Addressing Performance and Reliability Concerns with Thermal Analysis for RF Power Applications

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Overview

- Thermal Challenges
  - Reliability
  - Performance
  - Design flow bottlenecks
- In-Design Enablement
  - Thermal Analysis Options
  - Microwave Office In-Design Thermal Analysis
- Summary

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Thermal Challenges

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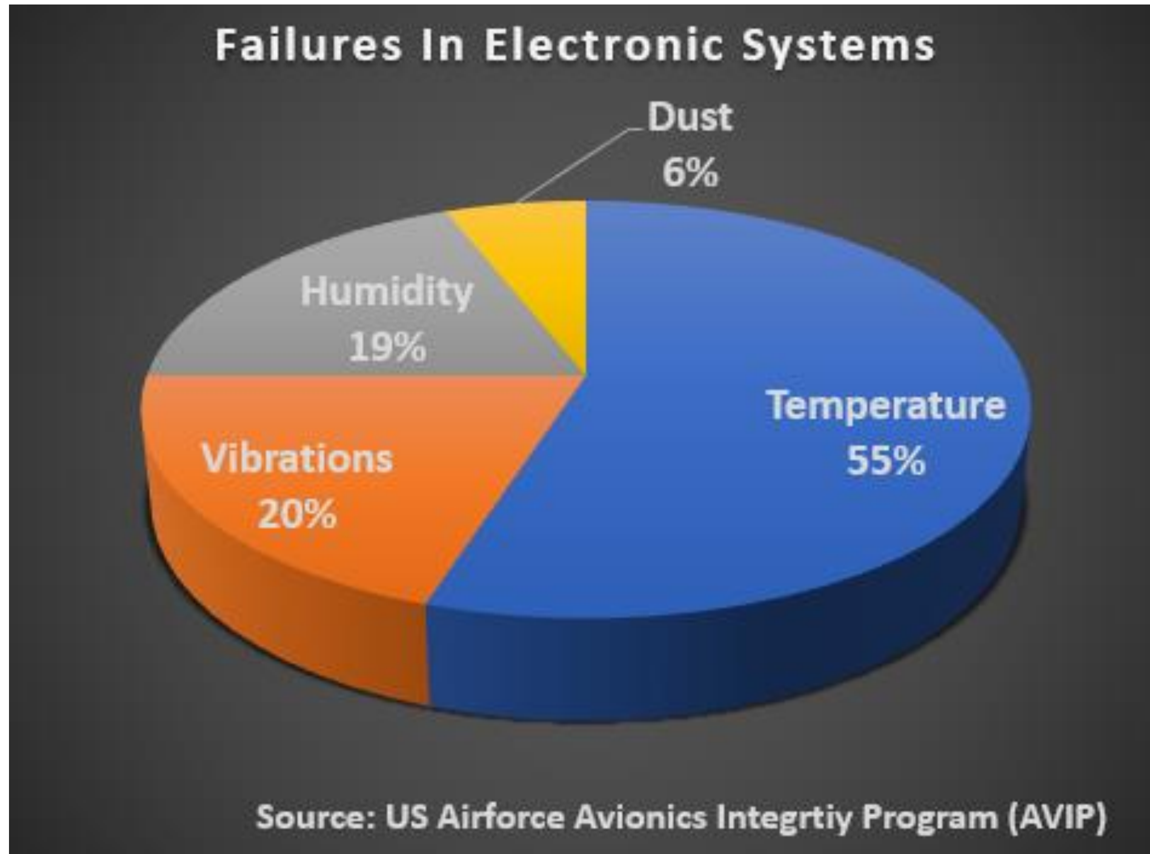
Thermal Design – A Key Concern for Electronics Design



- Reliability / product life-time degradation
  - Increased component stress
  - Component parameter drift
  - Open / short circuits
  - Thermal run-away
  - ...
- Performance degradation
  - Nonlinearity
  - Efficiency
  - Increase in noise-sensitivity
  - Device temperature bias mismatch
  - Shortening burst duration
  - …
- …

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The Effects of Temperature On Electronics

GaN HEMT High Power Amplifiers

- Time to Failure vs Temp

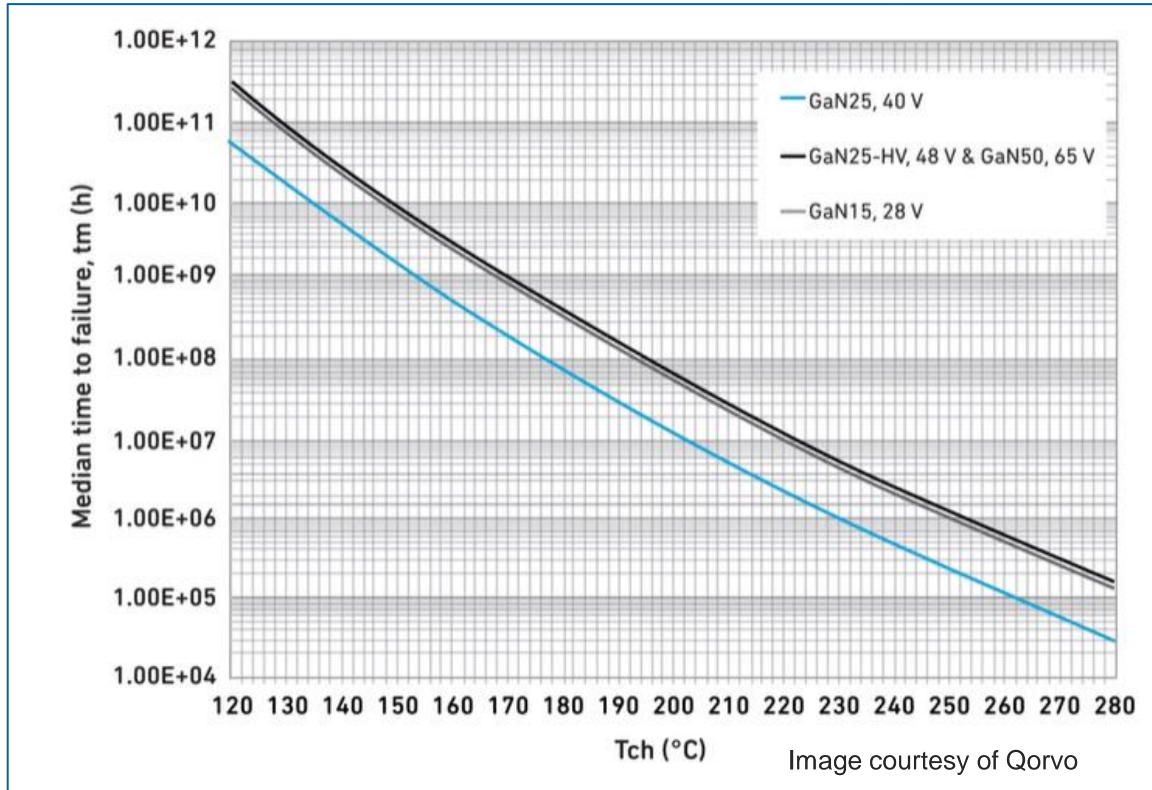

Image courtesy of Qorvo

- Performance w / wo self-heating

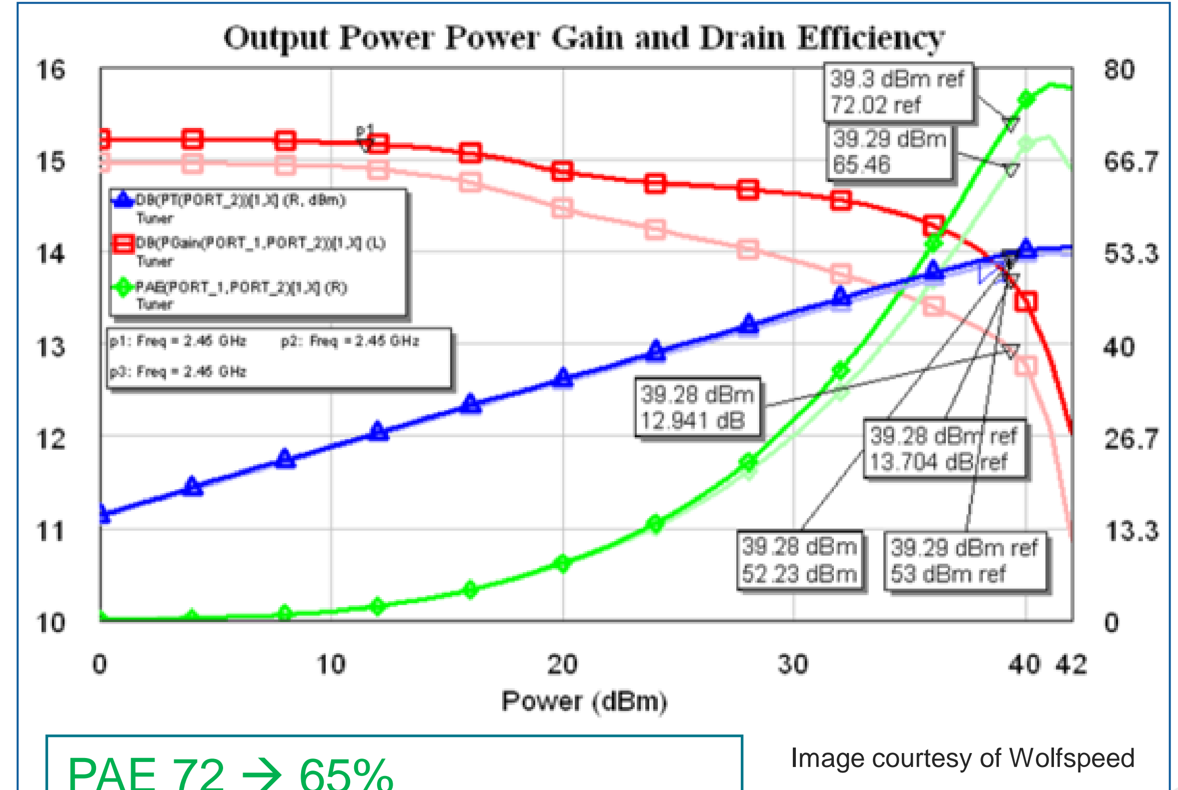

Image courtesy of Wolfspeed

PAE 72 → 65%
Power Gain 13.7→ 12.9 dB

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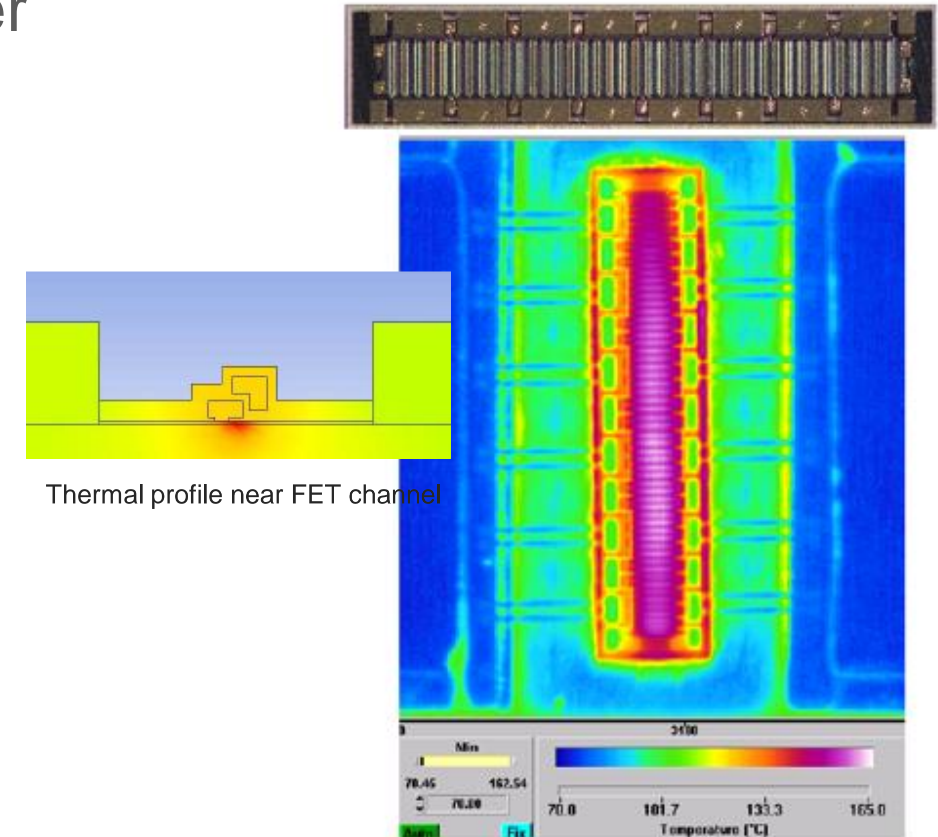
Heat Generation in PAs

Typical Heat development in a GaN Power Amplifier

- A GaN HEMT with gate periphery of 28.8mm operating at 28 volts drain voltage delivers 120 Watts CW
- For 60% DC to RF conversion efficiency there will be 80 Watts dissipated heat
- For an active chip area of 2.5 mm^2, the gate heat density exceeds 32 watts per mm^2 / 3.2kW per cm^2
- This heat must be dissipated from the device channel through the heatsink and the package / and PCB so requires **detailed** analysis of the **conduction path** including the FET layout – this is not suited for traditional Thermal CFD simulations



Thermal profile near FET channel

Infrared thermal measurement of 28.8mm GaN HEMT
Image courtesy of Cree

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Status

- The Cost of Heating
  - Reliability degradation / failure
  - Performance degradation

- Heat mitigation is required
  - Lower operating power – reduces performance
    - Impacts mobile & radar range, data rates, etc.
  - Increase heatsinking
    - increases cost, size, weight, complexity

- Desired solution
  - Address excessive heat with minimal mitigation to reduce impact on performance, costs, etc.
  - Minimize impact on engineering turnaround time

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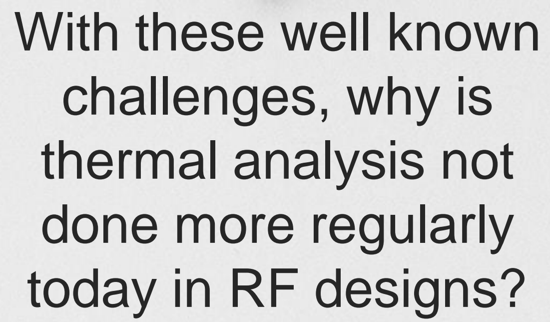
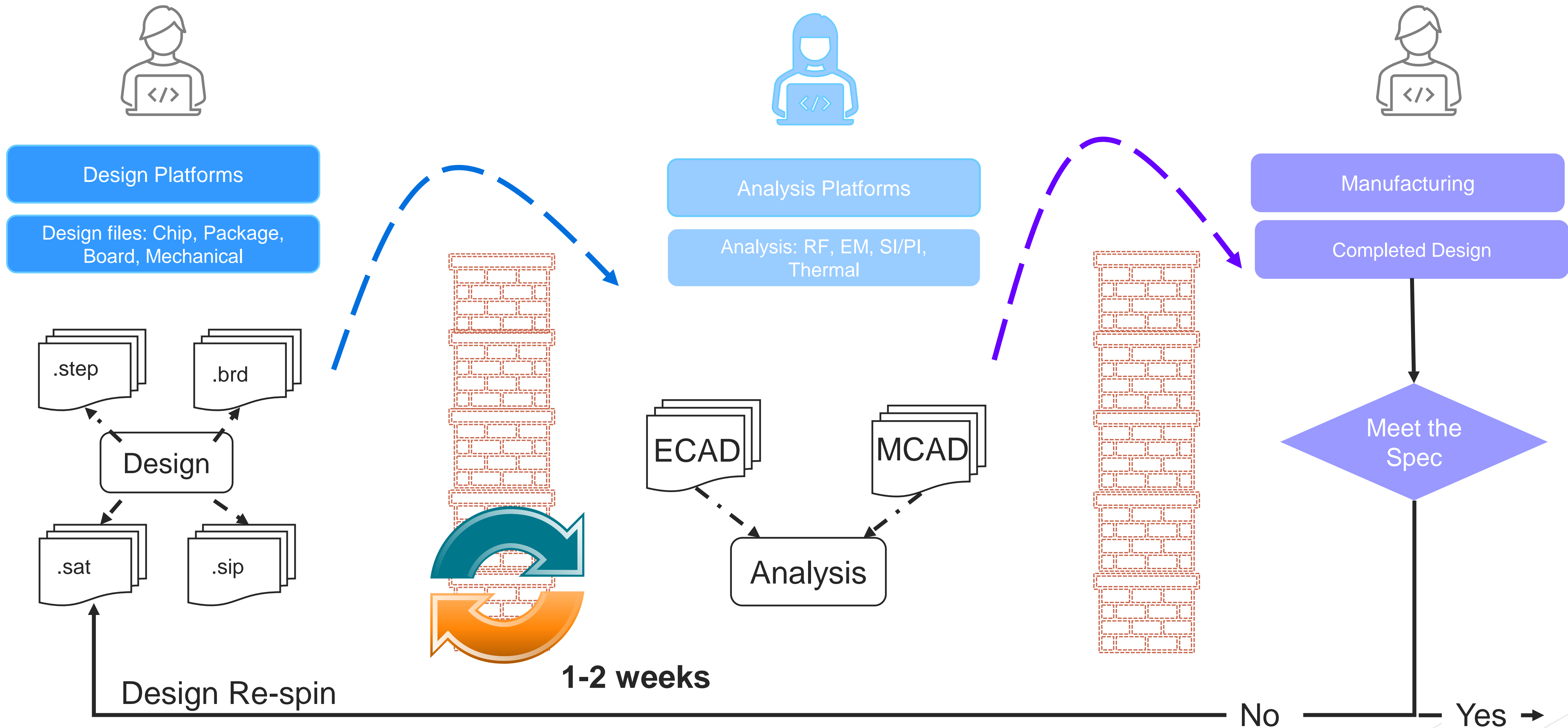

With these well known
challenges, why is
thermal analysis not
done more regularly
today in RF designs?

Multiple Platform and Lack of Workflow



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Addressing this flow Bottleneck

- **Enable** RF engineers with ability to perform their own thermal analysis and optimize heat mitigation solutions **during the design phase**
- Requirements
  - **Accessible** - thermal analysis needs to be easy to use, easy to implement (set up), integrated in existing design flows
  - **Fast** – offer significant time savings over alternative (existing) approach
  - **Accurate** – proven thermal solver with high degree of confidence in results and resilient to user errors

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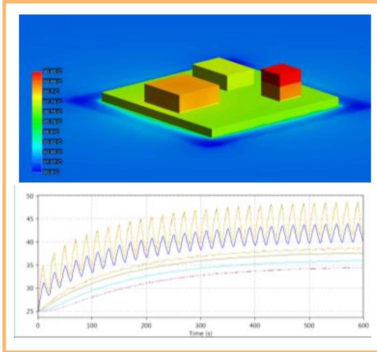
Celsius™ Thermal Solver: Electrical-Thermal Co-Simulation

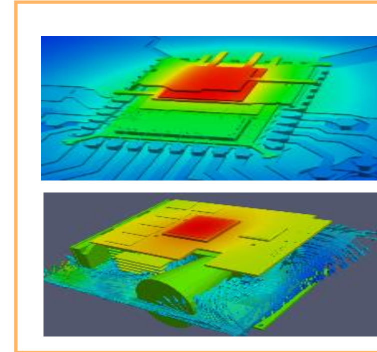
A complete solution for unprecedented performance and accuracy

Chip/PKG/System E-T Co-Simulation



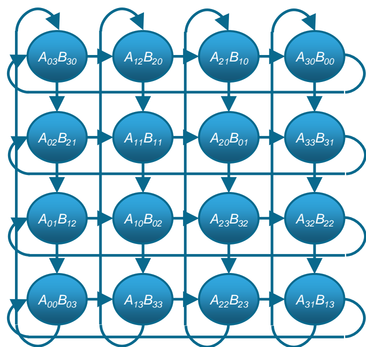
- Includes Chip/3DIC Analysis
- E-T Co-simulation
- Static and Transient

Accuracy Beyond CFD



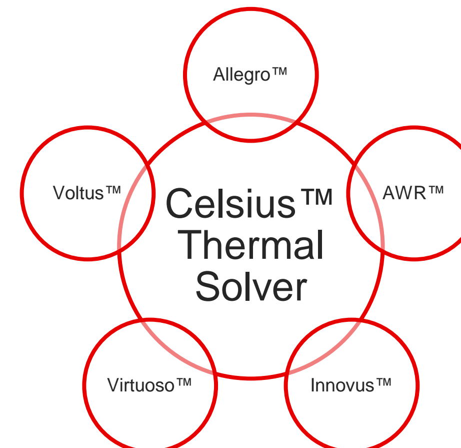
- FEA-CFD integration
- 3D fluid-flow simulation
- Stress Analysis
- Electrical/thermal co-sim

Unprecedented Performance and Capacity



- Massively parallel solver
- Linear scalability, cloud ready
- No loss in accuracy

Integration with Cadence® Design Platforms



- Single IC, 3D-IC
- Package, PCB
- Chassis, racks, systems

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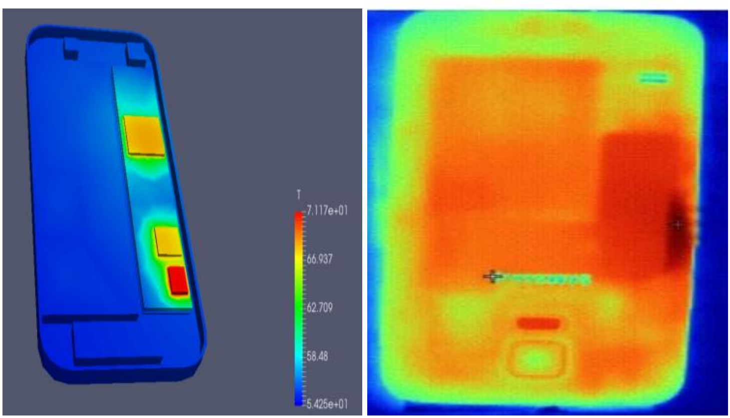
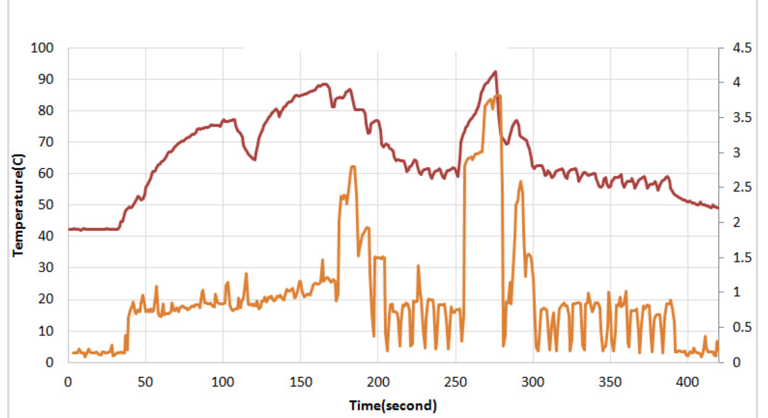
Thrmal Profiling in a Mobile Phone

IC-centric electrical-thermal co-simulation - transient analysis and system optimization

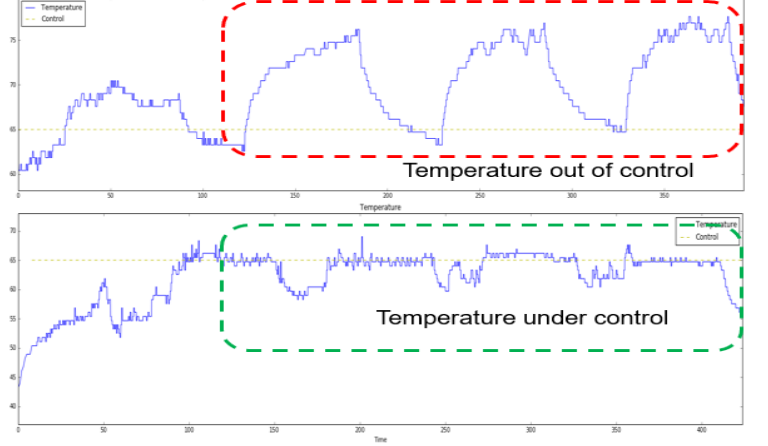
A Complete System: IC/PKG/PCB/Enclosure



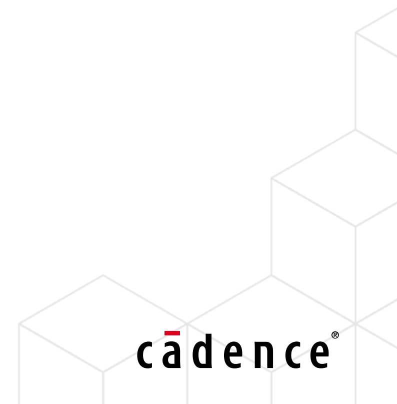
CPU Power Profile and Temperature Variations



GPU Power Profile and Temperature Variation



Transient thermal	• Accurately calculate transient temperatures under various power scenarios
Thermal SPEC verification	• Thermal runaway. CPU/GPU DVFS strategy for better thermal performance.
Thermal sensor optimization	• Optimization of temperature sensors on chips for detecting thermal runaway • Find Transient thermal hotspots with detailed power scenarios on each die



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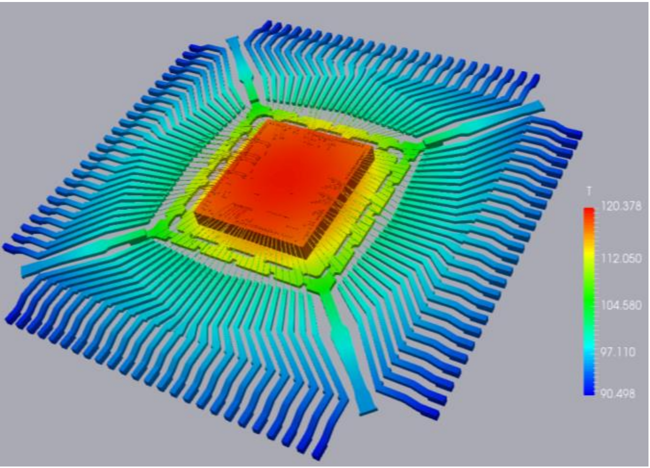
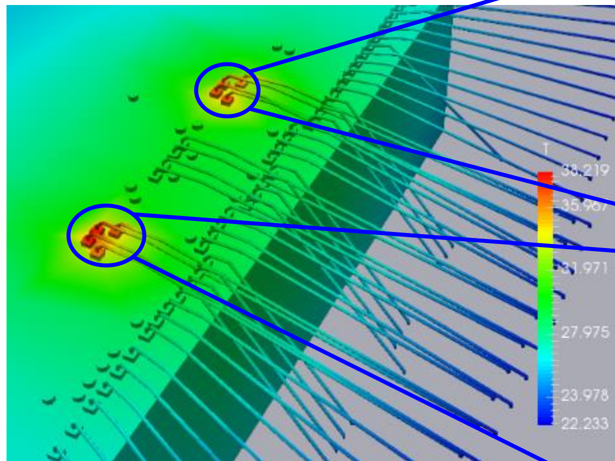
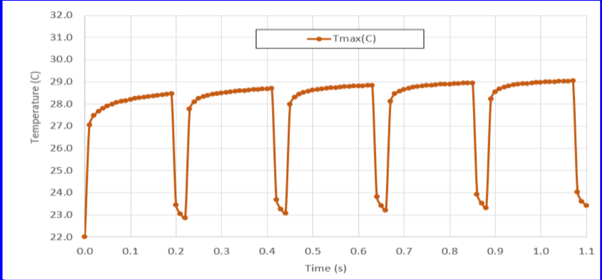
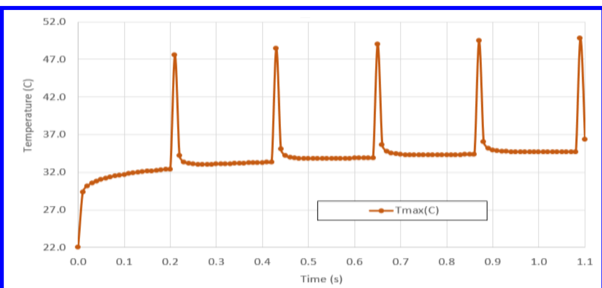
Advanced Lead-Frame Package and PCB

Transient Electrical-Thermal Analysis with Resolution of 3D Configuration









Design Import	• Package design imported from SiP layout • 3D structures created from SiP design
Electrical-Thermal Co-sim	• Detailed power profiling from chip simulation • Additional power source from electric current • Pulsed current going through bond wires
Thermal Results	• Transient and static analysis results generated • Detailed temperature profiles on bond wires

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In-Design Enablement

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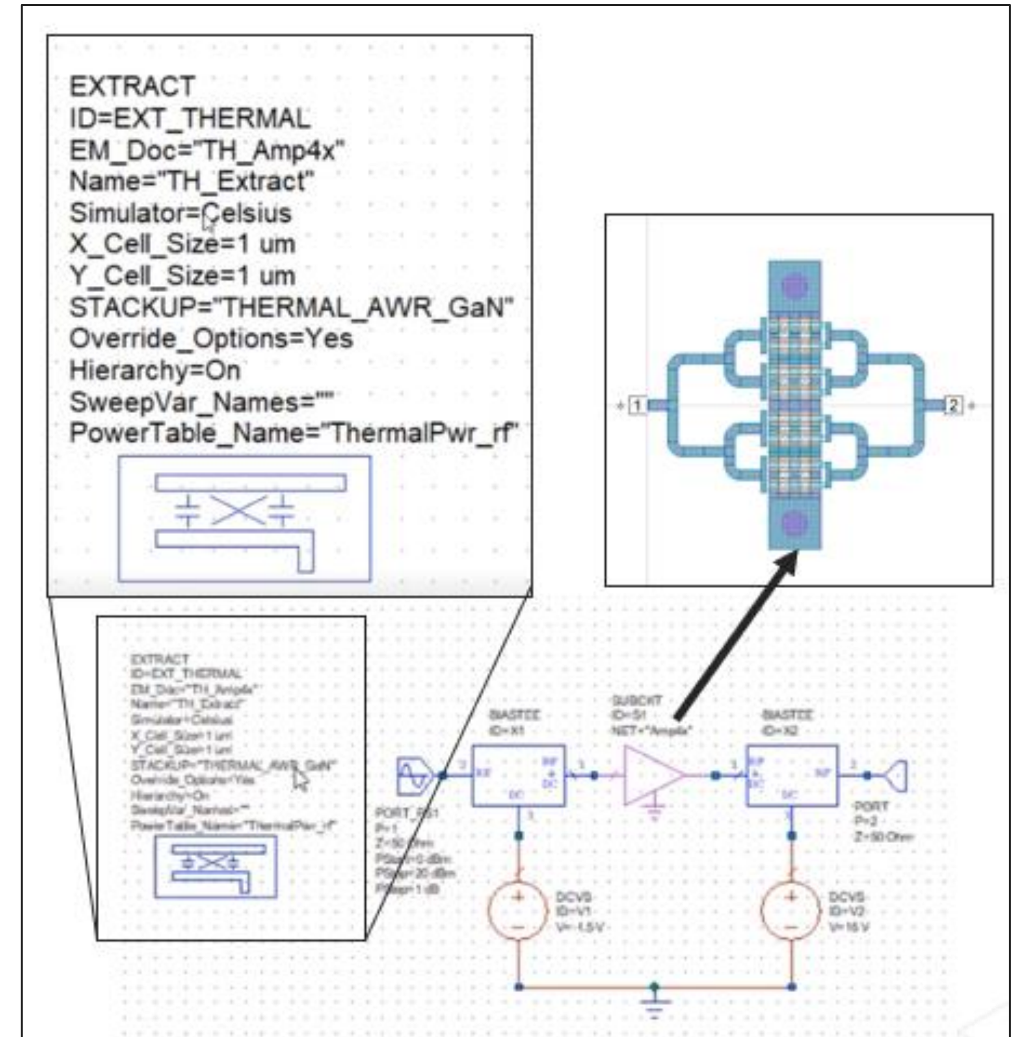
Thermal Extraction Setup – GaN FET Example

- **Add extraction block** to create thermal document
- New measurement - creates **power dissipation** data file from nonlinear simulation
- Associate extraction block with stackup and power dissipation data file
- Simulate in Microwave Office® software or send to Celsius™ Thermal Solver (native editor)
- Operating temps back-annotated into Microwave Office® and linked to user defined heat sources



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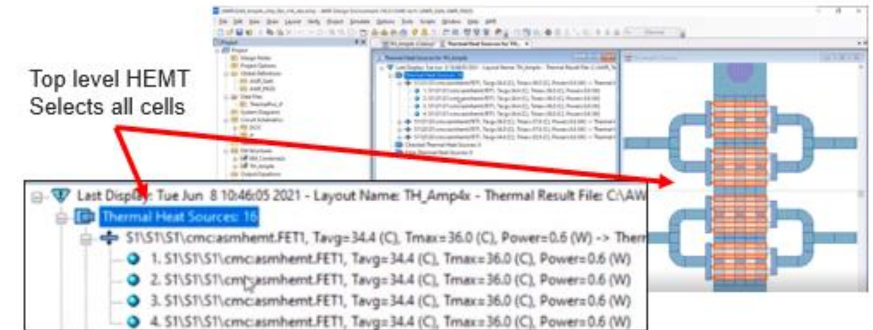
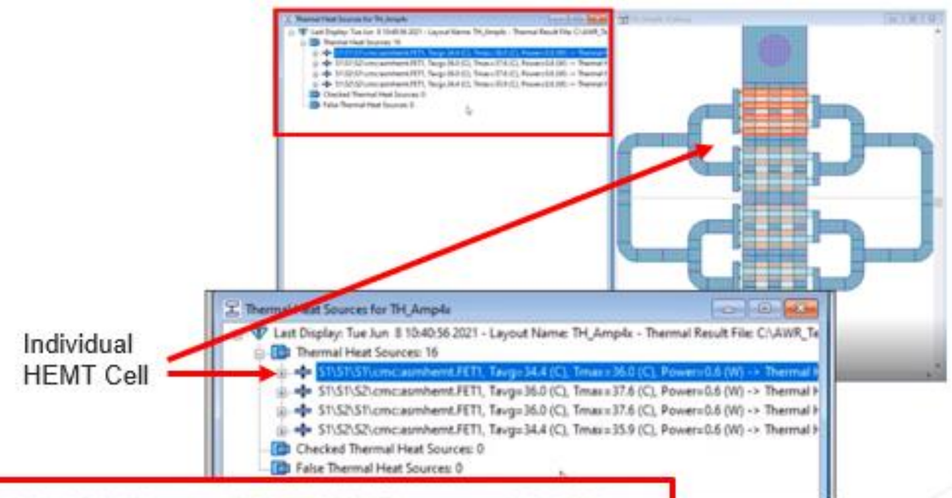
Thermal Analysis Results – GaN FET Example

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





1. S1\S1\S1\cmc:asmhemt.FET1, Tavg=34.4 (C), Tmax=36.0 (C), Power=0.6 (W)

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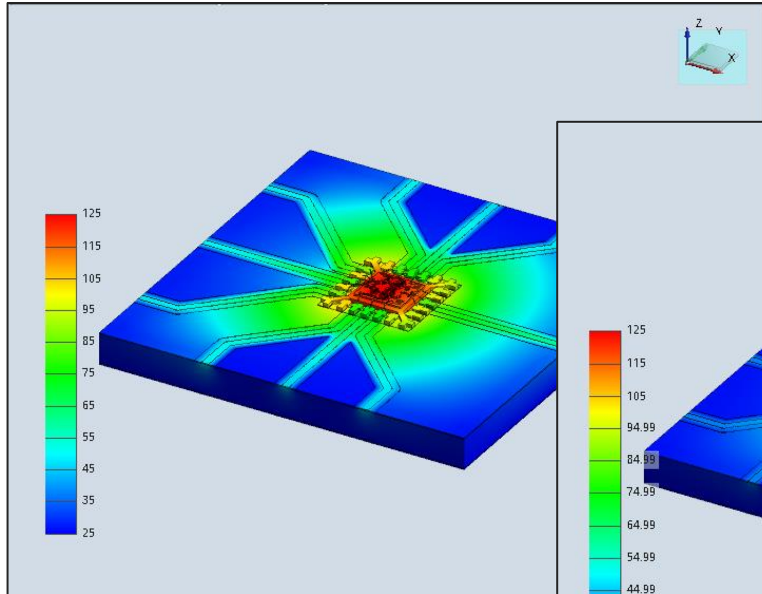
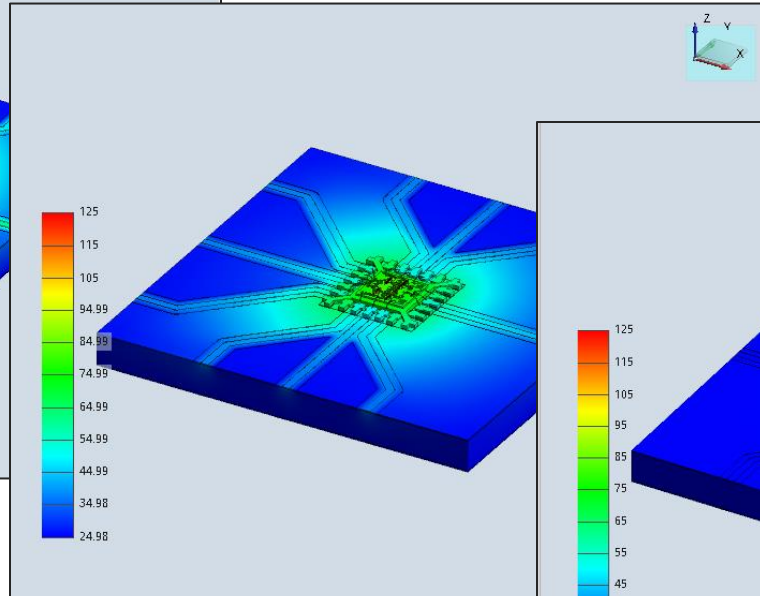
Thermal Analysis Results – Multi Technology Example

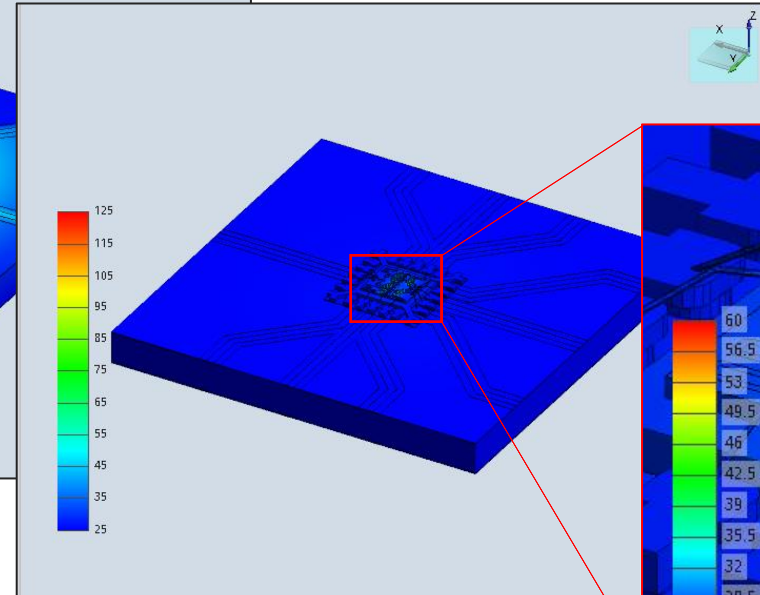
- Test structure – MMIC HPA in QFN package on PCB (identical temperature scale to 125 ^{o}C)



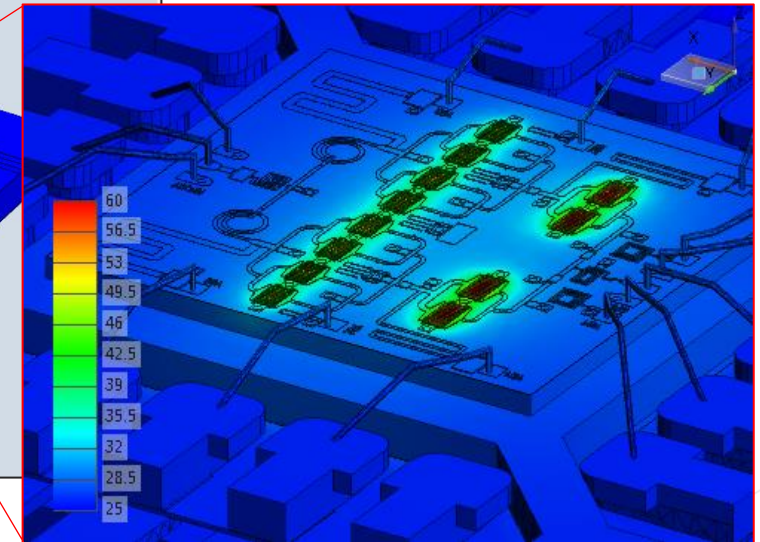
No thermal relief



Thermal vias under QFN



Heatsink under QFN



Enlarged view (60 ^{o}C temperature scale)

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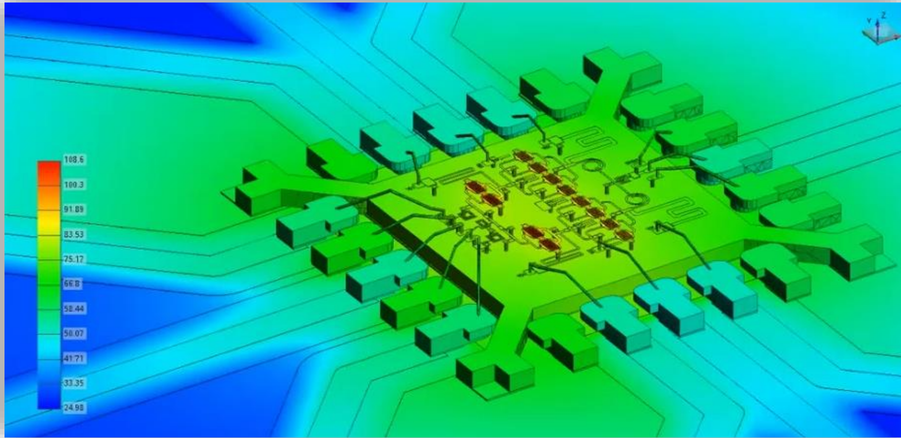
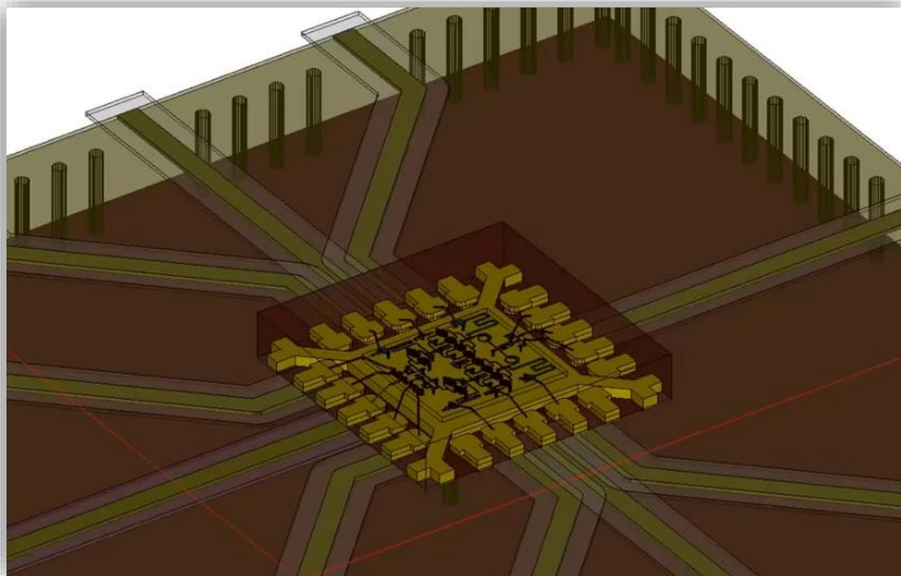
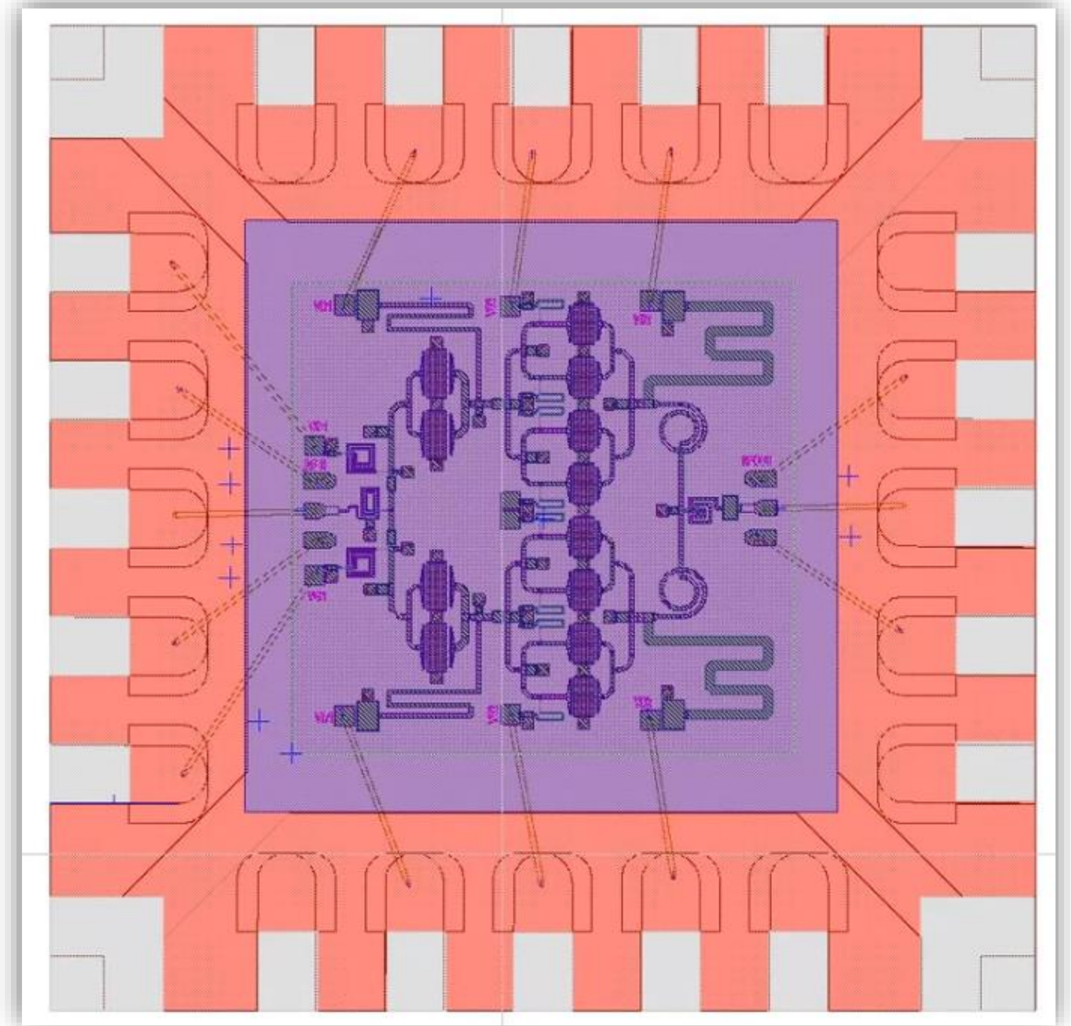
Please Contact us for a Demo!







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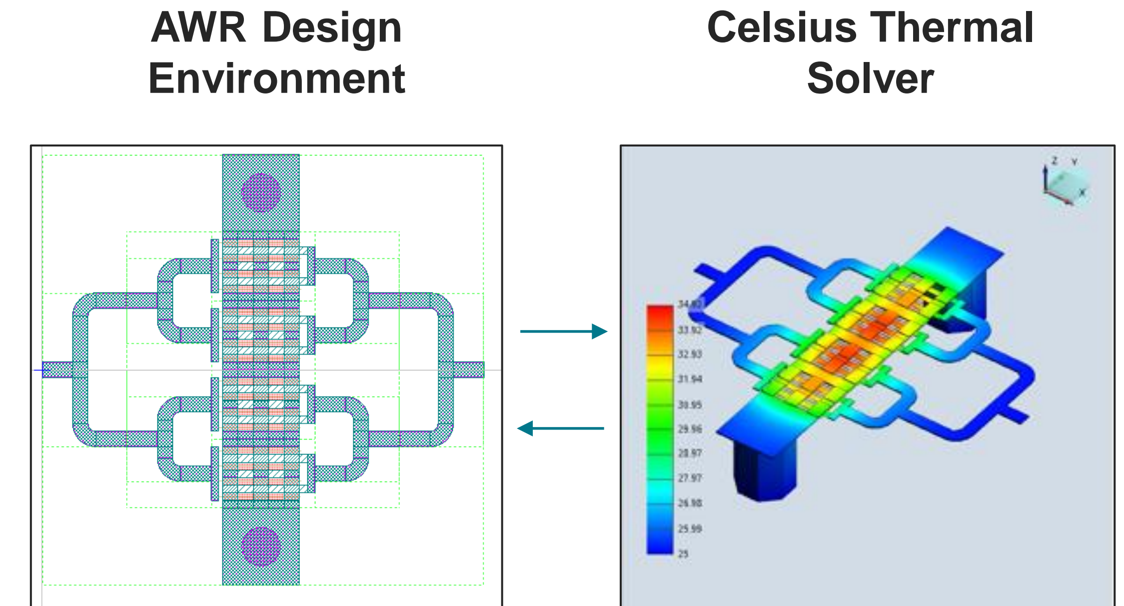
Celsius Thermal Solver for Thermal Analysis in Microwave Office Software

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™ 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



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Summary

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Cadence RF Electrothermal = Speed, Accessibility, Accuracy

- Predicting thermal behavior of RF designs is very important to ensure reliability and performance
- Traditional flows for thermal characterization are too slow and error prone to provide design-side guidance
- AWR/Celsius integration
  - Saves design re-entry
  - Utilizes existing data structure in AWR as enable
  - Provides near real-time access to critical thermal data using a sign-off quality thermal environment

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