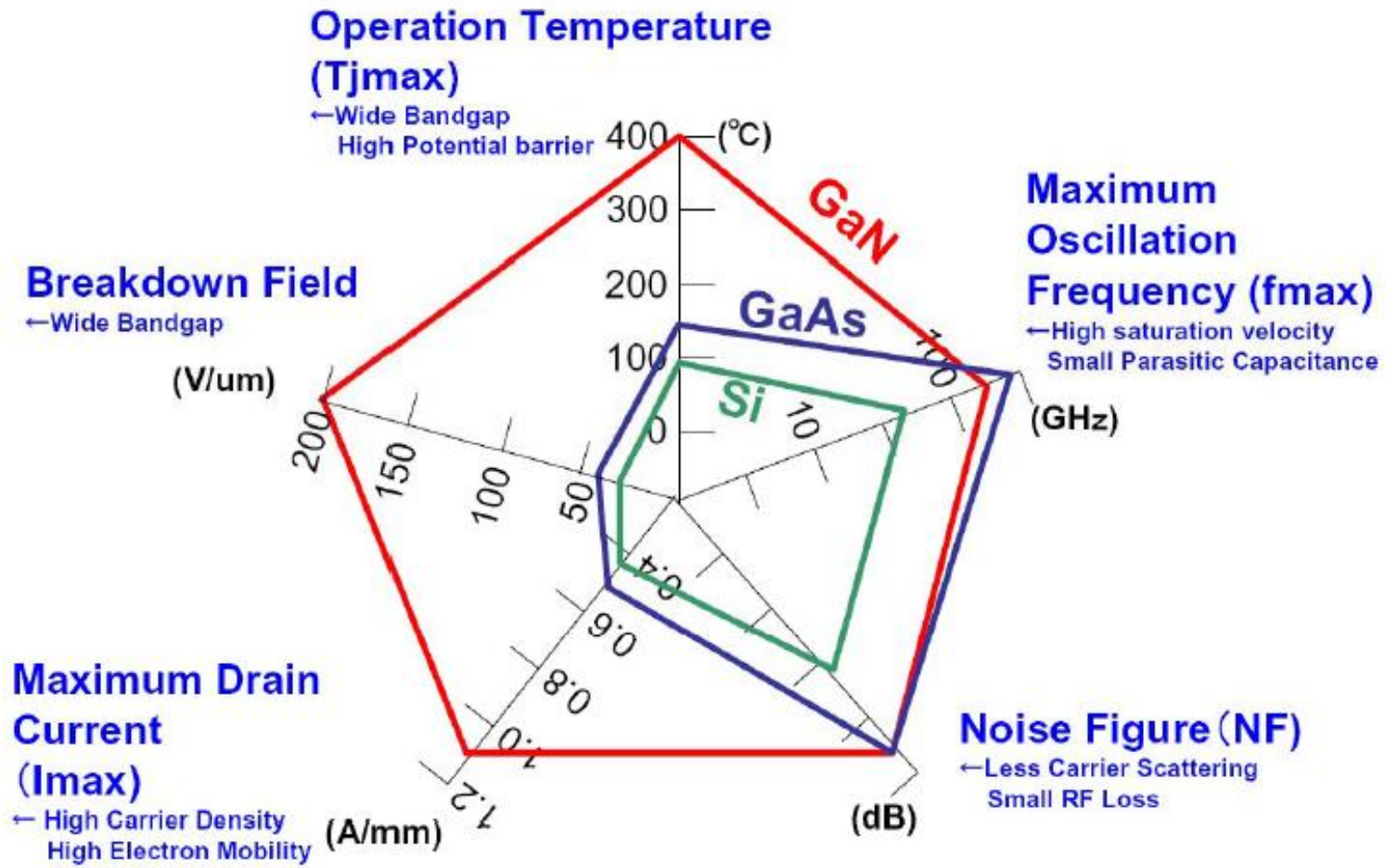
cadence®

Agenda

- GaN RF Design Trends and Challenges
- Cadence Solution in RF Design
- Design and Simulation
- RF Packaging and Thermal Analysis
- Rohde Schwarz – Cadence Collaboration
- Summary

GaN RF Design Trends and Challenges

Benefits of GaN for RF Applications

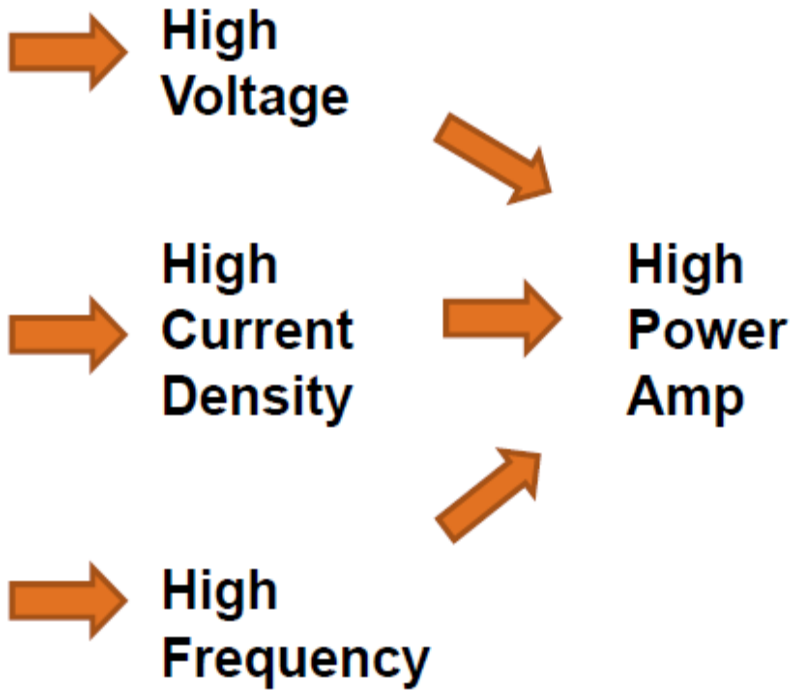


Panasonic

Tanaka, Current Status of AlGaN/GaN HFETs and MMICs for RF Applications, CSICS Short Course, 2005

GaN for PA Design

Property	Si	GaAs	SiC	GaN
Energy Gap (eV)	1.11	1.43	3.2	3.4
Critical Electric Field (MV/cm)	0.6	0.5	3.0	3.5
Charge Density (# x $1x10^{13}/cm^2$)	0.3	0.3	0.4	1
Thermal Conductivity (W/cm/K)	1.5	0.5	4.9	1.5
Mobility ($cm^2/V/s$)	1300	6000	600	1500
Saturation Velocity (x 10^7 cm/s)	1	1.3	2	2.7



- **GaN Is Natural Fit For High Power Applications**

Simulation and Design Tools Needed for an Effective Design Process

- Load pull analysis built into the design framework
  - Graphing capabilities to display load pull-based behavior in a convenient manner
- Nonlinear stability analysis tools
- Matching circuit synthesis
  - Input and Out matching circuits need to be synthesized
- Electromagnetic (EM) and circuit co-simulation

Cadence Solution in RF Design

Cadence Silicon RFIC, MMIC, and SiP Solutions

Design, analyze, and implement

Platform	**AWR Design Environment®** 	**Virtuoso®** 
Technologies	• GaN/GaAs and Si MMIC Chips, Acoustic modules • Smaller mmW and uW Si RFIC Blocks	• Si RFIC and Digital Chips • SiP and Heterogeneous Integration
Design	• Microwave Office® w/ APLAC • Visual System Simulator™	• Virtuoso w/ Spectre®
Analysis	• EMX®, AXIEM® (planar EM) • Clarity™, Analyst (3D FEM) • Celsius™ (Thermal)	• EMX, AXIEM (planar EM) • Clarity, Analyst (3D FEM) • Celsius (Thermal) • Innovus™
Implementation	• Front-to-back for MMIC • Interoperability to Virtuoso for backend	• Front-to-back for RFIC, SoC, SiP

Complete System-Level RF-Aware Design Platform

Efficient, reliable, extensible RF design and analysis from transistors to antennas

High-Performance RF Design Solution

Virtuoso®
Analog and custom IC design

AWR®
RF and microwave system design

Allegro®
PCB and package design

Clarity™ and Celsius™
Multiphysics analysis and signoff

Wireless and Radar Design

- **Optimized IC, package, and PCB workflows**
- **Integrated design data exchange**
- **Seamlessly embedded multiphysics analysis**

Only with Cadence

- Up to 5X designer productivity
- Eliminate point tool interoperability friction
- Quick turnaround system analysis

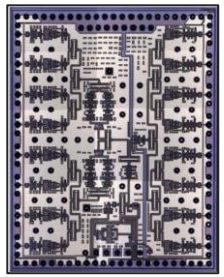
Design, Analysis, and Implementation Solutions

RFIC

Design and Implementation
- Virtuoso®

Analysis
- Spectre®
- EMX®

Verification
- Pegasus™

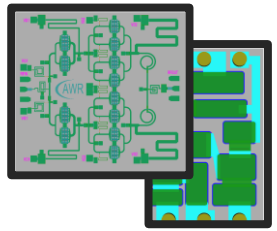


III-V MMICs and Acoustics

Design and Implementation
- Microwave Office®

Analysis
- APLAC®
- AXIEM®
- Clarity/ Celsius

Verification
- Microwave Office

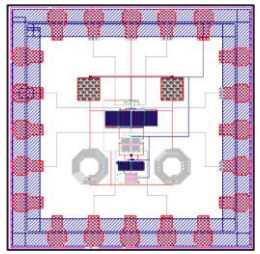


Silicon MMICs

Design and Implementation
- Microwave Office

Analysis
- APLAC/Spectre
- EMX

Verification
- Pegasus

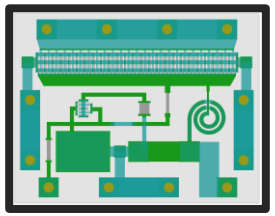


Wireless PAs

Design and Implementation
- Microwave Office

Analysis
- APLAC
- AXIEM/EMX

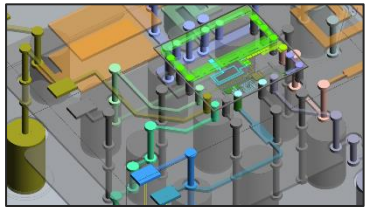
Implementation and Verification
- Pegasus



Packaged RFICs

Design and Implementation
- Virtuoso RF
- Allegro® Package Designer Plus

Analysis
- Spectre
- EMX
- Clarity
- Celsius

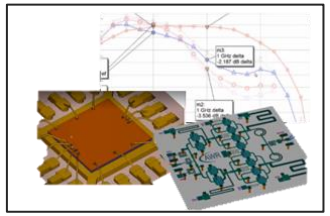


Verification
- Virtuoso/Allegro Package Designer Plus

Packaged MMICs

Design and Implementation
- Microwave Office
- Allegro Package Designer Plus

Analysis
- APLAC
- AXIEM
- Clarity/ Celsius

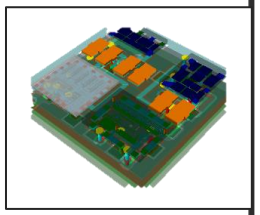


Verification
- Microwave Office/Allegro Package Designer Plus

RF Modules

Design and Implementation
- Virtuoso RF
- Microwave Office
- Allegro Package Designer Plus

Analysis
- Spectre/APLAC
- Clarity/Celsius
- AXIEM/EMX

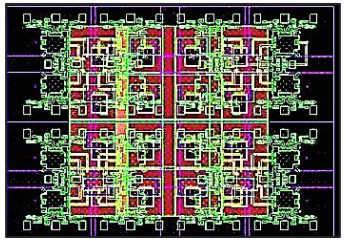


Verification
- Virtuoso/Allegro Package Designer Plus

RF Boards

Design and Implementation
- Microwave Office
- Allegro

Analysis
- APLAC
- AXIEM
- Clarity
- Celsius



Verification
- Allegro

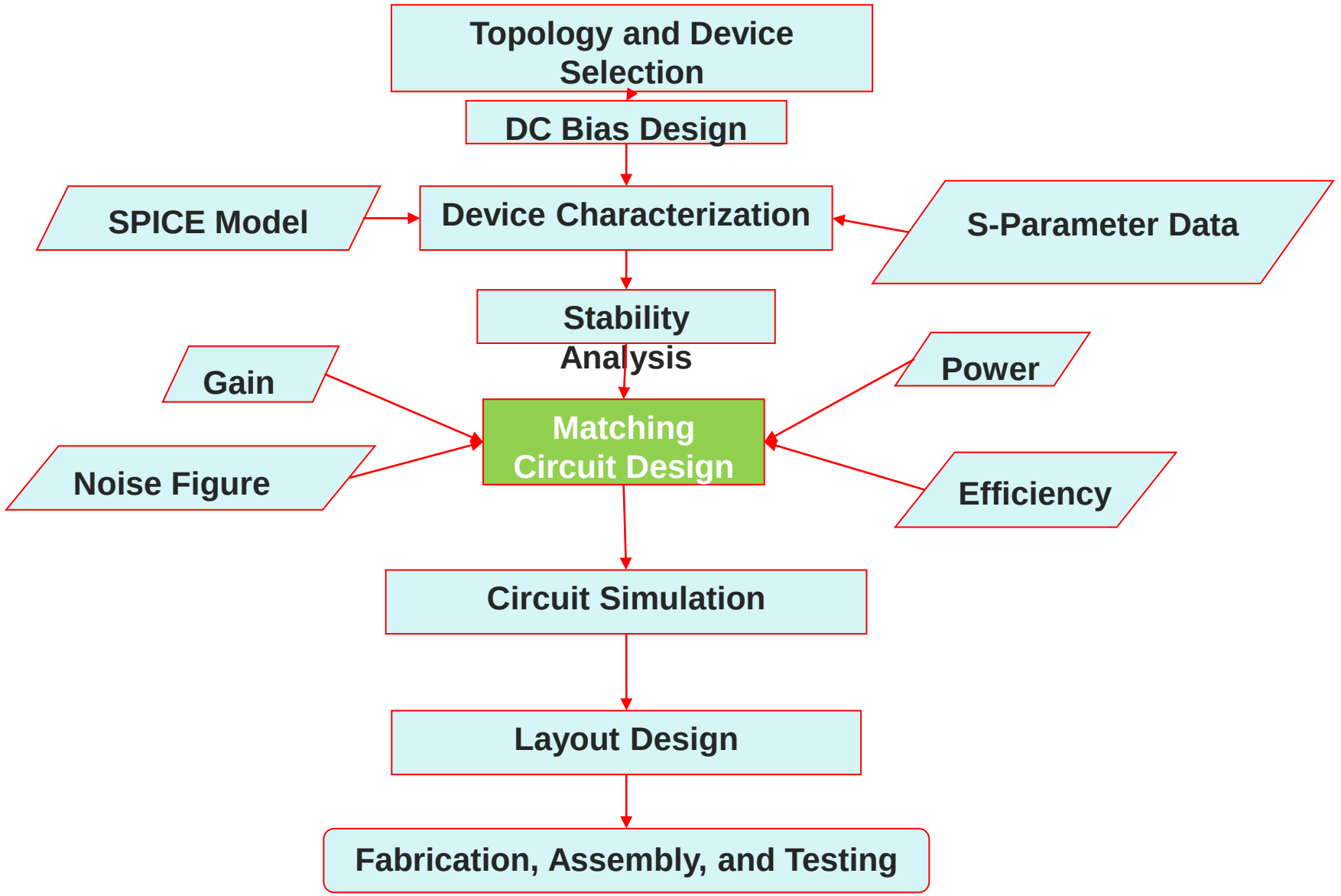
GaN PDK Partnerships

Global support of GaN foundries and integrated device manufacturers

- PDKs available from leading GaN, GaAs, SiGe, and silicon foundries
- Co-developed with foundries serving both commercial and aerospace/defense markets
- Global reach across North America, EMEA, and AP regions
- Feature-rich PDKs include:
  - Symbols and schematics
  - Fully-scalable Pcells
  - Scalable models nonlinear GaN transistor (HEMT, pHEMT) models for amplification and switching
  - Monte Carlo statistical/mismatch simulation
  - Advanced layout utilities
  - Accurate EM simulation featuring:
    - EM-enabled parameterized on-chip passives
    - Predefined substrate definitions and stack-ups with geometry simplification
    - Preconfigured simulation settings

Design and Simulation

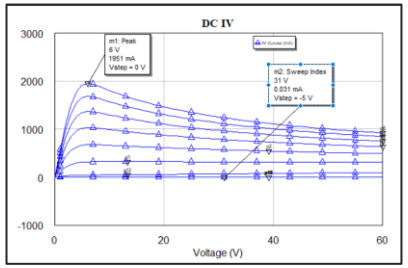
RF Power Amplifier Design Flow

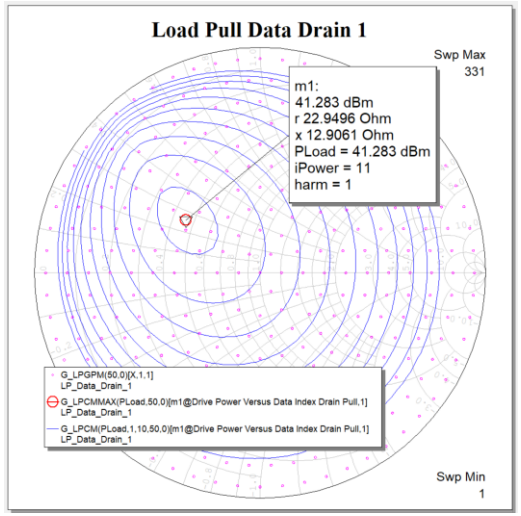


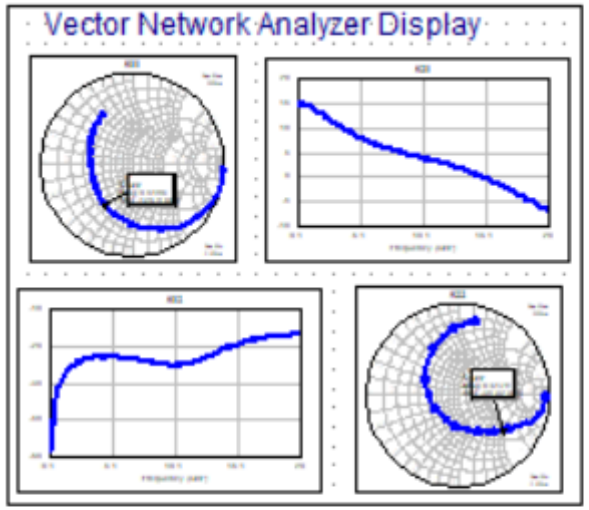
Simulation and Modeling Capabilities

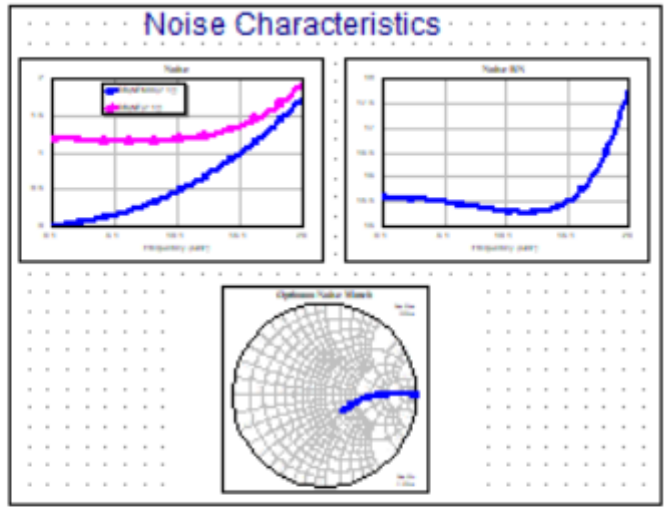
Analysis for all phases of RF circuit design and verification

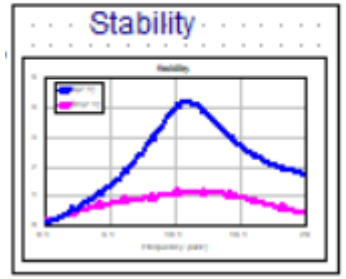
- DC IV
- Linear S-parameters
- Stability
- Harmonic balance
- Circuit envelope
- Load/source pull
- Yield
- Optimization
- EM analysis

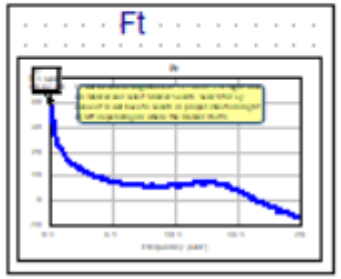


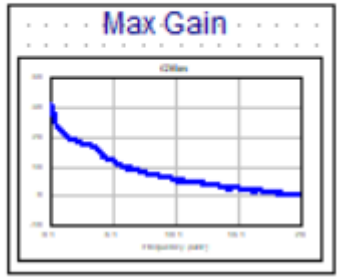








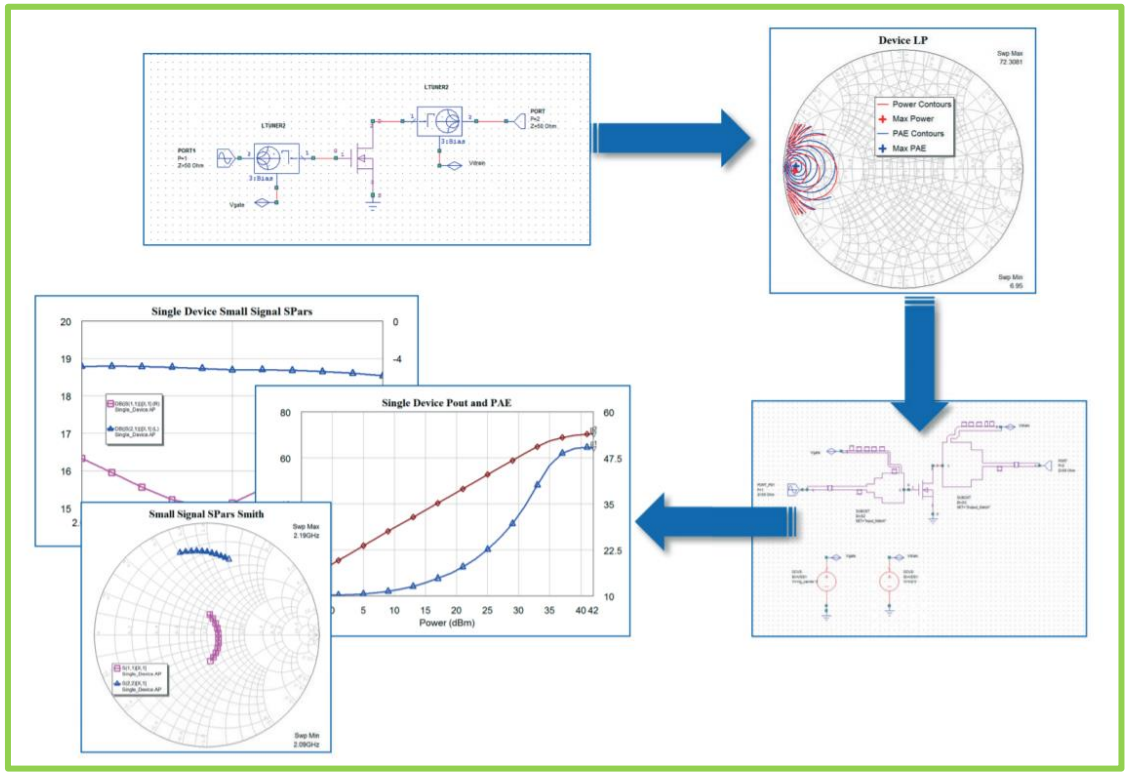




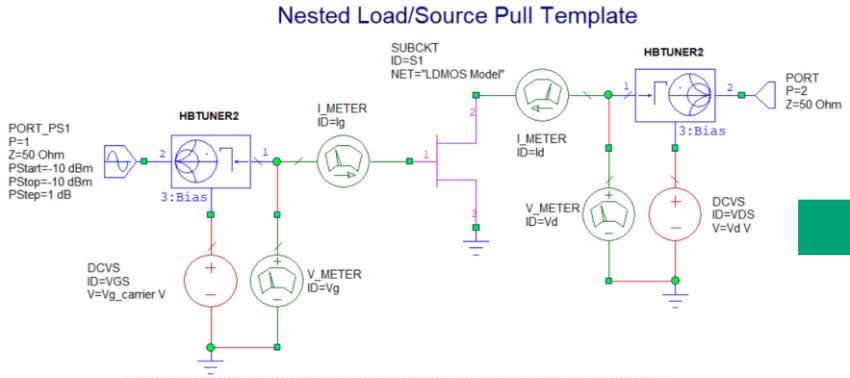
Load-Pull Analysis for Power Amplifier Design

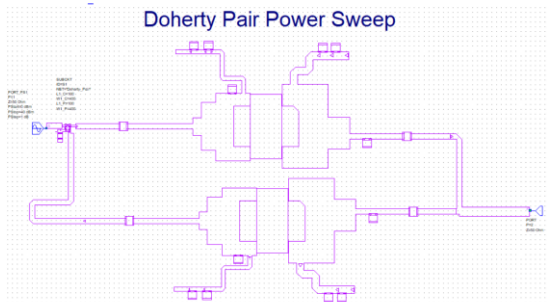
Determine load requirements for challenging specifications

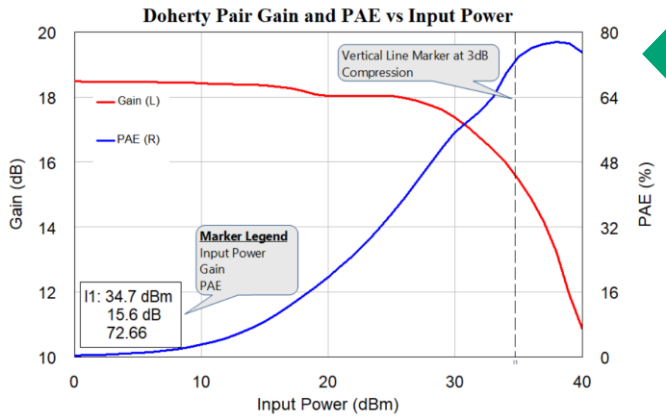
- Simulate nonlinear performance as a function of source and/or load impedance.
- Plot performance contours such as P_{out}, PAE
  - Provides key design information for matching circuit development
  - Supports nested source/load harmonic load-pull
  - Supports low-frequency (F2-F1) load-pull for two-tone excitations (new in v15)
- Can be performed over swept power, frequency, or other user-defined parameters

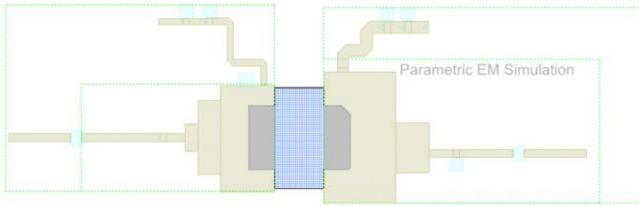


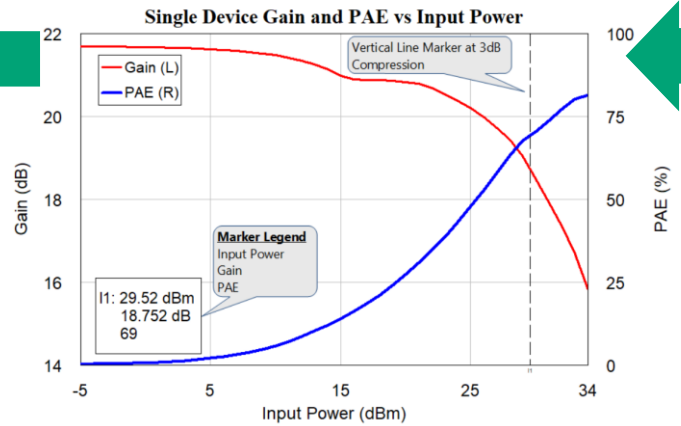
Load-Pull Analysis for PA

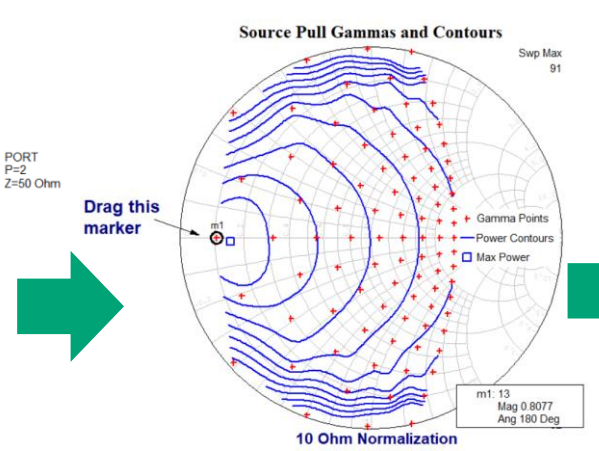


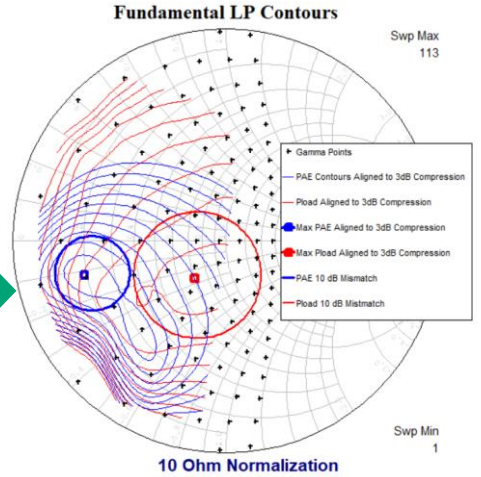


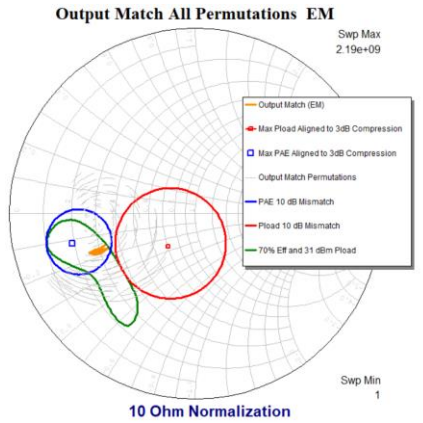






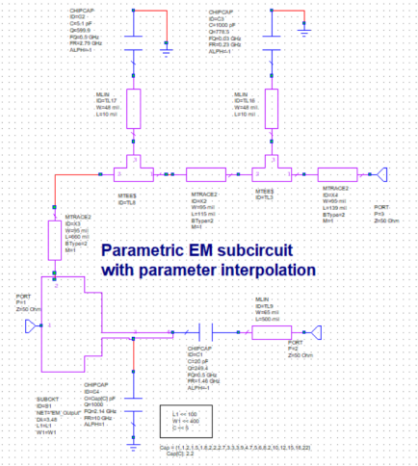


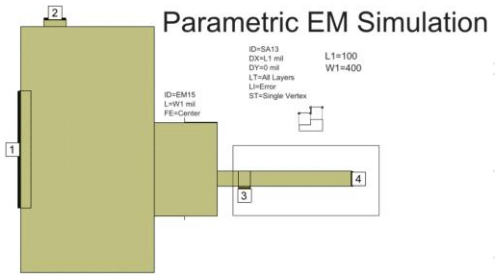




OR

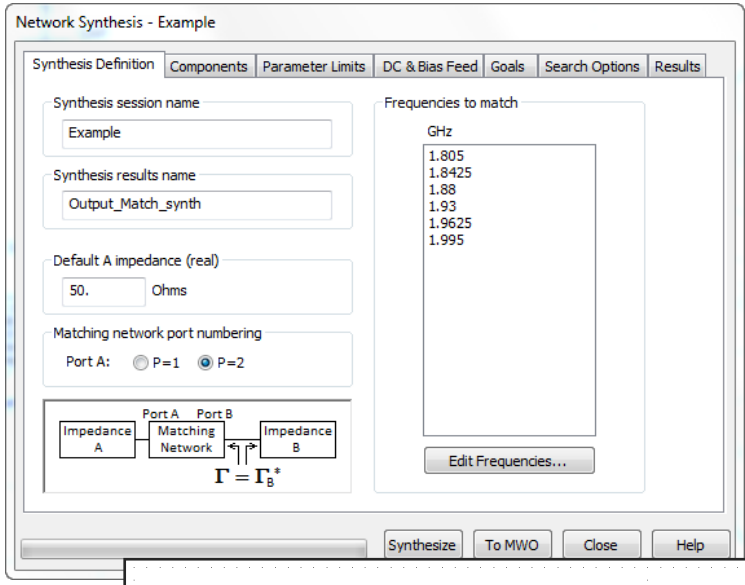
Network Synthesizer Wizard

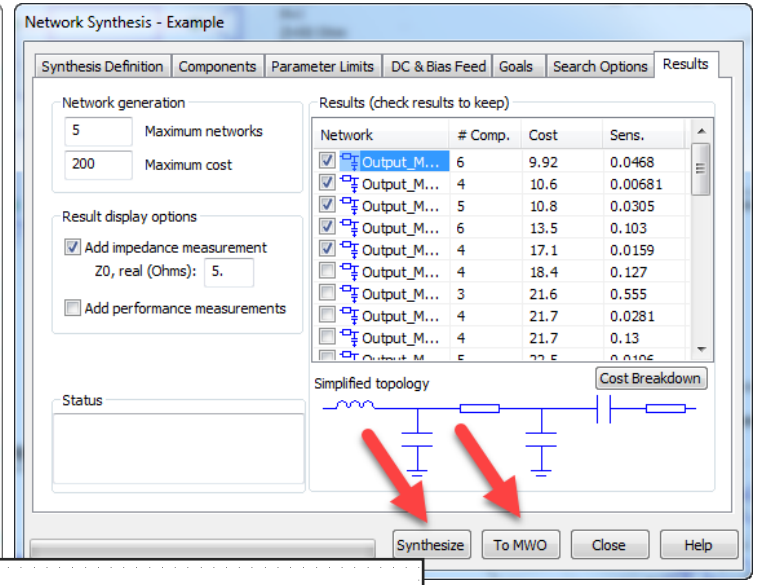


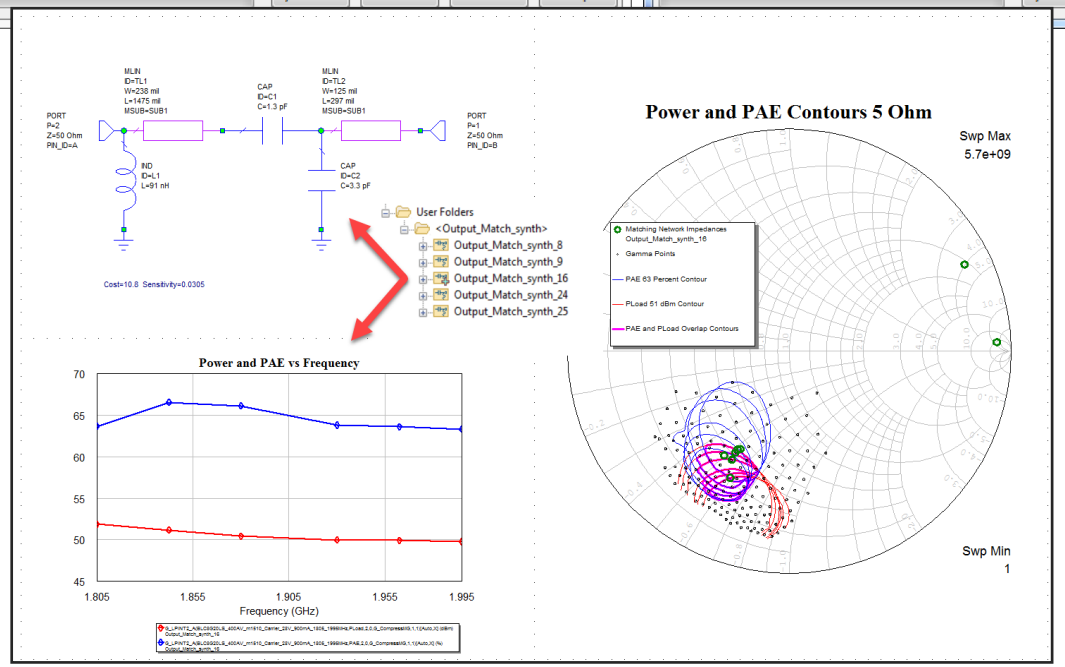


Network Synthesis Wizard

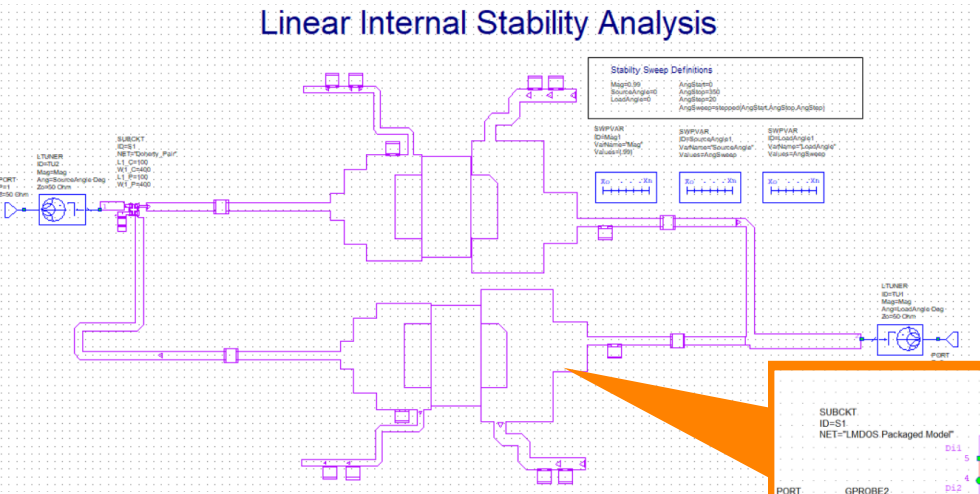
- Synthesis Definition - defines the "direction" of the matching network and frequency band(s) of interest
- Components - defines the available series and shunt components as well as first component and last component limitations
- Parameter Limits - defines the parameter limits, parameter rounding, component series, etc. for each component
- DC and Bias Feed - defines the matching network DC path constraints and the bias injection network that the wizard should consider
- Goals - defines the measurements and goals for the synthesis. Double-click on a Measurement or Goal to see the setup.
- Search Options - defines advanced search options
- Results - Shows Synthesis run results and controls how many networks and what additional data is sent back to Microwave Office® software

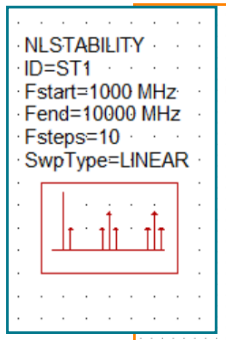


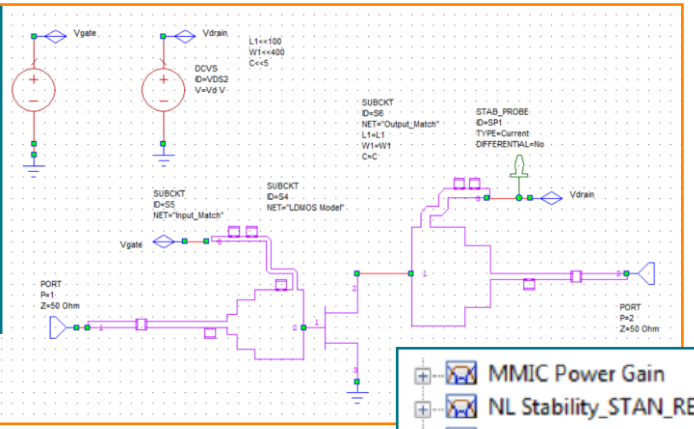


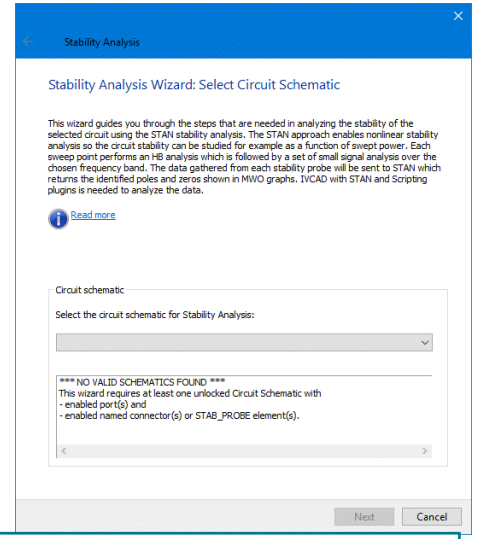


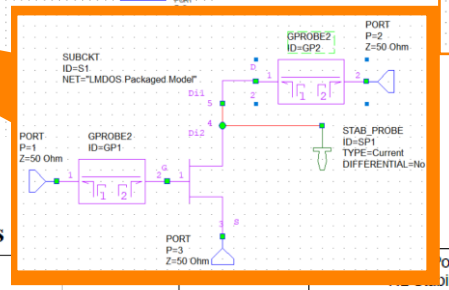
Linear and Nonlinear Stability Analysis

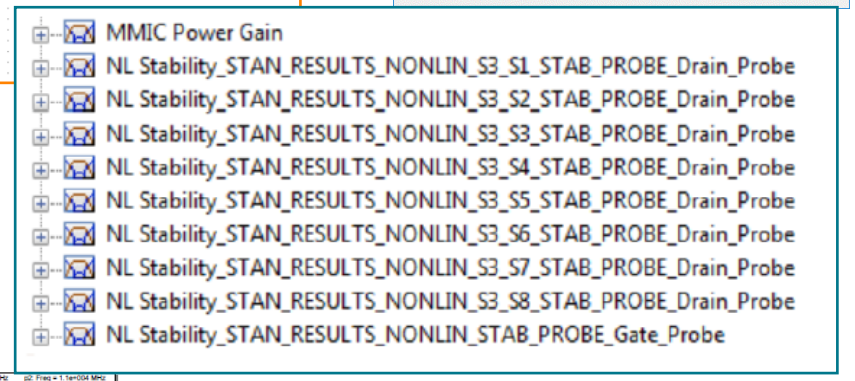


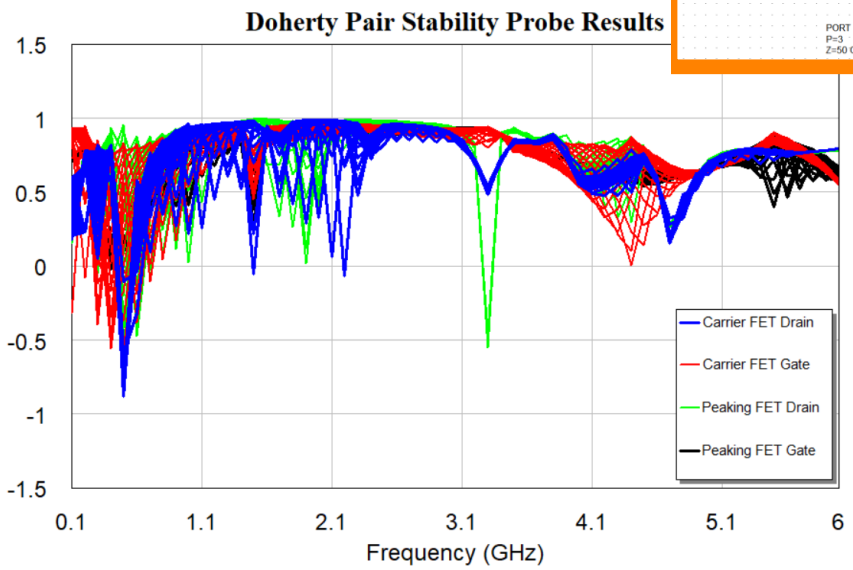


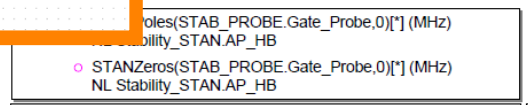


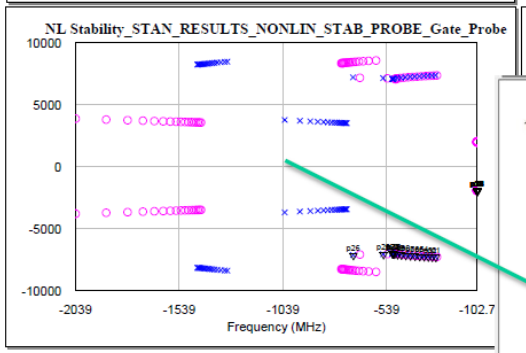


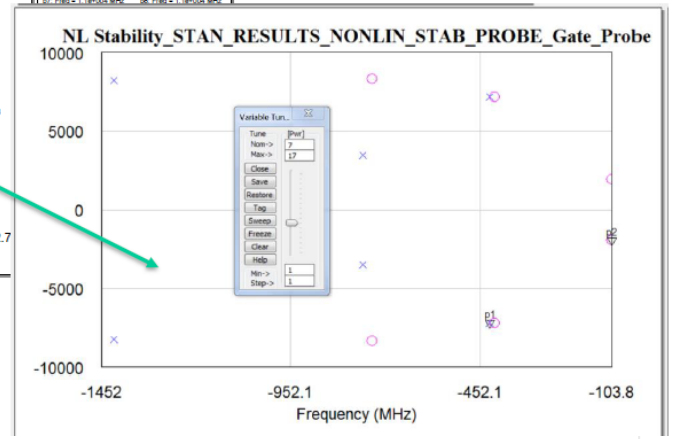






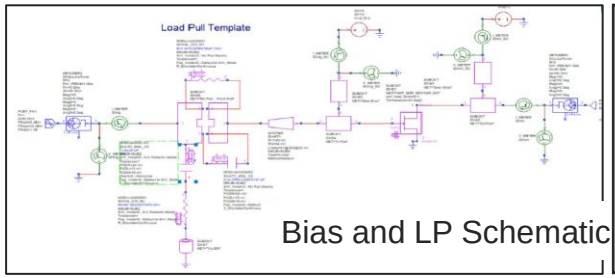


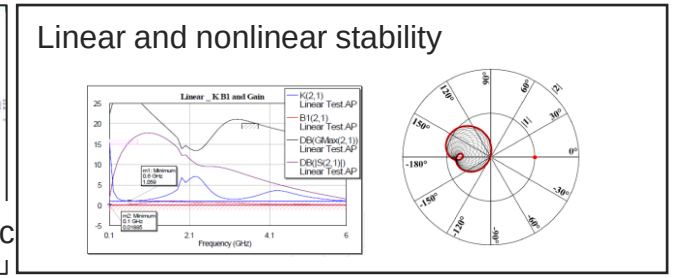


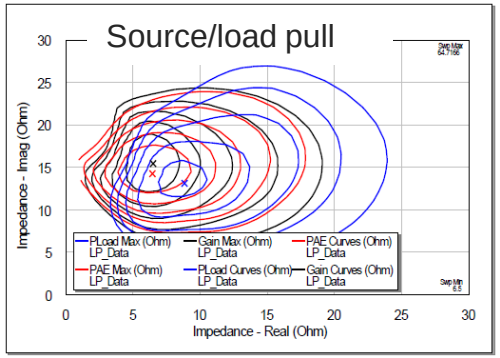


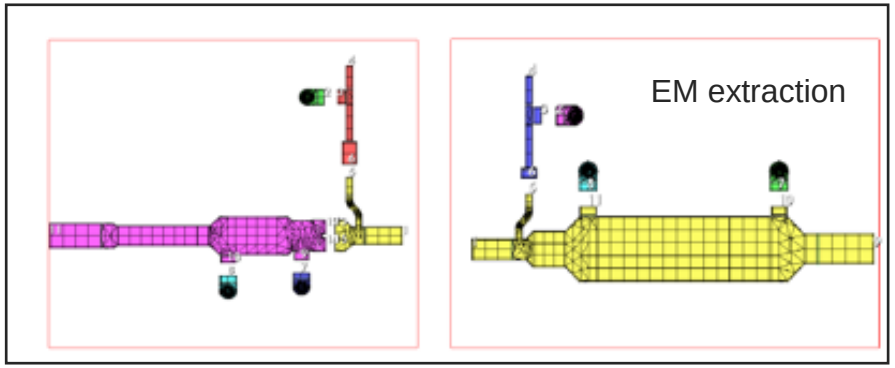
Front-to-Back RF GaN PA design

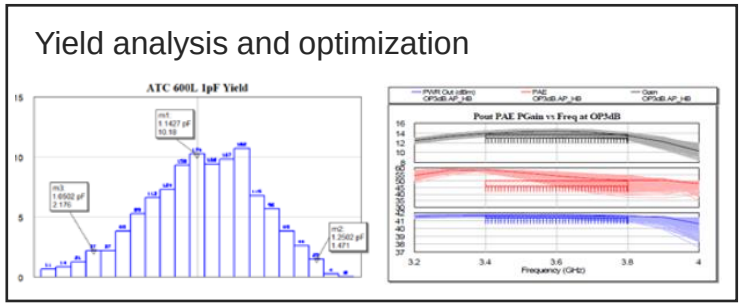
- Determine the biasing requirement
- Linear stability analysis and stabilization network (if needed)
- Impedance matching (source/load pull) and nonlinear optimization
- Physical design and EM extraction
- Optimization
- Yield Analysis
- Digital Modulation Analysis – EVM, ACPR, CCDF, Spectrum, IQ results

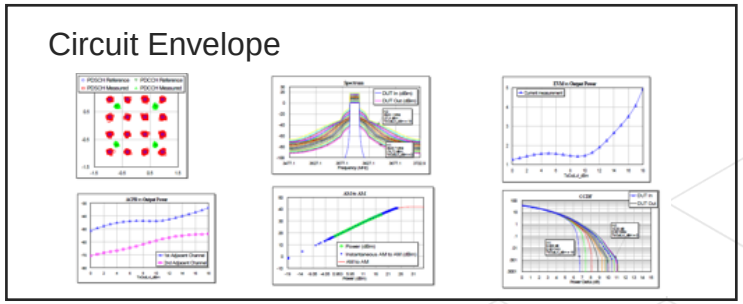












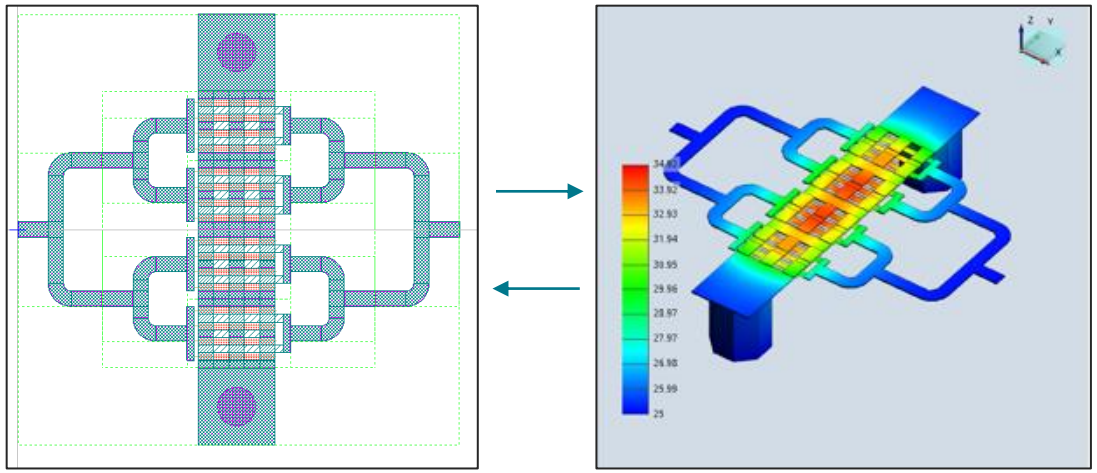
RF Packaging and Electrothermal Analysis

Why Celsius Thermal Solver in RF Design?

- Operating temperatures impact reliability (device lifetime) and performance
- Thermal analysis gives designers an understanding of operating temperature related to power dissipation
- Temperature information can be inserted into the electrothermal model to predict the impact on RF performance
- Heat maps can be used to help develop/optimize heatsink design
- Provide RF engineers with ready access to operating temperature data for reliability and performance studies

AWR Design Environment®

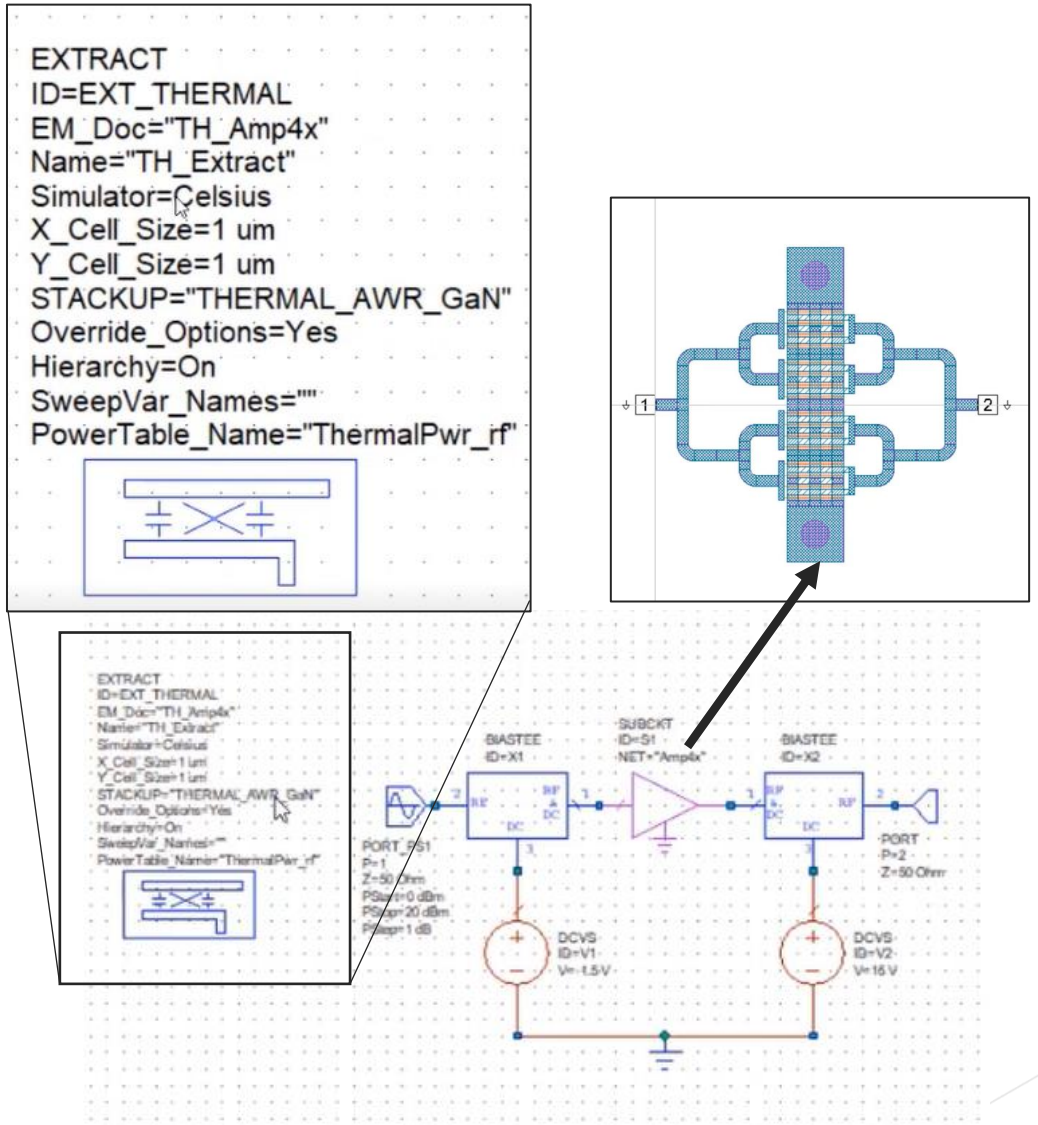
Celsius™ Thermal Solver



Celsius Thermal Solver for Thermal Analysis in Microwave Office Software

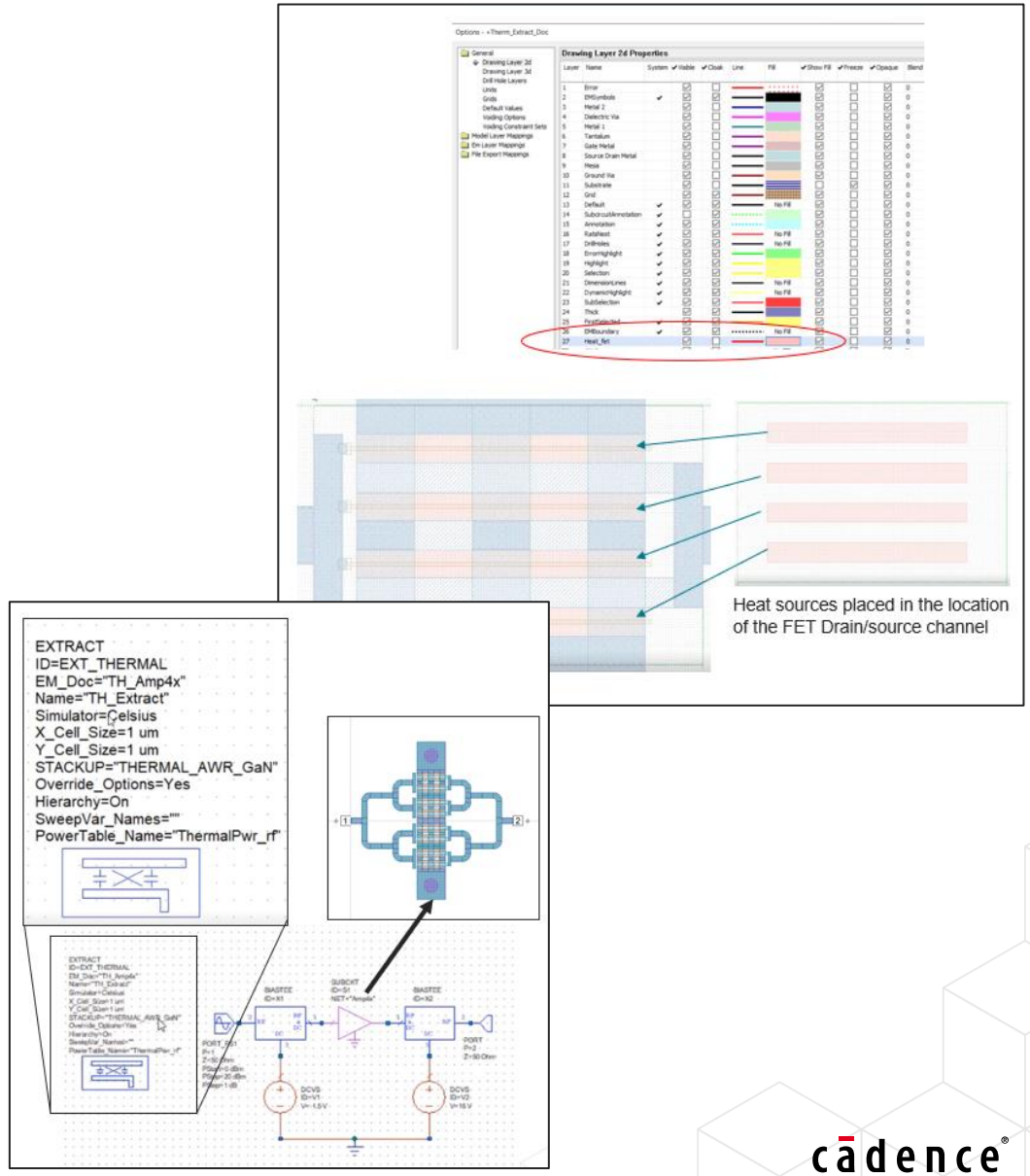
Key features and benefits

- Thermal structures are easily created using powerful Microwave Office® extraction block workflow
- Leverages existing structure data (geometries, materials, stack up) in Microwave Office software to define Celsius™ Thermal Solver structure
- Obtain power dissipation information from Microwave Office analysis
- Thermal simulations launched from inside AWR® platform, results automatically returned
- Easy-to-use flow allows RF design engineers to perform their own thermal analysis



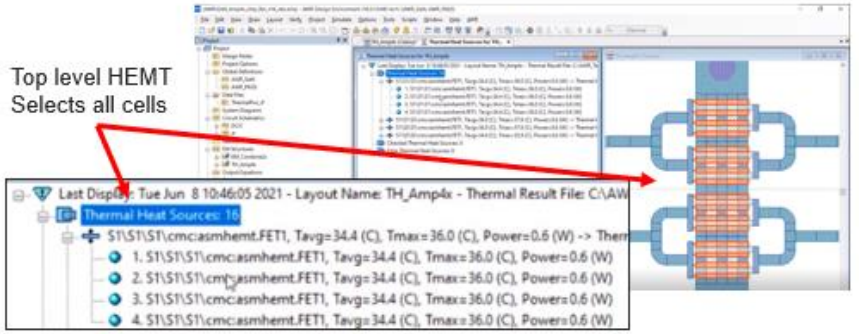
Microwave Office / Celsius Thermal Workflow

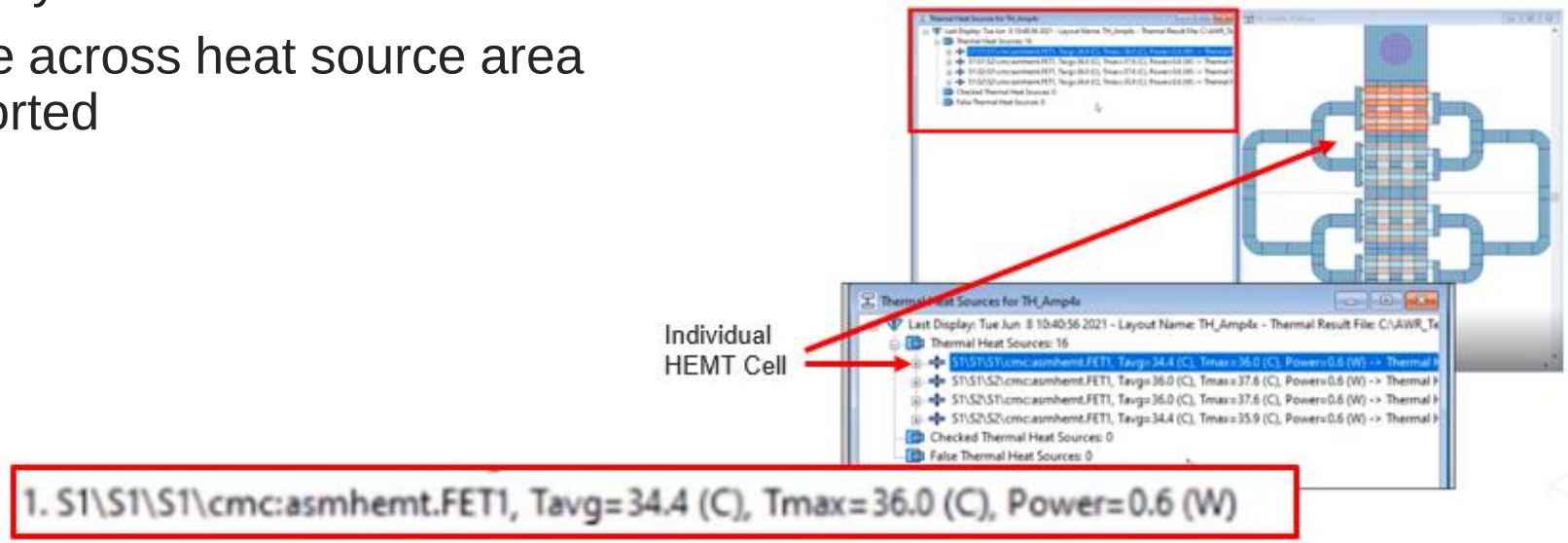
1. **Set-up** - thermal draw layers, EM layer mapping
2. Define heat source geometries in layout (or pCell)
3. **Add extraction block** to create a thermal document
4. Create **power dissipation** data file from nonlinear simulation (new measurement)
5. Associate extraction block with stackup and power dissipation data file
6. Simulate in Microwave Office® software or send to Celsius™ Thermal Solver (native editor)
7. Operating temps back-annotated into Microwave Office and linked to user-defined heat sources



Thermal Analysis Results – GaN FET Example

- Test structure – GaN HEMT devices, combiner network, and source to ground vias
- Celsius™ results automatically reported listed of all defined heat sources throughout the hierarchal design layout
- Selected thermal analysis results for individual heat sources are highlighted in the layout
- Average and peak temperature across heat source area and power dissipation are reported





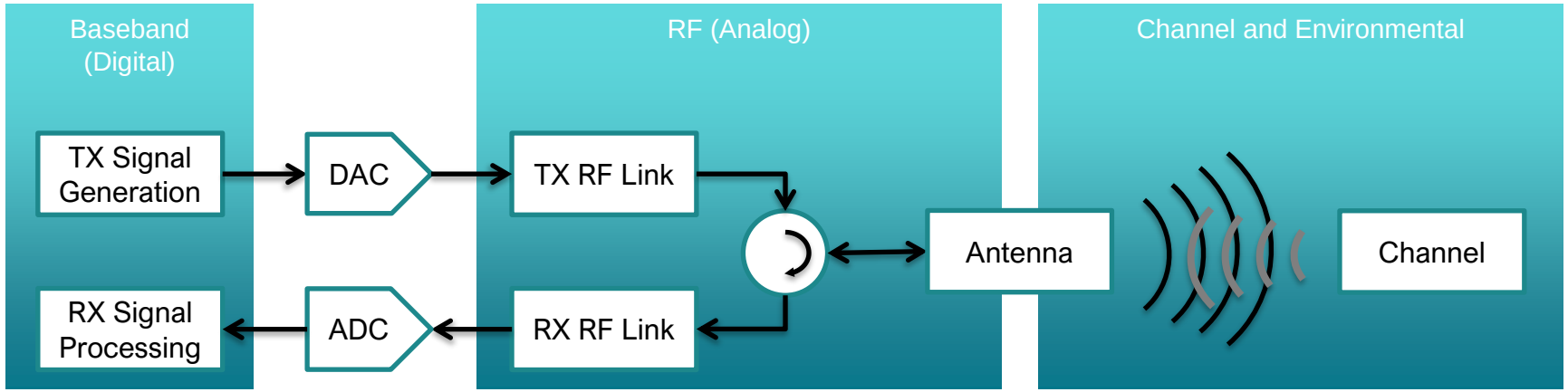
Rohde Schwarz – Cadence Collaboration

WinIQSim2 – VSS – VSE Product integration

Visual System Simulator (VSS)

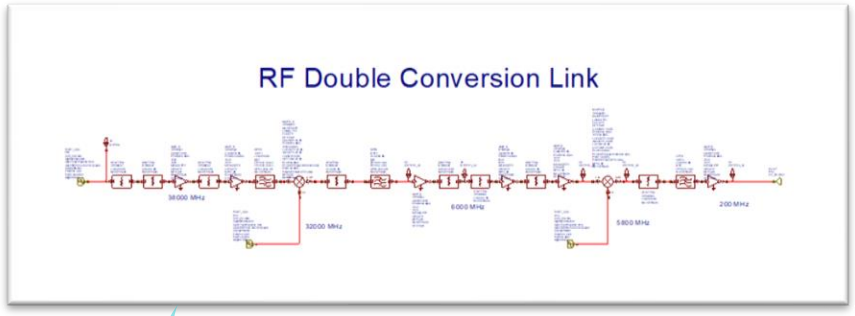
- Part of the Cadence® AWR Design Environment® platform
- Design and analyze anything from simple RF links to complete comm systems
  - RF budget analysis, RF spur heritage
  - Modeling and time-domain simulation of complete communication links
  - Phased array design, standard communication libraries, etc.

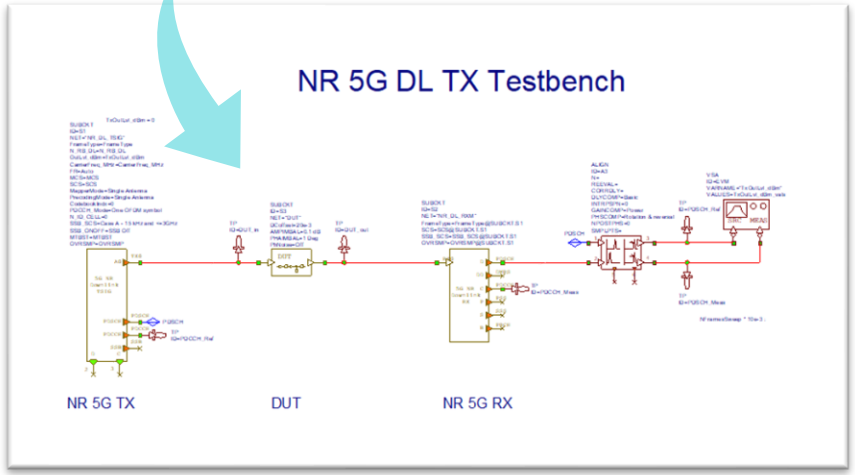
VSS includes models for every component in such systems!



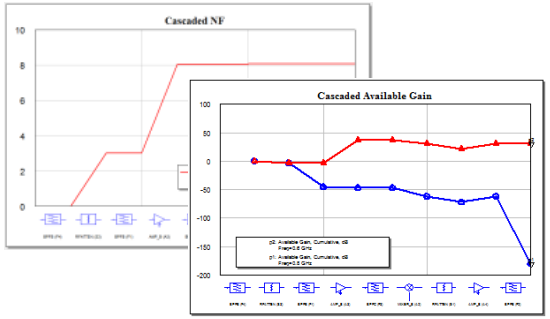
RF System Design and Analysis Flow in VSS

- Construct and analyze RF link

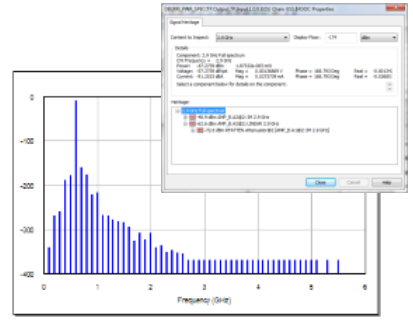




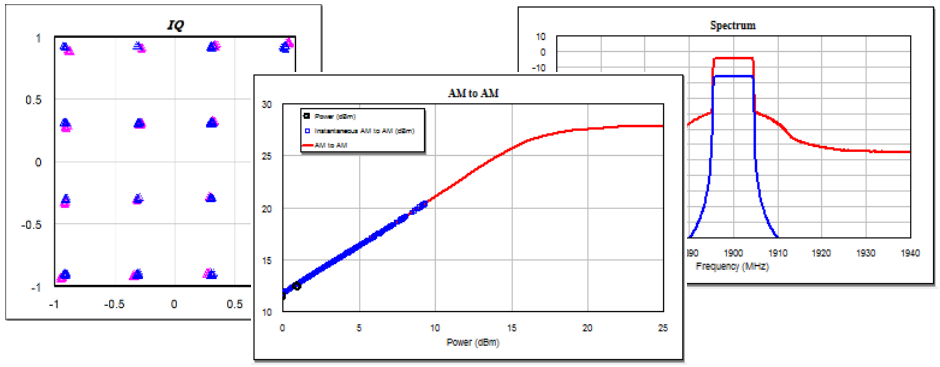
RF Budget Analysis



Spur Identification



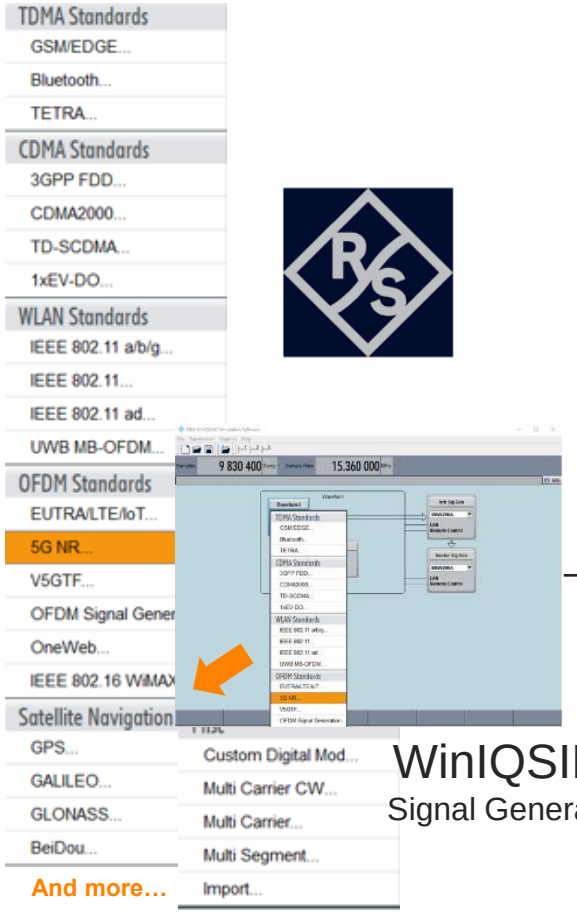
Time Domain Simulations



- Include in communication system/test bench

The same RF link is used by RF budget, spur analysis, and time domain simulators!

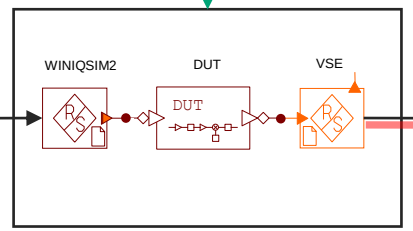
Joint solution: Rohde & Schwarz and Cadence



WinIQSIM2
Signal Generation

Encrypted IQ files

Feedback loop for DPD



VSS*
Visual System Simulator™

Behavior after DPD

Encrypted IQ file

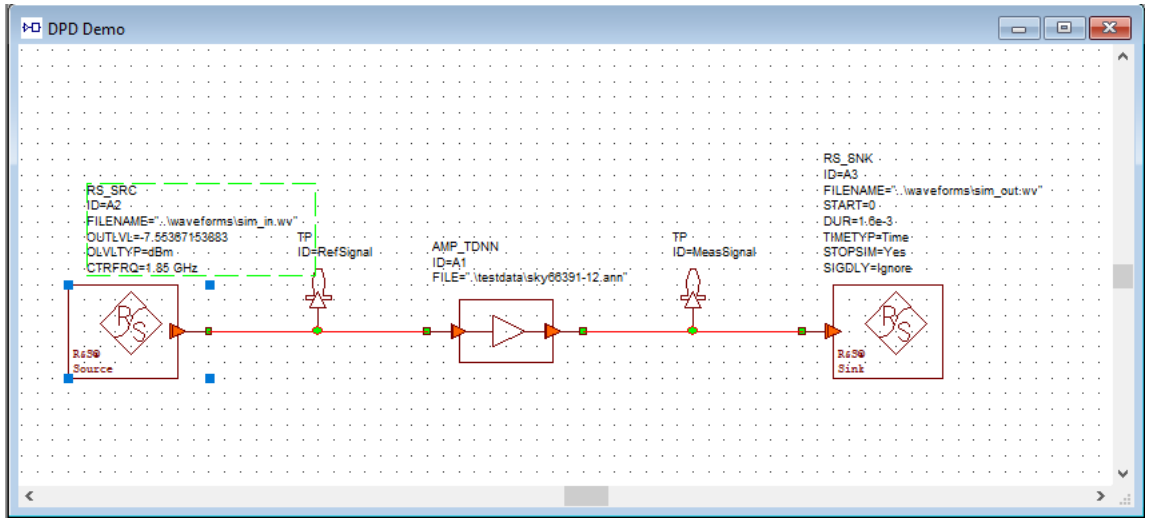
VSE
Signal Analysis

cadence®

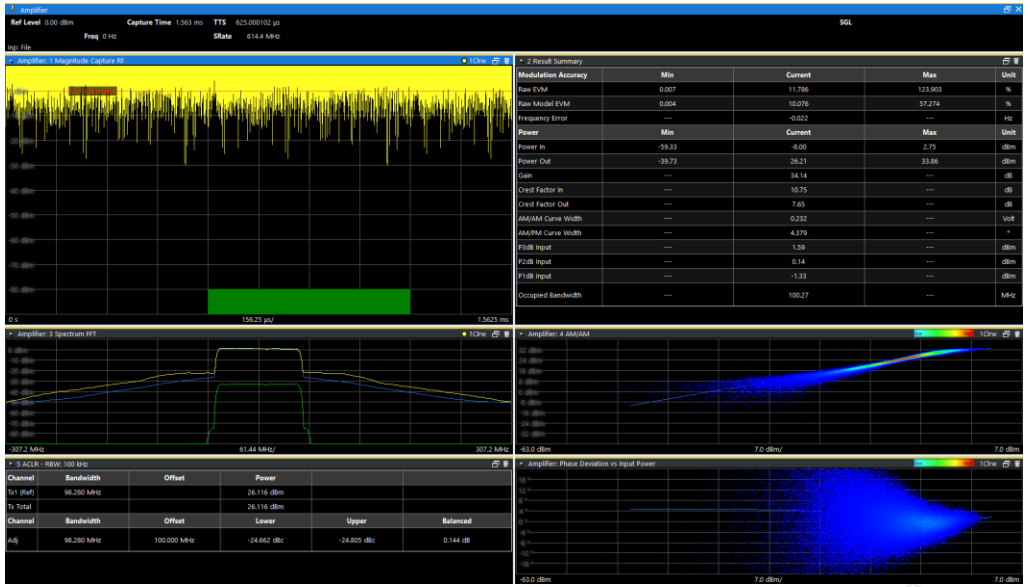
Pre-Distorting an RF Amplifier Purely in Simulation

Script controlling both
software packages:
Cadence VSS and R&S VSE

RF simulation of PA in Cadence VSS



Iterative Direct DPD in R&S VSE



Summary

- With superior electrical performance, GaN HEMT power amplifiers are being widely adopted for commercial and aerospace/defense applications
- To capitalize on this performance, designers need accurate device models, robust nonlinear RF circuit simulation, and specific design tools
- For MMIC-based PAs, designers need to use PDKs authorized by the GaN foundry to ensure simulation accuracy and proper layout
- The successful design and simulation of GaN PAs is based on multiple simulation technologies including EM analysis for parasitic extraction and possibly circuit envelope for simulation-modulated performance metrics
- Packaging plays a key role in thermal dissipation, internal impedance matching, and multi-technology integration