PathWave Electro-Thermal (ETH) Simulation Suite

Transient and Steady State ETH simulator integrated in the Advanced Design System (ADS) RF/Microwave EDA software

Introduction

The Keysight W3050E, W3051E and W3059E is a suite of electro-thermal (ETH) simulation tools that integrates with the transient and steady-state circuit simulators in ADS to deliver the highest accuracy in circuit simulation.

It accounts for layout-dependent localized steady-state and time-varying electro-thermal heating of circuit components that alters device characteristics, degrades RF/Microwave circuit performance, and reduces reliability. It replaces guesswork assumption of fixed ambient temperature settings for circuit simulation.

Based on the industry proven Keysight Heatwave simulation technology, the ADS ETH simulation suite enables accurate design of amplifiers and densely integrated RF modules that must handle not just steady state but also transient pulsed and modulated RF signals.

Transient ETH heating causes active impedance mismatch, Adjacent Channel Power Ratio (ACPR) and Error Vector Magnitude (EVM) degradation of digitally modulated RF signals. These critical ETH effects are not captured by traditional circuit simulations.

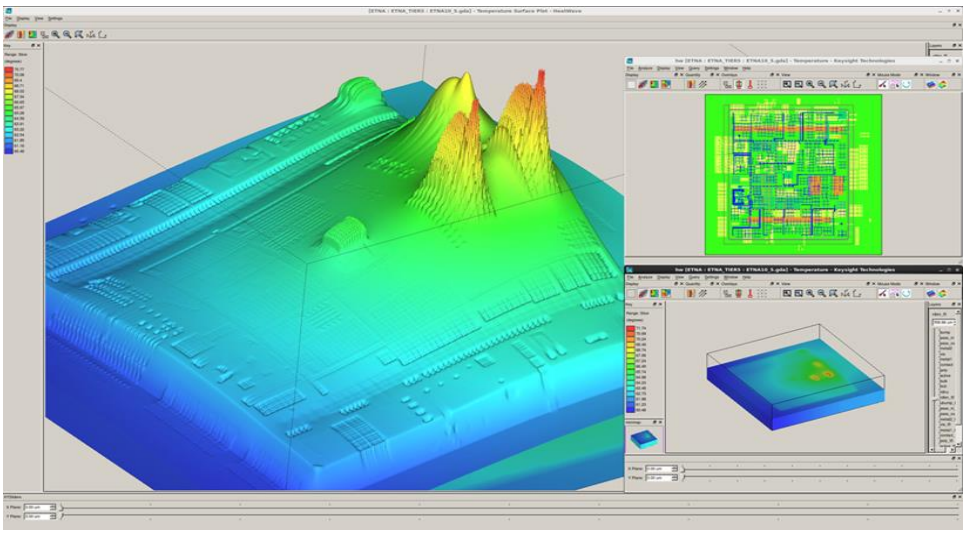

Figure 1. ADS Electro-Thermal simulation suite is the industry's fastest and most accurate transient and steady state ETH simulator for optimal amplifier and RF module designs under pulsed and digitally modulated RF signal excitation. Transient time-varying temperature rise from ETH heating is accurately predicted and visualized to physically pinpoint where to fix ETH related issues.

KEYSIGHT

Applications of ADS electro-thermal (ETH) simulation for RF/Microwave circuit design

- Today's RF/Microwave circuits often operate with not just steady state but pulsed and digitally modulated signals in densely integrated RF modules.
- The guesswork assumption of constant ambient temperature in regular circuit simulation does not account for the localized ETH temperatures of circuit components.
- Transient and time-varying ETH heating of the circuit components also causes transient variation in active device characteristics that must be considered during design to prevent costly failures after hardware deployment.

The following are examples of RF circuit and module applications optimized to meet performance and reliability specs under transient electro-thermal heating.

Power amplifiers under pulsed and modulated signals

- Power amplifiers operating under pulsed and modulated signals undergoes ETH time-varying changes in characteristics.
- Dynamic ETH heating degrades EVM and ACPR performance on digitally modulated signals
- Critical localized steady state or time varying ETH heating effects are not captured by regular circuit simulation, leading to costly hardware failure after field deployment.

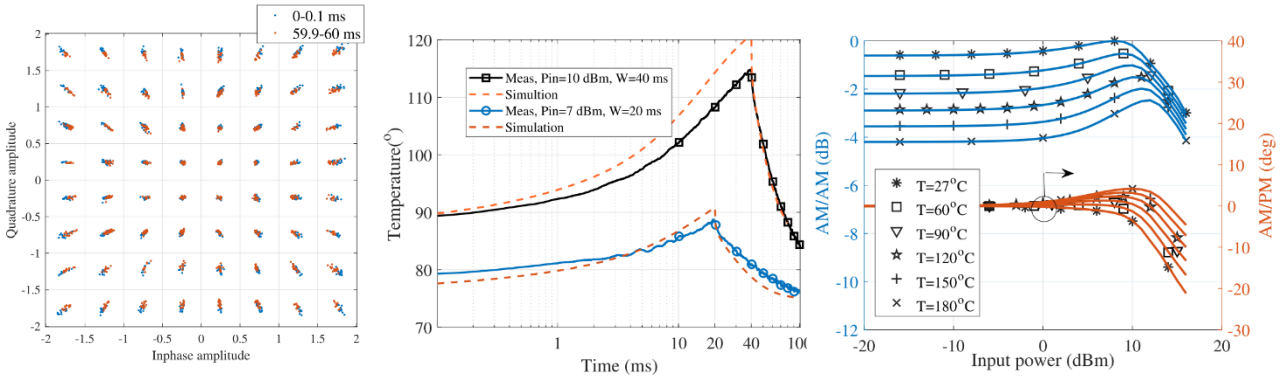

Figure 2. Localized time-varying electro-thermal heating cause corresponding changes in device characteristics leading to degradation of EVM and ACPR specs in amplifiers. These critical shifts in performance are not captured by regular circuit simulation.

Reference: Chalmers University of Technology, Gothenburg, Sweden: https://ieeexplore.ieee.org/document/9662280

RF module packaging ETH coupling

- Dense packaging in RF modules causes electro-thermal heating of neighboring devices are not analyzed in regular circuit simulations, resulting in off-target performance prediction.
- Localized steady state and time-varying electro-thermal heating causes active impedance shifts in devices and degradation of modulated signal specs such as EVM and ACLR.
- Dynamic ETH model generation and reuse result in 10x to 100x speedup of electro-thermal circuit simulation to enable thorough design exploration of layout-dependent transient ETH effects before making tedious layout changes.

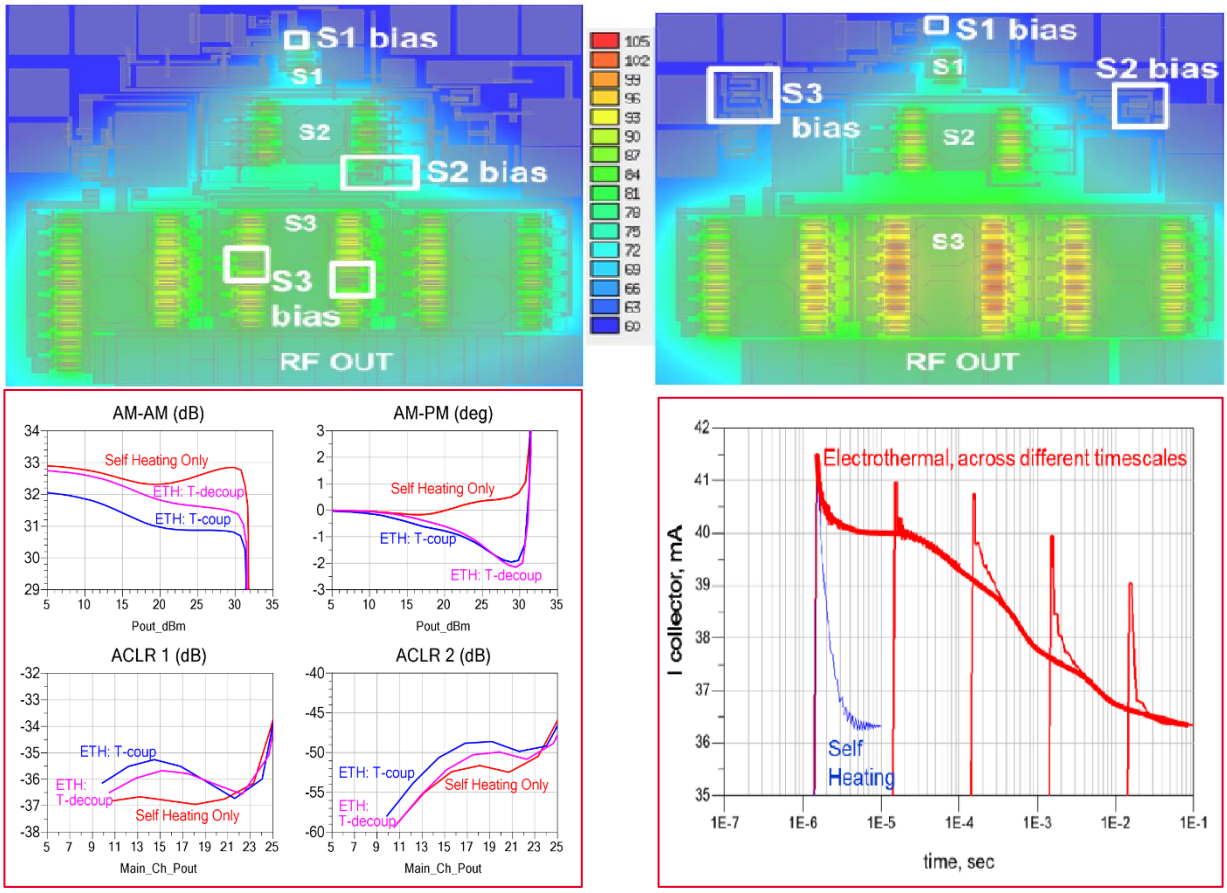

Figure 3. Localized layout dependent state-state and time-varying ETH heating causes degradation in performance specs that are not caught by regular circuit simulation. Reference: Matt Ozalas, Keysight Technologies

https://ieeexplore.ieee.org/document/6978582

Active impedance match at peak transient temperature for reliability

- Amplifier dissipated power depends on selected load termination, but localized layout-dependent electro-thermal heating alters device active impedance. Junction temperature is device-layout dependent and therefore ETH load pull is needed to obtain accurate load termination to match to.
- In mission critical commercial, industrial, military and space applications where component failure cannot be tolerated, optimal load is not for maximum output power, but for reliable junction temperature to ensure long Mean Time To Failure (MTTF).
- Power gain, efficiency, impedance match must be accurately optimized for performance and thermal reliability using a closed loop electro-thermal and nonlinear circuit simulation.
- For pulsed and modulated signal operation, dynamic ETH model generation and reuse speeds up ETH circuit simulation by 10x to 100x for thorough design exploration of ETH design options before tedious layout design changes.

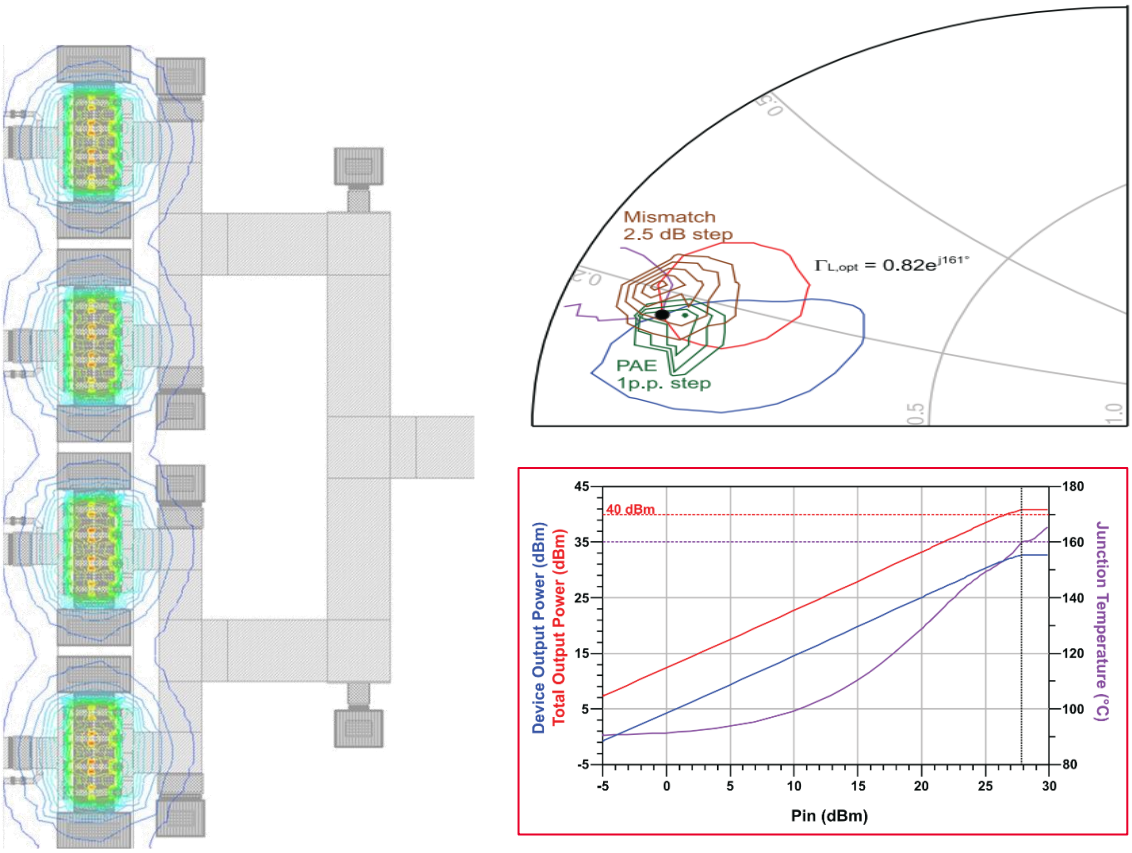

Figure 4. For mission critical and space applications, design for reliability depends on accurate closed loop ETH circuit simulation to ensure peak transient temperatures are not exceeded. Dynamic ETH model generation and reuse speeds up such simulations by 10x to 100x for thorough ETH design explorations of optimal layout for thermal reliability.

Reference: Chiara Ramella; Marco Pirola; Andrea Reale; Mariarcangela Ramundo; Paolo Colantonio; Matthias Auf Der Maur; Vittorio Camarchia Dept. Electronics Telecommunications, Politecnico di Torino, Torino, Italy.
https://ieeexplore.ieee.org/document/8958104

Foundry PDK support for Keysight electro-thermal simulation

Keysight Electro-Thermal simulation is supported by Silicon and III-V foundries to offer the optimum accuracy in circuit simulation.

Figure 5. The above foundries offer PDKs with support for Keysight Electro-Thermal simulation to optimize the accuracy of steady-state and transient-envelope circuit simulation.

See the latest Foundry PDK support here: https://www.keysight.com/find/design-software-foundry-pdks

A customer case study

- EnSilica's Ka-band (26.5 - 40 GHz) transceiver is a vehicle-mounted low-earth orbit (LEO) satellite terminal, where harsh temperatures can wear parts out faster than expected.
- ETH circuit simulation is vital in understanding its thermal operating margin and lifespan to determine optimal chip layout for thermal margins
- https://www.keysight.com/us/en/assets/3123-1139/case-studies/Predicting-Ka-band-Transceiver-Thermal-Margins-Wear-and-Lifespan.pdf

"Now, we know we can drive the Ka-band transceiver a bit harder than its requirements in the customer's system, and it's safe to do that while still meeting the 10-year reliability goals."

Alan Wong, Sr. VP of Engineering, EnSilica

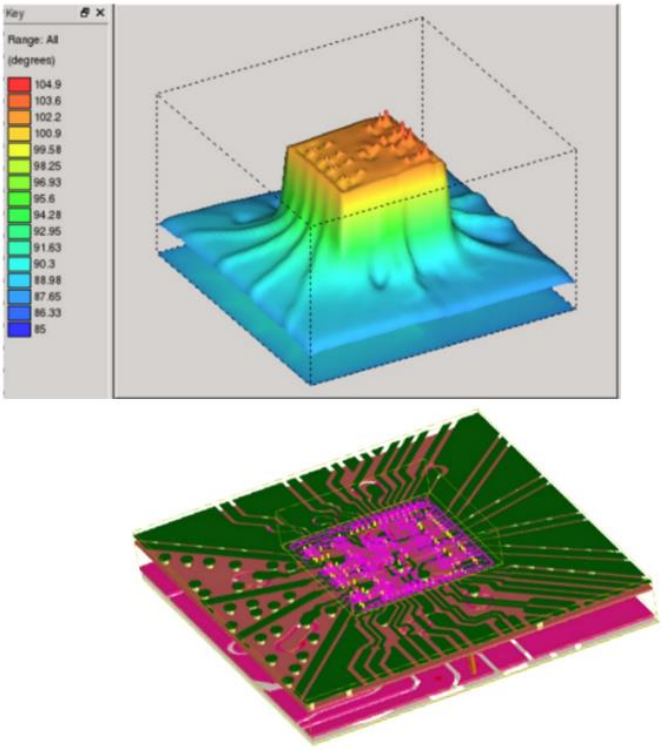

Figure 6. Hot spots revealed in an electro-thermal simulation of EnSilica's Ka-band transceiver with boundary heating effects

ADS electro-thermal simulation suite

The ADS ETH simulation suite is integrated into the Advanced Design System (ADS) core design environment with prerequisite circuit simulators and layout capabilities to function fully. It comprises the following modules for accurate RF/MW electro-thermal analysis.

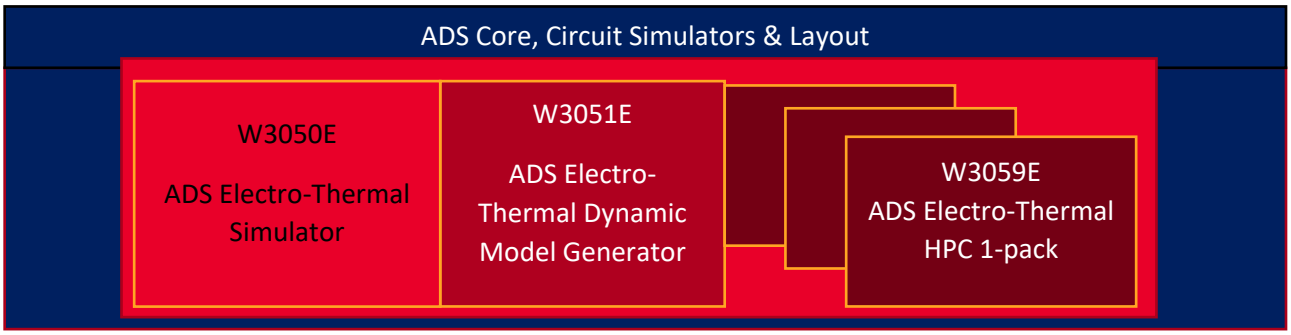

Figure 7. The ADS ETH simulation suite works inside ADS with prerequisite steady-state (HB) and transient/envelope circuit simulators and physical layout capabilities. The W3051E ETH Dynamic Model Generator produces transient ETH model of an entire circuit for subsequent reuse at 10x to 100x speedup during iterative design exploration. The W3059E ETH HPC 1-pack adds scalable parallel ETH simulation to accelerate analysis for fast and thorough ETH analysis coverage.

- ADS Electro-Thermal Simulator W3050E
  - Steady state and Transient ETH simulator
  - ETH data viewer
  - Requires companion ADS circuit simulators:
    - DC, HB (steady state),
    - Transient/Convolution, Circuit-Envelope (transient)
  - Requires ADS core and layout

- ADS Electro-Thermal Dynamic Model Generator W3051E
  - Generates transient time-varying ETH model for reuse at 10x to 100x speedup
  - Requires W3050E ETH simulator

- ADS Electro-Thermal HPC (High Performance Computing) 1-pack
  - Adds one parallel ETH simulation license for accelerated analysis
  - Parallelism can be scaled up by adding multiple HPC 1-packs
  - Requires a companion ADS Ckt-Sim HPC 1-pack W3029E

Summary

- Elevated temperature reduces device and interconnect lifetimes. Accurate temperature is needed in reliability models such as Negative/Positive Bias Temperature Instability (NBTI, PBTI), Time Dependent Dielectric Breakdown (TDDB) and signal Electromigration (sigEM) to predict Failures In Time (FIT) rates.
- Electro-thermal (ETH) simulation is an iterative closed loop thermal-circuit analysis to accurately predict circuit performance at localized steady-state or time-varying temperatures.
- It is critical to the accurate and reliable design of amplifiers and tightly integrated RF modules under pulsed, modulated, and steady-state RF excitation.
- Breakthrough dynamic ETH model generation and reuse cuts transient and envelope ETH circuit simulation time by 10x to 100x, enabling thorough exploration of optimal ETH design options to eliminate guesswork and tedious layout changes.

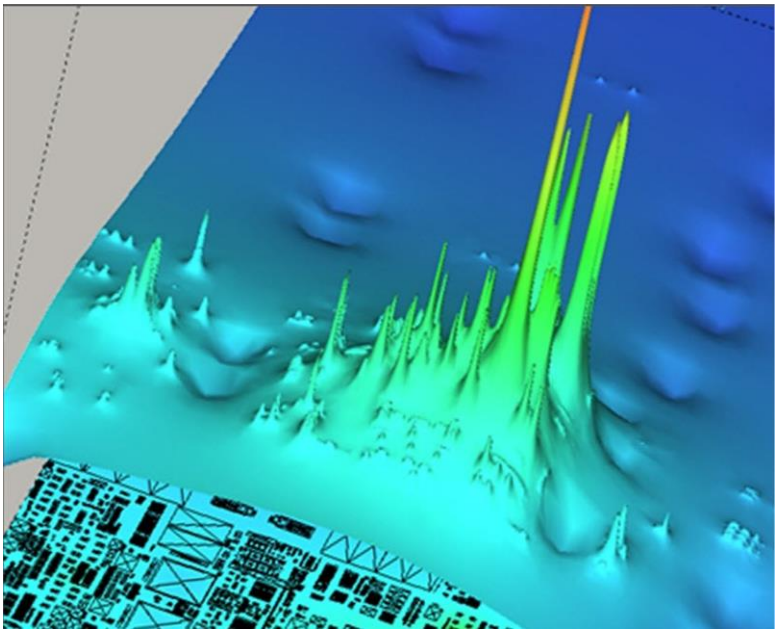

Figure 8. Keysight ETH circuit simulation accurately predicts localized time-varying temperature fluctuations that cause performance and reliability degradation. RF and microwave circuit and layout designs can then be optimized to account for ETH effects not captured by regular circuit simulation.