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Cooling of Automotive Electronic Control Unit and its Analysis with ANSYS Ice Pack

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***Abstract:** In recent years, electrical equipments are developing with technology. Higher integration of packages on single electronic board causes higher heat generation density. The operational temperature of electronics component is major cause of failure of them. This is due to fact that their life reduces exponentially with operating temperature. One such example of electronic device is Electronic Control Unit which is short termed as ECU of automotives. The function of electronic control unit is increased now days with more functionality. The paper study is concerned with overheating of ECU, its CFD analysis. After analysis temperature reduction parameters are to be studied. A thermally well designed electrical component applied in a thermally poor designed controller, will still result in a poor total design. And it is important that thermal design on controller should be included as early as possible in the overall design process.*
***Keywords:** ANSYS Icepack, CFD Analysis, Electronic Control Unit, Heat Generation, Printed Circuit Board*

I. INTRODUCTION

Electronics equipment's have its applications practically in every aspect of modern technology, from small chip to high configured computers. The reliability of the electronics of a system is a major factor in the overall reliability of the system. Electronics components working on factor of current that flows through them to perform their duties. Because of current flowing through electronic components, they become a potential site for heat generation. Since current flow and its resistance are cause for the heat generation.

Unless properly designed and controlled temperature ranges, heat generation amount are not there, the issue of their safety and reliability arises.

The failure rate of electronic devices increases exponentially with temperature range in which they operate. Also, the higher thermal stresses in the sold joints of electronic devices from temperature variations are major cause of failure. Therefore, thermal control has become increasingly important in the design and operation of electronic equipment. Electronic circuit devices can be used as essential part of computers, audio and video devices, automobiles or aero planes. They are also used in Telecommunication Satellite application. Glass reinforced plastic with copper tracks is used for manufacturing of the Printed Circuit Board. These copper tracks are linked in such manner that they form circuit. As electronic devices contain no any moving part, their life is more in the range of room temperature. The thermal characteristics of a component due to own power and upstream air heated by components were studied. The experimental results were compared with those of numerical solution for various conditions: surface temperature of the components, adiabatic temperature rise, and heat transfer coefficient. [1] In the design process of heat sink, the performance and heat dissipation performance are simultaneously considered. [3] Basically, the placement of the component has great impact on its thermal characteristics. [4]

Thermal problems of electronic components have been solved in recent years by installing some cooling equipments. [2] Heat generated within the unit coupled with ambient temperature makes the system reliability susceptible to thermal degradation which ultimately may result in failure. [6]

II. PROBLEM DEFINITION AND OBJECTIVES

In recent years, electronics equipments are developing with new and updated technology. Higher integration of semiconductor packages leads to this development. On the other hand higher integration causes higher heat generation density. Electronic Control Unit (ECU) is one of the example of electronic device which its wide application in automotive sector. It is expected that ECU will have good functionality with reduced size and weight as well. When vehicle is in loaded condition, ECU gets overheated. The control system of vehicle is disturbed due to overheating. The packages mounted on ECU damaged by high temperature operative condition. The temperature range is from -20˚c to 80˚c. Without increasing its volume and weight, cooling is required for ECU.

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Examples of Automotive Printed Circuit Board Applications are as follows,

1) Airbag Deployment
2) Antilock Brake Systems
3) Audio & Video Equipment
4) Communication Equipment
5) Digital Displays
6) Electronic Mirror Controls / Automatic Dimming
7) Engine Timing Systems
8) Global Positioning Systems (GPS)
9) Interior LED lighting systems
10) LED Brake Lights
11) Navigation Equipment
12) Power Distribution Junction Box
13) Transmission Sensors

In electronic cooling temperature is very important parameter without increasing the cost of the product. Following objectives will require reducing the temperature of the ECU.

a) To determine the temperature of Electronic circuit board experimentally.
b) Validate the experimental result with numerical method.
c) To determine the high temperature problem in ECU, when vehicle is loaded.
d) To determine the temperature in ECU by changing Copper percentage.
e) To determine the temperature in ECU by placement of components.
f) To determine the temperature in ECU by changing material of board.
g) Find out best suitable thermal design for electronic control unit with the help of computational fluid dynamics.

III. EXPERIMENTAL SET UP

The figure 1 shows the experimental layout. The thermocouple wires are attached on the surface of the packages. The temperature indicator with AC power supply is provided which gives the temperature reading for each component. The temperature at different locations of components is to be measured for accuracy. Vehicle starts normally under unloaded condition and temperature is measured up to steady state condition is occurred.

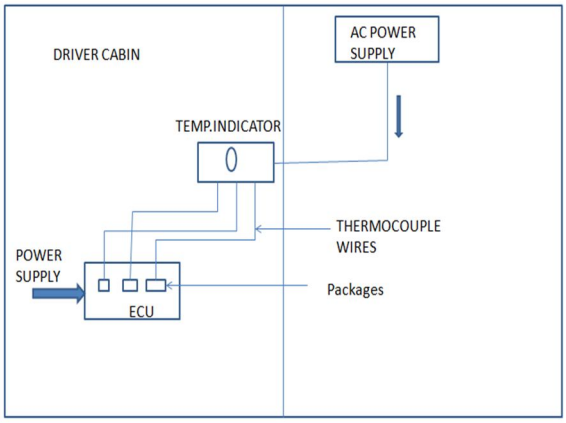


Figure 1: Schematic diagram of Experimental Setup

A. Thermocouple

A thermocouple is a temperature measuring device. Depending upon temperature range thermocouple is selected for particular application. Type J (iron – constantan)

B. Temperature Indicator

The temperature indicator works on AC supply. For this experiment different temperatures of components on ECU are indicated by Temperature indicator display.

C. Vehicle

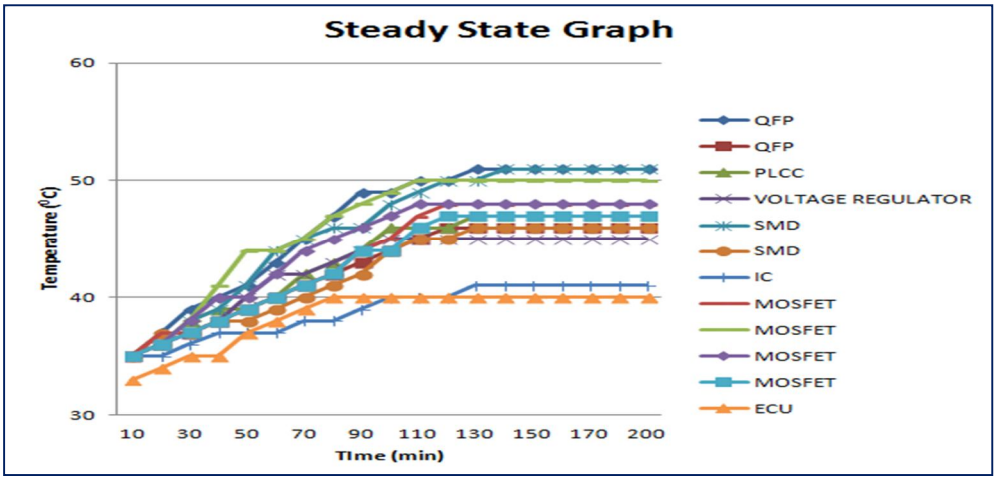
The Semi-Forward truck is selected for experiment. It is generally used for Intra-city applications. The ECU is located in driver cabin. Heavy duty vehicles are non AC type vehicles so that driver cabin having warm temperature. Due to this environment of high temperature ECU is overheated and its temperature is not decreased as per quantity.

1) Make all connections and take initial reading of environment and ECU.
2) Start vehicle and note down temperature at different points on packages.
3) Take readings up to steady state is occurred.
4) Repeat procedure for all packages of ECU.

The graph 1 represents the steady state condition after three hours. The graph represents the temperature of the electronic component increases gradually and then it occupies steady state. The temperature of the ECU enclosure cannot be exceeds than 40˚c. The maximum temperature is measured on the surface of the QFP and SMD packages. All the measurement is taken at the normal condition to validate the result. An actual problem of ECU is at loaded condition. Testing is only important to validate the result.

Some of components of ECU are listed below,

a) *MOSFET:* Metal Oxide Semiconductor Field Effect Transistor
b) *QFP:* Quad Flat Packages
c) *PLCC:* Plastic Lead Chip Carrier



Graph 1 : Temperature Graph for Different Packages

IV. CFD SIMULATION

The ANSYS Icepack software among the various CFD tools is used for heat transfer analysis of ECU.

A. Modelling of ECU

A figure 2 shows detailed model of ECU with different components mounted on PCB. All components having lower power dissipation were neglected viz. Capacitor, resistor, IC. The components like MOSFET, PLCC, QFP are main heat generating sources.

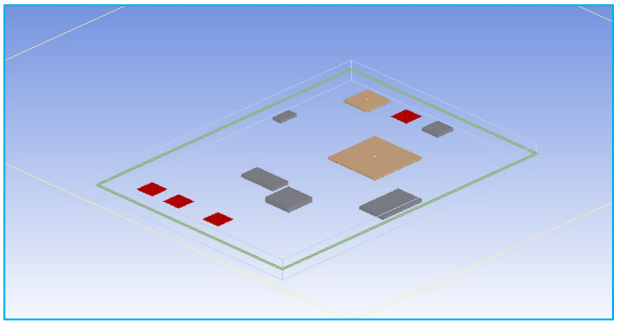


Figure 2: ANSYS model of ECU

Table 1: Packages and their dimension

Packages	Simplification	Dimension
MOSFET	Heat source	0.01 x 0 x 0.01 m
MOSFET	Heat source	0.01 x 0 x 0.01 m
MOSFET	Heat source	0.01 x 0 x 0.01 m
MOSFET	Heat source	0.01 x 0 x 0.01 m
SMD	Block	0.01 x 0.003 x 0.01 m
SMD	Block	0.005 x 0.003 x 0.01 m
PLCC	Block	0.015 x 0.003 x 0.025 m
IC	Block	0.02 x 0.003 x 0.01 m
VR	Block	0.015 x 0.005 x 0.015 m
QFP	QFP	default
QFP	QFP	default

Table 1 shows dimensions and simplification of all the packages. MOSFET are converted into planer heat sources and other components are specified as 3D volume. Material properties and input power are provided to these blocks. The rectangular shaped enclosure is provided. The CFD software ANSYS Ice pack requires the model to be placed in closed enclosure. Heat and mass transfer is allowed through enclosure. Figure 3 shows whole solution domain of ECU model. After completing the model meshing is required to solve the problem. In ANSYS Icepack Mesher HD, Hexa unstructured, Hexa Cartesian mesh is available. Depends upon Number of nodes and face alignment value the meshing type is selected. Figure 4 shows meshing for CFD analysis. For this problem Hexa unstructured meshing is suitable because of critical geometry.

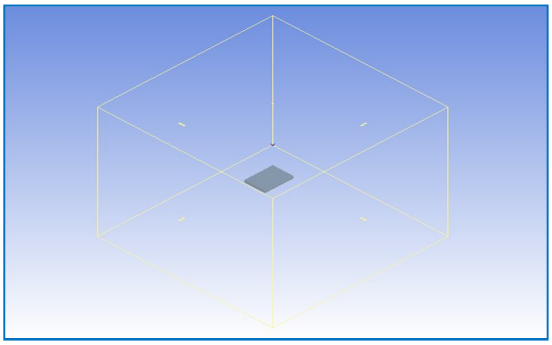


Figure 3: The whole solution domain

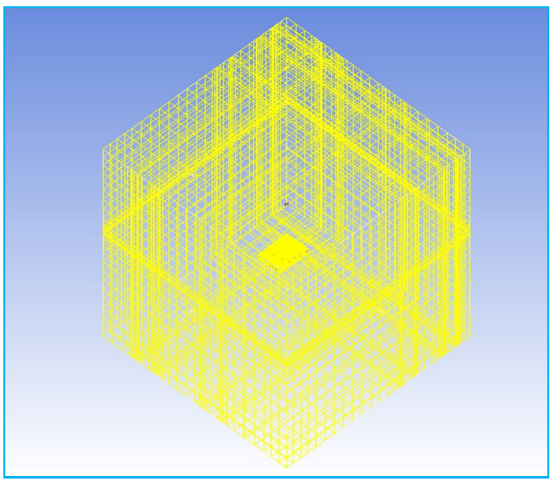


Figure 4: Meshing

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V. RESULTS AND DISCUSSION

A. Temperature Distribution of Board

The following figure 5 shows temperature distribution of the board and components at loaded condition. The temperature varies from 31˚c to 82.47˚c.

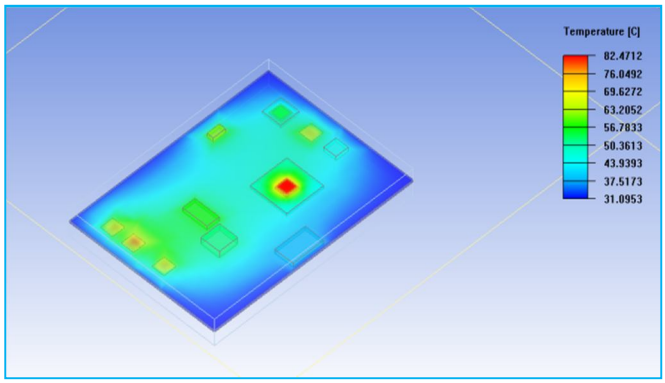

Figure 5: Temperature distribution of the board and components

Analysis of that temperature reduction of ECU under loaded condition is based on following three parameters,

1) Effect of Copper percentage
2) Effect of Component placement
3) Effect of Board material

After completing analysis for above three parameters with different input in ANSYS Ice pack we come to the following results.

B. Effect of Copper Percentage on the Board

The thermal conductivity of depends upon the percentage of copper. In case of ECU printed circuit board, copper tracks are there on which components are placed. The percentage of copper increases thermal conductivity of board increases. In this PCB copper percentage is 50% and thermal conductivity is 9.4568 W/mk in plane direction. The thermal conductivity is inversely proportionate with temperature. After increasing the percentage of copper temperature of ECU decreases from 82.47˚c to 80.77˚c. Figure 6 shows effect of copper percentage on the ECU temperature. A higher thermal conductivity increases heat dissipation rate of ECU. [5]

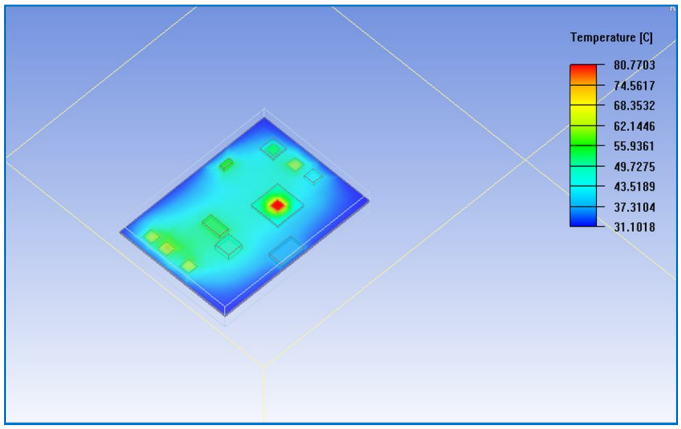

Figure 6: Effect of copper percentage on board

C. Effect of Component Placement on Temperature Field

The component placement is method of reduction of temperature of ECU. This method is consists of number of trials. The X and Y coordinates of the components are considered for the analysis. The temperature is reduced up to 79.22˚c. The optimal placement of electronic component on a printed circuit board requires satisfying conflicting design objectives as most of the component have different power dissipation, operating temperature, types of material and dimension.[7] Figure 7 shows the effect of component placement.

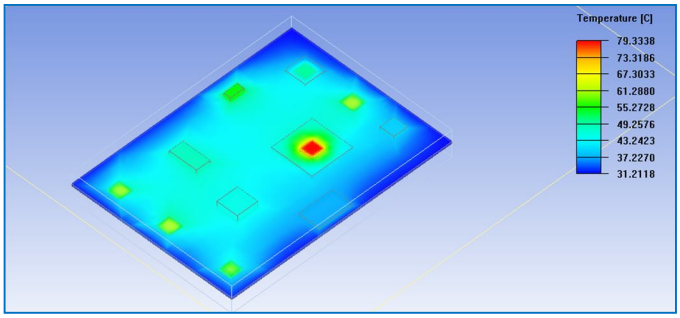

Figure 7: Effect of component placement on the board and components

VI. CONCLUSION

A. After taking number of trials on computational fluid dynamics it concluded that up to 65% percentage is recommended for a better thermal performance and manufacturing consideration.

B. Multiple trials for components location can be performed in order to achieve an optimal thermal design effect and suitable locations of components.

C. The third parameter of the ECU temperature reduction i.e. Effect of board material is to be studied

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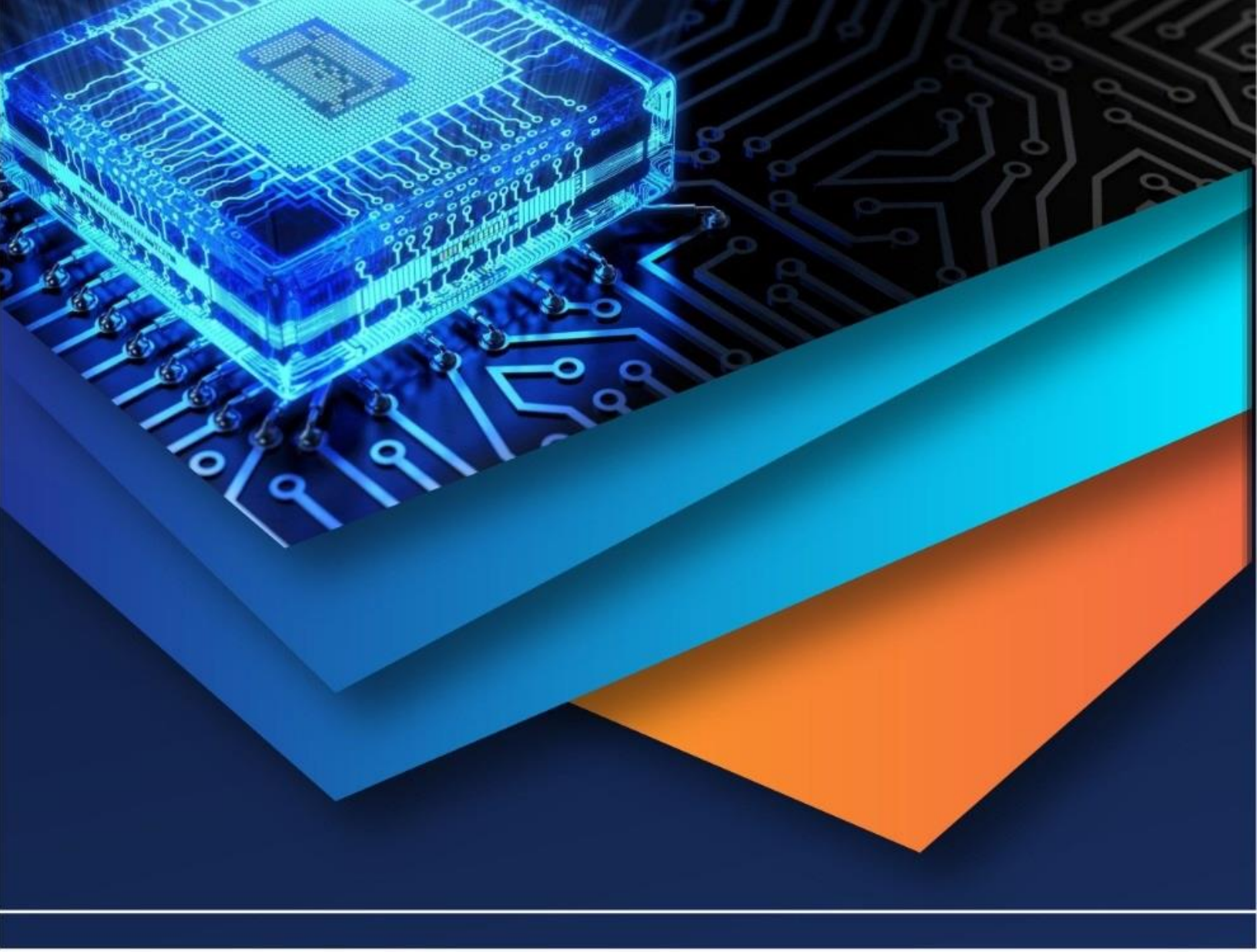

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