Thermal Management of Electronics Using ANSYS Icepak

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Agenda

• ANSYS Icepak Overview

• Sample Problem: Thermal analysis of electronics in downhole equipment
  • Background
  • Problem Description
  • System Model
  • Zoom-in Model

• Summary
ANSYS Icepak is an integrated electronics cooling solution for IC packages, printed circuit boards and complete electronic systems.

- Steady state and transient thermal-flow
- Conduction
- Convection
- Radiation
- Conjugate heat transfer

Velocity streamlines and temperature contours for a card array in a VME format box cooled by three axial fans modeled using a moving reference frame (MRF) fan model.
IC Package Thermal Analysis

Detailed and compact thermal models of IC packages

Import EDA data from a variety of layout tools

Detailed thermal conductivity map for package substrate

Import die power map from a variety of tools

Export temperatures to ANSYS Mechanical for thermal-stress

Create compact thermal models
- Two-resistor, star, DELPHI

Temperature contours on a 272-pin BGA package, package data imported from an MCM file
Cooling simulation for single and rack mounted boards

Import EDA layout data from a variety of board layout tools

Detailed thermal conductivity map for PCB layers

Resistive heating of traces

Export temperatures to ANSYS Mechanical for thermal-stress

Thermal-stress analysis of a computer graphics card
Design the flow and thermal elements for electronic systems

Import 3D MCAD via Workbench Geometry Interfaces

Simply and defeature geometry with ANSYS DesignModeler

Extensive libraries of standard electronic components and materials

Advanced fan modeling

Export temperatures to ANSYS Mechanical for thermal-stress

Temperature contours and fluid velocity vectors of a fan cooled rack mounted computer
Interface to Slwave

• Slwave and ANSYS Icepak exchange both power map and temperature data
  – Accounts for copper resistive losses in printed circuit boards and packages

Current Density (Slwave)

Power Map

Temperature

Temperature (Icepak)
Import temperature data from ANSYS Icepak to ANSYS Mechanical for thermal-stress analysis.

Thermal-stress simulation for a computer graphics card - performed in the ANSYS Workbench environment.
Sample Problem:
Thermal Analysis of Electronics Board in Down-hole Equipment
Electronics devices exist in down-hole tools to collect sensors data, drive actuators, multiplexing, data storage

- Wireline tools
- Logging While Drilling (LWD/ MWD) tools
- Permanent monitoring systems in oil wells

Rough operating conditions:
- Wells are getting deeper ⇒ sink temperature keeps rising
- Formation temperature is about 100 to 120°C at ~ 4 km
- IC packages rarely designed to withstand > 150 °C

Challenge:
- Narrow temperature band of operation ⇒ Thermal management of Electronics is critical
- Natural convection cooling only
- Accurate prediction of electronics reliability is needed—ANSYS Icepak
Case Study: Wireline Toolstring

Thermal analysis of electronics within wireline toolstring

- Complex geometry
  - Wide range of length scales
- Different operating conditions: drilling orientation
- Modeling methodology: System vs. detailed
Perform analysis in two steps

1. **System level analysis**
   - Get the big picture
   - Fewer details
   - Lumped PCB and IC modeling

2. **Zoom-in analysis**
   - More details included
   - Results profiles mapped from System level model
   - Hotspot detection
Problem Description

• **WIRELINE TOOLSTRING**
  - 7’ long, 2.5” dia

• **Houses 16” Electronic Section containing:**
  - PCB with ICs: Power = 11.1 W
  - IGBT FETs x 3: Power = 11 W ea
  - Actuator device: Power = 4 W

• **Tool string studied in 8” dia well**
  - Natural convection in well fluid
  - Natural convection and radiation within electronic section of tool
Problem Description (Contd.)

• Power components (red)
  • PCB components total 11.1 W
    – Details in next slide
  • IGBT x3 : 11 W each
    – Mounted on single heat sink
  • Actuator: 4 W

• All parts mounted on the Core
• Core slides into housing
• Contact resistances exists between parts
Problem Description (Contd.)

PCB DETAILS

• 14 ICs on PCB
• $\theta_{jc}$ and $\theta_{jb}$ data for different ICs
• 6 Cu layers in PCB

<table>
<thead>
<tr>
<th>Name</th>
<th>Q (W)</th>
<th>$\theta_{jb}$ (C/W)</th>
<th>$\theta_{jc}$ (C/W)</th>
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<td>-</td>
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<tr>
<td>Diode</td>
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</table>

**IC details**

Layer details

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thick (mil)</th>
<th>% Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>PCB</td>
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$k_p = 18.6 \text{ W/m.K}; k_N = 0.38 \text{ W/m.K}$

PCB trace layers details
Icepak can accept both MCAD and ECAD data.

CAD-to-Icepak conversion in ANSYS Design Modeler (DM)

1. Import native CAD using ANSYS CAD interface.
2. Use any DM tools to modify geometry as required.
3. **DM ELECTRONICS (DME)**: convert into Icepak objects.
Modeling: Geometry—PCB

- Import board layout and trace data directly into Icepak
  - Board outline and components layout ← IDF import
  - PCB traces ← ANSYS Ansoftlinks, Gerber, BRD formats
System Level Model

Get the BIG PICTURE

- Overall heat flow from tool to surroundings
  - Keep larger components
  - Reduced details $\rightarrow$ fewer mesh count $\rightarrow$ faster run

- All possible operating conditions external to tool
  - Well fluid properties, e.g. non-Newtonian
  - Different formation temperature conditions
  - Tool orientation – gravity direction
  - Model natural convection and radiation within tool
System Level Model

- Only larger components considered
- Board:
  - Individual components on PCB NOT modeled
  - PCB generates 11.1 W of component power
  - Uniform orthotropic conductivity of PCB – compact PCB model
- IGBTs: Network resistor model with $\theta_{jb}$ (C/W)
- Actuator: Actuator – lumped Fe block with 4 W

- Simpler model $\rightarrow$ Less details $\rightarrow$ Fewer mesh count
System Level Model

- 4 Different cases considered:
  - First three to determine worst case scenario
  - Working fluid: water
  - Domain height: 20’ for cases i, ii, and iii; 30’ for case iv

<table>
<thead>
<tr>
<th>Case</th>
<th>Top BC</th>
<th>Bottom BC</th>
<th>Side wall</th>
<th>Gravity</th>
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</thead>
<tbody>
<tr>
<td>i</td>
<td>Open</td>
<td>Open</td>
<td>T=100 °C</td>
<td>-9.81 ( \dot{j} )</td>
</tr>
<tr>
<td>ii</td>
<td>Open</td>
<td>T= 00 °C</td>
<td>T=100 °C</td>
<td>-9.81 ( \dot{j} )</td>
</tr>
<tr>
<td>iii</td>
<td>Open</td>
<td>T=100 °C</td>
<td>T=100 °C</td>
<td>-9.81 ( \dot{k} )</td>
</tr>
<tr>
<td>iv</td>
<td>Adiabatic</td>
<td>T=100 °C</td>
<td>T=100 °C</td>
<td>selected from worst case</td>
</tr>
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</table>
Results: System Level Flow – Cases i, ii, iii

• Well fluid flow structure
  – Reasonable to expect annular circulation
  – Low velocity vectors at bottom

• Case i – unidirectional upward flow → Not realistic
• Case ii – flow recirculation around tool → reasonable
• Case iii (horizontal)– Very different flow field as expected
• Temperatures for IGBTs and PCB
  • Similar temperatures in cases i, ii
  • Slightly lower temperatures for Case iii

  Component Temperatures in °C

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<tr>
<th>Component</th>
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<th>Case ii</th>
<th>Case iii</th>
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<tr>
<td>igbt.1</td>
<td>110.4</td>
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<td>108.7</td>
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<td>110.2</td>
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• Case ii may be considered as the *Worst* case scenario—Case iv

• Modeling concerns with case ii:
  – Top opening too close to tool – may numerically influence flow field
  – Complete recirculation is not visible
    – Extend domain
Results: Case iv

• Well extended above tool → $H_{total} = 30'$

• Top B.C. set to adiabatic wall:
  - Enforces circulation
  - Temperatures similar to case ii

Component Temperatures in °C

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• Further confidence in earlier results
• Case iv used to create zoom-in detailed model (discussed later)
Detailed Zoom-in Model

• Focus: Electronic section of the tool string
  • Detailed flow structure and temperature distribution
  • PCB hotspot detection

• Case iv solution used to create zoom-in model:
  – 1’ from electronic housing at the top → temperature within 1 °C rise from ambient
  – 3” from electronic housing at the bottom
  – P, U_x, U_y, U_z, and T profiles used as BC for zoom-in model
Detailed Zoom-in Model

• Detailed Board model
  – All PCB components included

• Two PCB modeling options applied

  1. Uniform orthotropic conductivity:
     – Uniform planar and normal conductivities \((k_P, k_N)\)
       used throughout the PCB

  2. Trace based conductivity
     – Computed from Cu pattern of each CFD cell
     – Each cell in the PCB has a unique triad of \((k_x, k_y, k_z)\)

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Orthotropic conductivity

Trace Distribution
Results: Zoom-in Model

- Comparison of conductivities of the PCB
- Lumped PCB:
  - Layer 1 – all components are mounted
    - Therefore most important to capture trace conductivity
    - Layers 2, 5 almost fully copper ($k \sim 385 \text{ W/m.K}$)
- Overdesign with lumped PCB

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$k_{PCB}$ in trace modeled PCB

Conductivity of Lumped orthotropic PCB
Results: Zoom-in Model

- Type of PCB model – important to temperature field
- Trace important for down hole tools → conduction dominated

<table>
<thead>
<tr>
<th>Component</th>
<th>Compact PCB</th>
<th>Trace PCB</th>
<th>% diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>U4-SO8</td>
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<td>109.9</td>
<td>-0.3</td>
</tr>
</tbody>
</table>

Higher temperature levels for compact PCB model
Results: Zoom-in Model

Compact PCB

Temperature
207.6
181.7
155.7
129.7
103.7

[C]

Detailed PCB

Temperature
163.6
147.6
131.6
115.6
99.6

[C]
• Icepak is integrated into ANSYS Workbench

• Goal: CFD and thermal only
• Focus limited to modeling with Icepak

• Goal: Thermo-Mechanical
• Detailed thermal field from Icepak
System Coupling: Thermo-Mechanical Analysis

- Interpolated temperatures on PCB in Mechanical
- Ready for Mechanical analysis
Summary

- Close integration of Icepak and Chip/package design tools
- Thermal analysis of downhole electronics conducted for different operating conditions
- System and zoom-in detailed models analyzed
  - System level: big picture analysis of flow and T profiles
  - Zoom-in: hot spot detection
- System coupling available with Icepak