CFD Analysis of two-PCB Architecture for the Application in Data Storage Industry

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Abstract— In the recent years electronic products are becoming more compact with higher performance and efficiency. For this purpose the printed circuit board (PCB) has to carry more components like IC packages, NANDs, capacitors, resistor and so on in the same compact space. The effective performance of the components depend critically on the junction temperature, if the junction temperature of the component exceeds the limiting value the performance of the component and thus the performance of the device reduces or may fail. In order to keep the components functioning efficiently, extracting the heat and to maintain the optimal junction temperature becomes crucial. In this work a compact two-PCB architecture storage drive is considered and optimal packaging solution is suggested with the effective cooling of the drive. For this purpose the CFD simulation is done using ANSYS- Icepak software and the results are validated using experimentation in a wind tunnel with geometry representing the actual server.

Index Terms— Ansys- Icepak, Computational Fluid Dynamics (CFD), Electronic packaging solution, Heat spreader, Printed Circuit Board (PCB), Thermally Insulating Material (TIM).

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1 INTRODUCTION

THE needs for compact, efficient and reliable electronic devices are on demand in the current trend of market. The reliability of the device makes it more sustainable in the market. The storage devices are using solid state drives (SSD) by the application of IC packages and flash memory like NAND components to replace existing hard disk drives (HDD) to make SSDs high capacity drives, highly reliable and efficient. SSDs use PCB boards with IC packages, flash memory like NANDs, DRAM, capacitors, resistors, diode and so on in the same compact space. These components become sources of heat generation during operation because of joules heating i.e. heat generation by a conductor by the passage of electric current through it and is quantified by Joule-Lenz law (Joule's first law), given by (1)

$$P \propto I^2 \times R \qquad (1)$$

Where *'P'* is the power dissipation in the form of heat energy,' *I'* is the current flowing through the conductor and *'R'* is the resistance of the conductor.

A lot of researches are going on for the thermal characterization and cooling solution of PCB and its component using CFD analysis. R. Boukhanouf [1] performed the CFD analysis for the electronic cooling enclosure which is used in telecommunication radar system, where the author redesign the benchmark model with new thermal spreader copper shelf and vapor chamber heat pipes which gives the best result. K. Dhinsa [2] et al. investigates the accuracy of the turbulence model in order to predict the cooling effect in an electronic package. Michael C. Yang [3] compares the accuracy of commercially available numerical tools, Ansys-Icepak and FloTHERM for fluid flow and heat transfer problem by checking thermal performance of aluminum plate for both natural and forced convection environment. The author justifies that both CFD tools gives same result but depends on the mesh quality and user to input correct boundary conditions. John Lohan et al. [4] studied the effect of copper layer in PCB on the thermal performance for both natural and forced convection environment. The authors suggest that the proximity of trace layer influence the surface temperature of the PCB and also the junction temperature. L T Yeh [5] performed CFD analysis for an electronic box containing two racks with six PCB cards and proposed a cooling solution by using two fans in each rack and studies the board temperature by varying fan speed and for different flow pattern of the fan arrangements. R K Ali et al. [6] investigated the effect of spacing between in-line packages on the heat transfer coefficient. In this author considered two in-line heat sources on a horizontal surface and conducted CFD analysis using Ansys-Fluent.

The thermal analysis of any electronic device involve three stages of analysis, they are component level, board level and system level thermal analysis. For a device to work properly, it should be tested and validated at all three levels. With the use of CFD tools any electronic devices can be virtually prototyped for all three stages of thermal analysis and thermal behavior can be studied. The major cause for the failure of electronic equipment is found to be temperature rise(55%) while the other causes includes vibration(20%), humidity and dust(25%)[7]. The various cooling methods of electronic equipment include the use of heat sink, thermal interface material (TIM), cold plates and heat pipes. The selection of above methods depends on the level of cooling required and the type of device. The cheap and best method commonly used in industry is use of heat sink and TIM in a forced cooling environment with air as coolant by the use of fans. These methods become conjugate heat transfer problems as they involve thermal interaction between solid and fluids domains. Such problems can be best solved using CFD tool to

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solve for flow and thermal parameters by solving continuity, momentum and energy equations, which are the governing equation in fluid flow problems.

2 METHODOLOGY

2.1 Description of the two-PCB architecture

The device consists of two PCB boards stacked one above the other. The PCB used will comply with 15mm SSD form factor. The PCB consists of many ICs components like controller, NAND packages, DRAM, resistors, capacitors, diode etc. Of all these components only those components which are sensitive to high temperature and also high source of heat generation are considered for modeling, which are controller, NAND and DRAM. The PCB considered is a multilayered PCB with FR4 as substrate material and copper layers as conducting layer. Thus the PCB components are present on both sides of the PCB, making the drive dense. The PCB boards are placed in the aluminum enclosure of thermal conductivity 110 W/mK and cold rolled steel bottom enclosure of thermal conductivity 63 W/mK. The compact PCB is attached to the casing using screws.

2.2 Numerical modeling- using Ansys-Icepak

As a case study, firstly, only PCB with component is considered. The assembly is inside the top and bottom enclosure, (case 1). The simulation is done for this case and results are tabulated. Secondly, the Aluminum heat spreader is placed between the two PCB board and all the PCB components are applied with TIM material of thermal conductivity 1.5 W/m K, (case2). Thus in case 2, all outer surface PCB components are in thermal contact with the enclosure via TIM, while the inner PCB components are in thermal contact with Al heat spreader via TIM. The assembly for both cases is shown in Fig. 1 and Fig. 2.

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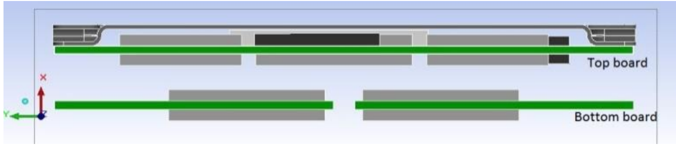


Fig. 1. Cross section of the drive for case 1 scenario

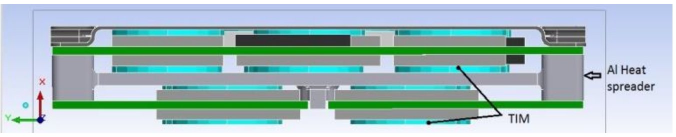


Fig. 2. Cross section of the drive for case 2 scenario

1) Geometry and modeling: The PCB is modeled in Ansys-Icepak using macro 'PCB' command. Geometry of the PCB is defined. In this project a compact model is created. FR-4 is considered as substrate material and copper layer as conducting layer material. The PCB considered is a 12 layer board with 15 μm of copper thickness. The effective in-plane conductivity is found to be 44.1 W/mK and through the plane conductivity of 0.45 W/mK. All PCB components are created using two resistor network models. The thermal resistance at a surface is obtained from the PCB component manufacturers. Theoretically it is given by 1-D Fourier law of conduction as given in (2),

$$R_{J-X} = \frac{T_J - T_X}{Q} \tag{2}$$

Where Rj-x is the thermal resistance between junction 'j' of the component and a reference point 'x', Tj and Tx are the temperature at junction of the component and reference point respectively and Q is the heat flux. The power, junction-to-case (Rjc) and junction–to-board (Rjb) resistance values are entered in the relevant field. The values considered for different PCB components are given in the TABLE 1.

TABLE 1

PCB COMPONENT PROPERTIES

PCB Component Name	Dimensions, $l \times b \times t$ (mm)	Power (W)	R_{jc} (K/W)	R_{jb} (K/W)
Controller	23×23×1.2	5.4	6.3	11.4
DRAM	13.3×9.6×1.2	0.25	2.1	18.6
NAND	18×14×1.4	0.39	2.8	7.5

Similarly, the top and bottom casing is modeled in Solidworks and converted to .step file and imported to ANSYS-Icepak using CAD data command. The imported CAD geometry is converted to block feature using the settings. Aluminum die cast material is selected for top casing and steel for bottom enclosure. TIM and heat spreaders are also imported as CAD model and converted into block feature with properties assigned.

2) Meshing and Boundary condition: The meshing defines the accuracy of the result. A fine mesh gives best result but requires higher version of hardware and it is time consuming. Thus to compensate between time consumption and accuracy non-conformal mesh is developed. In non-conformal meshing, fine meshing is developed in critical areas like PCB components and number of element and element size is defined for each component by grouping them using assembly command. The non-conformal meshing applied to the top PCB placed in the cabinet is shown in Fig. 3.

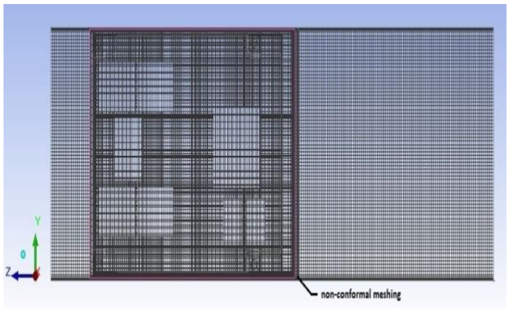


Fig. 3. Non-conformal meshing

A wind tunnel which represents the standard server geometry is constructed. Three drives are stacked in parallel as shown in Fig. 4. Air is considered as the cooling fluid at an ambient pressure of 1 atmosphere. The ambient temperature of 45ºC representing the worst cases scenario is considered. The fan is placed on the right end of the wind tunnel. Axial fan is considered for the study and volume flow rate of air through fan is varied for effective cooling solution.

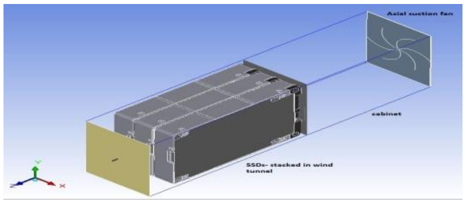


Fig. 4 Assembly of three drives in wind tunnel

For the solver, turbulence model (K-ε) is considered with 100 iterations for the residual to converge. The simulation is solved for both flow and temperature parameters while the radiation parameters are not considered.

2.3 Experimental setup

To validate the simulation result, the assembly with TIM and heat spreader is considered for experimentation (case 2). Since the other cases may fail the drives and cause loss of the prototypes, as the simulation for case 1 suggest the failure condition.

PCB components are attached with T-type thermocouples and connected to data logger for temperature reading. The IOPS are loaded to the drive using vdbench software. The drive with wind tunnel is kept inside the thermal chamber and ambient temperature of 45 ºC is set. The test is run for 11 hours and IOPS reading is continuously monitored to maintain it at 1800mbps otherwise the drive throttles. The junction temperature readings are obtained from Agilent software and mean temperature on each PCB component over the test duration is calculated and tabulated. The assembly setup in thermal chamber is shown in Fig. 5.

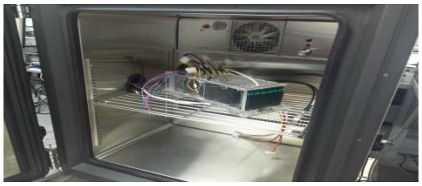
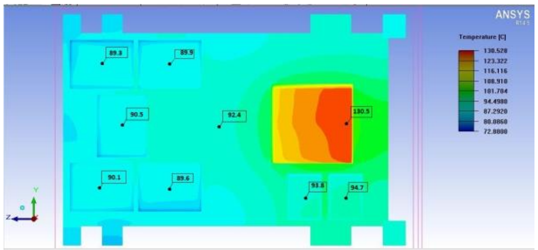


Fig. 5. Drive assembly with wind tunnel placed in thermal chamber

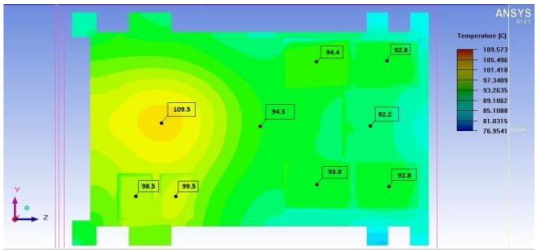
3 RESULTS AND DISCUSSION

3.1 Simulation results

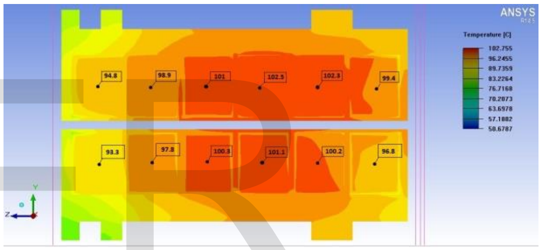
1) Case 1: The simulation results are obtained after the results are converged. The individual boards are selected to define contour plots for temperature profile. The results obtained for case 1 scenario is shown in Fig. 6a to Fig 6d. The contour plots are defined for both top and bottom side of all PCB boards. The results of junction temperature on all PCB components are also listed in Table 2. While for NAND, only the maximum temperature on each side is selected and listed. The temperature contour ranges are applied only to each board in each figure.



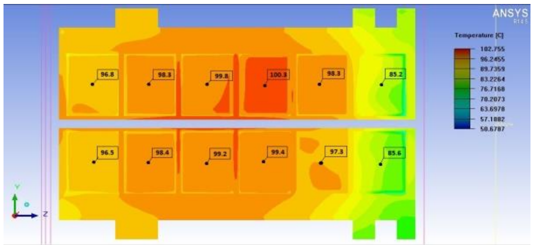
a. Top side of Top Board



b. Bottom side of Top Board



c. Top side of Bottom Board



d. Bottom side of Bottom Board

Fig. 6 Thermal profile on all PCB boards for Case 1

For the drive to operate normally without throttling, requires all the PCB components junction temperature to be within allowable limit. The allowable temperature limit is given by the component manufacturer.

TABLE 1

JUNCTION TEMPERATURE FOR CASE 1

Sl No.	PCB Component		Temperature Limit (ºC)	Obtained Junction Temperature (ºC)
1	Controller		125	130.5
2	DRAM		85	94.7
3	NAND	Top Board	80	94.4
		Bottom Board		102.5

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From the simulation results it can be observed that the temperature on controller is found to be 130.5ºC, which is more than the limit value by 10ºC, for DRAM the temperature is varying from 93.8ºC on the top side of top board to 99.5ºC on the bottom of the top board, while the limit value is 85ºC. The NAND temperatures for the top side of top board are varying from 89.3ºC to 90.5ºC, while for the bottom side of the top board it is in the range of 92.8ºC to 94.4ºC, thus for the case 1, all the components junction temperature exceeds the limit value. If the drive is made to work in this condition, the drive throttles and leads to its failure by overheating of the components.

The reason for higher temperature is, all the components are exposed only to convective heat transfer. The heat generated has to be carried by air only by convection mode of heat transfer. Also the gap between two boards is overheating the component in that region as the area exposed to air is minimal but the component placement is dense. For this case if only TIM is used on all PCB components the results will not be satisfactory particularly between two boards. This is because the heat generated between the two boards will be accumulated or overheat the adjacent board components.

The velocity profile giving the velocity distribution in the drive, near top PCB board is shown in Fig. 7.

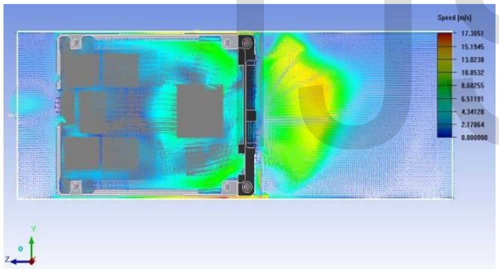
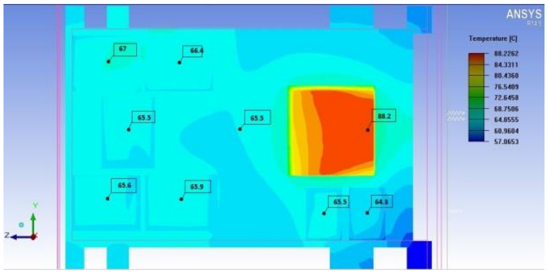


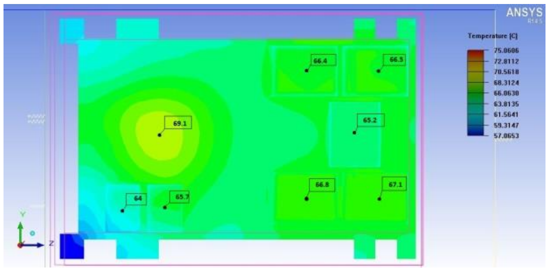
Fig. 7. Velocity profile near top board

2) Case 2: For this case, TIM on all PCB components with thermal conductivity of 1.5 W/mK and Aluminum heat spreader between the PCB boards are included in the simulation. The TIM on the outer surfaces PCB components makes contact with enclosures while the TIM on inner surface PCB components makes contact with Al heat spreader. The assembly is placed in the enclosure. Such assembly will overcome the drawback encountered in case 1. In this case all PCB components are making contact with enclosure via TIM. Thus the heat generated will be carried away and distributed over larger area of enclosure and heat spreader, as the aluminum is a good conductor of heat helps to absorb more heat from PCB components and act as heat sink.

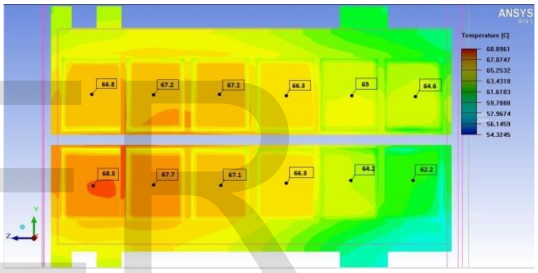
The post processing results obtained after the convergence is shown in Fig. 8a to Fig. 8d. The temperature on all PCB components as obtained in thermal profiles is listed in the Table 3. Here also only the maximum NAND junction temperature on each side is tabulated. The contour plots are defined for each board temperature range only rather than the assembly as it gives better visualization of the results.



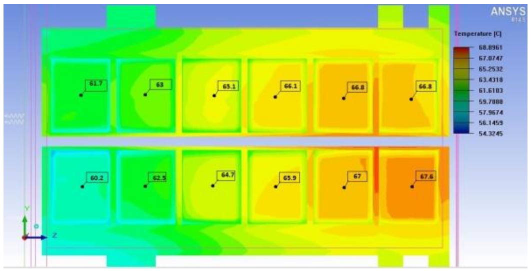
a. Top side of Top Board



b. Bottom side of Top Board



c. Top side of Bottom Board



d. Bottom side of Bottom Board

Fig. 8 Thermal profile of all PCB boards for Case 2

TABLE 3

JUNCTION TEMPERATURE FOR CASE 2

Sl No	PCB Component		Temperature Limit (°C)	Obtained Junction Temperature (°C)
1	Controller		125	88.2
2	DRAM		85	65.7
3	NAND	Top Board	80	67.1
		Bottom Board		68.3

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The simulation result of case 2 clearly indicates the reduction in junction temperature on all PCB components. The temperature on controller is found to be 88.2ºC, which is almost 32% reduction in the junction temperature compared to case 1 scenario. similarly a reduction of 30%, 28% and 33% of junction temperature compared to case 1 can be observed for DRAM, top board NAND and bottom board NAND respectively.

3.2 Experimental result

The experimental results obtained are at 45 ºC with 9 cfm air flow i.e. 3 cfm/SSD. The thermocouple readings are noted on the data logger and tabulated in Table 4.

TABLE 4
READING FROM EXPERIMENTATION

Sl No.	PCB Component		Thermocouple reading (ºC)
1	Controller		79.3
2	DRAM		69.5
3	NAND	Top board	66.1
		Bottom board	64.1

3.3 Correlating simulation and experimental result

The results obtained from simulation done in Ansys-Icepak and experimentation done in thermal chamber for the same boundary condition for case 2 scenario is tabulated in table 5. The correlation is made only for case 2 as simulation for case 1 already suggesting failure condition, experimenting the drive for case 1 makes the drive to fail and loss of a prototype drive.

TABLE 5
CORRELATING RESULT FOR CASE-2 SCENARIO

Sl No	PCB Component		Temperature Limit (ºC)	Simulation Result-Temperature (ºC)	Experimental Result-Temperature (ºC)
1	Controller		125	88.2	79.3
2	DRAM		85	65.7	69.5
3	NAND	Top Board	80	67.1	66.1
		Bottom Board		68.3	64.1

The result obtained from both simulation and experimentation is found to be within limit value of junction temperature. The simulation results are coming little higher than experimental result, this is because the simulation is done for worst case steady state loading conditon while in real practice the load on the drive is fluctuating and tansient.

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4 CONCLUSIONS

The presented work consist CFD simulation and validation of two-PCB architecture placed inside the enclosure. This device is mainly used in data storage industry as high capacity drive. The work done included two cases of simulation and made a correlation of simulation result with experimental testing for validation. From the work the following conclusions are drawn

1. The simulation on case 1 scenario indicated that the PCB components junction temperature are overshooting the limit value thus needed an optimal cooling solution.
2. The simulation on case 2 included TIM on all PCB components and an aluminum heat spreader between the two PCB boards in order to extract heat from inside PCB components. The result for case 2 is found to be satisfactory with all PCB components junction temperature being within the limit valve.

From this work it can be concluded that a 15mm drive with 15W power dissipation at an ambient temperature of 45ºC needs TIM on all PCB components with thermal conductivity of 1.5 W/mK and an aluminum heat spreader in between the two PCB board for uniform heat extraction. Also a volume flow rate of 3 cfm/SSD is necessary for the effective cooling of the drive.

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