



Calibration within T3Ster Measurement & FloTHERM

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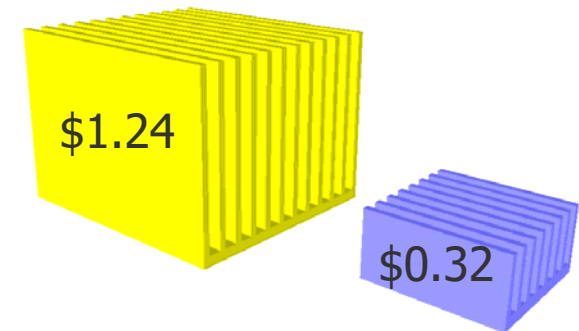
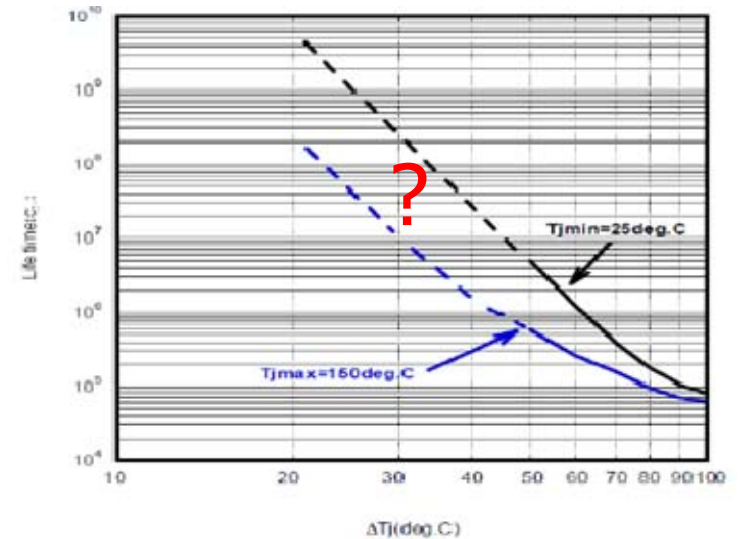
Sr. Application Engineer

June 14, 2017

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Electronics Thermal Challenges

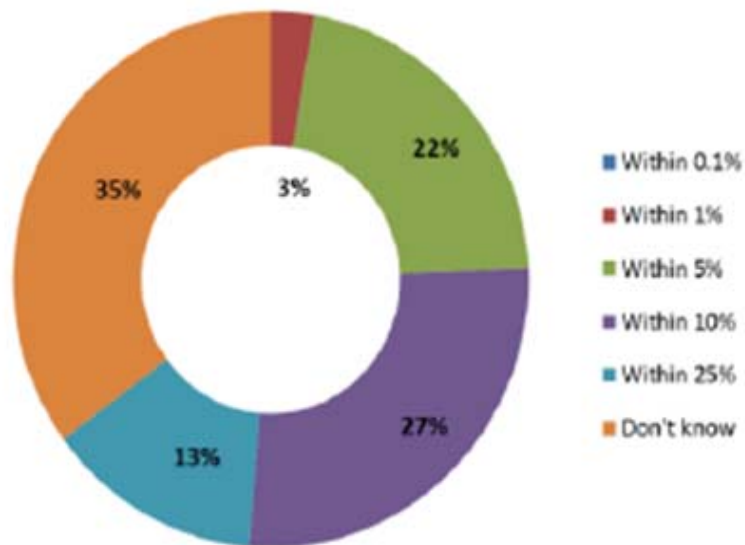
- Used to be 5-10% error was okay.
 - Now, we can do better
- Inaccurate or low temperature predictions
 - Incorrect lifetime predictions
 - Early field failures
- Too conservative thermal analysis
 - Costs go up when products are overdesigned.
 - Benefits of more accuracy; smaller more efficient designs that cost less.



Electronics Thermal Challenges

Certified Supply Chain – Feedback

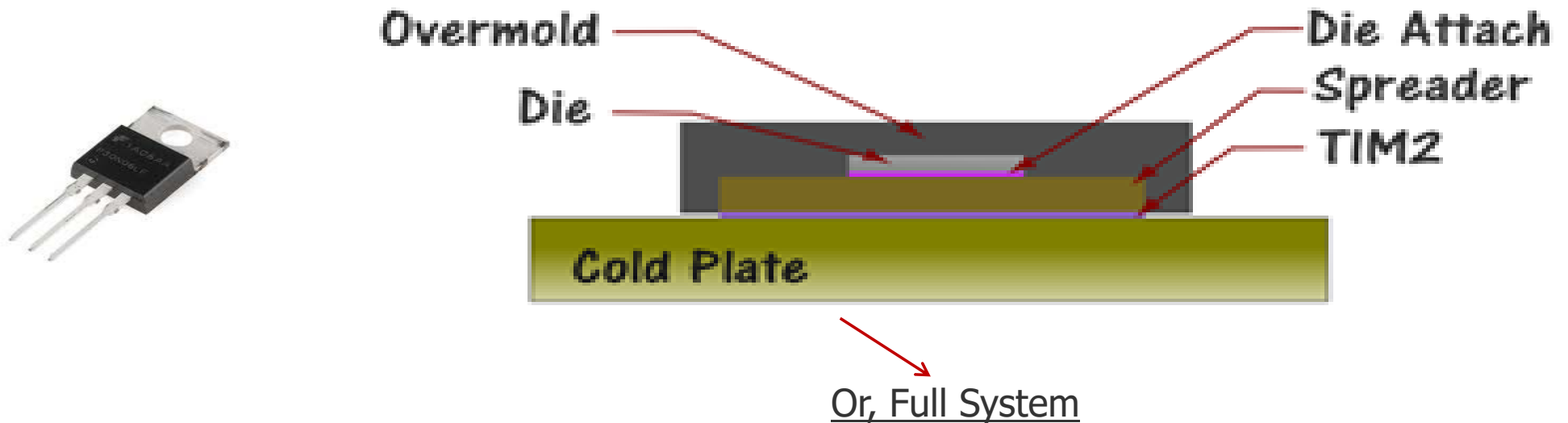
How accurately do you feel the detailed package models you use in FloTHERM can predict the transient response to an arbitrary power profile?



- Certify the accuracy of detailed models supplied to customers
- Supply test data along with the detailed package model at evidence the model will respond correctly to any driving waveform.
- Customer design decisions will be based on empirically certified data
- Compact Thermal Models accuracy will be improved as certified detailed model results are used to derive them.
- System integrators can (and should) demand to use "T3Ster-certified" component models, as all package time constants are proven to be captured by the detailed model.

Electronics Thermal Challenges

- Understanding Thermal Structure
 - Junction to Ambient metrics
 - Junction to Case
 - Resistance and Capacitance in layers
 - Accurately and consistently

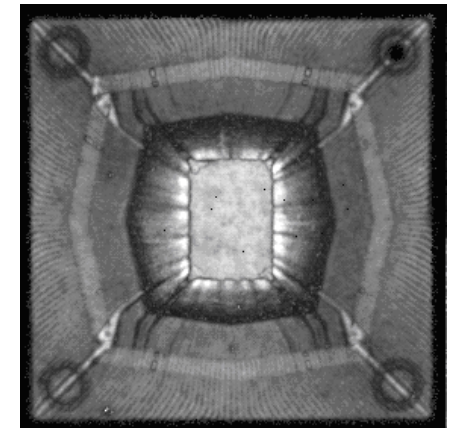
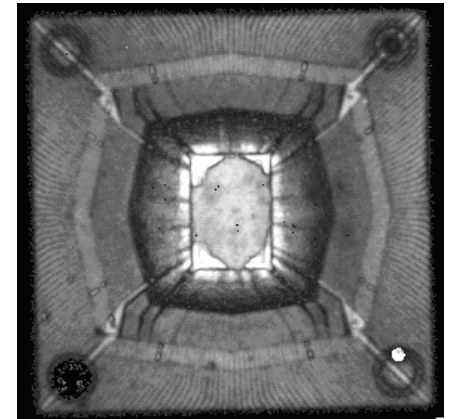


Electronics Thermal Challenges

Traditional Solutions: Structural Measurement Methods

How do we see into the package and learn more?

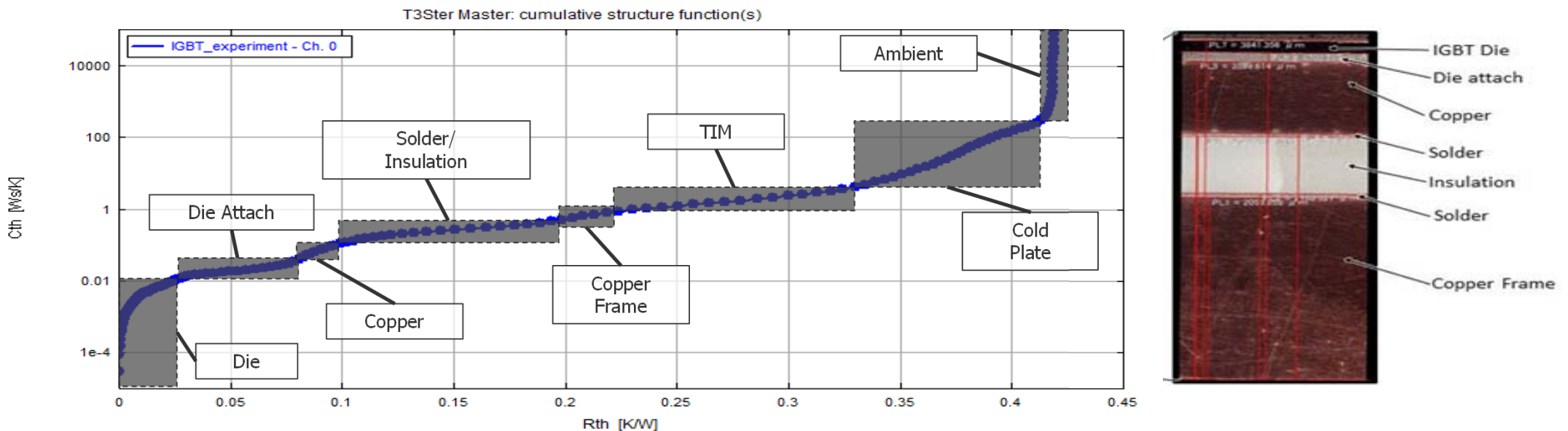
- Methods
 - X-Ray
 - Scanning Acoustic Microscopy (SAM)
- SAM can be used to determine voids within layers and thicknesses
 - $\sim 0.5\mu\text{m}$ accuracy
- X-Ray maps all detail to a single plane
- Visual appeal
- Geometric sizes
- Qualitative-does not determine thermal impact of details!



GENERAL PRINCIPALS OF PACKAGE THERMAL TRANSIENT MEASUREMENTS

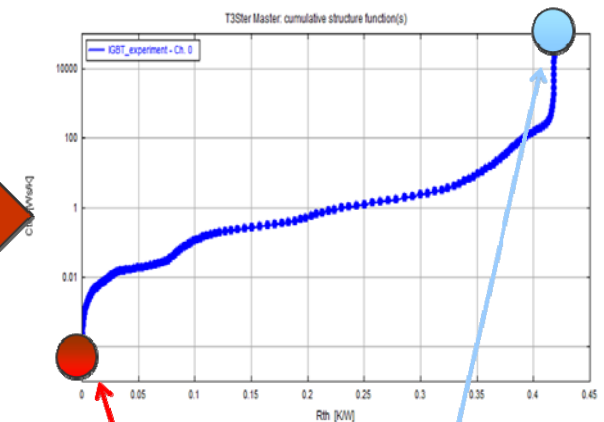
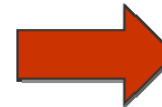
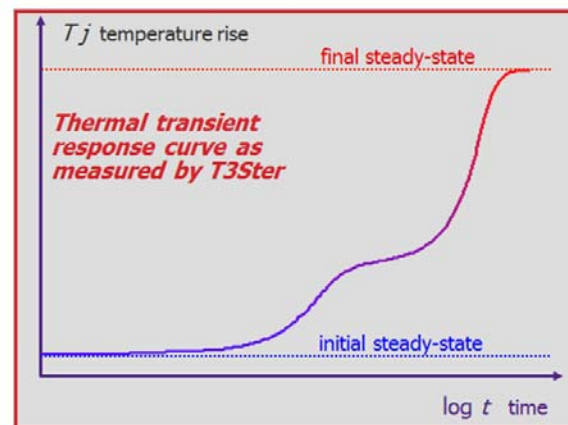
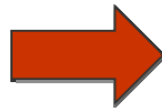
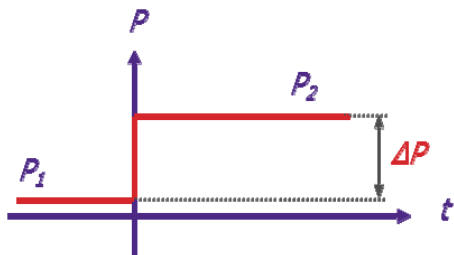
T3Ster - Transient Response Measurements

- 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.



T3Ster - Transient Response Measurements

- T3Ster is used to measure the transient thermal response of a package to a change in its power dissipation.
- JESD51-1: Electrical Test Method

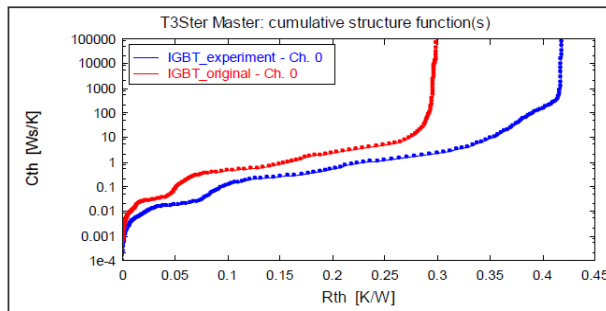


Heat Source at Junction

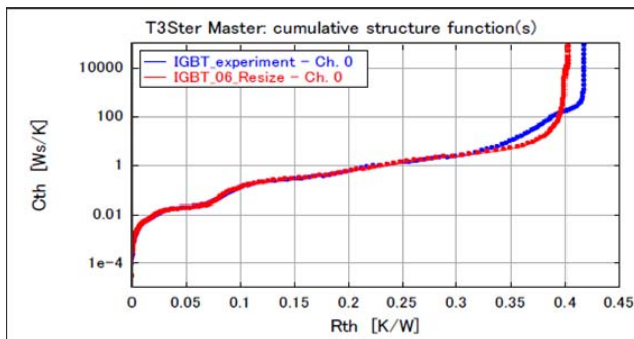
Infinite Capacity Ambient

Model Calibration

—Uncalibrated



—Calibrated

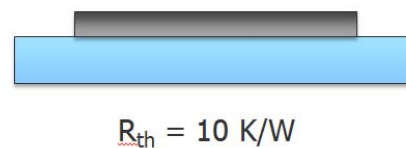
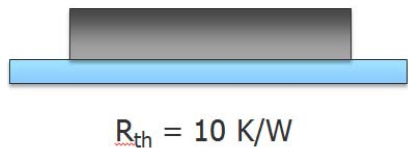


- To ensure model accuracy the FloTHERM Structure Function **must** match the T3Ster Structure Function across all package elements.
 - **Only then** are we ensured that each object in the package is modelled correctly.
 - **Only then** are we ensured that the 3D temperature field is accurate
 - **Only then** are we ensured the FloTHERM model includes all package time constants and will respond correctly for all driving power profiles.

**MANUAL CALIBRATION WORK FLOW
UTILIZING TEST METHOD
COMPARISON**

Thermocouple Calibration

Not Good Enough



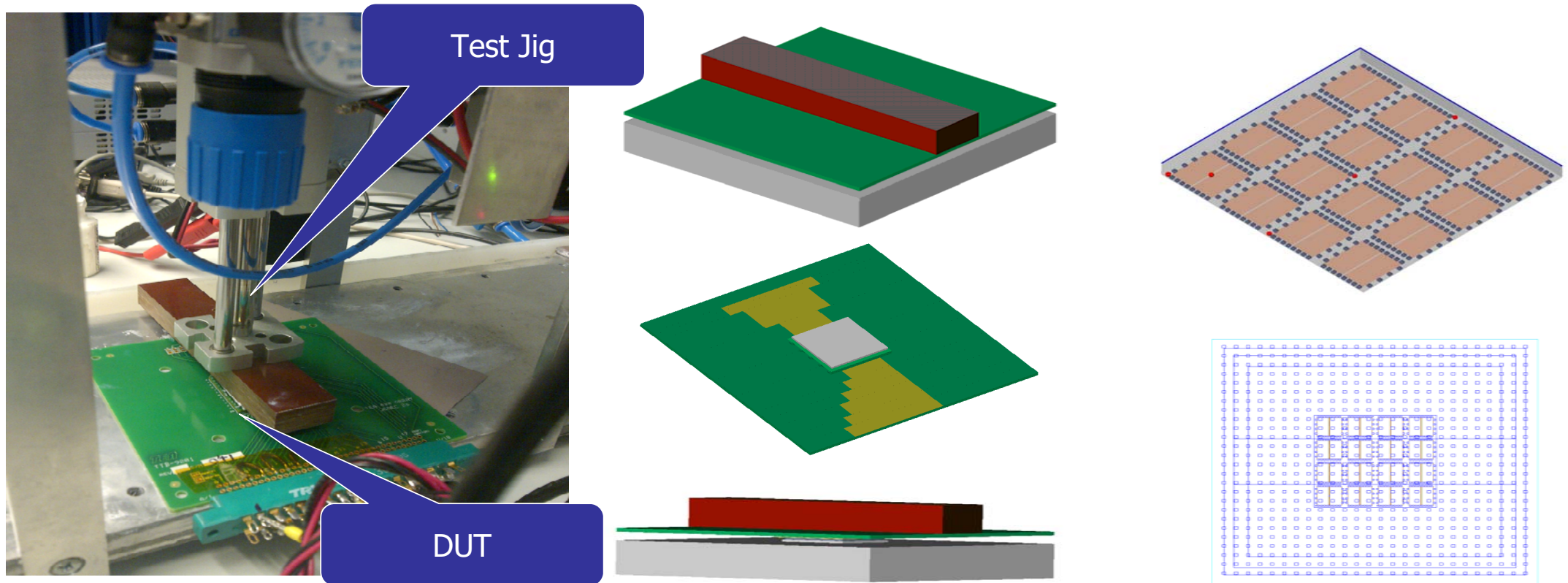
- Accuracy and repeatability issues ($\pm 1.5 \text{ degC}$)
- Dynamic response is poor. Small time constants cannot be captured.
- These issues mean that meaningful structure functions cannot be created from thermocouple T vs t data. No insight into structure is available and we are working blind.

Calibration Approach

- Adjust the model until a single target temperature measurement is hit
- This is very easy to achieve but we are likely to blunder into a right answer for the wrong reason scenario

T3Ster Calibration

FloTHERM - Model of T3Ster Characterization



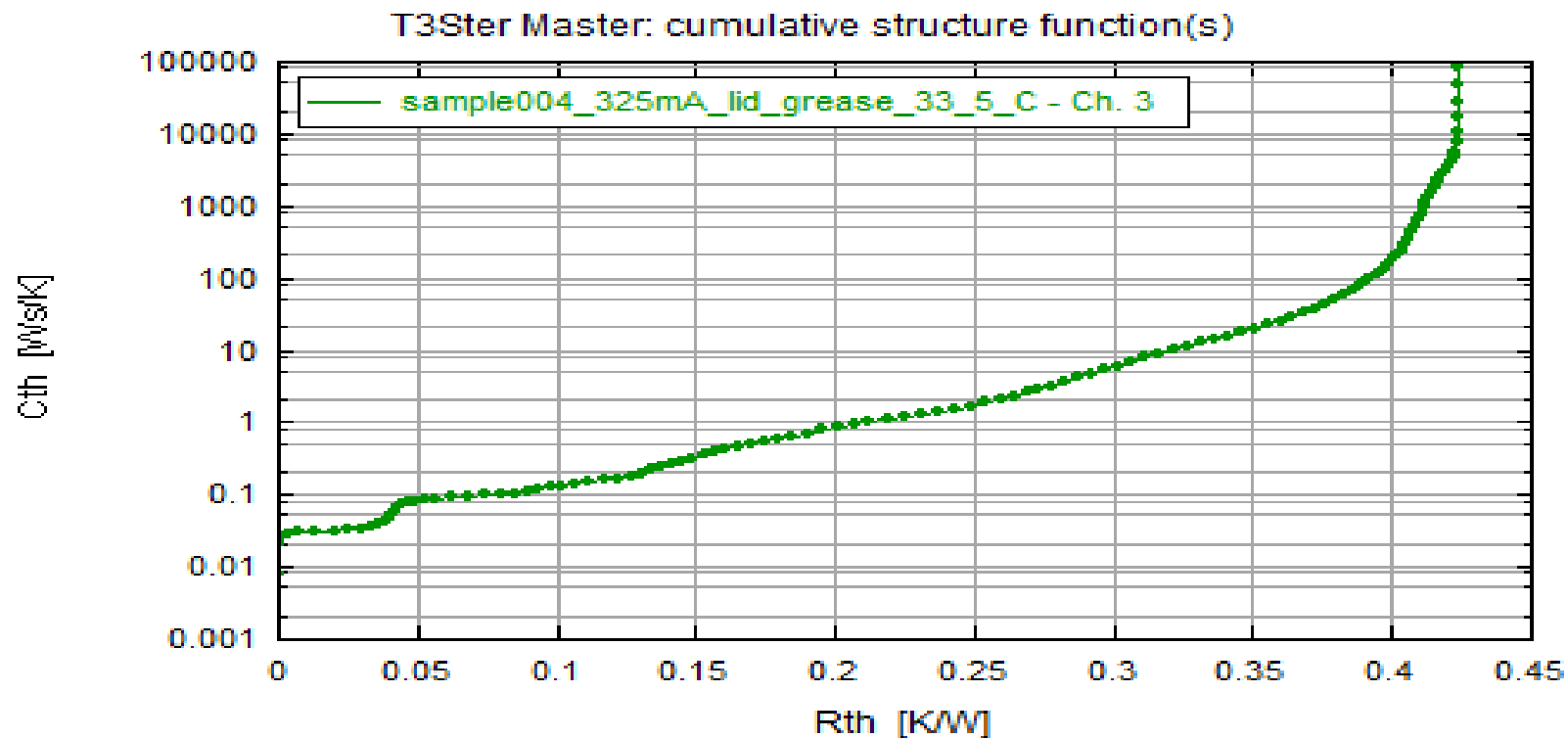
Utilize FloTHERM PACK and FloTHERM to create simulation model.

T3Ster Calibration Methodology

- Derive 'true' experimental structure function (SF)
- Replicate in FloTHERM to derive numerical equivalent
 - FloTHERM T vs. t > T3Ster Master
- Compare SFs to identify deviations
 - Where, and by how much, is the numerical model inaccurate
- Modify the FloTHERM model and rerun
- Resulting in a calibrated FloTHERM model
 - Ready for accurate simulation deployment in operating environments



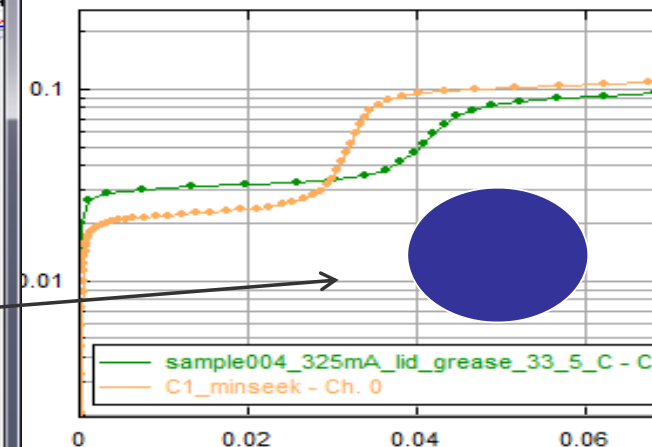
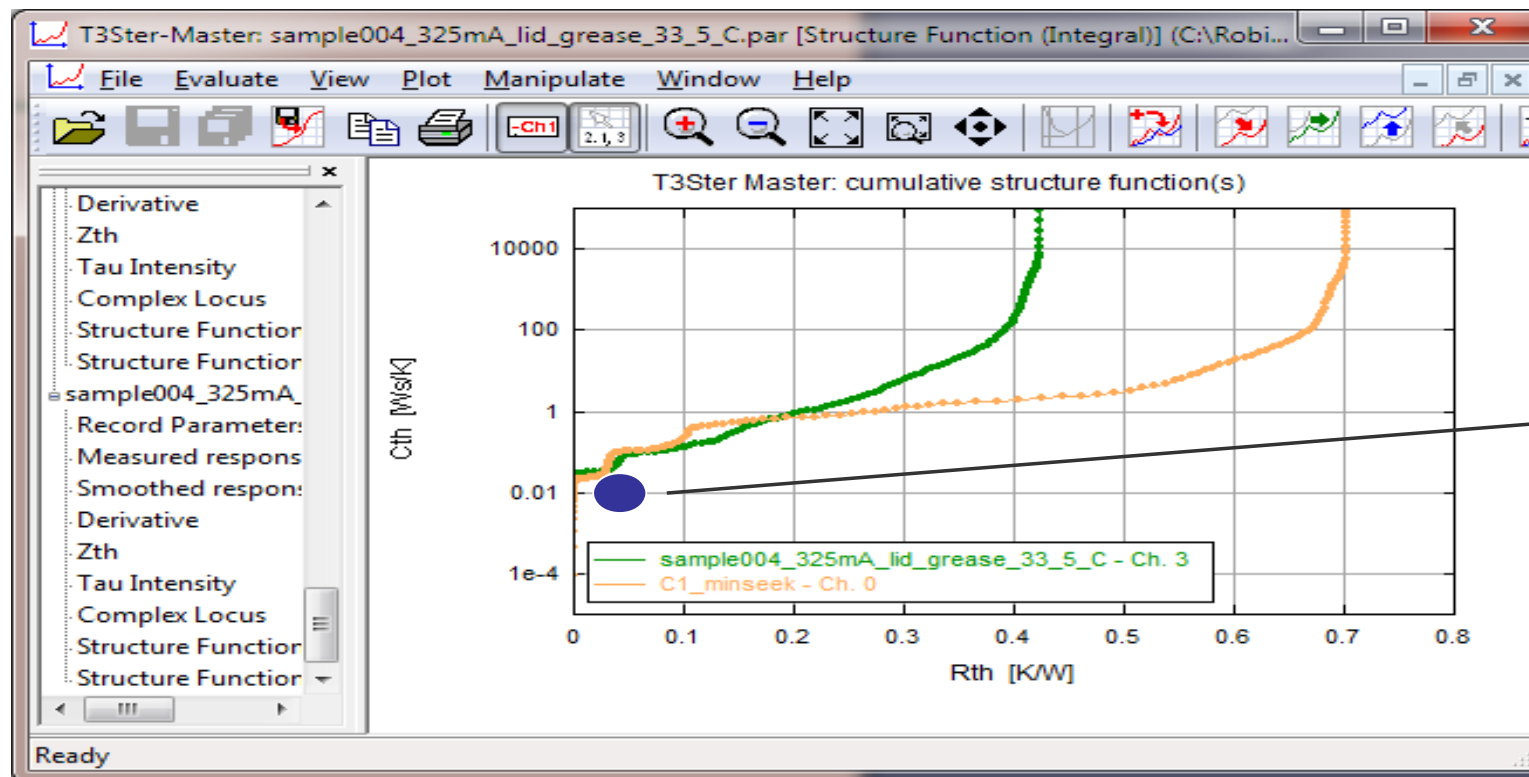
T3Ster Calibration fcBGA-H Results



■ 'True' SF:

T3Ster Calibration Initial Comparison

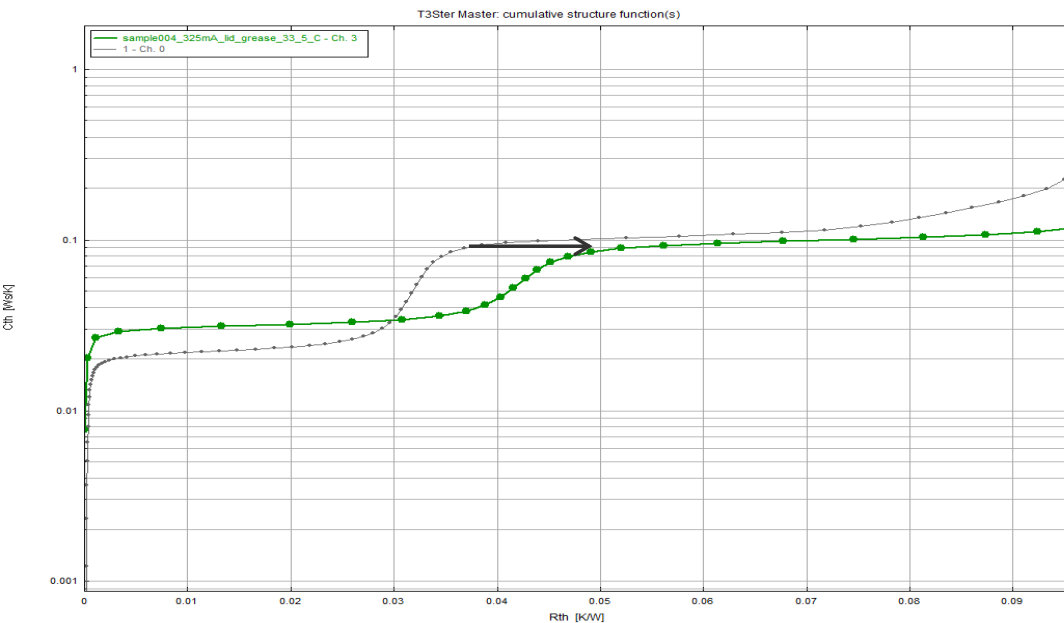
- Process: Start nearest the die and work outwards



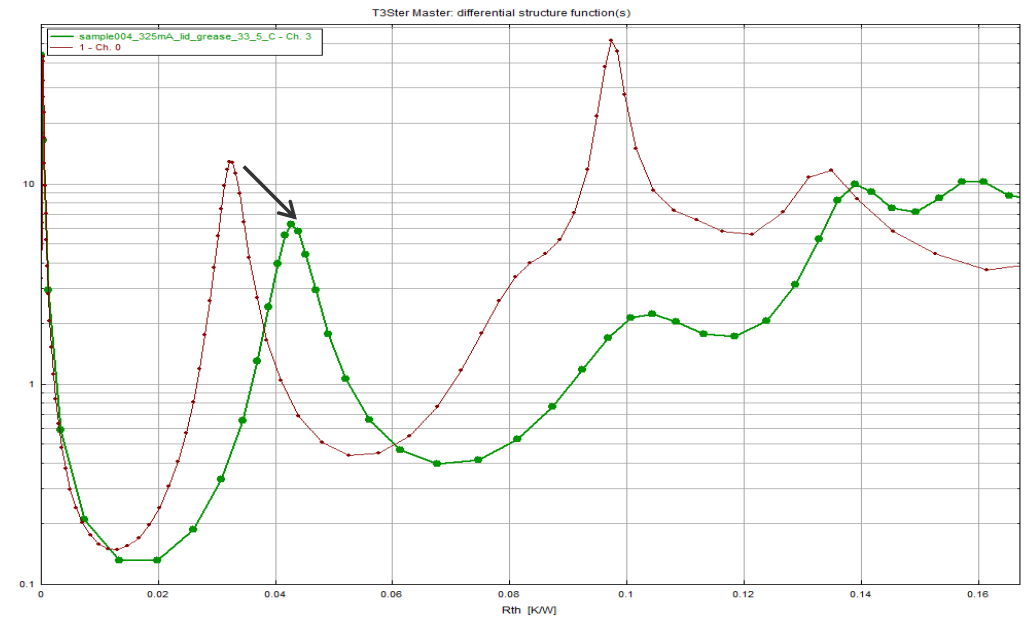
Structure Function Rth vs Cth

T3Ster Calibration Initial Comparison

- Process: Start nearest the die and work outwards



Structure Function Rth vs Cth

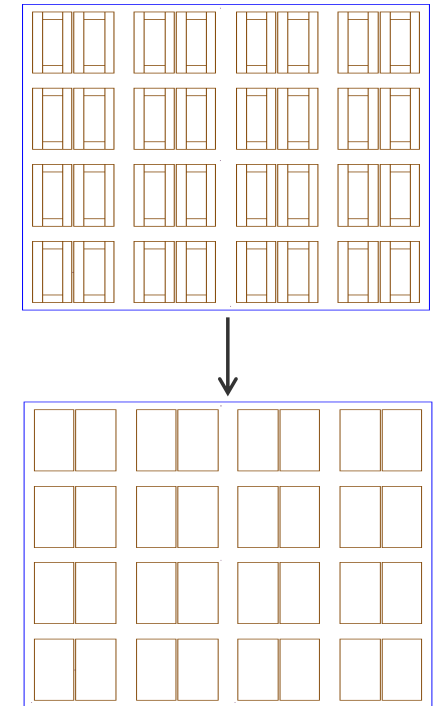
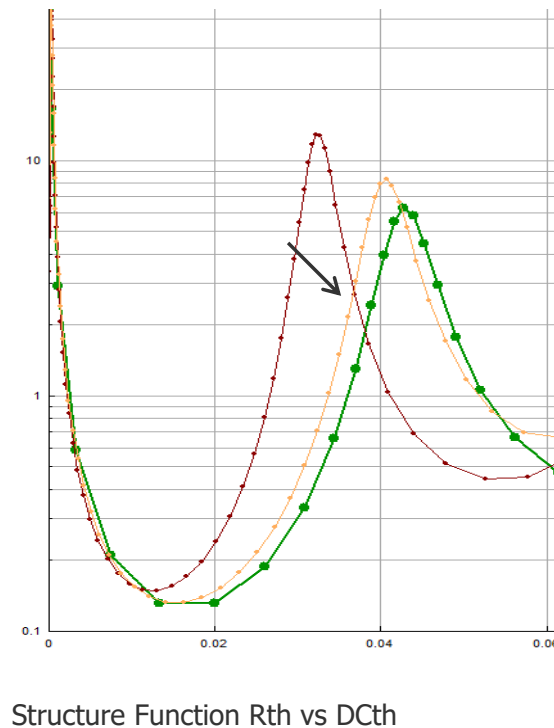
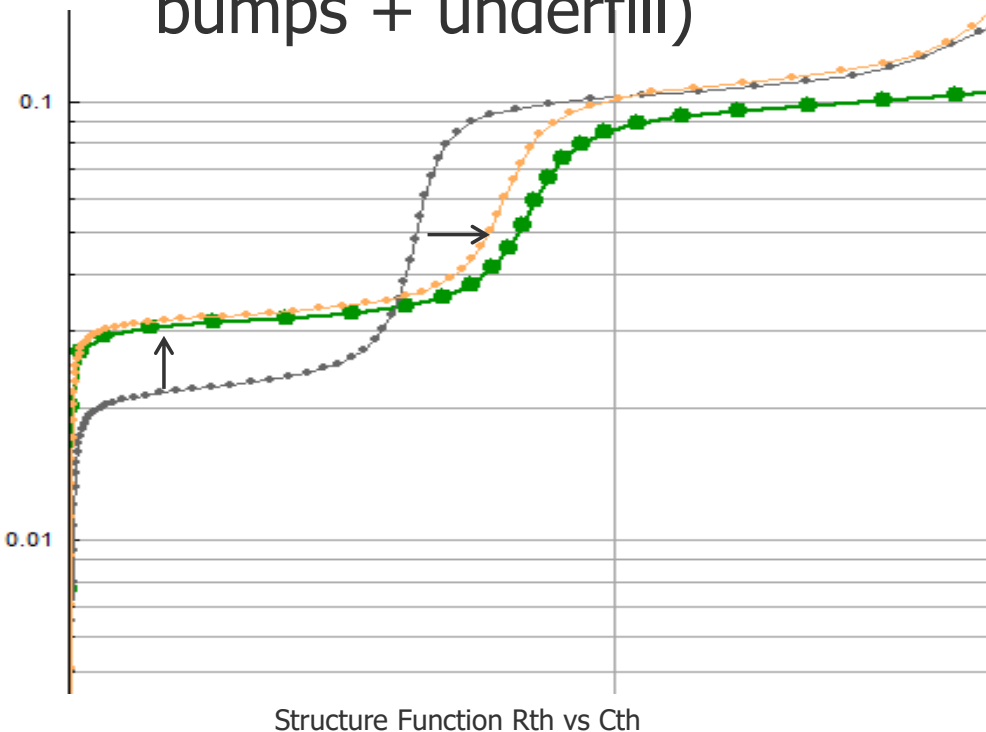


Structure Function Rth vs DCth

T3Ster Calibration

Step 1 – Modify Die Heat Source Active Area

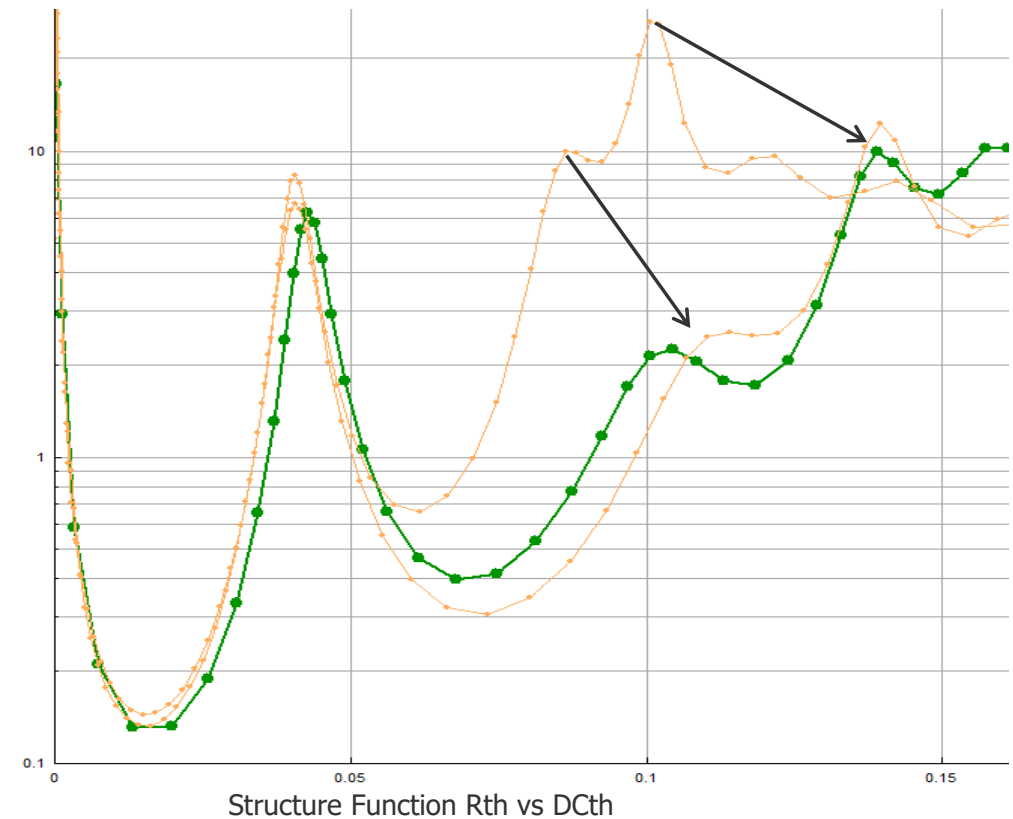
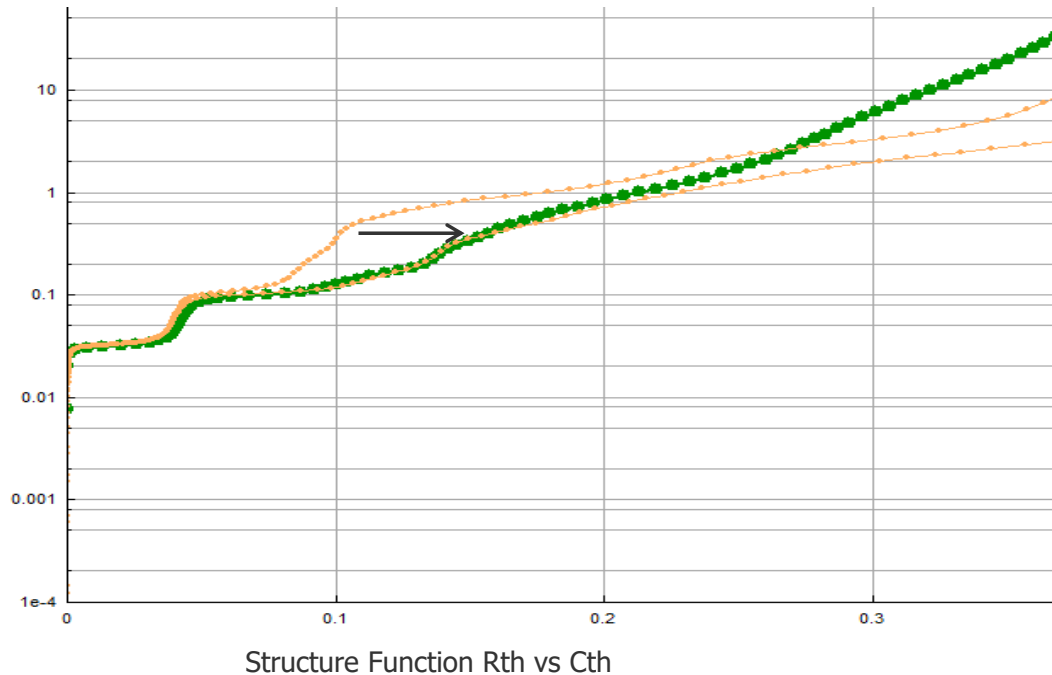
- Modify heat source shapes and explicitly model underfill and C4 bumps (instead of a lumped bumps + underfill)



T3Ster Calibration

Step 2 – Modify Lid Attach Resistance

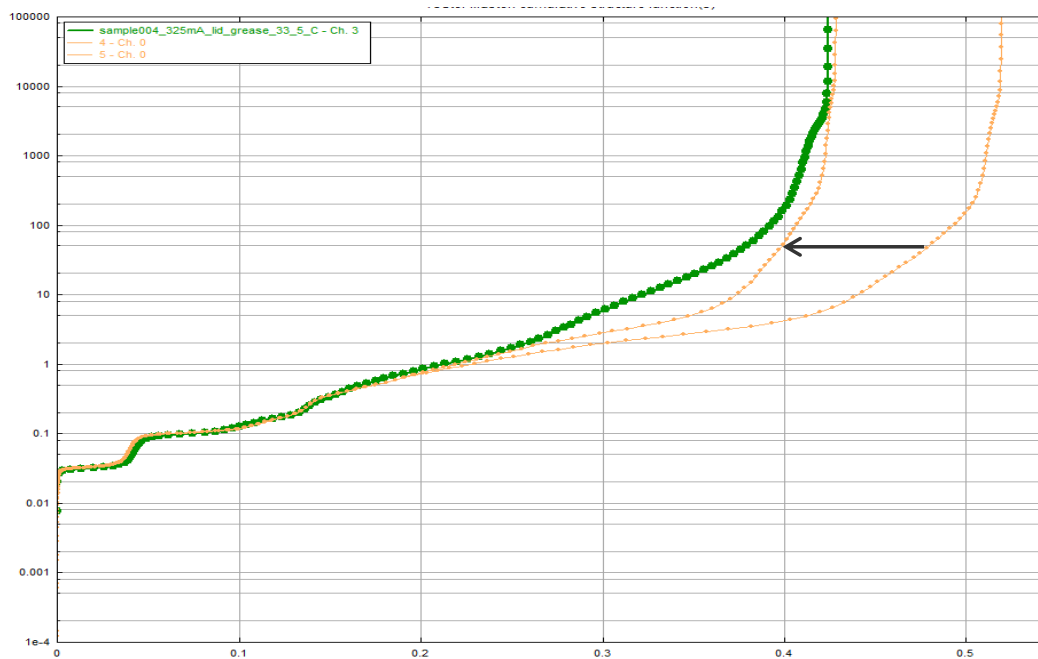
- Adjust die to lid attach Rth (increase)



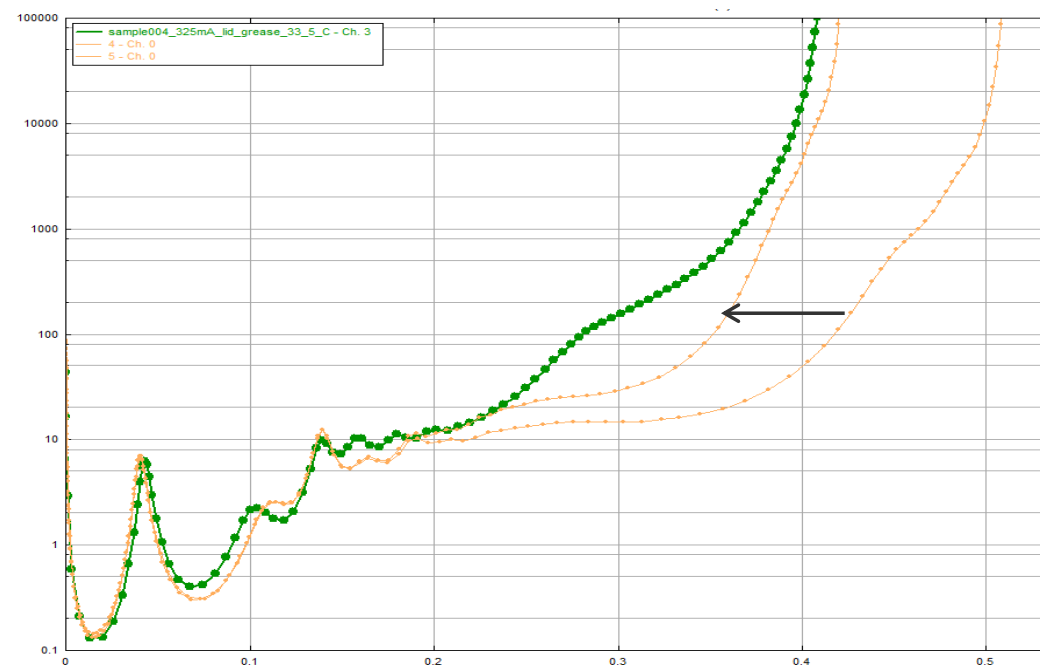
T3Ster Calibration

Step 3 – Modify Grease to Cold Plate Resistance

■ Reduce TIM2 (grease) Rth



Structure Function R_{th} vs C_{th}

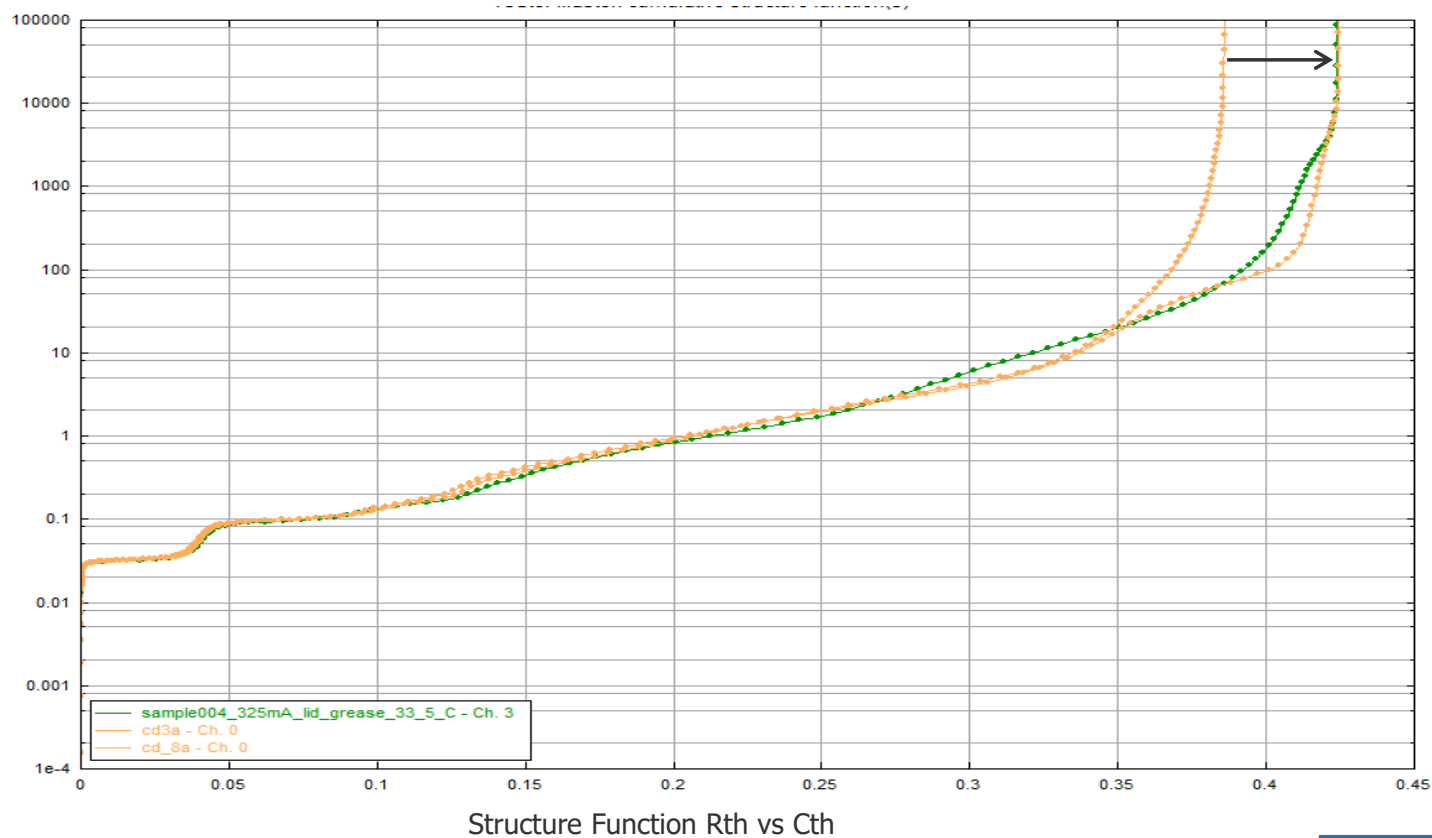


Structure Function R_{th} vs DC_{th}

T3Ster Calibration

Step 4 – Modify Cold Plate

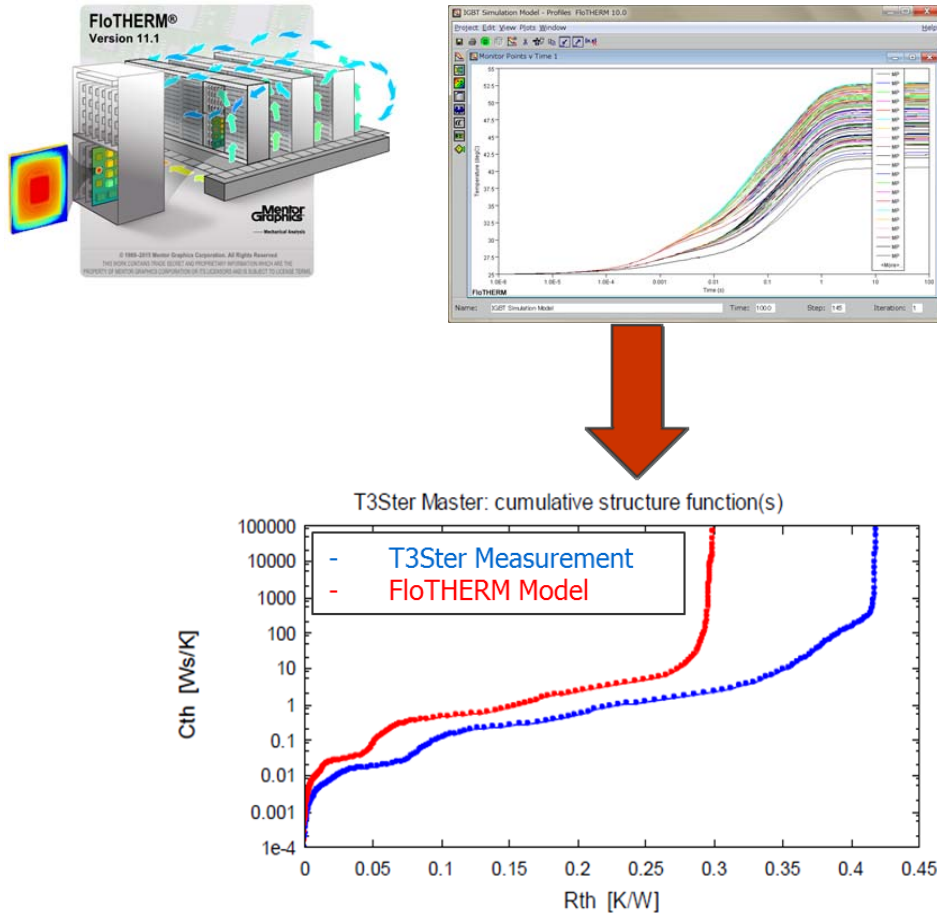
- Better representation of cold plate



**AUTOMATED WORK FLOW
WITH
FLOTHERM V11.1 ONWARD**

T3Ster - FloTHERM Calibration Work Flow

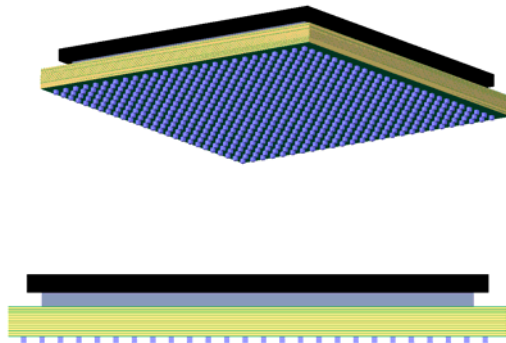
Setting up the Automatic Calibration



- A detailed FloTHERM model of the package can be simulated in a virtual test environment to predict a transient response as well.
- New in FloTHERM v11.1, the simulated transient response is converted into Structure Functions using exactly the same methods as T3Ster Master.
- This allows direct comparison of simulation to measurement in a format that correlates to the physical structure of the package.

T3Ster - FloTHERM Calibration Work Flow

1) Create Initial Model

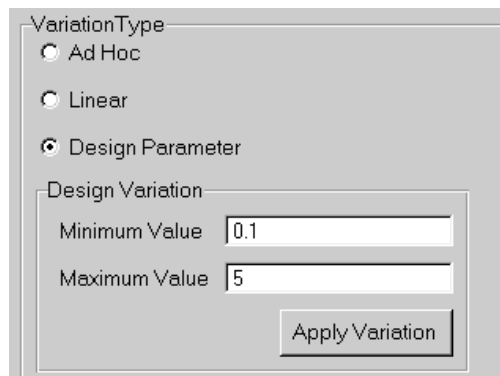
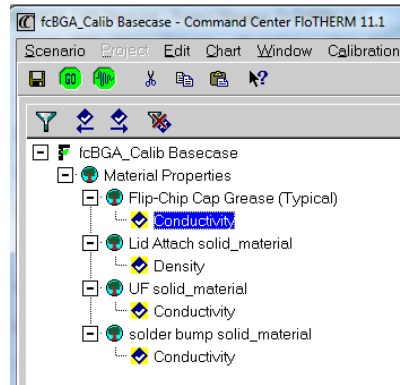


- Create the initial best guess detailed model of the package/module with the information that is available
- Use FloTHERM objects, FloTHERM Pack, or Automation Macros to create model
- Run a transient power step change simulation (same as T3Ster)



T3Ster - FloTHERM Calibration Work Flow

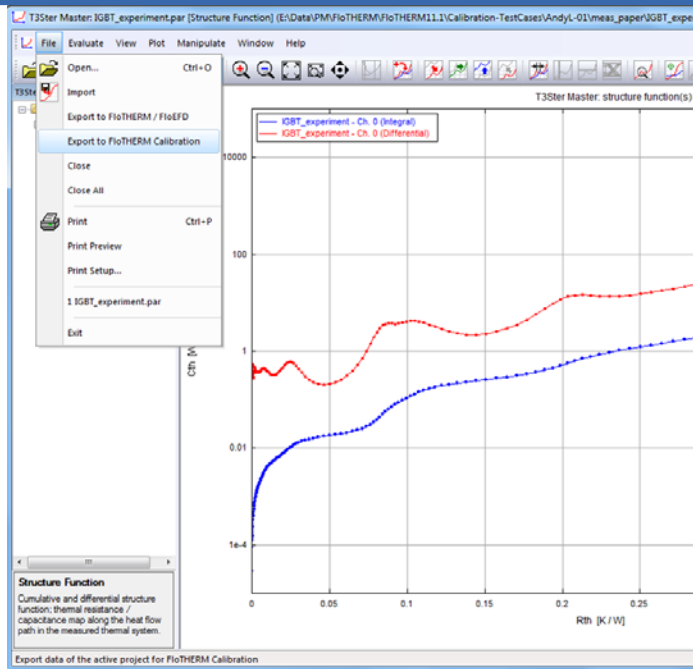
2) Nominate Parameters to Calibrate



- Decide what parameters of the package are not known with certainty and should be calibrated. Typically:
 - TIM thickness and effective material properties
 - Contact resistances
 - Die Active Area
- Define a range for the calibration parameters in Command Center. The optimal solution will be sought within the specified range for all calibration parameters.

T3Ster - FloTHERM Calibration Work Flow

3) Export Measurement data from T3Ster Master V2.4



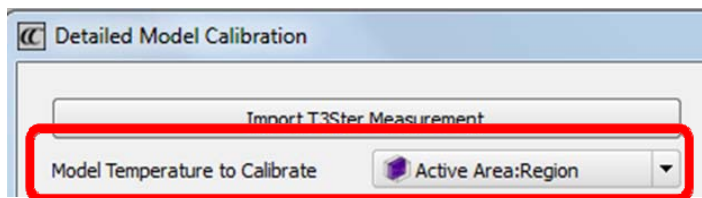
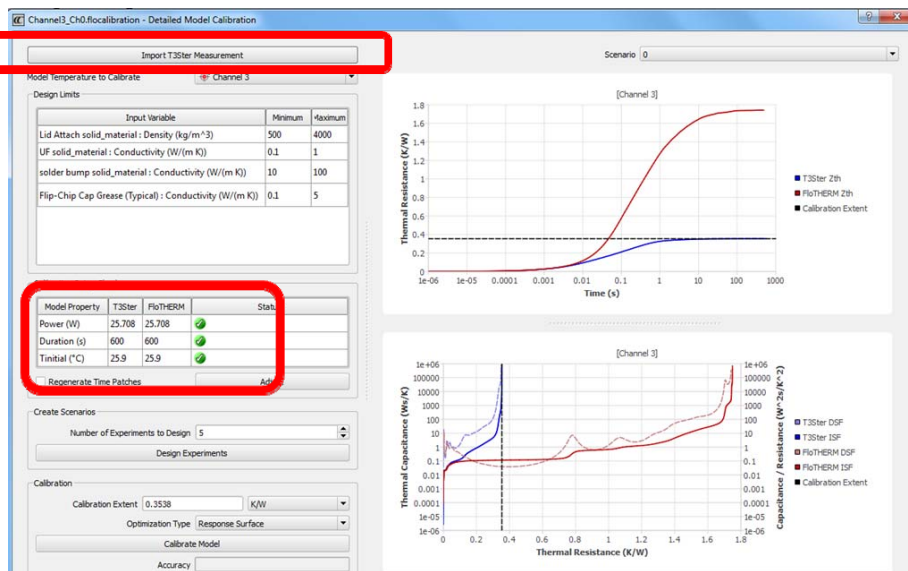
- Evaluate T3Ster measurement in T3Ster Master V2.4
- New 'Export to FloTHERM Calibration' command to create file usable by FloTHERM v11.1.



T3Ster - FloTHERM Calibration Work Flow

4) Import T3Ster data into FloTHERM and assign TSP

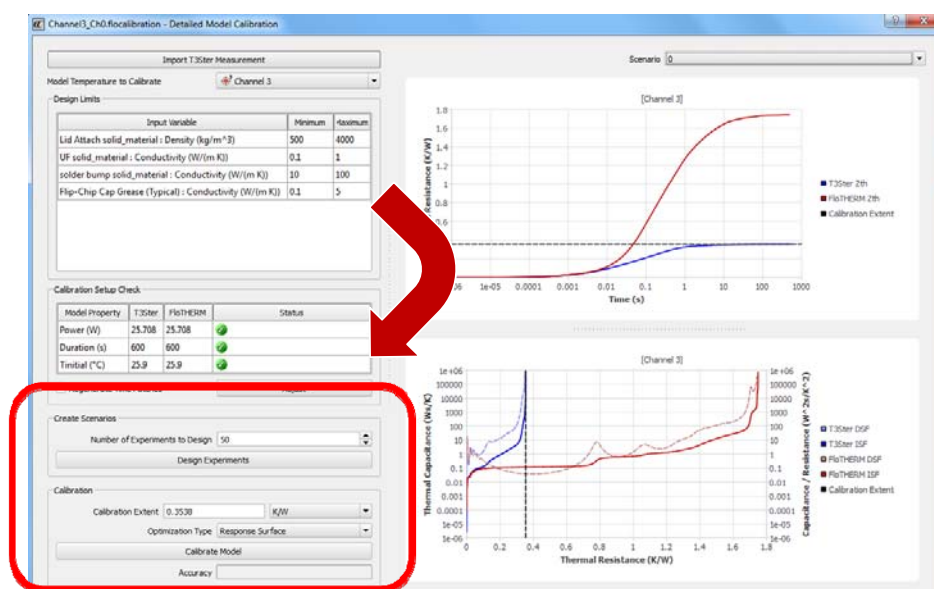
- Test information is displayed, and Zth and Structure Function comparisons are shown as well
- Specify what temperature in the FloTHERM results corresponds to the T3Ster measurement temperature
- In most cases T3Ster senses the average temperature in the active 'surface' (typically a few microns thick)
- Use a Volume Region coincident with the heat source object (new in FloTHERM v11.1)
- Applicable to power transistors, LEDs, simple ICs
- In some cases, T3Ster senses temperature at I/O pins of an IC
- Use a Monitor Point at the correct location at the external band of the chip.



T3Ster - FloTHERM Calibration Work Flow

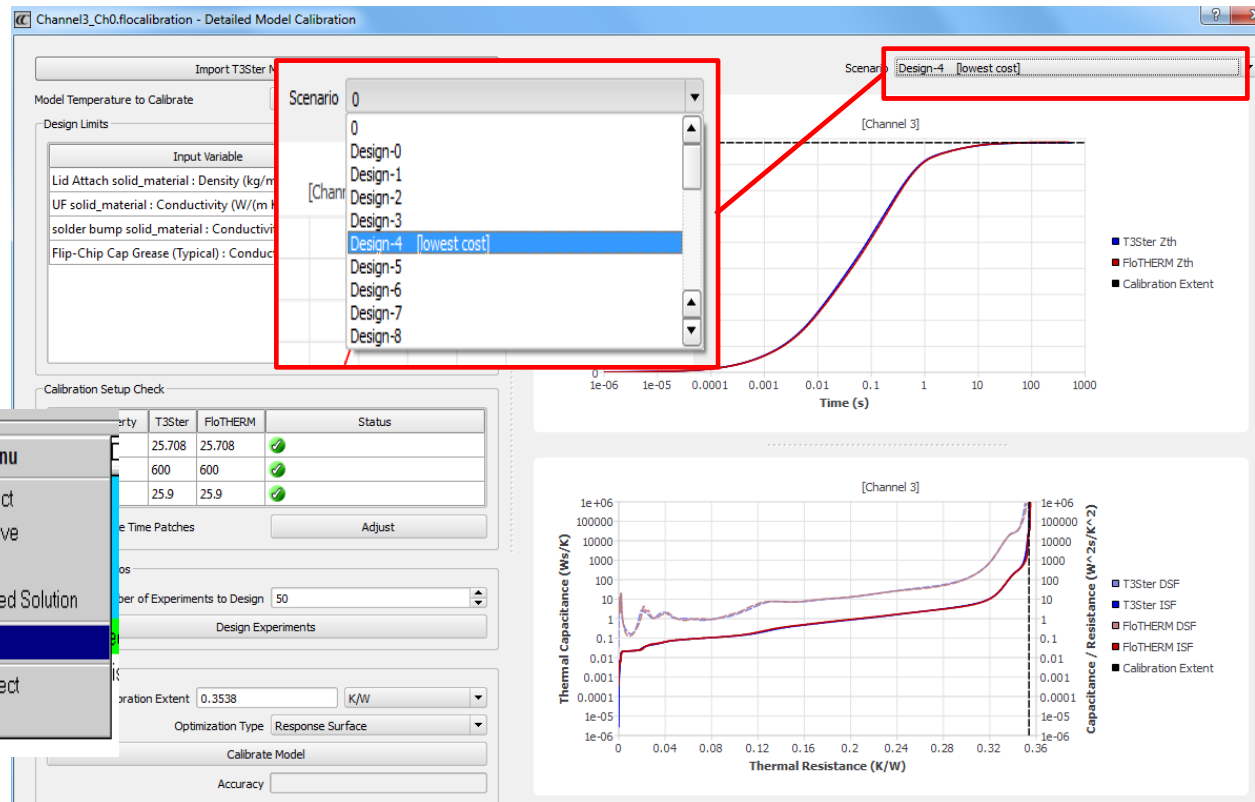
5) Run a 'Calibration' parametric study

- Define number of experiments (combinations of calibration parameters)
- 'Calibrate Model' will solve them and then optimize for the comparison of simulated and measured structure functions



T3Ster - FloTHERM Calibration Work Flow

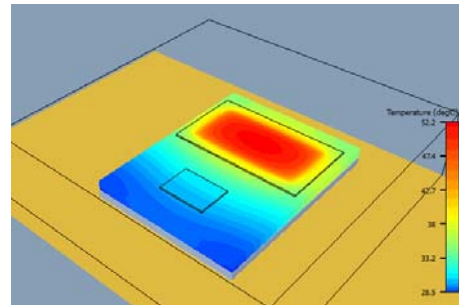
6) Optimal calibration parameters identified



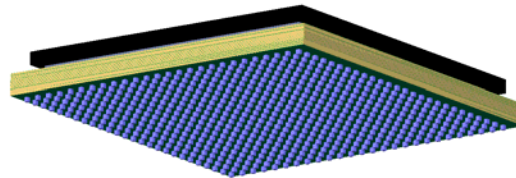
- Save As' the calibrated model from Command Center
- Then deploy the model in a FloTHERM or FloTHERM XT simulation

Example Applications

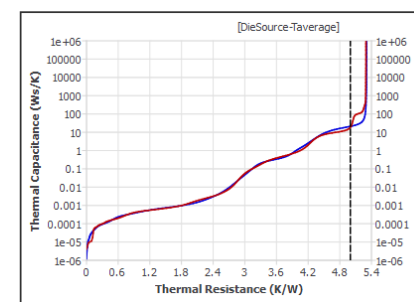
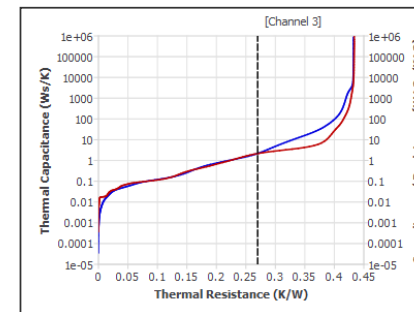
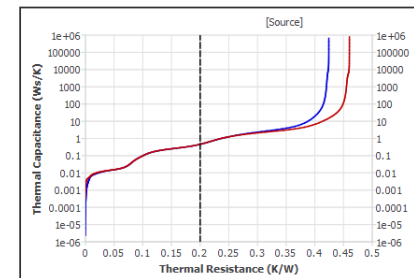
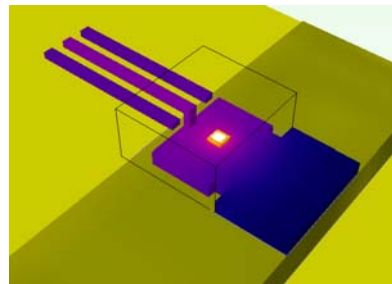
IGBT Module



fcBGA

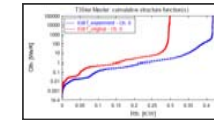


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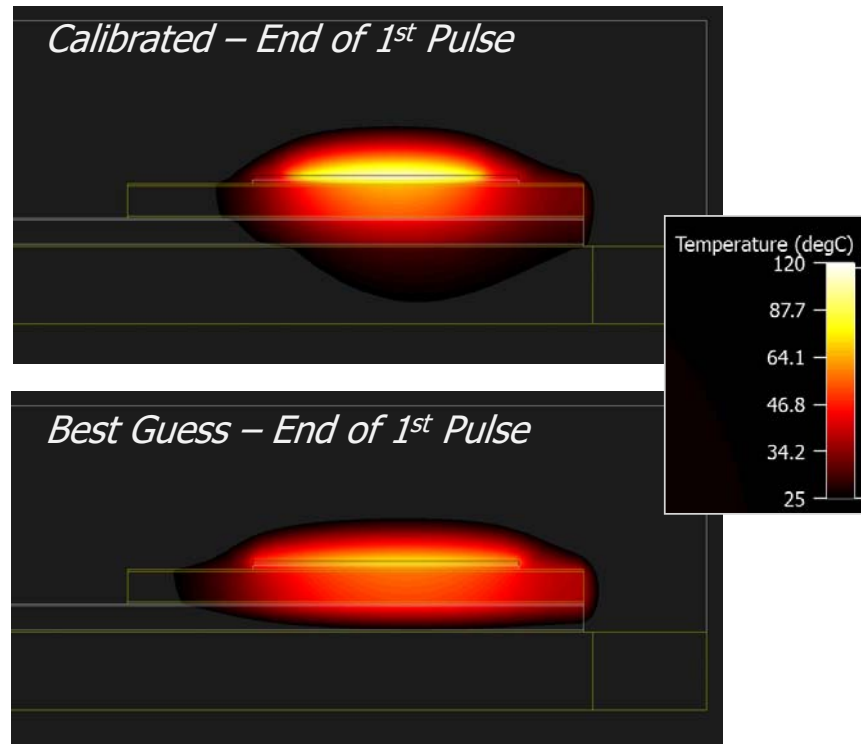
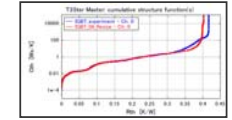


EXAMPLE

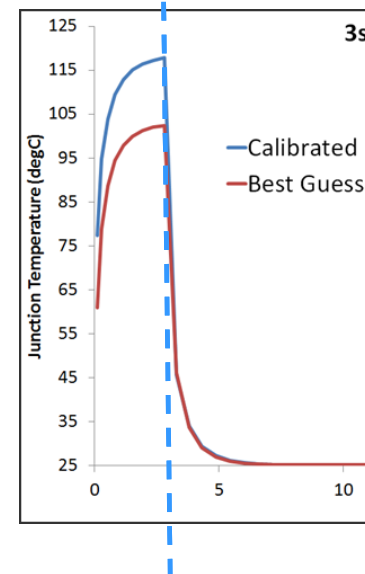
Maximize Model Accuracy



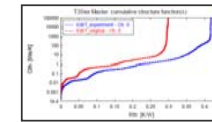
→
Calibrate



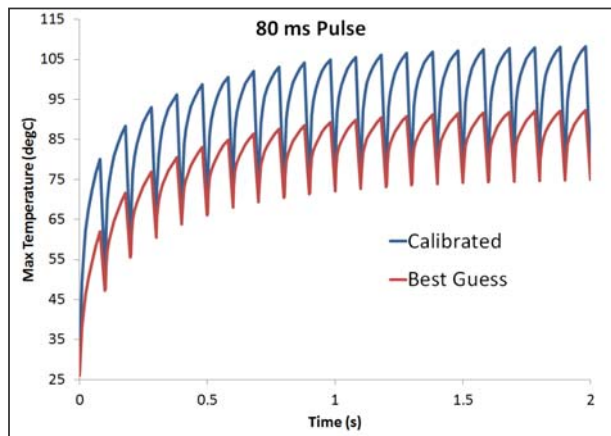
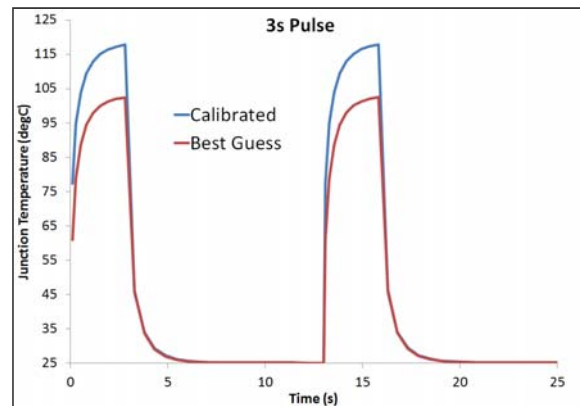
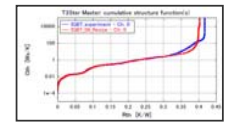
- Not only is the peak Junction Temperature incorrect. Typically, 3D Temperature and Temperature Gradient distributions are significantly different as well.



Maximize Model Accuracy

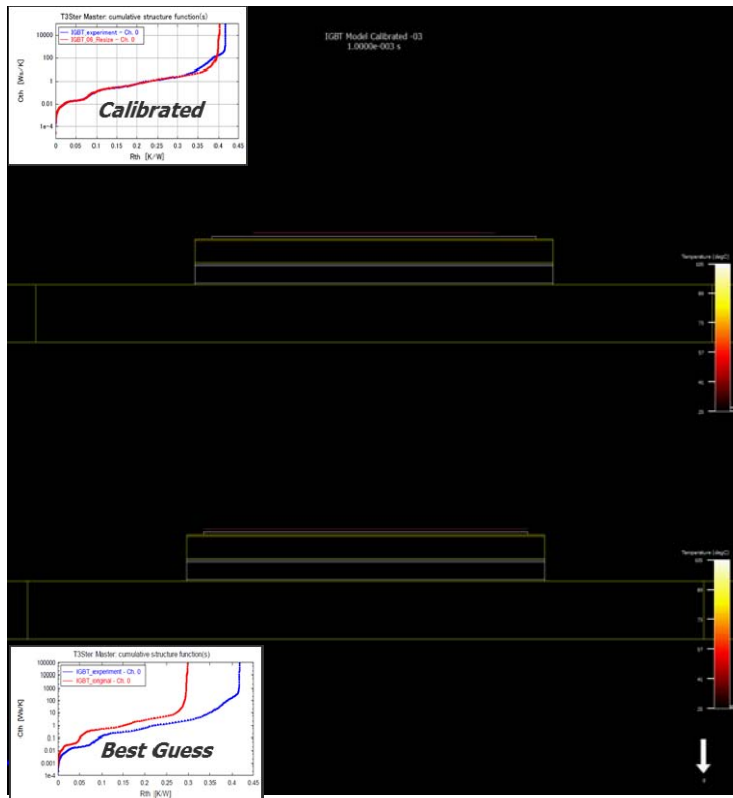


→ Calibrate



- A fully calibrated package model will respond accurately in steady state and all transient applications. Typically, uncalibrated 'Best Guess' models do not.
- Peak temperature, average temperature, and temperature deltas are incorrect

Maximize Model Accuracy

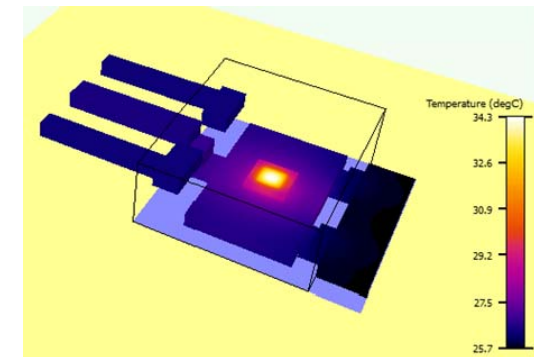
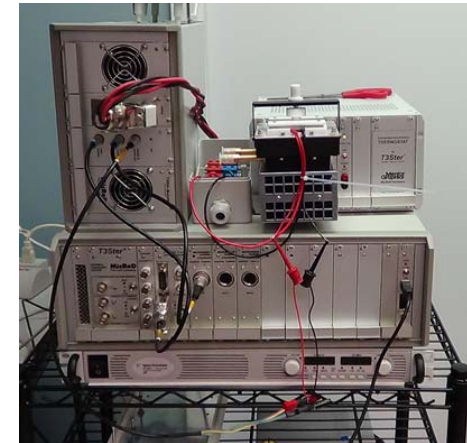


- Failure to model all package time constants correctly will introduce errors in temperature and temperature gradient predictions throughout a transient event.
- Errors here will propagate to reliability models that rely on temperature and dT data.
- Without Structure Function calibration, reliability predictions could easily be off by orders of magnitude

SUMMARY

Summary

- Automated calibration of thermal IC package models to match transient measurements results can allow for faster time to enhanced accuracy analysis to meet demanding requirements in for modern electronics thermal design.
- Maximize Model Accuracy
 - Calibrating all model aspects for all package time constants ensures the package will respond accurately for any steady state or transient application.
 - Relying on thermocouple metric type data is not enough
- Certified Supply Chain Models
 - Provide simulation models that will respond correctly to any driving power profile.
 - Provide empirical evidence that this is the case





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