Thermal Transient Testing of Semiconductor Components-Fundamentals

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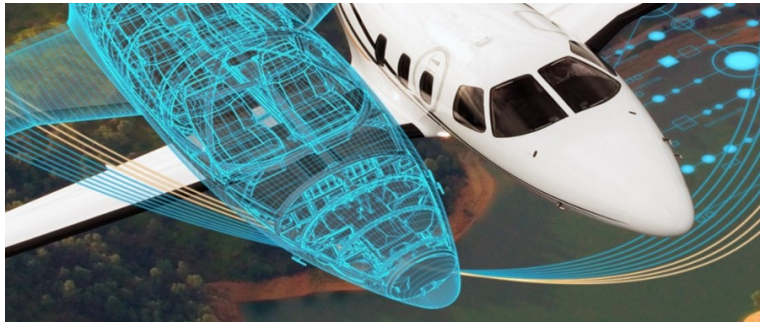
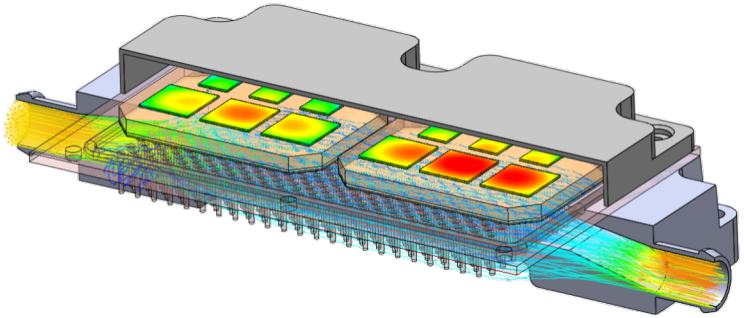
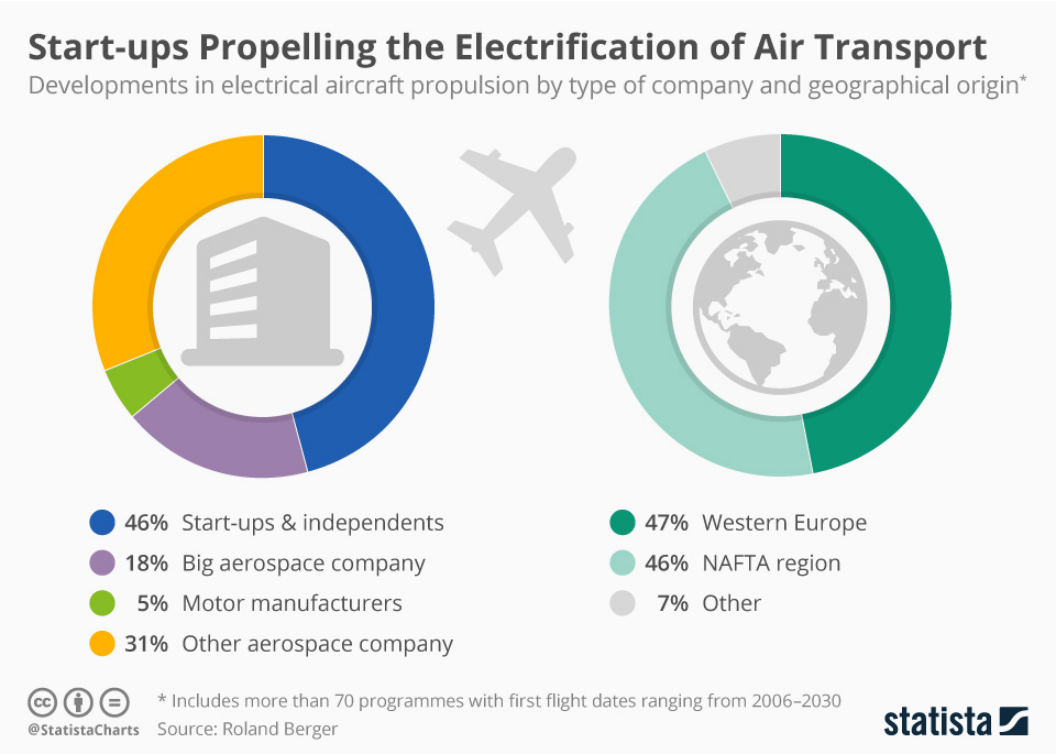
Topics

- Introduction to Thermal Transient Testing
- Structure Functions
- Thermal model calibration value, reasons and method
- Power cycling testing for lifetime estimation
- Summary and Q&A





Electrification and Aerospace Changing Industry Landscape

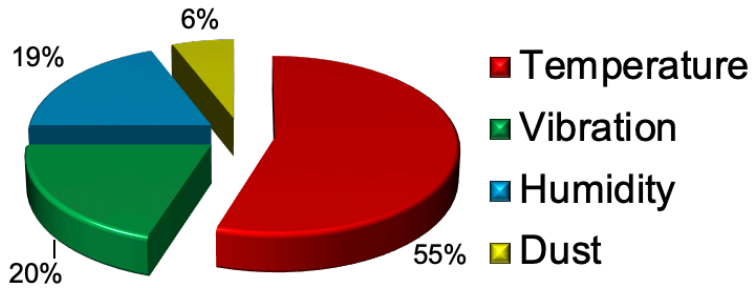


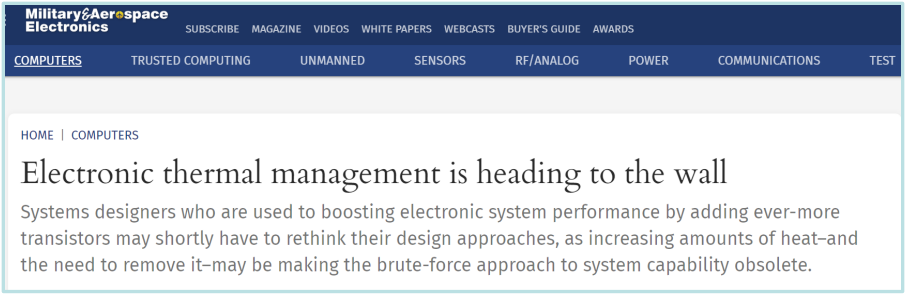
Airbus, Rolls-Royce & Siemens team up for electric future

All indications suggest that we are on the cusp of a revolution in the aerospace and aviation industries

- Roland Berger

Thermal Testing Challenges





Thermal challenges in the semiconductor industry are important:

Influence Reliability: High temperature will inevitably cause device/system failure

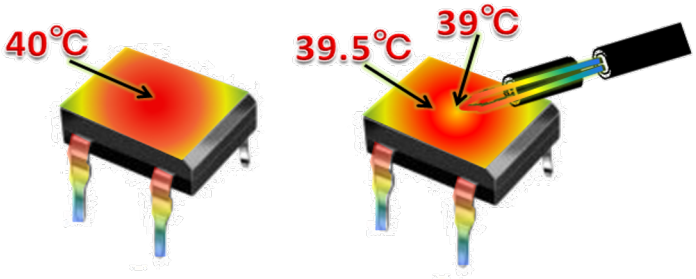
Improve Performance: Low temperature electronics may be more efficient (LED-s, IC-s)

Decrease system cost: Proper testing can help avoid thermal over-design, reducing weight and cost

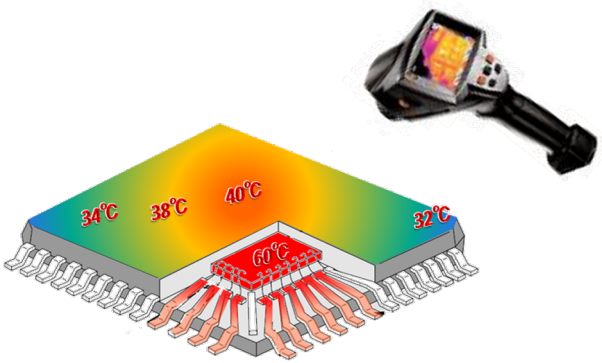
Traditional Temperature Test Methods

- Only surface temperature (Thermocouples, IR camera)
- Effect by thermocouple itself or surface, emissivity and absorptivity.

Thermocouples



IR camera

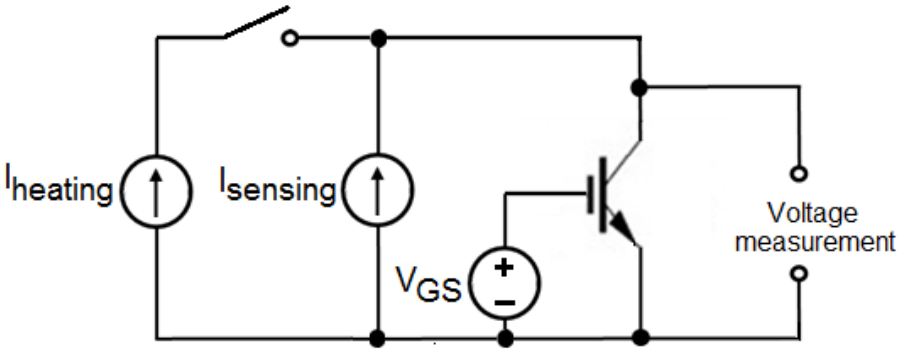


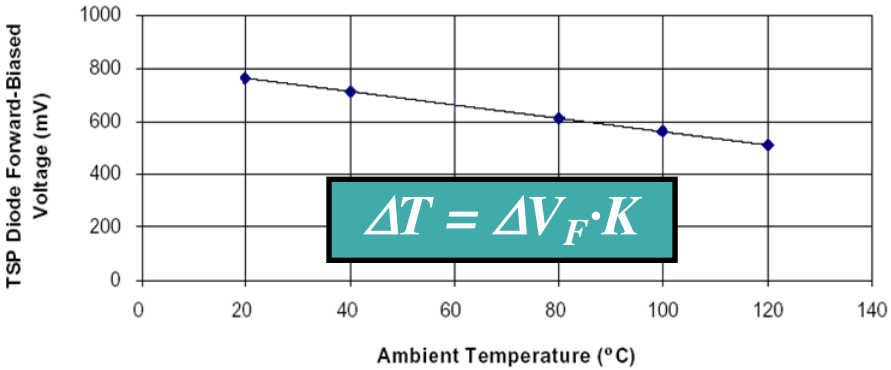
How do you know the real junction temperature (Tj)?

How Do We Know ΔT_J ?

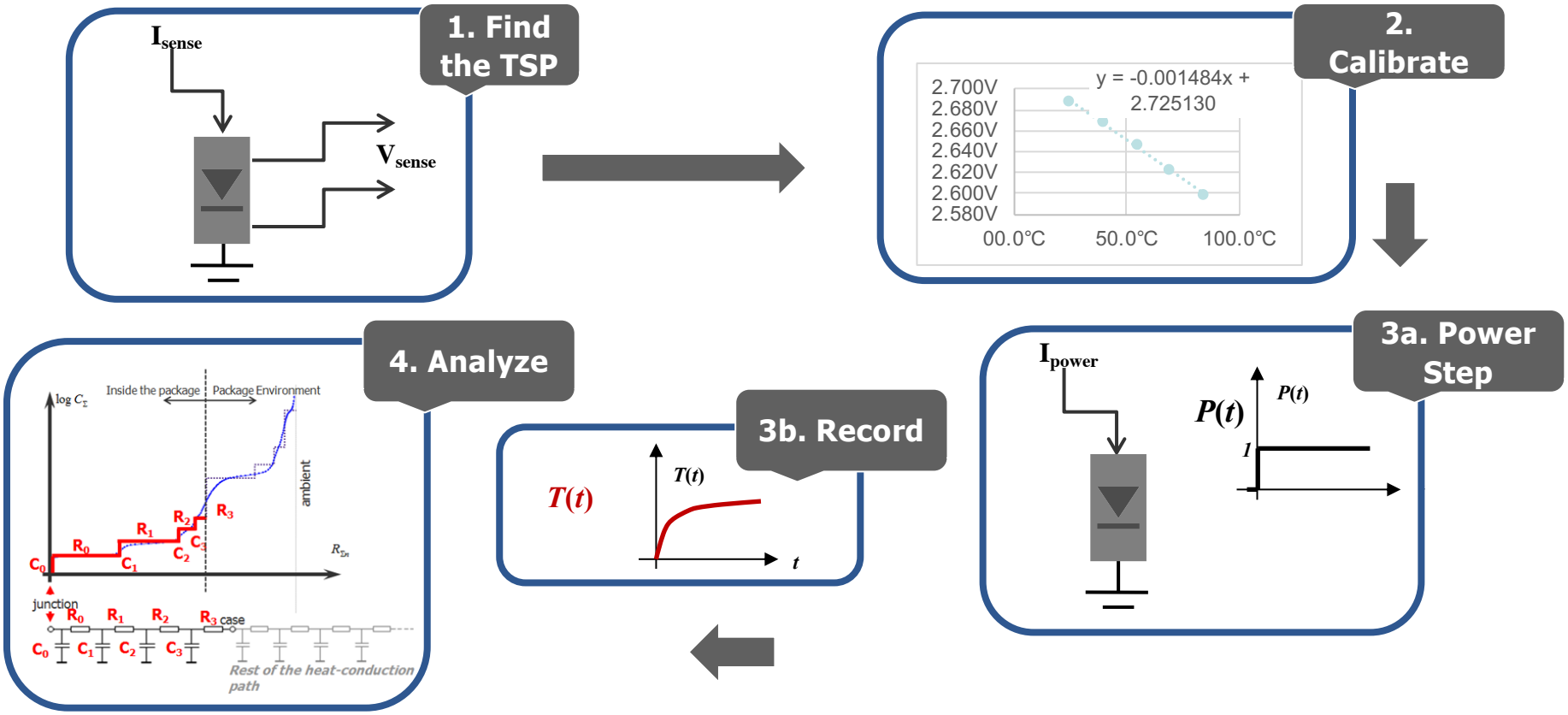
- The forward voltage of a PN junction under forced current condition can be used as a very accurate thermometer

- The change of the forward voltage (TSP – temperature sensitive parameter) should be carefully calibrated against the change of the temperature (see JEDEC JESD51-1 and MIL-STD-750D)
  - In the calibration process the S_{VF} temperature sensitivity of the forward voltage is obtained



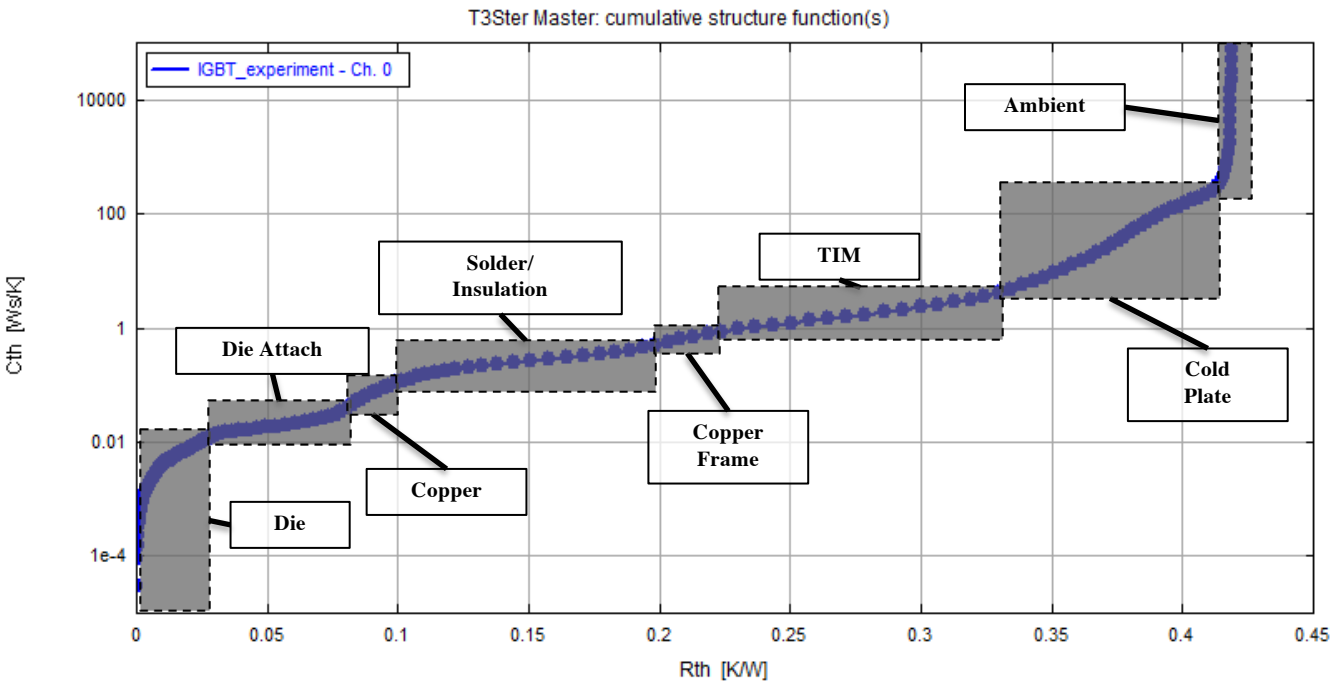


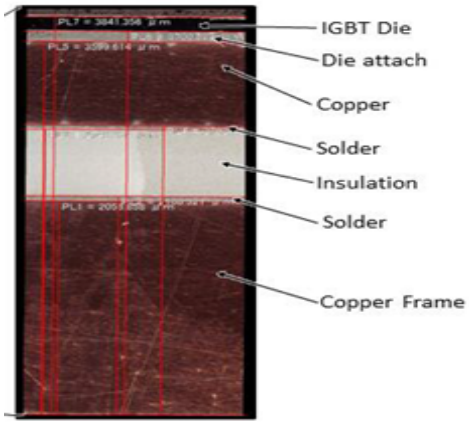
Thermal Transient Test Workflow



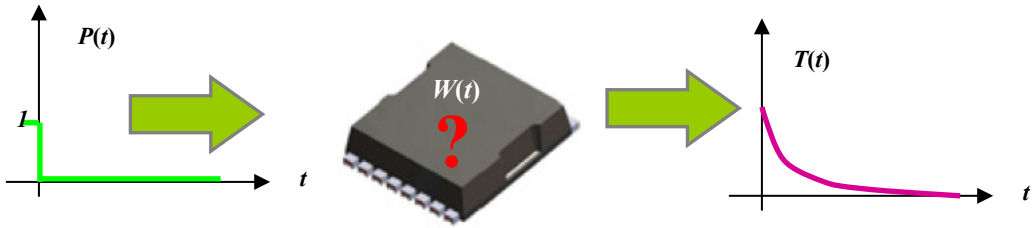
Thermal Characterization Utilizing Structure Function

- Each section of the Structure Function path represents physical objects the heat encounters. There is a correlation between physical objects and sections of the RC path.





Introduction to Structure Functions



or shortly:

$$P(t) \otimes W(t) = T(t)$$

$\otimes$ **= convolution**

- Through numerical manipulations, we can work out what thermal structure would have this effect! The thermal structure will be a manifestation of thermal R's and C's.

If the *T* response to the *P* excitation is

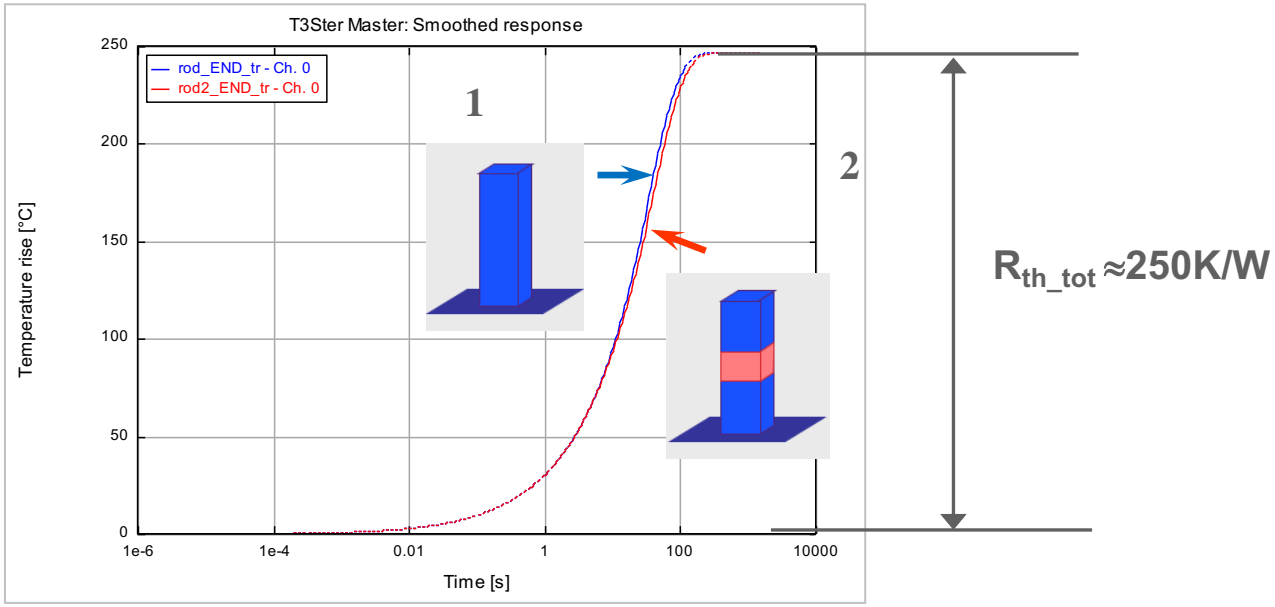
$W(t) = T(t) \otimes^{-1} P(t)$ **known:**

$\otimes^{-1}$ **= deconvolution** **(to be calculated numerically)**

Thermal Transient Technology - Transient Thermal Response

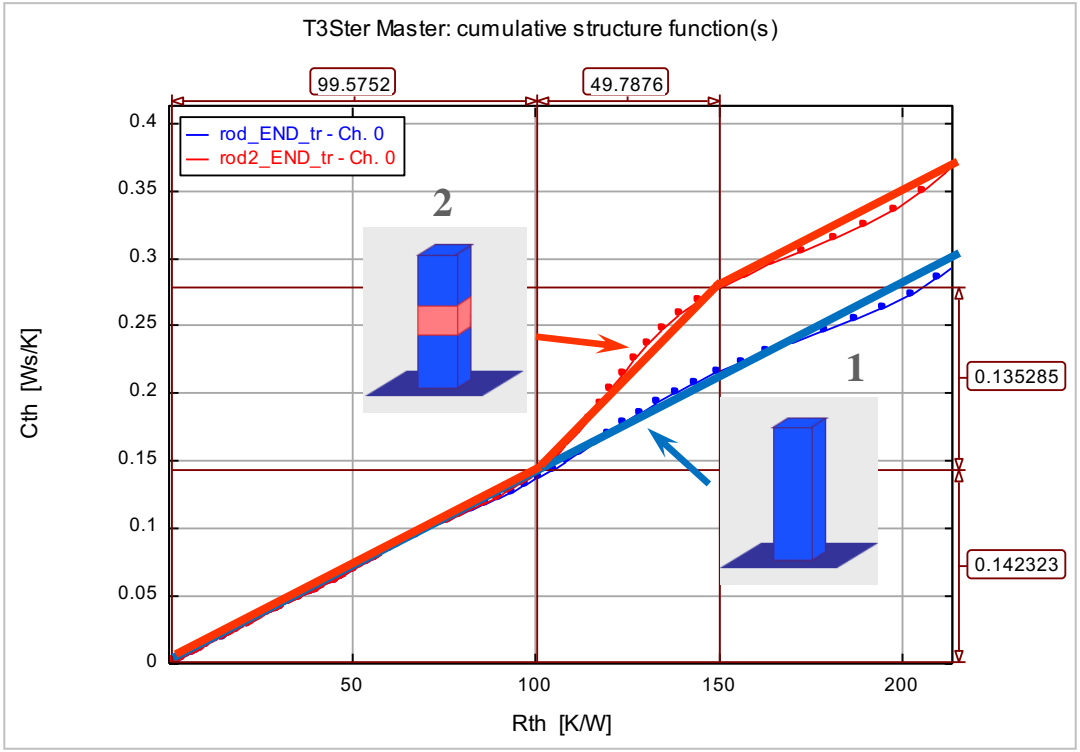
Consider a Cu rod of 1x1mm^2 cross-sectional area

- Rod 1: 100mm (λ, C_v)
- Rod 2: 40mm (λ, C_v), 20mm (λ, 2xC_v), 40mm (λ, C_v)

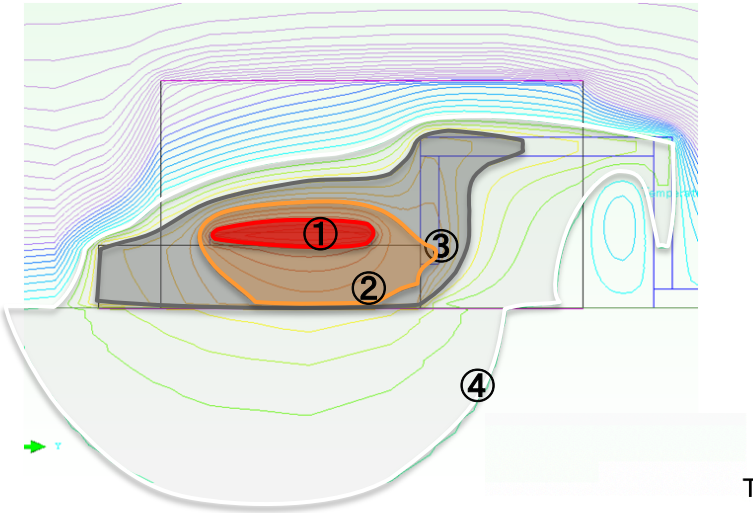


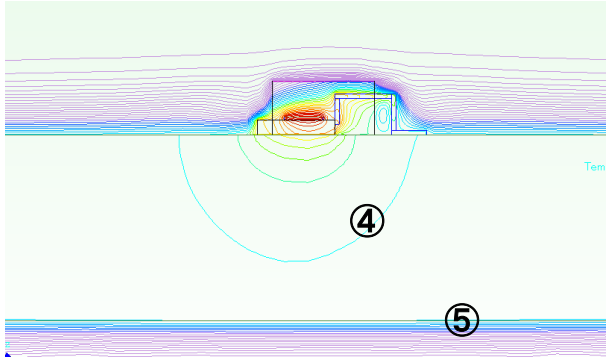
Thermal Transient Technology – Structure Functions

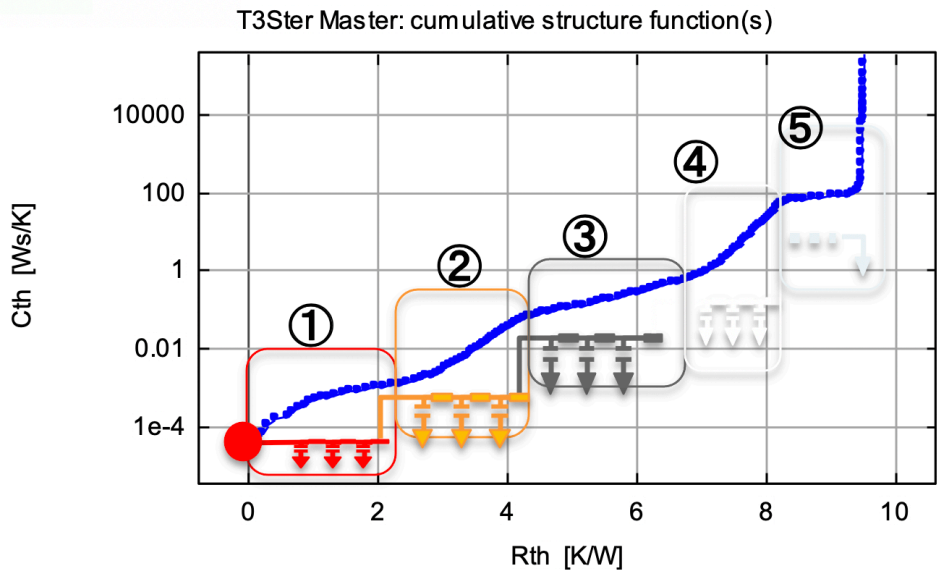
- **The same results in structure functions:**



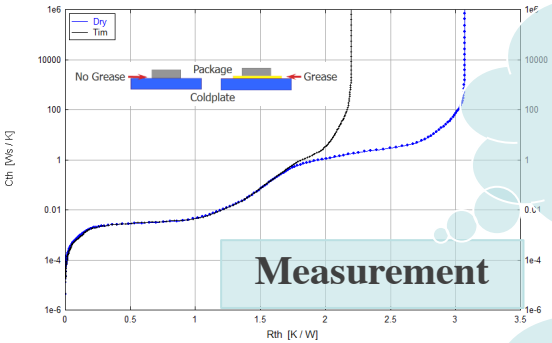
Structure Function of a Power MOSFET



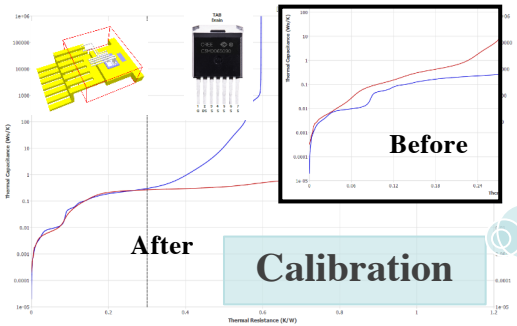




Applications of the Structure Function

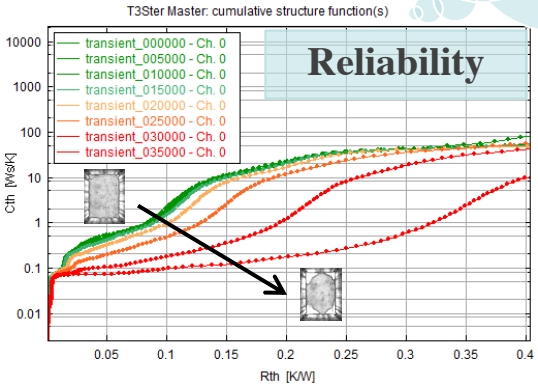


Obtain accurate and detailed component thermal metrics. A simple change to the environment reveals the package. (JEDEC Standard JESD51-14)

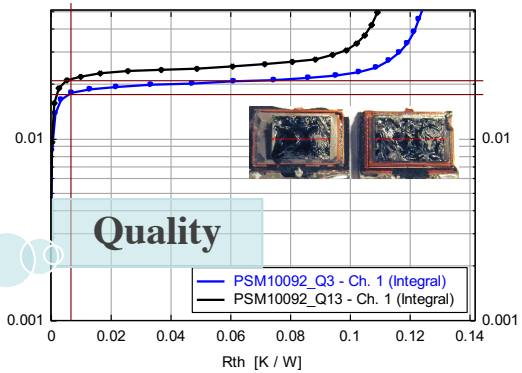


Utilize a combination of measurement and simulation to create extremely accurate thermal models.

Quantitatively measure changes in structure through cycling. Degradation of the die attach can be observed and measured throughout the test.

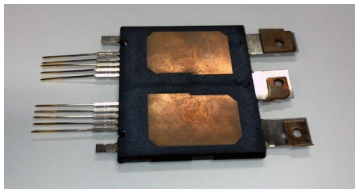


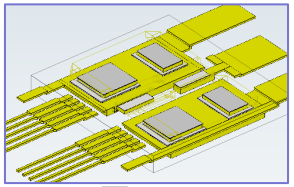
Identify quality issues for incoming/outgoing devices. Here the vendor made an unannounced change to the die size and T3STER detected it.



How Simulation and Test Support Each Other

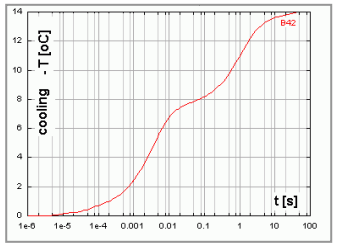
Real package





Model to validate

Thermal CFD

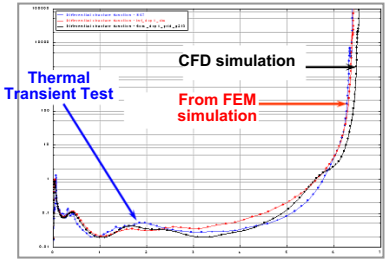


Thermal transient measurement

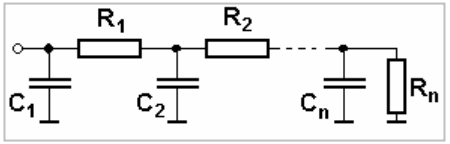
Simulated thermal transient

STF creation

Structure functions **for structural analysis and validation of detailed models**



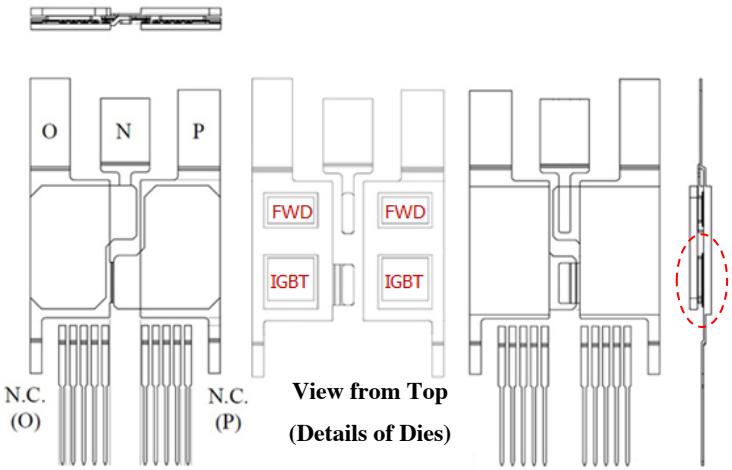
Validated detailed model



Test based compact mode

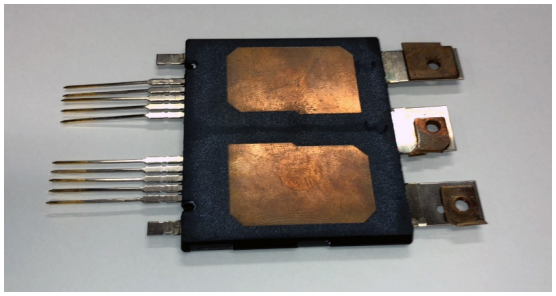
SIMULATOR

Dual Sided IGBT Package

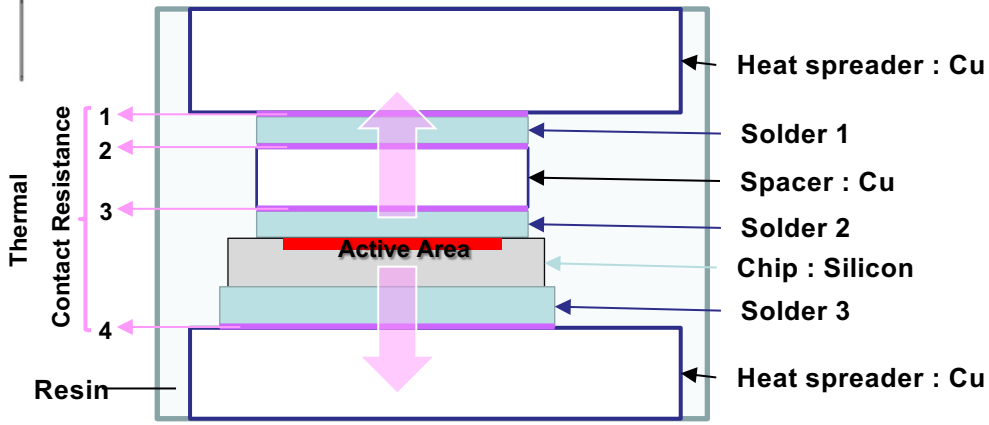


Top View

Bottom View

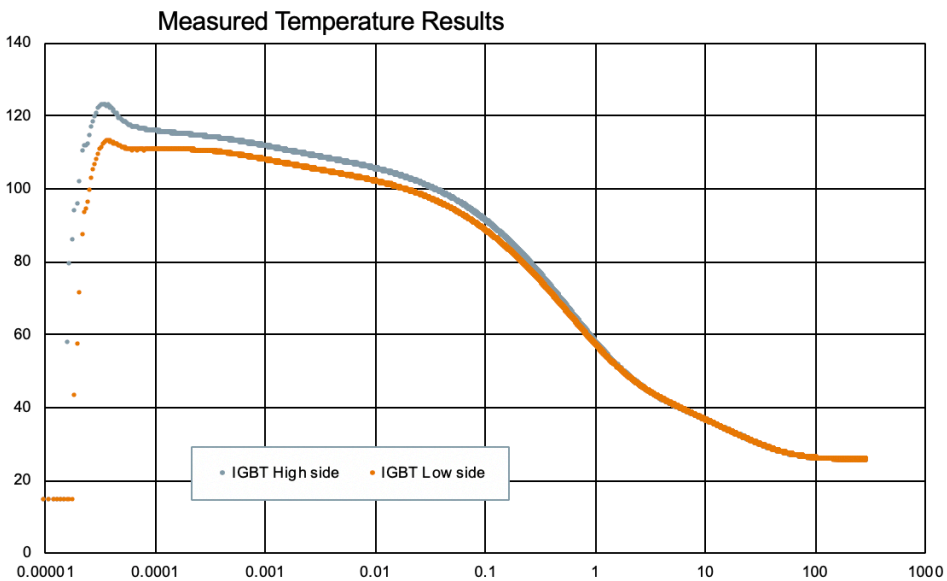


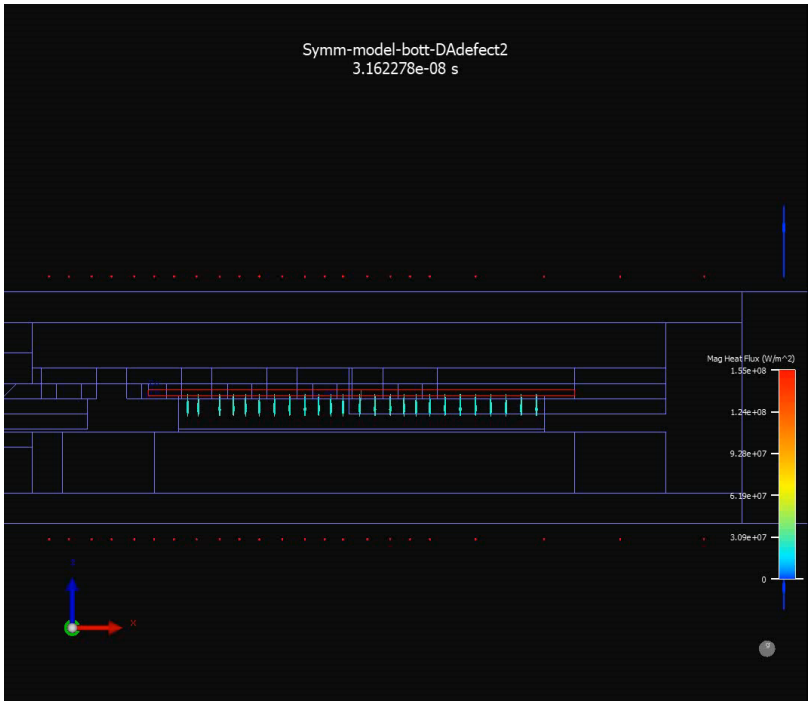
- The internal layout of the package is asymmetrical.
- The package had a lower thermal resistance for the top half of the package compared to the bottom half



Internal structure layout of the package

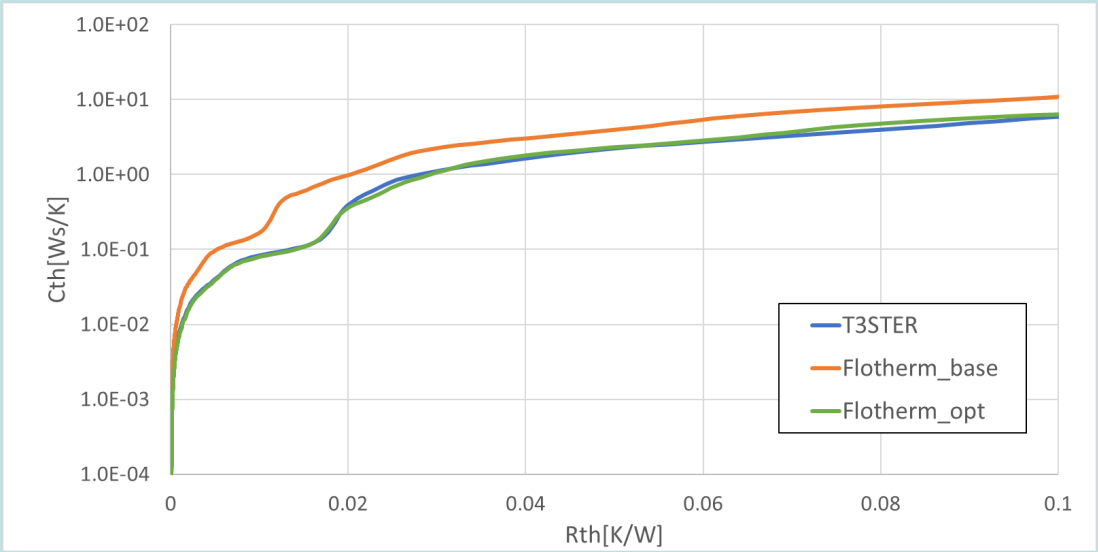
Experimental Temperature Results





3D Simulation Model Calibration Results

- The Structure Function graph on the right shows the initial (uncalibrated) and final (calibrated) results from the simulation model, in comparison to the measured results (blue line) obtained by thermal transient testing
- Thermal conductivity coefficients and interfacial thermal resistance values were aligned
- When calibrated, the 3D CFD model of the IGBT will behave in the same way as the actual package, including its transient heating and cooling characteristics.

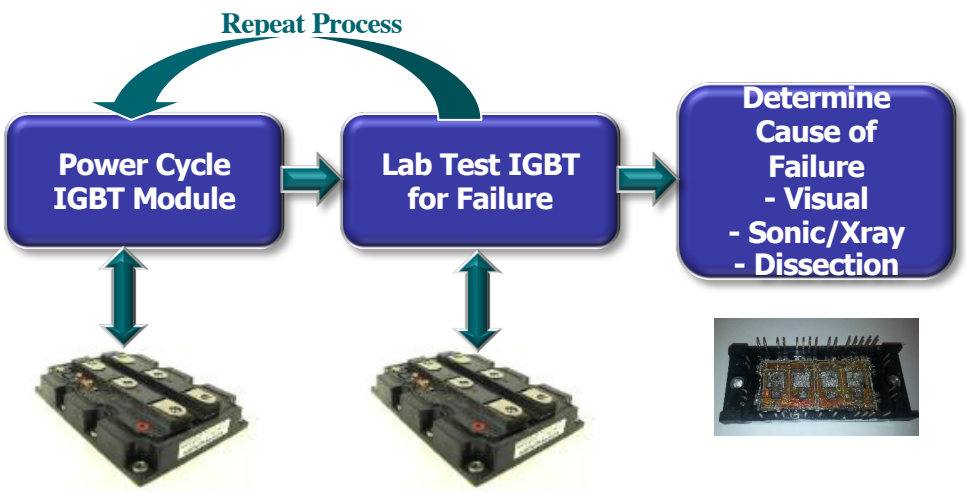


Traditional Power Cycling Processes

- Traditional Process:
  - Run set number of power cycles
  - Take to lab and test for failure
  - Repeat power cycling/lab testing cycle until failure
  - Take to lab and determine reason for failure

Issues:

- **Repetitive cycle/lab test process = long times**
- **No "real time" indication of failure in progress – only post mortem**
- **Failure cause requires lab analysis – typically internal to package**

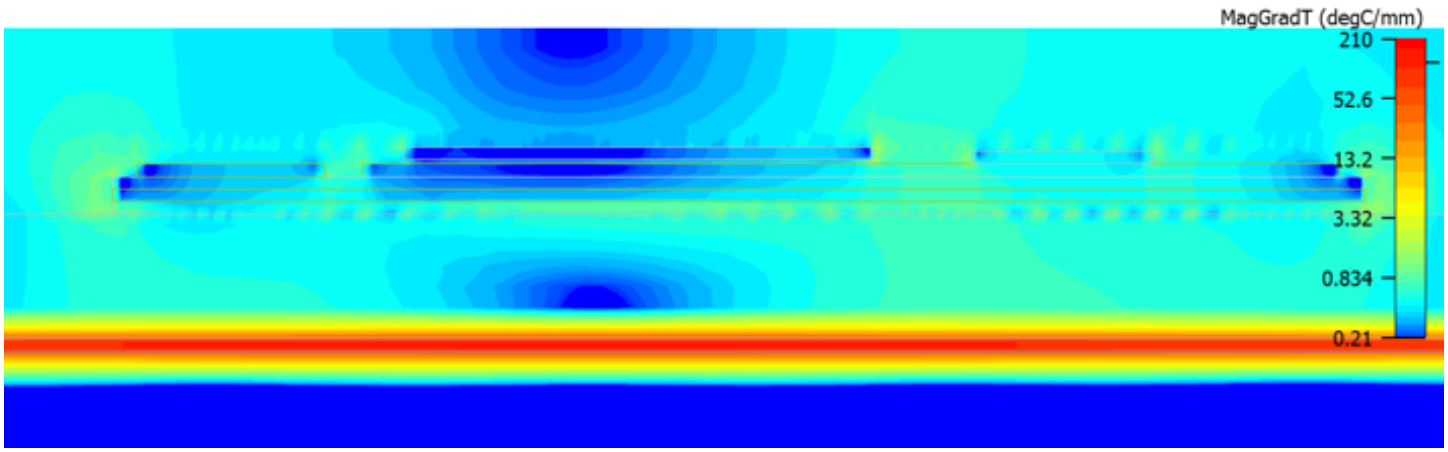


How about combining cycling and analysis to a single test set-up?

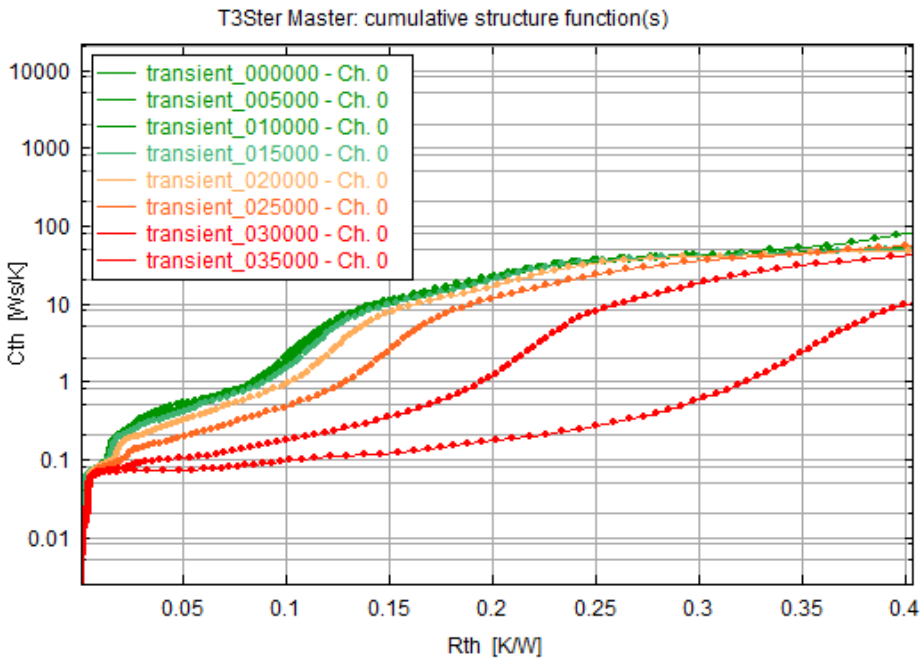
How about automating the workflow?

Power Cycling of a Component

- Simulation of the power cycling process on an IGBT, illustrated in Simcenter Flotherm
  - High internal temperature gradients highlight areas more likely to fail



Indicating Device Degradation: Power Cycling and Failure Diagnosis

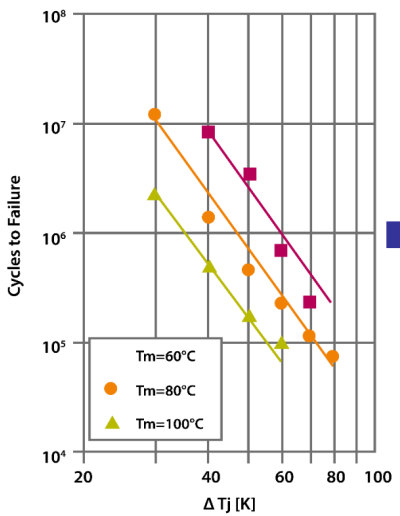


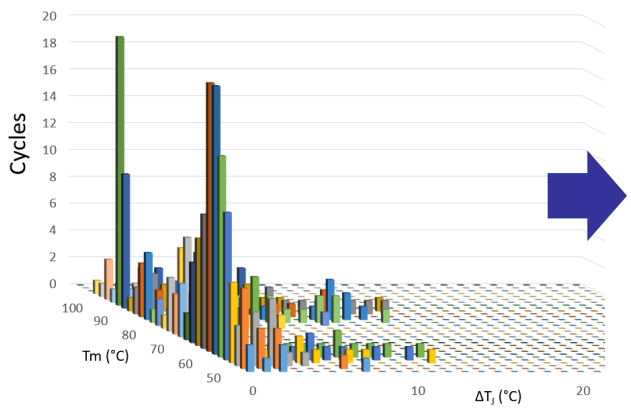
Continuous degradation of the die-attach layer can be observed after ~10,000 to 15,000 cycles

Assessing Field Reliability

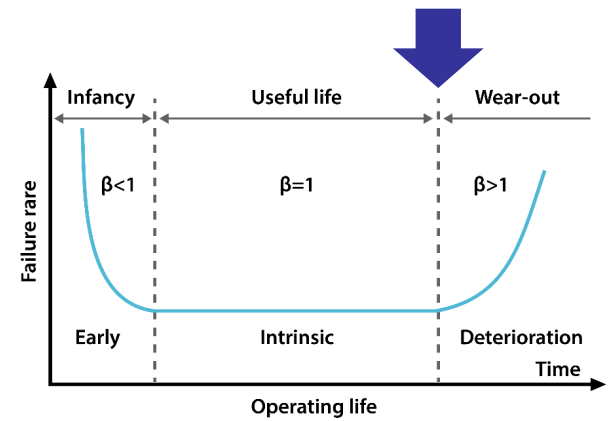
- Damage models developed based on active power cycling test results: $N_f = fn(\Delta T, Tm)$

- Rainflow-counting algorithm processes 3D Thermal CFD drive cycle temperature swings:





Results predict onset and rate of wear out:



Summary

- Thermal transient testing is an accurate way to characterize power electronics
- Structure functions will help you
  - understand package properties and the effect of external cooling solutions
  - serve a perfect reference for calibrating CFD thermal models
- You can measure cycle number to failure data as well as understand the degradation process
- You can use test and simulation to estimate mission profile based lifetime