# Improvement in Thermal Design and Analysis for ECB of Vehicle

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**Abstract: In recent years, electrical equipment are drastically developing and miniaturizing. Higher integration of semiconductor devices leads to these developments. On the other hand, higher integration of semiconductor devices on one chip and higher integration of electrical devices in one package means increase of heat generation density. The operation of integrated circuits (IC) at elevated temperature is a major cause of failures in electronic devices and a critical problem in developing more advanced electronic packages. This is because the life expectancy of electronic components reduces exponentially as the operating temperature rises. One such example of an electronic device is the electronic control unit (ECU) in automotives whose function has increased and is expected to further rise in the foreseeable future.**

**Thermal design of vehicle controller is an important element in the total design process, because of the impact of temperature on performance and reliability. 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:*** **Electronic Control Unit, Computational Fluid Dynamics, ANSYS ICEPAK, Temperature Distribution, Electronic packages.**

## I. INTRODUCTION

Nowadays, electronic circuit devices can be found everywhere around us. Electronic Circuit Boards (ECB) are an essential part of computers, audio and video devices, automobiles or airplanes, and also in less common applications as diverse elements of spacecrafts and telecommunication satellites. The boards are made from glass reinforced plastic with copper tracks in the place of wires. Components are fixed in position by drilling holes through the board, locating the components and then soldering them in place. The copper tracks link the components together forming a circuit. The resistance to the flow of electrical current through the leads, poly-silicon layers, and transistors comprising a semiconductor device, results in significant internal heat generation within an operating microelectronic component. As an individual electronic component contains no moving parts, it can often perform reliably for many years, especially when operating at or near room temperature. In practice, integrated circuits operate at substantially higher temperatures and, unfortunately, most electronic components are prone to failure from prolonged exposure to elevated temperatures. This accelerated failure rate results from mechanical creep in the bonding materials, parasitic chemical reactions, and do pant diffusion, to mention just a few possibilities. Thus, a rise in temperature from 75°C to 125°C can be expected to result in a five-fold increase in failure rate.

Under some conditions, a 10°C to 20°C increase in chip temperature can double the component failure rate.Electronic control unit (ECU) in automotives whose function has increased and is expected to further rise in the foreseeable future. The electronic content in today's automobiles is increasing staidly as numerous applications now use electronic control. Application from entertainment and comfort of power train and body electronics increasingly use electronic control circuits for better reliability and performance. Severe competition and stringer pollution and safety norms and fuel economy are some of the factors influencing auto industry to look for new technologies using electronic controls. For many electronic circuits printed circuit board forms the basic foundation for interconnecting and packaging. Microcontroller can be described in simple words as heart and brain of electronic circuits.

The thermal characteristic of a component due town power and upstream air heated by components were studied [1] study is concerned with forced convective heat transfer of the channel flow with line arrays of heated electric components mounted on a printed circuit board. The experimental results were compared with those of numerical solution for various conditions. The experimental results agree well with the numerical solution. The correlation between Nu (Nusselt number and Re (Reynolds Number) was presented to make possible the direct calculation of the adiabatic heat transfer coefficient on a non-uniform heated array. The IPM controls the rotational motion of the tube in a washing machine. A heat sink is installed in the IPM to prevent overheat during its operation [2]. In the design process of heat sink, the performance and heat dissipation performance are simultaneously considered. Three dimensional heat and fluid analysis of two plastic lead chip carrier packages mounted in tandem arrangement on a printed circuit board [3] exposed to the free stream velocity. The decrease in the junction temperature of the packages with the increase in approach air velocity is clearly observed. The results also show that the spacing between packages influences the thermal resistances and averages Nusselt number for both packages at a particular approach air velocity. Heat generated within the unit coupled with ambient temperature makes the system reliability susceptible to thermal degradation which ultimately may result in failure [4]

With studies suggesting that current TIMs contribute about 60% interfacial thermal resistance. A higher thermal conductivity material could improve heat dissipation formic [5]. 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. The SOGA (self-organizing genetic algorithm) gives a better optimal solution as compared to the other method [6]. The new placement configuration for the LED array could be used lowers the individual LED temperature. [7]

## II. EXPERIMENTAL SETUP

Figure (1) shows the experimental layout. J type thermocouple mounted on the different packages. On the packages thermocouple end attached with the help of thermal grease. These thermocouples are connected to the temperature indicator. Due to space limitation only three thermocouples attached at one time. This procedure repeated a three times and total 11 reading taken on different packages. In this experiment ECU present in the driver's cabin. As shown in figure power supply provided to the ECU. AC power supply provided to the temperature indicator. Vehicle starts normally after three hours steady state condition occur and different readings taken on the different packages.

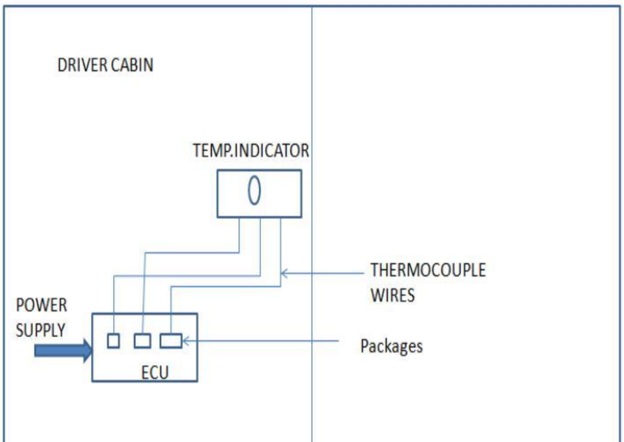


Figure 1: experimental layout

## III. CFD SIMULATION

The ANSYS ICEPAK software among various CFD tool specifically tailored for use in the electronic industry to perform the board and system level thermal analysis. In ICEPAK a variety of thermal limitation source elements are available, including heat dissipation, fixed temperature sources or heat flux sources. Typically controllers in vehicle are housed in sealed case, and rely solely on free convection and radiation for cooling. The heat flow path in controller is a series of conduction, convection and radiation path. Much of the generated in an integrated circuit chip is first conducted into printed circuit board. From here, heat is transported through the case wall, and finally removed to the environment by free convection.

### 3.1 Simulation Modeling

Figure (2) shows the actual ECU of vehicle. When the vehicle is driving under loaded condition the total power consumption is 10 to 15W. Figure (2) and figure (3) the controller consists of the printed circuit board with power electronic components mounted on it which is sealed in a metal case.

Figure 2: ECU of automotive vehicle

Figure 3: Electronic control board with enclosure

The following table indicate the detail specification of the electronic control unit for normal and loaded condition.

Table I
Specification of the ECU

| PACKAGES | NUMBER | POWER DISSIPATION (NORMAL CONDITION) W | POWER DISSIPATION (LOADED CONDITION) W |
|---|---|---|---|
| MOSFET | 4 | 0.5 | 1.32 |
| PLCC | 1 | 0.4 | 0.5 |
| QFD | 2 | 0.5 & 0.2 | 1 & 0.5 |
| SMD | 2 | 0.9 & 0.2 | 0.98 & 1.7 |
| IC | 1 | 0.2 | 0.5 |
| VOLTAGE REGULATOR | 1 | 03 | 1 |
| **TOTAL** | 11 | 5 | 11.46 |

A figure 2 shows the detail model of ECU with different component on the PCB. A number of simplifying assumptions were made in the modeling. All the smaller and lower power dissipation components on the circuit board (capacitor, resistor, mount IC) were neglected. The main generating heat sources (MOSFET, FET PLCC, QFP, Voltage regulator) were omitted.

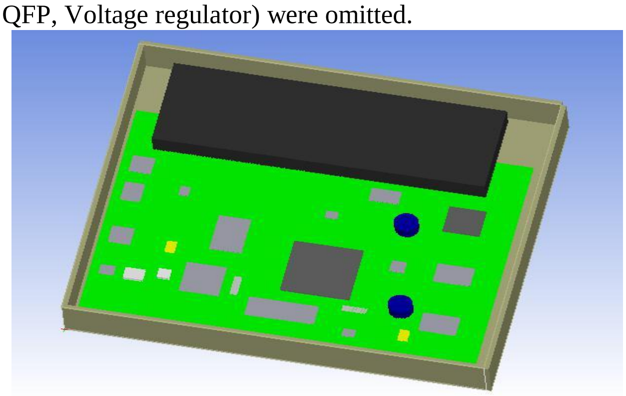

Figure 4: Thermal model for ECU

Small outline packages MOSFETs (metal oxide semiconductor field effect transistor) are simplified into planar heat sources. QFP (quad flat packages) and PLCC (plastic lead chip carrier) packages are directly mounted on the board. Other components which are represented by 3D solid volumes. The power supply provided to the all the components. The controller shell was modeled using enclosure which is 4mm thick and the material is aluminium.

The model case was constructed as being entirely sealed as a close approximation to the real case geometry. As four edges of the PCB (printed circuit board) are close in contact with the case, thermal contact resistance is also considered in the model. The CFD software requires the model placed within a solution domain which was created by enclosure, heat and mass transfer through enclosure is allowed.

The PCB element in the model is assumed to be homogeneously populated and consist of top layer and bottom layer copper were considered as 0.035mm thick. Copper traces that cover 50% of the board area.

Figure 5 shows the whole solution domain with six open faces. The finite volume method is adopted for converting governing equations to algebraic equation that can be solved normally. The simple algorithm is used to solve the pressure and convection-velocity coupling term. Discretization method is first order upwind scheme. In the solution domain the maximum size of element in three mutually perpendicular directions is less than 1/20 of every domain dimension. Figure 5 shows the meshing distribution of whole domain. The computational domain is discretized into unstructured hexahedral meshes that have a total of 164552 nodes.

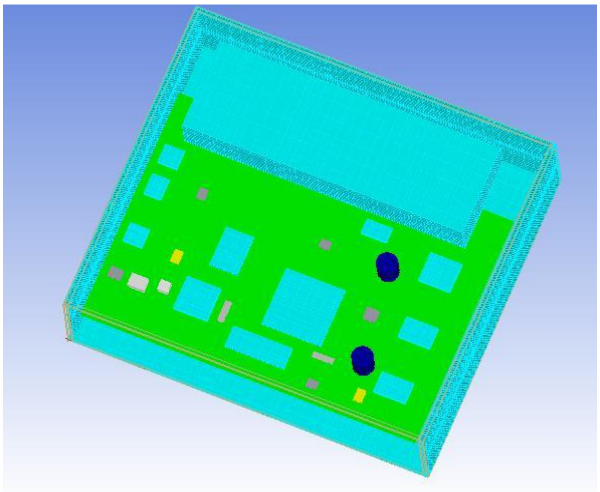

Figure 5: Meshing

The mesh elements are smaller near objects, to take accounts thermal and velocity gradient that are often present near the boundaries of an object. By contrast, the open spaces between objects are meshed with large elements, to minimize computational costs.

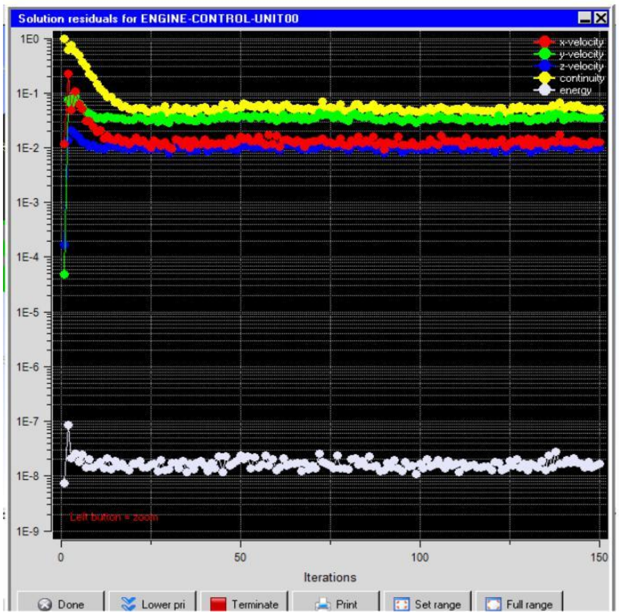


Figure 6: Different CFD values for 150 iterations

The graph shows the x, y, .z velocity, continuity, energy, k and epsilon. The 150 iterations are sufficient to calculate the above problem. Prior to solving the model, ANSYS ICEPAK will determine whether the flow will be dominated by forced or natural convection. For flows dominate by natural convection means buoyancy driven flow, ANSYS ICEPAK computes approximates value of the Rayleigh number and the Prandtl number. If the Rayleigh number is greater than 1.38 E + 6 and the Prandtl number is around is 0.70850574, the turbulent model with natural convection will be recommended. Based on the physical characteristic of the above model as defined , the calculated Rayleigh number and Prandtl number by software are 1.30E + 6 and 0.7085 respectively.

## IV. RESULT AND DISCUSSION

The following table shows the experimental and computational values.

Table II
Specification Comparison of the ECU

| Sr. No. | | Experimental Value | CFD value provided |
|---|---|---|---|
| 1 | Max Temp. | 95°c | 96.3956°c |
| 2 | P 103301813/ 03100957921 | 75.88°c | 78.6945°c |
| 3 | P 1042A | 94.2°C | 96.35°c |
| 4 | Board Temp (Max) | 65°C | NA |
| 5 | QFP | 51 | NA |

The maximum error between experimental and computational is 6.38. Figure 7 shows the temperature distribution on the board. The temperature range is 38.32 to 64.21. In the experimental measurement only surface temperature of different packages is measured and in CFD analysis temperature inside the chip is also detected. Figure 7 shows also surface temperature of the board for validation purpose. Once the normal condition temperature is validating with the CFD calculated temperature the loaded condition apply on the board in different result plotted with the help of ANSYSICEPAK.

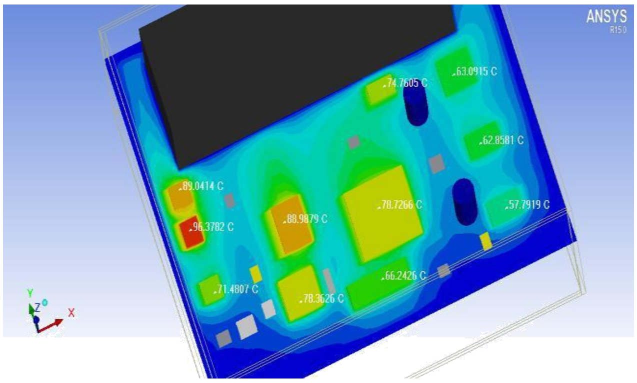


Figure 7: Temperature distribution at normal condition

After calculating 150 iterations the board temperature varies from 31 to 82.52 ˚c. The simulation predicted maximum temperature in QFP package and MOSFET with a value of 82.47$^{0}$c. The three MOSFET are very near that's why the temperature increases on the board. The QFP package and MOSFET are also close due to that average temperature of the board increases.

### 4.1 Effect of Component Placement on Temperature Field

The component placement is very effective and cheapest technique in electronic cooling. Figure (8) indicating the well component placed electronic circuit board. After the component placement temperature decrease 2 to 3$^{oc}$ in this ECU.

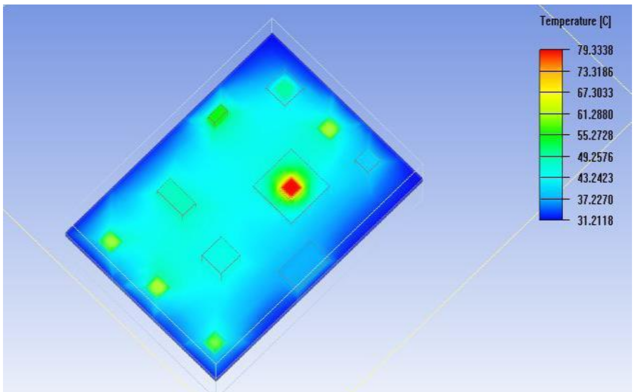


Figure 8: Effect of component placement on the Board and components

The three MOSFET on the board are very close due to that concentration of temperature increases in that particular region. Component placing temperature of the board decreases from 80.53 to 79.22. This is not final optimum placement of the board. Taking number of trials temperature will decrease for PCB.

**4.2 Effect of PCB Material on Temperature Distribution**

The printed circuit board itself becomes the heat sink. The FR-4 material which has very low conductivity is due to that temperature field concentration increases. Two types of most commonly substrate material used board substrate material are also examined. FR4 and composite epoxy material are very similar. Composite epoxy material is available at low cost reduced for FR4 in application such as home computer, vehicle electronics and car entertainment products.

The following table gives the different thermal propriety of FR4 material and composite epoxy material.

TABLE III
MATERIAL PROPERITY OF FR4 AND CEM

| | FR-4 | CEM |
|---|---|---|
| Conductivity(W/mK) | 0.35 | 1.0 |
| Density(Kg/m$^3$) | 1250 | 1000 |
| Specific Heat(j/Kg.k) | 1300 | 750 |
| Conductivity Type | Isotropic | Isotropic |

Figure (9) shows the predicted temperature field distribution of the board with substrate material of CEM-3(composite epoxy material)

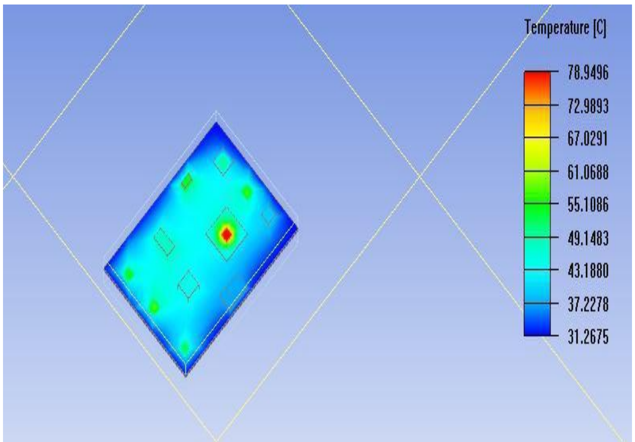


Figure 9: Effect of material on electronic circuit board

The composite epoxy material has high thermal conductivity compare to FR4 also specific heat is also low that's why it improve thermal management in the board .The maximum temperature is reduced to 78.94, which has lower compared to the79.33. The average temperature decreases from 0.5 to 1.5$^0$c. Thus it is more advantageous to reduce the board temperature to select high conductivity substrate materials.

## V. CONCLUSIONS

Thermal management and thermal management design in automotive ECUs has long been a challenging issue as it's compact on the devices reliability and endurances. A thermal analysis model for sealed vehicle controller is demonstrated in this paper, the main conclusion are summarized as the following:

1. More than 65% coverage percentage is recommended for a better thermal performance.
2. Selecting high conductivity substrate material is more advantageous to reduce board temperature.
3. Component placement is also an important factor for the board temperatures.
4. Multiple trials for components location can be performed in order achieve an optimal thermal design effect.

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