# DESIGN DEVELOPMENT AND ANALYSIS OF A HEATSINK OF A 7 kW SPLIT AIR CONDITIONER OUTDOOR UNIT

A DISSERTATION

SUBMITTED IN PARTIAL FULLFILMENT OF THE REQUIRMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY

IN

**THERMAL ENGINEERING**

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# CANDIDATE’S DECLARATION

I, ASHISH MADAAN, Roll No. 2K21/THE/05, student of M. Tech Thermal Engineering, hereby declare that the project Dissertation titled “DESIGN DEVELOPMENT AND ANALYSIS OF HEATSINK OF A 7 kW SPLIT AIR CONDITIONER OUTDOOR UNIT” which is submitted by me to Department of Mechanical engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Masters of Technology, is original and is not copied from any source proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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## CERTIFICATE

I hereby certify that the Project Dissertation titled “DESIGN DEVELOPMENT AND ANALYSIS OF HEATSINK OF A 7 kW SPLIT AIR CONDITIONER OUTDOOR UNIT”, which is submitted by Ashish Madaan 2K21/THE/05, Mechanical Department, Delhi Technological University, Delhi, in partial fulfilment of the requirement for the award of degree of Masters of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part of full for any Degree or Diploma to this University or elsewhere.

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# ABSTRACT

A heat sink development project has been mentioned in this study. The main aim was to design, develop and test a new heatsink for the outdoor unit of split air conditioner which is being upgraded with respect to cooling capacity from 5 kW to 7 kW. The increase in cooling capacity enhances the power requirement of the system which in turn increases the power across IC as well and increases its temperature too which needs to be taken care of. So, in order to take care of this high temperature across IC a heatsink design and development project was initiated. The various steps that were taken from start of project to its final completion have been briefed in this study. Starting from studying about heatsink its importance its use to studying various parameters related to heat sink effecting its performance and which parameter contributes how much towards its performance improvement in order to obtain the most optimized heatsink model which would be able to keep the temperature of IC of PCB within certain limit and prevent them from destroying themselves due to high enough temperature is the main goal here. This is achieved by first building a system that would replicate the test results on the base model and work my way up on various different models in order to obtain the most feasible model.

# ACKNOWLEDGEMENT

I would like to express my deepest appreciation to all those who provided me the possibility to go forward and complete this project. A special gratitude is due to Head of Department, **Professor S.K. Garg** whose contribution in stimulating suggestions and encouragement, helped me in the project.

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I feel proud and privileged in expressing my deep sense of gratitude to all those who have helped me in presenting this project.

Last but never the least I thank my respected parents and my brother for always being with me, in every sense.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| IC: | Integrated Circuit |
| PCB: | Programmable Circuit Board |
| b: | Base width |
| d: | Contact width |
| n: | Number of fins |
| h: | Height of fins |
| s1: | Spacing between initial fins |
| s2: | Spacing between central fins |
| t: | Thickness of fins |
| T: | Temperature at junction |

# CHAPTER 1

# INTRODUCTION

The importance of thermal management challenges in these applications has increased as a result of the ongoing rise in power densities in microelectronics and the parallel effort to lower the size and weight of electronic products. The usual electronic device's size and cost have greatly decreased over time, but its functional requirements, dependability, and operating temperatures have significantly increased. Additionally, the rate of automation is rapidly accelerating across all industries. The chip temperature at the junction of an electronics package is now the determining factor for the package's longevity. Using passive or active heat sinks is the most used technique for cooling packages. Passive heat sinks, which are very easy to use and do not require external power, are utilized in natural convection applications where the typical heat dissipation load is between 5 and 30 W.

Almost every major business in the world uses electronic equipment to conduct a wide range of tasks that depend on the flow and regulation of electrical current. A resistive element produces heat whenever electrical current passes through it. The quantity of heat produced in the element increases with an increase in current or resistance. As long as the current is flowing, heat will continue to be produced. Unless the heat can find a flow channel that gets it away from the element, the temperature of the resistive element starts to grow as the heat accumulates. Poor heat transfer pathways can cause temperatures to rise until the resistive element is destroyed and the current is cut off. The efficient dissipation of heat generated by the electronic components is a key factor in the design of electronic equipment. In order to prevent the apparatus from overheating, which might reduce dependability and lead to early failure, thermal management is required. As the electronic industry continues to develop, more delicate components are being created, making good heat management even more essential. All heat transfer methods (conduction, convection, and radiation) are used to disperse heat from electrical equipment by transferring it to the ambient environment outside. Common cooling methods used for electronic equipment with low to moderate power densities include computer chips, electronics, and telecommunication boxes are natural convection and radiation. Natural convection's primary benefits include great dependability, little noise, and low power consumption. The efficient dissipation of heat generated by the electronic components is a key factor in the design of electronic equipment. In order to prevent the apparatus from overheating, which might reduce dependability and lead to early failure, thermal management is required. As the electronic industry continues to develop, more delicate components are being created, making good heat management even more essential. All heat transfer methods (conduction, convection, and radiation) are used to disperse heat from electrical equipment by transferring it to the ambient environment outside. Common cooling methods used for electronic equipment with low to moderate power densities include computer chips, electronics, and telecommunication boxes are natural convection and radiation. Natural convection's primary benefits include great dependability, little noise, and low power consumption.

A heat sink is an electronic digital component or simply a device of an electronic circuit that typically disperses heat from other circuit components (primarily from the power transistors) into the adjacent medium and cools them in order to improve their own effectiveness, consistency, and also eliminate early element failure. It includes a fan or chilling mechanism for cooling purposes. It is a passive heat exchanger that typically transfers the heat produced by an electronic or mechanical device to a fluid medium, frequently air or a liquid coolant, where it is dissipated away from the device, allowing for the best possible temperature control. Heat sinks are used to cool central processing units and graphics processors in most computer systems. Heat sinks are tools for accelerating the transfer of heat from hot surfaces to colder air. The fins of heat sinks are often angled to allow an upward air draught caused by natural convection to pass through rectangular U-channels. Although there may be a variety of heat sink design objectives, the major focus is typically on optimizing the natural convection heat sink.

The improvement of the heat sink has turned into a standard procedure for designing electronic equipment. Heat sinks are tools for accelerating the transfer of heat from hot surfaces to colder air. The fins of heat sinks are often angled to allow an upward air draught caused by natural convection to pass through rectangular U-channels. Although there may be a variety of heat sink design objectives, the major focus is typically on optimizing the natural convection heat sink. The improvement of the heat sink has turned into a standard procedure for designing electronic equipment. They are device that are responsible for taking away the heat from high temperature source generally ICs of PCBs using either natural convection or forced convection heat transfer with the use of a fan. Heat transfer coefficient is the most critical property when it comes to heat dissipation, its value depends not only on the fluid that is either air or liquid taking away the heat from the fins of heat sink but also on the fact that if the flow is forced or not as in case of air if the flow is natural then the value of heat transfer coefficient value varies from 2 to 25 W/mK but in case of forced convection heat transfer the value becomes 25 to 300 W/mK. With the advancement in the field of electronics for smaller, faster the thing that pulling back on the innovation level is the heat they are generating, so in order to the innovation level high in the field of electronics the need for high innovation is needed in field of heat sink as well.

There are various parameters on which heat sink performance depends, these parameters control the heat transfer rate through the heat sink and maintains the temperature lower at the contact point between heat sink and the IC of PCB. These parameters include number of fins, spacing between fins, thickness of each fin, height of fins, shape of fins. There is specific relation between conduction and convection element relating to the heat sink which needs to be properly adjusted or maintained in order to optimize the heat transfer rate through the heat sink because decrease in conduction resistance at one place will result in increasing conduction resistance at the same place so overall their value have to be judged in order to optimize the heat transfer rate through the heat sink. This judging of values can be done on simulation software which than can be validated using experimental analysis with lesser number of iterations needed to be done.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1. LITERATURE REVIEW

Yoon et.al (2018) studied heatsink according to the location of the partial hot area, they evaluated and assessed the radiative heat efficiency in this experimental research. The heat transmission between the heatsink and the surrounding air was examined using numerical modelling models for forced convection. The optimum place for partial heat is explored in terms of the influence of the overall rate of heat transfer, air velocity, the proportion of the whole length of the heat sink to its hot wide surface, the heat sink's thermal conductivity, and the thickness of the heatsink's base. This research suggests that tests would establish a relationship to discover the optimal position for the heat. Therefore, by locating the ideal location for partial heating, it is feasible to minimize the heat resistance of heat by 30%. By moving the heating element's mounting position on the radiation, it is anticipated that the thermal efficiency will increase and the electronics will operate more effectively.

Hussain et.al (2019) studied, the effect of flow direction and fillet profile on the thermal performance of plate-fin heat sinks is demonstrated. The computational fluid dynamics (CFD) model is developed and validated through comparison with experimental data from the literature. A plate-fin heat sink with a fillet profile that is subject to parallel flow has specifically been compared to the traditional design (a plate-fin heat sink without a fillet profile that is subject to an impinging flow), and satisfactory results have been noted. The findings of this investigation demonstrate that the suggested design has a lower base temperature and thermal resistance of the heat sink. As a result, the established technique offers a great deal of potential for application in enhancing the thermal performance of heat sinks, leading to the development of more sophisticated and efficient cooling solutions.

Hasan et.al (2018) studied the bottom of the heat sink, a constant heat flux is applied, while the upper surfaces of the heat sink are subject to a mixed (convection and radiation) boundary condition. The findings demonstrated that the use of phase change materials in micro-channel heat sinks with various designs improved the cooling capacity of the micro heat sink. As different phase change materials caused different values of heat sink temperature reduction in the range of ambient temperature due to different PCM melting temperatures, the phase change material should be selected according to its melting temperature according to the specific application. The kind of PCM (organic or inorganic) and the quantity of PCMs used in a particular application determine the price of materials.

Liao et.al (2017) studied, numerical simulations and an experimental setup were used to assess the thermal conductivity of a pin-fin heat sink in a cross-flow with delta winglet vortex generators. The effects of Reynolds flow, the vortex machine's angle of attack, the shortest distance between each vortex generator and the vortex engine's heat sink, and the vortex machine's configuration on the impact of radiation had all been tested. The findings imply that while the extent of the reduction falls with Reynolds, the heat resistance lowers as Reynolds increases. When the distance between the generators is the shortest possible, distance between the vortex generators is greater than the length of the radiation. the heat resistance produced is smaller than that achieved when the shortest possible When the rotating generator is positioned in the center of the heat sink on both sides, the heat transmission of this sort of heat sink is high. Even though raising the vortex engine's height can boost heat transmission, it also widens the pressure gap. When compared to the heat generation of the vortex generators prepared in the overall stream, the heat sink equipped with vortex generators has a lower thermal resistance than the sink.

Jeon et.al (2016) carried out various experiments on the transport of heat from radial heat sinks with perforated rings in natural convectors were used. On the thermal efficiency, the effects of perforation count (0–6), hole diameter (0–3 mm), hole length (1.5–6 mm), and directional angle (0–180) were investigated. The findings showed that, when compared to heat sinks with imperforated rings, radial heat sinks had the best thermal performance. The radial heat sink with a 37% mass reduction and an optimized perforated ring has a 17% lower thermal resistance than the imperforated ring. This can be configured to allow natural convection to occur without obstruction through the incision.

Sudhakar et.al (2016) estimated the degree of temperature imbalance and mass temperature that diffuses through the base of the heat sink from the heat source to the cold side, the researcher in this article used the three-dimensional temporary pattern of the geometric structure of the substrate of the chip. This model includes heat that can be momentarily heated by several asteroids and can absorb heat from any source. The level of the same is represented as a function of the border state's shape. The approach used in this paper is helpful in assessing similar heat load circumstances that aren't fully filthy but are dispersed by radiation to the cool side instead.

Anbumeenakshi et.al (2016) studied the common impacts of nanofluids and uneven heat on the cooling effect of microchannel sinks were examined in this work through a series of tests. The 30 rectangles with a dimension of 0.727 millimeters are distributed by the microscopic radiation taken into account in this investigation. Three identically sized machines were employed in the experimental studies. By turning on two of the three heaters at once, uneven heat is produced. The chipper should be positioned above the flow for the pulse rays' maximum temperature to be at their lowest.

Nor Haziq Naqiuddin et.al (2017) conducted extensive research on microchannel heat sinks for maintaining the ideal temperature in mechanical microelectronic systems. The ratio of total heat transfer area to volume may improve overall heat transfer efficiency. He saw how straight channel design suffers when the flow deteriorates in the direction of the flow. This will have a negative impact on the device's overall thermal performance by causing inconsistent cooling performance. A geometrically graded microchannel heat sink is presented to address these flaws and boost the thermal efficiency of the traditional straight channel heat sink. The thermal performance of a heat sink with a fin microchannel and one with a straight channel was compared.

Duangthongsuk et.al (2015) studied the thermal conductivity and flow properties of heat sinks with geometries like circular and square pin (MCFHS and MSFHS) that were filled with SiO2, dispersed in DI water, at fractional volumes of 0.2, 0.4, and 0.6% of the sound strength, were evaluated in this paper. The influence of needle structure, particle concentration, heat exchanger flow rate, and pressure drop over the test site are described. It is presumable that as particle concentration and Reynolds numbers rise, so will the coefficient of heat emission. Finally, it would advise that when it comes to circular fin structures, the usage of square heat sinks should be avoided.

Afzal Husain et.al (2016) investigated the thermal performance, a 3-D model was created. Incompressible steady state circumstances with laminar flow were the focus of the study. Heat flux was applied to one side of the substrate, and microchannels, pillars, and jet impingements were set up on the opposite side. Regarding the ratios of standoff (the distance from the nozzle exit to the impingement surface) to jet diameter and jet pitch to jet diameter, the 11 novel designs were contrasted with the traditional models. Pressure drops, heat transfer efficiency, and overall thermal resistance were used to evaluate the thermal performance. High jet pitch to jet diameter ratios were found to offer minimal pressure decreases.

Daxiang Deng et.al (2015) created a novel re-entrant heat sink with 14 parallel copper microchannels with a hydraulic diameter of 781 m. Single phase convective heat transfer was the flow regime, and both experimental and numerical evaluations of the performances were done. De-ionized water with a Reynolds number of 150–1100, three distinct heat flux values, and two input temperatures of 33 and 60 °C were employed as the coolant. It was demonstrated that, as compared to a straightforward rectangular microchannel, the average thermal resistance decreased by 22%. In addition, their pressure losses were comparable. The fluid was accelerated and the flow of the fluid was mixed, which improved heat transfer.

Jamil A.Khan et.al. (2014) developed a two-phase microchannel heat sink using passive (nanostructures) and active (jet in microchannel) structures to handle high heat flux applications, particularly in military electronics. By utilizing a high surface area to volume ratio and a high latent heat of vaporization, this is accomplished. High heat dissipation rates make flow boiling appear like a highly attractive concept; however, it is accompanied by pressure changes and boiling instability. By adding turbulence into the flow field and changing the dynamics of the bubbles, active structures improved heat transmission, whereas passive structures achieved the same results by modifying the surface characteristics to improve boiling performance. Techniques for passive control can be used to remove a lot of heat from a small area.

M.Meis et.al. (2010) demonstrated how vortex promoters in a 2-D laminar flow in a microchannel affected heat transfer and pressure losses. Water was chosen as the working fluid because of its temperature-dependent viscosity and thermal conductivity. Circular, rectangular, and triangular cross sections were primarily examined at various aspect ratios. Additionally considered were the impact, the Reynolds number, and the relative position and orientation of the obstruction.

Dong-Kwon Kim et.al (2010) proven that when the dimensionless pumping power is low and the dimensionless length of the heat sinks is big, optimized pin-fin heat sinks have lower thermal resistances than optimized plate-fin heat sinks. On the other hand, when the dimensionless pumping power is high and the dimensionless length of the heat sinks is low, the optimized plate-fin heat sinks have lower thermal resistances.

Sidy Ndao et.al (2009) deduced that single objective optimization of either the thermal resistance or pumping power may not always produce the best performance from multi objective thermal design optimization and comparative analysis of electronic cooling systems. Because it offers a solution with various trade-offs from which designers can pick to suit their cooling needs, the multiple objective optimization approach is used. For a given cooling application, the choice of coolant has a big impact on the choice of cooling technology.

## 2.2. RESEARCH GAP

- From the literature review it can be noted that none of the research is focused extensively on the measurement of effect of various parameter on the performance of heat sink
- Also, none of them focused upon designing heatsink which are for a very high tonnage system and only focused their work on small micro level heat sink.
- Studying the effect of different parameters such as base width, fin height, fin thickness, spacing between fins and number of fins upon improving the performance of outdoor unit of split AC has not been carried out.

## 2.3. PROBLEM STATEMENT

Room air conditioning department of my company has increased power input of one of their air conditioning units from 5 kW to 7 kW due to which the power across ICs of their PCBs which are present on outdoor unit of air conditioner has increased. Due to this increase in power across ICs the temperature of those ICs is reaching a value which are much beyond their limit and has the potential of destroying themselves which can lead to shutting down of the AC unit or can lead to failure of certain parts involved in the air conditioning process.

## 2.4. OBJECTIVE

- The objective of the project is to work upon parameters like spacing between fins, thickness of fins, height of fins, number of fins, base width and contact width in order to achieve an optimal feasible model dimensionally for the new heatsink model.
- By working my way up on the base design in order to fulfill basic dimension constraint like length and width and varying one by one different parameters in order to achieve final optimal heat sink design.
- This optimal heatsink design will help bring temperature of the IC on the PCB within limits and prevent them from destroying themselves as well as any other part which they are controlling.

# CHAPTER 3

# SYSTEM DESCRIPTION AND MODELING

## 3.1. SYSTEM'S DESCRIPTION

In order to carry out this project successfully a plan was designed in which first basic information related to heat sink needed to studied like the various parameters involved effecting the performance of heat sink, material of heat sink. Second step was to work on the geometry of heat sink that is the base geometry of heat sink, geometry cleanup required in order to carry out simulations and derive a method/procedure in order to design each heat sink in the most effective manner. Third step was developing boundary conditions, assigning material. Fourth step was to reverse engineer the amount of heat flow that goes into the heat sink that would match the temperature of heat sink obtained from the test data. After the development of this system various different models can be iterated one by one by varying one variable at a time and obtain the corresponding value of temperature at junction for each case. This system designed will be able to produce a suitable heat sink design that could effectively take away the heat from the ICs of PCBs and keep their temperature within limits.

## 3.2. BASE MODEL

The base model of RA heat sink is used in order to setup the system according to the test conditions and using that system various models can be tested against it. This help generate comparative data between the initial model and the model further developed. Also using this model, a system is generated of creating new models in the most efficient way possible.

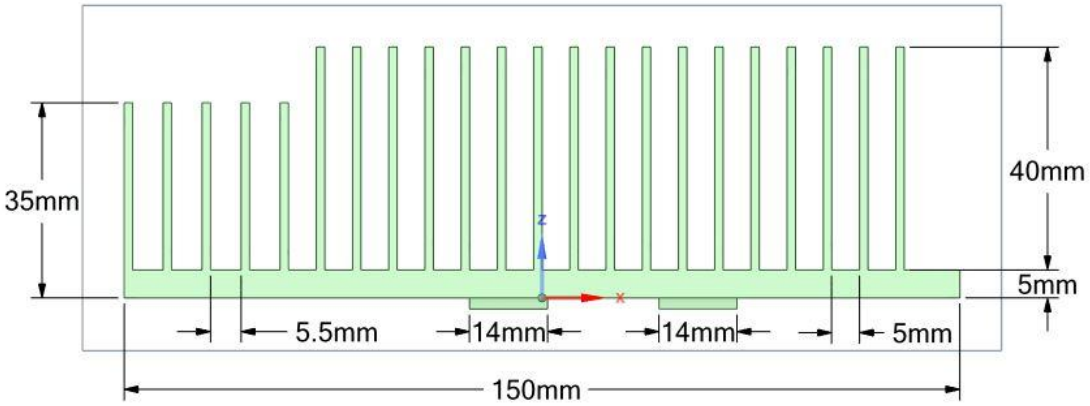

Figure 3.1: Base model front view

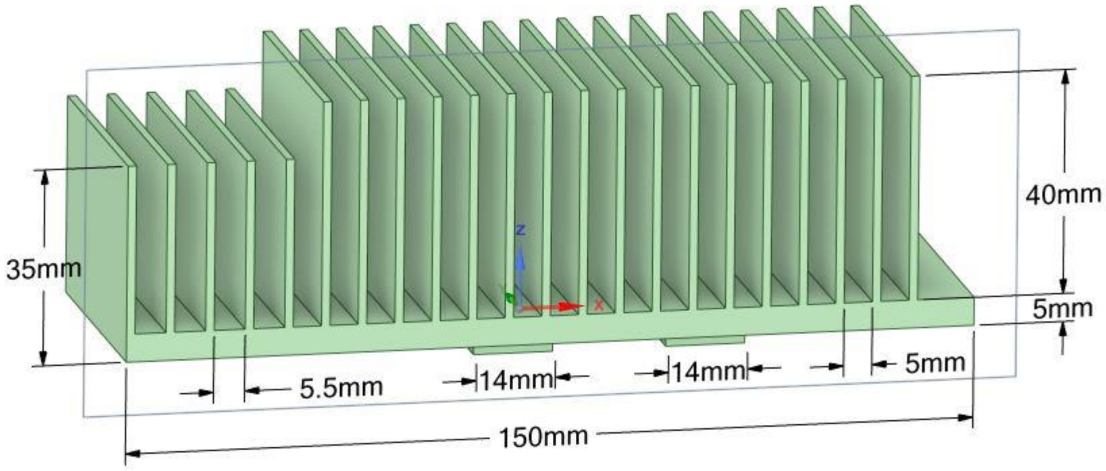

Figure 3.2: Base model 3D view

## 3.3. BOUNDARY CONDITIONS

In order to design new, heatsink first a system has to be prepared which gives results of temperature at junction on the base model same as that of the test data. Since once the system is prepared every new model can be tested against that system boundary condition in order to obtain comparative data between initial and new model and work our way in finding the final feasible model.

Table 3.1: Boundary conditions

| S.no. | Boundary Conditions | |
|---|---|---|
| 1 | Material | Aluminum |
| 2 | Conductivity | k = 210 W/mK |
| 3 | Mesh | Tetrahedral |
| 4 | Mesh size | 3 mm |
| 5 | Initial Temperature | 25 $^0$C |
| 6 | Ambient Temperature | 50 $^0$C |
| 7 | Convection coefficient | 25 W/m$^2$K |
| 8 | Heat flow, IC 1 | 90 W |
| 9 | Heat flow, IC 2 | 10 W |

## 3.4. DIMENTIONAL CONSTRAINT

There was certain dimensional constraint which were needed to be kept in mind before proceeding any further in terms of varying parameters due the constraint associated with the space, placement and clamping of heat sink and also agrees with the structural report provided by the structural team in order for it to withstand drop test.

Table 3.2: Dimensional constraint

| S.no. | Constraint | Initial Condition | Final Limit |
|---|---|---|---|
| 1 | Length | 150 | 150 |
| 2 | Width | 50 | 50 |
| 3 | Height | 30,40 | 50,60 |
| 4 | Base width | 5 | <10 |
| 5 | Number of fins | 22 | - |
| 6 | Spacing s1 | 5.5 | 4.5 |
| 7 | Spacing s2 | 5 | 4 |
| 8 | Thickness of fins | 1.5 | - |

## 3.5. MODELING

The modelling of system starts first with the preparation of base model in spaceclaim starting from the base plate to the creation of fins removing any fillets or circular holes that won't affect the final output but will increase the mesh count. After the base model has been generated then it is brought in steady state thermal analysis mechanical simulation software in which we first define our material of heat sink which is in this case is Aluminum having thermal conductivity of 210 W/mK. After defining our material, we assign that material to our heatsink and proceed further. After assigning our material we start working on contact region that is we define our contacting region between fins and base plate, base plate and contact plate in order to have continuity in terms of flow of heat from one surface to another. After defining contact region, we assign mesh to the whole domain which is heat sink in this case. The mesh that we used is tetrahedral mesh with the mesh size of 3mm. This mesh size is chosen due to constraint associated with ANSYS student version regarding the total file size and ram allocation during solving. After this we start assigning boundary conditions like the initial temperature value, ambient temperature value, heat transfer coefficient and the amount of heat flow into each IC. After setting up the entire system now we first generate mesh and then after mesh generation is complete, we start the solver and get the result in terms of output required which is temperature in this case and start noting down the values starting from the base case and for each individual iteration until the final feasible model is obtained.

# CHAPTER 4

# RESULTS & DISCUSSION

## 4.1. BASE MODEL TEST RESULT

Base model is tested under the boundary conditions mentioned above and is validated against the test result which showed a temperature of around 112.2 $^{0}$C for the ambient condition of 60 $^{0}$C and our simulated model showed a temperature of around 111.9 $^{0}$C for the same ambient condition of 60 $^{0}$C. So, there was an error of around 0.2674% between the real and simulated test result which is well within limits. So, the system generated using the base model was good and can now be used for testing future models.

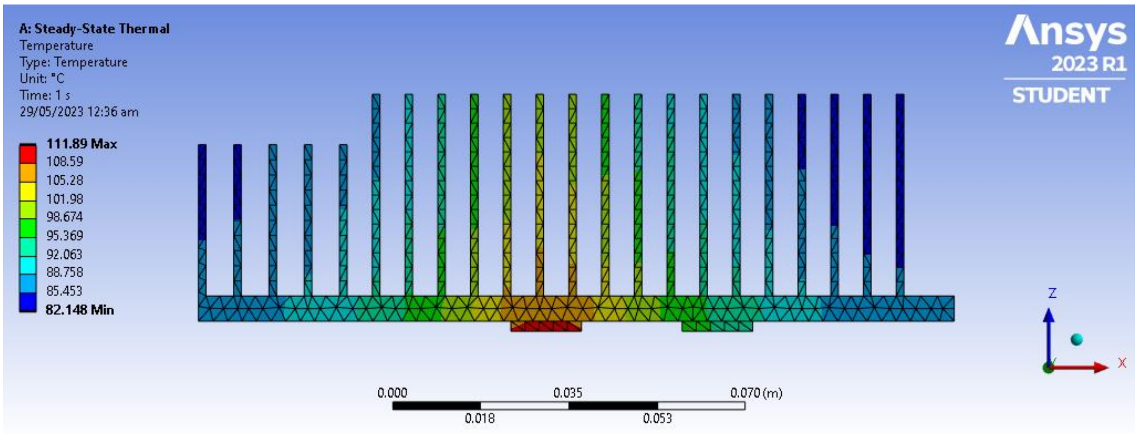

Figure 4.1: Base model test result front view

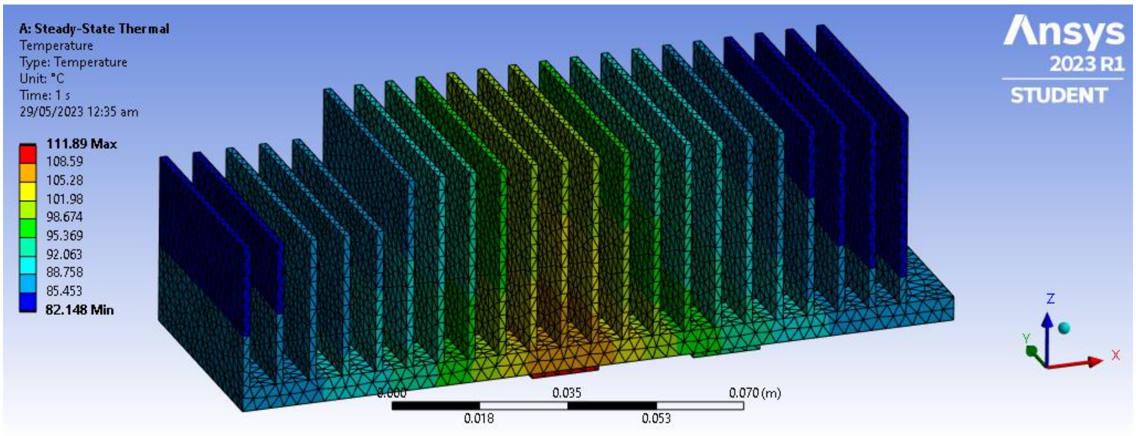

Figure 4.2: Base model test result 3D view

## 4.2. Varying the base width “b” while keeping other variables as constant

Base width “b” is varied from 1 mm to 10 mm while keeping other variables as constant in order to obtain impact of base width on temperature at junction which is the contact point between heat sink and IC.

Table 4.1: Variation of temperature at junction with base width

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run1 | 1 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 137.73 |
| Run2 | 2 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 123.28 |
| Run3 | 3 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 11705 |
| Run4 | 4 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 113.81 |
| Run5 | 5 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 111.97 |
| Run6 | 6 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.98 |
| Run7 | 7 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.46 |
| Run8 | 8 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.32 |
| Run9 | 9 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.44 |
| Run10 | 10 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.77 |

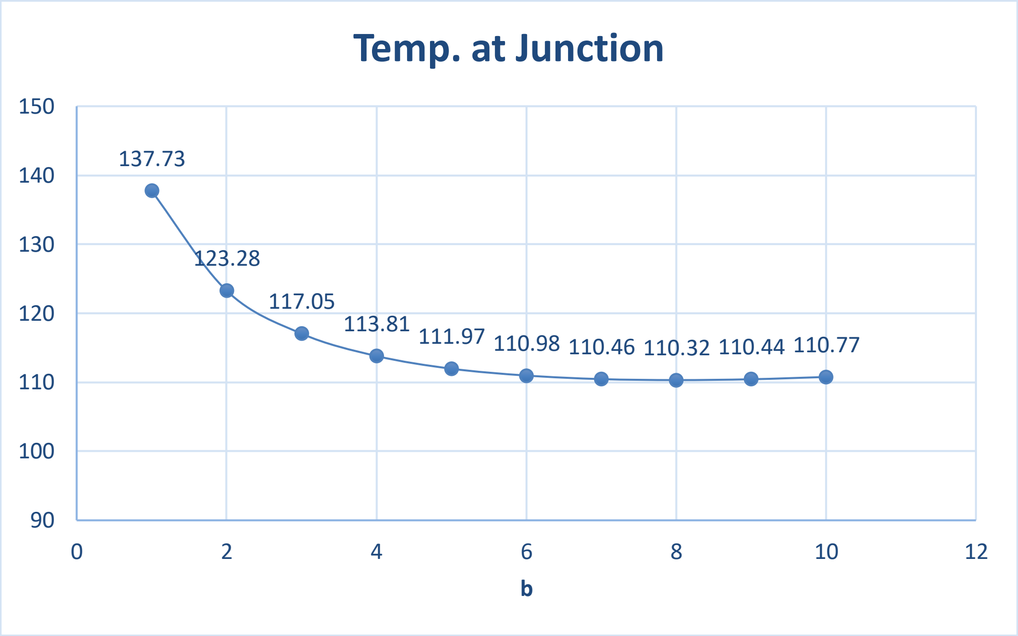

Figure 4.3: Temperature at junction vs b

## 4.3. Varying the contact thickness “d” while keeping other variables as constant

Now we keep base width “b” as constant which is the optimal value obtained from previous case and start varying other variable which is “d” in this case that is the width of contact between the base of the heat sink and IC.

Table 4.2: Variation of temperature at junction with contact width

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run11 | 8 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.32 |
| Run12 | 8 | 16 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.11 |
| Run13 | 8 | 18 | 22 | 30,40 | 5.5 | 5 | 1.5 | 109.93 |
| Run14 | 8 | 20 | 22 | 30,40 | 5.5 | 5 | 1.5 | 109.80 |
| Run15 | 8 | 22 | 22 | 30,40 | 5.5 | 5 | 1.5 | 109.68 |
| Run16 | 8 | 50 | 22 | 30,40 | 5.5 | 5 | 1.5 | 108.92 |

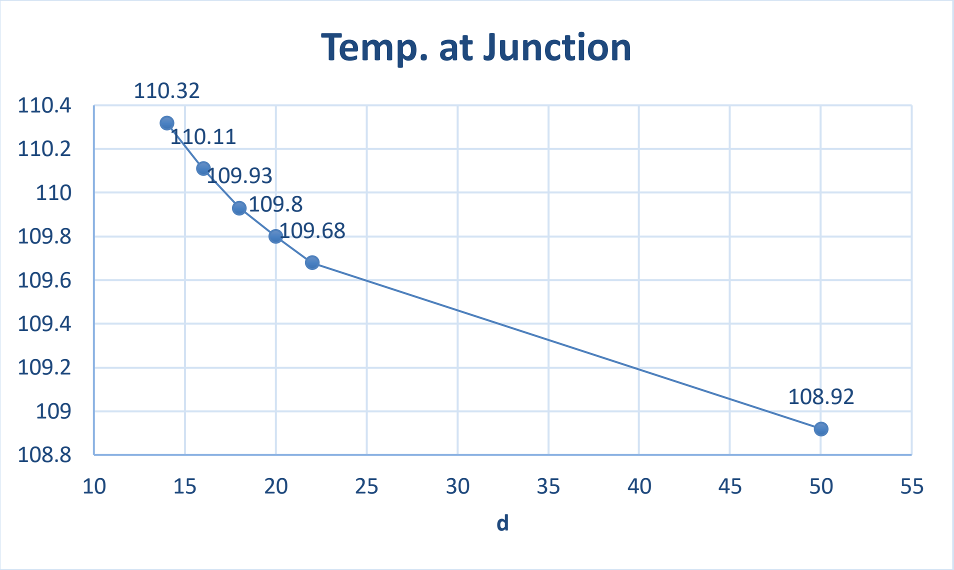

Figure 4.4: Temperature at junction vs d

## 4.4. Varying the height of fins “h” while keeping other variables as constant

Now we keep base width “b” and “d” value as constant as obtained from previous case which is the optimal value and start varying other variable which is “h” in this case that is the height of fins.

Table 4.3: Variation of temperature at junction with fin height

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run17 | 8 | 50 | 22 | 25,35 | 5.5 | 5 | 1.5 | 114.98 |
| Run18 | 8 | 50 | 22 | 30,40 | 5.5 | 5 | 1.5 | 108.92 |
| Run19 | 8 | 50 | 22 | 35,45 | 5.5 | 5 | 1.5 | 104.30 |
| Run20 | 8 | 50 | 22 | 40,50 | 5.5 | 5 | 1.5 | 100.70 |
| Run21 | 8 | 50 | 22 | 45,55 | 5.5 | 5 | 1.5 | 97.795 |
| Run22 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.5 | 95.448 |

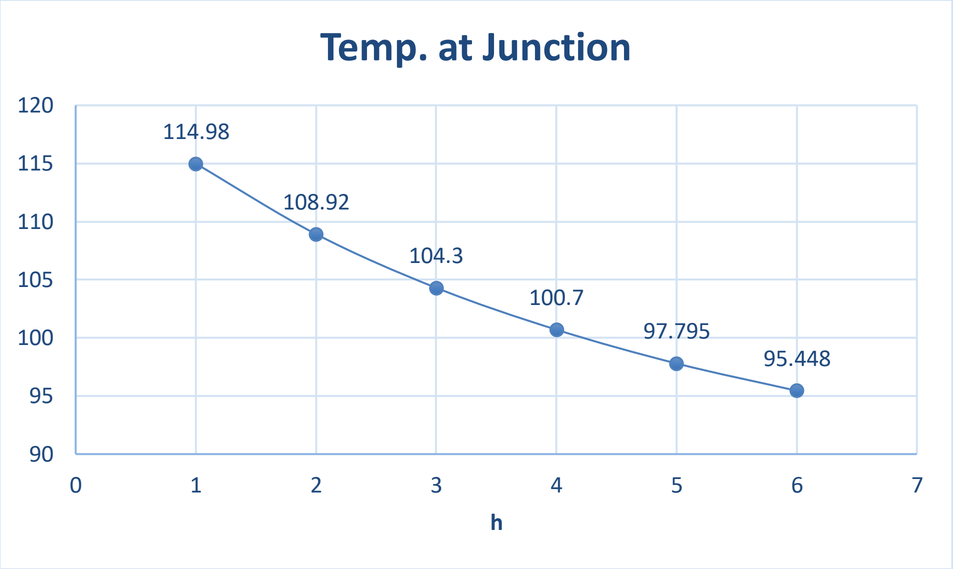

Figure 4.5: Temperature at junction vs h

## 4.5. Varying the fin thickness “t” while keeping other variables as constant

Now we keep “b”, “d” and “h” value as constant as obtained from previous case which is their optimal value and start varying other variable which is “t” in this case that is the thickness of fins.

Table 4.4: Variation of temperature at junction with fin thickness

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run23 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.2 | 96.293 |
| Run24 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.5 | 95.448 |
| Run25 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.8 | 93.898 |

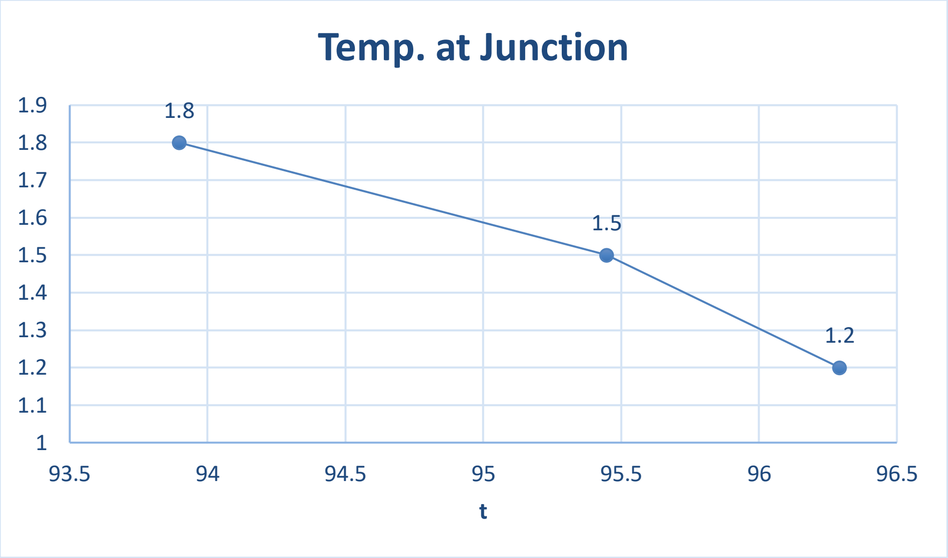

Figure 4.6: Temperature at junction vs t

## 4.6. Varying the number of fins “n” while keeping other variables as constant and keeping the thickness of fin “t” as 1.2

Now we keep “b”, “d” and “h” value as constant as obtained from previous case which is their optimal value and keep “t” value as 1.2 and start varying other variable which is “n” in this case that is the number of fins.

Table 4.5: Variation of temperature at junction with number of fins keeping fin thickness as 1.2

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run26 | 8 | 50 | 20 | 50,60 | 5.5 | 5 | 1.2 | 99.022 |
| Run27 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.2 | 96.293 |
| Run28 | 8 | 50 | 24 | 50,60 | 5.5 | 5 | 1.2 | 94.392 |

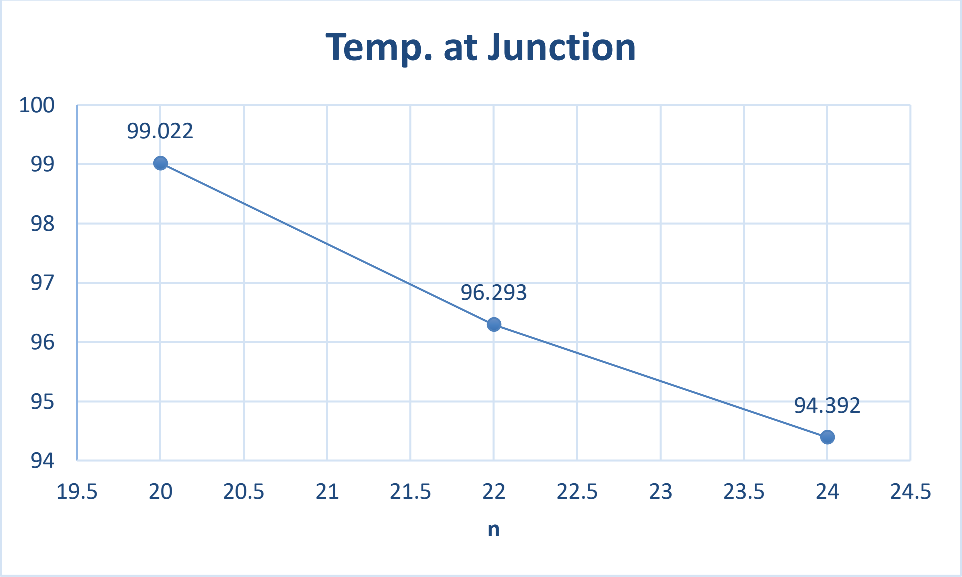

Figure 4.7: Temperature at junction vs n for t=1.2

## 4.7. Varying the number of fins "n" while keeping other variables as constant and keeping the thickness of fin "t" as 1.5

Now we keep "b", "d" and "h" value as constant as obtained from previous case which is their optimal value and keep "t" value as 1.5 and start varying other variable which is "n" in this case that is the number of fins.

Table 4.6: Variation of temperature at junction with number of fins keeping fin thickness as 1.5

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run29 | 8 | 50 | 20 | 50,60 | 5.5 | 5 | 1.5 | 96.649 |
| Run30 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.5 | 95.448 |
| Run31 | 8 | 50 | 24 | 50,60 | 5.5 | 5 | 1.5 | 93.414 |

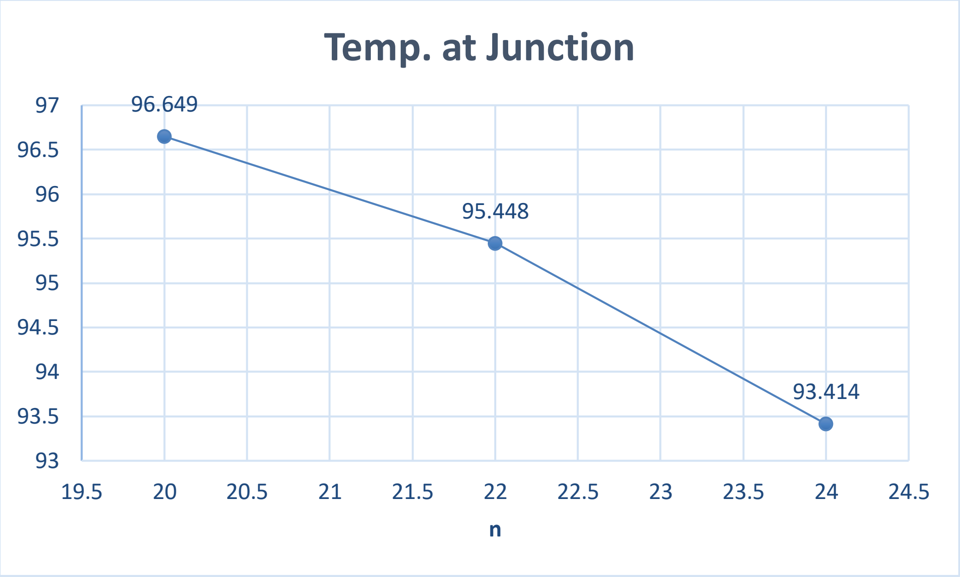

Figure 4.8: Temperature at junction vs n for t=1.5

## 4.8. Varying the number of fins “n” while keeping other variables as constant and keeping thickness of fin “t” as 1.8

Now we keep “b”, “d” and “h” value as constant as obtained from previous case which is their optimal value and keep “t” value as 1.8 and start varying other variable which is “n” in this case that is the number of fins.

Table 4.7: Variation of temperature at junction with number of fins keeping fin thickness as 1.8

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run32 | 8 | 50 | 20 | 50,60 | 5.5 | 5 | 1.8 | 95.935 |
| Run33 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.8 | 93.898 |
| Run34 | 8 | 50 | 24 | 50,60 | 5.5 | 5 | 1.8 | 92.888 |

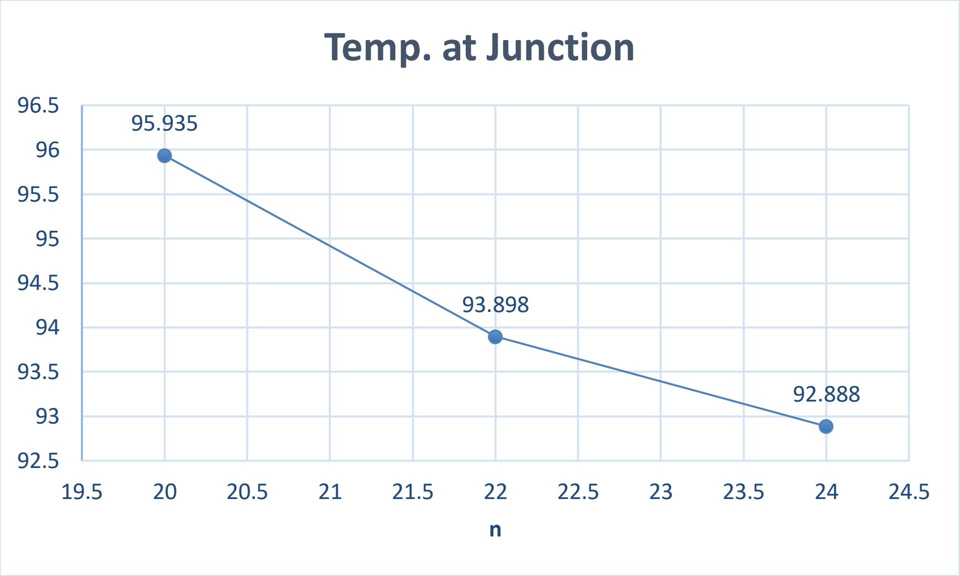

Figure 4.9: Temperature at junction vs n for t=1.8

## 4.9. Comparative analysis of varying "n" for various values of "t"

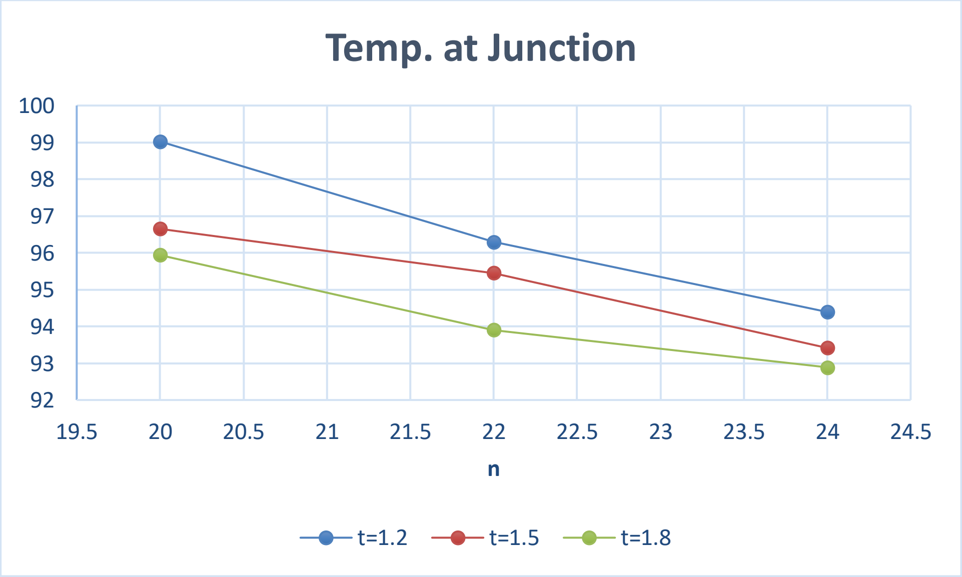

Figure 4.10: n vs temperature for various values of t

### 4.10. Varying the spacing "s1" between the fins while keeping other variables as constant and "t" as 1.2

Now we keep "b", "d" and "h" value as constant as obtained from previous case which is their optimal value and keep "t" value as 1.2 and start varying other variable which is "s1" in this case that is the spacing between fins.

Table 4.8: Variation of temperature at junction with spacing between the fins s1 keeping fin thickness constant as 1.2

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run35 | 8 | 50 | 22 | 50,60 | 4.5 | 5 | 1.2 | 95.187 |
| Run36 | 8 | 50 | 22 | 50,60 | 5 | 5 | 1.2 | 95.177 |
| Run37 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.2 | 95.171 |
| Run38 | 8 | 50 | 22 | 50,60 | 6 | 5 | 1.2 | 95.164 |

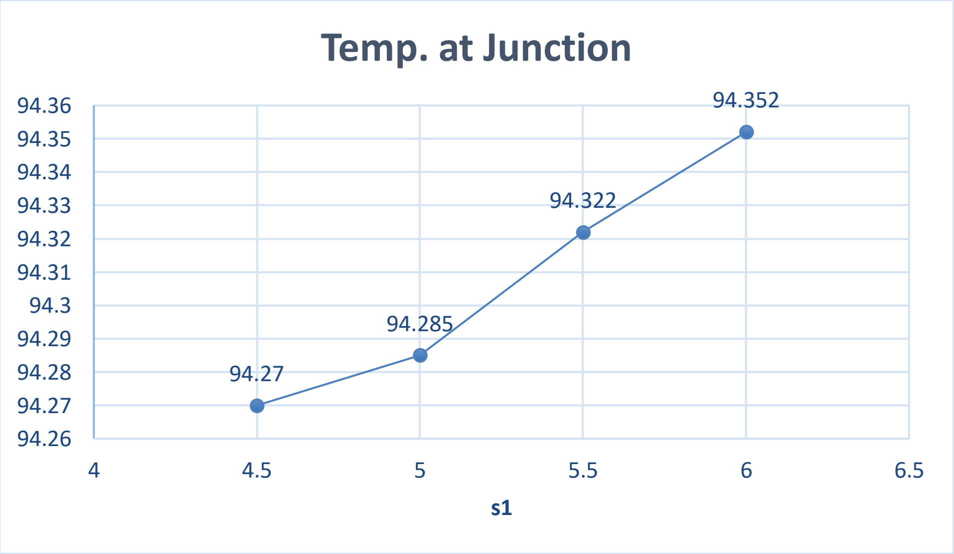

Figure 4.11: Temperature at junction vs s1 for t=1.2

## 4.11. Varying the spacing “s1” between the fins while keeping other variables as constant and “t” as 1.5

Now we keep “b”, “d” and “h” value as constant as obtained from previous case which is their optimal value and keep “t” value as 1.5 and start varying other variable which is “s1” in this case that is the spacing between fins.

Table 4.9: Variation of temperature at junction with spacing between the fins s1 keeping fin thickness constant as 1.5

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run39 | 8 | 50 | 22 | 50,60 | 4.5 | 5 | 1.5 | 94.270 |
| Run40 | 8 | 50 | 22 | 50,60 | 5 | 5 | 1.5 | 94.285 |
| Run41 | 8 | 50 | 22 | 50,60 | 5.5 | 5 | 1.5 | 94.322 |
| Run42 | 8 | 50 | 22 | 50,60 | 6 | 5 | 1.5 | 94.352 |

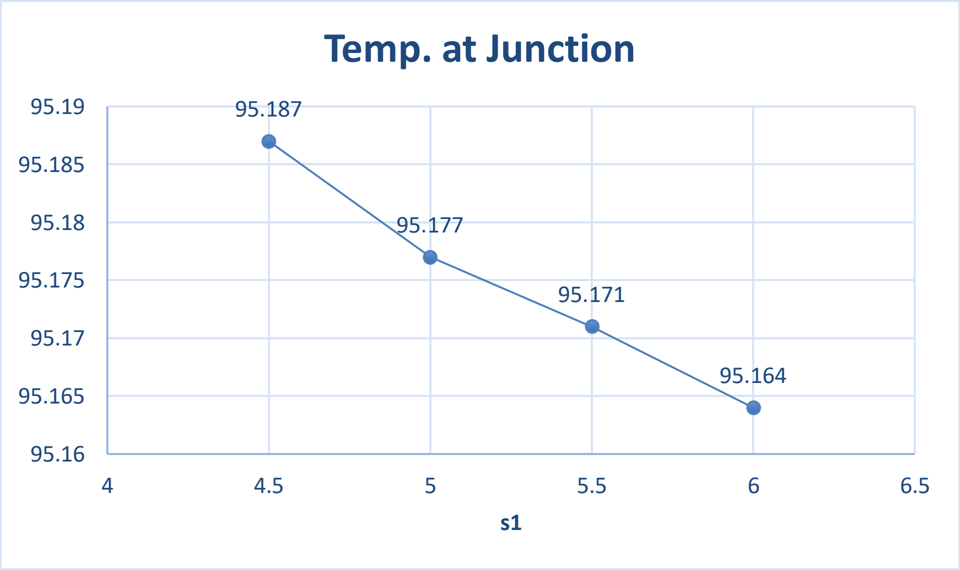

Figure 4.12: Temperature at junction vs s1 for t=1.5

## 4.12. Varying the spacing "s1" between the fins while keeping other variables as constant and "t" as 1.8

Now we keep "b", "d" and "h" value as constant as obtained from previous case which is their optimal value and keep "t" value as 1.8 and start varying other variable which is "s1" in this case that is the spacing between fins.

Table 4.10: Variation of temperature at junction with spacing between the fins s1 keeping fin thickness constant as 1.8

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run43 | 8 | 50 | 22 | 50,60 | 4.5 | 4 | 1.8 | 93.748 |
| Run44 | 8 | 50 | 22 | 50,60 | 4.5 | 4.5 | 1.8 | 93.792 |
| Run45 | 8 | 50 | 22 | 50,60 | 4.5 | 5 | 1.8 | 93.898 |
| Run46 | 8 | 50 | 22 | 50,60 | 4.5 | 5.5 | 1.8 | 93.990 |

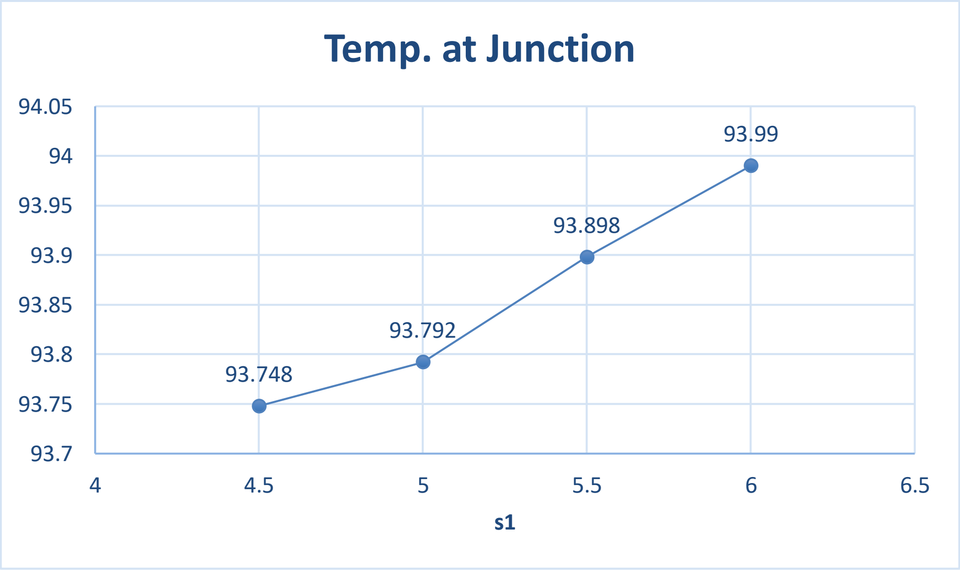

Figure 4.13: Temperature at junction vs s1 for t=1.8

## 4.13. Comparative analysis of varying “s1” for various values of “t”

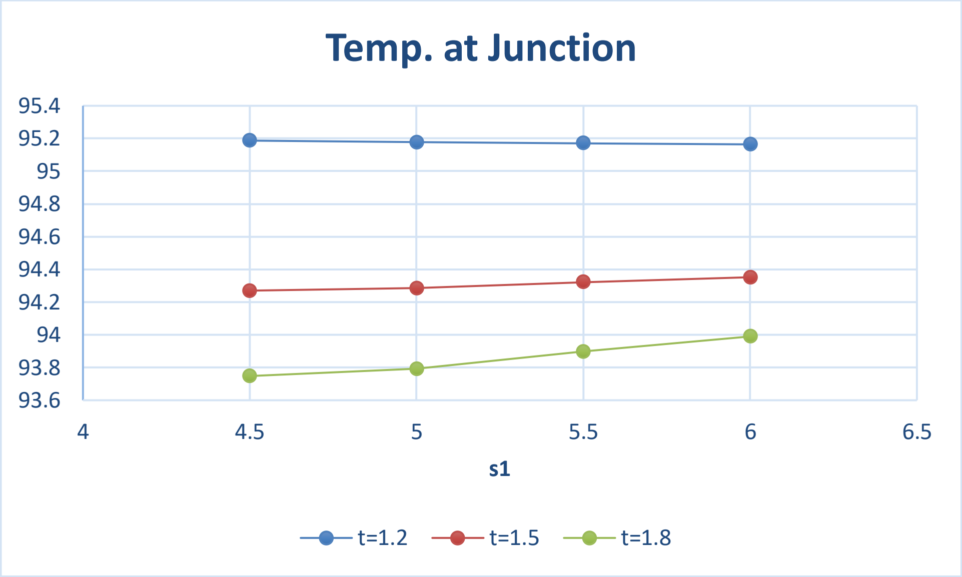

Figure 4.14 s1 vs temperature for various values of t

## 4.14. Varying the spacing “s2” between the fins while keeping other variables as constant and “t” as 1.2

Now we keep “b”, “d” and “h” value as constant as obtained from previous case which is their optimal value and keep “t” value as 1.2 and start varying other variable which is “s2” in this case that is the spacing between fins.

Table 4.11: Variation of temperature at junction with spacing between the fins s2 keeping fin thickness as constant as 1.2

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run47 | 8 | 50 | 22 | 50,60 | 4.5 | 4 | 1.2 | 94.412 |
| Run48 | 8 | 50 | 22 | 50,60 | 4.5 | 4.5 | 1.2 | 94.725 |
| Run49 | 8 | 50 | 22 | 50,60 | 4.5 | 5 | 1.2 | 95.222 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run50 | 8 | 50 | 22 | 50,60 | 4.5 | 5.5 | 1.2 | 95.827 |

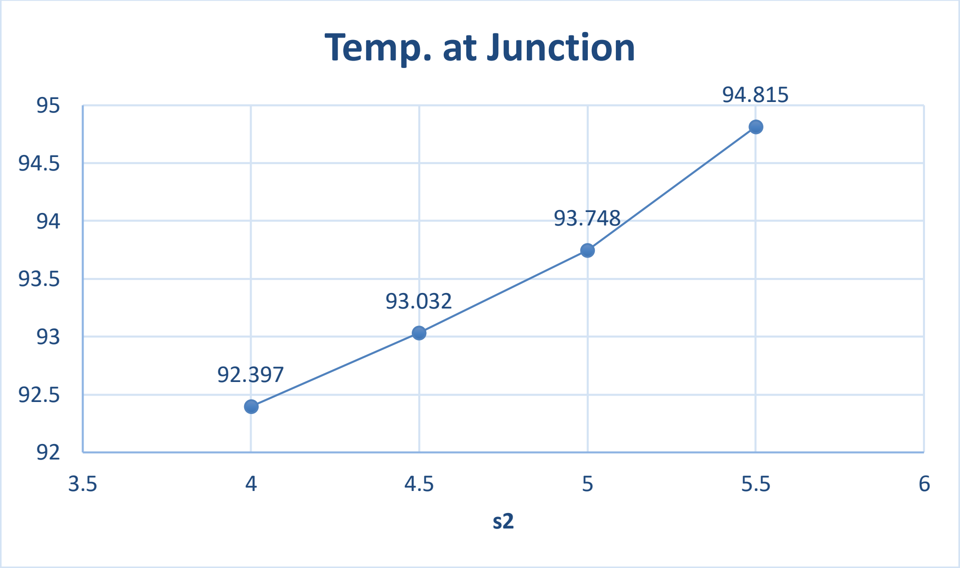

Figure 4.15 Temperature at junction vs s2 for t=1.2

## 4.15. Varying the spacing “s2” between the fins while keeping other variables as constant and “t” as 1.5

Now we keep “b”, “d” and “h” value as constant as obtained from previous case which is their optimal value and keep “t” value as 1.5 and start varying other variable which is “s2” in this case that is the spacing between fins.

Table 4.12: Variation of temperature at junction with spacing between the fins s2 keeping fin thickness as constant as 1.5

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run51 | 8 | 50 | 22 | 50,60 | 4.5 | 4 | 1.5 | 93.134 |
| Run52 | 8 | 50 | 22 | 50,60 | 4.5 | 4.5 | 1.5 | 93.645 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run53 | 8 | 50 | 22 | 50,60 | 4.5 | 5 | 1.5 | 94.254 |
| Run54 | 8 | 50 | 22 | 50,60 | 4.5 | 5.5 | 1.5 | 94.972 |

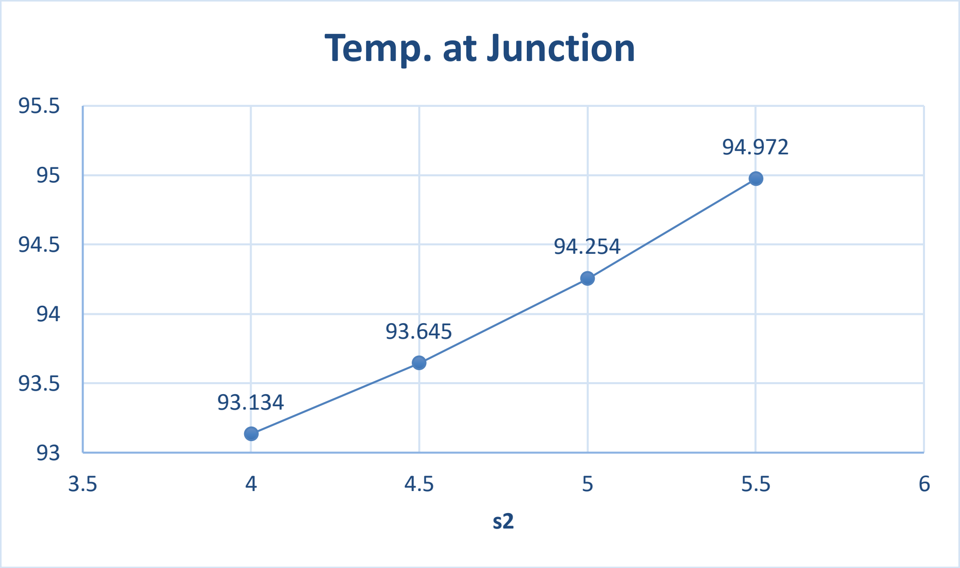

Figure 4.16: Temperature at junction vs s2 for t=1.5

## 4.16. Varying the spacing "s2" between the fins while keeping other variables as constant and "t" as 1.8

Now we keep "b", "d" and "h" value as constant as obtained from previous case which is their optimal value and keep "t" value as 1.8 and start varying other variable which is "s2" in this case that is the spacing between fins.

Table 4.13: Variation of temperature at junction with spacing between the fins s1 keeping fin thickness as constant as 1.8

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run55 | 8 | 50 | 22 | 50,60 | 4.5 | 4 | 1.8 | 92.397 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run56 | 8 | 50 | 22 | 50,60 | 4.5 | 4.5 | 1.8 | 93.032 |
| Run57 | 8 | 50 | 22 | 50,60 | 4.5 | 5 | 1.8 | 93.748 |
| Run58 | 8 | 50 | 22 | 50,60 | 4.5 | 5.5 | 1.8 | 94.815 |

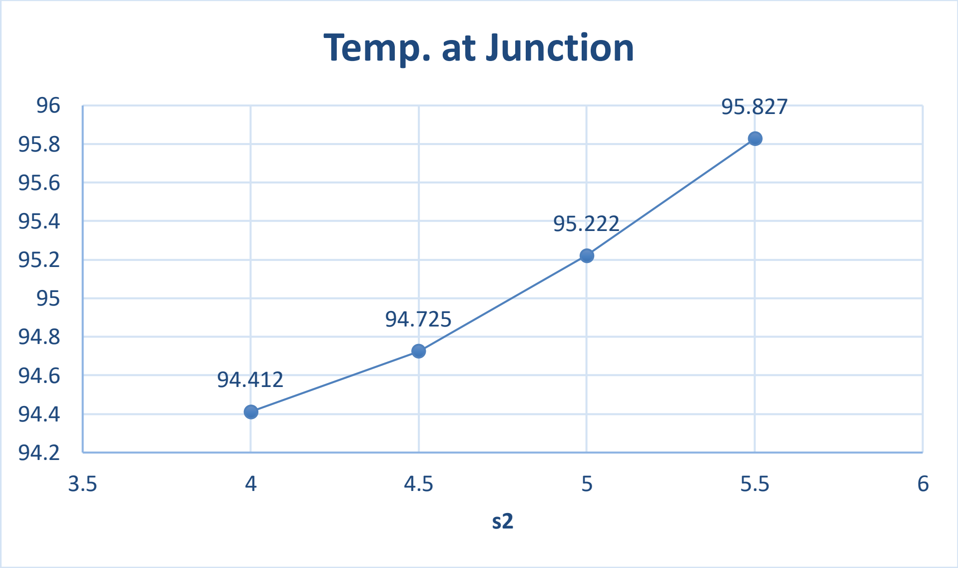

Figure 4.17: Temperature at junction vs s2 for t=1.8

## 4.17. Comparative analysis of varying “s2” for various values of “t”

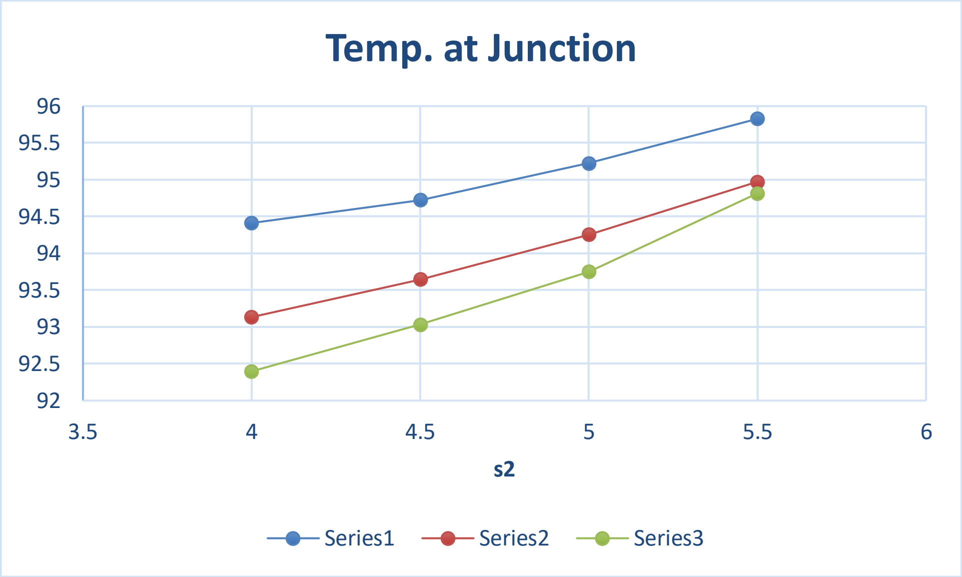

Figure 4.18: s2 vs temperature for various values of t

## 4.18. Varying the number of fins “n” while keeping other variables at their optimal value

Now we vary only the number of fins “n” keeping all other variables at their optimal value as obtained from previous iterations in order to reach minimal possible junction temperature.

Table 4.14: Variation of temperature at junction with number of fins

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run59 | 8 | 50 | 22 | 50,60 | 4.5 | 4 | 1.8 | 92.397 |
| Run60 | 8 | 50 | 23 | 50,60 | 4.5 | 4 | 1.8 | 91.34 |
| Run61 | 8 | 50 | 24 | 50,60 | 4.5 | 4 | 1.8 | 90.483 |
| Run62 | 8 | 50 | 25 | 50,60 | 4.5 | 4 | 1.8 | 89.731 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run63 | 8 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 89.137 |

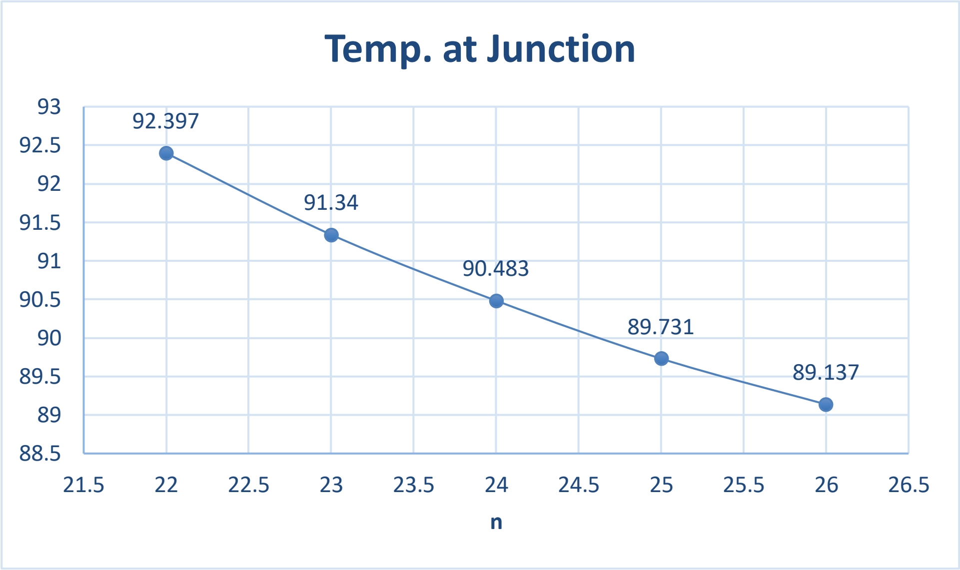

Figure 4.19: Temperature at junction vs n for t=1.8

## 4.19. Varying the base width "b" for final height "h" keeping other variables at their optimized value

Now we vary the base width "b" for final height "h" keeping other variables at their optimized value since "b" is the only variable that shows decreasing increasing curve for various geometries of heat sink and has varying optimized value for a particular geometry of heatsink.

Table 4.15: Base width variation at optimized condition

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run64 | 4 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 92.630 |
| Rin65 | 5 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 91.179 |
| Run66 | 6 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 90.246 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Run67 | 7 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 89.590 |
| Run68 | 8 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 89.137 |
| Run69 | 9 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 88.838 |
| Run70 | 10 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 88.652 |
| Run71 | 11 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 88.599 |
| Run72 | 12 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 88.587 |
| Run73 | 13 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 88.634 |
| Run74 | 14 | 50 | 26 | 50,60 | 4.5 | 4 | 1.8 | 88.748 |

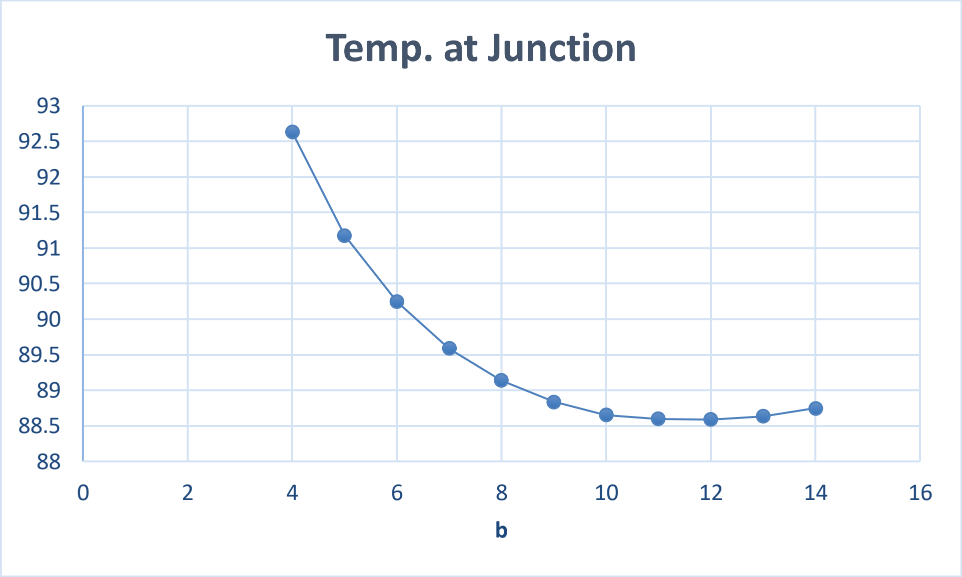

Figure 4.20: Base width vs temperature at optimized condition

Even though we are getting some temperature drop for decreasing value of "b" we cannot utilize that value for final optimized heatsink geometry due to the constraint associated with base width maximum value. Also, it can cause clamping problems when mounting heatsink over the PCB.

## 4.20. Temperature at junction for each individual parameter variation

Now we vary each individual parameter between their initial case and final case to obtain the corresponding temperature at junction against each variation

Table 4.16: Temperature at junction for each parameter variation

| | b (mm) | d (mm) | n | h (mm) | s1 (mm) | s2 (mm) | t (mm) | T (K) |
|---|---|---|---|---|---|---|---|---|
| Run75 | 5 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 111.9 |
| Run76 | 5 | 50 | 22 | 30,40 | 5.5 | 5 | 1.5 | 109.48 |
| Run77 | 8 | 14 | 22 | 30,40 | 5.5 | 5 | 1.5 | 110.27 |
| Run78 | 5 | 14 | 22 | 50,60 | 5.5 | 5 | 1.5 | 99.72 |
| Run79 | 5 | 14 | 22 | 30,40 | 4.5 | 5 | 1.5 | 111.76 |
| Run80 | 5 | 14 | 22 | 30,40 | 5.5 | 4 | 1.5 | 109.57 |
| Run81 | 5 | 14 | 22 | 30,40 | 5.5 | 5 | 1.8 | 111.87 |
| Run82 | 5 | 14 | 23 | 30,40 | 5.5 | 5 | 1.5 | 110.8 |

## 4.21. Percentage effect of each parameter on temperature at junction

Percentage changes each parameter has when varied from initial value to the final value is obtained and corresponding percentage variation in temperature is obtained.

Table 4.17: Percentage effect of each parameter on temperature at junction

| S.no. | Parameter | Initial Value | Final Value | Initial Temp. (K) | Final Temp. (K) | Percentage change (%) |
|---|---|---|---|---|---|---|
| 1 | b (mm) | 5 | 8 | 111.9 | 110.27 | 1.4567 |
| 2 | d (mm) | 14 | 50 | 111.9 | 109.48 | 2.1626 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3 | N | 22 | 26 | 111.9 | 110.8 | 1.1475 |
| 4 | h (mm) | 30,40 | 50,60 | 111.9 | 99.72 | 10.884 |
| 5 | s1 (mm) | 5.5 | 4.5 | 111.9 | 111.76 | 0.1251 |
| 6 | s2 (mm) | 5 | 4 | 111.9 | 109.57 | 2.0822 |
| 7 | t (mm) | 1.5 | 1.8 | 111.9 | 111.87 | 0.0268 |

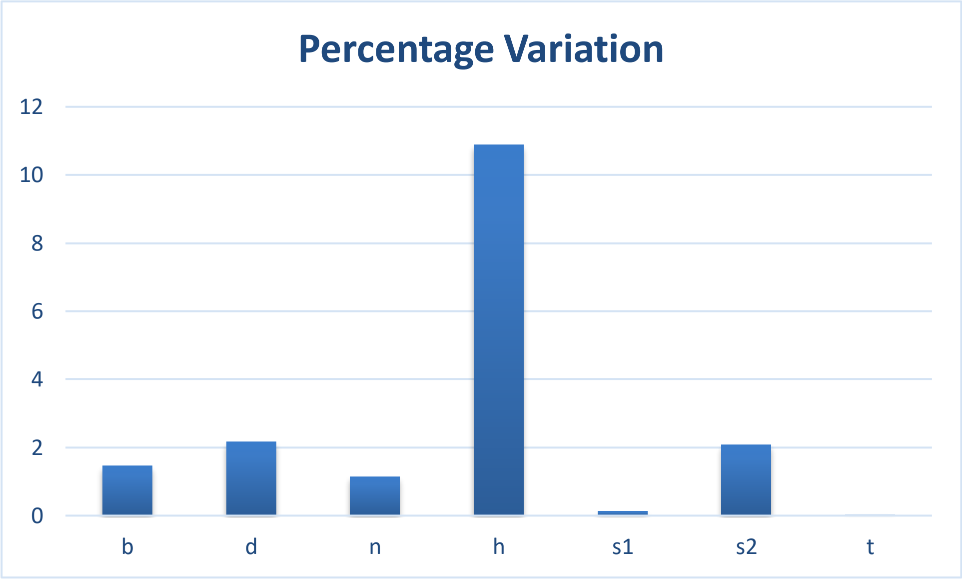

Figure 4.21: Percentage variation each parameter has on junction temperature

## 4.22. FINAL MODEL RESULT

The final model generated showed the temperature well within limits as it was showing the temperature of around 89.1 $^0$C against the required value of 94 $^0$C or below. After the testing has been carried out the temperature at the junction came out to be 92.3 $^0$C which is well within limits of 94 $^0$C and the percentage error between the real and simulated results is 3.46695 % which is well within limits so Run is the final model dimensions going for mass production satisfying all constraints and showing temperature value well within limits.

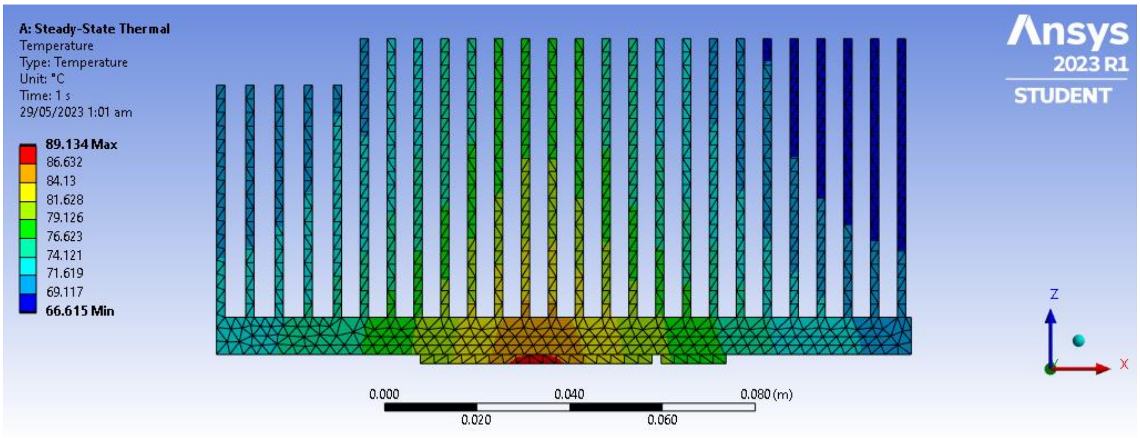

Figure 4.22: Final model front view

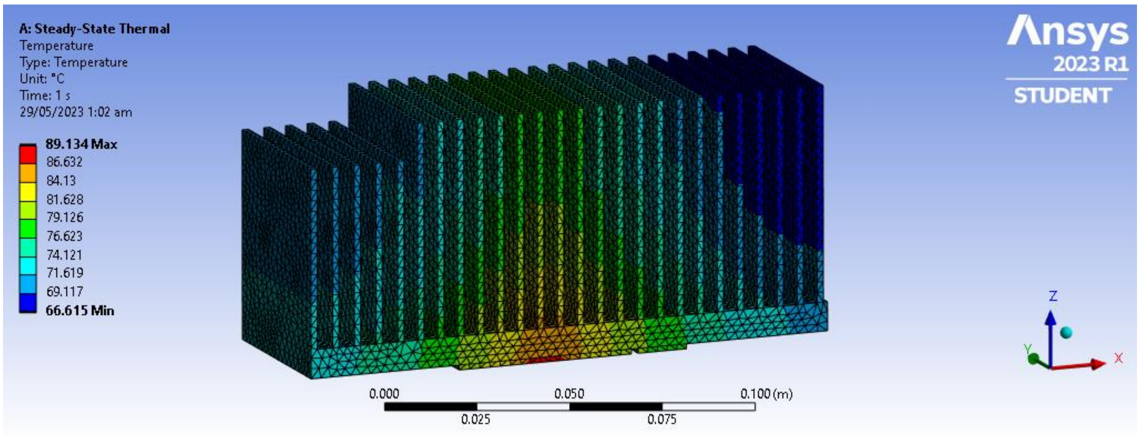

Figure 4.23: Final model 3D view

## 4.23. EXPERIMENTAL TESTING

In order to verify new, heatsink design, test was carried out in the lab in order to obtain temperature values at junction. In order to carry out testing first the heat sink is placed in its location that is the outdoor unit of air conditioner over the PCB in order to conform that there is no fitment issue. Then once it clears its first test then a hole is drilled from the top just above where the IC comes in contact with heat sink and thermocouple is inserted at this point in order to measure the temperature at the junction.

After setting up entire system the testing starts for various different ambient temperature conditions until maximum ambient temperature condition of 50 $^0$C is reached and the testing is carried out various number of times in order to obtain an average value or until the difference between consecutive temperature reading is within the tolerance value under the same ambient conditions.

# CHAPTER 5

# CONCLUSION AND FUTURE SCOPE

## 5.1. CONCLUSION

From all those iterations that have been carried out it can be seen that some parameters have more effect in reducing temperature at junction that is the contact point between heat sink and IC than the other parameters. It all depends upon the constraint that we have when we start varying these parameters. Out of all the parameters that are varied only base width shows increasing decreasing curve that means it has a certain optimized value for each heat sink depending upon its dimension. Also, the height of fins and number of fins has the biggest influence in terms of temperature decrement at the junction since they both increases the surface area which in turn increases the heat transfer rate but for increasing the number of fins the spacing between fins needs to be reduced or the fin thickness needs to be reduced in order to accommodate a greater number of fins in the same space. But reducing the fins thickness makes the heat sink structurally weak so for increasing the heat transfer rate the best parameter to vary is the height of heat sink but the space constraint for height needs to be checked first also the structural test needs to performed in order to obtain the permissible increment in height that was possible.

## 5.2. FUTURE SCOPE

- For even higher temperature drop one more option to explore is changing the geometry of fins that is the shape of fins.
- In future an algorithm development project is under way which uses automation-based software to carry out number of iterations and provide the most optimal solution in response to minimum value of certain output required.
- A python-based program can be developed which would be able to generate the dimensions of heat sink model based on the constraints input.
- More mass production-based method needed to be explored which would enable us to produce new heat sink geometries instead of going with the traditional method of producing rectangular based fins using extrusion method.
- A liquid based cooling method along with heatsink can be used when more temperature drop is required in the future.

# REFERENCES

[1] Anbumeenakshi, C., & Thansekhar, M. (2016). On the effectiveness of a nanofluid cooled microchannel heat sink under non-uniform heating condition. *Applied Thermal Engineering*, *113*, 1437-1443. https://doi.org/10.1016/j.applthermaleng.2016.11.144

[2] Deng, D., Wan, W., Tang, Y., Shao, H., & Huang, Y. (2015). Experimental and numerical study of thermal enhancement in reentrant copper microchannels. *International Journal of Heat and Mass Transfer*, *91*, 656-670. https://doi.org/10.1016/j.ijheatmasstransfer.2015.08.025

[3] Duangthongsuk, W., & Wongwises, S. (2015). A comparison of the heat transfer performance and pressure drop of nanofluid-cooled heat sinks with different miniature pin fin configurations. *Experimental Thermal and Fluid Science*, *69*, 111-118. https://doi.org/10.1016/j.expthermflusci.2015.07.019

[4] Hasan, M. I., & Tbena, H. L. (2018). Using of phase change materials to enhance the thermal performance of micro channel heat sink. *Engineering Science and Technology, an International Journal*, *21*(3), 517-526. https://doi.org/10.1016/j.jestch.2018.03.017

[5] Husain, A., Ariz, M., Al-Rawahi, N. Z., & Ansari, M. (2016). Thermal performance analysis of a hybrid micro-channel, -pillar and -jet impingement heat sink. *Applied Thermal Engineering*, *102*, 989-1000. https://doi.org/10.1016/j.applthermaleng.2016.03.048

[6] Hussain, A. A., Freegah, B., Khalaf, B. S., & Towsyfyan, H. (2019). Numerical investigation of heat transfer enhancement in plate-fin heat sinks: Effect of flow direction and fillet profile. *Case Studies in Thermal Engineering*, *13*, 100388. https://doi.org/10.1016/j.csite.2018.100388

[7] Khan, J. A., Morshed, A. M., & Fang, R. (2014). Towards ultra-compact high heat flux Microchannel heat sink. *Procedia Engineering*, *90*, 11-24. https://doi.org/10.1016/j.proeng.2014.11.798

[8] Li, H., Liao, W., Li, T., & Chang, Y. (2017). Application of vortex generators to heat transfer enhancement of a pin-fin heat sink. *International Journal of Heat and Mass Transfer*, *112*, 940-949. https://doi.org/10.1016/j.ijheatmasstransfer.2017.05.032

[9] Meis, M., Varas, F., Velázquez, A., & Vega, J. (2010). Heat transfer enhancement in micro-channels caused by vortex promoters. *International Journal of Heat and Mass Transfer*, *53*(1-3), 29-40. https://doi.org/10.1016/j.ijheatmasstransfer.2009.10.013

[10] Naqiuddin, N. H., Saw, L. H., Yew, M. C., Yew, M. K., & Yusof, F. (2017). Numerical study of the geometrically graded micro-channel heat sink for high heat flux application. *Energy Procedia*, *142*, 4016-4021. https://doi.org/10.1016/j.egypro.2017.12.319

[11] Sudhakar, S., & Weibel, J. A. (2016). Transient analysis of non-uniform heat input propagation through a heat sink base. *Volume 10: Micro- and Nano-Systems Engineering and Packaging*. https://doi.org/10.1115/imece2016-67639

[12] Yoon, Y., Park, S., Kim, D. R., & Lee, K. (2018). Thermal performance improvement based on the partial heating position of a heat sink. *International Journal of Heat and Mass Transfer*, *124*, 752-760. https://doi.org/10.1016/j.ijheatmasstransfer.2018.03.080

[13] Li, B., Jeon, S., & Byon, C. (2016). Investigation of natural convection heat transfer around a radial heat sink with a perforated ring. *International Journal of Heat and Mass Transfer*, *97*, 705-711. https://doi.org/10.1016/j.ijheatmasstransfer.2016.02.058

[14] Kim, D., Jung, J., & Kim, S. J. (2010). Thermal optimization of plate-fin heat sinks with variable fin thickness. *2010 14th International Heat Transfer Conference, Volume 3*. https://doi.org/10.1115/ihtc14-22728

[15] Ndao, S., Peles, Y., & Jensen, M. K. (2009). Multi-objective thermal design optimization and comparative analysis of electronics cooling technologies. *International Journal of Heat and Mass Transfer*, *52*(19-20), 4317-4326. https://doi.org/10.1016/j.ijheatmasstransfer.2009.03.069