

Thermal Test Chamber Evaluation



AGENDA

- PHISON introduction
- Thermal chamber evaluation
 - Simulation model
 - 2-Resistor CTM
 - DELPHI CTM
 - Simulation result
- Conclusion

Experience

20+ Years

3 Priorities

Consumer | Embedded | Enterprise



2500+ HC

70% R&D

600M

Average annual controller shipments



1900+

Worldwide patents



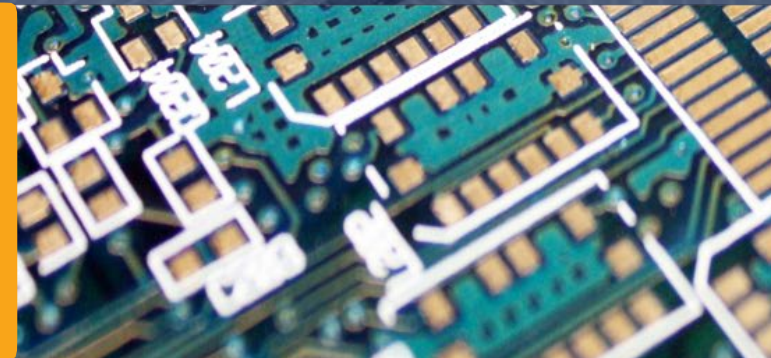
\$1.64B

2020 Revenue, no debt

Phison's Core Values

NAND Flash-based IC Design

Over 20 years of expertise developing NAND flash controllers
▶ 1900+ flash related patents¹, Internal Phy, ASIC,
and advanced NAND handling technologies



System Integration

Extensive expertise in mainstream applications
▶ Embedded, Enterprise, PC, and Mobile
▶ PATA, SATA, PCIe NVMe, USB, SD, eMMC, UFS

ODM

From Design to Manufacturing

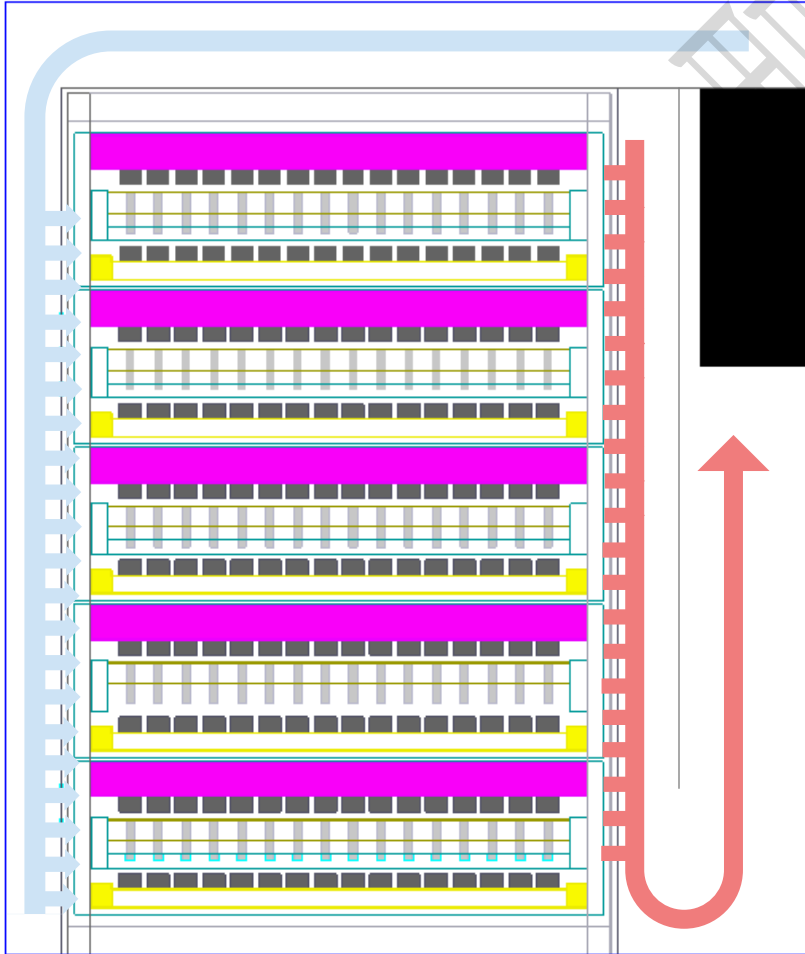


Turnkey

Flexible Business Model



Thermal Test Chamber Evaluation



Topic – How to evaluate the design of chamber in the early stage?

- The DUTs can't be overheat during test.
- The temperature difference of DUTs should be with an acceptable range.

The ways to do the simulation,

1.) Detailed model

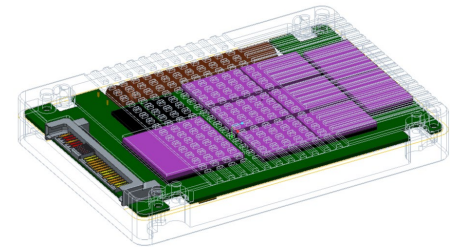
- Mesh, Computing resource and time consuming, ...

2.) Sub Model -> Create Zoom-in

- Convergence, Unable to get the temperature distribution of all tested device, ...

3.) Extract the compact model of DUT

- The way to extract accurate compact model



Compact thermal model overview

Properties of compact thermal model

- **Limited complexity**
- **Boundary Condition Independence**
- Software-neutral, the generation technique is adaptable to mainstream package-level thermal analysis, the CTM is capable to insert to system level analysis...

CTM method, incorporate several assumption

- The package contains a single heat source whose temperature is represented by a single temperature node.
- The package is mounted to a PCB.
- Heat flow paths
 - a.) The top surface: flows into the ambient fluid or heat sink.
 - b.) The side surfaces: transmit into the ambient fluid.
 - c.) The bottom surface and leads: flows into the PCB.
- Heat flow paths represent by thermal resistor.
- Each external surfaces are considered to be a single temperature by one node. However, the temperature node can be increased by divided the surface to several regions.

JEDEC defines 2 CTM methods, 2-Resistor and the DELPHI Model.

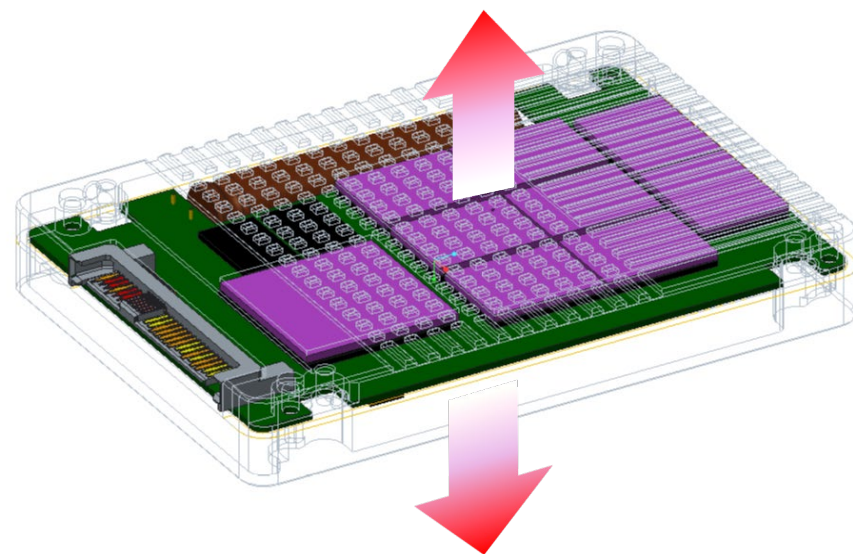
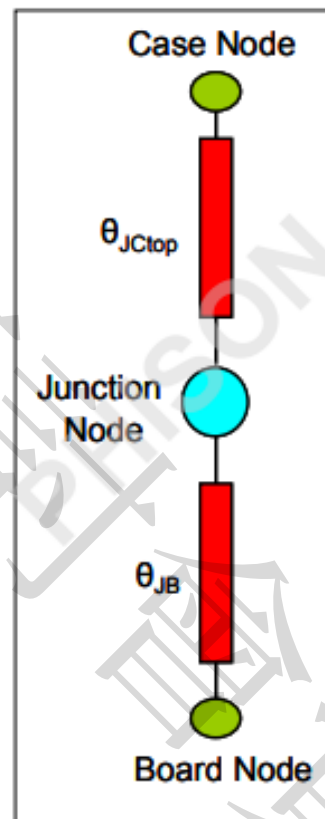
2-resistor CTM - Definition

Definition

1.) Consists of 3 nodes, case, junction and bottom are connected by 2 resistors.

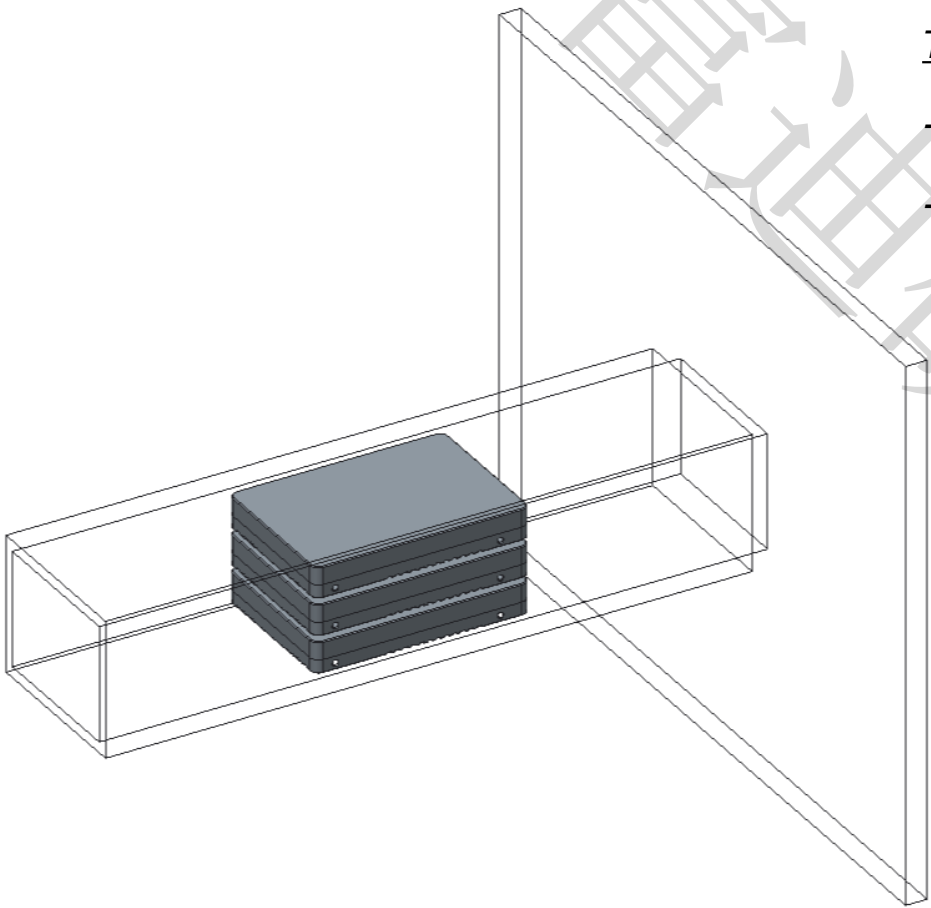
- It's the simplicity and intuitiveness of CTM.
- Generated from JEDEC standard tests for junction to case resistance and junction to board resistance.
- The 2-resistor CTM contains some artifacts from the test environments.

2.) There are only two paths for the heat to leave the junction node and flow into the environment - through the case node and through the board node. The model does not account for heat flow through the sides of the package.



Conduct most of the heat to top and bottom cover

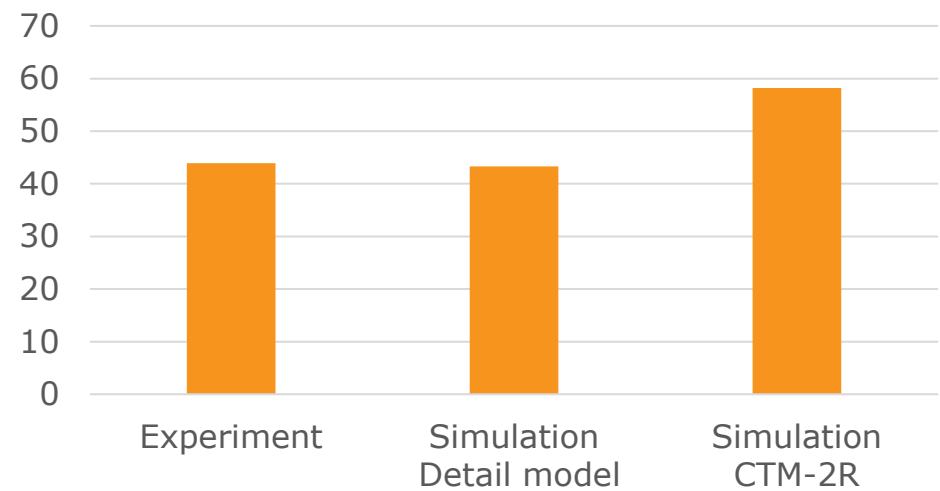
2-resistor CTM – Simulation result



Test Conditions

- T_a : 25°C
- 25.26 CFM

NAND Max. temperature

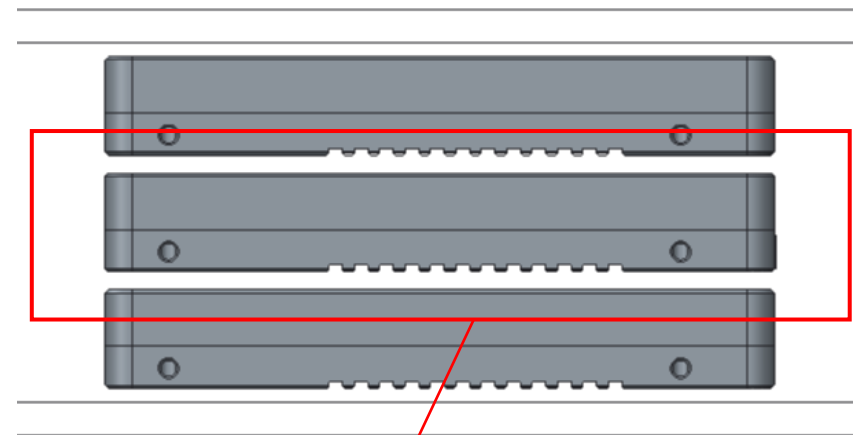


	Max. NAND Temp
Experiment	43.9 °C
Sim., Detail model	43.3 °C
Sim., CTM-2R	58.2 °C

2-resistor CTM – Simulation result

There are ~~only~~ two paths for the heat to leave the junction node and flow into the environment - through the case node and through the board node. The model does not account for heat flow through the sides of the package.

- In this case, a lot of heat is dissipated by the side surfaces, and its influence cannot be ignored.
- 2-resistor CTM is too simplified to describe the heat dissipation mechanism properly for this condition.
- The CTM should consider the effect of side surfaces.



Velocity contour, X-Y plane

DELPHI CTM

Definition

1.) Comprised of a limited number of nodes connected to each by thermal resistors.

- Each node associated with a single temperature only.
- Surface nodes are associated with a physical region of package surface and communicate with internal nodes and surrounding environment.
- Internal nodes do not communicate with the environment directly. However, it may associate with a heat source.
- The DELPHI CTM is simulation-based.
- The DELPHI CTM contains no artifact of the test environment.

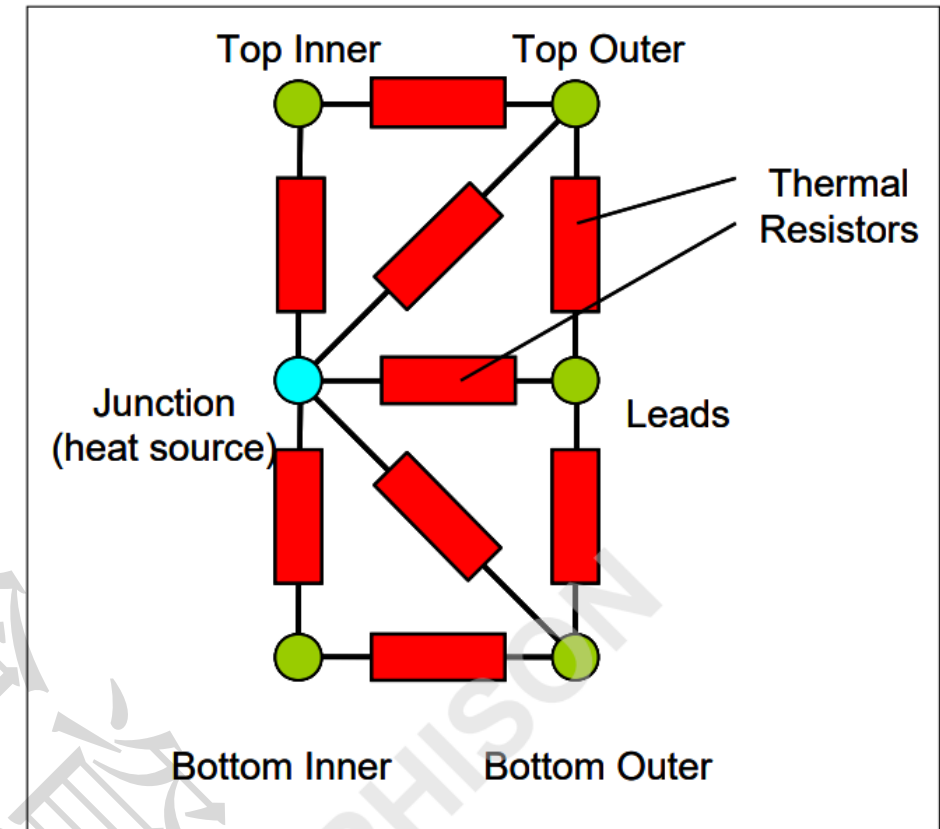
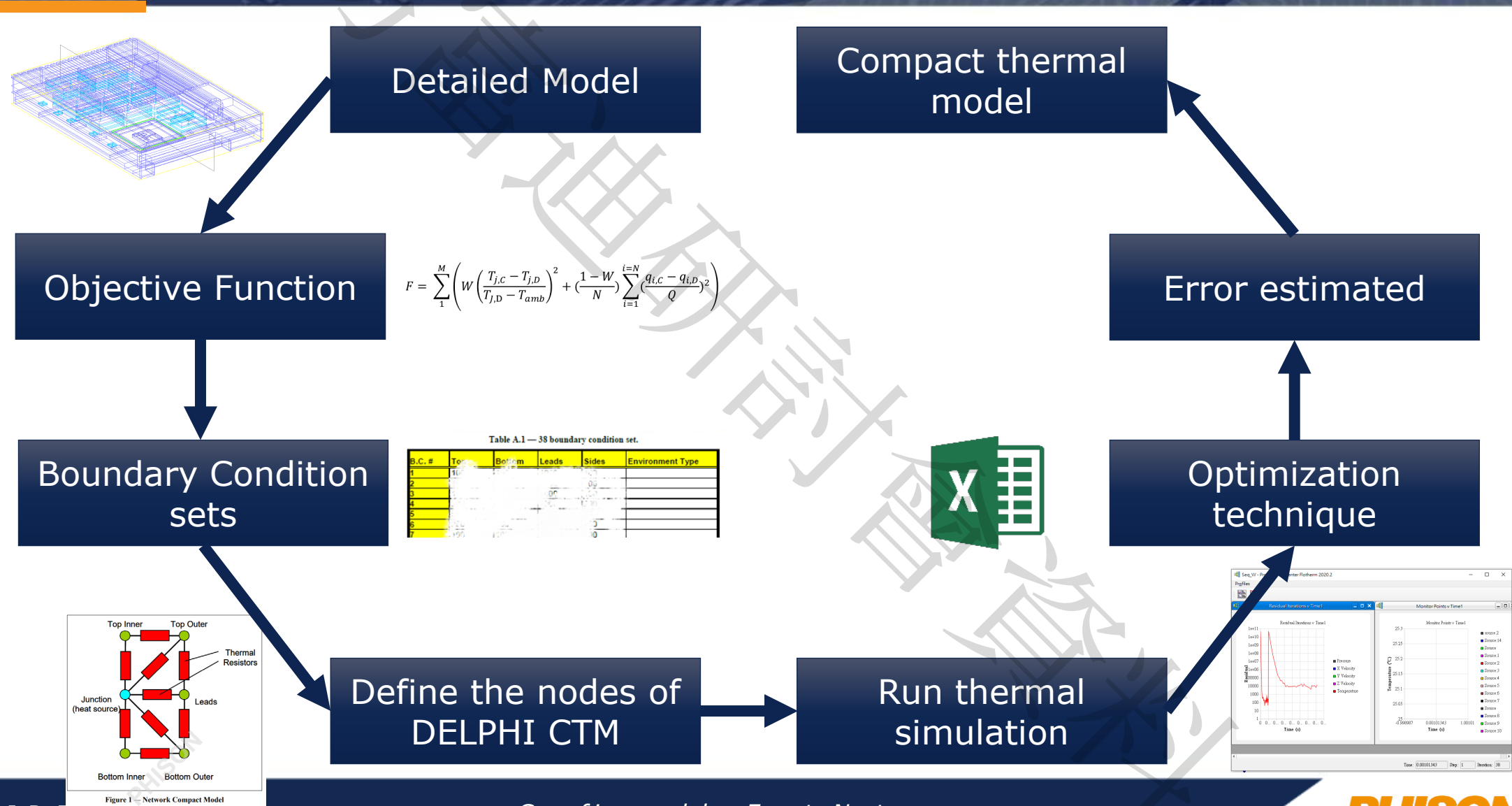


Figure 1 — Network Compact Model

DELPHI CTM generation flow



Objective function

- Defined as the discrepancy between the detailed model and prediction from the compact model summed.
- It can be constructed in several ways, but it is recommended that it include terms related to the heat flux from all surface nodes and junction temperature.

$$F = \sum_1^M \left(W \left(\frac{T_{j,C} - T_{j,D}}{T_{j,D} - T_{amb}} \right)^2 + \left(\frac{1 - W}{N} \right) \sum_{i=1}^N \left(\frac{q_{i,C} - q_{i,D}}{Q} \right)^2 \right)$$

M : the number of boundary condition sets

N : the number of external nodes

$T_{j,C}$: the junction temperature of compact model

$T_{j,D}$: the junction temperature of detailed model

T_{amb} : the ambient temperature

$q_{i,C}$: the junction temperature of compact model

$q_{i,D}$: the junction temperature of detailed model

T_{amb} : the ambient temperature

W : the weight factor

Boundary Condition sets

- A DELPHI CTM is derived using an optimization process over a universal boundary condition set.
- The boundary condition set should reflect the full spectrum of environment conditions encountered by the package in typical electronics applications.
- DELPHI consortium proposed a set of 38 boundary conditions.

Each column represent a particular class of boundary condition.

Table A.1 — 38 boundary condition set.

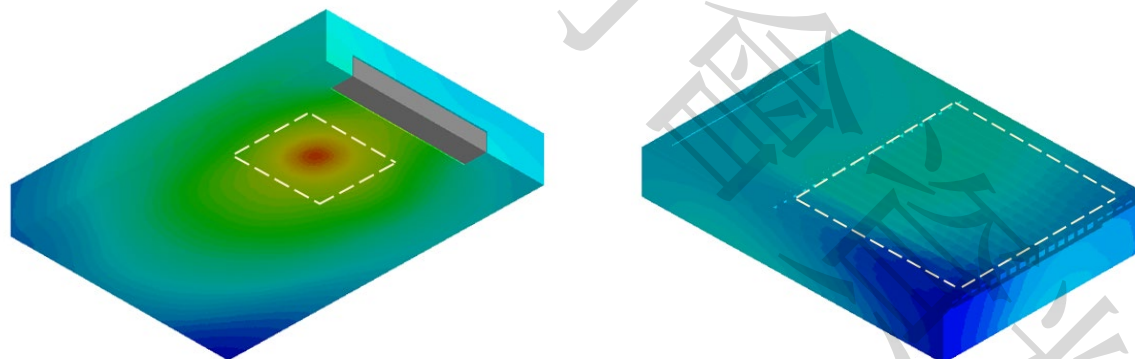
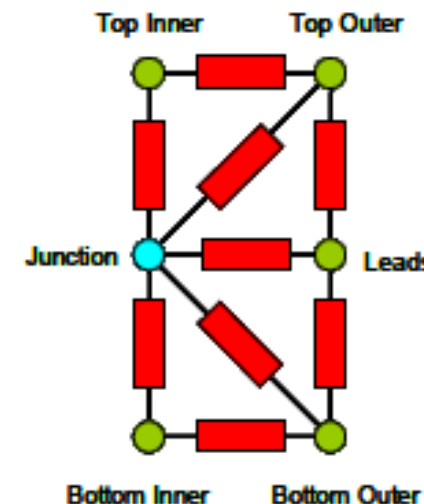
B.C. #	Top	Bottom	Leads	Sides	Environment Type
1	100				
2				00	
3			00		
4				10	
5					
6	100	00		0	
7	100	100		10	
8	100				Forced Convection
9					
10				10	
11	1				
12					
13					
14	100			00	
15	100	100			
16	100	00			
17	0				
18	0	10		0	Free Convection
19	10	10			
20	100				
21	100	100			
22	100	100	100	100	
23	0			10	
24	100	100	00		
25					Heat Sink
26					
27	1				
28	10				
29	100			10	
30				10	
31	100/K				
32		100/K			Cold Plate
33		100/K			
34		100			
35	100	100	100	100	09
36	100	100	100	100	
37			100	100	Fluid Bath
38			100	50	

All Heat transfer coefficients have units of W/m²·K

Define the nodes of DELPHI CTM

The definition of nodes is a critical part of DELPHI methodology because it should be enough to describe the cooling mechanism of detailed model.

- . If the surface is significantly non-isothermal, sub-divide the surface into several nodes is important. In most of the cases, two surface nodes, inner and outer, each on the top and bottom surfaces of package provide sufficient granularity to resolve the temperature gradients. The relative surface coverage of the inner and outer nodes can also affect the quality of the model.
- . In some cases, nodes defined for the sides of the package can improve the model accuracy.
- . If the effect of asymmetric boundary conditions is severe, the isothermal side node can be breakdown.



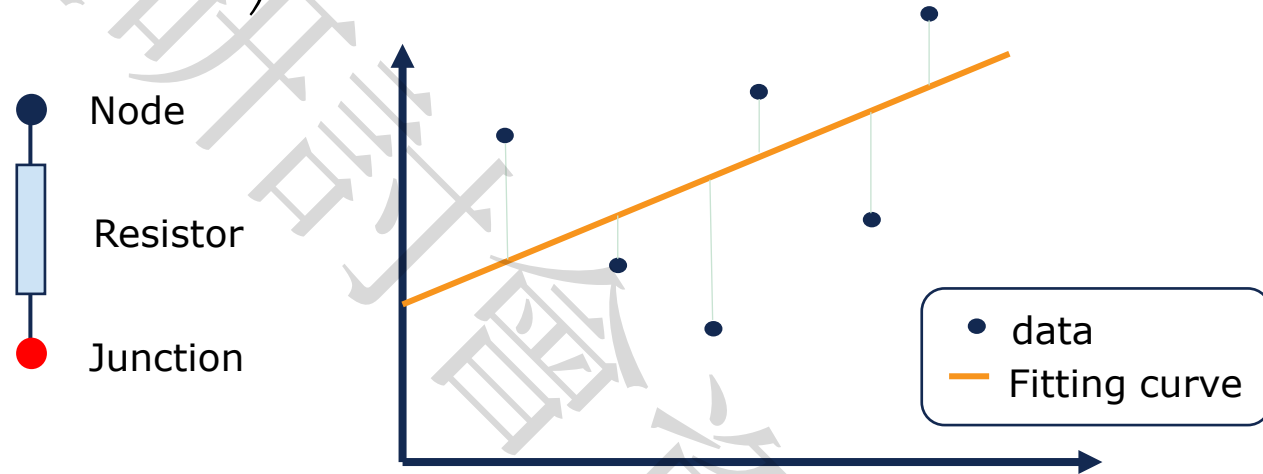
 : Inner region

Optimization technique

- Choosing a suitable optimization scheme to find out a set of resistor to make the objective function (F value) can be minimized.

$$F = \sum_1^M \left(W \left(\frac{T_{j,C} - T_{j,D}}{T_{J,D} - T_{amb}} \right)^2 + \left(\frac{1 - W}{N} \right) \sum_{i=1}^N \left(\frac{q_{i,C} - q_{i,D}}{Q} \right)^2 \right)$$

Ex. least-squares method

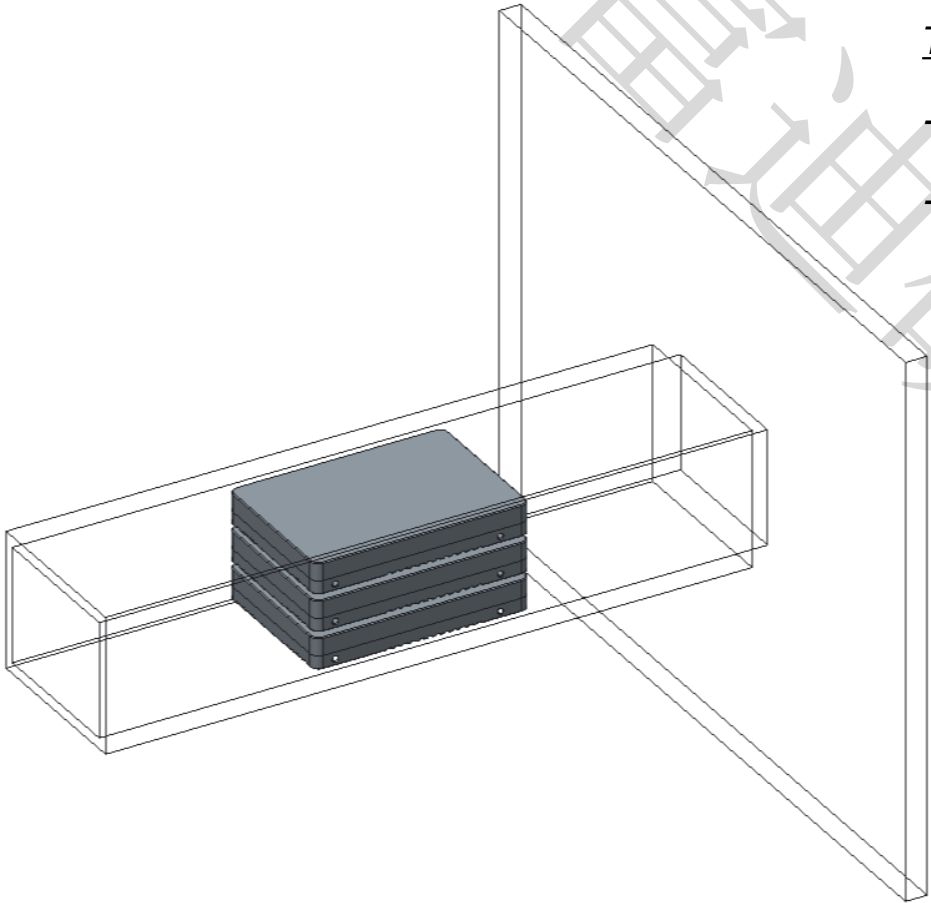


- There are several optimization schemes to choose from – ranging from the simpler least-squares type approaches to more complex non-linear techniques.
- It should be noted that some optimization techniques will yield more accurate models than others.

Error estimating

- . An important component of the DELPHI methodology is its inherent ability to generate a measure of the quality of the compact model.
- . The error estimate is obtained by exercising the compact network against the test boundary condition set.
- . The predicted results for the fluxes and/or junction temperatures for the compact model can then be compared against the detailed model data for each of these test boundary conditions, and the error reported.

Compact thermal model

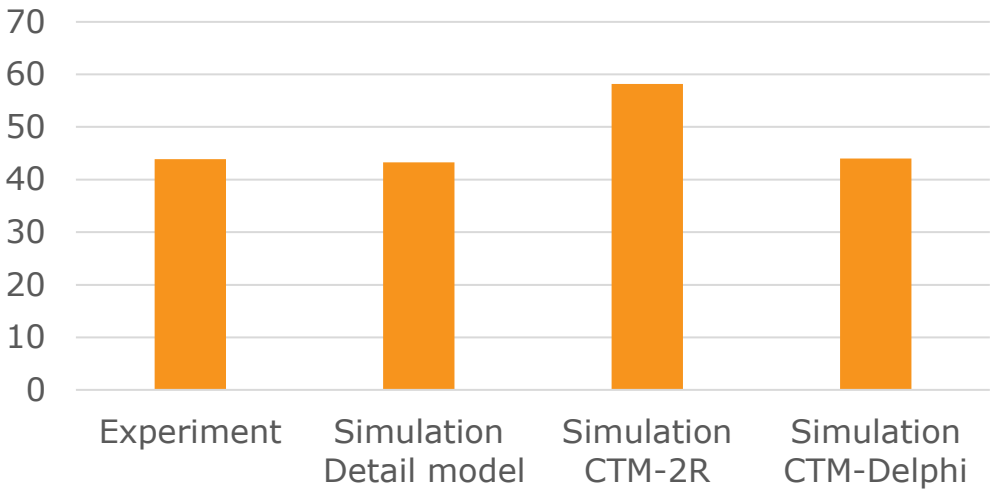


Test Conditions

- T_a : 25°C

- 25.26 CFM

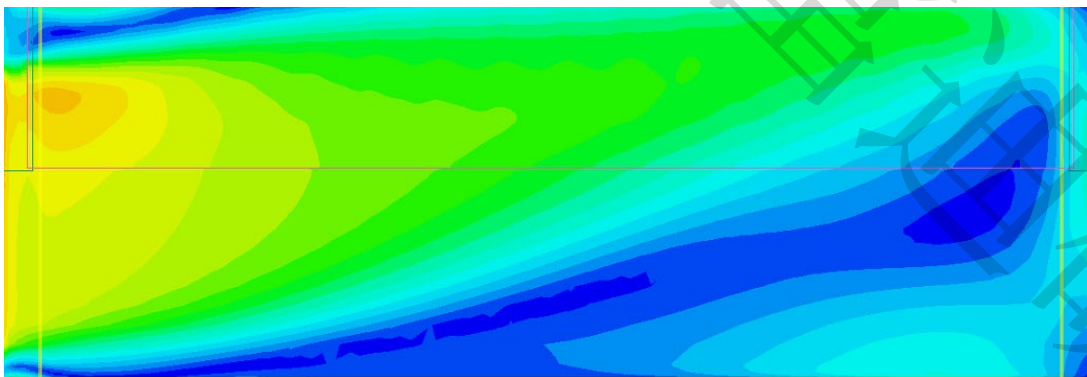
NAND Max. temperature



	Max. NAND Temp
Experiment	43.9 °C
Sim., Detail model	43.3 °C
Sim., CTM-2R	58.2 °C
Sim., CTM-Delphi	44.0 °C

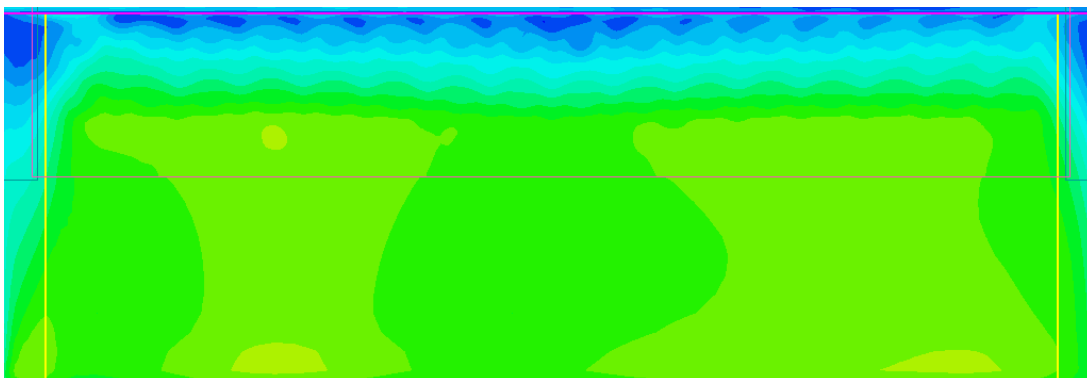
Thermal Test Chamber Evaluation

Topic – The way to evaluate the design of chamber in the early stage



Original - DUT temperature

133.9	115.1	107.1	105.1	104.7	104.4	104.2	104.0	103.9	103.9	104.1	105.0	106.0	105.7	107.5	118.9
131.4	115.9	108.4	105.4	104.7	104.2	104.1	104.0	103.9	103.9	104.0	104.1	105.1	106.6	108.3	120.3
130.3	115.2	107.7	104.7	103.9	103.5	103.4	103.3	103.3	103.4	103.5	103.8	104.9	106.2	108.1	124.8
130.0	115.0	107.3	103.9	103.0	102.7	102.6	102.7	102.7	102.9	103.3	103.8	105.0	106.2	108.1	126.9
129.5	114.7	107.2	103.8	102.8	102.4	102.2	102.0	101.9	101.9	102.0	102.2	102.4	102.1	100.6	99.3



Modified - DUT temperature

67.6	67.8	68.0	68.2	68.6	69.0	69.1	69.1	68.9	68.8	68.7	68.6	68.4	68.2	67.8	67.7
67.6	67.6	67.9	68.2	68.5	68.8	69.1	69.2	69.0	68.9	68.7	68.6	68.4	68.2	67.8	67.9
67.6	67.7	68.0	68.4	68.7	69.1	69.2	69.1	68.9	68.7	68.7	68.6	68.4	68.3	68.0	68.1
67.8	67.8	68.2	68.5	68.8	69.1	69.3	69.1	68.9	68.8	68.5	68.5	68.5	68.4	68.2	68.5
68.1	68.2	68.3	68.4	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.5	68.4	68.3	68.0	67.8

Improve the chamber design by optimizing the flow field, and the temperature is a quantitative index of improvement.

Conclusion

JEDEC defined 2 package CTM model, 2-Resistor and DELPHI, to eliminate the barriers encounter by system-level model, like lacks the detailed information of component structure, simulation efficiency...etc. This model extraction method may also can be used in system-level simulation where there consist of many devices and get an accuracy simulation result. However, it is necessary to consider whether the limitations of CTM are acceptable before the simulation.

- *Limited to single-die packages (source) that can be effectively represented by a single junction temperature.*
- *2-resistor CTM and DELPHI CTM are limited to use in steady state analysis, dynamic compact model is not covered.*
- *Flotherm provides another model extraction method that can simultaneously consider multiple heat sources and is used for transient analysis -> **BCI - ROM***

Reference

- JESD15, Thermal Modeling Overview
- JESD15-1, Compact Thermal Model Overview
- JESD15-3, Two-Resistor Compact Thermal Model Guideline
- JESD15-4, DELPHI Compact Thermal Model Guideline

PHISON

THANK YOU!

易會通有限公司

