26 March 2008

FLD-0117-01 ISSUE 1
ROACH PRELIMINARY STUDIES

1. Abbreviations and Definitions

EFD	Engineering Fluid Dynamics – a specific Computational Fluid Dynamics software package. (Sometimes EFD.Lab)
ES	Engineering Sessions
SW	SolidWorks – a 3D modelling software package in which EFD is integrated.

2. Synopsis

The first study on the 1U enclosure termed ROACH is reported in this document. Heat loads, as supplied by Etienne Bauermeister, were simulated using a Computational Fluid Dynamics software package called EFD.Lab. In this preliminary study, the thermal effect of the heat load is shown where there is no cooling scheme; mechanisms, such as heat sinks, heat pipes, fans and thermal interface materials, can now be added to the design to correct the problem areas as identified in this study.

At the given heat loading, all of the PCB exceeds 100ºC and ***a cooling scheme is required.***

3. Introduction

Etienne Bauermeister, the Digital Signal Processing Specialist of MeerKAT (Karoo Array Telescope) Project contacted Nicholas Sessions of Engineering Sessions with a request to simulate the heat transfer and thermal situation of an electronics 1U enclosure termed ROACH.

Etienne supplied power dissipation rates of chips on the PCBs and the solid model of the enclosure as modelled by Willem Esterhuyse.

The approach in this project is to first examine the heat loading on the enclosure without a cooling scheme, identify the problems and address those specific problems with, inter alia, fans and/or heatsinks and choose the most appropriate TIMs (Thermal Interface Materials).

The analysis was run twice: first with specific material properties and then secondly with more general properties. Neither will yield the correct answer as there is not enough information – but the picture that they both paint is similar and suggests the implementation of a serious cooling scheme.

4. Inputs

The following overlay (Figure 1) and associated power dissipation rates (Table 1) are given.

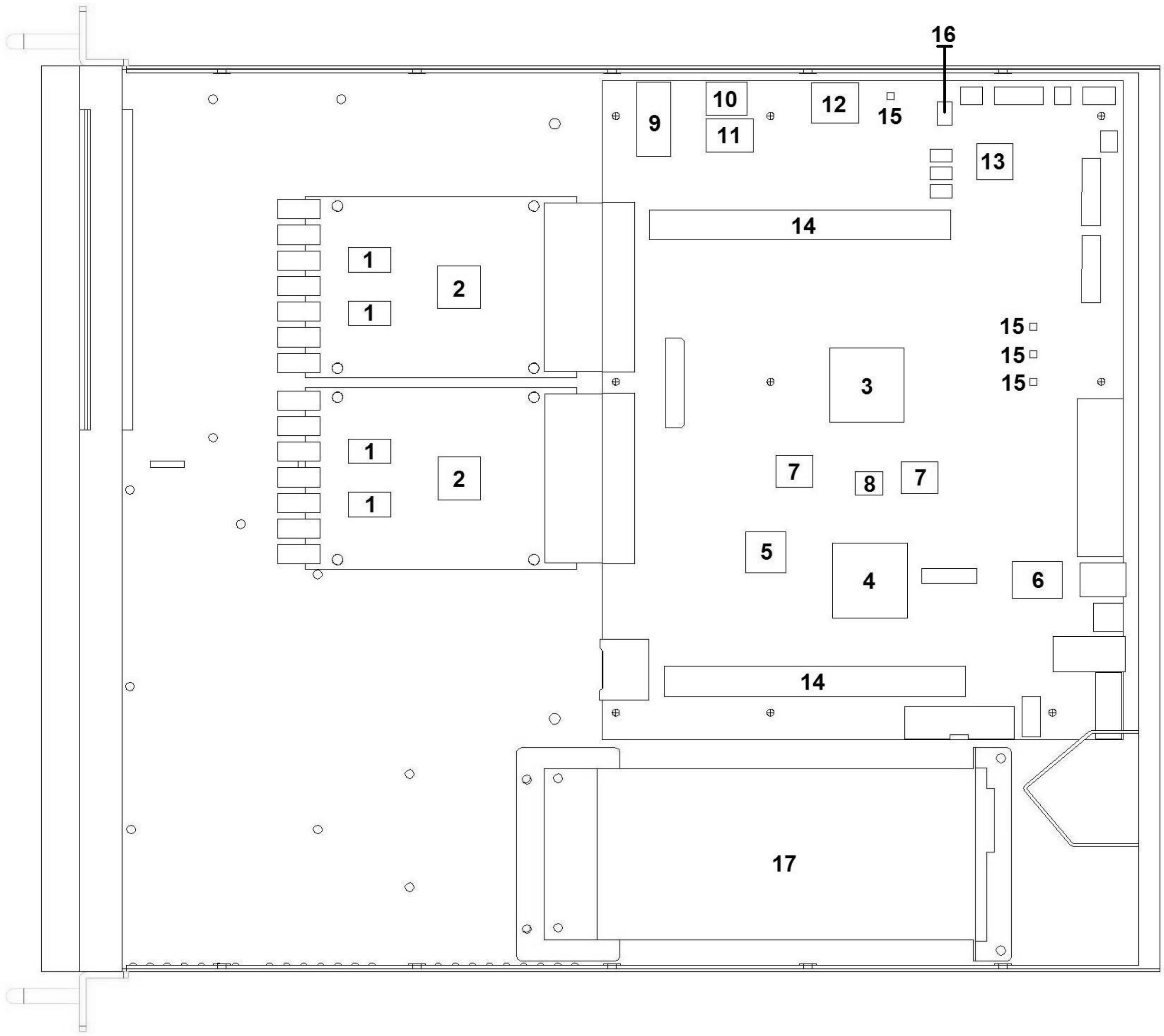

Figure 1: Overlay of 1U enclosure showing position of given power dissipation rates

Table 1: Dissipation Rates

Item #	Description	Power Dissipation	Comments
1	LT1963AEQ	2.95 W	1.5A x (5V - 3.3V) + (0.08A x 5V)
2	AT84AD001BCTD	1.7 W	
3	Virtex 5 SX95	40 W	Worst Case
4	AMCC 440EPC	3.77 W	
5	XC2C256	1.67 W	
6	DP83865	1.64 W	
7	K7S3218T4C-FC40	1.71 W	
8	S29AL032D	0.11 W	
9	PTH05T210WAD	5 W	Maximum Rating
10	PTH08T230WAD	2.5 W	Maximum Rating
11	PTH08T240WAD	3.75 W	Maximum Rating
12	PTH08T220WAD	5.5 W	Maximum Rating

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Item #	Description	Power Dissipation	Comments
13	AFS600	0.66 W	General Design Example
14	DIMM Memory Module	6 W	General Approximation Based on Micron Power Calculator
15	TPS74401RGWT	2.74 W	Maximum Rating
16	FJD3076TM	10 W	Maximum Rating
17	Power Supply	250 W	Maximum Rating

5. Analysis

The project has been analysed twice – each with a slightly different material set. The first, or Run One, uses materials from the EFD Electronics Module Library and the second, or Run Two, uses generic and “simple” materials.

Both analyses have Gravity acting downwards at 9.81 m/s and have radiation – both surface to surface and with the environment. The ambient condition used is 20ºC.

5.1. Run One

In this run a good guess at the properties of the PCB, chips and connectors was taken using typical values from the software’s library. Full details of the analysis are given in Appendix 1 on page 10 and material properties can be found and the end of that chapter.

The following results were obtained. The first set of figures show temperature plots of the solid on the surface. The top cover has been removed in order to see within the enclosure.

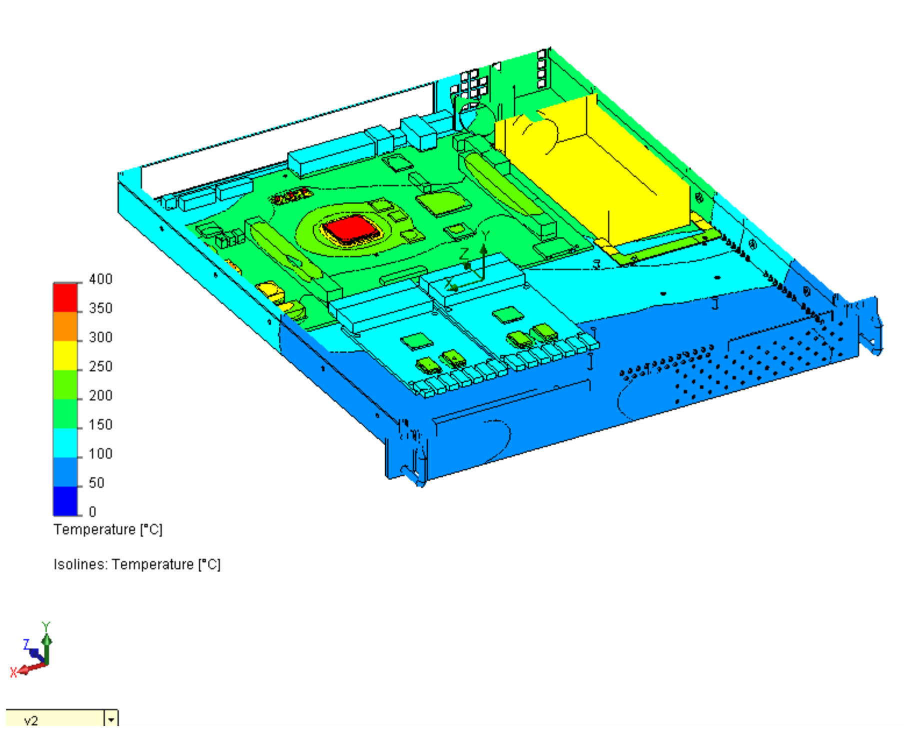

Figure 2: Oblique view of the enclosure without the top cover showing temperature

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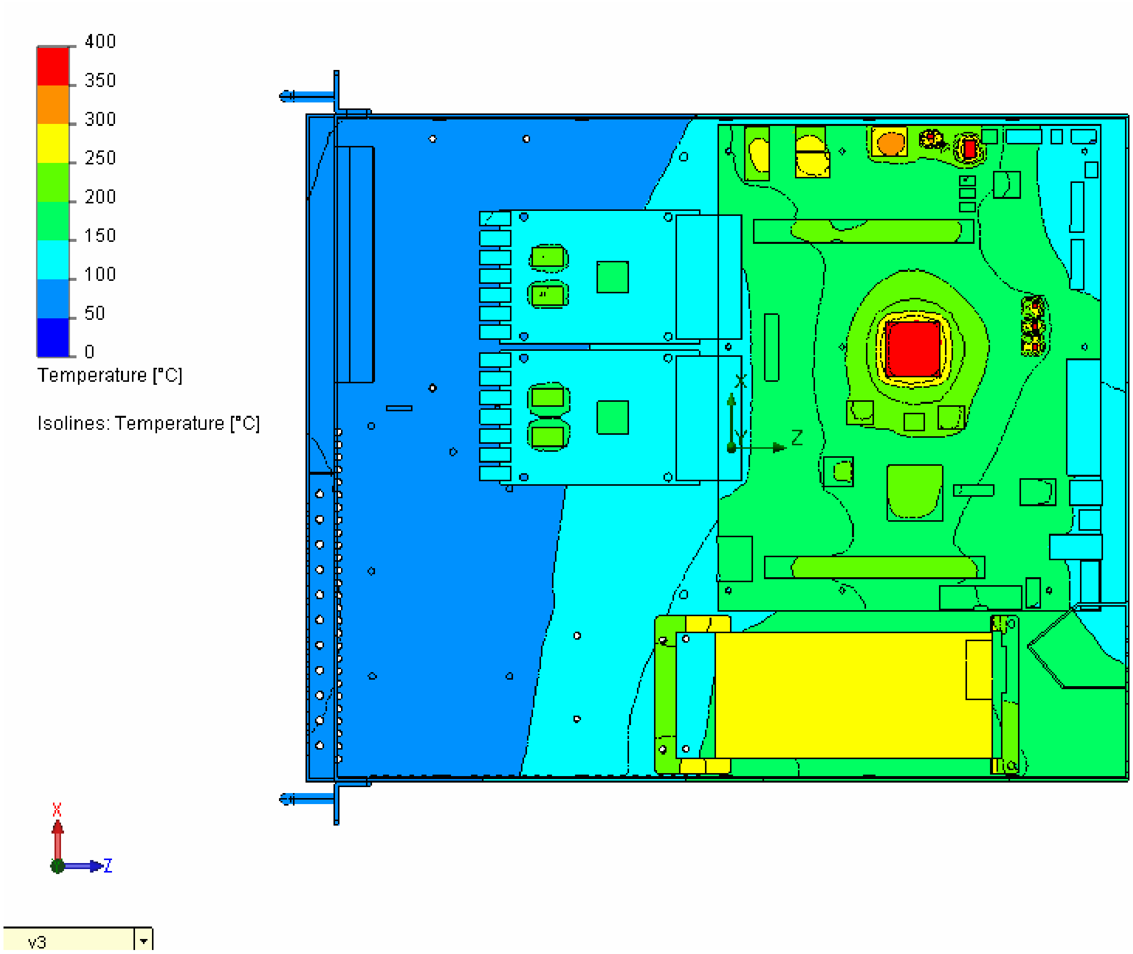

Figure 3: Top View of enclosure without top cover showing temperature of components

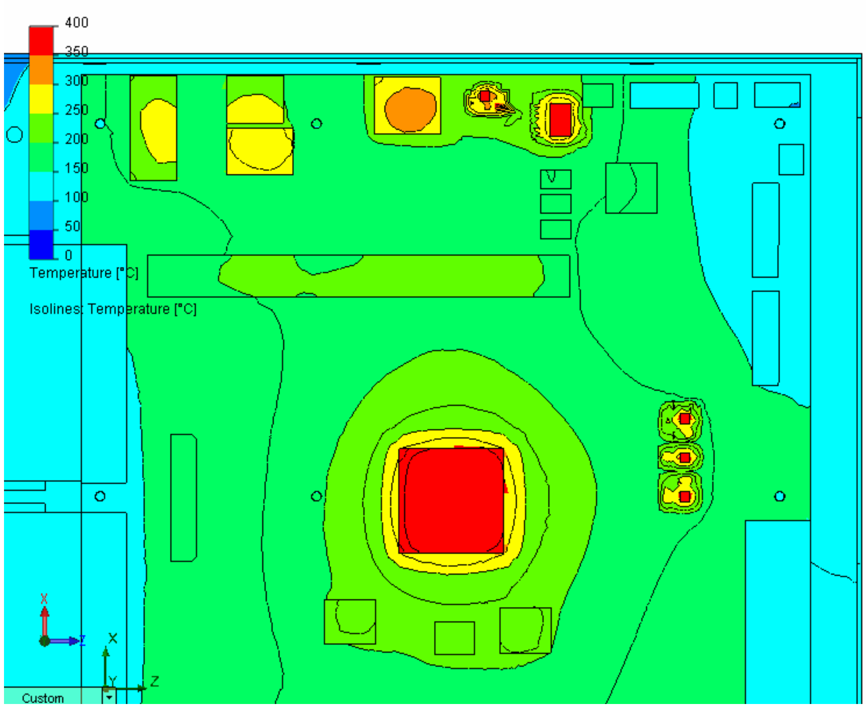

Figure 4: Zoomed in on the hot components

Here we see underneath the enclosure and see that the power supply generates a hot spot.

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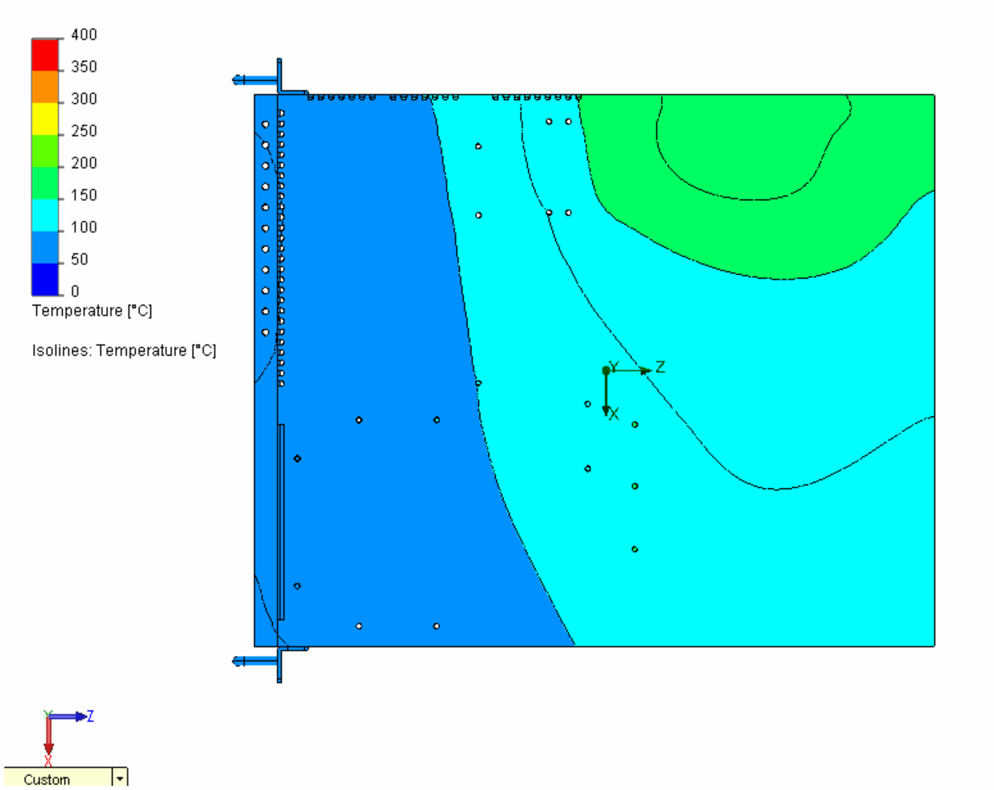

Figure 5: Underside of the enclosure. The Power Supply (250 W) is generating the hot spot

In Figure 6, we see the flow trajectories through the enclosure. The trajectories are "seeded" on the chips designated 3 and 4 (the two large chips in the middle).

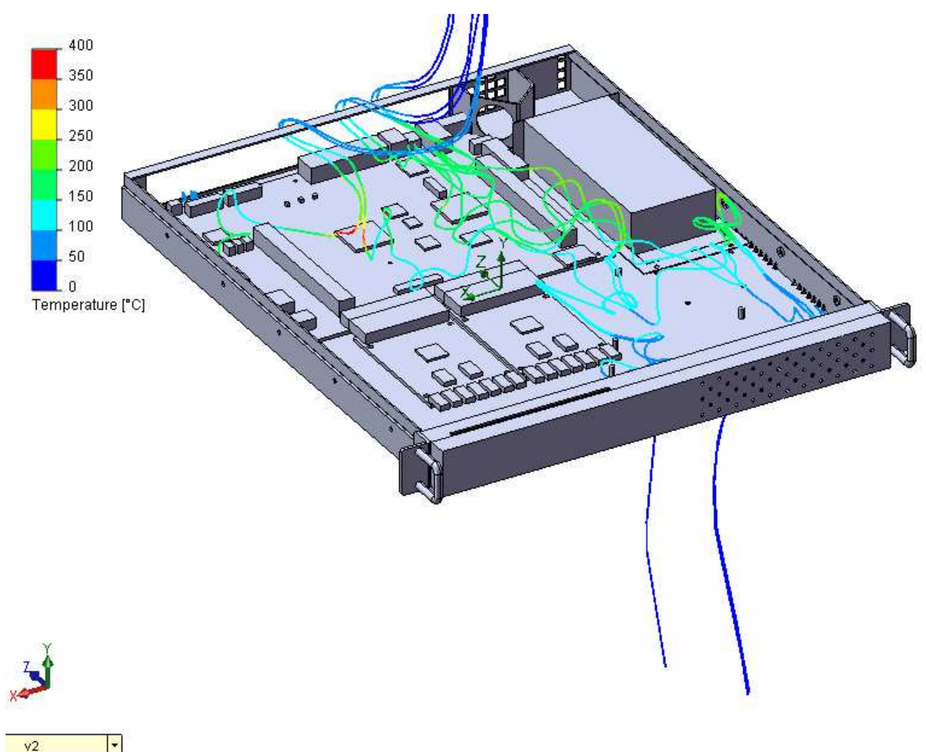

Figure 6: Flow Trajectories through the enclosure

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5.2. Run Two (with <u>Alternative</u> Materials)

In this study (Run 2) we see the analysis repeated with more “Standard” materials. The PCB is made from Epoxy – the non-isotropic properties of a PCB are ignored – and the chips are made from silicone. The purpose is to help ensure that the results obtained in the first analysis are believable.

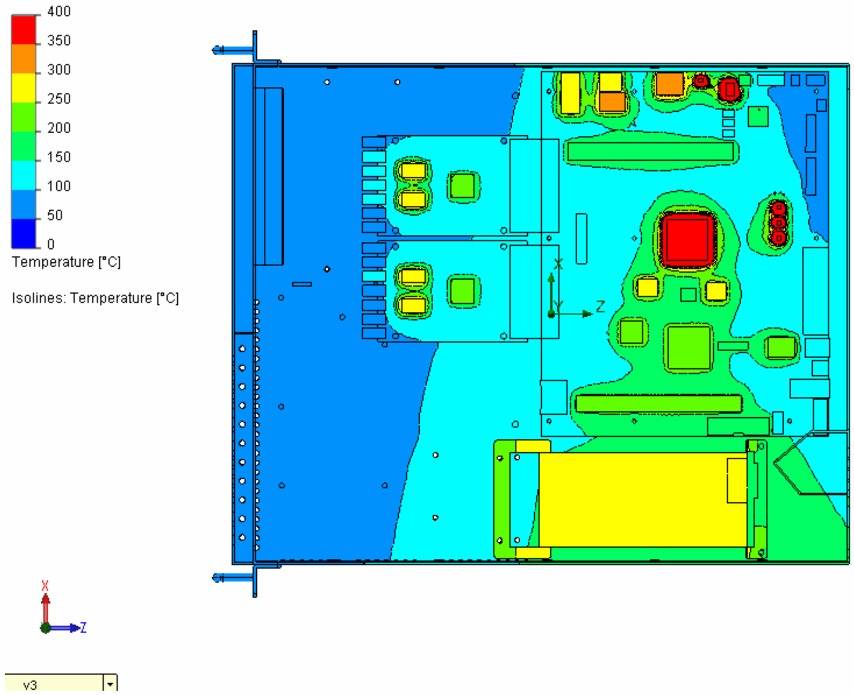

Figure 7: Top View of Enclosure (<u>Alternative</u> Materials)

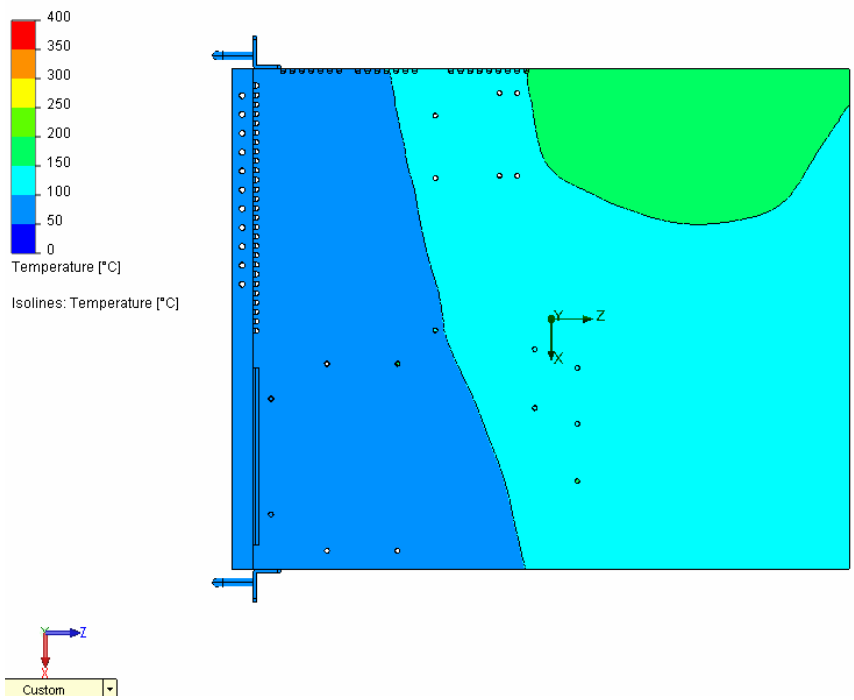

Figure 8: Bottom View of Enclosure (<u>Alternative</u> Materials)

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6. Presentation of Results and Discussion

The bulk average temperatures for each of the chips are shown in the table below. Where there are more than one component with the same designation then their temperatures are reported as a, b, c, etc where the numbering goes from left to right and top to bottom (e.g. the top left component is “a”, the one to the right of “a” is “b” and the one below “b” is “c”, etc)

Table 2: Chip Temperatures for the two Runs

Item #	Description	Power Dissipation (W)	Run 1 (ºC)	Run 2 (ºC)
1a	LT1963AEQ	2.95	215	287
1b			216	291
1c			212	296
1d			211	292
2a	AT84AD001BCTD	1.7	159	204
2b			160	205
3	Virtex 5 SX95	40	435	723
4	AMCC 440EPC	3.77	203	238
5	XC2C256	1.67	198	239
6	DP83865	1.64	179	219
7a	K7S3218T4C-FC40	1.71	227	272
7b			231	270
8	S29AL032D	0.11	210	177
9	PTH05T210WAD	5	240	266
10	PTH08T230WAD	2.5	245	279
11	PTH08T240WAD	3.75	267	310
12	PTH08T220WAD	5.5	289	325
13	AFS600	0.66	176	150
14a	DIMM Memory Module	6	201	188
14b			201	213
15a	TPS74401RGWT	2.74	1327	1050
15b			920	926
15c			909	909
15d			845	835
16	FJD3076TM	10	704	865
17	Power Supply	250	297	295

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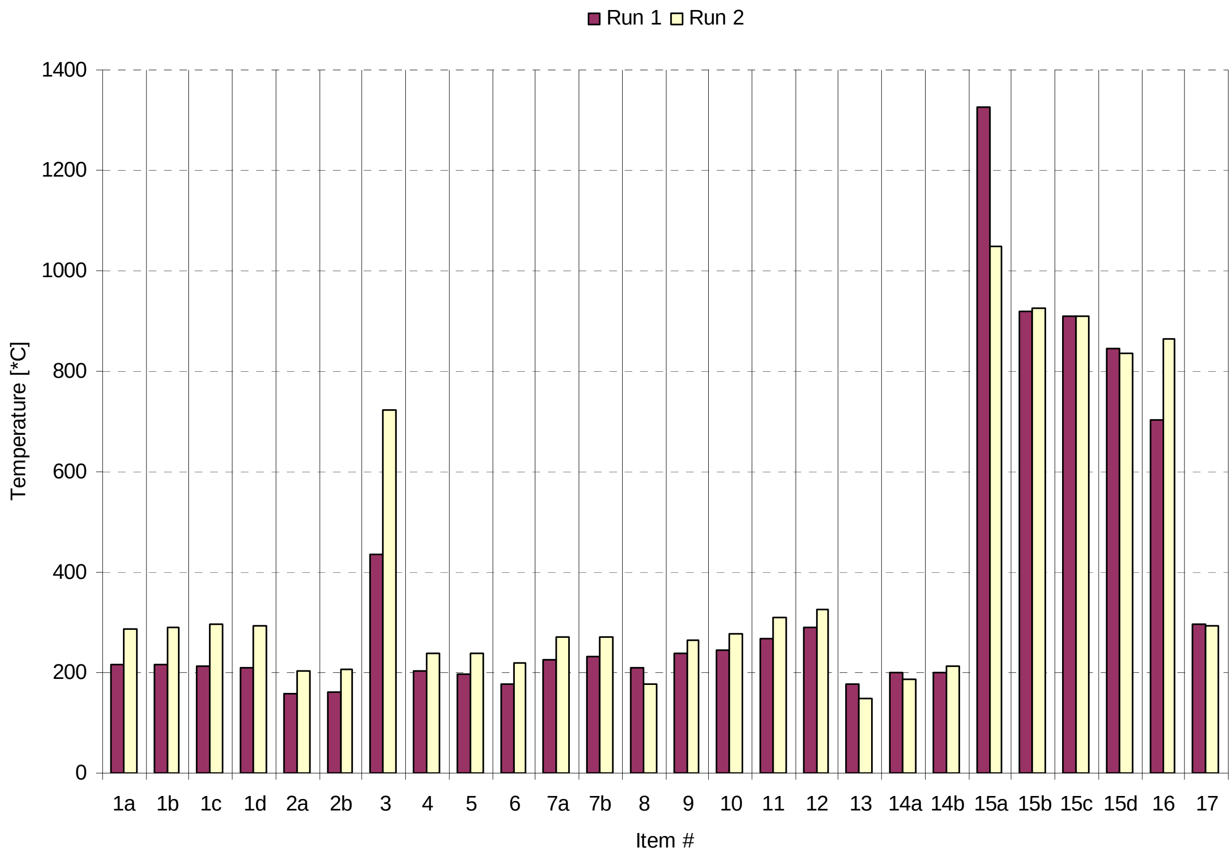

Figure 9: Temperatures for the chips are plotted on the same chart

The temperatures of Run Two differs by more than 20% of the reported temperature of Run One in the following instances: 1a; 1b; 1c; 1d; 2a; 2b; 3; 5; 6; 15a; 16.

Only 15a is one of the above mentioned cases where the temperature in Run One is reported to be higher than in Run Two.

In Run One the PCB material is non-isometric meaning there is greater heat transfer in-plane than through-plane unlike the case in Run Two. The layered copper in the PCB simulation allows the heat of the chip to be dissipated in-plane and so the chip reports at a lower temperature. In the case of the 15a – the chip is surrounded by other components that are contributing heat to the PCB.

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7. Recommendations

Examination of the results presented in the paper leads to the following observations:

- **If it is possible from a board layout perspective, it is recommended that the topmost chip designated 15 is moved into "a more open part" of the board.**

- The power dissipations should be considered in greater detail, for instance, are maximum loads always applicable? If there is a case of maximum load for a specific and short period then phase change materials may be considered to provide cooling in those high demand times.

- It is suggested that the enclosure unit next be analysed with fan units pulling air from the front of the enclosure and better material properties of the PCB should be programmed. Knowledge of the "greater system", the rack in which it resides and other environmental variables should be discussed.

- TIMs (Thermal Interface Materials) should be used in the following study, together with contact resistances, higher degree of physical modelling and greater mesh resolution. More accurate models of the chips can be done here.

- Should there still be requirements for additional cooling afterwards, heat pipes, thermoelectric coolers or liquid cooling can be discussed.

Furthermore it is noted that there is physical interference between the main Roach Board and the fan mounting unit at the back of the enclosure.

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Appendix 1. RUN ONE FULL REPORT

System Info

Product	EFD.Lab 8 1.0. Build: 413
Computer name	THERMO
Operating system	Microsoft Windows XP Professional Service Pack 2 (Build 2600)
CAD version	SolidWorks 2007 SP1

General Info

Model	D:\FLUID SESSIONS\FLD 0117 - KAT - Roach\1U_CHASSIS_ASM.sldasm
Project name	Default
Project path	D:\FLUID SESSIONS\FLD 0117 - KAT - Roach\1\1.fwp
Units system	esBAR
Analysis type	External (not exclude internal spaces)
Exclude cavities without flow conditions	Off
Coordinate system	Global coordinate system
Reference axis	X

INPUT DATA

Initial Mesh Settings

Automatic initial mesh: Off

Basic Mesh Dimensions

Number of cells in X	20
Number of cells in Y	24
Number of cells in Z	16

Control Planes

Control planes in X direction

Name	Minimum	Maximum	Number of cells	Ratio
X1	-0.373414	-0.2352	-	1.12387
X2	-0.2352	0	-	1
X3	0	0.2352	-	1
X4	0.2352	0.373414	-	0.889782

Control planes in Y direction

Name	Minimum	Maximum	Number of cells	Ratio
Y1	-0.313414	0.000444898	-	1.65274
Y2	0.000444898	0.0222499	-	1
Y3	0.0222499	0.044055	-	1
Y4	0.044055	0.324539	-	0.633606

Control planes in Z direction

Name	Minimum	Maximum	Number of cells	Ratio

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Z1	-0.385289	-0.282095	-	1.07925
Z2	-0.282095	-0.01725	-	1
Z3	-0.01725	0.247595	-	1
Z4	0.247595	0.376664	-	0.90004

Solid/Fluid Interface

Small solid features refinement level	6
Curvature refinement level	4
Curvature refinement criterion	0.350000001
Tolerance refinement level	2
Tolerance refinement criterion	0.0005 m

Narrow Channels

Advanced narrow channel refinement	On
Characteristic number of cells across a narrow channel	5
Narrow channels refinement level	3
The minimum height of narrow channels	Off
The maximum height of narrow channels	Off

Computational Domain

Size

X min	-0.37341401 m
X max	0.37341401 m
Y min	-0.313414035 m
Y max	0.32453901 m
Z min	-0.385289035 m
Z max	0.376664035 m

Boundary Conditions

2D plane flow	None
At X min	Default
At X max	Default
At Y min	Default
At Y max	Default
At Z min	Default
At Z max	Default

Physical Features

Heat conduction in solids: On
Heat conduction in solids only: Off
Radiation: On
Time dependent: Off
Gravitational effects: On
Flow type: Laminar and turbulent
High Mach number flow: Off

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Humidity: Off
Default roughness: 20 micrometer

Gravitational Settings

X component	0 m/s^2
Y component	-9.81 m/s^2
Z component	0 m/s^2

Radiation

Default wall radiative surface: Aluminum, commercial sheet
Environment radiative temperature: 293.15 K

Ambient Conditions

Thermodynamic parameters	Static Pressure: 1.01325 bar Temperature: 20 ℃
Velocity parameters	Velocity vector Velocity in X direction: 0 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 0 m/s
Solid parameters	Default material: Aluminum 6061 Initial solid temperature: 20 ℃
Turbulence parameters	Turbulence intensity and length Intensity: 0.1 % Length: 0.000445001031 m

Material Settings

Fluids

Air

Solids

Aluminum 6061
Typical PLCC
Typical Connector

Solid Materials

Typical PLCC Solid Material 1

Components	ASSY_ROACH-1/Part2-22 ASSY_ROACH-1/Part2-33 ASSY_ADC-2/Part1-10 ASSY_ROACH-1/Part2-23 ASSY_ROACH-1/Part2-34 ASSY_ADC-2/Part1-11 ASSY_ROACH-1/Part2-24 ASSY_ROACH-1/Part2-13 ASSY_ROACH-1/Part2-35 ASSY_ADC-2/Part1-12 ASSY_ROACH-1/Part2-25 ASSY_ROACH-1/Part2-14 ASSY_ROACH-1/Part2-36 ASSY_ROACH-1/Part2-26

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	ASSY_ROACH-1/Part2-37 ASSY_ROACH-1/Part2-15 ASSY_ROACH-1/Part2-38 ASSY_ROACH-1/Part2-27 ASSY_ROACH-1/Part2-16 ASSY_ROACH-1/Part2-2 ASSY_ADC-3/Part1-10 ASSY_ROACH-1/Part2-28 ASSY_ROACH-1/Part2-39 ASSY_ROACH-1/Part2-17 ASSY_ADC-3/Part1-11 ASSY_ROACH-1/Part2-29 ASSY_ROACH-1/Part2-18 ASSY_ADC-3/Part1-12 ASSY_ROACH-1/Part2-19 ASSY_ROACH-1/Part2-8 ASSY_ROACH-1/Part2-9 ASSY_ROACH-1/Part2-40 ASSY_ROACH-1/Part2-20 ASSY_ROACH-1/Part2-42 ASSY_ROACH-1/Part2-31 ASSY_ROACH-1/Part2-21
Solid substance	Typical PLCC

Typical Connector Solid Material 1

Components	ASSY_ADC-2/Part1-9 ASSY_ROACH-1/Part2-11 ASSY_ROACH-1/Part2-12 ASSY_ADC-3/Part1-2 ASSY_ROACH-1/Part2-3 ASSY_ADC-3/Part1-3 ASSY_ROACH-1/Part2-4 ASSY_ADC-3/Part1-4 ASSY_ROACH-1/Part2-5 ASSY_ADC-3/Part1-5 ASSY_ROACH-1/Part2-6 ASSY_ADC-2/Part1-2 ASSY_ADC-3/Part1-6 ASSY_ROACH-1/Part2-7 ASSY_ADC-2/Part1-3 ASSY_ADC-3/Part1-7 ASSY_ADC-2/Part1-4 ASSY_ADC-3/Part1-8 ASSY_ADC-2/Part1-5 ASSY_ADC-3/Part1-9 ASSY_ADC-2/Part1-6 ASSY_ROACH-1/Part2-30 ASSY_ROACH-1/Part2-41 ASSY_ADC-2/Part1-7 ASSY_ROACH-1/Part2-32 ASSY_ADC-2/Part1-8 ASSY_ROACH-1/Part2-10

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Solid substance	Typical Connector

Heat Volume Sources

VS Heat Generation Rate 23

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-39
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 22

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-40
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 21

Source type	Heat Generation Rate
Heat generation rate	6 W
Components	ASSY_ROACH-1/Part2-23
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 18

Source type	Heat Generation Rate
Heat generation rate	0.66 W
Components	ASSY_ROACH-1/Part2-27
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 8

Source type	Heat Generation Rate
Heat generation rate	3.77 W
Components	ASSY_ROACH-1/Part2-29
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 1

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-2/Part1-12
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 20

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-42
Coordinate system	Global coordinate system

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Reference axis	X

VS Heat Generation Rate 10

Source type	Heat Generation Rate
Heat generation rate	1.64 W
Components	ASSY_ROACH-1/Part2-9
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 16

Source type	Heat Generation Rate
Heat generation rate	3.75 W
Components	ASSY_ROACH-1/Part2-15
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 3

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-3/Part1-12
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 25

Source type	Heat Generation Rate
Heat generation rate	10 W
Components	ASSY_ROACH-1/Part2-37
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 14

Source type	Heat Generation Rate
Heat generation rate	5 W
Components	ASSY_ROACH-1/Part2-16
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 15

Source type	Heat Generation Rate
Heat generation rate	2.5 W
Components	ASSY_ROACH-1/Part2-14
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 2

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-2/Part1-11
Coordinate system	Global coordinate system
Reference axis	X

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VS Heat Generation Rate 19

Source type	Heat Generation Rate
Heat generation rate	6 W
Components	ASSY_ROACH-1/Part2-22
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 9

Source type	Heat Generation Rate
Heat generation rate	1.67 W
Components	ASSY_ROACH-1/Part2-18
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 24

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-38
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 17

Source type	Heat Generation Rate
Heat generation rate	5.5 W
Components	ASSY_ROACH-1/Part2-13
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 26

Source type	Heat Generation Rate
Heat generation rate	250 W
Components	POWER_SUPPLY-1
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 12

Source type	Heat Generation Rate
Heat generation rate	1.71 W
Components	ASSY_ROACH-1/Part2-19
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 11

Source type	Heat Generation Rate
Heat generation rate	1.71 W
Components	ASSY_ROACH-1/Part2-21
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 13

Source type	Heat Generation Rate

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Heat generation rate	0.11 W
Components	ASSY_ROACH-1/Part2-20
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 4

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-3/Part1-11
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 7

Source type	Heat Generation Rate
Heat generation rate	40 W
Components	ASSY_ROACH-1/Part2-28
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 6

Source type	Heat Generation Rate
Heat generation rate	1.7 W
Components	ASSY_ADC-3/Part1-10
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 5

Source type	Heat Generation Rate
Heat generation rate	1.7 W
Components	ASSY_ADC-2/Part1-10
Coordinate system	Global coordinate system
Reference axis	X

PCB Features

Printed Circuit Board 1

Components	ASSY_ROACH-1/Part2-1
Material	2S2P

Printed Circuit Board 2

Components	ASSY_ADC-2/Part1-1
Material	2S2P

Printed Circuit Board 3

Components	ASSY_ADC-3/Part1-1
Material	2S2P

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Goals

Global Goals

GG Av Density 1

Type	Global Goal
Goal type	Density
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

GG Max Temperature of Fluid 1

Type	Global Goal
Goal type	Temperature of Fluid
Calculate	Maximum value
Coordinate system	Global coordinate system
Use in convergence	On

GG Av Velocity 1

Type	Global Goal
Goal type	Velocity
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

GG Max Temperature of Solid 1

Type	Global Goal
Goal type	Temperature of Solid
Calculate	Maximum value
Coordinate system	Global coordinate system
Use in convergence	On

GG Av Static Pressure 1

Type	Global Goal
Goal type	Static Pressure
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

GG Min Temperature of Fluid 1

Type	Global Goal
Goal type	Temperature of Fluid
Calculate	Minimum value
Coordinate system	Global coordinate system
Use in convergence	On

GG Min Temperature of Solid 1

Type	Global Goal
Goal type	Temperature of Solid
Calculate	Minimum value
Coordinate system	Global coordinate system
Use in convergence	On

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Calculation Control Options

Finish Conditions

Finish conditions	If one is satisfied
Maximum travels	4
Goals convergence	Analysis interval: 0.5

Solver Refinement

Refinement: Disabled

Results Saving

Save before refinement	On

Advanced Control Options

Flow Freezing

Flow freezing strategy	Disabled

View factor resolution level: 3

RESULTS

General Info

Iterations: 242

Calculation Mesh

Basic Mesh Dimensions

Number of cells in X	20
Number of cells in Y	24
Number of cells in Z	16

Number Of Cells

Total cells	202567
Fluid cells	93345
Solid cells	19102
Partial cells	90120
Irregular cells	0
Trimmed cells	210

Maximum refinement level: 6

Goals

Name	Unit	Value	Progress	Use in convergence	Delta	Criteria
GG Av Density 1	kg/m^3	1.1892	100	On	0.000260585039	0.000525985774
GG Max	℃	1344.26	100	On	6.2587298	29.381449

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Temperature of Fluid 1					4	
GG Av Velocity 1	m/s	0.0592612	48.2	On	0.00456668034	0.00220283569
GG Max Temperature of Solid 1	℃	1397.06	100	On	4.28643547	29.9637316
GG Min Temperature of Solid 1	℃	72.1054	100	On	0.152073814	1.61859875
GG Min Temperature of Fluid 1	℃	18.8901	100	On	0.0747106367	0.13150764
GG Av Static Pressure 1	bar	1.01325	100	On	1.46424631e-009	1.01324935e-008

Min/Max Table

Name	Minimum	Maximum
Pressure [bar]	1.01321	1.01329
Temperature [℃]	18.8901	**1397.06**
Density [kg/m^3]	0.317034	1.20849
Velocity [m/s]	0	0.800918
X-velocity [m/s]	-0.391109	0.588469
Y-velocity [m/s]	-0.133393	0.79536
Z-velocity [m/s]	-0.281414	0.407904
Mach Number [ ]	0	0.00221567
Heat Transfer Coefficient [W/m^2/K]	3.54118e-006	101.025
Shear Stress [bar]	4.1665e-021	6.75905e-007
Surface Heat Flux [W/m^2]	-10816.1	54842.1
Air Mass Fraction [ ]	1	1
Air Volume Fraction [ ]	1	1
Fluid Temperature [℃]	18.8901	1344.26
Solid Temperature [℃]	72.1054	1397.06
Melting Temperature Exceed [K]	-1317.66	1397.59

Engineering Database

Radiative surfaces

Aluminum, commercial sheet

Path: Radiative FW Defined\Real Surfaces

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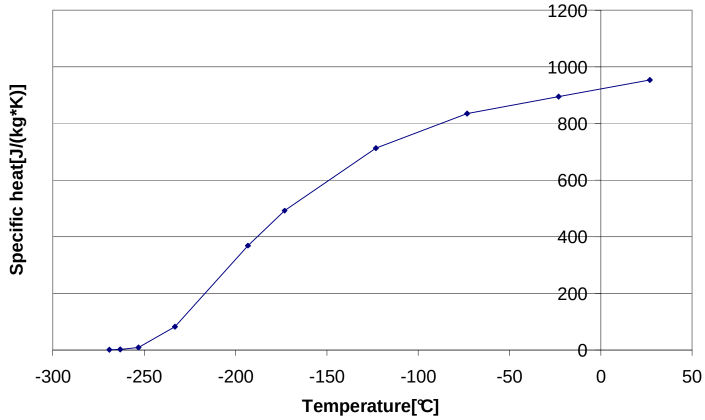
Radiative surface type: Wall
Emissivity coefficient: 0.09

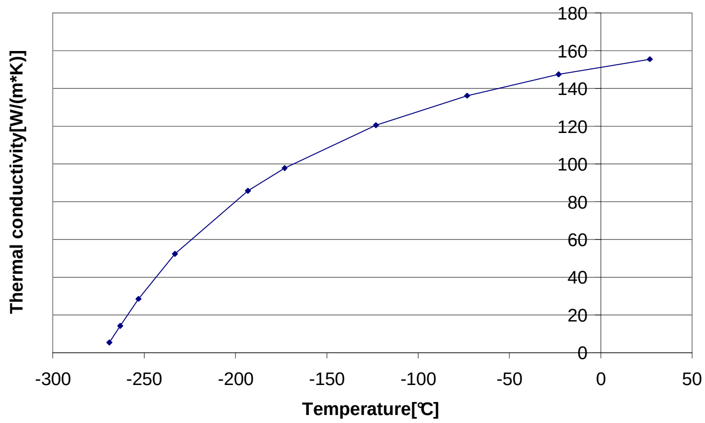
Solids

Aluminum 6061

Path: Solid FW Defined\Alloys
Density: 2700 kg/m^3
Specific heat



Conductivity type: Isotropic
Thermal conductivity



Electrical conductivity|Electrical conductivity|Axial electrical conductivity |Electrical conductivity in X: Conductor
Resistivity: 3.7e-008 m
Melting temperature: 582 ℃

Typical PLCC

Path: Solid FW Defined\IC Packages
Density: 2000 kg/m^3
Specific heat: 120 J/(kg*K)
Conductivity type: Isotropic
Thermal conductivity: 0.4 W/(m*K)
Electrical conductivity|Electrical conductivity|Axial electrical conductivity |Electrical conductivity in X: Dielectric
Melting temperature: 1415.05 ℃

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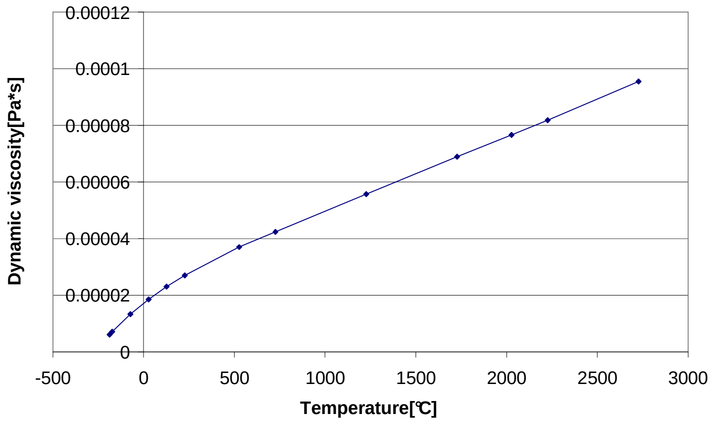
Typical Connector

Path: Solid FW Defined\IC Packages
Density: 2000 kg/m^3
Specific heat: 400 J/(kg*K)
Conductivity type: Orthotropic
Thermal conductivity in X: 5 W/(m*K)
Thermal conductivity in Y: 5 W/(m*K)
Thermal conductivity in Z: 20 W/(m*K)
Electrical conductivity|Electrical conductivity|Axial electrical conductivity |Electrical conductivity in X: Dielectric
Electrical conductivity|Electrical conductivity|Radial electrical conductivity |Electrical conductivity in Y: Dielectric
Electrical conductivity|Electrical conductivity|Axial electrical conductivity |Electrical conductivity in Z : Dielectric
Melting temperature: 1415.05 ℃

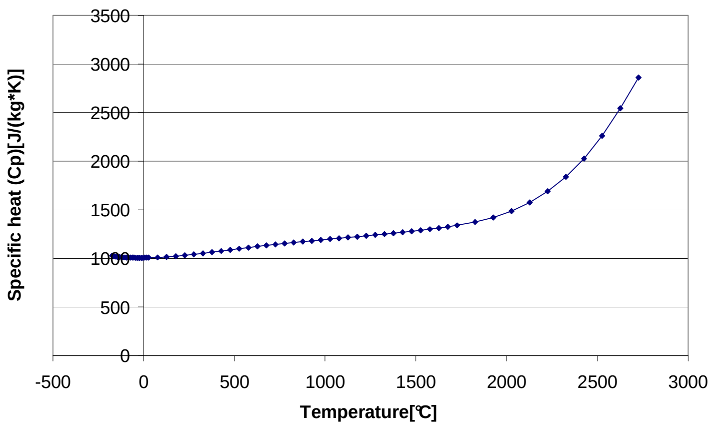
Gases

Air

Path: Gas FW Defined
Specific heat ratio (Cp/Cv): 1.399
Molecular mass: 0.02896 kg/mol
Dynamic viscosity



Specific heat (Cp)



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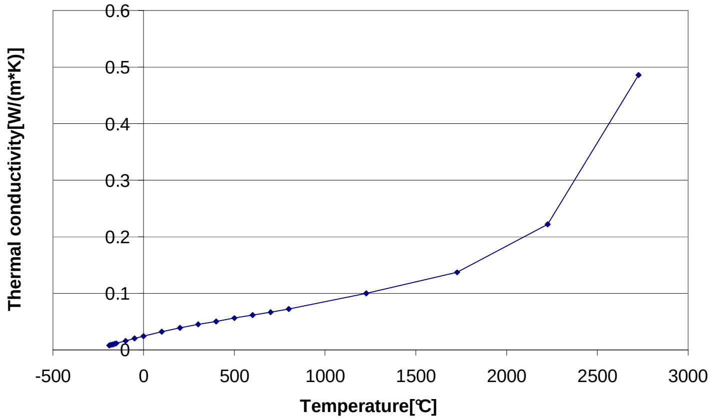
Thermal conductivity



Printed Circuit Boards

2S2P

Path: PCB FW Defined
Type: Layer Definition
Dielectric material density: 1200 kg/m^3
Dielectric material specific heat: 880 J/(kg*K)
Dielectric material conductivity: 0.3 W/(m*K)
Conductor material density: 8960 kg/m^3
Conductor material specific heat: 385 J/(kg*K)
Conductor material conductivity: 401 W/(m*K)
PCB total thickness: 0.0016 m

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Appendix 2. Run Two (alternative Materials) FULL REPORT

System Info

Product	EFD.Lab 8 1.0. Build: 413
Computer name	THERMO
Operating system	Microsoft Windows XP Professional Service Pack 2 (Build 2600)
CAD version	SolidWorks 2007 SP1

General Info

Model	D:\FLUID SESSIONS\FLD 0117 - KAT - Roach\1U_CHASSIS_ASM.sldasm
Project name	Std Materials
Project path	D:\FLUID SESSIONS\FLD 0117 - KAT - Roach\2\2.fwp
Units system	esBAR
Analysis type	External (not exclude internal spaces)
Exclude cavities without flow conditions	Off
Coordinate system	Global coordinate system
Reference axis	X

INPUT DATA

Initial Mesh Settings

Automatic initial mesh: Off

Basic Mesh Dimensions

Number of cells in X	20
Number of cells in Y	24
Number of cells in Z	16

Control Planes

Control planes in X direction

Name	Minimum	Maximum	Number of cells	Ratio
X1	-0.373414	-0.2352	-	1.12387
X2	-0.2352	0	-	1
X3	0	0.2352	-	1
X4	0.2352	0.373414	-	0.889782

Control planes in Y direction

Name	Minimum	Maximum	Number of cells	Ratio
Y1	-0.313414	0.000444898	-	1.65274
Y2	0.000444898	0.0222499	-	1
Y3	0.0222499	0.044055	-	1
Y4	0.044055	0.324539	-	0.633606

Control planes in Z direction

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Name	Minimum	Maximum	Number of cells	Ratio
Z1	-0.385289	-0.282095	-	1.07925
Z2	-0.282095	-0.01725	-	1
Z3	-0.01725	0.247595	-	1
Z4	0.247595	0.376664	-	0.90004

Solid/Fluid Interface

Small solid features refinement level	6
Curvature refinement level	4
Curvature refinement criterion	0.350000001
Tolerance refinement level	2
Tolerance refinement criterion	0.0005 m

Narrow Channels

Advanced narrow channel refinement	On
Characteristic number of cells across a narrow channel	5
Narrow channels refinement level	3
The minimum height of narrow channels	Off
The maximum height of narrow channels	Off

Computational Domain

Size

X min	-0.37341401 m
X max	0.37341401 m
Y min	-0.313414035 m
Y max	0.32453901 m
Z min	-0.385289035 m
Z max	0.376664035 m

Boundary Conditions

2D plane flow	None
At X min	Default
At X max	Default
At Y min	Default
At Y max	Default
At Z min	Default
At Z max	Default

Physical Features

Heat conduction in solids: On
Heat conduction in solids only: Off
Radiation: On
Time dependent: Off
Gravitational effects: On
Flow type: Laminar and turbulent

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High Mach number flow: Off
Humidity: Off
Default roughness: 20 micrometer

Gravitational Settings

X component	0 m/s^2
Y component	-9.81 m/s^2
Z component	0 m/s^2

Radiation

Default wall radiative surface: Aluminum, commercial sheet
Environment radiative temperature: 293.15 K

Ambient Conditions

Thermodynamic parameters	Static Pressure: 1.01325 bar Temperature: 20 ℃
Velocity parameters	Velocity vector Velocity in X direction: 0 m/s Velocity in Y direction: 0 m/s Velocity in Z direction: 0 m/s
Solid parameters	Default material: Aluminum 6061 Initial solid temperature: 20 ℃
Turbulence parameters	Turbulence intensity and length Intensity: 0.1 % Length: 0.000445001031 m

Material Settings

Fluids

Air

Solids

Aluminum 6061
Silicon
Epoxy Resin

Solid Materials

Silicon Solid Material 1

Components	ASSY_ADC-2/Part1-9 ASSY_ROACH-1/Part2-11 ASSY_ROACH-1/Part2-33 ASSY_ROACH-1/Part2-22 ASSY_ROACH-1/Part2-12 ASSY_ROACH-1/Part2-34 ASSY_ROACH-1/Part2-23 ASSY_ADC-2/Part1-10 ASSY_ROACH-1/Part2-35 ASSY_ROACH-1/Part2-13 ASSY_ROACH-1/Part2-24 ASSY_ADC-2/Part1-11 ASSY_ROACH-1/Part2-36

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	ASSY_ROACH-1/Part2-14 ASSY_ROACH-1/Part2-25 ASSY_ADC-2/Part1-12 ASSY_ROACH-1/Part2-15 ASSY_ROACH-1/Part2-37 ASSY_ROACH-1/Part2-26 ASSY_ROACH-1/Part2-2 ASSY_ROACH-1/Part2-16 ASSY_ROACH-1/Part2-27 ASSY_ROACH-1/Part2-38 ASSY_ADC-3/Part1-2 ASSY_ROACH-1/Part2-3 ASSY_ROACH-1/Part2-17 ASSY_ROACH-1/Part2-39 ASSY_ROACH-1/Part2-28 ASSY_ADC-3/Part1-10 ASSY_ADC-3/Part1-3 ASSY_ROACH-1/Part2-4 ASSY_ROACH-1/Part2-18 ASSY_ROACH-1/Part2-29 ASSY_ADC-3/Part1-11 ASSY_ADC-3/Part1-4 ASSY_ROACH-1/Part2-5 ASSY_ROACH-1/Part2-19 ASSY_ADC-3/Part1-12 ASSY_ADC-3/Part1-5 ASSY_ROACH-1/Part2-6 ASSY_ADC-3/Part1-6 ASSY_ADC-2/Part1-2 ASSY_ROACH-1/Part2-7 ASSY_ADC-3/Part1-7 ASSY_ADC-2/Part1-3 ASSY_ROACH-1/Part2-8 ASSY_ADC-2/Part1-4 ASSY_ADC-3/Part1-8 ASSY_ROACH-1/Part2-9 ASSY_ADC-3/Part1-9 ASSY_ADC-2/Part1-5 ASSY_ROACH-1/Part2-40 ASSY_ADC-2/Part1-6 ASSY_ROACH-1/Part2-41 ASSY_ROACH-1/Part2-30 ASSY_ADC-2/Part1-7 ASSY_ROACH-1/Part2-31 ASSY_ROACH-1/Part2-42 ASSY_ROACH-1/Part2-20 ASSY_ROACH-1/Part2-32 ASSY_ADC-2/Part1-8 ASSY_ROACH-1/Part2-10 ASSY_ROACH-1/Part2-21
Solid substance	Silicon

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Epoxy Resin Solid Material 1

Components	ASSY_ROACH-1/Part2-1 ASSY_ADC-3/Part1-1 ASSY_ADC-2/Part1-1
Solid substance	Epoxy Resin

Heat Volume Sources

VS Heat Generation Rate 21

Source type	Heat Generation Rate
Heat generation rate	6 W
Components	ASSY_ROACH-1/Part2-23
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 22

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-40
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 23

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-39
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 1

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-2/Part1-12
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 8

Source type	Heat Generation Rate
Heat generation rate	3.77 W
Components	ASSY_ROACH-1/Part2-29
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 18

Source type	Heat Generation Rate
Heat generation rate	0.66 W
Components	ASSY_ROACH-1/Part2-27
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 10

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Source type	Heat Generation Rate
Heat generation rate	1.64 W
Components	ASSY_ROACH-1/Part2-9
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 20

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-42
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 3

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-3/Part1-12
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 16

Source type	Heat Generation Rate
Heat generation rate	3.75 W
Components	ASSY_ROACH-1/Part2-15
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 14

Source type	Heat Generation Rate
Heat generation rate	5 W
Components	ASSY_ROACH-1/Part2-16
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 25

Source type	Heat Generation Rate
Heat generation rate	10 W
Components	ASSY_ROACH-1/Part2-37
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 2

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-2/Part1-11
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 15

Source type	Heat Generation Rate

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Heat generation rate	2.5 W
Components	ASSY_ROACH-1/Part2-14
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 9

Source type	Heat Generation Rate
Heat generation rate	1.67 W
Components	ASSY_ROACH-1/Part2-18
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 19

Source type	Heat Generation Rate
Heat generation rate	6 W
Components	ASSY_ROACH-1/Part2-22
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 17

Source type	Heat Generation Rate
Heat generation rate	5.5 W
Components	ASSY_ROACH-1/Part2-13
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 24

Source type	Heat Generation Rate
Heat generation rate	2.74 W
Components	ASSY_ROACH-1/Part2-38
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 26

Source type	Heat Generation Rate
Heat generation rate	250 W
Components	POWER_SUPPLY-1
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 11

Source type	Heat Generation Rate
Heat generation rate	1.71 W
Components	ASSY_ROACH-1/Part2-21
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 12

Source type	Heat Generation Rate
Heat generation rate	1.71 W

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Components	ASSY_ROACH-1/Part2-19
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 4

Source type	Heat Generation Rate
Heat generation rate	2.95 W
Components	ASSY_ADC-3/Part1-11
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 13

Source type	Heat Generation Rate
Heat generation rate	0.11 W
Components	ASSY_ROACH-1/Part2-20
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 5

Source type	Heat Generation Rate
Heat generation rate	1.7 W
Components	ASSY_ADC-2/Part1-10
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 6

Source type	Heat Generation Rate
Heat generation rate	1.7 W
Components	ASSY_ADC-3/Part1-10
Coordinate system	Global coordinate system
Reference axis	X

VS Heat Generation Rate 7

Source type	Heat Generation Rate
Heat generation rate	40 W
Components	ASSY_ROACH-1/Part2-28
Coordinate system	Global coordinate system
Reference axis	X

Goals

Global Goals

GG Av Density 1

Type	Global Goal
Goal type	Density
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

GG Max Temperature of Fluid 1

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Type	Global Goal
Goal type	Temperature of Fluid
Calculate	Maximum value
Coordinate system	Global coordinate system
Use in convergence	On

GG Av Velocity 1

Type	Global Goal
Goal type	Velocity
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

GG Max Temperature of Solid 1

Type	Global Goal
Goal type	Temperature of Solid
Calculate	Maximum value
Coordinate system	Global coordinate system
Use in convergence	On

GG Min Temperature of Solid 1

Type	Global Goal
Goal type	Temperature of Solid
Calculate	Minimum value
Coordinate system	Global coordinate system
Use in convergence	On

GG Min Temperature of Fluid 1

Type	Global Goal
Goal type	Temperature of Fluid
Calculate	Minimum value
Coordinate system	Global coordinate system
Use in convergence	On

GG Av Static Pressure 1

Type	Global Goal
Goal type	Static Pressure
Calculate	Average value
Coordinate system	Global coordinate system
Use in convergence	On

Calculation Control Options

Finish Conditions

Finish conditions	If one is satisfied
Maximum travels	4
Goals convergence	Analysis interval: 0.5

Solver Refinement

Refinement: Disabled

Results Saving

Save before refinement	On

Advanced Control Options

Flow Freezing

Flow freezing strategy	Disabled

View factor resolution level: 3

RESULTS

General Info

Iterations: 137

Calculation Mesh

Basic Mesh Dimensions

Number of cells in X	20
Number of cells in Y	24
Number of cells in Z	16

Number Of Cells

Total cells	202567
Fluid cells	93345
Solid cells	19150
Partial cells	90072
Irregular cells	0
Trimmed cells	218

Maximum refinement level: 6

Goals

Name	Unit	Value	Progress	Use in convergence	Delta	Criteria
GG Av Density 1	kg/m^3	1.18955	16.6	On	0.00322767696	0.000537565625
GG Max Temperature of Fluid 1	℃	1052.88	100	On	10.3887614	31.143411
GG Av Velocity 1	m/s	0.0430195	16.6	On	0.014589068	0.00243112637
GG Max Temperature of Solid 1	℃	1053.29	100	On	10.4539917	31.1551777

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GG Av Static Pressure 1	bar	1.01325	100	On	4.02429258e-009	1.01324934e-008
GG Min Temperature of Fluid 1	℃	19.4218	21.5	On	0.291505879	0.0628092476
GG Min Temperature of Solid 1	℃	58.417	14.7	On	11.2111658	1.64881204

Min/Max Table

Name	Minimum	Maximum
Pressure [bar]	1.01321	1.01329
Temperature [℃]	19.4218	**1053.29**
Density [kg/m^3]	0.304915	1.20629
Velocity [m/s]	0	0.596717
X-velocity [m/s]	-0.320902	0.283897
Y-velocity [m/s]	-0.133214	0.595878
Z-velocity [m/s]	-0.301172	0.422444
Mach Number [ ]	0	0.0016689
Heat Transfer Coefficient [W/m^2/K]	4.35665e-006	78.9707
Shear Stress [bar]	6.09207e-021	4.02694e-007
Surface Heat Flux [W/m^2]	-10533.8	33583.4
Air Mass Fraction [ ]	1	1
Air Volume Fraction [ ]	1	1
Fluid Temperature [℃]	19.4218	1052.88
Solid Temperature [℃]	58.417	1053.29
Melting Temperature Exceed [K]	-1352.92	923.283

Engineering Database

Radiative surfaces

Aluminum, commercial sheet

Path: Radiative FW Defined\Real Surfaces
Radiative surface type: Wall
Emissivity coefficient: 0.09

Solids

Aluminum 6061

Path: Solid FW Defined\Alloys
Density: 2700 kg/m^3

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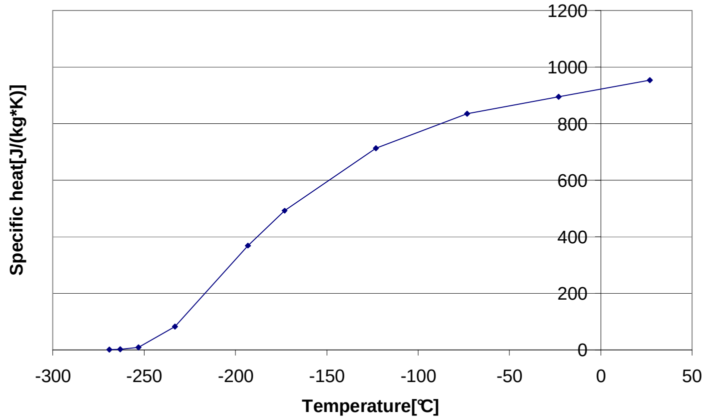
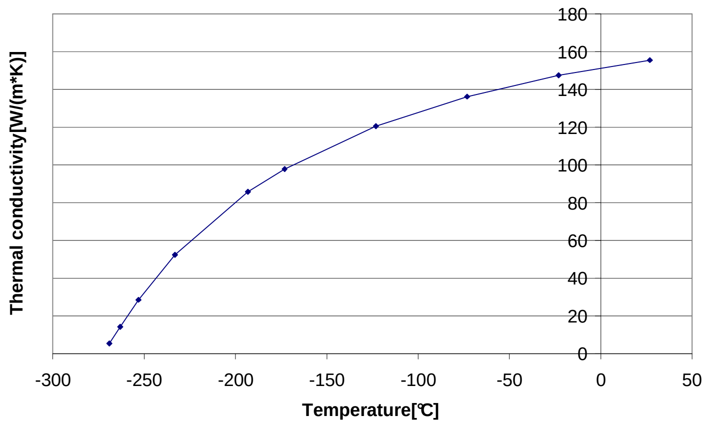
Specific heat



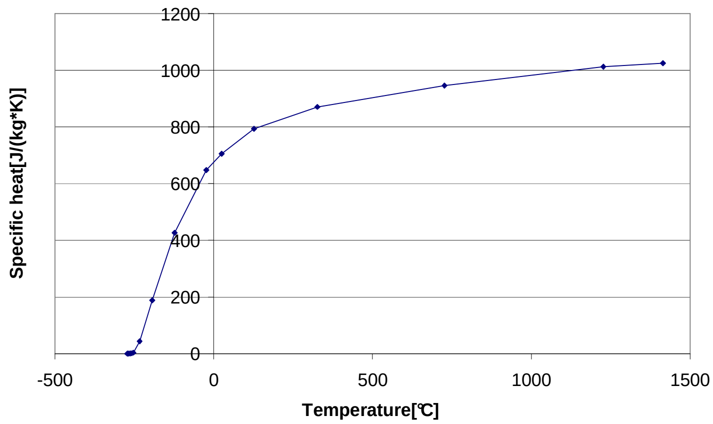
Conductivity type: Isotropic
Thermal conductivity



Electrical conductivity|Electrical conductivity|Axial electrical conductivity |Electrical conductivity in X: Conductor
Resistivity: 3.7e-008 m
Melting temperature: 582 ℃

Silicon

Path: Solid FW Defined\Semiconductors
Density: 2330 kg/m^3
Specific heat



Conductivity type: Isotropic

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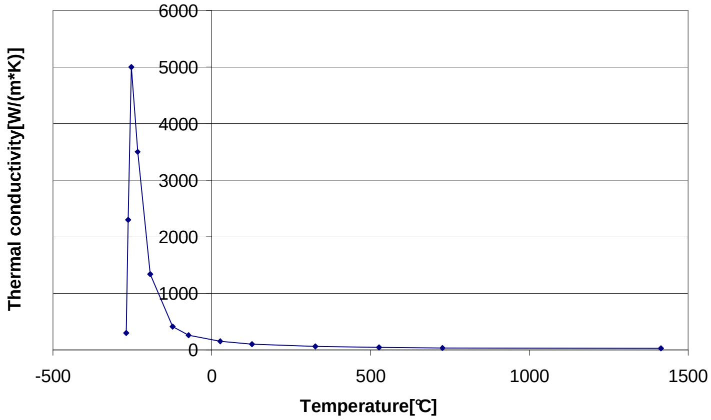
Thermal conductivity



Electrical conductivity|Electrical conductivity|Axial electrical conductivity |Electrical conductivity in X: Dielectric
Melting temperature: 1415.05 ℃

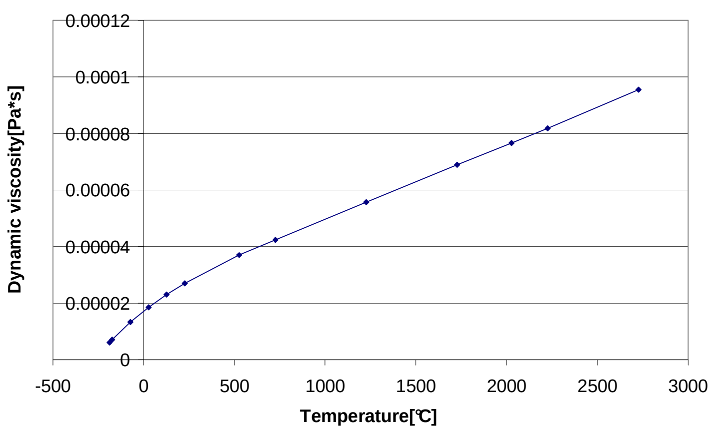
Epoxy Resin

Path: Solid FW Defined\Polymers
Density: 1120 kg/m^3
Specific heat: 1400 J/(kg*K)
Conductivity type: Isotropic
Thermal conductivity: 0.2 W/(m*K)
Electrical conductivity|Electrical conductivity|Axial electrical conductivity |Electrical conductivity in X: Dielectric
Melting temperature: 120 ℃

Gases

Air

Path: Gas FW Defined
Specific heat ratio (Cp/Cv): 1.399
Molecular mass: 0.02896 kg/mol
Dynamic viscosity



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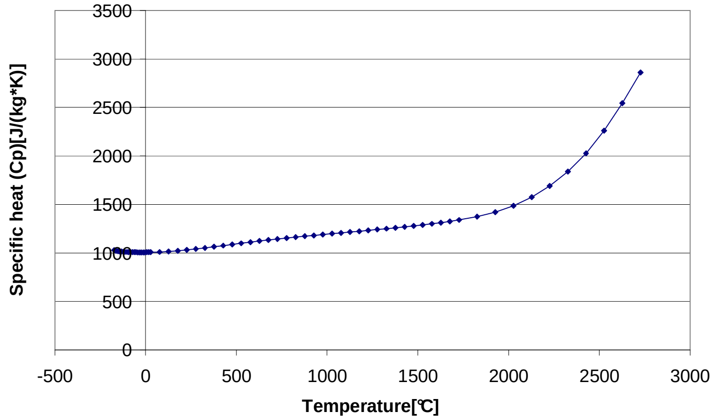
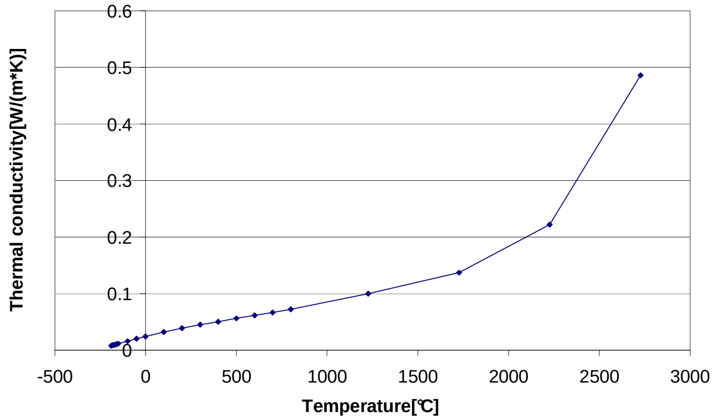
Specific heat (Cp)



Thermal conductivity



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