ABSTRACT 187

APPLICATION OF THERMO ELECTRIC COOLER (TEC) IN AVIONICS FOR THERMAL MANAGEMENT

YAN WEN, NG

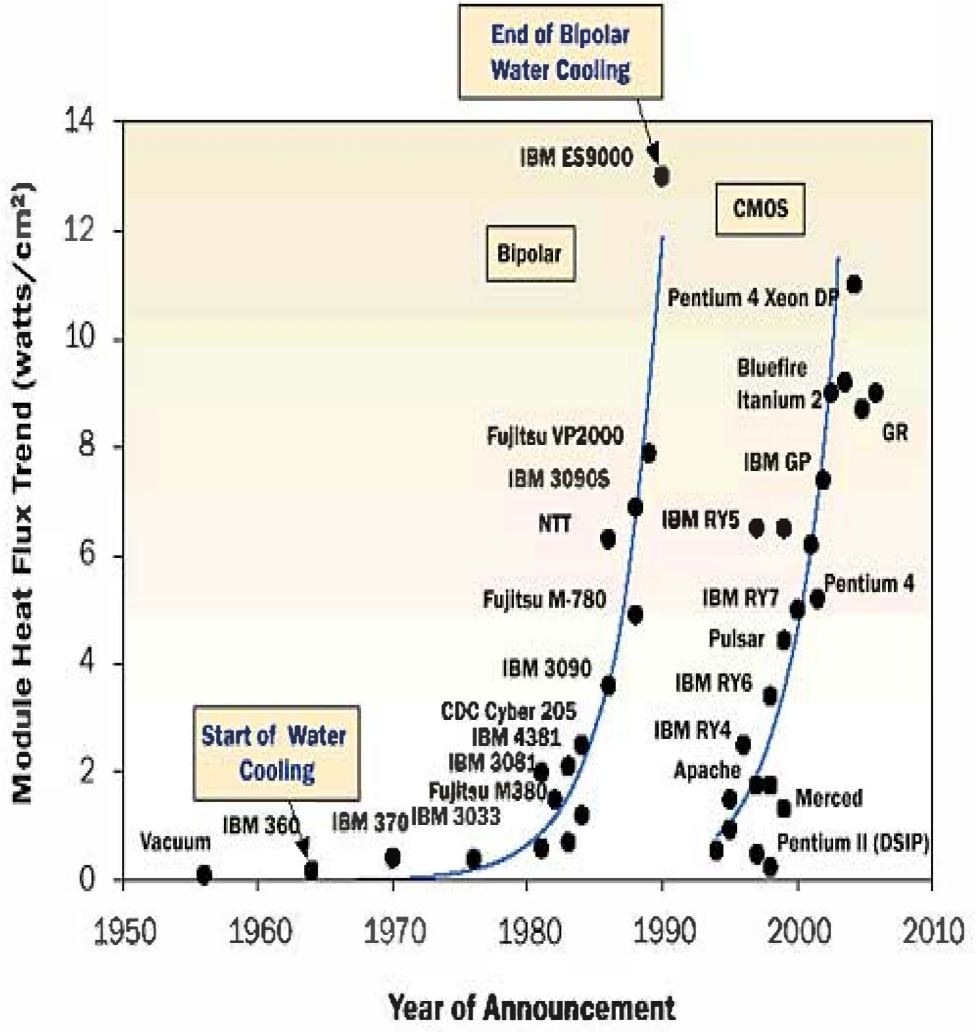
NANYANG TECHNOLOGICAL UNIVERSITY
SINGAPORE

Under Supervision of Asst. Prof. King Ho Holden, Li

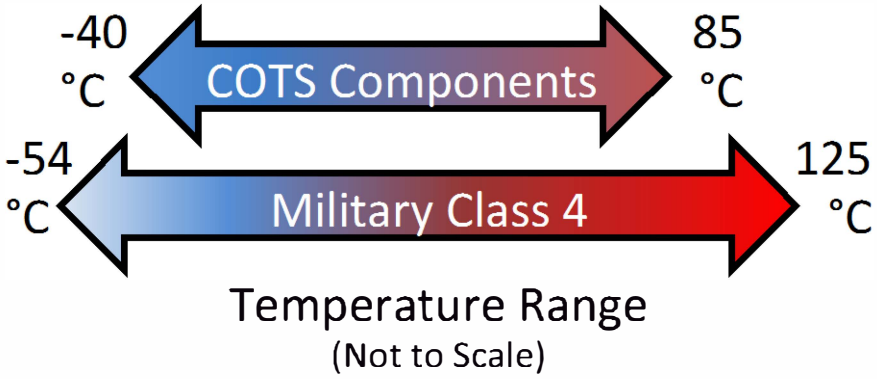
Scope of Presentation

- Introduction
- Avionics & Thermal Management
- Problem Definitions and Requirements
- Analysis Approach
- Analysis Results
- Limitations
- Future Research
- Recommendations

Introduction



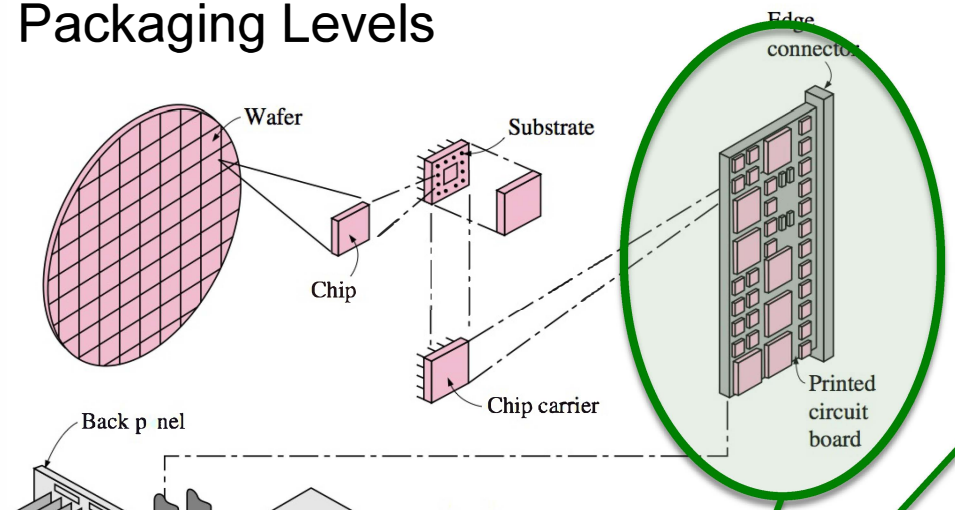
Source: www.electronics-cooling.com

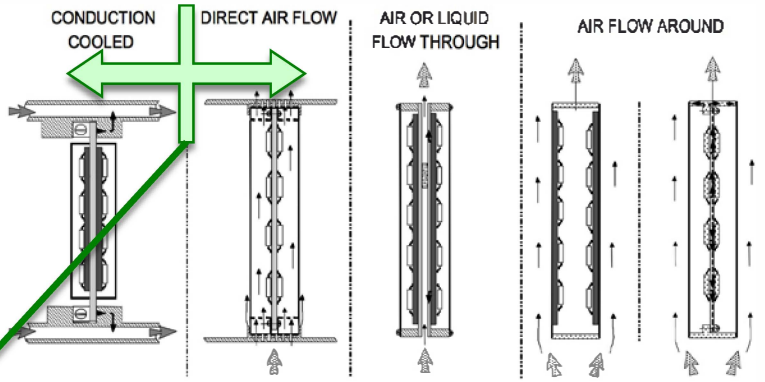


- Need for thermal management of avionics

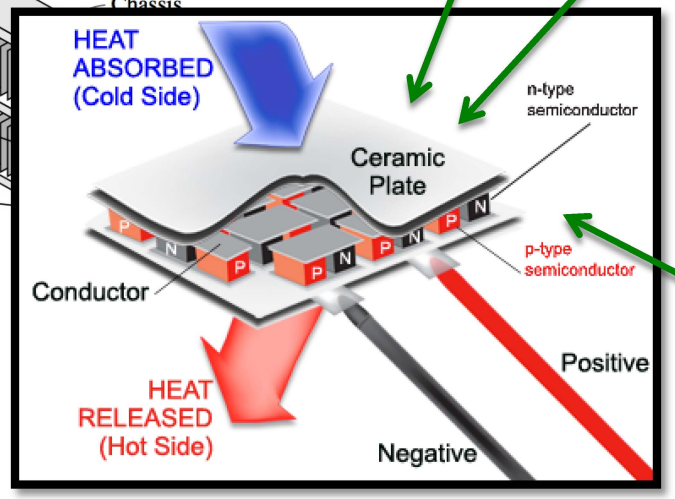
Avionics & Its Thermal Management

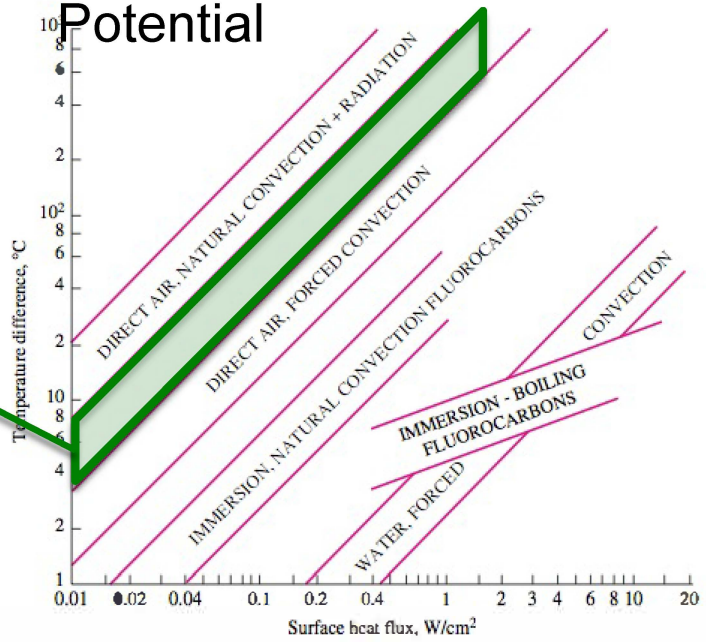
- Packaging Levels





- Cooling Techniques & Potential

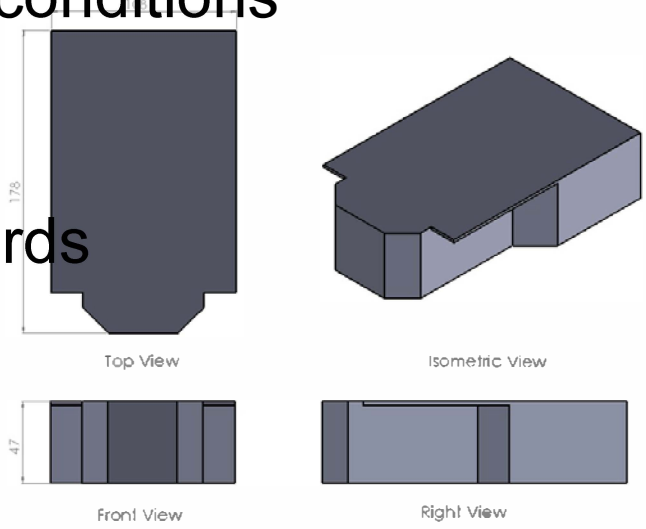




Problem Definition

- To make use of TECs to assist in thermal management of avionics, with the focus on module level insertion.
- Environment:
  - 55 °C still air – Class 1 Equipment as per *MIL-E-5400T Electronic Equipment, Airborne, General Specification For*
  - 1 atmospheric pressure – Sea level conditions
- Chassis:
  - 178 x 108 x 47 mm, 2mm thickness
  - Not governed by any specific standards for shape and form factor
  - AL6061-T6

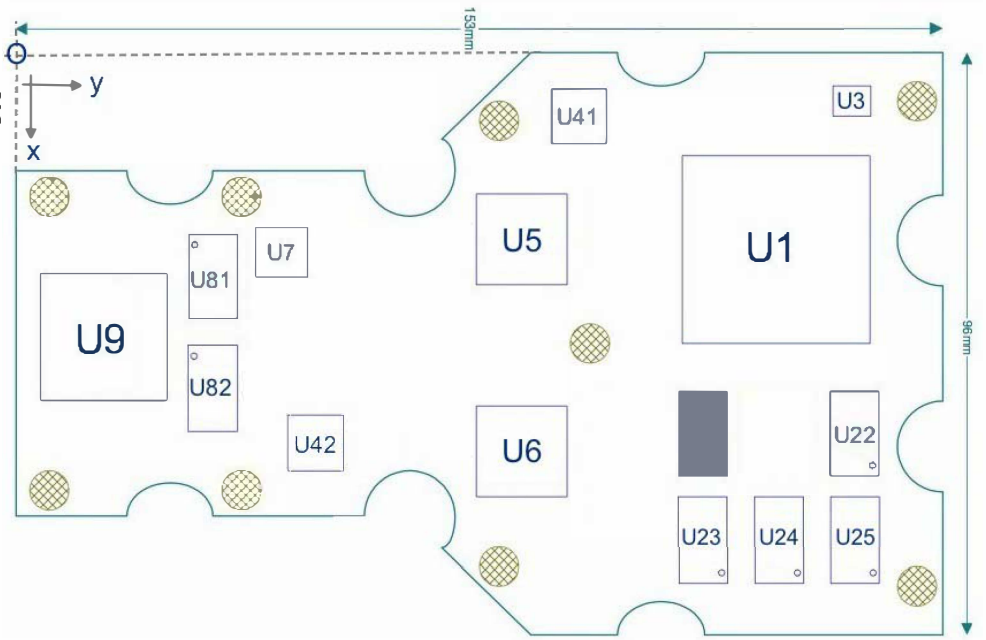
-



Problem Definition

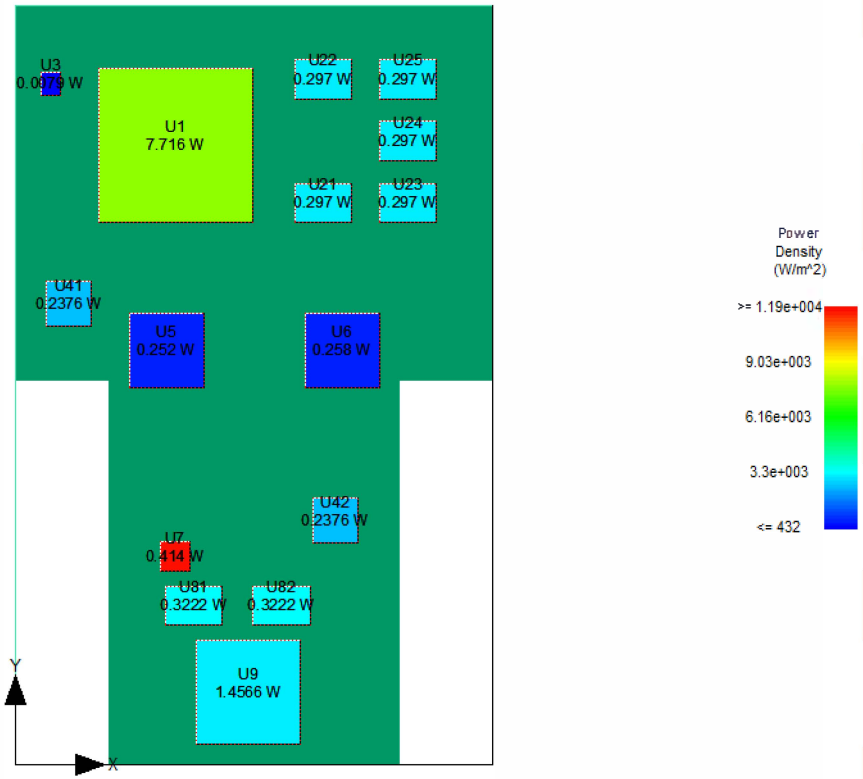
- PCB:
  - 3 cards, each 153 x 96 x 1.6 mm
  - $K_X=K_Y=10$ W/mK, $K_Z=0.405$ W/mK
  - Card 2 & 3 has negligible heat dissipation
- Components
  - 9 main component type on Card 1

-



Components' Properties

Component	Material	Length (mm)	Width (mm)	Height (mm)	x (mm)	y (mm)	Power (mW)	Heat Flux (W/cm²)	Target T_{Case} (°C)	θ_{JC} (K/W)	θ_{JB} (K/W)
Typ_EC											
U1							7716.0	0.80	73.9	5.0	7.0
U2							297.0	0.33	97.1	6.4	11.77
U3							7.9	0.04	121.1	48.0	55
U4							237.6	0.29	108.3	17.6	25.0
U5							252.0	0.11	111.0	6.0	8.0
U6							258.0	0.11	111.0	6.0	8.0
U7							414.0	1.19	134.2	2.0	5.0
U8							322.2	0.36	96.9	6.4	11.77
U9							1456.6	0.33	103.8	6.0	14.0
PBGA											



- Heat flux at Chassis Level: 12.71 W / 181 cm^2 = 0.070 W/cm^2

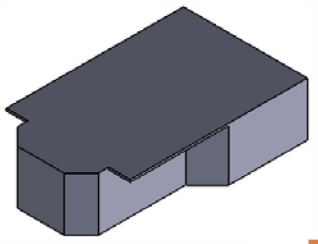
Analysis Approach

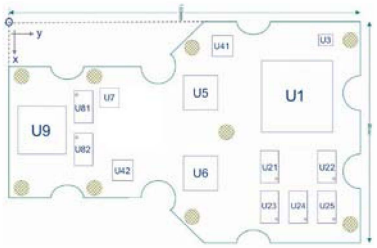
- Numerical – Simulation in FloTHERM
- Experimental – Data collection from physical mockup
- Measured variable
  - Component case temperature (T_{case})

-

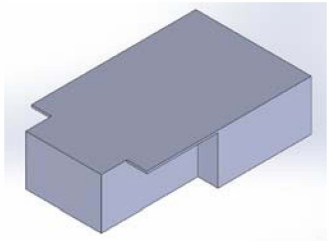
Modeling

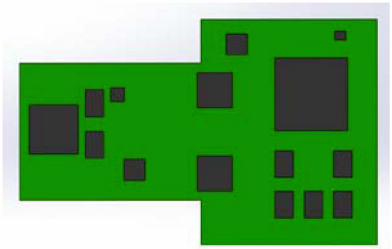
- Original



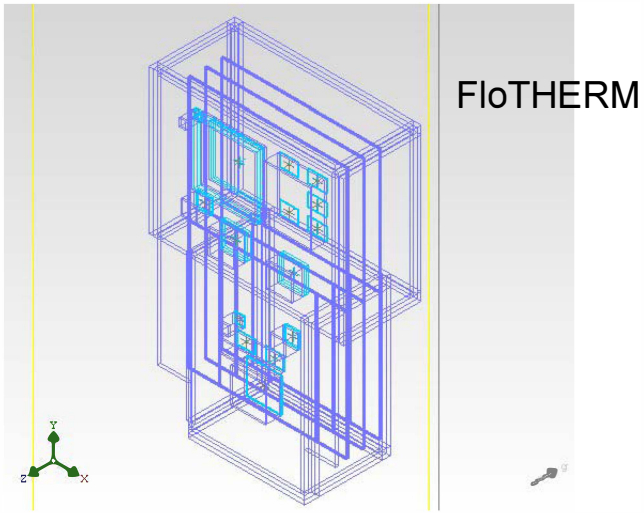


- Simplified

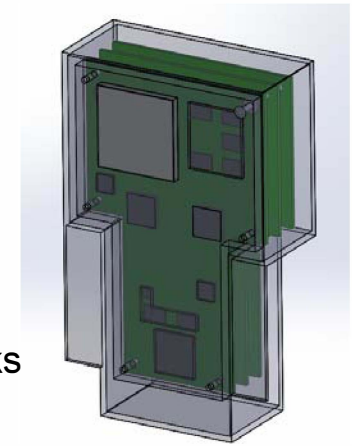




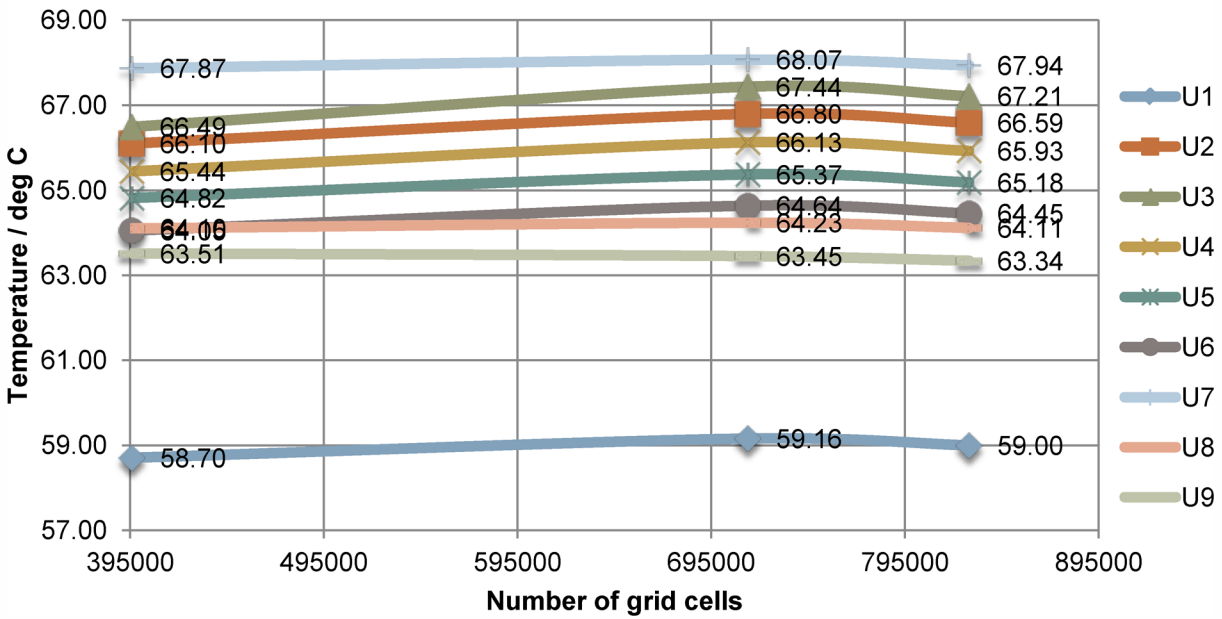
- Complete Model



SolidWorks



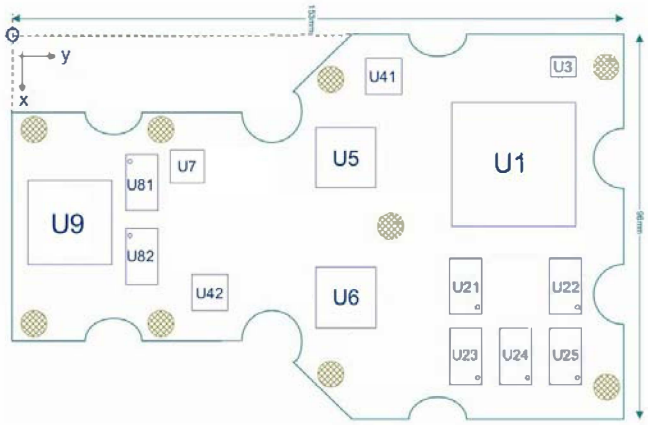
Mesh Independence Studies



Percentage change of case temperatures between successive runs

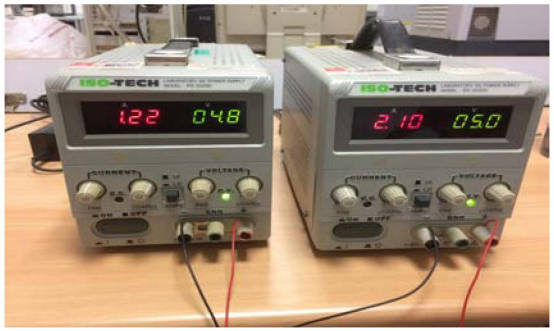
Components	Between 1st & 2nd run	Between 2nd & 3rd run
U1	0.77	-0.27
U2	1.05	-0.31
U3	1.43	-0.33
U4	1.05	-0.30
U5	0.85	-0.29
U6	0.91	-0.28
U7	0.30	-0.20
U8	0.21	-0.19
U9	-0.10	-0.17

- Done for Study 7
  - Most complete model, in terms of elements present
- ~700,000 grid cells were sufficient in resolution

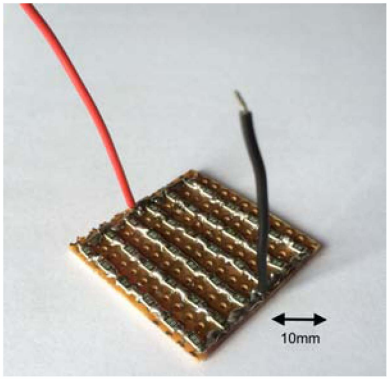


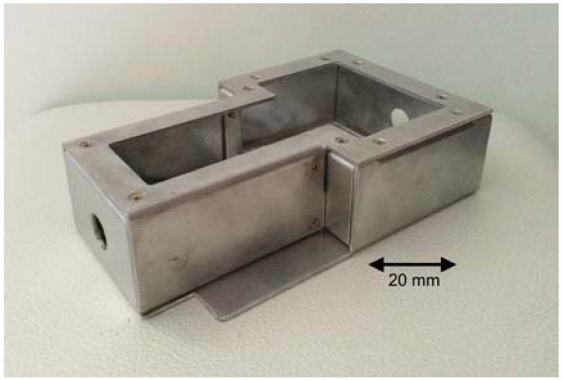
Experimental Setup

- Equipment:

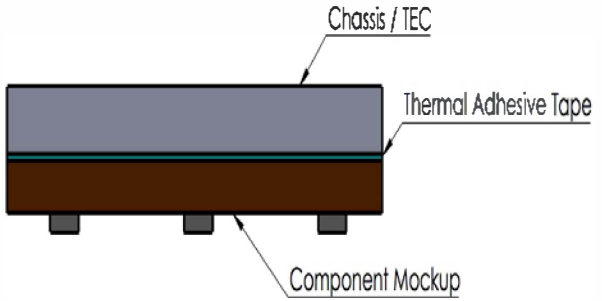


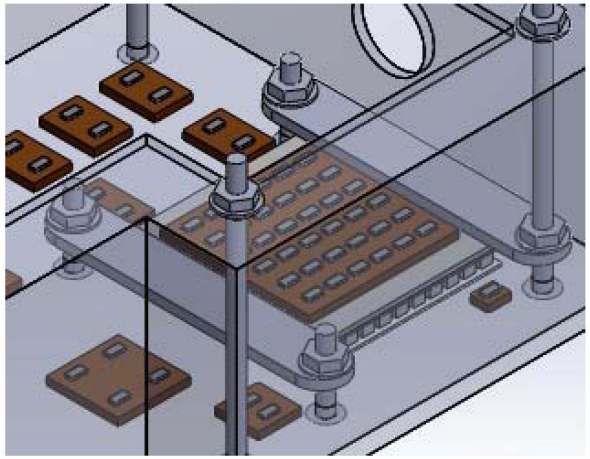
- Mockup:





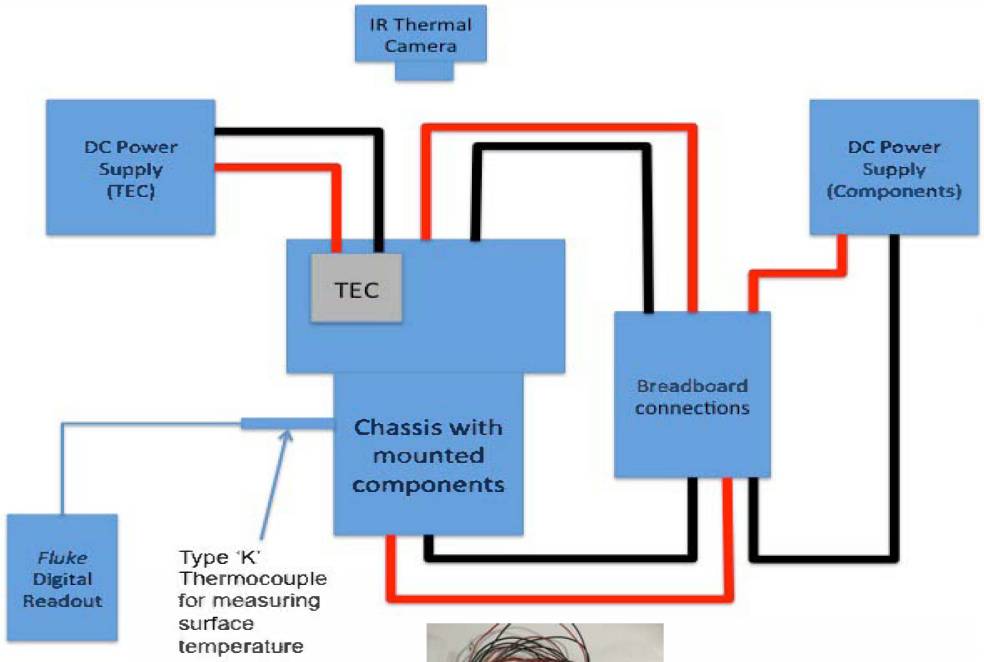
- Mounting:

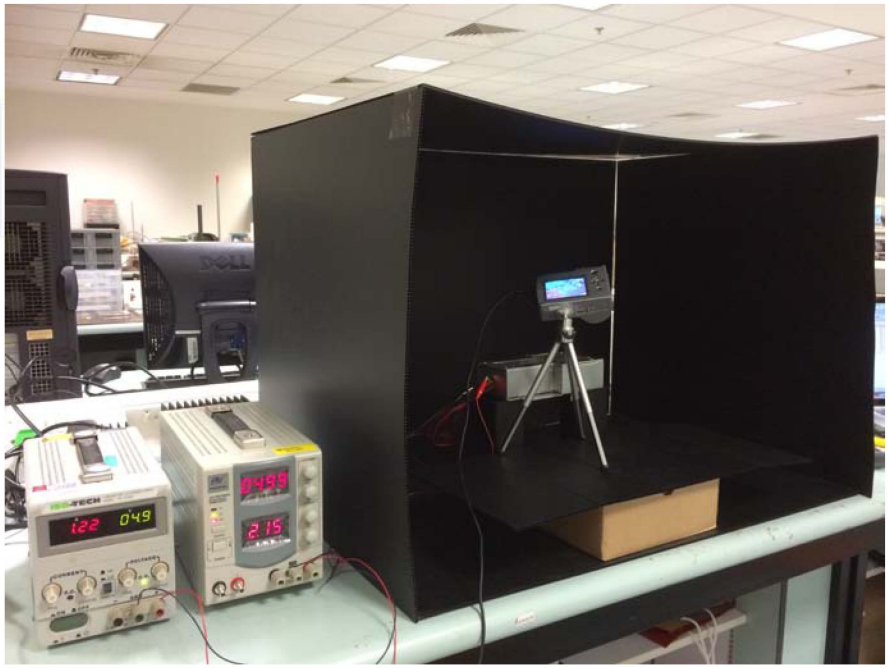




Experimental Setup

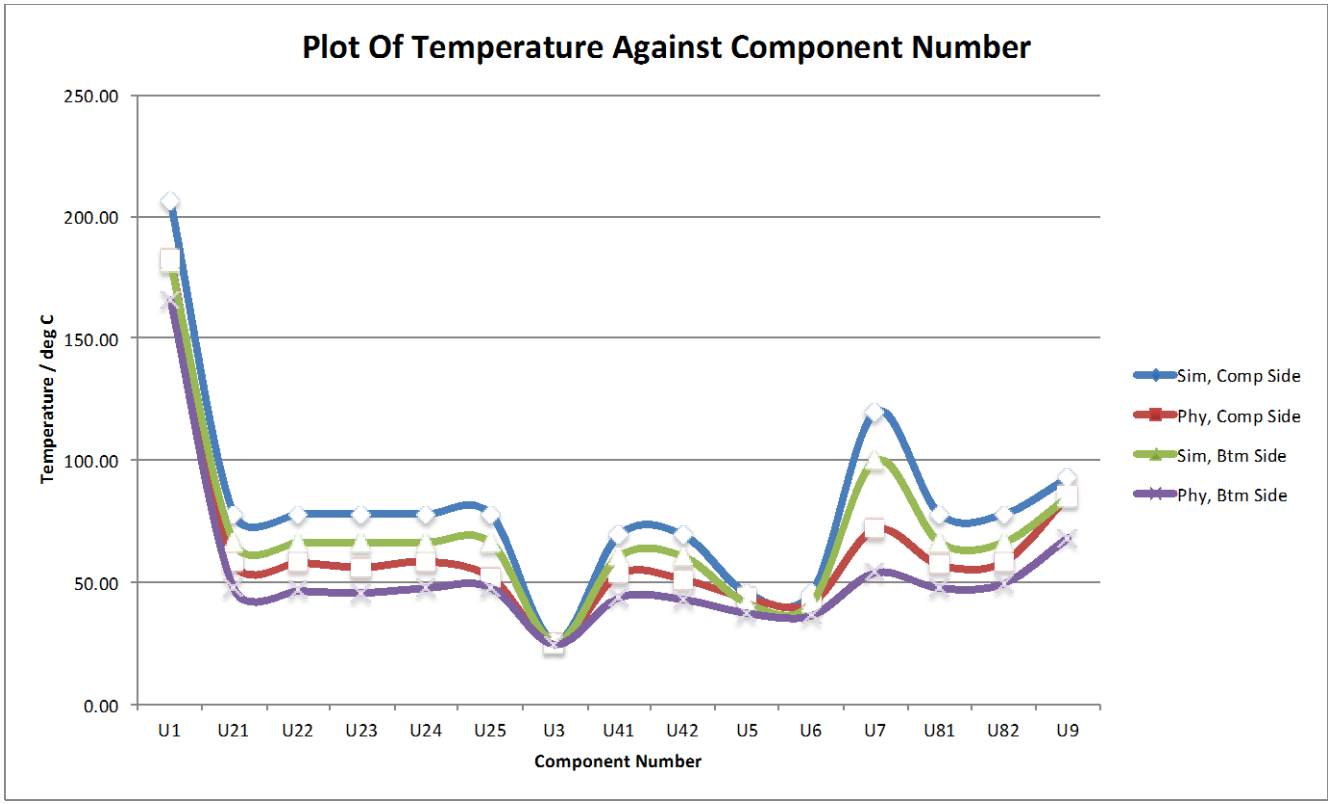
- Chassis level:

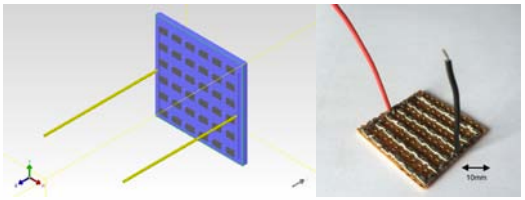


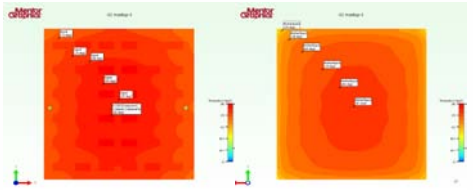


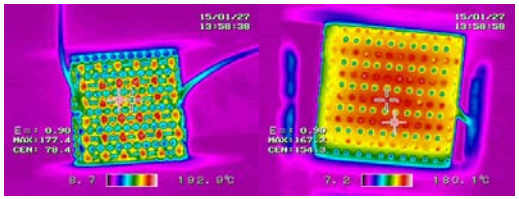
Validation of Thermal Model

- Thermal model created specifically to match physical mockup
- Component Level:



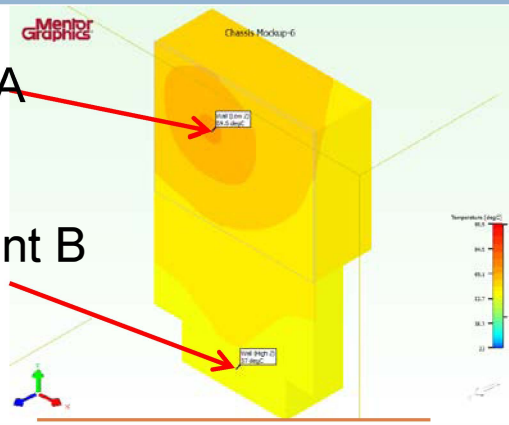






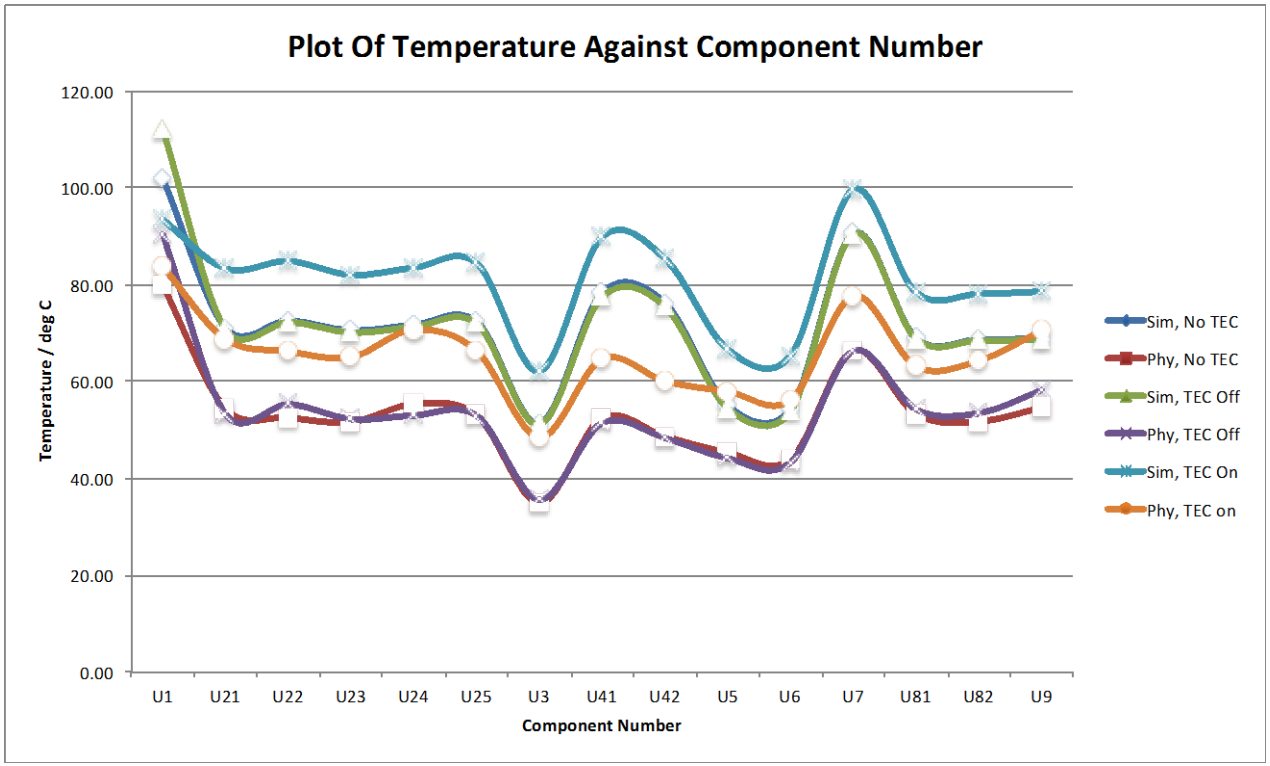
Validation of Thermal Model

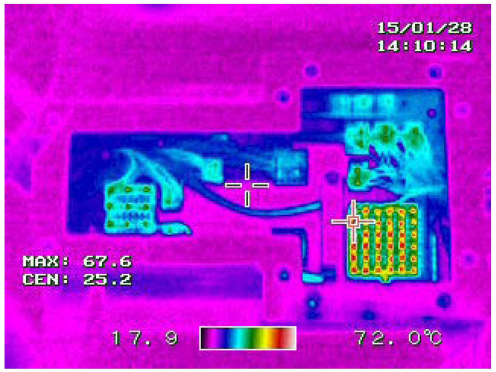
- Chassis Level



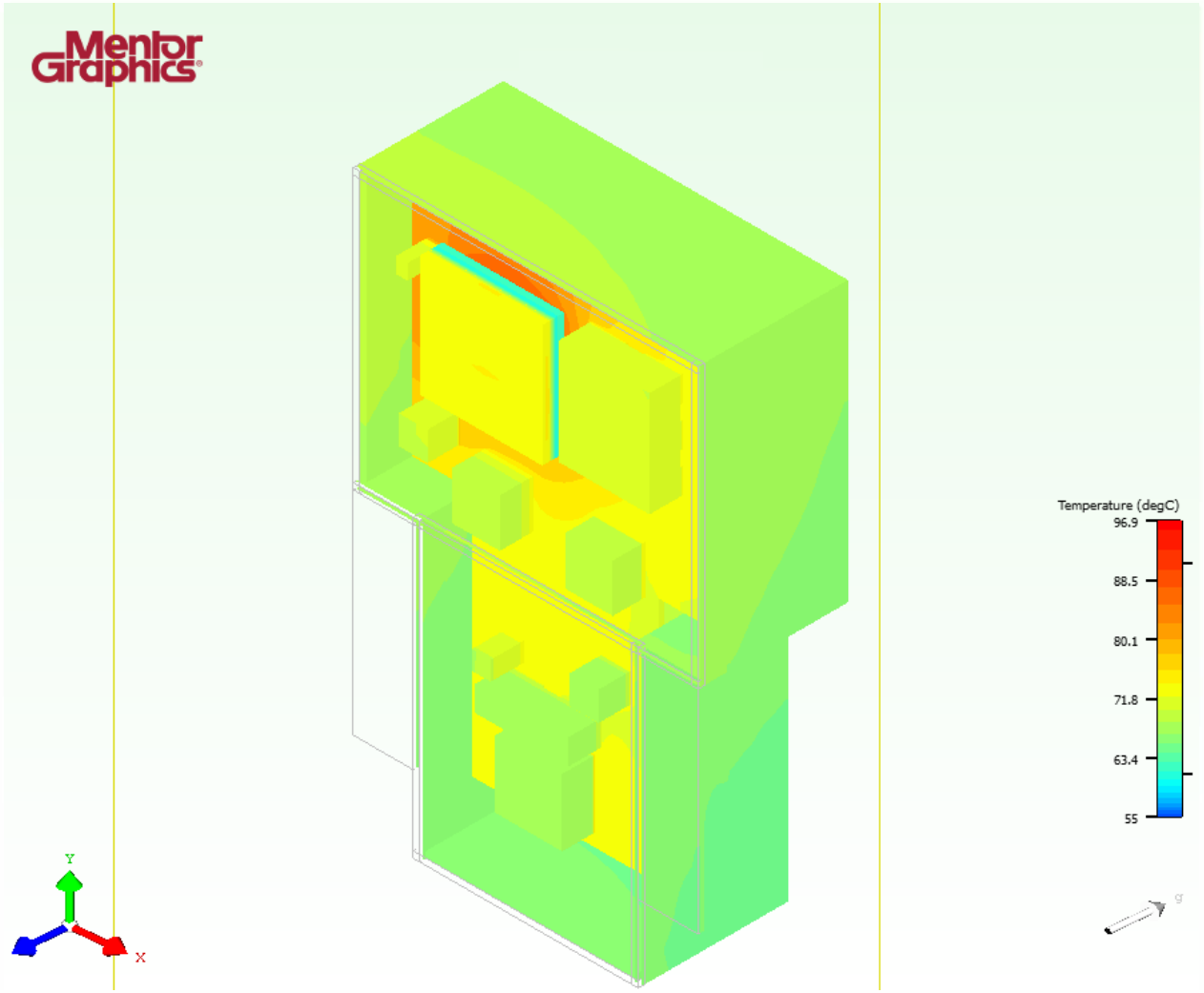
Point	Sim	Phy
A	69.6	59.6
B	57	46.7

(VALUES IN ºC)

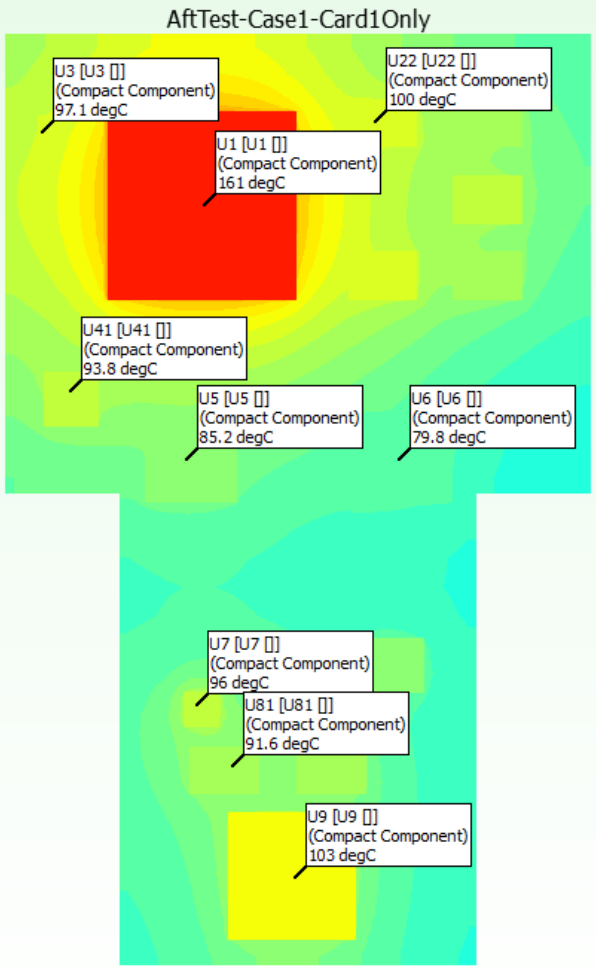




FloTHERM Analysis

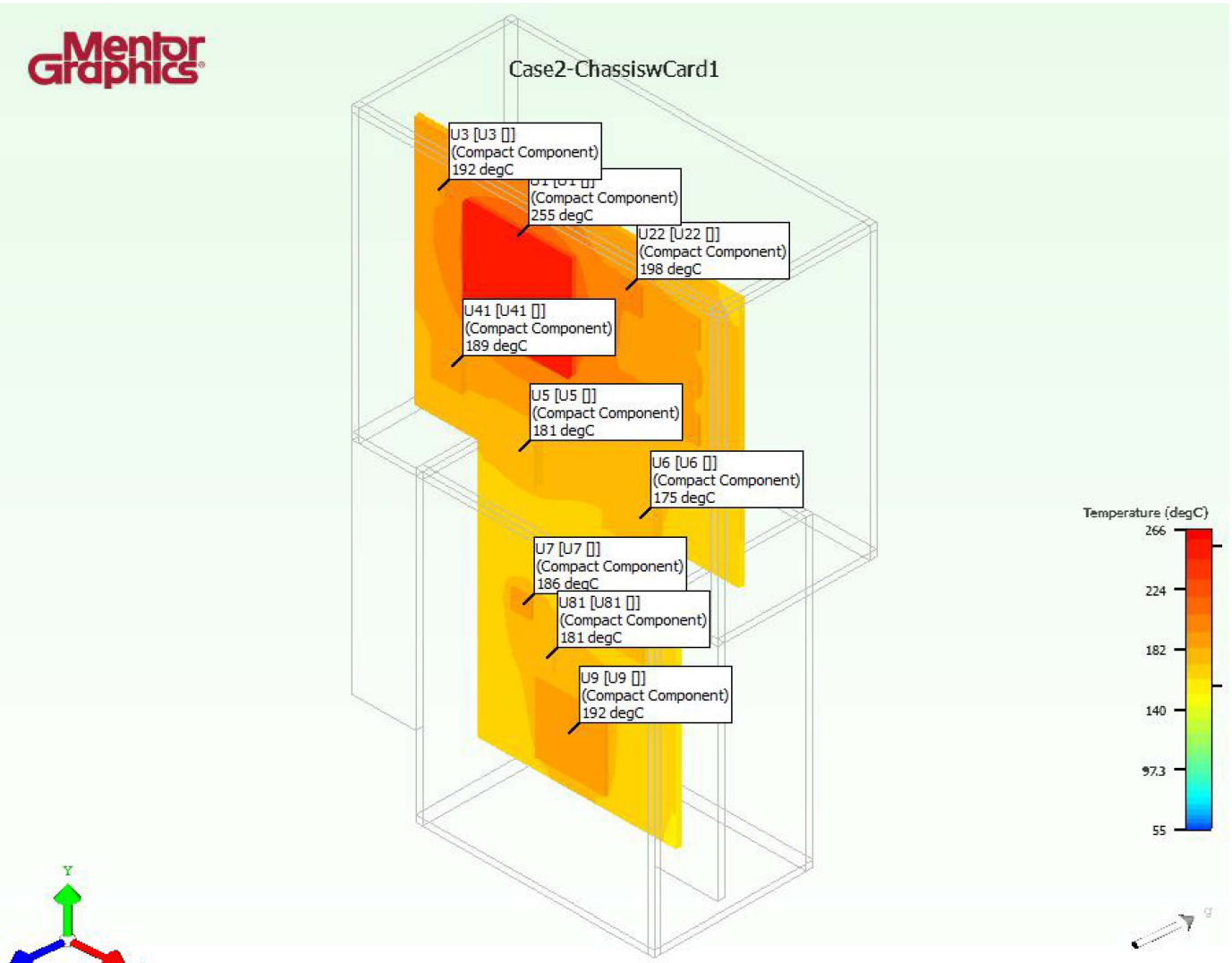


Study 1 – Card 1 only



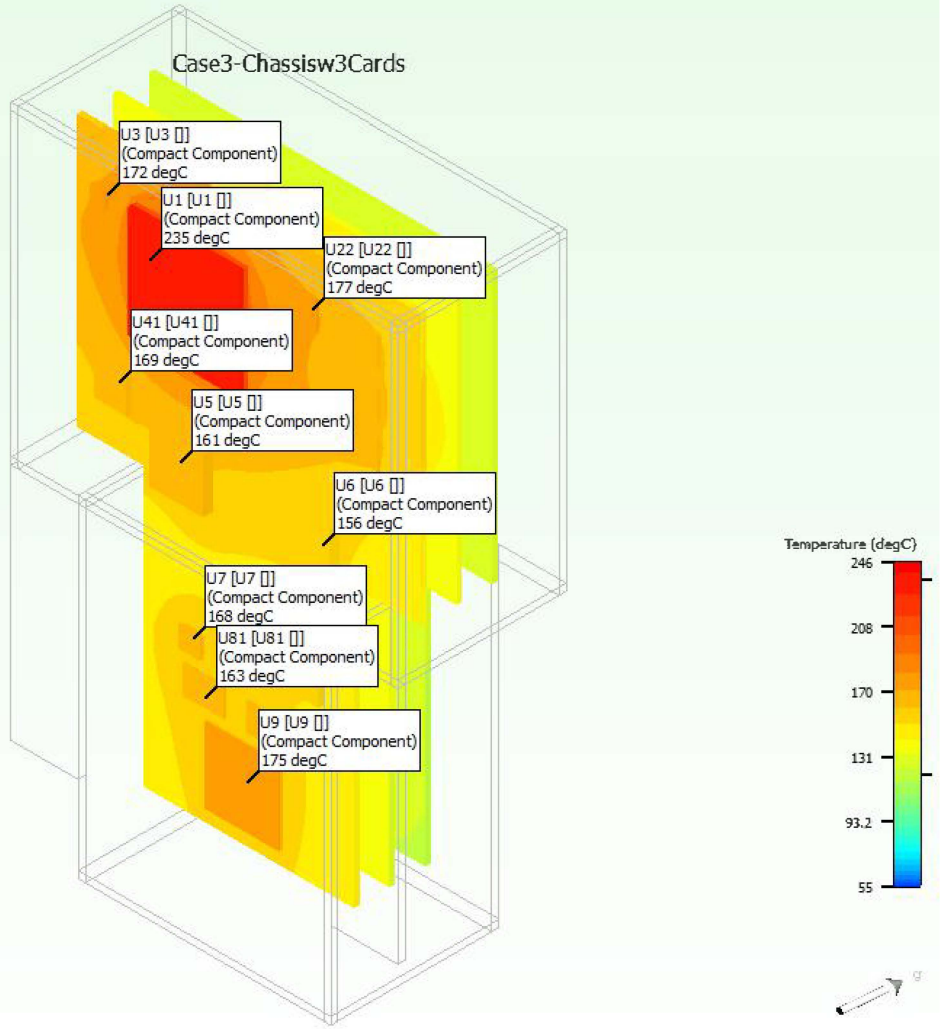
- Ambient
  - 55 °C still air
  - 1 atm
- U1 Heat flux = 0.8 W/cm^2
- $T_{case,U1}$
  - 160.81 °C
  - Problematic
  - Unacceptable
- Targeted cooling required

Study 2 – Chassis with Card 1



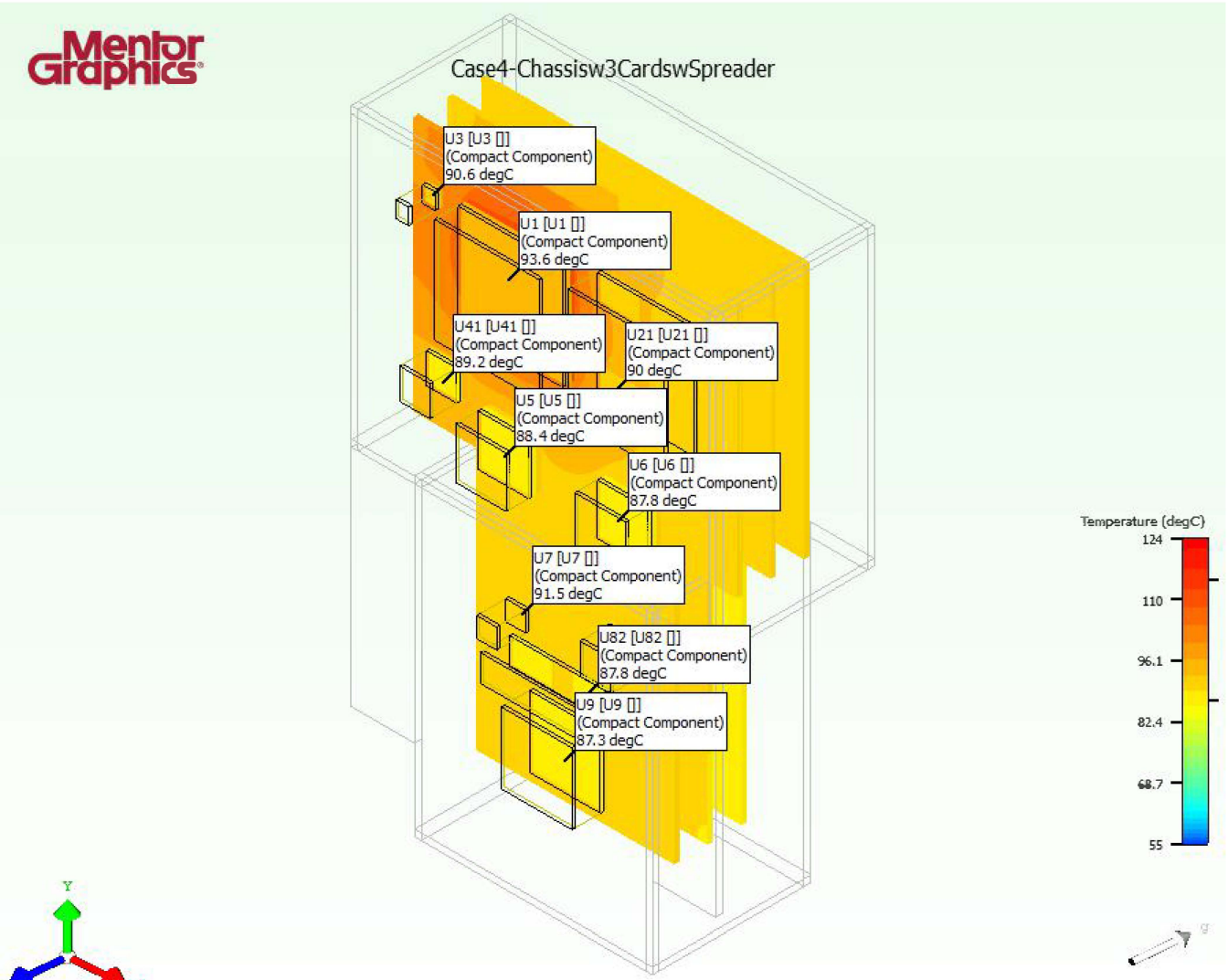
- Significant increase in T_{case} of components
- $T_{case,U1}$ = 252.31 °C
- Lack of thermal conduction path

Study 3 – Chassis with 3 cards



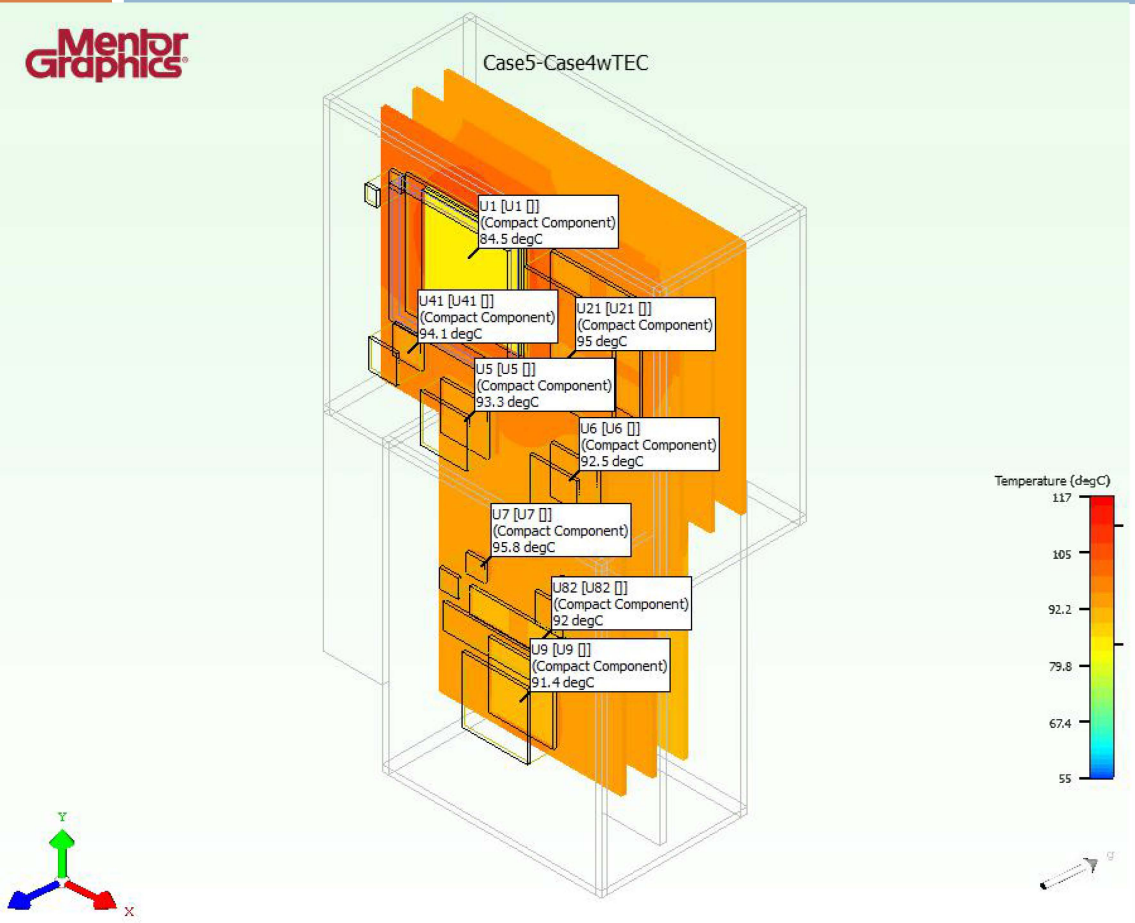
- Addition of 2 cards with P = 0 W
- Slight decrease in T_{case}
- $T_{case,U1}$ = 239.52 °C

Study 4 – Addition of heat spreaders



- Addition of heat spreaders
- Simple, Reliable, Effective
- $T_{case,U1}$ = 95.18 °C
- Only U1 with T_{case} > Target T_{case}

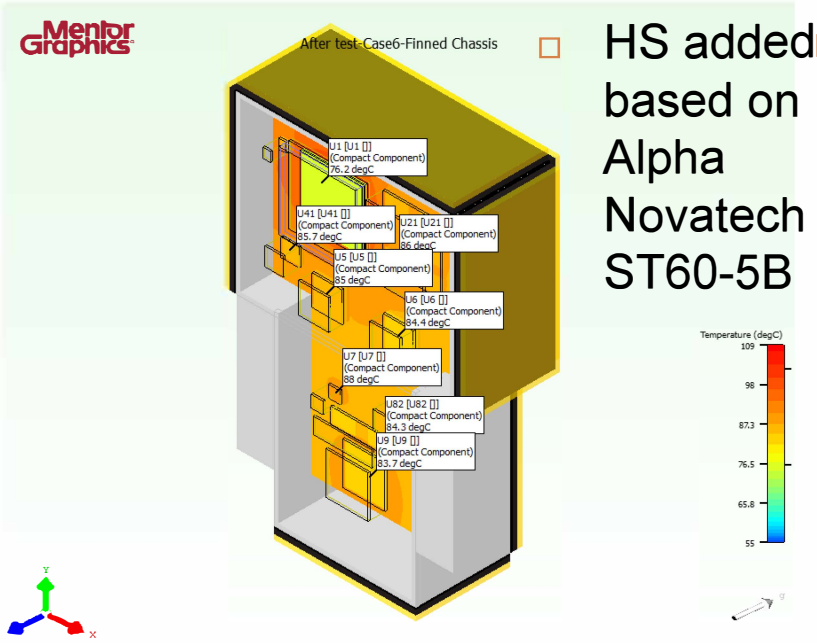
Study 5 – Addition of TEC



- Marlow RC12-6
  - ~40 x 40 x 4 mm
- Heat Spreader between U1 & TEC is of same area as TEC
- I_{TEC} = 0.75 A
- $T_{case,U1}$ = 86.16 °C
- Need to
  - Improve heat dissipation at TEC hot side
  - Optimize current

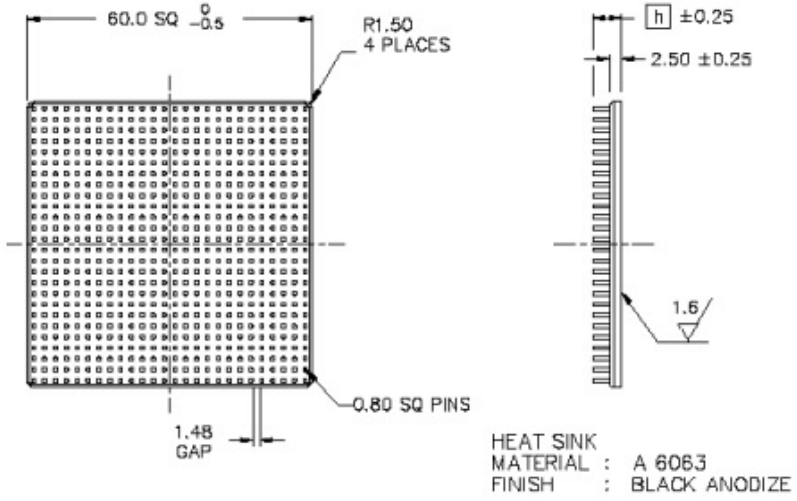
Study 6 – Addition of heat sink

- Modifications to chassis external geometry should remain within 10% of original dimensions
- Top face of the box should be left unaltered for mounting purpose



- HS added based on Alpha Novatech ST60-5B

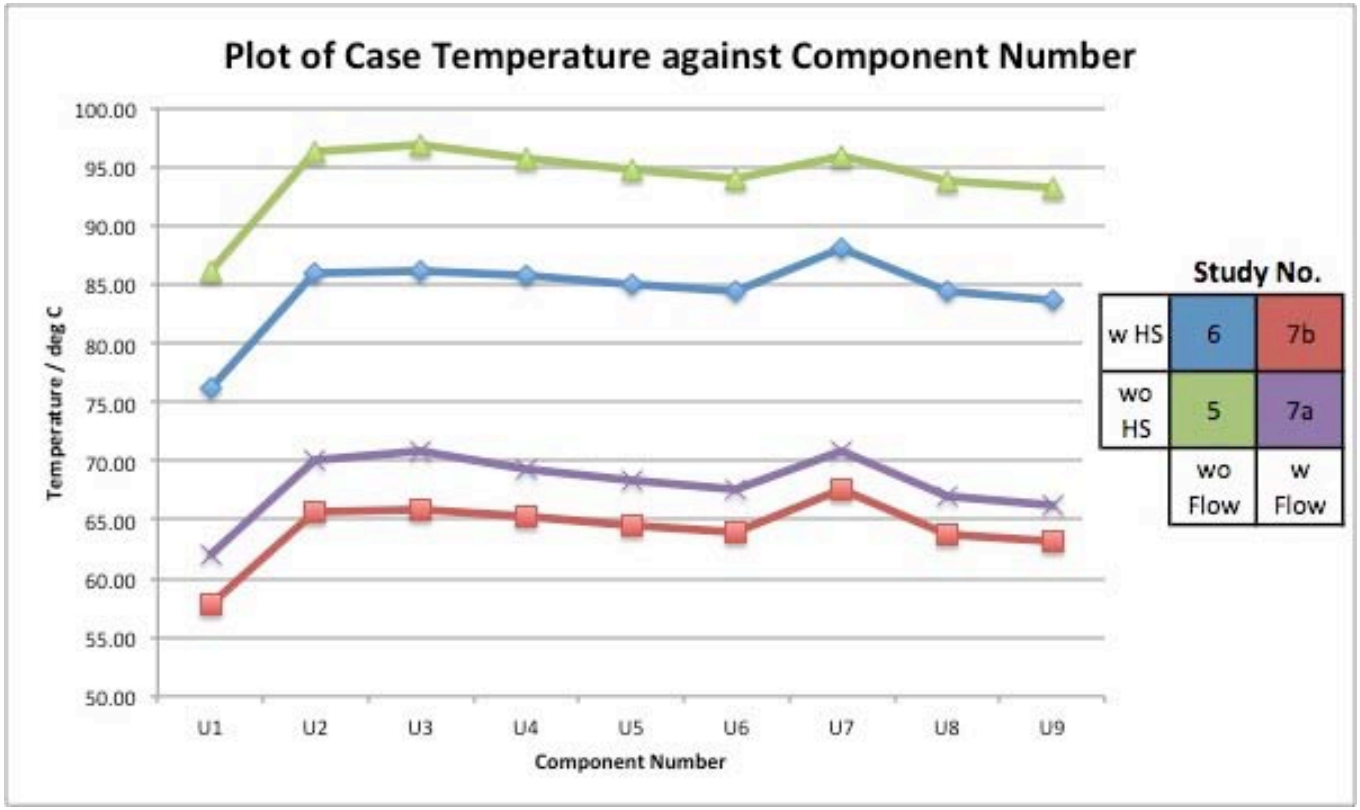
- Why ST60-5B was chosen
  - Pin fins → flow in both Y or Z – direction
  - Low profile pins → Applications with space constraints



- $T_{case,U1}$ = 76.23 °C
- Decrement of 9.68 °C

Study 7 – Introduction of flow

- Flow of 3 m/s
  - *EIA/JEDEC JESD51-6 Integrated Circuit Thermal Test Method Environmetal Conditions – Forced Convection*
  - 0.5 m/s ≤ Flow Velocity ≤ 5 m/s

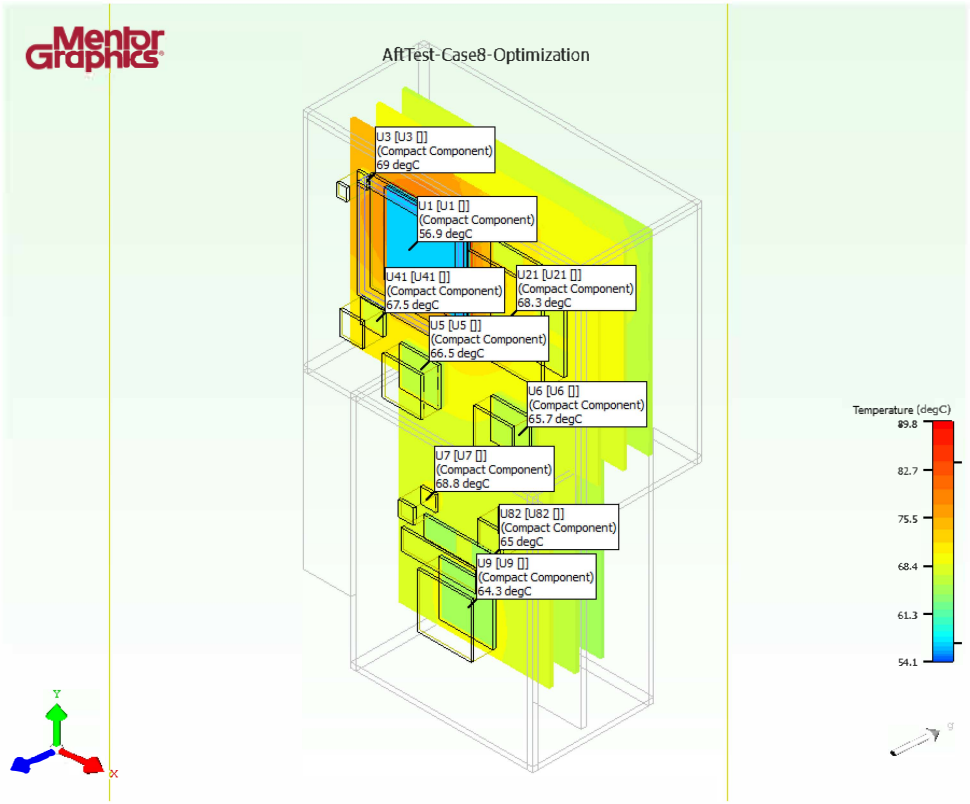


- $\Delta T_{Flow,woFlow}$ = ~28 ºC
- $T_{7a,U1}$ = 62.06 °C
- $\Delta T_{5,6}$ = ~10 ºC
- $\Delta T_{7a,7b}$ = ~4 ºC
- Difficult to justify use of heat sinks on chassis

Study 8 – Optimization

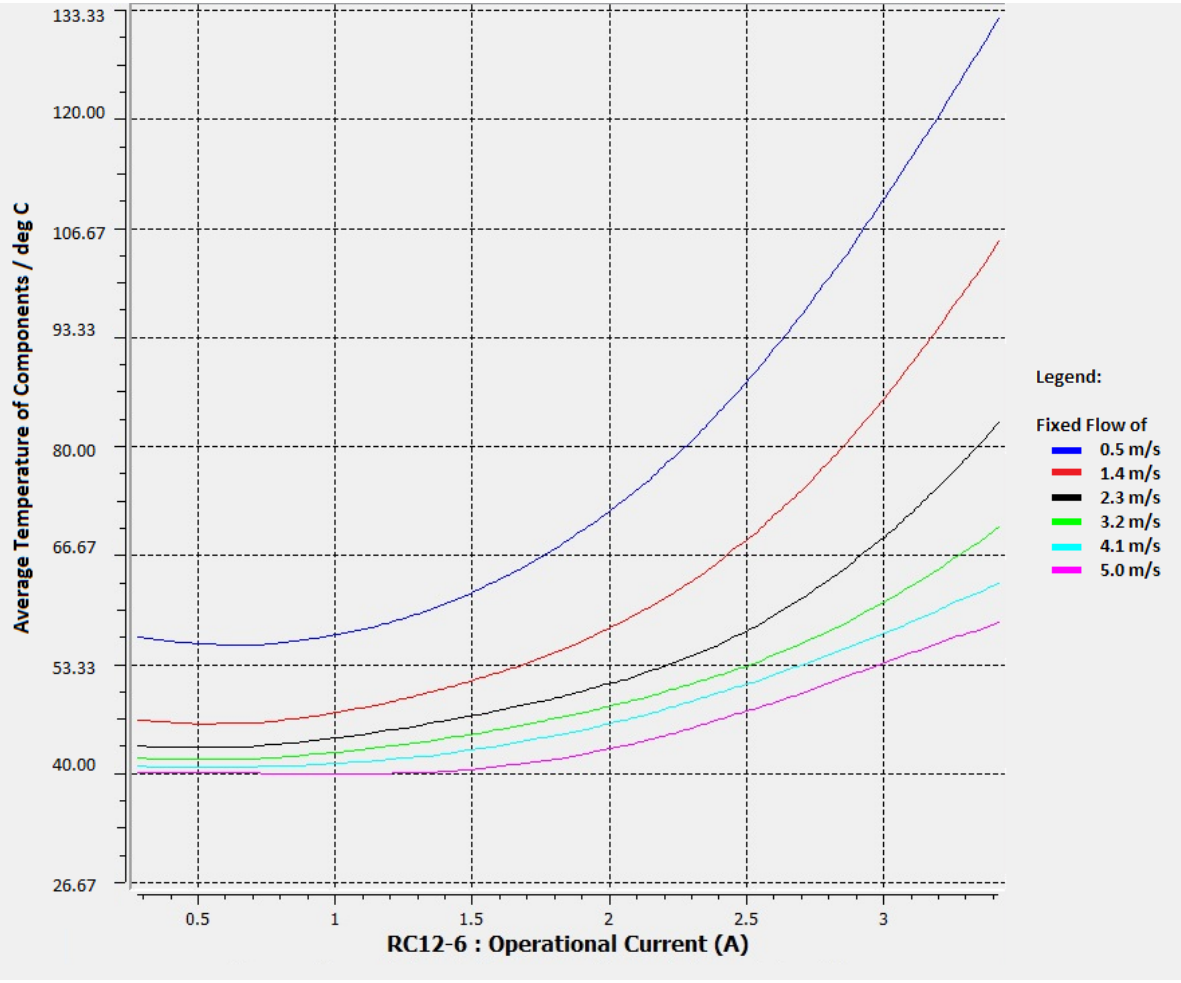
- Optimization of TEC operating current via Command Centre
- Input Variables
  - Normal velocity of flow: 0.5 m/s to 5 m/s
  - TEC operating current: 0.28 A to 3.42 A
- Output Variable
  - Case temperatures of all components
- Cost Function
  - Summation of case temperatures of all components, each with a weight of unity

-



Optimization Result

Plot of Cost function vs Operating Current at various



- Allows designer to determine optimal operating current at various flow velocities
- Lowest value of cost function at 5m/s
  - I_{TEC} = ~1 A
- $T_{case,U1}$ = 56.94 °C

Results Summary

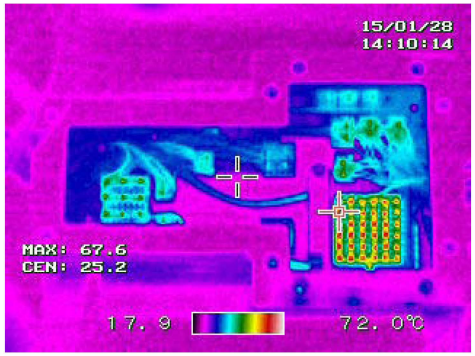
$T_{ambient}$ = 55 °C

Comp.	Target T_{Case}	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6	Study 7	Study 8
U1	73.9	160.8	252.3	239.5	95.2	86.2	76.2	62.1	56.9
U2	97.1	100.3	195.1	182.0	91.7	96.2	86.0	70.1	68.4
U3	121.1	97.1	190.4	177.0	92.5	96.9	86.2	70.8	69.0
U4	108.3	93.8	187.9	174.8	91.2	95.7	85.7	69.3	67.5
U5	111.0	85.2	178.8	165.4	90.4	94.8	85.0	68.3	66.5
U6	111.0	79.8	173.3	160.5	89.8	94.0	84.4	67.6	65.8
U7	134.2	96.0	183.3	169.5	93.4	96.0	88.0	70.8	68.8
U8	96.9	91.6	178.9	165.1	89.7	93.8	84.3	66.9	65.0
U9	103.8	103.1	189.2	176.0	89.0	93.1	83.7	66.3	64.3

Limitations

- Presence of mix convection environment
  - A simple enclosure to limit flow caused by air conditioning system
- Accuracy of IR camera
  - Use of Type ‘K’ surface probe to verify camera readings
- Connecting wires conducting heat
  - Fabrication of a PCB with necessary traces and pads

-



Future Research

- Use of TEC with other cooling methods
  - Use of Phase Change Materials
- Implementation of control method
  - Pulse-Width-Modulation
- System behaviour after failure of TEC

Recommendations

- Use of TEC is feasible under appropriate boundary conditions
- Suitable applications
  - Precise temperature control
  - Active cooling
- For the chassis in this project, addition of TEC alone is insufficient
  - Low profile heat sinks, and optimal TEC operating current
  - Introduction of flow

-

END OF PRESENTATION

ABSTRACT 187

APPLICATION OF THERMO ELECTRIC COOLER (TEC) IN AVIONICS FOR THERMAL MANAGEMENT